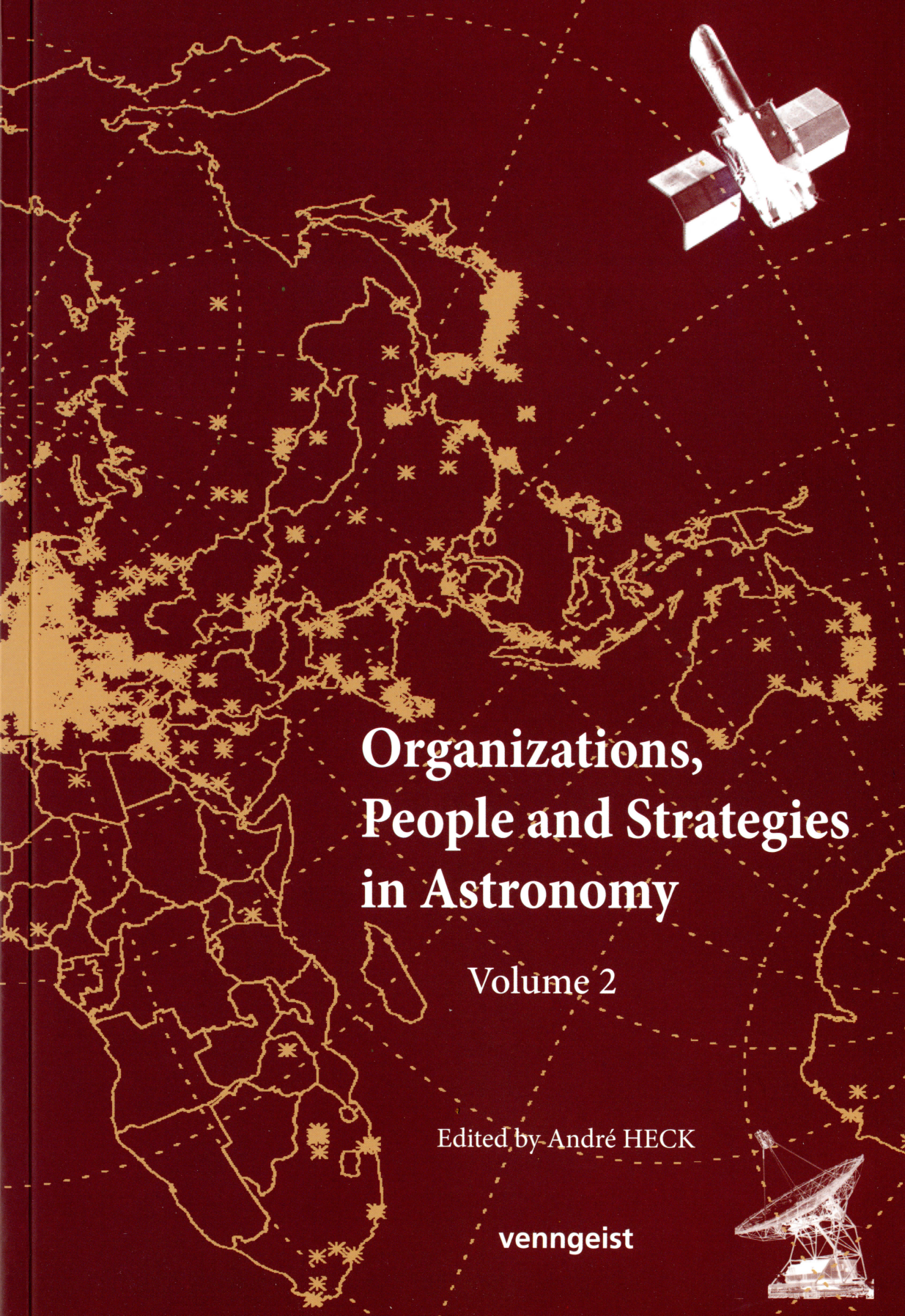


Organizations, People and Strategies in Astronomy

Volume 2

Edited by André HECK

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ISBN 978-2-9542677-1-5
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Organizations, People and Strategies in Astronomy

Volume 1

Edited by

André HECK

OPSA I

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EDITORIAL

A Matter of Quality of Life

"Baloney!"

The word actually used was a ruder one. My neighbor had jumped on his feet, shouting at the orator. We were on the French Riviera attending, in one of the local top-class hotels, a seminar where I had been sent as a young executive of an international organization. The purpose was to initiate the attendees to the latest theories for the best management of human resources (MHR).

My neighbor had shaken hands with me the day before: an American-educated executive of an oil company from the Persian Gulf, and privately an obviously brillant and urbane gentleman. Hence his violent reaction and his utterance were all the more unexpected. But I had been myself increasingly irritated by the speaker of that morning.

That lecturer had been introduced to us as having an evening tantric orgasm every time he could claim his regular work and schedule had been optimized better than the day before, allowing him to achieve more than his colleagues. And, of course, the greenhorns we were in his views were supposed to get the same from ourselves and the people we were managing. You can easily imagine him, full of his own importance, arrogantly delivering thousand and one tricks to save time. As if we had been waiting for his advice to be as efficient as possible in our own context ...

"Baloney!", repeated my neighbor, having successfully interrupted the flow of words from the speaker. "This is just non-sense. If you are still sticking to such primitive ideas about productivity and performance, your views on management are totally outdated." He went on explaining that executives, employees and workers alike had increasingly prioritized the quality of life, including at the working place. The days were not necessarily less active, but more oriented towards welfare and prosperity. Having relieved his heart, our oil man winked at us and disappeared for the day.

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Faithful to his principles, the cantor of the saved split-seconds acted as if nothing had happened, hurried back to the overhead projector and went on with his lecture. But, for many among his audience that morning, the lesson was probably not the one he was looking for.

This took place several decades ago. Since then, the trend in MHR has given ever more significance to the human substance within organizations. Where are we sitting within our scientific entities?

As already mentioned in these editorials, we are short of achieving a perfect situation. Too often in the course of a long international career have I seen managers primarily interested in their own careers and ignoring the legitimate aspirations of the people placed under their responsibilities, when not clumpsily if not deliberately hurting them, sometimes to the point of demotivating them, getting them to leave or, when no other choice, to simply shut down and do the strict minimum of work required. In such cases, the real loser is of course the organization itself.

This is most unfortunate for scientific institutions where creativity and initiative from scientists are of primary importance. Those qualities can only flourish and prosper in an adequately motivating context, first of all by receiving *ad hoc* respect and recognition.

Virtually all managers of scientific institutions, definitely of the small- and medium-size ones, are themselves scientists, most of them lacking however a decent training in handling human resources (HR). Such entities are also generally too poor to hire heads of personnel or HR officers. In large organizations with multiple locations, personnel departments are sometimes too remote to handle local problems and/or are unaware of local cultures and histories.

A Matter of DOBEs and MEEPs

Misconceptions and inconsistencies also abound. Improving the quality of working conditions does not necessarily mean organizing get-together parties and festivities. If these can help making the institutional atmosphere more pleasant, they can only be secondary factors. Some managers have become real professionals in organizing celebrations of all kinds. And successful too, but in appearance only as a non-negligible number of attendees are lured in mainly by free booze and a break in daily activities. The money spent that way would certainly be better used by helping out scientists financing their trips and equipment out of their own pockets. I do know places where this happens.

But I have seen also more perverse cases where wrong HR handling goes beyond simple blunder and lack of *ad hoc* training in HRM: cases where managers deliberately hurt people (sometimes simply because they do not

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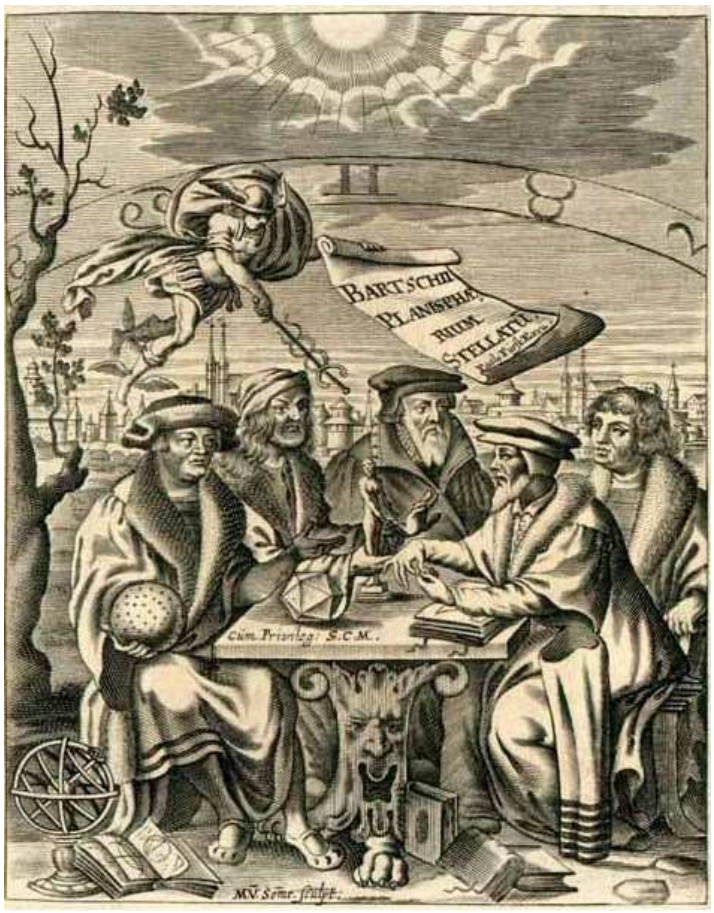


Figure 1. "[...] the frontispiece of Jacob Bartsch's *Planisphaerium stellatum* (1661) [...] depicts a group of men, among them Dürer easily identifiable to the left. He is one of the great men of Nuremburg, which is also depicted in the background, [... who ...] seem to be involved in a conversation about objects and books placed on and below the table. That astronomical books could also be part of such a conversation is made believable from the open book next to the armillary sphere in the foreground left. The open page of the book shows diagrams reminiscent of a book on astronomy. The place where books on astronomy would be displayed, discussed and used was obviously not only the sumptuous library or Kunstkammer of princes, but also in more modest collections, observatories and private houses. There it could be appropriate to discuss astronomical matters together with the other arts." This commentary extracted from Elmqvist Söderlund's (2010, p. 325) remarkable collection of frontispieces illustrates that the mingling of scientists with artists was already a fact centuries ago. Jacob (or Jakob) Bartsch (1600-1633) studied and taught in Strasbourg, married Johannes Kepler's daughter Susanna, and published numerous contributions to mathematics and astronomy. The book dated 1661 illustrated above is obviously a posthumous release printed in Nürnberg with a frontispiece due to Mathias van Somer. The chair left vacant in Strasbourg by Bartsch's death was filled in by the appointment of Julius Reichelt (1637-1717) who lobbied for establishing the first astronomical observing post in Strasbourg (cf. Heck 2012c). See also OPSA 1's editorial (Heck 2012b, p. 3) for another excerpt from Elmqvist's compendium. (Quotation courtesy I. Elmqvist Söderlund – Scan by A. Heck)

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serve their personal ambitions), then ostracize them, maliciously blame them for their subsequent distance, and use it as an excuse for blocking their career when not for ultimately getting rid of them. Such misbehaviors have to be talked about and not kept silenced as taboos.

I have a dream.

In this part of the world, it used to be a time when someone causing a car crash while being intoxicated with alcohol was granted this as an excuse: "You know, the poor guy has been celebrating this or that, or was coming back from a New Year party, and he could not master his vehicle". And whether or not he had a driving licence was not a serious issue. Fortunately we came a long way from that.

I dream of a time when lack of HRM training won't be used anymore as an excuse for blunders and mistreatment. "You know, he was the only one who applied for that job of manager and, well, he is inexperienced in dealing with people." No, managers are fully responsible for the positions they are accepting.

I dream of a time when an appropriate education will be required from anyone put in charge of people, not through occasional seminars like the one mentioned in the opening anecdote, but through real teaching and supervised practice. I dream of a time when any report or decision detrimental to a staff member won't be made without hearing the person concerned by an independent body. I dream of a time when people mistreated or hurt by clumpsy managers, or worse by malevolent ones, will be able to hold these accountable. I dream of a time when bullying and suffering at work[1] will be something of the past and we won't meet anymore people, scientists or technical personnel (generally in a weaker position), telling their stories with tears in their eyes. I dream of a time when we won't have anymore DOBE-type managers (Demotivating-Ostracizing-Blaming-Expelling ones) and only MEEP-type ones, *i.e.* those managers who Motivate, Entertain, Encourage and Promote their people.

A Matter of Appropriate Recognition

In scientific circles, ethics is too often restricted to matters dealing with experimental fraud, with hoaxes or with plagiarism in publications. In my view however, the above HR-related issues are fully part of professional ethics too.

MEEP-type managers will have realized that getting the talents of their personnel flourishing and prospering, making full usage of their initiative and capabilities, will benefit their institution, enhancing its reputation and

[1]Such issues have already been discussed in OPSA 1's editorial (Heck 2012b).

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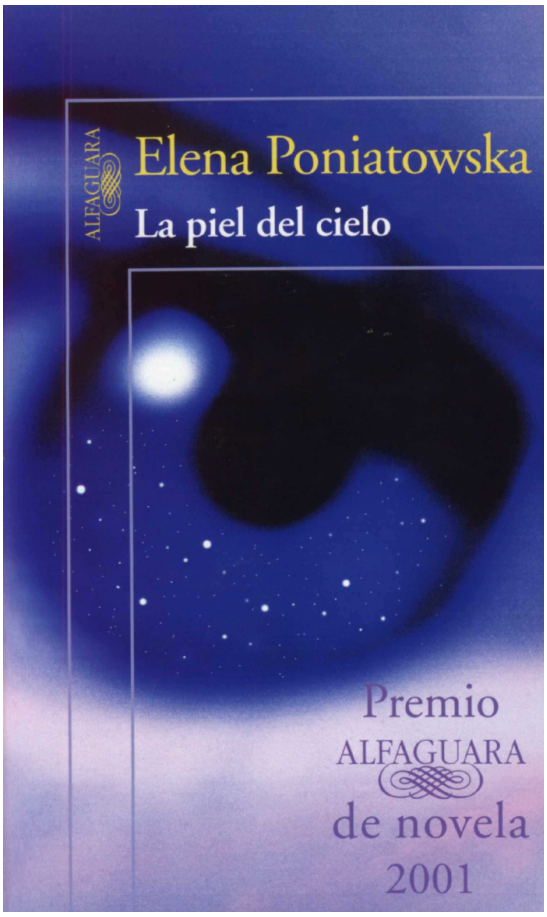


Figure 2. Astronomers fluent in Spanish and interested in astronomy of the past century will certainly enjoy reading this novel by Elena Poniatowska (1932-), recipient of the IVth Alfaguara Prize (2001). In *La piel del cielo* [The Skin of the Sky], the central character looks into the possibilities of science for explaining world and life on a XXth-century Mexican background. Poniatowska, the widow of Astronomer Guillermo Haro (1913-1988) who was in charge of Tonantzintla Institute of Astronomy and Observatory, was born in Paris to a Polish father and a Mexican mother. She had her life shared between France and Mexico due to World War II. Actual facts and historical events abound in the story. Poniatowska confessed (*El País*, 26 April 2001, p. 31) that probably her late husband would not have been too keen of her novel: if the book heavily drained from his biography for the scientific aspects, she could not help crediting him with imaginary events and numerous affairs (including naturally a few erotic scenes). Astronomical elements appear after the first third of the book. The central character goes to Harvard and meets actors of modern astronomy, such as Harlow Shapley (1885-1972), Subramanyan Chandrasekhar (1910-1995), Donald Menzel (1901-1976), Guido Münch (1921-), Paris Pishmish (1911-1999), among others. There are also a couple of astronomical blunders, like saying that astrometry is behind us in all observatories of the world, while only four American observatories are mentioned, but this does not significantly affect the story. See Nath (2001) for more details.

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prestige. And those managers themselves will ultimately benefit from such a positive approach.

Appropriate recognition is a key issue and it starts with respect. Respect for younger people because they have all their career ahead of them and a wrong inflection could have a desastrous influence on later stages. Respect for elder scientists for all their past contributions, sometimes ignored by newcomers who believe History begins with them. Not only plain human respect, but also respect towards the various facets of our activities, such as creativity. And creativity is not easy to be acknowledged properly.

By their very essence, novel approaches lie outside the established channels, funding ones in particular; they are sometimes unclassifiable among existing subdisciplines or rigidly defined categories; and, let's face it, they are felt by some as threatening prevailing situations. However not adequately recognizing creativity is opening the door to the sclerosis of a system.

According to a common anecdote from my college years, my fellow countryman Zénobe Gramme, the inventor of a DC-type dynamo bearing his name (and, by reversing it, of the first usefully powerful electrical motor) was attending one day a celebration of his brainchild. One of the orators was filling blackboard after blackboard with physical and mathematical explanations. After a while, Zénobe bent over to his neighbour whispering: "If I had to think of all that, I would have never invented my dynamo."[2]

As emphasized by Scammell (2009, p. 463), Koestler's basic point that the processes of discovery in science are different from those of testing and confirmation, once regarded as exaggerated, that thesis is now upheld.[3]

Differing timescales have also to be taken into account. Reference works, such as atlases, catalogues and databases, as well as the definition of standard sequences for instance, require infinitely more time for their completion. The underlying work is also commonly rated as unattractive, boring and poorly rewarding. It generally meets difficulties for obtaining *ad hoc* funding and, when needed, observing time. The paradox goes further as, while used by virtually every scientist, reference works are rarely included in bibliographical lists.

Of course, scientists themselves have also their own homework in terms of gaining their own recognition. There are good books available for helping scientists 'marketing' their work from the general-purpose old Carnegie's (1936) manual to more recent specific ones such Kuchner's (2012). But be aware that such books are generally written from personal experience within

[2]Zénobe Gramme (1826-1901) is also credited of another popular cue. To his wife Hortense reproaching him his quietness and absentmindedness, he answered (in Walloon): "Dju tûse, Hortense" (I think, Hortense).

[3]On creative processes, see also Heck (2001).

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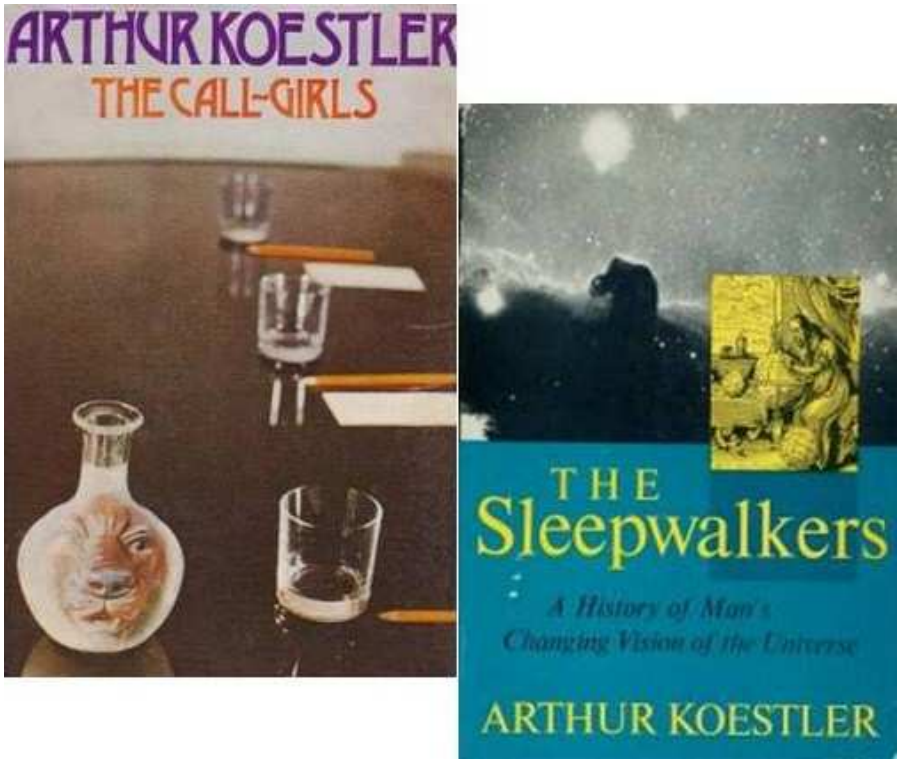


Figure 3. As a young scientist in the early 1970s, I wrote to Arthur Koestler (1905-1983) after reading his fictional novel *The Call-Girls* (1972): it had been real fun to identify his characters with some of those astronomers I had already been witnessing parading relentlessly to meetings round the world. Even the setting of the novel was evoking one of the European winter stations where astronomy gatherings were taking place (Nath 1983). To my surprize and delight, I received from Koestler a few sympathetic words dictated to his secretary – an exchange of letters that has unfortunately been lost in an accidental destruction of part of my archives. Koestler had a formidable and influential XX^{th}-century trajectory that cannot be summarized in this caption. Refer *e.g.* to the authoritative biography by Scammell (2009) who had access to all Koestler's papers. People interested in astronomy are more likely to have heard of another of Koestler's masterpieces: *The Sleepwalkers* (1959). "Novelist, essayist and policital man of action, Arthur Koestler emerges in this book as a historian of science. He traces, with a comic writer's eye and a moralist's sensibility, the curious, disjointed steps by which modern astronomy forged its fundamental principles and changed man's view of his place in the universe" (Frankel 1959). In *The Sleepwalkers*, Koestler critically reviewed and discussed the life and contributions of a few prestigious astronomers of the past while clearly showing his sympathies for some of them and his reservations (to say the least) for others. Those great figures are "sleepwalkers" for Koestler, as are most of the creative minds in science, since they never realized what they were doing. Says Koestler (preface of *The Sleepwalkers*): "The progress of Science is generally regarded as a kind of clean, rational advance along a straight ascending line; in fact it has followed a zigzag course, at times almost more bewildering than the evolution of political thought. [...] the manner in which some of the most important individual discoveries were arrived at reminds one more of a sleepwalker's performance than an electronic brain's".

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a specific context or culture and are not necessarily blindly applicable to all 'systems'.

Beware also media because their timescale (again) is different from ours, as pointed out recurrently by sensationalistic announcements sometimes made by scientists eager to get recognition, sometimes by uncautious Public Relations offices.

A Matter of Targeted Information

At ACM97, the conference celebrating the 50^{th} anniversary of the Association for Computing Machinery, Nobel Prize laureate Murray Gell-Mann (1997) called attention to the fact that, with the digital age producing an 'immense sea of data that threatens to drown humanity', people needed to adapt how they think so that true knowledge can be distilled from the deluge:

> *"We hear, in this dawn of the so-called information age, a great deal of talk about the explosion of information and new methods for its dissemination. It is important to realize, however, that most of what is disseminated is misinformation, badly organized information or irrelevant information. How can we establish a reward system such that many competing but skillful processors of information, acting as intermediaries, will arise to interpret for us this mass of unorganized, partially false material?"*

This question put forward a decade and half ago is of an acute topicality today, even in our science. Servers are echoing *ad libitum* and uncritically press releases from all over the world, some of these *communiqués* being of dubious interest.

Let me quote a few lines from a recent issue of the *AARP Bulletin*, a publication of the American Association of Retired Persons. Referring to advice given by one of his teachers half a century ago, the Editor (Toedtman 2012) summarizes quite well what should be in my view the fundamental role (hence the importance) of all editors and moderators active on all types of media nowadays:

> *"The good editor has a sense of context and gathers into relationship the miscellaneous events, the shreds and patches of our fragmented life. It keeps our heritage alive and reminds us of what we have forgotten – the things silented gone out of mind, or things violently destroyed.[..] The actual ingredient [is] the search. [...] The editorial dimension demands that we work to determine the accuracy, authenticity and relevance of what we see and hear. [...] Our search for the editorial dimension demands that we ask and get answers to the big questions, that we do the math and that we appreciate the context."*

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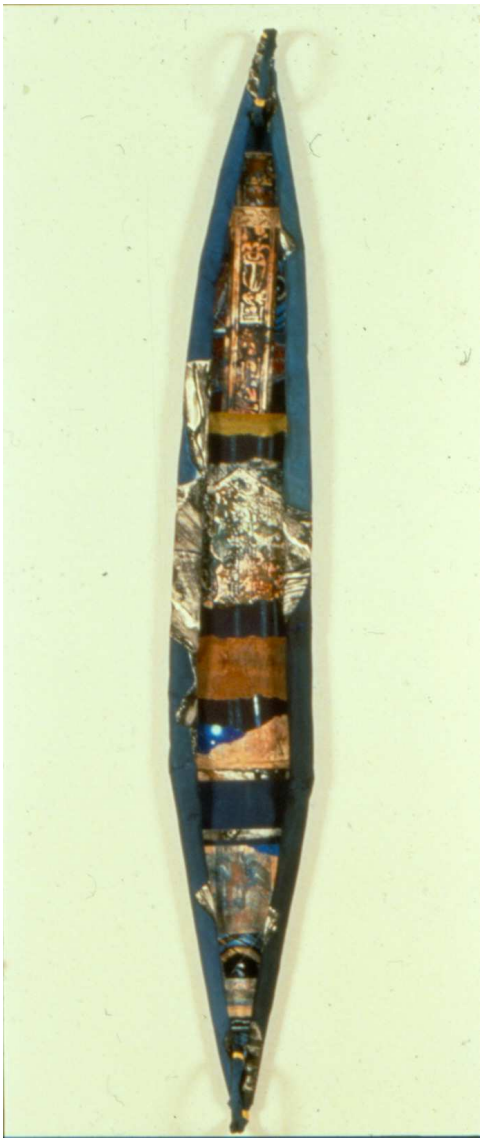


Figure 4. Stephanie Rayner's works have already been featured in the OSA/OPSA volumes: the *Galileo's Eyelid* and the *Labyrinth* appear in OSA 4's and OSA 7's Editorials respectively, while the *Dialogue Concerning the Two Chief World Systems* has illustrated OPSA 1's Editorial. The *Solar Boat* above, a three-dimensional work (183cm × 30cm × 15cm) belonging to the collection of the Art Gallery of Mississauga, is composed of intaglio prints on arches paper, satellite shots of Earth, butterfly wings and copper, including also a reproduction of the plaque sent aboard the Pioneer space probe and a computer circuit board. Rayner's commentary on that work reads as follows: "Egyptian solar boats were interred in Pharaohs' tombs and were thought to go on a celestial voyage carrying prayers back to the Godhead. In this work, the idea of the Egyptian solar boat is linked with NASA's Pioneer space probe." More on Rayner's works and her web site can be found at Nath (2003). (Courtesy Stephanie Rayner – Photograph by Rob Davidson)

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But editors cannot do their job alone, especially in specialized fields as ours. They must act like conductors of an orchestra made of independent readers (referees) playing each the best partition possible in their respective specialities.

The following definition from Wikipedia for refereeing is a pretty good one: "A process of subjecting an author's scholarly work, research, or ideas to the scrutiny of others who are experts in the same field, before a paper describing this work is published in a journal. The work may be accepted, considered acceptable with revisions, or rejected."

This is the key word: a process. And this process is independent from the substance of the paper, whether data collection/analysis or more social-sciences-oriented considerations. This process is also not the privilege of an aristocracy of journals. The way refereeing is applied (not the principle itself) is the source of endless controversies and discussions (cf. the many notes, letters and papers published in *Nature* or elsewhere), but it still is the 'less bad' system of ensuring the quality of publications, relying above all on the probity and dedication of the people involved (editors, referees).

This might surprise some of the readers, but it is sometimes much more delicate to referee (and to handle for the editors!) social-science papers than those dealing with sound scientific data analysis and research.

Our communication channels are also suffering from the economic globalization of the planet, and the story of these OPSA volumes is an illustration. They are the continuation, with more emphasis on human aspects, of the earlier series *Organizations and Strategies in Astronomy (OSA)* (Heck 2000-2006). The seven OSA volumes, distinguished by the International Stroobant Prize, have been published under the label Kluwer from 2000 to 2004, then Springer in 2005 and 2006 after the two companies merged.

The financial games continuing within the planetary globalization, the holding behind Springer has since become the same one as other players for which the low-cost argumentation prevails over the search for quality, imposing delocalization of the production department towards so-called third-world countries. The appalling quality of the proofs I received for the new volume OPSA I after a long wait (the volume was ready in September 2011) led to my amicable divorce from my traditional publisher in April 2012 ... and the need to look for another publisher.

After signing a contract with another publisher, it came out, after a number of steps forth and back, that this new editor simply could not reproduce the book pdf. Surprizing, but real. Hence, second amicable divorce in July 2012 ...

Those vagaries led me to pull forward a project I was keeping for after my retirement: my own non-commercial publishing venture Venngeist. At least it allows a very fast production of the paper edition with its distribution

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Figure 5. A number of Anselm Kiefer's sizeable masterpieces display an astronomical sky with outlined constellations and identifications of astronomical objects. If the stellar names are generally correct (with seldom confusions or omissions), the numerical identifiers (most on rectangular white labels) are imaginary, not respecting an increasing right-ascension sequence or overflowing in number of digits what would normally be expected from coordinate data. There is also occasionally some artistic licence with the Messier list, totalling only 110 objects, with identifiers over that range. The 560cm × 500cm work reproduced here, dated from 2001 and entitled *Himmelspaläste 1 (Hydra)* [Heavenly Palaces 1 (Hydra)], belongs to the Würth Collection (Inv. 7753). It is oil on canvas, together with emulsion, lacquer, plaster and straw. For more on Kiefer's extensively documented works, their background and their interpretations, see *e.g.* Kiefer (2011), Kiefer & Arasse (2010) and Weber (2011), to quote just a few recent publications. See also OPSA 1 for an illustration of *Himmelspaläste 2 (Bootes* [Heavenly Palaces 2 (Boötes)] (Heck 2012b, p. 9). (Courtesy Würth Collection and Galerie Thaddeus Ropac, Paris – Special thanks to Marie-France Bertrand, Musée Würth France Erstein, and to her team)

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at the cost of production, together with an immediate availability of the electronic version of the individual chapters and an access via ADS where they appear as refereed contributions.

It should be noted that all those changes in the specialized publishing world were already transpiring from the colloquia on the *Future Professional Communication in Astronomy (FPCA I & II)* organized, with the participation of the corresponding professionals, respectively at the Royal Academy in Brussels in 2007[4] and at Harvard Center for Astrophysics in 2010[5].

*
* *

This OPSA II Volume

In line with the OSA series (Heck 2000-2006) and the first OPSA volume (Heck 2012a), this OPSA 2 gathers together chapters covering matters dealing with socio-dynamical aspects of the astronomy (and related space sciences) community.

M. Grewing and G. Debouzy open the book by reviewing the phenomenology of new projects in astronomy while J. Tuunainen reflects on the way science is transformed by knowledge production.

This is followed by a set of chapters, typical in the OSA/OPSA series, presenting the status of astronomy in various countries: Argentina (by H. Muriel), Brazil (by B. Barbuy & W.J. Maciel), Italy (by S. Sciortino), Mexico (by W.H. Lee), the Netherlands (by W. Boland & H. Habing), Poland (by M. Kubiak & K. Stepien), Turkey (by Z. Eker *et al.*), and the Vatican City State (by G. Consolmagno & Chr. Corbally).

The next set of papers deal with another classical theme of the volumes – how programs are selected, scheduled and carried out at various observing facilities: ESO (by F. Patat & G.A.J. Hussain), Gemini (by A. Adamson *et al.*), LBTO (by R.F. Green), SALT (by D.A.H. Buckley), and the Subaru Telescope (by M. Imanishi).

Ethics is at the center of the following three chapters: K. Marvel for the American Astronomical Society (AAS), P. Murdin for the Royal Astronomical Society (RAS), and Cl. Bertout for the journal *Astronomy & Astrophysics*.

Chr. Impey ponders then on the science literacy of undergraduates in the USA, followed by A. Landolt describing the rewards of adhering to the

[4]See *e.g.* `http://www.aheck.org/fpca.htm`.
[5]See *e.g.* `http://conf.adsabs.harvard.edu/FPCA2/`.

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International Astronomical Union. Next, K. Marvel details the organization of the AAS Meetings, while L. Bryson recalls the history and purpose of the *International Astronomy Meetings List*.

Staying in the field of history, A.J. Willis recounts the origins and legacy of the International Ultraviolet Explorer, while D.H. DeVorkin reflects on the role astronomers should play in contributing to the history of their science. A compilation by P. Hingley† and co-authors gathers then together sources of all kinds for biographies and portraits of astronomers, primarily for British ones. The book concludes with a chapter by M. Morris on astrophilately.

As in the OSA series and the first OPSA volume, this editorial highlights several examples of astronomy-related art – one of the facets participating to the general communication process for astronomy – with the double purpose of giving visibility to those astronomy-related artists through these publications as well as to show astronomers how artists can use and interpret the objects of their everyday research. See the figure captions for details as well as Bolt (2006) and White (2000) for art+astronomy-related meetings.

Acknowledgments

It has been a privilege and a great honor to be given the opportunity of compiling this book and interacting with the various contributors. The quality of the authors, the scope of expertise they cover, the messages they convey make this book a natural continuation of the OSAs and the previous OPSA volume.

The reader will certainly enjoy as much as I did going through such a variety of well-inspired chapters from so many different perspectives. I am specially grateful to the various independent readers ("referees") who ensured prompt and constructive reading of the contributions.

My gratefulness goes also to Harry Blom and Sonja Japenga at Kluwer, later Springer after the merger of the two companies, who were instrumental in launching and keeping running the initial OSA series.

The Editor
Lu Prâdj-låhe
December 2012.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 15-42
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NEW PROJECTS IN ASTRONOMY: WHERE DO THEY COME FROM AND HOW DO THEY GET REALIZED?

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Abstract. New observing facilities in astronomy today require very big investments, both on the ground and in space. The high priority scientific goals that the communities have identified and included in their "Vision" and "Roadmap" documents, lead to a push for increased sensitivity, meaning larger aperture telescopes and more efficient detectors, and a push for increased angular resolution, meaning again larger apertures or large interferometers, not only in one part of the electro-magnetic spectrum but at all wavelengths. The recent roadmap plans for astronomy, both in Europe and elsewhere reflect these high ambitions. What does it take to make them come true? In this contribution, which represents a personal point of view, we reflect on some of the structures, mechanisms and processes that have contributed to the very successful, dynamic evolution of European astronomy during the last few decades, and that provide the basis on which the even bigger scientific and technical challenges of the future can successfully be tackled.

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1. Introduction

As much as new ideas have been crucial to advance our understanding of the world around us, new projects, new technical facilities have been instrumental in testing these ideas and stimulating new ones.

In astronomy, except for the in situ exploration of our immediate neighborhood, the moon, the planets, comets, asteroids, and the vicinity of the Sun, all objects must be studied remotely, at the distance where they are.

It is obvious that signals travelling huge distances are inevitable extremely weak. Two key parameters have therefore always driven the development of new observing facilities in astronomy: collecting area and angular resolution. Both are linked to the size of the aperture of the telescopes. A third parameter is the efficiency with which the radiation received by the telescopes is actually detected. For centuries, the human eye was the only means to "visualize" the incoming signals. This changed during the first half of the 19^{th} century when photographic plates started to play a more and more important role in astronomy, and the situation changed even more radically in the middle of the 20^{th} century when modern electronic detectors became available. They achieve quantum efficiencies of almost 100%, *i.e.* every incoming photon gets converted into a recordable signal.

For centuries, astronomical research has been limited to the "optical window", where our eyes are sensitive, and where the Earth's atmosphere is transparent. The "optical wavelengths range" extends from about 0.3 to 0.8 micrometers (microns), a very narrow range indeed, which carries, however, an enormous amount of information about the objects in the Universe, especially the most numerous ones, the stars.

About 60 years ago, astronomers started to systematically exploit a second wavelength range where the Earth's atmosphere is transparent, the "radio window".

About 50 years ago, launchers had been developed that were able to carry satellites into space. Above the Earth's atmosphere, the entire electromagnetic spectrum of radiation is accessible, and a new era of astronomy began, with new branches like X-ray and gamma-ray astronomy, ultraviolet and infrared astronomy.

Each part of the electro-magnetic spectrum carries its own, specific information which is hard or even impossible to obtain in any of the other wavelengths bands. At the shortest wavelengths, the gamma-rays and the X-rays, one learns about the hottest regions in the Universe where some of the most energetic phenomena occur, while at longer wavelengths, in the infrared to millimeter-wavelengths domain one learns about the coolest regions in the Universe where molecules and dust particles prevail and new stars are born, and throughout the entire electromagnetic spectrum one

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sees the signatures of non-thermal radiation processes caused by extremely energetic particles moving in cosmic magnetic fields. These "cosmic-ray particles" are found everywhere in the Universe and are subject of intensive study on their own right.

It is no surprise that these enormous changes have not only affected the scientific community and the way it organizes itself, but also the way in which new projects, new observing facilities, the development of new equipment, and last but not least new software tools are initiated, prioritized, constructed and utilized, and how all this is funded. Questions one may ask are:
Who takes the initiative for such new projects, and how does this happen?
Who takes the responsibility for their detailed conceptual design and realization?
Who takes responsibility for the operation, maintenance and eventual upgrading?
Who will have access in order to exploit the new capabilities?
Who will provide all the manpower, investment and running costs that are needed?
Who will set up the necessary legal and administrative framework that is needed?

In the following chapters we shall address some of these issues, quoting examples where possible and making some observations and comments.

2. The 1950s and 1960s: The era where a small number of individual scientists started initiatives that had a lasting impact on ground-based astronomy in Europe

The desire to (re-)gain competitiveness in optical astronomy: The creation of ESO

We mention it here as the most outstanding example of a bottom-up initiative in European astronomy taken by a few leading European scientists who agreed to work together towards the creation of the European Southern Observatory (ESO). This happened at a time when the biggest telescope available in Europe had a diameter of 1-2m, and no single country in Europe felt strong enough to build a much bigger telescope alone. At the same time, in the United States, in California, the 5m diameter Mount Palomar telescope had started to produce outstanding scientific results, in particular in the field of extragalactic astronomy.

The founding fathers of ESO persuaded the governments of Belgium, France, Germany, the Netherlands, and Sweden to create an intergovernmental organization, following the example of CERN. Establishing

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the European Southern Observatory at this very high level turned out to be extremely fortunate for the further development of the organization.

That this could be achieved at the time is the more remarkable as the initial goals set out for ESO in its Convention, which was signed in 1962, are very modest as judged by today's standards. The initial mandate given to ESO was: "the construction, installation and operation of an observatory in the southern hemisphere, consisting of (a) a telescope with an aperture of about 3m, (b) a Schmidt telescope with an aperture of about 1.20m, (c) not more than three telescopes with a maximum aperture of 1m, and (d) a meridian circle." In addition, auxiliary equipment and buildings, etc. were included (cf. ESO Basic Texts, 1987).

A detailed description of ESO's development from the very beginning to 1975 has been given by A. Blauuw in his book *ESO's Early History* published by ESO. He explains why La Silla, a mountain near La Serena in Chile was chosen as ESO's first observatory site.

As ESO evolved, the center of gravity of ESO's activity in Chile moved to Paranal, and with its participation in the Atacama Large Millimeter Array project (ALMA, see also below), the very high altitude (about 5000m) site at Chajnantor was added.

In retrospect, it seems remarkable that this first common effort of European astronomers was focused on the idea to (re-)gain competitiveness. The technical approach for achieving this was rather conservative, not aiming at technical leadership. The much more ambitious goals that drive ESO today and that aim at leadership in ground-based optical and near-infrared astronomy have been set out much more recently. The Very Large Telescope (VLT[1]), comprising four 8m telescopes is in operation since 1998 on Paranal, and ESO will soon start the construction of a yet more ambitious project, the European Extremely Large Telescope (E-ELT[2]) to be erected on Cerro Amazones in Chile.

Despite the fact that we would characterize the first generation of ESO telescopes today as small to medium size facilities, they allowed a growing number of European astronomers to actively participate in their exploitation by winning observing time on one or the other of these telescopes in a competitive process. The more so, as new member states joined ESO in the course of time, and more nationally provided telescopes were added to the suite of instruments on La Silla.

With the ESO telescopes, a wealth of scientific data was produced, that could hardly have been gathered with any of the telescopes that existed and continued to be operated in the northern hemisphere by some of the ESO member states. One reason for this high level of productivity is, of course,

[1] `http://www.eso.org/public/teles-instr/vlt.html`
[2] `http://www.eso.org/public/teles-instr/e-elt.html`

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Figure 1. ESO's Very Large Telescope on Paranal in Northern Chile with its four 8m telescopes and smaller auxiliary telescopes for interferometry. (courtesy ESO)

linked to the superior quality of the site in Chile. It is, however, also owned to the initiatives taken within ESO to develop and disseminate data reduction software that would allow the occasional user of a particular instrument a state-of-the art data analysis. Helping the scientists to efficiently reduce their data was a first step towards what is now becoming more and more common practice: "pipeline processing", *i.e.* the observer receives not only his raw data, but also data that have already been processed according to some standard scheme.

National initiatives to build large radio telescopes

During World War II, radar technology had matured. The technical foundations were laid for radio astronomy, and a scientific impetus was given by the pioneering work of Jansky and Reber, and by the theoretical prediction (H.C. van de Hulst 1945) that the most abundant element in the Universe, atomic hydrogen, may be detectable through its 21cm hyperfinestructure line despite its extremely low transition probability. Two groups independently detected the galactic HI emission in 1951. Also, it was known from the observation of cosmic rays, that very energetic, relativistic electrons exist in our Galaxy. Theoretical studies indicated that when these particles interact with the galactic magnetic field, they would emit a non-thermal continuum radiation which was named "synchrotron

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radiation" because the same type of radiation occurs in synchrotrons, the accelerators built to study nuclear interactions.

Whereas in ground-based optical astronomy leading astronomers from different countries decided to work together towards the creation of the European Southern Observatory, radio-astronomy took a different road. Building on the radar development during World War II, scientists and engineers in several European countries, some of whom had personally been involved in this development, constructed the first fully steerable radio telescopes like the 25m-diameter telescope in Dwingeloo in the Netherlands, and the 76m-diameter Lovell Telescope in Jodrell Bank in the United Kingdom. When these telescopes went into operation in 1956 and 1957, respectively, they were the biggest astronomical telescopes on Earth. Whereas these telescopes were fully steerable, scientists in France opted for a transit telescope with large collecting surface, built in Nancay and officially opened in 1965.

In the same timeframe, a very small group of scientists based at the University of Bonn had initiated the construction of the 25m-diameter Stockert telescope near Münstereifel in Germany, and went on, during the early 1960s, to initiate the construction of the 100m-diameter Effelsberg radio telescope which celebrated its 40^{th} anniversary in 2011. For several decades, until the construction of the Green Bank Telescope (GBT[3]) in the United States, it was the largest fully steerable telescope in the world, and it is still one of the biggest of its kind. A radio telescope with this large diameter, and a surface accuracy that allows operation to as short a wavelength as 3mm, represented a quantum jump in the size and accuracy of such structures. It was technically feasible and financially affordable only because a novel design principle had been developed, the so called "homology principle" (see also Sect. 6).

It is remarkable, that a project of this caliber and with such a long-lasting lead position could be initiated by a very small group of people, based in one small university institute, later in a newly founded Max Planck Institute, and financed by what today is called "soft money" (a grant from the Volkswagen Foundation). The determination and competence of the scientists was a key element in this success story, but equally important has been the close collaboration with an industrial consortium throughout the conceptual design and construction phase of the project.

3. High-Level Initiatives in the Last Few Decades

The last few decades have seen significant changes in the way that new projects have emerged. In part these changes are driven by the fact that subsequent generations of experiments tend to be more and more demand-

[3]http://www.gb.nrao.edu/gbt/

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ing, because the scientific goals become more ambitious, more human resources are needed, and the investment level rises from a few million Euros to hundreds of millions of Euros. This trend inevitably surpasses, sooner or later, what individual scientists from one institute or a small group of institutes can handle.

The last two decades have indeed seen initiatives towards new projects taken at all possible scales: global projects discussed *e.g.* at the OECD Megascience Forum, projects involving partners from three or more continents like the Atacama Large Millimeter Array (ALMA[4]) initiated by existing large organization in Europe, the US and Japan, projects discussed *e.g.* at a pan-European level in the ESFRI context (see below), projects discussed at European level by national funding agencies who have agreed to coordinate their future activities in astronomy like in ASTRONET (see below), and projects discussed by the member-countries of existing big international organizations like ESA and ESO.

OECD Megascience Forum

Astronomy was indeed the first scientific field to be studied in the framework of the Megascience Forum. Leading scientists from 17 of the 22 countries that are members of the OECD Megascience Forum met for the first time in 1992 to "... examine the situation of megascience in astronomy and to discuss the role of international co-operation." (in "Astronomy" – OECD Megascience Forum 1993). At that meeting it became evident that similar project ideas existed around the world, both in ground-based and in space astronomy. By combining efforts, especially the very big projects would obviously stand a better chance to be realized in a timely manner. The Megascience Forum provided, however, only a platform for the exchange of information and for discussion, but not a decision making mechanism that would lead to a priority list of new projects within a given financial framework.

The European Strategy Forum on Research Infrastructures set up by Governments

The European Strategy Forum on Research Infrastructures (ESFRI[5]) was established in 2002 to support a coherent approach to policy-making on Research Infrastructures in Europe. It brings together representatives of EU Member States and Associated States, appointed by the Ministers in charge of research, and one representative of the European Commission.

ESFRI was called upon to develop a strategic roadmap for Europe in the field of Research Infrastructures. It did this with the help of expert groups, appointed through the national ministries, and on the basis of input from

[4] http://www.almaobservatory.org/
[5] http://ec.europa/research/esfri

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the national ministries, who submitted proposals they had received from their respective communities to a joint evaluation and ranking process. The first roadmap was presented in October 2006, and an updated roadmap[6] in 2010.

As far as astronomy is concerned, four projects entered the high priority list that came out of the ESFRI roadmapping process, which did not include any space projects: the European Extremely Large Telescope (E-ELT), led by ESO (see below), the Kilometer Cube Neutrino Telescope (KM3NeT[7]), the Cherenkov Telescope Array (CTA[8]), a ground-based facility for high-energy gamma-ray astronomy, and the Square Kilometer Array (SKA), the next generation radio telescope (see below). The boundary conditions under which these four projects will be pursued in the future differ significantly from one to the other, as does the level of contribution that each country will sign up for. This national engagement will reflect the pressure exerted by the scientists and the institutes in each country, and it will normally also reflect the effort already invested into a particular field, *e.g.* through smaller, nationally funded pre-cursor projects.

ASTRONET

In 2005 the largest funding agencies concerned with astronomy in Europe formed a consortium that included also both the European Space Agency (ESA) and the European Southern Observatory (ESO). The consortium's mission is to "establish a strategic planning mechanism for all of European astronomy for the next 5-25 years"[9]. It is the first initiative of its kind in Europe, whereas in the United States "Decadal Plans" have been produced since a number of decades[10]. The ASTRONET discussions cover topics from the "Sun and Solar System to the limits of the observable Universe and research tools from the radio domain to gamma-rays and particles, on the ground as well as in space; but also theory and computing, outreach, training and recruitment of the vital human resources. And, most importantly, ASTRONET aims to engage all astronomical communities and relevant funding agencies in the new map of Europe"[9]. This new and very ambitious project is supported since 2005 by the European Commission through an ERA-NET grant. It has produced first *A Science Vision for European Astronomy* (2007) and more recently an *Infrastructure Roadmap* (2008).

Inter-governmental organizations in astronomy: ESA and ESO

[6] `http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri-roadmap&section=update-2010`
[7] `http://www.km3net.org/`
[8] `http://www.cta-observatory.org/`
[9] quoted from `http://www.astronet-eu.org/`
[10] `http://www.science.org.au/natcoms/nc-astronomy`

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Organizations like the European Space Agency (ESA) with its Directorate for Science (now Directorate of Science and Robotic Exploration), and the European Southern Observatory (ESO) have their own, well-established mechanisms for preparing the next generation of experiments and projects.

As inter-governmental organizations with a long-term mission, they can count on an annual budget, which is a mandatory budget, formally approved year by year by their Councils, and also on its extrapolation into the future. They have indeed a mandate to not only prepare the budget for the following year, but to present also a 5-year forward-looking plan that is "taken note of". It gets updated every year.

Long-term planning is indeed mandatory because major new ground-based facilities and a fortiori satellite projects take well over 10 years, from the initial idea to their completion, commissioning and scientific exploitation. Below we will take a closer look at the different phases through which a project goes. Here we only mention that both ESA and ESO have established procedures how to solicit ideas for new projects from their respective scientific communities, how to evaluate and rank them on purely scientific grounds, how to identify and study early on what may be technically critical components, and how to arrive at a first cost estimate.

The details of the decision making processes that take a new project from the state of being one of several "candidates" to the state of being the "approved next project" are not the same between ground-based projects and space projects. This concerns the role of the communities at large, the advisory structures of both organization, and the way the final decisions are taken. One reason is that for the ground based facilities, there are usually many years where "new projects" means "new equipment" for existing telescopes, that is an important investment but not at the same level as a new generation telescope would require. The really big decisions, *e.g.* to build the Very Large Telescope (VLT) with four 8m-diameter telescopes, or at present the decision to build a European Extremely Large Telescope (E-ELT) resemble more closely the decisions that must be taken for a new space project, because the order of magnitude of the investments is very similar. ESA's space science program has the additional challenge that it has to serve not only one but several scientific communities working on solar system topics, in astronomy, and in fundamental physics. As a result there are usually many more candidate projects than possibly can be studied in some detail, and again many more than can finally be approved.

Decision for new ground-based projects and for a new space mission at ESA and ESO level have a more and more important impact also at the national level. Both, for new large telescopes and for a satellite project, experiments are expected to be provided by nationally funded institutes

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who may team up, across country borders, to build consortia. The cost of such experiments can be very significant, often tens of millions of Euros, and sometimes even well over 100 million Euros in the case of space experiments to fly on a satellite (see also Sect. 4).

Bi-lateral or multi-lateral initiatives

Funding agencies concerned with astronomy have, of course, been talking to each other before ASTRONET was founded, and there are a number of examples where as a result of such coordination bi-lateral or multi-lateral projects have been created that each of the partners could not have done alone.

We quote here just one of the very early examples, the decision in the 1970s of the CNRS and the Max Planck Society (MPG) to create and jointly fund the Institute for Radioastronomy at Millimeter Wavelengths (IRAM[11]) with its Headquarters in Saint-Martin-d'Hères near Grenoble, and to construct and operate two high-altitude observatories in the Spanish Sierra Nevada on Pico Veleta near Granada, the site for the 30m telescope, and on the Plateau de Bure (PdB), in the French Alps near Gap, the site for the PdB Interferometer with today six 15m-diameter telescopes. Both are world-class facilities, and not only astronomers from France, Germany and Spain have been using these facilities but astronomers in other parts of Europe and around the world, too. The contract between the CNRS and the MPG was signed in 1979, and in 1990 the Spanish Instituto Geográfico Nacional (IGN) joined as a third partner.

The hope seems justified that through the ASTRONET process mentioned above, there will be more such examples in the future.

4. Joint initiatives from hardware institutes: consortia to develop, build and operate new instruments and facilities

Decisions to create new inter-governmental organizations, or long-term commitments from national funding agencies to guarantee the funds for major new infrastructures with big one-time investments of 100 MEuros or more, and for new institutes with operational budgets in the order of 10 MEuros per year or more (typically 10% of the investment), appear more difficult to obtain today than in the past, and take in any case many years of preparation.

Institutes that want to develop new experiments and new observing facilities are therefore taking more and more an alternative approach: they agree amongst themselves to combine their manpower and financial re-

[11] http://www.iram-institute.org/

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sources in order to achieve common goals that correspond to their common scientific interests.

The contractual arrangements for such collaborations will usually differ from case to case, and their financial stability is usually only secured for a limited period of time, but they are relatively easy and fast to implement. A memorandum of Understanding (MOU), or a Multi-lateral Agreement (MLA) may suffice. Depending on the country, national funding agencies may join the collaboration as a partner, or may support the activity through grants to their national institutes.

Instruments for ESA satellites and ESO facilities

ESA and ESO have well established mechanisms to issue calls for tender for instrument contributions. The call contains the performance requirements that must be met, and especially in the case of space experiments, it will contain additional boundary conditions like volume and mass and power consumption limitations. Ideally there will be several responses for each instrument needed, but given the limited number of institutes in Europe that have the capacity and knowledge to build hardware according to the standards set by ESA and ESO, it is not unlikely that only one consortium will answer the call for each particular instrument.

If all goes well, this is a win-win situation: the agencies can draw on the know-how and expertise in the wider scientific community, and the hardware institutes can utilize, maintain and develop further their experimental capabilities. They will usually have a scientific reward in the form of guaranteed observing time, and they are in any case in the best position to push the performance of their instrument to the limits, thereby doing experiments that a standard user of the equipment will probably not be able to do.

Financially, it can also be a win-win situation. For space experiments, the cost of the instruments are typically in the range of 30%, but may go up to 50% of the total satellite costs, and as a rule these instrument contributions are nationally funded and do not have to be paid from ESA's mandatory science budget. The institutes in the consortia will also benefit, because they will normally be financially supported through their national space agencies. This is absolutely necessary not only because the institutes may have to temporarily increase the in-house manpower, but also because a large fraction of the money they spend usually goes into subcontracts with industry.

The EVN and JIVE

Given that in many European countries radio telescopes exist, and that Very Long Baseline Interferometry (VLBI) benefits from having as large a network of telescopes as possible that look at the same target at the same

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moment, radio-astronomers in Europe formed a large consortium in order to coordinate such VLBI observations, the European VLBI Network[12]. To actually detect interferometric fringes and produce high resolution maps of the observed targets, the data from all the participating telescopes must be correlated with each other. This needs a powerful correlator, and the decision was taken by the EVN institutes to build up a correlator center funded by contributions from its members, and also by money from the European Commission. Details can be found online[13]. This is an example of a very successful bottom-up initiative.

Ground-based gamma-ray astronomy

It is impressive to see how many institutes, from astronomy, but the majority physics departments, have organized themselves to combine their resources in order to build facilities to observe high-energy phenomena in the Universe. The very high-energy gamma rays from cosmic sources that arrive at the Earth interact with the upper atmosphere, generate air showers of secondary particles that produce Cherenkov radiation which can be detected by imaging atmospheric Cherenkov Telescopes. This technique is used in several projects, like MAGIC[14] on La Palma, Canary Islands, H.E.S.S.[15] in Namibia, or in the future CTA project[8].

In a project like MAGIC, university groups, faculty departments and research institutes work together. 17 institutes from 9 countries have teamed up. The project was set up in 2001, with one very big telescope (236m^2) joined by a second one in 2009.

The Cherenkov Telescope Array (CTA) consortium includes more than 500 scientists working in 25 countries. Tens of telescopes of three different types will dramatically improve the number of detectable gamma-ray sources. This project has been mentioned above in the context of the ESFRI process, because to build the CTA, a new level of funding will be required. National funding agencies will have to commit to this as foreseen in the ESFRI process.

Preparatory efforts for the Square Kilometer Array

55 institutes from 19 countries are presently involved in preparatory activities for the next generation project in radio astronomy, the Square Kilometer Array (SKA[16]). They have together set up a coordination office, and pursue a number of development activities, including the construction of pathfinder experiments in South Africa (MeerKAT[17]) and Australia

[12] http://www.evlbi.org/
[13] http://www.jive.nl/
[14] http://magic,mppmu.mpg.de/
[15] http://www.mpi-hd.mpg.de/hfm/HESS/
[16] http://www.skatelescope.org/
[17] http://www.ska.ac.za/meerkat/index.php

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(ASKAP[18]).

This project will operate at wavelengths between about 3cm and roughly 4m. By operating a large number of telescopes together as an interferometer, a total collecting area of one million square meters will be achieved as well as a superb angular resolution, thus pushing the two key parameters mentioned in the introduction to new limits.

Until recently, the momentum in this project was entirely carried by the scientists. However, since April 2011 nine national governmental and research organizations have signed a letter of intent to work together to secure funding for the next phase of the project which will take it from the current study phase closer to the construction of the array, and in May 2012 a decision on the site selection has been taken.

Once the project has become real, it will be a remarkable example of what bottom-up initiatives, enduring over many years, can achieve.

5. National initiatives leading to international cooperation at an advanced stage

Today most large observatories operate a variety of focal-plane equipment that is versatile enough to allow most users to carry out their favourite research projects. There are, however, research projects that require new, more advanced experimental capabilities. If scientists and their groups have the technical knowledge and the resources to develop a new instrument adapted to their ambitious research project, they will do so and should have no problem to get observing time on existing telescopes. There are two outstanding examples of such an approach that will be mentioned here because they produced unique scientific data.

One is the development of a dedicated instrument, a high-resolution near-infrared camera (SHARP), to determine the mass of the black hole in the center of our Galaxy by Reinhard Genzel and his group in Garching (Eckart & Genzel 1996). The other is the development of a spectrograph that allows to measure radial velocities of stars with such high precision that the very small movements of a star can be traced that are caused by the presence of one or more planets that orbit around the star like the Earth orbits around the Sun. Such instrument was built at the Geneva Observatory, under the leadership of Michel Mayor. The discovery of the first extra-solar planet at the Observatoire de Haute Provence (OHP/France) by Mayor and his group in 1995 opened a whole new field of research (Mayor & Queloz 1995). Today, the second and third generation of such instruments are available at large international facilities like the ESO Very Large Telescope in Chile.

[18] http://www.atnf.csiro.au/projects/ska

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If scientists want to pursue a research project that requires more than just a new focal-plane instrument on a ground-based telescope, the development effort will, of course, be much bigger. Depending on the wavelength range to be observed, the experiment may have to be put on a research aircraft that flies above 10km altitude like the Stratospheric Observatory for Infrared Astronomy (SOFIA[19]), on a balloon that can reach altitudes above 40km where the Earth's atmosphere becomes at least partially transparent for hard X/gamma rays and at infrared wavelengths, on a rocket, or on a satellite.

Ideally, a national space program will allow to systematically develop the required capabilities, both in institutes and in industry, by starting with aircraft, balloon and rocket experiments before engaging in a satellite project. In the United States, there are indeed many examples of very successful small- and medium-size Explorer satellite missions which have been prepared *e.g.* by rocket experiments beforehand.

In Europe, a few satellite projects have been started at national level, but most of them were internationalized at some stage. The more advanced a project already is when it is opened to international participation, the lower is the risk that it still becomes a victim of often complicated and time-consuming international decision making processes, which often have an unpredictable outcome. For a new partner, a well advanced project offers several advantages because he can see what he is signing up for. Many bilateral and tri-lateral missions have resulted from this process which allows each partner to tailor his contribution to his interest and his resources.

In the following we mention two examples where very successful satellite projects have taken this course.

ROSAT

In the early 1970s, X-ray astronomy was still a young field with most of the groups being in the US. In Germany, J. Trümper, initially at the University of Tübingen, and then at the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, systematically built up expertise in the field of experimental X-ray astronomy, starting in the early 1970s. Major components, detectors, telescopes, electronic subsystems etc., as well as the necessary software tools, were developed in-house by the scientists and engineers, and a large number of graduate students who were fascinated by the opportunity. The instruments were first flown on high-altitude balloons, then on rockets, and eventually a satellite project was prepared, and the groups also participated in the preparation and exploitation of ESA and NASA X-ray satellite missions.

[19] `http://www.sofia.usra.edu/`

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These activities culminated with the successful preparation, launch (1990), and operation of the ROSAT satellite for which an imaging X-ray telescope had been developed in close cooperation with industry (Zeiss, Oberkochen). This telescope allowed to survey the sky with unprecedented sensitivity in the 0.1-2 keV range. These measurements were complemented by a second instrument, built at the University of Leicester in the UK, under the leadership of K. Pounds, which surveyed the sky in the extreme ultraviolet range[20].

ROSAT, initially called Robisat, had been proposed to and approved by the German Space Agency as part of a national program for major new infrastructure in the mid 1970s. Only later did it become a tri-lateral program with the United States and Great Britain as important partners.

COROT

Corot (COnvection, ROtation et Transit Plantaires) was first proposed by three French laboratories (LESIA, LAS, IAS) to CNES, the French Space Agency, in 1993, following a call for mission concepts to use the PROTEUS platform[21]. Its first objective was astero-seismology by measuring stellar oscillations similar to those observed in the Sun. The discovery of the first exo-planet in 1995 added a new objective to the mission: the search of exo-planets by a transit method through very precise photometry.

In 1998, Corot was approved for Phases C/D by CNES. In 1999 it was almost cancelled for budgetary reasons before new partners joined and saved the project (ESA, Germany, Austria, Belgium, Spain and Brazil).

Corot was successfully launched at the end of 2006, and has since then produced a wealth of scientific data, including the discovery of many exo-planets of different sizes. The mission operations have recently been extended to 2013.

In times of stagnant or even decreasing national budgets for space research, the opportunities for institutes to systematically build up experience and competence over time, by first working in the laboratory, then going to balloon or rocket experiments with the aim to participate eventually in satellite experiments, become more and more scarce. This is a concern, and some of the difficulties in ESA's space program that result from problems with the technical readiness of mission critical components (cf. Sect. 8), could be probably avoided, or at least in number, if more experimental opportunities would (again) become available.

[20] http://www.mpe.mpg.de/xray/wave/rosat/mission/rosat/index.php
[21] http://smsc.cnes.fr/COROT/GP_satellite.htm

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6. The role of "enabling technology"

The feasibility of new projects and their improved capabilities often depend not only on doing things bigger and better than anybody else has done before, but on the application of new technical solutions that have not been applied before in an astronomical research project.

New technical solutions can either come from outside, *e.g.* from a military development program, once the technology becomes unclassified, or they are the result of a dedicated, usually multi-year in-house development by scientists, engineers and technicians in an astronomical institute who realize that the equipment they need does not exist elsewhere but can be built with the knowledge and resources they have. A third possibility exists: the scientists can try to trigger a research and development within existing programs, like *e.g.* the ESA programs: GSTP (General Support Technology Programme), TRP (Technology Research Programme), and CTP (Core Technology Programme).

Examples for all these approaches will briefly be mentioned, going from big structures to smaller ones.

New technologies in radio astronomy

We have mentioned before the 100m-diameter Effelsberg telescope which was the first to apply the "homology principle", *i.e.* the telescope was allowed to vary its shape under the influence of gravity and wind with the only condition that the shape had to remain always parabolic, but allowing the focus to move around in a predictable manner.

Computer calculations, based on finite-element techniques, allowed to predict how the choice of certain structural elements in the support structure of the telescope would influence its response to changes in elevation, *i.e.* changes in the influence of gravity, and under changing wind-load conditions. These calculations were easy to repeat for a large set of design parameters until a solution was found that satisfied the specifications.

Gravity and wind are always key parameters in designing a telescope, but its thermal behavior is a key parameter, too. In designing mm-wavelength telescopes that should maintain a root-mean-square (rms) surface accuracy in the order of 50 microns or better for telescope apertures of 10-30m, independent of whether the sun is in front, on the side, or in the back, the thermal response to such varying conditions becomes crucial. There are two possible solutions which have both been applied *e.g.* at the IRAM telescopes:

(i) to allow the structure to change with temperature but maintain its parabolic surface by forcing isothermality, *e.g.* with a powerful air ventilation system, or

(ii) to resort to structural elements in the telescope support structure that

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change very little or not at all with changing thermal conditions, like carbon fibre elements.

New technologies in optical astronomy

The current and the future generation of optical telescopes would not have been feasible if the mirror technology would not have radically been changed. In the past, optical mirrors had to maintain the very high quality of their polished surface under all possible load conditions. The bigger they were, the thicker they had to be, and the heavier they became, with severe consequences for the entire telescope structure.

As telescopes were sent into space, weight was a real problem, and the idea of "light-weighted"-mirrors quickly came up. The challenge was to make sure that they would have a perfect optical shape under zero-gravity conditions while they had to be worked on and weight-reduced under 1g-conditions. Engineers solved this problem brilliantly.

The concept of weight-reduced mirrors quickly became an issue also for large ground-based telescopes for the reasons indicated above. To make sure that their surface shape maintained its high quality not only in horizontal but also under varying tilt-conditions, they needed a special, actively controlled multi-element support structure behind the mirror. After a series of studies, ESO successfully applied this technique in its 3.58m New Technology Telescope (NTT[22]), which saw its first light in 1989.

In ground-based optical telescopes not only the influence of gravity is a problem, but also the behavior of the atmosphere above the telescope, described by the so-called seeing conditions. Observatory sites like La Silla or Paranal, both in Chile, were chosen because they offer good seeing conditions. But even then the telescope performances never reach the diffraction limit, unless active and adaptive optics are applied to correct for atmospheric effects in real time.

Imaging telescopes for X-ray astronomy

Only if the photons collected through the aperture of a telescope can be imaged onto a focal plane, can the two-dimensional information be preserved and the light be recorded by the detector. Conventional, normal incidence telescopes no longer work at wavelengths much shorter than about 0.1 micron, because no coating materials exist that would reflect the incoming light efficiently over a wider range of wavelengths. Special multi-layer coatings have successfully been applied at much shorter wavelengths, but they only work for narrow wavelength ranges.

The solution is to go from normal incidence to grazing incidence reflections, bouncing light off the surface of a mirror under an angle of only a few degrees. This is a principle that is well known in physics, but it took special,

[22] http://www.eso.org/sci/facilities/lasilla/telescopes/ntt/

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dedicated development efforts to apply it in astronomy. The first such telescope design was described by Wolter (1952). After that it took many years before such X-ray telescopes, following this concept, could be manufactured, and several techniques have been tried to produce thin mirror shells, with high precision surfaces and not too much weight. Electro-forming is one of these techniques. The first Wolter-type telescope was launched into orbit on the HEAO 2 Einstein[23] mission in 1978 by NASA, followed by ESA's EXOSAT[24] mission, launched in 1983. Today grazing incidence telescopes, usually in a nested configuration to increase the effective collecting area, are in use on a number of satellite projects, *e.g.* NASA's Chandra[25] and ESA's XMM/NEWTON[26] missions.

Imaging systems for gamma-ray astronomy

At hard X-rays and low-energy gamma-rays in the range of 30 keV to 2 MeV, direct imaging fails, and when astronomical observations started by the end of the 1960s, the biggest problem was to know from where the radiation that had triggered the detector (see below) came. Even in the best of cases, the positional uncertainty was in the order of a few degrees. This changed when French groups developed the SIGMA telescope which was launched in 1989 on board of the Soviet GRANAT[27] spacecraft. This was the first system that was able to directly locate the gamma-ray sources with a positional accuracy of a few arcminutes by using a combination of a coded aperture mask derived from the Hadamard mask (a mathematical model), and a gamma-ray camera, a NaI (Tl) position-sensitive detector used in nuclear medical imaging. Today, a similar kind of technique is used on ESA's INTEGRAL[28] satellite.

New detector technology

Many discoveries would not have happened without the new types of detectors that became available during the last few decades. That is true not only in classical astronomical applications like optical astronomy where the Charge Coupled Devices (CCDs) have an enormous impact, and in radio astronomy were *e.g.* broad-band heterodyne receivers using new mixer technologies play an increasingly important role, but equally in young fields like X-ray astronomy, hard X-ray and gamma-ray astronomy, and most recently in infrared astronomy.

The last two fields are examples were developments that have initially been driven by military interests have opened up new windows for astron-

[23] http://heasarc.nasa.gov/docs/einstein/heao2.html
[24] http://www.rssd.esa.int/index.php?project=EXOSAT
[25] http://chandra.si.edu/
[26] http://sci.esa.int/xmm
[27] http://sigma-2.cesr.fr/sigma/home&source
[28] http://sci.esa.int/integral/

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Figure 2. ESA's X-ray multi-mirror mission XMM, ranamed "Newton" in honor of Isaac Newton. It was launched in 1999 on an Ariane 5 rocket into an elliptical orbit with an apogee of nearly 114,000km and is still in operations. (courtesy ESA)

omy. Gamma-ray detectors, surrounded by an anticoincidence systems, to get at least some directional information, detect photons with energies between 30 keV and 2 MeV upon their interaction with crystal material (sodium iodide, cesium iodide). They were initially developed to detect nuclear explosions. Sensitive infrared detectors, based on semi-conductor materials were developed to detect and image heat sources. The development started with single pixel devices, but the requirement to produce images rapidly led to the development of detector arrays.

Once their potential for astronomical research had been recognized, these detectors were better and better adapted to the needs in astronomy. Parameters such as sensitivity, pixel size and number, bandwidth, array

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size, etc., have systematically been pushed in connection with new projects in astronomy.

If one realizes how important the impact of new detector technology has been in all fields of modern astronomy, one wonders if enough is done to support the development of new techniques in university and research laboratories, and in industry. Initiatives still come mostly from individual groups who are motivated by their own research interests, or from industries that see a market opening, like in the case of the CCD development for digital cameras.

In summary, encouraging the development of new technologies and providing sustained support during the many years it normally takes before they are mature and ready to apply, seems a very good investment, from which a field like astronomy could benefit a lot also in the future.

7. Technical readiness – who judges when?

Proposals for new instruments and/or facilities are first of all judged on the basis of their scientific potential. Which important scientific question will be tackled with a good chance to obtain answers that cannot be obtained with any of the existing instruments and facilities.

This applies equally to unsolicited proposals and to proposals submitted in response to an announcement of opportunity and the invitation to submit new ideas.

Of course, the proposal must contain in addition to the scientific justification a technical concept how to achieve the scientific goals.

In a first evaluation round by expert teams drawn from the scientific community at large, the focus is on the science potential, and technical and financial aspects play a secondary role unless there is a suspicion that they could become show-stoppers.

The science potential should convince and fascinate the science advisory groups. But technical requirements to achieve the science goals may equally fascinate the engineers, asked to look into their technical feasibility. Sometimes the missing step may just be to space qualify devices which work well on the ground. Sometimes, however, a project may trigger intensive development efforts that lead to entirely new solutions that open new possibilities.

Once the scientific criteria that will make the project a success are specified, and the decision has been taken to include this project into the list of candidates for the next selection round, the scientific requirements will be translated into technical specifications that must be met. In practice, the full system is early on broken down into subsystems and each subsystem

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into components. Components that are mission critical and could take a long time to develop should be identified as such as early as possible.

What we sketch here is a multi-year learning process which is traditionally organized in a sequence of project phases. The typical scheme comprises six phases, from Phase 0 (assessment study) to Phase E (commissioning and scientific exploitation).

In principle this is a safe road to success unless one really hits a show-stopper. Still, in many cases, the development of certain project-critical items has taken longer than anticipated (cf. ESA's Science Program Review Team Report 2007, p. 25[29]).

If the development of a project takes longer, its cost will normally go up. In some cases the time to develop a complex instrument has gone up by more than a factor of two, and so has the cost. A clear understanding of technical readiness is therefore mandatory, and the sooner it is achieved, *i.e.* during the early phases of a project, the better it is.

Technological readiness can to a considerable extent be quantified. NASA has defined a standard classification model that industry is generally applying, too. It ranges from TRL1 (basic principles established and documented) through TRL4 (component and/or breadboard validation in laboratory environment) and TRL5 (validation in a relevant environment) to TRL9 in the case of space experiments (successful operation in flight). See ESA's SPRT 2007 report mentioned above, especially Pages 25-26.

The question is, who will apply these criteria and when. The "when"-question is particularly important in relation to the decision making process: When does a project advance from the initial design and development phase into the real production phase where the bulk of the money will be spent. Where is the "point of no return"?

The dilemma is obvious: scientists and engineers may have already worked for years on a project when one of the critical components shows a technical readiness problem. They will do everything to "keep going", even if time and costs are running.

There is no one recipe how to avoid that this will happen. One precaution would, however, be to take several candidate projects through Phases 0, A, and a full Phase B before the main industrial contracts are written and signed. Funding agencies should be convinced that supporting such activities in parallel is a very worthwhile investment, even if the costs reach 10% -15% of the full project costs. If a project is stopped at an advanced phase because it loses the competition with others on scientific grounds, or because the technical analysis has shown that performance critical components will not be ready (with guarantee) within a given amount of time,

[29]http://www.esa.int/esapub/br/br267/br267.pdf

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there will still be a very important learning process from which future missions can benefit.

What is described here has actually happened in space research over many decades: institutes and industry worked on typically five times more assessment studies than projects that were later on selected for detailed design and construction. What would be desirable is to make the down selection as late as possible.

The need to address the technical readiness issue in a much more serious manner increases as the number of new projects started per decade decreases because the individual projects become more and more expensive and the budget envelope does not increase proportionally.

Finally, the question remains: who are the judges? They must be competent but without a conflict of interest. In a community with fewer and fewer institutes engaged in hardware development, and the fact that in order to contribute to a big project they usually form big consortia, which involves many if not all of them, this is not a simple question. Still, it is a joint responsibility of scientists and engineers involved in the evaluation process that the technical readiness of all critical components of a new project is judged correctly in order to avoid that large amounts of extra money must be spent. That money could better be spent on another new mission.

8. Project costs is "design-to-cost" an option, or is it always "cost-to-design"?

As explained in the previous section, all bigger projects pass through a number of different phases, spread over many years.

When the forward looking budget plan of an organization like ESA or ESO shows that a certain amount of money becomes available in future years for new projects, they will usually issue a call for ideas towards the scientific community, which may be an entirely open call, or a call that takes into account priorities for future activities that have previously been decided

The answers to an open call may range from ideas for new projects based mostly on theoretical studies to proposals that include not only a strong scientific case but also an idea for technical solutions that are based on existing know-how and experience.

The full range of answers is welcome, the effort it takes before a realistic cost estimate can be attached to the proposal, is, however, quite different.

At the beginning that does not matter, because the evaluation of the proposals by expert groups will focus on the scientific potential, and technical and financial aspects will play a secondary role.

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If the call has, however, been for projects of a certain size, like in the case for ESA in connection with the *Cosmic Vision* implementation plan, then the cost issue may come in early on. In 2007, ESA invited proposals for Medium (M) and Large (L) missions, with price tags of 300 and 600 MEuros, respectively.

Who can tell the evaluation team what it will cost to build the proposed project? If they have been involved in projects of similar complexity before, they may have an idea themselves. If they have good connections to an experienced space agency or industry, they may obtain advice from them. In the end, the organization to which the proposal was made, take again ESA, will make its own preliminary internal evaluation and decide which "basket" the proposal fits in.

Usually a range of projects of different estimated sizes are retained, at least for an assessment study, if their scientific value is judged to be very high. If several options of small, medium and large missions exist, the flexibility to implement new projects into a given budget envelope or its projection, is naturally higher. This flexibility may become even bigger if there is a chance that some of the projects under study may attract external partners who would reduce the cost within Europe.

Experience has shown that "flexibility" is a volatile quantity which can very quickly completely disappear. The reason is that not only the time and money it takes to phase a new mission into the long-term plan are not so well known, but that also the manpower and time and cost it takes to execute those projects that are already in the pipeline, *i.e.* that have been formerly approved, have the tendency to evolve with time. Some of the reasons for this are clear:

– scientists want their proposal to win, so they build into the proposed facility as much scientific potential as seems possible without losing credibility; that necessarily raises the complexity of the mission, and that means rising costs;

– industry wants to win the contract to build the project.

As the price is one of the key criteria for selecting the contractor, the offers tend to be on the low side.

The question is: when comes the moment of truth? It will come, sooner or later, and the later it comes the bigger will be the crisis.

Even if only one of the projects that are in an advanced planning phase (C/D) produces a severe cost overrun, the impact on all other projects, approved ones as well as new ones, can be very damaging. There may be delays in the construction phase, launches may be delayed, and there may be no room anymore for some time to start a new project.

In communities that have a wide range of scientific interests, like it is the case for the ESA communities, and the need for a correspondingly large

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number of different missions that allow European scientists to take a lead position in their field, this is unacceptable in the long run. It leads to a scientifically no longer justifiable imbalance of opportunities to start new projects.

As soon as time delays and cost increases can no longer be absorbed in the contingencies of a project, which can happen despite all efforts of the Project Manager to keep the cost under control, the first proposal is often to "de-scope" the mission in order to come back to the original, approved cost estimate, *i.e.* to a "design-to-cost".

We do not know of any example where this has worked, at least not for space projects. One can quote two prominent examples: Herschel/Planck and Bepi Colombo.

In the case of Herschel and Planck, two ESA astronomy projects, which were originally proposed as two separate missions, ESA felt that by combining them into a single mission, thereby having to pay only one launcher, they could be built for two thirds of the initial costs of the separate projects. When Herschel/Planck satellites were finally launched, the cost was almost back to the original cost level.

In the case of Bepi Colombo[30], Europe's first mission to the planet Mercury, the technical difficulties have been severely underestimated throughout all the early phases. As a result, the cost has almost doubled between the end of the feasibility study and the phase C/D. As a consequences, all other projects under development had to be delayed, and some of them had even to be deferred to the next 5-year planning cycle.

Will design-to-cost ever work? From the experience so far one may have doubts as far as space projects are concerned. The cost evaluation of the proposals received by ESA in response to the call for "M" missions in 2007 has shown that not even one of the pre-selected mission proposals fitted into the envelope of 300 MEuros, the cost ceiling that had been announced. As a new, higher ceiling is adopted, new delays are pre-programmed in the implementation of the Cosmic Vision plan.

In ground-based astronomy, and more specifically with large international projects, the experience is more positive. The most recent example is the Atacama Large Millimeter Array (ALMA[4]) project which underwent a severe descoping in 2005 after the cost started to increase and the project was reviewed. The nature of the project with its large number of modules made it easier to de-scope, and as it is a ground-based project, there is always the possibility to come back later and do an upgrade. With Japan officially joining Europe and the US in this project, its scope re-expanded.

[30] `http://sci.esa.int/bepicolombo`

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9. The management of large projects: is a central management structure always needed?

We have seen in previous chapters that co-operation between institutes, often across country borders, plays an important role in astronomy. This has traditionally been so. Scientific projects, *e.g.* large sky surveys, or major technical development projects have successfully been realized in this way, especially if the manpower, the facilities, and the money that each partner could bring in where sufficient to reach the common goal.

The costs of many current and future large infrastructure projects are at a level, where this approach no longer works. Resources are needed that can no longer be decided at the level of individual institutes but need a decision at the level of national funding agencies, or even at government level, like is the case for ESA and ESO.

In the latter case, the money will be entrusted to these intergovernmental organizations, and they are responsible for the way it is spent to build the new facility, *e.g.* a new satellite, or a new ground-based telescope.

Over time, these organizations have developed a unique expertise for the handling of large and complex projects in their staff, ESA at the European Space Technology Center (ESTEC) in Noordwijk/The Netherlands, ESO at its Headquarter in Garching.

Even if sub-systems or components of a new project are subcontracted to scientific institutes that have the necessary technical and managerial competence, the system level management remains of crucial importance for the successful implementation of a big and complex project. Industry has come to this conclusion long before the scientific world, and some companies have focused on system management, including documentation, quality assurance etc., even at the expense that the actual construction and assembly work is done elsewhere in the industrial consortium.

Recognizing the importance of this system level competence, which exists only in a few national agencies and international organizations, there have been reflections if not all big new projects in astronomy and space science should be managed by ESO and ESA, respectively. One can hear different opinions about this idea.

It remains to be seen what will happen with future large projects, like e.g. the Square Kilometer Array (SKA[16]), that are not in ESO's proper domain of optical astronomy. Also, it remains to be seen how the interaction between ESA and ESO and institutes and/or consortia of institutes that provide important subsystems or components for new large facilities will evolve. Despite the fact that the distribution of tasks has been practiced since two decades or more by now, it is probably fair to say that it is still a learning process.

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10. Changes in the self-organization of the user community

As was mentioned before, the hardware building institutes in Europe have demonstrated on many occasions how to collaborate in order to achieve something that they could not achieve individually. They are sharing not only the same scientific goal, but also their manpower, the engineering capabilities, their mechanical and electronic workshop capacities, their software development expertise, and last but not least their financial resources.

The users of existing facilities, like *e.g.* the ESO telescopes, or ESA satellites, have a priori much less incentive to enter into very large cooperations, at least until rather recently.

The situation has changed. When one looks at the authorship of articles in refereed astronomical journals from 30 or 40 years ago, one finds many with a single author or a small number of co-authors. Looking at nuclear physics journals at the same period, the number of co-authors on papers based *e.g.* on data obtained at big facilities like CERN was much larger.

When one looks at the authorship of observing proposals submitted to large facilities, and the authorship of articles submitted to refereed astronomical journals, one finds a very similar trend to that observed in nuclear or particle physics already a long time ago.

Some reasons for this development are easy to name. We mention a few:
– observing proposals look stronger if the list of co-authors includes many people known to be experts in the field, ideally with complementary expertise;
– multi-wavelengths observations play an increasingly bigger role. In many cases observations in one wavelength band trigger follow-up observations in other parts of the electro-magnetic spectrum, and teams with access to these different facilities decide to collaborate;
– the big impact that the Hubble Deep Field and the follow-up observations have made on extragalactic astronomy, has triggered many more large surveys; the large data volumes that they produce require many collaborators from many institutes who will work on the analysis as well as on follow-up observations;
– observations may need sophisticated model calculations to interpret them; theoreticians are therefore often invited to join the observers' groups.

Experienced astronomers will have no difficulty either to lead or to join one or more collaborations. This is a dynamic process where the membership of the collaboration changes all the time depending on the interest and availability of the individual scientists.

What about young astronomers? For them this new development is a chance and a challenge. If they are given the possibility to participate in a collaborative project, the chance is that they will do competitive science,

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will learn at lot quickly, will become part of an international network, and will have their name on a publication. The hazard is that they will appear as one of many co-authors which makes it difficult to evaluate their contribution from the outside. If, on the other side, they are given the chance to be the lead authors of such a paper, that carries weight in their curriculum vitae.

11. Conclusions

In the previous chapters we have tried to describe and comment on some of the evolutionary changes that we see happening in European, and to some extent also in world-wide astronomy. These are personal observations, and neither did we aim for completeness nor for a balanced presentation. The chapters largely reflect our personal experience and judgment.

Some of the issues we addressed merit much deeper analysis and discussion than we have been able to do, and a much more detailed documentation than we have included here.

It is obvious that the size and complexity of projects in astronomy has grown dramatically between the previous, the current, and the future generation of facilities. Given that the resources available for ground-based and space astronomy have already reached a level where further growth will probably not continue at the same pace, it will hardly be possible to do all what has been written into roadmap plans, or at least not in the timeframe for which the plans have been made. The United States have experienced this already with their last Decadal Plan, and in Europe we have to be careful that we keep the balance between high ambitions and reality.

As an example, the ESA Cosmic Vision plan contains scientific objectives which would require to launch many more missions than will be possible in the next 10-15 years. In the end, scientists must judge for themselves if they see a realistic chance for a mission coming in their field of interest, or if they turn away to other activities. As we have tried to explain above, some new developments inevitably have a very long lead-time, and they should be undertaken, despite the many years of "no guarantee" that the R&D work will ever bear fruit and produce scientific results in a future project. The more so as the concept, whereby a new facility like *e.g.* a big new telescope and its focal plane instrumentation can be developed (almost) independently from each other, may no longer be valid. The E-ELT, mentioned above, seems to be a good example for this.

Such developments make coordination all the more important. The platforms for exchange of information and coordination that have emerged over the past two decades seem promising. Initiatives and pressure for new

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projects must still be developed by individual scientists, but they need an audience, first their colleagues, then the technical experts, and then the decision makers, to whom they can talk.

When it comes to setting priorities and that will be more and more needed, scientists should always remain in charge. Scientific ambitions can in general be translated into rather firm technical requirements. After translating these into technical options that are feasible, possibly after some special development effort, it should in theory be possible to determine the cost of a project with some accuracy, leaving an uncertainty of say less than 20%.

The question is how the scientific prioritization and the cost information are put together. This normally happens when the focus switches from the individual project to a multi-year implementation plan in which several projects have to find their place within a given envelope, and where one perhaps even wants to keep some room for flexibility. This is normally handled at a level where the wider scientific community is not directly involved. But that may change with the new possibilities for more direct communication between scientists, organizations, funding agencies and government representatives. Astronomy can only benefit from this because it has a strong scientific case to make.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 43-71
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SCIENCE TRANSFORMED? REFLECTIONS ON PROFESSED CHANGES IN KNOWLEDGE PRODUCTION

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Abstract. Universities are central institutions in the current knowledge society. Their role is to provide new scientific and technological knowledge, to educate people to serve the society and to alleviate societal problems of various kinds. Because of their importance, universities have been streamlined to make them more efficient and capable of fulfilling their scientific, economic and social missions. Simultaneously, the separate institutional spheres of science, university, government, industry and the civil society have intermingled giving rise to many theoretical interpretations that underline the professed radical change of universities and sciences. Of these theories, the current article focuses on two, namely, the Mode-2 knowledge production and triple-helix of university-industry-government relations. The triple-helix model claims that the increasing interaction between university, industry and government has given rise to a new kind of research that not only seeks to advance knowledge but also tries to attain commercially viable products. The Mode-2 thesis, in turn, argues that science is being fused with other forms of social practice, such as industrial development and societal problem-solving. The present article summarizes the major viewpoints of these theories and reflects on the commentary given to them. To better understand their vices and virtues, the article also analyzes their distinct theoretical statuses and claims that Mode-2 represents a specific kind of sociological theory, the diagnosis of an era, while triple helix is more ambiguous combining three types of theory, namely, diagnoses of an era, general sociological theories and empirically-based research theories. The article is brought to an end by emphasizing the need for a more inductive analysis of the developments taking place in the current academia.

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1. Introduction

Within the current knowledge society, universities are central knowledge producing institutions. Their role is to provide new scientific and technological knowledge for the renewal of industrial bases of different countries, to educate people to work in different roles in society and to alleviate the societal and environmental problems of our age. The societal role of universities and sciences has also been reflected in major reforms in different countries. To combat social, economic and environmental hazards, governments have prioritized certain areas of development, such as biotechnology (Gottweis 1998), and created advisory bodies to review scientific and technical information (Jasanoff 1994). At the level of national innovation systems (Lundvall 1992), universities have been streamlined and merged to make them more efficient and capable of fulfilling their social and economic missions (Pelkonen *et al.* 2010). Universities are thus becoming organizational actors with strategic goals and effective internal management systems. This has also engendered new kinds of governance structures within universities, such as creating a stronger role of central authorities in determining organizational goals and strengthening the role of individual leaders (Bleiklie & Kogan 2007). Supported by major external funding instruments, new initiatives under the rubric of the third mission of the university have also been introduced (Nedeva 2007).

The new societal role of the university is by no means novel in a historical perspective (Geiger 1988). What is new in the current situation is, however, the broad structural movement towards an intermingling of the previously separate institutional spheres of science, government, industry and the civil society (Kleinman & Vallas 2006). In the literature, this transformation has given rise to many interpretations that underline the fact that universities and sciences have become isomorphic with other societal organizations and activities. Among the theories that have fostered this kind of understanding in the fields of science and technology studies, higher education research and research policy are the Mode-2 knowledge production (Gibbons *et al.* 1994), triple helix of university-industry-government relations (Etzkowitz 2003a), academic capitalism (Slaughter & Leslie 1997), entrepreneurial university (Etzkowitz *et al.* 2000a&b, Clark 1998, Marginson & Considine 2000), as well as post-academic (Ziman 2000) and post-normal science (Ravetz 1999).

Of these alternative theoretical models, the current article focuses on the first two notions, namely, the Mode-2 knowledge production and the triple-helix theses. These theories are the most famous and cited examples of the above-mentioned transformation theories with 2 471 (Mode 2) and 1 292 (triple helix) citations in the SciVerse Scopus bibliographic database[1].

[1]Retrieved on May 16, 2012.

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Both of the conceptualizations are similar in the sense that they claim that a radical transformation with respect to knowledge production has taken place. Characterized as the "triple helix" by Henry Etzkowitz (2003a), the increasing interaction between previously isolated institutional spheres of the university, government and industry has given rise to the kind of research that not only seeks to advance scientific knowledge but also tries to attain commercially viable products. This is precisely what the Mode-2 thesis argues, too: it states that science is becoming fused with other forms of social practice, such as industrial development or societal problem-solving (Gibbons *et al.* 1994). Given the strong influence of these models in science and technology studies, higher education research and research policy debates, I shall ask in this article: What is the theoretical status of these models and do they provide a reasonable basis for interpreting actual empirical developments?

The present article is structured as follows: After briefly summarizing the major viewpoints of these two theories, I shall delve into the commentary given about them. When doing so I shall suggest that the Mode-2 thesis represents what some scholars have called the diagnosis-of-the-era theorizing. The theoretical status of the triple-helix model, on the other hand, is more ambiguous, as it combines elements drawn not only from the diagnoses of the era but from general social theories and research theories, too. The article will be brought to an end by emphasizing the need for a more inductive analysis of the developments and contradictions taking place in the current academia.

2. Mode-2 Knowledge Production

The thesis about the Mode-2 knowledge production was developed by Michael Gibbons, Helga Nowotny, Peter Scott and co-workers (Gibbons 2000a, Gibbons *et al.* 1994, Nowotny *et al.* 2001) during the early 1990s. Sprouting from a project funded and guided by the Swedish Council for Research and Planning, the work sought to develop "a useful heuristic for those seeking to understand what is changing in the sciences and what this implies for the future of our principal knowledge producing institutions" (Gibbons *et al.* 1994, p. viii). During the subsequent years, the Mode-2 thesis became a popular topic of interest rousing intensive academic discussion and stimulating a wide range of empirical research projects.

According to Nowotny *et al.* (2003, pp. 181-184), the analysis emerged from a set of trends and tendencies present in science and technology policy. First, there has been an increase in the steering of research priorities by means of top-down approaches of thematic research programmes and foresight exercises. This has, in turn, diminished opportunities for directing

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science bottom-up, for instance, by using open calls for research proposals. The second trend, the growing commercialization of science, has been evident in terms of an increasing search for alternative research funding sources by academics in the face of declining public research budgets and of the attempts by universities to protect their intellectual property rights. Science has thus become privatized instead of remaining freely available on a public domain. Finally, the third trend, the increasing accountability of science, refers to the growing emphasis placed upon the management of research and, especially, on the use of research assessment exercises by national science and technology funding agencies. Having become professionalized activities the assessments have been transferred away from the hands of collegial academic bodies into those of special governmental agencies and university task forces.

As a result of these trends and tendencies, knowledge production has altered: it has changed from the "Mode-1 knowledge production" to a new mode called "Mode 2." According to Gibbons *et al.* (1994), the Mode-1 type of research designates reliable academic knowledge produced within autonomous disciplinary contexts. In this sort of research, there was only a little direct linkage between academic research conducted at universities and societal application of knowledge. As a result of this, boundaries between universities and other social institutions were clear and clean-cut, and academics were quite autonomous in terms of choosing their research topics and problems.

Compared with the Mode-1 science, which subscribes to reliable academic knowledge produced within autonomous disciplinary contexts, Mode-2 research takes place in "the context of application", which ascribes to the mutual interpenetration of scientific knowledge and the larger society. The relationship between science and society has thus become reflexive, meaning that not only does science "speak to society", as has always happened, but "society now speaks back to science". In the simplest of terms, this "reverse communication" is what the authors mean when they speak about contextualization of knowledge production meaning that its scope is expanded so that problems of various societal groups and organizations are set as starting points of research (Nowotny *et al.* 2001, pp. 50, 65, 106). The contextualisation has slowly crept into the very core of science while some parts of science have simultaneously oriented outwards. This has taken place via various mechanisms, such as more intensive university-industry relations, national R&D programs, or increasing consulting by academics. These developments indicate that knowledge production currently occurs within open and shifting boundaries, and is managed for the achievement of particular useful purposes. Gibbons and others call this imperative of usefulness and state that it is present in knowledge production from the

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very beginning of research projects (Gibbons *et al.* 1994, p. 4).

Science, in this view, does not have an intrinsic character in its own right but becomes intermingled with the rest of society in a place called "agora", *i.e.*, a piazza where public meetings were held in ancient Greece. According to Gibbons (1999, p. C83), agora is the space where science meets the public. As elaborated by Nowotny (2003), it is, in fact, a metaphor: "a public space, which is neither state, nor market, neither public, nor private, but all of this in different configurations. Indeed, the agora is everywhere". It has also been characterized as a place in which science and scientists receive feedback from society, namely, from the consumer and civil movements, media, research funding agencies and business life (Nowotny *et al.* 2001, pp. 206-207). The end-result of this is "socially robust knowledge", which is being produced in order to increase economic prosperity of nations, to pay attention to the needs of the users of technologies and to solve various kinds of ethical problems (ibid., p. 166).

The new kind of Mode-2 knowledge, which emerges from the agora, can be characterized as follows: it is transdisciplinary, organizationally heterogeneous, socially accountable and reflexive as well as subject to new kinds of quality control procedures. Of these epithets, transdisciplinarity refers to the mobilization of a whole range of theoretical perspectives and research methodologies in the work of solving practical problems. The creative act here lies in "the capacity to mobilize and manage these perspectives and methodologies, their 'external' orchestration, as in the development of new theories or conceptualizations, or the refinement of research methods, the 'internal' dynamics of scientific creativity" (Nowotny *et al.* 2003, p. 186).

Organizational heterogeneousness, in turn, stands for the fact that Mode-2 knowledge is produced in "virtual" communities that span across national and cultural boundaries. Mode-2 research communities are open organizations that have permeable boundaries, which makes it possible for new actors and organizations, such as think-tanks, consultancies and societal interest groups, to take an active role in the research process (Nowotny *et al.* 2003, p. 187). As s result of this, knowledge production is no longer firmly institutionalised in a single setting with homogeneous skills and experience, such as the university, but is carried out in multiple "temporary work teams and networks which dissolve when a problem is solved" (Gibbons *et al.* 1994, p. 6). Various locales and practitioners are thus involved in knowledge production, spanning from researchers from different academic disciplines to industrial scientists and other societal actors.

Social accountability and the reflexivity of the Mode-2 research implies that the research process can no longer be characterized as an objective investigation of the social or natural world but instead can be seen as "an intense (and perhaps endless) 'conversation' between research actors and

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research subjects". In other words, "problem-solving environments influence topic-choice and research-design as well as end-uses" (Nowotny *et al.* 2003, p. 187). Nowadays, various groups of people are more aware than before of the ways in which science and technology affect nature and society. As a result of this, they also are interested in influencing the research process. Social accountability thus permeates the whole of the research process, from the definition of research problems to the interpretation and diffusion of the end-results (Gibbons *et al.* 1994, p. 7).

Finally, Mode-2 knowledge is subject to new kinds of quality control procedures. Because knowledge production no more relies on stable disciplinary structures, the traditional form of academic quality control – peer review – is no longer applicable. Instead, the quality of the research outcomes is "determined by a wider set of criteria which reflects the broadening social composition of the review system" (Gibbons *et al.* 1994, p. 8). Due to the more intensive interaction among various kinds of actors, strong social responsibility and accountability permeate the Mode-2 research. This is to say, a broader set of social interests act as new quality control criteria vis--vis the internal scientific peer review of Mode-1 science (ibid., p. 32-33).

Despite the general shift from Mode 1 to Mode 2, there is not, however, any clear historical demarcation line where the former ceased and the latter started. Instead, the change has been gradual and, at present, both modes are said to coexist (Gibbons *et al.* 1994, pp. 9, 14). According to the protagonists of the model, a prime example of Mode-2 science is biotechnology, where researchers no longer try to reveal "the basic principles of the world" but seek to produce specific commercial applications and understand "concrete systems and processes" related to such applications (ibid., pp. 23-24, 147). The main differences between the two modes of knowledge production are depicted in Table below.

The contextualization of knowledge not only pertains to the ways in which new knowledge is being produced but also applies to the institutional structure of university. The authors state, that the demarcation between universities and other organizations, such as industrial enterprises, has eroded and university scientists have become more responsive to the needs of industry. Universities have therefore become "stretched" institutions encountering competitive and even contradictory demands, such as missions to produce new scientific knowledge and to satisfy mass education demands (Gibbons *et al.* 1994, pp. 70-89, Nowotny *et al.* 2001, pp. 79-94). When it comes to the relationship between scientific research and commercial development, the different societal roles of the university may be mutually sustaining, too. This is the case, for instance, with "hybrid institutions" (*e.g.*, small and medium-sized high-tech companies) that play a decisive role in increasing the contacts between universities and industries

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TABLE 1. Descriptions used by Gibbons (2000b, p. 40) to differentiate the two modes of knowledge production.

Mode-1 Knowledge Production	**Mode-2 Knowledge Production**
Problems set and solved in a context governed by the interests of a specific academic community	Knowledge produced in the context of application
Disciplinary knowledge	Transdisciplinary knowledge
Homogeneity of skills	Heterogeneity of skills
Hierarchical organizations that tend to preserve their forms	Flat hierarchies and transient organizational structures
Less socially accountable and reflexive	More socially accountable and reflexive
Quality control based on peer review	Expanded system of quality control which is based on a wider, more temporary and heterogeneous set of practitioners, collaborating on a problem defined in a specific and localized context

(Gibbons *et al.* 1994, pp. 137-138, 144). Biotechnology, again, is a field of study where these developments have been most prominent. In that area, the traditional separation between university and industry has broken down as university-based scientists not only routinely move into entrepreneurial roles but governments worldwide encourage academics to team up with outside firms or, alternatively, to start up their own companies (Nowotny *et al.* 2001, p. 60).

The emergence of Mode-2 science is not an isolated phenomenon but parallels wider transformations in society, too. As claimed by Gibbons (2000a, p. 160), openness in knowledge production "reflects, and is reflected in, the emergence of a more open type of society." The whole of society has thus become transgressive, meaning that such modern categories as science, politics, culture and the market have become subject to the same co-evolutionary trends and have started to invade each other's domains (Nowotny *et al.* 2001, p. 4). As a result of this, it has become increasingly difficult to determine where one institution ends and the other begins. The end-result of this is the Mode-2 society, which is characterised by "an overall increase in complexity which embraces a pervasive uncertainty in social relations, greater institutional permeability, the emergence of new forms of economic rationality, the emergence of a greater degree of self-organization

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amongst social actors, and a profound shift in our perceptions of time and space" (Gibbons 2000a, p. 160). Emphasising the convergence between the institutions of university, industry and government the concept of Mode-2 society shifts the argument in the direction of the triple-helix view, a theory which will be addressed next.

3. Triple Helix of University-Industry-Government Relations

A closely related idea to the Mode-2 knowledge production is "the triple helix of university-industry-government relations" introduced by Henry Etzkowitz (1998) during the mid-1990s. Having emerged from Etzkowitz's earlier research on university-industry relations the triple helix is a metaphor representing the close interaction and, indeed, increasing overlap between previously separate institutional spheres of the university, industry and government. The basic idea behind the metaphor is simple: it states that in the era of knowledge society, university, industry and government have equal roles in enhancing innovation through more intensive mutual interaction. According to Etzkowitz *et al.* (2007), the triple-helix model, depicted below, comprises three basic elements:

1. a more important role for the university in fostering innovation,
2. a movement toward more intensive interaction and collaboration between the institutions of university, industry and government, and
3. transformation of the conventional functions of the above-mentioned institutions so as to take the role of the other.

In the knowledge-based society, the central function of the triple-helix interaction is to stimulate innovation. This is especially pursued by new, hybrid forms of organizations and networks located at the section areas of the triple-helix model. According to Etzkowitz & Viale (2010, p. 596), the whole of society is being transformed "as public-private dichotomies in knowledge, institutions, organizations and roles evolve from pure-bred to hybrid". Because different countries have dissimilar histories before entering into the knowledge-based society, the model takes, however, different configurations in different parts of the world (Etzkowitz & Leydesdorff 2000). Etzkowitz *et al.* (2007) differentiate between three distinct routes to triple-helix relations.

In the first of them – the statist Triple Helix I, which is found, for instance, in the former Soviet Union and China – the nation state encompasses the university and industry and directs their mutual relationships through central planning and coordination mechanisms. Here, it is the role of the government to pull the other two spheres into collaboration with one another to foster successful innovation.

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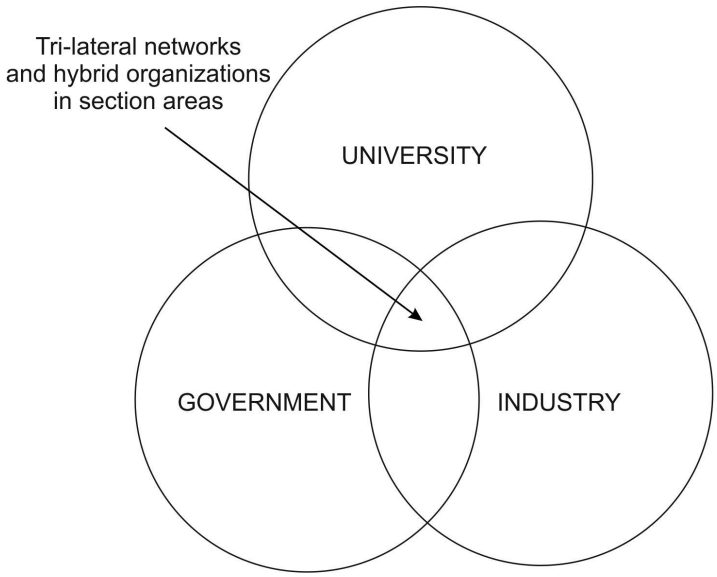


Figure 1. The triple-helix model (adapted from Etzkowitz 2003a, p. 302).

The second triple-helix configuration – the *laissez-faire* Triple Helix II exemplified by the Unites States, Canada and Sweden – consists of three separate institutional spheres with strong borders and highly circumscribed relations among them. In this model, each institution has a single purpose: For the university it is to provide research and educated personnel. The role of the government is limited to solving problems that inhibit the proper operation of the free market. Industry, in turn, consists of independent firms operating in a competitive market environment so as to turn scientific inventions into commercial innovations.

Finally, the third variant of the model – the interactive Triple Helix III – denotes a knowledge infrastructure made up of overlapping, yet relatively independent institutions that take the roles of each other and produce hybrid organizations. In this variant, which is sought for in most of the countries, the "objective is to realize an innovative environment consisting of university spin-off firms, tri-lateral initiatives for knowledge based economic development, and strategic alliances among firms (...), government laboratories, and academic research groups" (Etzkowitz & Leydesdorff 2000, p. 112). Here, the role of the university is to contribute to firm-foundation and regional development, in addition to its traditional missions of scientific research and higher education. The government seeks to support commercialization of university research by means of providing tax incentives, venture capital and developing a regulatory environment. The industry, in

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turn, pursues its economic mission in addition to taking "the role of the university in developing training and research, often at the same high level as universities" (Etzkowitz *et al.* 2007, p. 16). According to Etzkowitz *et al.* (ibid.), the Triple Helix III is the type of institutional relations presently sought after by most countries and regions.

As often claimed by Etzkowitz, countries all around the globe are presently on the threshold of a new era: the next great transformation, already well underway, is the coming of the Triple Helix III, that is, the increasing interaction and overlap between the university, industry and government. The characteristic feature of this radical change is the fact that it leads to the transformation of each of the three institutions mentioned above. While the Mode-2 thesis underlined the de-institutionalization of the current mode of knowledge production the triple-helix model suggests, in a similar vein, that universities and industries are taking the roles of each other; that is, universities start to emphasize entrepreneurial tasks simultaneously as industrial enterprises take on the academic dimension of sharing knowledge and training employees (Etzkowitz *et al.* 1998, Etzkowitz *et al.* 2007). Such a dynamic is currently evident, for instance, at the level of research practice: By putting forth the notion of "an entrepreneurial science", Etzkowitz draws attention to the simultaneous presence of theoretical, methodological and commercial dimensions of research and highlights the integration of academic investigation with corporate activity (Etzkowitz 1998, pp. 826-827).

Etzkowitz & Leydesdorff (1997, 1998 & 2000) claim, indeed, that the economic logic is strengthening within universities, consequently boosting the commercialization of academic knowledge and transformation of the traditional university into an entrepreneurial organization. This process begins, according to Etzkowitz (2011), through internal transformation of academic research groups into "quasi-firms". Research groups that are called quasi-firms are firm-like entities that are managed by professors who no longer work at the laboratory bench but devote most of their time and energy to acquiring research funds, managing collaborative relations and taking care of other organizational tasks (Etzkowitz 2003b). Once these quasi-firms start directly to participate in the capitalization of knowledge and technologies, the university begins to transform itself into an entrepreneurial one.

The "entrepreneurial university" involves the incorporation of the traditional academic mission – "the extension of knowledge" – into a compatible relationship with the "capitalization of knowledge". In other words, scientists in many fields start to look at their research results from the viewpoint of commercial potential in addition to theoretical and methodological advancement (Etzkowitz 1998, pp. 824-829). The entrepreneurial university

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is thus a hybrid organization which incorporates "the third mission" of the university – that is, economic development – alongside scientific research and higher education. Being supported by national and supra-national innovation policies this entails, at the level of the university organization, establishment of technology transfer offices, science parks and business incubators, as well as various kinds of administrative offices and committees that respond to problems and opportunities created by emergent entrepreneurial activities (Etzkowitz 2003b, Etzkowitz 2011).

The entrepreneurial science that sprouts from the triple-helix relations becomes institutionalized not only at the level of the university organization but at the normative structure of science, too. Here, Etzkowitz (2011) builds on the work of a famous sociologist Robert K.Merton. According to Merton (1942/1959), science is characterized by a particular kind of cultural ethos that guides the appropriate scientific practice and supports the goal of science – the extension of certified knowledge. The ethos of science is manifested by a set of institutionalized imperatives – universalism, communism, disinterestedness and organized scepticism[2] – that reward those who follow the norms of science and sanction those who violate them.

The norms of science as articulated by Merton are not compatible with entrepreneurial science, which seeks to privatize knowledge and gain economic benefits from it. According to Etzkowitz (2011), a normative change in academic science is, therefore, going on. Instead of defining entrepreneurial scientists as deviant, the new set of norms, currently emerging, supports entrepreneurship. During the 1980s, for instance, as the US patent legislation was altered, the Mertonian norm of communism, *i.e.* collective ownership of scientific findings, was modified to "'limited secrecy', with research results kept under wraps until their economic value could be protected" (ibid., p. 551). Etzkowitz claims that the same holds for disinterestedness, too: Scientists are no longer required to disengage their personal interests from their work but they may have personal economic and social interests that drive their research problems (ibid., p. 552; also Dzisah 2010). The new emerging norms of science do not, however, replace older norms once and for all but become conflated with them. This is done in various ways, for instance, by showing that entrepreneurial activities are in accor-

[2]Merton (1942/1959) describes the norms as follows. Universalism requires that the evaluation of scientific claims is made using pre-established impersonal criteria: "the acceptance or rejection of claims [...] is not to depend on the personal or social attributes of their protagonist; his race, nationality, religion, class and personal qualities are as such irrelevant (ibid., p. 553). Communism states that findings of science are to be kept a product of social collaboration and are thus owned by the scientific community. Disinterestedness refers to the pattern of scientists to disengage their personal interests from their work, implying a virtual absence of fraud in science. Finally, organized scepticism refers to the tendency of the scientific community to avoid making claims on issues that are not yet firmly supported by data.

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dance with research and teaching through the establishment of technology transfer organizations, or by means of creating organizational policies to deal with conflicts of interests. In doing so, universities "produce rationalizations to show how old norms are not violated by new forms of behaviour, thus laying the foundations for normative change" (ibid., p. 561).

In Etzkowitz's (2002a, p. 121) perspective, the emergence of the entrepreneurial university is an irresistible, unavoidable development: it "is not so much a matter of evolution, the capture and retention of change events, but of an internal dynamic working itself out." Because of this internal dynamic, the emergence of the entrepreneurial university is not confined to some particular countries or regions but is a phenomenon observable all over the world (Etzkowitz *et al.* 2000a&b). In his research, Etzkowitz has found examples of entrepreneurial universities from the United States (Etzkowitz 2002b), the Netherlands (Etzkowitz *et al.* 2007), Canada (Etzkowitz *et al.* 2007) and Sweden (Etzkowitz & Klofsten 2005). Furthermore, he is convicted that this tendency will become even stronger in the future: "The University of the Future" will be a business incubator entirely. That is, the technology transfer and incubation of new firms will convert from happenstance into a permanent activity, taking place in each and every department. Even the potentially controversial activities of the contemporary university – academic research, higher education and societal service – do not hinder this development as the university incorporates these functions and reconciles their apparently contradictory objectives (Etzkowitz 2002a, p. 127). In effect, various kinds of problems are just symptoms of the changing role of the organization. These will disappear as the new type of university takes hold: "the 'opposing' norms and orientations are reinterpreted, emphasizing harmony rather than disharmony, mutual reinforcement rather than detraction from each goal" (Etzkowitz 2003b, p. 116).

Having been initiated in the mid-1990s, the constant flow of research associated with the triple-helix model and the entrepreneurial university has evidenced the vitality of the original idea. The research utilizing the model has gained momentum by means of an international Triple Helix Association[3] and a set of regular triple-helix conferences. Because these institutions gather together not only academic researchers but policy-makers and administrators, too, triple helix has evolved from being a descriptive framework and an analytic tool into a normative model used in many countries and regions to foster technological innovation and economic growth. An early example of developmental use of triple-helix was a stage model of knowledge-based regional development, which consisted of four phases:

[3] http://www.triplehelixassociation.org/

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1) developing the idea of a new regional model,
2) starting new activities,
3) the consolidation and adjustment of activities and
4) self-sustaining growth (Etzkowitz & Klofsten 2005).

Later on, the developmental models based on the triple-helix idea were directed at improving the innovation systems of the third world countries by means of putting the basic elements of an innovation system in place and by enhancing the circulation of people, ideas and innovations between the three helices (Dzisah & Etzkowitz 2008).

Furthermore, the analytical and developmental use of the model in such diverse societal settings as Germany, Sweden, China, Brazil and Ethiopia has led to theoretical divergence of the model from the original idea. Etzkowitz, in collaboration with Zhou, has, for instance, proposed a distinct concept of sustainability triple helix to complement the innovation-related triple helix described above. The central difference between the two is to substitute public for industry in order to account for issues of public concern, such as controversies over new technologies (Etzkowitz & Zhou 2006). Another major theoretical development within the triple-helix literature is the difference made between neo-institutional or neo-corporatist interpretation of the triple helix, represented by Etzkowitz, and the systems-theoretical evolutionary model developed by Leydesdorff (1996, 2000 and 2005) and Viale and co-workers (Viale & Campodall'Orto 2002, Viale & Pozzali 2010). Only time will tell whether or not these and other developments will lead to a strengthening of the triple-helix model or cause its gradual disintegration into competitive rival camps.

4. Reflections on the Two Models

Clearly, as brought out by some commentators (Audétat 2001, Krücken 2002, Shinn 1999, Weingart 1997), the Mode-2 thesis and the Triple-Helix model are important attempts to come to grips with many recent phenomena concerning the university research, its societal application and the broader institutional framework within which universities currently operate. For instance, they draw attention to the practicality of research, to the direct collaboration between university research groups and industrial enterprises as well as to the emergence of hybrid modes of activity. It might well be that some of these, such as the extensiveness and the diversity of university-industry networks, are signs of something new coming up; that is, they are cues for fundamental changes taking place in some high-technology industries, such as biotechnology (*e.g.*, Powell *et al.* 2005). Moreover, it has been claimed that the significance of these relations has increased over time: The excitement about industrial involvement in university research should

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thus not be received with a déjà-vu attitude but rather the distinctive nature of the current situation should be appreciated. First, the industry is willing to make huge, long-term contractual commitments supporting university research. Second, the universities are apparently eager to seek out these contracts. Third, there is a whole diversity of new arrangements that have been worked out by governments and universities to facilitate technology transfer, such as those listed in the previous sections (Geiger 1988).

4.1. CONTESTED CHARACTERISTICS OF MODE 2

Since its publication in 1994, the thesis about the emergence of the Mode-2 knowledge production (Gibbons *et al.* 1994) has been very influential in the field of science, technology and innovation studies. Most of the citations it has received are, according to Hessels & van Lente (2008) positive, treating the model as an accepted description of the changes in the sciences during the recent decades. These articles, however, do not usually scrutinize the key contents of the Mode-2 thesis but use it as a general conceptual framework for empirical research that is being reported. An example of this sort of research is the description of orphan drug networks by Crompton (2007) who examines the ways in which the lay public contributes to the knowledge production in medicine. Another example is provided by Bruun *et al.* (2005) who use the distinction between Mode 1 and Mode 2 in classifying university departments and provide policy recommendations on that basis for smooth transition from Mode 1 to Mode 2 research education.

In addition to such positive applications of Mode 2, a significant part of the literature takes the legitimacy of the model as a contested issue and puts its validity to the test (Hessels & van Lente 2008). This literature can be grouped into two categories:
1) studies that empirically investigate the legitimacy of individual attributes given to Mode 2 and
2) those that criticize the model's political underpinning and normative character.

When it comes to the first group of research, the theory is generally regarded as fairly problematical. In addition to the fact that it has been seen to underestimate the relevance of path-dependent trajectories and the boundaries of established scientific organizations and institutions (Jansen 2002, Krücken 2003, Shinn 1999), the model's assertion that the nature of scientific research has altered during the recent decades has been questioned. In contrast to the claim made by Gibbons and others, Etzkowitz & Leydesdorff (2000, pp. 115-116), for instance, state that Mode-2 science is not a new phenomenon at all. Referring to a dissertation by Merton (1938), the authors argue that about half of the discoveries in the seventeenth cen-

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tury had their origins in attempts to solve the problems of navigation, mining and so forth. Therefore, rather than being a novel phenomenon, the Mode-2 type of research was the original form of science prior to its institutionalization into the university system in the nineteenth century. Similarly, Godin (1998, pp. 470-474; also Pestre 2003 and Edqvist 2003) refer to a number of historical studies and claim that research has always shifted between fundamental and applied spheres. Indeed, there is a long tradition in science and technology studies claiming that science always should be seen in relation to society (*e.g.*, Bernal 1967). In line with this, Muller (2000, p. 79; also Fuller 2000, pp. 79-80), in turn, argue that the Mode 2 thesis over-dichotomizes the evolution of science and presents it as two discrete ideal types that probably never existed in a pure form in the real world. On the other hand, Rip (2000, pp. 35-36), describing the European Renaissance from the 14th to the 16th centuries, states that the ambivalent position of the so-called professors of secrets, who collected recipes from different crafts and sold them to sponsors, closely resembles that of present-day biotechnologists and other scientists working in commercially important areas.

In addition to the historical perspective, different characterizations of the Mode-2 science have been subjected to empirical scrutiny. When it comes to the transdisciplinarity, that is, the claim according to which the Mode-2 research is pursued by a diverse range of specialists to solve practical, social problems, Bonaccorsi (2010) suggests that collaboration across specialisms may be motivated, not only by efforts to solve societal problems, but by intrinsic, internally driven motivation to produce valid knowledge, too. Godin (1998) and Weingart (1997), in turn, reject the claim that recombination of different disciplines is a new phenomenon. In their perspective, research has always involved an amalgamation of elements coming from different fields of research. Weingart also notes that one should be very careful when speaking about transdisciplinarity: What may appear to be trans- or interdisciplinary research at the research program level may well turn out to be disciplinary research at the level of actual research practice.

The Mode-2 science also involves a heterogeneous combination of actors coming from different walks of life. In their bibliometrical study, Godin & Gingras (2000) indeed find that there is an increase in the share of scientific publications that includes non-university actors as contributors. On the basis of data coming from Norway, Gulbrandsen & Langfeldt (2004, p. 246) come to an opposite conclusion: "With the exception of a few, entrepreneurially oriented professors, we find little support for the 'Mode 2' proposition that these sectors [*i.e.*, basic and applied research, JT] are converging". Weingart (1997), in turn, claims that the issue is very much contingent upon the country and field of research under investigation. Because

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organization of research differs from country to country and from industry to industry, as does the type of knowledge, careful comparison is needed "to distinguish fact from fad" (Weingart 1997, p. 595).

The Mode-2 knowledge production is also characterized by novel types of quality control. According to Gibbons *et al.* (1994, p. 8), Mode-2 knowledge is determined by "a wider set of criteria which reflects the broadening social composition of the review system". Positive results supporting this thesis are provided by Hemlin & Rasmussen (2006) who argue on the basis of illustrative case examples from Scandinavia, that traditional quality control is giving way to quality monitoring. In other words, the emphasis is being shifted from the cognitive control of products of science to an ongoing organizational monitoring of entire research processes. Interestingly enough, the attempt by Albert *et al.* (2012) to empirically test the possible change in quality control procedures in the field of Canadian health sciences produces opposite results: The vast majority of academics are aligned with the traditional Mode 1 peer-review. Similar kinds of results are presented by Gulbrandsen & Langfeldt (2004) on the basis of Norwegian data.

This sort of counter-evidence lends support to the judgment that the Mode-2 thesis is very controversial in terms of empirical evidence. Therefore, it seems to be the case that the model overstates the change science has undergone while simultaneously dismissing relevant earlier literature and empirical research results. Given the fact that the validity of the different attributes of the Mode-2 knowledge production are contentious there seems to be no reason to tie them together under a common heading – the Mode 2 (Hessels & van Lente 2008). Doing so, makes the model seem "one-eyed and reductionist," mainly focusing on "a relatively small – albeit significant and dramatically changing – domain of the vast diverse landscape of science in society" (Elzinga 2002, p. 3). This conclusion is further substantiated by empirical evidence provided by Ylijoki *et al.* (2011) as well as Heimeriks *et al.* (2008) who claim that scientific enterprise is a very heterogeneous entity as a whole. We might thus let Mode 2 go away, as such, and concentrate our future efforts on better understanding the different kinds of trends that are going on in different kinds of sciences in different countries.

An additional point of criticism has been that the Mode-2 thesis has a close affinity to the political neo-liberalism and the language of innovation policy (Häyrinen-Alestalo 1999, Krücken 2002, Shinn 2002, Weingart 1997). Terry Shinn (1999, p. 172), for instance, maintains that the Mode-2 argument easily links to "a partisan political agenda and ideology" rather than "a serious-minded history and sociology." Hence, it seems that "The New Production of Knowledge" is neither a solid empirical study nor a general sociological theory, but rather a type of theory Noro (2000) calls a diagnosis

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of the era (also Tuunainen 2002). As discussed by Noro, diagnoses of the era usually are normative and seek to generate new topical insight instead of building elaborate theoretical models or data-bound research theories. As such, diagnoses are messages sent out from scholarly discussion to a wider learned public. Their primary place is not so much within scholarly deliberation but rather in broader societal and political debate. Therefore, as noted by Noro, one should not simply seek to verify or rebut their general vision; that would be way too difficult because of their overly-abstract nature.

Given the wide publicity and heated debate over the central characteristics of the Mode-2 thesis, this seems to be true indeed. Many scholars have explicitly noted that the advantage of the model is that it gives food for thought and opens up new interesting questions (Edqvist 2003, Krücken 2002, de la Mothe 2003, Strathern 2003). These kind of "performative histories" (Godin 1998) may thus be effectively used in policy-making, as illustrated by Mode 2 in the context of South African higher education policy (Kraak 2000). The strong affinity of Mode 2 with the diagnoses of the era is further substantiated by Gibbons's (1994, p. viii) avowal that the style of the work was largely set by a governmental agency, namely, the Swedish Council for Planning and Coordination of Research, and that the book should be taken as a "heuristic for those seeking to understand what is changing in the sciences and what this implies for the future of our principal knowledge producing institutions."

4.2. AMBIGUOUS NATURE OF TRIPLE HELIX

Whereas the Mode-2 thesis has over the years been expanded into an increasingly abstract and encompassing theory concerning the place of knowledge production in the post-modern age, the triple helix has a stronger empirical footing. When it comes to the thesis according to which there is increasing interaction between different institutional spheres of society, the empirical research done in different countries confirms the thesis on a general level. One example of the countries studied is Finland, which belongs to the leading knowledge-based economies in the world (*e.g.*, Dahlman *et al.* 2007).

Drawing from the triple-helix idea, Kaukonen & Nieminen (1999) claim that there has been a long-term transition in Finland towards more intensive university-industry-government relations. These connections began to evolve in the late 1970s, as research expenditures increased substantially in private industry and in governmental research institutes while the relative share of research funding of universities declined. As a result of this development, which continued throughout the 1980s and 1990s, the entire

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Finnish research system was gradually restructured and the priorities of the national science and technology policy were altered (Kaukonen 1987, p. 24; Nieminen & Kaukonen 2001). The authors, then, assume that these changing funding patterns and the related competitiveness-oriented innovation policy reveal a transformation of the relationships between universities and industries. Although the statistical data used by Nieminen & Kaukonen (2001) did not allow for the analysis of actual interactions between universities, government and industries, the authors (Nieminen & Kaukonen 1999, p. 338; also Kivinen & Varelius 2003) argue that it is justified to speak about the development of "a Finnish Triple Helix." Similar results emphasizing a general transition towards closer interaction between the three institutional spheres of society have also been found in other countries, including the United States (Giesecke 2000), Germany (Leydesdorff & Fritsch 2006), Sweden (Benner & Sandström 2000), Singapore (Leong *et al.* 2008, Wong 2007), Malaysia (Razak & Saad 2007), China (Zhou & Peng 2008), Mexico (Rivera Vargas 2010) and Brazil (Etzkowitz *et al.* 2005).

As a result of the more intensive interaction across institutional spheres, different kinds of intermediary organizations, such as foundations, associations and consortia, have developed on the inter-institutional borderland. While drawing attention to these certainly is the strength of the triple-helix model, it is regarded as its weakness, too. Amy Scott Metcalfe (2010), for example, complains that the model is limited in its reliance on the three institutional sectors of the university, industry and government. In her view, this structural bias inhibits understanding of the influences sprouting from other kinds of organizations, including independent actors like patenting and licensing companies and technology transfer units. In agreement with this, Nina Suvinen *et al.* (2010) propose that the intermediary organizations should be implemented in the triple-helix model as independent elements, in addition to which their differential roles in dissimilar regional or sectoral circumstances should be appreciated. One approach to this direction is provided by the process-oriented model of an intermediary organization developed by Metcalfe (2010, pp. 507-509).

According to the triple-helix model, the increasing interaction between university, industry and government not only brings about the birth of intermediary actors but also induces transformation of each of the institutions, either through innovative individuals (Göktepe-Hultén 2008) or changing governmental policies (Zhou & Peng 2008). As maintained by Etzkowitz (2003a), this holds true for all major organizations, including the traditional university, the transformation of which into an entrepreneurial university is a major line of research within the triple-helix literature. Catholic University of Leuven (KU Leuven) is an early example of a European university, which has transformed itself into an entrepreneurial mould (Etzkowitz *et*

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al. 2007). Already since the 1970s, the university established a technology transfer unit, KU Leuven Research and Development (LRD), which played an essential role in the development of entrepreneurial capabilities of the university's personnel. Unlike other Flemish universities, where technology transfer was managed through regular university administration, LRD enjoyed considerable autonomy at KU Leuven while still being integrated into the university structure. LRD was free to manage the revenues earned from entrepreneurial activities, which helped it to create a broad spectrum of advisory, co-ordinating, administrative and clearing services that made it a model for other universities in terms of supporting academic entrepreneurship. The results of LRD in promoting commercial activities were substantial: at the turn of the millennium, the university owned 171 patents, in addition to which it co-ordinated 58 spin-offs and provided 24 per cent of KU Leuven's R&D budget. Other case examples of operating or emerging entrepreneurial universities include the prestigious US universities, such as MIT (Etzkowitz 2002b) and Stanford University (Etzkowitz 2003b) as well as the University of Saskatchewan in Western Canada (Etzkowitz *et al.* 2007), Lund University in Sweden (Göktepe-Hultén 2008) and the University of Singapore (Leong *et al.* 2008, Wong 2006). Initial steps towards entrepreneurial activities in universities have also been found in China (Zhou & Peng 2008).

This empirical evidence is convincing in demonstrating that commercial exploitation of research results has become an all the more important mission of contemporary universities. Etzkowitz and his co-workers (Etzkowitz 2002a & 2003b, Etzkowitz *et al.* 2000a, Etzkowitz *et al.* 2008) pursue, however, a stronger interpretation of the recent developments than this. They not only assert that some universities are increasingly engaged in supporting entrepreneurship through auxiliary structures and functions, such as technology transfer units, but claim that the university's evolvement into an entrepreneurial one is an all-encompassing, inevitable and global phenomenon covering all types of organizations in each and every country. Furthermore, economic functions, such as incubation of new firms, will be spread throughout the university structure: Incubation will be decentralized, that is, it will become a regular feature in each department or academic unit (Etzkowitz 2002a, p. 127). This bold thesis is often substantiated by chronicling the histories of MIT and Stanford and holding that other institutions worldwide are emulating these models. While this is evidently true for some universities, as indicated above, there are opposite findings, too, that assert that only a minority of academics and universities are highly-oriented towards financial activities (*e.g.*, Albert 2003, Deem & Johnson 2003, Harrison & Leitch 2010, Philpott *et al.* 2011).

Further evidence on the problematic nature of the entrepreneurial uni-

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versity thesis is provided by studies that shift the analytical focus away from the university organization to the actual practices that take place at the grass-roots level of university departments. Juha Tuunainen (2005), for instance, studied a case of a hybrid firm at the University of Helsinki, Finland. A hybrid firm is a company that straddles the public and private spheres of activity. It is a commercial enterprise which is still located "within the university and dependent on the university for a degree of administrative and financial support" (Etzkowitz *et al.* 2000b, p. 320). Because the staff of such a firm occupies academic and company positions concurrently, the hybrid firm may be regarded as a useful touchstone for the viability of the entrepreneurial university model in practice. In the case analyzed by Tuunainen, serious conflicts emerged between the members of the hybrid firm and the university administrators. As a result of this, the hybrid entity was eventually abandoned and the firm sealed away from the university department in a peripheral organizational position, with the business incubator operating in a science park. Tuunainen takes this case as counter-evidence for Etzkowitz's assertion that commercial impulses penetrate the entire university organization in a straightforward and thorough manner. In contrast to this, he suggests that a distinction should be made between special intermediary structures that assist technology transfer within the university and the core academic units, such as departments. While the auxiliary parts of the university may, indeed, reach out to the corporate world, the academic core may still dissociate itself from entrepreneurship. These results were later augmented by another study with essentially similar kinds of results (Tuunainen & Knuuttila 2009).

Commenting on this case study, Etzkowitz & Zhou (2008) draw attention to a normative shift that is probably going on in the case university: The initial negative reaction of the university administration to the existence of the hybrid firm may not remain valid in the long run. In their perspective, the normative change within evolving entrepreneurial universities incorporates gradual resolution of conflicts by means of re-interpretation of the commercial activities as broadly compatible with existing university activities. This is to say, controversies over entrepreneurship are indications of ongoing transformations and they will be reconciled in terms of new normative structures that make business activities compatible with the advancement of knowledge (Etzkowitz 2011). Tuunainen & Knuuttila (2008), in their study on the normative change at the grass-roots level of the university departments did not find, however, any sign of this but concluded that the scientific community and the university institution are still largely operating according to some rather stable, traditional norms of science, such as the primacy of teaching and research over commercialization and the collective ownership of research results. In comparison to academics, the role

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of technology transfer officials in the maintenance of boundaries between organizations is different; these professionals make efforts to accommodate academic and commercial norms for one another while simultaneously protecting academia from direct entrepreneurial influence by setting the terms of exchange between the two institutional spheres (Sanders & Miller 2010).

So, what should be concluded on the basis of a debate like this? First, the point made by Etzkowitz & Zhou (2008, p. 633) is evident: To pursue entrepreneurial science is a highly risky venture in a university bound by traditional principles of separation between research and commercial activities. Finding a balance between commercial activities and research and teaching is, thus, an ongoing practical debate, the results of which are far from certain. The second lesson to be learnt from the case example is the fact that a more differentiated understanding of the university's internal structure should be made within the triple-helix literature. Otherwise put, universities are complex entities that may simultaneously incorporate contradictory activities in different parts of their organization. It is thus questionable to make broad generalizations about the university's overall development without simultaneously acknowledging that goals and missions may differ from one internal unit to another. Third, universities and disciplines they cater for are dissimilar: While universities may lean towards commercialization, this general pattern may be differentiated, not only by university type (Häyrinen-Alestalo *et al.* 2000) but also according to scientific disciplines and specialties; some universities and departments may be nearer to industry than others (*e.g.*, Martinelli *et al.* 2008, Mathieu *et al.* 2008, Nieminen & Kaukonen 1999, Ylijoki 2003). This does not necessarily retard their economic impact, however. As concluded by Mathieu *et al.* (2008, p. 678), universities do not need to turn "all entrepreneurial" in an organizational sense to contribute to national or regional prosperity.

Finally, it is important to note here that the triple-helix thesis is not intended to be an empirical description or analytic device only; it involves a strong political aspect as well. In line with this, Dzisah & Etzkowitz (2008) suggest that triple helix should be regarded as a developmental method of creating more effective innovation systems especially in developing countries. Despite the limited analytical capacity of the triple-helix model (Suvinen *et al.* 2010) several scholars have made attempts to develop the innovation systems of their particular countries by using the triple helix as a normative ideal and methodological tool. Examples of this involve the application of the triple helix as a motor for developing telematics in Portugal (de Castro 2000) or university-industry relations in Latin America (Sutz 2000). Etzkowitz (2003a, p. 334), too, refers to the triple helix as providing a useful framework for knowledge-based economic and social development. On the basis of comparisons made between the USA, Japan, Sweden and

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Brazil, he and his co-workers (Etzkowitz *et al.* 2008), for instance, suggest that it is high time to make massive investments in the technology transfer and translational research capacity especially in Europe so as to foster the development of entrepreneurial universities. Whereas the triple helix in this mould clearly represents just another version of the diagnosis-of-the-era type of theorizing, the growing body of empirical research counterbalances and neutralizes at least some of its normative tendency and over-theorization, as noted by Elzinga (2002, pp. 15, 25).

In summary, then, the two theories are substantially different from one another with regard their theoretical statuses. While the Mode-2 thesis clearly represents diagnoses of the era type of thinking, the nature of the triple-helix model is more ambiguous. It may be characterised as a hybrid entity that combines an increasing amount of empirical evidence, overt normative orientation and a complex systems-theoretical underpinning (Leydesdorff 1996, 2000 & 2005). This means, in other words, that it involves aspects of all kinds of sociological theory discussed by Noro (2000), namely,
1) the diagnosis of the era,
2) research theories, *i.e.*, theories that are directly linked to empirical evidence of particular phenomena, and
3) general sociological theories that address very broad issues like the constitution of society or culture.

5. Conclusion

I began this article by reviewing the recent literature according to which science and the university have dramatically changed in their character. Of the many alternatives that have tried to capture the typical features of this transformation, I chose to focus on two prominent conceptualizations, namely, Mode-2 knowledge production and the triple helix of university-industry-government relations. I summarized the main points of these theories and considered criticisms directed at them. What might be concluded from such an endeavor?

Given the fact that the two theories were dissimilar in terms of their theoretical statuses, their assessment must acknowledge that difference. To begin with, I claimed that Mode-2 knowledge production was representative of diagnosis-of-the-era type of theorizing. Such "performative histories" (Godin 1998) are messages sent out from scholarly conversation to a wider learned public. As such, their primary place may not be so much within scholarly discussion but rather in broader societal and political debate. Therefore, as noted by Noro (2000), one should not simply verify or rebut their general claims. Because they usually contain components that are being developed at the levels of general sociological theories or

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empirically-based research theories, some parts of the diagnoses of the era may be subjected to sociological perusal. Mode 2 did have such elements. For instance, it made use of empirical research to substantiate its claim that the emphasis in science is being shifted from fundamental research towards a more applied orientation. Due to its all-embracing character, empirical research cannot, however, confirm or refute these sorts of general claims, as was evidenced by the controversial research results concerning different attributes of the Mode-2 knowledge production. What empirical research can do is effectively point out issues that could be better appreciated by such "diagnoses." In this respect, it was concluded in this article that the Mode-2 thesis was far too generalized and biased to provide an adequate description of today's science and university, in addition to the fact that it did not distinguish between many internal dimensions of academic research, such as differences between disciplines.

The triple helix, on the other hand, was far more ambiguous with regard its theoretical status. I claimed that it was not exclusively an example of diagnoses of the era but sought to be a research theory as well. In conjunction with many other scholars, Etzkowitz has endeavored to establish a strong linkage between the general claims of the triple-helix model and empirical data, thereby making the theory more amenable to empirical scrutiny than would be the case with Mode 2. During the ensuing debate, at least two issues have become clear. First, there can be little doubt that in recent years universities have changed in many respects. Analysts have attributed these changes to the emergence of the global knowledge economy, new public policy priorities and increased economic competition between nations. For instance, as noted by Kleinman & Vallas (2001, p. 455) "universities are increasingly viewed as mechanisms for enhancing national competitiveness." Second, while not wanting to question such general statements, which may be too obvious to contest, I would argue that the changes universities are going through are neither uniform nor pervasive. Instead of being isomorphic to one another, there are vastly different kinds of universities in today's world. Moreover, each university is comprised of various activities that are not always mutually harmonious. Therefore, it is questionable as to whether or not any all-embracing conceptualization of the transformation of the university is defensible as such.

In summary, what is problematic with the conceptualizations addressed in this article is the fact that they tend to describe transformation of science and the university through indistinct and totalizing language, which glosses over all too many important conceptual, social and institutional dimensions of academia. Instead of overarching claims, then, scientific work and universities should be seen as complex and occasionally contradictory entities whose developmental trajectories are shaped by multiple – and often

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contradictory – historical, political and cultural characteristics. Addressing these in terms of inductive empirical research would, in my opinion, give good starting points for further understanding the role of the university in the current knowledge society.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 73-98
Ed. A. Heck, © 2013 Venngeist.

ASTRONOMY IN ARGENTINA

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Abstract. This article analyses the current state of Astronomy in Argentina and describes its origins. We[1] briefly describe the institutions where astronomical research takes place, the observational facilities available, the training of staff and professionals, and the role of the institutions in scientific promotion. We also discuss the outreach of Astronomy towards the general public, as well as amateur activities. The article ends with an analysis of the future prospects of astronomy in Argentina[2].

1. Introduction

Argentina has an important scientific tradition, in which astronomy has been one of the pioneering areas. There are interesting documents recording astronomical observations carried out at the beginning of the 18^{th} century, but systematic studies of astronomy in Argentina began with the creation of the *Observatorio Nacional Argentino* (ONA, National Argentine Observatory, today the *Observatorio Astronómico de Córdoba*, see Fig. 1) in Córdoba on 14 Oct 1871. The President, Domingo Faustino Sarmiento, entrusted the study of the southern skies to the renowned US astronomer Benjamin Gould (who was the founder, among other projects, of *The Astronomical Journal*). With ONA's foundation, Sarmiento's intention was

[1]Hernán Muriel was President of the Argentinian Astronomical Society for the period 2008-2011.

[2]Although we have tried to be as objective as possible, some statements inevitably contain some personal views.

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Figure 1. The Astronomical Observatory of Córdoba. (© Hernán Muriel)

to send a clear message to the country and to the world, as he declared on the occasion of the inauguration of the new observatory: *"We should renounce our standing as a Nation, or our title as a civilized people, if we do not take our part in the progress and development of natural sciences"*. Some historians assign such importance to ONA's creation, and particularly to Benjamin Gould's presence, that they consider *that* moment as the introduction of modern science in Argentina.

The second milestone in the history of astronomy in Argentina was the creation of the Astronomical Observatory of La Plata in 1883 (see Fig. 2). This institution was the cradle of the first school of astronomy, founded in 1935, where the first Argentinian astronomers were formed, including local pioneer astronomers such as Jorge Sahade, José Luis Sérsic and Carlos Cesco.

In spite of these strong beginnings, the growth of science in Argentina has not been easy, as it has been always complicated by the to-and-fros of the country's politics, with periods of great impetus mixed with other, very dark times, which resulted in a significant exodus of Argentinian scientists, who found positions in research centres all over the world. Amid this constant flux, one undeniably positive fact has been the creation of the

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Figure 2. The Astronomical Observatory of La Plata. (courtesy Guillermo Sierra)

Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET[3], National Council for Scientific and Technical Investigation) in 1958; nowadays, together with the universities, CONICET provides essential support to the development of science and particularly to astronomy in this country. Currently, one hundred and forty years after ONA's foundation, there are a variety of Argentine astronomical institutions, where about two hundred researchers work on a wide range of topics.

2. Astronomical Institutions in Argentina

There are approximately a dozen institutions where astronomical research is taking place in Argentina. In spite of having started with a defined research profile in one specific area, most of these nowadays have scientists doing research in a great diversity of topics (see Tables 1a and 1b), including the most conventional fields along with novel ones.

Since the second half of the last century, a series of research institutes depending from CONICET have been created, some of which function within the observatories, and in most cases depend on the universities as well. From a geographical point of view, the vast majority of astronomical research in Argentina is centred in three provinces: Buenos Aires, Córdoba and San Juan, located in the east-centre, centre and west-centre of the

[3]http://www.conicet.gov.ar/

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Table 1. Principal research areas per institution.

FCAGLP & IALP	OAC & IATE	OAFA
Interstellar Medium and Galactic Structure	Astrometry, Instrumentation and observational techniques	Planetary Systems
Globular Clusters and Dwarf Galaxies	Planetary Systems: Celestial Mechanics and the Dynamics of planetary systems	Astrometry
Dynamics of Stellar Systems	Stellar Astrophysics: Stellar Systems, Stellar Atmospheres, Stellar Formation, Stellar variables and binaries	Galactic Structure
Astrophysics of Open Clusters	Interstellar medium and Galactic Structure	Astronomical Reference Systems
Stellar Astrophysics: Stellar Evolution; massive stars; Peculiar Stars; Binaries and Symbiotic Systems	Extragalactic and Cosmological Astronomy: Systems of Galaxies, Active Nucleus, Large-Scale Structure of the Universe, Galaxies.	Solar Physics
Celestial Mechanics and Planetary Sciences	Solar Physics and Astrophysical Plasma	
Cosmology	Characterization of Astronomical sites	
Relativistic Astrophysics		
Radioastronomy		
Magnetohydrodynamics		

IAFE	IAR	ICATE
High energy astrophysics	High energy astrophysics and compact objects	Galaxies
Astrophysics of the interplanetary medium	Clusters of galaxies and active galactic nuclei	Solar Physics
Stellar Astrophysics	Circumstellar Disk	Stellar Astrophysics, theoretical and observational
Numerical Astrophysics	Interstellar medium and Early Stars	Cosmochemistry
Planetary Science	Large radioastronomical database	
Planetary and Stellar physics	Planetary Systems	
Solar Physics and Astrophysical Plasma		
Supernova Remnants and interstellar medium		
Quantum, Relativity and Gravitation		

country, respectively (see Fig. 3); however, in the future, more groups may well consolidate in other regions where incipient activity is occurring.

The following is a summary of institutions whose main activity is astronomical research:

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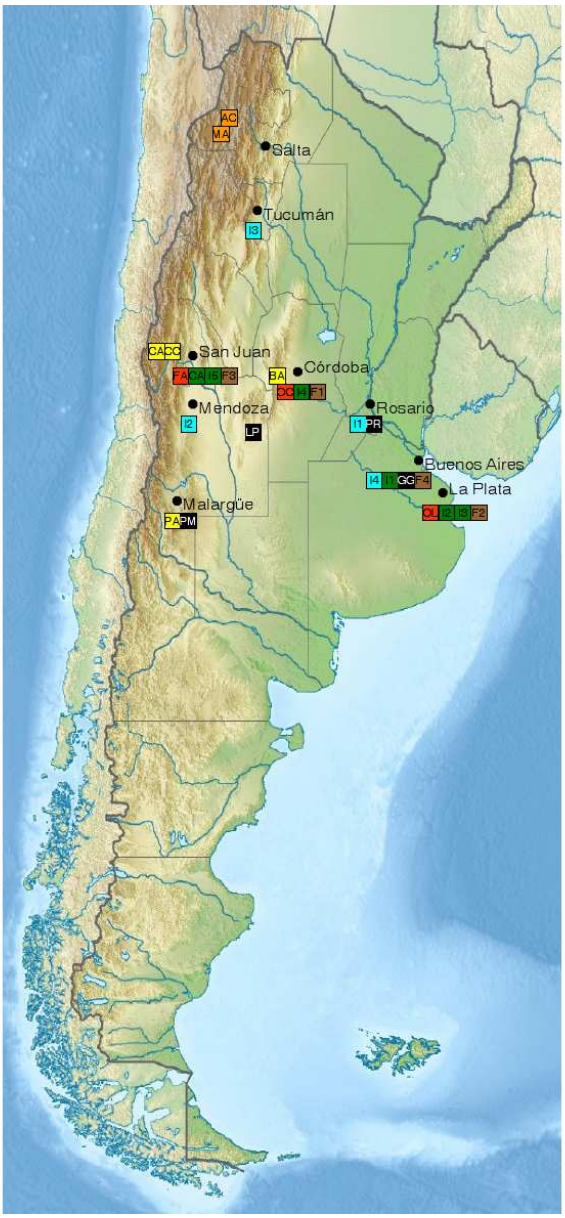


Figure 3. A map of Argentina showing the location of observatories (in red), institutes of CONICET where the main activity is astronomy (in green), institutes of CONICET where astronomy is a secondary activity (in light blue), astronomical facilities in the mountains (in yellow), planetariums (in black), characterized sites for astronomical facilities (in orange), and Universities where Astronomy or related sciences are taught (in brown). (graphics by Victor Renzi)

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Observatorio Astronómico de Córdoba (OAC) de la Universidad National de Córdoba (UNC[4]*)*
Instituto de Astronomía Teórica y Experimental (IATE[5]*, Córdoba)*

As mentioned, astronomy in Argentina began with the creation of the National Argentine Observatory (Observatorio Nacional Argentino) in 1871. After going through several changes in its institutional status, it finally became part of the National University of Córdoba (UNC), the oldest university in the country (almost four hundred years old), and its second largest.

The scientific profile of the institution was defined by the celebrated Benjamin Gould, who initiated various astronomical projects, among which the *Uranometry of Córdoba* was a pioneer work, cataloguing the position and brightness of all stars visible to the naked eye from Córdoba. The star survey *Córdoba Durchmusterung* was by no doubt one of the greatest astronomical achievements in Córdoba during the nineteenth century. Argentina later also participated in the international *Carte du Ciel* project at the beginning of the 20^{th} century.

Astrophysics arrived at the NAO with its director, Charles Perrine, who also proposed and initiated the foundations for the construction of a big reflector telescope. The project was completed with the help of Enrique Gaviola, and inaugurated, in 1942, in the Astrophysical Station of Bosque Alegre, 40km from the city of Córdoba. This 1.54m reflecting telescope enabled Córdoba Observatory to position itself as a pioneer in astrophysical studies in the southern hemisphere, and to give a strong impulse to extragalactic astronomy, led by José Luís Sérsic, who later published the renowned *Atlas of Southern Galaxies*[6] in 1968. In 1956, Gaviola initiated the foundation of the Institute of Mathematics, Astronomy and Physics within Córdoba National University, which in 1983 would become the Faculty of Mathematics, Astronomy and Physics (FaMAF[7]), in which a considerable number of astronomers have been formed.

The Astronomical Observatory of the UNC is today one of the most important astronomical centres in the country, with approximately sixty professors, who carry out research in varied areas of Astronomy. They are also responsible for the teaching and training of graduate and postgraduate astronomy students studying at the FaMAF.

[4]Astronomical Observatory of the National University of Córdoba (`http://www.oac.uncor.edu/`).
[5]Institute for Theoretical and Experimental Astronomy (`http://www.iate.oac.uncor.edu/`).
[6]Published by the Astronomical Observatory of the UNC.
[7]`http://www.famaf.unc.edu.ar/`

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Within the OAC, and under the auspices of the UNC and CONICET, the Institute of Theoretical and Experimental Astronomy (IATE) was created, as a continuation of the Extra-Galactic Studies group founded by Sérsic more than three decades earlier. In spite of having started merely as an extra-galactic research project, other areas have been incorporated since then, such as solar physics, extra-solar planets and the search for new astronomical sites. The IATE nowadays has more than thirty post-graduate researchers, many of whom are also professors in the OAC.

Observatorio Astronómico de La Plata (OALP[8])
Instituto de Astrofísica de La Plata (IALP[9])

The creation of the Astronomical Observatory of La Plata was related to Argentina's participation in the transit of Venus observations in 1882, together with the need to endow the new city with public buildings. Among the aims of founding the OALP was the realisation of mapping studies, for which reason its first activities were basically of services. As from the thirties, systematic astronomical observations have been made of occultations, eclipses, asteroids and comets.

It is important to note that the Observatory is older than the University of La Plata (UNLP), which, founded in 1905, is nowadays one of the most important in the country. The insertion of the OALP into the UNLP, together with Félix Aguilar's special interest, led to the creation of the first School of Astronomy in the country in 1935, which was to have a strong impact on the future of astronomy in Argentina. With its first graduates, some of whom had completed further studies abroad, and the presence of Livio Gratton, the Observatory of La Plata initiated its astrophysical studies, as well as the idea of developing a large telescope. This idea would be materialized some decades later by Jorge Sahade, with the creation of the Astronomical Complex of "Leoncito" (CASLEO) in the province of San Juan.

In 1982, the OALP School of Astronomy became the Faculty of Astronomical Science and Geophysics (FCAGLP), permitting it to recover from the harsh decade of the seventies and to begin a period of growth, which has been sustained up to the present. The Observatory of La Plata has traditionally offered the study of varied astronomical areas such as Astrometry and Stellar Astrophysics, though nowadays research is carried out in most areas of contemporary astronomy. The FCAGLP today has more

[8]Astronomical Observatory of La Plata, nowadays the Faculty of Astronomical Sciences and Geophysics of La Plata (*Facultad de Ciencias Astronómicas y Geofísicas de La Plata, FCAGLP* (`http://www.fcaglp.edu.ar/`).

[9]Institute of Astrophysics of La Plata
(`http://www.fcaglp.unlp.edu.ar/~gladys/ialp/`).

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than fifty professors in astronomical fields, and is one of the most important astronomy institutions in Argentina.

In 1999, the Institute of Astrophysics of La Plata (IALP) was created, housed in the FCAGLP and under the UNLP and the CONICET. In the IALP, research is carried out in areas such as Dynamics, Stellar and Planetary Evolution and Formation. Most IALP researchers are also professors at the FCAGLP, and its staff of more than fifty includes graduate students and postdoctoral fellows.

Observatorio Astronómico Félix Aguilar (OAFA[10]*, San Juan)*

The Félix Aguilar Astronomical Observatory (OAFA), now under the Faculty of Exact, Physical and Natural Sciences of the National University of San Juan (UNSJ), was inaugurated on September 28th, 1953 by a small group of professors from the Engineering School (nowadays a Faculty) of the National University of Cuyo, led by Carlos Cesco, with the aim of forming geographers. Its main astronomical facilities are in the Andes Range in the province of San Juan, in the locality of Calingasta, named Estación de Altura (Altitude Station) Carlos Cesco. Over the years, and thanks to international cooperation, the OAFA has consolidated a strong profile in the field of Positional Astronomy, which still distinguishes it nowadays.

Fundamental in the history of the institution has been its agreement with the University of Yale. Between 1973 and 1974, as the University of Columbia had withdrawn from its agreement with Yale, an agreement was signed between the newly created National University of San Juan and the University of Yale. This Yale Southern Observatory-OAFA agreement is still current today, and its main scientific objective is linked to the study of Proper Motion of more than thirty million stars. At present, there is also an agreement with the Chinese Academy of Sciences to operate a Satellite Laser Ranging station. Other current activities in the OAFA focus on Planetary Systems and the study of the sun, activities which are mostly performed by engineers.

Instituto Argentino de Radioastronomía (IAR[11]*, La Plata)*

The Argentine Institute of Radio Astronomy (IAR) was created in 1962, only 22 years after the publishing of the first radio astronomical observation, which proves the highly pioneering character of Argentinian Astronomy in the mid-twentieth century.

The idea behind IAR first emerged as a project for the creation of a regional Radio Astronomy Observatory in South America, as an initiative

[10]Félix Aguilar Astronomical Observatory (`http://www.oafa.fcefn.unsj-cuim.edu.ar/`).
[11]Argentine Institute of Radioastronomy (`http://www.iar.unlp.edu.ar/`).

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of Merle Tuve of the Carnegie Institution of Washington. The project began with the installation of a 30 meter antenna, with the active participation of Carlos Varsavsky. Later, a second antenna of similar characteristics was assembled, allowing important surveys of neutral hydrogen to be carried out. Neither antenna is operating nowadays, although there are plans to have one of them running again as a School Telescope. As is the case with other institutions in Argentina, the IAR has suffered from the political and economic turbulence of the country, affecting its initial growth.

As from 2002, the IAR started to perform assignments related to technology transfer for the National Commission of Space Activities. Nowadays, the IAR is strongly committed to technology transfer and continues to perform astronomical research, for which it has an active scientific staff of ten researchers in a variety of fields, being particularly productive in the area of High Energy Astrophysics.

Instituto de Astronomía y Física del Espacio (IAFE[12], Buenos Aires)

The Institute of Space Astronomy and Physics (IAFE) is under CONICET and was created in 1969 as a result of a restructuring of the *Centro Nacional de Radiación Cósmica* (CNRC, National Centre for Cosmic Radiation). The institute included members from the CNRC, the Faculty of Exact and Natural Sciences, and astronomers from the OALP, among which was the first director of IAFE, Jorge Sahade. The IAFE emerged as a pioneer institute in experiments in cosmic radiation, in γ, X and infra-red rays, with a strong observational profile, taking great advantage of technological developments carried out in the country.

At present, the IAFE has more than seventy researchers in different astronomical subjects, some of which have started in recent years as a result of the migration of researchers from other national institutions. Due to its location in the city of Buenos Aires and within the University of Buenos Aires, which is the biggest in the country, the IAFE has experienced steady growth.

Complejo Astronómico El Leoncito (CASLEO[13], San Juan)

During the sixties, the OALP purchased a Ritchey-Chrétien optical reflector telescope, with a 215cm mirror. The installation carried out in cooperation with the Universities of Córdoba and San Juan, together with CONICET, as a national observation facility. After a process of searching and characterization of potential astronomical sites, an area was chosen close to the OAFA altitude station, in the province of San Juan.

[12]Institute of Space Astronomy and Physics (`http://www.iafe.uba.ar/`).

[13]Leoncito Astronomical Complex (`http://www.casleo.gov.ar/`).

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For budgetary problems, it was not possible to set up the telescope at the site selected, and it was installed nearby, but at a lower altitude, with astronomical conditions inferior to those of the first site. Nowadays, the agreement between the universities and CONICET in relation to the CASLEO has expired, and a new agreement is being negotiated.

Despite having started as a services institution, over the years CASLEO acquired a small astronomical staff. However, with the creation of the Institute of Earth and Space Astronomical Sciences (ICATE) in 2009, these astronomers became part of the new institution, and so CASLEO has returned to its original format, with a staff mainly consisting of engineers and technicians.

Although this telescope has lost its competitiveness, due mainly to its age, it is still in high demand by the astronomy community in Argentina, especially by stellar astronomers. Numerous PhD theses have been produced in the last twenty years with data obtained through this telescope, and it is still the astronomical instrument most widely used by the astronomy community in Argentina.

Besides the 215cm Jorge Sahade telescope (named after the outstanding Argentinian astronomer), CASLEO also has other instruments: the Helen Sawyer Hogg 60cm telescope, in Cerro Burek (the site originally chosen for the 215); the Solar Sub-millimeter Telescope, built by international collaboration with the Mackenzie Centre for Radio Astronomy and Astrophysics of Brazil; and finally, the Astrograph for the Southern Hemisphere, also installed in Cerro Burek in collaboration with the Astrophysical Institute of Andalucía, Spain.

Instituto de Ciencias Astronómicas, de la Tierra y del Espacio (ICATE[14]*, San Juan)*

Founded in 2009, the Institute of Earth and Space Astronomical Sciences (ICATE) is the youngest astronomical institute in the country, and its members are mostly former scientific staff from CASLEO. Nowadays it has about ten researchers, who carry out studies in areas such as Galaxies, Solar Physics, Stellar Physics and Cosmochemistry. Some members of ICATE are also professors at the Faculty of Exact, Physical and Natural Sciences at the University of San Juan, teaching in the *Licenciatura*[15] and PhD in Astronomy.

Among other institutions where astronomical research takes place are the Institute of Physics of Rosario (Rosario), the Institute of Geological Correlation (Tucumán), the Regional Centre of Scientific Research (Men-

[14]Institute of Earth and Space Astronomical Sciences (`http://www.icate-conicet.gob.ar/`).

[15]*Licenciatura* is a five-year first degree obtained in Argentinian Universities. The following degree would be a PhD.

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doza) and the Institute of Detection Technologies and Astroparticle Physics (Buenos Aires and Mendoza).

3. Observational Facilities

Gemini[16]

Since its beginnings, Argentina has participated in the International Gemini Partnership, which operates two eight meter diameter optical/infrared telescopes, one in Chile and the other in Hawaii, USA. Despite having a small share in the partnership (approx. 2.5%), this infrastructure is highly regarded by the Argentinian astronomy community, since it offers a concrete possibility to access the latest generation of telescope.

The participation of Argentina in this project has not always been constant or easy. In the past, two factors constituted an obstacle to the normal development of the project. Firstly, the project arrived here as an initiative of the United States, instead of being suggested by the local community. Secondly, during several years the project did not have decisive support from the national institutions responsible for its financing and management. As a consequence, there was not only scant participation of Argentina in the political, technical and scientific discussions regarding the project, but also the loss of actual telescope time between the years 2003 and 2008.

In 2009, the *Ministerio de Ciencia, Tecnología e Innovación Productiva* (MinCyT[17] took over the project; this, together with the commitment of numerous astronomers, led to the gradual normalization of Argentinian participation in the partnership. Nowadays, Argentina has its payment contributions up to date, has adhered to the renovation of the international partnership, and it actively participates in the different international committees.

Argentina is eligible for a total of forty hours observation-time per semester in both telescopes. On average, the demand is fifty percent higher than the time actually available.

CASLEO

As mentioned above, CASLEO includes a series of operating instruments. For most of these, telescope time allocation depends on a scientific committee made up of representatives from the three Universities involved and CONICET. Time is assigned each semester, and in most cases the demands for observation time are satisfied.

[16] `http://www.geminiargentina.mincyt.gob.ar/`

[17] Ministry of Science, Technology and Productive Innovation (`http://www.mincyt.gov.ar/`).

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The Jorge Sahade Telescope, with a 215cm diameter primary mirror, contains a variety of instruments: direct CCD of 1340 × 1300 pixels; two spectrographs, one of which is Échelle type, and two photopolarimeters, one of which was designed and built in CASLEO.

High Altitude Station "Carlos U. Cesco"

The main astronomical facilities of the OAFA are found in the locality of Barreal, San Juan. Some of the operating instruments are: Photoelectric Astrolabe; Double Astrograph Telescope (in agreement with Yale Southern Observatory); Automatic Meridian Circle (in agreement with the Royal Observatory of the Spanish Navy). There are also two instruments for the study of the sun: MICA (Mirror Coronograph for Argentina) and HASTA (Hα Solar Telescope for Argentina).

Bosque Alegre

The 154cm diameter telescope of the OAC, located in the Córdoba hills, had been out of use for many years. At the end of 2008 it was decided to put it back into operation as an educational telescope and for scientific uses, and this project received a major boost during 2011. It is expected that it will soon be possible to invite proposals for observation,

Pierre Auger Observatory[18]

The Pierre Auger Observatory, the result of the collaboration of nineteen countries including Argentina, is located in the province of Mendoza and is studying ultra-high energy cosmic rays. Although a correlation has been suggested between cosmic rays and extragalactic objects, these results have not been confirmed, and therefore the participation of astronomers in the field is still limited. The positive results of Argentinian collaboration in this project are commonly used as an example of the capability of our country to successfully host scientific projects of great magnitude.

4. Computational Resources

In Argentina there are diverse groups with significant experience in the utilization and undertaking of simulations and of numerical models. Consequently, there has been a need to acquire high performance computational resources. Nowadays, the computational infrastructure available at Argentinian institutions is somewhat obsolete, so that they have to recur to the infrastructure of other countries through international collaborations. Recently, the MinCyT created the High Performance National Computation System, which aims to integrate computer clusters throughout the country into one distributed calculation facility, which will enable an optimal use of

[18] `http://www.auger.org.ar/`

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this technology. This is a tentative project in formation, which, if successful, will allow the Argentinian astronomical community to access significant computational resources.

In 2009, with the involvement of most Argentinian astronomical institutions, the *Nuevo Observatorio Virtual Argentino* (NOVA[19]) was created, aimed at the national and international coordination of resources relating to data-centres, software tools and information about inter-operational standards. Recently, the International Virtual Observatory Alliance[20] accepted NOVA's membership; the new virtual institution is now studying the first projects to be run, as well as searching for sources of funding to permit sustained medium-term operation.

5. The Argentinian Astronomical Society

The *Asociación Argentina de Astronomía* (AAA[21]), which has recently turned fifty years old, brings together the vast majority of Argentinian astronomers, with the main objective of the promotion and progress of astronomy and its related activities in the country. Its specific functions are: to provide appropriate spaces for discussion and promotion of research activities in astronomy and in related sciences; supply institutional back-up to initiatives in the area; organize scientific meetings where astronomers may exchange information; give support to young astronomers by means of scholarships and work-contracts; act as a contact between astronomers and organizations which support science in Argentina and the world; and finally, the outreach of astronomy among the general public.

The AAA is economically sustained by its members' fees, and is administered by a Board elected by the member's general Assembly, renewed every three years. The Assembly also votes for the National Committee of Astronomy, which is responsible for liaison with the International Astronomical Union (IAU[22]).

The AAA also has an important publishing role. The *Boletín de la Asociación Argentina de Astronomía* (BAAA) is produced annually by an editorial committee, which is independent of the Board. Following a refereeing process, the BAAA publishes the papers presented during the annual meetings, where numerous astronomers and undergraduates get together, creating a good environment for scientific and policy discussions. Special debates or sessions on specific topics are held. The AAA also publishes the

[19]New Virtual Argentinian Observatory (`http://www.nova.org.ar/`).
[20]`http://www.ivoa.net/`
[21]Argentinian Astronomical Society (`http://www.astronomiaargentina.org.ar/`).
[22]`http://www.iau.org/`

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Workshops and Books series, as well as a newsletter. As from 2006, the AAA holds annual workshops related to a variety of topics. Among the recent have been Observational Astronomy, Theoretical Astronomy, the outreach of Astronomy, History of Argentinian Astronomy, the Gemini Project and Computational Astronomy.

The Argentinian Astronomical Association grants three prestigious awards: the *Carlos Varsavsky Award* for the best Doctoral Thesis, the *José Luis Sérsic Award* for the outstanding Senior Researcher and the *Jorge Sahade Award* for Scientific Trajectory. The first two awards are granted every two years, and the latter, every three.

6. Education in Argentina

Argentina has historically had a very high literacy level among its population, and a great level of achievement of its University graduates. Nevertheless, there are nowadays some warning signs, especially as regards Elementary and Middle education levels. Clearly reflecting the problem is the noticeably low achievement of Argentinian secondary students in the last PISA (*Programme for International Student Assessment*[23]), an exam for 15-year old middle school students, which located Argentina in the 58th place. Secondary school education, of course, affects studies at university, which has led to the creation of preparatory courses in order to bring students' knowledge and training to the level of the new demands they need to face at university.

Traditionally, the educational system in Argentina has been public and free, including universities. Moreover, the highest academic levels and achievements are well known to have originated and been found in public universities, despite the rapid growth in the private education sector nowadays. Free education in Argentina at all levels has permitted unlimited access to higher education for all social levels, with a strong presence of the middle class.

The vast majority of Argentinian astronomers studied for their degrees in Argentina, and a large number have undertaken postdoctoral studies abroad. Most researchers who nowadays carry out astronomy studies in our country were formed and trained in the Universities of La Plata, Córdoba and San Juan, although some have graduated in Physics.

In Argentina, about ten students per year obtain their PhD with an astronomical orientation, in one of the following institutions:

Facultad de Ciencias Astronómicas y Geofísicas de La Plata[24] *(FCAGLP), La Plata*

[23] `http://www.pisa.oecd.org/`
[24] Faculty of Astronomical and Geophysical Sciences

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As mentioned above, this was the first School of Astronomy in the country. Here students work towards the *Licenciatura* and PhD in Astronomy, the latter having the highest category given by the *Comisión Nacional de Evaluación y Acreditación Universitaria* (CONEAU[25]). Although the average duration of a *Licenciatura* is of five years (containing 30-35 subjects), it is taking students longer lately.

Facultad de Matemática, Astronomía y Física (FaMAF[26]), Córdoba

This is the second School of Astronomy founded in the country, and this and the one in La Plata are the two most traditional ones. Although FaMAF is independent of the Astronomical Observatory, the professors of the Observatory are in charge of the academic formation of astronomy students in these specific subject-areas. FaMAF students work towards the *Licenciatura* and PhD in Astronomy, and the latter has the highest category given by the CONEAU. As in La Plata, the average period of studies for the *Licenciatura* has extended, possibly due to its demanding level, which may be compared to a Master studies in Universities abroad.

Faculty of Exact, Physical and Natural Sciences of the UNSJ[27], San Juán

Since 1995, students can work for the *Licenciatura* in astronomy in San Juan. This was originally a four-year degree, but nowadays it has been extended to the same period as in other Universities. Not long ago, there was no possibility of completing a PhD in astronomy or in related sciences in San Juan; consequently, most graduates then migrated to other national or international universities, to complete their postgraduate studies. Some of these researchers are now returning to San Juan, presaging a powerful growth for local astronomy. In 2009, a PhD program in Astronomy was started, specializing in Observational Astronomy.

An important contribution to research in the area of Astronomy has come from doctors in physics, mainly from the University of Buenos Aires (UBA[28]). Thanks to its strategic location and joint dependency on the UBA and CONICET, IAFE attracts physics students from the Faculty of Exact, Physical and Natural Sciences, who are interested in astronomical topics.

[25]National Commission of University Evaluations and Accreditations (`http://www.coneau.edu.ar/`).
[26]Faculty of Mathematics, Astronomy and Physics.
[27]`http://www.unsj.edu.ar/facu_exacta.php`
[28]`http://www.uba.ar/`

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7. Institutions and Resources for the Promotion of Science

According to the 2010 UNESCO Science Report[29], Argentina has the third largest gross domestic product (GDP) in Latin America, after Brazil and Mexico (2009 figures), while its Gross Expenditure on Research and Development (GERD) represents 0.51% of the GDP, setting Argentina again in the third place, after Brazil and Chile (2007 figures). Compared to other countries of the region, Argentina has a low percentage of funds provided by the business sector, while a high percentage of the scientific activity carried out in Argentina is financed by the State.

In 2007, the Argentine government transformed the previous Secretary of Science and Technology into the Ministry of Science, Technology and Productive Innovation (MinCyT), with CONICET as one of its most important agencies for the development of science. The national universities are the other pillar sustaining the Argentinian Science System. Other institutions which provide resources for the promotion of science are the National Agency for the Promotion of Science (also dependent on the MinCyT), as well Secretariats and Ministries dependent on the provinces.

Perhaps as a result of the constant crises the Argentinian scientific system has been subject to, its astronomical community has acquired great experience in obtaining funds abroad, in many cases as a result of international scientific collaboration programs. Contributions from private national funds in Argentina are hardly existent. Nonetheless, a great part of the Argentinian scientific community remembers with gratitude the Antorchas Foundation, which before disappearing in 2006, financed numerous astronomical projects.

CONICET

CONICET is, no doubt, one of the main driving forces behind scientific development in Argentina. Since its creation more than half a century ago, CONICET has implemented the so-called "career of scientific researcher" (*Carrera del Investigador Científico y Tecnológico, CIC*), by which it hires researchers to enable them to carry out their activities in one of the national scientific institutions. Nowadays, CONICET has 6350 researchers, of which 114 are in the area of astronomy (2010 figures).

The CIC has a scale of five categories, access to which includes peer evaluation; except for the first category (assistant researcher), permanency in the career is guaranteed by merely achieving a passing mark in the biannual evaluations. Following long decades of scarce income and a lack of senior researchers, a radical change in the last decade has provided CONICET with approximately 500 annual positions for all areas of research,

[29] http://www.unesco.org/new/en/natural-sciences/science-technology/prospective-studies/unesco-science-report/unesco-science-report-2010/

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which allows, within the range of the exact sciences at least, inclusion in the CIC of a large proportion of those who qualify for it.

Currently, around ten astronomers qualify to enter the CIC annually, which has resulted in the sustained growth of Argentinian astronomy in all its aspects. The qualification criteria to enter the CIC are basically having graduated as a PhD and having published internationally refereed articles in first level journals. However, one drawback of this policy is the limited mobility of researchers who, in many cases, obtain a permanent position without undertaking previous postdoctoral activities. CONICET, aware of this complication, has implemented scholarships for researchers who are interested in working abroad, though this measure has not yet been shown to be successful.

Another important input of CONICET in the human resources area is the award of doctoral scholarships. Most doctoral theses in astronomy undertaken in Argentina are funded by CONICET scholarships, with a duration of five years. CONICET also contributes funds for research projects which are quite accessible for most researchers. Nevertheless, these funds only cover the basic expenses of a group of researchers and part of their travel expenses, thus limiting their presence and participation in international scientific events or scientific visits to other research centres. The typical ratio between funds in research grants and salaries ranges between 0.1 and 0.3, significantly lower than international standards.

CONICET promotes research by creating and financing scientific institutions. At present, most researchers in the area of astronomy work in one of the following institutions: IAFE, IALP, IAR, IATE, ICATE, CASLEO, IFIR[30], CRICYT[31], INSUGEO[32], ITEDA[33]. The present policy of CONICET is that the institutes will ideally work in co-management with the National Universities, as is the case of several of the institutions mentioned above. CONICET also provides funding for organizing scientific meetings and, particularly as regards astronomy, for the Argentinian membership of the IAU and for the *Astronomy & Astrophysics* journal.

National Universities

Universities are undoubtedly the principal actor in Argentinian scientific development. They are responsible for undergraduate and graduate studies, without which there would be no science in Argentina. It is important to

[30]Instituto de Física de Rosario
(`http://www.new.ifir-conicet.gov.ar/`).
[31]Centro Regional de Investigaciones Científicas y Tecnológicas
(`http://www.mendoza-conicet.gob.ar/`.
[32]Instituto Superior de Correlación Geológica
(`http://www.insugeo.org.ar/`).
[33]Instituto de Tecnologías en Detección y Astropartículas
(`http://www.iteda.org/`).

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remember and point out that the public university is free of charge in Argentina and in some cases, low-income students may get some financial help.

The universities in Argentina are autonomous and so it is difficult to generalise about them. However, the most relevant aspects of all the universities are as follows: universities provide an important number of jobs for researchers in astronomy; these may be full-time ("exclusive") or part-time ("semi" or "simple") posts; in the first two categories, undertaking scientific research is compulsory. At present, very few new posts are being created, and thus the possibilities for entering the university system are mainly limited to vacancies. Usually, researchers may qualify for these posts through a selection committee, and this process may be renewed periodically.

Universities also finance doctoral scholarships and provide grants for basic expenses of research projects. It is important to point out that universities support the running of Observatories and co-finance CONICET institutes with double dependency. In fact, a large number of professors are also CONICET researchers.

Agencia Nacional de Promoción Científica y Tecnológica (ANPCT[34]

Dependent on the MinCyT, the ANPCT has as one of its central goals the funding of large-scale research projects; however, in our case, these are hard to obtain due to the fact that the area of astronomy is not considered a priority.

8. Scientific Meetings

The Argentinian astronomical community has a long tradition of holding scientific events. The most traditional one is the annual meeting of the AAA, which brings together more than 300 students and graduates in a different part of the country every year. For the 2011 series, and for the first time, the event was jointly organized with the Chilean Society of Astronomy.

Numerous international scientific meetings have taken place in Argentina in the last fifty years. In 1991, Buenos Aires hosted the 21^{st} IAU General Assembly; in the years 1983 and 2001, two IAU Latin American regional meetings were held, the third in Buenos Aires and the tenth in Córdoba, respectively. Since 1969, eight IAU Symposiums have taken place: *The Problem of the Variation of the Geographical Coordinates in the Southern Hemisphere* (IAUC 1, La Plata 1968); *Spectral Classification and Multicolour Photometry* (IAUS 50, Córdoba 1971); *Wolf-Rayet and High-Temperatures Stars* (IAUS 49, Buenos Aires 1971); *Solar Gamma-, X-, and*

[34]National Agency for the Promotion of Science and Technology.

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EUV Radiation (IAUS 68, Buenos Aires 1974); *Evolutionary Processes in Interacting Binary Stars* (IAUS 151, Córdoba 1991); *Eruptive Solar Flares* (IAUC 133, Iguazú, 1991); *Jets at All Scales* (IAUS 275, Buenos Aires 2010); and *Comparative Magnetic Minima: Characterizing quiet times in the Sun and Stars* (IAUS 286, Mendoza 2011). There is currently a special emphasis on the organization of scientific meetings: during 2011, at least nine events of different features and topics were organized.

9. Promoting Astronomy within the Society at Large

The outreach of astronomy to the general public in Argentina has grown significantly in the last few years. Historically, it was an activity reserved for only a few and, even though the traditional institutions carried out related activities, these were not innovative and were mainly related to specific astronomical events or to the systematic attention to observatory visitors.

Nowadays, a great part of the astronomical community is seen to be clearly committed to performing extension activities for the general public. No doubt, the International Year of Astronomy in 2009 gave a mighty impulse to the development of these activities, which were not limited to traditional institutions such as the OLP or OAC, but expanded to the vast majority of astronomical institutions, as well as to others not devoted directly to scientific investigation, but which also took on a great role in the promotion of astronomy.

OAC, OALP, and OAFA have their own museums, while there are two traditional planetariums, in Rosario and, the most emblematic one, the Galileo Galilei Planetarium in the city of Buenos Aires, which has recently been refunctionalized to include full-dome digital technology. In the city of Malarge, in the province of Mendoza, there is a high technology digital planetarium; in San Luis, the University of La Punta also operates one. Moreover, the National University of La Plata is building a large digital planetarium, while in Córdoba an opto-mechanical planetarium is being built, based on an instrument donated by the city of Nantes in France, and the possible construction of a digital one is being studied. Three examples of astronomical promotion at non-traditional sites are the La Punta Astronomy Park[35] in the city of San Luis, the Sky Plaza[36] in the city of Esquel and the awi Puna Observatory in the small locality of Tolar Grande (150 inhabitants), Salta, 3500m above sea level in the middle of the Andean Puna.

[35] http://www.palp.edu.ar/
[36] http://www.plaza-del-cielo.com.ar/

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10. Amateur Astronomy

The fascination astronomy has always evoked has not escaped the Argentinian people, and that is why there are numerous Friends of Astronomy associations, reflecting a long tradition of interest in astronomy in the country. The most important of these groups is the Argentinian Association of Friends of Astronomy (AAAA[37]), which dates back 81 years and is thus older than the professional association AAA, and is the oldest of its kind in Latin-America.

On some occasions, amateur astronomers also engage in scientific projects, for example devoted to precision astrometry of minor bodies of the Solar System. The Association of Argentinian Observatories of Minor Bodies[38] groups the amateur observatories accredited by the Minor Planet Centre[39]. At present, there are fourteen amateur observatories which hold a certification of the Minor Planet Center of the IAU.

11. Future Astronomical Projects

Except for Gemini, it is noticeable how far behind Argentina is in terms of latest generation observational infrastructure. For this reason, the Argentinian astronomical community has an agenda of numerous new astronomical infrastructure projects, some of which are national projects, while others are international collaborations. Recently, the National Ministry of Science and Technology has created a committee of Astronomy and Sciences of the Universe, with the purpose of evaluating projects in these areas. After inviting the scientific community to present possible projects, and a prior evaluation process, the committee has selected and ranked four greatly varied projects for possible funding.

The projects are the following:

Long Latin American Millimeter Array (LLAMA)

This is a bi-national project in collaboration with Brazil, for the installation of one or two antennas in the millimeter/sub-millimeter wavelengths in the northwest of Argentina at a height of 4600m. The project includes the possibility of setting up a Very Long Baseline Interferometer by means of integration with projects such as ALMA[40], ASTE[41] and/or APEX[42] in the Chilean northeast. The Argentinian side is led by IAR researchers.

[37] http://www.asaramas.com/
[38] http://www.aoacm.com.ar/
[39] http://www.minorplanetcenter.net/iau/mpc.html
[40] http://www.almaobservatory.org
[41] http://www.ioa.s.u-tokyo.ac.jp/~kkohno/ASTE
[42] http://www.apex-telescope.org

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Cherenkov Telescope Array (CTA)

This project consists of a mega-international collaboration to build and operate the next generation of ground-based very high energy gamma-ray instruments to provide a deep insight into the non-thermal high-energy universe. CTA is made up of 25 countries and is considering the building of different types of telescopes in both hemispheres. Some of the Argentinian institutions involved in the project are IAFE, IAR and ITEDA. One of the main reasons for Argentina to participate in this project is its possible location within Argentinian territory, probably in the northwest or at sites close to CASLEO in the province of San Juan.

Doubling the Time at Gemini

This project consists in doubling Argentina's time in the international Gemini partnership, which would be possible due to the withdrawal of Great Britain. This proposal is not led by any particular institution, but has the support of numerous astronomers and institutions at national level.

Argentina-Brazil Astronomical Centre (ABRAS)

This is a bi-national project which consists in the joint installation of a 1m/1.2m infrared robotic telescope with a medium size field of view in the Macon site, Salta Province at 4600m above sea level where an 8m-diameter dome is under construction. The Argentinian side is led by the IATE.

12. Human Resources

As mentioned, the national universities and CONICET are responsible for almost all astronomical posts available in Argentina. If we take into account teaching and research positions, the number amounts to approximately 250 scientists (considering that many of them depend on both these institutions). Table 2 shows the number of CONICET researchers by category (2010 figures). If we assume that, from the category of "Independent" and upwards, we are looking at senior researchers, we may conclude that the population pyramid is reasonable, which has been achieved during recent years thanks to the steady entry of young researchers.

Most PhD students undertake their studies with some kind of scholarship, the most numerous being those of CONICET. There is also a possibility of access to university scholarships, or ANPC grants. The present number of postgraduate students and postdoctoral fellows from CONICET in the area of astronomy is 62, which indicates that the human resources of astronomy will continue growing in Argentina.

Nowadays, approximately half the astronomical community in Argentina are women, and these are expected to become the majority in the medium term, taking into account that women are already a majority among un-

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Table 2. Number of CONICET researchers per category.

Assistant	32
Attached	32
Independent	40
Principal	14
Superior	4

dergraduate students. It is important to point out as well that Argentina has the highest percentage of women members in the IAU[43], 48 out of 131.

Although Argentinian astronomy was initiated by citizens of other countries, with Benjamin Gould being NAO's first director, and that this tradition lasted many years, nowadays almost all scientific posts are held by Argentinian citizens. One of the reasons for this is the policies of the institutions for the promotion of science, which do not have easy procedures for the incorporation of foreign citizens into the system; it is currently not possible to enter the CIC of the CONICET without Argentine residence, while the entry of foreign citizens to universities is by means of exception. In the case of postgraduate student scholarships, there is a CONICET program aimed specifically for Latin American citizens. Although most postdoctoral fellows are Argentinian as well, there are programs suited for foreigners.

The history of salaries in the scientific sector in Argentina is complex, with extreme ups and downs. Nowadays the situation may be qualified as fairly good, although there is a noticeable difference with other countries of the region, Brazil or Chile for instance, where scientific activity is much better paid.

Due to successive economical and political crises, as well as to the search for new scientific horizons, a great number of Argentinian astronomers reside in foreign countries, many of whom have gained international prestige. Nowadays, most astronomers migrate to attain training and expertise, and with the hope of coming home after completing their postdoctoral activities. It is important to point out that many Argentinian astronomers living abroad maintain ties with their local peers, and that this is supported by national subsidies devoted specifically to this kind of interchange, as in the case of the PICT-Raíces (Roots) grant of the ANPCT and the Cesar Milstein[44] grant of the MinCyT.

[43]http://www.iau.org/administration/membership/individual/distribution/
[44]http://www.raices.mincyt.gov.ar/aplicar_milstein.htm

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13. Scientific Production

The Digital Library for Physics and Astronomy for the Astrophysics Data System (ADS[45]) shows that about 300 articles[46] with at least one author from an Argentinian institution were published during 2010. If we assume that the number of active astronomers, including postgraduate students, is approximately 250, the result is a little more than one article for each researcher, similar to all other sciences in Argentina. If we consider only the four non-specialist publications used, *The Astrophysical Journal (ApJ)*, *The Astronomical Journal (AJ)*, *The Monthly Notices of the Royal Astronomical Society (MNRAS)*, and *Astronomy & Astrophysics (A&A)*, the total of publications in the same period is 105, distributed as follows: A&A (38), MNRAS (35), ApJ (22) and AJ (9), which shows a clear preference of the Argentinian astronomers for publishing in European journals.

This may be explained principally by the high costs per page in North American publications, which are hard to afford with the limited grants given in Argentina. Needless to say, Argentinian astronomers do not pay for publication in A&A, due to Argentinian membership in the A&A partnership since 2004; actually, Argentina was the first non-European country to be incorporated to the A&A.

14. Technological Development

From its beginnings, Argentinian astronomy brought about and has been associated with promising instrumental development. It is sufficient to remember Charles Perrine, who built a 76cm reflecting telescope in the OAC at the beginning of the twentieth century. Nonetheless, with the passing of the years, this activity has lost competitiveness and support. There is a general consensus that this situation should be reversed, but to date there is no certainty regarding the possibility of making it happen in the short term. One of the paths being explored is to encourage high technology companies, such as INVAP[47], to participate, in conjunction with astronomers and astronomical institutions, in the development of future instruments for Gemini.

The IAR is also an institution of great potential; although the advanced technological development carried out there is mainly aimed at the satellite area, the necessary tools and expertise exist there to reorient it to the development of radio-astronomical instruments.

[45] `http://www.adsabs.harvard.edu/`

[46] This number should be taken only as an approximate figure due to the possible incompleteness of ADS as well as the techniques used to choose the articles, which may include thematic contaminations or omissions.

[47] `http://www.invap.com.ar/`

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15. Argentina as a Site for Large Astronomical Facilities

The western border of Argentina lies on the high summits of the Andes Range, which extends over 4000km. Moreover, between the central region and the northern border there are significant peaks and great plains at considerable altitude, such as the Puna which, 150km wide and 350km long, and an average of about 4000m in altitude, constitutes one of the major highlands in the world. The climatic characteristics of this region are of a very dry area with a high percentage of clear nights, similar to those in the north of Chile.

All these features of the region have generated numerous initiatives from the astronomical community to attract important international projects to Argentina. Since the year 2000 there has been intense activity, aimed not only at selecting potential sites, but also advancing in their characterization. Probably the work with the greatest breadth in this direction has been undertaken by researchers of the IATE, who were in charge of the astronomical characterization of the Cerro Macón, in the Province of Salta. This study was carried out in agreement with the European Southern Observatory[48] within the framework of site selection for the European Extremely Large Telescope[49]. Though Argentina was not finally chosen for the installation of the telescope, the region has been thoroughly characterized in all its aspects, which has given rise to new projects such as ABRAS, mentioned above. Under the IAR's responsibility, this site was studied in reference to its vapour content, as well as other regions of the Puna, such as Alto Chorrillo, which is being considered for the LLAMA project. The region has also been studied for high-energy projects. The central region of the Andes, especially the zone close to CASLEO, has also been proposed for international projects, particularly the Square Kilometre Array[50]. Led by researchers of the IAFE and the IAR, Argentina actively participated to establish this project in the region. Although Argentina was not selected for this project either, the Argentinian astronomical community has proved its strong vocation to encourage such initiatives. What is more, it has been demonstrated that there are sites of great potential, and thus it is only a matter of time before a project of great magnitude, as in the case of the Pierre Auger Cosmic Rays Observatory, is attracted.

[48] http://www.eso.org/
[49] http://www.eso.org/sci/facilities/eelt
[50] http://www.skatelescope.org/

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16. Future challenges

Astronomy in Argentina may be considered as one of the foundational areas of science in our country. It has a long tradition as well as significant regional and international recognition. Despite repeated periods of crisis, nowadays it is experiencing sustained growth, especially in terms of human resources. Astronomical research is carried out in traditional institutions as well as in novel ones, in at least ten scientific centres. As long as no more local or international crises interfere, this tendency of constant growth should consolidate in the forthcoming years.

Yet the Argentinian astronomical community, together with the institutions for the promotion of science, have a series of challenges ahead of them: to update the observation infrastructure, improve young researchers' mobility, improve scientific production and its impact, recover high-technology development of astronomical instruments, raise the amounts of grants destined to research, encourage astronomical research in more regions of the country, enable greater inclusion of foreign researchers and, last but not least, attract international astronomical projects of great magnitude to be set up in the country.

Acknowledgments

This work would have not been possible without the collaboration of numerous colleagues who contributed important data and precision regarding a diversity of topics. I would like to thank Mario Abadi for his contributions and advice, and Galit Shani and Joss Heywood for their help with the manuscript.

I am also grateful to anonymous referees for their suggestions and linguistic improvements brought to the paper.

Bibliography

One of the main sources used for the historical institutional aspects was the book *Historia de la Astronomía Argentina* (History of Argentinian Astronomy), AAABS 2 from the Book Series of the Argentinian Association of Astronomy. The other important sources of information were the web pages quoted in this article, as well as colleagues whom I consulted.

Abbreviations

AAA	The Argentinian Astronomical Society
ANPCT	The National Agency for the Promotion of Science and Technology

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BAAA	Journal of the Argentinian Astronomical Society
CASLEO	The Leoncito Astronomical Complex
CIC	Career of the scientific researcher of the CONICET
CONEAU	The National Commission of University Evaluations and Accreditations (Comisión Nacional de Evaluaciones y Acreditaciones Universitarias)
CONICET	The National Council for Scientific and Technical Research (Consejo Nacional de Investigaciones Científicas y Técnicas)
CRICYT	Regional Centre for Scientific and Technical Research (Centro Regional de Investigaciones Científicas y Técnicas)
FaMAF	Faculty of Mathematics, Astronomy and Physics
FCGALP	Faculty of Astronomical Sciences and Geophysics
IAFE	The Institute of Space Astronomy and Physics
IALP	Institute of Astrophysics of La Plata
IAR	Argentinian Institute of Radioastronomy
IATE	Institute of Theoretical and Experimental Astronomy
IAU	International Astronomical Union
ICATE	Institute of Earth and Space Astronomical Sciences
IFIR	Institute of Physics of Rosario
INSUGEO	Superior Institute of Geological Correlation
ITEDA	Institute of Technologies in Detection and Astroparticles
MinCyT	Ministry of Science, Technology and Productive Innovation
NOVA	New Virtual Observatory
OAC	Astronomical Observatory of Cordoba
OAFA	Félix Aguilar Astronomical Observatory
OALP	Astronomical Observatory of La Plata (nowadays the Faculty of Astronomical Sciences and Geophysics)
NAO	The National Argentinian Observatory (nowadays OAC)
UBA	University of Buenos Aires
UNC	National University of Cordoba
UNSJ	National University of San Juan

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 99-118
Ed. A. Heck, © 2013 Venngeist.

ASTRONOMY IN BRAZIL

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Abstract. A historical background combined with political decisions along time explain the increasing importance of Brazil in the world's astronomical scenario. Professional astronomy was triggered in the late sixties and early seventies by the two main historical institutions then existing (ON and IAG/USP[1]), together with the creation of agencies for research and combined with individual actions. There are presently 670 astronomers working in the country, including permanent jobs and graduate students. A brief description of observational facilities and plans to increase access to other facilities is presented.

1. Historical Background

The discovery of Brazil by the Portuguese led by Pedro Álvares Cabral took place on April 22, 1500. For about 300 years the colonialist approach of the Portuguese consisted basically in the exploitation of the newly found land, especially by extracting gold, precious stones, wood, and whatever goods the country would produce, with very little concern for the education and development of its largely transient population. As a consequence, no higher learning institutions were founded, and even by the 19th century affluent "Brazilians" would have to take their studies in Europe. Therefore, practically no science was developed in the country, with some very few exceptions, in particular concerning the activities of the Jesuits of the

[1]See the list of abbreviations at the end of the paper.

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Figure 1. The observatory on the roof of Count Nassau residence. (Watercolor by Zacharias Wagner – Courtesy Kupferstich-Kabinett, Staatl. Kunstsammlungen Dresden)

Companhia de Jesus, like Valentim Estancel, a professor at the Colégio da Bahia, whose observations of a comet of 1668 were referenced in Newton's *Principia Mathematica*.

One of these exceptions, which is particularly remarkable in an astronomical context, was the establishment of the first truly astronomical observatory in the southern hemisphere during the Dutch occupation of the Brazilian northeast (1630-1654). The observatory was built in 1639 in Recife, presently the capital of the state of Pernambuco, by the Colonial Governor at the head of the Brazilian colony of Nieuw Holland, Count Johan Maurits van Nassau-Siegen. The observatory was located at the top of the governor's house (Fig. 1), and, according to some sources, later on transferred to one of the towers of the newly built Freiburg palace. No traces of these observatories are left. The main responsible for the astronomical observations was the German naturalist, cartographer and astronomer Georg Markgraf (1610-1644). Markgraf is better known for the publication of the *Historia Naturalis Brasiliae* with the Dutch physician and naturalist Willem Pies (1611-1678) and edited by the geographer Johannes de Laet (1581-1649) (Leiden/Amsterdam, 1648), but for about four years between 1638 and 1643 performed detailed astronomical observations until his departure for Angola, Africa, and to his untimely death.

An important change in this situation which boosted the country as an autonomous nation was triggered by the invasion of Portugal by Napoleon in 1807. The Portuguese royal family and Court decided to flee to Brazil,

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just one day before Napoleon troops reached the Portuguese capital, Lisbon. The court in exile was established in Rio de Janeiro, declared as the new capital of the Kingdom of Portugal, under the authority of Regent Prince Dom João VI. In 1816 Dom João VI was recognized as King of Portugal, but he continued to reside in Brazil, which he had raised to the status of a Kingdom on 16 December 1815.

An era of effervescence then started, triggered partly by the opening of ports to commerce in 1808 and in particular by the arrival of many European scientists and explorers, who for the first time had access to the largely unknown natural resources of the country, especially its flora and fauna. The presence of the royal court in Brazil greatly helped to bring a clear progress in the cultural and scientific activities. Dom João VI created the Royal Library, the National Museum, the Naval and Military Academies, and the Botanical Garden.

Dom João VI returned to Portugal in 1821. His elder son and heir, Pedro, declared Brazil independent from Portugal on 7 September 1822, and subsequently declared himself Emperor Pedro I. The independence was recognized by Portugal in 1825. Dom Pedro I created several institutions such as the Academy of Fine Arts, the Justice Supreme Court, the Post, and in particular, the Imperial Observatory, the latter created on October 15, 1827.

2. From the Imperial Observatory to the National Observatory

The Imperial Observatory was later (1900) renamed as the National Observatory, and its main aims were the mapping of the territory, the measurements of longitudes, and the reference local time, services that continue presently with the now existing branches of Official Time Service, and Geomagnetism services of the National Observatory. After several years facing bureaucratic problems, the observatory was able to develop several research projects related to classical astronomy and to participate in several scientific expeditions, especially under the direction of Emmanuel Liais (1826-1900), a former director of the Paris Observatory, Louis Cruls (1848-1908), Henrique Morize (1860-1930) and Lelio Gama (1892-1981). Fig. 2 shows the historical building of the National Observatory.

3. Additional Milestones up to the First Half of the 20th century

Before the second half of the 20th century, some additional important facts worth mentioning regarding astronomy, can be summarized as follows:

- The School of Engineering in Porto Alegre inaugurated an Observatory in 1908, then called Instituto Astronômico e Meteorológico (IAM) with

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Figure 2. Observatório Nacional in Rio de Janeiro. This building is now the Museum of Astronomy MAST/MCT. The staff of Observatório Nacional is located in buildings at the same site. (Courtesy MAST/ON/CNPq)

the aim of preparing engineers for work in geodesy and astronomy. The historical building in the center of Porto Alegre (Fig. 3) is a listed building considered of historic interest and has outreach activities, belonging now to the Universidade Federal do Rio Grande do Sul (UFRGS).

- In 1912 the Observatório de São Paulo was inaugurated as the seat of the Meteorological Service of the Geographic and Geological Commission, at Avenida Paulista 69 (now the location of the Museum of Art of São Paulo, MASP). The observatory was moved to Parque do Estado in 1932, then called Instituto Astronômico e Geofísico, as a complementary institute to the recently created Universidade de São Paulo (USP) in 1934. It was eventually incorporated to USP in 1946. Fig. 4 shows the historical building of IAG, built in 1932. This is presently part of the São Paulo state science park, as the astronomical institute moved to the main university campus in 2002.
- Eddington's expedition to measure the bending of light during the Solar Eclipse of May 29, 1919: the measurements obtained in Sobral, in the state of Ceará, together with those in the Principe Island, consisted in the first confirmation of the Einstein theory of relativity. In a visit to Rio de janeiro in 1925, Albert Einstein declared "The idea that my

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Figure 3. Historical building of the Observatório Astronômico da Universidade Federal do Rio Grande do Sul (UFRGS). (Courtesy R.A. Frantz/UFRGS)

mind formulated, was confirmed in the bright skies of Brazil", a phrase reported by a local newspaper. Fig. 5 shows Albert Einstein at the National Observatory, in 1925.

4. Creation of the Universidade de São Paulo - USP

In 1932, the state of São Paulo started a revolution against the governing dictatorship in favour of the establishment of a constitution, called the "constitutionalist revolution". They were defeated after a few months. As a consequence, there has been a decision to carry out an intellectual and scientific revolution. One of the main actions was the creation of the Uni-

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Figure 4. Instituto Astronômico e Geofísico (IAG/USP), building from 1932. The site is now a state outreach science Park and the IAG/USP staff was relocated at the University of São Paulo main campus. (Courtesy IAG/USP)

versidade de São Paulo, led by the appointed governor Armando Salles de Oliveira.

European professors, that became widely well-known later on, were hired to start groups in the new University in all scientific fields. In physics, Gleb Wathagin and Giuseppe Occhialini formed a group working in cosmic rays, which included experiments held in Bolivia. Important names in Brazilian physics were formed in that nucleus: Paulus Aulus Pompéia, Marcelo Damy de Souza, Cesar Lattes, Mario Schemberg. Results of the research on cosmic rays can be found, for example, in Pompéia *et al.* (1940), Wataghin *et al.* (1940a&b) and Souza Santos *et al.* (1941).

Cesar Lattes in particular missed a Nobel prize: he worked with Cecil Powell, and published the discovery of the meson pi in *Nature*, as first author (1947). Cecil Powell alone was awarded the Nobel Prize of Physics in 1950, and it was told that the policy at the time was that the head of a research group would be the one awarded.

Mario Schemberg was a foremost scientist, with two major contributions related to Astronomy: with George Gamow, they created the URCA process, a reaction that emits neutrinos, during the cooling of neutron stars – the name was an allusion to the casino URCA in Rio de Janeiro, to ex-

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Figure 5. Visit of Albert Einstein to the Observatório Nacional in 1925. (Courtesy ON)

plain energy disappearing similarly to money disappearing in the casino (Gamow & Schoenberg 1940, & 1941). With Chandrasekhar, he published the Schemberg-Chandrasekhar limit (1942).

It should be noted that Schemberg signed the papers with a modified spelling of his own name: instead of Schemberg, he adapted it to "Schoenberg" or "Schönberg", so that he is often not identified as a Brazilian in some studies.

These beginnings in research related to Astrophysics did not have immediate follow-up with these scientists. Despite this, Cesar Lattes formed and inspired many students.

The University of São Paulo is to this day a leading university, with over 5000 professors, 70 000 undergraduate students, and 22 000 graduate students. It produces 25% of refereed papers in the country, and forms over 2000 PhDs/year.

It is interesting to note that the State of São Paulo research universities, institutes and centers, are among the 20 most productive regions in the world, according to the report "Knowledge, networks and nations – Global scientific collaborations in the 21st century" issued by the Royal Society (UK), in March 2011.

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5. The Creation of the National Agencies CNPq and CAPES

A most important step taken by the Brazilian government in 1951, was the creation of the national research council CNPq (nowadays Conselho Nacional de Desenvolvimento Científico e Tecnológico), and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), the latter within the Ministry of Education. Both institutions have graduate studies and development of research as their main focus. Presently the country has reached a rate of 11,000 PhDs per year.

6. Creation of FAPESP and FINEP

In 1962 FAPESP (Fundação de Amparo Pesquisa do Estado de São Paulo) was created. The Foundation was already planned in the state constitution of 1947, according to which its budget would be based on a transfer of 0.5% from the state taxes. In 1989, it was increased to 1% of state taxes, and this steady transfer of resources has been the fundamental basis of the success of FAPESP. Since then other state foundations were created, and in particular among those that provide presently a support to their communities, we mention FAPERJ (Rio de Janeiro), FAPEMIG (Minas Gerais), FAPESB (Bahia), and FAPRN (Rio Grande do Norte).

FINEP (Financiadora de Estudos e Projetos) was created in 1967, with the aim of promoting and financing applied scientific and technological research and innovation in industries, universities, centers of research, government and the so-called third sector. These state institutions, CNPq, CAPES, FINEP, and FAPESP were, and still are, the main mechanisms for funding research in the country.

7. First Steps in Building Professional Astronomy

Professional astronomy only started in the 1960's, due to government as well as individual initiatives: In 1961 the first Law of Guidelines and Bases (Lei das Diretrizes e Bases – LDO), concerning the educational system, proposed a restructuring of universities, leading to university teaching connected with research and graduate studies.

Also in 1961, the physicist and mathematician Abrahão de Moraes working on celestial mechanics, Director of the Instituto de Astronomia e Geofísica da Universidade de São Paulo (IAG-USP), proposed and obtained the affiliation of Brazil to the International Astronomical Union (IAU), approved in the General Assembly in Berkeley in 1961. Abrahão de Moraes also articulated and promoted the formation of Brazilian PhDs in Astronomy abroad, funded by FAPESP and CNPq fellowships.

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8. The Beginning of Graduate Astronomy Courses

In the late 1960s and early 1970s, the first PhD astronomers formed abroad returned to the country: Sylvio Ferraz Mello, Paulo Benevides, and José Antonio de Freitas Pacheco came to São Paulo, along with a few astronomers then working in France, and Licio da Silva, in Rio de Janeiro. These astronomers have had a fundamental role in nucleating astronomical centers in the country, by forming groups of students, and fostering their graduation and obtention of PhDs both abroad and in the country. Since then the process has continued sucessfully, as a snowball.

It is difficult to make science without adequate equipment, but it is impossible for science to develop without people. Probably the main reason for the impressive growth of astronomical research in the country was the successful creation of graduate astronomy courses in the late sixties and beginning seventies. The first courses were implemented at the well known aeronautics engineering school ITA, the Instituto Tecnológico de Aeronáutica, located in São José dos Campos, state of São Paulo, boosted by the construction of an observatory featuring a 60cm reflecting telescope (Fig. 6). Graduate courses at IAG/USP and Mackenzie University followed, and later on the decade ON, UFRGS and UFMG started their own courses. Nowadays, about 20 institutions offer graduate MSc courses, and many also PhD courses. These institutions produce in average about 50 new MSc/PhD graduates per year.

9. The Brazilian Astronomical Society (SAB)

In 1974, the Sociedade Astronômica Brasileira (SAB) was founded, and its foundation document was signed by 48 astronomers, many still students at the time. It has now over 500 members, with a very important role in the conduction of the astronomical community. Since its foundation, it has distinguished itself in the organization of annual meetings and supporting other scientific events in the country, so that Brazilian astronomers, including students, could have an opportunity to present and discuss their own research in a friendly environment. Frequently well known foreign astronomers are invited to participate in these meetings, which frequently opens the opportunity of new collaboration work.

10. The Itapetinga Radiotelescope

Since 1960, a group of students and amateur astronomers, led by Pierre Kaufmann, started efforts to build a radiotelescope, and an agreement with Mackenzie University was concluded. A larger agreement between Mackenzie, UFRN (Universidade Federal do Rio Grande do Norte), and the North-

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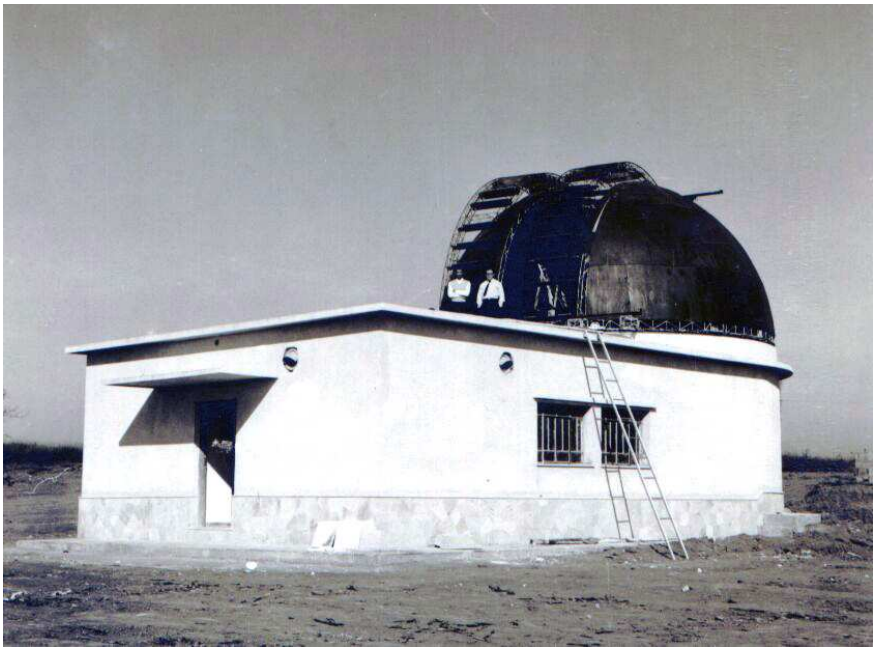


Figure 6. Construction of the ITA Observatory, São José dos Campos, state of São Paulo. (Courtesy ITA/CTA)

American Air Force Geophysics Laboratory (AFGL), led to the building in 1971, of the Itapetinga millimeter radiotelescope, with a diameter of 13.7m (Fig. 7). This radiotelescope was able to measure frequencies in the range 7 GHz to 94 GHz, and was built with resources from BNDES (Banco Nacional de Desenvolvimento), CNPq, and Mackenzie University. Several Nature papers were produced with the Itapetinga Radiotelescope, and a graduate course focussing on Radioastronomy was launched. Research concentrated mainly in solar physics and galactic and extragalactic astronomy, in particular with the observations of several water and SiO maser sources, as well as studies on the variability of quasars and radiosources.

11. The First Professional Optical Observatory – OAB

Since 1962, the geophysicist Luís Muniz Barreto, Director of Observatório Nacional (ON) (formerly Imperial Observatory), together with Abrahão de Moraes, Director of IAG/USP, started to plan the implementation of an optical Observatory, that should have a national amplitude. Led by these two scientists, the two main institutions at that time, ON and IAG/USP, prepared a plan for the creation of the Observatório Astrofísico Brasileiro (OAB), consisting in a first step, of the choice of best site for astronomi-

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Figure 7. The Itapetinga 13.7m radiotelescope. (Courtesy ROI/DAS/INPE)

cal observations. The immediate consequence of this plan was the visit of the French astronomers Jean Rösch, from the University of Paris VI and Director of the Pic du Midi Observatory; Jean Delhaye, Director of the Observatory of Besançon, and Roger Cayrel, Head of Astrophysics at the Observatory of Paris. Jean Rösch had already been part of the team that chose the La Silla site in Chile for the European Southern Observatory.

In 1963 CNPq created the Comissão Brasileira de Astronomia (CBA), composed by: Abrahão de Morais (IAG); Lélio I. Gama and Luís Muniz Barreto (ON), and Fernando de Mendonça (Comissão Nacional de Atividades Espaciais – CNAE, nowadays Institute Nacional de Pesquisas Espaciais, INPE), in order to work on the project of a national observatory.

In 1972, the agency FINEP approved the project of installation of an

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Figure 8. Observatory at Pico dos Dias, of the Laboratório Nacional de Astrofísica linked to the Ministry of Science & Technology, near Brasópolis, Minas Gerais. (Courtesy C.D. Gneiding/LNA)

Astrophysical Observatory in the site chosen previously, which was near Brasópolis, in the state of Minas Gerais. On April 22, 1980 a reflecting cassegrain-coudé telescope, with mirror of 1.60m started operations. In February 1981, Muniz Barreto, Director of ON, officially inaugurated the installations of the Observatório Astrofísico Brasileiro (OAB). On March 13, 1985, OAB was split from ON, giving place to a new institution, the Laboratório Nacional de Astrofísica (LNA), a truly national facility. Fig. 8 shows the Observatory of Pico dos Dias of LNA, and Fig. 9 shows the 1.6 Perkin-Elmer reflecting telescope.

Together with the main action towards the building of OAB, smaller 60cm telescopes were installed at Piedade Observatory (Minas Gerais), Valinhos (São Paulo) and Porto Alegre (Rio Grande do Sul).

12. The Gemini and SOAR Consortia

In 1993 Brazil joined the Gemini consortium, a two 8-m telescope facility in Chile and Hawaii, with a fraction of 2.5% of the observing time. In 1995, we joined another consortium for the building of a 4m telescope SOAR,

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Figure 9. The 1.6m Perkin-Elmer reflecting telescope of the Laboratório Nacional de Astrofísica (LNA). (Courtesy LNA)

with a fraction of 34% of the observing time. These facilities were useful in the sense of allowing Brazilian astronomers to participate in international committees, and instrumentation programs. In particular, in the last 10 years, we were able to build 3 spectrographs for the SOAR telescope: SIFS, BTFi and STELES, that should be operative in 2012. Figs. 10 and 11 show, respectively, the SOAR telescope in Chile, and the SIFS spectrograph built by LNA/MCT and IAG/USP.

In the last 3 years Brazilian astronomers also rented 10 nights/year at the CFHT telescope, providing access to a wide field, and high resolution spectroscopy in a 4m telescope.

13. The General Assembly of the International Astronomical Union in Rio de Janeiro

In the last century, the only General Assembly of the International Astronomical Union (IAU) in South America was held in 1991, in Buenos Aires, Argentina. In 2000, the Brazilian representative at the IAU Walter Maciel, sent a first letter of intent to host the General Assembly in Brazil. In 2003, an official invitation was sent, and approved in the Executive Committee (EC) session during the General Assembly in Sydney. The organization of

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Figure 10. The 4m SOAR telescope at Cerro Pachón, Chile. Brazil has a share of 34% of the observing time. (Courtesy SOAR Telescope Consortium)

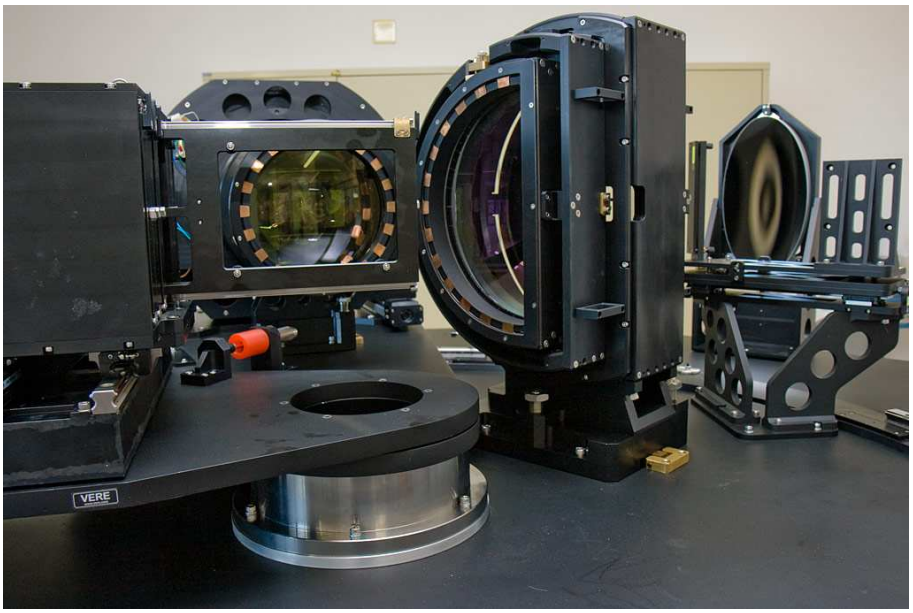


Figure 11. The SIFS – SOAR Integral Field Unit Spectrograph, the first spectrograph built by Brazilian astronomers. (© B. Barbuy)

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TABLE 1. Distribution per institution

Institution	**Staff**	**Postdocs**	**Graduate students**	**Total**
IAG-USP	35	26	57	118
ON/MCT	28	12	33	73
INPE/MCT	27	7	26	60
Obs.Valongo/UFRJ	16	1	13	30
UFRGS	13	3	18	34
UFMG	11		8	19
UFRN	10	4	20	34
UNIVAP	10		10	20

TABLE 2. Distribution per state or region

State	**Staff**	**Postdocs**	**Graduate students**	**Total**
São Paulo	116	41	140	297
Rio de Janeiro	53	15	61	129
Minas Gerais	29	3	45	77
Rio Grande do Sul	28	3	24	55
Rio Grande do Norte	15	6	20	41
Bahia	14		5	19
SC + PR[a]	15	2	7	24
DF + G + MT[b]	9		4	13
PB + PE + RR +S [c]	12		4	16

[a] Santa Catarina + Paraná
[b] Distrito Federal + Goiás + Mato Grosso
[c] Paraíba + Pernambuco + Roraima + Sergipe

the GA had as chairpersons Daniela Lazzaro (ON) and Beatriz Barbuy (IAU Vice-President, USP). In that same year, the EC, and at the General Assembly approved the idea of proposing to UNESCO and UN the year of 2009 as the Year of Astronomy, in commemoration of 400 years of the first telescope observations by Galileo Galilei. A successful General Assembly took place in Rio de Janeiro in 2009, assembling about 2800 participants.

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TABLE 3. Number of women astronomers

	Women astronomers	**Total of astronomers**	**Percentage of women**
permanent staff	69	311	22.2%
post-doctoral fellows	20	74	27%
PhD students	40	154	26%
MSc students	35	132	26.5%

14. Present Status of Brazilian Astronomy

Since the beginning of the astronomy graduate courses in the late 1960's, an impressive growth has occurred, and nowadays about 20 courses are in operation, providing MSc degrees and in half of them also PhD degrees. This has expanded considerably the scope of the astronomical research in the country, encompassing previously areas that did not have enough attention, such as the study of gravitational waves and X-ray astronomy, along with more traditional approach in the optical, infrared and radio domains.

In the last few years the system of universities has been largely expanded, in particular the federal universities, as well as private universities and new state universities. The result of all this is that, presently, there are over 60 institutions where there is at least one astronomer. In total there are 311 professional astronomers with permanent jobs, including 291 PhDs, and 20 Masters, 59 postdocs, and 290 graduate students, amounting to a total of 660 astronomers in activity in the country. A recent census is available online[2]. The distribution of staff members, postdocs and PhD plus Master students is given in Tables 1 & 2. In a few cases, there are staff members with a Master degree. The largest institutions, with more than 10 staff PhD members are listed in Table 1, as well as the distribution of astronomers per State or region in Table 2.

15. Women Astronomers

The proportion of women astronomers in Brazil is presently around 25%. This fraction is higher than in most countries, but still not satisfactory. The current estimates are shown in Table 3.

[2]http://www.sab-astro.org.br/levantamento_2011.htm

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16. Scientific Profile – Papers in ISI (2010)

A consultation on the Institute for Scientific Information – ISI data base shows that, in the year of 2010, in the field of Astronomy, there are 550 papers from Brazilian authors. More than half of these are from physicists, in journals such as Physical Review.

By selecting the papers that can be identified with astronomy (mostly from being published in the main astronomy journals), 210 papers remain. Among these, the distribution of fields of research can be subdivided in:
• Optical/IR/mid-IR: stellar – 63 (30%) (4 of these with COROT data);
• Optical/IR/mid-IR: extragalactic – 43 (including 3 multiwavelength studies) (20.5%);
• Optical/IR/mid-IR: HII regions, Planetary Nebulae, Interstellar Medium – 11 (5.24%);
• Solar system – 20 (9.52%);
• Sun – 3 (1.43%);
• Astrobiology – 7 (3.33%);
• X-rays – 6 (2.86%);
• Gravitational waves – 6 (2.86%);
• Exoplanets – 13 (6.2%) (11 of these with COROT data);
• Theoretical: dense objects, magnetic fields, turbulence, jets, galaxies, bulges, black holes, general relativity: 26 (12.4%);
• Theoretical: cosmology – 14 (6.7%).

These numbers deserve a few comments:
a) it is clear that astronomy with optical-IR-mid-IR telescopes represents the main profile of Brazilian astronomy, with 62% of publications;
b) it has to be said that many more theoretical papers in cosmology are produced, if physicists would be gathered all together;
c) radioastronomy is employed in one paper that uses multiwavelength data, and in another on solar physics; COROT participation has brought a strong interest from our community and strengthened the exoplanet field.

It is also important to mention that Brazil joined the Journal Astronomy & Astrophysics, as a member, in 2006, together with Chile and Argentina.

17. Joining the European Southern Observatory (ESO)

A historical step in Brazilian astronomy has been the signing of access agreement to become a Member of the European Southern Observatory, signed between the Minister of Science and Technology Sergio Rezende, and the Director of ESO Tim de Zeeuw, on December 29, 2010. It is clear from the numbers in the previous section that optical/ir/mid-ir astronomy is the area where we need more facilities, which would be largely provided

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by ESO; on the other hand, the weak activity in radioastronomy also shows that we will greatly benefit from joining ALMA, through ESO.

The final decision on joining ESO still depends on confirmation by the Brazilian Congress. It will represent a clear change in category for Brazilian astronomy, and its science and technology in general.

18. Conclusions

Brazilian astronomy has been growing steadily since the late 1960s, and has now a solid community, apart from a strong attractive power over students and researchers from several latin american countries. Fig. 12 shows the 25 States and 1 territory that compose the Brazilian Federation, and overplotted are the numbers of astronomers per State. The south-east (São Paulo, Rio de Janeiro, Minas Gerais) is the strongest region in all fields, such as Economy, Science, Education, and this is also reflected in number of astronomers.

We need however to take big steps to keep the pace of international astronomy. Joining ESO is a great step in this sense. With this, we should greatly improve our interactions with the industry, forming engineers in astroengineering, and as well getting into space astronomy.

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List of Abbreviatons

BNDES	Banco Nacional de Desenvolvimento
BTFi	Brazilian Tunable Filter
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico

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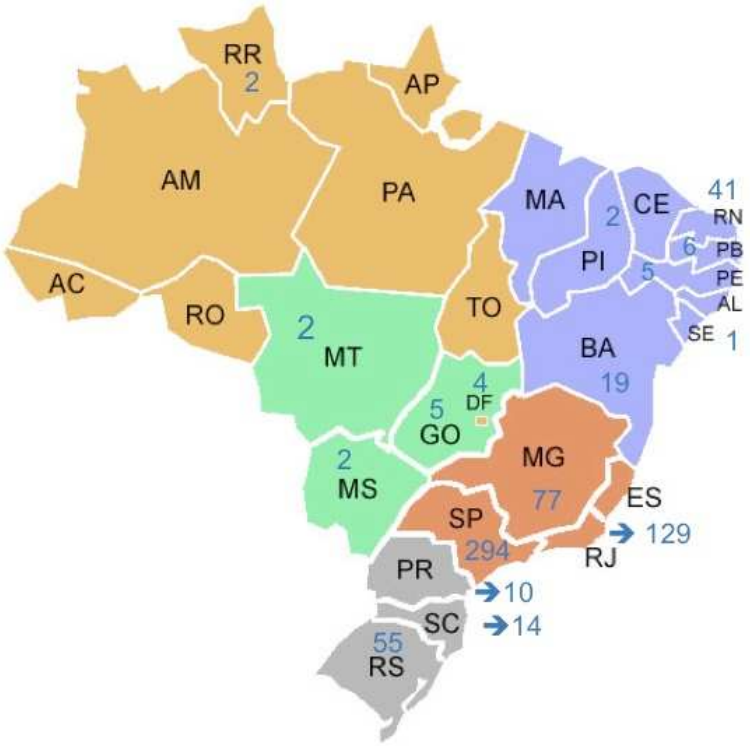


Figure 12. Brasil is a Federation with 25 States and one territory. In the figure the number of astronomers per State are overplotted. Abbreviations can be decoded as follows: AC = Acre (territory), AL = Alagoas, AM = Amazonas, AP = Amapá, BA = Bahia, CE = Ceará, DF = Distrito Federal, ES = Espírito Santo, GO = Goiás, MA = Maranhão, MG = Minas Gerais, MS = Mato Grosso do Sul, MT = Mato Grosso, PA = Pará, PB = Paraíba, PE = Pernambuco, PI = Piauí, PR = Paraná, RJ = Rio de Janeiro, RN = Rio Grande do Norte, RO = Rondônia, RR = Roraima, RS = Rio Grande do Sul, SC = Santa Catarina, SE = Sergipe, SP = São Paulo, and TO = Tocantins

COROT	COnvection, ROtation & planetary Transits satellite
ESO	European Southern Observatory
FAPEMIG	Fundação de Amparo Pesquisa do Estado de Minas Gerais
FAPERJ	Fundação de Amparo Pesquisa do Estado do Rio de Janeiro
FAPESB	Fundação de Amparo Pesquisa do Estado da Bahia
FAPESP	Fundação de Amparo Pesquisa do Estado de São Paulo
FAPRN	Fundação de Amparo Pesquisa do Estado do Rio Grande do Norte
FINEP	Financiadora de Estudos e Projetos

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IAG	Instituto de Astronomia, Geofísica e Ciências Atmosféricas
IAU	International Astronomical Union
INPE	Instituto Nacional de Pesquisas Espaciais
IR	Infrared
ISI	Institute for Scientific Information
LNA	Laboratório Nacional de Astrofísica
MCT	Ministério de Ciência e Tecnologia
OAB	Observatório Astrofísico Brasileiro
Obs. Valongo	Observatório do Valongo
ON	Observatório Nacional
SAB	Sociedade Astronômica Brasileira
SIFS	SOAR integral field spectrograph
SOAR	SOuthern Astrophysics Research telescope
STELES	SOAR Telescope echelle spectrograph
UFMG	Universidade Federal de Minas Gerais
UFRGS	Universidade Federal do Rio Grande do Sul
UFRJ	Universidade Federal do Rio de Janeiro
UFRN	Universidade Federal do Rio Grande do Norte
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIVAP	Universidade do Vale do Paraíba
USP	Universidade de São Paulo

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 119-132
Ed. A. Heck, © 2013 Venngeist.

ITALIAN ASTRONOMY AT THE BEGINNING OF THE 21ST CENTURY

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Abstract. The end of the 20th century has seen a major reorganization of Italian astronomy. In about a decade, from 1999 to 2011, three successive laws have moved Italian astronomy from a system based on three major pillars (the twelve independent national astronomical observatories coordinated by the Public Education, University and Research Ministry through a consultative committee; the three CNR institutes devoted to astrophysics; and several university departments, either of astronomy or physics), to a single National Institute for Astrophysics (INAF). It includes all astronomical abservatories and the three CNR institutes, and collaborates with university groups operating within multi-thematic physics departments. This paper briefly describes the status, achievements and projects of Italian astrophysics, as well as some of the likely further changes coming up.

1. Introduction

Castellani (2003) has provided a vibrant and thorough description of the historical roots and of the evolution of Italian astronomy from the foundation of the *Collegio Romano* (1551) to the major reorganization at the horizon in 2003, the date of his writing. In the following I shall briefly describe the important changes that have occurred from the late 1960s to 2012 while Italian (and world-wide) astronomy was evolving in a so-called "big science", *i.e.* a scientific discipline requiring the realization of complex and costly infrastructures thanks to international cooperation and collaborations.

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2. Italian Astronomy from the Late 1960s till 2000

Since the late 1960s, Italian astronomy was organized in three major pillars:

- the 12 (9 until the late 1980s) independent national astronomical observatories,
- the 7 territorial sections (formerly laboratories) of the three CNR (*Consiglio Nazionale delle Ricerche*, National Research Council) institutes devoted to astrophysics, and
- about 20 university departments, either of astronomy or physics, hosting groups of professors and university researchers.

These three pillars remained in place for about 40 years, but with some important changes. In 1982, the astronomical observatories were reorganized in university-like structures; the scientific personnel was then selected through procedures similar to those applied to university professors. The coordination of "local" activities in a national context was assigned to the *Consiglio delle Ricerche Astronomiche (CRA)* – a national consultant committee for the Ministry of Research, mainly composed by senior university professors and observatory scientists – issuing recommendations on the allocation of ordinary funds and permanent staff positions.

At the beginning of 2002, a major reorganization of the CNR was concluded with the 7 CNR laboratories devoted to astrophysics transformed into three multi-territorial/multi-section CNR institutes. Moreover, in 1996, by express request from the Ministry of Research, was constituted the CNAA (*Consorzio Nazionale per l'Astronomia e l'Astrofisica*), a consortium among the 13 astronomical observatories active at that time[1]. With a dotation of fresh economic resources, the CNAA was able to complete the construction and to start operating the TNG (*Telescopio Nazionale Galileo*, Italian National Telescope), as well as to sustain other national scientific and technological programs.

With such an organization, Italian astronomy went through a period of rapid and healthy growth as illustrated (cf. Fig. 1) by its world-wide absolute rank position (clearly a world-wide excellence according to the *SCImago Journal & Country Rank* analysis). It played an active role within ESO and ESA, and initiated several major national and international programs for new instruments and observational infrastructures on ground as well as in space. Space programs were made possible thanks to the cooperation with and funds from ASI (*Agenzia Spaziale Italiana*, Italian Space Agency) founded in 1988 on the roots of the CNR National Space Plan. Looking back, the CNAA was a step toward the major subsequent reorganization of Italian astronomy initiated in 1999.

[1]As a result of the founding of the Osservatorio Astronomico di Cagliari.

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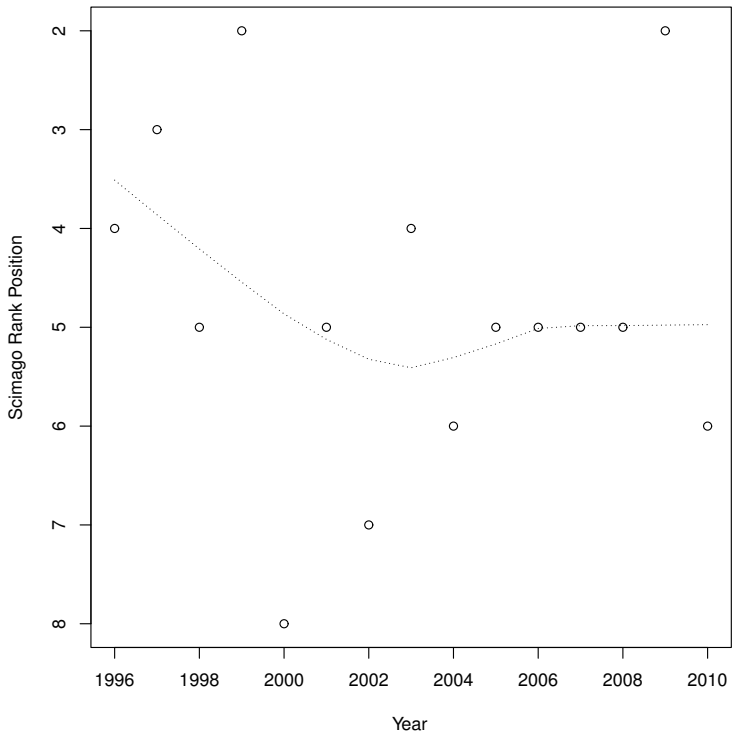


Figure 1. Absolute world-wide rank position of Italian astronomy according to Scimago (2007) (data retrieved June 01, 2012, from `http://www.scimagojr.com/`). The dashed line is a smooth interpolation to data showing the long time-scale trend. These data reflect the world-wide excellence of Italian Astronomy.

3. Italian Astronomy in the First Decade of the 21^{st} Century

2001 marks the actual start of activities for INAF (*Istituto Nazionale di Astrofisica*, National Institute for Astrophysics), then incorporating all the Italian Astronomical Observatories. Contrary to the astronomical observatories that had a university-like status, INAF was constituted as a national research institute[2] (like the CNR).

In 2003, while INAF was still at the beginning of its operational life and Italian astronomy was metabolizing this major re-organization, INAF was restructured to include also the three newly constituted CNR insti-

[2]However the 1999 INAF institution law maintains that the INAF scientists had a status and a career equivalent to that of university professors.

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tutes devoted to astrophysics. This reorganization has definitively moved INAF within the system of national research institutes: as an example, scientific staff started to be hired and selected according to the rules valid for CNR. As a result of this reorganization, INAF had a President chairing a four-member administration board (*Consiglio di Amministrazione*, CdA), all chosen by the Ministry of Research, a Scientific Council of 12 members (partly elected and partly selected by INAF's CdA), a territorial network of 19 research structures each headed by a Director appointed by the CdA, and 5 national thematic committees each consisting of 5 elected members. The thematic groups and corresponding elected committees were the way adopted to organize the scientific debate with the aim to incorporate the contributions from the university professors associated to INAF. The central management structure was divided in three branches: Administrative Direction, Scientific Project Department and Scientific Research Structure Department, each with its Head appointed by the CdA.

In late 2011, after a two-year long process, INAF, as well as all other Italian national research institutes, has again been reorganized. The expectation for this reorganization were quite high, probably too high; the changes can be factually summarized as follows:
1) a minor reduction of the number of research structures (currently 17);
2) a Scientific Council of 7 members appointed by the CdA taking into account community indications with a closer connection with the 5 thematic committees;
3) a new central management structure with a single General Direction, under which operated the central administration offices, the national Scientific Direction and the territorial network of research structures;
4) the formalization of the Research Structure Director Board chaired by the General Director (or by the Scientific Director) and of a 4 Director subcommittee for a closer interface with the INAF top management and/or CdA.

At the time of writing this contribution, the organization has just started its operation and any judgment on its efficiency would be premature. While I was finishing revising this paper, the Italian Government, for readjusting public expenditures in response to world-wide economic crisis, has passed a law requiring a compulsory major regional or interregional reorganization of all public organizations and offices, including all national research institutes. Thus, before the end of 2012, we will very likely see a further reorganization of Italian astrophysics and of the entire Italian research system. In my opinion, an appropriate and intelligent usage of this opportunity could result in a virtuous outcome for INAF with a major reorganization of the territorial network of the research structures (including a major reduction of their number) and a profound simplification and optimization of

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the INAF management and administration system. We will see in the next few years if this will be the case and if the Italian astronomical community will be able to properly respond to major changes occurring at the entire country level.

4. The Italian Astronomy and the University System

During the last decade, the Italian university system has also been subject to major changes (the last reform law approved at end of 2010 is still in the process of being implemented): the main life-motivation of all those changes is the quest for simplification, efficiency and cost reduction. This has in fact determined a reduction in the number of *Laurea*[3] courses, of university departments and of university professors, a process that will very likely continue in the next coming years. As a result, essentially all astronomy departments have been merged into bigger, multi-thematic physics department (or similar ones), the *Laurea* in Astronomy degree has largely disappeared, and astrophysics is today one of the subtopics of the specialization of the *Laurea* in Physics degree. We will know in the next few coming years whether this reorganization will ultimately have (unfortunate) negative or, hopefully, positive consequences.

5. The new Institutional Landscape of Italian Astronomy

In summary, we have since 2005 a single national institute for astrophysics, the new INAF, acting in collaboration with university groups usually working within multi-thematic Physics Departments and, typically, with university professors teaching within physics curricula. A new national regulation of Doctorate is expected to be approved soon; based on the circulated draft version of the new regulation, I can predict that, notwithstanding the new possibility for INAF to play an active role in the constitution of Doctorate curricula in astrophysics, their constitution will require joint efforts in order to reach critical mass (very likely in a given geographical territory). Otherwise Astrophysics will turn into one of several research lines of a broader Doctorate in Physics.

6. Financial resources

In the last decade, substantial changes have occurred as to the sources, level and distribution of funds supporting the activity of Italian astronomy. The interested reader can found a description of the pre-INAF status in

[3]Graduate study.

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Castellani (2003); since then, in my opinions, the most notable changes have been:

- the severe restriction for INAF staff researchers to access to the MIUR funds of the so-called co-financing system (COFIN) for the university research[4]; since the INAF researchers largely outnumber (by about a factor four) the university professors involved in astrophysical research, this has resulted in a major loss of funds available to the entire Italian astrophysics community; considering that astronomy is still mostly a science in which small/medium size researcher groups gain competitive access to medium/large size observational facilities (either on ground or in space) the fund reduction risks to severely hamper a key part of current today research based on the exploitation of the data collected at the observing facilities;
- the redefinition of the objectives of ASI has resulted in a major reduction of the funds available both for the scientific exploitation of space mission data as well as for the development of enabling technologies for new space missions; the latter, in particular, could easily result in the vanishing of technological capabilities accumulated, often, in the course of several decades;
- the adoption at national level of a policy aiming to allocate the vast majority of funds to few selected strategic projects; brought to its current extreme application, this "per se" rationale approach has the drawback of reducing too drastically the seed funds needed for the growth of new ideas.

At the same time, the overall funding transferred since 2005 – the start year of the "new" INAF – by MIUR to support the INAF activities (including the permanent staff cost) has evolved as summarized in Fig. 2. Considering inflation, the reduction of the overall purchase power is obvious with respect to 2005. It is worth to notice that, since 2004, these funds include also the resources required for the construction and maintenance of logistic infrastructures (including the buildings hosting the territorial Research Structures and their laboratories). Before 2004, these expenses, amounting yearly to several MEuros were covered, at least in the case of the observatories, by additional specific funds. They now represent an additional burden for the INAF budget.

In this scenario of contracting purchase power, Italian astrophysics had and has to cope with the completion of two major observing infrastructures and the start of their operations: the LBT (Large Binocular Telescope) with

[4]COFIN was initiated in 1996 and provides (on a competitive basis) 70% of the total cost of a research project; until 2004, INAF scientists were able to apply in the same conditions as the University professors.

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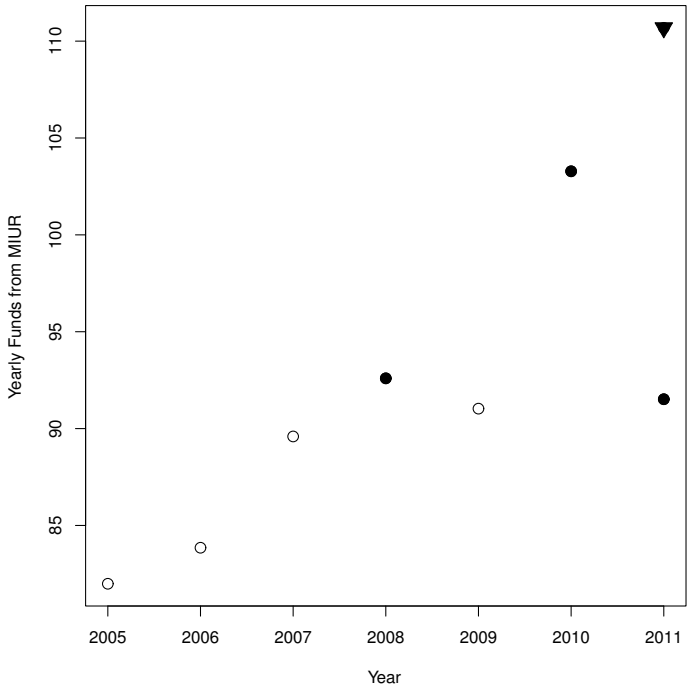


Figure 2. Yearly funds transferred to INAF by the MIUR since 2005, the year of start of "new" INAF incorporating scientists and infrastructures previously part of the Italian CNR. The filled symbols indicate the years in which fund transfers include the, so called, special contributions. The big filled triangle at year 2011 indicates the value the fund transfer should have to maintain the 2005 purchase power taking into account the 13.47% overall inflation from 2005 to 2011. The 2001 value includes funds for the so-called "FlagShip Projects", but since their amount was still unknown at the time of this writing, does not include the additional funds that will be allocated by MIUR to national research institutes in reply to specific project proposals. The amount of resources to be distributed to these latter projects amount, on average, to 8% of the "standard" (running cost) funds. (Transferred fund values retrieved from the MIUR web site, inflation data retrieved from the Italian official statistical institute, ISTAT.)

a quarter of the construction and running cost budget covered by INAF, and the SRT (Sardinia Radio Telescope, a single dish antenna of 64m diameter) realized by INAF with some financial contribution of Italian Space Agency interested to use the antenna for deep-space transmission. The resources required by the operations of these new infrastructures, as well as the running costs of the 4m-class TNG (Galileo National Telescope), has unavoidably generated substantial tensions in the allocation of resources within the INAF budget, tensions that had an impact on the entire Ital-

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TABLE 1. 2008 expenses covered with the ordinary MIUR funds to INAF.

Spending Item	MEuros
Salaries of Staff Personnel	70
Research structure network running costs	12
Research programs and observing infrastructure	9

ian astronomy. Major spending cuts have been required, and they, in my opinion, are above the level of just a proper pruning of the system. As a result, valuable expenses, *i.e.* those for Doctorate fellowships and/or seeding innovative research activities, have been drastically reduced well below the level adequate to a world-wide excellence community like the Italian astronomy.

7. General Considerations

It is worth to mention that, overall, the INAF system, and in general the entire Italian astronomy, is very efficient, since the amount of funds per person is by far the smallest among the Italian research institutes: INAF stays at the level of about 70.000 Euros per person (including salaries), while other similar Italian research institutes are positioned at twice that amount. At the same time, the cost for publication by INAF scientists in professional international refereed journals, is by far the lowest one. As an example of the current financial situation, Table 1 shows the allocation to the macro-expenditure items of the MIUR "ordinary" fund transferred to INAF in the 2008 (amounting to about 91 MEuros). This allocation has remained more or less the same since then[5].

In the course of 2008, INAF has obtained additional funds through competitive processes (from the EU, ASI, and other national and international sources) for about 30 MEuros. Those funds, allocated to specific projects and activities, show the INAF scientist capacity to attract external resources, but hardly can solve some of the systemic needs of Italian astronomy.

The amount of today available resources challenges the orderly planning of Italian astrophysics in the European and world-wide contexts, and this is further amplified by the major limitation imposed by several laws approved in the course of the last couple of years, to the substitution of staff members as they reach the retirement age as well as by the compulsory 10% con-

[5]The "special" resources have been largely allocated to non-recurrent expenses.

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traction on the number of supporting employees (excluding the scientists and technologists) very recently approved by Government to reduce public expenditures.

In the last few years, INAF has opened a number of permanent staff positions at the entrance level of the scientist career with the aim of recruiting, notwithstanding the severe constraints on recruitment and budget resources, some of the brilliant young Italian scientists working as postdocs in Italy and abroad whose expertise would be crucial for the frontier research programs of Italian astronomy. On the other hand, the severe turnover and budget limitations have prevented so far the career advancements of many outstanding Italian astronomers with a solid international reputation. As a result, some of them decided to leave Italy and to accept higher-level positions abroad, while at the same time an analogous return flux toward Italy has not been possible. To prevent the risk of losing entire generations of brilliant scientists, a stable flux of recruitment of young scientists as well as of advancement of career of senior ones is without any doubt one of the major problems Italian astronomy has to face and to address in the near future.

8. The Community and its Scientific Interests

Scientists carrying out astronomical research in Italy are working either within INAF[6] or within research groups active in about 25 universities all over the country. These scientists are either permanent or temporary staff members, or junior, even senior post-docs. At the time of this writing (June 2012) the Italian astrophysical community include about 450 INAF[7] permanent staff, 70 INAF temporary staff, 270 INAF postdocs or fellows, 95 university professors, 73 university researchers and 30 university postdocs. About 90 (30 for each of the three-year doctorate course) graduate students are engaged in a PhD thesis in astrophysics, either in an astronomy or in a physics PhD curriculum.

The number of permanent staff employees devoted to research in astrophysics in Italy has slightly decreased in the last few years; in 2005 INAF, had 1037 permanent staff employees, 540 of them were scientists or technologists; in June 2012 the number of permanent staff employees is 991, 450 of them being scientists or technologists. While one can hardly know the precise numbers for the university system, the diminution of university professors over the last few years is a well-known fact.

The vast majority of university professors, researchers, postdocs and fellows are associated to INAF and play an active role in its research activities.

[6]There is also a small number of INFN (*Istituto Nazionale di Fisica Nucleare*, Italian Institute for Nuclear Physics) scientists pursuing research in astro-particle physics or very

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TABLE 2. Distribution of INAF staff and associated (non-INAF) scientists among the thematic areas.

Thematic Area	Membership
Galaxies and Cosmology	155
Relativistic and Particle Astrophysics	138
Stars, Stellar Population and Interstellar Medium	170
Sun and Solar System	133
Advanced Technologies and Instrumentation	154

Table 2 gives a breakdown of researchers according to their choice for one of the five INAF's major scientific thematic areas.

9. Selected Science Highlights

Many great results have been obtained by Italian scientists in a wide range of areas in astronomy and astrophysics. The Italian satellite AGILE, built thanks to ASI funding and whose PI is an INAF staff member, has led to important results about the high-energy universe and the study of black holes (like Cygnus X-3). Apart from its impact on astrophysics, AGILE has also discovered something relevant to commercial aviation system security, namely that our own atmosphere can produce under certain conditions (supercell tropical thunderstorms) phenomena such as terrestrial gamma-ray bursts that have to be taken into account in the proper design of the Faraday cage of commercial airplanes.

Amongst the international collaborations is worth citing the realization of the LBT (Large Binocular Telescope), the largest of its type and one of the most advanced in the world. Thanks to its new adaptive optics system, developed by researchers at the INAF-Arcetri Observatory, the LBT has been able, at optical wavelengths, to exceed the image sharpness of the Hubble Space Telescope, something considered impossible until recently for a ground-based telescope.

VIMS and VIRTIS are two instruments designed and built by INAF; the first operates on the Cassini probe that has been revealing important properties of Saturn and its moons since 2004, like the recent discovery of water on Titan. VIRTIS, on ESA's Venus Express probe, has been designed particularly to study the greenhouse effect on this planet, something relevant

related subjects.

[7]In 2012, the number of INAF employees, including postdocs and fellows, amounts to about 1370 persons.

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Figure 3. A view of the *Telescopio Nazionale Galileo* (TNG), a 3.58m optical/infrared telescope located on the Island of San Miguel de La Palma and inaugurated in 1996. The available focal plane instruments include: HARPS-N (High Accuracy Radial velocity Planet Searcher in North hemisphere), an echelle spectrograph covering the wavelength range between 383 to 693nm, with a spectral resolution R = 115000; NICS (Near Infrared Camera Spectrometer), an infrared (0.9-2.5μm) multimode instrument which is based on a HgCdTe Hawaii 1024×1024 array; DOLORES (Device Optimized for the LOw RESolution) which allows imaging through broad and narrow band filters as well as spectroscopic observations with resolving powers between RS = ∼500 and RS = ∼6000. A multislit mode, based on custom masks manufactured by a dedicate cutting machine, is also available. (Courtesy Giovanni Tessicini, Telescopio Nazionale Galileo)

also for understanding how climate change and non-reversible effects could result from careless behavior on our own planet. The ESA Planck satellite, thanks to its LFI instrument built by a team of researchers coordinated by

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INAF, is making the best map ever of the cosmic microwave background radiation, emitted 13.7 billion years ago. Finally it is worth mentioning that Italian astronomers are among the major users of ESO's and ESA's telescopes and that they have played key roles for their realization, as for example, in the case of INTEGRAL, XMM-Newton and Hershel, three still very active ESA space observatories.

10. Current and Future Major Programs

Italian astronomy, and specifically INAF, is currently engaged in starting operations of large research infrastructures such as the SRT (Sardinia Radio Telescope), in collaboration with ASI, and the LBT (Large Binocular Telescope) in Arizona, as part of an international collaboration with US and Germany institutions. INAF maintains, and makes available to the community, the TNG (Telescopio Nazionale Galileo) in the Canaries. It has recently completed the construction of the VST (VLT Survey Telescope) that has started to operate at ESO's premises in the Chilean Andes, and contributes to the upgrade of scientific instrumentation for the ESO Very Large Telescope.

INAF is busy in programs that are defining the future of astronomy and astrophysics: CTA (Čerenkov Telescope Array), an array of many tens of Cerenkov telescopes of diameters ranging from about 4 to 24m that will allow the detection of gamma-ray (from ∼50 Gev to ∼10 Tev) induced cascades over a large area on the ground, E-ELT (European-Extremely Large Telescope), a gigantic 42m ground based optical telescope whose construction has been recently approved by ESO, SKA (Square Kilometer Array), a system of over 1,500 radio antennas that together will make the largest radio telescope ever constructed, and for which the Italian government has proposed Rome as the project headquarters. Following the 2010 agreement for the construction and installation of HARP-N(orth) at the TNG, this new spectrograph has recently entered into operation, with a large fraction of observing time open to national and international community. HARP-N, a copy of HARP-S(outh), is the most powerful "hunter" of extra-solar planets. It is currently the only instrument with such capabilities that operates in the northern hemisphere and provides to the Italian community an extremely precious instrument for playing a relevant role in the international search for Earth-like planets.

The search for such planets in the habitable zone of their stars is among the most promising and exciting fields of today's research. The Italian community also participates, thanks to the support of the Italian Space Agency, to many science missions which are part of ESA's science and exploration programs. Italian scientists are deeply involved in scientific missions near-

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Figure 4. A view of the 64m Sardinia Radio Telescope recently built by INAF. SRT is the second largest single-dish radiotelescope ever realized. Its innovative design includes an active surface and four focal stations that can operate from 0.3 to 100GHz. SRT's first light took place on 8 August 2012. (© INAF-OAC, photogr. Gianni Alvito)

ing their launch, such as GAIA and Bepi-Colombo, or presently in development, such as EXOMARS, as well as those of the Cosmic Vision program. In particular, members of the Italian community are partners of the international collaborations pursuing all the astronomy and planetology projects currently under study: ECHO (Exoplanet Characterization Observatory), LOFT (Large Observatory For X-ray Timing), MarcoPolo-R (Sample return from a primitive Near-Earth Asteroid), PLATO (PLAnetary Transits and Oscillations of stars). Italian scientists actively participate to the international teams of the ESA missions already selected for implementation: Solar Orbiter (Exploring the Sun-heliosphere connection), Euclid (Mapping the geometry of the dark Universe) and JUICE (JUpiter ICy moons Explorer). In all these latter missions, Italian scientists plan to and/or will participate, thanks to the financial support of ASI to scientific groups and Italian industries, to the realization of the (focal plane) instruments and reduction and interpretation of collected data.

11. Relation with the Society

Since many years, Italian astronomers are engaged in various public outreach activities aiming at increasing people awareness of the achievements of Italian scientists, of the relevance of developed technologies for the so-

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ciety as well as to stimulate and respond to the interest of students since the very early years of school. INAF has developed a web site specifically devoted to public outreach[8] illustrating the complex of public outreach activities and events. INAF has developed, as part of the MEDIA-INAF effort, Astrochannel, the INAF web-tv which broadcasts SIDEREUS, the INAF Web news, illustrating some of the major events and major current discoveries of astrophysics and, more generally, of physics.

This public outreach activity is either based on local initiatives, often taking advantage of the INAF telescopes operating in Italy, or on their coordination, as in the case of major astronomical events, as well as on nationwide initiatives, as for example, the "AstroKids laboratories", a "learning while playing" activity, purposely thought for elementary school students, ideate by INAF in collaboration with the Feltrinelli Italian bookshop network.

12. Final Remarks

Notwithstanding the fact that Italian astrophysics is today of world-wide excellence, keeping its status in the near- and medium-term future is not granted. While it is hardly understandable how, even blowing-up the entire 1200 people doing astrophysics in Italy at world-wide excellence level, could have any real impact on the status of public expenditures, it is clear that it would surely result in the loss of one of the Italian excellences with unavoidable severe impact on the "high tech" Italian industries and companies involved in world-wide realizations of challenging research infrastructures. I hope that in the next coming years there will be around enough Italian astrophysicists that could write the next chapter of the healthy Italian astrophysics adventure.

Acknowledgements

I would like to thank the many enlightening discussions with many colleagues, in particular E. Cappellaro, F. Palla, G. Malaguti and A. Maggio, that are at the basis of this work.

I am also grateful to anonymous referees for their suggestions and linguistic improvements brought to the paper.

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[8] `http://www.media.inaf.it/` (in Italian).

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 133-144
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ASTRONOMY IN MEXICO

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Abstract. Mexican astronomy has a long standing tradition of excellence in research. After a brief review of its history, I outline the current profile of the community, the available infrastructure and participating institutions, and give a glimpse into the future through current projects. The development of astronomy can serve as a powerful lever for science, technological development, education and outreach, as well as for improving the much needed link between basic research and industry development.

1. Brief History

Astronomy in Mexico has a long tradition, and the achievements of all the major prehispanic cultures, beginning with the Olmecs are deeply ingrained in the popular culture. The creation of the Long Count Calendar, the orientation of large architectural complexes and observatories, and all the basic timekeeping knowledge creates a heritage of which people are justifiably proud (Aveni 2001, Coe & Koontz 2002). Although the Spanish conquest took place in the context of the less enlightened post-classic, the basic knowledge has remained, and modern scholarship and museum exhibits have easily allowed the population to connect with this more remote past. During the Colonial period, various Spanish expeditions and initiatives led to the study of astronomy, often linked to engineering ventures. After independence, the major thrust for the creation of an official astronomical research body came in the context of observing the transits of venus which ocurred in the late 19th century(Ávila *et al.* 2008).

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The Observatorio Astronómico Nacional (OAN) was founded in 1878, and was initially located in downtown Mexico City. It operated as a national facility, without being associated to a particular government body. In 1929, the national university, Universidad Nacional Autónoma de México (UNAM, Moreno Corral & Ávila 2009, Bartolucci 2000)) underwent a major restructuring, gaining autonomy from the government in its bylaws. At that point the OAN was attached to the University and it was charged with its development and maintenance. In 1942, Luis Enrique Erro founded the Observatorio Astrofísico Nacional in Tonantzintla, Puebla, where a large Schmidt camera became the preeminent research instrument. The OAN grew as several renowned directors and faculty members came to work within it, notably Paris Pishmish (1911-1999) and Guillermo Haro (1913-1988), to name but two. During Haro's tenure as Director, in 1967 the OAN was transformed into Instituto de Astronomía (IA[1]) within UNAM, which was at the time undergoing yet another distinctive transformation in its structure, and spawning a number of research institutes on a par with its existing system of undergraduate schools.

Fleeing the city lights, the observing facilities of the OAN itself had moved in 1908 from downtown to what was then the outskirts, in the neighborhood of Tacubaya, and in 1951 relocated to Tonantzintla as well, on the grounds adjacent to to where Erro had moved in 1942. Here the 1m telescope, still in use, was comissioned in 1961. The rapid growth of the city of Puebla, along with that of Mexico City, forced the consideration of an alternative site, and exploration of the mountains of Baja California revealed that the Sierra of San Pedro Mártir (SPM) was a good locale. Development began in the 1960s and continued through the 70s, and what started in Ensenada as a base of operations for the OAN-SPM became a branch of IA in 1974. This culminated in the installation of the 2.1m telescope, dedicated in 1979, which remains today one of the two largest optical telescopes in Mexico.

During the 1990s, a group of faculty members of IA, led by the eminent radioastronomer Luis Felipe Rodríguez, established a new branch of the Institute in the city of Morelia, Michoacán. It thrived over the next few years, and in 2003 separated from IA to become, within the University's structure, a separate center for Astronomy, the Centro de Radioastronomía y Astrofísica (CRyA[2]).

After his term as Director of IA expired, Haro left UNAM and in 1971 founded the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE) from the Observatory created by Erro three decades earlier[3]. Over

[1] http://www.astroscu.unam.mx/
[2] http://www.crya.unam.mx/
[3] http://www.inaoep.mx/

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the next few years, INAOE grew in size and impact, and began operations of its own 2.1m telescope in Cananea, Sonora, now Observatorio Astrofísico Guillermo Haro (OAGH). It is now a national center operated by the federal Consejo Nacional de Ciencia y Tecnología (CONACyT[4]).

Throughout this era, most of Mexico's astronomers came from Physics majors as undergraduates, who, after learning from the few faculty members at these small institutions, obtained graduate degrees abroad (mainly in the US) and returned to Mexico to further strengthen UNAM and INAOE. In the last 15 years or so this has slightly shifted, as graduate programs within Mexico (again mostly within UNAM and INAOE), have contributed to the pool of researchers, and posdoctoral exchange has increased, adding as well to the number of foreign nationals working in astronomy in the country today (Aretxaga 2008).

2. Community and Institutions

The astronomical community in Mexico is still quite concentrated in a small number of institutes and universities. The bulk resides in Mexico City, and the states of Puebla, Michoacán and Baja California, reflecting the historical role of UNAM and INAOE. Smaller groups have been created more recently, particularly at Universidad de Guanajuato, which currently has 11 researchers, Universidad de Guadalajara, where 9 people are currently dedicated to astronomy, and Universidad de Sonora in Hermosillo, with 4 members. The current distribution is shown in Table 1, and includes both astronomers and technical support staff and instumentation engineers (for INAOE only the Astrophysics division is included).

The number of people thus dedicated to astronomy is close to 200, for a country of 112 million according to the 2010 census, or 1/560,000. For comparison, this number is closer to 1/50,000 in the USA, and 1/80,000 in Spain. The comparison is not exclusive to astronomy, and reflects the low fraction of GNP that in general is dedicated to science and technology, hovering at 0.3-0.4% for the last 25 years at least[5].

Nevertheless, astronomy remains one of the highest ranking disciplines, if not the highest (CNCT 2007), in Mexico in terms of impact, and has international recognition as such in various fields, such as studies of the interstellar medium, chemical abundances, planetary nebuale, radioastronomy and AGN studies, to name a few.

[4]http://www.conacyt.mx/
[5]http://www.amc.mx/recomendaciones_2012.pdf

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TABLE 1. Staff per institution

Institution	**Staff**
Instituto de Astronomía, UNAM Mexico City http://www.astroscu.unam.mx/	70
Instituto de Astronomía, UNAM Ensenada, B.C. http://www.astroscu.unam.mx/	52
Centro de Radioastronomía y Astrofísica, Morelia, Mich. http://www.crya.unam.mx/	18
Instituto Nacional de Astrofísica, Óptica y Electrónica, Tonantzintla, Pue. http://www.inaoep.mx/	35
Escuela Superior de Física y Matemáticas, Instituto Politécnico Nacional http://www.esfm.ipn.mx/	3
Departamento de Astronomía, Universidad de Guanajuato, Guanajuato, Gto. http://www.astro.ugto.mx/	11
Departamento de Astronomía y Meteorología, Universidad de Guadalajara, Guadalajara, Jal. http://www.iam.udg.mx/	9
Área de Astronomía, Universidad de Sonora, Hermosillo, Son. http://www.astro.uson.mx/	4

3. Research and Instrumentation

In terms of astronomical research, measured as the output of refereed scientific papers in international journals (ApJ, MNRAS, A&A, AJ, PRD, Phys Rev Lett., Science, Nature), Mexican astronomy contributes about 250-300 papers per year in all disciplines, from observation to theory, from radio to gamma rays and numerical modeling and simulation. Traditionally, most of the observational emphasis has been on optical-infrared, and radio astronomy, although studies at high energies have in the last ten years or so grown substantially, through the use of satellite observatories like Chandra, XMM-Newton, Swift and Fermi and the advent of HAWC (see below Sect. 4). Theory work has likewise covered all areas, and access to powerful computing facilities and networks has been a constant feature of astronomical research (the first node of the internet in Mexico was on the roof of the Instituto de Astronomía at UNAM in the late 1980s). Strictly outside

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of large institutions formally dedicated to astronomy, physicists in other locales also pursue research interests with ties to astrophysics. This is notably the case at instituto de Física-UNAM[6], the Centro de Investigación y Estudios Avanzados-Instituto Politécnico Nacional[7], and the Instituto de Física at Universidad Michoacana de San Nicolás de Hidalgo[8].

Considering the highest ranking faculty members at all institutions, through their membership in Mexico's Sistema Nacional de Investigadores (SNI), which has four levels (Candidate, I, II, III), one finds that those with Levels II and III have an average Hirsch Index of h∼18. This indicates a certain maturity of the available human resources. If the restriction is made to those at Level III, this rises to h∼28 or so[9], comparable to those found in high ranking institutions in the US and the UK, for example.

Maintaining observatories (OAN and OAGH in the past, and HAWC and the LMT more recently) has required the large institutes to have their own instrumentation departments, both for maintenance proper and for the development of new astronomical instruments to make available to their communities. This has proven to be a crucial advantage, and allowed participation in large scale international projects such as GTC (see below) and innovate solutions internally, as is the case with a hydrodynamical polishing tool developed at IA-UNAM over the past ten years and which is the object of several international patents, and possible licensing agreements with private companies in the near future.

GRADUATE PROGRAMS

The graduate programs have grown substantially over the last 15 years, both at the MS and PhD level. Currently UNAM has a Graduate Program in Astrophysics, where IA, CRyA, the School of Science and the Institute for Nuclear Science all participate. Each has associated students and contributes advisors to the overall pool, allowing students to choose from a variety of topics in institutes with their own particular emphasis. INAOE has its own program, where students are also in direct contact with the Electronics, Optics and Computer Science divisons of the center[10]. Finally , the department in Guanajuato also has its own graduate program[11]. Altogether, about 20 PhDs are awarded in astronomy every year, still far short of the level required to attain large scale growth of the community through that processs alone. A large number of students still go abroad, mainly to

[6] http://www.fisica.unam.mx/
[7] http://www.cinvestav.mx/
[8] http://www.ifm.umich.mx/
[9] http://www.amc.mx/recomendaciones_2012.pdf
[10] http://www.inaoep.mx/
[11] http://www.astro.ugto.mx/

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the US and Europe, to obtain postgraduate degrees and represent potential hires in the mid to long term.

4. Facilities

OBSERVATORIO ASTRONÓMICO NACIONAL-SAN PEDRO MÁRTIR, B.C. (OAN-SPM)

The site at SPM is one of the best in the world for optical-infrared astronomy in terms of sky darkness (V$\sim$21.2mag/arcsec^2 in dark time), atmospheric stability and quality, resulting in superb seeing of about 0.61 arcsec, and number of clear nights (63% photometric, 81% spectroscopic), along with Hawaii, the Canary Islands and Chile (Tapia 2003). It has been continuously operated by IAUNAM since the 1960s, and currently has three telescopes of 0.84m, 1.5m and 2.1m, equipped with optical and infrared instrumentation for imaging and spectroscopy. The site is within the limits of the Parque Nacional San Pedro Mártir, and is thus a protected natural reserve. Within the park, with over 70,000ha, a surface of 3048ha is reserved for astronomical research by grant of the National Comission for Natural Protected Areas (López & Gutierrez 2003). Facilities include a lodge, machine and electronics shops, power generators, with a microwave link for telecommunications. The road from Ensenada to the Observatory is fully paved (completed in 2009), and infrastructure upgrades to the site in terms of energy and telecommunications are in progress.

Long-term monitoring of the site by groups from UNAM (Tapia 2003) and INAOE (Carrasco *et al.* 2012) has characterized the site over a long baseline, and the SPM site was tested extensively for the Large Synoptic Survey Telescope (LSST[12]), and the Thirty Meter Telescope (TMT, Schöck *et al.* 2009), confirming its excellent qualities for astronomical research. Several projects are in process or in planning to further exploit the unique qualities of this site with national and international partners (we detail some below in Sect. 5).

Protecting the sky of SPM is a priority of IAUNAM. The lack of water in Baja California has kept population density at low levels, but the border corridor of Tijuana-Mexicali-San Diego-Yuma grows rapidly, and threatens the site with light pollution. To counter these effects, an ordinance for the Municipality of Ensenada, which covers all the way to the border with Baja California Sur at 28'N, was promoted and went into effect in 2006[13]. It then became state law for Baja California in 2010[14], and the municipality

[12] http://www.lsst.org/

[13] http://www.astroscu.unam.mx/ia/reglamentos/Reglamento-Ensenada-29sep2006.pdf

[14] http://inapramex.com/normatividad/lpabc-decreto339.pdf

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of Mexicali enacted its own version in 2011[15]. The ground is set thus for proper protection of the sky darkness for years to come, providing security for further projects at the site.

OBSERVATORIO ASTRONÓMICO NACIONAL-TONANTZINTLA, PUE. (OAN-T)

The IAUNAM still maintains the site of OAN-T and operates the 1m telescope, although light pollution has degraded the science capabilities of the observatory, making it more attractive for teaching and outreach purposes, which are routinely carried out, frequently in collaboration with INAOE[16].

OBSERVATORIO ASTROFíSICO GUILLERMO HARO, CANANEA, SON. (OAGH)

INAOE operates the OAGH in Cananea, Sonora, just 30km south of the border with Arizona. It is equipped with a 2.1m telescope with optical and infrared instrumentation for imaging and spectroscopy which is open to the national community[17].

LARGE MILLIMETER TELESCOPE/GRAN TELESCOPIO MILIMÉTRICO (LMT/GTM)

The LMT[18] is the largest millimeter antenna designed for astronomical observations, at the summit of Sierra Negra (4500m above sea level), and is a collaboration between INAOE and the University of Massachusetts (UMass). With a planned aperture of 50m, the LMT is designed to observe at between 0.85mm and 3mm wavelengths with unprecedented accuracy, and is the largest science project ever undertaken in Mexico. Currently the dish is at 30m aperture, and completion is planned in the next few years. Science observations have succesfully been carried out at 3mm in 2011. The LMT, besides its enormous potential as a research tool for the national community, can also in principle be linked to the VLBI network and further profit from the access of other groups, notably at CRyA-UNAM, to large scale radio astronomy infrastructure.

[15] http://www.bajacalifornia.gob.mx/portal/gobierno/legislacion/periodico/2011/julio/SECC-I-08-07-2011.pdf

[16] http://www.astroscu.unam.mx/Tonantzintla/

[17] http:// www.inaoep.mx/∼astrofi/cananea/

[18] http://www.lmtgtm.org/

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HIGH ALTITUDE WATER ČERENKOV OBSERVATORY (HAWC)

HAWC[19] is a collaboration between Mexico and the US involving about a dozen institutions in each country, led by Los Alamos National Laboratory and the University of Maryland in the US, and UNAM and INAOE in Mexico. It is located on the border between Puebla and Veracruz at 4100m just below the LMT/GMT site at Sierra Negra. It will consist when completed of 300 water tanks 4m high and 7m in diameter, and wil observe the entire sky visible from the site between 100GeV and 100TeV, through Čerenkov radiation in water, performing an all-sky map as well as searching for transient sources. The project involves a large community which has brought together astronomers as well as high energy physicists from various research institutes and is currently in the construction stage, with the prototype array, VAMOS, operating in 2011.

GRAN TELESCOPIO CANARIAS (GTC)

Mexico is a 5% partner in the GTC at Observatorio Roque de los Muchachos on La Palma[20]. Spain is the lead partner at 90%, and the University of Florida is also a member at 5%. Besides the associated share of observing time for the Mexican astronomical community, in itself a major benefit, instruments have been developed in Mexico for the telescope. The first was the comissioning instrument, awarded through international competition and built in Mexico through a collaboration between IAUNAM and Centro de Ingeniería y Desarrollo Industrial (CIDESI), a CONACyT center[21]. The second was OSIRIS, and optical imager and spectrograph, partially designed and built at IAUNAM and currently operating at GTC. The third is FRIDA, (in**FR**ared **I**mager and **D**issector for **A**daptive optics), an integral field spectrograph for the near infrared with imaging capability that will make use of the adaptive optics system of the GTC, scheduled for delivery in 2015. FRIDA is led by IAUNAM in collaboration with UF, Instituto de Astrofísico de Canarias, Universidad Complutense de Madrid (UCM), Laboratoire dAstrophysique-Observatoire Midi-Pyrénées, and CIDESI. In addition, MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía) is an optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) for GTC led by UCM with strong participation from INAOE. All of these projects have substantially contributed to the capabilities for astronomical instrumentation within Mexico, and are key in the development and proposal of national infrastructure projects.

[19] http://www.hawc.umd.edu/
[20] http://www.gtc.iac.es/
[21] http://www.cidesi.mx/

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THE EXPANDED VERY LARGE ARRAY (E-VLA)

The Mexican radioastronomy community has been extremely successful in doing research with the VLA, operated by NRAO. Lacking sufficient funds to become a direct partner in ALMA, which has started operations in Chile, the Mexican community obtained access to NRAO facilities, including ALMA[22], through partial financing of the e-VLA with the USA and Canada[23]. The e-VLA gives a ten-fold increase in sensitivity over the VLA, and widens the spectral range from 1GHz to 50GHz. Acces to ALMA ensures that the outstanding radioastronomy tradition, led by the group at CRyA-UNAM will continue to produce high impact results and benefit the community as a whole.

5. The Future

The astronomical community in Mexico is currently participating in several projects, at various stages of development, that seek to promote its growth in quality, number and diversity. A strong emphasis is placed on the development of new observational infrastructure and seeking investment, from national and international partners for mid- and large scale projects. I briefly detail some of the most relevant here. In particular, development of the site of San Pedro Mártir for optical-infrared astronomy into an international, large scale observatory is desired.

TAOS-II

The first stage of the TAOS project, let by Academia Sinica-Institute of Astronomy and Astrophysics of Taiwan (ASIAA) and Smithsonian Astrophysical Observatory (SAO) installed at Lulin Observatory in Taiwan, with participation from Yonsei University in South Korea, sought to detect transneptunian objects through stellar occulations with 50cm telescopes. The second phase, the Trans-Neptunian Automated Occultation Survey-II[24], in which IAUNAM is a partner, will install three 1.3m robotic telescopes at SPM by 2013 to carry out a deeper survey in search of Kuiper Belt objects. The site for installation has been selected, and telescope and building design and construction are under way, as is camera design. This is the first international project to mount telescopes at SPM, and will represent the first telescopes to be built since the inauguration of the 2.1m in 1979. The project represents an investment of approximately 13MUSD.

[22] http://www.almaobservatory.org/
[23] http://www.nrao.edu/index.php/about/facilities/vlaevla
[24] http://taos2.asiaa.sinica.edu.tw/

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GROUND FOLLOW-UP TELESCOPE ASSOCIATED TO THE SVOM MISSION (GFT)

The satellite SVOM mission for high energy observations between France and China is nominally scheduled for launch in 2015 (Götz *et al.* 2009). As an integral part of the mission, robotic ground telescopes of 1m class will observe optical-infrared counterparts of transient high-energy events. One such telescope is set to be installed at SPM in collaboration with IAU-NAM, and among other things, will seek to characterize the onset of the afterglow of Gamma-Ray Bursts, and detect distant events through photometric redshift determinations. The associated investment is approximately 3MUSD.

THE SAN PEDRO MÁRTIR TELESCOPE (SPMT)

A wide-field optical-infrared telescope is projected for the site of San Pedro Mártir, in possible collaboration with international partners. Through an agreement between INAOE and the University of Arizona, a 6.5m primary mirror has been cast at the UA and will undergo figuring and polishing over the next two years. The general plan calls for the design, construction and operation of a wide-field telescope that could be equipped with optical-infrared instrumentation, taking advantage of the superb seeing and sky darkness conditions at SPM. A possible project for this telescope is the Synoptic All-Sky InfraRed Survey, aimed at a deep, multi-color NIR characterization of the sky visible from SPM, with particular emphasis on the characterization of the transient sky, in collaboration with the University of California[25].

THE ČERENKOV TELESCOPE ARRAY (CTA)

Mexico has become a member of the CTA collaboration in May 2012[26]. The project considers the construction of two atmospheric Čerenkov arrays, one in each hemisphere. One candidate for CTA North is the site of San Pedro Mártir, and a viable site has been identified with the area available for astronomical research in the national park. Final site selection will take place in 2014. CTA will be the most sensitive instrument for high-energy sources, operating above 100GeV and up to 10TeV, and will allow monitoring of persistent and transient sources, continuing the opening of this electromagnetic window through ground-based observatories like MILAGRO, HAWC, VERITAS, MAGIC and HESS. Groups from five institutions (Instituto de Astronomía-UNAM, Instituto de Física-UNAM, Insti-

[25] http://www.sasir.org/
[26] http://www.cta-observatory.org/

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tuto de Ciencias Nucleares-UNAM, Instituto de Geofísica-UNAM, Instituto Nacional de Astrofísica, Óptica y Electrónica) have either committed their participation or expressed their interest in doing so. Given the participation of the Mexican community in HAWC, it is only natural to continue pursuing research at very high energies, and entry into CTA will allow for this in the next generation of observatories.

OTHER SITES FOR OPTICAL INFRARED ASTRONOMY, THE DEVELOPMENT OF NEW CENTERS FOR ASTRONOMY AND GROWTH OF THE COMMUNITY

The Astronomy Department at Universidad de Guanajuato[27] operates its own observatory, "La Luz" close to the city. A 57cm optical telescope, and two radio antennas, are in use for research by department staff, teaching and outreach. Plans for the comissioning of a robotic telescope are in place.

One of the largest public universities in Mexico, Universidad Autónoma de Nuevo Léon, in Monterrey, N.L., has current plans to develop an astronomy group in close connection to its engineering school, and to install modern facilities at its observatory in San Pedro Iturbide, close to Monterrey[28]. The site has been used for outreach, and the University has for a number of years successfully collaborated with amateur astronomers. The possible contributions of UANL to other national astronomical projects at the OAN is desirable and would allow for further decentralization of working groups.

Finally, in Zacatecas, the Observatory founded by José Árbol y Bonilla in the late 19th century, which now bears his name, is being refurbished by Universidad Autónoma de Zacatecas[29] and plans for further growth of the astronomy group will hopefully bear fruit over the next few years.

The above is important in terms of future growth of the astronomical community in Mexico. It is essential that not only the existing institutes grow and enter into new projects, but that the number of centers where astronomy is carried out is increased. Most of the public state universities in Mexico have physics departments, and these are natural starting points for the placement of Astronomy groups, along with some national centers operated by the CONACyT. This would also allow the graduates from the growing Master's and PhD programs to eventually find permanent positions and foster competition, in the best sense of the term, between all centers. In turn, this will enable securing the funding and other resources that are necessary to sustain a healthy, national community that is not dependent on a small number of institutes for its development and growth.

[27] http://www.astro.ugto.mx/
[28] http://www.uanl.edu.mx/
[29] http://www.uaz.edu.mx/

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 145-174
Ed. A. Heck, © 2013 Venngeist.

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Abstract. We describe the state of astronomical research in the Netherlands per early 2012. We add some notes on its history of this research and on the strategic choices for the future. Compared to the size of the country (16 million people) the Netherlands is maintaining a high profile in astronomical research over a period of more than one century. The professional research community consists of about 650 people. This includes research staff, postdocs, PhD students, technical staff working on instrumentation projects and people involved in the operations of ground-based telescopes and astronomical space missions. We do not take into account staff working for international organizations based in the Netherlands. Astronomical research in the Netherlands is carried out at four university institutes and two national research institutes that fall under the umbrella of the national funding agency NWO. The Netherlands is the host of two international organizations: ESTEC, the technology division of the European Space Agency (ESA), and the Joint Institute for VLBI in Europe (JIVE). The Netherlands are one of the founding members of the European Southern Observatory (ESO) and of ESA. This paper will address a number of significant multilateral collaborations.

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1. Organization

1.1. NOVA AND UNIVERSITY ASTRONOMY

The four university astronomical institutes are federated in the Netherlands Research School for Astronomy (NOVA, Nederlandse Onderzoekschool Voor Astronomie). NOVA started in 1992 as a national 'research school' recognized as such by the Royal Academy of Science (KNAW). E.P.J. van den Heuvel was chairman of the board of NOVA and P.T. de Zeeuw became director. NOVA consisted then of the astronomical institutes of the Universities of Amsterdam, Groningen, Leiden and Utrecht, with some participation by the Free University (VU) at Amsterdam. In 1998 the VU terminated astronomical education and left NOVA.

Recognition by the KNAW brought very few funding and the main achievements of NOVA were the harmonization of the astronomical education programs at the four universities and the introduction of a monitor of the progress of PhD projects.

In 1997 the Dutch government initiated a ten-year research program to allocate considerable grants for Research Schools that compared favourably with the best research institutes elsewhere. The training of outstanding young scientists was one of the objectives of the program. NOVA submitted an innovative research program entitled 'The Life-Cycle of Stars and Galaxies'. In April 1998 six proposals were selected out of the 34 proposals covering all academic disciplines and NOVA was ranked highest among the six. The six schools all received a grant from the Minister of Education, Culture and Science (OCW) in order to carry out its proposed programme. The NOVA programme combines key investments in permanent and temporary personnel at the participating universities in three related areas of research interlinked with a strong program of instrumentation development.

After an extensive review in 2003 the grants for the six top-research schools were continued for another period of five years up to and inclusive 2008 and in 2006 the funding was extended for five more years. The six schools were reviewed again in 2010. The review panel qualified four schools as excellent and two, including NOVA, as "exemplary", to be understood as 'better than excellent'! As a result of this process the funding for NOVA was extended up to and inclusive 2018.

In 2002 the Radboud University Nijmegen (RUN) started an astronomy programme and joined the NOVA federation. Unfortunately the Utrecht University decided to close down its astronomy institute by late 2011 and to leave the NOVA collaboration.

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1.1.1. *University of Amsterdam (UvA)*

The Astronomical Institute Anton Pannekoek (API) is one of the research institutes within the Faculty of Science of the University of Amsterdam (UvA). It has been founded by Anton Pannekoek in 1921; in recent decades the institute was led by E.P.J. van den Heuvel (1974-2005), M. van der Klis (2005-2011) and R.A.M.J. Wijers (2011-present). API executes astronomical research and carries out the PhD program. It is responsible for the astronomical components in the bachelor program and for the master program in astronomy and astrophysics. API's research program is concentrated in two areas, (1) high energy astrophysics, neutron stars and black holes; and (2) low energy astrophysics, star formation and exoplanets.

In 2011 the Science Faculty of the UvA established the GRAPPA Institute (Gravitation Astro-Particle Physics Amsterdam) as a collaboration between the institutes for Theoretical Physics, Astronomy and High Energy Physics. In total six new staff members are or will be appointed. Their research interests include dark matter, dark energy, neutrinos, and cosmic rays, with a focus on both theoretical modeling of astrophysical source physics as well as (in)direct detection. In addition, there are about 15 affiliated staff members from the collaborating institutes, who are involved in experimental work at various physics and astrophysics projects, as well as theory.

1.1.2. *University of Groningen (RuG)*

The Kapteyn Astronomical Institute is part of the Faculty of Mathematics and Natural Sciences of the University of Groningen (RuG). It is founded by J.C. Kapteyn in 1878, a leader of Milky Way research. He was succeeded in the early 1920s by P.J. van Rhijn who continued the work of Kapteyn. In 1956 A. Blaauw succeeded van Rhijn and began a modernization of the institute's program. In recent decades the institute was led by H. van Woerden until 1998, and subsequently by P.C. van der Kruit (1998-2006), J.M. van der Hulst (2006-2011) and R.F. Peletier (2011-present). At the RuG, the Kapteyn Institute is responsible for the astronomical components in the bachelor education in physics and astronomy, for the master study in astronomy and for the PhD education. The focus of the research is in cosmology, in the study of galaxies and in the formation of stars and planets. Charting of the Epoch of Reionization (EoR) with LOFAR is one such item; 'Galactic archaeology', *i.e.* probing evolving structures in the Milky Way and in nearby galaxies is another.

One of the two laboratories of SRON, the Space Research Organisation of the Netherlands, is located in Groningen in the same building as the Kapteyn Astronomical Institute. This has stimulated strategic alliances in the area of far-infrared and submm astronomy. One example is the SIS

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heterodyne detector successfully developed for Herschel/HIFI by SRON and the University of Delft and now used in the Atacama Large Millimeter-submillimeter Array (ALMA).

The Kapteyn Institute has similar strategic alliances with ASTRON for the scientific exploitation of the WSRT and LOFAR and for the development of new instrumentation for these facilities. The central computer facility for the correlation of the LOFAR data is located at the Donald Smits Center for Information Technology of the RuG. A long term aim is the participation in SKA.

1.1.3. *University Leiden (UL)*

Leiden Observatory (Sterrewacht Leiden) was established in 1633 to house the quadrant of Snellius. It is part of the faculty of mathematics and natural sciences of University Leiden (UL). It is the oldest university observatory still in operation in the world and has a rich tradition built around important figures such as F. Kaiser, W. de Sitter, E. Hertzsprung, J.H. Oort and H.C. van de Hulst. These men were not only formidable scientists, but they have also been very much involved in shaping Dutch and international astronomy into what it is today. In recent decades Leiden Observatory was led in succession by H. van der Laan, H.J. Habing, G.K. Miley, P.T. de Zeeuw, K.H. Kuijken and H. Röttgering (since mid 2012). The Sterrewacht is responsible for the astronomical components in the bachelor education in physics and astronomy, for the master program in astronomy and astrophysics and for the PhD program. The research at the Sterrewacht spans a wide range of closely interlinked areas, focusing on understanding the universe as seen today. Astronomy world-wide is undergoing a tremendous technological evolution, leading to ever more sensitive, sharper, and broader multi-wavelength views of the sky. The staff of the Sterrewacht is using many new observing facilities to study the formation and evolution of galaxies in the early phases of the Universe, regions around massive black holes at the centers of nearby galaxies, the formation of complex molecules in nearby star forming regions and the formation and evolution of proto-planetary systems. In recent years exoplanets were included as a new research area. The development of new instruments has gained in importance, in part by the influx of technical astronomers from the University of Utrecht when that closed the astronomy department in late 2011.

1.1.4. *Radboud University Nijmegen (RUN)*

The Department of Astrophysics of the Radboud University Nijmegen (RUN) is a young group that started in 2001. It has grown quickly over the years since, from two scientific staff at the start to 10 staff members from February 2012 onwards. The Department has been led in the first

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years by J.M.E. Kuijpers (2001-2006), and thereafter led by P.J. Groot (2006-present). The Department of Astrophysics is part of the Institute of Mathematics, Astrophysics and Particle Physics (IMAPP). The Astronomy Department is responsible and for the astronomical components in the bachelor education, for the master astronomy and astrophysics and for the PhD program. The Department focuses its research activities on high energy astrophysics (in particular on compact objects and in binaries), on the radio detection of high energy cosmic rays and on gravitational waves. It participates in new facilities such as LOFAR, the Pierre Auger Observatory (PAO) and the X-Shooter spectrograph on the VLT. The Department is a leader in the fields of ultra-compact binaries and in radio detection of high energy cosmic rays. In early 2012 the Department of Astrophysics saw a major expansion from 6 to 10 staff members when four staff and their research groups moved from Utrecht to Nijmegen.

1.1.5. *Utrecht: Utrecht University (UU)*

The Astronomical Institute (Sterrekundig Instituut Utrecht, SIU) in Utrecht was founded by the university in 1642. The SIU has been part of the Department of Physics and Astronomy of the Faculty of Science. It was led by A. Achterberg (1998-2002), N. Langer (2002-2008) and C.U. Keller (2008-2011). At the UU, the SIU was responsible for the astronomical components of the bachelor education, for the master in astronomy and astrophysics and for a PhD program. The subjects of research at the SIU were various, ranging from stellar and binary evolution, theoretical high-energy astrophysics, and instrumentation for both ground and space-based facilities.

SIU and SRON's High Energy Astrophysics and Earth and Planetary Science divisions – both located next to each other at the university campus – collaborated on leading research in high-energy astrophysics and exoplanetary and planetary atmospheres. The proximity of SRON provided an excellent environment also for PhD and MSc students as they could participate in the latest space research and mission developments carried out at SRON.

On 16 June 2011, the Faculty of Science of the UU announced its plan to restructure its efforts in research and education. This decision effectively led to the termination of the 370-year old tradition of education and research in astronomy and astrophysics in Utrecht, which not only has produced eminent scientists such as M. Minnaert, H.C. van de Hulst, C. de Jager and E.P.J. van den Heuvel, but in recent times also promising scientists who received major national research grants and international prestigious fellowships. The formal closing ceremony took place on 5 April 2012 after the symposium to celebrate 370-years of astronomy in Utrecht. Staff and

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their research groups have moved to other NOVA institutes in Nijmegen (A. Achterberg, S. Larsen, O. Pols and F. Verbunt), Amsterdam (J. Vink and M. van den Berg) and Leiden (C.U. Keller).

1.1.6. *NOVA organization*

The NOVA Board consists of the directors of the participating university astronomy institutes. The chair was held by E.P.J. van den Heuvel (1992-2003), P.C. van der Kruit (2003-2007), M. van der Klis (2007-2011) and K.H. Kuijken (2011-present). The Board has the overall responsibility for the NOVA program, chooses the overall strategy and decides on the distribution of the funding to the several programmes.

The NOVA directorate is responsible for the execution of the program, preparation of policy decisions and of strategic issues, not only with the participating universities but also with external (international) institutes and agencies. The directorate is supported by a small office that carries out the secretariat, the financial administration and control of spending. P.T. de Zeeuw was the scientific director of NOVA between 1992 and 2007. W. Boland was deputy director from 1999 to 2007. From 2007 until present the NOVA directorate consists of E.F. van Dishoeck (scientific) and W. Boland (executive).

The legal representation of NOVA has rotated between the participating universities in five year cycles. Accordingly, University Leiden (1992-1997), University of Amsterdam (1997-2002), University of Groningen (2002-2007) and University Utrecht (2007-2011) held this role. Since 2012 NOVA is legally represented by University Leiden for an indefinite period.

Further information about the NOVA organization and program can be found online[1] as well as about the NOVA public outreach activities[2].

1.2. ASTRON, NETHERLANDS INSTITUTE FOR RADIO ASTRONOMY

ASTRON is a foundation under the umbrella of NWO. Its mission is to develop novel and innovative technologies for radio telescopes and to pursue fundamental astronomical research. The ASTRON institute employs approximately 160 staff. In addition, it hosts JIVE and the NOVA laboratory for Optical-IR instrumentation. ASTRON has been led by H. van der Laan (1970-1987), W.N. Brouw (1987-1990), H.R. Butcher (1991-2006) and M.A. Garrett (2007-present). Further information can be found on the web[3]. An overview of the development of radio astronomy in the Netherlands is provided in Sect. 3.1.

[1] `http://www.strw.leidenuniv.nl/nova`
[2] `http://www.astronomie.nl/`
[3] `http://www.astron.nl/`

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Figure 1. Six of the 73 ALMA Band-9 cartridges, a main part of the Dutch contribution to the ALMA project, designed and produced in a collaboration between NOVA, SRON and TuD. (Courtesy NOVA)

ASTRON has initiated the successful fund-raising for the LOFAR telescope and is now responsible for LOFARs construction and operations. In addition it has to keep the Westerbork Synthesis Radio Telescope (WSRT) up to date and to explore new technologies for radio astronomy. ASTRON is actively participating in discussions of and research for the future of radio astronomy. It is involved in the developments for SKA, the Square Kilometer Array, contributing its experiences with LOFAR, the prototype for SKA. ASTRON collaborates with international organizations, with major national industries and it is involved in the transfer of knowledge to national and regional/local businesses.

1.3. SRON, NETHERLANDS INSTITUTE FOR SPACE RESEARCH

SRON's mission is to conceive and develop innovative space instruments for astrophysical and earth-oriented research, and to analyze the data provided by these instruments, in collaboration with astronomers and other scientists, for example, those in atmospheric research. SRON has two laboratories; one at the University of Groningen for low-energy astrophysics and the other at Utrecht University for high-energy astrophysics. SRON advises the Dutch government on participation in international space research programs, in particular those of ESA, and supports the economy by making its knowledge and expertise available. SRON has been led by J.A.M. Bleeker

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(1983-2002), K. Wakker (2003-2009) and R. Waters (2010-present).

Research at SRON is concentrated on harvesting the scientific results obtained with the X-ray spectrometers on the Chandra and XMM space observatories, for which it provided the gratings, and with the HIFI instrument on board of the Herschel Space Observatory. SRON has been the PI institute for these instruments. For the next decade, SRON has the ambition to become PI of the far-infrared SAFARI instrument on the Japanese SPICA mission and contributes to the JAXA-ESA ASTRO-H X-ray mission. In the long term, SRON aims for a (co-)PI role in an international consortium for building one of the instruments on the next generation international or European X-ray space mission. At its institutes in Utrecht and Groningen together, SRON employs about 200 staff. Further information is available on the web[4]. An overview of the development of astronomical space research in the Netherlands is provided in Sect. 3.2.

1.4. JOINT INSTITUTE FOR VLBI IN EUROPE (JIVE)

JIVE, the Joint Institute for VLBI in Europe, was established in 1993 by the Consortium for VLBI in Europe. The Institute is governed by a Board nominated by the research councils and national radio astronomy facilities of the Netherlands (NWO and ASTRON), CNRS (France), MPIfR (Germany), INAF (Italy), NAOC (PR China), IGN (Spain), OSO (Sweden) and STFC (United Kingdom). JIVE is located in Dwingeloo, the Netherlands, and hosted by ASTRON. JIVE has been led by R.T. Schilizzi (1993-2003), M.A. Garrett (2003-2007) and H.J. van Langevelde (2007-present).

The mission of JIVE is to operate and further develop the VLBI data processor and to support EVN users and operations of the EVN facility. The Institute carries out a broad range of technical research and development activities in VLBI related fields. JIVE staff, consisting of about 20 scientists, also carries out research in various fields of galactic and extragalactic radio astronomy, planetary and space sciences. The Institute is actively involved in several large international projects, among which there is SKA. JIVE acts as a coordinator in several projects funded by the European Commission.

Further information can be found at the web[5].

1.5. THE NETHERLANDS ORGANIZATION FOR SCIENTIFIC RESEARCH (NWO)

NWO is the national funding agency for scientific research in the Netherlands. Science policy within NWO is determined by discipline-oriented re-

[4] http://www.sron.nl/
[5] http://www.jive.nl/

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search councils. Astronomy together with mathematics and computer sciences is part of the NWO Council for Physical Sciences (EW). NWO-EW acts as the policy and granting organization for NWO-supported astronomical research. It funds individual research grant applications without any thematic boundary conditions (free competition grants that cover a single PhD or postdoc position) as well as positions in thematic (interdisciplinary) research programs. NWO-EW also has a budget line for medium sized instrumentation projects up to 900 kEuros. Competitions are held twice per year; oversubscription factors are typically 3 to 5. NWO-EW provides access to the Isaac Newton Group (ING) of optical telescopes on La Palma and, until March 2013, the submillimeter-wave telescope JCMT on Mauna Kea, Hawaii. It supports JIVE and the ALMA regional expertise center ALLEGRO based at Leiden Observatory.

NWO finances a very successful programme called VENI-VIDI-VICI through which personal grants are awarded to university staff. Of particular relevance are the VIDI (experienced researchers; maximum 8 years after PhD, up to 800 kEuros) and VICI (researchers of professorial quality; maximum 15 years after PhD, up to 1.5 MEuros). VIDI and VICI allow new staff to build up their own independent groups. Oversubscription is typically a factor of 5-10. In recent years on average 3 astronomers per year received a VENI grant, 2 a VIDI grant and 0.5 per year a VICI grant.

NWO finances the organisations ASTRON and SRON, and funds additionally large national instrumentation projects. New funds are made available every 2 years with awards typically between 2 and 6 MEuros. Recent astronomy awards include the grant for the Dutch contribution to JWST-MIRI in 2002 and the grants to ASTRON to develop and build the new wide field imager APERTIF for the WSRT in 2006 and 2010.

NWO carries out the evaluation and selection procedure for the 'Roadmap program' for Dutch participation in large-scale European research infrastructures; it acts on behalf of the Ministry of OCW. So far three astronomy programs were selected: in 2008 18.8 MEuros was granted to NOVA and its collaborators for the participation in the design and construction of instrumentation for the E-ELT; in 2012 18 MEuros was allocated to SRON for their PI role in the Spica-SAFARI instrument. The ASTRON participation in SKA was identified as a 'Roadmap program' with a possible funding allocation in the coming years.

NWO awards the most prestigious prizes for scientific research in the Netherlands, the Spinoza prize. Since its introduction in 1995 the price has been awarded to six astronomers: E.P.J. van den Heuvel (1995), E.F. van Dishoeck (2000), M. van der Klis (2004), M. Franx (2009), H. Falcke (2011) and A. Tielens (2012).

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1.6. MINISTRY OF EDUCATION, CULTURE AND SCIENCE (OCW)

The Dutch universities and NWO receive their funding directly from the Ministry of OCW. The funds for NOVA come directly from OCW. The Ministry is the national representative in the treaty organization of the European Southern Observatory (ESO). The national contribution to ESO is administered at the Ministry level. The Ministry of Economic Affairs, Agriculture and Innovation (EL&I) is the national representative of the European Space Agency (ESA). OCW provides the funding for the science program of ESA. The national funding for de construction of LOFAR of order 70 MEuros was provided by OCW through a special program for investment in knowledge based infrastructures.

1.7. THE ROYAL DUTCH ACADEMY OF SCIENCE (KNAW) AND THE EUROPEAN UNION (EU)

The Royal Netherlands Academy of Arts and Sciences (KNAW) donates yearly a prestigious KNAW academy professorship. This is an award typical 1 MEuros in total for senior scientists and allows them to concentrate fully on teaching and research. Astronomers who received such an award are G.K. Miley (2003), M. van der Klis (2010) and E.F. van Dishoeck (2012).

The European Union (EU) is a growing source of funding. Every 4 to 7 years a new Framework Program (FP) is developed which defines the strategy and programs for that period. The initial training networks (ITN) have been an important component of most FP cycles; they typically fund teams of 6-12 institutes across Europe to carry out a collaborative program. Recent changes include a shift from funding of postdocs to mostly PhD student positions and a stronger emphasis on links with industry. The latter requirement makes it more difficult for astronomy projects to get funding. A new prestigious program to promote individual investigator-driven frontier research was launched in 2008 by the European Research Council (ERC). It has a budget line for young investigators (starting-ERC grant, typically 1.5 MEuros) and for established scientists (advanced ERC grant, typically 2.5 MEuros). Oversubscriptions for all EU programs are typically a factor of 20. Advanced ERC grants (see also Fig. 2) were awarded to the following astronomers in the Netherlands: H. Falcke (2008), M. Franx (2008), A. Tielens (2009), R. Wijers (2009), E.F. van Dishoeck (2011) and J.M. van der Hulst (2011).

1.8. RELATIONS WITH ESA AND ESO

Dutch astronomers have contributed to ESA and ESO as official representative for the governing bodies of these organisations and also, on the

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basis of personal merit, as adviser to the various special committees of these organisations. The foundation of ESA owes much to the Dutch astrophysicists H.C. van de Hulst and C. de Jager. J.H. Oort took the first decisive steps toward the foundation of ESO. Four Dutch astronomers (A. Blaauw, J. Woltjer, H. van der Laan and P.T. de Zeeuw) have been or are Director-General of ESO.

A special case is ESTEC, the large international development and testing facility of ESA and located in Noordwijk, the Netherlands. Approximately 2000 employees are involved in typically a dozen projects at any time. In recent years ESA has moved most of the scientists to its science centre in Vilspa near Madrid, with the exception of the project scientists and their teams. There are contacts with Dutch universities, ASTRON and SRON at the individual project level. The space sector has an intrinsic value, offering unique economic and societal benefits for the Netherlands; the location of ESTEC reinforces those benefits manifold. Dutch companies and research institutes have direct and easy access to ESTEC's unique knowledge and facilities, with direct and indirect benefits for their technical capabilities.

1.9. RELATIONS BETWEEN OCW, NWO, NOVA, ASTRON, SRON AND NCA

ASTRON, NOVA, NWO, and SRON share together the responsibility for the finances for research in astronomy. The university institutes combined in NOVA are funded by their universities. In 2007-2008, a major policy change occurred when OCW transferred about 100 MEuros from the universities to NWO to strengthen the international reputation of Dutch scientific research though the VENI-VIDI-VICI scheme but without any significant extra investment in scientific research. As a result, university funding of PhD students has now almost completely disappeared. This reduces the flexibility of the staffs at the universities in accepting new PhD students.

To summarize, the main responsibilities are

- NOVA: research and education, granting of PhDs; home base for ESO
- ASTRON: national institute for radio astronomy
- SRON: national institute for space research; home base for ESA
- NWO-EW: various research grants; ING, JCMT and JIVE
- OCW: funding of the universities, funding of NWO, funding special, large projects (*e.g.* LOFAR)

The joint national strategy for astronomy is set at the Netherlands Committee for Astronomy (NCA), an informal body of representatives from the university institutes and from ASTRON and SRON. ASTRON, SRON, NWO and NOVA plan the strategy for the future of astronomy in the

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Netherlands. The latest strategic plan dates from June 2012 and is available from the NOVA website. The NCA represents the Netherlands in the International Astronomical Union and constitutes the astronomy 'chamber' of the Association of Universities in the Netherlands (VSNU), but does not itself fund any scientific research.

The interactions between NOVA, ASTRON and SRON are many. First, several ASTRON and SRON scientific staff members have partial appointments (0.5-1 day per week) at one of the universities. There they participate in teaching at master level and in PhD supervision. Second, university and ASTRON/SRON scientists work closely together to develop and exploit scientific instruments. Many university scientists are fortunate to have (had) privileged access to the world class instruments to which SRON or ASTRON contributed, such as WSRT, IRAS, Beppo-SAX, ISO-SWS, Herschel-HIFI, JIVE, and LOFAR, or built with NOVA contributions for use on ESO's VLT, VLTI and VST and the ALMA observatory. Conversely, university astronomers support ASTRON and SRON in building these instruments. This includes conception of the instruments, the writing of science cases, performing simulations, promoting and lobbying for the projects (inter)nationally, etc. It typically takes 20-25 yr from conception to science, emphasizing the long term commitments that all parties need to be able to make.

Since 2007, NWO has been implementing a new governance model for its institutes. The board of the institute has been placed 'more at a distance' and contains no or a few stakeholders. The scientific advisory council of each of these institutes is largely international. This results in longer lines between university astronomers and the upper management. One wonders whether this governance model is efficient from the point of view of the united future planning and coordination of astronomical research in the Netherlands.

2. Access to Observing Facilities

Astronomy is among the science disciplines that require large and expensive observing facilities that are nowadays affordable only in international and even world-wide collaborations. Astronomers in the Netherlands are successful users of the observing facilities made available through the European organizations ESO and ESA. ESO provides access to the Very Large Telescope (VLT), the VLT Interferometer (VLTI), the survey telescopes VISTA and VST, the two 3.6m-class telescopes at La Silla (Chile), the Atacama Pathfinder Experiment (APEX) and the Atacama Large Millimeter/submillimeter Array (ALMA). Through ESO, Dutch astronomers expect to have access to the European Extremely Large Telescope (E-ELT,

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with an effective diameter of 39.3m) that will become operational in 2022. ESA provides access to the Hubble Space Telescope (HST), the X-ray observatory XMM-Newton, the gamma ray mission INTEGRAL, the far-IR Herschel Space Observatory, and in the future the James Webb Space Telescope (JWST), Gaia (astrometric mission) and Euclid (test for dark matter and dark energy models). Through the national funding agency NWO astronomers in the Netherlands have access to the optical telescopes in the northern hemisphere of the Isaac Newton Group (ING) on La Palma (UK-NL-Spain). Because ALMA became operational the Dutch access to the submillimeter James Clerk Maxwell Telescope (JCMT) on Hawaii will be ended in March 2013. The radio domain is well covered with access to the WSRT, LOFAR and the EVN-JIVE interferometer; there are good prospects on participation in the future Square Kilometer Array (SKA). Dutch astronomers either as individuals or through collaborations have been successful in getting time on a wide variety of telescopes funded by other agencies across the world, both on the ground (*e.g.*, ATCA, Gemini, SMA, GranTeCan) and in space (*e.g.*, Chandra, RXTE, Spitzer, Fermi, Swift). For all of these facilities, observing time is obtained only through a competitive proposal process, with oversubscription factors of more than a factor of 5 for the most powerful telescopes.

Dutch astronomers collaborate with physicists through the Committee for Astroparticle physics in the Netherlands (CAN) to develop opportunities at the interface of these fields in furthering our understanding of extreme processes by detecting neutrinos, cosmic rays, gravitational waves, and high-energy gamma rays.

2.1. RADIO ASTRONOMY IN THE NETHERLANDS

Following the discovery of radio radiation from the Milky Way by Jansky (1932) and Reber (1940) J.H. Oort wondered whether line radiation in the radio spectrum would make it possible to map the structure of the Galaxy. He asked H.C. van de Hulst, then a PhD student at Utrecht, if such lines might exist. At a colloquium on 15 April 1944, Van de Hulst showed that hydrogen atoms in the ground state should have a hyperfine transition at 21cm wavelength. In 1945 the Netherlands were much impoverished by WW II and plans for significant new investments for science were not easy to find. But Oort followed a ministerial suggestion and in 1946, together with M. Minnaert from Utrecht, he founded the 'Stichting Radiostraling van Zon en Melkweg' (Netherlands Foundation for Radio Astronomy, NFRA) under the umbrella of ZWO (precursor of NWO), to investigate radiation at radio wavelengths from the Sun and the Milky Way. The electronic firm of Philips, the Post and Telecom Service (PTT), and The Royal Mete-

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orological Institute (KNMI) joined the Leiden and Utrecht observatories in NFRA. At PTT's Kootwijk Radio Station the director, A.H. de Voogt, made a German 7.5m Wrzburg radar dish available, and in the fall of 1950 a promising young engineer, C.A. Muller, was appointed to develop a suitable receiver. Muller's receiver detected the 21cm line in May 1951. Technically supported by Muller, a group of Leiden astronomers, lead by Oort and van de Hulst, measured the Galactic rotation curve (1954), mapped the distribution of atomic hydrogen in the Galaxy and demonstrated its spiral structure (1954-1958). Further information about the early development of radio astronomy in the Netherlands is provided by Van Woerden and Strom (2006).

After the success of the 21-cm line map of the Galaxy, funds for a 25m diameter radio telescope were made available by ZWO. The 25m Dwingeloo Telescope was inaugurated in 1956, and over a period of forty years it made many major contributions to radio astronomy. These included: a catalogue of radio-continuum sources at 22cm wavelength; discovery of strong radial motions of hydrogen around the Galactic Centre; measurement of the atomic hydrogen distribution and rotation in the Andromeda Nebula; demonstration of systematic non-circular motions of atomic hydrogen in the Galaxy; mapping of the distribution, spectrum and polarization of the radio continuum radiation at several wavelengths; studies of interstellar OH molecules; discovery and mapping of hydrogen clouds at highly anomalous velocities; and in the 1990's a high-quality, full-sky map of galactic atomic hydrogen which also lead to the discovery of 'Dwingeloo 1' and 'Dwingeloo 2', nearby galaxies hidden behind the absorbing Milky Way. For a summary of the instrumental developments and scientific achievements of the Dwingeloo Telescope see Van Woerden and Strom (2007).

Plans for a still larger radio telescope were developed soon after 1956. The first plan was for the so-called 'Benelux Cross Antenna Project' a joint project of the Netherlands and Belgium for a telescope on the principles of a successful 'cross antenna' in Australia. The project stranded in 1964 and that led to a major change of direction. Now plans were made for a telescope-array using the earth-rotation aperture-synthesis principle developed by Ryle at Cambridge. The Westerbork Synthesis Radio Telescope (WSRT), consisting of twelve 25m dishes on a 1.6km east-west baseline, was inaugurated in 1970, and extended in 1980 to 14 dishes (10 fixed and 4 movable) on a 3km baseline. H. van der Laan played a key role in the adaptation of the structure and management of NFRA to the requirements set by this new, large instrument.

Several upgrades of the dishes, frontends, backends and software have kept the WSRT at the international forefront. These developments have been documented in a series of papers: Allen, Hamaker & Wellington (1974);

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Baars & Hooghoudt (1974); Casse & Muller (1974); Högbom and Brouw (1974); Van Someren Greve (1981), Noordam & De Bruyn (1982). Highlights of WSRT research have been described by Allen & Ekers (1980) and by Strom (1996).

Since the early experiments in the 1980's the WSRT was an active partner in the first VLBI experiments in Europe leading to the founding of the European VLBI Network (EVN) and the Joint Institute for VLBI in Europe (JIVE). For the Netherlands the initiatives were led and coordinated by R.T. Schilizzi who became the first director of JIVE; the present director is H.J. van Langevelde. The VLBI initiatives were motivated to obtain the sharpest and most detailed images possible in astronomy.

To keep the WSRT at the forefront of its technical capabilities the telescope's Multi-Frequency-Frontends were replaced (in 2010-2012) by the APERTIF focal plane arrays. This new receiver system increased the field of view by a factor of 25 and will enable the WSRT to conduct fast surveys of the radio sky with the spatial resolution typical of a radio interferometer. With the experiences made in the operation of such systems and in the scientific exploitation of large radio surveys, the WSRT will play a crucial role in the preparation of the SKA.

In the early 1990's the concept of the Square Kilometer Array (SKA) emerged with the realization that the study of the formation and evolution of galaxies in the early universe requires a next generation radio telescope facility with a collecting area at least 100 times larger than what was available at existing telescopes. In the Netherlands the early developments were led by H.R. Butcher and A. van Ardenne. It was realized that such a project required innovative software and hardware techniques that were not yet available but should be developed. A worldwide collaboration appeared to be required.

In the 1990s G.K. Miley realized that the existing experience and technical means in the Netherlands would be sufficient to build a prototype for SKA for measurements at the lowest radio frequencies for which the Earth atmosphere is still fully transparent. This inspired ASTRONs director, H.R. Butcher and his deputy, E. de Geus, to start fund-raising for such a telescope, named LOFAR (Low Frequency Array). It was a hard and long way, but they found the support that they needed: funding by the Dutch government and by the Northern provinces of the Netherlands. The telescope is operational although it has not yet reached completion; its first paper with scientific results has been published. At present the key LOFAR science projects are: (1) epoch of reionization, (2) deep extragalactic surveys, (3) transient sources, and (4) cosmic rays.

LOFAR is being developed by a consortium of knowledge institutes, universities and industrial parties, led by ASTRON. All participating institutes

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provide as well in-kind contributions to the development of LOFAR. International partners including Germany, the UK, Sweden and France joined during the construction of the project, providing in kind contributions, mainly through remote LOFAR stations in their countries. Together they constitute the International LOFAR Telescope (ILT). LOFAR consists of two distinct antenna types: the Low Band Antenna (LBA) operating at frequencies between 10 and 90 MHz and the High Band Antenna (HBA) operating between 110 and 250 MHz. In total 36 stations have been constructed in the Netherlands; these are distributed over an area about one hundred kilometres in diameter (located in the North-East of the Netherlands). Half the stations in the Netherlands are located in a 2 $\times$3 km^2 core area near the village of Exloo. The remaining stations are distributed around this core at distances of up to 50km. The largest baselines across Europe will be of the order of 1500km.

2.2. ASTRONOMICAL SPACE RESEARCH IN THE NETHERLANDS

Astrophysical space research started around 1960 at the universities of Utrecht, Leiden and Groningen, through special government funding. In 1983 these three groups were formally brought together in a research institute under the umbrella of ZWO (now NWO). Since then SRON has been the national institute for scientific space research. In its advisory role to government ministries and the Netherlands Space Office (NSO) SRON has been contributed to the developments in national and international space policies. As a consequence SRON became engaged in new fields of space research, notably in earth observation. By participation in continued series of both high-energy (X-rays and gamma-rays) and infrared missions of ESA and NASA (commitments that often have exceeded 20 or more years) SRON has built space instruments for high-resolution spectroscopy, specifically through the development of gratings, heterodyne technology and more recently cryogenic direct detectors in ESA and NASA satellites.

In the 1960s many small rocket and balloon-borne experiments were conducted, but a major step was the A stronomische Nederlandse Satelliet (ANS; active 1974-1977), initiated by J. Borgman from Groningen and built by a Dutch industrial consortium and the space research institutes in Groningen, Utrecht and Leiden. While ANS had a UV camera from Groningen, under the leadership of Borgmans successor, R.J. van Duinen, the Groningen laboratory further specialized in infrared science and technology. Van Duinen led also the successful fund raising for an infrared satellite that was done in collaboration with NASA: IRAS, the InfraRed Astronomical Satellite. In 1981 van Duinen left astronomy and his role in IRAS was taken over by H.J. Habing. IRAS was launched in 1983 with an American

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built set of photon detectors and with an additional low-resolution spectrograph (LRS) built in Groningen. IRAS provided the breakthrough for science in the infrared with a.o. the discovery of ultraluminous IR-galaxies. IRAS was immensely successful and made ESA to select the Infrared Space Observatory (ISO) as one of its next missions. SRON became PI for the Short Wavelength Spectrometer (SWS). ISO was active between 1995 and 1998. The SWS revealed many molecular lines in a variety of objects and uncovered for the first time spectral bands of crystalline dust and ices. The SWS experience was later used in the VLT-instrument VISIR and in the concepts of the Dutch contribution to the JWST-MIRI instrument.

After the ANS project SRON/Utrecht and SRON/Leiden developed new X-ray spectrographs with became important contributions to NASA's Einstein observatory (1978-1981) and ESA's EXOSAT satellite (1983-1986). It also delivered the novel Coded Mask Imaging Spectrometer COMIS to the Russian KVANT-module of the MIR station. Since 1990 SRON participated in parallel in the development of three X-ray satellite missions: BeppoSAX (operational: 1996-2002), Chandra (operational since 1999) and XMM-Newton (also operational since 1999). For all three, SRON was the PI for the development and construction of an instrument. Additionally, SRON contributed to ESA's pioneering gamma-ray satellite COS-B (1975-1982) that opened the high-energy gamma-ray window above 100 MeV. SRON was involved in the operation of the ESA's gamma-ray satellite INTEGRAL. In all of these missions SRON was also active in the processing and interpretation of the data that the instruments provided. In the 1990s SRON built the imaging Compton telescope COMPTEL aboard NASA's Compton Gamma-Ray Observatory (CGRO; 1991-2000). On the Dutch-Italian satellite BeppoSAX there were two wide-field X-ray cameras that SRON had developed to image variable X-ray sources over a longer period of time. These cameras had a particularly large field of view of 40 by 40 degrees and under the leadership of J.A. van Paradijs it played a key role in ascertaining the origin of Gamma Ray Bursts and understanding their cosmological origin.

For future X-ray missions SRON develops a new type of detector for X-ray spectroscopic studies, the microcalorimeter. The detector is able to precisely determine the energy of each photon captured with a spectral resolution matching that achieved with gratings. An array of microcalorimeters has the advantage over a grating spectrometer that it can simultaneously produce images. For the eventual flight instrument, the aim is to place more than one thousand microcalorimeters in an array. In the SPICA/SAFARI project these developments for an imaging X-ray spectrometer are transferred to extremely sensitive far-IR detectors.

SRON participates in the Japanese-European ASTRO-H mission with

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a launch planned for 2014. This mission shall use observations of cosmic X-rays to study collapsing material in the vicinity of black holes, turbulences in clusters of galaxies, the shockwaves caused by supernova explosions and large-scale structures in the universe. Dark matter and the acceleration of cosmic particles to high energies shall also be investigated during the mission. SRON is supplying technology for the Soft X-ray Spectrometer (SXS) of ASTRO-H. This spectrometer shall be the first instrument to simultaneously provide maps and extremely accurate spectra of clusters of galaxies and the remains of supernovas.

From 2009 onwards, astronomers throughout the world use HIFI (Heterodyne Instrument for the Far-Infrared), a very-high resolution spectrograph onboard of ESA's Herschel space telescope that was launched and operated by ESA. M. de Graauw (SRON/Groningen) led the international consortium of 25 institutes that actually built HIFI. Through ultra-high spectral resolution HIFI combines high spectral resolution in a wide wavelength range using partially in a up to then inaccessible part of the infrared spectrum. This became possible by new cryogenic detector technology developed by T. Klapwijk at the Technical University of Delft. HIFI provides access to details of hundreds of thousands of molecular, atomic and ionic spectral lines thus probing physical and chemical conditions in molecular clouds, star-forming regions and galaxy cores. Herschel carries out the observations from the L2 Lagrange point at a distance of 1.5 million km from Earth. It is expected that the helium in the cryostat of Herschel will be boiled off in 2013 and then the instruments will stop functioning. Even at the time of writing it is clear that Herschel and its three instruments are a major scientific success.

Based on the instrument end-to-end development necessary for the PI-ships on ISO and Herschel SRON became the Principal Investigator Institute for the long wavelength spectrometer (SAFARI) on the next big far-infrared mission SPICA, led by the Japanese Space Agency (JAXA). SRON successfully applied to the national committee for the roadmap on large scale research infrastructures and is now able to contribute about a third of the SAFARI instrument including some of the most challenging detector arrays. A final go ahead decision from JAXA is expected in the middle of 2013. SAFARI will be able to map galaxies in large volumes of space and to characterize these galaxies spectroscopically.

2.3. UK/NL COLLABORATION IN ASTRONOMY

In 1981 the British Science and Engineering Research Council (SERC, now STFC) and the Nederlandse Organisatie voor Zuiver-Wetenschappelijk onderzoek (ZWO, now NWO) signed the protocol on the collaboration in

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astronomical research. The initial agreement was for 30 years starting in 1979. The basis of the collaboration was the recognition that astronomers in the UK and The Netherlands need to have access to first-class telescopes on good sites in the Northern Hemisphere and that these telescopes will need to the developed and updated throughout their useful life. The protocol covered four telescopes with their associated equipment and buildings: the 1.0m Jacobus Kapteyn Telescope, the 2.5m Isaac Newton Telescope and the 4.2m William Herschel Telescope, sited on the Roque de los Muchachos on the Canary Island La Palma, Spain, becoming the Isaac Newton Group (ING). The fourth telescope is the 15m diameter James Clerk Maxwell Telescope located on Mauna Kea, Hawaii, optimized for observations at millimetre and submillimetre wavelengths. The INT and JKT began scheduled use by the astronomical community in 1984 and the WHT and JCMT in 1987.

In the Netherlands the UK/NL collaboration was initiated by H. van der Laan. His UK counterpart was H. Atkinson. Both recognized that multi wavelengths observations were needed to obtain further insight in astrophysical processes and objects. The radio observations obtained with the WSRT require follow-up observations in the optical and (sub)millimetre wavelength regime and the X-ray and IR observations from space need groundbased follow-up as well with ESO in the south and ING in the north.

At RZM in Dwingeloo, coordinated by J.L. Casse and W.N. Brouw, the laboratory for the development of radio receivers broadened its scope to become involved in work for optical telescopes and its instrumentation (CCD controllers, database and archiving system) and equipment for the JCMT (345 GHz receiver system, telescope thermal analysis).

At the KSW in Roden, coordinated by H.R. Butcher and J.W. Pel, the group contributed the development and construction of two instruments and one facility tool: TAURUS II, an imaging Fabry-Pert spectrometer on the WHT, the Multi Purpose Photometer on the JKT, and the Nasmyth acquisition and guiding system for the WHT.

At UU R. Hoekstra and J. van Nieuwkoop developed and constructed the High Dispersion Spectrograph for the WHT and H. van de Stadt coordinated the design and construction of the chopping secondary mirror for the JCMT. The antenna structure of the JCMT was built by a company in the Netherlands, Genius Fabricage BV in IJmuiden.

The UL/NL collaboration required that Dutch staff was seconded to RGO and RAL in the UK to participate in various joint work packages. Staff was also seconded to La Palma en Hawaii to contribute to commissioning of the telescopes and its instrumentation and thereafter to regular telescope operations. The ING was led twice by a Dutchman, J. Lub and R.G.M. Rutten.

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A Steering Committee was set up to coordinate the Dutch part of the UK/NL coordination. It was chaired by H. van der Laan and P.C. van der Kruit. H. Weijma represented NWO in the Steering Committee. He was the key-person to coordinate the role of NWO. In the early years these three people represented the Netherlands in the governing boards that were set-up of the ING and JCMT, respectively.

In 1987 Canada jointed the JCMT collaboration. From that year onwards the share and observing time were distributed as follows over the partners: UK-Cnd-NL 55-25-20%. For the further development of the JCMT the Netherlands contributed an upgraded spectral line receiver for the 320-370 GHz band, SIS junctions for the HARP B-band array receiver and parts for SCUBA-II array camera.

In 2002 the Instituto de Astrofsica de Canarias (IAC) jointed the ING as an official partner. From that year onwards the observing time was distributed as follows over the partners: UK-Es-NL $\sim$ 48-32-20%. In 2009 the three partners decided to extend their collaboration for a period of three years. Now discussions regarding the future of the ING are ongoing. One likely option is that the WHT will be upgraded with a wide-field fibre-fed survey instruments capable to take hundreds of spectra simultaneously to study the dynamics and evolution of our Galaxy and the role of dark matter and dark energy in the evolution of galaxies and the universe as a whole.

3. NOVA and University Strategy Towards Research

NOVA is a collaborative and coherent research effort at all astronomy departments at Dutch universities. Its program is centred on the theme 'The lifecycle of stars and galaxies: from high redshift to the present'. There are three interconnected programs each executed by a national network of researchers and lead by researchers with a strong scientific record. Dutch astronomy is very productive and its research is internationally well appreciated. Its quality, as measured through various citation analyses and other indicators of leadership, is at the level of the leading countries worldwide. Dutch PhD students compete successfully for the most prestigious fellowships worldwide and find good jobs in astronomy (Fig. 2) and elsewhere in society.

NOVA's objectives are: 1) to continue scientific innovation in the three main lines of NOVA's coherent research program while maintaining its high quality; 2) to further strengthen its instrumentation program by having a leading role in designing and realizing cutting-edge instrumentation for the E-ELT; 3) to keep attracting very talented PhD students and educating them to levels where they compete successfully for the best positions in science and elsewhere; and 4) to share our increased understanding of the

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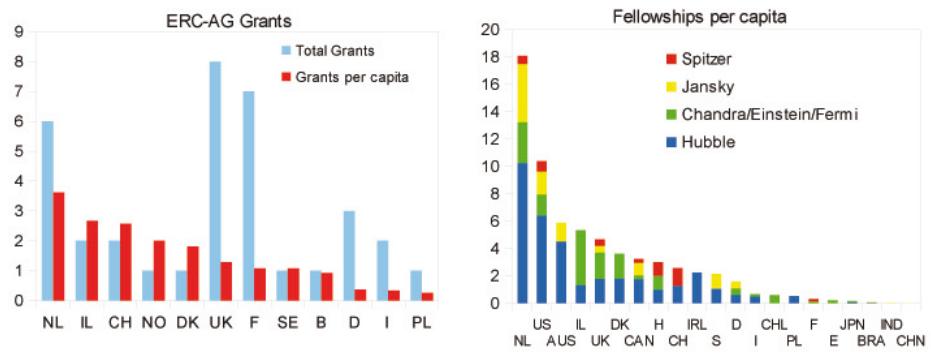


Figure 2. Performance indicators of Dutch astronomy. Left: the total number of ERC Advanced Grants in astronomy per country in 2008-2011 (light blue), and normalized per inhabitant (red). Credit P. Groot. Right: a similar plot of the total number of (highly competitive) US fellowships awarded by NASA to PhD graduates of different countries. In both cases the Netherlands can be seen to be leading the field, illustrating the high level and visibility of its astronomy programme. The USA itself is off-scale. (Courtesy J. Brinchmann)

Universe with the general public.

The research program carried out by NOVA is organized along the following three interconnected thematic programs:

- Network 1: Formation and evolution of galaxies: from high redshift to the present
- Network 2: Formation of stars and planetary systems
- Network 3: The astrophysics of black holes, neutron stars and white dwarfs

The NOVA Grant from the Ministry of OCW helps funding an equivalent of about 40 fulltime people per year of PhD and postdoc positions and through the so-called 'overlap' appointments for permanent staff, which makes it possible to appoint successors to retiring faculty staff several years before retirement. It also stimulates astronomers at the universities to undertake the design and building of instruments for use at telescopes or satellites provided by ESO, ESA or ASTRON, to carry out technical research and development for the next generation of instruments, and to develop specialized software pipelines for data calibration and analyzes. The integrated research and instrumentation program enables Dutch astronomers to obtain a rich harvest of results from ground-based and space-based facilities, in conjunction with strong theory, numerical modeling, and laboratory astrophysics efforts. Over the last decade NOVA has revitalized optical-infrared astronomical instrument-building in the Netherlands involving many uni-

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versity astronomers and has positioned itself well for participation in future major projects.

3.1. STAFF INVOLVED IN NOVA'S PROGRAM

The NOVA program involves about 290 fte[6] scientific staff members spread over the participating universities: 60 fte senior staff in permanent and tenure-track positions, 55 fte postdoctoral fellows, 140 fte PhD students, and 35 fte staff working on instrumentation projects. These numbers are for 2009. The permanent staff includes full professors, associate professors and assistant professors (often on tenure-track positions). The ratio of permanent to temporary staff is about 1:5 at each of the institutes. 95% of the permanent scientific staff carries out research in one or more of the NOVA networks. The staff working on instrumentation projects includes postdoctoral fellows with technical and scientific programming expertise. Over the period 2003-2009 the research staff numbers increased from about 200 to 290, mainly in the categories PhD students, postdocs and staff working on instrumentation projects.

The staff positions at the university institutes are funded by the universities (43%), NOVA Grant (18%), grants from NWO, KNAW and ERC (total 25%), ESO contracts (6%), and other contractual work including EU network funding (8%). These figures are averaged over the period 2003-2009. It is a clear trend that grants from NWO and the European Commission increase over the years whereas direct funding by the universities decreases.

Each of the three national research networks is led by the network coordinator and contains 6-10 senior researchers. With input from the other university astronomers these senior researchers determine the research plans within and across the networks. NOVA-funded research positions have a second supervisor or mentor from another university or from ASTRON or SRON, stimulating collaboration between the institutes. In total, there are 27 permanent staff members associated with Network 1, 12 with Network 2 and 19 with Network 3. There are also cross network projects and several staff members participate in the activities of more than one network. These activities include regular 1-day scientific meetings.

The NOVA instrumentation program is monitored by the Instrument Steering Committee (ISC). All PIs of instrumentation projects submit detailed progress reports to the ISC twice per year, which are discussed in a 1-day face-to-face meeting. The ISC monitors ongoing developments and project risks, reviews intermediate milestones, and, if necessary, recommends corrective actions, including use of contingency funds. One of the major tasks of the NOVA executive director (at present: W. Boland) is

[6]Full-time equivalent.

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Figure 3. Top left: The Westerbork Radio Synthesis Telescope (WSRT). Top right: The LOFAR core station. Bottom: the three astronomy projects on the National Road Map Large-scale Research Facilities. Left: the E-ELT on a Chilean mountain top above the clouds, middle: the SKA high-band dishes in a desert setting, right: the SPICA satellite in space. (Courtesy top: ASTRON, bottom: ESO/SKA/ESA-JAXA)

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to oversee and guide the instrumentation program on a daily basis, represent its organization in international steering committees for the projects to which NOVA is making contributions and, where necessary, renegotiate existing contractual arrangements. This strict oversight has proven to be essential in keeping the NOVA projects within budget and time.

In 2008 NOVA took over the responsibility for the optical-infrared instrumentation group based at ASTRON in Dwingeloo and employed by NWO. The expert group of optical and mechanical designers and instrument engineers and technicians of about ten people have to be added to the staff members specified above. Over the last decade this group, largely financed by NOVA projects, carried out most of the optical-IR instrumentation projects for which NOVA had the final responsibility toward ESO, ESA, and international partners.

3.2. NOVA'S RESEARCH STRATEGY

The three NOVA research networks address many of the main questions of modern astronomy. Network 1 is concerned with the biggest structures: how did galaxies and galaxy clusters evolve out of the tiny quantum fluctuations observed in the microwave background? How did our own Milky Way galaxy form and what is the feedback of stars onto their host galaxies? Network 2 focuses on the early life of stars and planets. How do stars – high- and low-mass – form from large, tenuous clouds of gas and dust? How are planets such as the Earth made out of the submicron-sized dust grains circling these stars? Network 3 probes the most extreme physical conditions in and around compact objects: white dwarfs, neutron stars and black holes, where the extremes of gravity, density, energy and radiation occur. How are these objects formed and in which environment, what is their internal structure and the relevant physics?

All these questions cannot be studied in isolation but are intimately linked. Galaxies and galaxy clusters are ecologies in which stars, gas and dust, stellar remnants and supermassive black holes all interact with each other, thus linking the subject matter of all three networks. The galaxies and galaxy clusters themselves are descendents from a hot Universe dominated by the laws of quantum mechanics and general relativity (Networks 1 and 3). Massive star formation, evolution and death combine topics in Networks 2 and 3. The interstellar medium in galaxies connects Networks 1 and 2 and it is probed at high redshift through bright gamma ray bursts, a topic in Network 3.

Given the size of the Netherlands and its astronomical community, it is clear that choices have to be made and that not every topic in astronomy can be pursued in depth. For example, the Netherlands has had no or little

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involvement in solar system and cosmic microwave background research, and has only recently entered the exoplanet research field.

The networks typically organize 1-2 one-day meetings per year with typically 30-50 people attending. Presentations of on-going research are mostly by PhD students with sometimes a guest speaker from abroad. There are also smaller meetings of other groups. For example, a cross-network group on stellar populations and stellar evolution in galaxies meets regularly, as does a group on exoplanet research. Here the Netherlands truly benefits from its small physical size: all universities can easily participate in one-day meetings (no flights or overnight stays needed).

In the past several years innovative research plans have emerged from all three science networks including plans for newly emerging research fields such as exoplanet atmospheres and the transient radio sky Dutch astronomers are deeply involved in national and international multi-disciplinary programs on astroparticle physics, computational astrophysics and astrochemistry. They have made important contributions to the building of some of the major new facilities of the next decade. They are confident to be scientifically well prepared for the exploitation of these instrumental developments. NOVA also has the ambition to lead some instrumentation projects for the E-ELT, the next European flagship, and significant national funding for this ambition has been secured.

New discoveries in astronomy are often made possible by new observational facilities; instrumental developments, in turn, are driven by astrophysical questions. Access to world-class telescopes across the electromagnetic spectrum is vital to Dutch astronomy, and astronomers in the Netherlands are fortunate to have access to major telescopes (VLT, ALMA, HST, XMM-Newton, Gaia, Herschel, JCMT, WSRT, LOFAR) through government funding lines. In the present system NOVA and the universities, the NWO-funded institutes ASTRON and SRON, NWO and the Ministry of OCW each have complementary roles in realizing, running and providing access to these facilities.

Astronomy inspires the general public, and Dutch astronomers take their responsibility very seriously to share their excitement and knowledge about the Universe with a wide audience through hundreds of lectures, newspaper and magazine articles, television and radio appearances, as well as educational programs for school children. Astronomy also stimulates the 'knowledge society' by driving technology, interacting with industry, and training PhD students in a variety of transferable skills related to mining of large volumes of data, software development, high-performance computing, project management, grant writing and strategic thinking.

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Figure 4. The MIRI spectrometer main optics for the JWST satellite in the NOVA Op-IR instrumentation group located at ASTRON. (Courtesy NOVA)

3.3. NOVA'S APPROACH TO INSTRUMENTATION

There are various reasons for NOVA to be actively involved in building instruments. The first is to ensure that instruments are built with the required capabilities to address the major scientific questions of great interest to astronomers in the Netherlands. All instruments are designed with specific science goals in mind. For some instruments only participation in the design and construction can ensure that they become reality. An example is the design and construction of the near-IR spectroscopic arm on the second generation VLT instrument X-Shooter. The second reason is to gain expert knowledge of the increasingly complex instruments, necessary to be among the first to harvest the scientific results and, ultimately, to get the most out of the data. Third, and very importantly, the guaranteed time: participating institutes have privileged early access to the telescopes. This makes it possible to carry out large coherent programs with exclusive data as well as smaller seed programs that prepare for the use of subsequent open time. NOVA policy is to make guaranteed time for NOVA-funded projects available to the entire Dutch community.

Building instrumentation is also an excellent way to capitalize on the Dutch investments in the world-wide facilities provided by ESO and ESA. In fact, both organizations expect the member countries to design, build and finance the instruments that go on the billion-euro telescopes. Thus, a relatively small investment of 1-10 MEuros can still have a large impact. An example is the contribution of the spectrometer main optics and the

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collimator-grating camera optics for the mid-infrared instrument (MIRI) for the James Webb Space Telescope (JWST). Finally, NOVA's involvement in instrumentation strengthens the technical expertise at the universities and provides 'hands-on' experience with the technical intricacies and project management of instrument building and training of a new generation of instrumentalists. Collaboration with nearby physics groups provides fertile ground for technical innovation. In 1996 an astronomy foreign evaluation committee judged a lack of involvement of university staff in instrument to be a weakness that needed to be addressed. The NOVA Grant gave the opportunity to do so starting in 1999 and the program is now in full swing.

Another example of the integrated research-instrumentation approach is OmegaCAM, the wide-field camera for optical wavelengths for ESO's VLT Survey Telescope (VST). NOVA astronomers contributed the data archiving and reduction software. In parallel OmegaCEN was developed to become the national datacenter for wide-field imaging and the expertise center for astronomical information technology. It is situated at the Kapteyn Astronomical Institute of the RUG. The center brings together astronomers and astronomical IT experts. It is partner in various optical and radio wide field surveys, conducted by international collaborations. The largest of these is the Kilo Degree Survey (KiDS).

The knowledge obtained with the development of SIS heterodyne detectors for HIFI at SRON and TuD allowed NOVA astronomers to take a pro-active role in the development of the so called Band-9 receivers for ALMA covering the frequency range between 610-720 GHz, the highest frequency band of the initial set of receivers for ALMA. After the initial design, verification and prototyping phases (2000-2007) 73 Band-9 receiver cartridges were constructed and delivered by the NOVA-ALMA team at the RuG by end 2011.

3.4. OPTICAL-INFRARED INSTRUMENTATION

There is a clear division in technical focus between NOVA, ASTRON and SRON. NOVA has grown into the national 'home base' for instrumentation on the ESO telescopes including the VLT, VLTI, VST, ALMA and in the future the E-ELT. The NOVA-funded program is the long-desired national complement for the ESO program, similar to what has existed for decades with respect to ESA and CERN. The NOVA Optical-Infrared instrumentation group has built up a solid reputation in various areas of optical and infrared instrument design (especially the optical-mechanical design of components that have to operate in cryogenic conditions). This group started as instrumentation workshops at the universities in Groningen, Leiden and Utrecht. In 1982 the university instrumentation workshops

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in Leiden and Groningen were merged into the Kapteyn Sterrenwacht Werkgroep (KSW) based in Roden and operating under the leadership of H.R. Butcher and J.W. Pel. They gained experience with optical instrumentation for the Dutch Telescope at La Silla, for the UK/NL Isaac Newton Group of telescopes of the Observatorio del Roque de los Muchachos on La Palma, and for the ESO's VLT.

With the advent of 8-10 meter class telescopes the scale and complexity of instrumentation projects increased significantly and it became mandatory to embed the optical instrumentation work in a broader technological environment. In 1996 the optical group moved to Dwingeloo where it became part of ASTRON. The first large instrumentation project was the mid-infrared instrument for the VLT together with the Service d'Astrophysique (Saclay, France). Thereafter (1999-2004) NOVA, ASTRON, and the Max Planck Institute for Astronomy (MPIA) together designed and built the first two-beam combiner, MIDI, for the VLT Interferometer. NOVA and ASTRON were responsible for the design and construction of the cold optics including the beam combiner. In addition NOVA staff at Leiden made a significant contribution to the data reduction software for MIDI.

Engineering state-of-the-art instrumentation is only possible when improved and novel techniques can be applied. The group has built up a reputation in achieving excellent solutions in opto-mechanical engineering, and inventing new solutions to meet the stringent requirements. Examples are the innovative cryogenic lens mounts for the Spiffi camera (for the Sinfoni instrument on the VLT); development of the Adaptive Secondary Setup and Instrument Stimulator (ASSIST), the primary test-bench for ESO's Deformable Secondary Mirror (DSM) for the VLT, used for verifying control algorithms and hardware, functional validation of the adaptive optics facility needed for the 2nd generation instruments such as MUSE and ensuring the DSM operates at specification before being deployed at the VLT; development together with ETH in Zurich of the ZIMPOL system for the SPHERE instrument for ESO's VLT, which is a sensitive imaging polarimeter to detect the faint reflected light signal from extrasolar gas planets in wide orbits in exo-solar planetary systems.

The Netherlands is one of the ten European countries making contributions to the Mid-Infrared camera/spectrometer Instrument (MIRI) for the James Webb Space Telescope (JWST) covering the wavelength range between 5-28 μm. The spectrometer input/pre-optics (SPO) with the dichroics and IFU's are provided by the UK whereas the actual spectrometer main optics (SMO) with collimator-grating camera optics are the responsibility of the Netherlands. The gratings mechanism is contributed by Germany and the detector units are US responsibility. The Dutch contributions organized through NOVA were initiated by E.F. van Dishoeck, R. Waters

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and J.W. Pel and were designed and constructed by the optical-infrared instrumentation at ASTRON. The work was completed and delivered to the European MIRI consortium in early 2009.

At the same time (2003-2008) the Optical-IR instrumentation group together with NOVA astronomers (L. Kaper and P. Groot) and technical staff at the Radboud University Nijmegen designed and manufactured the near-infrared spectroscopic arm of X-Shooter, the first second generation instrument at the VLT in operation since 2010. X-shooter is a powerful optical and near-infrared medium-resolution spectrograph, with a unique spectral coverage from 300 to 2500 nm in one shot.

From January 2008, NOVA took over the leadership and responsibility of the optical-IR instrument group located at ASTRON. The group together with a number of university astronomers made significant contributions to the Phase A studies for four E-ELT instruments: EPICS (C.U. Keller), METIS (B. Brandl), Micado (K.H. Kuijken succeeded in 2012 by E. Tolstoy) and Optimos-EVE (Kaper). The study work was completed in early 2010. The involvement in the Phase-A studies led to the role of NOVA in two of the three first instruments for the E-ELT (Micado and METIS).

The national funding for the Dutch contributions to the E-ELT instrumentation was partly secured in 2008 through a national Roadmap grant in a collaborative proposal by NOVA, ASTRON, SRON, TNO (organisation for industrial technology development) and several industrial partners. Under the supervision of W. Boland the partners in the collaboration started a program to distinguish areas in which readiness still had to be demonstrated or further improved. Ongoing technical R&D projects include the advanced chopper, immersed gratings and sorption cooling technology for METIS, and polarimetry system engineering and high-speed computer systems and algorithms for adaptive optics corrections for EPICS.

3.5. UNIVERSITY ASTRONOMY EDUCATION

All graduate astronomy education in the Netherlands is concentrated in NOVA, *i.e.*, all PhD students in the Netherlands are part of NOVA even if funded from other sources. The NOVA educational program has three aims (1) Broadening of the astronomical knowledge of the PhD students; this is accomplished through courses at the annual NOVA fall school as well as attendance of colloquia at the home institution; (2) Deepening of insight in topics related to the thesis project; this is mostly done through literature studies and courses at the home institution, the NOVA network meetings, as well as international summer schools. (3) Presentation: opportunities and training in presenting scientific results are provided at the NOVA school, home institution, the annual Netherlands Astronomy Conference and in-

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ternational conferences. The progress of each PhD student is monitored annually by the NOVA PhD review committee at each institution.

Acknowledgements

The authors appreciated the comments and suggestions received from several colleagues in the Netherlands, in particular H. van Woerden, W. Hermsen, F. Helmich, P. Groot, G. Cornet and D. Baneke.

TABLE 1. **Some Institutional Links**

ASTRON Netherlands Institute for Radio astronomy	http://www.astron.nl/
JIVE – Joint Institute for VLBI in Europe	http://www.jive.nl/
NOVA – Netherlands Research School for Astronomy:	http://www.strw.leidenuniv.nl/nova
SRON Netherlands for Space Research	http://www.sron.nl/
European VLBI Network	http://www.evlbi.org/
Astronomical Institute Anton Pannekoek	http://www.astro.uva.nl/
Kapteyn Astronomical Institute	http://www.rug.nl/sterrenkunde
Leiden Observatory	http://www.strw.leidenuniv.nl/
Astronomy Department Radboud University Nijmegen	http://www.astro.ru.nl/

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 175-194
Ed. A. Heck, © 2013 Venngeist.

ASTRONOMY IN POLAND

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Abstract. A historical outline of the development of Polish astronomy shows its strong dependence on national history. The present state and main activities of Polish astronomical institutes and organizations are described in the context of the general management and funding of science in the country.

1. Historical Introduction

The beginnings of astronomy in Poland were closely related to the creation of its first university. The last King from the Piast dynasty, Kazimierz Wielki (Casimir the Great, 1310-1370), founded in 1364 in Kraków (Cracow) the so-called *Studium Generale* consisting of three departments: liberal arts, medicine and law. After the King's death in 1370, and in view of the total lack of interest in science by his successor, Louis d'Anjou (1326-1386), the Cracow Academy did not develop any further for the next several decades.

The situation improved with the election to the Polish throne of Jadwiga d'Anjou (1373-1399), the 11y old daughter of King Louis. She was crowned in 1384 (as a King and not a Queen, to emphasize her position as a monarch and not a mere crown consort). Two years later, she married the Great Duke of Lithuania, known after he was baptized as Władysław Jagiełło (∼1351-1434), the founder of the Polish-Lithuanian Jagiellonian dynasty. Both Jadwiga, renowned for her excellent education and broad cultural interest, and her husband did a lot to restore the academic activity in Cracow. The solid financial foundation of the Academy was created by Jadwiga's generous bequest of her personal jewelry. Although this philan-

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thropic gesture was not the main reason, Jadwiga after a somewhat lengthy process was canonized in 1997 for her charity works.

Following the good example of the Kings, a wealthy Cracow citizen, Jan Stobner, founded in 1406 a chair of astronomy as a part of the department of liberal arts. Professors of astronomy at that time were teaching geometry, arithmetic, principles of music, and the Ptolemaic theory of planetary movements. The practical part of astronomy dealt with calendar keeping and reduction of astronomical ephemerides to the local meridian. Although astrology was closely related to astronomy, a separate chair of astrology was established in Cracow Academy almost half a century later, in 1459.

The first Cracow astronomer who influenced markedly the state of astronomical research in Poland was Wojciech Brudzewski (1446-1495), from ∼1487 a professor at the Academy. His main works were the *Tabulae Resolutae* – Alphonsian Tables of planetary ephemerides reduced to Cracow and *Commentum planetarium in theoricas Georgii Purbachii*, containing many critical remarks on the consistency and reality of the Ptolemaic system, however without any doubts about the truth of the geocentric system itself. Most probably Copernicus attended his lectures when studying the liberal arts at the Cracow Academy in 1491-1496.

The importance of Mikołaj Kopernik (Nicolaus Copernicus, 1473-1543) work in the creation of modern astronomy is well known and does not require a detailed description here.

The end of the 15^{th} century meant golden years for the Academy. From the 16^{th} till the middle of the 18^{th} century, astronomy in Cracow was in a state of permanent decline and became reduced in practice to astrology. An exception to this was the relatively short period when a professor of mathematics and later rector of the Academy became the most famous Polish mathematician of the 17^{th} century: Jan Brożek (Jan Broscius, 1585-1652). He is remembered in the history of science as the first researcher of Kopernik's life and the propagator of his work.

Hundred years later, Polish astronomy reached again a high level thanks to Jan Heweliusz (Johannes Hevelius, 1611-1687). The son of a wealthy brewers' family with Czech-German background living in Gdańsk, he became interested in astronomy early at high school. As the expected future manager of the family business, he was sent to complete his law studies at Leiden University and to pay longer visits in England and France, where he had the opportunity to meet some of the distinguished representatives of the European science, such as the Huygens family, John Wallis, Pierre Gassendi and others. After returning to Gdańsk, where he spent the rest of his life, he took an active part in the municipal administration, becoming a leader of the beer brewing guild and a town councilor.

His main interest, however, remained astronomy. In 1641 he built his

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Figure 1. Mikołaj Kopernik in his Frombork observatory. Painting by Jan Matejko (1838-1893).

private observatory on the specially adapted roofs of his three neighboring houses in Gdańsk. The observatory was equipped with excellent instruments of his own making. The most renowned was a refractor (45m focal length, 12cm diameter) used for observations of celestial bodies. The other instruments, measuring stellar positions, were of old, "naked-eye" type, but of a precision comparable to that attainable with refractors. Heweliusz' observatory was certainly the finest observatory in the world at that time and the results it produced were enormous. In 1647, Heweliusz published his most famous work, *Selenographia*, containing 60 carefully executed drawings of the Moon's surface and the first description of the Moon's libration in longitude. This work marks the beginning of lunar topography.

The discovery and motions of six comets were described in *Prodromus cometicus* (1665) and in *Cometographia* (1668). The results of very precise measurements of the positions of 1564 stars were published in *Catalogus Stellarum Fixarum* (1687). Heweliusz observed sunspots and, from these observations, he determined the solar rotation period with surprisingly good accuracy, much better than it was done before. He also left a lasting trace in astronomical nomenclature, devising the term *faculae* for the bright regions surrounding the sunspots, naming "Mira" the variable star *o* Ceti, and, in his sky atlas *Firmamentum Sobiescianum* (1690), introducing several new constellations which are still in use today (*Canes Venatici, Lacerta,*

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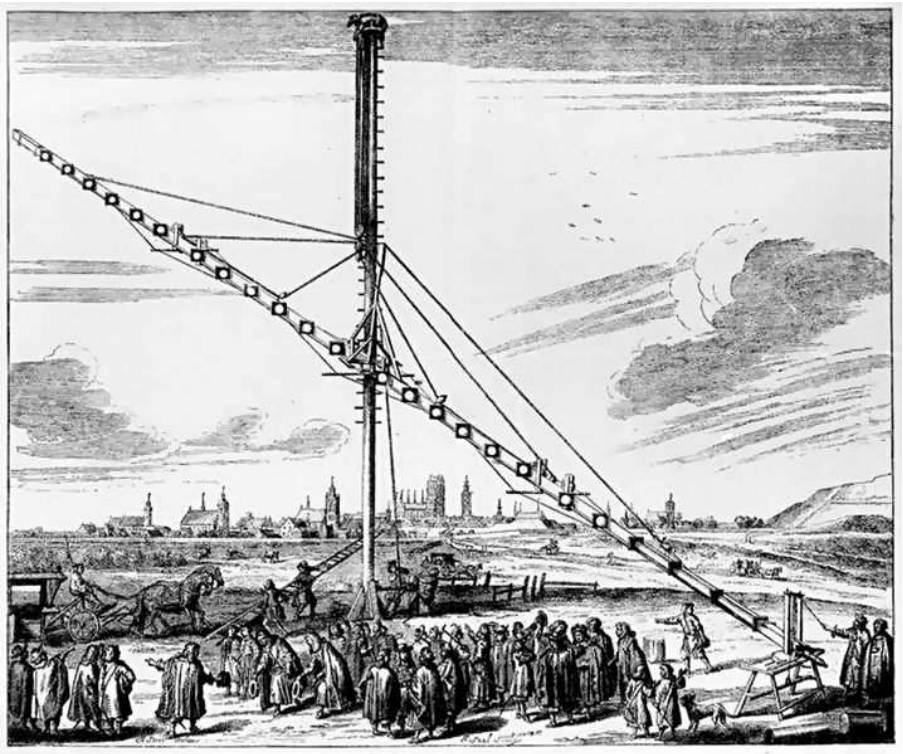


Figure 2. Heweliusz' giant telescope (focal length of 45m).

Sextans, Leo Minor, Vulpecula, Lynx and *Scutum*). He was a precursor of observations of visual double stars and was the first to use a pendulum for time measurements in astronomical observations.

Heweliusz's astronomical work was soon broadly recognized in Europe. He was elected the first foreign member of the Royal Society of London in 1664 and was offered in 1966 the directorship of the newly organized Paris Observatory. Although he declined the offer, King Louis XIV granted him financial support for eight years. Steady support was coming from the Polish Kings of that time, in particular from Jan III Sobieski (1629-1696) who funded in 1677 his lifelong salary and endowed his brewery with many lucrative commercial privileges. In return, Heweliusz depicted the constellation *Scutum Sobiescii* in a shape of the Sobieskis family coat of arm: the empty shield with a cross added to commemorate the victorious battle of Jan III over the Turks in 1683 near Vienna.

In the 17^{th} century, Poland was a multinational country. In particular, its northern part was populated by people of German, Polish, Dutch, Prussian origin. A good example may be Heweliusz himself, who independently of

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his complicated ethnic roots considered himself as being – in his own words – *civis Orbis Poloniae*, *i.e.* citizen of the Polish world.

When talking about Heweliusz, it is impossible not to mention his second wife Elisabeth Koopmann (1647-1693), daughter of rich Gdańsk merchants of Dutch origin. Thirty six years younger than her husband, she assisted him in all astronomical observations, and after his death completed and published three of his important works. In the Polish tradition she is considered one of the first, if not the first, female astronomer.

The observatories of Kopernik and Heweliusz were fully private initiatives unrelated to any scientific center. A more general interest in astronomical research was renewed in Poland in the mid-18^{th} century. The growing astronomical knowledge in the period of Enlightment necessitated the creation of observatories as separate university units.

The first university observatory in Polish territory was organized in Wilno (now Vilnius, Lithuania) where King Stefan Batory (1533-1586) raised the old Jesuit's College to the rank of university in 1579. The observatory was then set up in 1753 by Tomasz Żebrowski (1714-1758), professor of trigonometry and astronomy. Systematic observations were started by Marcin Poczobutt-Odlanicki (1728-1810). A former student of astronomy in Italy and France, nominated to be Royal Astronomer by the last King of Poland Stanisław August Poniatowski (1732-1798), after having ordered modern astronomical instruments from Ramsden and Dollond, he started astrometric observations of stars, planets and newly discovered asteroids. His results served Lalande for the correction of the orbit of Mercury. Scientific activity at Wilno observatory continued, including after the partition of Poland in 1795, by other distinguished astronomers: Jan Śniadecki (1756-1830) and Piotr Sławiński (1795-1856). In 1832, the Russian government closed Wilno University as a repression after the November uprising of 1830, but the observatory remained, subordinated to the Academy of Sciences in Petersburg, till 1876 when a fire destroyed it almost completely; the instruments saved and the valuable library were moved to Pulkovo Observatory.

The Stefan Batory University in Wilno came back to life in 1919. The reactivation of the observatory was undertaken by Władysław Dziewulski (1878-1962). It started from nothing, but in the mid-1930s became a modern astronomical institution in Poland, concentrating mainly on astrophysical observations and actual problems of stellar astronomy. After the Second World War (WWII), Wilno was incorporated to the Lithuanian Soviet Republic and its Polish astronomers moved to Toruń.

Cracow Academy was recovering from the long-lasting decline thanks to the reforms undertaken in 1780 by the Commission for National Education – the first "ministry of education" in Poland, created in order to modernize the education on every level after a long period of stagnation under the

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reign of the Saxon dynasty. Shortly afterwards, fulfilling the old postulate of Cracow astronomers, the decision to build Cracow Observatory was made and necessary funds were provided. The task of organizing the observatory was entrusted to Jan Śniadecki. He was one of the most outstanding Polish astronomers of his time. A student of mathematics and physics at Cracow Academy, he received his PhD degree at the age of 19. As a candidate for a professorship at the Academy, he was sent to Paris to continue studies under the direction of Laplace and d'Alambert. Nominated professor at the Academy in 1781, he broke the old tradition and started lecturing in Polish instead of the previously mandatory Latin. His organizing efforts succeeded and Cracow Observatory was opened in 1792. Its vast observational program covered the typical problems of the observational astronomy of that time, such as the measurements of precise positions of stars, planets, comets and the newly discovered bodies, as also the first observations of periodic light variations of fixed stars.

After the third partition of Poland, Cracow was annexed first to Prussia and later to Austria. The occupants were not interested in supporting the development of Polish science and culture, and the normal activity of the observatory met increasing difficulties. At last, Śniadecki discouraged by growing problems, gave up and left Cracow in 1803, going abroad and then assuming his post in Wilno. The work at Cracow Observatory continued on a limited scale until the First World War, enriching slowly its instrumentation and observational programs. More significant progress followed in the inter-war period under the directorship of Tadeusz Banachiewicz (1882-1954), best known for his theoretical works on matrix calculation (Cracovians) and promotion of the modern program of eclipsing-binary observations. Under German occupation during WWII, Cracow Observatory was not closed, but Banachiewicz was imprisoned for three months in the Sachsenhausen concentration camp, then dismissed from his position and replaced by a German director.

The other scientific and cultural center in Poland was Lwów (now Lviv, Ukraine), where a university was founded in 1661 by the Polish King Jan Kazimierz (1609-1672). However, the astronomical research was marginal till 1907 when the Chair of Astronomy was established. It was not until 1935 that the Chair was expanded to the Observatory under the directorship of Lucjan Grabowski (1871-1941). A modern program of photographic observations of bright stars in three colors was barely initiated when first the Russian invasion in 1939 and then the German occupation after 1941 completely paralyzed the work of the Observatory. After annexion of Lwów to the Ukrainian Soviet Republic, the Polish scientific staff of the Observatory moved to Wrocław.

The scientific tradition in Poznań dates back to the 16^{th} century: in 1519,

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the bishop of Poznań founded the *Academia Posnaniensis* where, among other disciplines, mathematics, geography and astronomy were lectured. In 1571, another bishop of Poznań founded the Jesuit's College, which two centuries later, in 1764, set up its own Observatory equipped with astrometric instruments donated by Maria Leszczyńska (1703-1768), daughter of the King of Poland Stanisław Leszczyński (1677-1766), and later the wife of the King of France Louis XV. The actual organizer of the Observatory and its main observer was the Jesuit Józef Rogaliński (1728-1802). Alas, the war waging in the northern part of Poland, the dissolution of the Society of Jesus in 1773, and the partition of Poland which took place shortly after, stopped any scientific activity in Poznań until the beginning of the 20^{th} century.

In independent Poland, Poznań University was established as soon as in 1919 and two years later its observatory started to be organized under the direction of Bohdan Zaleski (1887-1927), a Polish astronomer working previously in Pulkovo in Russia. The equipment of the Observatory was sufficient to develop both classical positional and modern astrophysical observations. WWII stopped any scientific activity of the observatory: Polish astronomers were fired and some of them arrested. After WWII, the Observatory returned to the reactivated Adam Mickiewicz University in Poznań.

Capital of Poland since 1596, Warsaw played for a long time only a limited role in the academic life of the country. Paradoxically enough, Warsaw University was founded by Czar Alexander I only in 1816 after the loss of independence, *i.e.* in the period of general decline of intellectual activities in Poland. In the same year, Franciszek Armiński (1789-1848), a former student of Delambre and Arago, was nominated professor of astronomy. Thanks to his enthusiasm and efficiency in fighting Russian bureaucracy, Warsaw Observatory was officially opened in 1825. Its imposing building was well equipped with modern instruments, comparable to those used at that time in European observatories. The good prospects of the Observatory were promptly shattered by the changing fates of Warsaw University. After the fall of the anti-Russian uprising of 1830 the University was closed down. In 1856 it was partly reactivated as a Polish medical school and in 1862, after adding a few other departments, was named "Main School". Not for long, however. After the January 1863 uprising, all the Polish-speaking schools were closed down and the Main School was replaced with the Russian-speaking Imperial University of Warsaw.

Warsaw Observatory survived all these perturbations, although under Russian directorship and with very limited Polish personnel. Nevertheless, the name of Adam Prażmowski (1821-1885), one of the most distinguished Polish astronomers of the 19^{th} century, should be mentioned. He worked at Warsaw Observatory from 1839 till 1862. He was first engaged in a program

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of measuring the length of the Earth's meridian. He was also the author of a useful method of determining the observer's personal error. Later on he became famous for discovering the polarization of the solar corona and for a proof that the corona belongs to the Sun and not to the Moon, as it was generally accepted before. After the 1863 uprising, he left Poland and went to Paris where he devoted himself to constructing excellent optical instruments. Prażmowski was the first Polish astrophysicist.

After the First World War, Warsaw Observatory possessed only its building. Russians retreating from Warsaw had moved all the instruments to Rostov. They were sent back to Poland in 1925, but it was evident that they were then too primitive to allow any modern observational program. As a consequence, the activities carried out at the observatory were mainly theoretical, concentrating on issues of celestial mechanics. At the same time, a new astrophysical observing station was built in the East Carpathian Mountains at Pop Iwan (2020m above sea level). A 33cm Grubb Parsons astrograph was installed in 1937 and the first photographic observations were initiated. The station was never completed. A Russian invasion in September 1939 led almost immediately to its total destruction. Under German occupation, Warsaw University was closed, as all Polish educational institutions at a level higher than primary schools. The observatory surprisingly survived, but under German commissary directorship. However, it did not escape its fate as, in the first days of Warsaw's uprising in August 1944, it was bombarded by German tanks and burned down together with all its instruments, archives and rich library.

About 30 professional astronomers were working in Poland just before WWII. Almost one fourth of them died in the period 1939-1945. After WWII, Polish astronomy faced a new political situation and an urgent necessity for restoring its material equipment and human resources.

Cracow Observatory avoided severe losses and resumed relatively easily its pre-war activity under the direction of its former director Tadeusz Banachiewicz.

Wrocław Observatory, formerly a part of the German Friedrich-Wilhelms University, happened to survive WWII in surprisingly good shape and resumed its activity already in 1945, under the directorship of Eugeniusz Rybka (1898-1988) with astronomers from Lwów as scientific staff.

In Toruń, the new Nicolaus Copernicus University was created in 1945 and shortly after, in 1948, an observatory was set up in Piwnice near Toruń by Władysław Dziewulski and Wilhelmina Iwanowska (1905-1999).

Warsaw Observatory, which suffered most during WWII, was reactivated in 1950 under the directorship of Włodzimierz Zonn (1905-1975). In 1953, Stefan Piotrowski (1910-1985) initiated the Working Group for the Central Astronomical Observatory, which in 1957 was expanded into the

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Institute of Astronomy of the Polish Academy of Sciences, intended to be a scientific center of leading astronomical research in Poland. Both these institutions, working very closely, succeeded in creating the "Warsaw school of astronomy". Its most prominent representative was Bohdan Paczyński (1940-2007), a brilliant theoretician, well known for his pioneering work in theory of stellar structure, evolution of single and binary stars, structure of the thick accretion disks, as well as for inventing the new method of investigation of low-mass objects using the phenomenon of the microlensing of starlight, the correct interpretation of the γ bursters, and many other achievements in modern astrophysics. From 1981, after the imposition the martial law in Poland, he lived in the United States working at the Princeton University.

2. Management and Funding of Higher Education and Research

There are currently about 61,000 research workers and academics employed in Polish educational and research institutions. Of these, 38,000 work as academics in Higher Education Institutions (HEI), 4,500 in institutes of the Polish Academy of Sciences (PAS), and the rest in Research and Development Institutes. About 20% of those workers do research in natural and exact sciences, of which about 1.5% are astronomers.

2.1. HIGHER EDUCATION

The lion's share of the public HEI funds is financed by the national budget. The figure for 2012 is at the level of 2.5 billions euros. All public money spent for research and higher education is distributed by the Ministry of Science and Higher Education (MSaHE). Public HEIs receive a financial support proportional to the size of academic staff and the number of under- and postgraduate students.

The Polish Constitution guarantees free education at all levels, which means that regular students at public HEIs pay no tuition fees. On the other hand, the public HEIs have a right to determine the enrollment level and to accept only the best candidates. All other candidates can attend either extramural or evening study programs at the public HEIs or go to private HEIs. In both cases, they must pay the tuition fees. After a system restructuring in 1989, the need for higher education increased enormously among young people. The number of students raised sharply, reaching almost two millions in 2009, a fivefold increase compared to the end of the 1980s. The public HEIs could not afford to fulfill this need although they accepted about 3-4 times more students than earlier. The pressure from young people resulted in the creation of a large number of private HEIs, virtually out of nothing. Their managers hired academics from the pub-

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lic HEIs as a second (third, fourth ...) job, rented classrooms after hours and opened programs almost exclusively in humanities and social sciences. No libraries, no laboratories, just oral lectures during the afternoons and weekends. There are presently over 300 private HEIs – almost three times more than public ones – although they educate only about a third of all the students. As a result of this boom, the proportion of graduates in the different fields became badly distorted. In 2007, for example, there were 64,000 graduates in pedagogy – many times more than the number of new job openings, but only 40,000 in engineering – less than the demand from industry.

Astronomy can be studied from the first year at 6 universities: in Warsaw, Cracow, Poznań, Toruń, Wrocław and Zielona Góra. The total number of graduates in astronomy is 20-30 per year. In agreement with the Bologna process, majors receive BSc degree after 3 years and MSc after an additional 2 years. Separate graduate studies in astronomy exist in the Nicolaus Copernicus Astronomical Center of PAS and in the Astronomical Observatory of the Warsaw University. Joint graduate studies in physics and astronomy are conducted in Cracow, Toruń, Wrocław and Zielona Góra. About 10 students receive PhD degree every year, of which perhaps a half find jobs as scientists, usually after the post-doc stay at a foreign astronomical institution. Less successful graduates and PhD holders in astronomy have no problems in finding jobs in banking, computer centers, as school teachers etc.

2.2. RESEARCH

As in many other countries, the financing of research comes from three main sources: the state budget, the industrial sector and international means. In 2011, the approximate figures were: 1.1 billion euros came from the state budget, the industrial sector provided 1 billion euros, and 0.8 billion euros came through international means, mostly from the European structural funds. All three funds together amount to 0.7% of the Gross National Product, which is quite far from the Lisbon strategy target and places Poland in the tail of European countries.

Research funding goes into three major parts. The first one is core funding, directed to institute directors or deans of faculties. It depends but very weakly on the category given to each unit based on the assessment of its scientific achievements. Otherwise it depends on the size of the unit and on the level of the funding during the previous years. About half the budget money is distributed in this way. This is the largest and most important part of financing for the PAS institutes carrying out research in basic sciences and humanities. Basic salaries and most of the current spending in

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these institutes are covered by the core funding.

The second major part of the finances is received from two granting agencies: the National Science Centre (NSC) awards grants in basic sciences and the National Centre for Research and Development (NCRD) does it in applied sciences. Grants from NSC are directed to individual scientists acting as PIs for the planned projects. Following a peer review process, the best projects are selected and approved. Roughly about one fourth of the applications are successful. Due to a low share of the total research funding distributed through grants, the granted amount of money is very modest. It is not sufficient to hire young scientists or to buy more expensive equipment and is usually spent for inexpensive auxiliary instruments, like personal computers, short visits to conferences or to outside scientific institutions (*e.g.* for carrying out astronomical observations) and low supplementary honoraries for the investigators.

The grant money is at the disposal of the grantee, apart from some overhead expenses, being however submitted to possible restrictions from the grant conditions. Substantially higher grants are awarded by the NCRD. Here consortia of research groups or institutes with the industrial enterprises can apply for a partial financial support of the proposed project, provided that the rest comes from industry. In addition to the scientific value, the assessment process includes the estimate of the usefulness of the project for the future development of the Polish economics and the agreement with the priorities specified in the development perspectives.

The third significant part is devoted to the investment in large scientific infrastructures. Applications from individual institutions or consortia are directed to the Minister, who grants the budget money to the successful applicants, following the assessment process. Funds from three operational programs of the European Union (Innovative Economy, Infrastructure and Environment, and Human Capital) are distributed in the same way. By the end of 2011, the Minister had approved the membership of Poland in two large astronomical infrastructures from the European Strategic Forum for the Research Infrastructures (ESFRI) list: the Cherenkov Telescope Array (CTA) and the Low Frequency Array (LOFAR), applicable also in environmental sciences. Poland has just joined the European Space Agency (ESA). The astronomical community hopes that Poland will also join the European Southern Observatory in a near future.

2.3. FOUNDATION FOR POLISH SCIENCE

A very special role in management and funding of research in Poland is played by the non-governmental organization Foundation for Polish Science (FPS), formed in 1991. Its yearly budget consists of only about 1%

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of the state budget, but its influence on the quality of Polish research is much higher. Following its principle "Supporting only the best so that they can become even better", the Foundation runs several programs focussed exclusively on outstanding individuals. The subsidies are awarded on the basis of their past achievements, assessed within the peer review process including foreign referees and according to the best international standards. The competition is severe but winning it is highly valued among the scientists. The prestigious FPS Prize is awarded every year to four scientists from four different research fields. Three astronomers have so far received the prize in exact sciences: Alex Wolszczan in 1992 for the discovery of the first extrasolar planetary system, Bohdan Paczyński in 1996 for inventing and implementing a new method of detecting and investigating low-mass objects (cool stars, substellar objects and extrasolar planets) based on the microlensing of starlight and Andrzej Udalski in 2002 for the revision of the distance scale of the Universe and the detection of many candidates for extrasolar planets with the use of the microlensing technique. The approach of FPS to the funding of research often serves as a good example to other institutions managing science, including the Ministry.

2.4. COPERNICUS FOUNDATION FOR POLISH ASTRONOMY

It was founded in 1990 by a group of Polish astronomers. Its main purpose is to support all scientific initiatives in Polish astronomy and to initiate actions serving the consolidation of astronomical community in Poland. The Foundation fulfills its goals through supporting financially the creation of instrumental basis of astronomical institutions, awarding stipends for young researchers, helping astronomers in their personal problems, and supporting popularization of astronomy. The Copernicus Foundation is also the publisher of the international quarterly journal *Acta Astronomica*.

3. Astronomical Institutions

There are currently about 250 professional astronomers in Poland, most of them working in two PAS institutes and six separate astronomical institutes within HEIs. The rest is dispersed in smaller units usually within institutes of physics. As to the productivity of Polish astronomers, the total number of scientific publications per year is at the level of other countries with comparable numbers of scientists, but their quality is relatively higher: according to the Thomson Reuters Institute for Scientific Information, the citation rate of the papers with the Polish authors/coauthors is about 1.2 times the world average[1].

[1] http://archive.sciencewatch.com/dr/sci/11/jan23-11_1/

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3.1. NICOLAUS COPERNICUS ASTRONOMICA CENTER OF PAS (NCAC)

NCAC[2] is the largest astronomical institute in Poland, with its headquarters in Warsaw and a subsidiary in Toruń. Altogether 36 scientists work at NCAC, of which six in Toruń. In addition, there are between 15 and 20 graduate students completing their PhDs. The research fields include high-energy astrophysics, cosmology and gravitation, nuclear astrophysics and physics of condensed matter, variable stars, star clusters, star pulsations, physical processes close to black holes, circumstellar disks, dynamics of stellar systems and planet search. The international cooperation is concentrated around large-infrastructure facilities such as CTA and HESS (High-Energy Stereoscopic System), both measuring high-energy γ rays, or the 10m South African Large Telescope (SALT). NCAC astronomers are members of teams carrying out some of the cosmic experiments, like Integral, Herschel or Brite-PL (the Canadian-Austrian-Polish project for observations of stellar pulsations with the use of six photometric nanosatellites). A permanent cooperation with French astronomers takes place within the frame of a special Polish-French program, funded by both sides. Occasional collaboration takes place with astronomers from several leading astronomical institutions, like Princeton, Harvard, Oxford, Cambridge and many others. Worth mentioning is the new program Solaris, aimed at the accurate spectroscopic observations of binaries with four small-size, automated telescopes distributed around the world.

3.2. ASTRONOMICAL OBSERVATORY OF THE JAGIELLONIAN UNIVERSITY

Cracow Observatory[3], the institution with the most notable astronomical tradition, is presently part of the Faculty of Physics, Astronomy and Applied Informatics. There are 24 academics employed at the Observatory. A number of small radio and optical telescopes are located at Fort Skała Observatory in the outskirts of Cracow. The main scientific programs include high-energy astrophysics, investigation of active galactic nuclei, diffuse matter, binary stars, galactic magnetic fields and radio monitoring of the Sun. The Observatory is involved in exploiting large facilities such as HESS, CTA, LOFAR and SALT.

There is another small, yet worth mentioning, group of astronomers in Cracow. Nine academics are employed in the Astronomy Chair within the Institute of Physics at the Pedagogical University[4]. They have a small observing station with a 60cm optical telescope located at the top of Mount

[2] http://www.camk.edu.pl/
[3] http://www.oa.uj.edu.pl/
[4] http://www.as.up.krakow.pl/

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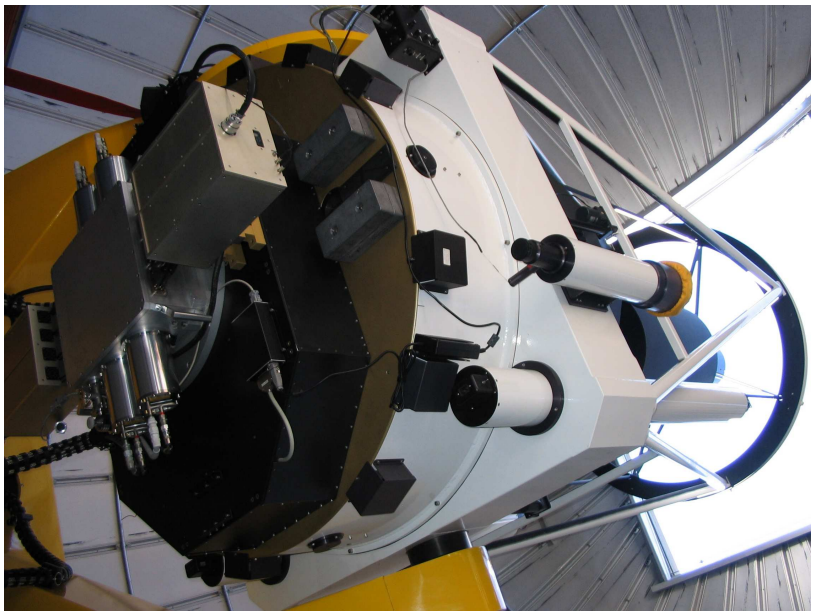


Figure 3. Warsaw 1.3m telescope in Las Campanas with its 32 chip CCD camera of the OGLE project.

Suhora in the Western Carpathian Mountains, 1000m above sea level, which is a relatively good astronomical site for Poland. The main research activities concentrate on observing variable stars, mostly pulsating and eclipsing binaries. The telescope is a part of the Whole Earth Telescope, used for obtaining long, uninterrupted observational runs of selected stars.

3.3. WARSAW UNIVERSITY OBSERVATORY

Warsaw Observatory[5] is organizationally part of the Faculty of Physics, but in practice has a great deal of autonomy. Its present academic staff comprises of 18 astronomers. It has the right of awarding PhD degrees in astronomy, and the degree of *doctor habilitatus*. The observatory conducts astronomical studies at undergraduate and graduate levels for about 70 students.

The equipment of the observatory consists of a 60cm reflector located at an observing station near Warsaw, used mainly for educational purposes, and a 1.3m reflector located in the Southern Hemisphere, at Las Campanas Observatory of the Carnegie Institution of Washington. The latter telescope is dedicated to the long-term project of massive stellar photometry OGLE

[5] `http://astrouw.edu.pl/`

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(Optical Gravitational Lensing Experiment), since 1992 regularly bringing top quality scientific discoveries and providing a rich observational basis for research in many fields. The other long-term sky survey, ASAS (All Sky Automated Survey), monitoring stars brighter than 14 mag, is using an array of small CCD cameras located at two stations: Las Campanas, Chile, and Haleakala, Hawaii.

Warsaw astronomers are involved in international collaborations such as ARAUKARIA, HESS, CTA, LIGO/VIRGO as well as in the satellite missions PLANCK and GAIA. Theoretical activities concentrate on broad fields of modeling stellar pulsations and evolution of stars and stellar systems.

3.4. ASTRONOMICAL OBSERVATORY OF THE ADAM MICKIEWICZ UNIVERSITY

This observatory[6] is part of the Faculty of Physics at Adam Mickiewicz University in Poznań and employs 17 academics. A few small instruments are located at Borowiec observing station, near Poznań. The main scientific interests deal with traditional areas of research at the Observatory, *i.e.* classical astronomy. In particular, specific programs are concentrated on fundamental astrometry, dynamics of small bodies in the Solar System and dynamics of artificial satellites. Recently, the scientific scope has been broadened to stellar astrophysics, with the investigation of binary stars as a main subject.

3.5. CENTRE FOR ASTRONOMY OF THE NICOLAUS COPERNICUS UNIVERSITY

The Centre for Astronomy[7] is a part of the Faculty of Physics, Astronomy and Applied Informatics at the Nicolaus Copernicus University in Toruń. The university was formed after the WWII by academics from the former Stefan Batory University. There are 17 academics working presently in the Centre (of which six are radioastronomers) and 16 members of engineering staff.

The Centre is located in Piwnice, a village 15km north of Toruń. The site contains a 32m radio telescope and a few optical instruments, among which a 90cm Schmidt-Cassegrain telescope and a 60cm photometric telescope. The optical telescopes are used mainly for student training and modest research projects.

The main research topics include: search for extrasolar planets, dynamics of planetary systems, physics and chemistry of interstellar matter, variable

[6] http://www.astro.amu.edu.pl/
[7] http://www.astri.uni.torun.pl/

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Figure 4. Toruń 32m radiotelescope.

stars, late stellar evolutionary stages, cosmic magnetism, active galactic nuclei, radiospectroscopy, cosmology, high-energy astrophysics and computational astrophysics.

The Centre for Astronomy is involved in international collaborations such as the VLBI network, HESS, SALT, and in collaborations with a number of astronomical institutions, including Jodrell Bank Centre for Astrophysics, Manchester University (radioastronomy), Penn State University (planet search) and the University Observatory in Munich (cosmic magnetism).

3.6. ASTRONOMICAL INSTITUTE OF THE WROCŁAW UNIVERSITY

The institute[8], part of the Faculty of Physics and Astronomy, is hosting 18 academics and about 10 graduate students. Research is being done on

[8] http://www.astro.uni.wroc.pl/

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two main subjects: investigation of the solar activity and of variable stars, mainly pulsating, using the asteroseismology technique.

The main local facilities, a 53cm coronograph and a 60cm optical telescope, are located at Białków observing station near Wrocław. The institute is involved in analyzing data obtained from cosmic experiments such as Yohkoh, DOHO, TRACE, RHESSI, CoRoT and Kepler. The staff members collaborate with astronomers from various foreign institutions in Austria, Belgium, Bulgaria, the Czech Republic, France, Slovakia and the United Kingdom.

3.7. INSTITUTE OF ASTRONOMY OF THE ZIELONA GÓRA UNIVERSITY

This is the youngest astronomical institute[9] in Poland, founded in 2000. Professional astronomical activity had however started at Zielona Góra Pedagogical University in 1988. The institute belongs to the Faculty of Physics and Astronomy and employs 12 academics. Their research mostly deals with investigations of pulsars, neutron stars (including their magnetospheres), black holes, high-energy astrophysics, celestial mechanics and planet search. The Institute cooperates with a number of foreign institutions in Germany, UK, USA, France, Holland, Japan, India Australia and China. The Institute is involved in POLFAR (Polish LOFAR) and POLGRAV international projects.

3.8. SPACE RESEARCH CENTER OF PAS (SRC)

SRC[10] has its headquarters in Warsaw and two divisions in Poznań and Wrocław. There are 44 scientists employed in SRC, but only a fraction of them do research in astronomy, more precisely in solar physics, planetary science, comets, interplanetary medium and cosmic weather. All Polish instruments flown in cosmic experiments have been built at SRC. The first of two nanosatellites for the program Brite-PL (see above) has also been built there. Astronomers from SRC take (or have taken) part in important international cosmic programs such as Cassini, Integral, Herschel, Rosetta, Brite-PL, a number of solar experiments (including Solar Orbiter) and others. The possibilities for space research will increase substantially when Poland joins ESA, hopefully very soon.

[9] http://www.astro.ia.uz.zgora.pl/
[10] http://www.cbk.waw.pl/

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4. Professional and Amateur Organizations

4.1. COMMITTEE FOR ASTRONOMY OF THE POLISH ACADEMY OF SCIENCES

PAS' Scientific Committees were formed at the same time as the Academy which replaced in 1952 the traditional learned society, The Polish Academy of Arts and Sciences existing, under different names, since 1815. The main duties of the Committee for Astronomy[11] are to represent the professional astronomical community in outside relations, to assess new research initiatives, particularly those involving substantial funding, to report periodically to the PAS authorities on astronomical activities and to express its opinion about candidates to PAS membership. The Committee also acts as the National Committee for the International Astronomical Union. It is a body of about 30 members, elected every four years from among astronomers holding at least the habilitation degree, supplemented by the PAS members who are the Committee members *ex officio*.

4.2. POLISH ASTRONOMICAL SOCIETY

The Polish Astronomical Society[12] was founded in 1923 on the 450^{th} anniversary of the Copernicus birth. It is a society of professional astronomers, although many graduates in astronomy not working actively in scientific institutions are also members. Currently the society gathers together about 250 members.

The society aims mainly at promoting astronomy as well as the cooperation with educational institutions on astronomy programs in high schools and the popularization of science. Every two years, the Society holds a meeting in one of the astronomical institutions of the country. The program consists of a scientific session with invited and contributed papers (plus a poster session) and a general assembly dealing with administrative matters and the election of a new executive committee. Between 1953 and 1998, an advanced popular journal *Postępy Astronomii* (Progress in Astronomy) was published by the society. The society awards three prizes: the Paczyński Medal for the best research achievements, the Young Astronomer Prize to the best research achievements by a young astronomer and the Zonn Prize for outstanding popularization of astronomy.

[11] http://www.ka.pan.pl/
[12] http://www.pta.edu.pl/

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4.3. POLISH AMATEUR ASTRONOMICAL SOCIETY

The Society[13] was founded in 1919 as an organization of amateurs and astronomy enthusiasts who wanted to promote the knowledge on the Universe and to actively participate in simple observational programs. Presently several hundred people, mostly high-school students, are members of the Society. It has 16 subsidiaries covering the whole country. They currently carry out observational programs including observations of comets, meteorites, planets, transits, Sun and variable stars. Some of the groups use sophisticated instruments and produce valuable results. Between 1922 and 1998, a popular journal *Urania* was published by the society. Since 1998, the journal is published together with the Polish Astronomical Society under the title *Urania – Postępy Astronomii*.

5. Concluding Remarks

For the last few centuries the Polish astronomy shared ups and downs of the whole country. The Polish soil was a battlefield in innumerable wars sweeping the country at almost every generation. Whenever the people recovered from the disaster and tried to organize a new life, the next war destroyed everything again. This has changed after World War II. The post-war period is perhaps the longest peaceful time in the recent history of Poland. Although its major part was spent under the communist regime, the scientific community had been gradually regenerated. Astronomy was more fortunate than *e.g.* social sciences because it was not considered as potentially dangerous for the ideology in power. At small concessions (like appreciating the leadership of the Soviet science) astronomers were permitted to contact Western colleagues, to attend international conferences (although without any financial support from the State) and to spend extended periods of time at American and West European observatories. The professors who organized the Polish astronomical institutes after the WWII were aware of the necessity for close collaboration with the world community. Thanks to them, almost all present professors went as young postdocs to world leading scientific institutions. That quickly benefited to Polish astronomy, allowing to approach a world level of research. It should also be stressed that several Western (most notably American) scientific organizations and institutions helped us materially in the early post-war years by providing scientific literature and some instruments to the Polish observatories. This enabled teaching new generations of scientists and doing valuable research.

The prospects for the further development of astronomy in Poland are promising. At present, one does not see any threat to a prosperous future

[13] `http://www.ptma.pl/`

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of the country. If only state authorities understand that further progress is conditioned on generous financing of the best research, the Polish astronomers can look optimistically into the future.

Acknowledgements

The authors are grateful to anonymous referees for their suggestions and linguistic improvements brought to the paper.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 195-216
Ed. A. Heck, © 2013 Venngeist.

ASTRONOMY IN MODERN TURKEY

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Abstract. Present-day astronomy and its development in the recent history of Turkey are described. Current astronomy education in modern-day Turkish Republic from primary to high schools, including modern-day university education is discussed. Astronomical and space research together with the existing observatories and present-day Turkish astronomy in the global state is presented.

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1. Introduction

Early contacts with the Copernican heliocentric system and modern astronomy in the modern Turkey were made through translations of astronomical tables, *e.g.* Noël Duret (d. 1650) translated by Tezkireci Köse İbrahim in 1660-64, and through many translated maps and atlases, *e.g.* Atlas Major by Wilhelm Blaeu (d. 1638) (Unat 2008). However, full acceptance of the new astronomy was not achieved until the middle of 19^{th} century. The two military schools, the Marine Engineering School and the Army Engineering School were founded in 1773 and 1795 respectively, and astronomy courses began to be taught in these schools[1]. Among the three systems of the world (geocentric, heliocentric and Tycho Brahe's hybrid system), the heliocentric system was favoured.

A fundamental modernising reform in the Ottoman education system was implemented in 1839. In the aftermath of this reform, astronomy courses were introduced as a separate subject to be taught in schools, both at the secondary and university level. This arrangement continued until 1937, thereafter, the study of astronomy was integrated into the mathematics curriculum. Nevertheless it was redesigned as a separate elective course and began to be taught as an independent subject in high schools in 1974 (Tunca 1974). Until then instruction was given in a purely descriptive manner since it was regarded as a suitable form for developing the mental discipline of high-school students. Note that this era corresponds to the aftermath of the launch of Sputnik in 1957 and the Moon-landing of American astronauts in 1969. The significance of astronomy also came to be appreciated by Turkish governments, as did most of the countries of the world. In addition the relationship between different disciplines emerged as an important subject amongst science educators. This newly-found appreciation was reflected in the earlier words of E. Miller (1895) on the role of astronomy giving a mental discipline to a high-school student: "A course in Astronomy ... would certainly do as much for the average high-school boy or girl in strengthening the intellectual faculties, in broadening the character, in elevating and stimulating thought, desire, and purpose, and in creating a strong and pure imagination, as in any other subject, whether scientific or literary, embraced within any course for high schools."

Recently, a research was conducted by the Turkish Scientific and Technical Research Council among youngsters (aged from 15 to 24) for measuring scientific literacy. It showed that the most attractive subjects for Turkish youngsters were the "internet" and "astronomy". Such demands and the known developments in space sciences obliged education authorities to take

[1] `http:// www.kktc.itu.edu.tr/`

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necessary measures to fill the gap especially in teaching material, *i.e.* text books and necessary instrumentation in the subject of astronomy.

In 1992 a change was enforced in the curriculum and the name of the program was called "Astronomy and Space Science Course" for which an appropriate textbook was ordered from university scholars. Indeed a textbook was written by five scholars in 1996 to be used by secondary-school teachers in high schools.

In 2010 the Ministry of Education decided to lay aside the previous "Astronomy and Space Science Course" programme. In the context of the restructuring of secondary schools a new programme was developed by a committee whose members were from the Ministry of Education, an astronomy professor from a university and secondary-school teachers (in mathematics, physics, educators specialized in programme development and measurement and evaluation). The group of eleven specialists have prepared a new programme which was accepted by the Ministry of Education. It has been in force since the beginning of the 2010-2011 calendar years.

The program was designed to cover:

i. Description of astronomy and its development.
ii. Getting familiar with the universe
iii. Coordinate systems and apparent motion
iv. Apparent motion of the Moon and the Sun
v. Time and calendar.
vi. Space sciences and space activities

It should be remarked that astronomy teaching, as an elective course in schools, has not been very effective hitherto. First the elective course system was not a familiar tradition, neither to students nor to teachers so choosing a course as an elective was not something that was practised before. Another reason is that the subject of astronomy has not been included in the "University Entrance" exam which determines the students' motivation, and for that reason students generally do not choose to study astronomy during their high-school education. An even more serious reason is that astronomy graduates are not employed by the Ministry of Education to teach astronomy in secondary schools.

Nevertheless some astronomy subjects have also been included in the physics programme of high schools, within the context of the latest curriculum developed for physics in 2007. Details of the subjects are: stellar structure, white dwarfs, supernovae, stellar luminosity, Doppler effect and expansion of the universe.

Astronomers have been trying hard to have astronomy courses properly included in the high-school curriculum for some time. It looks as though a good deal has been achieved but is not completely satisfactory yet. Another

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thing is that astronomers have been pushing so that Ministry of Education must hire astronomy graduates as teachers in high schools, and this subject is still hot among astronomers and the Ministry of Education authorities.

Turkish astronomers took advantage of the International Year of Astronomy in 2009 and thus several meetings were held to discuss the subject of "Expanding Astronomy Education in Primary and High Schools in Turkey[2]". One of these meetings was held on 24-25 October 2009, at Kuşadası, Aydın. Participants of this meeting were university professors and high-school teachers.

There is a growing interest and demand in space science activities and related educational devices in Turkey. To meet such demands, several national companies or entrepreneurs started to produce simple astronomical devices or kits for both schools and public[3]. Mostly, instrumentation and devices are produced to allow school children and ordinary people to visualize and comprehend the whole of space and the solar system.

2. Astronomy and Astrophysics Education in Universities

Astronomical and astrophysical studies are mainly organized in universities. Both educational and research activities are done simultaneously. Astronomy and space science departments require students to take basic astronomy and astrophysics and some fundamental physics and math courses. In addition students are all learning how to use computers and run basic computational programs.

In some universities where there is no formal astronomy department but there may be astrophysics minor program in which fundamental astronomy and astrophysics courses are offered.

The following are the five Turkish state universities which have independent Astronomy and Space Science Departments:

i. İstanbul University (1936)
ii. Ankara University (1954)
iii. Ege University (İzmir, 1962)
iv. Erciyes University (Kayseri, 2001)
v. İnönü University (Malatya, 2012)

Each department enrols about 60 undergraduate students yearly. Both MSc and PhD programmes were offered.

In addition there are new departments, which are named "Space Sciences and Technologies" founded in Çanakkale, 18 Mart University (COMU) and

[2]http://www.istanbul.edu.tr/fen/astronomy/sempozyum2009/?page_id=185
[3]http://www.renkoltd.com.tr/

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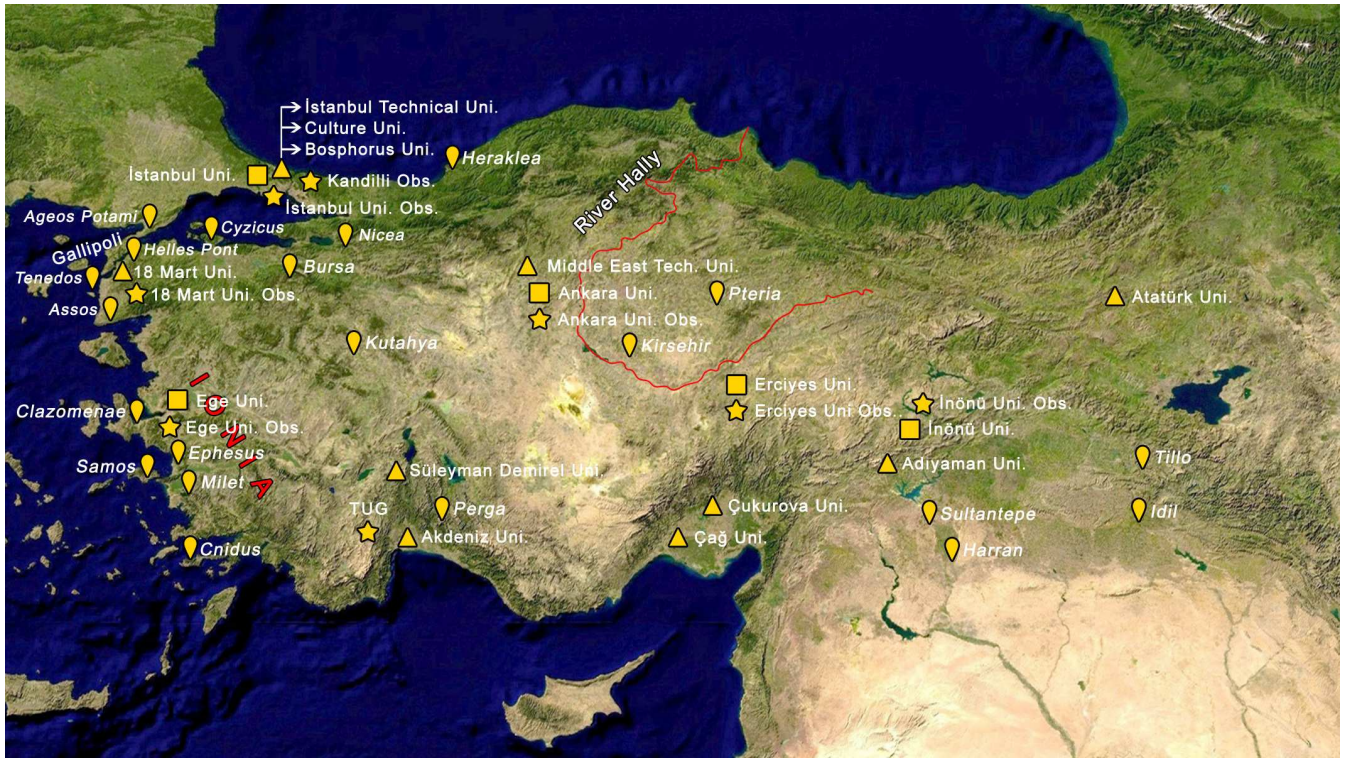


Figure 1. Map of Turkey with independent astronomy and space science departments (squares), physics with astronomy subfield and newly established departments of space sciences and technologies (triangles), observatories (stars) and ancient historical cities (balloons) connected with history of astronomy.

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Antalya, Akdeniz University. Both have not begun formal undergraduate education yet. Nevertheless, COMU began accepting MSc students.

There are a dozen additional universities with physics departments including astronomy and/or astrophysics as a minor activity.

Fig. 1 shows the location of modern Turkish universities and astronomical observatories. The total number of modern day Turkish astronomers with PhD degrees including the retired ones is about 153.

Astronomy Departments, by taking the advantage of the "International Year of Astronomy" in 2009 decided to review their undergraduate curricula for the sake of uniformity in parallel departments. The aim was to make their students benefit from a national exchange program called Farabi Exchange program which has been in effect since 2008. For that matter, the chairpersons of the Astronomy and Space Science Departments and representatives of astronomy groups within physics departments in other universities met several times and they agreed upon a new program. The Farabi Exchange program is similar to the European counterpart called "Erasmus" exchange program. Erasmus exchange program was founded within the Bologna process. It may be appropriate to give some information about the Bologna process and how Turkey is integrated to the system. The aim of the process is to cohere a uniform and better education within the European community that began with the Bologna Declaration signed by 29 countries on 9 June 1999. Turkey became involved in this organization in the year of 2001 and thereafter Turkish universities began to be integrated into the Bologna process. To increase the effectiveness of especially student exchange, universities did their homework in adapting themselves to the European Credit Transfer System (ECTS). After a uniform credit system is completed, it is expected a more extensive exchange of undergraduate and graduate students will take place. The name of the program under which university students of different nationalities go to another country and spent some time there during their education is called "Erasmus" after the famous philosopher from Netherlands. The idea of such an exchange is to recognize and learn about other cultures and societies while they do their undergraduate studies.

As for the astronomical observations, they are done in university observatories and in the National Observatory, TUG (TÜBİTAK National Observatory) in Antalya. Both educational and research activities are going on effectively with the available telescopes in university observatories. In addition, they are also open to the public on certain occasions during the year for popular astronomical activities.

Undergraduate education covers four years in Turkey. Students will obtain the title *astronomer* when they finish their courses after four years. Graduate programs are accepting applications twice a year. An MSc stu-

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dent prepares a thesis after his/her course work corresponding 24 credit hours in total. Normally it takes one year for course work and one year for the thesis. According to new regulations, there is no upper limit. Similar rules apply to the PhD curriculum with two years of courses and two years of thesis work. PhD holders are expected to publish their thesis and a few articles in journals listed SCI as independent from the thesis in order to apply for Assistant Professor positions. Such positions are not permanent ones. Renewals are subject to academic performance including research, teaching and public activities. To be promoted to an associate professorship requires an evaluation of scientific and academic activities by a jury, followed by an oral examination. An Associate Professor may apply for professorship after five years. A candidate must get a positive evaluation report from the jury selected by the university council.

3. Research Opportunities for Scientific Studies

Astronomical researches in Turkey have a chance for a support by Scientific Research Projects (SRP) departments of the universities themselves, by the Scientific and Research Council of Turkey (TÜBİTAK), by the Ministry of Development (MD) and from international sources if available at the time. Incipient graduate students may receive limited support for their thesis studies by applying to their universities SRPs and having their supervisors as the project coordinator. University staff can also apply to SRP for various types of projects and can obtain additional levels of funding for their researches.

The projects with larger budgets are supported by the Ministry of Development. These projects are generally for establishing infrastructure and founding new research centres. Some of the research projects are primarily administered by the university observatories within their capacities. When university telescopes are insufficient in size or unsuitable for the proposed project then, TÜBİTAK National Observatory (TUG) and national telescopes can be used. Observational project applications to TUG are evaluated and approved by the TUG's academic council. Observers whose projects are accepted by TUG receive travel and accommodation support from TUG.

4. The Observatories in Turkey

4.1. THE ROYAL (KANDILLI) OBSERVATORY

A 1m-class telescope was bought for educational purposes for the Army (Harbiye) School, but it was fully destroyed in a big fire during the Kırım (Crimean) war (1853-1856). The first western style observatory was estab-

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lished as a meteorological station in 1868, known as "Rasathane-i Amire" (The Imperial Observatory) at Pera in İstanbul. It could be considered the national observatory of the Ottoman Empire. According to a report by a French engineer Aristide Coumbary it received a warm and considerable support from the state and he was appointed as the first director of the Observatory. It is unfortunate that this observatory too was destroyed during an uprising in April 1909. In fact with the assistance of Salih Zeki who was one of the most important mathematicians of the late Ottoman period (Topdemir 2007), Fatin Gökmen was appointed as the director of this observatory (Kaçar 2007). Besides Fatin Gökmen was also given the responsibility of establishing a new observatory. He started working on the project in 1910 and this later became the Kandilli Observatory as we know it today. At the beginning it served only as a meteorological station and it published its first results in meteorology bulletins in 1911/1912. Fatin Gökmen's work later became more astronomically oriented and continued to be so until today.

Other departments, such as solar physics, radio astronomy, time measurement, seismology and geo-magnetism were developed in the years after 1925. After the Turkish Republic was founded in 1923, Fatin Gökmen proposed to establish an astronomy and geophysical observatory. The proposal was accepted and a full-fledged astronomical observatory with equatorial refractor of 20cm diameter and 305cm focal length began to operate. The name "Rasathane-i Amire" (Royal Observatory) was abandoned, and "Kandilli Observatory" as a new name was accepted after 1928. Thus the Royal (Kandilli) Observatory can be considered as having been the National Observatory of the Ottoman Empire until 1923. It was astronomically specialized more on solar observations, but has served basically for seismology since 1982 in which year the Observatory became a part of Bosphorus University. Its name has become the "Kandilli Observatory and Earthquake Research Institute" and it is administered by the Bosphorus University. The main building and the 20cm equatorial refractor are displayed in Fig. 2.

4.2. ISTANBUL UNIVERSITY OBSERVATORY

Istanbul University Observatory[4] which was established in 1936 is the first modern observatory of the Turkish Republic. It was established on the Beyazit Campus of Istanbul University by Erwin F. Freundlich as the laboratory of the Astronomy Institute which was formed just after the 1933 university reform in the young Turkish Republic. The 30cm Carl-Zeiss astrograph installed in 1936 in the observatory (Fig. 3) is still used for solar observations. Two small reflectors (30cm and 20cm) are still used for pop-

[4] http://www.istanbul.edu.tr/fen/astronomy/

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Figure 2. Kandilli Observatory which was originally a Royal Ottoman Observatory (top). Equatorial refractor of 20cm diameter at Kandilli Observatory (bottom). (Courtesy Kandilli Observatory)

ular astronomical activities. The observatory site is now under heavy light pollution. To get away from the light pollution the observatory started operating a joint 60cm robotic telescope installed at the Çanakkale (Dardanelles) 18 Mart University Observatory in 2011.

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Figure 3. The dome of Istanbul University Observatory (top) and the 30cm Carl Zeiss astrograph (bottom) installed in 1936 (right). (Courtesy Istanbul University Observatory)

4.3. ANKARA UNIVERSITY OBSERVATORY

The idea of building the Ankara University Observatory[5] was initiated by Edberg A. Kreiken in 1958 at Ahlatlibel/Ankara and The Observatory was opened formally in 1963 with an international NATO Summer school at the Observatory. A 15cm Zeiss Coude refractor, a 15cm photographic refractor and a small radio antenna (Fig. 4) were installed in the Observatory in 1964. A 30cm Maksutov telescope started photometric research on different classes of variable stars in 1974. Later on three more telescopes with

[5] `http://rasathane.ankara.edu.tr/`

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D=12.7cm, 35.6cm and 40cm were added to the assets of the observatory. Because of urbanization the Observatory site is polluted with light and thus astronomers in Ankara University submitted a project to the Ministry of Development for a modern observatory with a two meter size telescope to be established at a site 75km from Ankara.

4.4. EGE UNIVERSITY OBSERVATORY

The construction of the Ege University Observatory[6] (EUO) was started at the end of 1963 and completed in 1965, just 10 years after the foundation of Ege University in 1955 in İzmir, the third largest city in Turkey. The Science Faculty was established in 1962. In early 1963 Abdullah Kizilirmak from Ankara University was appointed to the faculty to establish the Department of Astronomy and the Observatory.

The first instruments of the observatory were a 15cm Unitron telescope, a Foucault pendulum and an Iris photometer. The telescopes and instruments used in the Observatory are the following ones (construction years in parenthesis): 13cm spectrograph (1967), 48cm Cassegrain telescope (1968 – Fig. 5), 30cm Meade telescope (1999), 35cm Meade telescope (2004), 40cm Meade telescope (2004) respectively.

As of today there are 21 researchers with PhD and five research assistants in the department and the observatory. So far about 40 astronomers have completed their PhD thesis using the facilities of the observatory. The Department has 350 undergraduate and 27 graduate students who are continuing their education. The number of papers published in the most-cited journals and the citations given to these papers reached 18 and 64 per year, respectively.

Furthermore the observatory performs an intensive educational program both for schools and public, including short courses and one-week multifaceted international public outreach programs. The observatory is open to the public and schools on Friday evenings. EUO conducts special programs for hundreds of elementary and secondary-school teachers and students. Such a popular night-time public program includes a presentation, observing through a 30cm telescope with assistance of a telescope operator, and a sack dinner. Visitors can enjoy fine views of the Moon, the planets and some of the best-loved features of the sky. One-week educational programs are designed to inspire and motivate students and are suitable for ages from 8 to 18 years. Programs are also available for groups who have special needs and access requirements. All educational programs are conducted by well-trained astronomers. Participants are divided into groups of 15 students and are accompanied by an astronomer at all times. Participants are

[6] http://astronomy.ege.edu.tr/EUGUAM/TR/

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Figure 4. Ankara University Observatory. The 40cm Kreiken telescope dome and the radio antenna built in 1964 (top) with the 15cm Coudé telescope (bottom). (Courtesy Ankara University Observatory)

encouraged to ask questions throughout the courses. The courses includes units on exploring the heavens, astronomical concepts, star gazing skills and using a small telescope, variable stars, stellar evolution, universe and cosmology.

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Figure 5. Ege University Observatory (top) and the 48cm Cassegrain telescope (bottom). (Courtesy of Ege University Observatory)

Since the 1990s, the rapid urbanization of İzmir has resulted in a significant increase in the amount of sky glow. If such light pollution continues to increase, it will seriously reduce the effectiveness of the Ege University Observatory for a good science. The observatory has already applied to the Ministry of Development for a modern observatory with a 2m-class telescope at a light pollution free area, around İzmir.

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4.5. ÇANAKKALE 18 MART UNIVERSITY OBSERVATORY (ÇOMU)

ÇOMU Observatory[7] started operating with a 40cm reflector in 2002. To meet the needs of researchers to study on variable stars more intensely three more reflectors with D=20, 30 and 30cm were purchased within five years of its foundation. They are mostly used for post-graduate studies and research projects.

There are about 30 researchers, half of whom hold PhD degrees, working in the Observatory. To do spectroscopic observations, a new telescope with a relatively large aperture (D=122cm) was purchased and installed in the Observatory in 2009 (Fig. 6). In accordance with the joint project between ÇOMU and Istanbul University a 60cm robotic telescope owned by Istanbul University is installed at ÇOMU's site in 2011.

As in almost all other observatories ÇOMU Observatory also organizes popular astronomy activities. The observatory infrastructure with 30cm telescope, a Foucault pendulum and a detailed sundial are used for science and society activities.

4.6. TÜBİTAK NATIONAL OBSERVATORY (TUG)

Early ideas and intentions to have a national observatory goes as far back as 1968. Nüzhet Gökdogan, the first Turkish astronomer of Istanbul University, Abdullah Kızılırmak, the founder of Ege University Astronomy Department and the Observatory, and Dilhan Eryurt from the Middle East Technical University were among the pioneers of the idea of having a national observatory. They convinced the new generation of young astronomers about having such an observatory during the years from 1968 to 1978. The kick off meeting dedicated to the establishment of a national observatory was held in Ankara University on May 26, 1978. The same issue was discussed in more detail in a general meeting of Turkish astronomers in Istanbul (Silivri) on 11-16 September 1978. A real step forward came after the formation of the "Space Science Research Unit" (SSRU) within TBAG (Basic Science Research Group) at TÜBİTAK in 1979. Under the patronage and guidance of SSRU a site selection investigation started in 1983. Seven astronomers representing Ankara University, Istanbul University, Ege University, Boğaziçi (Bosphorus) University and Middle East Technical University formed a kind of council to guide the selection of candidate sites all over Turkey. Seventeen candidate locations were pre-examined. Among them with 1612m altitude Kurdu (Muğla), 2159m altitude Ödemiş (İzmir), 2206m altitude Nemrut (Adıyaman) and 2547m altitude Bakırlıtepe (Antalya) were chosen for simultaneous site testing observations. Almost all

[7] http://physics.comu.edu.tr/caam/

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Figure 6. Çanakkale 18 March University Observatory with the 122cm alt-azimuth telescope building (top) and the telescope itself (bottom). (Courtesy Çanakkale 18 March University Observatory)

Turkish astronomers participated and contributed to site testing observations in these locations. These observations continued for four years from 1982 to 1986. Finally a concluding report was prepared and published by Aslan *et al.* (1989). Bakırlıtepe (Antalya) was chosen as the best place for

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Figure 7. Panoramic view of TÜBİTAK National Observatory (TUG). From the top RTT150, T60, ROTSEIIId telescopes, Central Guest House, Security Building respectively and T100 telescope at lower left. (Photo: Raşid Tuğral)

the location of the National Observatory.

The foundation work started in 1991 and with the leadership of principal investigator Zeki Aslan who later became the first director of the observatory, the project was realized. The road and electricity had reached the top of the hill (Bakırlıtepe) where the observatory was to be built, in 1994. After bureaucratic procedures and regulations were completed in 1995, the work of construction began on the site and the main building and the first generation telescope domes were completed within two years (1996 and 1997). Finally, the TÜBİTAK National Observatory[8] was officially opened on 5 September 1997 by the President of the Turkish Republic Süleyman Demirel. Fig. 7 offers a panoramic view of the observatory.

The first observatory telescope was a 40cm Utrecht-made equatorial reflector that saw its first light in January 1997. This telescope was replaced in 2006 by a robotic 40cm aperture Meade LX200GPS and, later on, this telescope itself was replaced by an American-made OMI (Optical Mechanics Inc.) robotic telescope with 60cm aperture. Currently named T60, it is serving scheduled CCD observations and is dedicated to long-period variables since August 2010.

[8]http://www.tug.tubitak.gov.tr/

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The main telescope of the National Observatory is owned by Kazan State University, Kazan (Tataristan). In accordance with the triple protocol among TÜBİTAK, KSU (Kazan State University) and IKI (Russian Academy of Sciences) signed in 1995, the telescope operates on a time-sharing basis since its first light in September 2001. The name of the telescope RTT150 implies Russian-Turkish telescope with 150cm aperture. The telescope has three changeable foci capabilities. Two are used commonly by interchanging manually: one is a Coudé focus (f/48) that is used for high-resolution (R=40000) spectroscopy; and the other is a Cassegrain (f/7.7) focus that is used for low-resolution spectroscopy and imaging.

The Robotic Optical Transient Search Experiment (ROTSE) which is located at Bakırlıtepe is one of the four optical telescopes operating around the world for observing gamma-ray bursts. The four telescopes are scattered around the world such that any event that occurred in space could be observable by at least one of the telescopes. ROTSE IIId telescopes are 45cm aperture and fully robotic. It is at Bakırlıtepe in the site of TÜBİTAK National Observatory in accordance with a collaboration signed between Michigan University and TÜBİTAK since 2003.

The most recent telescope installed on Bakırlıtepe is the T100 telescope with 100cm aperture reflector made by Optical Mechanics Inc. (USA). The T100 is a Richey-Chrétien type telescope with a wide field of view. It is equipped with a 4k×4k CCD camera giving an image of 21.5×21.5 arcmin^2. The T100 telescope has been serving Turkish astronomers since October 2010. It is dedicated primarily to solar system objects, wide field studies and any other kind of imaging.

Apart from Turkish National Observatory (TUG) the university observatories, there are few attempts to have larger size telescopes: three of them by Ege, Ankara and Anadolu Universities. Two more projects, one by TUG, and the other by Atatürk University (at Eastern Anatolia) ask two 3-4m-class telescopes. Atatürk University considers an infrared telescope to be installed in the high plateau of Eastern Anatolia (Palandöken Mountains).

5. National and International Organizations

The Turkish National Astronomy Meetings hold in every two years. Most of the astronomers participate to these meetings with an oral or a poster presentation. Some foreign astronomers are also invited to give a talk on a selected topic which are chosen to be a current research subject or a relevant topic to Turkish astronomers. National or international papers to be presented are selected by a scientific committee. Besides these national and regular meetings, astronomers have small group meetings which do not have to be regular, on certain and specific topics, such as "Data Reduc-

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tion Techniques" in various observational branches of astronomy and astrophysics. Turkish astronomers collaborate also with the Turkish Physics Society whose general meetings always have a section that belongs to astronomy and astrophysics.

As for international activities, Turkey became a member of International Astronomical Union (IAU) in 1961. It is a member of this organization via Turk Astronomi Derneği[9] (TAD) (Turkish Astronomical Society). There are certain criteria to become an IAU member. Every two years, TAD presents a list to the General Assembly of the IAU of the Turkish astronomers who satisfy the criteria to become IAU individual members and, if accepted by the General Assembly, they are admitted as such. Currently there are 53 Turkish astronomers registered as IAU members.

Most of the astronomers on the list are currently active in astronomy, but some who passed away still appear on the list.

Turkish astronomers are generally very active in demanding observing times at international observatories through international projects. Apart from such direct involvements in international projects, they also benefit from data made available by international space organizations and satellites.

6. Turkish Astronomy in Global Scale

To have an idea where Turkish astronomy stands in the world a statistical study that covers a period of 30 years was undertaken. The *ISI Web of Science Knowledge* was searched with articles published in journals listed by the *Science Citation Index (SCI)* selected for this study. The result of the investigation is presented in Fig. 8. It should be noted that only articles originating from Turkey have been considered. It has been found out that there are about 832 articles published by the Turkish astronomers in the past 30 years (1980-2010).

In Fig. 8, the number of articles published in astronomy and astrophysics can be grouped in three periods:
– between 1980 and 1986, with an average of 7 articles/year,
– between 1987 and 2000, with an average of 18 articles/year and
– between 2001 and 2010, with an average of 53 articles/year.

The main research areas that covered by the published articles are stellar astrophysics, galactic structure, galaxies and cosmology, high energy astrophysics, binary stars, stellar evolution and solar physics.

[9] http://www.tad.org.tr/

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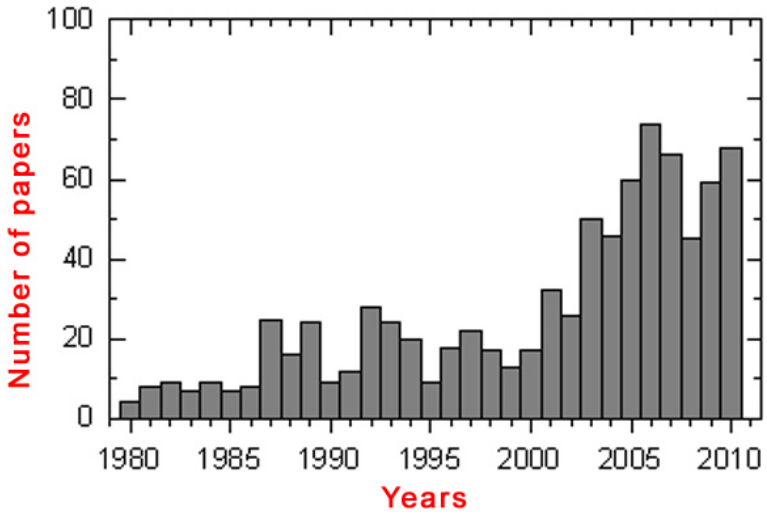


Figure 8. Number of astronomy and astrophysics papers with Turkish addresses within SCI, between 1980 and 2010.

7. Amateur Astronomy in Turkey

Amateur astronomy in Turkey began in 1980s with the initiatives of undergraduate students from the astronomy and space sciences and physics departments. These experienced amateur groups organize astronomical activities to share their knowledge and experiences with their friends and public. These activities were passed on to other amateurs with presentations, competitions, panels and unassisted-eye sky observations and thus were able to capture the attention of the public in general. Eventually popular astronomy topics became widespread with astronomical photographs and variable stars' observations conducted by amateurs.

With the fast development of computer technology in the early 1990s, high-resolution images taken from large telescopes and especially Hubble Space Telescope created great curiosity and enthusiasm among people. Those who had no amateur telescope nevertheless could have a chance to find popular software which taught them about the sky with the help of publicly available computer programs. Especially in the mid-1990s, the internet became widely reachable all over the country, and through electronic bulletins, e-mail lists, forums and portals, amateurs from distant regions had the chance to communicate with each other. This period of time overlaps with the foundation of observatories and planetariums by some private secondary schools which attracted the attention of both students and their parents. These initiatives led to astronomy awareness among stu-

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dents and people who then chose astronomy and space science subjects for their university education.

Amateur astronomers with the help of professionals started to make their own telescopes by simply grinding their own mirrors in years after 2000. Meanwhile a big change in the focal plane instruments occurred after CCD cameras became widespread. For example, amateur sky photographs taken with CCD cameras and professional SLR started to publish their results in the famous web sites and magazines like APOD, TUG and *Sky & Telescope*.

Another turning point of amateur astronomy in Turkey was the International Year of Astronomy (IYA) activities in 2009. Hundred hours of astronomy, *Astronomy and World Heritage*, *Understanding the Universe*, *Female Astronomers*, *Universal Almanac*, *Galileo Nights*, *Galileoskope*, *Earth at Night and Cassini the Scientist*, were carried out by the Turkish Astronomy Association (TAD) and reached thousands of people. All activities done in universities, schools, private and state bodies were advertised in a private web site of TAD[10]. This web site was followed by approximately 100 000 people in between February 2009 and January 2010. TAD made a contribution to popularizing the astronomy with a magazine in which one can find astronomy news, popular articles and announcements related to activities. This magazine which has approximately 1200 fans is published monthly and subscribers are more numerous by the day.

The biggest amateur astronomy meeting in our country is organized every year by the lead of TÜBİTAK National Observatory (TUG) since 1997. This activity is already recognized as the National Sky Observation Festival with participation of approximately 500 amateur astronomers. Presentations of popular astronomy topics are done during daytime while observations of constellations, planets, satellites, galactic objects and other galaxies are conducted until the morning's first light.

One week Summer schools which contain astronomy education and observations have been organized for people with cooperation of astronomers and club members of Ege University and Çanakkale 18 Mart University. Courses about astronomical subjects such as sky and objects, telescopes, the Sun and Solar system, Milky Way, other galaxies and the universe are given in such Summer schools. On the other hand, the staff of Istanbul University shared their theoretical and observational knowledge with primary-school students in the context of the Kid's University in 2010.

Another education facility and activity center about space technology is the "Space Camp Turkey" located in the Free Zone of İzmir. The Space Camp Turkey which is a space and science centre concentrates on such sub-

[10]http://www.astronomi2009.org/

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Table 2 – Amateur astronomy clubs, groups and forums in Turkey.

Clubs	Web Site
Erciyes University Astronomy Club	http://aster.erciyes.edu.tr/
İstanbul University Sci. Fac. Amateur Astronomers Club	http://astronomi.istanbul.edu.tr/aak/
İstanbul Technical University Astronomy Club	http://www.astronomi.itu.edu.tr/
19 Mayıs University Astronomy Club	http://astom.omu.edu.tr/
Groups	
AKAT – Ali Kuşçu Astronomy Group	http://www.akat.org/
ASART – Ankara University Astronomy Research Group	http://asart.science.ankara.edu.tr/
Bilkent University Astronomy Group	http://www.fen.bilkent.edu.tr/~astro/
Çanakkale 18 Mart Univ. Physics and Astronomy Group	http://physics.comu.edu.tr/ogrenciler/fizast
ODTÜ Amateur Astronomy Group	http://www.gokyuzu.org/
Portals	
Gökbilim Forumu (Astronomy Forum)	http://gokbilim.com/forum/
Gökyüzü Forumu (Sky Forum)	http://*Forum.gokyuzu.org*
Web Sites	
Amateur Rocket	http://www.oktanyumroket.com/
Astronomi Diyarı (Astronomy Land)	http://www.astronomidiyari.com/
Bulutsu (Nebula)	http://www.bulutsu.org/ggg/
Gökbilgi Blog (Sky-Info Blog)	http://gokbilgi.blogspot.com/
Gökbilim (Astronomy)	http://gokbilim.com/
Türkçe Gökbilim (Astronomy in Turkish)	http://gokbilimci.wikidot.com/
Uzay ve Astronomi (Space and Astronomy)	http://www.uzayveastronomi.com/
Planetariums	
Cacabey Planetarium *(Bursa)*	http://www.cacabey.com
Derinmavi Planetarium *(İstanbul)*	http://www.derinmavi.com.tr
FMV Erenköy Işık Lisesi Planetarium *(İstanbul)*	http://www.fmv.edu.tr
İzmir Türk Koleji Gezegenevi (İzmir)	http://www.gezegenevi.com
Ondokuz Mayıs Üniversitesi (Samsun)	http://planetaryum.omu.edu.tr/
Rahmi M. Koç Müzesi Discovery Sphere (İstanbul)	http://www.kesifkuresi.com
Tuzla Deniz Harp Okulu Uluğ Bey Planetarium *(İstanbul)*	http://www.dho.edu.tr
Space Camp Turkey Planetarium *(İzmir)*	http://www.spacecampturkey.com

jects to motivate the youth to have a career and getting interested in math, science and technology. In this camp both children and adults can have education about space, communication, team work and leadership by using simulations in a very dynamical ambiance. The Space Camp Turkey is the fourth largest in the world, and the first and the only camp in the Middle East, southeastern Europe and western/middle Asia. Active amateur astronomy clubs, groups and forums in Turkey are listed in Table 2.

8. Concluding Remarks

In this review the state of astronomy in Turkey has been summarized. From what has been said it is clear that the number of astronomers compared to the total population is rather low. However, Turkish astronomers showed a great improvement in performance measured by publication of their research studies in respected journals. Besides it is really motivating that Turkish astronomy is getting reasonable support from both Governmental and private sources. All this support is given to project-based applications.

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It is a common belief in Turkey that Turkish astronomy will make a good leap forward in coming years, both in education and in research.

Acknowledgements

The authors of this paper would especially like to acknowledge the State Planning Organization (now the Ministry of Development) and TÜBİTAK for their continuing support for space science projects in Turkey. The authors would like to thank to Julian Saurin for reading of the text, correcting it grammatically and linguistically. They are also grateful to Özgecan Önal, Nazlı Derya Dağtekin and Talar Yontan for their help during preparation of the manuscript, as well as to Tuncay Özışık for improving the quality of figures and for making Fig. 3. Special thanks are due to anonymous referees for suggestions on the paper structure and for improvements to the English.

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[11] http://www.ua.gov.tr/
[12] http://www.yok.gov.tr/
[13] http://www.biluzay.bilkent.edu.tr/
[14] http://www.tubitak.gov.tr/
[15] http://www.fedu.metu.edu.tr/ufbmek-5/b_kitabi/PDF/Astronomi/panel/t1-5d.pdf

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 217-230
Ed. A. Heck, © 2013 Venngeist.

THE SPECOLA VATICANA: ASTRONOMY AT THE VATICAN

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Abstract. The Vatican is an independent nation, with its own national astronomical observatory, the Specola Vaticana (Vatican Observatory). Astronomy has been supported at the Vatican since the 1582 reform of the calendar; the present-day Observatory has been in operation since 1891. The work of the observatory is divided between two sites, one in the papal summer gardens south of Rome, Italy, and the other affiliated with the Steward Observatory at the University of Arizona, in Tucson, Arizona, USA. Research undertaken by current staff members ranges from cosmology and the study of galactic evolution to meteoritics and meteors. Given the stable funding provided by the Vatican, the Observatory has specialized in long-term mapping and cataloguing projects that would be difficult to mount under a traditional three-year funding cycle. These have included participation in the Carte du Ciel photographic map of the sky; the atlases of spectra produced by its Spectrochemical Laboratory; surveys of star clusters and peculiar stars; and the cataloguing of meteorite physical properties.

1. Astronomy in the Holy See Before 1891

To the Christian church, the study of creation has long been supported as an act of worshipping the Creator. Astronomy was one of the seven subjects that made up the curriculum of the medieval universities, which were themselves founded by the Church. Understanding the motions of objects seen in the sky had philosophical and theological implications in the cosmology of those times; the physical universe was thought to parallel the metaphysical universe.

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However, the first specific hiring of astronomers by the Holy See itself had a much more practical purpose: to reform the calendar. Following the instructions of the Council of Trent, Pope Gregory XIII (1502-1585) assembled a group of scholars in 1580 to help determine how to correct the roughly one-day-per-century shortfall of the ancient Roman calendar, and how to determine the date of Easter in a way that would be practical for a Christendom that was now spreading from East Asia to the Americas. Along with the resulting Gregorian reform, promulgated in 1582, the Dominican mathematician Ignazio Danti (1536-1586) installed a meridian line in the top room of the newly-constructed Tower of the Winds (so named because it was decorated with depictions of the four winds on its walls, and contained an elaborate mechanical wind vane), which could be used to demonstrate the ten-day error in the unreformed calendar.

The Jesuit priest Christopher Clavius (1537-1612) was one of the mathematicians involved in the reform. At the Pope's request, he wrote a lengthy explanation of the reasons for the reform, published in 1602; but even after that work was completed he and other Jesuits at the Roman College continued to do astronomical research. They were among the first to confirm Galileo's telescopic observations, though they remained skeptical about the Copernican system.

Eventually, however, Galileo angered many of the Jesuits by claiming priority over the German Jesuit Christof Scheiner (1575-1650) on the discovery of sunspots, and belittling the (essentially accurate) observations of comets by the Roman Jesuit Orazio Grassi (1583-1654). Ten years later, Galileo was brought to his infamous trial; historians still argue over the reasons for that trial, which may have had as much to do with politics as with philosophical differences (the trial occurred at the height of the Thirty Years War), but it is clear that this enmity with the Jesuits cost him their friendship when it would have been most helpful.

Astronomy remained a rich field of study for the Jesuits at the Roman College even during and after the Galileo trial, however. In 1616, Nicholas Zucchi (1586-1670) built what was perhaps the first reflecting telescope; Gilles-Franois de Gottignies (1630-1689) observed the comets of 1664, 1665, and 1668; and Athanasius Kircher (1601-1680) made detailed telescopic drawings of Jupiter and Saturn. [In addition, see Heilbron (2001) for a description of the use of cathedrals as astronomical observatories during this time; and Graney (2012) on the work of the Jesuits Riccioli and Grimaldi during this era.]

In the following century, Roger Boscovich (1711-1787) convinced the Vatican to lift its formal opposition to the Copernican system; in addition, he studied transits, cometary orbits, and the optics of telescopes. In the latter years of the 18^{th} century, small Pontifical observatories were set up in

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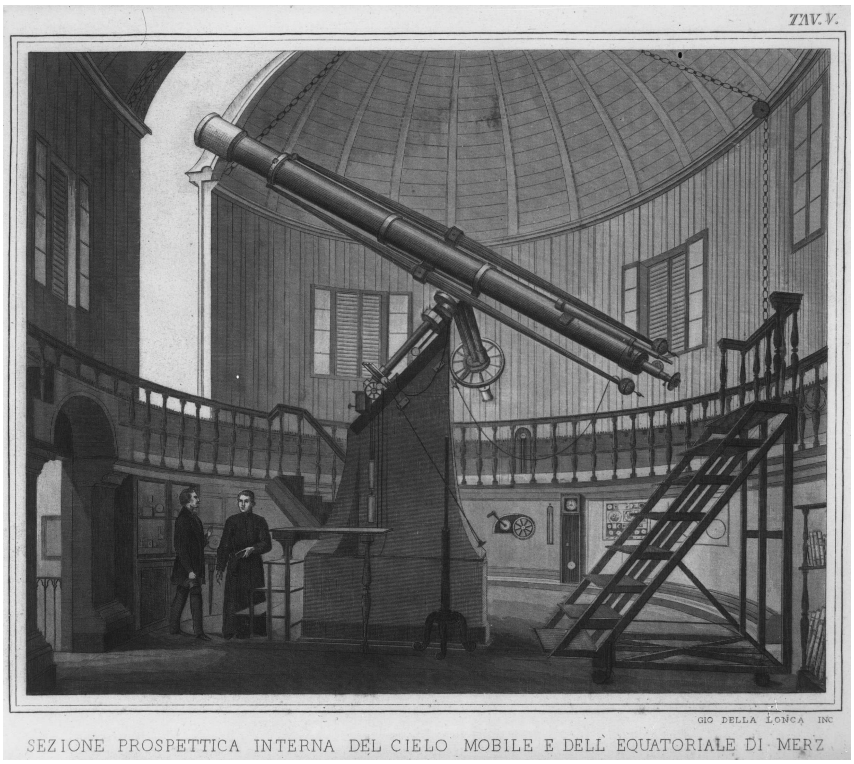


Figure 1. The image of Secchi's telescope on the roof of Saint Ignatius Church, prepared by Giovanni della Longa circa 1870. This image is reprinted in *L'Astronomia in Roma nel Pontificato di Pio IX, Memoria del P. A. Secchi*, Tipografia della Pace, Roma (1877).

the Tower of the Winds in the Vatican, and at the Jesuits' Roman College.

These two observatories continued to operate in parallel into the 19^{th} century. At the Roman College, Giuseppe Calandrelli (1749-1827), Andrea Conti (1777-1840), and Giacomo Ricchebach (1776-1841) produced eight volumes of *Opuscoli Astronomici* (*Astronomical Tracts*), detailing their research on the sun, planets, comets, and stellar occultations. Other Jesuit astronomers in Rome, including Etienne Dumouchel (1773-1840) and Francesco de Vico (1805-1848), were the first to recover Comet Halley in 1835; De Vico also observed the Saturnian satellites Mimas and Enceladus, determining their orbits. Meanwhile, from the towers of the Vatican itself, Feliciano Scarpellini (1762-1840), Ignazio Calandrelli (1792-1866; nephew of Giuseppe Caladrelli), and Lorenzo Respighi (1824-1889) observed the solar chromosphere and made astrometric observations.

But by far the most notable astronomer in Rome during this century was Angelo Secchi (1818-1878), a Jesuit at the Roman College. His reputation

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went far beyond Italy; he was honored by both the Emperor of Brazil and Napoleon III of France (who named him an Officer of the Legion of Honour). He published more than 700 scientific papers on topics as diverse as terrestrial magnetism and solar physics, and established the connection between sunspots and solar flares. He was also a pioneer in spectroscopy, the first to systematically classify stars by their spectral features. His spectral work included the first identification of carbon in stars, comets, meteors, and nebulae. And his work on solar physics was so fundamental that even today it has been honored in the naming of the Sun Earth Connection Coronal and Heleospheric Investigation (SECCHI) instrument package on NASA's Stereo spacecraft. So great was his reputation that when the anti-clerical Italian government confiscated the Roman College following the capture of Rome from the Holy See in 1870, Secchi was still allowed to continue his work even though he refused to take an oath to the new government. Secchi died in 1878, however, leading to a hiatus in Vatican sponsored astronomy until Pope Leo XIII formally re-established an observatory in 1891. The present day Vatican Observatory dates itself from this moment.

[For more details on the early history of astronomy and the Vatican, see Maffeo (2001) and Consolmagno (2006).]

2. Three Epochs of the Specola

In Pope Leo XIII's *Motu Propio*, a personal decree that re-established the *Specola Vaticana* ("specola" is an antique Italian word meaning observatory), the Pope explained the apologetic need for supporting a scientific institution. "This plan," he wrote, "is simply that everyone might see clearly that the Church and her Pastors are not opposed to true and solid science, whether human or divine, but that they embrace it, encourage it, and promote it with the fullest possible dedication."

The original Specola Vaticana was located once more in the Tower of the Winds, with additional telescopes located on the ancient walls of the Vatican. Its original work embraced both astronomy and meteorology, and it went through a number of directors in its early years before the arrival of Johann Hagen (1847-1930) in 1906. He was the first Jesuit in the reformed observatory, which included at that time a combination of clerical and lay staff. Hagen made the decision to concentrate the work of the observatory purely on astronomy; his own research centered on cataloging nebulae, especially dark nebulae (which he correctly deduced were masses of interstellar matter), and variable stars.

A more curious interest of Hagen's was a series of experiments to demonstrate the rotation of the Earth. Though no one doubted by this time that the Earth was spinning, its actual motion had only been shown by Fou-

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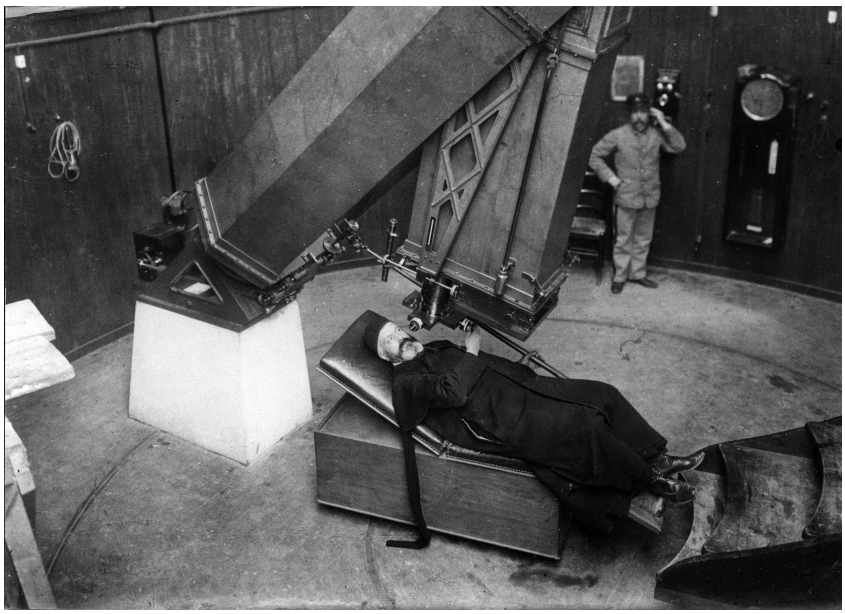


Figure 2. Giuseppe Lais at the Carte du Ciel telescope, circa 1900. From Maffeo (2001).

cault's Pendulum in 1851. Hagen devised a series of clever experiments to demonstrate the action of the Coriolis force arising from motions on the Earth's spinning surface. These including the very careful observation of a falling weight (via an Atwood machine) in a stairwell at the Vatican; the mapping of the apsidal rotation of a pendulum; and the motion of a long suspended beam on which heavy weights traveled in a north-south direction. Thus arose the irony that the Vatican, infamous for having opposed Galileo and his championing of the Copernicus system, three centuries later supported some of the first laboratory experiments that confirmed the Copernican hypothesis of the Earth's spin.

However, the most notable work of the observatory during this time was its participation in the Carte du Ciel photographic map of the sky. The inspiration that the Vatican take part in this international project came from the Specola's first director, the Barnabite priest Francesco Denza (1834-1894); but following his untimely death, the work proceeded under the direction of the Oratorian priest Giuseppe Lais (1845-1921). This project met the desire of the Vatican to participate in work that was both scientifically important and internationally recognized. Though never stated in so many words, one can infer that the Specola played an important political role for the Vatican at this time: by being accepted as a full participant in this program, the astronomical world was in effect recognizing The Holy

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See itself as an independent nation, the equal to the other nations participating in this project – including Italy, which at that time still claimed authority over the Vatican.

In 1929, Italy and the Holy See came to an agreement which acknowledged the independence of the Vatican and restored territory to the Popes that had been confiscated in 1870. Among this territory were the gardens and palace in Castel Gandolfo that had previously served as the papal summer residence. These grounds were renovated in the 1930s, and in 1934 the Observatory itself moved to these quarters, fleeing the city lights of Rome.

With this move, the Specola entered its second phase. At the death of Hagen in 1930, Pope Pius XI had entrusted the Observatory and its staffing to the Jesuit order; with this move to new quarters, the Jesuits provided a number of young scientists, notably specialists in laboratory spectroscopy Josef Junkes (1900-1984) and Ernst Salpeter (1912-1976) under the direction of Alois Gatterer (1886-1953). Over the next forty years this laboratory would produce a number of atlases of the spectra of metals of interest to astronomers, and it was instrumental in the founding of the journal *Spectrochimica Acta*.

At the same time, the observation of stellar spectra was promoted with two telescopes provided by the Vatican: a 60 cm/40 cm Zeiss Double Astrograph installed in 1934 on the roof of the Papal Palace itself, and a 65/98 cm Schmidt telescope placed in the adjacent gardens in 1957. Among the projects performed on these telescopes were the completion of Hagen's Atlas of Variable Stars and the final cataloguing of the Carte du Ciel plates.

Another project which was begun, but not particularly developed at this time, was the study of meteorites. In 1905, the French meteorite collector Adrien-Charles, the Marquis de Mauroy (1848-1927) had donated a small selection of his samples to the Vatican; in 1935 his widow donated the bulk of his collection, amounting to more than one thousand meteorite samples. Early plans to take spectra of these samples did not proceed beyond the measurement of two meteorites, however, as it was found that the metal from these samples produced a spectra far too complex to be interpreted at that time.

The onset of World War II did not bring scientific work at the Specola to a halt. The observatory grounds, on Papal territory, were neutral and the Jesuit staff continued to live and work together even though they had come from countries on both sides of the conflict (many of the staff were Germans, but Gatterer was Belgian and the Specola's director, Johan Stein, was Dutch). The Papal territory in which the telescopes and summer palace were located became the home to thousands of refugees during the invasion of nearby Anzio in the winter of 1944, and the Jesuits in residence dealt on a daily basis with the trials of living in a war zone.

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Figure 3. Spectrochemical Laboratory, circa 1940. From Maffeo (2001).

Research after the war continued both the laboratory spectra work (the journal *Spectrochimica Acta* was actually published and printed at the Vatican from 1945 to 1949) and the completion of the Carte du Ciel catalogues. Under Daniel O'Connell (1896-1982), director from 1952 to 1970, a young trio of astronomers – Martin McCarthy (1923-2010), Florent Bertiau (1919-1995), and Patrick Treanor (1920-1978) – began a project to map the Milky Way via observations of Cepheid and RR Lyrae stars.

The third phase of the observatory began with the appointment of George Coyne as director in 1979. At this point, a number of the Jesuits appointed before the war had either retired, died, or returned to their home countries. In their place a new cohort of astronomers arrived, primarily British and American. The research topics covered by these astronomers ranged from the study of the polarization of light due to interstellar and circumstellar dust (the work of Coyne), an expanded mapping of the Milky Way via observations of stellar clusters (Richard Boyle) and normal and peculiar stars (Christopher Corbally) and a new emphasis on cosmology and the interrelation of astronomy, theology, and philosophy (William Stoeger).

It was clear by then that Castel Gandolfo was no longer suitable for research observations because of the ever-increasing encroachment of city lights. Instead, the best telescopes of that era were to be found in the Americas, primarily Chile and the desert southwest regions of the United States. Furthermore, in the post-war world of astronomy, many of the most productive young European astronomers had moved to America to work with

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American colleagues; to participate in cutting edge theoretical research, it was necessary to live among such researchers. As it happened, a number of the new members at the Observatory already had significant contacts with the astronomy community in Tucson, Arizona; Coyne himself had served as acting chair of the University of Arizona's Steward Observatory before taking over the reins at the Specola.

The obvious step was to set up an outpost with a set of offices at the Steward Observatory. Thus in 1980, the Specola entered into a formal agreement with the University of Arizona where the Vatican Observatory would set up a research group with access to the facilities of the University, including the library system and Arizona's telescopes.

An unexpected opportunity came to the Specola in 1987 with the development by Roger Angel at the University of Arizona of the first "spin cast" telescope mirror. A difficulty facing astronomy at that time was the practical problem of making large mirrors for telescopes. The Mount Palomar 200-inch (5 m) telescope had reigned for 40 years as the largest telescope available for regular use. Its construction had been a herculean effort, taking nearly 20 years to complete; the 40-ton mass of its mirror required a massive support structure, and its long focal length necessitated a cathedral-sized dome. To make an even larger mirror in the same way would be beyond the resources of any observatory. A new way of fabricating mirrors would be necessary to get around these physical limits, and in the 1980s a number of different concepts including segmented and multiple mirrors were developed. Angel's idea was to melt glass over a honeycomb form in a rotating oven; the honeycomb would provide strength at low mass, while the spin of the furnace would shape the mirror into a short focal length. His idea was first tested on a 1.8 m mirror, and proved to be very successful. The University then approached the Vatican Observatory Research Group in Tucson with the proposal to provide this mirror, if the Vatican would raise the funds necessary to build a telescope around the mirror. With the Vatican's approval, a tax-exempt foundation (The Vatican Observatory Foundation) was established, the necessary funds raised from private donors, and the telescope saw first light on Mt. Graham, Arizona in 1993.

3. Current facilities

The Specola Vaticana today consists of two sites. The headquarters is located in the gardens of the Papal Summer Residence, extraterritorial Vatican property in Castel Gandolfo, 30 km south of Rome, Italy; and the Vatican Observatory Research Group[1] is associated with the University of Arizona in Tucson, Arizona, USA.

[1] http://www.vaticanobservatory.org/

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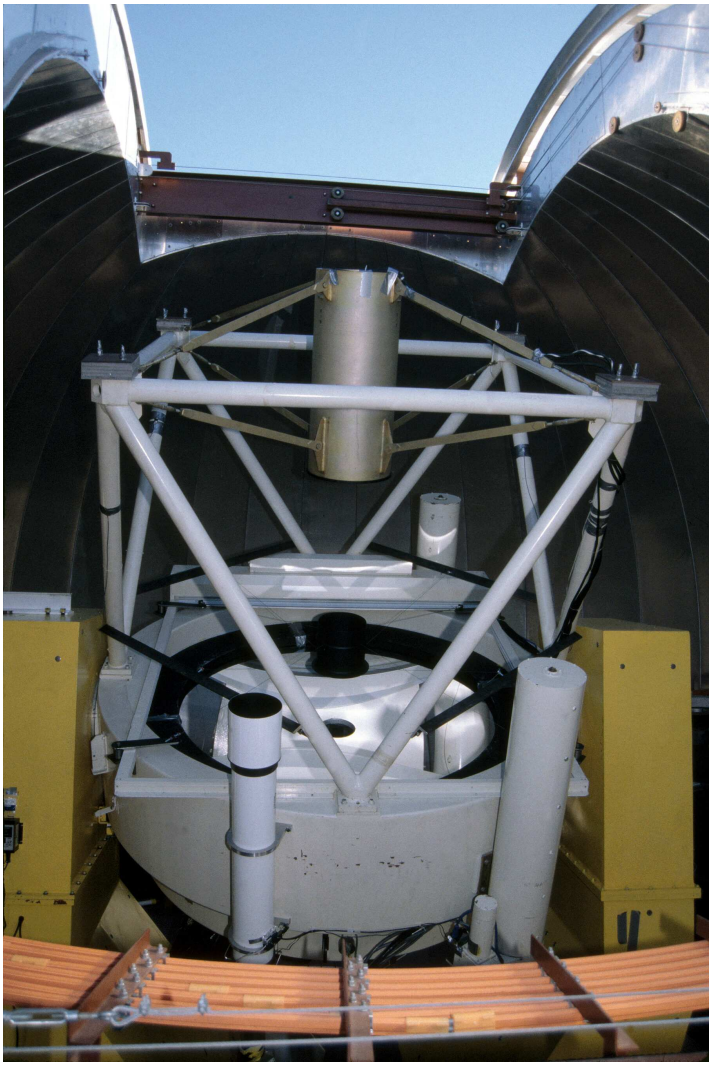


Figure 4. The Vatican Advanced Technology Telescope on Mount Graham, Arizona.

The headquarters is physically located at the southern end of the Papal summer gardens, adjacent to Piazza Pia of the Italian city of Albano. Besides containing the offices and the living quarters of the Jesuit community, this building (originally a convent dating from the 18^{th} century, completely rebuilt in 2009) houses the Specola's library, plate vault, and meteorite collection and laboratory, along with a classroom for the biennial Vatican Observatory summer schools. The library contains more than 22,000 items, mostly 20^{th} century astronomical journals and 19^{th} and 20^{th} century ob-

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servatory reports, but also including many astronomy and physics journals and rare antique books dating back to the 16^{th} century, including original copies of works of Copernicus, Galileo, Newton, Kepler, Brahe, Clavius, and Secchi. The plate vault contains roughly 10,000 items, including plates from the Specola telescopes described below, dating to 1891. [These plates are currently being digitized by Alessandro Omizzolo.] The meteorite collection holds more than 1,000 samples of more than 500 different falls; the laboratory includes stereo and petrographic microscopes and instruments to measure meteorite physical properties such as density, porosity, and magnetic susceptibility.

Additional facilities in the papal gardens include a building erected in 1942 to house the Carte du Ciel telescope with a second dome added in 1957 for the Schmidt telescope. The Carte du Ciel telescope, made by Gilon in Paris in 1891, consists of two optical systems in a single tube: a photographic camera with a 33 cm aperture lens and 3.43 m focal length, and a guider telescope of 20 cm aperture and 3.6 m focal length. The field of view of the camera is 2° onto 13 cm × 13 cm plates, for an image scale of 1 arcminute per mm. The Schmidt has a 98 cm spherical mirror with a 2.4 m focal length taking light from a 65 cm correcting lens; it has a 5° field of view onto 20 cm × 20 cm plates, for a image scale of 1.26 arcminutes per mm. Neither telescope is operational at the moment, though there is a proposal to convert this structure into a museum of astronomical photography.

On the roof of the Papal Palace itself the two telescopes set up in 1934 still remain operational. In a dome over the central staircase is a Zeiss (Jena) 40 cm refractor with a 6 m focal length; attached to it is a Coronado solar telescope. A second dome on the roof houses a Zeiss Double Astrograph, consisting of two telescopes on a common German mount: a 60 cm reflector which can be set up either as a Newtonian or a Cassegrain, and a 40 cm refractor camera designed to be used with photographic plates. The latter has an 8° field of view onto 30 cm × 30 cm plates, for a 1.42 arcminute/mm image scale. The reflector is usually set up in Cassegrain mode; it has a 15 cm convex secondary mirror and an equivalent focal length of 1.82 m. The reflector is still functional, but the camera is no longer used.

The only Vatican telescope currently used for research on a regular basis is the Vatican Advanced Technology Telescope at the Mount Graham International Observatory in Arizona, an especially steady and dark site at an altitude of 3191 m (and also home of the twin 8.4 m spin-cast mirrors of the Large Binocular Telescope). It consists of a 1.8 m f/1 mirror with a 38 cm concave secondary set up as a Gregorian to provide an effective f/9 optics. There are three primary instruments used on this telescope at the moment. The VATT 4k imager is a thinned back-illuminated CCD camera

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with 4032 × 4032 pixels, each 15 microns (square), covering a 12.5 arcminute field of view, for an effective plate scale of 0.1875 arcseconds per pixel. The VATTSpec spectrometer is a medium dispersion spectrograph with a 30 arcsecond slit capable of covering 1000 Å at a 1 Å resolution over a spectral range from 0.36 to 0.95 microns. Finally, on long-term loan from the National University of Ireland, Galway, is the high speed Galway Ultrafast Imaging (GUFI) CCD camera. This is a 512 × 512 pixel camera with a 1.5 arcminute field of view that is capable of imaging up to 400 frames per second. A filter wheel with space for up to eight filters is mounted on the telescope; at present, the filters available for use include Johnson-Cousins UBVRI, the Vilnius/Strömvil, and the SDSS ugriz systems, along with an H-alpha and various neutral density filters.

4. Staffing

Since 1930 the staffing of the Specola Vaticana has been entrusted by the Vatican to the Society of Jesus, a religious order of priests and brothers (popularly known as "Jesuits") whose typical work has been in higher education, and whose style of spirituality is particularly suited for scientific work. As noted above, Jesuits have produced a number of excellent scientists throughout their history. Thirty five craters on the Moon bear the names of Jesuit scientists; the fact that the original nomenclature for lunar features was in fact devised by the Jesuit Riccioli only emphasizes the historical presence of Jesuits in astronomy.

However, even given that the Jesuits are the largest men's order in the Catholic Church (presently numbering about 17,000 members) and have founded and staffed a number of institutes of higher education world-wide, the actual number of PhD level research astronomers in this population is likely to be small. Furthermore, the Observatory must share this limited number of personnel with all the other institutions of higher learning it is responsible for staffing. Thus the number of astronomers actually available to work at the observatory can vary significantly over time.

Historically, what has happened is that a cohort of researchers has come to the observatory, worked together for twenty or so years, and then been replaced by a new cohort. The majority of the astronomers from the 1930s and 1940s came from central Europe (Germany, the Netherlands, Austria, and Belgium); following the war years, the next wave of astronomers were primarily from the United Kingdom and the United States. A significant turnover in staffing occurred in the early 1980s, but after that only two new full-time astronomers were added over the next twenty years. Since 2006, however, four young Jesuits have joined the staff and several more have been tapped for future assignment once their training is complete. At

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present, the staffing of the observatory is unusually international, including the United States, Italy, Britain, the Czech Republic, Argentina, and the Congo.

Originally, members of the Observatory staff were chosen among men who had already received advanced degrees in science, but in recent times a number of the Jesuits have had their astronomical education funded by the Specola. Of the six Jesuits who have been added in the past twenty years, two already had PhDs (Guy Consolmagno, who studied meteoritics at Arizona, and Gabriele Gionti, who studied physics at Trieste). Four others, who had undergraduate degrees in science and had expressed interest in working with the Specola, were specifically sent to obtain appropriate doctoral degrees. These include the current director, José Funes, who studied galaxies in Padua; Pavel Gabor, who worked on instrumentation for the detection of exoplanets in Paris; David Brown, who studied stellar evolution at Oxford; and Jean-Baptiste Kikwaya, who studied meteors at Western Ontario. The choice of degree programs and research topics was based primarily on the interests of the men in question, although language and visa requirements also played a role. [None of these four studied in their native country, and three of the four worked in a language other than their native tongue.]

5. The Nature of Vatican Astronomy

This eclectic history demonstrates three important points about the nature of astronomy supported by the Vatican. First of all, it is clear that there has never been an agenda to Vatican's support of astronomy beyond doing good science, and to be seen supporting this science. Next, we can see that the astronomy done is the result of the interests of the astronomers who happen to be on staff which is, for the most part, the chance result of whoever happens to be available at any given moment. And finally, this research is often the result of the chance occurrence of opportunities: the Carte du Ciel project, for example, or the availability of the VATT spin cast mirror, or the collection of meteorites that was donated more than 50 years before it was fully utilized. The success of these projects arises entirely from the freedom and flexibility that comes from not having an agenda, not have a pre-conceived notion of what an observatory ought to be doing.

This freedom is perhaps the most notable aspect of research at the Specola Vaticana today. Once appointed to the Observatory, the staff are not tied to the constraints that often limit research at modern universities. There is no need to apply for grants, and thus no restriction on research topics dependent on what grant programs are well funded. And there is no

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time limit based on the need to renew grants or stand for tenure, so that projects that may take may years to come to fruition can be undertaken and supported.

The research underway at the Observatory today well illustrates the result of this freedom. Boyle and Corbally are both involved in long-term classification of stars within the Milky Way, projects that have been underway for nearly 30 years. Consolmagno is working on a lengthy cataloguing of the physical properties of meteorites, a program that has gone on for 15 years. Stoeger and Gionti are both working in speculative realms of cosmology that would be far too risky for most young scholars looking for secure positions in academia.

This is not to say that such work is divorced from the mainstream of astronomical research, however. All of the astronomers at the Specola work in collaboration with colleagues in the academic world, and several participate as unfunded co-investigators on traditional research grants. In many cases, such grants have only been funded after several years of unfunded research at the Observatory had demonstrated the feasibility and utility of the work in question. For example, the meteorite measurements were first demonstrated on the Vatican collection; the techniques are now in use world-wide in projects funded by agencies in Europe, Canada, and the United States. And this integration into the larger astronomical community can be seen in the election over the years of a number of Specola astronomers to leadership positions in the International Astronomical Union, the American Astronomical Society, and other scientific societies.

Given the lack of overall "agenda" to the work of the Specola, one may well ask why exactly the Vatican continues to support an astronomical observatory, at a budget of roughly one half of one percent of the annual Vatican budget. The practical need of reforming the calendar and setting the date of Easter has been solved for more than 400 years. What benefit does the Vatican expect from its astronomers?

Certainly, having a world-class astronomical observatory is a source of good publicity for the Vatican. The newly renovated headquarters in the Papal Gardens of Castel Gandolfo were specifically developed to be, in the words of one high ranking official involved in their development, a "feather in the cap" showpiece for the Vatican. However, to merely dismiss this work as "public relations" misses the point both of the importance of this good repute and the nature of the work of the Vatican itself.

When Pope Leo XIII established the modern version of the Specola in 1891, a perceived need was to counter the prevailing notion that there was a conflict between science and religion. But in fact the idea of such a conflict only arose in the late 19^{th} century (see the discussion in Gould 2002), while the Vatican's interest in astronomy long predates the need to address this

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relatively modern misconception.

Perhaps the words of the Popes (as cited in Consolmagno 2009) themselves can best express the relationship they saw between the religious institution that is the Vatican and the scientific institution that is the Vatican Observatory. Pope Pius XI, who was responsible for bringing the Observatory to the Summer Palace, wrote at the time of its dedication in 1935 of the many places where scripture used the image of stars and heaven to invoke the beauty and grandeur of God. "From no part of Creation does there arise a more eloquent or stronger invitation to prayer and to adoration," he concluded. His successor, Pope Pius XII, noted in an address to the Pontifical Academy of Sciences in 1939 that "man ascends to God by climbing the ladder of the Universe." And most recently, Pope Benedict XVI in 2008 remarked that "the laws of nature ... are a great incentive to contemplate the works of the Lord with gratitude."

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 231-256
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SELECTING AND SCHEDULING OBSERVING PROGRAMMES AT ESO

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Abstract. The European Southern Observatory (ESO) manages the largest astronomical ground-based optical and near-IR facility on the planet. It typically receives one thousand applications per semester, and it serves about one third of the astronomical community world-wide. In this paper we review the procedures currently in place at ESO for proposal selection and telescope time allocation.

1. Introduction

The history of the European Southern Observatory (ESO) is marked by steady growth, which has turned it into one of the world-leading, ground-based astronomical facilities[1]. ESO currently operates two observing sites located on the Chilean Andes: Cerro La Silla and Cerro Paranal. In addition ESO is a partner in the Atacama Large Millimeter/submillimeter Array (ALMA) observatory, but the telescope allocation process for this facility is independent. The La Silla and Paranal observatories are equipped with a number of telescopes. At La Silla ESO operates the 2.2m, the 3.6m, and 3.5m New Technology Telescope. Cerro Paranal is equipped with the four 8.2m unit telescopes of the Very Large Telescope (VLT), the 4.1m Visible and Infrared Survey Telescope for Astronomy (VISTA), the 2.6m VLT Survey Telescope (VST), and the four 1.8m auxiliary telescopes of

[1]Founded in 1962, ESO just celebrated its 50^{th} birthday. Given a dramatically evolution of conditions in the past decade, this paper updates and replaces an earlier contribution in the OSA/OPSA series by Breysacher & Waelkens (2001)

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the VLT Interferometer (VLTI). The four VLT unit telescopes (UT) can be operated in interferometric mode, combining two, three and four units, with a maximum baseline of 134m. Each of the UTs features 3 foci (2 Nasmyth platforms and one Cassegrain focus), so that up to 12 instruments can be simultaneously offered and easily switched during the night. Currently 11 instruments are offered for normal operations.

The VLTI is equipped with two interchangeable instruments (MIDI and AMBER), plus one visitor instrument (PIONIER). The two survey telescopes feature one single wide-field imager each. Finally, five instruments are permanently mounted and offered on the La Silla telescopes[2].

ESO also operates the Atacama Pathfinder Experiment (APEX), a 12m single-dish millimeter and sub-millimeter telescope located on the Chajnantor plateau in Chile. APEX is an international collaboration involving the Max-Planck-Institut für Radioastronomie (MPIfR), Onsala Space Observatory (OSO), and ESO. ESO receives about 25% of the observing time, which is allotted in pre-determined time slots. The remaining time is administered and allocated by the other partners.

With this suite of telescopes and instruments it is natural to expect a high interest from the astronomical community worldwide. This is shown in more quantitative terms in Fig. 1, which presents the evolution of the number of distinct co-Investigators (co-I) on ESO proposals from the start of VLT operations to the current day. The plot gives an effective view of the scale of the users community ESO is serving. The number of users applying for time on ESO telescopes changed from about 1200 in 1998 to more than 3000 during the last years, with applicants distributed over about 50 different countries[3]. This corresponds to one third of the International Astronomical Union members, implying that ESO serves about 30% of the astronomical community.

A similar perspective, although more directly related to the telescope time allocation load, is presented in Fig. 2, which shows the history of the number of proposals submitted to ESO (per semester) in the last 35 years. In the pre-VLT era (*i.e.* before period 63), the number of proposals kept growing and stabilized at around 500. The start of VLT operations can be marked by a rapid increase, bringing the number of proposal submissions above ∼700, followed by a renewed steady growth that finally stabilized at today's ∼950 proposals per semester, submitted by about 700 distinct Principal Investigators (PI). The total time request averaged over the last 4 years is about 3170 nights per semester (about 65% for Paranal only), of

[2]The 2.2m telescope is operated by ESO only on a five months per year basis. The remaining time is managed internally by the Max Planck Society.

[3]Although most of the applications come from scientists affiliated to the fourteen ESO member countries and the host country (Chile), there is no restriction for other countries.

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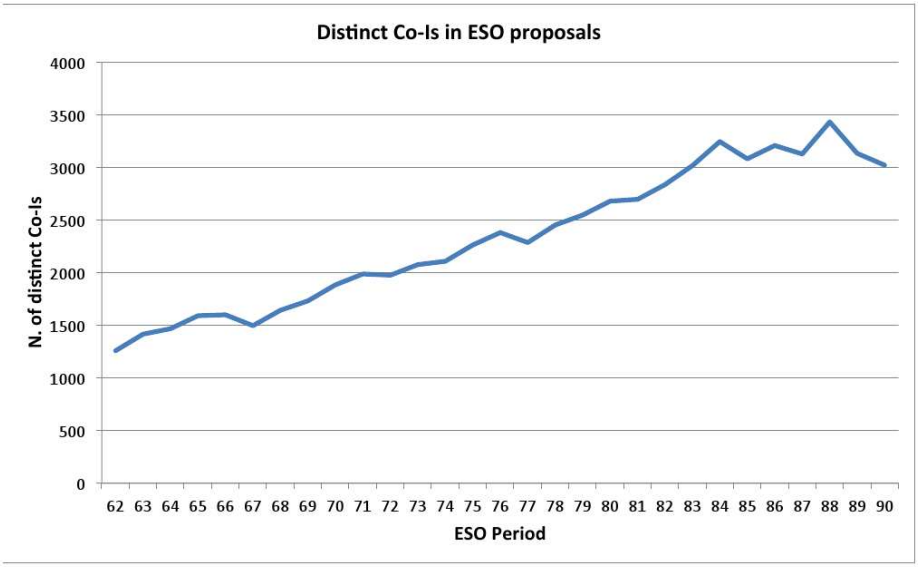


Figure 1. Number of distinct co-investigators (co-I) in ESO proposals from the start of VLT operations (P62, October 1998) to ESO period 90 (October 2012).

which about 1070 are scheduled for execution in visitor mode or in one of the three service mode rank classes (see Sect. 4.3). The overall observatory pressure (defined here as the ratio between the submitted and the scheduled time) is ∼3.0. However, at some telescopes (and particularly at some instruments, *e.g.* FORS2, X-SHOOTER, HARPS), this exceeds 5.0.

The distribution of submitted proposals per site is presented in Fig. 3, which illustrates the evolution since the beginning of VLT operations. In the initial phases of the VLT era, La Silla was receiving about 400 proposals per semester. Following the ramping up of the Paranal facility in terms of available telescopes and instruments (and the progressive close-outs of several La Silla telescopes), this number has been steadily decreasing since then, and it is now stable around 110 proposals per semester. This can be compared with the approximately 800 proposals received for Paranal each semester. However, it is clear that the demand on La Silla is still significant if one compares the time requested at the different sites (see Fig. 4). Despite the fact that the number of proposals has decreased by almost a factor of 4,

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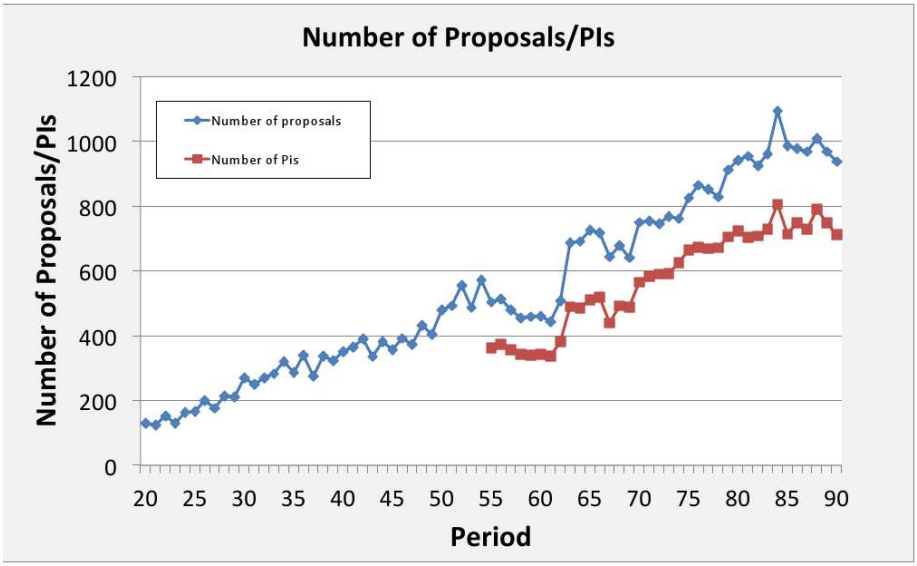


Figure 2. Number of distinct proposals received by ESO from period 20 (1977) to P90 (2012). This is also known as the "Breysacher-plot", after ESO astronomer Jaques Breysacher, who produced the first version of the diagram. The number of distinct principal investigators (PI) is also plotted. The peak observed on P84 coincides with the start of X-Shooter operations.

the time request averaged over the last 3 years is about 900 nights/semester, to be compared with the ∼1450 nights/semester during the first 3 years of VLT operations. The NTT and the 3.6m telescope remain in high demand, and the tendency is to request the time through Large Programmes[4] (LPs). This is reflected in the time allocation: in P90 at the 3.6m telescope ∼73% of the time was allotted to LPs, 18% to Normal programmes and 9% to GTO. With the deployment of the PESSTO public spectroscopic survey (which has an allocation of 90 nights/year), the NTT is moving towards a very similar configuration.

[4]Large Programme proposals request over 100 hours of telescope time that can be distributed up to four consecutive years on La Silla (or two consecutive years on Paranal). See also Sect. 2.3.

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2. Call for proposals and proposal submission

The process of time allocation, which is called Phase 1 at ESO, starts with the preparation and the distribution of the call for proposals. This is released twice a year: in August for the semester that runs April to September and in February for the semester that runs October to March (of the following year)[5]. The call for proposals serves a double purpose: it is the official document for the Science Policy of ESO, and it contains all the technical information required to prepare a proposal, including news about the availability of instrumentation in the upcoming semester. The call is edited by the Observing Programmes Office (OPO), with the input provided by all the parties involved in telescope operations. It is released four weeks before the proposal submission deadline.

Proposals are submitted through a web-based interface, accessible via the ESO User Portal (UP)[6]. In the current implementation, the proposal is prepared by editing a LaTeX template, which forms part of the proposal package, called the ESOFORM package. This is released together with each call for proposals.

Once a proposal is ready, it can be submitted via the UP, through the ESO Web Application for Submitting Proposals (WASP). On uploading the proposal, WASP carries out a series of formal checks to ensure that the proposal complies with the conditions set out in the call for proposals. The WASP interface can be used by the applicants at any time prior to submission to validate their proposals. When the proposals have passed these checks, they can be submitted. At this stage their content is stored in a dedicated database. Although the LaTeX-based system has been used for a few decades, ESO is now considering a new system that would be fully web-based and that would incorporate a number of new features that would help the user configure their proposal more precisely according to their requirements, (*e.g.*, target visibility windows, exposure time calculations, verification of target conflicts).

While the proposal system is open for submissions four weeks before the deadline, the vast majority of the submissions take place during the last few days, with close to 800 proposals submitted during the last 24 hours.

2.1. PROPOSAL TYPES

In the current implementation, there are 6 different types of proposals:

1. Normal: programmes require less than 100 hours, and spanning one semester;

[5]For an example call, see `http://www.eso.org/sci/observing/phase1.html`.
[6]`http://www.eso.org/UserPortal`

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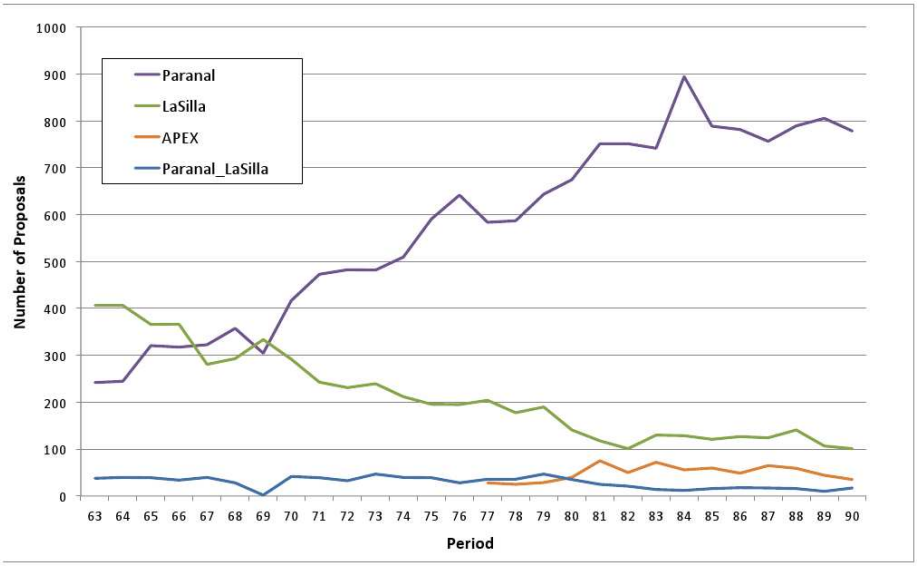


Figure 3. Number of proposals (all types) per site as a function of time since the beginning of VLT operations.

2. Large: programmes require more than 100 hours and can span one or more semesters (up to 4 for Paranal, up to 8 for La Silla). A large programme typically has the potential to lead to a major advance or breakthrough in the field of study, has a strong scientific justification, and a plan for a quick and comprehensive effort of data reduction and analysis by a dedicated team.
3. Target of Opportunity (ToO): up to 5% of the available ESO general observing time may be used for ToO proposals. Within this framework it is also possible to apply for the Rapid Response Mode (RRM) implemented at the VLT. This allows the users to trigger observations with a very fast reaction time (a few minutes), by sending a signal directly to the telescope and instrument control software.
4. Guaranteed Time Observations (GTO) arise from contractual obligations of ESO vis-a-vis the external consortia who build ESO instruments. This time is only accessible to the GTO Consortia.
5. Calibration: this type of proposals was introduced to allow users to

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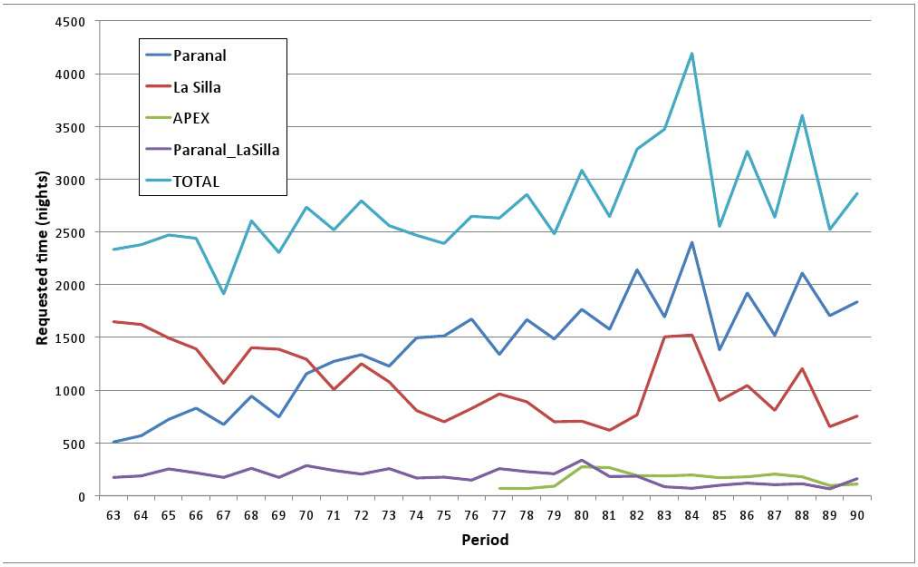


Figure 4. Requested time (nights) per site as a function of time since the beginning of VLT operations. All programme types are included, while public surveys are not counted.

complement the existing calibration of ESO instruments and to fill any gaps that might exist in the calibration coverage.

6. Director's Discretionary Time (DDT): Up to 5% of the available general observing time at ESO may be used for DDT proposals in the current period. As opposed to the other proposal types described above, DDTs can be submitted at any time during the semester.

Most of the proposals received are for Normal programmes. Typically ESO receives 15 to 20 Large Programme proposals each semester[7].

Since the beginning of VLT operations, time on ESO telescopes can be requested either in Visitor Mode (VM) or in Service Mode (SM)[8]. VM is the classical observing mode, in which the observations are carried out by

[7]At the time of writing, a new programme type, dubbed Monitoring Programmes, is being implemented by ESO. This is for projects requesting small amounts of time (of the order of tens of hours) spanning across several periods and it is meant to secure continuity to programmes aiming, for instance, at time coverage of slowly varying targets.

[8]In the current schema SM is not offered for La Silla telescopes, which are operated in VM only.

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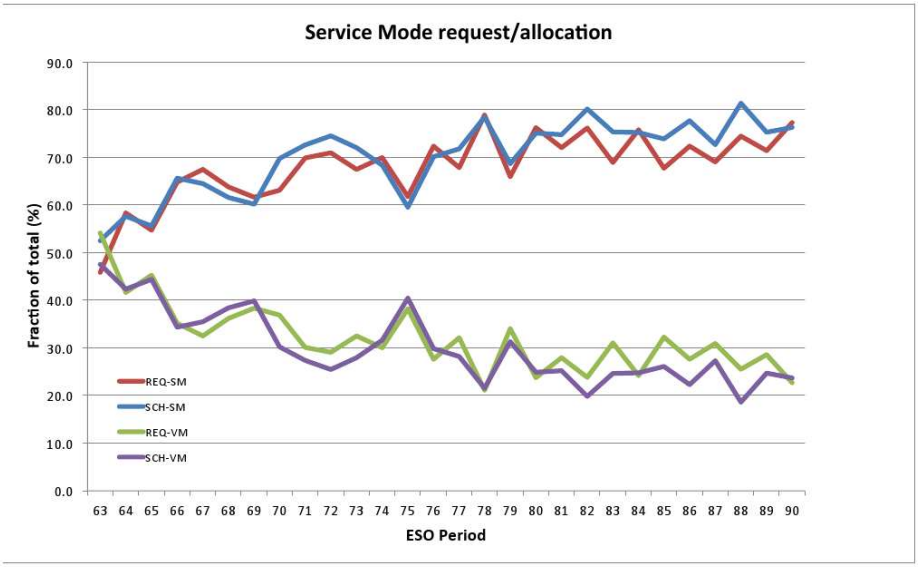


Figure 5. Time evolution of the fraction of requested and scheduled time in SM (upper curves) and VM (lower curves) at the UTs since the beginning of VLT operations. Statistics refer only to Normal and ToO programmes. Large Programmes and GTO proposals are not considered.

a visiting astronomer selected by the proposing team. SM observations are instead performed by ESO staff. If a SM proposal is allocated time, the successful applicant is required to prepare observing material that is first checked and validated by the User Support Department (USD) before the observations can be carried out. While VM allows the observer to take on-the-fly decisions and to make use of non-standard modes, SM enables the exploitation of the best atmospheric conditions, and repeated short visits to the same target during a semester.

Although the original operations plan had foreseen a 50/50 distribution between the two modes, the popularity of SM steadily increased during the first five years of VLT operations. This is very clearly demonstrated by the evolution of the time request for the two modes (see Fig. 5). From an almost equal 50% fraction recorded on the first semester, the share has evolved to the current situation, in which about 75% of the time is requested in SM. Rather than enforcing the original operations plan, ESO has followed the

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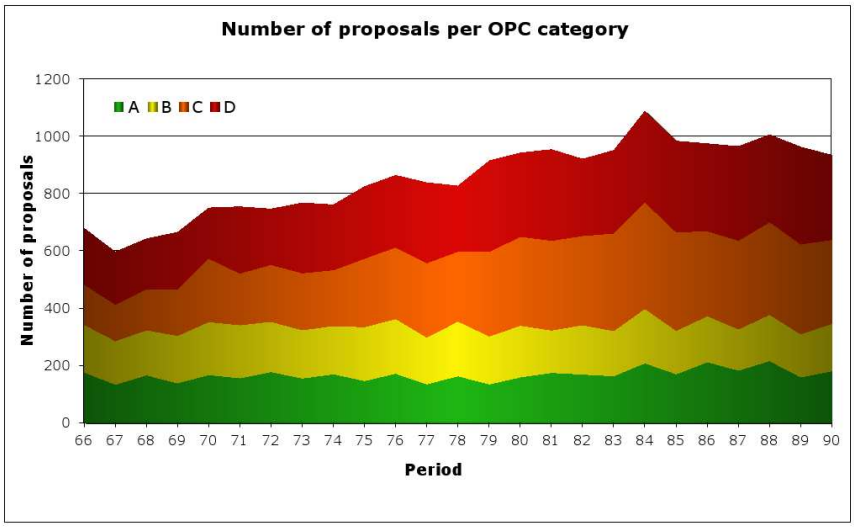


Figure 6. Distribution of submitted proposal per scientific category for the last twelve years (A: Cosmology; B: Galaxies and galactic nuclei; C: ISM, star formation and planetary systems; D: Stellar evolution).

demand by the community, *i.e.* scheduling the observing modes according to the request.

3. Observing Programmes Committee and Proposal Review

Telescope time at ESO is allocated following the recommendations of the Observing Programmes Committee (OPC). It is the function of the OPC to review, evaluate, and rank all proposals submitted in response to the call on scientific merit. Through this review, the committee advises the Director General (DG) on the distribution of observing time taking account ESO's scientific policy. The OPC includes 13 panels to cover 4 science categories:

- A: Cosmology (3 panels);
- B: Galaxies and galactic nuclei (2 panels);
- C: ISM, star formation and planetary systems (4 panels);
- D: Stellar evolution (4 panels).

The different number of panels within each category is due to the different number of proposals these categories receive each period. Interestingly,

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this has significantly evolved since the beginning of the VLT operations, when the proposals were evenly distributed across the four categories. The data covering the last twelve years of operations (see Fig. 6) clearly show an increase of D (stellar evolution) and especially C (star formation and planetary systems) proposals. The latter is related to the growth of the exo-planets field.

Each panel has 6 members, including one panel Chair and one panel co-Chair. Apart from the individual panels, the advisory committee, the OPC is composed of the 13 panel Chairs, 3 panel co-Chairs (1 in A, 2 in B), and the OPC Chair, who is not a panel member. This sums up to a total of 17 OPC members and 72 panel members, for a total of 79 scientists.

OPC and Panel members are selected on the basis of their scientific competence. During the selection, some allowance is made for gender balance, and for distribution across member states, but this is not rigidly enforced. The candidates are proposed by the OPC Nominating Committee (NomCom). This board is advisory to the DG, and it is composed by the Director for Science, the Head of the OPO, the former OPC Chair and two members of notable accomplishment in astronomy. The NomCom provides the OPO with candidate names, which are then entered into the database that is used for the recruitment process.

The OPC members serve for two years (four ESO periods), while Panel members serve for one year (two ESO periods). A fraction of the Panel members are invited to serve an extended, second year term, to ensure sufficient continuity in the review process. The high turnover ensures that, with time, a significant fraction of the community gains experience in the process from inside.

ESO facilitates the OPC process, but does not take active part in the scientific evaluation of the proposals. ESO time allocation is carried out by implementing the OPC recommendations while accounting for any technical and scheduling constraints.

3.1. THE OPC PROCESS

3.1.1. *Pre-OPC phase*

The OPC and Panels meet twice a year at ESO, about 50 days after the proposal submission deadlines. After a first check of the proposals in each scientific category (followed by possible category re-assignments), the OPO distributes the proposals to the panels members, according to the declared expertise areas. The tool which is used for this task automatically takes institutional conflicts into account. The referees are then given about one week to report scientific conflicts and to request changes in the scientific category assignments to the OPO. Once this is done the refereeing process

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starts. In order to facilitate the review process, ESO provides the referees with a software package that enables them to search through proposals via a web interface. This python based package consists of a browser, a search engine that is directly linked to the proposal files and enables reviewers to access detailed information and statistics about the proposals.

All panel members read all the proposals assigned to their panel provided that they do not have a conflict of interest. The panel members then grade each run of each of these proposals[9]. A scale between 1 and 5 is used:

- 1.0 outstanding: breakthrough science
- 1.5 excellent: definitely above average
- 2.0 very good: no significant weaknesses
- 2.5 good: minor deficiencies do not detract from strong scientific case
- 3.0 fair: good scientific case, but with definite weaknesses
- 3.5 rather weak: limited science return prospects
- 4.0 weak: little scientific value and/or questionable scientific strategy
- 4.5 very weak: deficiencies outweigh strengths
- 5.0 rejected

The grades are entered by the referees using the Web OPC Tool (WOT), which is accessible via the UP. This tool is used to enter both grades and text comments, via the so-called comment cards. The referees are given about four weeks to complete the process.

Once this is done, the grades of all referees are normalised so that the distribution of the grades of each of them has the same mean and standard deviation. A single ranked list per telescope is built from these normalised grades (excluding Large Programmes, GTO and Chilean proposals[10]).

In the last few years, following the increasing workload on the OPC, ESO has implemented a triage procedure to limit the number of proposals to be discussed during the OPC meeting. Large, Chilean and GTO proposals are exempt from the triage process. The cumulative requested time per telescope is computed down each list of all normal and ToO proposals, ordered according to their normalised grades, and the triage line is drawn when the cumulative time exceeds 70% of the total requested time on the considered telescope. As a rule, proposals below the triage line are not considered any further. However, there are a couple of exceptions to this rule: proposals for which the spread of the individual referee grades exceeds a certain threshold are brought above the line; all the runs in a proposal

[9]In the current implementation, users can apply for time using different runs within the same proposal. These may be used for requesting time at different instruments/telescopes, with different setups, or at different epochs.

[10]Following the agreement between ESO and the host country, Chile, proposals with PIs affiliated to Chilean institutions are guaranteed a 10% time fraction on all ESO telescopes.

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would be brought above the triage line if some runs were below the triage line and some above. Furthermore, triaged proposals can be re-considered upon the request of any panel member.

The lists of triaged proposals per panel are compiled from the lists per telescope, and distributed to the panel members prior to the OPC meeting.

The 70% triage limit was set after an extensive testing based on a-posteriori statistics drawn from the data stored in the Phase 1 ESO database. With this limit, the fraction of discarded proposals that could potentially qualify for scheduling is below 0.5%.

3.1.2. *The OPC meeting*

The OPC meeting is divided into a number of sessions that involve the OPC proper and the Panels.

In the Panel sessions, for each proposal the primary referee gives a short presentation of the proposal under discussion, and presents her/his evaluation. All other (non-conflicted) panel members present their assessment. Finally, after a general discussion, a vote takes place. For this, each panel member fills a voting slip with her/his ID, the proposal ID, and a grade (using the same grading scale as in the pre-OPC phase)[11]. The Panel Assistant collects the voting slips and enters the votes in the ESO database via the PanelTool (the voting slips are kept in the archives for some years, in case doubts or questions should arise). The average and standard deviation of the individual votes are computed by the PanelTool and assigned to the proposal.

The Panel meetings last 2.5 days. The goal of the meetings is to grade all non-triaged proposals of Normal, ToO and GTO programmes, and to build a panel ranked list of the corresponding proposals. Also, the Panels identify the ToO runs that are suitable for implementation. These runs are then discussed in a separate session by the OPC (see below). Finally, the Panels provide expert input to the OPC for the final evaluation of the LPs.

The primary referee is responsible for writing feedback comments to be communicated to the PI. The feedback comments are based on the discussion of the proposals at the meeting. For the triaged proposals, they are based on the pre-OPC meeting report cards (see Sect. 3.1.1.). The primary referees submit their comment cards via the WOT within one week of the end of the OPC meeting. Before the final comment is entered in the ESO database, it is usually discussed within the panel members for a final review.

During the OPC proper sessions, the OPC:

[11]Runs with an average grade above 3.0 will not be considered for scheduling.

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1. reviews the progress of the LPs approved in previous periods, and provides recommendations regarding their continuation;
2. reviews the final ranked lists of observing runs per telescope. For this purpose, the lists are merged across panels after panel grades are normalised, following a similar process to the pre-OPC phase (see above);
3. recommends ToO programmes for implementation based on panel evaluations;
4. discusses in detail the newly submitted LP proposals and provides recommendations on their implementation.

The final ranked lists per telescope approved by the OPC serve as a basis for the telescope scheduling.

4. Telescope Scheduling at ESO

The task of telescope scheduling at ESO is complicated by the large numbers of telescopes and instruments, and the consequent level of interdependencies and constraints that these set on the schedule (*e.g.* presence of runs at different UTs, time coordination, etc). This is particularly important for the programmes performing interferometry with two or more UTs, which introduces interdependencies between schedules on each of the VLT units, complicating the scheduling of each of these telescopes. Another source of complexity is the presence of fixed reserved slots for runs making use of the Laser Guide Star (LGS), currently deployed for adaptive optics instruments at UT4[12].

4.1. PREPARATORY WORK

The scheduling process starts with the ingestion of the runs and their OPC grades into an operational database, which will be accessed by the time allocation tool (see Sect. 4.2). This is followed by a number of consistency checks, to make sure that all runs (including those of ongoing LPs approved in previous periods) are properly inserted. During this process, the runs with original grades above 3.0 are rejected (see Sect. 3.1.1.). For this a flag is set in the database using the time allocation tool, so that they will not be considered for the telescope scheduling. The same procedure is applied to the ToO runs not recommended for implementation by the OPC. In addition, for each UT the 5% fraction of the available time is computed. The available time is the time left after subtracting all other commitments at

[12]In the current operations plan LGS slots are pre-determined, as this requires a dedicated team to operate the facility. At the time of writing ESO is starting the deployment of a new system, which is designed for continuous operation, and can be used any time this is needed.

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the given telescope (ongoing LPs, GTO, technical time, commissioning, etc. See below). As the experience shows, about 50% of the allocated ToO time remains unused at the end of the observing semester. This is compensated by setting the actual ToO cut-off at 10%. The cumulative time request is computed by going down the ToO ranked list, and all runs above the cut-off limit are rejected.

Following the agreement with the host country, the certified Chilean runs are automatically flagged upon proposal submission[13]. This allows the scheduling tool to treat them with a special priority up to the 10% of the cumulative request for any given telescope. Above this threshold the special flag is removed at this stage, and the runs are treated like all other runs.

Although the OPC is instructed to consider the time requested for each run as specified in the proposal, in special cases the referees may want to recommend time reductions. A record of these requests is kept during the OPC meeting, and the proposed changes are applied to the non-rejected runs during the preparatory phase.

Every period, and well ahead of the start of the scheduling phase, the Director of Operations (DOP) issues a call for applications for technical time, which is released to all internal bodies involved in telescope operations. This includes both ordinary technical activities (*e.g.* mirror coatings, calibration plan, maintenance, software upgrades) and extra-ordinary activities (*e.g.* new instrument commissioning, science verification, special instrument/telescope maintenance and upgrades). This is reviewed by the DOP, submitted to the DG for the formal approval, and forwarded to the OPO for the implementation into the schedule. The technical slots are inserted into the operational database at this stage, using the time allocation tool.

While proposals using special instruments/modes (VLTI and LGS) undergo a technical feasibility assessment before the OPC meeting, the majority of the technical feasibility checks are only carried out by the instrument scientists after the final rankings per telescope have been compiled. Given the large amount of proposals, only those that have a substantial probability of being scheduled are sent to the technical feasibility assessment. After computing the cumulative time request per telescope down the ranked lists, all the runs are selected until 130% of the available time at the given telescope is reached. The corresponding proposals are forwarded to the Paranal Science Operations Department (PSO), which distributes them to the relevant experts. The 130% limit is an empirical estimate based on experience, and it ensures that the vast majority of the runs that will actually be scheduled have a technical feasibility report when this is needed for

[13]To avoid abuses of the system, ESO asks an appointed Chilean representative to verify the effective affiliation of the PI submitting the proposal.

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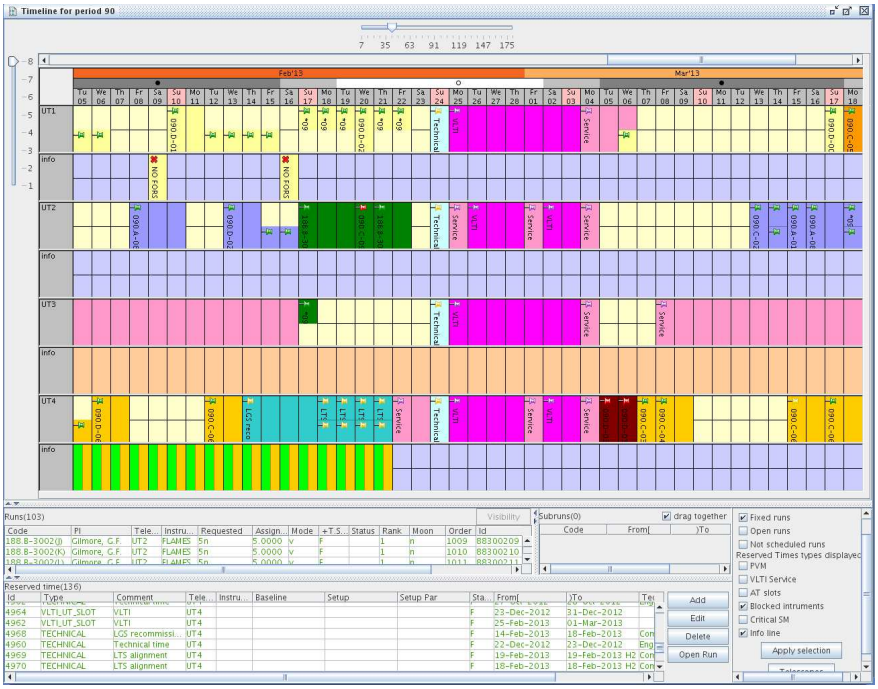


Figure 7. Example of Timeline view in TaTOO. The instruments are color-coded. The pink color denotes time allocated to SM runs. The purple blocks indicate slots reserved for the VLTI with the UTs.

the final evaluation by the person in charge of scheduling. A second round of technical feasibilities is submitted to PSO during the final stages of the scheduling process. This typically includes a few tens of runs, mostly fillers (see Sect. 4.4).

The time allocation tool can deal with time constraints specified in the proposals (either relative or absolute). As the implementation of time-critical runs (especially if they are highly ranked) poses strong constraints on the schedule, a series of checks is performed at this stage, to avoid problems later on. For this purpose, all proposals with time critical aspects are reviewed, and the correctness of the specified constraints verified and corrected when applicable.

4.2. THE TIME ALLOCATION TOOL: TATOO

In general, telescope time scheduling is a complex, multi-constrained optimization problem. Given the number of runs, instruments and telescopes, with the beginning of the VLT operations (1999) ESO has started considering the deployment of a computer-based scheduling tool. After a testing

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phase with SPIKE (Johnston & Miller 1994), ESO decided to develop its own Time Allocation Tool (TaToo; Alves 2005), which is currently in use. TaToo is based on a combination of the Solver/Scheduler ILOG system, and it directly accesses the Phase 1 information (including the OPC normalized grades) from the ESO database.

The scheduling engine is hosted on the Scheduling Server. The data are stored in two databases on the DB Server, while the client(s) can connect to the system through a graphical user interface (GUI). Each observing programme sets a range of requirements and conditions on the scheduling (atmospheric conditions, astronomical circumstances, time windows, etc.). The Control Logic reads them from the Phase 1 database and transfers them to the Scheduling Engine, which generates the constraints which are then sent to the Solver/Scheduler. The output results are stored back to the Operational database. The operator has access to all relevant data and control over the process via the GUI client. An example of the Timeline view is presented in Fig. 7.

The two observing modes (VM and SM) are scheduled using two different methods. VM observations consist of runs. A run is typically a set of adjacent nights (or fractions of nights), which TaToo allocates possibly using sub-runs, *i.e.* the smallest VM schedulable entities. SM is scheduled using one-hour Observation Blocks (OB). In the current implementation VM sub-runs occupy at least half a night. The main difference with the scheduling of SM resides in the search space in which the process takes place. The VM sub-runs are scheduled on the timeline, where they block fixed and specific time slots. For SM the concept is radically different, as this is scheduled in the resources space. In other words, a SM run is accepted only if there are enough resources available for its execution. This is done by evaluating the availability of given conditions (*i.e.* seeing, transparency, target visibility, possible time constraints, etc) and taking into account the OPC ranking and other implementation policies (host country fraction, program type priorities, etc). For doing this, TaToo uses an internal Scheduling Order (SO), which combines the OPC ranking and the program type priorities. The calculation of cumulative time per telescope is done using the SO as a sorting parameter.

SM is scheduled in two steps. First, TaToo generates pseudo-VM (PVM) runs. The right ascension (RA) of the targets included in the SM run is used to compute visibility windows. For each target, PVMs are generated taking into account the constraints (including Moon illumination if applicable). In this process a large number of interchangeable PVMs can be created. These are then mixed with the VM sub-runs taking into account the OPC ranking and passed to the Scheduling engine. In the second step, TaToo uses a RA/Moon/Seeing/Transparency algorithm (RMST; see Silva 2001)

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to schedule the runs by consumption of available time. This is based on pre-compiled statistical tables for the availability of given atmospheric constraints, in addition to pre-computed astronomical ephemeris.

TaToo features a number of reports, which allow the operator to quickly check possible problems in the scheduling. This is particularly important when the solution found by TaToo is overridden by a manual intervention. An example is shown in Fig. 8, which illustrates the Visibility view.

A number of parameters can be configured in TaToo. These include the initial VM and SM maximum fractions (see Sect. 2.1) and the time percentage per scientific category (see Sect. 3.1.2). For the UTs the first parameter is initially set to 60% (SM) and 50% (VM), but it is typically changed during the process, and set to different values at each UT (on UT2 the final SM fraction is around 65%, while this reaches about 85% at UT1). The second parameter is set per telescope, and it initially reflects the original demand in the proposals. Although the values are adjusted during the refinement of the schedule, they typically follow the original request. The adjustment is aimed at having the last scheduled run of each category with a similar grade for the given telescope.

Another important parameter is the so-called reserved time. This is used, for instance, to make provision for the DDT time (see Sect. 2.1 & 5). The reserved time is kept unscheduled by TaToo, and evenly distributed across the scheduling period.

Once TaToo is properly setup, the scheduler is launched for each telescope. The output is inspected with the aim of identifying highly-ranked runs rejected by the scheduler. The reasons for rejection can vary from instrument unavailability coupled to the time constraints or target visibility, to exhaustion of conditions when the constraints are very stringent. The critical cases are examined in detail, and if a solution cannot be found, the runs are rejected.

Notwithstanding the sophistication of the software, the whole process requires a fair amount of human interaction and scientific/technical judgement, especially during the optimization phase. The total time required to fully schedule the four UTs, the two survey telescopes, APEX and the three La Silla telescopes is about 30 working days. This includes the preparatory phase and the distribution of the final notifications to the applicants. The process is described in more detail in the next section.

4.3. PRODUCING THE SCHEDULE

4.3.1. *Time critical VLT programmes*

One of the first steps is the identification of highly ranked time-critical VLT runs (including interferometric runs). The ones requested in VM are

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Figure 8. Example of Visibility view in TaToo. For each target of the example run the view shows the total visibility (in hours; upper panel), the visibility during the first and the second half of the night (middle panels), and the target-Moon distance (bottom panel). The green vertical bar marks the night in which that runs has been scheduled, while the blue rectangle marks the time interval indicated in the proposal.

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fixed on the timeline, so that subsequent runs of the TaToo Scheduler do not change their scheduling status. Also, by doing so, they implicitly block the relevant time intervals, preventing the operator from scheduling other activities in those slots. At this stage possible conflicts with technical activities are also identified, and actions taken if deemed to be justified (technical activities may be moved after negotiating with the DOP). For the SM time-critical runs, forced SM slots are introduced as place-holders in the timeline.

4.3.2. *VLTI with the Unit Telescopes*

Given the impact it produces on the timeline, the VLTI with the UTs (hereafter VLTI-UT) is scheduled next. This is done reserving blocks of nights according to the demand, both in terms of time and RA distribution. Because of the technical activities, it often happens that not all UTs are simultaneously available, making the whole process rather cumbersome at times. TaTo does not provide an initial guess for the VLTI-UT slots, which are currently determined externally to the tool, and then entered into the TaToo timeline. Once this is done the Scheduler can be run to get a first guess solution. VM runs are then manually fixed on the timeline. In this process, when the programme is asking for different UT baselines, the schedule is optimized in terms of permanence of the visiting astronomer on the mountain. Also, a first cut-off for the VLTI-UT is set, so that the last scheduled run has a grade which is consistent with what is most likely to happen at the single UTs. This sets an initial cut-off, which will be refined during the optimization phase. For the runs above the cut-off the technical feasibility assessment is examined; if needed, technically unfeasible runs are rejected at this stage (TaToo allows the operator to enter specific scheduling comments, which are saved into the operational database, and used during the preparation of the final notifications. See Sect. 4.5). The SM allocation is done using the TaToo Scheduler. The initial slots are adjusted (in duration and position) until a reasonable solution is found. At the end of the process, the unused nights (or fractions of nights) are returned to the normal, single-UT time.

During the VLTI-UT scheduling, technical slots typically need to be modified, as the scientific return is the main driver. However, it may happen that the proposed changes are incompatible with other constraints or commitments between the Observatory and external teams (*e.g.* instrument consortia). For these reasons, as soon as a preliminary version of the VLTI-UT schedule is ready, it is forwarded to the DOP for confirmation. Typically, in a semester about 30 nights are allocated for VLTI-UT programmes. Most of them make use of 2 and 3 UTs, while the 4-UT configuration is used only in a few cases. VLTI-UT observations are mostly requested (and

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scheduled) in VM.

4.3.3. *VLTI with the Auxiliary Telescopes*

As they make use of the same instrumentation and part of the same interferometric infrastructure, it is not possible to operate the VLTI with the UTs and the ATs simultaneously. This is the reason why, having higher priority, VLTI-UT is scheduled first, and VLTI with the ATs (hereafter VLTI-AT) is scheduled in the remaining time slots. Typically in each semester ESO offers three baseline quadruplet configurations, which are used by the applicants to sample the u-v plane according to their scientific needs. The change from one quadruplet to another implies the physical movement of the ATs to fixed stations located on the platform of Paranal. Depending on the number of telescopes that need to be moved, this requires one or two reconfiguration nights. Therefore, the VLTI-AT is scheduled in blocks, and the runs requesting the same quadruplet are grouped together. The distribution of the baselines is optimized in order to minimize the number of reconfigurations. As in the case of VLTI-UT, the current version of TaToo does not include the calculation of the number of slots and their position along the timeline for each offered quadruplet. These are determined based on RA, baseline and time request distributions, after setting a preliminary time cut-off.

Once the initial slots are fixed, the scheduling proceeds in the same way as described for the VLTI-UT. As in that case, the vast majority of the time is scheduled in VM.

4.3.4. *Scheduling the Unit Telescopes*

At the time of writing the LGS runs are still scheduled in pre-allocated time slots at UT4. One requirement set by the Observatory is that during these slots the other UTs are operated in SM. Violations of this condition are considered only under special circumstances (*e.g.* highly ranked time critical runs). For this reason, UT4 is scheduled first, as it poses some constraints on the other VLT units.

Similarly to what is done for the VLTI, the number and position of the LGS slots is determined from the RA and time demand, after a suitable cut-off is set. Once all highly-ranked LGS runs are accommodated, forced SM slots are inserted in the timelines of the other three UTs. The remaining runs are then processed using the TaToo scheduler, until the available time is exhausted. During this process some runs may turn out to be non-schedulable, for a number of reasons. This is typically because of exhaustion of conditions at certain RA ranges by higher graded programmes. After considering allocation time reductions or the removal of some targets in the critical RA ranges, if a solution cannot be found the

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runs are rejected with a special scheduling comment, which is logged into the operational database.

A final adjustment to the scientific category fractions is done in order to ensure that the cut-off grades are similar for all categories. This is achieved modifying the science category percentages in the TaToo configuration file and re-running the Scheduler until the category distribution is even.

In general, scheduling the remaining UTs is similar to scheduling UT4, with the difference that there are no LGS slots at these telescopes. One peculiarity at UT1 is represented by the availability of two detectors at FORS2, which offer different spectral responses (MIT: red-optimized, E2V: blue-optimized). The MIT chip is offered as the default detector, and it stays mounted most of the time. The E2V detector is only offered in VM. The replacement of the detector requires two technical nights, during which FORS2 is not available. For this reason, the runs requesting the E2V slots are first identified and grouped together according time and RA request, as to minimize the instrument unavailability. The slots are then inserted and the E2V VM runs fixed on the UT2 timeline. From that point on the allocation proceeds using the TaToo Scheduler.

In P88 the public spectroscopic survey GAIA was recommended for implementation at UT2 by the OPC. This survey will run for five years, with a constant allocation of 30 nights per semester. The nights are allocated in VM, in six slots of five nights each, evenly distributed across the period.

4.3.5. *Scheduling the Survey Telescopes*

The survey telescopes (VISTA and VST) are fully scheduled in SM. Most of the time is allocated to the Public Surveys (PS). Six PS were allocated on VISTA and three on VST. The allocation is revised on a period-by-period basis by the ESO Survey Team (EST), who recommends to the OPO the amount of new time to be allocated to each survey and the time that needs to be reserved for carry-over observations that could not be completed during previous periods. At the time of writing, no normal time is offered at the VST (only the PS, host country and GTO programmes are scheduled at this telescope), while at VISTA up to 10% of the science time is available to normal proposals.

4.3.6. *Scheduling the La Silla Telescopes*

La Silla telescopes are currently scheduled in VM only, and the runs have a minimum duration of 3 nights. The schedule computed by TaToo is used as a first guess, and it is optimized manually. At the 2.2m telescope the time reserved for the MPG is allocated in long, pre-determined slots, so that the scheduling of the ESO time requires some adjustment to the time allocation of single runs.

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A similar procedure is used at the NTT and the 3.6m telescope. At the NTT the process starts fixing possible time-critical runs and allocating the nights to the PESSTO survey. The observing runs of this public spectroscopic survey, which will run for five years, are split in three sub-runs, separated by a few nights. This, coupled to the 3-nights minimum run duration, often requires manual adjustments of the timeline. Finally, scheduling the 3.6m telescope is made somewhat complex by the presence of time-critical runs, often related to planetary transits to be followed on specific time windows with HARPS.

4.4. DEFINING THE RANK CLASSES

Scheduled SM runs are executed at the telescope following an established priority order. For each telescope the runs are grouped in three queues, which reflect their scientific ranking. The rank classes are defined as follows:

- **Class A**: All possible efforts will be made to execute all observations corresponding to the runs in the requested observing period.;
- **Class B**: These runs will be executed in the requested observing period on a best-effort basis;
- **Class C**: Filler runs. Observations will only be executed if the observing conditions do not permit observations for runs within classes A and B.

The rank is assigned to all allocated SM runs at the end of the scheduling process. The runs successfully scheduled by TaToo are classified in the A and B rank, while the C rank class is populated with runs that qualify as fillers, and which are formally not included in the schedule but were judged as eligible by the OPC (*i.e.* their grades were below 3.0). The A to B transition is set to a configurable fraction of the total allocated time for a given telescope. TaToo computes the cumulative time starting with the top ranked run and going down the scheduling order (see Sect. 4.2). All the runs above the input fraction are classified in the A-rank, while the remaining runs below the input fraction are placed in the B-rank. In the current implementation the fraction is set to 50%.

It must be noticed that although based on the OPC ranking, the A/B classification also depends on the exact time distribution. A few highly ranked programmes with large time allocations may cause the the A/B transition to occur at an earlier position down the scheduling order. This means, in practice, that the A/B transition may occur at different grades for different telescopes. This ensures that the commitment to complete the A-rank programmes can be fulfilled with a high probability. The experience accumulated during more than ten years of VLT operations shows that this is indeed the case.

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As mentioned earlier, A- and B-rank runs fully exhaust the available time by construction. In order to avoid idle time, the schedule is actually built with a 10% oversubscription so that the B-rank programmes are scheduled in excess of the available time already. This is a mandatory condition is any queue-mode schedule, in order to account for the statistical fluctuations in the observing conditions (see for instance Johnston 1989). In the ESO system the oversubscription is further extended by allocating time to the so-called filler programmes, which are grouped into the C-rank class. In the ESO definition, a filler is a programme with very loose constraints on seeing, transparency and Moon illumination, free of time constraints, and using standard instrument modes. The purpose of the filler runs is to fill in regions of the parameters space which are typically not populated by highly ranked proposals[14].

During the technical feasibility, the Observatory flags the candidate filler runs. Based on this recommendation, the eligible runs are selected and assigned the C-rank flag. The fraction of filler runs changes from telescope to telescope, according to the pressure factor. For some instruments it is often hard to find filler programmes, as very few proposals are submitted for relaxed conditions. This is a typical issue with VIMOS, for which there are practically no requests for bright time and/or bad seeing conditions. In some cases, and only if the technical feasibility assessment allows, VM runs are converted to SM (which is a mandatory status for a filler programme).

When the rank classification has been finalized, the list of scheduled ToO runs is inspected. Since a ToO run must be in the A-rank class, all ToO runs having OPC grades above the A/B transition are rejected at this stage.

The schedule is presented to the DG, the director of Operations and the director for Science for the formal approval. The three Directors are presented with a Scheduling Report, which lists potentially critical issues and contains relevant statistics on the time allocation. The report is discussed in a meeting, during which the Directors may propose changes and/or revisions that are put in place by the OPO before finally releasing the schedule.

4.5. PREPARATION AND RELEASE OF THE WEB-LETTERS

Before the outcome of the time selection process is communicated to the applicants, the schedule undergoes a series of checks and optimizations. Once these are completed the schedule is exported from the operational database to the production database.

[14]Although there are exceptions, top-ranked science cases typically require relatively stringent constraints.

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The technical feasibility notes prepared by PSO are revised and ingested into the database. Then, the scheduling information is prepared. This contains the pressure factor for the relevant telescope, the quartile classification, and possible scheduling comments (*e.g.* explaining why a given run was rejected during the scheduling, although it was not rejected by the OPC). Technical and scheduling notes together with the OPC comment prepared by the Panels (see Sect. 3.1.2) and all the relevant information about the time allocation form the so-called web-letter.

After running a series of spot checks, the web-letters are made public and a bulk notification is sent out to all PIs, who can access them via the UP.

The release of the web-letters marks the start of Phase 2, during which the successful SM applicants prepare their observing material to be revised by the USD.

5. Director's Discretionary Time

Up to 5% of the total science time is under the direct control of the DG. DDT proposals can be submitted any time using a special template in the same framework used for the normal cycles.

A DDT proposal must necessarily belong to one of the following categories:

- proposals of ToO nature requiring the immediate observation of a sudden and unexpected astronomical event;
- proposals requesting observations on a hot and highly competitive scientific topic,
- proposals asking for follow-up observations of a programme recently conducted from ground-based and/or space facilities, where a quick implementation should provide break-through results;
- proposals of a somewhat risky nature requesting a small amount of observing time to test the feasibility of a programme.

DDT proposals can only be carried out in Service Mode (therefore, they are normally considered for Paranal telescopes only). Non-time-critical DDT proposals are approved only under exceptional circumstances. In these case the applicants must provide a very clear justification why the programme should be considered for DDT allocation and was not submitted through the normal OPC procedure. In the absence of such a justification, the proposals are normally rejected.

The DDT proposals are reviewed by an ESO internal standing board, the DDT Committee (DDTC). The DDTC is chaired by the Head of the OPO, and it includes ESO Faculty Astronomers, the Director for Science and the VLT Programme Scientist. The DDTC members are proposed by

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the Head of the OPO and appointed by the Director for Science. They typically serve for a two-years term. The DDTC is advisory to the DG, who takes the final decision based on a recommendation prepared by the Chair and discussed within the DDTC.

Upon submission, an automatic notification is sent to all members of the DDTC, who can access the proposal for review via an internal web interface. The referees send their feed-back to the Chair who, after collecting the feedback on possible target duplications (from the USD) and technical issues (from the PSO), writes a recommendation to the DG. This includes an evaluation of the impact on the schedule. Although a 5% provision is built into the Paranal schedule (see Sect. 4.1), the current schedule needs to be analyzed and possible conflicts with highly ranked, time critical proposals identified and addressed.

The outcome of the review is communicated to the PI as soon as the decision is taken by the DG. When the submission occurs during a week-end and the observations are urgent, the Director of the Paranal Observatory is in charge of taking a decision. The reaction time (measured from the proposal submission to the final notification to the user) ranges from six hours to about ten days, depending on the urgency of the observations.

Typically ESO receives 50 to 60 DDT proposals per semester (at an average rate of 2 proposals per week), with requests that range from tens of minutes to a few hours. The total time request is below 2% of the VLT time. The successful DDT applicants are asked to submit a report within 4 weeks from the completion of the observations.

6. Conclusions and perspectives

In this paper we have provided a summary of the activities related to the time allocation at ESO, a world-class ground-based facility that serves a third of the entire astronomical community. The process of handling about 1000 proposals per semester, 14 telescopes and 23 permanently mounted instruments unavoidably adds complexity and some degree of rigidity to the Phase 1 system.

Although the present situation can partially be improved within the current architecture, a major step forward will require a radical change, affecting the whole Phase 1 chain, from proposal submission, through proposal review, to telescope scheduling. As part of the European Extremely Large Telescope (E-ELT) project, ESO has started defining a new roadmap for telescope operations, which includes the revision of the Phase 1 philosophy and tools. At the time of writing this paper, the OPO is studying the implementation of a new proposal submission system, which will feature a more integrated and user-friendly approach.

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As for the telescope scheduling, this can be certainly and substantially improved. Although TaToo represents a major step forward with respect to the pre-VLT scheduling era, we are still very far from an ideal [and probably unattainable] situation where a fully optimized, multi telescope, mixed mode schedule is produced just pushing a button. If on the one hand this is a matter of more sophisticated algorithms, on the other this requires redesigning the way the information needed by the process is collected and stored.

This is all the more true if one is to move from a practically static scheduling system (as is the case now), to a dynamical scheduling, in which it is possible to have an "enhanced DDT" (*i.e.*, a significant fraction of continuous proposal submission), and a closed-loop scheduling-analysis-rescheduling system. The latter necessitates retro-fitting the prevailing status of the schedule to the scheduling tool, enabling the recalculation of a new version that accounts for the completion of runs already in the system so that it can allocate runs from a standing pool or from newly submitted proposals. This could have a severe impact on operations beyond Phase 1 therefore the potential advantages of such a system will have to be weighted against the costs in terms of performance and operations. One of the nightmares of all people in charge of scheduling 8m class telescopes, namely idle time, is currently cured by over-subscription. If on the one hand this reduces the idle time to a minimum, on the other it creates expectations in the user community, and may even generate less-than-useful data (*e.g.*, B-rank runs that are only partially completed). Dynamical scheduling may represent an alternative approach.

Acknowledgements

The authors are grateful to G. Mathys, former head of the OPO, for his fundamental input on the time allocation procedures and policies at ESO.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 257-266
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GEMINI OBSERVATORY TIME ALLOCATION AND PROGRAM EXECUTION

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Abstract. Gemini Observatory caters to a diverse community of six partner nations (Argentina, Australia, Brazil, Canada, US and the UK) and two hosts (Chile and the University of Hawaii). This paper describes the current methods for time allocation, scheduling and execution of science programs for Gemini users.

1. Introduction

Gemini has operated a full multi-instrument queue on both of its telescopes (Gemini North and South, hereafter referred to as GN and GS respectively) since 2005. The queue operation is interspersed with classical programs, at a rate which is quite variable but which over the period 2005-2012 averages about 10% classical time (this fraction is set entirely by user demand). The evolution of queue operations since 2005 has been described elsewhere (*e.g.* Jørgensen *et al.* 2010)); Fig. 1 provides an overview. We restrict our discussion to the present-day operation.

The essential shape of Gemini science scheduling and execution is currently set by two factors: (i) the desire of the Gemini partners to execute

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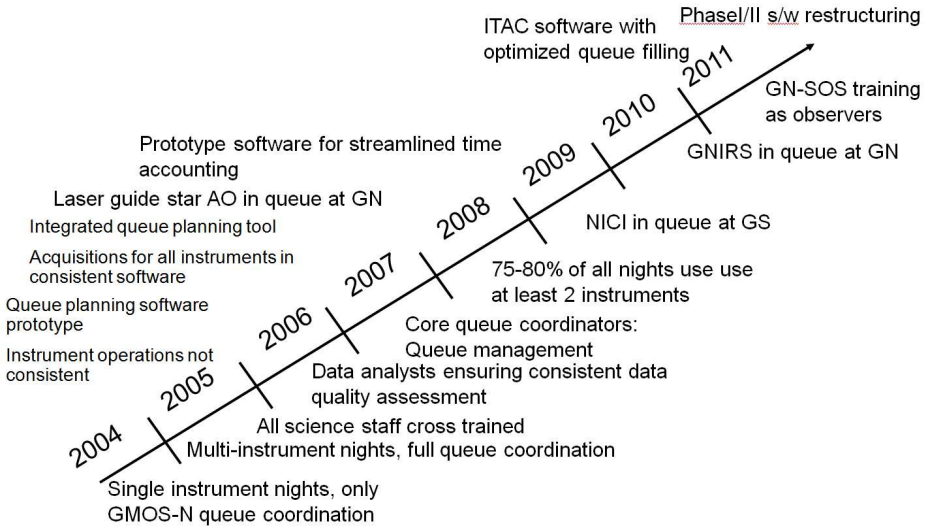


Figure 1. Developments in Gemini Queue operations since 2004.

science observations on the two telescopes in proportion to their financial contributions to the observatory and (ii) targets for completion rate of queue observing programs, set by the Gemini Board of Directors. Each partner, including the hosts, maintains its own telescope time allocation (TAC) system and provides the observatory with its own sets of science programs to observe each semester. The TAC processes are informed by statistics which indicate, for the coming semester, the amount of time available and its distribution within "conditions bins" characterizing cloud cover, seeing, atmospheric water vapour and sky background. A merging process (carried out by the International TAC, ITAC) is used to ensure that the final program for the semester is broadly consistent with long-term conditions statistics.

A key feature of the Gemini queue operation is that the queue is not systematically monitored for partner shares during the course of the semester; if the outcome of a given semester is that a given partner is significantly over or under their nominal share for the semester, the time made available to that partner is adjusted in subsequent semesters. In this way, the time average of the partner imbalances tends toward zero.

Policies on queue filling and execution are set by the Board, advised by the Operations Working Group (which comprises the heads of the National Gemini Offices (NGO) or their delegates, and a number of representatives of Gemini Science Operations staff.

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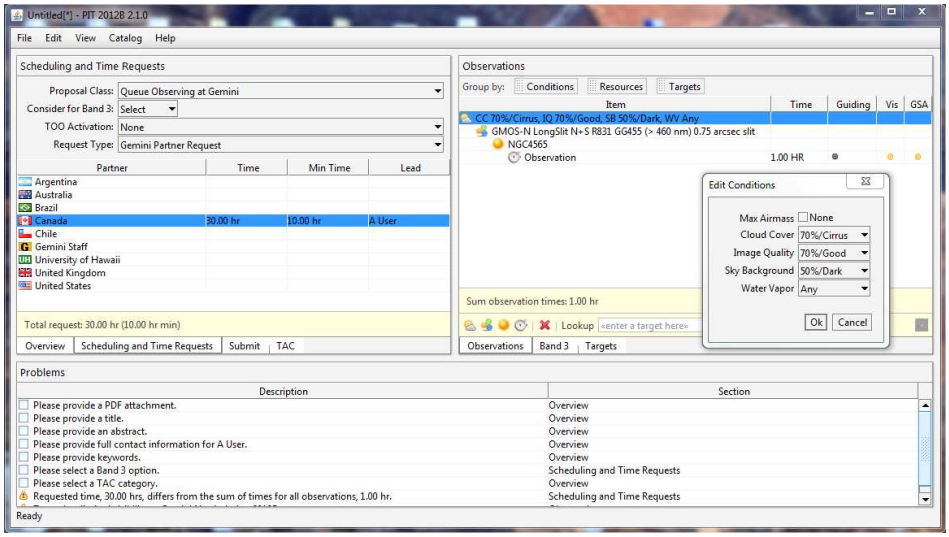


Figure 2. The 2012B Phase I tool. Top left: TAC and proposal type details; top right: observation/target/conditions specifications; bottom: real-time display of items remaining to work on before the proposal is complete.

2. Proposal Stage

The Phase I proposal submission process is supported by staff in the NGOs. Most PIs apply for telescope time via the Gemini "Phase I Tool" (PIT), a recently-upgraded software package which allows them to provide a science justification, target lists and conditions requirements. Fig. 2 shows one of the PIT's panes, being used to specify observing conditions and an airmass constraint. PIs can specify, for queue programs, the cloud cover and water vapour content (selecting from 20%-ile, 50%-ile, 80%-ile or "any" in both cases), the seeing (selecting from 20%, 70%, 85% and "any") and the cloud cover (selecting from 50%, 70%, 80% or "any"; here, 50% corresponds to photometric conditions).

Selecting from percentile bins in this way has the advantage that the PI naturally gets an indication of the likelihood of their observations being executed as they add in additional constraints; and the ITAC queue filling process automatically gets the information it needs to fill the conditions bins appropriately for the "average" semester.

3. Time Allocation

Fig. 3 shows a schematic of the phase I process, involving national TACs and the ITAC to merge classical and queue programs into a workable semester schedule and queue respectively.

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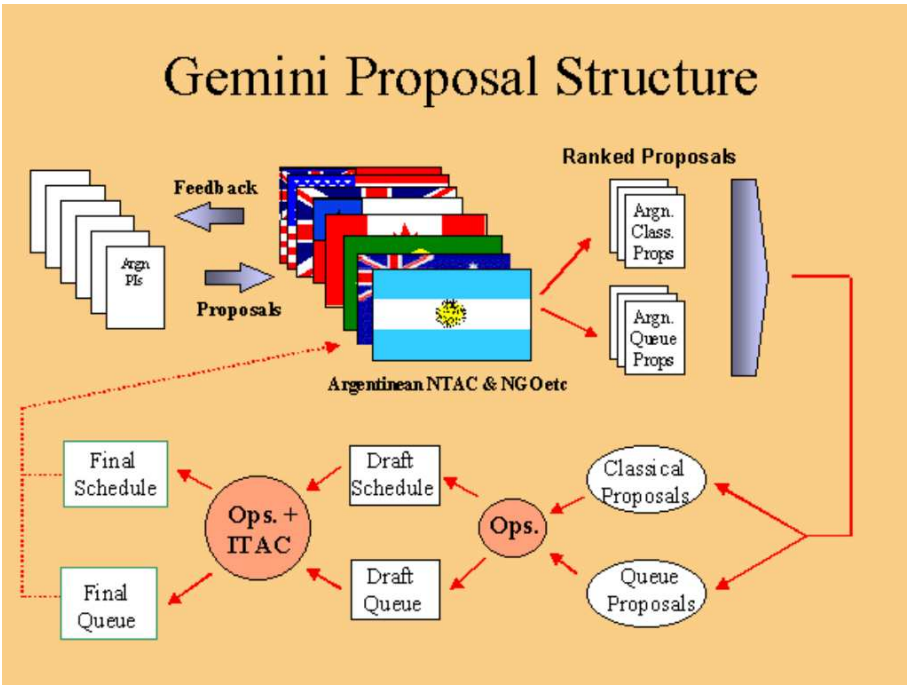


Figure 3. The NTAC/ITAC process.

The national TAC outputs comprise the rankings, recommended time awards and the full proposals. The national TAC-forwarded proposals are merged together, along with the output of the Gemini staff TAC[1], to produce a draft schedule and draft queue. For the merging to work effectively, the group of top-rated proposals that would fill a given partner's share of the time available must contain a reasonable balance of requested observing constraints. For example, not all proposals can request the best image quality, or dark time. In practice, more proposals than the minimum are forwarded, to provide flexibility during merging. Queue programs assigned by the ITAC into queue Science Ranking Band 1 are eligible for rollover into the next semester, for no more than two consecutive semesters, in order to increase their likelihood of completion. Rollover cannot be assigned to Target-of-Opportunity programs, and ITAC representatives have discretion to recommend withdrawal of execution and rollover status.

The draft schedule and draft queue, along with notification of any target or scheduling conflicts identified during the merging process, are sent to the

[1]At the time of writing, a 5% Director's Discretionary time allocation is provided to a peer-review process for Science Staff proposals.

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ITAC. The ITAC consists of representatives from each national TAC and from Gemini Observatory. After resolution of any conflicts and consideration of duplicate and joint proposals, the recommended schedule, queue and the position of the queue bands are forwarded to the Gemini Director for final approval. A typical ITAC meeting presently lasts one day and involves the generation of between 10 and 20 draft queues; this process is carried out with the assistance of a bespoke software package (the "ITAC Software").

The queues which emerge from the ITAC are divided into three main priority bands, labeled 1, 2 and 3 in order of decreasing priority. Each band has its own completion rate goals, as set by the Gemini Board (it is of course understood that these are targets which may turn out to be impossible to meet, *e.g.* in a semester with particularly bad weather).

Band 1: 90% or more of programs are completed (100% of requested data) for all instruments, after roll-over period.
Band 2: 75% or more of programs are completed (100% of requested data) for all instruments.
Band 2: 85% of started programs should have at least 75% of requested data taken. Programs with only GMOS pre-imaging data are excluded from the determination.
Band 3: 80% of started programs should have at least 75% of PI defined minimum requested data taken. Programs with only GMOS pre-imaging data are excluded from the determination.

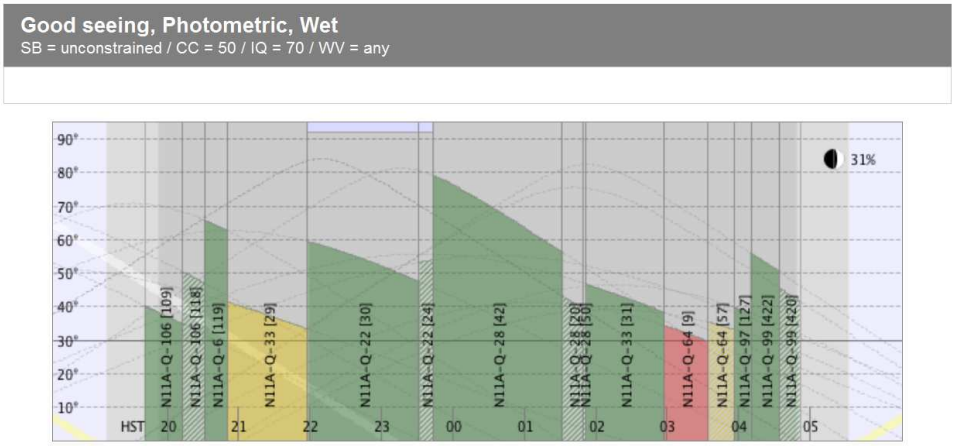
In addition, there is a "poor weather" band (Band 4), into which PIs can submit projects at any time, and for which there are no completion rate requirements.

4. Scheduling

Semester scheduling consists of fitting the classical blocks into the pre-planned instrument schedule, determining optimum dates for instrument swaps as a function of demand, and staffing the summit night-time operation. Queue observations are undertaken by Gemini staff members, from two distinct groups: (i) Astronomers and Scientists with research allocations and (ii) the Science Operations Specialists group which is a non-research group formed as a result of the transition of Gemini to a reduced-funding envelope after the UK partner withdraws at the end of 2012.

Every weekday, data taken on the previous night(s) are subjected to rigorous data checking (by Science Operations Specialists) to determine whether they were taken within the PI's requested conditions and that all the required calibrations are available. The "queue coordinator" works on both the previous night's time accounting (assisted by the outcome

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Start	Dur	BG	Observation	Steps	Inst	Config	WFS	Target
19:09	Sunset							
19:41	00:31	100%	N11A-Q-106 [109]	1 - 26	GNIRS	32, 0.45	PWFS2	SDSS J(
19:52	Evening 12° Twilight							
20:13	00:18	80%	N11A-Q-106 [118]	1 - 4	GNIRS	32, 0.45	PWFS2	hip4985
20:31	00:19	50%	N11A-Q-6 [119]	1 - 8	NIRI+AO	Kprime, H2 1-0, Brgamma, NGS	Altair AOWFS	Titan.ep
	Titan							
20:50	01:06	80%	N11A-Q-33 [29]	1 - 4	GMOS-N	E2V, R400, GG455	OIWFS	PS1-201

Figure 4. (Subset of) Queue plan for good seeing, photometric, low water vapour for a Gemini North night late in Semester 2011A.

of the data checking) and puts in place a number of nightly plans as a function of weather conditions. Fig. 4 shows an example of a queue plan provided by the queue coordinator to the observers; similar plans are made for all reasonably likely combinations of weather conditions. As conditions change at the summit, observers switch from plan to plan as necessary. The planning process takes into account factors such as instrument schedules, grating changes in the GMOS spectrographs, completion rates of programs, and efficient use of the best conditions.

5. Execution and Time Accounting

Program execution proceeds in such a way as to achieve the completion targets per band set by the Gemini Board. The following points are the main features of the time accounting.

(i) The overall aim of the time accounting is to ensure that the Gemini partners obtain their share of the *executed* time (defined immediately below).
(ii) *Executed* time is defined as the sum of (a) science observing time and

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baseline calibrations[2] which meet the PI's stated requirements (queue mode), and (b) 75% of the time from twilight to twilight on all classical nights in the semester (classical mode).

(iii) The time actually executed in a semester is intended to be distributed between the partners according to their share.

(iv) We attempt to ensure the appropriate distribution of *executed* time *preemptively*, by filling the semester according to the partner's share.

(v) Where a partner obtains more or less executed time than is appropriate in the Semester, the "imbalance" is applied to subsequent semester's available (Call for Proposals) time.

(vi) Over time, the executed time imbalance between partners is intended to average to zero.

Executed time is, in turn, a function of the details of the observing process. The following describes how this time is calculated (resulting in item (ii) above):

(i) Queue time is charged only for executed observations. Planned, but unexecuted, observations have no influence on the total time charged.

(ii) Queue time is charged from start of slew to the target and until the start of the slew to the next target, or alternatively to the end of the observation sequence if this ends because of twilight, weather or other causes.

(iii) Queue time is not charged for observations that fail to meet the PI requirements, as revealed by data checking (Sect. 4).

(iv) For Band 4 (poor weather programs) queue time is charged to the program, but not counted in the determination of the partner imbalances, *i.e.* the time is "free" to the partner.

(v) Classical time is charged for the full night between nautical twilight and nautical twilight, independent of weather losses or losses due to equipment problems. The time is charged at a 75% rate. *E.g.*, for a 10 hour night, the time charged is 7.5 hours, independent of time lost to weather or equipment problems. Parts of classical nights may be used for queue observations if the conditions do not allow the classical program or its backup program to be executed. In practice, this decision most often is made by the PI of the classical program. In this case, the charge to the classical program is determined as the time between

[2]Baseline calibrations are calibration frames taken by Gemini staff in support of all queue programs. These data may be shared between programs and are distributed to the appropriate users. PI's programs are not charged for these calibrations. Any night time used to obtain baseline calibrations is charged to the partner country whose national TAC recommended the time (*i.e.* it is part of the partner's *executed* time and counts in the estimation of partner imbalance). The time is charged in proportion to the number of programs that receive the calibration data.

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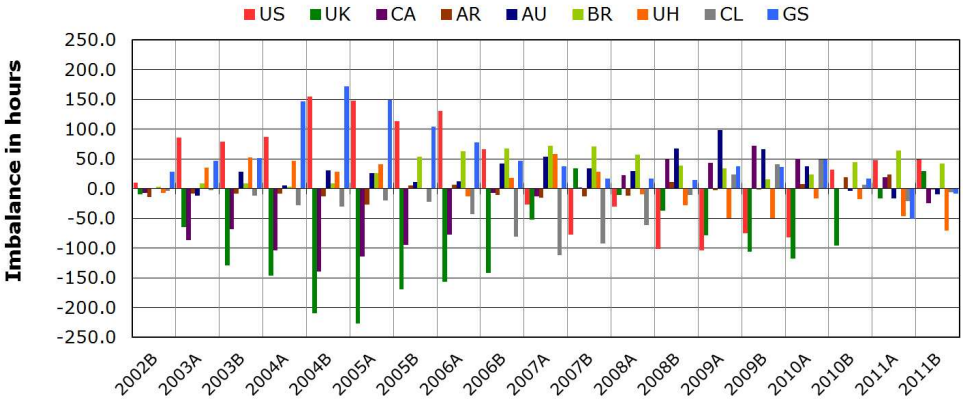


Figure 5. Partner imbalances (of executed time). Within each semester, the order of the histogram bars is as shown at the top of the chart. Above zero, the partner has accumulated too much executed time and an adjustment is applied to their available time in the subsequent semester.

nautical twilight and nautical twilight, less any time charged to queue programs. The time is charged at the 75% rate.

(vi) At the end of each semester the partner imbalances are calculated using the partner shares (with deductions for any time off the top for whatever reason).

It is important to note again the distinction between executed and allocated time. The time advertised for a partner in the call for proposals (and therefore available for the partner to allocate to their science programs) is the partner's nominal share of the available science time in the semester. This may be adjusted by an imbalance correction, calculated to reduce the partner's accumulated imbalance of executed time to zero over a reasonably short period of time. Fig. 5 shows the time development of partner-share imbalances over the past few years. A "closed-loop" correction method for the imbalances was implemented in 2007, leading to demonstrably smaller imbalances.

6. Outcomes, Issues and Possible Enhancements

Here we briefly describe the performance of the system described above, and lay out some known issues, some of which are inherent due to requirements set by Governance, others of which may be the subject of future enhancement.

Completion of programs: the main quantitative metrics set by the Gemini Board relate to completion of science programs. See Sect. 3 for a concise description of the meanings of the targets, particularly in Band 3. Fig. 6

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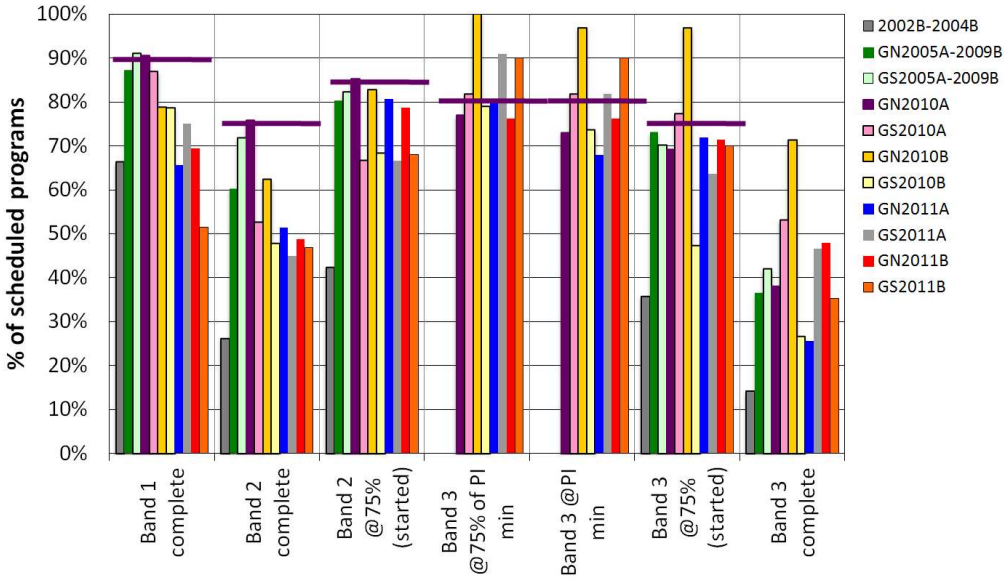


Figure 6. Completion rate of programs in the Gemini queues. Horizontal bars represent targets, where they are set by the Gemini Board. In each band category charted, the blocks are in the same order (shown in the legend): Gemini-wide completion for 2002B-2004B, North and South completion separately for 2005A-2009B, and then alternating North/South per semester up to 2011B. Note that the 2011A and 2011B values are not yet complete, as many Band 1 programs from those two semesters still retain rollover status into the 2012 Semesters.

shows the completion rate of programs over the past 10 years. This period includes the implementation of full multi-instrument queue observing in 2005, which immediately resulted in a significant improvement in completion rates. Multiple instrument use per night enables observing across a broad range of weather conditions.

The main current issue apparent in Fig. 6 is the relatively wide gap between target and actuality for programs in Band 2 in recent semesters. This is currently being addressed via revised queue filling (filling the queue to 80% of the available time by reducing the time allocated in Band 3). The outcome of this change is not yet known.

Labour intensiveness: the queue coordination process occupies the coordinator for at least four hours on an average day, even with the software tools available. Recent changes in time accounting (requiring less precision and not applying corrections for time discrepancies less than one hour) have saved a significant amount of time and will remain in place pending new software tools for the time accounting.

Effect of blocked time: At Gemini South since early 2011, significant

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amounts of time have been blocked from the semester as a result of instrument commissioning (for the infrared imager/spectrometer FLAMINGOS-2 and the multiconjugate AO system GeMS). These blocks are typically of order one week in duration. Although generally scheduled in bright time, they nonetheless appear to have had a negative impact on queue program completion as targets set irretrievably, etc. The inadvertent experiment that has been done with these blocks may be to demonstrate that with current Gemini South instrumentation, there is an upper limit to the amount of non-queue time for the queue to be effective.

Conditions constraints: As described in Sect. 2, PIs request that their observations be undertaken in particular conditions, specified as percentile bins (*e.g.* 20-percentile of image quality, occurring on average 1/5 of the time). While this provides a direct way of filling the queue to a level which would "work" in an average semester, it leaves room for the observation to meet the formal requirement but not to meet the PI's science needs (*e.g.* observations taken on an image quality 20-percentile night but at an airmass large enough that the target cannot be resolved). To be able to specify the required image quality in the bandpass of the observation would be an improvement, but one which with the current software infrastructure is not consistent.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 267-274
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SELECTING, SCHEDULING AND CARRYING OUT OBSERVING PROGRAMMES AT THE LARGE BINOCULAR TELESCOPE

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Abstract. The diverse LBT partnership allocates time through various partner-based mechanisms. Each of the four major partner groups receives blocks of observing time, with the fraction of the total proportional to its share of investment in the Observatory. The allocation is currently about one week per lunation per partner, but the week centered on full moon is for technical time devoted to commissioning of telescope and new instrumentation. The partners typically observe their own programs in queue fashion, with strong support from LBTO astronomers.

1. The Telescope and Its Instruments

The Large Binocular Telescope (LBT) is unique among telescopes in providing two optical trains with 8.4m diameter primary mirrors on a common mount. There will be three pairs of facility instruments for observing the same field of view on each side. They can be used as like pairs with identical configurations, as like pairs with different configurations, or as mixed pairs. The other main mode of observation is coherent combination of the beams from the two sides in one of two Fizeau interferometers, in mid-infrared and near infrared. The f/15 secondary mirrors are adaptive, providing compensation for atmospheric turbulence for the pair of near-IR facility imager/spectrographs and the interferometers. The Italian team integrating the system has demonstrated very high Strehl ratios on sky with their system.

The facility instrument complement consists of optical wide-field imagers, optical imaging multi-object spectrographs, and near-IR imaging

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multi-object spectrographs. The Large Binocular Camera (LBC) imagers produced by the Italian partners are at prime focus. Each is a 36-megapixel CCD mosaic. One is optimized for performance in the UV through green, the other in yellow through deep red. The optical spectrographs from Ohio State, MODS 1 and 2, are mounted at the direct Gregorian foci. Each is dual-beam, providing the option for full optical band coverage, or blue or red only. A cassette can be loaded daily with laser cut multi-object masks that are robotically inserted into the focal plane. LUCI 1 and 2 from the German partners can take near-IR images and spectra at seeing-limited and diffraction-limited scales. They are mounted at bent Gregorian focal stations. A cassette of custom-cut multi-object masks is inserted cold into the instrument, with masks robotically selected for observation. One cassette with 23 masks is loaded per lunation, covering three partner observing runs, as discussed below.

As of this writing, observers may choose from the pair of LBCs, MODS 1 and LUCI 1. MODS 2 and LUCI 2 are on track for lab acceptance in the last quarter of 2012. When they are fully commissioned, observers will have the option of choosing any combination of instruments, one from the left side and one from the right. The most straightforward observational mode will be 12-meter mode, where the same object(s) is observed with the same instrument and configuration on both sides. Any dithering will be done with the mount, and the exposure times will be identical for the instrument pair. The other extreme is using one instrument on one side and another on the other, with different MOS masks set at different position angles. The two sides can be run asynchronously, with small dither motions performed independently by each optics train, until the parallel sequences complete. All facility instruments are available all the time on "hot standby". The focal stations can be addressed by establishing the desired optical train. The prime focus cameras, AO secondaries, and tertiaries are all on swing arms to take them into and out of the telescope beams. The telescope can be dynamically rebalanced by pumping fluid among various storage tanks on the mount structure. The longest change takes about 20 minutes; rotation of the tertiary to address a different bent Gregorian port is a matter of minutes.

Two instruments are being developed to combine the beams coherently in Fizeau mode. The LBT Interferometer (LBTI) covers $2 - 11$ microns with two cameras, and has a nulling mode at longer wavelengths. It has recorded first fringes with both AO loops closed, and achieved fringe contrast very close to theoretical predictions. The plan is for science data collection for circumstellar environments by spring of 2013. LINC-NIRVANA will cover 1-2.5 microns, with both ground-layer and high-layer AO correction prior to the fringe tracker and science camera. The team will exercise one ground-

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Figure 1. A view of the Large Binocular Telescope on Mt. Graham through the open enclosure. Image courtesy of LBTO.

layer wavefront sensor in early 2013, with the goal of deployment of the full instrument in 2014.

There will also be a PI instrument PEPSI planned for commissioning in 2013 from the AIP in Potsdam that is a fiber-fed, bench-mounted echelle spectrograph with high dispersion and high stability. Its science goal is long-term synoptic monitoring of stellar activity, but the PI also intends to make time available to other observing partners for their programs.

2. Organization of the Observatory

The Large Binocular Telescope Observatory (LBTO) is a collaboration among institutions in Arizona, Italy, Germany, and the US. The fractional share of observing time for each partner institution is equal to the share it provided for construction plus the initial instrument complement. That fraction is also equal to the fraction of the annual operations budget supported by each institution.

The partners are as follows. The concept for the LBT was initially developed by the University of Arizona and the Arcetri Observatory in Florence, Italy, starting in the 1980s. Today, the University of Arizona is the interface for the 25% share belonging to the entire state university system, including Arizona State University and Northern Arizona University. Arcetri is

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one participant among the whole group of Italian astronomical research institutes with 25% share supported by INAF, the Istituto Nazionale di Astrofisica. The German 25% share is represented by the LBT Beteiligungsgesellschaft, which is composed of the Max-Planck-Institut für Astronomie (MPIA) in Heidelberg, the Zentrum für Astronomie der Universität Heidelberg, the Max-Planck-Institut für Radioastronomie in Bonn, the Max-Planck-Institut für Extraterrestrische Physik in Munich and the Leibniz Institut für Astrophysik Potsdam. The Ohio State University (OSU) has a 1/8 share. Research Corporation for Science Advancement (RCSA) supports the final 1/8 share on behalf of the University of Minnesota, the University of Notre Dame, the University of Virginia (UVa), the University of Arizona, and the Ohio State University.

3. Observing Time Allocation

At the time of this writing, the observatory is in transition from completion and commissioning to science operations. Observations are carried out for ten months of the year. Of that time, 60% is allocated to partner science and 40% to commissioning of the telescope and newly provided instruments. That split will be trending toward a higher fraction for partner science in coming semesters. Two months of the year are the summer monsoons in July and August. These typically have less than 30% workable hours, and are used for major upgrades and maintenance projects with daytime efforts that do not leave the telescope usable for nighttime operations.

The Director assigns nights in blocks to each major partner on a semester basis, with the semesters running from August 1 – January 31 and February 1 – July 31. (OSU and the RCSA partners are assigned time together in a single block.) There are three partner science blocks per lunation plus one commissioning block centered on full moon. A partner science block therefore averages six – seven nights in length, alternating among grey time with moon at the end of the night, dark time, and grey time with moon at the beginning.

The partnership has diverse scientific goals, and the partners put varying procedures in place to select and forward observing programs. They each select their own programs, and there is no consortium-level TAC. For INAF, the telescope is a national facility, so they issue national calls for proposals on a semester basis, which are read and ranked by a nationally constituted time allocation committee. The University of Arizona solicits proposals within the Arizona system (formerly by trimester but now by semester) and has a multi-institutional TAC for proposal selection. Their time allocation has a complexity, in that they have accelerated the commissioning of LBTI by allocating some technical nights within their science time blocks. That

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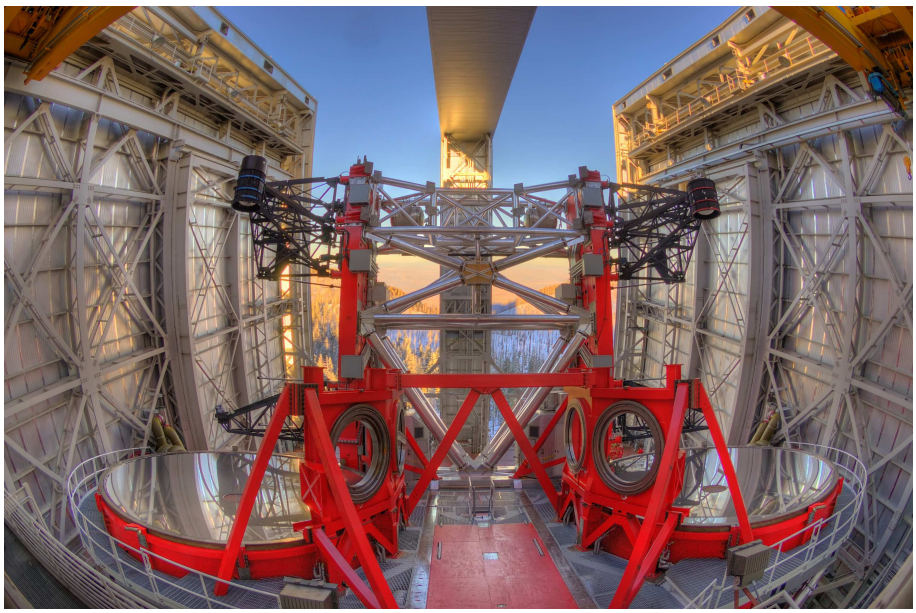


Figure 2. Interior of the Large Binocular Telescope (prior to installation of the main instrument complement) looking out at sunset. Image courtesy of Wiphu Rujopakarn and LBTO.

approach was required because of the higher priority claims on off-the-top commissioning time by facility instruments and telescope performance upgrades. The competition in these TAC processes heavily oversubscribes the time available.

At OSU, they have a call for proposals every semester, once the LBT schedule of partner science blocks is known. They have a TAC of four people evaluating the proposals and then issuing rankings (basically, Band 1, 2 or 3). Since they received some support for the building of MODS from the US National Science Foundation, a certain number of their nights will be made available to the US astronomy community through proposals to the NOAO TAC.

The RCSA partners have diverse approaches to time assignment. At UVa they have a TAC that consists of two faculty members. They solicit proposals once per semester, after the initial schedule is released. They make sure people are aware of the time and equipment constraints, so that proposals are realistic. Then they assign time in order of rank. They make small adjustments to assignments during a semester according to the priority ranking and completion statistics.

Notre Dame operates differently. To date, they've mostly had two groups using their time, so they've essentially divided the time, with some consid-

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eration for who had some time pressures for observations. Largely they reevaluate the needs before each OSU/RC run. That gives them a great deal of flexibility, especially for transient studies. Programs are approved by the individual PIs. The priority is set by consensus, based on who has a more pressing need, who has gotten more time recently, and what grad student projects need to make headway. The matching to the time available is done on a very rough basis, because we work within the OSU/RC merged queue. They therefore do not receive a set fraction of time being set aside per run, since that gets assessed on an annual basis, roughly. Notre Dame astronomers submit requests for a bit more time than they would nominally get on a given run, and they accept what actually gets observed. It is then up to the PIs to decide if they want to resubmit unobserved objects for the next OSU/RC run.

Currently the astronomers at Minnesota are in the Institute for Astrophysics within the School of Physics and Astronomy. They arrange time allocation by a semi-annual consensus activity whereby they match science needs and requirements based on deliverables necessary to meet externally funded program activities and support commitments. They have a similar issue to that of Notre Dame in that they cannot count on specific program completion in any given run, because of their inclusion in the larger OSU/RC queue.

The German LBTB partners also have a diverse set of time allocation procedures, depending on the individual institute. MPIA has an internal proposal process. The Center at the University of Heidelberg received some state and national grant money for construction of the LUCI instruments, so may ultimately need to make some limited time available to the broader university community. The programs for each observing block are prioritized and merged in advance by the LBTB Partner Coordinator, who is currently on the staff at the MPIA.

4. Program Execution

Partners tend to manage each of their blocks as a mini-queue. Partner observers come to the Observatory on Mt. Graham in southeastern Arizona, since there is not (yet) support for fully remote observing. At least one partner, LBTB, is experimenting with eavesdropping, where the PI of a proposal is online during its execution, so that s/he can interact with the observers and perform near real-time quality assurance on the data. The goal is, of course, to achieve the scientific objective, which can require some expert judgment, particularly when the data are being acquired under non-optimal conditions. The three facility instruments are always available, and it is routine to use two of them on a given night, depending on lunar phase

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and distribution of high priority programs in right ascension.

The advantage of the current arrangement is that each partner has control over the execution of their programs, and can manage completion of the highest priorities. Often one of the observers will be the PI on a major high priority program to be executed, adding to the probability of successful completion. The disadvantages arise from the limited scope of one partner's program for any given month. There can be uneven distribution of targets over the night and single high-priority programs calling for an instrument otherwise not used. Calibration overheads can be somewhat higher for the multiple configurations required with a variety of small programs. Although the Board that sets policy and the Science and Technical Committee have both discussed the option of a single merged queue, that has not been the chosen direction to date. Partners are free to combine or otherwise share their time, but they do so on a limited and case-by-case basis, primarily for time-critical targets.

A more challenging problem for all partners is having enough backup programs for non-optimal conditions. The excitement of access to the world's largest telescope prompts proposals that exploit its limiting capabilities in light-gathering power and angular resolution. Mt. Graham can have workable nights with bad seeing or reduced transparency that push long exposures under ideal conditions beyond the limit. The partners are beginning to develop the culture of soliciting proposals that can be successfully executed under less than ideal conditions, which should enhance the ultimate scientific productivity.

Partners are urged to send at least one expert and experienced observer for each of their blocks. Nevertheless, the instruments are relatively new and the telescope performance is being continually upgraded, with consequent changes to interfaces and new techniques to learn for efficiency and error recovery. Therefore, one of the three support astronomers spends the full partner block at the telescope assisting the visiting observers. In addition, they check the observing scripts in advance of the block, and provide feedback to the PIs for improvements in approach that make the program more likely to achieve the stated scientific goals. Formal manuals and performance updates are accessed by partner observers through an instrumentation website in the first instance, and a less formal wiki page in the second. A near term priority is to improve the online documentation, particularly to facilitate observing preparation. In parallel, the LBTO science support group will initiate the definition and production of a comprehensive observing planning tool. It will incorporate the best of the features provided by the instrument teams, and is intended to make observing script production more straightforward and observing sequences more robust (as guide stars follow dither patterns around the patrol field).

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5. Conclusion

The LBT is just coming to life as a scientifically productive facility. The ongoing challenge is creating the interfaces that will allow efficient exploitation of its unique capabilities: use of two facility instruments on 8-meter telescopes simultaneously, seamless integration of adaptive optics modes, and ultimately routine interferometric observations covering the Fizeau field of view.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 275-304
Ed. A. Heck, © 2013 Venngeist.

SELECTING, SCHEDULING AND CARRYING OUT OBSERVING PROGRAMMES AT SALT

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Abstract. This paper describes the manner in which Southern African Large Telescope (SALT) observations are carried out, from the observation proposal process to the final distribution of data to the SALT users. As a background, the general operational model for SALT is also described. In addition I discuss the main top-level design and performance characteristics of both the telescope and instruments, which informs the nature of SALT observing programmes and leads to a natural selection of competitive science projects. Since SALT is a 100% queue-scheduled and service-observing telescope, there is a significant level of flexibility regarding how observations are undertaken. A single observation block can involve different instruments and modes, including calibrations. To support the often complex manner in which observations can be configured, a set of observation proposal and planning tools have been developed for both users and support staff, and these are described in this paper. SALT users can plan their observations using these tools and submit their proposals over the internet in two phases. The Phase 1 proposal contains the scientific and technical justification and target information, but only a basic description of the instrumental and observation configurations. Following approval of the proposals, the Phase 2 proposal is completed which contains all of the details of every observing block, including configurations, exposure times, signal-to-noise requirements, time windows (if applicable), total block observation time and calibration requirements. How SALT observations are undertaken, monitored and reduced is also described.

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1. Introduction and History

The Southern African Large Telescope (SALT) is now one of five 10m-class segmented mirror telescopes, the only one in the southern hemisphere (Buckley 2006b). It is closely modeled on the pioneering design of the fixed-altitude Hobby Eberly Telescope (HET) at McDonald Observatory, Texas. HET and SALT represent a completely new design paradigm for optical telescopes (Ramsey *et al.* 1998, Buckley 2001), being analogues of the Arecibo radio telescope (although not zenith pointing). The SALT primary mirror consists of a 10m × 11m hexagonal array of 91 identical 1.2m × 1.0m hexagonal mirror segments with spherical surfaces with a radius of curvature of 23.2m, tilted 37° to the zenith. This array directs light to a 4-mirror spherical aberration corrector (SAC), mounted on a moving tracker at the prime focus. The telescope can only access an annular region of the sky, 12° wide, centred at the zenith, which represents ∼12% of the instantaneously visible sky at an airmass of <2.5 (see Fig. 1). This geometry implies that only objects in the Declination range +10° to -75° are observable, and the total uninterrupted observation times typically range from 1-2 hours, although they can be extended to 4-5 hours at the extreme Declinations if the telescope is re-pointed in azimuth. This design also implies that the entrance pupil of the telescope (11m in diameter) is not fixed on the primary mirror array, but rather moves over it during the course of an observation. This means that the effective aperture varies during an observation, at worst being equivalent to an un-obscured 7m diameter mirror, and at best (centred pupil) equivalent to a ∼8.5m diameter mirror. This changing pupil also poses additional complexities when it comes to calibrations, which require a calibration system which can mimic the pupil geometry of the on-sky observation.

SALT is owned by a private Foundation, set up to fund its construction and operation, which represents a collaboration of universities and institutes from Africa, India, Europe, New Zealand and North America. The South African National Research Foundation is a majority shareholder with ∼33% of the current observing shares. Other major shareholders are Dartmouth College (9%), University of Wisconsin-Madison (15%), Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences (9%) and Rutgers University (10%). Other shareholders (at < 6% level) include the American Museum of Natural History, Carnegie Mellon University, the Indian Inter-University Centre for Astronomy and Astrophysics, University of Canterbury, University of North Carolina, Göttingen University and the UK SALT Consortium, the latter representing the Universities of Central Lancashire, Keele, Nottingham and Southampton, the Open University and the Armagh Observatory. The percentage shareholding as mentioned above

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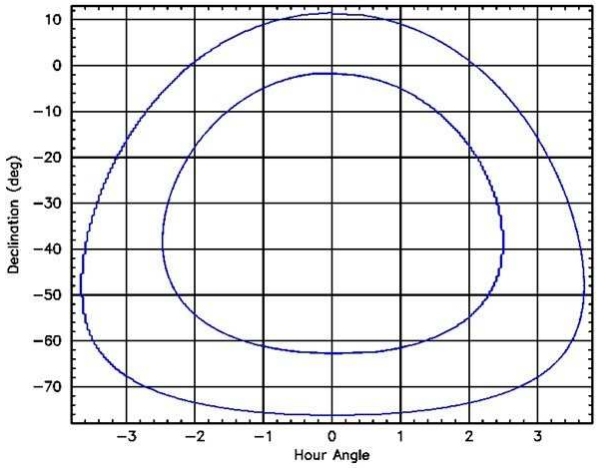


Figure 1. The SALT visibility annulus. Only objects inside the annulus are visible to SALT.

(as at May 2011) do not quite reflect the percentage allocation of SALT observing time, since there are additional allocations over fixed periods for in-kind contributions to the project, one example being for the HET Consortium, for intellectual knowledge and assistance provided for the design of SALT.

Participation in SALT was attractive to its partners for a number of reasons, the most signifcant being:
• access to a 10-m class telescope, at an affordable cost, with versatile observational capabilities;
• access to the southern hemisphere;
• affordable ownership (∼$20M for telescope; ∼$8M for first-light instruments; ∼$3M per annum for operations);
• a good observatory site (50% photometric; 75% spectroscopic; 0.9 arcsec median seeing; dark; dry);
• synergies with other facilities accessible by SALT partners (*e.g.* HET, WIYN, SOAR);
• relatively inexpensive and flexible queue-scheduled service operations;
• assisting in the development of science & technology and educational opportunities in South Africa.

2. Completion and Commissioning

SALT was inaugurated in November 2005, when the construction phase was essentially completed (Buckley *et al.* 2006a). Two of the First Gen-

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eration instruments, were mounted on the telescope and a third was still in its planning stages. Following this, SALT entered an intensive period of commissioning and performance verification, which included the initial science observations. "First Science" was announced in 2006, following the beginning of commissioning in mid-2005 of the UV-Visible imaging camera, SALTICAM (O'Donoghue *et al.* 2003), which culminated in the first SALT science paper (O'Donoghue *et al.* 2006). In parallel, the commissioning of the Robert Stobie Spectrograph (RSS; formerly known as PFIS; Burgh *et al.* 2003), began in October 2005 and continued through to November 2006 (Buckley *et al.* 2008). RSS is a versatile, but highly complex, imaging spectrograph, supporting multiple modes, namely:

- Longlsit and Multi-Object Spectroscopy from 320-900nm using a suite of fully tunable VPH diffraction gratings;
- Fabry-Perot imaging spectroscopy, including dual etalon and tunable filter modes;
- Polarimetry, both imaging and spectro polarimetry, in linear, circular or all-Stokes modes;
- High time resolution observations, by virtue of frame transfer CCDs.

It was during this commissioning period that problems with the telescope's image quality and the throughput of RSS were uncovered, which led to the eventual removal (in November 2006) of RSS for optical repairs (Nordsieck *et al.* 2010).

Despite the problems with image quality, SALT was scheduled regularly (∼50% of nights) for science observations from 2006-2009, although there was still significant continuing engineering work being carried out by the operations team, much related to various subsystems not fully completed before the Project Team left in late 2005/early 2006. Three major performance issues were uncovered during commissioning: the aforementioned problems with telescope image quality and low spectrograph throughput, and the failure of the capacitive mirror edge sensor system to meet its design specifications. The first problem culminated in a 15-month engineering downtime from April 2009 in order to effect opto-mechanical modifications to the SAC, in order to improve the telescope's image quality (O'Donoghue *et al.* 2010). This was completed by mid-2010 when the telescope became operational again. In the meantime the RSS optics were also removed and the throughput issues addressed (Buckley *et al.* 2008; Nordsieck *et al.* 2010). Modifications were also made to improve the performance of SALTICAM.

Both RSS and SALTICAM were re-installed on the telescope in early 2011 and science commissioning programs were initiated to characterise the performance of the telescope and instruments (Buckley 2012). This phase transitioned into the first science semester in September 2011, when 75% of the telescope time was set aside for charged science time for the SALT

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partners. The remaining 25% of the time was retained to complete the commissioning of outstanding instrument modes. A total of 144 proposals were accepted for this first semester and as at the end of the semester, the average completion was just ∼55%. The reasons for such a low completion rate were due to several factors:

1. A 40% increase in the time lost to weather;
2. Unavailability of certain modes due to incomplete commissioning or subsequent instrument problems;
3. Difficulty with attempting some programs which were pushing the current limits of the telescopes and instruments;

The last points are currently being addressed and indeed some progress was made for Item 2, with the first successful MOS (Multi-Object Spectroscopy) commissioning observations beginning towards the end of the semester.

3. Designing to Science and Operations Requirements

For SALT much effort and thought went into correctly defining the top-level "science requirements" of the telescope as a whole and then the specifications for the SALT system, subsystems and their constituent components. In addition, the entire design process is one based upon systems engineering: an iterative process whereby the high level goals or requirements of the astronomers were converted or translated into a set of technical specifications (Swart & Buckley 2004). The engineers responsible for the latter needed to trade off such things as performance, cost and schedule to arrive at a suitable solution which, in the first instance, satisfied the top-level requirements. The outcome of this process was that the astronomers and engineers arrived at a revised set of overall specifications, which were broadly acceptable scientifically and conformed to the various budgetary, technical and schedule constraints imposed on the project. This iterative process of compromise continued until a satisfactory solution was found, ideally with enough margin for de-scope options, should they have been necessary, to alleviate potential future contingencies.

While a systems engineering approach was crucial for successful design, it also played a role in subsequent phases of the project, particularly in the integration and implementation stages. Here it is often necessary to revisit choices made during the design phase in order to address technical or schedule difficulties. The evolution from high-level goals, or requirements, through to the final development are many and varied, and typically involve a sequence of steps and feedback loops. These vary according to the design complexity, whether the technologies are established or novel, and issues relating to funding, legal, and partner/shareholder agreements, etc.

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TABLE 1. Telescope efficiency comparisons.

Telescope	**Bad weather**	**Faults**	**Engineering & Calibrations**	**Science time (incl. overheads)**
SALT (by design)	25%	3%	7%	65%
SALT (May 2012)	35%	13%	12%	40%
HET (2001)	30%	6%	20%	44%
Keck*	16%	4%	11%	69%
Gemini*	20%	3%	10%	67%
VLT*	12%	3%	5%	80%

* circa ∼2004

In addition to the science driven requirements, which determined many of the design specifications at the system and subsystem level, operational considerations also had to be considered in defining these specifications. These included those relating to the scientific productivity and efficiency, like the telescope scheduling, remote observing, data handling, processing and archiving, creation of observing proposals and observing scripts, etc.

4. SALT Operational Criteria

In designing SALT, the basic overall operational criteria aimed at for the total system (*i.e.* telescope) can be condensed into several key efficiency parameters, as presented in Table 1. The figures in table apply to several telescopes at different times. The HET figures were for the initial operating science operations, before mirror edge sensors were installed. Thus the larger fraction for "Engineering & Calibrations" reflects the additional regular loss of observing time needed for mirror alignment, which can amount to 10-20% of a night, depending upon conditions.

A new mirror segment edge sensing system has been designed, based on inductive sensor technology, and is expected to be installed over the next two years. This will reduce the need for optical alignments (using the Shack-Hartmann wavefront camera at the mirror array centre of curvature) of the mirror array to several times a night, to once every ∼5 days. In principle the alignment can also be started during twilight and even in overcast (but not precipitating!) conditions, which will help in lessening the impact on science operations. SALT's design goals with an active mirror control system using edge sensors and actuators, reduced this loss – by design – to 0%, but the current lack of this on SALT reflects this larger fraction as at May 2011.

Calibration observations are somewhat of an unknown at present, al-

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though it is clear that such observations will need to be done both during the night (*e.g.* spectral calibrations with arc lamps) and during the day (*e.g.* flat fields simulating the pupil motions of completed observation). SALT's instruments, particularly the main work-horse instrument, the Robert Stobie Spectrograph (RSS), will have various observing modes, and potentially many such modes will be used in a single night, all requiring relevant calibration observations.

In all aspects of both telescope and instrument design, the operational philosophies adopted have been purposely developed for a queue scheduled operation where getting to the target and observing it in whatever available instrument mode happens in the fastest and most efficient manner. In addition, instrument mode changes (*i.e.* from SALTICAM to RSS) can take place by simply inserting a fold mirror (< 60s).

5. Operating SALT

The South African Astronomical Observatory, the national facility for optical/IR astronomy in South Africa, has been contracted by the SALT Foundation to operate and maintain SALT, for an initial period of ten years (until 2015). The SAAO, which was founded in 1972, owns and operates its major observing station near Sutherland, in the arid central Karoo region of South Africa, ∼380km north east of its headquarters in Cape Town. Apart from SALT, nearly 20 telescopes, ranging from 0.042 to 1.9m in diameter are operated at the site. Many of the more recent additions (*e.g.* KELT South, MONET South, SuperWASP, SOLARIS) are robotic telescopes. Five telescopes, namely the SAAO 1.9, 1.0, 0.75 and 0.5m telescopes and the 1.4m Japanese IR Survey Facility telescope (IRSF), are scheduled and operated in the traditional manner, i.e. with weekly allocations to a specific astronomer.

The obvious departures, brought about by SALT, from previous experiences in operating the smaller SAAO telescopes includes the 100% queue scheduled 'service observing' mode in which SALT operates. In addition, the telescope is of such a different and complex design that the experience of SAAO's older and more conventional equatorially mounted telescopes provided little experience in knowing how to efficiently operate and maintain SALT. Indeed many of the SALT subsystems have used new technologies which had not previously been used at SAAO. Examples included:

- Active optics control (*i.e.* the primary mirror system of edge sensors and actuators);
- The primary mirror optical alignment system (*i.e.* the Shack-Hartmann wavefront sensor);

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- Embedded control systems, precision actuators, sensors and associated control software;
- The LabVIEW graphical programming language, which is at the heart of the subsystem controllers and the Telescope Control System (TCS);
- Experience in web-based software (*e.g.* Java), queue scheduling software and database design and management;
- Operational experience with interferometers, optical alignment procedures, etc.

Many of the skills required for the above were subsequently acquired through a combination of appointing new experienced engineering and technical staff and training existing SAAO staff. This has resulted in the appointment of a core of 10 sufficiently qualified engineering staff within the SALT Technical Operations division (established in 2005), based at SALT, and supported by an additional logistics staff of five. The skills within the division cover all of the major disciplines required for supporting and developing a modern telescope, namely optical, electronic, mechanical and software engineering, mechatronics, information technology, etc. The SALT-based operations staff are also supported by six additional personnel, mostly based in Cape Town, who focus on software support (three), drive many of the current engineering developments (three), and also support technical operational activities at SALT as needed.

The scientific support staff for SALT reside within the SALT Astronomy Operations division of the SAAO, consisting of eight astronomers and a supporting software developer, plus three telescope operators. Most of the staff are based at the Cape Town headquarters of SAAO and astronomers are regularly scheduled (typically one week in six) for SALT support on a rotating roster arrangement. The operators, who are mostly based in Sutherland, are scheduled one week in three, but also have some daytime responsibilities during non-observing weeks. Each duty SALT Astronomer (SA) and SALT Operator (SO) spend seven full nights at the telescope, plus an additional half night during the weekly transition period. The SALT duty astronomer is supported by a Cape Town based support astronomer during their week, who checks on issues like data transfers from Sutherland to Cape Town, completion of the automatic data reduction pipeline, basic data quality checks and the distribution of data to the SALT users. Additional support duties undertaken by the SALT Astronomy Operations group includes:

- Assisting users in writing observing proposals, performing technical reviews of proposals, and liaising with the different partner Time Assignment Committees (TACs);
- Liaising with the Principal Investigators (PIs) of SALT proposals in formulating their observations, performing technical reviews of proposals, assisting with data reduction enquiries and general trouble shooting;

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- Supporting the operational modes of the telescope and instruments by characterizing the current performance and assisting in the development of the data reduction pipeline for different instrument modes;
- Assisting in instrument and telescope commissioning, performing tests and updating information on the websites, wikis, etc.;
- Developing software tools for users (*e.g.* instrument simulators) and support astronomers to monitor program progress, schedule observations, update status and interact with the SALT Science Database;
- Undertake miscellaneous observatory duties, including such things as outreach activities (to users, students, the public), involvement in graduate student teaching and supervision, involvement in other SAAO activities (*e.g.* instrumentation projects);
- Monitoring and reporting of the general performance of the observatory in terms of key performance parameters (*e.g.* system throughput, image quality) and completion statistics for observing programs;
- In addition to the above duties, SALT Astronomers are given time (nominally 40%) to undertake research, focusing on the utilization of SALT.

The systems engineering approach used in constructing SALT has assisted in ensuring that the telescope, which is a complex machine involving many subsystems, is a well integrated system which can be operated easily and efficiently. One crucial area is the overall science efficiency of the telescope, which is affected by such things as how quickly the telescope can move from target to target. The design of the Telescope Control System (TCS) GUIs (Graphical User Interfaces), which both the SALT Operators and Astronomers use to control the telescope and its subsystems, are designed with ergonomics and efficiency in mind. The overall maxim is to be able to issue commands with the fewest number of mouse clicks or keyboard entries.

6. SALT Science Observations

Unlike all of the existing SAAO telescopes, the approved observational programs undertaken with SALT are not conducted by their respective proposers, but rather by SALT astronomy operations staff, namely the SALT Operator and SALT Astronomer. The manner in which a typical observation with SALT progresses, from the proposal phases to the relevant Time Allocation Committees (TACs; see Table 2), and then through to the eventual observation, quality assessment and data dissemination are summarized in the Tables 3 & 4. SALT users can apply for SALT observations twice a year, with observing semesters running from 1 May – 31 October and 1 November – 30 April.

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TABLE 2. The full SALT proposal sequence.

Step #	Activity	Description
1	Complete Phase I web-based proposal form using a basic template	Write scientific justification and use web based tools to ascertain viability
2	Submit Phase I proposal	Send to SALT Astronomy Operations
3	Phase I technically reviewed and sent to respective partner TACs	Phase I proposals loaded into database. SALT Astronomy Operations perform tech feasibility & determine statistics
4	Phase I proposal reviewed and time allocated	PI alerted of allocation
5	Complete Phase II web-based proposal form	More detailed time-line and telescope and telescope and instrument configurations defined; SALT Astronomers (SAs) check viability, etc.

The observational efficiency of SALT is mostly determined by the time it takes various telescope and instrument subsystems to perform their respective tasks and the two basic timescales, as specified in the SALT Systems Specification, namely slew time to target (<180 s) and setup time to begin observations (<360 s). The telescope slewing involves the parallel execution of several TCS commands (*e.g.* dome rotate, structure rotate, tracker position, payload configuration). Most of these commands are transparent to the SALT Operator, who will simply issue a command to 'go to next target' via a single mouse click on a GUI, rather than issuing a sequence of subsystem commands. The observation set up time includes closed loop guidance and focus initiation and instrument set ups (*e.g.* alignment of targets on slit masks). SALT Astronomer and SALT Operator actions involving the observation itself occur in parallel, like the assessment of data quality (*e.g.* S/N ratio, spectral resolution, flux) and adjustment of the observing schedule as conditions or circumstances change.

An observation block (the smallest scheduled unit of a program) will more often than not consist of a set of repeat exposures, during which the data quality of the penultimate observation can be assessed in real time as the current observation is still in progress using the quick-look analysis tool (SALTFIRST; see Section 13 & Fig. 5). Adjustment of subsequent exposure times, as necessary, is then possible, provided the observation block time

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TABLE 3. The full SALT observation process.

Step #	**Activity**	**Description**
1	Plan weekly observation priorities	look at viable programs for coming week; coordinate any engineering activities; define required filters/etalons for the week
2	Schedule observations, including calibrations	Review target availability (continuously during the night) and observing conditions; schedule suitable observing block(s)
3	Prepare to observe	Select specific observing block/target; send info to Observation Control System (OCS)
4	Acquire target; configure instrument; focus; acquire and setup guide/focus star	Point telescope and guide probes
5	Conduct observation	Take any requested calibration observations if requested (*e.g.* arcs); begin on-sky observations
6	Monitor observation	Check telescope guidance & focus; Run quick-look data reduction tool SALTFIRST; assess data quality (e.g. S/N)
7	Complete observation; store and transfer data; complete logs	Data copied to quick-look & quality control computer (QCPC); complete on-line logging logging as required
8	Primary mirror alignment	Assess delivered telescope image quality; monitor seeing; optically realign mirror
9	If observing conditions acceptable, go to step 3	Assess weather, seeing, transparency

is not exceeded. Many observations have observing blocks closely matching the maximum allowable track time (as determined by the target position and time), inclusive of any acquisition and setup overheads (typically 300-600s depending on complexity).

SALT observations are scheduled in real time by running the Observa-

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TABLE 4. Daytime SALT astronomy operations

Step #	**Activity**	**Description**
1	End of night procedures	Do twilight calibrations (observe standards) if appropriate; park telescope & instruments and close down
2	Plan and schedule day calibrations	Mainly for accurate flat fielding using moving pupil baffle
3	Data delivery and problem solving	Check data was sent to Cape Town HQ & pipeline completed OK; look at night logs; contact PIs if needed; liaise with Tech Ops staff

tion Planning Tool (OPT), a LabVIEW program which interrogates the MySQL Science Database (SDB) which contains all observing program information. A search can be made of all active observing blocks currently accessible to SALT, and the resulting list can then be filtered to select appropriate programs (*e.g.* for the current Moon, seeing and transparency conditions). The start/end track times are displayed, as well as other information, and the SALT Astronomer (SA) can then select appropriate observing blocks and add them to a schedule. This schedule can then be sent to the SALT Operators control GUI from which the telescope can be pointed to a particular object with a single "point to target" command, which command the Telescope Control System. This sets in motion all of the various telescope subsystems to move the telescope to the target. In parallel, the SA can load the defined instrument configuration for the observing block into the Observation Control System, which configures the instrument (*e.g.* selects and inserts appropriate grating, filter, etalon, slit and rotates to the requested grating and camera angles, and position angle). The OCS is a sophisticated tool which allows for telescope – instrument communications, for example setting up dithering patterns, control nod & shuffle modes, etc.

A graphical display of the observing blocks is also now provided by a GUI, based on the SALT visibility plot (Fig. 1), which displays the instantaneous positions (at any given time) of all active targets, colour coded for project priority. This allows, at a glance, the SA to see which alternative programs are available, or will be available soon, or will be lost from the visibility annulus. Blocks can also be filtered on current observing conditions.

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7. SALT Proposal Submission Tool

Observing with SALT involves three separate phases. In phase one the Principal Investigator (PI) uses the Principal Investigator Proposal Tool (PIPT) to submit a proposal containing a scientific justification and basic information about the planned observations. Submitted proposals are stored in the Science Database (SDB). The Time Allocation Committees of the partners included in the proposal use the Web Manager (see Section 11) to view the proposal and to allocate observing time to it. In phase two the PI downloads the accepted proposal (together with the information how much time has been allocated to it) into the PIPT, adds the detailed information required by SALT Astronomy Operations for performing the observations and resubmits the proposal. In the third and final phase the SALT Astronomers carry out the requested observations, and the observational data, and ancillary information (*e.g.* environmental and guide star data) are made available to the PI through a data download FTP site and eventually through a Web Manager interface, accessible through any internet browser.

Various tools are provided to aid the PI in planning the observations: instrument setups can be configured with the SALTICAM simulator and the RSS simulator. The availability of targets can be checked with the Visibility Tool. Slitmasks for multiple object spectroscopy (MOS) with RSS can be created with the RSS Slit Mask Tool. These tools are explained in detail in the following sections (Sections 8, 9 & 10). With the exception of the Web Manager, all the tools are Java applications and can be downloaded as a Windows executable, a Mac OS X application or a platform-independent jar file[1].

Observation proposals for SALT are submitted as XML documents. While these could in principle be written manually, due to the complexity this would be an extremely cumbersome task. The XML creation is therefore handled by the Principal Investigator Proposal Tool (PIPT), a Java application. This tool maps the XML of a proposal to a hierarchical tree structure, which can be used for navigating the proposal content. Each node of this navigation tree links to a form for entering proposal details. As mentioned in the introduction, the PIPT is used for both proposal phases, with the Phase 2 proposal tool requesting more details on observation blocks, instrument configurations, etc. At top level, the navigation structure includes four types of information.

Firstly, **general information**, such as the Principal Investigator and contact person, an abstract and a scientific justification need to be defined. The scientific justification is imported from a PDF and is displayed as a

[1] `http://www.salt.ac.za/wm`

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thumbnail image. Template proposal forms (*e.g.* in MS-Word and LaTeX) are available to PIs, who fill in sections (with word limits) covering the following:
1.) a *scientific rationale*,
2.) *immediate objectives*,
3.) *technical justification*,
4.) a *summary of previous SALT results*, and
5.) the *role of the PI* (only for South African proposers).

Secondly, the **contact details** of all the investigators must be supplied, although there is functionality to automatically insert these details from the Science Database if a given email address is contained in the database already. Third, each observed target has to be defined. In case of a target with a non-sidereal motion (such as an asteroid), a file containing a list of dates and times and corresponding positions must be supplied, which is submitted along with the rest of the proposal. Objects with high proper motions are also catered for. If a chosen target name already exists in the database, the PI is notified and can view the target information from the database. A name resolver which checks the SIMBAD database is used to automatically populate target information for an already catalogued object. A proposal with existing target names can only be submitted if the target information in the database is consistent with that in the proposal.

For Phase 1 proposals, only a table of target names and positions need to be completed in the Phase 1 form, including the Moon conditions required for each. Other conditions, like maximum seeing and degree of atmospheric transparency are also stipulated for the proposal as a whole. Both mandatory and optional targets are allowed, where the latter are a list of up to 50 targets (with potentially different priorities), from which a subset is expected to be observed, the choice of which is entirely up to the SALT Astronomers, for flexibility. The last information supplied in the Phase 1 proposal is a list of instrument modes and configurations.

Once a proposal is accepted by the TAC, PIs can then complete their Phase 2 proposal, starting by converting their existing Phase 1 proposal, thus avoiding the need to duplicate information already entered. The major additional information added in the Phase 2 proposal is:
1.) finding charts for all targets or fields, for which a tool is provided to generate these in a standard format (see Fig. 2),
2.) guide star information (optional),
3.) observation block definitions, including instrument and observation configurations, and
4.) calibration requirements (*e.g.* arcs, flat fields), whether done immediately prior to or after the observations (which are charged), or during twilight or daytime (which are free).

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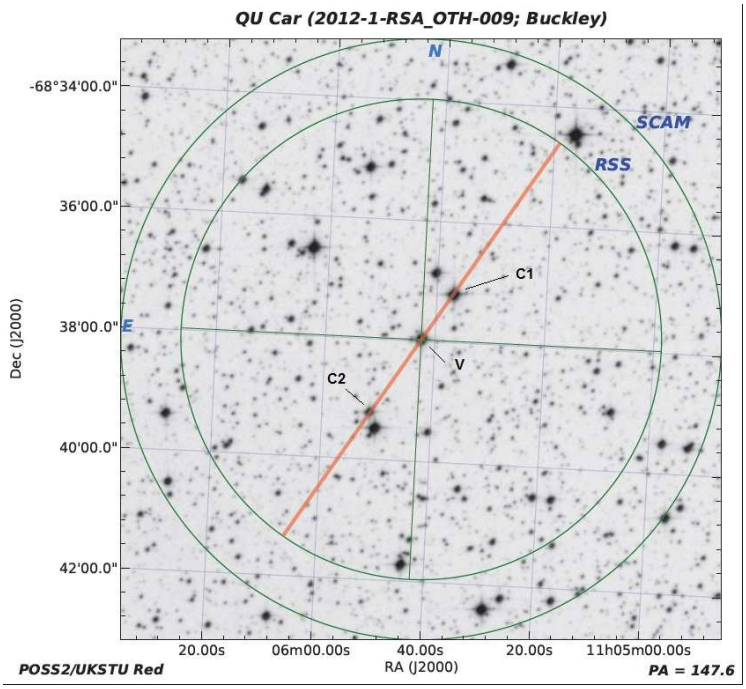


Figure 2. An example of a finding chart generated by the SALT finding chart tool, showing the field of view of the two current instruments (SALTICAM imager and the RSS spectrograph), with the slit position for the latter indicated.

Observation blocks are the smallest schedulable unit, and contain one acquisition observation and a list of science observations, potentially with different instruments/modes and repeat exposure iterations or cycles of repeated configurations (*e.g.* filter cycles). Each observation in turn contains a list of instrument configurations. The software checks total observing time for a block doesn't exceed the maximum track length available for the observed target.

When proposal information is entered, the PIPT checks whether it is valid. If it isn't, the new value is rejected and the user is presented with a message dialog explaining the error. On a similar note, values which are technically correct but likely to be wrong are flagged as such. The PI is shown a list of warnings for these values before the proposal is submitted. Missing values are highlighted both in the input form and in the navigation tree. Most information entry boxes in the tool have a "help" text box which pops up when the cursor hovers over the box.

After finishing the proposal the PI can use the PIPT to submit it. During this submission process the proposal is validated, the PI is shown the list of any warnings in the proposal, it is checked whether there are any

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inconsistencies between target information in the proposal and in the SDB, and a summary of the proposal structure is shown to the user. A submission is only possible if the proposal is found to be valid, but not all warnings necessarily invalidates submission. The submission itself consists of collecting the proposal XML, scientific justification, finding charts, target data files and slitmask files (see Section 10) in a single zip file and then sending that file to a server at the SAAO via an HTTP request. After unzipping the file, the server checks that the proposal is valid and that the submitting PI is allowed to submit. If that is the case, it maps the XML to the SDB by means of the Mapping Tool, an external Java application. Otherwise it sends back an error message to the PI.

While the schemas for describing a proposal and its instrument configurations and the structure of the SDB have been designed to be as similar as possible, there are still considerable differences. These are mainly due to the discrepancy between XML and SQL, but also due to their different operation purposes – the XML needs to work closely with the PIPT, whereas the SDB is the basis for operating the telescope. This makes parts of the Mapping Tool quite complex and a reverse mapping impossible, *i.e.* no XML file can be created from the SDB. Not all the data of a proposal is written into the SDB. Files like finding charts and scientific justifications are kept in the file system and are linked to from the SDB.

If the mapping is successful, an email notification is sent to all the investigators and a proposal code identifying the proposal is returned to the PIPT. The PIPT then inserts the proposal code into the proposal. On the other hand, if the mapping fails, an error message is sent back.

8. SALT Visibility Tool

As mentioned in Section 1, due to the fixed elevation angle of SALT's primary mirror (37°), target visibility is constrained to an annulus in the sky. The available "track length", *i.e.*, the amount of time SALT is able to follow continuously any given target, changes according to date, time and target position on sky. In order to check the visibility and available track length the PI may use the SALT Visibility Tool, a Java application which can be launched from the PIPT or run as a standalone tool. After the observation date and the target location has been entered, this tool displays a plot of the target visibility during the specified night. If the PI clicks in this plot, the track length available from the clicked time onwards is calculated (see Fig. 3).

The inverted parabolic curve shows the location of the target as a function of time. The target is visible if it is located in the horizontal shaded area, defined in the airmass range ∼1.16 (elevation = 59°) to 1.37 (eleva-

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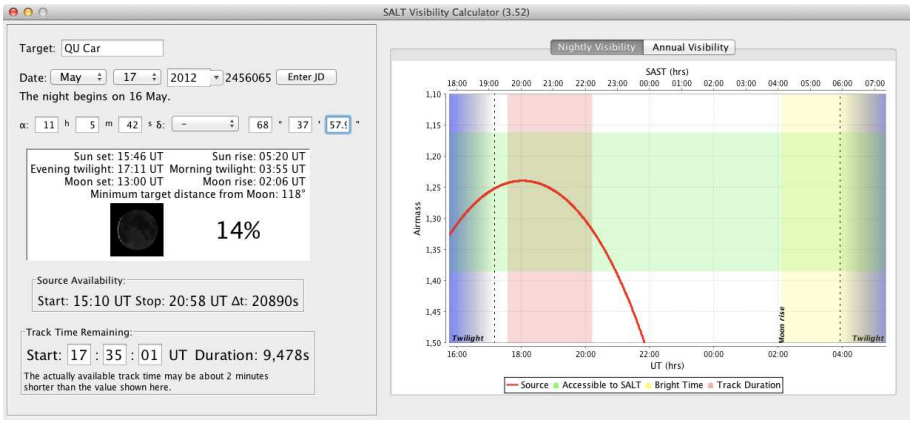


Figure 3. The SALT Visibility Tool, used to see when and how long objects are visible to SALT on a given night.

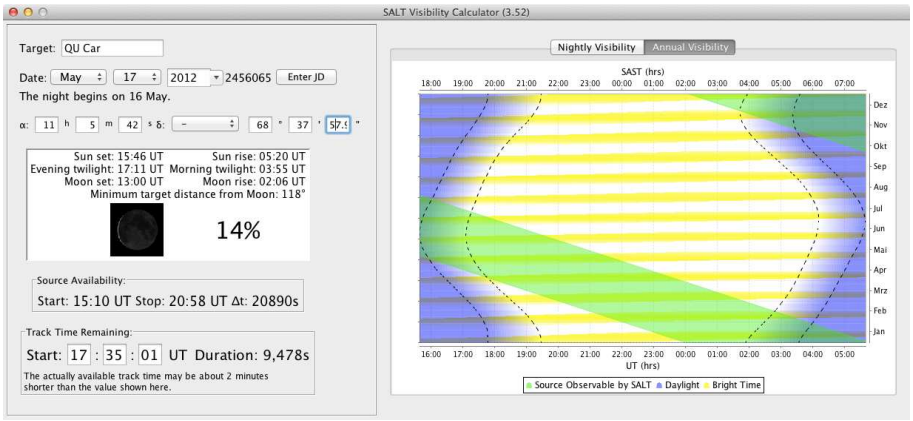


Figure 4. SALT Visibility tool showing annual visibility of a target (green diagonal strips) and the periods when the Moon is above and below the horizon (yellow and white horizontal bands).

tion = 47°). The available track length is highlighted by a horizontal shaded area and is also given at the bottom left of the window. Other quantities shown in the tool for the given date are the sunrise and sunset times, the start and end times of the evening and morning twilight, the moonrise and moonset times, the lunar phase and the minimum angular distance between the target and Moon. Furthermore, the Visibility Tool contains a plot displaying the visibility over the course of the whole year (Fig. 4), including when new and full Moon occur.

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9. Instrument Simulation Tools

In order to plan an observational setup with any of the SALT instrument, PIs can use the respective Java simulation tools. Currently they exist for the two First Light instrument, SALTICAM and RSS. These tools can be run as a standalone application, but it may also be launched from the PIPT. The simulation is a two step process, the first step being to define a target spectrum. The simulators offers the user a choice from a list of asteroid, blackbody, galaxy, stellar atmosphere (Kurucz models) and power law spectra, some of which may be further customized. In addition, spectra may be imported from an ASCII file. The user may superpose an arbitrary number of these spectra to model a more complex composite target spectrum. A redshift can also be applied to the target spectrum.

Along with the spectrum, the location of the Sun and Moon relative to the target, the lunar phase and the year of observation have to be specified, as these are required for the background calculation. The sky background used for the SNR calculation is made up of three components. First, the airglow, based on a high resolution moonless sky UVES spectrum (Hanuschik 2003) which has been corrected to the dark sky at Sutherland. Second, the zodiacal light contribution is obtained by normalizing the solar spectrum at 550nm, correcting for atmospheric extinction, and multiplying by a fit of zodiacal light photometry by Levasseur-Regourd & Dumont (1980). Thirdly, if the Moon is above the horizon, the simulated moonlight is based on a model for the V-band brightness of moonlight (Krisciunas & Schaefer 1991), extrapolated to other wavelengths.

Both the target and the sky spectrum are represented by arrays of flux values for an equidistant grid of wavelengths. The propagation through the telescope and instrument is simulated by applying the mirror efficiency, losses for the optical elements and the detector quantum efficiency to these flux values.

The second step is to provide the instrument setup details, for either SALTICAM or RSS. If the simulators are launched from the PIPT, updates made in the simulators are automatically reflected in the PIPT, and vice versa. After supplying all the information, the PI may calculate the expected photon count rates as well as the signal-to-noise ratios ("SNRs") for the given exposure times. The next step is to select the observation mode (*e.g.* various imaging modes for SALTICAM and imaging, spectroscopy or Fabry-Perot in the case of RSS) and provide the required setup information.

When launching the simulator from within the PIPT, the instrument configuration defined in the PIPT will automatically be used by the simulators. In case of spectroscopy the simulator displays the wavelength coverage of the CCD as well as the resolution for the selected grating, grating angle

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and camera angle, and it also suggests an appropriate order-blocking filter to use for the setup.

The third and final step is to specify the exposure time and detector setup, including the pixel binning parameter, gain setting and readout speed. After all information has been supplied, the PI may calculate the expected photon count rate as well as the S/N ratio for a given exposure time. In case of a spectroscopic observation, the detection rate and the S/N are plotted as a function of the wavelength. Wavelengths for which more than 5% of the second order light is let through the order blocking filter are clearly marked in these plots.

Alternatively, the PI may calculate the required exposure time for a requested SNR. If the latter is done for spectroscopy, the PI may specify the wavelength for which the SNR is given. In this case the expected detection rate is plotted as a function of the wavelength, and the expected SNR is plotted as a function of the exposure time. As above, order contamination is indicated in the detection rate plot. Irrespective of whether the exposure time or the SNR is calculated, it is shown, either defined per bin or per resolution element. Here the size of the resolution element is calculated from the grating equation, taking anamorphic demagnification into account.

10. The SALT Slitmask Generation Tool

When requesting an RSS observation with multiple object spectroscopy (MOS), the PI has to design the slitmask to use. This is used to generate the required g-code used to laser-cut slitlets, typically up to $\sim$50, in a thin (200μ) carbon fibre mask. This can be created with the RSS Slit Mask Tool (RSMT), a standalone Java application based on JSky[2].

The Slitmask Tool lets the user add slits, boxes for reference and alignment stars, or arbitrary shaped slitlets, on top of a FITS image. Annotations in the form of text and simple graphics may be added. A created slitmask can be validated to ensure that all slits, slitlets and reference stars boxes are situated in the field of view, that all spectra fall on the CCD and, most importantly, that there are no overlapping spectra.

In order to support survey mode observations with many targets in a field, a recent Python-based version includes an optimizer. This assigns weights to the slitmask elements and varies the position and angle on sky of the slitmask to find the combination for which the sum of weights of the valid slitmask elements reaches its maximum. It can also be used to create a set of several slitmasks for the same field.

The slitmask can be exported to an XML file which is bundled with any annotations and (optionally) the file path of the FITS image or the FITS

[2]`http://jsky.sourceforge.net/index.html`

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image itself in a zip file. This file then has to be imported into the PIPT and is included with the proposal when a submission is made. The slitmask XML is later translated into the sequence of laser cutter commands to use for cutting the slitmask.

11. The SALT Web Manager

The Web Manager (WM) is a web application for accessing observing proposals, submitted to the SALT Database by the PIPT, which is written in PHP and JavaScript and uses the template engine Smarty[3] for generating its web pages. The purpose of the WM is to access information about observing programs and their status (*e.g.* completed observing blocks), both for users and SALT Astronomers. The only requirements for using it are internet access and a web browser.

Before using the Web Manager, the user has to create an account. Primarily this is used for authorization purposes, but the user management is also used for restricting access to submitted proposals in both the Web Manager and the PIPT. There are different access rights for the three groups of Web Manager users:

1. Normal users can access proposals that have been submitted with them as an investigator.
2. Time Allocation Committee members can access proposals that request time from the SALT partner they are responsible for. They can also assign time allocations directly into the WM.
3. The most comprehensive access is allowed for SALT Astronomy Operations, who can access all proposals.

The WM allows programs to be assigned a different status, for example completed, deactivated or unfinalized, the latter to allow PIs to make approved changes to some details of their programs, or to activate Target of Opportunity programs, or to put observations on hold.

After logging in, the Web Manager shows a page that is freely configurable by the user. Possible information on this page is weather data, proposal statistics, some news about the SALT software itself and one or more lists of proposals. The lists show the results of user-defined queries of the SDB. The default configuration is to show the list of proposals in which the currently logged-in user is included as an investigator.

For every proposal there is a page displaying all the proposal information in a human-friendly form. This information includes all the data that has been entered into the PIPT prior to the submission, as well as some additional information such as the proposal status. A copious amount of

[3] `http://www.smarty.net/`

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cross-links is provided throughout the page in order to facilitate navigating within a proposal. In a future version there will also be live status messages, e.g. about what has been observed when and where the observation data is available for download.

The WM consists of different sections which display the following information, all derived from the Science Database:

- Title, abstract, total time allocated in different priority and Moon classes
- Flags for ToO or time critical observations, name of Liaison SALT Astronomer, program status
- Status summary (dates and observing times of completed or attempted observing blocks)
- Instructions and critical aspects of programs (written by the PIs for the SALT Astronomers carrying out the observations)
- Feedback comments to the PIs from the SALT Astronomers attempting the observations
- Details on the investigators (names, institutions, contact details) and contact person
- Observations Block details (total observation time, number of visitis, frequency of visits)
- Observation Configuration details
- Target information (coordinates, type, brightness, proper motion, finding charts)
- Instrument Configurations (filters, gratings, angles, detector modes, individual exposure times, number of iterations, number of repeat cycles)

An additional task for which the Web Manager is used is the approval of proposals. When a proposal is first submitted, each investigator receives an email containing a link with a unique identifier. This link leads to a page where the investigator may accept (or reject) the proposal. As the user is identified by the identifier in the link, there is no need for the user to have a Web Manager account for accepting a proposal, although an account is required for viewing it. Finally, after observations are done, an email is sent to the investigators to inform them that there exists new observational data. The investigators can then use the Web Manager to request the download of their data.

12. Data Handling by the PIPT and Web Manager

The XML of a proposal contains eight levels of nesting. As most of this complexity usually isn't required, a custom tree model reducing the number of levels to three is used for the navigation tree. However, the PI can customize the PIPT so that the usually hidden levels are displayed as well.

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The tree model also automatically replaces references to an element with the element itself.

As the PIPT uses an interface rather than concrete classes for handling instruments, new instruments can be added without making changes to the existing Java code. Hence the workflow for adding an instrument just involves creating a schema for the instrument, using the data model generator to obtain the instrument classes, creating a GUI for entering the instrument configuration, supplying a configuration file and collecting all these in a jar file. The jar file serves as a plugin, which can be put in a dedicated plugins directory, from where it will be picked up by the PIPT. Similarly, if a class for mapping the XML to the Science Database is included in the plugin, no changes are required in the mapping tool for it to handle the new instrument.

The Web Manager similarly wraps the SQL required for accessing the Science Database by getter and setter methods contained in dedicated classes, which are created directly from the database schema by means of a PHP script. Where a table contains a reference to a value in a lookup table, a getter method resolving this reference is provided. Similarly to the PIPT, the automatically created classes are extended by classes which may contain custom code. Both the PIPT data model generator and the Web Manager script for generating the database access classes are fairly generic. They therefore may also be of interest to projects which are completely unrelated to SALT.

An important functionality of the Web Manager is the ability to conduct sophisticated queries of the SDB, without resorting to complex SQL queries. A tab in the WM allows approved users to search for information about proposals in the SDB. All PIs can query their own proposal, or ones for which they are also a CoI, and vice versa. SALT Astronomy Operations staff can query all proposals, since they potentially will be observing all proposals. This also allows searches for statistical information on project completion, etc., towards the end of a semester.

A sophisticated database query can be constructed, whereby various keywords can be searched in an "and"/"or" manner. Examples of common proposal queries include searching for:

- Specific PIs or CoIs or SAs
- Specific objects (or coordinates, magnitudes)
- Object type
- Proposal title or sub-string
- Instrument modes (and filters, gratings, etalons, polarizers)
- Observing conditions (Moon, seeing, transparency)
- Coordinates
- Program priority class set by the TACs

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- Year/Semester
- Proposal code or ID
- SALT Partner institution
- Proposal status (completed, active, rejected, being reviewed, on hold, accepted)

13. PYSALT: The SALT Data Reduction Pipeline

In order to add maximum value to the data which SALT users receive, SALT Astronomy Operations have been developing a SALT data reduction package based on PyRAF ("Pythonized IRAF"), which has been customized specifically for SALT instruments and has been named PySALT. This is a challenging task, given the complexity of instrument modes. However, since the start of the first semester of charged science (1 September 2011) all PIs have routinely been receiving both raw FITS data and pipeline reduced data, albeit only covering basic reductions at present. The same data reduction procedures that have been developed for the quick-look data analysis tool used at the telescope, SALTFIRST, is being expanded into the full PySALT versions.

The primary goal for the development of SALT science software is to increase the scientific productivity of the telescope. By providing fast access to high quality data, we can minimize the effort required to publish scientific results. Furthermore, by having a central resource provide the tools necessary for data reduction, the amount of redundant work done by the diverse SALT partnership is minimized. To achieve this goal, we have identified three critical areas of software development:

1. Provide science quality reductions for the major operational modes of SALT.
2. Create analysis tools for the unique modes of SALT.
3. Create a framework for the archiving and rapid distribution of SALT data.

Obviously providing science quality data reductions to users will have an immediate return by minimizing the amount of work required for the principal investigators to publish their results. As it is a large consortium with many members having similar data reduction needs, the existence of a common framework for data reduction minimizes the amount of redundant work that needs to be done.

Our choice of Python[4] and PyRAF[5] as a development environment for the SALT science data reduction pipeline software was due to several rea-

[4] `http://www.python.org/`
[5] `http://www.stsci.edu/resources/software_hardware/pyraf`

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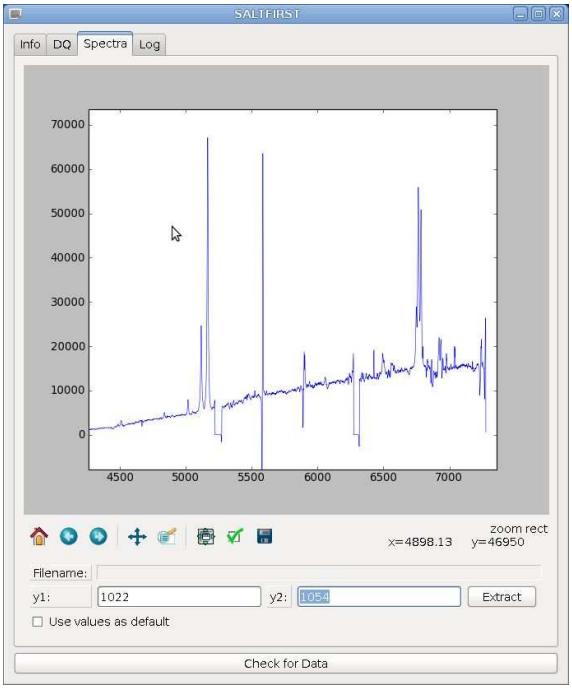


Figure 5. An example of an automatic spectrum extraction plot from the SALT quick--look data reduction tool, SALTFIRST, which runs at the telescope continuously during observations.

sons. First, Python is a well supported high-level language that has been rapidly gaining support in the astronomical community. As a scripting language, Python provides an easy environment for information manipulation, interaction with databases, and different communication protocols. The *numpy*[6], *scipy*[7] and *pyfits*[8] libraries provide access to very fast array handling and manipulation software, and *matplotlib*[9] is a sophisticated software library for data visualization.

The ease in wrapping other software with Python has provided low-level access to a wide range of astronomical software such as ds9, Sextractor, and IRAF. Further, PyRAF is the Python wrapper for IRAF developed by Space Telescope Science Institute. The software provides access to existing IRAF tasks that greatly enhances the ability of Python for reduction of astronomy data. However, it also is an enhancement of the IRAF operating

[6]`http://numpy.scipy.org/`
[7]`http://www.scipy.org/`
[8]`http;//www.stsci.edu/resources/software_hardware/pyfits`
[9]`http://matplotlib.sourceforge.net/`

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environment, so that Python libraries can be imported into a working environment that behaves in a very similar manner to the IRAF environment.

PyRAF tasks still have parameter and help files, but can interface both with IRAF and Python tools. The resulting combination of the extensive library of astronomy data reduction tools for IRAF along with the flexibility of Python is a powerful tool for data handling and analysis.

An important aspect of this development is the open-source nature of these tools. In the South African and many other African research communities, software with restrictive or expensive licenses are prohibited due to the lack of resources. Along with contributing to the cost-effective nature of SALT, open source software is far more accessible to these communities. As such, we have also adopted an open source license for all SALT science software and have avoided requiring any closed source or cost prohibitive software.

Basic CCD data reductions are implemented as part of the SALTRED package in PySALT. The full list of tasks that will be implemented as part of the SALTRED package are listed in Table 5. For imaging, it will provide tools for image reduction including gain and cross-talk correction, bias subtraction, flat-fielding and fringe correction, distortion correction, and astrometric solutions. For other modes, it will provide the same reductions through to distortion correction, at which point further reductions will be handled by packages specific to that mode. Further descriptions of each task are provided on the SALT website[10].

All of the tasks have been implemented with both speed and flexibility in mind. When available, the first implementation of each task utilized an IRAF task (or other existing software) and took advantage of existing tools for these corrections. To increase the speed and performance of the tasks, we have replaced the IRAF task with a Python implementation for certain modes of operation. In the end, we have leveraged the extensive history of selected IRAF tools to provide the user with reliable existing tools while enhancing the performance with new, more powerful code. In the current pipeline, reduction of SALT observations are handled by *saltclean*. The task identifies the images and required calibration data, and then applies each of the reduction steps. Currently, we only implement gain, crosstalk, overscan, and distortion corrections. Overscan subtractions are sufficient to correct for the bias levels for SALT data. Flat-fielding or fringe correction is not yet being routinely handled due to repeatability issues, probably a result of the varying pupil, some unexpected additional vignetting and possible scattered, which are being addressed. Along with cosmic ray cleaning and astrometric solutions, we expect all of these steps to be performed in the

[10]`http://pysalt.salt.ac.za/`

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TABLE 5. Tasks included in the SALTRED reduction package of PySALT*

Task Name	**Description or Function**
specprepare	Prepare FITS file for SALTSPEC reduction
specgain	Gain correct images
specxtalk	Correct images for amplifier cross talk
specbias	Create master bias frame and/or de-bias images
specflat*	Faltfield correct the images
saltfringe*	Fringe correct the images
saltcrclean	Clean cosmic rays
saltmosaic	Mosaic CCD amplifier images and apply distortion correction
saltastrom	Determine astrometric solution
salttimes	Convert to different time systems
saltslot	Reduce SALTICAM slotmode data
saltclean*	Fully reduce SALT data

* not all are yet implemented yet

near future. SALTICAM Slotmode (high-speed photometry) reductions are handled by the *saltslot* package.

To further enhance the performance of the data reductions, the files are only opened once and all of the reductions tasks are performed sequentially on the file. Only three corrections are applied currently as part of the pipeline process, which include gain, cross-talk, and overscan subtraction. Future development of the code is focused on increasing performance and usability of the functions. An important addition will be to implement variance and bad pixel frames. Furthermore, we hope to replace some of the IRAF tasks with faster algorithms for data reduction to further improve the performance of the pipeline.

Spectroscopic reductions are part of the SALTSPEC package and include all the steps necessary to produce wavelength calibrated 1-D spectra from long slit spectra. The tasks that form part of this package are listed in Table 6. The package was designed to provide automated reduction of SALT images aimed at producing high quality scientific reductions and are built for general use. They should be applicable to different observing modes and targets. However, different reductions tools may provide better results, but these should be applicable to most tasks.

The main task of the package is *specidentify*, which determines the wavelength solution for the arc lamps. Although the task includes an interactive mode, it is primarily designed to work without any human intervention and calculates the wavelength solution over the full frame. The *specidentify* task is built around the PySpectrograph package that produces a model

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TABLE 6. Tasks included in the SALTSPEC reduction package of PySALT

Task Name	Description or Function
specprepare	Prepare FITS file for SALTSPEC reduction
specidentify	Do wavelength calibration using arc lines
specrectify	Rectify the spectra
specsky	Sky subtract spectral data
specextract	Extract 1-D spectra for RSS image
specreduce	Fully reduce RSS spectroscopic data

of the spectrograph. Because the configuration of RSS is known very well, the model of the spectrograph provides a solution that is within a few percent of the actual solution. The model can be updated with calibration data to improve its performance further, but for many purposes, this model provides a sufficient solution for the images. However, *specidentify* only uses this model for a first guess for the wavelength solution. The actual wavelength solution is determined by cross-correlating the observed arc line observations with an artificial spectrum. The artificial spectrum is created from the line list that includes both wavelength information and line ratios. Having extensive and well maintained line lists will be critical for delivering automated data reductions. By having a very close approximation to the wavelength solution, we can produce an artificial spectrum with similar resolution as the observations, which minimizes the problem of line blending. The PySpectrograph model uses information about the system to model the spectrograph and is built upon the grating equation.

An example of this process is given in Fig. 6, which in the top frame provides an example of the spectra created using the PySpectrograph model for RSS. In the next frame, we provide an example of a Xe arc lamp image from SALT. Finally, we show the same spectra after wavelength calibration in the bottom frame, showing the removal of the distortion of the arc lines. The wavelength solution was generated automatically. Future development of the SALT spectroscopy software package will include providing support for multi-object and high speed modes. An important part of the spectrograph package will be integrating it into the data reduction pipeline to automatically produce wavelength calibrated data. The quicklook tool, SALTFIRST, currently does this using the PySpectrograph model (Fig. 5).

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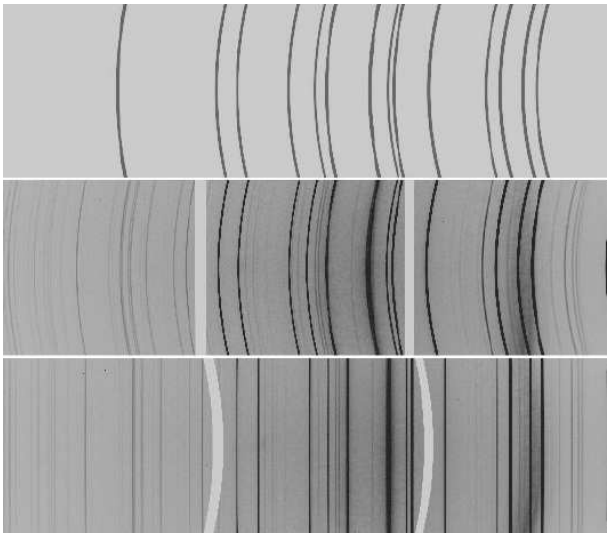


Figure 6. An Example of an RSS long slit observation of an Xe arc lamp using the PG3000 grating. The top image is an artificial image created from the Xe line list, the middle image is an RSS observation of the lamp, and the bottom image is the image after applying the automatically-determined wavelength solution. The strong spatial curvature of the spectral lines in the upper two panels is a consequence of the nature of the off-axis behaviour of Volume Phase Holographic (VPH) diffraction gratings.

14. Concluding Remarks

SALT is now a fully operational telescope and has been routinely obtaining science observations for the SALT partners, delivering ∼650GB of data in the first semester (30 April 2012). Although SALT, by design, imposes restrictions on how observations can be conducted, the overall design of the telescope – from hardware to software – has been done with efficiency and ease of operation in mind. A variety of tools have been produced for SALT users to enable the writing and submitting of observing proposals, modifications of their observing programs, monitoring of progress, collection of data and pipeline data reductions.

SALT has some significant competitive advantages, mostly associated with the queued service observing mode, coupled with the flexible range of instrument capabilities, which can be switched quickly (within minutes) from one instrument or mode to the next. Data is routinely available to users within 24 hours of the observation blocks having been completed, allowing for a quick response by PIs to the results as they occur and allowing for reconfigurations of observations or instruments, if appropriate. This has a particular benefit for Target of Opportunity type observations. Likewise the queue-scheduled *modus operandii* is also well suited to time critical

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observations and synoptic monitoring on a range of timescales (days, weeks, months, years).

At the time of writing, the first science semester with SALT is just behind us and we are embarking on the second. While there is still some commissioning to complete for some instrument modes (*e.g.* RSS polarimetry and MOS), these are expected to be mostly completed within the semester. Late in 2012 a new instrument, a stable high resolution (R ∼70,000) fibre-fed vacuum spectrograph (Bramall *et al.* 2010) will be installed on SALT, giving additional capabilities, and as with the exiting two instruments, able to be swopped between with minutes.

SALT users have keenly anticipated the potential for exciting new science afforded by SALT, and this was reflected in the first semester's over-subscription numbers for many partners (2-4). While current research papers highlighting SALT science is only just beginning to flow (only 35 refereed publication to date), this is anticipated to vastly accelerate over the next year or two. In addition, when a new near IR mode (currently under construction) is added to the RSS, probably in ∼2 year time, the range of capabilities will be greatly enhanced again.

Acknowledgments

The author acknowledges the enormous effort by many individuals within the SALT Technical and Astronomy Operations divisions and others at SAAO, plus the instrument teams, in helping to see SALT to completion and achieving full science operations. A team effort has resulted in this success and special mention goes to the following people for the development of the many SALT observational software support tools that are described in this paper: Christian Hettlage, Encarni Romero Colmenero, Steve Crawford, Tim Oliver Husser, Janus Brink, Anthony Koeslag, Deney Maartens, Luis Balona, Tim Pickering, Keith Smith and Brent Miszalski.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 305-322
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SELECTING, SCHEDULING, AND CARRYING OUT OBSERVATION PROGRAMS AT THE SUBARU TELESCOPE

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Abstract. I explain the current systems for evaluating and selecting observation programs at the Subaru telescope, and how individual programs are scheduled and executed, to maximize scientific outputs.

1. Subaru Proposal Systems

The Japanese-built Subaru telescope is one of the world's largest optical and infrared telescopes (with a primary mirror diameter of 8.2 m), located on the summit of Mauna Kea, Hawaii. The telescope is equipped with highly competitive observing capabilities, including wide-field imaging and spectroscopy, high-spatial-resolution imaging and spectroscopy, and various dispersion long-slit and multi-object spectroscopy, from optical to mid-infrared wavelengths. Tables 1 & 2 and Fig. 1 summarize the current instrumentation of the Subaru telescope. More detailed descriptions are found in Iye *et al.* (2004).

The Subaru telescope has produced many important scientific discoveries, extending from our solar system, through the Milky Way galaxy, to nearby galaxies and active galactic nuclei, as well as very distant objects in the early universe, only 800 million years after the Big Bang. This article explains the current systems for evaluating and selecting observation programs at the Subaru telescope, and how individual programs are scheduled and executed.

Of the available Subaru telescope time, 65% is for open-use programs, and 52 nights per year (∼15%) are allocated to astronomers at the University of Hawaii. The remaining ∼20% is reserved as director discretionary time (DDT) for performing necessary engineering work on the telescope

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TABLE 1. A brief description of the imaging capabilities of Subaru facility instruments*.

Semester	Field of view	Pixel scale	Filters
COMICS	$42'' \times 32''$	$0.133''$	15
FOCAS	$6'$ diameter	$0.1''$	14
IRCS	$21''$, $54''$	$0.020''$, $0.052''$	18
MOIRCS	$4' \times 7'$	$0.117''$	3
Suprime-Cam	$34' \times 27'$	$0.20''$	12

* `http://www.naoj.org/Observing/Instruments/index.html`

TABLE 2. A brief description of the spectroscopic capabilities of Subaru facility instruments**. Spectral resolutions in the second column are for given slit widths shown in parentheses.

Instrument	Resolution	Slit length	Pixel scale
COMICS	10000 ($0.33''$)	$40''$	$0.165''$
FMOS	500-2200 ($1.2''$ fiber)	$30'$, multi	—
FOCAS	250-7500 ($0.4''$)	$6'$, multi	$0.1''$
HDS	100000 ($0.38''$)	$10''$, $60''$	$0.13''$
IRCS (grism)	50-1400 (0.15-$0.90''$)	$21''$, $54''$	$0.020''$, $0.052''$
IRCS (echelle)	5000-20000 (0.14-$0.55''$)	4.8-$9.6''$	$0.060''$
MOIRCS	640-1600 ($0.5''$)	multi	$0.117''$

** `http://www.naoj.org/Observing/Instruments/index.html`

and existing instruments, and for commissioning new instruments. If time is available, scientific observations may be carried out by the Subaru staff during DDT.

Subaru open-use observations are divided into two semesters. Semester A starts in February and ends in July. Semester B extends from August to January of the following year. Calls for proposals regarding Subaru open-use telescope time are issued twice annually, usually in early August for semester A and early February for semester B.

Four types of proposals are considered for Subaru open-use time: (1) normal, (2) service, (3) intensive, and (4) Subaru strategic program (SSP).

1. Normal program
   - The most common type of proposal is a "normal" proposal. Applicants can request up to five nights, generally in whole nights. However, a 0.5 night request is possible and is acceptable if a

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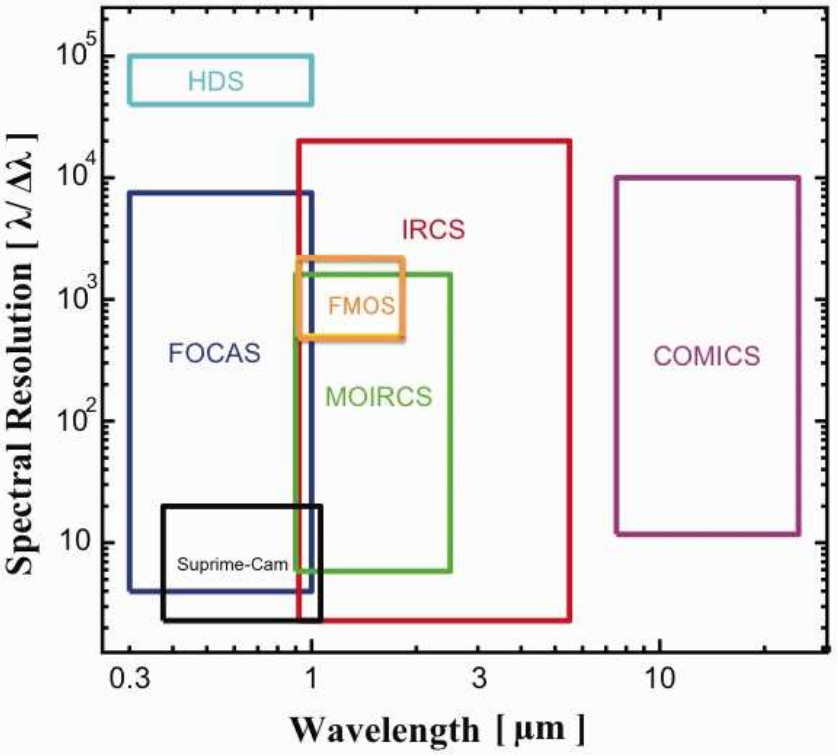


Figure 1. Wavelength coverage and spectral resolution of currently available Subaru facility instruments (`http://www.naoj.org/Observing/Instruments/index.html`). Note that field of view and spectroscopic multiplicity information is not included in this figure.

suitable program is found for the other half night. The proposal submission deadline is usually about one month after the call has been issued, namely in early September for semester A and early March for semester B. Approved normal programs are executed in a classic mode, so that at least one observer must be present for actual observations at the Subaru telescope atop Mauna Kea, Hawaii, or at the Subaru base facility in Hilo, Hawaii. Astronomers throughout the world are eligible to apply for normal programs, regardless of their nationalities or affiliations.

2. Service program

   – Some types of science may not require a full night and can be accomplished with shorter exposure time. A "service" program is more suitable in such cases, for which a maximum of four hours can be requested, including observation overhead. Service programs are

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also useful for finishing previously uncompleted observations that were interrupted by, *e.g.*, bad weather. Accepted service programs are executed by the Subaru observatory staff, and the researchers themselves need not be present. If observations are successfully carried out under good weather conditions, the resulting data are delivered to the researchers. Any astronomers can submit service proposals.

3. Intensive program

– There has been an increasing demand for telescope time allocation of more than five nights to perform systematic studies on astronomically interesting scientific topics. The "intensive" proposal concept was developed for this purpose. Up to 10 nights per semester, and a maximum of 20 nights over four semesters, can be requested. Accepted intensive programs are executed in a classic mode. The submission of intensive proposals is basically restricted to Japanese principal investigators (PIs) who satisfy one of the following criteria: (a) astronomers of Japanese nationality, either working in Japan or in foreign institutes outside Japan, or (b) non-Japanese astronomers affiliated with Japanese institutes. However, an exception is made for FMOS. Since FMOS was developed under a collaboration between Japan and the United Kingdom (UK), astronomers affiliated with UK institutes are allowed to submit intensive proposals for the use of FMOS as PIs.

4. Subaru Strategic Program (SSP)

– Because more than 10 years have passed since 8-10m class large telescopes were put into operation, the Subaru advisory committee (SAC) has established a proposal system for performing legacy-type observations using more than 100 nights called the Subaru Strategic Program (SSP). SSP applicants are limited to Japanese PIs, and SSP observations are executed in a classic mode. The fraction of telescope time used for SSP per semester is currently limited to no more than 25% of the Subaru open-use time (*i.e.*, a maximum of $\sim$30 nights per semester) to ensure that opportunities will be available for a variety of scientific topics by a wide range of astronomers within the framework of Subaru open-use.

Table 3 summarizes these proposal submission schemes for Subaru open-use time.

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TABLE 3. A brief summary of the current Subaru open-use time proposal system, consisting of normal, service, intensive, and SSP proposals.

Proposal	Nights	PI
Normal	up to 5 nights	Any astronomer
Service	up to 4 hours	Any astronomer
Intensive	up to 20 nights over 4 semesters	Basically Japanese ***
SSP	up to 300 nights over 5 years	Japanese

*** UK astronomers can exceptionally become the PIs of intensive proposals using FMOS.

2. Proposal evaluation

2.1. SUBARU TIME ALLOCATION COMMITTEE (TAC)

2.1.1. *Normal program*

A normal proposal consists of a two-page scientific justification section, cover pages for the applicant and observation information, as well as a technical description. All normal proposals are evaluated by the Subaru Time Allocation Committee (TAC). The Subaru TAC consists of about 10 astronomers from various research fields. Members of the TAC usually serve for 2+2 years and review proposals 4 + 4 times every six months (semesters A and B). Since the telescope time requested generally exceeds the available nights (Fig. 2), the Subaru TAC must carefully select the programs that will be executed on the given available nights.

First, the applicant must select a scientific category that is most relevant to the objective of the proposal. Soon after the proposal submission deadline for each semester, the Subaru TAC meets and divides the proposals into several groups based on scientific category. The basic policy is that proposals with similar scientific goals be reviewed by the same referees. If necessary, some proposals are transferred to categories other than those specified by the applicants. The total number of proposals in each group is usually <30, so that reviewers can read each proposal carefully and provide sufficient feedback. Since the total number of submissions has ranged from 100 to 150 during the past several years (Fig. 3), proposals are categorized into several groups. Principal and secondary TAC members are then assigned to each group, and these are responsible for selecting referees from outside the Subaru TAC (typically five, but in some cases six). The referees include Japanese and non-Japanese researchers from various fields, including γ-ray, X-ray, optical, infrared, and radio observational astronomers, as well as theorists.

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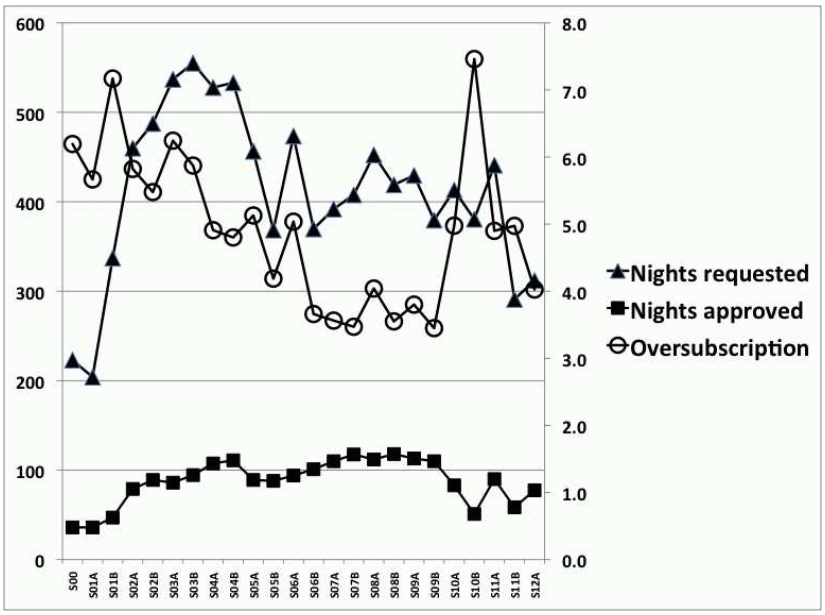


Figure 2. Normal and intensive proposal statistics per semester since the start of Subaru open-use operation in 2000 (S00). Service and SSP programs are not included in the statistics. Filled triangles: The number of requested nights (left label). Filled squares: The number of approved nights (left label). Open circles: Oversubscription rate on a per-night basis (right label). The total number of approved nights can vary per semester, depending on factors such as telescope down time for primary mirror re-aluminization and commissioning of new instruments, guaranteed time observations for Subaru facility instrument development teams (20 nights for each, distributed over a few semesters), and nights used for SSP.

The selected referees are asked to rank the proposals and provide feedback within one month. Ranking is based mainly on scientific merit, but technical feasibility can also be taken into account. Parallel to the referee's review, an expert technical evaluation is provided by the support astronomers for the proposed instruments at the Subaru telescope.

After the referee reports and technical comments have been received, the Subaru TAC meeting is held about two months after the proposal submission deadline, usually in early November for semester A and early May for semester B. The meeting lasts two full days. The primary and secondary TAC members of each group review the overall referees' scores and scientific/technical comments, and then decide which programs will be accepted, so that the maximum scientific output can be obtained from the Subaru telescope. The night allocation for each group is roughly proportional to the total requested nights of the normal and intensive proposals assigned to that group. In previous semesters, many applications have come from

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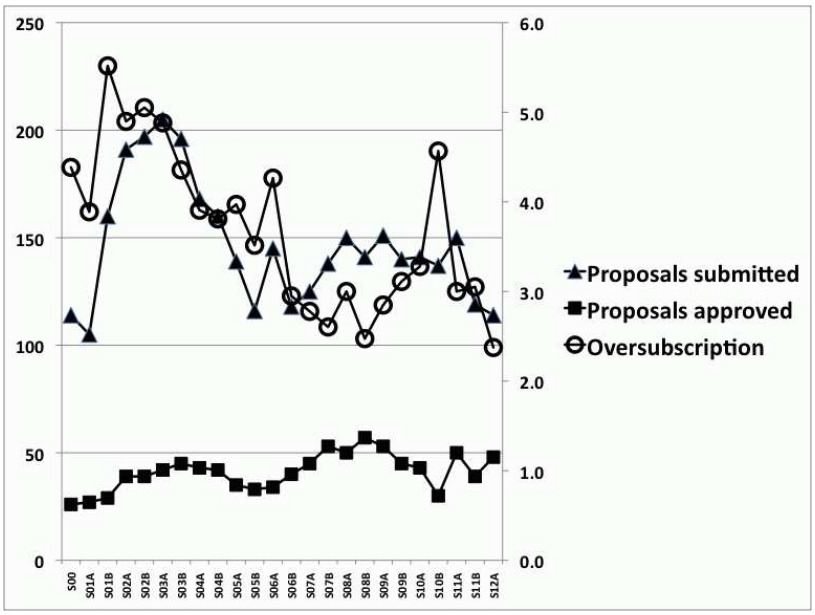


Figure 3. Same statistics as in Fig. 2, but in terms of the number of proposals. Filled triangles: The number of submitted proposals (left label). Filled squares: The number of approved proposals (left label). Open circles: Oversubscription rate on a per-proposal basis (right label). Since many proposals are approved with night allocations lower than the original requests, the oversubscription rate is smaller on a per-proposal basis than a per-night basis.

non-Japanese PIs (non-Japanese astronomers working at foreign institutes) (Fig. 4), and Subaru open-use telescope time was actually assigned to such individuals if their proposals receive high scientific rankings and are judged to be technically feasible (Fig. 5), demonstrating the international nature of the Subaru telescope.

2.1.2. *Service program*

For service proposals, since the requested time is shorter than 4 hours, scientific justification is limited to one page, and cover pages are simpler than those of normal proposals. The submission deadline for service proposals is usually about 1 month later than that of normal proposals. Service proposals are evaluated by Subaru TAC members themselves, rather than outside referees. Generally, three TAC members read the individual service proposals and assign scores based on scientific merit. After considering the technical comments provided by the instrument experts, final rankings are given to the service proposals.

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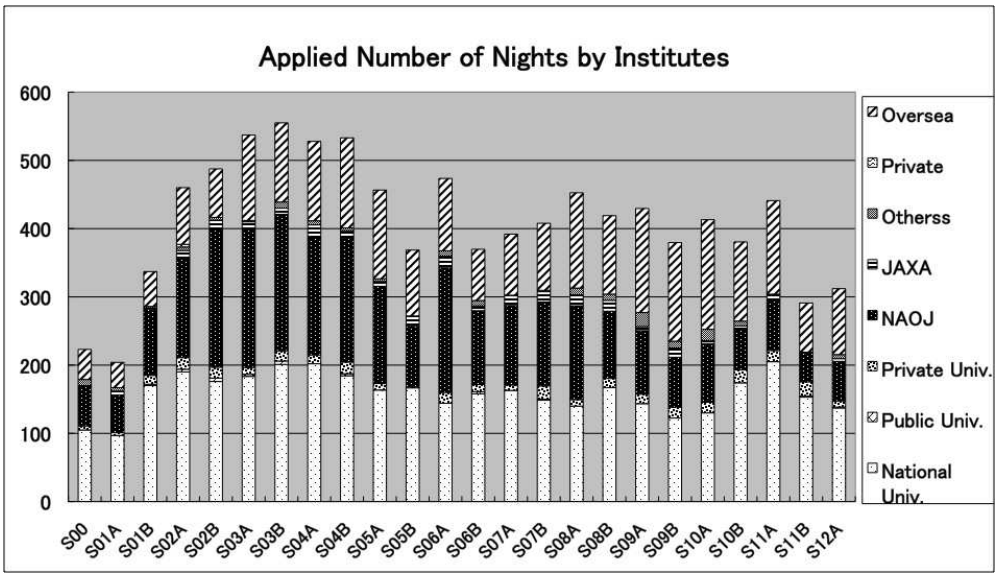


Figure 4. Application of Subaru open-use time. The category "Overseas" includes astronomers working at foreign institutes, and the bulk of them are non-Japanese (non–Japanese PIs). The other categories pertain to Japanese institutes. A large number of applications come from non-Japanese PIs.

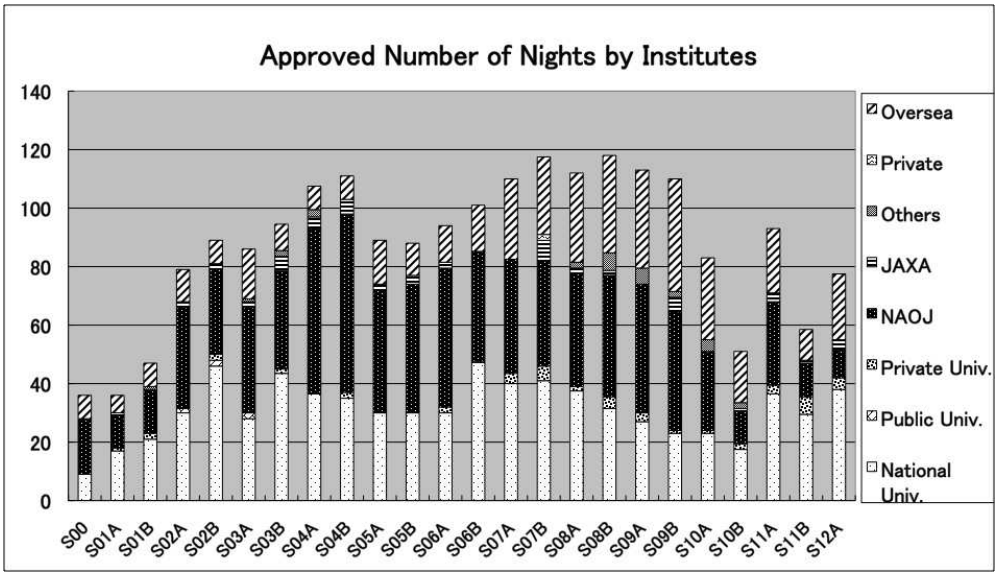


Figure 5. Allocation of Subaru open-use telescope time. The symbols are the same as in Fig. 4. A significant fraction of Subaru open-use telescope time is allocated to non-Japanese PIs.

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2.1.3. *Intensive program*
For intensive proposals, the length of the scientific justification can be a maximum of five pages, since more detailed scientific information is necessary to carefully judge whether such a proposal deserves an allocation that may entail >5 Subaru nights. Among the 100-150 proposals for Subaru open-use time submitted during recent years (Fig. 3), only a few have been intensive programs. Intensive proposals are also reviewed by outside referees, in a manner similar to normal proposals. However, unlike normal proposals, final acceptance of an intensive proposal requires an oral presentation to Subaru TAC members during the Subaru TAC meeting. Based on the referees' scores, the Subaru TAC preselects highly ranked intensive proposals and holds a special hearing for them. This oral interview is important for the Subaru TAC to better understand the feasibility of, and strategy for, achieving the proposed scientific goals, and make a final decision on whether so many (>5) Subaru nights should be allotted.

2.1.4. *Subaru Strategic Program (SSP)*
For proposals that require >20 nights, the Subaru Strategic Program (SSP) has been established. Since an SSP proposal involves a large number of observation nights (>100), a very careful review process is required. The basic SSP selection policy is as follows.

1. The SSP was recently initiated with the intent of producing unprecedented and outstanding scientific outcomes by using unique/expedient observing instruments, while also bringing out the capabilities of the Subaru telescope as much as possible, so that a decisive leadership position may be established in the relevant fields of astronomical science.
2. The SSP is intended for systematic observations to collect a large and controlled volume of scientific data, based on an exceptionally large amount of allocated nights, over a time span of several years (*e.g.*, up to 200-300 nights over 3-5 years).
3. Because of the extraordinary character of the program, an SSP proposal should be outstanding and unprecedentedly creative. Preferably, either of the following descriptions should apply.

   (a) Category A
   - Heritage/Treasury Database (excellence of the 'data')
     - Subaru telescope time will be intensively or continually devoted to strategic survey observations, with the intent of systematically collecting a large amount of data to achieve an epoch-making scientific end. That is, the prospective data will remain an invaluable treasure and will be widely used by researchers far into the future.

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(b) Category B

– Decisive Scientific Impact (excellence of the expected 'discovery')

• Systematic observations will be intensively or continually conducted, with the solid and sustained intent of accomplishing a definite and challenging objective that will clarify unresolved astronomical problems of enormous scientific importance. That is, the outcome of the project is expected to be so important that it will have a major impact on our knowledge about the universe.

4. Call for Proposals

– A call for the SSP proposals will include the following requirements and remarks.

• Requirements

∗ Since the SSP should be executed in close collaboration with the Subaru telescope staff, the PI (who is responsible for the overall project) must be in close contact with the director of the Subaru observatory prior to submitting the proposal. Also, at least one Subaru staff member must be included as a co-PI who, as a resident staff member in Hawaii, will share the PI's responsibility for managing the project.

• Remarks

∗ For the time being, at most one SSP project may be approved for each newly commissioned instrument, no matter how many proposals are submitted. While no strict limitation exists on the size of a project, the typical period is expected to be ∼3 years (the maximum duration would be ∼5 years or so). The allocation of telescope time per semester (6 months) will be restricted to about 30 nights.

5. Review Process

(a) First Screening Process

– Review by prominent Japanese astronomers + the Subaru advisory committee (SAC)

• At most, two proposals will be accepted for the second review process. The accepted proposals will be immediately announced and made available to the Japanese Subaru community.

(b) Second Review Process

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- Accepted proposals will be reviewed by ∼20 referees, and the TAC will review the proposals from the point of view of astronomy and astrophysics.
- TAC may recommend at most one proposal to the SAC as the SSP.
- The PI of the accepted SSP proposal immediately reorganizes the project team, which should include all Japanese astronomers who want to participate in the project.

(c) Third Review Process

- The SAC will review the SSP proposal to determine whether the project is well organized (science, team members, and cooperation with Subaru).
- The SAC may approve one SSP project.
- If the project is not well planned, the SAC can reject the SSP proposal, even if it was recommended by the TAC.

(d) Final Decision

- The PI of the SSP submits the final version of the proposal, which includes a detailed schedule of observational runs and a list of all team members, including the Hawaii Subaru staff.
- The SAC will make a final decision on the starting semester of the approved SSP.

2.2. TELESCOPE TIME EXCHANGE WITH KECK AND GEMINI

Since 2008, Subaru and Keck, and Subaru and Gemini, have been exchanging their telescope time, so that the Subaru community can have access to the unique observing capabilities of Keck and Gemini, and vice versa. For example, since classic runs are the basic observing mode of the Subaru telescope, accommodating programs that require repeated observations with short exposure in each run is difficult. Such programs are more easily managed with the Gemini telescope, since the queue observing mode occupies the dominant fraction of Gemini telescope time. Other advantages of this telescope time exchange program for the Subaru community include (but are not limited to) access to
(1) multi-object optical spectroscopy with a wider field of view than that available at the Subaru telescope (Keck DEIMOS),
(2) objects in the Southern Hemisphere (Gemini South), and
(3) infrared integral field unit observing capability (Keck OSIRIS and Gemini NIFS).
On the other hand, the Keck and Gemini communities can make use of

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Subaru's unique capabilities for wide-field imaging and spectroscopy at the primary focus (Suprime-Cam and FMOS). Thus, this program is very important to each community for enlarging scientific output.

The Subaru TAC selects the programs from the Subaru community that use Keck and Gemini. The Keck and Gemini TACs are responsible for selecting the respective Keck and Gemini community programs that use Subaru. So far, the exchange time per semester ranges from few to several nights for both Keck and Gemini, and this amount is variable, depending on the demands of each community in a given semester. The exchange is made within the framework of the Subaru open-use programs. Specifically, if we use five Keck nights and five Gemini nights in a semester, 10 (= 5 + 5) nights are subtracted from the Subaru open-use time and are made available to Keck and Gemini observers.

2.3. UNIVERSITY OF HAWAII TIME

Twenty-six nights per semester are allotted to astronomers at the University of Hawaii (UH). The UH TAC selects the programs and sends the list to the director of the Subaru telescope. Accepted programs are distributed into dark, gray, and bright nights, at roughly one-third each. Observation dates should also be reasonably divided into six months in individual semesters.

3. Proposal Scheduling

Subaru has four foci: Cassegrain, infrared Nasmyth, optical Nasmyth, and primary focus (Fig. 6). Currently, seven facility instruments are attached to one of the four foci (Fig. 7). These instruments are Suprime-Cam (primary focus), FOCAS (Cassegrain), HDS (optical Nasmyth), FMOS (primary focus), IRCS (infrared Nasmyth), MOIRCS (Cassegrain), and COMICS (Cassegrain). The PI instrument[1] HiCIAO (Tamura *et al.* 2006) is regularly used two or three times per semester at the infrared Nasmyth focus. IRCS and HiCIAO can be combined with the Subaru adaptive optics (AO) system to obtain images with higher spatial resolution.

In principle, optical observations of faint objects, particularly imaging and low-resolution spectroscopy at the blue optical wavelength, should be allocated to the darkest nights, since lunar effects are severest under these conditions. Suprime-Cam imaging and FOCAS spectroscopy are best assigned to nights around the new moon. Infrared observations and high-resolution optical spectroscopy can be performed on brighter nights, since lunar effects are less troublesome in these cases. Among infrared observations, those using laser-guide-star adaptive optics (LGS-AO) should be

[1]Maintenance is generally performed by the instrument teams, not by Subaru staff.

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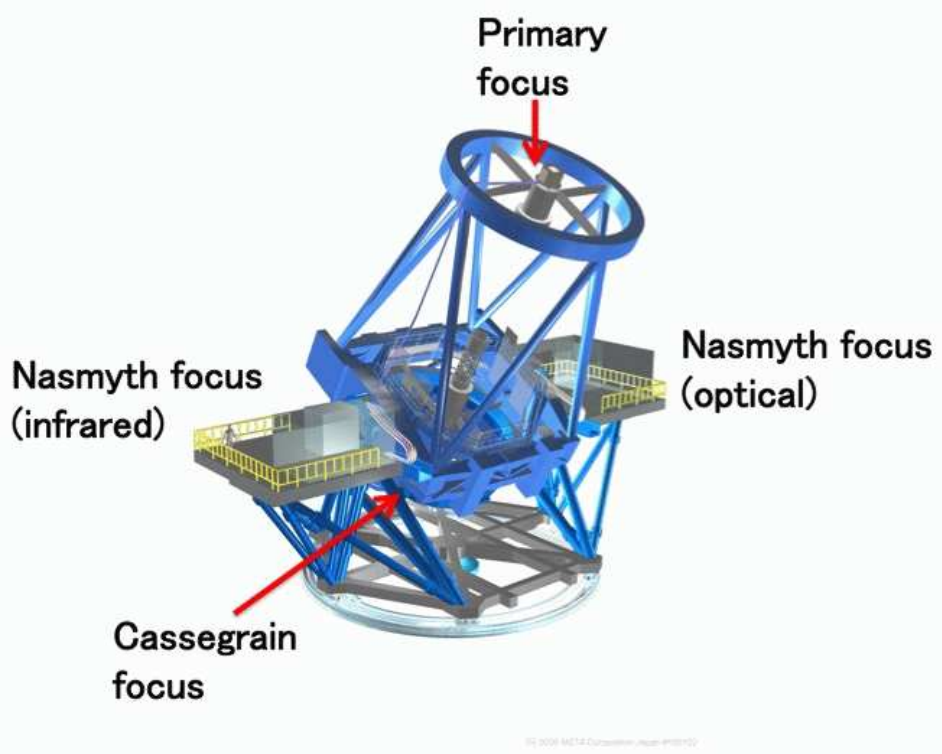


Figure 6. The four foci of the Subaru telescope. Image credit: Meta Corporations Japan.

scheduled on darker nights, since moonlight causes degradation of LGS-AO performance due to the gradient of sky brightness as a function of the distance from the moon.

In reality, Subaru telescope time allocation is not so simple because we cannot change a secondary mirror and an instrument at the same focus during the night, or on weekends and holidays. For Nasmyth and Cassegrain observations, three secondary mirrors are prepared: optical Cassegrain, optical Nasmyth, and infrared. At the primary focus, no secondary mirror is used; instead, an individual primary focus unit, including an image corrector, must be attached for both Suprime-Cam and FMOS. These secondary mirrors and primary focus units can be switched only in the daytime on *weekdays*, excluding holidays. Accordingly, once an instrument is selected for a Friday night, the same secondary mirror or primary focus unit must be used on the subsequent Saturday and Sunday nights. For example, if Suprime-Cam is attached on a Friday night, the instrument used on the subsequent Saturday and Sunday must be Suprime-Cam. The situation is the same for FOCAS, HDS, and FMOS. The same policy is applied on the

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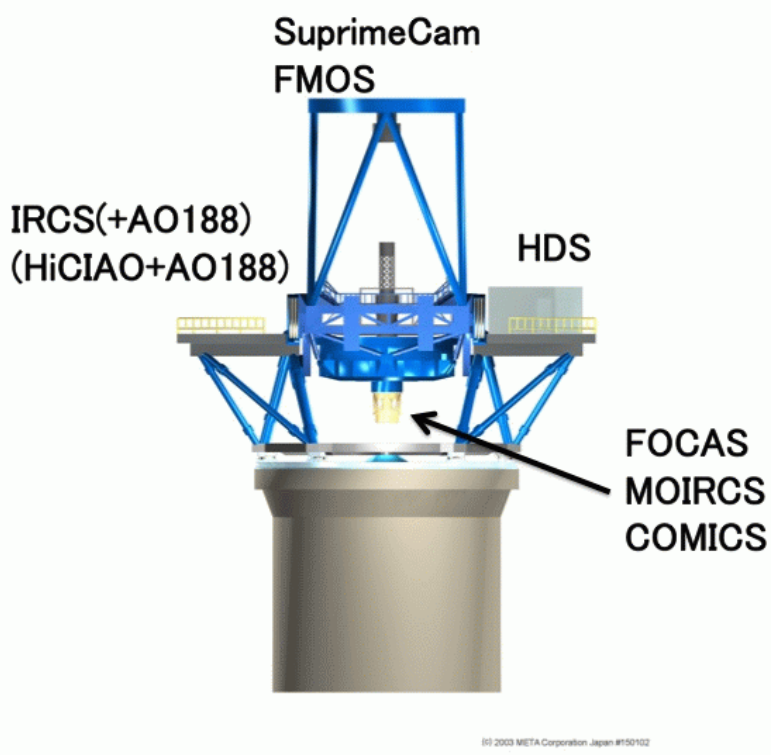


Figure 7. Currently available Subaru instruments at each focus. The right (left) side is the optical (infrared) Nasmyth focus. Image credit: Meta Corporation Japan.

night before a holiday and the night of the holiday.

For infrared instruments at the Cassegrain and infrared Nasmyth foci, we provide slightly more flexibility. Specifically, an infrared instrument at the Cassegrain focus can be switched to an instrument at the Nasmyth focus during a night or weekend, since we can use the same infrared secondary mirror and only need to remove or insert a tertiary mirror, which takes ∼20 minutes. For example, we can combine observations using MOIRCS or COMICS at the Cassegrain, and IRCS+AO or IRCS without AO or HiCIAO+AO at the infrared Nasmyth focus, on Fridays and weekends. Some types of HDS observations of bright objects may be performed using an infrared secondary mirror, instead of the original optical Nasmyth secondary. In this case, HDS programs can be combined with a Cassegrain infrared instrument (MOIRCS or COMICS) and a Nasmyth infrared instrument (IRCS+AO or IRCS without AO or HiCIAO+AO) on Fridays and weekends.

Changing instruments at the same focus, namely FOCAS, MOIRCS, and

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COMICS at the Cassegrain, requires one daytime work on a weekday. IRCS and HiCIAO share the same infrared Nasmyth and can only be exchanged during the daytime on a weekday. Since switching these instruments at the infrared Nasmyth focus entails a lot of work and resources, ideally, more than one night interval is desirable. As for the primary focus instruments, Suprime-Cam and FMOS, since exchanging them in only one daytime is difficult, their consecutive allocation should be avoided.

After taking into account these complicated restrictions on instrument exchanges, the Subaru telescope schedule is determined. Telescope time allocation for some proposals on the borderline between approval and rejection at the Subaru TAC meeting can be affected by these limitations.

Only after finalizing the schedule of accepted normal, intensive, and SSP programs, as well as necessary engineering/commissioning work on instruments/telescope, service programs are assigned in the remaining available time slots. For this reason, some service programs with high scientific rankings may not receive time allocations.

4. Program Execution

All normal, intensive, and SSP programs are executed in a classic mode. At least one observer must be present during the actual observations at the Subaru telescope atop Mauna Kea, Hawaii, or at the Hilo Subaru base facility, from which remote observations are possible for some instruments. For normal and intensive programs, at least one telescope operator and one instrument support scientist are on duty on all classic nights and assist with observations throughout the night. Because of this extensive support, classic observations at the Subaru telescope proceed very smoothly, minimizing the loss of precious telescope time due to the unfamiliarity of observers with actual instrument operational procedures. The basic task of the observers is to establish an observation strategy. By consultation with support astronomers and telescope operators, observers can verify whether the telescope is pointed at the desired objects, and then set each exposure time so that the signal level is kept within the linearity limits of the array of applied instruments. Appropriate calibration data should also be collected. Since weather conditions are variable, observers should inspect the quality of the data obtained in previous exposures, judge when to slew the telescope to a next desired object, and provide this information to the telescope operator and instrument scientist. For SSP programs, although a telescope operator is assigned, no instrument support scientist is provided. Hence, SSP proposals must include experts on the instruments used for the observations. This is based on the policy that SSP programs should proceed according to the all-Japan system, making it comparatively unnecessary to

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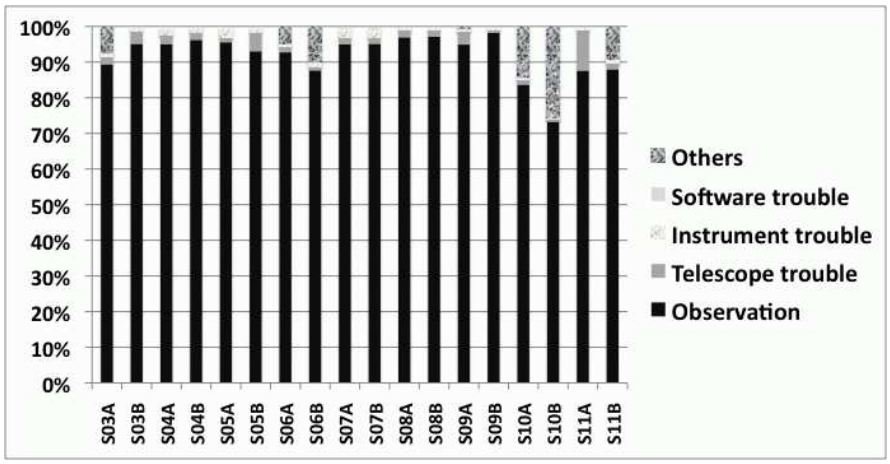


Figure 8. Subaru operating statistics, excluding bad weather. The category "Others" includes telescope down time due to earthquakes and re-aluminization of the primary mirror. Under normal circumstances, a very high percentage of trouble-free operation is achieved.

assign a support scientist.

Fig. 8 shows the time percentages actually used for astronomical observations. Subaru operation has proved to be very stable and efficient, with a minimal amount of time loss due to telescope/instrument/software troubles.

Fig. 9 shows publication statistics for research based on observations using the Subaru telescope. The number of refereed papers is steadily increasing, demonstrating that the Subaru telescope has achieved a high production rate for scientific papers with the current systems of proposal evaluation and operation. Of course, these systems are subject to future changes. The hope is that the Subaru telescope will continue to be at the forefront of many research fields in observationally uncovering the mysteries of the universe.

Acknowledgments

I would like to thank all of the Subaru staff members and proposal reviewers for their tremendous efforts, which make the present sophisticated level of Subaru operation possible. I am grateful to Yoichi Takeda and Hiroshi Terada for their useful comment on this manuscript, and to Chie Yoshida and Tomoko Fuselier for kindly providing me with Subaru open-use statistical data and assisting with the preparation of some figures.

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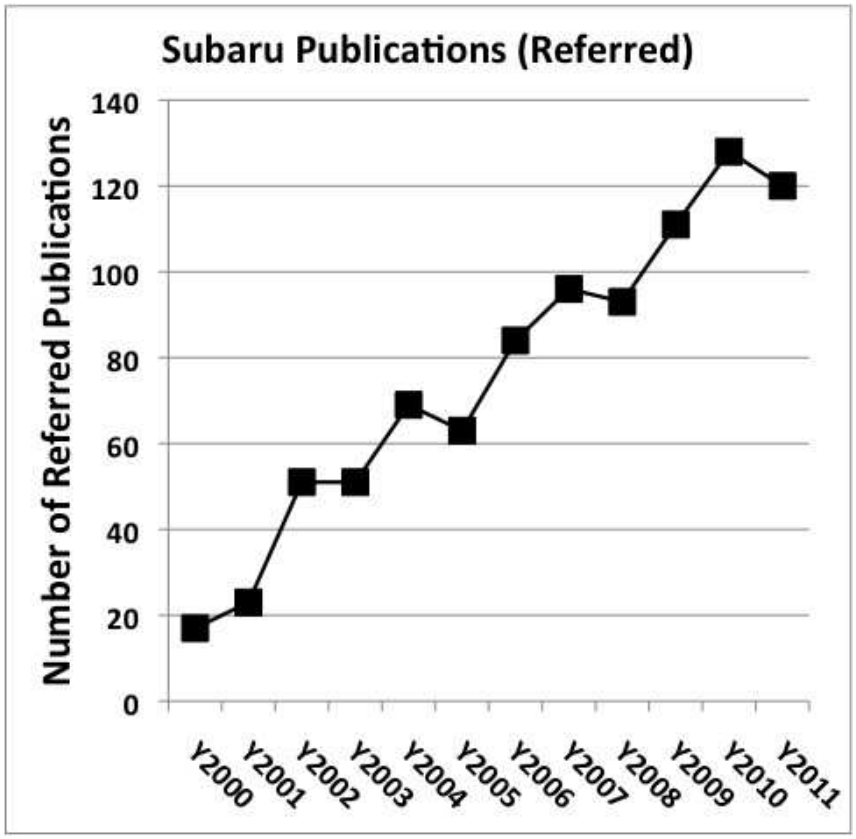


Figure 9. The number of refereed papers based on Subaru observations in each year from 2000 to 2011. See `http://www.naoj.org/Observing/Proposals/Publish/index.html` for more details.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 323-333
Ed. A. Heck, © 2013 Venngeist.

PROFESSIONAL ETHICS IN ASTRONOMY: THE AAS ETHICS STATEMENT

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Abstract. It is fundamental to the advancement of science that practicing scientists adhere to a consistent set of professional ethical principles. Recent violations of these principles have led a decreased trust in the process of science and scientific results. Although astronomy is less in the spotlight on these issues than medical science or climate change research, it is still incumbent on the field to follow sound scientific process guided by basic ethical guidelines. The American Astronomical Society, developed a set of such guidelines in 2010. This contribution summarizes the motivation and process by which the AAS Ethics Statement was produced.

1. Introduction

The news in recent years has featured a number of events in which scientists violated accepted ethical guidelines in the prosecution of their research work and professional lives[1]. These violations occurred across all scientific disciplines and were not isolated to areas of research normally regarded as fraught with ethical challenges (*e.g.* human subject research). Such violations damage the reputation of the scientists involved and the enterprise of science more broadly. They are violations of the public trust in the process of science and cause grave harm to the credibility of scientific knowledge, which can ultimately damage the very Society that science seeks to help and support.

[1]See *e.g.*: http://en.wikipedia.org/wiki/Jan_Hendrik_Schön, http://classic.the-scientist.com/news/home/24445/

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The result of this seeming rise in ethical violations in science, combined with the high-profile nature of some occurrences led many scientific societies to undertake the development of professional codes of ethics (see sidebar for sample listing of societies and their various codes of ethics) or a review of existing guidelines. Although few scientific societies provide a policing mechanism to enforce these codes (except in the case of journal publication), their intent is to set a high standard for members of the discipline(s) the society represents and to benefit the execution of scientific research in a particular discipline.

Other groups have undertaken substantial education of their early-career members on the topic of proper conduct in research. The National Academies of Science (of the United States), for example, publish an excellent booklet entitled "On Being a Scientist" (also available for download[2]). The American Astronomical Society provides a copy of this booklet and a similar pamphlet published by Sigma Xi to its junior members when they are first accepted for membership. It is also common for graduate departments in physics or astronomy to provide some training in the general area of proper ethical behavior, though the practice is not uniform across all departments[3]. Given the importance of the topic and the relative ease in presenting a seminar for students along these lines, I think that all departments granting graduate degrees in any science, let alone astronomy, should include this kind of education in their curriculum by default. The omission of this content from a scientist's education borders on the irresponsible.

From time to time the American Astronomical Society has hosted sessions at its annual meetings on the topic of professional ethics. I organized a session in 2005 at the Minneapolis meeting of the AAS and others have been held in the past as well. The most recent session I organized was entitled "Professional Ethics in Astronomy: An Ongoing Dialogue" and was held at the January 2012 meeting of the Society in Austin, Texas. The session featured a panel of four including: the Editor-in-Chief of the ApJ, Ethan Vishniac, discussing plagiarism; John F. Ahearne, Emeritus Director of Sigma Xi's Ethics Program, discussing honesty in professional activities; Linda Sparke, of NASA Headquarters discussing ethics for proposal review; and Richard Bissell, Director for Policy and Global Affairs at the National Academy of Sciences , who presented the principal findings of several reports issued by the National Research Council/National Academy of Sciences over the past several years.

[2]`http:// www.nap.edu/catalog.php?record_id=12192`

[3]See for example `http://astro.berkeley.edu/∼kalas/ethics/`, or `http://www.spsnational.org/governance/ethics/seminar_treatment.pdf` for two descriptions of seminars, among many tens available easily online

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The point of such sessions is to bring focus to the issue and to provide expert speakers to address recurrent issues or problems, while answering questions from session attendees that might highlight specific personal issues or experiences. These sessions are unusually well attended, especially given that they are scheduled in parallel with other scientific sessions. The AAS is not alone in this regard. Many other scientific societies (*e.g.* APS, AGU, OSA, MRS, ACS, etc.) provide venues for the discussion of this topic.

The increasing attention to the issue of ethics in science, as evidenced by the growing number of scientific society guidelines and the well-attended sessions at our own and other society meetings indicates to me that scientists at all career levels understand the importance of the topic and want to learn more. Fundamentally, our professional lives rest on our credibility, our reputation and our execution of scientific practices. Ethical violations threaten all of these fundamental areas and undercut the whole concept of the scientific enterprise.

2. Origin of the AAS Statement

In 2002, incidents of data fabrication shocked the physics community and sparked the American Physical Society's Panel on Public Affairs to form a Task Force on Ethics[4]. After a year or so of work, the task force produced updated ethics statements, which were completed in January 2004 and widely disseminated in the physics community. A summary of the response of early-career physicists to the revised statements may be found online[5]. The release of these statements was also noticed within the astronomy community.

As the AAS did not have an ethics statement at the time, I responded to the release of these statements by proposing to the AAS meeting planning committee in June of 2004 to hold a panel session on professional ethics at the January 2005 meeting of the Society in Minneapolis, mentioned above. My intention (naïve as it turns out) was to spark enough discussion that the Society would decide to craft its own statement. The session in any event was well-attended and the standing-room only crowd included many leaders in our organization as well as early-career members. The panelists included the then Editor-in-Chief of the ApJ, Robert Kennicutt, who discussed issues of plagiarism and Kate Kirby, chair of the APS POPA Task Force on Ethics as well as representatives from NSF and NASA who discussed ethics from the point of view of proposal review. Although the session itself did not spark proposals by the Council to formulate an ethics statement, discussion

[4]http://www.nytimes.com/2002/11/19/science/after-two-scandals-physics-group-expands-ethics-guidelines.html?ref=jhendrikschon

[5]http://people.hao.ucar.edu/travis/seminar/ethics.pdf

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about the session (especially Rob Kennicutt's penetrating discussion of plagiarism) spread and ultimately reached the ears of John Huchra, who for many years felt this was an important issue and brought it up regularly with colleagues and students, as well maintaining a separate section of his web home page on the topic[6]. He (and others) sent me an email thanking me for organizing the session and that he hoped the topic would become a regular subject of discussion among AAS members.

As fate would have it, John Huchra was subsequently nominated as a candidate for president of the AAS in 2006 and won election to that post beginning in the summer of 2008. AAS presidents spend a year as president-elect, two years as president and one year as past-president, so John became president-elect in June of 2007. Soon after, he and I attended a workshop sponsored by the Council for Engineering and Scientific Society Executives for Chief Elected Officers and Chief Executive Officers of participating organizations (November 2007). The goal of these (useful) workshops is to allow the CEO-CEO partnership to develop in advance of the elected officer actually taking office, while exposing them to best practices in non-profit management. Additionally, the executive gets to understand the priorities of the newly elected volunteer leader and provide advice on how to best achieve those goals. All new Presidents-elect now attend these sessions with the AAS Executive Officer.

At this meeting, he told me that one of his priorities was to develop an AAS statement on professional ethics. He followed up on this initial conversation by inserting the issue as an agenda item for the January 2009 Council meeting in Long Beach, his first winter Council meeting as AAS President. The Council was highly supportive of this goal and a subcommittee was formed to develop a draft statement, which John chaired. The process had begun. He summarized the Council discussion and the actions taken by the APS in an AAS Newsletter column in the March/April 2009 issue[7].

3. Development of the Ethics Statement

John chaired an ad hoc committee of the Council to produce the outline of an ethics statement. Basing it in large part on the APS statement, the committee delivered the draft to the full Council in late spring and a discussion was held at the Council retreat day, held just prior to the normal Council meeting at the summer 2009 AAS meeting. The Council then approved the draft version, but felt that the membership of the Society should be allowed to weigh in on the statement prior to the Council adopting it.

[6]https://www.cfa.harvard.edu/∼dfabricant/huchra/#Conduct
[7]http://aas.org/archives/Newsletter/Newsletter_145_2009_03_March_April.pdf

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Figure 1. John Huchra at the Natonal Academy of Sciences Decadal Survey roll out, August 13, 2010. (© Kevin Marvel)

Lee Anne Willson, AAS Vice President, volunteered to moderate a public forum accessible by all members and we announced the opportunity to participate in an online discussion of the statement in an emailed request to all AAS members sent on 2 July 2009. The text of the email is presented here:

AAS Informational Email – 2009-14

AAS Council Seeks Input On Ethics Statement

The Council of the AAS has developed and endorsed the following draft ethics statement, pending input from our members. It is intended to represent a consensus, and thus necessarily may not include every issue that is important to each member of the AAS. It is our hope that it will be a useful starting point for discussion of professional ethics with students moving into a professional career. It may also prove useful as a reference to standard practice in US astronomy in some cases where there is an issue that arises, perhaps in the context of cultural differences between areas of science or parts of the world.

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While the text of the ethics statement remains the responsibility of the AAS Council, we are interested in hearing from members before we make a final version public. To this end, we have opened a forum on the Ethics Statement at `http://forums.aas.org`. This will be open from now through 15 August. Comments will then be compiled and considered by the Council in preparing the final version.

The draft Ethics Statement is also posted on in this AAS forum and comments may be sent directly to the moderator, Lee Anne Willson, AAS Vice President. Unless you specify otherwise, she will assume you intend your comments to be posted on the forum. You will need to create a login for the forum to post if you do not already have one.

4. The AAS Ethics Statement

The discussion on the forum was minimal, but the input was highly valuable and some modifications to the statement were incorporated in a new version, which was finalized at the fall Executive Meeting. Final approval of the statement was then included as an agenda item at the winter meeting of the Council and was adopted by the AAS Council on the eighth of January 2010. The statement is reproduced here in its entirety.

AAS Statement on Ethics

The mission of the American Astronomical Society is to enhance and share humanity's scientific understanding of the Universe. We believe the advancement of astronomy requires that we provide ethical guidelines for AAS members and, for that matter, anyone involved in professional astronomical activities.

Every astronomer is a citizen of the community of science. Each of us shares responsibility for the welfare of this community. We endorse the statement of the American Physical Society that "Science is best advanced when there is mutual trust, based upon honest behavior, throughout the community." All scientists should act ethically in the conduct of their research, in teaching and education, and in relations with both members of the public and other members of the scientific community. We have a special responsibility to students and postdoctoral fellows to train them in ethical conduct.

The American Astronomical Society believes that the following are the minimal standards of ethical behavior relating to the profession.

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Conduct Towards Others

All people encountered in one's professional life should be treated with respect. At no time is abusive behavior acceptable. Scientists should work to provide an environment that encourages the free expression and exchange of scientific ideas. They should promote equality of opportunity and treatment for all their colleagues, regardless of gender, race, ethnic and national origin, religion, age, marital status, sexual orientation, disabilities, or any other reason not related to scientific merit.

This principle is clearly stated in our By-Laws (`http://aas.org/governance/bylaws.php`).

More senior members of the profession, especially research supervisors, have a special responsibility to facilitate the research, educational, and professional development of students and subordinates. This includes providing safe, supportive work environments, fair compensation and appropriate acknowledgment of their contribution to any research results. In addition, supervisors should encourage the timely advance of graduate students and young professionals in their career aspirations.

It is also incumbent on senior members of our profession to inform more junior members of these ethical issues and of institutional and government guidelines, policies and procedures related to the oversight and maintenance of ethical standards for research and conduct. It is the responsibility of all members of our Society to familiarize themselves with such guidelines, policies and procedures.

Research

Data and research results should be recorded and maintained in a form that allows review, analysis, and reproduction by others. It is incumbent on researchers involved in large, publicly supported studies to make results available in a timely manner.

Fabrication of data or selective reporting of data with the intent to mislead or deceive is unethical, unacceptable and fraudulent, as is the appropriation of unpublished data or research results from others without permission and attribution.

It should be recognized that honest error is an integral part of the scientific enterprise. It is not unethical to be wrong, provided that errors are promptly acknowledged and corrected when they are detected.

Publication and Authorship Practices

All persons who have made significant contributions to a work intended for publication should be offered the opportunity to be listed as authors.

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This includes all those who have contributed significantly to the inception, design, execution, or interpretation of the research to be reported. People who have not contributed significantly should not be included as authors. Other individuals who have contributed to a study should be appropriately acknowledged. The sources of financial support for any project should be acknowledged/disclosed. All collaborators share responsibility for any paper they coauthor, and every coauthor should have the opportunity to review a manuscript before its submission. It is the responsibility of the first author to ensure these.

Proper acknowledgement of the work of others should always be given, and complete referencing is an essential part of any astronomical research publication. Authors have an obligation to their colleagues and the scientific community to include a set of references that communicates the precedents, sources, and context of the reported work. Deliberate omission of a pertinent author or reference is unacceptable. Data provided by others must be cited appropriately, even if obtained from a public database.

All authors are responsible for providing prompt corrections or retractions if errors are found in published works with the first author bearing primary responsibility. Plagiarism is the presentation of others' words, ideas or scientific results as if they were one's own. Citations to others' work must be clear, complete, and correct. Plagiarism is unethical behavior and is never acceptable.

These statements apply not only to scholarly journals but to all forms of scientific communication including but not limited to press releases, proposals, websites, popular books, and podcasts.

Authors, editors and referees should also be aware of the professional and ethical standards that have been adopted for the AAS journals (`http://aas.org/ethicsPolicy`).

Peer Review

Peer review is an essential component of many aspects of the scientific process such as evaluating research proposals, publishing research results, and evaluating colleagues for career advancement.

Peer review can serve its intended function only if the members of the scientific community are prepared to provide thorough, fair, and objective evaluations based on requisite expertise. Although peer review can be difficult and time-consuming, scientists have an obligation to participate in the process.

Reviewers should disclose conflicts of interest resulting from direct competitive, collaborative, or other relationships with those they are review-

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ing and recuse themselves from cases where such conflicts preclude an objective evaluation. It is unethical to seek to gain an advantage by means of reviewing the work of others, either through use of private information or biased reviews of other's work.

Privileged information or ideas that are obtained through peer review must be kept confidential and not used for competitive gain.

Conflicts of Interest

Many activities of scientists and educators have the potential for a conflict of interest. Any professional relationship or action that may either be, or be perceived to be, a conflict of interest should be fully disclosed. Conflict of interest includes, but is not limited to, situations where the outcome of a deliberation will influence the financial status of one of the participants, or situations where decisions will affect the status of a person who is close to one of the participants. Most organizations or activities have mechanisms for managing conflicts, for example, through recusal. If a conflict of interest cannot be properly managed, the activity should be avoided or discontinued.

5. Impact and Concluding Thoughts

It is hard to tell what the impact of the AAS Ethics Statement will be as its future depends on how well the community incorporates the principles detailed in the statement into the education of students and into the professional lives of practicing astronomers. However, within a year of the statement being approved, the Society received several queries, usually from early-career members, asking the Society to in some sense "enforce" the statement. Usually, the individual had experienced some kind of treatment contrary to the principles of the Ethics Statement and was seeking help from the Society to resolve the matter. A generalized example was the perceived improper ordering of authors on a grant proposal. In many cases, it was clear that the complainant was in fact the victim of poor ethical behavior or at least unintentional decision-making.

However, the intent of the ethics statement was never to be a set of laws, enforceable in some way by the AAS. The intent – as is common for most such Society statements – was to establish a set of principles that members should strive to achieve and implement as professional scientists. They are therefore somewhat broadly defined and not specific enough to be used to enable enforcement. That said, the AAS journals have their own ethical guidelines[8] and enforcement mechanisms (rarely, if ever used, thankfully),

[8]http://iopscience.iop.org/0004-637X/page/Ethics%20policy

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with the Editors-in-Chief and ultimately the publications board serving as the deciding authorities.

Professional societies should develop their own ethical guidelines, primarily as specific scientific practices that vary discipline-to-discipline may also impose unique ethical requirements, although certain principles stand in common across disciplines. Ethical standards should be based on member input, discussion and approval. Efforts should be made to educate and inform members of the ethical guidelines and the reasoning behind them. However, in large part, it is incumbent on the members themselves to live up to the standards and to educate the next generation of members as to their value and importance. Additionally, as times change, as technologies evolve and as the ways scientists interact, collaborate and research change, the ethical guidelines of the profession should be reviewed. From time, to time, perhaps once a decade, they should be considered carefully and perhaps revised.

Although the death of John Huchra in 2010 took away a valued leader in our field well before his time, we are exceedingly lucky to have had his guidance and leadership in the development of the AAS Ethics Statement. I view it as a small, but important piece of his overall legacy and a major component of his accomplishments as AAS president.

John hoped mainly to help inform students about the right way to do 'our business', hence his efforts reaching out to students at the CfA, at meetings and on his colloquium visits, but he also hoped that the statement would help all astronomers work well together, treat each other fairly and with dignity and respect. I think the statement meets these goals and I know my colleagues, the members of the AAS and indeed, all practicing astronomers will find benefit in reading and considering its aspirational guidance.

Acknowledgement

John Huchra was originally planning to write this chapter for OPSA series before his untimely death. It was a pleasure to work with John as president of the AAS and in the development of the AAS Ethics Statement. I am sure my version of his article would meet with his approval, perhaps after a few revisions, a handful of edits and some deep discussion, not necessarily in that order. That is what I liked best about John, he made you perform better and feel good doing the extra work to meet his expectations.

In response to a well-intentioned member comment he received in midsummer 2010 (stating, essentially, that the portion of the ethics statement regarding professional civility was not necessary) John wrote the following response, which I think provides some clear insight to why he felt the work

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to develop and pass the statement was so necessary: ethical guidelines – uniformly followed – could provide protection for students and those less able to defend themselves from the inappropriate or unfair behavior of others. This is also clear in the words of the second paragraph of the AAS Ethics Statement itself, which John crafted.

> Dear [xxx],
>
> Thanks for the note. I grew up outisde New York City and very poor so it was hard to play at being an astronomer. Sandlot baseball was much easier for me and my scruffy friends. But I did play at being a chemist and blew things up whenever I could find the right ingredients – and escape parental supervision.
>
> On your other point, unfortunately there is incivility, sometimes at meetings but very often in the editorial process (both referees and authors stooping to ad hominem slurs all too regularly). This past meeting was pretty good, but at the DC meeting there were several incidents that required some disentangling, and that generally means there are more problems that aren't being reported. The most egregious ones at meetings are when senior people browbeat students, either at talks or at posters, going beyond just a good scientific debate.
>
> Take care,
>
> John Huchra

Resources

There are many sources of ethics information and case studies appropriate to astronomers. Here is a selected subset of relevant information available online:
– The American Physical Society Guidelines for Professional Conduct:
(`http://www.aps.org/policy/statements/02_2.cfm`)
– The DHHS Office of Research Integrity guide An Introduction to the Responsible Conduct of Research.
(`http://ori.dhhs.gov/documents/rcrintro.pdf`)
– The Federal policy on research misconduct.
(`http://www.ostp.gov/cs/federal_policy_on_research_misconduct`)

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 335-346
Ed. A. Heck, © 2013 Venngeist.

THE CODE OF ETHICS AND EDITORIAL CODE OF PRACTICE OF THE ROYAL ASTRONOMICAL SOCIETY

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Abstract. Whilst the Royal Astronomical Society has got by for more than 100 years without a written code of ethics, modern standards of governance suggested that such a code could be useful in the resolution of disputes. In 2005, the RAS adopted the Universal Code of Ethics for Science that had been formulated by the Royal Society of London. At the same time and for similar reasons the RAS adopted an Editorial Code of Practice.

1. Historical governance of the Royal Astronomical Society

In the nineteenth century in Britain the astronomical community consisted of a very few professional astronomers, including academics and some government employees at publicly supported observatories. There was a larger number of wealthy amateurs, such as landed gentry, industrialists or retired servicemen, and professional people such as stock-brokers, doctors, clergymen and school-teachers with some leisure, a comfortable life and the inherited wealth to indulge their interest. Not having modern communications, or a local academic network, some of the amateurs group met socially from time to time to discuss the latest news of their science. In an attempt to widen participation in astronomy beyond these small, informal groups and concerned at the malaise into which British astronomy had fallen at the time, a group of 14 of them who sat down to dinner in 1820 at the Freemason's Tavern, in Lincoln's Inn Fields, London, conceived the foundation of the "Astronomical Society of London", of which they themselves would be the founder members.

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According to regulations drawn up briefly at the original meeting, which became part of a larger body of regulations that has developed over the years and is known now as the Byelaws, further members could be admitted if recommended by an existing member, and now in addition if the recommendation is accepted by the governing Council of the Society (on the advice of a Membership Committee). Only ten years after its foundation, the Society was able to obtain a Royal Charter from the king, William IV and was thereafter able to take up the name Royal Astronomical Society (RAS). In Britain, a Royal Charter is a constitutional document by which the State, in the person of the monarch, directly establishes an organisation as a legal entity, and by which its governance is defined.

Nowhere in any of these governance documents (the Charter and the Byelaws) is there defined any particular qualification for a person to be a member of the RAS, only that they should be acceptable as members to the existing members. The culture of the first members has thus propagated through the Byelaws down the years and the Society has continued to offer membership to the same wide range of people as the founders belonged to – all that is required is an interest in astronomy (in the widest sense of the word, and including geophysics) and agreement with the objectives and regulations of the Society, as well as acceptability to the existing members.

That the range of this culture defining suitability for membership of the RAS had limitations was demonstrated by the fact that there were no women among the 14 founders. In spite of several attempts being made to admit specific women to membership over the years, no women were elected until 1916, after a Supplemental Royal Charter had been sought and granted from the then king, George V, in order to make it clear to some more legalistic, pedantic and/or reactionary of the members of the time that the use of masculine pronouns in the original Charter was a grammatical convention and did not exclude women. (In well-intentioned but inadequate workaround solutions to this issue of gender politics, Caroline Herschel and Mary Somerville were among the distinguished women scientists who were, however, earlier admitted as honorary fellows, and a patronising procedure was introduced by which anyone, including women, could be admitted to a meeting by direct invitation from the President.)

As a matter of practice, and given the range of activities of two other, large, national astronomical societies that cater for present-day amateurs in Britain, the RAS has become a society of, primarily, professional scientists. The range of professional activities and interests of the Society provide the attraction for people to apply for membership, so these activities are unattractive to any but committed amateurs or to people who wish to support the Society (by paying a membership fee) but not to participate in it.

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Although the Byelaws are silent on the qualifications for membership, they do, however, provide a mechanism for the expulsion of a member from the Society through a vote of other members at a meeting called for the purpose, 'whenever there may appear cause'. It appears therefore that there has for a long time existed a body of standards to which members should adhere. In effect it has been operationally defined in the past by an unwritten code of ethics kept in the hearts of members, which they can express at a meeting, case by case. At the time of the foundation of the Society, this code of ethics was, presumably, considering the social status of the founders, the unwritten code of honour of an English gentleman. It has evolved in modern times to be the professional standards of the, primarily but not exclusively, university academics who now dominate the membership, but remained unwritten until 2005.

2. Some modern ethical issues

In the ten years that I was the Treasurer of the RAS from 2001 to 2011, I participated in discussions, usually with the Executive Secretary as the full-time Chief Executive Officer of the Society, about a number of cases of greater or lesser weight and controversy, where someone's membership, actual or prospective, was in question. The less serious cases were about someone who was said to be an astrologer, or to have astrological sympathies. A more serious case was a complaint by one member, a self-employed lecturer, about another lecturer, who was therefore a competitor, who was said in advertisements to have exaggerated his qualifications for the job, and therefore was believed to be competing unfairly. A third case was about a historian of astronomy who had publicly denied the usually accepted scale of the Holocaust of the Second World War, and was as a consequence being criticised for holding an opinion that was held by some to be so abhorrent that he should be ostracised, even from membership of an organisation unconnected with the matter complained of. In the same period, the editors of the Society's publications were involved, as they are on a routine basis, in various disputes, again of greater or lesser weight, over papers for publication (or, more often, papers that had been rejected for publication). These disputes usually stayed within the editorial process, but in one or two cases threatened to break out into a wider arena.

The issues in all these cases were resolved well enough, to the tolerable satisfaction of those concerned. This was a tribute to the skill, professionalism, tact and diplomacy of those who took on the task of resolution (including particularly the patience shown by the boards of editors). But the process left some of us concerned whether the procedures that the Society had used would have withstood the test of a public scrutiny.

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We were also concerned at the position that members had been put in. Where do members stand if they belong to a Society which evidently has a code of ethics, one that they had to sign up to blindly and could not consult? In modern times and with the more democratic principles of the 21^{st} century, is it acceptable for a Society to assume that in the event of a dispute everyone will agree to a commonly held unwritten code? (Indeed, was this ever really the case, even in a well-defined English social class of the nineteenth century? Some histories and novels suggest that that was not always the case.) In an extreme but conceivable practical possibility, where would the Society find firm ground if it was subjected to a law suit brought by someone who did not agree with what had been done by the Society during a dispute? If the dispute strayed out from the confines of the Society and its members, what would the press and the public think of how we were conducting our business?

These concerns were brought together for the RAS in the context of a wider discussion in the global scientific community at that time in the first decade of the 21^{st} century about various, very serious ethical issues of specific concern to scientists, such as the falsification of scientific data, plagiarism, and the like, and issues about the practice of science of considerable concern to the public at large, such as the conduct of scientific research on human beings and animals, the development of technologies that could be used for warfare or in issues of human fertility, the making of claims for work that went beyond the evidence, either for publicity or to attract reward, and so on. Readers can no doubt call to mind some recent, famous, extreme cases which damaged public confidence in science: the case of Jan Henrick Schön of Bell Laboratories, who might have become the youngest ever co-director of a Max Planck Institute if the appointment had been made before he was found to have falsified data and before he was fired by his employer in 2002; or the case of Hwang Woo-suk, a professor at Seoul National University, who coerced his female researchers to donate eggs for research and who counterfeited results and data on cloned human embryos. There was widespread discussion whether a code of ethics for scientists was desirable, which could not only serve to regulate scientists' behaviour but would also serve to protect junior staff who were wondering whether to blow the whistle on unethical behaviour by senior colleagues or an employer.

3. Adoption of a Code of Ethics

In the light of cases like those of Schön and Woo-suk, the issue of a code of ethics that could apply to all scientists was discussed in 2005 at a meeting of science ministers and advisers from G8 countries. As a result of this, in Britain, the Royal Society provided the forum for the Government's Chief

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Scientific Adviser, Sir David King, to lead an international working party to draw up a Universal Code of Ethics for Scientists. In 2005, King circulated a draft version of his code to learned societies in Britain, including the RAS, saying that its purpose was to raise awareness among scientists and the public of the ethical and professional responsibilities of scientists; it was hoped that individual scientists and scientific institutions would adopt it voluntarily. When the final version became available in the summer, the Council of the RAS agreed that the principles enshrined in the Code deserved support and agreed to adopt it as the Code to which all its members should adhere. It would be made public on the RAS web site and included in material sent to newly elected members, and members who renewed their membership each year.

David King's Universal Ethical Code for Scientists is very short. Earlier codes of ethics for scientists had been rather too long for an individual scientist to keep in the back of his or her mind, the record being a code produced for the Royal Society of New Zealand which stood at 250 pages. King noted with some self-congratulation that his code of ethics has three fewer points than the Ten Commandments. It reads as follows:

Rigour, respect and responsibility: a universal ethical code for scientists

Rigour, honesty and integrity

* Act with skill and care in all scientific work. Maintain up to date skills and assist their development in others.

* Take steps to prevent corrupt practices and professional misconduct. Declare conflicts of interest.

* Be alert to the ways in which research derives from and affects the work of other people, and respect the rights and reputations of others.

Respect for life, the law and the public good

* Ensure that your work is lawful and justified.

* Minimise and justify any adverse effect your work may have on people, animals and the natural environment.

Responsible communication: listening and informing

* Seek to discuss the issues that science raises for society. Listen to the aspirations and concerns of others.

* Do not knowingly mislead, or allow others to be misled, about scientific matters. Present and review scientific evidence, theory or interpretation honestly and accurately.

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The Royal Society of London has also been active in addressing issues that arise from on the dual use of science, for good or for bad. The issues are discussed in a document, *Royal Society activities on reducing the risk of the misuse of scientific research* (RS policy document 17/08[1]); the majority of issues addressed are biological, without much applicability to astronomy.

4. Adoption of an Editorial Code of Practice

At the same time as adopting this general Code of Ethics, the RAS adopted an Editorial Code of Practice. Although the Society's publications, principally in astronomy the *Monthly Notices of the Royal Astronomical Society*, are the main activity of the Society, as judged by any quantitative measure, the Society's Byelaws are almost silent on their conduct, doing little more than to designate the Council as the body that appoints editors; nor do the Byelaws deal with the matter of any disputes arising from the editorial process.

Some of the disputes about the Society's publications that have happened have been about issues of what ought to be done, rather than whether what was done was done well. The specific spur for compiling the Code was a dispute with an author about (damaging, verging on defamatory) comments on a paper submitted to *MNRAS*, which the author had pre-posted on Astro-ph. The comments were sent unsolicited to an *MNRAS* editor by a third party, based on his reading of the preprint. How should the editor deal with this view, which was outside the formal peer review process? In this case the editor chose to pass the comments to the author – one imagines that the editor was taking an open, 'scientific' point of view, that this was a comment that had been made by a member of the community and the author should know it and take it into consideration to the appropriate extent. But the third party critic had made a condition on his communication that his identity should be kept confidential. The author took offence at some of the comments (for which, having read the comments, I cannot criticise him), and accused the Editorial Board of acting unfairly by exposing him to a critic whose motives might be unworthy and of protecting him by the cloak of anonymity, even though the communication was outside the formal relationship between the Society and its Editorial Board and a referee, in which anonymity was an accepted contractual agreement, and within normal, professional, academic practice.

This issue was brought out from the confines of the editorial process into the administration of the Society. Not only did the Society find that its editorial procedures were silent on this specific issue, it also realised in tracking down its paperwork that its procedures were defined in an incoherent set

[1] `http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5487`

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of statements and documents originating from various sources, which had not been drawn together, and which had not been formally admitted to the documents that govern the Society, *i.e.* they had not been formally agreed by the Council. The procedures primarily lived operationally in an instinctive unwritten code that was being followed by the editorial boards and maintained by the continuity of the Editors in Chief. This code was, it was true, well-founded in editorial standards that were commonly upheld by the academic community. But, in principle, it was as unsatisfactory for the Society to be relying on an unwritten code about its editorial practices held by modern academics as it was to rely on an unwritten code of ethics for members originating from nineteenth century gentlemen, even if most of us probably felt more alignment with the former than the latter.

Since the editorial boards are being constantly refreshed, with members leaving and new members joining, the Editorial Code of Practice that was drawn up in the wake of this incident had the benefit that it instructed newly-appointed editors on procedures as well as defined them for authors. The Editorial Code of Practice could not be kept as short as the Code of Ethics; nor did it prove possible simply to adopt an existing document. The Society drew up the Editorial Code of Practice by synthesising and adapting material from the following sources: Committee on Publications Ethics, *Guidelines on Good Publication Practice*; British Psychological Society, *Principles of Publishing*; American Geophysical Union, *Guidelines to Publication of Geophysical Research*; and American Chemical Society, *Ethical Guidelines to Publication of Chemical Research*. The Editorial Code of Practice addressed the specific issue that had caused the problem (see Sections A4-5, C6, below) and defined a procedure for the adjudication of disputes (Section B10), which was what had happened in that case. The Editorial Code of Practice is reproduced at the end of this paper.

5. The future

I have not been able to identify any other European astronomical organisation that has a written Code of Ethics as has been adopted by the RAS, although the other European journal of *Astronomy & Astrophysics* has published a stand on ethical issues; see Claude Bertout's article in this volume. Astronomy is not a science in which ethical issues loom large – at least compared to biomedicine, with a subject matter that touches difficult areas of human life and morality, the sciences with applicability to warfare, and/or some other sciences where the financial stakes are high and temptation correspondingly strong. Nor is a Code of Ethics an issue in which an astronomical society would seek to take a proactive interest. It would be generally the academy of sciences or the national scientific society in whose

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area of competence such an issue would lie. Indeed, that was the source of the Code of Ethics adopted by the RAS. But, as I have set out, there are disputes possible in any organisation of members, and a code of ethics forms a benchmark by reference to which it is more possible to resolve them.

However, in the few years in which the RAS has had these ethical codes, they have not been much tested in the heat of battle. Critics in the wider community of the Universal Code of Ethics have suggested that it might fail under the strain of an acute test, since it is not specific enough. The Editorial Code of Practice has certainly been used as a training tool for newly-appointed editors. The RAS will have to see whether either Code proves its worth in future.

Appendix: RAS Editorial Code of Practice

The Royal Astronomical Society serves the astronomical and geophysical communities in several ways, among them through publishing journals which present the results of scientific research. The editor of a RAS journal has the responsibility to maintain the Society's guidelines for reviewing and accepting papers submitted to that journal. Issues of duplicate publication (1) and plagiarism (2) in scientific journal papers can cause considerable conflict among members of research teams and embarrassment for both authors and editors. Accordingly, the RAS has produced the following set of guidelines for authors, referees and editors. (In what follows the terms 'referee' and 'reviewer' are inter-changeable).

GUIDELINES

A. Obligations of Editors of Scientific Journals

1. While ensuring that manuscripts are processed promptly, the aim of an editor is to ensure that the published work will be as accurate, comprehensive, and scientifically valuable as possible. The editors of the RAS journals will give unbiased consideration to all manuscripts offered for publication, judging each on its merits.
2. The Editor has complete responsibility and authority to accept a submitted paper for publication or to reject it. The Editor may confer with other editors and may consult with referees for an evaluation to use in making this decision.
3. The Editor and other editorial staff will not disclose any information about a manuscript under consideration to anyone other than reviewers and potential reviewers.
4. Where an author has chosen to post a paper submitted to a RAS journal to a publicly accessible web site or to present material from the paper in a

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public forum (*e.g.* at a conference) s/he may receive comments from third parties which they wish to reflect in the submitted manuscript. The Editor will decide whether to allow such changes to be made or require the paper to be withdrawn and re-submitted.
5. Where in the circumstances outlined in paragraph 4 comments are directed to the Managing Editor or Editor they will decide either to act on them and if appropriate share them with the relevant referee(s), or request the third party to contact the author(s) directly. Circumstances where the former course of action is more appropriate include comments from bona fide scholars which make serious charges of professional misdemeanour by the author(s). In investigating these charges the Managing Editor or Editor will decide whether to involve the author(s). Except where anonymity is essential to protect a complainant from unfair repercussions their identity and the nature of their charge will be divulged to the parties involved in the investigation.
6. Editorial responsibility and authority for any manuscript authored by an Editor and submitted to the Editors journal will be delegated to some other qualified Editor.
7. Editors should avoid situations of real or perceived conflicts of interest. Such conflicts may include, but are not limited to, handling papers from present and former students, from colleagues with whom the editor has recently collaborated, and from those in the same research group.
8. Where, subsequent to publication, errors are identified in a paper, the Editor will facilitate publication of an erratum.

B. Obligations of Authors

1. An author's central obligation is to present a concise, accurate account of the research performed as well as an objective discussion of its significance.
2. A paper should contain sufficient detailed information and references to public sources of information to a) permit the author's peers to evaluate it comprehensively and b) enable the reader to reconstruct how the results were obtained
3. An author, where appropriate following a literature search, should cite those publications that have been influential in determining the nature of the reported work and that will guide the reader quickly to the earlier work that is essential for understanding the present investigation.
4. Information obtained in the course of confidential services, such as refereeing manuscripts or grant applications, cannot be used without permission of the author of the work being used.
5. Fragmentation of research papers should be avoided. Authors who fragment their work into a series of papers must be able to justify doing so on the grounds that it enhances scientific communication.

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6. It is unethical for an author to publish manuscripts describing essentially the same research in more than one journal of primary publication. Submitting the same manuscript to more than one journal concurrently is unethical and unacceptable.
7. An author may make changes to a paper after receiving referee's comments but should make no changes to a paper after it has been accepted. If there is a compelling reason to make changes, the author is obligated to inform the editor directly of the nature of the desired change. Only the editor has the final authority to approve any such requested changes.
8. A criticism of a published paper may be justified; however, in no case is personal criticism considered acceptable.
9. Only persons who have significantly contributed to the research should be listed as authors.
10. Any author who believes that this Code of Practice has been breached may register a complaint, in writing, through the Managing Editor of the RAS journal concerned. If the complaint is not resolved satisfactorily it will be passed to the Executive Secretary of the Society together with all relevant correspondence. Complaints about the substance (rather than the process) of editorial decisions, or criticisms about editorial content will not be entertained. The Executive Secretary will investigate the complaint and either will dismiss it or conclude that a breach of this Code has taken place. In the latter case appropriate redress, for example, an apology to the author or a change to editorial reviewing procedures, will be recommended to the Managing Editor.

C. Obligations of Referees of Manuscripts

1. Any referee who feels inadequately qualified or lacks the time to judge the research reported in a manuscript should inform the editorial staff.
2. A referee should judge objectively the quality of the manuscript and respect the intellectual independence of the authors. In no case is personal criticism appropriate.
3. A referee should be sensitive even to the appearance of a conflict of interest when the manuscript under review is closely related to the reviewer's work in progress or published. If in doubt, s/he should return the manuscript promptly without review, advising the editor of the conflict of interest or bias.
4. A reviewer should not evaluate a manuscript authored or co-authored by a person with whom the reviewer has a personal or professional connection if the relationship would bias judgment of the manuscript.
5. A referee should treat a manuscript sent for review as a confidential document. It should neither be shown to nor discussed with others except, in special cases, to persons from whom specific advice may be sought; in that

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event, the identities of those consulted should be disclosed to the editor, and the identities of the authors should not be disclosed to those consulted.
6. If the author(s) post a pre-publication version of the submitted paper to a publicly accessible web site or present material from the paper in a public forum (such as a seminar or conference) and comments arise they may be taken into account by the reviewer as described in paragraphs A4 and A5 above.
7. Referees should explain and support their judgments adequately so that editors and authors may understand the basis of their comments. Any statement that an observation, derivation, or argument has been previously reported should be accompanied by the relevant citation.
8. A referee should be alert to failure of authors to cite relevant work by other scientists. A referee should call to the editor's attention any substantial similarity between the manuscript under consideration and any published paper or any manuscript submitted concurrently to another journal.
9. Referees should not use or disclose unpublished information, arguments, or interpretations contained in a manuscript under consideration, except with the consent of the author.
10. The identity of the referee will not be disclosed to the author(s) unless s/he chooses so to do.

Notes

(1) Duplicate publication occurs when authors pass off, as original, research that has been published either substantially or in its entirety elsewhere. Duplicate papers have shared hypotheses, data, discussion points, or conclusions, but do not cross-reference the prior publication. Not only does duplicate publication constitute a possible copyright violation, it also deceives the scientific community as the extent of knowledge in a given field. While ultimately the decision to publish lies with the journal editor, the burden of responsibility for preventing duplication falls to the author(s). Authors should not submit identical or substantially similar work if it has already been published in another outlet. Examples of alternative outlets include book chapters and published conference proceedings of whole papers (as opposed to abstracts. The prior publication of any similar work (*e.g.* other papers based on the same data and methods, or using the same sample) should be clearly referenced in the manuscript. Authors should also inform the editor of any such work already existing, or about to be published. The editor must then decide whether the manuscript includes enough new information to warrant publication.
Authors should avoid 'cutting and pasting' (*i.e.* copying verbatim) substantial chunks of text from their own previously published work. Moderate du-

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plication, involving no more than a few paragraphs throughout the paper, is acceptable provided that reference is made to the publication in which the material first appeared.

(2) Plagiarism is defined as taking another person's ideas or writings and using them as if they were one's own. Plagiarism applies to both published and unpublished ideas, and electronic (*e.g.* internet publications, e-mail) as well as print versions of material. When another's written words are lifted directly from a text, whether published or unpublished, quotation marks should be used and the source of the quotation cited. If paraphrasing is used (summarizing or slightly altering the original exposition of a written idea), the source of the paraphrase must be credited. All sources of ideas that were not conceived by the author(s) should be acknowledged in the paper. This includes ideas received in the form of personal communications and comments from reviewers, colleagues, or peers.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 347-351
Ed. A. Heck, © 2013 Venngeist.

THE "ASTRONOMY & ASTROPHYSICS" JOURNAL: ORIGIN, PURVIEW, AND ETHICAL REQUIREMENTS

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Abstract. We provide a brief presentation[1] of *Astronomy & Astrophysics*, the youngest core astronomy journal, focusing mainly on its scope and the ethical conduct expected from authors.

European astronomers first contemplated the possibility of establishing an international journal devoted to publishing the results of their research in the wake of ESO's creation. At that time, there were a number of national journals devoted to publishing national research in their country's own language, as well as several observatory publications where the observational data were archived. The United Kingdom had a long-established journal, the *Monthly Notices of the Royal Astronomical Society (MNRAS)*, which at that time mainly served the astronomers of the Royal Astronomical Society[2]. By the end of the 1950s, frustration was running high among European astronomers because their work had very little impact outside their own countries. *Astronomy & Astrophysics* (A&A) was founded in 1969 to remedy this situation. Stuart Pottasch, who with Jean-Louis Steinberg was a major proponent for merging various national astronomy journals into a single international one, has summarized the early history of A&A in Pottasch (1999 & 2011).

A&A belongs to the astronomers of the countries that sponsor its operations through modest annual contributions of the national agencies that fund astronomy. The sponsoring countries form the A&A consortium. They

[1]This text is based on the more detailed presentation of A&A given in Bertout (2011).
[2]MNRAS has since then become an international journal with two-thirds of its contents originating outside the UK.

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subsidize and run the Journal's operations, in return for which authors from these countries are not charged for publishing in A&A. Each of the sponsoring countries elects one representative to the A&A Board of Directors, the owning and governing body of the Journal. The Directors in turn appoint the A&A Editors, who are responsible for the contents of the Journal and are accountable to the Board.

Over the years, A&A has grown to become one of the largest astronomy Journal (with currently more than 20,000 pages per year) serving researchers from more than sixty countries. Twenty-four of them currently sponsor the Journal; these are not only European but also South American. The current sponsors are Argentina, Austria, Belgium, Brazil, Bulgaria, Chile, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, the Netherlands, Poland, Portugal, the Slovak Republic, Spain, Sweden, and Switzerland.

A&A is a wide-ranging journal that publishes new results of astronomical research, regardless of the technique used to obtain them, and it accepts papers from any origin; i.e., it is not restricted to serving the sponsoring countries of the Journal. Papers published in A&A should present new astronomical results or ideas of sufficient interest to the community as concisely as possible, but comprehensive enough to allow for duplicating the results by others.

In contrast to other astronomy journals, A&A uses sections to order the published papers. Each section corresponds to a broad scientific area of astronomy or astrophysics to help the reader find the papers that match her scientific interest in the table of contents more easily. The main sections deal with stellar astrophysics and Galactic structure (25% of the contents), cosmology and extragalactic astronomy (25%), interstellar medium studies (13%), solar physics and planetary sciences (10% each). As it turns out, the division into sections allows for a natural and progressive transition to online-only publication of the Journal. The sections dealing with astronomical instrumentation, data and catalogs, numerical methods and codes, as well as atomic and molecular data, are published online only, as are the A&A Letters to the Editor. These sections are also in full open access without any embargo time. The two reasons behind this policy are to provide maximum visibility to those sections that are of interest to a relatively wide part of the community and to promote online publication.

Like other refereed journals, A&A requires its authors to adhere to the strict ethical principles that rule academic endeavors. Respect of intellectual property is the most important of these principles. The copyright on publications represents one way to protect intellectual property, and academic journals usually request that authors transfer the copyright of their works to them. The copyright holder of A&A articles is ESO, which in turn

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transfers the copyright for a limited amount of time to the A&A publisher. In the case of A&A, the transfer of copyright does not keep the author from advertising her/his work in the most efficient way (e.g., by distributing it widely in abstract and reprint databases). When speaking of copyright we are touching on much wider issues such as the so-called open access to scientific information. We only need to stress here that the respect of intellectual property has several practical consequences for authors, and we mention them in turn below, beginning with plagiarism.

Plagiarism is defined in the Instructions for Authors as *"the act of reproducing text or other content from works written by others without giving proper credit to the source of that content"*. Citing a copied text literally is not the only condition for determining plagiarism, which also includes any paraphrased text that discusses an already published idea without citing its source[3].

Plagiarism is a major ethical fault that may also constitute a legal breach of copyright if the reproduced material has already been published. This is particularly true when authors cite text from their own previously published works. A&A Editors refer to this as *"self-plagiarism"*. Authors who wish to quote directly from other published work must cite the original reference and include any cited text in quotation marks. Likewise, figures may only be reproduced with permission. Because A&A focuses on publishing results of original research , authors are discouraged from using any direct quotations and figures[4] of previously published papers. Software tools are available to help Editors locate plagiarized material in submitted articles and are used routinely at A&A.

Papers published in A&A should cite previously published papers that are directly relevant to the results being presented or discussed. *Improper attribution* – i.e., the deliberate refusal to cite prior, corroborating, or contradicting results – represents an ethical breach on a par with plagiarism.

[3]Reproducing or adapting in one's writings material taken from Internet pages, e.g., from Wikipedia articles, without mentioning the original source also constitutes plagiarism. The fact that Wikipedia is a free encyclopedia to which everyone can contribute does not mean that its contents can be used freely. Wikipedia's terms of use state clearly that *"Each copy or modified version that you distribute must include a licensing notice stating that the work is released under the Creative Commons Attribution/Share-Alike License 3.0 (Unported) and either (a) a hyperlink or URL to the text of the license or (b) a copy of the license."* Similar restrictions hold for most material available on the Internet.

[4]Figures that have appeared elsewhere (i.e., copyrighted pictures) are not acceptable unless they are absolutely necessary for understanding the article submitted to A&A. In such a case, the author should request written permission to reproduce from both the original publisher of the figure and its author and send these documents to the editorial office when submitting the article.

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Plagiarism, self-plagiarism, and improper attribution can result in the summary rejection of a manuscript submitted to A&A. In the severest cases of plagiarism, offending authors can be banned from publishing in A&A for a determined period of time. In such cases, the Editor in Chief can also inform the Editors in Chief of the other professional astronomy journals of this ethical misconduct. Mercifully, such breaches remain a relatively rare occurrence.

When you submit an article to A&A, you must attest that your coauthors have read the work and agree with the paper's contents. Adding prominent scientists to the authorship who had nothing to do with the paper is a practice that seems to be developing in some corners, perhaps in the hope that the article will be accepted more easily. This is, of course, another reason for summary rejection.

One should also mention that any given paper cannot be submitted simultaneously to more than one refereed journal. We must emphasize in this context that A&A does not systematically refuse papers that have been previously rejected by another journal, however, the Editors expect a candid attitude from authors concerning these papers. If an author tells the Editor about that paper's previous history, it is likely that A&A will give it a second chance to be published. Some authors choose not to tell us when their submitted paper has already been refused elsewhere, but since we use the same pool of referees as other leading journals, chances are that the Editor in charge of the paper will find out anyway. In this case, summary rejection is likely to follow.

Finally, a given work cannot be published in more than one refereed journal. Doing so – and we have seen a couple of cases in the recent past – is *not* the best idea for increasing the length of one's list of publications. Instead, it constitutes the ultimate ethical and copyright breach, and results in a long-term ban of the culprit from publishing in A&A.

A&A does not require authors to sign a chart of good ethical conduct, but considers that by submitting their paper, they implicitly adhere to the ethical principles outlined above. We thus rely on the good faith of our authors and consider that, as professional scientists, they are keen to follow the rules of the game. However, we have witnessed in recent years some cases of fraudulent behavior that may indicate that time has come to adopt a more formal ethical code and to explicitly request authors to adhere to it, as other journals are also doing. We have thus recently introduced, as a first step in that direction, two explicit actions that concern ethics and copyright issues. First, authors are asked to answer two questions when you submit a manuscript to A&A via the webpage of the Manuscript Management

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System[5]:

– Have all co-authors read the manuscript?
– Has this work been previously submitted to another journal?

If your answer is not 'yes', A&A editors expect you to provide an explanation of why all co-authors did not read the paper, or give a detailed account of the previous history of the paper.

Second, you will be requested to sign a copyright transfer to ESO after your paper has been accepted. The statement, which explains the author's duties and rights, is very similar to the one you would sign if your paper had been accepted in another one of the major astronomy and astrophysics journals.

A full-fledged ethical code should address the attitude expected not only from authors, but also from the other actors of the peer review, i.e, the referees and editors. As mentioned earlier, A&A has traditionally relied on confidence and good faith, and had not yet found it useful to develop such a comprehensive ethical chart. Given the growing number of contentious cases, which reflects an unwelcome but palpable societal trend, writing an extensive chart nevertheless seems a worthy near-term goal for the Journal.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 353-364
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SCIENCE LITERACY OF UNDERGRADUATES IN THE UNITED STATES

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Abstract. Science literacy is a matter of broad concern among scientists, educators, and many policy-makers. National Science Foundation surveys of the general public for biannual Science Indicators series show that respondents on average score less than 2/3 correct on a series of science knowledge questions, and less than half display an understanding of the process of scientific inquiry. Both measures are essentially unchanged over two decades. At the University of Arizona, we have gathered over 11,000 undergraduate student responses to a survey of knowledge and beliefs that is tethered in the NSF survey. This non-science major population demographically represents ten million students nationwide. There is a less than 10% gain in performance in the science knowledge score between the incoming freshmen and seniors who graduate having completed their requirement of three science classes. Belief levels in pseudoscience and supernatural phenomena are disconcertingly high, mostly resistant to college science instruction, and weakly correlated with performance on the science knowledge questions. The Internet is rapidly becoming the primary information source for anyone interested in science so students may not get most of their information from the classroom. Educators and policy makers need to decide what aspects of science knowledge and process are important for adults to know. College science educators have major challenges in better in preparing graduates for participation in a civic society largely driven by science and technology.

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1. Rationale and Definitions

Science and technology act like an "amniotic fluid" around everyone living in the industrialized world. Americans encounter science in their various roles as citizens, workers, and consumers. They vote for political candidates with diverse views on climate change, stem cell research, nuclear power, or the space program. They vie for jobs in technology-driven sectors of the economy that didn't exist a generation ago. They are consumers of ubiquitous high-technology devices, and are mostly content to use these emblems of scientific ingenuity without substantial knowledge of how they work. Science is profoundly shaping human culture, yet any ability to assimilate new insights into the natural world depends on an understanding of how scientific knowledge is gained and on how to distinguish scientific facts from other kinds of information. This collection of skills and basic knowledge is often referred to as "science literacy".

Scientists and educators in different fields may not agree on a core set of concepts, principles and facts that every citizen should know, but they are mostly in accord that the health of civic society depends on science literacy. Various policy groups have weighed in. The Organization for Economic Cooperation (OECD) defines it as understanding key scientific concepts and frameworks, the methods by which science builds explanations based on evidence, and being able to critically assess scientific claims and make decisions based on this knowledge (OECD 2002). The American Association for the Advancement of Science (AAAS) says scientifically literate citizens should be aware that science, mathematics and technology all have strengths and limitations and are interdependent human enterprises, they should recognize the unity and diversity of the natural world, and they should be able to use scientific ways of thinking and knowledge for individual and social purposes (AAAS 1993). The National Research Council (NRC) sets even more lofty goals: education should promote science as one of the pinnacles of human thinking capacity, provide a laboratory of common experience for developing language, logic, and problem-solving skills, and prepare students for a democracy which demands that its citizens make personal and community decisions on scientific issues (NRC 2007).

The National Science Foundation has carried out a survey of science knowledge and attitudes for over twenty years, published every two years in the *Science and Engineering Indicators* series, a report to the National Science Board and the US Congress that is used to shape national research and education policy and guide workforce development in technical fields. From their inception, these reports defined literacy criteria based on: (1) a vocabulary of basic scientific constructs, (2) an understanding of the process or nature of science inquiry, and (3) a level of understanding the impact

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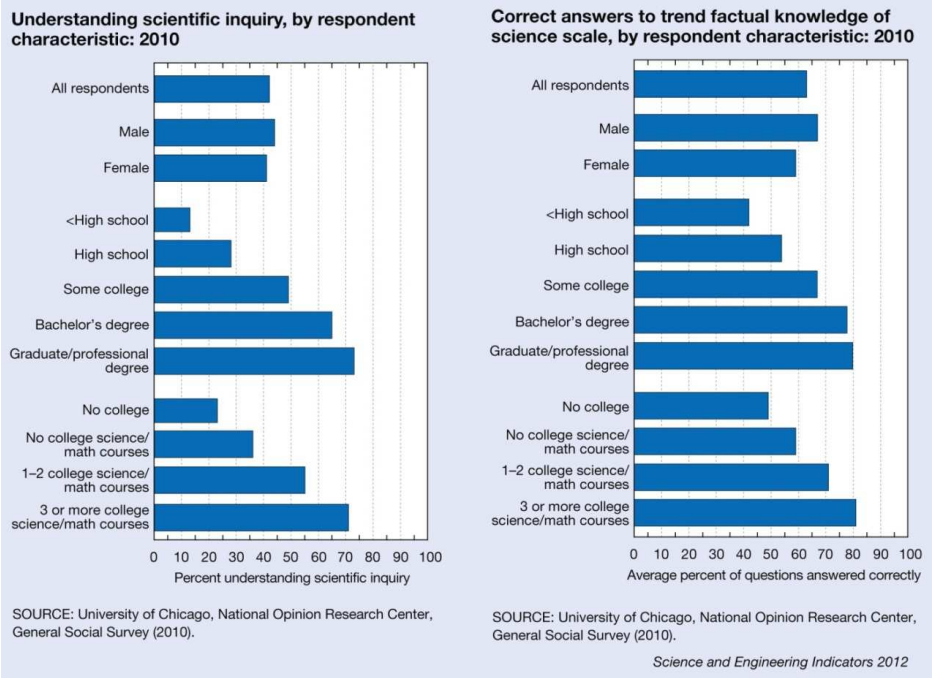


Figure 1. Percentage of the US adult population able to recognize key attributes of scientific inquiry (left) and percentage of correct answers on a 9-question test of basic science knowledge (right). Details of the instruments and coding are given in the *Science and Engineering Indicators 2012* report (NSB 2012). There is a strong dependence of both metrics on formal level of education level and the number of college science classes taken.

of science and technology on individuals and on society. Using thresholds based on (1) the coding of open-ended responses to the question "What does it mean to study something scientifically?" (2) the recognition that astrology is not at all scientific, and (3) correct answers to six or more out of nine knowledge questions, only one in ten American adults was declared scientifically literate (Miller 1987).

In more detail, the level of public science knowledge and familiarity with science as a method of inquiry depends strongly on level of education, and, for those who attended college, on the number of science courses taken (Fig. 1). Traditional models of science literacy imply that the public has a "deficit" of knowledge or understanding relative to a benchmark that may be unrealistic, unattainable, or even irrelevant. Recent discussion of science literacy has become more nuanced, deemphasizing treatment of the public as proxy scientists and recognizing instead that citizens may need to have an active role in the science policy process, but only for topics of particular

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interest (Miller 2002). Workshops sponsored by the NSF have fostered this debate, saying for example that "The starting point for public knowledge of science is the need of the citizen or the information consumer, as opposed to a microcosm of what a scientist knows" (Tuomey 2011).

2. College Science Classes

Advanced math and science are voluntary in most high schools. The majority of students take biology, but less than half takes chemistry, a quarter takes physics, and only 1 in 20 takes calculus (Blank *et al.* 2007). University provides the last formal exposure to science for most Americans. There, students face a smorgasbord of choices, and despite the emergence of General Education science requirements, science is being taken less frequently overall. The National Academy of Scholars surveyed science curricula used in BA degrees from the top fifty institutions in the *US News and World Report*s rankings – the percentage having science requirements dropped from 90% in 1964 to 34% in 1993, and the percentage with both math and science requirements dropped over the same period from 36% to 12% (Balch & Zircher 1996). A Department of Education analysis of the "empirical curriculum" found that science accounted for just 7 of the 100 course categories with the most undergraduates, while a third of all future school teachers do not take any college-level math (Adelman 2004).

The people who teach undergraduate science play an important role in our society. If they teach science majors, they help to fulfill the need for a technically trained workforce by preparing students who are numerate and who have inquiring and analytic habits of mind. If they teach non-science majors, they provide a formal exposure to evidence-based reasoning and the ideas that have transformed our understanding of the natural world, and they are crucial in the efforts to improve public science literacy. For example, introductory astronomy college classes for non-science majors enroll over 250,000 students per year and often represent a student's last formal exposure to science. Nationwide, about 10% of all students take such a class (Fraknoi 2002). Therefore, the astronomy class that serves as a requirement for non-science majors is a useful vehicle for testing new approaches to improving science literacy.

Most educators have goals that go beyond conveying astronomy knowledge and instilling an appreciation for the subject; they also want students to learn about the rational way of thinking and experimenting that has been so successful in revealing the underlying rules of the natural world. Constructivism, a theory of how people learn, posits that students do not enter the college classroom as "empty vessels", ready to be filled with science knowledge (Bransford *et al.* 2000). Rather, students have a complex

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web of prior belief systems and understandings about nature based on their experience, upbringing, popular culture, and social interactions (Donovan & Bransford 2005). Some of the beliefs may align with scientific understanding, while others can be classified as superstitions. Another category is called pseudo-science: a belief system that presents itself as scientific or that has some of the trappings of science, but is not based on logic or evidence (Shermer 1997). Many science educators argue that non-science beliefs interfere with the learning of science and hence with increasing science literacy (Losh *et al.* 2003; Martin 1994). However, it is an open question whether or not non-scientific views or belief systems actually interfere with or compromise learning science or having a scientific worldview.

3. A Survey of Undergraduates

We have been surveying non-science majors regarding their scientific knowledge, attitudes toward science, and pseudoscience beliefs for over twenty years. Initial results from the survey have recently been published (Impey *et al.* 2011, 2012; Antonellis *et al.* 2012; Buxner *et al.* 2010). The University of Arizona sample is representative of the roughly 15 million students at public universities in the US who will graduate with degrees in non-technical subjects. The survey instrument used in this study has been stable since 1988 and has two parts. The first is based on, and has a large degree of overlap with, the instrument used by the NSF in the *Science Indicators* series. It is designed to measure general scientific knowledge using a set of 21 knowledge-based questions, four of which are open-ended with short written answers and the rest of which require true/false or multiple choice responses. The second part measures attitudes to science and technology, perceptions of and susceptibility to certain forms of pseudoscience, and aspects of faith and religious belief. It uses 24 statements where the responses are on a five-point Likert scale. Details of the instrument, its reliability and completion rate, plus a description of the data entry and coding process, are given by Impey *et al.* (2011).

The knowledge-based questions cover a broad range of scientific subjects, from physics ("Which travels faster, light or sound?") and astronomy ("Does the Earth go around the Sun or does the Sun go around the Earth?") to biology ("The oxygen we breathe comes from plants, true or false?"). In the survey instrument, 15 of the 17 questions overlap the NSF Science Indicators survey; a core set of 9 questions have consistently been part of the NSF survey, giving us a twenty year baseline of comparison (Fig. 2). Open-ended questions asked for definitions of the scientific method, DNA, radiation, and computer software. Students also responded to a set of 24 statements on a five-point Likert scale of "strongly agree, agree, no opin-

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ion, disagree, and strongly disagree". Items sample a spectrum of attitudes and beliefs. For example, statements like "Pure science should be funded regardless of its lack of immediate benefit to society" probe general attitudes to science and technology. Others, like "There are circumstances when medical science should not be used to prolong life", address ethical issues. Another set of items probes superstitions and beliefs in pseudoscience, such as "Some numbers are especially lucky for some people" and "The positions of the planets have an effect on everyday life". There are also statements relating to religious belief, like "The Biblical story of creation should be taught alongside evolution in our schools" and "Faith healing is a valid alternative to conventional medicine".

4. Results of the Survey

The University of Arizona survey continues, providing a unique longitudinal view representative of the US undergraduate basic science knowledge, attitudes, and beliefs, with direct tether to an ongoing NSF survey. With half a million individual responses in the database, there is great statistical power for measuring subtle and small effects. The results quoted below include only students taking non-science majors. The most important results so far are:

- *Entering freshmen* perform somewhat higher on knowledge questions than the general public. The UA students at all levels got an average of 7.2 items correct out 9 (80%), compared with 5.6 out of 9 (62%) for the general public in the NSF survey. Neither undergraduates nor the general public show any change in knowledge score over two decades. There are no good predictors of knowledge score, but among the different fields of study, the Education majors (and so future teachers) perform the worst.
- *Gains in knowledge* on any particular item through the time that students graduate are 10 to 15%. That corresponds to a gain of only one additional correct item out of nine between the time a student graduates high school and the time they graduate college, despite taking three science courses. Women score slightly lower than men on knowledge questions.
- *Gaps in knowledge* of graduating seniors are disconcerting. One in three think that antibiotics kill viruses as well as bacteria, one in four think that lasers work by focusing sounds waves, one in five think atoms are smaller than electrons. One in five either does not believe or is unaware that of the fact that humans evolved from earlier species of animals and that the Earth orbits the Sun in a year, two of the central tenets of modern science.

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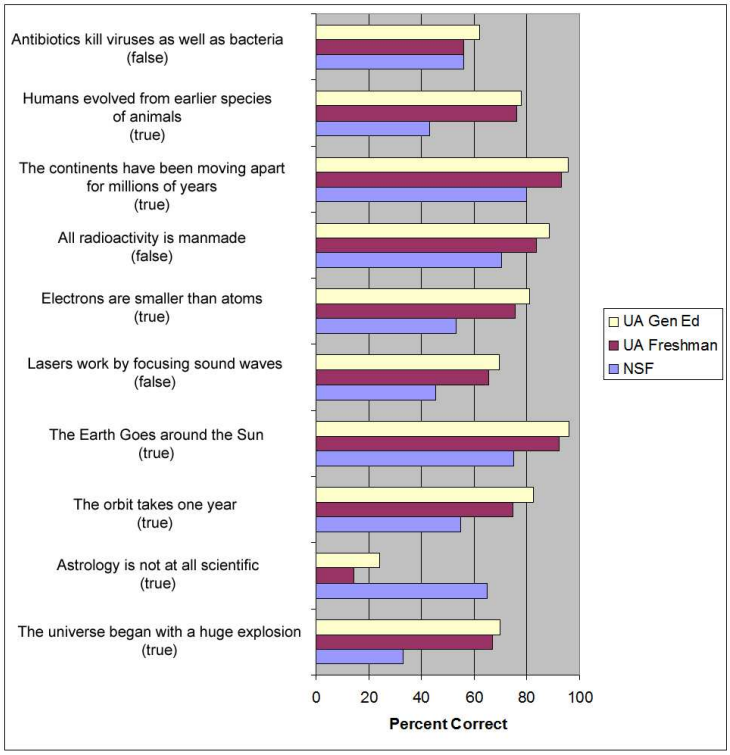


Figure 2. Responses to subset of items on the University of Arizona (UA) science literacy instrument. These items form the basis for a NSF knowledge-based metric of public science literacy. Freshmen have not taken any science classes, whereas Gen Ed students have taken 2 to 3 science classes. Sample sizes are 1864 for NSF, 1275 for UA Freshmen, 828 for UA Gen Ed; the data is 2006 for NSF and 2004 to 2008 for UA.

- *Support of science* and positive attitudes towards research are widespread. Over 90% strongly agreed or agreed with the statement that "Overall, the progress of science and technology has been beneficial to our civilization", and by a ratio of 4:1 students agreed that "Pure science should be funded regardless of its lack of immediate benefit to society". There was also solid support for the space program and the search for life in the universe.
- *Belief in pseudoscience* runs high. About 40% believe that the positions of the planets affect everyday life (Sugarman *et al.* 2011); a similar percentage thinks some people have psychic powers. About 1 in 6 think aliens visited ancient civilizations, 1 in 4 think that faith healing is a legitimate alternative to normal medicine, and a quarter believe in lucky numbers. Surprisingly, none of these beliefs is strongly correlated with level of science literacy.

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- *Beliefs and knowledge* are weakly related. There is a significant negative correlation between the knowledge score and either the level of faith-based beliefs or the level of susceptibility to pseudoscience, but it amount to less than 10% across the full span of beliefs. Taking college science courses has only a small effect on belief in pseudoscience (Goode 2002).

5. Implications for Science Literacy

The most striking results of this research are the weak effects and the null results. There are no major changes in understanding over two decades, and apart from a small gender effect, no demographic variable is a good predictor of level of science knowledge. Undergraduates do not show a marked improvement after taking three university science courses. Miller (2007) analyzed the NSF data to conclude that the number of college science courses taken is the best predictor of civic science literacy (Hobson 2008), closely followed by formal educational attainment, which indicates that overall college experience has as much impact as science instruction. Over the full baseline from 1988-2008, there's no improvement in undergraduate scientific literacy over twenty years. Perhaps the most striking result is the weak relationship between science knowledge and level of belief in pseudoscience and the very modest change in that level of belief after satisfying the standard science requirement for non-science majors (Impey *et al.* 2012; Buxner *et al.* 2010).

There is good and bad news in the Science Indicators surveys and the data from UA surveys. Even though the general public's scores on the knowledge questions have not improved over twenty years, overall public understanding of science has improved over time when cohorts are tracked, even after controlling for the formal level of education (Bauer 2009). Unfortunately, this improvement coexists with strong, and in some cases growing, beliefs in pseudoscience and in non-scientific phenomena (Losh 2011). In NSF surveys, the biggest gains in factual knowledge and in understanding the nature of scientific inquiry accrue to education level and the number of science or math courses taken at college. Undergraduates score 60% before they have taken any science or math courses, which rises to 80% when they have taken three or more. However the gain from high school graduation to college graduation is even larger, from 54% up to 78%, so much of the improvement may be attributed to maturation and the overall educational experience. The percentage understanding the nature of scientific inquiry rises from 36% to 70% when three of more science courses have been taken, but the rise from high school graduation to college graduation

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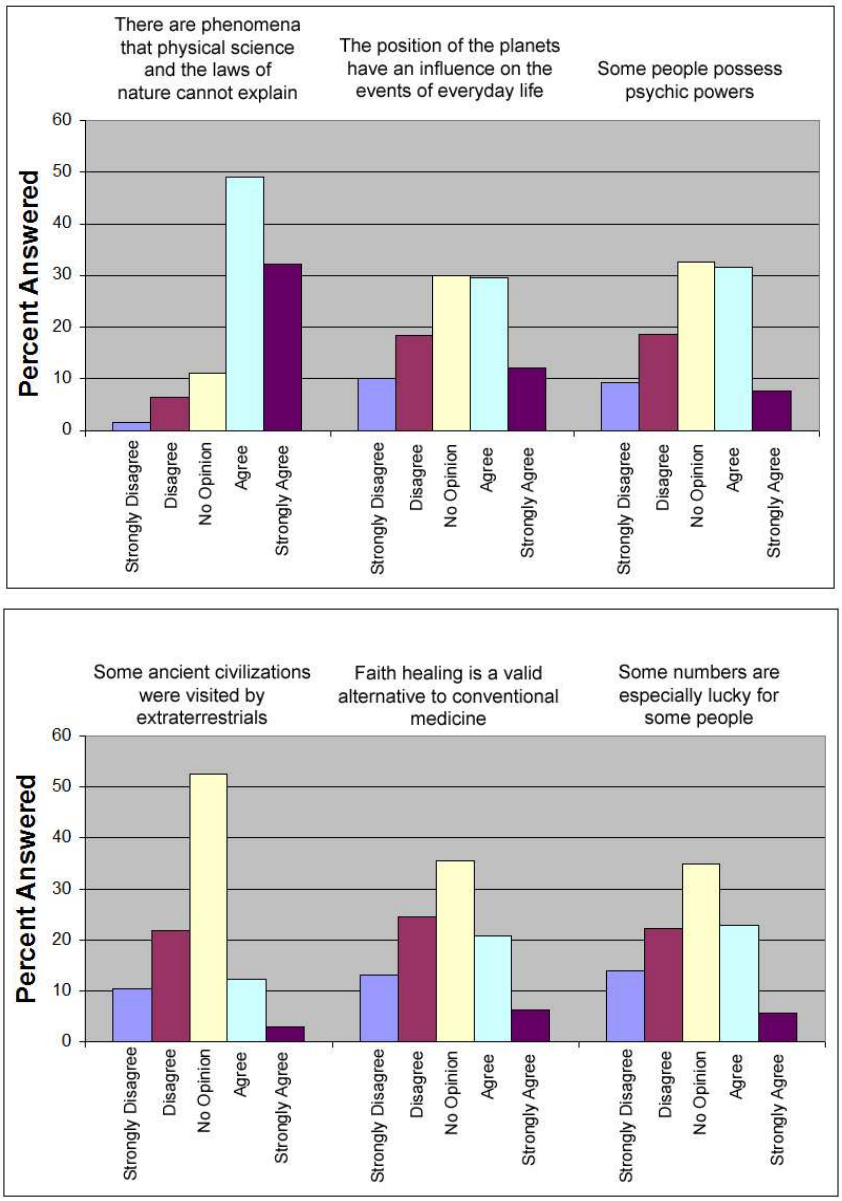


Figure 3. Overall responses, by nearly 10,000 undergraduates over a period of 20 years, to 6 out of 24 statements about science and technology, all items relating to pseudo-science or non-scientific belief systems. These beliefs often coexist with an above-average performance on science knowledge questions.

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is even larger, from 29% to 73%. The NSF data don't support attributing these gains primarily to science classes taken by non-science majors.

This story is mirrored in the UA data. The average knowledge score on the items used by the NSF rises from 76% for students who have taken no science classes to 85% when they have taken three or more, with the same modest gain going from freshmen to seniors. This data cannot be used to follow cohorts, nor are we able to correlate performance on specific biology or physics or astronomy items with the students having taken those particular courses, so as with the national data there's no indication that required science courses are having the desired effect on student knowledge. However, it is clear that students graduate with sizeable holes in their knowledge and with a diverse set of non-scientific beliefs intact.

A typical non-science major at a large university will take three science classes as part of their General Education or distribution requirement. Those several hundred hours of formal science training have varying efficacy, depending on the modes of instruction and the quality of the pedagogy. A recent national report on the science education pipeline stated that "A significant barrier to the broad implementation of evidence-based teaching approaches is that most faculty lack any experience using these methods and they are unfamiliar with the vast body of research indicating their impact on learning" (PCAST 2012). But the classroom does not completely determine the literacy landscape. Surveys by the Pew Research Center, quoted in Science Indicators (NSB 2012), show that the Internet is the primary source of general science information and it eclipses television and print media by a large factor for specific scientific issues (Fig. 4). Wikipedia is notably influential, since it is the most visited information site on the Internet, used by a majority of adult Internet users (Zickuhr & Rainey 2011). The ability of students (and also the public) to distinguish reliable and unreliable sources of science information is currently un-documented.

The pervasiveness of belief in pseudoscience and supernatural phenomena among undergraduates suggests at the very least that their capacity for critical thinking is unevenly applied (Lindeman & Aarnio 2007). It might even mean that relatively high scores on knowledge items give an illusory sense of mastery, because they are unable to apply rational criteria to subjects such as astrology, psychic powers, and lucky numbers. Belief in pseudoscience is such a poor predictor of performance on knowledge questions it begs the question: do irrational beliefs actually matter? The path to improving the science comprehension of students and the public is unclear and represents an interesting challenge for science educators.

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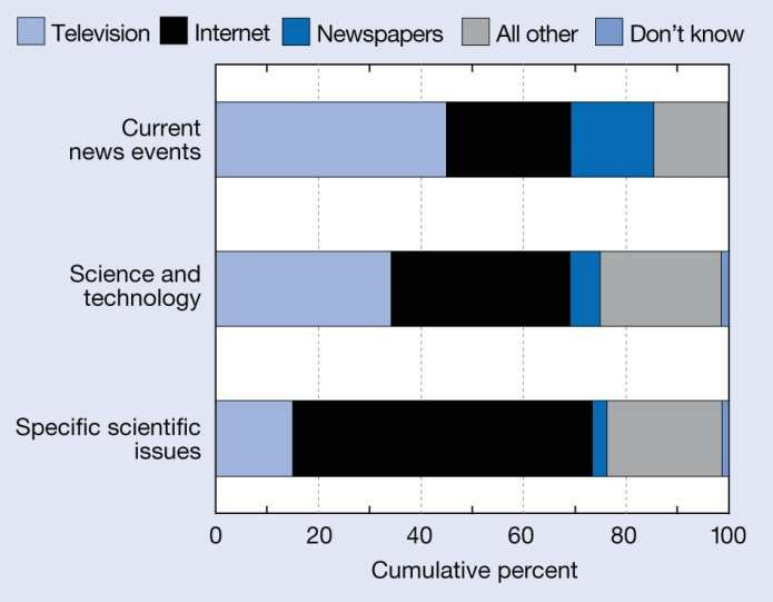


Figure 4. Where the American public gets its science information. This survey from the National Opinion Research Center at the University of Chicago shows that the Internet has grown to rival television as a source of information about science and technology, and is now the primary information source on specific issues in science (NSB 2012).

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 365-369
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THE REWARDS OF MEMBERSHIP IN THE IAU

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Abstract. The International Astronomical Union is an international organization dedicated to the advancement of all aspects of the science of astronomy. Importantly, its triennial meetings provide opportunities to discuss the latest astronomical concepts and the most recently acquired data from telescopes, both on Earth and in space. The membership is encouraged to help in advancing astronomical education and opportunities world-wide. Equally important, the meetings provide opportunities to greet old friends, make new friends, and to learn about and to enjoy the thrills resulting from discoveries associated with one of the oldest and spectacular sciences

1. The International Astronomical Union

The International Astronomical Union (IAU) was conceived in 1919 in the aftermath of the First World War. It was formed on 28 July 1919 in Brussels (Blaauw 1994) under the auspices of the International Research Council (IRC), astronomy thereby becoming the first science to be recognized and organized under the aegis of the IRC. A goal of the IAU is to provide opportunities for astronomers from around the world to come together, to interact, to plan, and to execute astronomical research projects which were too large for any one individual, group or nation. A second goal is to encourage the development of astronomical opportunities around the world as a means of ensuring the continued vitality of astronomy. Early reviews of the IAU's formative years were written by Stratton (1934) and Pecker (1966).

The policies of the IAU are formulated by an Executive Committee. These policies are overseen and executed by the IAU Officers and Commis-

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sion Presidents, aided by a small Secretariat Office in Paris. The evolution of these activities is described more fully by Blaauw (1994).

The IAU has the goal and mission of promoting the discipline of astronomy through international efforts and interactions. The most important of these endeavors is the triennial meeting called the General Assembly. The General Assemblies, held in different geographical locations over the years, bring together a few thousand astronomers. Smaller Symposia are held each year, in different locales, and cover a more limited set of, or single, topics, and are hosted by specialists in the content of the symposium topic. Major efforts continue to be made by the IAU Executive Committee, Division Presidents and Commission Presidents to ensure that strong scientific programs are produced for the membership.

The superstructure called the IAU is composed of Divisions, Commissions, Working Groups and Program Groups. The IAU is the only international organization within the IRC which has individual members. These individuals are professionals scattered around the world, working at the PhD level, and participate in research and educational activities in astronomy. Although research historically has been the main reason for the existence of the IAU, in recent years efforts by the IAU Executive Committee have been to make available opportunities to participate in astronomical education and research programs by individuals throughout the international community.

The IAU Divisions are composed of more focused areas of astronomical interest and research. For example, there are Divisions studying the Sun, Galaxies, Radio Astronomy, Close Binary Stars, among several dozen others. These groups, varying between several dozen and several hundred of like-minded astronomers, plan and concentrate on efforts to better understand their subset of the universe. Results of the efforts often are presented at the General Assemblies through the Invited Discourses, Special Sessions, Joint Discussions and General Assembly Symposia.

The IAU has responsibility for the nomenclature identifying objects on the celestial sphere. The assignment of names to celestial objects makes possible the correlation of different observers' data and other information for the named object. The organization must approve names of and for features on the planets, moons, asteroids and comets in our solar system. The IAU also has the obligation for approving the values of astronomical constants, e.g., the length of the astronomical unit, roughly the mean distance between the Earth and Sun, the definition for the astronomical unit of time, the day, and the definition for the astronomical unit of mass, the mass of our sun. These constants are used in a variety of calculations by the physical sciences including studies of possible inconsistencies between the mathematical formalisms and the constants themselves. Additional in-

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formation concerning the responsibilities, effort involved and the challenges which need to be faced, may be found in van der Hucht (2009) and Corbett (2010a&b).

There have been times in world politics when the IAU was one of the few conduits between astronomers, and science in general, and cultures of different persuasions with differing political agendas. Whereas one might hope for a community of understanding among humankind, history continues to show otherwise. International scientific organizations such as the IAU therefore will continue to have a role, in addition to the science itself, in advancing human endeavors.

A history of the IAU's first fifty years by Blauuw (1994) gives a complete background of the organization. The book is highly recommended. Modern information is kept current through the IAU's website[1].

2. The Reward of the IAU

Astronomers began the practice centuries ago of collaborating in gathering data for projects which demanded that observations be made world-wide. One early effort followed a recommendation in 1761 from Edmund Halley that the length of the astronomical unit could be determined by timing the transit of the planet Venus as its image moved across the Sun's disk. Another effort was the Carte du Ciel, a concept initiated in 1887 by A. Mouchez of the Paris Observatory. That huge endeavor involved a photographic survey of the entire sky which resulted in accurate stellar positions. Observatories the world over were apportioned declination bands around the sky for which they were responsible to acquire the photographic plates. A third early effort was The Selected Area campaign initiated by J. Kapteyn, designed to study characteristics of the galactic system as understood in the early twentieth century.

There is strong evidence that the astronomical community believes in the usefulness of the IAU as evidenced by the large attendance at each of its triennial meetings. Something like one fourth to one third of the membership of nearly 10,000 individuals, attends the triennial meetings held in interesting locales around the world. The host country's astronomical organization identifies a site which is representative both of the country's science and culture. The author's experience as an officer and councilor in a number of large scientific organizations indicates that unless science, culture and amenities all are present, people will not attend. Not all astronomers care for such large meetings, preferring much smaller workshop-like, narrowly defined symposia. However, those astronomers who do attend are richly rewarded, as are the home institutions who many times help fund the

[1]http://www.iau.org/

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participants' meeting costs. Attendance is a broadening mechanism since the majority of astronomers also are educators, who can use the breadth of offerings at a General Assembly to enhance their lectures back home. This author always has found it interesting that so many attendees themselves pay a large fraction, if not the entire cost, of their participation in professional meetings such as the IAU's General Assemblies.

Perhaps the most important aspect of meetings as large as the General Assemblies is the opportunity to network. It is true that THE major function of a General Assembly meeting is to be exposed to the science. It equally is important to be exposed, to meet, to interact with those doing the science. In particular young attendees, usually only recently having acquired their PhDs, have the opportunity to meet the experts, not in an intimidating classroom, but in small discussion groups, over a meal or snack, perhaps complete with a raised glass. Such meetings also allow the young to meet members of their cohort, ever important since they will be the future workers, innovators and leaders. In addition, of course, it is instructive and fun and intellectually stimulating to see different parts of the world. And again, one cannot over-emphasize the importance of net-working in the process of enhancing knowledge and understanding.

This author remembers occasions like his first IAU meeting in Berkeley in 1961. Each US astronomy department was allowed to send as guests to the General Assembly ten percent of their graduate student body. Our department was allowed 2.5 attendees, and I was the 0.5 one (it did not hurt too much). At the General Assembly, then President J. Oort opened the General Assembly in the open air on the University of California, Berkeley, campus, giving the welcome message six times, in six languages. In those days, and in a few of the following IAU General Assemblies, each of the attendees wore colored dots stuck to their name badges, several individuals with six or seven colored dots. The presence of those dots signified the ability to converse in the language identified by the colored dot. Those were the days when foreign journals still were written in the language of the author and host country. Those were the days when a student had to show the ability to read two foreign languages as a requirement for their PhD (in the US). The formal requirements have disappeared, but many professionals in Europe and Asia still have such capabilities. It is to their great advantage, aiding in the ever important task of networking, and being able to function more easily world-wide.

July 1964 saw the Ranger 7 space craft crash into the Moon, returning pictures taken on the way to impact. A special session was held at the IAU meeting in Hamburg in August 1964 where the Ranger program was discussed. The special session featured G. Kuiper who guided the audience through the stream of images leading up to the crash landing, images which

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had been swiftly transported to the General Assembly. This meeting, as they all do, one way or the other, featured evenings of scientific exchange over beer in a tavern interrupted by songs appropriate to the locale. Perhaps one ought not be surprised by the breadth of the repertoires of some of the leaders of our science!

Stories abound from the General Assemblies, ranging from the Invited Discourse to the Joint Discussions to the scientific content of the Commission meetings. An aspect little mentioned is that whereas there are many meetings around the world where diverse astronomical discoveries are dissected and reviewed, the IAU historically has played another important role, the role of conducting the business of the international astronomical community. During its meetings, international compacts are secured, world wide programs are put into motion, inter-cultural understandings are achieved, and efforts are finalized, to help each other achieve a variety of goals otherwise less easily attainable, if at all attainable.

Beginning in and since 1961, this author has attended and participated in all IAU General Assemblies except for three, as a contributor, as a Commission President and as a Division President. A summary would indicate the positiveness of a sense of belonging to, of having a place within, the international community of one's discipline, as well as the ability to promulgate and enhance the science that we love.

Acknowledgements

The author acknowledges with thanks the interesting comments of the referee. The author's research in recent years has been funded by the US National Science Foundation.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 371-392
Ed. A. Heck, © 2013 Venngeist.

THE MANAGEMENT OF AAS MEETINGS

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Abstract. The American Astronomical Society organizes the largest astronomical conferences in the world. This article describes the way we organize our own conferences, the content of our meetings and how it is developed and provides some tips for successfully organizing scientific conferences generally, both financially and scientifically. Organizing meetings is difficult and requires specialized skills and experience. It is often best to have scientists focus on organizing the scientific aspects of conferences while leaving the logistical and financial aspects to professional meeting organizers. The AAS provides these services for its own meetings, the meetings of its Divisions and to others on a case-by-case basis.

1. Introduction

Science proceeds through communication. An isolated scientist, filling personal notebooks with amazing results that are never shared, is not helping move human knowledge forward; however much their personal knowledge of the world is enhanced. This is why written communication – beginning with the authorship of books (at first scrolls!), writing letters to fellow scientists, and the publication of scientific journals – has been used to share scientific knowledge. However, the written word alone is insufficient to allow scientific progress. Scientists have always gathered together in small and large groups to discuss ideas and data and to challenge each other with alternative viewpoints or interpretations. Although the mode of interaction has shifted over time, the fundamental benefit of gathering and sharing ideas has remained the same.

Meetings of a handful of scientists require no substantial planning. A shade tree and good weather often host ad hoc gatherings at campuses

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everywhere. And where would the typical science department be without the coffee room, departmental library, or student study lounge for ad hoc discussions of the latest interesting results? However, as the numbers of scientists gathering at one time grow, logistics become more complex. This is fundamentally driven by the desire to have all (or most) attendees actually "present" their research, whether in spoken or printed form (as scientific posters), or both. Audio amplification is required, as session halls grow larger. Projection of presentation materials must be arranged and ample chairs, lighting and physical comforts must be provided. Lodging must be arranged for meetings longer than a single day. Even the simple progression of the meeting, whether singular talks by individuals, panel sessions or workshops must be scheduled and shared with the planned attendees. As meetings get larger, a single session room will be unable to host all the presentations and the flow of the meeting must be considered and planned, sometimes with any given room being reconfigured throughout any given day as appropriate. Even smaller meetings often require contracts with third-party service providers, whether simply for catering needs or for audiovisual support, security or even provision of poster boards, chairs and other temporary infrastructure. Truly large meetings are events unto themselves, requiring substantial advance planning, many additional service providers and greater attention to a wider range of ever-evolving requirements, special requests and unique situations. To put it bluntly: planning and executing a scientific conference is hard.

Clearly, once meetings progress to a certain size – typically 50 or more people – the additional planning and services required to ensure the scientific value of the meeting entail substantial costs. Those costs are typically recovered via participant registration and so; an additional area of concern, financial planning, budgeting and collection of fees comes into play. This is an important, yet many times neglected area of effort. Without sound budgeting, regular assessment of costs and dynamic adjustment in the lead-up to the meeting, financial losses are nearly guaranteed. Changes made at the last minute or while on-site can have devastating financial results. For example, handing out a complementary ticket to a banquet at the last minute, after confirmed numbers have been provided to a caterer, can have a double-whammy effect financially as the ticket is provided at no charge *and* a penalty may be incurred from the provider. Banquets are not unique in this regard. Sound financial management and oversight combined with careful decision making in the final weeks of planning as well as while on-site is critical to a positive result.

Each year the American Astronomical Society organizes a winter meeting with more than 2,500 attendees (occasionally greater than 3,500 attendees), a summer meeting of roughly 1,000 attendees, between one and four

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Division meetings from 100 to over 1000 people each and a wide range of smaller meetings, mainly necessary for Society governance. In addition, the Society now provides meeting management services to scientific conferences not specifically sponsored by the AAS or one of its Divisions (*e.g.* the 2011 Extreme Solar Systems II meeting held in Jackson Hole, Wyoming, USA) and has recently announced the establishment of an AAS topical conference program beginning in summer 2013[1].

Because of all this meeting activity, the Society has invested carefully in its meeting planning and execution systems. Based fundamentally on talented professionals who are non-scientist employees of the AAS Executive Office, the Society has moved from a management system that relied heavily on local organizing committees and volunteer efforts to a system fully managed in-house by the AAS Executive Office as our preferred model. Additionally, substantial infrastructure is now in place, along with proper separation of function and accounting practices, to allow reliable financial success for all meetings as well. This is important, as meeting cost overruns represent funds that cannot be used to achieve other goals and are essentially wasted. Every dollar not paid out in penalty or for unbudgeted expense is a dollar that can be used to enhance and share humanity's understanding of the Universe, the mission of the American Astronomical Society and, I would argue, the main reason we hold any science conferences at all.

This contribution to OPSA II is meant to accomplish several things. First and foremost, it is a detailed snapshot of how the AAS operates its meetings at this point and time in its history. Second, it lays out the systems by which the Society will interact with meeting organizers in the astronomy community to carry out a successful astronomical conference. Finally, it can serve as a guide to those who are undertaking their own meeting organization and hopefully help them avoid common mistakes. I hope that by sharing the AAS perspective on the management of meetings, I can help others in our field achieve this common goal.

2. AAS Meeting Management: The Basics

The AAS maintains a meeting services group, consisting currently of a Director (part time), a Meetings Manager, a Registrar & Meetings Coordinator, an Exhibits & Sponsorship Coordinator (part time) and a Meetings Abstract Administrator. The Executive Officer, Chief Financial Officer and other finance staff provide substantial additional planning and support functions. For our large meetings, a large fraction of the entire office of 16 people travels to and works on-site, in addition to contracted support staff. For a typical AAS meeting, we utilize substantial fractions of five

[1]For details, please see `http://www.aas.org/meetings/aastcs`

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staff member's time throughout the two years leading up to the meeting itself. This workload is not constant, but it builds over time. We have the additional challenge of organizing multiple meetings at the same time and several years in advance. At any given time our staff could be handling nine or ten meetings at the same time. It is a tremendous challenge and one our staff is expert at handling.

Volunteer meeting organizers should realize that they should be spending a day or so (at least) every month in planning work starting two or more years in advance of the meeting, increasing to multiple days a week as the meeting approaches. Inattention to details and planning well in advance will make the process unduly challenging in the final months.

Because substantial savings can be attained and preferred dates retained by planning well in advance, the AAS regularly identifies meeting locations many years ahead of time. At the present time, we have contracts in hand for winter meetings six years in advance and summer meetings four years in advance. The process of site selection is complex. No single criteria or formula can be used to select a given location, but many aspects have to be favorable before we present a possible location to our meetings committee and elected leaders. We select meeting locations primarily based on geographic location; whether they are close to a large population of astronomers or not, with many astronomers close by being preferred. Adequate and easy connection to an airport is also nearly always a requirement. Also important is whether they present attractive pricing for lodging and for the meeting location itself. Sometimes hotels provide free meeting space if a certain room block is filled or food and beverage purchases made. Sometimes local Convention and Visitors Bureaus (CVBs) provide subsidy to organizers to cover expenses if a certain number of attendees will be staying at local hotels. The variety of possibilities is nearly boundless.

This key point, that there are a variety of possibilities during contract negotiation available to a meeting organizer is not widely known, especially to amateur meeting organizers or those who organize a meeting only occasionally. Understanding contract details and undertaking contract negotiation BEFORE signing are highly important. Once you sign, its normally too late to change key components of the arrangement with nearly all vendors. A few key points to remember:

a.) Sales people from hotels and meeting venues often receive bonuses for landing new business. This usually happens quarterly. They will often express a need for haste, or a chance for missed opportunity as quarter boundaries approach. Consider this carefully as you negotiate meeting contracts. Sometimes the pressure is false and driven by this commission compensation scheme, sometimes it is real, with a chance for a preferred date range really being lost if a contract is not signed. The

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best approach is to know what you want and be prepared to adjust if an opportunity is really lost. Direct communication with the location representative can be helpful. Sometimes Convention and Visitor's Bureaus can advise you here. Be sure they are independent and represent the location, not a coalition of local hotels, before getting their advice however.

b.) This may be obvious, but it is very important to read and understand all parts of any contract you sign. Very often, secondary documents are referenced and included as part of the contract. Get them and read them too (often referred to as 'terms and conditions').

c.) In the United States it is common to include additional fees and taxes as a percentage of the total expense. This is most common with food and beverage expense (F&B). Most states do not allow non-profit organizations to avoid paying tax on food and beverage, some do. However, nearly all contracts I have signed for food and beverage provision at our meetings include (the dreaded) 'plus-plus'. This term refers to a service charge (usually 18-25% of the total) and a tax on the service charge (varies, but 7-10% is not uncommon). If an F&B price is quoted, make sure it either includes the 'plus-plus', or be sure to incorporate this addition in your budgeting.

d.) On the non-profit status point included in point c), it is possible that if you represent a non-profit organization you can avoid paying tax simply by registering in the state where the meeting will be held. Sometimes states won't allow this, sometimes they will. Check well in advance.

e.) Termination penalties are very important to understand. Hotels often require payment of a significant fraction, if not all, of the expected meeting revenue if the meeting is canceled ... be sure you understand these penalties and under what conditions (and when) the meeting can be canceled without penalty (however, note too that hotels are often willing to secure you for a future meeting or meetings to avoid any payment of penalty for the current meeting ... this is sometimes an option if you are facing a significant penalty for cancellation or other reasons).

f.) If you sign a contract to fill a certain number of rooms, be sure to be conservative on this commitment. It is likely some of your attendees will find lodging elsewhere, share rooms or stay with friends (we've even had people camp at a nearby campground!). This will limit the number of rooms sold. DO NOT OVERCOMMIT! (read those bold letters again). It is nearly always advisable to be conservative, as additional rooms can often be had at the contracted hotel, or a nearby partner hotel, while hotels are very resistant to leniency if you don't fill the contracted number of rooms (typically called a "room block"). Remember, your

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responsibility is to organize and hold a financially viable meeting, not ensure every single attendee has a room. Overcommitting to a large room block nearly ensures, nay, guarantees you will end up paying a penalty ... called 'attrition'. Dont let that happen to you!

g.) Also, remember that many attendees don't stay for the whole meeting. Plan on fewer rooms at the front end and back end of the meeting (dubbed the 'shoulders').

h.) Hotels will often provide a monetary incentive per each room night actualized. Note that this money more or less comes directly from your attendees' pockets. You can utilize this to offset meeting costs, in which case it serves as a second source of revenue to the registration fees. You can negotiate the level of this payment and whether to even have it or to simply provide lower room rates to your attendees.

i.) Sometimes you can negotiate benefits to your attendees at the hotels ... for example, free breakfast, free Internet access, free bottled water in the rooms or whatever. Ask and see what the hotels are willing to provide.

j.) Secondary vendors are sometimes limited by contract with the primary venue. For example, external caterers may not be allowed, or only allowed under certain conditions (or by payment to the primary). Be sure you understand any limitations contained in your primary (and all other) contracts on additional service providers.

k.) Audiovisual provision is a profit center for most hotels and meeting venues. However, you can nearly always find a better deal from an external provider ... review venue costs carefully in this area and make your decision accordingly.

l.) Instead of ordering food off of the stock menu any F&B provider delivers, consider setting a price-point (don't forget the plus-plus) that you can afford and asking the provider to do what they can at this price point (usually a per-person cost). You'd be amazed at what venues can provide given this challenge. The stock menus are often not your best purchasing deal for F&B. This option is not always available; it varies based on location.

m.) If you do have a problem with the meeting that is contractually controlled, don't forget that most venues are willing to work with you to ensure success. You may have to promise (sometimes in writing) a future meeting to be held at the location, referencing the venue in professional communications or something else, but you can often negotiate your way out of financial penalty. The best way forward is not getting into trouble in the first place.

n.) Finally, be clear what your signature means on the contracts. Are you signing as an individual, as a representative of your organization or

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for a third party or entity? Be clear here as this is a legal matter and inattention to this detail could make you financially responsible for costs exceeding several hundred thousand dollars or more.

By following the above hints and negotiating firmly, you can secure far better financial conditions for your meeting than by just accepting what you are initially provided.

As a general guideline, you will need the following services for most meetings (optional items are included in this list in italics).

1. Meeting room space (sometimes at the hotel(s), sometimes at a convention center or university)
2. Hotel rooms for meeting attendees
3. Food and Beverage (F&B) ... your attendees have to eat and drink!
4. Audiovisual services (sometimes with the venue, sometimes an outside vendor)
5. Abstract services or proceedings services
6. Poster board rentals or exhibit setups, registration desks etc.
7. Registration support staff or meeting assistance, sometimes provided by venue or through CVB (*e.g.* restaurant reservation assistants, etc.)
8. Security (sometimes the hotel or convention center can provide this, more important for meetings with exhibit halls).
9. Meeting cancellation insurance ... available from many reputable insurance brokers ... covers termination costs in the case of certain natural disasters.
10. Entertainment
11. Transportation (to/from airport, to/from offsite activity locations).
12. Offsite locations for any meeting-related events.
13. Tours for attending spouses or attendees.
14. Support equipment for particular needs (*e.g.* outside tents in case of rain, port-a-potty rentals, etc.).

3. Basic Financial Practices and Structures

It is important to properly budget for a meeting to ensure financial success. Such a budget needs to change over time, as costs become known. Shown below is a snapshot of a typical spreadsheet for a small meeting organized by the AAS from the expenses section and including the bottom-line. Using a spreadsheet is an obvious piece of advice that likely goes without saying these days, but a functional spreadsheet program provides a wide array of useful tools so I view using one to budget any meeting a necessity.

The AAS begins meeting planning by establishing what costs we may encounter. Until we know for sure the majority of the costs, we do not set the

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registration fee. I highly recommend this procedure. By setting registration fees early, without knowing all costs, it is possible to end up with more costs than revenues, which is not a comfortable situation. When tabulating expenses, we always incorporate a reasonable contingency. There are nearly always last-minute expenses that crop up, or free registrations that need to be provided to special guests or whatnot. Plan ahead for these unknowns by incorporating an adequate contingency reserve. A rule of thumb is 3 to 6% of your total known costs. If you planned well and don't need your contingency, you can easily dispose of the surplus by providing additional food and beverage to your attendees or donating the surplus to your host institution or professional organization (hint, hint).

Sometimes, hotels require deposits ahead of the meeting. You can negotiate this, or arrange for deposits to be made that coincide with your registration deadlines. Sometimes cash flow is not an issue as an institution or non-profit entity (*e.g.* the AAS) is providing the cash up front. Be clear before signing any contract about when deposits are due and how much they are. Ensure you will have the ability to pay.

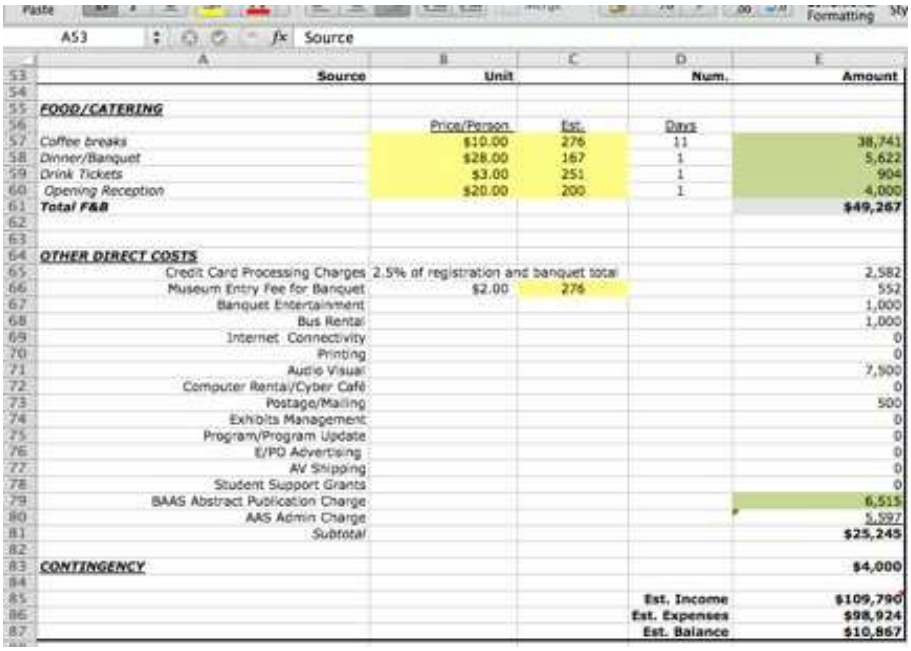
Calculating revenues is far trickier than determining expenses. You are never sure how many attendees you may actually get. If you have a student rate and a regular rate, and an on-time rate and a late rate, you now have an eight variable problem, with no known quantities, only unknowns. Be careful!

The general rule of thumb for budgeting attendance is to be highly conservative. Do not use your optimal attendance number as your budgeting number; assume at least 10% and as much as 30% fewer attendees as your hoped-for attendance. This conservative stance, combined with a comprehensive tally of your expenses will allow you to calculate a reasonable registration rate that guarantees no loss. Unless your host institution or you are independently wealthy, this is something to pay attention to. Again, ending up with a small positive is much better than ending up with a large or small negative ... the goal of the modern science conference organizer is to arrange a successful meeting that highlights the science without financial loss.

As the planning for the meeting continues and registration begins, keep your spreadsheet up-to-date with a column for actuals. Monitor your progress regularly. If multiple people are organizing the meeting, keep only one master spreadsheet from which all organizers work. Do not have multiple spreadsheets as this leads to errors and extra work.

After the meeting concludes, go over the bills very carefully. Many times errors or extra charges creep in that you are not ultimately responsible for. My favorite was a hotel that tried to implement cancellation fees on the AAS for rooms canceled at the last minute by meeting attendees ...

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	Source	Unit		Num.	Amount
	FOOD/CATERING				
		Price/Person	Est.	Days	
	Coffee breaks	$10.00	276	11	38,741
	Dinner/Banquet	$28.00	167	1	5,622
	Drink Tickets	$3.00	251	1	904
	Opening Reception	$20.00	200	1	4,000
	Total F&B				**$49,267**
	OTHER DIRECT COSTS				
	Credit Card Processing Charges	2.5% of registration and banquet total			2,582
	Museum Entry Fee for Banquet	$2.00	276		552
	Banquet Entertainment				1,000
	Bus Rental				1,000
	Internet Connectivity				0
	Printing				0
	Audio Visual				7,500
	Computer Rental/Cyber Café				0
	Postage/Mailing				500
	Exhibits Management				0
	Program/Program Update				0
	E/PO Advertising				0
	AV Shipping				0
	Student Support Grants				0
	BAAS Abstract Publication Charge				6,515
	AAS Admin Charge				5,597
	Subtotal				**$25,245**
	CONTINGENCY				**$4,000**
				Est. Income	**$109,790**
				Est. Expenses	**$98,924**
				Est. Balance	**$10,867**

Figure 1. A portion of a typical small meeting budget worksheet showing expenses and the bottom line. Note the inclusion of a contingency. 'Plus-plus' has been included in the calculation of the food and beverage expenses (noted in the 'notes' , but omitted here).

unfortunately for the hotel, these costs were not in our contract, although they were regularly a part of other contracts the hotel made. The finance department simply did what they normally do ... luckily we caught the error and had the multiple thousands of dollars removed from the bottom line.

These days it is important to maintain records that are auditable and accurate. Keep all contracts and paperwork, make no verbal agreements or contracts and ensure all payments provided to vendors result in a receipt. A final note of caution, don't risk your reputation and that of your institution by paying for inappropriate expenses. For anything that takes place at your meeting or is associated with your meeting, you should be sure you are comfortable with a description showing up on the front page of the New York Times highlighting it. Recent meeting excesses[2] have been in the spotlight, don't make a misstep and bring ruin on yourself and your reputation.

[2]See for example `http://www.washingtonpost.com/blogs/post-leadership/post/may-the-gsa-resignation-serve-as-warning-to-all-leaders-considering-lame-training-conferences/2011/04/01/gIQAvKgBtS_blog.html`

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4. Scientific Content

AAS general meetings are structurally and thematically complex. The range of content at each meeting is diverse and can take many forms. However, it is fairly easy to define the vast majority of activities at our meetings and these types are common among other meetings as well. There are some differences between our winter and summer meetings and these are detailed below within this list of meeting content and explanatory description.

4.1. CONTRIBUTED SESSIONS

Attendee contributions are a core component of all AAS general meetings. Every Full, Emeritus, Associate and Junior (with advisor approval) member of the Society is entitled to make a (meaning one, singular) contributed presentation at each AAS meeting, whether orally or via a poster. Additional contributions may be made in the areas of History and Education. This rule does not apply to Division meetings or to Divisions who meet with the Society. These Divisions may set their own limitations on submissions to their meeting or their portion of the overall AAS meeting.

Historically, contributions have been referred to as 'papers', and we still sometimes hear references to presenting a 'paper' at an AAS meeting. This linguistic habit should not be construed as a requirement that only published content can be presented. The Society welcomes works in progress along with published results. Non-members are allowed to submit contributed content as well, although they may do so only once and must have a sponsor, who is a full member of the Society.

Contributions are either presented orally or in the form of a poster. Posters are hung in the exhibition hall, while oral talks are in one of the numerous rooms reserved for the meeting at either a convention center, hotel or conference center.

At the very early meetings of the Society, all presentations were oral and substantial time was allocated for presentations. As meetings grew in size, multiple parallel sessions were first introduced, typically broken up by subject area, while the allotted time for oral presentations progressively shrank. The Society now provides five minutes for each contributed oral presentation, with a few minutes for questions and 15 minutes for a dissertation talk with five minutes for questions. With such limited time constraints and an ever-growing number of submissions, the Society's meetings will eventually have to grow to five days in length or some submissions will have to be rejected. As we wish to encourage the research and presentations of our members, it is likely the AAS Council would opt to extend the length of the meeting *vs.* turning away member content. The primary constraint is simply the number of co-located meeting rooms in any given facility. We

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Figure 2. A typical session room at an AAS meeting ... screen, LCD projector, podium, microphone, audience ... let the scientific dialog begin! (© AAS)

currently don't want to have a meeting at two disparate locations or at very large, expensive locations, so the tradeoff to these requirements is expanding the length of the meeting or turning away submissions.

The AAS establishes deadlines for the submission of contributions and utilizes an online submission system that ties the membership database to an external vendor who processes meeting abstracts. This way, the various rules regarding submissions can be effectively administered without (much) human interaction or attention. Exceptions always crop up and are handled by meeting staff, with special cases being handled by the senior Vice President or Executive Officer.

Rules & procedures governing the submission of member contributions and deadlines and appropriate submission forms are published online well ahead of each meeting, approximately three months before the actual meeting date. This allows all potential submitters to fully understand the details and meet defined deadlines.

Submission deadlines must necessarily be two or more months in advance of the meeting as the contributed abstracts for oral and poster presentations are sorted by member-volunteers and the resultant sessions are organized

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into a logical structure by the senior Vice-President with advice and help of the junior VPs and AAS staff. Lead-time is also required for the printing of meeting materials, which increases the time between the meeting and the submission deadline. Although we strictly adhere to our submission deadlines, very occasionally exceptions are made for late-breaking scientifically exceptional results. Allowing an exception occasionally expands the scientific impact of the meeting and adds to its newsworthiness. A late deadline exists for the submission of contributions until just a month or so before the date of the meeting, but all late submissions are by default poster contributions and are preferentially placed on the last day of the meeting.

During AAS Winter Meetings, posters are displayed for one day, so a new set of posters is displayed each day of the meeting. As mentioned above, late submissions are displayed on the final day of the meeting. During Summer Meetings posters are sometimes displayed for two or more days, depending on how many posters we have received for the meeting in question and space constraints.

4.2. INVITED SPEAKER SESSIONS

Invited Speakers are chosen by the Committee on Meetings, composed of the Society's three Vice-Presidents, the Executive Officer and the President of the Society. The senior VP is the chair of the committee. Input from members is welcome and some Invited Speakers have been selected from member suggestions.

The Committee selects individuals to be Invited Speakers who are typically good communicators and who have undertaken research in some particular area of astronomy, related sciences or performed some other activity of benefit to our discipline. As there are only a limited number of Invited Speaker Sessions at each general AAS meeting, there is a degree of prestige to the invitation, and individuals are typically invited to speak no more frequently than once per decade.

Invited Speaker sessions are plenary sessions, with no other meeting content held concurrently. Right now, each Invited Speaker session is fifty (50) minutes in length and has been for some years. Speakers are encouraged to speak for approximately 40-45 minutes and reserve the balance of their time for questions. Due to the tight scheduling of the meetings and available rooms, it is not usually possible (in fact it is nearly never possible) to extend an Invited Speaker Session (or any other session) beyond the allocated time allowed.

The AAS has established partnerships with the Kavli Foundation and the New York Community Trust, both of which sponsor an Invited Speaker

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Figure 3. An AAS Press Conference. Scientists use modified versions of their professional presentations to describe results to members of the media. A special room is set aside for these events and they are mainly attended by the press only, although members may attend if they wish. (© AAS)

at one or more AAS meetings per year. These partnerships expand the range of possible Invited Speakers by providing resources to enable travel for astronomers overseas, for example.

4.3. PRIZE SESSIONS

The Society awards prizes for meritorious work in our discipline and some of these prizes include an opportunity to address a general meeting of the Society. Functionally, they are treated in the same way as Invited Speaker sessions. Currently, the honors or prizes awarded by the Society that come with a speaking opportunity are:

– Henry Norris Russell Lectureship
– Newton Lacy Pierce Prize in Astronomy
– Helen B. Warner Prize
– Annie J. Cannon Award in Astronomy
– Lancelot M. Berkeley – New York Community Trust Prize for Meritorious Work in Astronomy

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In addition, some of the AAS Divisions, who meet with the AAS are provided speaking slots for their prize winners. Other Division prize lectures are presented at Division-specific meetings. These include:
– George Ellery Hale Prize – Solar Physics Division
– Karen Harvey Prize – Solar Physics Division
– Dirk Brouwer Award - Division on Dynamical Astronomy
– Bruno Rossi Prize - High Energy Astrophysics Division
– Leroy Dogget Prize - Historical Astronomy Division

Through its relationship with the American Institute of Physics, the AAS has Prize Sessions for the Dannie Heineman Prize for Astrophysics and sometimes for the Andrew Gemant Award, depending on whether the winner prefers to speak at an AAS meeting.

4.4. SESSION VIDEOS

The AAS began recording Invited and Prize Sessions in 2007. Although initially they were full video and audio, we found that capturing the on-screen slides and audio of a presentation could adequately convey the core content of a given presentation. This greatly reduced the price for production of these videos and decreased the required bandwidth to provide this service. As technology improves, we anticipate being able to provide full video capture of the speaker, their slides and the audio of their presentation. Archived videos of Invited and Prize Sessions are available to all, six months after the meeting takes place. We archive these sessions online[3].

4.5. SPECIAL SESSIONS

Special Sessions are scheduled in response to proposals from AAS members and are held at both winter and summer meetings of the Society. Special Sessions have a length of 90 minutes and are scheduled in parallel with other special sessions and contributed oral sessions. Special sessions may be held on any of the days of an AAS meeting and do not have a required format. Some sessions have several speakers, some have a panel discussion, sometimes they are short workshops; the structure is left entirely up to the proposer, with only the time limit of 90 minutes being critical.

Deadlines and submission details are available online at the AAS website. Proposals are submitted online and collected in an underlying database. The meeting committee, led by the AAS Vice Presidents, is responsible for selecting from among the proposed special sessions. Submission of a proposal does not guarantee acceptance and acceptance does not imply the proposer's selected day and time will be provided. Special

[3]`http://aas.org/meetings/meetings_past.php`

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Figure 4. The plenary session hall at an AAS Summer Meeting. Seating for approximately 1500, two screens, podium in center, good lighting, audiovisual technician seated at the rear and (mostly) comfortable seats. (© AAS)

sessions should represent the overall demographic composition of the Society and a list of session presenters are required to be submitted with the proposal. Proposals with confirmed speakers are given higher weight than those with tentative lists of speakers.

Special session proposers must meet certain deadlines for providing descriptions of their sessions and confirmed speaker lists, which occur well in advance of the meeting itself. These deadlines facilitate the inclusion of all meeting content in the final meeting materials.

4.6. MEETING-IN-A-MEETING SESSIONS

"Meeting-in-a-Meeting", or MiM, sessions are meant to fill a gap in demand between a 90 minute Special Session and a full-week specialized conference. The goal of the MiM program is to provide (at the AAS Summer meeting), a longer format session available to attendees. MiM sessions are scheduled in response to proposals submitted (online at the AAS website) to the AAS Committee on Meetings, led by the Vice-Presidents, by AAS members. MiM's may be from two to eight sessions, with each session being 90 minutes long. They are scheduled in parallel with other special and contributed sessions.

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As they are meant to be highly focused in nature, but take place at a general meeting of the Society, the format requires an opening introductory talk suitable for a non-specialist audience. The hope is that every meeting attendee could attend the first session and understand the general nature of the topic being presented, perhaps deciding to attend further sessions to gain a deeper understanding of the specialized area.

4.7. TOWN HALL MEETINGS

Town Hall meetings grew out of a request from the major US funding agencies for astronomy to provide a question and answer session for the community they serve. Due to demand, they have been broadened and now include sessions from high-profile missions or facilities; AAS or non-AAS Committees, or others who want a short, open session centered around dialog between the session proposers and the community of astronomers represented at the meeting.

They are scheduled in response to proposals submitted by AAS members and approved by the Committee on Meetings. They are held at both winter and summer meetings of the society and typically take place during the 12:45 to 1:45 pm and sometimes in the early evenings. This is considered the meeting lunch hour and other Town Hall Meetings will be scheduled in parallel. Efforts are made to avoid strong overlap in content.

4.8. WORKSHOPS

Workshops are scheduled in response to proposals from AAS members and are highly flexible in content and timing. However, they typically only take place on the weekend prior to the first full day of the meeting (which is typically a Monday). Workshops can be one or two days in length. Registration fees may be charged and are collected by the AAS to cover expenses required, such as food and beverage, audiovisual expenses and so on. Any proceeds from such workshops are retained by the Society and directed toward supporting activities at AAS meetings such as the undergraduate student reception. Workshops may be full- or half-day or held all day long on both days, and any combination thereof. Very, very occasionally, workshops are held during the meeting itself, either in the evening or on the days following a meeting. They are never scheduled in parallel with contributed, special or MiM sessions. Abstracts are not published for workshops. Workshops are meant to be hands-on learning.

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Figure 5. The AAS Press Services Room ... a place to work with fax, photocopy, Internet and phone. (© AAS)

4.9. SPLINTER MEETINGS

Splinter meetings are defined to provide a venue for meetings to be held at AAS conferences, which are not scientific sessions. Examples would include planning meetings for scientific missions or facilities, research team get-togethers, meetings of an administrative nature and so on. They may not be used as an optional outlet for a special session and are subject to review and approval by the Executive Officer or the Committee on Meetings. Splinter meetings can be scheduled before, during or after AAS conference days (additional fees may apply to meetings scheduled after the AAS meeting closes). Any AAS member can request a Splinter meeting however; participants must be registered for the meeting for at least the day of the Splinter meeting itself. A summary of the meeting topic and content must be submitted. Public Splinter meetings must not conflict with Invited or Prize sessions. Private (invitation only) Splinter meetings can be scheduled at any time. Costs associated with catering and equipment rental are the responsibility of the splinter meeting organizer. The fees will be invoiced by the AAS once the meeting closes and is audited. Meeting requests are honored and assigned on a first-come, first-served basis depending on meeting room availability. Other requirements and details are available online at the AAS Meeting Services website.

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5. Building the Scientific Content of an AAS Meeting

The AAS contracts with a third-party vendor to collect, process and help organize the abstracts associated with our meetings. The way we construct the scientific content of the meeting plays into this process and is detailed here.

The AAS organizes its meetings with the help of a Meeting Committee. This committee is led by the senior Vice-President, with the other VPs as members along with the current President and the Executive Officer. The Past-President or President-Elect are sometimes called upon to help as well. This task is actually one of the most rewarding our elected leaders participate in.

About a year before any given meeting, the AAS begins reminding members through email and other communications and on our website about deadlines for submission of Special Session and Meeting-in-a-Meeting proposals. Planning for the next AAS meeting takes place at the AAS meeting just prior. Once the deadline for submission of these proposals passes (usually a month before the next AAS meeting), AAS staff collates the proposals and prepares a summary listing that is then provided to the Meeting Committee. At the AAS meeting prior to the meeting being planned, the Meeting Committee meets to select the session proposals, invited speakers, town halls and any other generic content.

The Meeting Committee chair then sends out invitations to Invited Speakers and prizewinners. The Meeting Committee chooses days and times for each during the planning session. Special session and Meeting-in-a-Meeting session proposers are informed and must then submit abstracts from their speakers for inclusion in the abstract database. This often takes a while, which is why we start well ahead of time gathering this critical input.

Several months before the meeting takes place, we have an 'on-time' abstract deadline for submission of individual member contributions. These abstracts come in tagged with a generic subject category and are then sorted by member volunteers using an online system into coherent sessions following timing rules, limits on the number of dissertation abstracts allowed in each session and any individual timing constraints (*e.g.* personal travel limitations, or wanting to have two talks back-to-back). A final deadline allows last minute, poster-only contributions to be included on the final day of the meeting. The Meeting Committee, usually in the form of the senior VP, then arranges all the contributed sessions to augment the fixed schedule of Invited Speakers, Prizewinners, Special Sessions, Town Halls and Meeting-in-a-Meeting sessions. This is a subtle task, but one that all VPs have enjoyed. The final sorted sessions and abstracts are assembled

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Figure 6. A typical AAS Exhibit hall showing mainly the scientific posters lined up into the distance. (© AAS)



Figure 7. The area in and around the posters is used for interactions amongst colleagues, with more people in the exhibit hall between sessions. (© AAS)

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into various schedules and into online programs that allow access to the abstracts as well as the physical scheduling information.

The end result of this process is a coherent program, which augments the scientific impact of the meeting by providing logical flow and structure. Members do not have to jump around among different rooms to hear talks of a similar subject. We attempt to not schedule similar subjects at the same time, while spreading content out over the whole meeting to ensure attendance for all days and also maximize the impact and exposure for any given meeting attendee. It is much more an art than a science to arrange a large meeting like the AAS meetings, but the value to the attendees is, we feel, substantial and central to our mission.

6. Press Functions

As many interesting scientific discoveries are presented at AAS meetings, many press-related activities and functions are scheduled at the conferences. First and foremost, a suite of press conferences takes place, usually three per day for the core part of the meeting. The Society's Press Officer selects topics for these press conferences, who reviews all meeting abstracts seeking results of interest to the general public (*e.g.* black hole research, supernovae results, dark energy, etc.) The Press Conferences are structured to have at least two presenting authors and a non-affiliated scientist who provides expert comments from outside the research teams. The Press Officer or a Deputy Press Officer moderates the Press Conferences. The AAS started recording these events in 2010 and they are available online to view[4]. Members of the press who pre-register with the Press Officer, may view the Press Conferences in real-time via the Internet. The AAS Press Officer also contacts authors who have submitted interesting scientific results, but who were not selected for a press conference, and encourages them to issue a press release at the meeting. These, along with other press releases submitted to the Society, are distributed to the media during the meeting. The Society also operates a press room, which provides services to attending media representatives including Internet access, fax and photocopy machines, desk space, telephone service and refreshments.

7. Exhibit Hall

A key part of the AAS meetings is the exhibition hall, which serves as a quasi-trade show and the location for the display of contributed posters. The AAS contracts with a meetings and exhibitions contractor to build the exhibit booths, to provide electricity and Internet services, to rent furni-

[4]`http://aas.org/press/archived_press_conferences`

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Figure 8. A typical exhibit booth at an AAS meeting, with pop up display, chairs and a table for distributing information and "freebies". (© AAS)

ture for the booths and so on. A member of the AAS staff distributes an exhibitor prospectus roughly four months before the meeting in question. The prospectus provides all relevant details for potential exhibitors such as the hours the exhibit hall will be open, the cost of booth space and rental equipment and other details. For the cost of a booth rental, two registrations are included, which are intended for the people who will be staffing the booth.

A wide variety of exhibitors opt to participate in AAS meetings. Examples include government agencies, space missions, telescope facilities, vendors selling research-related articles (such as high-quality filters, gratings or instruments ... even whole telescopes!), vendors selling pedagogical materials, textbook publishers, other publishers, curiosity vendors (*e.g.* fossils or meteorites) and so on. A typical winter meeting has 70 or more exhibitors and summer meetings about one-third as many.

Hosting an exhibit hall provides an important venue for communication between organizations and people, while making the meeting about more than just oral presentations. The exhibition floor space also provides room for the display of the contributed posters, which are changed daily at winter meetings and sometimes less frequently at summer meetings. Of course, the added revenue from the exhibition hall also helps with overall meeting costs, although the costs for building the booths, providing electricity and so on are not inconsequential.

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The AAS makes use of the hall itself for a self-promotional booth, booths for our Divisions who opt to have one and, at winter meetings, the AAS Job Center, which serves to connect Job Seekers with Employers.

The population of the Exhibit Hall ebbs and flows throughout the day. When a popular plenary session or the normal parallel oral sessions are taking place, the number of people in the Exhibit Hall decreases substantially, while at other times it can be quite crowded. Nearly all the attendees enter the Exhibit Hall sometime during the day, many more than several times. It is viewed as a central meeting spot and somewhere to 'be' when not in a scientific session.

As wireless devices became widely adopted, the AAS undertook the provision of Internet connectivity via wireless networks. This is a non-trivial expense. Not only must high-end routers be purchased and installed by trained staff or contractors, but the bandwidth required must also be paid for as well. Few attendees appreciate that roughly $50 of their registration cost is used to provide Internet access on site. This incorporates all costs, including staff preparation time and on-site setup and support. Special Internet access points provide Exhibitor-only access, for which Exhibitors pay a premium.

8. Conclusions

Meetings – of any size – are difficult to plan and execute. They are, however, fundamental to the communication of scientific knowledge and ensuring further scientific progress. When planning for a meeting, the goal that should be foremost in everyones mind is to provide the most conducive environment for scientific discourse and collaboration at the lowest possible cost. Efficiency, cutting out the extras and focusing on what is truly important will ensure a successful meeting. Along the way, be conservative when estimating your revenues, comprehensive in tallying your expenses (ahead of time!) and careful in your contracting. Utilize engaged volunteers or professionals who are willing to work hard well ahead of the actual meeting dates and start planning earlier than you think you should. Negotiate seriously with meeting sites, hotels and other vendors. Be careful what you sign. Don't undertake inappropriate expenses. If you need help, just ask. The AAS is happy to help meeting planners, whether they are looking for a full partner to help undertake their meeting planning or just need some specific or general advice. We're here to help further our science, not just our own meetings. Proper organization of scientific meetings is central to furthering human knowledge; it deserves just as much attention and care as we put into our research projects or writing scientific papers or the care and attention of professional meeting planners.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 393-394
Ed. A. Heck, © 2013 Venngeist.

INTERNATIONAL ASTRONOMY MEETINGS LIST: ITS ORIGIN AND EVOLUTION

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Abstract. The author tells the origin and evolution of the International Astronomy Meetings List, a service hosted by the Canadian Astronomy Data Center (CADC).

In 1983, I attended my first Special Libraries Association meeting held in New Orleans, Louisiana. At that time, I became acquainted with the Physics-Astronomy-Math (aka 'PAM') Division, a division that was to become my professional lifeline for the next twenty-eight years.

The Astronomy division was my initial introduction to the 'Giants' of the PAM network : Joyce Watson, Ellen Bouton, Sarah Stevens-Rayburn, and Brenda Corbin were among the names I remember. The special ties with our colleagues were essential in those pre-internet years. In addition, I oversaw a library located in Hawaii, Earth's furthest archipelago from a continental land mass. From the onset, I ascertained that acquiring and disseminating current, scientific data and information was going to be a formidable task.

At the time, there were a number of recurring library concerns, including how to keep abreast of the many astrophysics meetings that were held every year. This matter was particularly troublesome for events occurring in countries requiring a Visa or special travel arrangements. Oftentimes, conference announcements would arrive at Canada-France-Hawaii Telescope (CFHT) after the deadlines required for applicants to register and attend an event.

One day, in 1987, I was discussing this dilemma with Robert "Bob" McLaren, CFHT's Executive Director, and he recommended I start a monthly compilation of all meetings, conferences and workshops. I con-

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curred and began a small distribution to other astrophysics libraries. The idea grew, and before I knew it, I was copying and mailing the list every month to over 600 observatories and libraries! By 1991, *The Observatory* took notice and began publishing the list and at the same time, with the advancements of computer technology, I offered access to the list via 'ftp' and other current electronic distributions.

By 1993, Doug Simons and Dennis Crabtree joined me to produce a revolutionary version of the meetings list available via NCSA Mosaic, which enabled filling out a registration form, downloading maps, browsing abstracts, etc. This service caught on quickly and encouraged meeting organizers to take advantage of the newest available technology.

From the onset, CADC has provided the server for the meetings[1]. This love match has been successful because Liz was the care taker and compiler of the information and CADC provided the maintenance and upgrade of a complex computer system. To date, CADC maintains the meetings list, archiving as far back as 1996.

Besides the hosting web server, CADC supplies access to the SYBASE database as well as the RSS and iCal feeds and the older email distribution list.

There were about 280,000 visits to the meeting list in 2011, from almost 30,000 unique IP addresses. The numbers were similar in 2010.

Now that I have retired, I have left the meeting legacy to David Bohlender and Daniel Durand, who are intent on keeping this worthwhile service on going. This is a wonderful example of a program that has evolved and kept apace with the current needs of our community.

[1] `http://www.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/meetings/`

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 395-416
Ed. A. Heck, © 2013 Venngeist.

THE INTERNATIONAL ULTRAVIOLET EXPLORER: ORIGINS AND LEGACY

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Abstract. The International Ultraviolet Explorer (IUE) satellite was launched on 26 January 1978, and operated as a Guest Observer space observatory for nearly 19 years. IUE was, without doubt, one of the most successful astronomical facilities ever developed. Used by thousands of astronomers worldwide, it yielded over 100,000 UV spectra (in the wavelength range 1150-3250Å), covering stars of all types, the interstellar medium in our own galaxy and other local galaxies, the galactic halo, normal and active galaxies and QSO's, X-ray binaries, novae and supernovae, and in our solar system comets, planets and their moons. Over 3500 refereed papers have been published based on IUE results, and a similar number of papers in conference proceedings. Over 600 PhD theses have been produced based on IUE data. All IUE data are available in archives maintained by the three agencies involved in the mission: NASA, ESA and the UK Science Research Council. In this paper I will discuss the origins of the IUE mission, the special design and operation which led to its spectacular success and the legacy it left for UV astronomy.

1. Introduction

The wavelength range from 3250-912Å is referred to in astrophysics as the vacuum ultraviolet (UV) region. The upper bound reflects the approximate cut-off in the transmission of the Earth's atmosphere due to absorption by Ozone, whilst the lower bound corresponds to the ionisation energy of the neutral Hydrogen atom – below which interstellar H largely absorbs background radiation from distant sources. With suitable reflecting coatings

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Figure 1. Sir Robert Wilson (1927-2002). Wilson led the initial LAS and UVAS proposals to ESRO for an Ultraviolet Space Observatory, which led to the development with NASA of the IUE mission. (Courtesy D. Rooks/UCL)

the optical elements for UV instrumentation are similar to those which are generally used at visible wavelengths: *i.e.* normal-incidence telescopes, photometers and spectrographs, with either photographic or electronic detectors.

The UV region is one of the richest in spectral lines in the electromagnetic spectrum, encompassing a very large number of resonance lines of many common elements, covering many of their ionisation stages, *e.g.* HI, CI, CII, CIII, CIV, NI, NII, NIII, NV, OI, OII, OIII, OV, OVI, PIV, PV, SiI, SiII, SiIII, SiIV, SI, SII, SIII, SIV, FeI, FeII, MgI, MgII. These lines provide crucial diagnostics for low-excitation plasmas covering a range of temperatures from a few degrees up to about 1 million degrees, found in the interstellar medium, stellar atmospheres, galaxies and AGN and planets and comets. For these reasons, the UV was a natural spectral range for development in the early phases of space science.

For nearly 20 years one such UV mission formed a cornerstone of modern astrophysics – the International Ultraviolet Explorer (IUE) satellite. In this paper I will discuss the historical origin of IUE, its unique design and operation which led to its stupendous success and the legacy it has

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left. I was fortunate to become involved with the IUE mission some years before launch through my association at UCL with Robert Wilson – then Project Director of the UK involvement in the satellite (Fig. 1). Although, of course, IUE owed its success to many hundreds of scientist and engineers, there can be little doubt the Wilson played an absolutely seminal role in getting the mission developed – see below – and is generally regarded as the "father of IUE". My own involvement included pre-launch preparations for the commissioning phase, the UK High Priority Observing programme conducted a few months after launch, as a Guest Observer (GO) with IUE over many years, as a member of the UK TAC and as Chairman of the European IUE Time Allocation Committee.

2. Ultraviolet Astronomy in the pre-IUE Years

The development of UV astronomy during the 1960's followed a similar pattern in both the USA and (to a smaller extent) in Europe, with groups at Universities and Government establishments pioneering, ever-more sophisticated experiments using rocket-borne instrumentation, followed by longer-lived and more massive satellite payloads. In the US the Aerobee rockets could deliver payloads of up to 100Kg to altitudes of around 180km. Groups at the Goddard Space Flight Center (GSFC), Universities of Wisconsin, Princeton and Johns Hopkins, together with the Naval Research laboratory, produced a range of spectrometers to yield the first detailed UV spectra of early-type OB stars at sufficient spectral resolution to detect and measure individual spectral lines, particularly with the development of a 3-axis stabilisation system for the Aerobee rockets. These programmes led, inter alia, to the first measurements of UV P-Cygni profiles of Zeta Puppis and other OB stars, yielding estimates of wind velocities and mass-loss rates (Morton 1967), and analyses of interstellar lines in atomic species and molecular Hydrogen (*e.g.* Caruthers 1970). In addition the first measurements of the UV interstellar extinction curve, including the discovery of the broad 2200Å band, were secured.

In Europe, and particularly in the UK, university-based teams were also developing UV spectrometers. The UK group at the Culham Laboratory led by Robert Wilson, used Skylark rockets to launch 3-axis stabilised payloads from Woomera, South Australia, to secure high-resolution spectra of the Sun, to identify and study lines formed in the solar chromosphere transition region and corona at both UV and soft-X-ray wavelengths (Burton *et al.* 1967). These programmes included an echelle-spectrum of the solar limb during a total eclipse in 1970 (Gabriel *et al.* 1971) and high-resolution spectra of Zeta Puppis and the Wolf-Rayet star Gamma Velorum covering the wavelength range 900-3200Å at 0.3Å resolution. Since the duration of a

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typical rocket flight was limited to about 5 minutes or less, each flight could only yield data on one or at best 2-3 objects. Over time successive flights built up data for many of the bright OB stars, some late-type stars, and planets. They had demonstrated the importance of the UV spectral region in furthering astrophysics in the solar, stellar and interstellar fields, and pointed to the potential for further advances if fainter and more diverse objects could be observed with larger instruments and longer exposure times, which required the use of stabilised satellite platforms.

This recognition led NASA to embark on a long-range programme of development of ultraviolet satellites, which was to culminate with the Hubble Space Telescope. Starting in the mid-1960's this programme centred around the NASA Orbiting Astronomical Observatories (OAO-series). OAO-1 was launched in 1966, but due to a power failure was terminated after only 3 days. Its spare parts were used to develop OAO-2, launched in 1968, with a spectrometer developed by the Goddard Space Flight Center yielding medium-resolution spectrophotometry, at about 10Å resolution, covering the wavelength range 1100-3200Å. This instrument was highly successful, obtaining data on hundreds of early-type stars and measurements of UV interstellar extinction curves, as well as photometry of some galaxies (Code *et al.* 1970; Davies *et al.* 1972).

OAO-3 (re-named Copernicus) was launched in 1972, with an 80cm telescope feeding a high-resolution UV spectrograph provided by Princeton University (Rogerson *et al.* 1973). Scanning photomultiplier detectors were used to record spectra at either 0.05Å or 0.2Å resolution, yielding line strength and profile measurements of the plethora of atomic and molecular species in the wavelength range of 900-3200Å. Rather long exposure times were needed to record the spectra, such that the higher resolution mode was restricted to observations of OB stars with V$<\sim$2, and about 6^{th} mag for the lower resolution mode. The mission was a huge success, providing data on stellar mass-loss rates in the upper HR diagram, the effective temperature scale for OB stars, the discovery of OVI in the galactic halo, and the distribution of molecular hydrogen and chemical composition of the atomic gas in the ISM. Copernicus was also what one might term the first "long-lived" space observatory, continuing operations until about 1980.

In Europe the fledgling European Space Research Organisation (ESRO) launched its first 3-axis stabilised satellite – TD-1 – in 1972, which carried two UV instruments. The Dutch/Utrecht S59 instrument comprised a low-resolution spectrometer covering 3 bands in the 2160-2870Å range (Hoekstra *et al.* 1973). The second instrument – S2/68 – was developed by a joint UK/Belgium team, from Culham-UCL/ROE/Liège, and comprised a 27cm telescope feeding a scanning spectrophotometer. This covered the wavelength range 1350-2740Å at about 35Å spectral resolution, and per-

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formed an all-sky UV survey yielding data on stars of all types down to about 9^{th} magnitude (Boksenberg *et al.* 1973). The data from S2/68 were put in the public domain through its Bright Star and Faint Star Catalogues (Thompson *et al.* 1978), and the high photometric integrity of the S2/68 calibraton formed the basis of the calibrations for succeeding UV missions, including IUE and the HST. The ANS satellite (Astronomical Netherlands Satellite) launched in 1974, provided broad-band UV photometry in 5 bands covering 1540-3340Å of a range of sources including white dwarfs, planetary nebulae, stars, clusters and galaxies.

3. The Origins of IUE

In October 1964 the Director General of ESRO (P. Auger) issued a letter to member states inviting proposals for a Large Astronomical Satellite (LAS) against a deadline of December 1964. In response, three proposals were submitted from groups in Germany/Holland, France/Belgium/Switzerland and the UK, and each was charged with developing detailed designs for a further deadline of January 1966. After assessment the UK proposal was accepted for further development, and this was undertaken by a team from Culham, UCL and Aldermaston, with Robert Wilson as project leader. The final report for the LAS was submitted to ESRO in September 1967 (Wilson 1967).

The design centred around an 80cm Cassegrain telescope feeding a Paschen-Runge spectrometer operating in the wavelength range of 900-3200Å, providing spectral resolution of 0.1-0.2Å, allowing observations of stars down to a limiting magnitude of V<9. A subsidiary X-ray telescope array was included at the prime focus, operating in the spectral range 2-100Å. A key element of the LAS strategy in the UK proposal was its recognition that "the wide range of astrophysical studies made possible by the main (UV) instrument ... emphasises the suitability of this payload as an observatory enabling wide participation by European astronomers with varied interests". In other words, at the outset, LAS was to be a true guest observer facility. The total cost of the LAS was estimated at 38.3M Swiss Francs (probably about 250M US$ in today's prices). This cost was greater than ESRO had expected and it decided to abandon the LAS project.

Undaunted, Wilson and his team embarked on a major re-design of the system. As noted above, his group at Culham had used echelle spectrographs in their rocket programme and this experience was used to produce a new proposal called the Ultraviolet Astronomical Satellite (UVAS). The UVAS plan was based on a 45cm Cassegrain telescope feeding an echelle spectrometer giving a resolving power of about 10^4 over the wavelength range 1150-3200Å, using an SEC Vidicon as the detector. The use of

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an echelle grating provided the high spectral resolution AFTER the light passed through the spectrograph entrance aperture (which could now be several arcsec) allowing about a factor of ten reduction in the pointing, thermal a nd mechanical tolerances compared to the original LAS requirements. This greatly reduced the cost of the system. UVAS was to be launched by a US Thor-Delta rocket into a low-earth orbit, with an interactive operations system with the satellite and instrument responding to command when visible from a ground-station.

The final UVAS proposal was submitted to ESRO in November 1968 (Wilson 1968), but again was not accepted for further development. After checking the propriety rights for the UVAS study with the UK authorities, Wilson decided to send the UVAS design report to NASA for consideration by copying it to Leo Goldberg (then Chairman of the NASA Astronomy Missions Board). After positive assessments by Goldberg and his Board, NASA HQ and GSFC, Wilson was invited to Goddard to discuss the possibility of a joint NASA-UK project at meetings held in May 1969 (see Boggess & Wilson 1987). The Goddard team (led by L. Meredith) recognised that with the planned enhancements to the Delta rocket, it would be possible to launch the mission into a geosynchronous orbit and thus provide continual ground-station contact. This in turn would allow a real-time interactive control and operation with the guest observer identifying sources in the telescope field of view (using ground-based finding charts) going much fainter than could otherwise be accomplished. In addition a "low-resolution" spectral mode was included by the option, on command, of flipping a plane mirror in front of the echelle grating, producing a low-dispersion spectrum from the cross disperser (used to separate the individual echelle orders in the high-dispersion mode). The sensitivity of the system would thus be around V$\sim$10 at high resolution and about V$\sim$15 at low resolution. The true guest observer philosophy of UVAS was maintained and the observatory nature of what was to become IUE was established.

Subsequent discussions between NASA, the UK authorities and ESRO took place and agreements to proceed with a 3-Agency project were in place in 1970 and finalised in 1971 after Phase A studies for the SAS-D project (as it was now called in the US, Krueger *et al.* 1971) had been carried out. NASA would provide the spacecraft, telescope and ground-station at GSFC; the UK would provide the onboard Vidicon detectors and software; ESRO would provide a European Ground Station (subsequently located at Villafranca del Castillo, Spain) and solar panels. The division of observing time would be 2/3 US, and 1/6th each to UK and European astronomers.

The memoranda of understanding between the three agencies, agreed in 1972, further enshrined the international use of what had now formally become the International Ultraviolet Explorer (IUE) mission formally stating:

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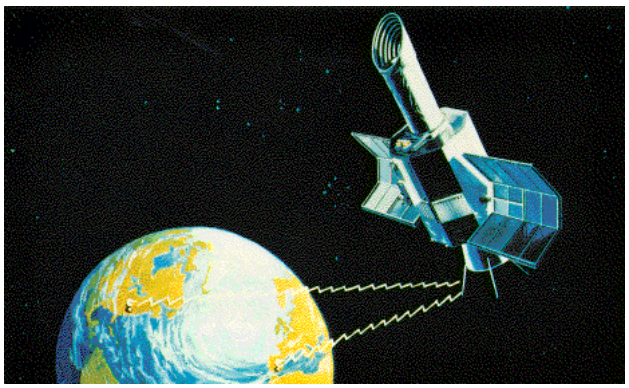


Figure 2. An impression of the IUE satellite in its geosynchronous orbit and the two ground stations at GSFC, Maryland USA, and VILSPA in Spain. (Courtesy NASA/ESA/SERC)

(a) "SRC, ESRO and NASA plan that, to the greatest extent possible, the available viewing time shall be made available to guest observers from the astronomy community, regardless of their nationality and on the basis of the scientific merit of proposals made to the three agencies", and (b) "use of the data will be reserved for the observer for a six month period beginning from receipt of data in a form suitable for analysis. Subsequent to the period of exclusive observer usage, the reduced data will be deposited with the UK Radio and Space Research Station (RSRS), with the US National Space Science Data Center (NSSDC), and with the Data Library of the European Space Research Operations Center (ESOC)". This latter aspect formed the basis of what was to become the IUE Data Archives, in the three agencies, which allowed for the widest possible dissemination of IUE data to astronomers throughout the world.

4. IUE Design, Development and Operations

The basic system parameters of IUE are summarised in Table 1. A detailed description of the IUE spacecraft and scientific instrument have been given by Boggess *et al.* (1978) and Boggess & Wilson (1987). As noted above, much of the basic design of the UVAS instrument was incorporated into IUE, notably the 45cm telescope, echelle spectrographs and SEC Vidicon camera detectors.

However, there were several important changes and enhancements. Probably the most important, from an operations standpoint, was the change from a low orbit to a geosynchronous one (Fig. 2). This had tremendous advantages for the scientific operation of the mission. The telescope baffling system allowed observations to be made in full sunlight, anywhere in the

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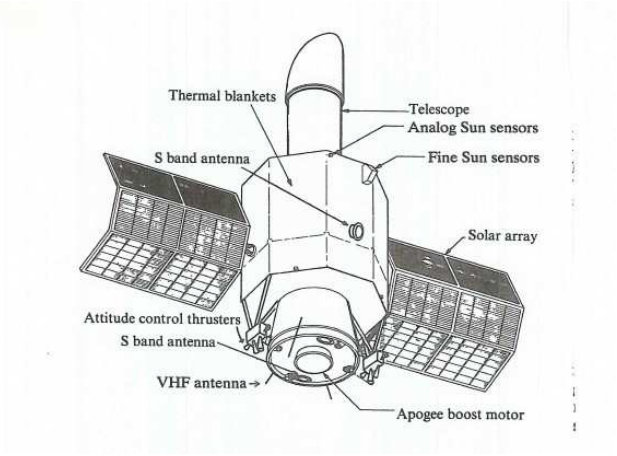


Figure 3. A schematic of the IUE spacecraft with the solar panels deployed, the apogee boost motor, telescope and baffle, VHF and S-band antennas and Sun sensors. (Courtesy NASA/ESA/SERC)

sky more than 43 degrees from the Sun; with the earth only subtending an angle of about 17 degrees, the unconstrained area of sky available at any one time was much greater than from low orbits. This allowed a capability to conduct long, uninterrupted exposures, allowing observations of faint sources as well as monitoring variable sources. The IUE orbit was arranged so that the satellite was in continuous real-time control from the US ground station at GSFC, and for at least 10hrs per day from the European ground station located at Villafranca del Castillo, near Madrid in Spain (VILSPA) – see Fig. 2. Unlike any previous mission (and indeed any since) the scientific observations of IUE were carried out by the Guest Observers themselves at one of these ground stations – as they would normally do in a ground-based observatory.

The satellite 3-axis stabilisation and pointing/slewing package comprised 6 gyroscopes, two star-trackers (Fine Error Sensors, FES), Sun sensors, a set of momentum-exchange reaction wheels for attitude control, and hydrazine thrusters for momentum dumping. Power supplied by the on-board Solar panels was supplemented during eclipses by two on-board Ni-Cd batteries. Communications between the two ground stations and spacecraft used VHF transmitters/receivers and S-band antennae (used for telemetry), with two, redundant ON-Board Computers (OBC) processing commands and controlling the operations of the scientific payload.

Fig. 3 shows the layout of the IUE spacecraft and Fig. 4 a schematic of one of the spectrographs, FES and cameras. An important element of the design was to incorporate considerable redundancy in the systems.

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Thus there were two FES's, and two cameras each for the short-wavelength ranges (Short Wavelength Prime – SWP, and Short Wavelength Redundant – SWR), and long-wavelength ranges (Long Wavelength Prime – LWP and Redundant – LWR) cameras, covering respectively the wavelength ranges 1150-1950Å and 1850-3250Å. The short-wavelength limit of 1150Å was the result of the MgF_2 reflective coatings selected for all the system optical components, to maximise throughput above that limit. Fig. 5 provides a schematic view of the IUE cameras employed, which consisted of a front-end UV-Visible converter, a Secondary Electron Conduction (SEC) image section and the backend SEC readout section. This provided a 2-D 768×768 pixel image of the spectral data (see Figs. 6 & 7).

The echelle gratings provided a spectral resolution of about 0.1Å in the SWP range and 0.2Å in the LWR range, with an overall system sensitivity allowing spectra to be obtained of blue objects down to about 12^{th} magnitude in exposures of about 2hrs. By flipping a plane mirror in front of the echelle grating, spectra at around 6Å resolution could be secured using the cross disperser alone, again covering either the short- or long-wavelength range. In this case high quality, low-resolution spectra could be secured in an hour exposure of blue objects down to a magnitude of about V∼16. It quickly became apparent that the spectral resolution was similar whether the small ($3''$) or large ($10''\times20''$) aperture was used, and since the latter retained the full photometric integrity of the data it was most often used. Additionally, the signals from the FES were found to be stable and calibrated to provide an optical photometric measurement of the target source, which was routinely supplied to the observer. This proved most useful in the study of variable sources providing simultaneous coverage of UV and optical changes.

At the outset, each agency (NASA, ESA and the UK) solicited observing proposals from their respective communities, which were peer reviewed by separate Time Allocation Committees, on an annual basis. NASA operated two 8-hour observing shifts per day from GSFC, and ESA/UK the third 8-hour shift from VILSPA. Successful proposers would then be scheduled for their allocated number of shifts during an optimal time of year and would go to the relevant ground station to conduct their programme with the assistance of resident astronomers and spacecraft operators.

The GO would arrive armed with finding charts for his/her target fields, estimated exposure times and observation strategy for the programme. The satellite would be commanded to slew to the first target, take an FES image of the sky and telemeter this to the ground console for the observer to identify the field and desired target, which would then be directed to the desired spectrograph aperture and camera (SWP or LWR) and the exposure commenced. At the end of the exposure the camera would be read out and

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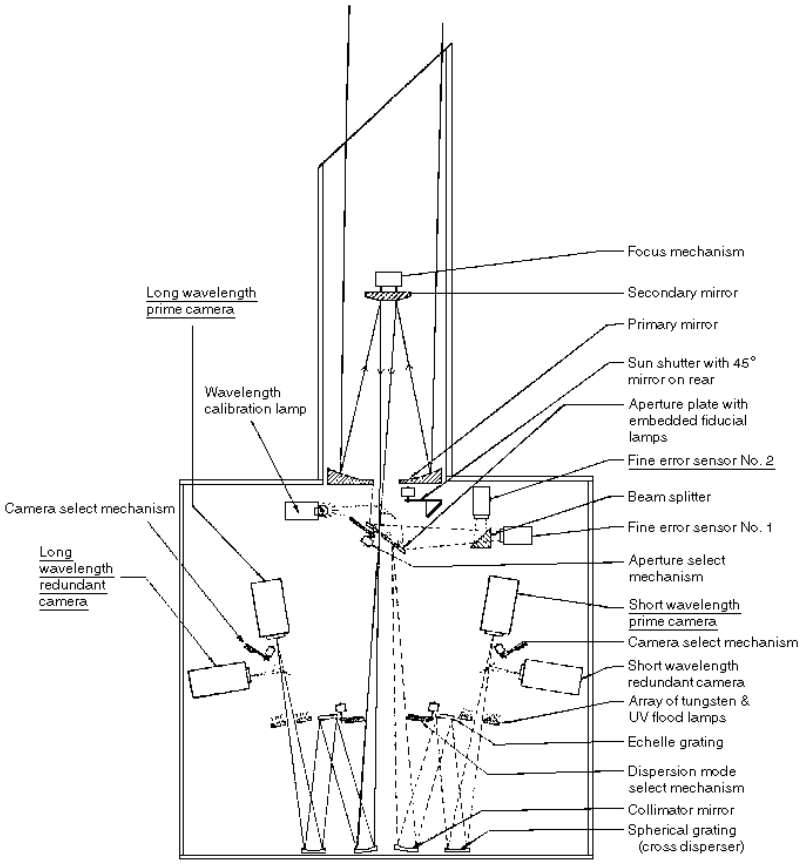


Figure 4. A schematic of the IUE scientific instrument. The locations of the echelle and cross-disperser gratings, collimator, camera mirror and duplicate SEC Vidicon camera detectors are shown, as are the duplicate Fine error Sensors imaging the telescope 16′ field of view. (Courtesy NASA/ESA/SERC)

spectrograph image transmitted to the ground for immediate inspection by the GO. In this way the GO could gauge immediately whether or not the data were of the desired quality and could either command another exposure, different camera or move to the next target. At the end of each shift the acquired data would be pipelined processed and the observer would receive magnetic tapes with their raw and processed data for immediate analysis back at their home institution.

It was recognised by each of the three agencies that IUE had the potential to make significant advances in a wide range of astrophysical fields, and each TAC comprised specialist panels to consider applications in six main

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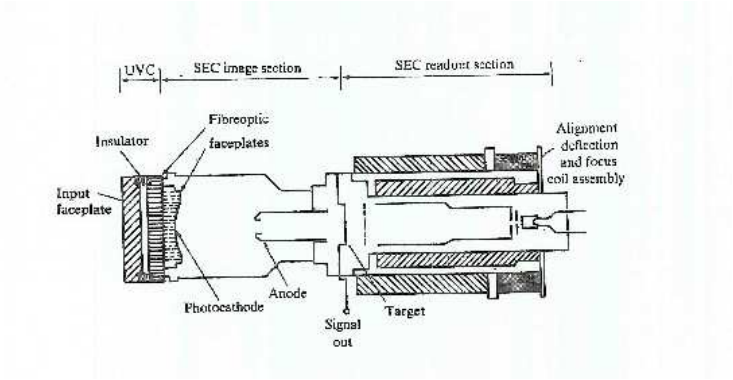


Figure 5. A schematic of one of the four SEC Vidicon Detectors used to record each spectral image, showing the front-end UV-to-visible converter, the secondary electron conduction section and back-end readout section. The cameras proved remarkably stable showing only a few percent sensitivity reduction after 18.5 years operation. (Courtesy NASA/ESA/SERC)

areas: Interstellar medium; Hot stars; Cool stars, Active galaxies; Normal galaxies; and the Solar System. Each area had a preliminary total shift allocation to ensure that the mission would yield a balanced programme – a pattern that would become the norm for subsequent space observatories.

The TACs operated independently, and often approved programmes included sources duplicated in US, UK and European allocations. At first sight, this might have been considered inefficient, but in fact it turned out to have profound scientific advantages, especially when it was discovered that sources showed significant spectral variability. In addition, the high orbit and real-time control of the mission meant that IUE could react swiftly to unexpected events, designated Targets of Opportunity and each TAC/agency agreed that such TOO would be incorporated as override priorities in the observing schedules. Examples included Novae, Supernovae and Comets, but in addition Guest Observers could bid for additional TOO targets on scientific merit. Throughout its lifetime the oversubscription for observing time remained high at the 4-5 level.

IUE was launched from Cape Canaveral (now Cape Kennedy) on a Delta 2914 rocket on 26 January 1978 into a transfer orbit and then, using the onboard Apogee Boost motor, into a 24-hour Geosynchronous orbit, located over the South Atlantic. The mission hardware was designed for a minimum lifetime of three years.

It is a testament to those who designed and built the mission that in fact it lasted for 18.5 years, and during that time the overall system sensitivity showed a degradation of only about 15%. The extended lifetime of IUE was also made possible by the superb ingenuity of the operations and engineer-

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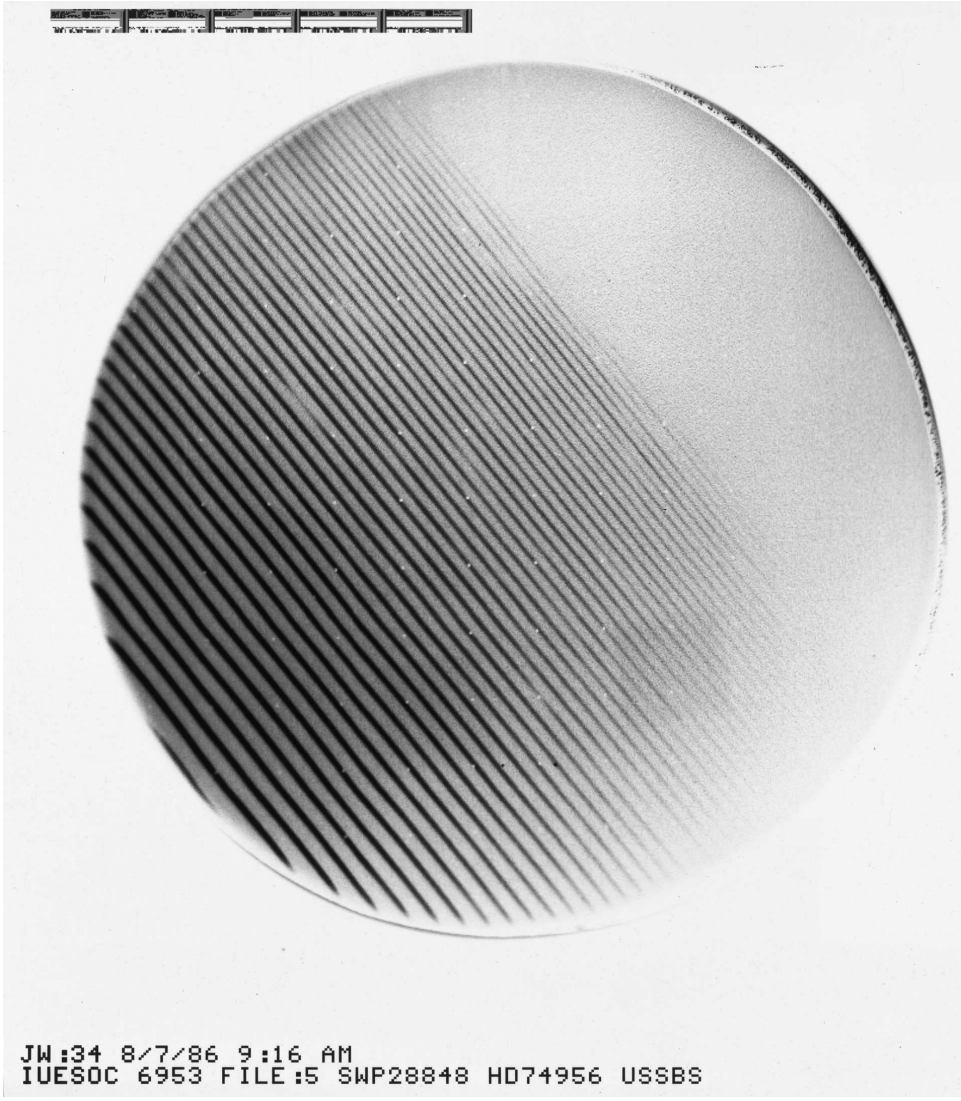


Figure 6. An example 2-D image from a high-resolution echelle spectrum, with a 768x768 pixel format. Pipeline processing of such data included corrections for geometrical distortion, photometric correction and scanning each order and inter-order background, to yield a flux-calibrated spectrum covering 1150-1950Å at about 0.1Å resolution. The long-wavelength spectrograph produced similar images and spectra covering 1850-3250Å. (Courtesy NASA/ESA/SERC)

ing staff, in coping with inevitable system failures and consumables usage. Careful optimisation of slews and systems preparations minimised the use of the on-board hydrazine, whilst the engineering teams developed novels

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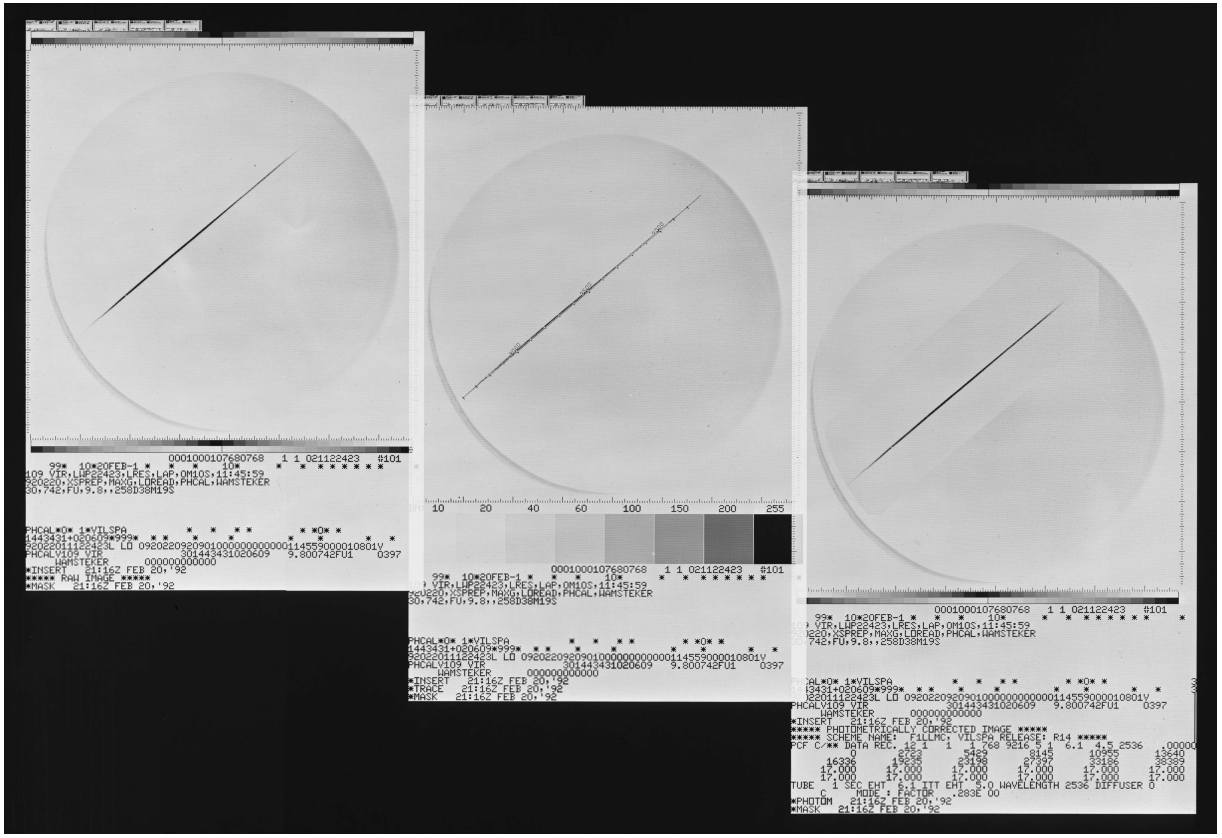


Figure 7. An example of a low-resolution IUE spectrum, from the cross-disperser grating alone, in the short-wavelength region covering 1150-1950Å. Two spectra are shown on one image produced by locating the object in the 3″ and 20″×20″ apertures. Similar low-resolution spectra were secured using the long-wavelength spectrograph covering 1850-3250Å. (Courtesy NASA/ESA/SERC)

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TABLE 1. Design Parameters of the IUE Mission

Launch:	Delta 2914 rocket on 26 January 1978
Orbit:	Geosynchronous period 23.927hrs Perigee: 25669km Apogee: 45887km Inclination: 28.6 degree
Ground Stations and visibility:	
	Goddard Space Flight Center (USA) 24hrs per day Villafranca del Castillo (Spain) 16hrs per day
Scientific Instrument:	
	45-cm f/15 Richey-Cretien Cassegrain telescope Telescope Image quality $3''$ Two echelle spectrographs + cross dispersers Wavelength ranges: 1150-1950Å, 1850-3250Å High resolution mode: $\sim$0.1Å Low resolution mode: $\sim$6Å Two spectrograph entrance apertures: $3''$ and $10''\times20''$
SEC Vidicon Detectors: 768×768 pixels	
Fine Error sensor for $16'$ Field of View for target identification and acquisition	

ways of pointing and slewing algorithms to accommodate gyro failures. The tremendous impact that IUE had on modern astrophysics is summarised in the next section. Its great success was recognised after its first ten years of operation when the IUE Project was selected for the 1988 US Presidential Award for Design Excellence, the first, and as far as I am aware the only time that an astronomical facility has won such an accolade.

5. The IUE Archive and Data Distribution

As noted above, the three agencies agreed in the MOUs that all IUE data should be made available to the widest astronomical communities world-wide, after the 6-month period of propriety rights to data secured by the original guest observer. To achieve this goal the IUE project developed pioneering techniques to provide an archive of all IUE data and procedures for

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delivering data as a "service" to the community in response to requests for specific observations. This concept was in stark contrast to the situation which was commonplace for data obtained from ground-based observatories up to that time. There observers would take their data (usually in photographic plate form) back to their home institutions and no "copies" were held at the observatories themselves. Thus such data, generally, remained soley the property of the initial observer and not made widely available. The observatory would hold files of observing logs specifying which object had been observed, when and in what form (*i.e.* spectral or photometry), but another astronomer essentially had to contact the initial observer to ask whether they could access the original data. A similar pattern of data access, or lack of it, effectively applied to earlier space missions. All this was to dramatically change with IUE.

The development of the IUE archives has been described by Harris & Sonneborn (1987) and Giaretta *et al.* (1987), and further comments of how the archive evolved have also been summarised by Benvenuti (2002). To inform the wide community of what data had been obtained the project maintained an IUE Merged Observing Log (combining the data secured at the two ground stations, VILSPA and at GSFC) updated every two months and, initially, made available on microfiche (to be supplanted later on via interactive facilities on the WWW).

The three agencies agreed that explicit identifications would be required for all targets in the logs, with HD numbers being used for stars and NGC numbers for non-stellar sources. This mandatory harmonisation procedure provided a much-needed standardization of log records, avoidance of any unnecessary duplication of observations and subsequent smooth exploitation of the archives. The Log provided information on the specific astronomical target, the IUE instrument configuration and data calibration. These included the Object identification, coordinates, object class, camera employed, exposure time, aperture used etc, and any special observing procedures such as blind-offsets, multiple exposures in the LORES mode using the large aperture. Often the FES image associated with a specific spectral image was also archived. For the spectrum, the camera image number, the raw, geometric-corrected image and the calibrated image was also archived, as well as the calibrated, extracted spectrum. Photowrites of the three types of image were also archived and made available to allow the user to quickly access data quality.

A key aspect of the operation of the IUE archives run by the three agencies was to make the resource easily and speedily accessible to the requesting astronomer, and to provide a service which was essentially cost free to them. In the early phases of the mission the requester would scan the Logs, identify the source(s) he/she was interested in a send in to the

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relevant agency a paper request of the image numbers required. The data center would then undertake a tape-copying job of all the relevant data and send a tape of the requested data to the requestor via normal mail service. Typically, the requestor would receive their desired data within a few weeks.

As time progressed, this whole process would be supplanted by e-mailed requests and data transmission over the Internet. This speedy transmission of IUE data to the wider community represented a massive advance over previous facilities and set a benchmark which was to be followed by subsequent missions, including the HST. As the IUE mission progressed in time, it was recognised that improvements to the calibration and data extraction procedures should be incorporated in the archival data. To that end, special teams in the three agencies developed standardised techniques for re-processing all IUE data to allow, inter alia, homogeneity of data taken at different epochs to maximise the scientific integrity of the data. This reprocessing led to the Uniform Low Dispersion Archive (ULDA) and, for high resolution spectra, the IUE Newly extracted Spectra (INES) archive.

The ease of access and speedy availability of IUE data to the wider community, ensured that the usage, exploitation and scientific return from the mission was greatly enhanced. It was clear from the outset, and inherent in the initial planning of the three agencies, that IUE data could and would be of scientific importance above and beyond the goals of the initial observing proposal. This was essentially a result of the full spectral range coverage of each exposure and especially so in the case of the high resolution echelle data. A few examples will illustrate this. In the study of stellar winds from massive OB and WR stars, hundreds of stars were observed in the Galaxy and Magellanic Clouds, to study their P Cygni profiles in species like SiIV, CIV, NV and other stellar features. Each stellar spectrum also had superimposed a plethora of interstellar absorption lines produced in the intervening interstellar gas. Thus these data were of great interest to astronomers studying the ISM in the disk of our galaxy, the galactic halo and the ISM in the Magellanic Clouds themselves.

Similarly, HIRES data initially secured for the purpose of studying the ISM was of great interest to the hot star fraternity. By making the IUE data accessible to the broader community, after the initial propriety period, a wider range of scientific outcomes could be achieved. A second example, which relates to the longevity of the mission, and the fact that the three agencies operated independent guest observing allocations, meant that repeat observations of individual sources were obtained which led to the discovery of significant time-variability in their UV spectra, often hitherto unknown. This led to significant changes to our understanding of the structure and variability in the winds and atmospheres of hot and cool stars,

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and in AGN (see below). By making the IUE data to readily accessible via the archives ensured an enhanced and optimal scientific return. During the course of the mission the number of scientific papers published based on use of archival data became comparable to those from the ongoing guest observer data.

Subsequent space observatories, especially the HST, were able to learn from and capitalise on the experience of the development of the IUE archive to provide a comparable service and maximise the scientific return from their own data.

6. The IUE Legacy

During its long lifetime IUE proved to be one of the most successful astronomical observatories ever developed. It was used by thousands of astronomers from all over the world, generating over 100,000 ultraviolet spectroscopic observations of a very wide range of objects. Over 3500 refereed papers have appeared based on IUE data, and the proceedings of 10 international conferences dedicated to IUE results have also been published. It is estimated that some 600 PhD theses have been produced based on IUE data. All IUE data, in both raw image and processed spectral form are available in Data Archives, easily accessible from the three agencies. These IUE data archives are still being "mined" at the time of writing. The main legacy of the IUE mission has been its impact on astrophysics. I refer the reader to the volume "Exploring the Universe with the IUE Satellite" (Kondo *et al.* 1987) in order to gain a fuller appreciation of the huge range of scientific advances that the mission engendered. A few examples are given below to illustrate the special mission characteristics and operations that led to its success, notably its sensitivity, orbit and real-time control, and longevity.

The increase in sensitivity over previous missions can be illustrated by the following: the Copernicus satellite yielded the full UV spectrum of the V=2 O4f star Zeta Puppis in an integration time of about 24hrs – the IUE spectrum of the same star was achieved in a few seconds. This huge advance in sensitivity extended observations of the UV spectra of luminous OB and related WR stars from the Copernicus limit of 6^{th} magnitude to objects as faint as 16^{th} magnitude in the Galaxy and Magellanic Clouds. This allowed the study of mass loss and stellar winds in different galaxy and metallicity environments, the discovery of mass loss and winds from subluminous OB subdwarf stars and central stars of planetary nebulae, testing the theory of radiation-pressure-driven winds over a ten-decade range of stellar luminosities. Repeat observations of individual OB (and WR) stars showed variability in their UV P-Cygni profiles and the ubiquitous occurrence of

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Discrete Absorption Components (DAC), whilst the ability with IUE to monitor individual stars for many days uninterrupted led to the discovery that these DACs varied in strength and velocity on timescales associated with stellar rotation.

The concept that hot star winds were steady and spherically symmetric was refuted and led to the realisation that their winds are highly structured and variable, the physical origin of which is still poorly understood but probably linked to radiatively-induced instabilities and non-radial pulsations. This has had a profound effect on models of stellar evolution when mass loss has to be included. The longevity of IUE further revolutionised massive star astrophysics when it was discovered that some OB stars altered their spectral appearance dramatically, changing from a high-temperature O or WR appearance to a low-temperature Luminous Blue Variable appearance in only a few years – for the first time it became possible to investigate the advanced phases of massive stellar evolution in "real time". The increase in sensitivity provided the first UV spectral data for a huge range of different stellar types, including Pre-Main Sequence stars, Symbiotic stars, interacting binaries, Be stars, White Dwarfs, Planetary Nebulae, the Chromospheres and Coronae of Late-Type, cool stars and their mass outflows.

The IUE sensitivity greatly extended studies of the Interstellar Medium, in both gas and dust phases by probing sightlines out to large distances using stars in the Magellanic Clouds and other galaxies as background sources. This lead, inter alia, to the mapping and extent of a hot phase in CIV, SiIV and NV, in the Galactic Halo and tests of the Galactic Fountain model for the ejection of hot gas from supernovae and subsequent cooling and infall – of importance in the interpretation of QSO absorption lines. In addition, studies of the chemistry and dynamics of the interstellar gas in diffuse and dark clouds became possible throughout the Galaxy and Magellanic Clouds, and the nature of the UV interstellar extinction could be determined in different metallicity environments.

The geosynchronous IUE orbit allowed multiple observations of individual sources to continue uninterrupted for days at a time, and this greatly facilitated multi-wavelength observing campaigns, using ground-based telescopes at different longitudes (*e.g.* in Australia, South Africa, Canaries and the USA) to achieve 24-hour coverage, as well as X-ray satellites. One example of this was a two-week campaign in 1979 known as the X-ray Binary Fortnight, when US, UK and European scientists agreed to pool their time in a coordinated study of four prime X-ray binary sources: Cyg X-1, Sco X-1, Her X-1 and HD153519 (Dupree *et al.* 1980, Gursky *et al.* 1980, Treves *et al.* 1980, Willis *et al.* 1980). For each source, variations in the IUE UV spectra were combined with simultaneous data from optical spectroscopy

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and photometry and X-ray data, to lead to great advances in our understanding of the accretion phemonenon onto compact stars (White Dwarfs and neutron stars) in binary systems.

A second example was the multi-wavelength campaign studying variations in Active Galactic Nuclei, especially the Seyfert galaxy NGC4151 (Penston *et al.* 1979). As well as improving our understanding of the ionisation and structure of the narrow- and broad-lined regions in these AGN, the different timescales and velocities measured in the variations seen in the FeII, SiIV, CIV and NV emission lines in NGC4151 allowed the mass of the central black hole in that object to be measured accurately for the first time.

The high IUE orbit and real-time control also greatly facilitated the ability to respond quickly to the occurrence of targets of Opportunity like classical Novae and Supernovae, and to monitor the development of the source UV spectrum after outburst. As an example, Nova Cygni 1978 reached V=6.2 on 12 September 1978, and observations with IUE started a few hours later, and continued monitoring with 194 spectra secured until near the end of 1980 when it had declined to V=14. The analysis of the nebular phase of this nova showed that enhanced CNO abundances, expansion velocities, ejected mass and kinetic energy were all consistent with the proposed theoretical explanation for a nova as a CNO outburst onto a 1.0 solar mass white dwarf from material accretion from a late-type companion (Stickland *et al.* 1979).

In subsequent years many more novae were observed in a similar fashion. Many Supernovae were also observed with IUE soon after their initial outbursts, including SN 1987 A in the LMC. IUE monitoring of this source led to the discovery a enhanced NIII emission some 1.7 years after the initial explosion, the light-time-travel to a precursor ejected ring of material confirming the evolutionary nature of the precursor star and also allowing an accurate measurement of the distance to the LMC.

Although primarily intended as a mission to investigate stars, the ISM and galaxies, IUE was also used to study objects in the solar system, and provided pioneering spectroscopy of planetary atmospheres and Aurorae, planetary satellites and Comets (the latter as targets of opportunity). As an example, one of the earliest discoveries was the variable Sulphur emissions lines in the spectra of Jupiter which were shown to arise from volcanic emissions from its moon Io (see Moos & Encrenaz 1987).

As the mission progressed, its sensitivity limit was pushed to further extremes from that originally envisaged, in some cases employing single exposure times as long as 36hrs. A good example here involved the pioneering UV study of the Double Quasar 0957+581 A,B undertaken by Wilson, Gondhalekar, Burke and Dupree. At some 19^{th} magnitude this source was

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one of the faintest objects successfully observed in the low-resolution mode. IUE was used to monitor the UV variations in the A/B lensed components of the Quasar over several years. Variations in the UV brightness ratio A/B was found to be the same as found at radio wavelengths, confirming a basic prediction of a gravitational lens – NO chromatic aberration, whilst the measured time delay between variations in components A and B provided a direct measurement of the Hubble constant of H = 67 ±8 km/s/MPC^{-1}, in very good agreement with later determinations from the Hubble Space telescope (Gondhalekar & Wilson 1982).

IUE is the only space facility to have been operated like a "normal" ground-based observatory with guest astronomers going to the ground stations at GSFC and VILSPA to conduct their own science programmes and "see" their data in real-time. This was possible through the choice of a geosynchronous orbit with constant ground-station contact. The observer was thus able to ensure the optimum quality of his/her data, by adjusting observing times accordingly, and the on-source operational efficiency was extremely high at about 80-90 percent. The system also allowed for considerable flexibility in observing targets and modes, unlike the case of a low-orbit mission where observations are generally pre-programmed days or weeks in advance. Guest observers also had a unique opportunity to understand the intricacies of the satellite and instruments through direct interactions and contact with the spacecraft engineers and ground-station support staff and resident astronomers. This and the near-annual IUE conferences greatly facilitated international science collaborations and new initiatives.

The extraordinary lifetime of the IUE mission at 18.5 years did, perhaps, have one unfortunate legacy. Despite numerous attempts and proposals to ESA for a follow-up UV mission during the period 1979-1995, none were selected in the competitive mission selection exercises. It was, perhaps, generally considered that with HST up, and IUE still operational, there was less of a need for a further facility, despite the great improvements in sensitivity and wavelength coverage that were being proposed.

Whilst NASA did go ahead with the Far Ultraviolet Satellite Explorer (FUSE) mission, launched in 1999 (lasting to 2006), there has been and remains no plans in the ESA programme for a UV spectroscopic observatory to follow the great success of IUE, which is a pity. Has the UV field, at least in Europe, been the "victim of its own success" ?

Acknowledgements

I am grateful to Karen Levay (IUE archive team at StSci) for providing copies of the IUE photowrites in Figs. 6 & 7, and to David Stickland for a careful reading of this paper.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 417-440
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HISTORY IS TOO IMPORTANT TO BE LEFT TO THE HISTORIANS

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Abstract. The author reflects on previous essays by historians of astronomy and by the astronomer Donald Osterbrock as to what it takes to create useful and accessible history of astronomy. Suggestions are put forward for astronomers in particular who may be interested in following Don's example of contributing to the history of astronomy.

1. "The View from the Observatory"

At the January 2002 annual meeting of the AAS, the Historical Astronomy Division awarded the third LeRoy E. Doggett Prize for Historical Astronomy to Donald E. Osterbrock. The citation read that he won the Prize "for his many books and articles on the history of astronomy." Don delivered the Doggett Prize Address at the meeting, and its blatantly provocative title, "The View from the Observatory: History is Too Important to be left to the Historians," insured a large audience and much anticipation. Unlike the first two Doggett Prize winners, Curtis Wilson and Owen Gingerich, who surveyed the state of their particular specialties and concentrated on internally directed intellectual themes, Don painted with a broader brush. His essay was later published in *Organizations and Strategies in Astronomy III* (Osterbrock 2002b).

Don's essay was, indeed, memorable and thought-provoking. It helps us appreciate Don's view of what it takes to do history and reminds us indeed that history is not the exclusive province of historians. Certainly he was projecting that message in the subtitle to his talk, assigning to his perspective the authority of place. Given the fact that the American

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Astronomical Society and the International Astronomical Union have been strong supporters of the history of astronomy, I wanted to interpret the title of Don's talk as an affirmation that this support had been worthwhile, and that he was arguing that astronomers should be invested in their history. There were some historians of astronomy, however, who bristled at the title, sensing that it also raised the question of "who owns history?" Although that was a continuing question among historians at the time, this was not the intention of Don's essay, nor was it the way I took it.[1]

Don's message was, in fact, a far cry from when, during my days as a fledgling astronomer in the 1960s, I acquired an interest in history from spending cloudy nights spelunking in the old records in the attics of Lick and Yerkes. Referee's letters and commentary and personal correspondence revealed evidence that statements in the published record were not always true to "what happened" but were linearized rationalizations that were crafted to make a convincing argument. The process of discovery was rarely as clean and direct as their reports would have us believe. I told some people about this and was puzzled when my fellow astronomy students expressed annoyance that I was just stirring the waters, and that the published record was as far as anyone should be allowed to go. But I persisted, and as an historian have been exploring this revealing characteristic practice ever since.[2]

The published record is not a record of what happened, and Don certainly agreed with that. But one can find examples, even today, however, of astronomers, writing popularly on historical topics, who apparently do not appreciate this fact, or do not wish to explore it in public. Clearly they are not writing for an historical audience, rather for the popular reader, which from a marketing standpoint is understandable, as there are not that many historians available to consume astronomical history. But this is a loss to history and this essay is in a way an appeal to astronomers to try and be more helpful to history, or at least to the preservation of their own history.

2. Contributing to the History of Astronomy

Astronomers make the history of astronomy possible, of course, and professional historians of astronomy will forever be in their debt for doing so. But the fact is that adequately capturing the nature and many flavors of a profession that has grown by orders of magnitude in size and complexity in recent times (see Fig. 1) has become a daunting challenge for professional historians and archivists. So this is a plea for help. I will express this plea by

[1]Among others, see Crew (1996), Miller (1998), Munro (1994) and Matson (2011).
[2]See, for instance, DeVorkin (1975) and DeVorkin (2000).

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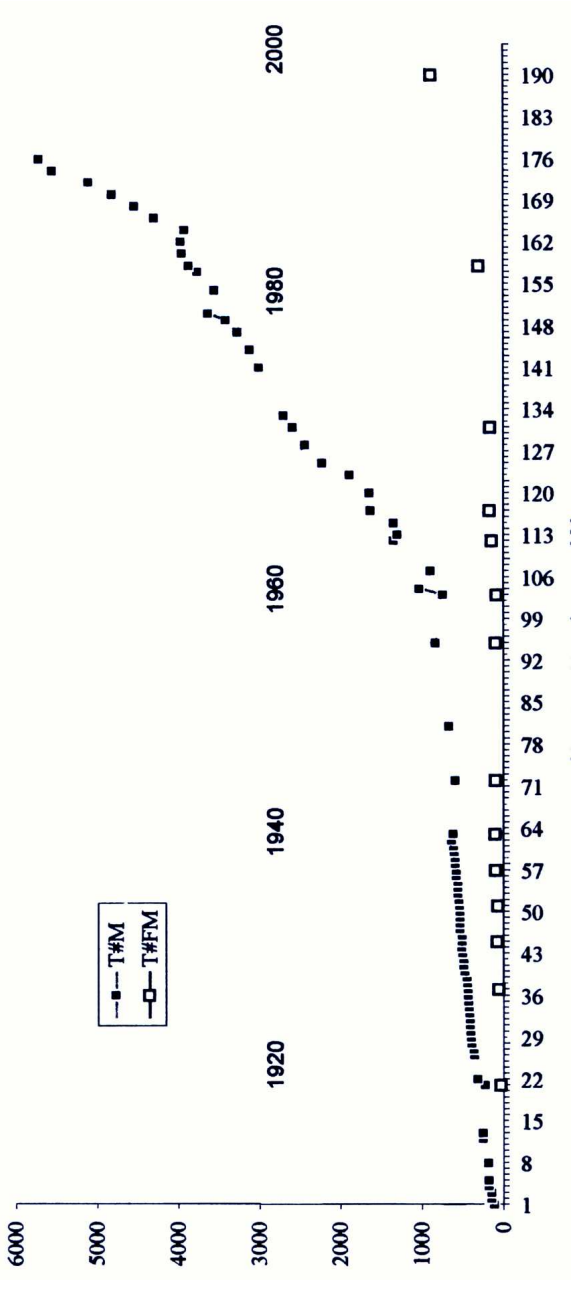


Figure 1. Membership trends in the AAS. Horizontal axis: meeting number and year. Vertical axis: number of members. Dark squares represent total number of males; open squares, females. Membership numbers derived from a variety of sources, including AAS records, AIP membership statistics, AAS Council records. The AIP and AAS statistics differed by up to 10% in the 1980s, possibly due to different polling techniques or to the inclusion or exclusion of corporate members and affiliates. (from DeVorkin & Routly 1999, p. 128)

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reflecting on Don's 2002 essay, juxtaposing it with one by Marc Rothenberg in 1985.

In an *Osiris* theme volume devoted to writing on American science (*Osiris* is a journal central to history of science but probably read by few if any astronomers), Marc identified three general types of writers who contribute to the history of American astronomy: historians of American science primarily interested in the social, cultural and institutional frameworks within which astronomy has flourished; specialist historians of science more interested in the intellectual content; and practicing astronomers who have been passionate writers of chronologies, biographies, and anecdotal episodes (Rothenberg 1985, p. 117).

In the ensuing three decades since Marc's essay, these categories still hold, more or less, for writing on astronomical history, not only American history but beyond American boundaries. But there seems now to be considerable overlap in the three groups; especially in the first two. And today there are many more defined specialties that pay attention to astronomy, in its sociological, anthropological, and technological contexts. What still holds true is Marc's original observation that the "diversity of interest, background, and methodology" of these three groups gives the field robustness and intellectual breadth.

So in this informal and somewhat impressionistic essay, I'd like to explore some of Don's contributions, in light of Marc's categories, as exemplars of how the third group, practicing astronomers, might make even more valuable contributions to history, and what they might expect as a result of their labors. Of particular importance, however, and the point I will try to get across here, is what I wished Don had done during his lifetime: first, to more deeply engage the efforts of the first two groups in his research and writing, giving them feedback from the perspective of a gifted practitioner, and second, to make more of an effort to preserve the history of his own generation.

In his acceptance speech for the Historical Astronomy Division, Don talked about how he got interested in history, and then he thanked people who nurtured his interests and activities in the history of astronomy – these included Mary Lea Heger Shane, who pioneered the creation, formation and maintenance of the Lick Observatory Archives, now named in her memory.[3] Don also thanked Helen Wright, who as Hale's biographer was a prolific writer of 20th century history of astronomy, and whose writings made many astronomers aware of history (Lankford 1999). Third came the eminent historian and Harvard astronomer Owen Gingerich, the most widely known name to American astronomers and who continues to inspire

[3]See Shane (1971), Vasilevskis & Osterbrock (1989) and Osterbrock (1984).

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Figure 2. Don Osterbrock surrounded by other historians of astronomy at the January 2002 meeting of the Historical Astronomy Division of the American Astronomical Society in Washington, DC. From left to right: Craig Waff, Ron Brashear, Brenda Corbin, Don Osterbrock, Marc Rothenberg, and André Heck.

us all. And fourth, Bill Hoyt, whose series of books on the Lowell Observatory stimulated much interest in history at that famous observatory and beyond, among astronomers at least.

Don made clear what he thought was required to do proper history of astronomy, giving us examples of writers he admired. As he said in his abstract (Osterbrock 2002a):

> *"I believe it helps anyone who wants to understand the history of astronomy to know and understand astronomy. History must be based on facts, which archives, scientific papers, and books can provide. Immersion in a field like astronomy makes one better qualified to understand what others have done in that field, and how they did it, as Ibsen, Hemingway, Tuchman, and Grisham have all stated and proved by example."*

Don's choices call for comment. I failed to ask Don, after his talk, or subsequently, just what he meant. Were Ibsen, Hemingway, Tuchman and Grisham especially adept at exploring the histories of their respective fields? Or was Don saying that these luminaries were especially adept at observing their own professions, acting as, for instance, critics? Daniel Fuchs (1965, p. 431) asks this question about Hemingway, suggesting he was "a critic in spite of himself." Ibsen's dramas were informed by his own life, and he has been credited with establishing modern playwriting through his penchant for critical analysis, personal introspection and confrontational morality.

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All of Don's exemplars were terrific writers and communicators, of course, but is this what Don was suggesting? Maybe Tuchman comes closest as an exemplar we can apply, with a BA in history and a distinguished career as a journalist and a widely influential Pulitzer-winner for history writing. Tuchman devoted much ink to the practice of historical writing but couched it in context of her fascination with political ambition. As a writer of non-fiction, she was not trained specifically in the subject areas she wrote about. However, as did Don, she spoke passionately of the importance of reading and knowing history. Unlike Don, she strongly interacted with the relevant historical literature. This is what I'm asking astronomers to do if they care to write history.

Possibly what Don was really trying to say was that history is all about telling stories, and telling them well; and well-armed with defensible points of view. But of the exemplars cited by Don who wrote non-fiction, none were professional practitioners in the subject matter fields they typically wrote about.

Historians, including historians of science, generally craft contextual arguments for why they are telling a story. Whether they call it a point of view, a perspective, or a historiographical argument, it almost always is a way to frame a more or less chronological narrative in order to make a point or uncover patterns of cultural behavior that provide useful insight. An excellent example is what historians call the center-periphery view, which can be explored as a geographic or demographic model. For the history of astronomy, centers are not necessarily spatial, but typically have been. For instance, if you were a theorist in Cambridge in the 1930s, you were subject to close scrutiny to adhere to the standards of practice so successful in that center. This could explain in 20th century history why individuals as widely spaced as Henry Norris Russell and Meghnad Saha were able to make important breakthroughs in unconventional ways. Both were far from centers of rigorous physical theory and methodologies, and thus both were freer than, say Eddington, Milne, Jeans or even Bohr to play fast and loose with theory. Gamow, once at Georgetown, enjoyed similar freedom, as no doubt did Luyten at Minnesota. Similarly, the standards of conduct of colleagues in large dense disciplines tends to be more constrained and diplomatic than those in smaller, more esoteric specialties. Karl Hufbauer has utilized this perspective in his landmark studies of Bengt Edlén and Bernard Lyot (Hufbauer 1993 & 1994).

There are plenty of other examples of perspectives taken by historians that might help astronomers as they ponder the significance of their astronomical experience. The journal *Osiris*[4], noted above, can be useful here. It

[4] *Osiris*, "A research journal devoted to the History of Science and its cultural influences" Chicago: University of Chicago Press.

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offers yearly thematic compilations that address issues of current interest. Volume 9, in 1993, compiled and edited by Albert van Helden and Thomas Hankins, was devoted to Instruments, juxtaposing them into four separate contextual frameworks, including Authority, Audience and Culture. Volume 11 explored Science in the Field, looking at how the place where the work was done played into the nature of the work, and its reception by audiences, intended and accidental. There was also a volume devoted to identifying and describing Research Schools (Vol. 8) as literal, figurative, and symbolic collectives which I found most helpful appreciating the influence of an astronomer like Henry Norris Russell.

3. Resources for History

Don listed what he considered are the main resources for historical study. He placed archival resources first, then published scientific papers, and finally books, which historians call secondary sources whether they be written by historians, by astronomers, journalists, etc. Even though this may seem standard practice today, his view was indeed progressive for his time, and especially among astronomers and popular authors who write history. And I mark that from the beginning of his activity in historical writing in the mid-1970s.

Don also made a passionate point, reflected in his title, that one needed to know astronomy in order to comprehend its history. Few specialist historians of astronomy, I feel, would seriously disagree with this assertion, certainly not members of Marc's second two groups. And it is quite true that Don's first foray into history dealt with a phenomenon he experienced. His early series of papers on the California-Wisconsin axis was perceptive and gained positive attention among historians of astronomy. He had been Director of the Lick Observatory since 1972, having arrived there from the University of Wisconsin, and apparently was stimulated to trace the legacy of his personal move. These two papers, written for a popular but technically savvy audience, were in fact case studies in a genre historians call "prosopography" or collective biography (Stone 1971 and Shapin & Thackray 1974). He examined how staff and students moved between Wisconsin, Lick and Mount Wilson showing how the relationship was synergistic. At the same time, David Dewhirst explored the same relationship between Cambridge and Greenwich. Neither knew of the other's work, I believe, nor did either give evidence of absorbing the literature then available about collective biography. If they had, this might have led them to more generally useful conclusions beyond the "anecdotal," to reflect on Marc's observation. Still, I found these articles helpful in better understanding issues like regionalism in astronomy, and the dynamic between an observatory-based

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discipline and a campus-based discipline. The 20th century saw a profound transition in astronomical practice, and Don's papers offer glimpses of how astronomers regarded and reacted to that transformation (Osterbrock 1976, 1978 and Dewhirst 1976).

But one might also argue that having a practitioner's knowledge of astronomy alone might render a writer insensitive to external perspectives that might prove useful in comprehending and rationalizing the behavior of individuals and institutions under the circumstances they find themselves in. For instance, practitioners strongly objected when Paul Forman (1971) argued that quantum physics in Weimar Germany reflected, and indeed was intimately influenced by, Weimar culture. This work sparked intense debate among historians of science and raised many new and helpful issues that practitioners have, oddly, generally ignored. It is my firm belief that, if practitioners had continued to engage Forman's message and the commentary that followed which generalized his arguments, this would have enhanced their ability to insure that their science was value free.

Indeed, for me, one of the purposes of researching and writing the history of astronomy is to provide practical and useful insights into the forces and drives that have shaped astronomy. This was certainly my original motivation, for as a high school student I wondered where all the physics came from: wasn't astronomy all about "minding the heavens" in the words of the Herschels? Looking through telescopes? Much of my historical effort has been devoted to answering that question.

Certainly it helps to have a certain familiarity with astronomy in order to intelligently frame questions that can be answered by studying its history. But it also requires a sensitivity to, and facility with, the broader history that encompasses astronomy, social and cultural. Further, this level of familiarity need not be practitioner knowledge, unless the primary focus of the study is internally directed to an autobiographical critique of the process of knowledge formation. But this gets uncomfortably close to philosophical speculation even if the arguments are firmly grounded in documentary evidence revealing the actual process of discovery. It's a question of how the quest for objectivity is influenced by belief systems.

I keenly recall a galaxy conference in 1977, when Spencer Weart and I passed out a questionnaire to the attending astronomers that included various questions, such as do they believe in the Big Bang, and if so why? One senior and highly respected astronomer from Princeton walked right up to me, poked his finger into my chest repeatedly, and proudly proclaimed that "Astronomers have no beliefs." He was quite serious.

One astronomer quite aware of the influence of beliefs and of the workings of the unconscious was Fred Whipple. Near the end of his long life, he prepared a talk for the venerable Examiner Club in Boston entitled "My

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conversion to Atheism."[5] A biting and somewhat superficial polemic, reflecting more on his personal life, which, underneath the spectacular accomplishments, had experienced considerable pain and doubt, Whipple equated the lure of religion to the unconscious mind. "My unconscious mind likes to please or amuse me." For this reason,

> *"I have to watch my unconscious very carefully when doing science. I have had what seemed like very bright ideas involving a number of uncertain numerical quantities poorly determined. In making up numbers the best I could for each of the combined quantities on two different occasions, I came out very close to the number that I wanted to get. Later on, I found that the numbers were really not at all right and that the brilliant ideas were absolutely wrong."* (Whipple 2000)

In his obituary of Whipple, Brian Marsden (2005, p. 1458) noted "Not only is this an interesting admission from one of the giants of 20th century astronomy, but it should surely be a lesson to us all."

The recognition of the role of belief systems and the workings of the unconscious have been the subject of debate for decades.[6] I do suspect that astronomers have beliefs, and I want to assume that they realize that they do, like Whipple, and are able to account for them when making assumptions or drawing conclusions about the physical universe. There is a literature on the subject well worth pursuing. The social historian Harry Collins wholly accepts that "for all its fallibility, science is the best institution for generating knowledge about the natural world that we have" (Collins 1985[7]). But he also shows how "our concepts and social conventions reinforce each other" and offers numerous examples of areas where fallibility lies, including the belief that experimentation can be exactly replicated.[8]

If senior astronomers wrote memoirs exploring their cultural views and their belief structure and how they overcame them in their work, or found that they had been misled by them in their scientific lives, then this might make it more acceptable to their younger colleagues to be more probing of their own personal equations. This is the first plea I make to astronomers: share your personal insights into the beliefs you harbored and how you overcame them. Also share the doubts you may have had about how to proceed with a problem, and the many challenges you faced, and your colleagues faced, in striving to make contributions to astronomical knowledge.

[5]One of the editors of the Unitarian periodical the Christian Examiner, Joseph Henry Allen, formed the Examiner Club in 1863 (Litton 1994 and Luther Mott 1957, Vol. 1, p. 287).

[6]See, for instance, Collins (1969).

[7]Quote from p. 185. I thank Teasel Muir-Harmony for this citation and its implications. A most perceptive work on the origins and history of experimentation in science that asks how experimentation became accepted as evidence is Shapin & Schaffer (1985).

[8]Teasel Muir-Harmony, working notes.

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4. "Why Be Interested in History?"

Don employed the Socratic method to explore "Why be Interested in History?" First he stated a thesis, then an antithesis, and finally his synthesis. Echoing the finest reforms of the French Annales School of the 1920s, Don quoted Herodotus. History should be embraced: "So that the memory of what men have done shall not perish from the world nor their achievement, whether of Greeks or barbarians." Don passionately expressed this point, that the "true aim of history" must be "what happened and what people did" no matter who they were, good or bad, famous, obscure, high or low. Annales School history, of course, is best known for incorporating social scientific methods into history.[9] It remains one of the core views of how history should be done today, a core view shared by most mainstream professional historians. It combines many disciplines, including geography, history, and the sociological approaches ranging widely from community studies to prosopography, or collective biography, that stimulates attention to the history of common folk, as distinct from the traditional focus on the elite, who had heretofore exemplified history – the politicians, kings and diplomats – those who won the wars. Followers of the Annales School and its methods looked for frameworks, or enabling or defining modes of thought, for trends, modes, what we today call "context" to appreciate the nature and cause of change in society. Some even refer to it as the psychology of an epoch, a collective consciousness.

Don probably did not think of what he was doing in these terms. But he practiced some of it, and set an example for those who have eagerly read his works. His study of the Yerkes Observatory demonstrated these qualities. Here, Don demonstrated that institutions are not permanent or foreordained, and that people of all backgrounds and talents contribute to their health and, indeed, to their erosion (Osterbrock 1997). But again, one can only imagine what additional insights Don might have gained if he had absorbed the substantial literature on institutional histories and their dynamics.

The first outward signs of Don's interest in the history of astronomy appeared after his move to Santa Cruz. It was there that he found what we refer to today as the Mary Lea Shane Archives of the Lick Observatory. There, in beautifully organized drawers and files on the second floor of the Dean McHenry Library, a treasure trove awaited him (Shane 1971). With all these riches at his fingertips, and with Mary Shane encouraging him, it is not surprising to read in Don's essay that: "The Shane Archives were and are a tremendous advantage for me. I can look up almost any astronomer since 1880 and find letters to him or her there, can take notes

[9]Among numerous sources, there is Wesseling (1978).

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on those letters, and if I need more details, go back and consult them easily" (Osterbrock 2002b, p. 206).

Don made good use of these archives, searching out, identifying and most definitely appreciating the first true astrophysicist to work at Lick, James Keeler. But Don also examined the extraordinary legacy of Holden's efforts at mounting and executing eclipse expeditions. He documented how these expeditions were planned and funded, and explored their professional and intellectual consequences. Unlike many astronomers before him, Don did not rely on the published scientific literature alone; he incorporated the archival record as well, as he found it in Mary Shane's file cabinets, and eventually in archives across the land. Would that there were more Mary Shanes at more observatories across this land stimulating more Don Osterbrocks to examine their legacies!

5. Is Living the History Important?

As already mentioned, throughout his Doggett Prize essay, Don stressed the importance of having lived the history one writes about. He argues that at the least, it is helpful to have brushed up against that history to sense its weight, warp and rush: as he wrote "You have a feel for the place, the people ... the concepts ... the problems ... the unspoken (or unwritten) thoughts" (Osterbrock 2002b, p. 207). All this is absolutely true. It is not the only way to write history, of course, but it enlivens and illuminates history, as well as the writers of history. I only wish he had done more of this sort of writing himself, to help preserve and illuminate the history he experienced firsthand.

This is my second plea to astronomers. Preserve and share your history. Take proactive steps to preserve your papers (these may be correspondence, proposals, funded and unfunded, proposals for observing time, manuscript drafts, editorial correspondence, etc) and, if you like, provide commentary on those parts of your life these records cover. Yours may well be the most intimate account of "what happened" in your life, and this perspective, while not the only one, is of great value to history. And, equally valuable, talk about the people you know and have had substantive relations with. This gets us to Don's next point.

Don also acknowledged that "human relationships are important." He more than demonstrated this conviction in his dual biography of Hale and Ritchey (Osterbrock 1993). The effort he made to resurrect Ritchey was, indeed, a laudable example of the teachings of the Annales School. Although I differed with Don's interpretation of Hale's motivations and behavior in managing, or attempting to manage, Ritchey, and also feel he needed to better appreciate Hale's progressive style as a observatory director at a time

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when most were uncompromising taskmasters, yet I feel Don performed a positive service in highlighting the importance of this passionate instrument designer and craftsman in the emergence of the great reflector era. Even more than that, Don explored the relationship between Ritchey and Hale, between builder and user, much in the tradition of the historian's exploration of the relationship of instrument users to their providers, and vice versa.[10] Don somehow felt, however, that Ritchey had been wronged by Hale and so his goal was to set the story straight. But in so doing, he did not reflect on previous studies of Hale which offered insights that might have benefitted his analysis, mainly the importance of considering both sides of the relationship equation, better appreciating the perception each person had of the other in terms of the norms of practice of the day. Historians I've consulted in preparing this essay strongly suggested this, referencing a fascinating essay by Roy Porter (1985[11]). Here, Porter argues that it is not sufficient that "the history of healing is par excellence the history of doctors." Medical history, he contends, is really about "the two-way encounters between doctors and patients." It is not only about inclusion, as important as that might be, but it is about the totality of the human experience.

6. Engaging History and Historians

My discussions with Don over the years frequently centered on his puzzlement over historians of astronomy who expressed disappointment with, and sometimes outright dismissal of, his work. Don, however, bluntly rejected the value of engaging their remarks, or even the extant historical literature. He was not writing, he said to me, for historians. Even so, when they critiqued his efforts, in book reviews in *Isis*, and sometimes even in the *Journal for the History of Astronomy (JHA)*, he sensed that he was being attacked. I tried to explain that his reviewers were trying to engage his work, to relate it to work they felt needed to be done, or, more often, to work that had been done.

We could have conversations like these because of an incident that arose when he submitted an article to the JHA in 1989 on W.W. Campbell's spectroscopic studies of Mars. The editor sent the manuscript to me for review. I remarked that I had covered almost exactly the same subject using the same materials in a paper published in the *Quarterly Journal of the Royal Astronomical Society (QJRAS)* over a decade prior. When Don learned this fact, he reacted positively and dutifully cited my paper, but changed nothing else. That was the extent of our interaction. It would have

[10] An early classic is Bedini (1975).
[11] With thanks to Robert Smith for pointing this paper out.

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been much more interesting if Don had engaged my original effort, which had a strong point of view, and reflected on areas where he thought more could be done or something needed correction. He had been stimulated to write the paper, he stated, because Mars had recently been at a favorable opposition, and apparently there was no further motivation. The editor also did not encourage Don to alter his manuscript, justifying his decision to me by saying that no one read the QJRAS anyway, which only meant that neither Don nor the editor read that central journal, unless they were pulling my leg. This episode, though, made it possible for me to engage Don when others raised issues with his work. One of my tactics was to suggest parallels between the disciplines.

Don accepted that there were "flavors of the month" and trends in modern astronomical research, but this view did not extend to history. Topics, techniques and tools in astronomy change constantly. And similarly, I argued, writing on the history of astronomy is ephemeral. The stuff of history, whatever that is, or whatever we think of it, doesn't necessarily change. But our perception of it and what we do with it certainly does. And so, accordingly, our writing of history changes. Biographies of Galileo in the 19th and early 20th centuries are distinctly different from those of the late 20th century. The act of biography has changed; the questions asked, the perspectives taken, the interpretive tools applied, all change, constantly. I think Don eventually accepted this, but was not comfortable with it, expressing at times his feeling that "history is what it is." He seemed to be less aware that a tendency to be trendy is even stronger in the social sciences than in the hard sciences. For instance, at one point in his essay he felt that "many academic historians of science automatically consider astronomers trying to publish in their field as "Whig historians." Don's take on "Whiggishness" was that it was a polite way of saying "no good!" Correctly citing Herbert Butterfield as the instigator of the term, but neglecting to say that Butterfield coined the term in the 1920s, it was, in fact, a simple way to say that when history is written only by the winners, everything seems to lead inevitably to the winners winning! Butterfield, in fact a distant member of the Annales School in mind and spirit, believed that history was true only in relative terms. And indeed, Don agreed with this, pointing out in very Butterfieldian terms in the same paragraph that "We can never write down all that happened in the past. There is no one correct way to look at the past."

Indeed, there are many ways to look at the past, but is it only a question of writing "down all that happened?" My colleagues constantly remind me, especially after they read my book drafts, that completeness is not necessarily a virtue. Completeness can lend veracity to anecdotal accounts, but it can also be an overpowering and ultimately futile goal. As Marc Rothen-

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berg observed, although his third group of writers definitely concentrate on anecdotal accounts, the first group ideally prefer to state a thesis and then apply just enough evidence to support it. The more evidence that is collected, the greater the chance of hitting the mark; but then not all that evidence needs to be displayed, and, more than often, it gets in the way.

And here we get to the crux of this present essay: another restatement of my plea to astronomers: collect and preserve the evidence, but also offer personal perspective on what it all means. Engage the historical literature, offering your insights into how well it reflects your experience, or differs from it. Don became interested in the history of the institutions he encountered during his career as astronomer, and set about preserving this history through writing about it. He also was not shy to present snippets of his personal experiences as an astronomer and of the astronomers he knew (Osterbrock 1999). I wish Don had done more of this, and had, as well, engaged the ideas presented in the writings of others. In my own experience, when I looked at Campbell's Mars work I was struck that there were few if any quantitative standards in astronomical spectroscopy in that day. Campbell in fact tried to create them in this work, and his failure haunted him until he took his own life. In writing about the same subject and same episode ten years later, Don could have engaged my observation and pointed out how it rationalized the great effort and expense Campbell went to forming an expedition to observe Mars from Mount Whitney.

I'm using this instance in my contact with Don to appeal to astronomers to continue his practice, but to do so taking in historians as partners. The partners Don did engage, of course, were all most worthy and helpful. Mary Shane was a trained astronomer, but in her day she could not practice as a married woman.[12] Yet she contributed in many ways, most recently initiating the preservation of the papers that were the legacy of her husband, Donald Shane, who had been associated with Lick Observatory since the 1920s and was singularly responsible for its modernization post World War II, having been sensitized to the possibilities of truly "big science" during his tour of duty as assistant manager first for the Radiation Laboratory in Berkeley and then for Los Alamos, under Oppenheimer. And once Osterbrock arrived at Lick he greatly facilitated her work. His wife, Irene Osterbrock, also participated substantially, assisting Shane in the identification and organization of the records that were streaming down from Mount Hamilton.

[12]Shane, Mary Lea Heger Oral History, American Institute of Physics. The AIP Center for History of Physics houses the bulk of known oral histories taken with astronomers. Many are now available on line.
See `http://www.aip.org/history/nbl/oralhistory.html` (accessed 4/13/12).

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Don's use of primary archival resources in his research, and his support of the archival efforts at Lick, strongly demonstrate the importance for going beyond a mere recycling of already published information. With the Keeler book, he had certainly made an important historical contribution, which happily continued on with the Lick history, in 1988, collaborating with John R. Gustafson and W.J. Shiloh Unruh, authoring Eye on the Sky: Lick Observatory's First Century.

When Don went beyond the history of his own institutions, as in his attention to Edwin Hubble at the centennial of his birth in 1989, he did so collaboratively. Teaming up with Joel Gwinn, a physicist at the University of Louisville who had turned up interesting information about Hubble's time in that city, and historian of science Ronald Brashear, then the curator of the Hubble Papers at the Huntington Library, they managed to show that Hubble's early years were often quite different than the stories that had been spread and printed about him after his death. Don's collaborations stand as some of his best efforts. They offer a good model to follow.

7. Astronomers Who Write History

Needless to say Don Osterbrock was not the first trained and practicing astronomer to contribute to the historical literature on astronomy. One of his primary influences, as he stated, was Owen Gingerich, well known among historians of science and astronomers. Gingerich had devoted his energies to stellar atmospheres research in the 1950s and early 1960s. But he also harbored deep interests in a broad swath of history contributing to computer-assisted planetary position tables and eclipse tables covering classical antiquity as well as to a thorough analysis of the accuracy of Kepler's Mars calculations (Gingerich 1967 and Stahlman & Gingerich 1963). Owen, along with Michael Hoskin, nurtured the specialty for years through their editorial roles for the *Journal for the History of Astronomy*, founded by Hoskin. They were following the example set by Arthur Beer, who in his founding of *Vistas in Astronomy* provided the first modern platform for history of astronomy. Beer had collaborated with F.J.M. Stratton, R.O. Redman, Z. Kopal and S. Chandrasekhar from the 1920s through the 1950s, contributing consistently to binary star research and stellar atmospheres. Then, in the first volume of *Vistas in Astronomy*, published in 1955, Beer organized a series of papers on the history and philosophy of science that brought together papers by pioneer historians of science, such as George Sarton, Otto Neugebauer, Joseph Needham, Willy Hartner and Derek Price. These were joined by papers from astronomers who wrote history and philosophy, such as Herbert Dingle, David Dewhirst and Anton Pannekoek. Those in this early generation of historians of science, indeed,

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were well versed in the sciences; Neugebauer in mathematics at the Courant Institute, where he turned to its history for his doctorate, and Hartner a professor of physics at Goethe University who founded the Institute for the History of Natural Sciences there.

One can name many others from this era, well before it (Agnes Clerke, of course) and more recently who have contributed mightily. Don, of course, has been one of the most visible contributors on the American scene in recent decades. He also was very active in the Historical Astronomy Division of the American Astronomical Society and in the history commission of the International Astronomical Union.

Don stands out among most of these scientists-turned-historians in one important way. He spent the majority of his career attaining visibility and considerable status as an astronomer, and only near the end of his career did he turn to history. And he chose to focus on an era, the late 19th century through the mid-20th century, that framed the nature of his own training and created the astronomical community as he found it. What's missing, save for the occasional talk on his own life experience noted above, is Don's sense of the nature of astronomy and astronomical practice in his day, that is to say, the latter half of the 20th century.

8. What Can You Do?

From our outline of Don's contributions we can list the ways astronomers can continue to aid history: In order of priority: preserve your historical record! There is no question that astronomers are major stakeholders in this area. As more than one historian and archivist has said in the past: the record that is preserved today becomes the history of tomorrow. So contact your campus archivist and ask what it would take to have them pay attention to your papers, or to preserve the work of your department. If you need a translator, a friendly campus historian might help out. If you are a member of the American Astronomical Society, for instance, you might consider searching for members of the Historical Astronomy Division on your campus. There are also national resources, like the American Institute of Physics Center for History of Physics that maintain services for the identification, collection and preservation of papers.

Beyond preserving papers, preserve your recollections, impressions, and indeed the assumptions you made and the beliefs you harbored at different times in your life via an autobiographical statement. These efforts have proven to be extremely valuable, helping future historians focus on issues that otherwise might not come to their attention. In the mid 1970s, Spencer Weart, then director of the American Institute of Physics' Center for History of Physics, organized and executed a series of oral history

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programs, one of which in the late 1970s and early 1980s concentrated on modern astronomy. I was hired to assist, and the AIP team conducted, as well as collected from other efforts, some 120 oral history interviews with astronomers (Weart & DeVorkin 1981 and DeVorkin 1990). In addition, the AIP encouraged physicists, astronomers and others in its member organizations to contribute biographical materials to the Center, and this practice continues today. During our survey in the 1970s, we made an effort to encourage individual astronomers and their institutions to preserve and organize their archival legacy. Some, like the Lowell and Lick Observatories, responded positively, accepting small grants-in-aid. The Center also maintained materials that would help to stimulate and to direct the collection of additional oral histories, including a "skeleton question list" that covers the sorts of things historians feel should be preserved.[13]

Among historians of physics and astronomy, primarily in his years as the Center Director, Spencer Weart thought more than most about ways to both stimulate and prepare practicing astronomers to contribute to their history. As I was preparing this essay, Spencer provided this cogent statement:

> *"History, alone among fields of scholarship, is both an art and a science. It is an art, because it necessarily involves a personal viewpoint and writing skills as good as a journeyman novelist's. It is a science, indeed an observational science like astronomy, because it aims rigorously to represent factual reality.*
> *Why writing skills? Admittedly, there are plenty of historical articles that are as turgid and jargon-laden as anything in ApJ. If you want to set down a bunch of facts in some kind of order, it will be useful raw data for future historians. But if you want to be actually read and understood by more than a handful of people, you'll have to write well. You'll have to be clear, which is hard, and well-organized, which is harder, and lively, which is hardest of all. You should dig out and review your old Strunk & White (you have read it, haven't you?). More, youll need to look carefully at the writings of authors you admire – historians, novelists, anyone – to see how they do it, from the overall structure of the work to the mechanics of commas. And if you have not yet put in the ten thousand hours of writing that's necessary to become fluent, you will need to draft, rewrite, submit to others for criticism, and rewrite again. Above all, remember the words of historian Marc Bloch: "The good historian resembles the legendary ogre. Where he smells human flesh, there he finds his prey." Tell interesting stories about people, and you will be a good historian.*

[13] `http://www.aip.org/history/oral_history/questions.html`

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But the stories must be true; that's where the science comes in. Of course you have your memory. But let us be guided by Nietzsche: "Memory says, 'I did that.' Pride replies, 'I could not have done that.' In the end-memory yields." Many studies have corroborated how poorly memory captures the past. The good historian therefore always checks a memory against a document from the time in question, such as a letter, a proposal, or a published scientific paper. Lacking these, it is well to check against other people's memories. Here is where practicing scientists can apply the skills of their own trade, skeptically inspecting every statement, and perhaps especially the ones that seem most innocent and plausible, testing them against new evidence. Imagine that your work will be peer-reviewed by all the people living or dead that you write about. You are satisfied as an astronomer when you have accurately described a celestial phenomenon; just so you will be satisfied as a historian when you have saved a true piece of the human past from the mangling jaws of time."

Spencer provides terrific advice, not only for scientists, but for historians. Another historian of science, Robert W. Smith, the author of an award-winning book on the Hubble Space Telescope (Smith 1989) – which relied heavily not only on the preserved record, but on the recollections of many dozens of participants – responded, when I inquired, that the most useful writings by astronomers for the historical record are the lengthy critical review essays for peers, such as in the *Annual Reviews of Astronomy and Astrophysics*. Understood as authoritative reviews of scientific subjects, *Annual Reviews* essays, and similar ones in many venues ranging from the *IAU Transactions* to encyclopedic entries, and the classic *Stars and Stellar Systems* volumes, all provide essential perspective on the science. But translating these efforts into a historical framework has had pitfalls, as Michael Hoskin and Owen Gingerich have advised. After an early round collecting essays from astronomers they had hoped would contribute to the IAU-endorsed General History of Astronomy they remarked "it is all too easy to find oneself writing not history, but modern science with historical references" (Hoskin & Gingerich 1980). They also wanted their authors to provide the General History something more than an uninterpretive narrative chronicle, which, they noted, could well be "grist for historical studies, [but] it is not by itself history."

Reflecting these sentiments, Robert Smith provided some general observations that bear on the issues we are addressing here:

"It seems to me that there is good history and bad history and all sorts of stuff in between. It is in principle very useful to address historical topics and themes from a range of perspectives. Who writes it does not matter. There are good histories by astronomers and bad histories by

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historians. But if someone writes history then they need to expect to be judged by appropriate historical standards."

It is just those "appropriate historical standards" that framed many of my conversations with Don and other astronomers. This leads to my last plea: directly engage what historians have written about the subjects that interest you; whether you agree or not, your additional insights are invaluable. You can either collaborate with historians, as Don did at least once or twice, or consult friendly historians of astronomy who may be only too eager to introduce you to the relevant literature. As far as gaining an awareness of the literature, there are powerful search engines available. You know of the Astrophysics Data System (ADS[14]), but there is also JSTOR[15] for the humanities. I find it great fun using either of them in their full text search modes seeking out literature that includes combinations of words like "astronomy," "funding," "competition," or "belief."

One collaboration I particularly enjoyed playing a role in was the occasion of the centenary of the American Astronomical Society (DeVorkin 1999). Historians of astronomy joined with astronomers to prepare this volume, sanctioned and supported by the Society. Don contributed chapters on the early Society, and I collaborated with Paul Routly to quantify its history. Paul, however, also provided many insights through oral history interviews as did Laurence Frederick and Arlo Landolt. They, along with Peter Boyce and some two dozen others also prepared chapters based upon personal experiences in various roles ranging from being officers of the Society to reminiscences on the changing structure of the Society by the creation of divisions, the publications of the Society, changing demographics, the role of the Society in the discipline, and commentary by recent AAS presidents.

The occasion of an anniversary is always a stimulus to historical reflection and there are many ways to do it. Helmut Abt, in particular, chose another equally helpful route, using the centennial to reprint some 53 papers from the *Astrophysical Journal* selected by a panel of astronomers nominated by the AAS Centennial Committee. The great value in this effort was that those who selected each article then wrote an extensive commentary, and many of them benefitted from direct experience. This is also very much the stuff of history (Abt 1999).

Finally, it should be obvious to readers of the volumes that have been organized by André Heck for more than a decade, such as the one now in your hands, that this forum has provided many astronomers, as well as historians and sociologists, the chance to reflect on the discipline of astronomy including its history, lore, organization, and dissemination. In

[14]`http://adsabs.harvard.edu/`
[15]`http://www.jstor.org/`

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addition, the *Publications of the Astronomical Society of the Pacific*, as well as the *Annual Reviews of Astronomy and Astrophysics*, have devoted considerable space to reflective memoirs that have provided useful insights into personal, institutional and disciplinary history. Some have been direct reflections on the nature of funding and the responsibilities of the offices that fund astronomy. Others have reflected on their duties as editors, as team leaders, as communicators, as organizers of meetings, or as scientists who are also clerics.[16]

Whatever your role has been in the discipline of astronomy, or relating to it, your reflections on your life and work are of value to history. However you choose to participate will be appreciated, especially if you choose to engage any of the questions historians of astronomy have been asking in their own contributions, as they strive for a deeper and more complete understanding of their subject and its place in culture.

9. In Summary

As valuable as Don's efforts have been to the specialty of the history of astronomy, I feel they could have been even more useful to historians had he engaged issues that historians of astronomy debate when they address episodes in the history of astronomy, or that mainstream historians utilize to make larger points about history. This does not mean that I wanted Don to be an historian; just to be sensitive to the issues they raise about his discipline. His contributions to history, as with other astronomers before him and since, have immensely enriched the literature and have provided much insight for historians who find, in the historical writings of astronomers, added insights into the state of the contemporary profession. As Robert Smith also observed:

> *"I fully agree that it would be a futile effort to try to turn working astronomers into historians. I further agree ... that it would be much more fruitful to get astronomers to think about their current activities such that later commentators on current astronomy could write accounts that would be more useful than might otherwise have been the case ... Often the astronomers think only about the science, but that is much too limiting."*

So with Robert, I encourage you to ask questions about your discipline, the community you work in, the overall nature of your practice, as you experienced it. This would include how problems are chosen, how support for the work was secured, and what compromises, if any, were made in

[16]To mention only a few: Friel (2002), McCrea (1987), Abt (1988), Steinberg (2001), Robinson (2002), Alexander (2003), and Coyne (2004).

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order to see the work to completion. Scientists who were diarists and who tended to include such information, recording most of all how they "felt" about the work of a single day or week, how they felt about their future, and the future steps they needed to take, are like angels to historians. If you want your contribution to be appreciated, give us as many hints as you can! These include, but are not limited to, the three requests made here, in summary:

1. Through formal or informal published memoirs, diaries, or autobiographical statements preserved in your personal records, share your personal insights into the beliefs you harbored and how you overcame them in the production of your science. Also share the doubts you may have had about how to proceed with a problem, and the many challenges you faced, and your colleagues faced, in striving to make contributions to astronomical knowledge.
2. Take the effort to preserve a core file of records, including your correspondence, minutes of meetings, formal directives, job applications, research proposals (funded and unfunded), proposals for observing time, manuscript drafts, editorial correspondence, and reprints. Recently astronomers have expressed concern for the preservation of the records of projects they have been involved in. Some have even gone to the trouble of having volumes of records scanned for preservation. A few have even budgeted for it! These are exemplars to follow, but be sure to make the files fully readable in a format that stands a chance to be readable in the future!
3. Provide commentary on why you are choosing these particular records to preserve, and not others. Seek out the advice and counsel of archivists at your institution, or historians of science, in what to preserve and how to preserve it. Most of all, be proactive to preserve your papers and provide commentary on those parts of your life these records cover.

Acknowledgments

I would like to thank, but not implicate, those I pestered to read earlier versions of this essay. They all provided wonderfully helpful personal insights, and shared their knowledge of the relevant literature helping to improve the utility of the effort. In alphabetical order, they are: Barbara Becker, Steve Dick, Owen Gingerich, Patrick McCray, Teasel Muir-Harmony, Marc Rothenberg, Robert Smith and Spencer Weart.

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 441-460
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BIOGRAPHIES AND PORTRAITS OF BRITISH AND OTHER ASTRONOMERS

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Abstract. This paper originated as a document intended to serve as a general guide to the sources of biographies and portraits of astronomers for historians of astronomy and other researchers, particularly British astronomers. It was first compiled by the Librarian of the Royal Astronomical Society, Peter Hingley (1921-2012).

1. Introduction

You have written a paper or a book that includes some history of astronomy, which, the referee says, could be improved with additional background information about some of the actors in the drama which you recount. Also, the editor has asked for some illustrations. So you are looking for biographies and portraits of astronomers, including some rather obscure British figures. You stumble from the bright streets of London, from the bustle of Piccadilly, into the quiet gloom of the Library of the Royal Astronomical Society (RAS)[1] in Burlington House, and stand inside the door, gazing about at the books, blinking like an owl; the Librarian is nowhere to be seen. In another scenario leading to the same problem, you are working at your desk a long way from any well-stocked library of historical books about astronomy, but fortunately with a computer and an internet connection at your elbow. What next?

[1] http://www.ras.org.uk/library

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2. Biographical Sources

The chance of a successful search for useful material is improved if as much information as possible is assembled in advance; for example, the full name (correctly spelt!), nationality, approximate dates of birth and death, places of work, specialisms, society memberships, awards, and so on. Initial draft material, suitable for checking in the following editorially-certified sources, might be gathered from the World Wide Web through Google and Wikipedia (*caveat lector*). The sources below are arranged roughly in order of the prospect of finding useful information, tempered by accessibility. Some of the out-of-print versions of the books mentioned below are available on-line via Google Books[2] and second-hand copies can sometimes be bought from the usual sources; you can try to locate individual copies via Abebooks[3].

2.1. IF THE SUBJECT IS ALIVE, OR DIED RECENTLY

Information on living astronomers, or those who have very recently died, can be the most difficult of all to obtain, as obituaries have not yet been published. Google is the first port of call, to locate news sources or death notices. Obvious current biographical sources for prominent British astronomers include *Who's Who* (available electronically)[4], and the *Year Book of the Royal Society* (published annually, biographical information on every living FRS)[5]. Books by the subject may have biographical information on their covers or inside pages. The RAS does not give out addresses of its 4,000 living Fellows, although their contact details are available to other Fellows who can log in to a restricted access area of the RAS website[6], and any Fellow can be written to by anyone c/o the Society. *Astronomy & Geophysics*, and its predecessor, the *Quarterly Journal*, report citations made on presentation of RAS awards, which may include biographical details, and *The Observatory* reports on meetings to commemorate distinguished Fellows. Awards with a wider appeal, such as appointments of Astronomers Royal, are often reported in journals such as *Nature* and *Astronomy Now*.

A list of 11,000 IAU members and their affiliations is publicly accessible on the International Astronomical Union's website[7]. US astronomers may be listed in *Who's Who in America*[8] and *American Men and Women of*

[2] http://books.google.com/?hl=EN
[3] http://www.abebooks.co.uk/
[4] http://www.ukwhoswho.com/
[5] http://royalsocietypublishing.org/site/othertitles/yearbook.xhtml
[6] http://www.ras.org.uk/
[7] http://www.iau.org/administration/membership/individual/
[8] http://www.marquiswhoswho.com/

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Science[9]. Some US astronomers omitted from the latter are included in the *American National Biography*[10] (the on-line version updated semi-annually; successor to *The Dictionary of American Biography*).

Information on living astronomers world-wide can also be gleaned by using the NASA Astrophysics Data System (ADS) website[11] to find their recent papers, and perhaps affiliation. ADS queries also point to the database *StarHeads*[12] of personal web pages of professional astronomers (Heck 1995).

2.2. IF THE SUBJECT IS DECEASED

If the subject is a deceased British astronomer, try *Who Was Who*[13] (biographies back to 1897). Or consult the *Dictionary of Scientific Biography*[14], published between 1970-1980, supplemented by the *New Dictionary of Scientific Biography* and an electronic version called the *Complete Dictionary of Scientific Biography*[15] (2007) that merges both publications. This work includes short biographies of many past scientists and excellent bibliographies which can be used to find the significant literature on the subject up to the date of publication. For recent British and other European scientists try *Who's Who in Science in Europe*, last published in 1995 just before the publisher went into liquidation.

Many Australian figures feature in *Australian Astronomers* by Bhathal (1996) and *Explorers of the Southern Sky: A History of Australian Astronomy* by Haynes *et al.* (1996). Canadians figure in *Cold Light of Dawn: A History of Canadian Astronomy* by Jarrell (1988).

Pasachoff (2011) references the obituaries of members of the American Astronomical Society in OPSA I. NASA's *Astrophysics Data System (ADS)*[16] has a text-search facility operating with Optical Character Recognition software that has been well tuned to be slightly fuzzy and inclusive. It can be used to search for the name of the subject, to find obituaries and other mentions of the subject in the astronomical literature, often with the text available immediately on-line.

The following also contain information on scientists of earlier years: *American Men and Women of Science*; *American National Biography*; *Biographical Dictionary* by Abbott (1984), especially *Vol. 1, Astronomers*; and *World Who's Who in Science* by Debus (1968). For Russians, or citizens

[9] http://en.wikipedia.org/wiki/American_Men_and_Women_of_Science
[10] http://www.anb.org/
[11] http://adsabs.harvard.edu/abstract_service.html
[12] http://astro.u-strasbg.fr/~heck/sfheads.htm
[13] http://www.oup.com/whoswho/about/whowaswho/
[14] http://en.wikipedia.org/wiki/Dictionary_of_Scientific_Biography
[15] http://www.gale.cengage.com/ndsb/about.htm
[16] http://labs.adsabs.harvard.edu/fulltext/

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of countries in the former USSR, try *Soviet Men of Science* by Turkevich (1963). For Lithuanians, consult *Astronomers: Bibliographical Index* by Matulaityte (1965).

The *Encyclopedia of Astronomy and Astrophysics*, edited by Murdin (2001), has a number of short biographies of astronomers[17].

2.3. GENERAL COLLECTIONS OF BIOGRAPHIES

The single most useful reference for biographies of about 1,000 astronomers born before about 1918 is the massive *Biographical Encyclopedia of Astronomers* edited by Hockey (2007). It exists in printed form and on-line, and a supplemented second edition is in preparation (in 2012).

The website *Astronomiae Historia/History of Astronomy*[18] provides information for historians of astronomy and related fields. It includes short biographies of 2,000 astronomers and a very comprehensive selection of links to biographical websites, organised into categories, including 9,000 obituaries. It was originally created for the Astronomische Gesellschaft. Since 1998 it has also been maintained on behalf of Commission 41 (History of Astronomy) of the International Astronomical Union.

The website *Astro Info Service*[19] was formed in 1982 by Dave Shayler, co-founder and chairman of the Midlands Spaceflight Society, to distribute information on human space exploration, including that from the former USSR, using official documentation from major space agencies. Their services include biographical profiles of astronauts and cosmonauts.

The *MacTutor History of Mathematics Archive*[20], of the University of St Andrews, is a collection of over 1,000 biographies of mathematicians, including many astronomers, and historical articles of a mathematical nature. Features include birthplace maps, the facility to check mathematicians who were born or died on a given date, and the Davis Archive of women who graduated in mathematics from British and Irish universities prior to 1940. Portraits of many individuals are available.

The RAS library has a collection of biographical books and pamphlets, the majority of them about British astronomers. Look in the subject catalogue (a unique document available only to personal visitors), where such material is listed in alphabetical order of subject. Biographies of scientists in fields other than astronomy have also been put there for convenience in a single sequence. It might also be worth browsing through the QB 35 subject category, which lists collected biographical works.

[17] http://eaa.crcpress.com/
[18] http://www.astro.uni-bonn.de/∼pbrosche/astoria.html
[19] http://www.astroinfoservice.co.uk/
[20] ttp://www-history.mcs.st-and.ac.uk/

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It may be worth consulting the index to *The Times* (of London) for any valedictory notes on British astronomers. It exists in printed form and the paper itself is available on microfilm. The Times digital archive, available at major libraries, spans 1785-2006 and the text can be searched digitally[21] through not-always-reliable Optical Character Recognition software. Most large libraries have the *Encyclopaedia Britannica* 11^{th} Ed. (1911), the best edition for pre-1910 history and biography, British and foreign; the last print edition was published in 2012, but the on-line edition continues[22].

2.4. RAS MEMBERS

Did the subject live beyond 1820 (when the RAS was founded)? Then if they were a member of the RAS (normally a Fellow, but possibly an Associate, *i.e.* a distinguished, foreign honorary fellow), they may have been recorded in the RAS journals by an obituary on their death.

An *Index to Obituary Notices of RAS Fellows and Associates*[23], with links to the original papers, is available online. Mostly the obituaries appeared in the Society's own publications (*Quarterly Journal*, *Monthly Notices*, *Memoirs*, etc.) but links are also given to obituaries in other sources that are available online. In 1997 a new journal, *Astronomy & Geophysics*, replaced the RAS's *Quarterly Journal*. However, its obituaries are not as yet included in the *Index*.

For the majority of RAS Fellows (the exceptions being a few of the early ones) the Library should have the form or proposal for election, giving the address, titles, and sponsors. (Note that this information will normally only be given for Fellows who have been dead for at least 40 years.) As a double check against omissions, it may be worth consulting the lists of new members given in early volumes of *Monthly Notices* and *Memoirs*.

If an obituary exists, it normally indicates that the member was held in a certain esteem by the Society although, as in most journals, the number of published obituaries has declined over the years (see Lankford 1984[24] , "A Crisis in Documentation", for a description of this process). Obituaries generally give a good amount of personal and professional information, and may also give clues to other sources such as memberships of other societies.

The RAS Library's *Online Catalogue*[25] should be checked for books and pamphlets by and about the subject, and the *Catalogue of Archives and Manuscripts*[26] for any papers and correspondence held by the Library. A

[21] http://gale.cengage.co.uk/times.aspx/
[22] http://www.britannica.com/
[23] http://www.ras.org.uk/library/obituaries/1277-ras-obituaries-01
[24] http://adsabs.harvard.edu/abs/1984BAAS...16..560L
[25] http://ras.heritage4.com/
[26] http://www.ras.org.uk/library/biographies/77

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supplement to the published Archive catalogue can be consulted in the Library. Detailed information and anecdotal accounts of many figures in the RAS's history to 1980 can be found in the two-volume *History of the Royal Astronomical Society* by Dreyer & Turner (1923) and Tayler (1987).

Another journal, associated with the Society but not published by it, is *The Observatory*. In its earlier years this included many biographical snippets, along with a few portraits and group photographs, and there are cumulative indexes up to Vol. 90 (1970). Links to obituaries published in *The Observatory* are included in the online RAS *Index to Obituary Notices*.

2.5. OBITUARIES IN OTHER SOURCES

If it is likely that the person was a Fellow of the Royal Society (FRS), the RS has produced an invaluable *List of Fellows*[27] from 1660 to date. The RS maintains the *Sackler Archive Resource*, a database[28] offering links and other access to biographical and bibliographical information on all Fellows. Obituaries were published from 1830 in the *Proceedings of the Royal Society* (1800-1932), the *Obituary Notices of Fellows of the Royal Society* (1932-1955), and the *Biographical Memoirs of Fellows of the Royal Society* (1955 to date; available on line[29]).

A *Finding List of Obituary Notes of Astronomers (1900-1997)*, compiled by Hilmar W. Duerbeck and Beatrix Ott, with contributions by Wolfgang R. Dick, is on the Web[30].

Obituaries are also to be found in a number of other journals specialised by subject or nationality:

- The *Journal of the British Astronomical Association* contains obituaries of the BAA's members who died after 1890, particularly of amateur astronomers. There are published indices to Vols. 1-50 (1890-1940) and Vols. 51-100 (1940-1990). A.J. Kinder, Honorary Librarian of the British Astronomical Association, has compiled a list of all BAA members from 1890; he may be able to answer postal enquiries on particular names[31].
- The *Astrophysical Journal* formerly included obituaries of internationally famous figures and those associated with the journal.
- *L'Astronomie* (formerly *Bulletin de la Société Astronomique de France*) has many obituaries since 1888, mainly of French astronomers, but some US/international ones also (in French); annual indices only.

[27] `http://royalsociety.org/uploadedFiles/Royal_Society_Content/about-us/fellowship/Fellows1660-2007.pdf`
[28] `http://royalsociety.org/library/collections/biographical-records/`
[29] `http://rsbm.royalsocietypublishing.org/content/by/year`
[30] `http://www.astro.uni-bonn.de/~pbrosche/persons/obit/index.html`
[31] A.J. Kinder, c/o BAA, Burlington House, Piccadilly, London W1J 0DU.

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– The *Journal of the Association of Lunar & Planetary Observers* has some short notices; some years indexed, but not all.
– The *Publications of the Astronomical Society of the Pacific* regularly included obituaries up to Vol. 82 (1970; less regularly thereafter), with an emphasis on West Coast Americans, but also many British and European figures. Indexes exist for each 25 volumes then 76-82.

The above journals are indexed on the on-line bibliographical data base for astronomical references, ARIBIB[32], as well as NASA's ADS[11] , with scanned versions of most articles.

2.6. MISCELLANEOUS BIOGRAPHICAL SOURCES

The Nobel[33] and Kavli[34] laureates for physics (including astronomers) and astrophysics respectively are well documented by biographies in the archives of the two organisations. Some of the recent astrophysicists write revealing autobiographical material.

For about 60,000 biographies of British figures of any period try the new *Oxford Dictionary of National Biography (ODNB)* edited by Lawrence Goldman (2012), whose 60 volumes and a supplement published in 2009 contain many revised biographies of British astronomers, up to date with subjects who died before 2004. The integrated online version is up to date to 2008[35]. This book is the successor to the *Dictionary of National Biography (DNB)* last published in 1908-1909, with a succession of supplements and spin-out editions up to 1996 (including *Missing Persons* 1993). A less well-known supplement to *DNB*, which is a fertile source of eighteenth and nineteenth century nonentities, is Boase's *Modern English Biography* (2000).

Eva Taylor's books on the *Mathematical Practitioners of Tudor and Stuart England* and the *Mathematical Practitioners of Hanoverian England to 1840* contain much information on instrument makers and others associated with astronomy but must be used with caution in the light of later research. These books have been supplanted for instrument makers, though not for other figures such as publishers, by Gloria Clifton's (1995) *Directory of British Scientific Instrument Makers* (see Crawforth's 1987 article "Makers and Dates" in the *Bulletin of the Scientific Instrument Society* for a guide to the use of this and other printed and manuscript sources on instrument makers). The Germanic equivalent of this book is Zinner's work (1967) on German and Dutch instrument makers.

[32] http://www.ari.uni-heidelberg.de/aribib/
[33] http://www.nobelprize.org/nobel_prizes/physics/laureates/
[34] http://www.kavliprize.no/
[35] http://www.oxforddnb.com/

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Two books of collected short essays contain a number of biographical notes and portraits including some obscure figures; Patrick Moore's (1984) *Armchair Astronomy* and Ashbrook's (1984) *Astronomical Scrapbook*.

Two less well-known sources of considerable use for minor British figures (especially clergymen) are Venn & Venn's *Alumni Cantabrigienses* (1922-1954), Foster's *Alumni Oxonienses* (1888-1892) and Emden's *Biographical Registers of the Universities of Oxford and Cambridge* (1963). Together these provide details on all Oxford and Cambridge graduates up to 1886 and 1900 respectively.

The Royal Commission on Historical Manuscripts' *The Manuscript Papers of British Scientists* (1982) is a useful source, as is Peter Harper's (1993) *Guide to the Manuscript Papers of British Scientists* catalogued by the Contemporary Scientific Archives Centre and the National Cataloguing Unit for the Archives of Contemporary Scientists, 1973-1993, although the originating organisation, the National Cataloguing Unit for the Archives of Contemporary Scientists, is now defunct. The Historical Manuscripts Commission has compiled a *UK National Register of Archives*[36], which includes references to papers of persons and families relating to British history, plus connected records, in a network of locations in the UK and abroad.

Astronomers associated with survey work in India up to 1843 may be found in the numerous biographical notes in Phillimore's four-volume work on the *Historical Records of the Survey of India* (1945-1958), amplified by Markham's book (1871, 1878).

There are many biographical references in *Sky & Telescope* magazine (naturally strong on American astronomers). An unpublished biographical index to *Sky & Telescope*, last revised 2005, has been compiled by Kevin Krisciunas and can be accessed on his website[37].

DeVorkin's (1982) bibliography *The History of Modern Mathematics* contains many references to biographical articles, including those where the influence of a subject's work is discussed in context. Also try Abbott's (1984) *Biographical Dictionary*, Debus's (1968) *World Who's Who in Science*, and Poggendorff's *Biographisch-Literarisches Handwörterbuch* (1863 to date).

For references to contemporary articles, obituaries and portraits in journals such as *Nature and Philosophical Magazine* up to about 1930, see Scott Barr (1973) *Index to Biographical Fragments in Unspecialized Scientific Journals*.

Records of French scientists may well be sought in the Academie des Sciences *Index Biographique*. Large quantities of biographical material are

[36] `http://www.nationalarchives.gov.uk/nra/default.asp`
[37] `http://faculty.physics.tamu.edu/krisciunas/st.html`

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available on line through the website of the Bibliothèque Nationale de France's "Bibliothèque Numérique", *Gallica*[38].

Begian astronomers figure in the *Biographie Nationale* and *Nouvelle Biographie Nationale* of the Belgian Royal Academy[39] Prominent deceased American astronomers are the subjects of extensive biographies in the *Biographical Memoirs of the US National Academy of Sciences* (1877-)[40].

2.7. BIBLIOGRAPHICAL MATERIALS USED AS BIOGRAPHICAL SOURCES

NASA's Astrophysics Data System (ADS)[11] includes free bibliographic access to astronomical and geophysical article abstracts, and direct access to many of the older papers; its coverage of older material is less comprehensive than ARIBIB[32].

ARIBIB is the Astronomisches Rechen-Institut Heidelberg Bibliographical Database for Astronomical References . It is the most comprehensive, free, Web index to bibliographies of older astronomical material. It includes articles indexed by Houzeau & Lancaster (1964) and bibliographies of older astronomical material; also articles indexed by *Bibliographie Générale de l'Astronomie*, *Astronomischer Jahresbericht* and *Astronomy and Astrophysics Abstracts*. It does not (currently) include material published after 2000.

Bibliographical sources may be consulted to find books and articles by the subject and some may also reveal obituaries if the volumes near a known date of death are scrutinized. These include:

- Up to 1925: Royal Society *Catalogue of Scientific Papers*.
- Up to 1880: Houzeau & Lancaster (1964) *Bibliographie Générale de l'Astronomie* – consult the "biographie/necrologie" sections of Vols. I & II and the name index to Vol. I, in the 1964 edition. Covers material up to 1880. Included in ARIBIB index[32].
- 1881-1898: Stroobant, P. and Belgian National Committee for Astronomy. *Bibliography of Astronomy 1881-1898*.
- 1899-1968: *Astronomischer Jahresbericht*. Biographical articles, perversely indexed under author not subject, necessary to look in biographical section. Included in ARIBIB index[32].
- 1969-2000: *Astronomy and Astrophysics Abstracts*. Similarly look in sections 005/006/007 (Biography, Personal Notes, Obituaries); again, subjects' names are not indexed. Included in ARIBIB index[32].

[38] http://gallica.bnf.fr/?lang=EN

[39] http://www.academieroyale.be/cgi?usr=c6qkm8a2q4&lg=fr&pag=658&rec=0&frm=0&par=aybabtu&id=4342&flux=2745919

[40] http://www.nasonline.org/publications/biographical-memoirs/

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The *Isis Current Bibliography* is published annually as a fifth issue of *Isis*, the journal of the history of science. It is a bibliography of recent publications in the history of science and related fields, including books, book reviews, and journal articles. The bibliographies from 1913 to 1995 have been gathered into the *Isis Cumulative Bibliography* in four series.

COPAC[41] is a meta-catalogue providing free access to the merged online catalogues of the 70 largest university research libraries in the UK and Ireland, using records supplied by the Research Libraries UK (formerly the Consortium of Research Libraries). It can produce items not included on other bibliographical websites, *e.g.*, catalogues of items bequeathed by a particular person.

2.8. NOMENCLATURE FOR LUNAR FEATURES AND OTHER CELESTIAL OBJECTS

Requests are often received at the RAS as to the identity of people whose names are attached to lunar features, or for the location of a named feature. The following items will give a start. Menzel's (1971) *Report on Lunar Nomenclature* is an authoritative reference[42]. Recent works to illuminate this complex field include Cocks & Cocks' (1995) *Who's Who in the Moon*, and Ewen Whitaker's book (1999) *Mapping and Naming the Moon*. Earlier sources include the British Astronomical Association's *Who's Who in the Moon* and Wilkins & Moore's (1958) *The Moon*. Andersson & Whitaker's (1982) *NASA Catalogue of Lunar Nomenclature* gives a detailed list of names and positions, while Rukl's (1972) *Maps of Lunar Hemispheres* provides key maps.

The IAU's Committee on Small Body Nomenclature (CSBN) replaced the Working Group for Small Body Nomenclature (WGPSN) and authorises the naming of important features on the surface of planets and satellites. Their *Gazetteer of Planetary Nomenclature* is maintained by the United States Geological Survey[43].

There are many astronomers, and others, whose achievements are recorded in the naming of a Minor Planet. Potted biographies are to be found in Lutz Schmadel's (2012) *Dictionary of Minor Planet Names* now in a sixth edition, with searchable CD-ROM and on-line versions. The JPL's Small Body Database Browser[44] briefly quotes the citations used to name minor planets, including one line biographies of large numbers of astronomers, many of them lesser-known figures in astronomy.

[41] `http://copac.ac.uk/`
[42] `http://adsabs.harvard.edu/abs/1971SSRv...12..136M/`
[43] `http://planetarynames.wr.usgs.gov/`
[44] `http://ssd.jpl.nasa.gov/sbdb.cgi`

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There are a few objects which have non-systematic 'customary' names from astronomers, such as the Gum Nebula, or Barnard's Star, and the best place to start to research these is in the various dictionaries of astronomy, such as Ian Ridpath's (2012) *Dictionary of Astronomy*, or Jacqueline Mitton's (2001, 2008) *Cambridge Dictionary of Astronomy* (the new edition is illustrated).

2.9. ARCHIVAL MATERIAL

There is not space here to list all the possible sources of manuscript material, and a research project of this kind is in any case a different matter from looking up printed references. The archives of the Royal Greenwich Observatory (held at the Cambridge University Library), of the RAS, and of the Royal Observatory Edinburgh contain much material of use to the would-be biographer. The *Catalogue of RAS Archives and Manuscripts*, compiled by J.A. Bennett and originally published in the *Memoirs* of the Royal Astronomical Society Vol. 85 (1978), is available on-line[45], as is a catalogue of the Herschel Archive[46] of papers by William, John and Caroline Herschel. A scanned version of the full Herschel Archive is available from the RAS on CD and DVD.

A useful, but not exhaustive, guide to locations is provided by the RCHMs in a list of papers of British scientists; the latter holdings are included in the Historical Manuscripts Commission's UK National Register of Archives[47] which includes references to papers of persons and families relating to British history, plus connected records, in a network of national and local record offices, university libraries and specialist repositories in the UK and abroad.

Other websites which may be of use include Archives Hub[48], maintained on behalf of the Research Libraries UK, which provides a single point of access to descriptions of archives held in UK universities and colleges, and forms one part of the UK's National Archives Network. Access to Archives (A2A)[49] is maintained at the Public Record Office, and contains catalogues of archives (largely local record offices) from all over England and includes section of web links for family historians.

[45] http://www.ras.org.uk/library/about-the-library/77?task=view
[46] http://www.ras.org.uk/library/about-the-library/78?task=view
[47] http://www.nationalarchives.gov.uk/nra/default.asp
[48] http://archiveshub.ac.uk/
[49] http://www.nationalarchives.gov.uk/a2a/

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3. Portraits

Google Images will find many on-line portraits. Though many portraits have been published, many more remain un-reproduced, and some searches may need recourse to original material. Some sources listed in Sect. 2.3 above, General Collections of Biographies, will also include portraits. For historical figures, the nature of material available will depend on when the subject lived.

Where portraits are required for reproduction the need to obtain permission to reproduce copyright images should be borne in mind. It is often necessary to pay a fee for the supply of the image and a fee for the reproduction rights; it is curious that authors often forget about this when signing contracts with publishers that require the author to pay for resources that should be part of the publication cost of a book.

It should also be borne in mind that there are some quite notable astronomical figures for whom no portrait has been traced, and it is quite likely that none ever will be. Examples include the notable solar astronomer, R.C. Carrington, and Newton's rival, Robert Hooke. Portraits may exist but it is rarely possible to identify the subject of a portrait if there is no label or provenance.

The obvious source for portraits of living or recently-deceased astronomers is the department, society or other institution to which they are, or were, affiliated.

3.1. PUBLISHED SOURCES

Lucinda Douglas-Menzies (2009) has published a book of 38 formal black and white portrait photographs of British astronomers, available through the Emilio Segre Visual Archives[50]. Max Alexander's colour photographs[51] put about 50 British astronomers into attractive association with their science. Portraits of the Astronomers Royal are available at the National Maritime Museum[52]. A good, free and varied collection of about 100 pictures of astronomers (some duplicates) is available from the archival collections of the Institute of Astronomy, Cambridge[53]. It spans all nationalities and a range of historical epochs from Aratus and Copernicus to the modern day but is strongest on British astronomers, Cambridge astronomers in particular.

[50] http://photos.aip.org/
[51] http://www.maxalexander.com/astronomy/astroNP1.html
[52] http://www.rmg.co.uk/explore/astronomy-and-time/astronomy-facts/history/portraits-of-the-astronomers-royal
[53] http://www.ast.cam.ac.uk/library/pictures/astronomers

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The Dibner Library of the History of Science and Technology at the Smithsonian Institution has publication-quality pictures of scientists at a high resolution: the scientists are classified by scientific discipline and include 200 astronomers[54] and a dozen astrologers[55] (some duplicates). The images may be freely downloaded for personal, research and study purposes, but there are reproduction fees.

Photographs of the Nobel[33] and Kavli[34] laureates for physics (including astronomers) and astrophysics respectively appear in the archives of the two organisations, often studio portraits, sometimes stiff pictures taken at the prize ceremonies.

There are many books and journal articles illustrated by portraits. Some books including numerous portrait illustrations are those by Hockey (2007), by Berendzen, Hart and Seeley (1976) (this book includes many modern astrophysicists), by Hoskin (1996) and by Learner (1981). The Astronomische Gesellschaft's collection of many small medallion portraits of astrophysicists (1904-1931) is worldwide in scope but strong on European figures.

The *MacTutor History of Mathematics Archive*[56] of the University of St Andrews shows many portraits of individuals, thought to be free of copyright, which can be downloaded as relatively low resolution images or posters. Jeff Miller's web pages include images of mathematicians on postage stamps[57]; Joachim Reinhardt's web pages exhibit stamps displaying physicists[58]; both collections show a number of astronomers. The database *StarHeads* of personal web pages of professional astronomers[12] is another sources of photographs for registered living and recently deceased astronomers.

Patrick Moore's *The Astronomy Encyclopedia* includes a number of portraits. Portrait photographs of BAA Presidents are often published in the *Journal of the British Astronomical Association* about the time of their presidency, as well as some other notable figures. In the case of astronomers noted for work in specific fields, it is well worth looking in books on that field, other than overtly historical ones, as they will often include an historical summary (for example, Cunningham's 1988 book on asteroids). Quite a few International Astronomical Union Symposia include such summaries.

For British sitters there is a 4-volume reference work, Ormond & Rogers' (1979-1981) *Dictionary of British Portraiture*, giving locations of many images. To this may be added Yung's (1981) *Catalogue* of National Portrait

[54] http://www.sil.si.edu/digitalcollections/hst/scientific-identity/CF/by_discipline_display_results.cfm?Research_Discipline_1=Astronomy

[55] http://www.sil.si.edu/digitalcollections/hst/scientific-identity/CF/by/by_discipline_display_results.cfm?Research_Discipline_1=Astrology

[56] http://www-history.mcs.st-and.ac.uk/history/BiogIndex.html

[57] http://jeff560.tripod.com/stamps.html

[58] http://th.physik.uni-frankfurt.de/~jr/physstamps.html

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Gallery holdings (1981), Franklin's 1995 supplement to this, and the older work by O'Donoghue on the British Museum's holdings of portrait engravings.

The RAS has a collection of portraits, predominantly photographs but including some engravings and paintings; most date from between 1850 and 1940, but there is some older and newer material. Most of the Society's collection of portraits is available instantly for reproduction on line through the Science Photo Library[59], which offers in total 1,500 portraits of astronomers for reproduction. A portrait is held of every President the Society has had. In the Library itself a card index exists of most of the collection, which is being progressively included in the supplement to the Archives catalogue. A Microsoft Word version of Bennett's (1978) *Catalogue of the RAS Archives* is available in the Library, together with a large draft addendum in which archives or portraits of individuals may be sought; the catalogue is online[60]. Original photographic portraits in the hands of the British Astronomical Association are included in the RAS card index, and may be viewed by permission of the Officers of the Association.

For scientists of sufficient eminence to be commemorated in Westminster Abbey, Hall's (1966) *The Abbey Scientists* indicates memorials, busts etc.

Some published lists will be a guide to sitters distinguished by nationality or Society. Portraits of Fellows of the Royal Society are catalogued in books by Robinson (1980) and Hammill (1976), and the older *Catalogue of Pictures and Medals* held by the Royal Society of 1912. Scots may well feature in Guthrie's (1950/1960) *List of Portraits in the Royal Society of Edinburgh*, while for Oxford figures there is Lane Poole's (1912-1926) *Catalogue of Portraits in the possession of the University, Colleges, City and County.*

NASA websites can be used to locate portraits of astronauts, and cosmonauts involved in US space missions. Images may be downloaded, often in multiple formats, including high-resolution versions suitable for printing. Publication-standard copies of NASA images may also be obtained by media representatives or NASA research partners by contacting the Public Affairs Office of the responsible NASA Center – a good one for portraits is the Johnson Space Center (JSC); they may also be purchased from certain commercial sources – those in the UK include the Science Photo Library[59] and the Hulton|Archive[61]. 'Off-the-peg' NASA images and products are available from local science centres and planetaria.

NASA's Multimedia Gallery[62] is the portal for the Agency's photo,

[59] http://www.sciencephoto.com/
[60] http://www.ras.org.uk/library/about-the-library/77?task=view
[61] http://www.gettyimages.com/creative/frontdoor/hultonarchive
[62] http://www.nasa.gov/multimedia/

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video, audio and arts galleries, including the NASA Image eXchange. It is not a unified searchable data base.

3.2. PRIVATE SOURCES

There are several commercial picture agencies that supply relevant portrait material. Of course, they charge for access and for supply of material. Portraits of historical figures may be found in the *Mary Evans Picture Library*[63]. Similar sources potentially useful for more recent astronomers, astronauts, and cosmonauts include the Science Photo Library[59] and the Hulton|Archive[61] Their stock includes portraits of astronauts and of cosmonauts from the period of collaboration between Russia and the USA. Pictures of cosmonauts from the USSR period can be ordered from the Russian Information Agency-Novosti (RIA-Novosti)[64], whose London office retains an archive of photographs from the Soviet/Russian space programme. Finally, the British Interplanetary Society[65] is a potential source of space material, but is normally only open to its own members.

3.3. ARCHIVAL SOURCES

Many archival sources are privately run, and it is normal courtesy to make preliminary contact by letter (enclosing s.a.e.) or telephone to ascertain whether it is possible to visit. Information is sometimes available on the relevant website.

The National Portrait Gallery is the national repository of portraiture and has many portraits of British scientists. They can also supply references to portrait holdings in other repositories. Portraits in the Gallery's Primary Collection are held in the Picture Library[66]; the Heinz Archive and Library[67] should be contacted for more complex enquiries.

The *Image Library*[68] of the Museum of the History of Science holds a large collection of photographs, including portraits of scientists and instrument makers.

The Royal Greenwich Observatory archives[69] are now held by Cambridge University Library. These have a number of portraits including all the Astronomers Royal and some other figures connected with Greenwich Observatory.

[63] http://www.maryevans.com/
[64] http://visualrian.ru/en/
[65] http://www.bis-space.com/
[66] http://www.npg.org.uk/collections.php
[67] http://www.npg.org.uk/research/archive.php
[68] ttp://www.mhs.ox.ac.uk/images/
[69] http://www.lib.cam.ac.uk/deptserv/manuscripts/rgo.html

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The Royal Society[70] has numerous portraits, mainly of former Fellows (see Sect. 3.1).

The *Science & Society Picture Library*[71] has since 1998 represented the collections of the National Museum of Science and Industry, comprising the Science Museum, the National Museum of Photography, Film & Television, and the National Railway Museum. It holds numerous portraits (not restricted to British subjects).

A project to compile an international index of holdings of portraits of astronomers was begun at the Archenhold Observatory, prior to the rise of the WWW. The project is now indefinitely suspended, but a useful interim version of the catalogue was published by K. Friedrich (1984).

The archives of the Observatoire de Paris have portraits of about 50 astronomers available, mainly historical French astronomers associated with the Observatory[72].

The American Institute of Physics[73] includes the Center for History of Physics containing the *Emilio Segre Visual Archives*[50], focusing on portraits of 20^{th} century American physicists and astronomers, but including many scientists in Europe and elsewhere, and in earlier times. Some of the most attractive pictures are not the formal portraits but pictures of the scientists at work.

The Caltech Archives contain the *Caltech Archives PhotoNet*[74], an online database containing thousands of images, including portraits.

The NASA Johnson Space Center (JSC) Imagery Service contains the NASA *JSC Digital Image Collection*[75], the most comprehensive NASA collection for portraits, which spans the whole manned space programme and includes portraits of cosmonauts for missions on which the USA and Russia collaborated.

An excellent source for portraits, especially 20th century and American figures, is the *Mary Lea Shane Archives*[76] of the Lick Observatory A browseable index to this collection is available on their website[77], and a dated paper copy is available at the RAS Library (Lick Observatory 1980).

San Diego State University's Malcolm A. Love Library[78] holds the *Ernst*

[70] http://royalsociety.org/
[71] http://www.scienceandsociety.co.uk/
[72] http://alidade.obspm.fr/sdx/alidade/toc.xsp?id=FROBSPM-ALIDADE-PEIN00001_c-archdesc&fmt=alidade-peintures&idtoc=FROBSPM-ALIDADE-PEIN00001-pleadetoc&ss=true&as=true&ai=|peintures|
[73] http://www.aip.org/
[74] http://archives.caltech.edu/collections/photos-images.html
[75] http://images.jsc.nasa.gov/
[76] http://library.ucsc.edu/speccoll/lick-observatory-archives
[77] http://digitalcollections.ucsc.edu/cdm/landingpage/collection/p265101coll10
[78] http://library.sdsu.edu/

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Zinner Collection of books, pictures and portraits, mainly of astronomers, though many are secondary copies. There is a printed catalogue by G. Johns (1975). High-resolution digital scans of the portraits are available for a small fee through contact with the Special Collections Archive at the Library.

List of Abbreviations

A2A	Access to Archives
ARIBIB	Astronomisches Rechen-Institut Bibliographical Database for Astronomical References
BAA	British Astronomical Association
CSBN	Committee on Small Body Nomenclature of the IAU
CURL	Consortium of University Research Libraries (now Research Libraries UK)
DNB	Dictionary of National Biography
IAU	International Astronomical Union
ADS	NASA's Astrophysics Data System
RAS	Royal Astronomical Society
RCHMs	Royal Commission on Historical Manuscripts

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Organizations, People and Strategies in Astronomy 2 (OPSA 2), 461-474
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ASTRONOMY AND PHILATELY

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Abstract. Both astronomy and philately are multi-faceted disciplines and their interaction makes a fascinating study. In attempting to demonstrate the breadth and complexity of philately, the author describes her own collection which has been in process of formation for some seventy years. Over this time, awareness of the rich variety of collectables has grown and these will be gradually introduced throughout the paper. As with other forms of human activity, the hobby is subject to fashion and some of the resultant developments are described.

1. Introduction

With a large collection formed over such a long period, some organisation has been essential. As a rough-sort, three main subdivisions have been adopted – although there is a certain amount of overspill between them. The three sections consist of: the sky objects and phenomena which have been there to be noticed by mankind from earliest times right up to the present; the lives and work of astronomers, both unnamed and famous; the tools of astronomy from a simple pole stuck in the ground to the giant arrays of modern radio telescopes. It is a breathtaking span but is dealt with under the simple titles of **The Observables**, **The Observers** and **The Observations**. Because philately consists of much more than just stamps, other related items will be introduced and described. As this happens, the appropriate terminology will appear in *italics*. All illustrations are of items in the personal collection of the author. Stamp designs of 70 years and over are considered to be in the public domain. In the case of more recent designs, permission to reproduce in this paper has been applied for and granted.

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2. The Observables

The world's first *postage stamp* was the famous Penny Black issued by Great Britain on 1840 May 06 (Easton 1946). The design consisted of a finely engraved head of Queen Victoria against a background created by engine-turning so as to make forgery nigh impossible. The lower corners of each stamp were occupied by a letter of the alphabet uniquely indicating the position of individual stamps on the sheet. The upper corners were filled with what were popularly known as "stars". In actual fact, this "star" is based on the "croix pattée" element of the King George IV state diadem which the Queen is wearing. Later, the design of the penny stamps had letters in all four corners. However, the earlier "Penny Stars" may, just possibly, count as a candidate for the first astronomical design – even although a sobriquet.

The first true astronomical object to appear as a stamp design was Crux Australis on stamps of Brazil and, in stylised form, on stamps from New South Wales, Victoria and similar southern hemisphere territories.



Figure 1. Left to right: Penny Black with "stars" in the upper corners, Brazil 1887, New South Wales 1897 and Victoria from 1890.

Other early issues featuring astronomical objects would include the first stamps of Uruguay in a design known as the "Montevideo Sun". Also, turning the stamps over to look at the paper on which they were printed, astronomical *watermarks* may be found. Suns and stars were popular devices and a particularly attractive watermark on the 1866 issues of Egypt had an appropriate design of a pyramid and star (see Fig. 2).

Apart from such rather limited, stylised or armorial representations of sun, stars and constellations, many years had to pass before anything more exciting came along. In 1929 Uruguay introduced a long set of air mail stamps depicting a winged horse set against a background of the constellation Pegasus as viewed from the southern hemisphere.

A daring transatlantic mass formation flight from Rome to Rio was planned to take place in 1930. Devised by the Air Minister, General Italo Balbo, a squadron of twelve Savoia-Marchetti S55 seaplanes took off on Dec 17 (Dehn 1981). Prior to the flight, Balbo had ordered his volunteer pilots to

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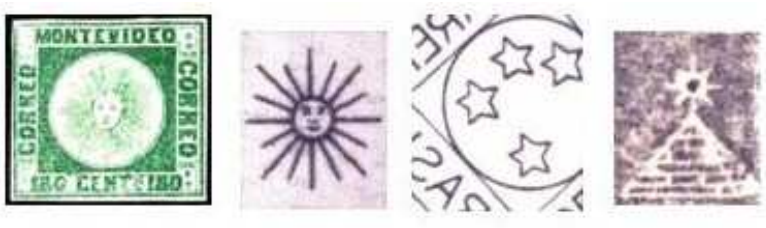


Figure 2. The Montevideo "Sun" of 1858, Sun watermark of Argentina 1892, Crux Australis on a watermark of Brazil and the Pyramid and Star watermark on Egyptian stamps of 1866.

attend the Planetarium Romanum where they were to become familiarised with the southern constellations as an aid to navigation (Chant 1935). A commemorative stamp was issued in time to be used on envelopes carried on the flight but not generally available to the public until June 1931. This stamp depicted Crux Australis with six stars and some of the aircraft. A well known constant *variety* occurs on stamp no. 22 of each sheet of 50 stamps; an extra "star" appears to the left of the constellation.

Three years later another mass formation flight took place – this time from Rome to Chicago. For this flight, the Italian colony of Cyrenaica issued a pair of beautiful stamps showing Ursa Minor and the asterism of The Plough or Big Dipper in Ursa Major along with a representation of the squadron. The ITL 44.75 value is shown below.



Figure 3. Left to right: The Italian stamp issued for the 1930 Rome to Rio flight; enlargement showing the variety "Extra Star"; ITL 44.75 value of the pair issued for the Rome to Chicago flight. The ITL 19.75 value is in the same design but coloured deep blue and green.

Still considering just the designs of stamps, a striking set of six square stamps was issued by Mexico in 1942 on the occasion of the inauguration of the Tonanzintla Astrophysical Observatory. These are favourites with collectors and many people were familiar with such images as a total solar eclipse, the Whirlpool Nebula M51, and the Horsehead Nebula in Orion. However, there was one surprise as the top value illustrated the

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Hertzsprung-Russell diagram and this design needed a bit of explanation in the philatelic press of the day!

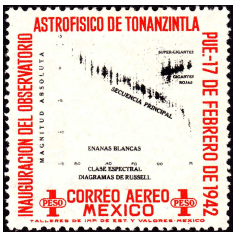


Figure 4. The H-R diagram as a stamp design.

A 1969 stamp design from New Zealand commemorated the bicentenary of the voyage of Captain Cook in HM Bark "Endeavour" to observe the Transit of Venus. The design included the Wedgwood medallion with Flaxman portrait of Cook, an octant and a red disc representing the Sun with a small black dot representing Venus. In modern high-speed printing methods there can sometimes occur a small glitch which results in a shift of one of the colours. In this case, there was a 1.5mm shift of the black colour so that the little dot really appears to "move" across the Sun. This is an example of a non-constant variety, but interesting as it can be used in the collection to demonstrate an astronomical phenomenon. These stamps were printed in sheets of 100 and it is not known how many sheets could have been affected[1].



Figure 5. 1969 stamp. Left: normal printing. Right: 1.5mm shift of black colour, so that "Venus" appears to "transit". Permission to illustrate this design kindly granted by New Zealand Post.

Another philatelic area to explore is that of *postmarks* and various types of *cancellations* with astronomical significance. China, for example, at one time used postal markings known to collectors as "Sun and Moon cancellations". Mail carried prior to the advent of postage stamps often had

[1]Personal correspondence (via e-mail) with Warwick Paterson of Campbell Paterson, publishers of the New Zealand stamp catalogue.

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markings to indicate a route and an example is shown of the Compañia del Sol which operated c. 1845-1849. Some cancellations were intended simply to obliterate the stamp (there was a real preoccupation with fraudulent cleaning and reuse of stamps). Later on, postmarks would indicate the town of posting along with the date and often the time of posting. A very attractive example of this kind of cancellation comes from Rhodesia and clearly shows "Arcturus P.O." This town grew up around the Arcturus Gold Mine. It opened as a postal agency in Feb 1910 and the postmark remained in use until 1937.



Figure 6. Left to right: Type 3 handstamp indicating that this letter has been carried by the Compañia del Sol, obliterator from Stellartown (Canada), the "Paris Star", Postmark of Arcturus.

Commemorative envelopes or *covers* are often produced for special events and these usually have an appropriate design or wording printed towards the left side with the right side bearing the address, postage stamp and cancellation.

Many ships have been named after astronomical bodies or phenomena – for example, "Eclipse", "Comet", "Meteor" – or have been given the names of individual stars and constellations. *Manuscript endorsements* or the ships' *cachets* make interesting additions to the collection.

During the International Geophysical Year 1958-1959, a number of stamp designs were produced featuring astronomical phenomena such as the aurorae. Over succeeding years, the development of space exploration and the beautiful images captured by various space probes have provided the excuse for territories all over the world to issue a wealth of attractive stamps which almost threaten to swamp the collector.

3. The Observers

This section starts with the dawn of civilisation and the preoccupation of early man with seedtime and harvest. Mythological interpretations of astronomical events have provided some fascinating designs. In Fig. 7 is shown a Greek design for the 1906 Olympic Games issue depicting Hercules temporarily supporting the heavens while Atlas returns, having obtained the

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golden apples of the Hesperides. Also in Fig. 7 are shown designs featuring the Indian Sun-god, Surya, seated in a single-wheeled chariot of fire, drawn by a horse with seven heads; his charioteer is Aruna, the Dawn.



Figure 7. Pair of *imperforate colour proofs* of the Greek issue for the 1906 Olympic Games and images of the Indian Sun-god Surya.

The discoveries and inventions of, *e.g.*, individual Chinese, Islamic, Greek and other early astronomers are well represented in philately.

In 1923 Poland issued a stamp to commemorate the 450^{th} anniversary of the birth of Copernicus – a single dark blue stamp based on the Toruń portrait and with a high face value of 1000 Marks. This was during the *inflationary period* and some five months later the same design was reissued in red with a face value of 5000 Marks. Over succeeding months the cost of posting letters rose to such an extent that on 1924 May 1, new currency was introduced and the use of these Copernicus stamps ended. Both values have interesting printing flaws and varieties of paper – partly due to the difficult times – and a good description of these along with illustrations is to be found in the catalogue of the international philatelic exhibition held in Poznań in 1973 to mark the quincentenary of his birth (Czernik 1973).



Figure 8. Registered cover from Warsaw to London, 1924 Jan 29. Franked with stamps to a total value of 1,216,000 marks, including both values of the Copernicus stamp.

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On the occasion of the Copernicus quincentenary, almost every country in the world issued stamps, special cancellations and other sorts of souvenir. It became almost a collection on its own – and indeed started a trend. Over recent times the same thing has happened on other occasions such as the return of Comet Halley in 1986. There can be problems in trying to balance the desire for completeness with the need for selectivity.

The next "Big Three" of astronomy – Kepler, Galileo and Newton – are all well represented in the stamp album and can also be found on *Cinderella* items. These are stamp-like labels which have been produced sometimes by a charity, or to advertise a company's products, or maybe by a town associated with the personage.



Figure 9. Labels with portraits of famous astronomers.

However, the most interesting aspect of this section is perhaps the fact that *letters* can be included. Prior to the invention of the envelope, letters would be written usually on one side of a sheet of paper; the paper would then be folded over, the back secured with sealing wax and the address written on the front. This is known to philatelists and especially postal historians as an *entire* (or *entire letter*) and you have in one item the words of the writer and the postal markings acquired en route to its destination.

A portion of one charming letter in the collection is illustrated. In Fig. 10 you will see a sketch of Ursa Minor, the Pole Star indicated and nearby a comet. The letter is dated 1742 Mar 24 and addressed to George Clerk, Laird of Drumcrieff near Dumfries, Scotland (an ancestor of James Clerk Maxwell). The writer was his cousin who urges him to make a point of observing the comet and writes: *"All in my family had a fine sight of the Comet between 9 and 10 on Sunday last. ... The distance of the Comet F from the polar star A was about 6 degrees".*

Although the letter incorporates only a crude sketch, the path of this comet through the heavens is well illustrated in a beautiful map by Mattheus Seutter which is reproduced in "The Mapping of the Heavens" (Whitfield 1995).

One favourite section of the collection consists in 19^{th} century letters with sidelights on the problems of life at distant observatories. For instance,

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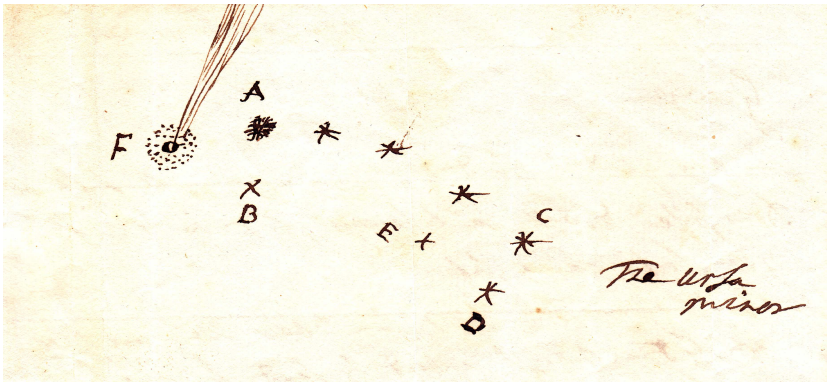


Figure 10. Sketch of the position of the 1742 comet, in a letter dated Mar 24 of that year.

in a letter dated 1846 Apr 01, Thomas Maclear, HM Astronomer at the Cape, discusses Gambart's Comet, the new planet (Neptune) and other astronomical matters and then continues: *"There is to be a Caffre War. The Governor is gone to the Frontier".* Interesting times, indeed! The large Maclear family kept in touch but the length of time taken for exchange of letters before steam replaced sail is sadly demonstrated by a letter from Mrs Maclear's brother in England bringing the news that her sister had been gravely ill for some months.

Stamps continue to be issued commemorating astronomers both past and present. Sweden has a special issue each year in honour of Nobel Prize winners and a fair number of them have been astronomers. Such stamps together with their associated special cancellations and other collectables make for an attractive pictorial display.

Not many women astronomers have appeared on stamps – only such notables as Elisabeth Hevelius, Caroline Herschel and Maria Mitchell. However, as the 21^{st} century progresses, no doubt at least a few present-day well known ladies will be honoured.

4. The Observations

In this section are considered the tools of the astronomer. Probably the very earliest of these would be a simple upright pole by which means shadows cast by the Sun could be measured. Later, more sophisticated devices would include the various sites of standing stones and stone circles. All of these early attempts at recording and understanding can be found on the designs of stamps and other philatelic material. Later on, we find the Antikythera mechanism and the Nebra Disk have also featured on stamps while from

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the New World there are the Aztec Calendar Stone and Maya stele.

The beautiful astrolabe is found on a number of stamp designs as well as its more rugged version – the mariner's astrolabe, especially on issues associated with voyages of discovery. Other early navigational instruments such as the cross-staff, back-staff and nocturnal also form part of this section.

A small instrument which appears to be a miniature armillary sphere is shown in a well known portrait of Humphrey Gilbert used for the 1c value of a set issued by Newfoundland in 1933. This is an example of an engraved stamp and in Fig. 11 are seen *progressive proofs* – stages in preparing the die for use in making up a printing plate. The skilled engraver checks his work at various stages by taking a pull from a hand press as the die at this time is not yet hardened. Several progressive proofs are seen here, including one in rose as an alternative to grey-black. Finally, the issued stamp is shown.



Figure 11. Progressive stages in engraving a steel die.

All aspects of time-keeping are included with many stamps and other items depicting sandglasses, sundials and clocks. Similarly, everything relating to the Calendar is important and in this connection may be mentioned the special French Revolutionary Calendar with the names of the months related to their characteristics. From 1870 when the first *postal stationery postcards* came into use, astronomers found these a less expensive means of communication than letters. It is interesting to look for examples of exchange of data by postcard, especially in the case of cards addressed to Russia which show double dating as Russia was late in adopting the Gregorian Calendar. A similar anomaly occurred when aircraft started crossing the International Date Line and postal markings appeared to show that they had arrived before their departure.

However, perhaps the most important instrument in astronomy is the telescope. The central portion of a stamp design for the territory of St. Kitts-Nevis introduces another feature of collecting astronomy – namely, *errors of design* many of which are described in Irvine & Seshold (1979). Here in the badge of the colony we find Christopher Columbus (who died in 1506) supposedly sighting the territory with the use of a telescope (invented c. 1609). This erroneous design was perpetuated right up until 1938.

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UNESCO declared 2009 International Year of Astronomy and this was intended to commemorate the four hundred years since the application of the telescope to astronomy. In a brochure[2] for this event with introduction by the IAU President, Page 25 was headed "IYA2009 Special Task Groups". One of these was Philately. Well over one hundred territories announced their intention to issue stamps to commemorate this occasion – a daunting prospect for the collector!

Many of the IYA designs were imaginative and beautiful, however one issue from Azerbaijan is a reminder that errors of the kind referred to in the St. Kitts-Nevis example above are still being perpetrated. Here we find the name of Nesireddin Tusi with his dates of birth and death clearly printed as 1201-1274, and what is he doing? Looking through a telescope!

It was particularly nice to see that some territories issued stamps closely associated with astronomy in their own country. In the case of Malta, two stamps were issued. The EUR 0.37 value showed a portrait of Galileo, Apollo spacecraft and Moon. However the EUR 1.19 value illustrated the 1.2m (4 ft) aperture telescope on equatorial mount designed and built by William Lassell (discoverer of Triton) and taken by him to Malta in 1861. Here he spent three years observing objects not visible from England. This is the only known depiction on a stamp of this seminal telescope.



Figure 12. William Lassell's telescope on a stamp issued for International Year of Astronomy 2009. Permission to illustrate this design kindly granted by Malta Post.

The great observatories of the world and many important instruments have been shown on stamps and also on *picture postcards* which started to appear in the early 1890s. A type of pictorial card with the words "Gruss aus" or "Gruss vom" (greetings from) preceding the name of a town or area became very popular for the tourist trade (see Fig. 13). This continues and it is possible, for example, to show the complete history of Palomar Mountain Observatory starting with a postcard of the dome in skeletal stage of construction, the mirror blank, views of the observatory as the trees gradually grew and amusing cards for tourist use.

[2]Brochure announcing the International Year of Astronomy 2009 produced by the IAU, UNESCO and Organisational Associates.

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Figure 13. Picture postcard with dramatic view of Königstuhl Observatory, postally used 1898 Nov (the observatory was inaugurated in June of that year).

Incidentally, it may be mentioned that the scientists who work in such establishments perhaps do not realise that the *meter marks* or *franks* applied in the mail room could have interest for collectors of the astronomy theme!

So far, it is Earth-based facilities that have been considered but from the Montgolfier Brothers through the development of aircraft to the rocket experiments of Tsiolkovski and Goddard, man was attempting to leave the surface of the earth. All of these stages can be found well documented in the stamp album.

Prior to the Space Age, rocket experiments during the 1930s carried (and were indeed funded by) souvenir mail. Pioneers such as F. Schmiedl in Austria, Gerhard Zucker in Germany and Britain, Stephen H. Smith in India, Karl Roberti in the Netherlands and their contemporaries elsewhere, continued their trials almost until the start of World War II and it was during and after that conflict that rockets became sufficiently powerful to launch the first small earth satellites and eventually to achieve manned space flight, planetary probes sent to great distances and orbiting telescopes such as the Hubble Space Telescope (HST).

Here it may be mentioned that the author (see *e.g.* Morris 1988) coined the term "Astro-philately" to describe her method of collecting, but now Astrophilately (without the hyphen) is one of the recognised Commissions of the Fédération Internationale de Philatélie (FIP) and is regarded as quite separate from Thematic collections on Space. Astrophilately is described as consisting of covers and cards cancelled at the place and date of special events associated with Space Exploration – *e.g.* launches and landings of

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Figure 14. Rocket flight by Karl Roberti on 1935 Apr 23 with "Icarus". 260 items of mail carried.

spacecraft. Cancellations of the post office nearest to the appropriate Mission Control Centre are acceptable when dated for EVAs, dockings, etc., as are postmarks from tracking sites and recovery ships. This has opened up a whole new area of collecting and is regarded by the author as unsuited to a collection on pure astronomy; only those items with special reference to astronomy are included but even so these account for a growing sub-section.

5. Fusion

To draw together the twin strands of astronomy and philately, it is worth considering the life of one remarkable man who combined these in the highest degree. This was The Earl of Crawford, KT, 1847-1913.



Figure 15. Detail of a photograph of the Earl of Crawford by Dover Street Studios. A similar photograph hangs in the Meeting Room of the Royal Philatelic Society London.

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Born to a life of duty, he found time for various activities and was a great traveller and explorer, ornithologist and sportsman. As if those pursuits and his duties as owner of some great estates were not enough, he was keenly interested in astronomy and between 1872-92 had a well equipped private observatory at Dun Echt in Aberdeenshire where one of his assistants was David Gill. With Gill and Ralph Copeland, he travelled to Mauritius for the 1874 Transit of Venus, funding the expedition himself.

Crawford was President of the Royal Astronomical Society in 1878 and 1879 and was elected a Fellow of the Royal Society in 1878. His use of photography to record his astronomical observations was recognised when he served as President of the Royal Photographic Society from 1897 to 1900.

Later in life he returned to philately with the purchase at auction of a "fat" album containing a number of stamps (Negus 2002). He continued to add to the collection – not only material but also knowledge. An enthusiastic yachtsman, he spent most winters abroad, cruising to warm climates for relief from rheumatism and asthma. During these cruises he spent many hours studying his stamp collection and wrote that since his purchase of the "fat" album – *"I must have sailed nearly 100,000 miles about the world, and I have always taken on my travels some stamps for study and arrangement, thus providing myself with interesting and unfailing occupation".*

He joined the Philatelic Society London in June 1900 and was elected Vice-President two years later. In 1906, he called a meeting of the Council to discuss the possibility of seeking the approval of the King to add the word "Royal" to the Society's name. Crawford then wrote to HRH the Prince of Wales (at that time President of the Society) and received a reply to the effect that the organisation should be known as "the Royal Philatelic Society of London". (The "of" was dropped in more recent times).

In addition to all his other pursuits, Crawford was a well known bibliophile who had purchased some notable libraries. On his death, his philatelic library was bequeathed to the British Library where it would be accessible to collectors. In his memory, the Royal Philatelic Society London awards annually the Crawford Medal for the most valuable and original contribution to the study and knowledge of philately published in book form during the two years preceding the award.

Crawford's library of astronomical books was gifted to the Royal Observatory Edinburgh in 1888 on condition that a new Observatory distant from the city's pollution should be constructed. This new Observatory was opened by the Earl of Crawford in 1896.

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6. Conclusion

This paper provides merely an overview of the many ways in which astronomy and philately may be linked and in fact only scratches the surface of what is a totally absorbing hobby. There is the constant search for suitable items and new issues appear at frequent intervals. At the very least there is plenty of entertainment for those nights when the skies are cloud-covered! Readers are advised that, like astronomy, philately has a huge bibliography at all levels. A general introduction will be found in "Stamp Collecting: A Guide to Modern Philately" (Phillips 1983).

Acknowledgments

The author wishes to thank New Zealand Post for permission to reproduce the stamp design shown in Fig. 5 and Malta Post for permission to reproduce the stamp design shown in Fig. 12.

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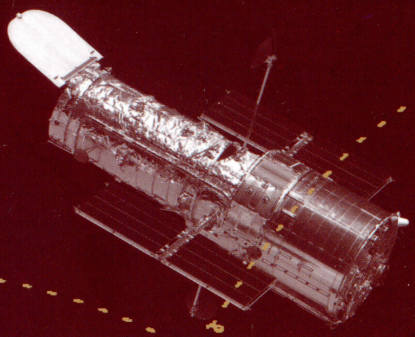
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Organizations, People and Strategies in Astronomy

Volume 2

André Heck (Editor)

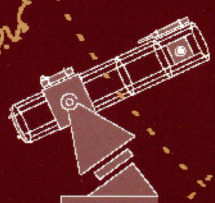
The OPSA volumes are in line with the earlier prize-winning series *Organizations and Strategies in Astronomy (OSA)*, with more emphasis on people. Rather than being devoted to the publication of hard-science results, these books describe how astronomy research lives: how it is planned, funded and organized, how it interacts with other disciplines and the rest of the world, how it communicates, etc.

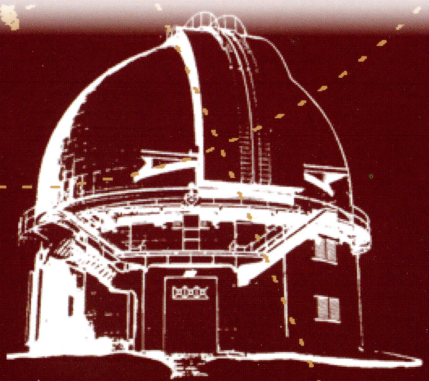
Thus the OSA/OPSA volumes have been and are a unique medium for scientists and nonscientists (sometimes from outside astronomy) to describe their experience and to elaborate, often for the first time at such a level, on non-purely scientific matters, many of them of fundamental importance for the efficient conduct of their activities. The volumes cover a large range of fields and themes: in practice, one could say that all aspects of astronomy-related life and environment are considered in the spirit of sharing specific expertise and lessons learned.

The chapters of the present volume are dealing with socio-dynamical aspects of the astronomy (and related space sciences) community: genesis and implementation of projects, knowledge production, characteristics of organizations, demography of astronomy, workforce development, evaluation and selection procedures, professional ethics, science literacy, organization of meetings, career policies, contemporary history, art and astronomy, and so on.

The experts contributing to this volume have done their best to write in a way understandable to readers not necessarily hyperspecialized in astronomy while providing specific detailed information and sometimes enlightening 'lessons learned' sections.

This volume will be most usefully read by researchers, teachers, editors, publishers, librarians, sociologists of science, research planners and strategists, project managers, public-relations officers, plus those in charge of astronomy-related organizations, as well as by students aiming at a career in astronomy or related space science.





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