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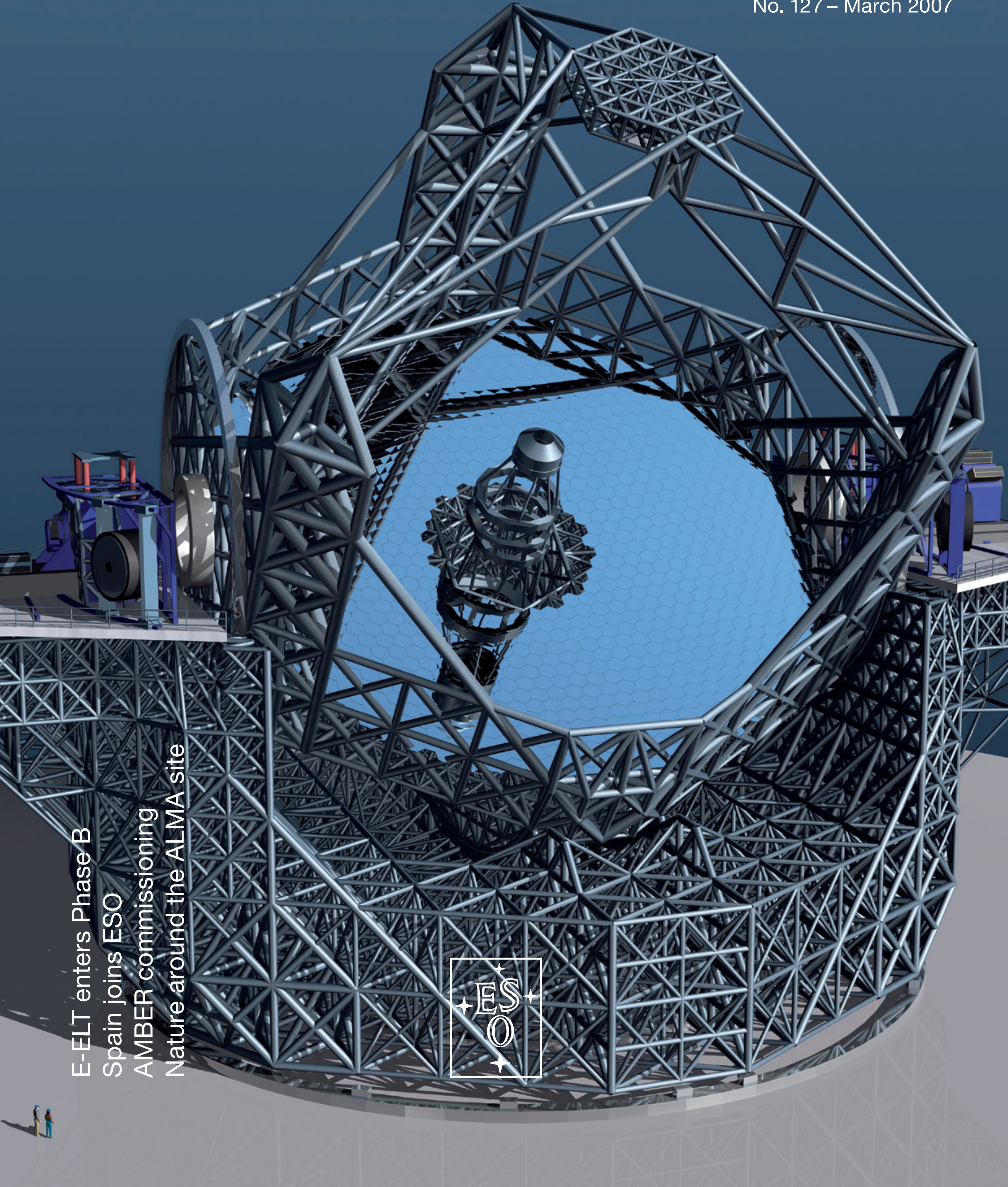


E-ELT enters Phase B
Spain joins ESO
AMBER commissioning
Nature around the ALMA site

Editorial

Catherine Cesarsky
(ESO Director General)

The birth of the European ELT

At ESO, we will all remember 2006 as the year of the birth of the E-ELT (European Extremely Large Telescope). The gestation period has been quite long. Astronomers have been discussing for many years the wondrous scientific programmes they hoped to conduct with an ELT. I remember the enthusiasm of scientists who gathered in the first workshops organised by OPTICON, in Edinburgh in 2000, followed by the two-week-long Leiden meeting in 2001. These were followed by a number of meetings and workshops, one of them in conjunction with "Exploring the cosmic frontier", in Berlin in May 2004, which prefigured the science vision discussions our community is now having in the framework of ASTRONET. An important point about these discussions is that many of them were shared with our colleagues from across the Atlantic. A worldwide meeting took place as an IAU Symposium, in Cape Town in November 2005. Also in 2005, under the leadership of Isobel Hook, the first European ELT science case appeared, in the form of a short and well-illustrated document geared to decision makers followed by a lengthy volume for astronomers.

In parallel, studies of telescope concepts were pursued. At ESO, it was all started in the second half of the 1990s by Roberto Gilmozzi challenging the engineers to create a concept for a 100-m telescope. This prompted work from our opticians to devise ways of sharpening the blurred images that would be obtained with a spherical primary mirror, as it appeared that this simple and relatively inexpensive shape would be a requisite for such a mammoth telescope to be feasible. The mechanical engineers looked into finding ways of constructing large structures with the required stiffness, yet still relatively light and inexpensive to be produced by using many similar pieces (the Lego model). Meanwhile, the ESO Adaptive Optics (AO) specialists, in collaboration with European colleagues, while still delivering all the devices necessary for VLT and VLTI, were methodically investigating more and more advanced schemes, necessary for an ELT. The OWL studies at ESO were for a long time one of the lowest priorities in our programme, as at that time Council asked us to concentrate our efforts on completing the Paranal Observatory and on starting the ALMA construction.

The situation was completely changed when in December 2004, Council, adopting the recommendation by the Council Science Strategy WG chaired by Ralf Bender, announced the now famous resolution which, at last, gave ELT studies a high priority within the Organisation. In 2005, while the first complete Science Case was being completed, at ESO all the work performed on the OWL concept was written up. Another very important activity in 2005, organised by Sandro D'Odorico in a broad cooperation with the community, was to provide instrumentation concepts for OWL. Finally, the FP6 ELT Design Study was started by a European-wide consortium led by ESO, aimed at evaluating critical technologies needed to build a giant telescope.

By the end of 2005, following the OWL review, we decided at ESO to reorient the ELT effort towards the best affordable ELT facility, with a diameter from 30 to 60 m that could be built on a competitive timescale and with acceptable risks, with strong involvement of the community. I had great confidence in the ESO staff, which I knew was well prepared to design an ELT, and in the community, which had shown prowess in developing telescope concepts, various aspects of adaptive optics and in instrumentation design. In the last week of December 2005, I solicited 88 astronomers and engineers from the community and ESO, to participate in five working groups (Science, AO, Instruments, Telescope design and Site evaluation), to elaborate within two months a 'toolbox', a compendium of the relevant knowledge for designing an ELT, including trade-offs and prioritisation criteria. I was extremely pleased to see that almost all accepted readily. They rose to the challenge, and provided me with an excellent document that was a starting point towards the very ambitious goal I had set: to present the concept study of the E-ELT to Council for Phase B approval in December of 2006. Soon after, the chairs and co-chairs of the WG's came together in the ELT Science and Engineering WG (ESE), chaired by Daniel Enard, and provided the E-ELT basic requirements: a multipurpose telescope and instrumentation which was 'laser guide star friendly' and fast in switching. Adaptive Optics was to be integrated in the telescope. The diameter, 42 m, was considered by the committees as a good starting compromise between ambitious scientific goals and schedule, cost and risk.

The design principles are described in the article by Roberto Gilmozzi and Jason Spyromilio in this issue (page 11). I had high expectations, but these were much surpassed when I was presented with the novel five-mirror design, which corresponds to all ESE requirements and not only provides excellent image quality across the field of view but also improves performance and reduces risk by separating the functions of field stabilisation from those of AO. Other attractive features are that it is cheaper than a classical telescope, is faster to build and thus can be timely, and is upgradeable at a reasonable cost.

First our advisory committees (in this case, ESE and STC, and the Council ELT Advisory Committee ESRC), then our community, at a historic meeting at the end of November in Marseilles (see the meeting report on page 20), and finally Council on 6 December 2006, were convinced by this novel design, leaving it to the ESO E-ELT Project Office to undertake a Phase B study with the community and industry. The real work is starting now!

Spain has joined ESO

On 14 February 2007, I was notified by the French Council delegate, Mr. Julien Galabru, that Spain had deposited the instrument of accession to ESO in the archives of the French Ministry of Foreign Affairs. This was the last formal step required for Spain to become the 12th ESO Member State, and it appropriately happened on Valentine's day, a good omen for the future.

In fact, Council and the Spanish negotiating team, then headed by Carlos Alejaldre

Losilla, Director General for Technological Policy, had agreed on all the conditions for Spain's accession on 7 December 2005. In February 2006, the then Spanish minister of Education, Mrs. María Jesús San Segundo, and I signed an agreement towards the entrance of Spain in ESO as of 1 July 2006. The entrance of Spain into ESO had been agreed by both parties to be retroactive to mid-2006, even if the required approvals and administrative steps dragged on beyond that date. Thus, in the second part of last year, we already treated our Spanish astronomer colleagues as members, and immediately we could see their enthusiasm, effectiveness and commitment in the various events, work groups and committees in which they took part. I am truly delighted that we have accreted this vibrant community, with which we were already very familiar.

Tim de Zeeuw to Become the Next Director General of ESO

The ESO Council has appointed Tim de Zeeuw, as the next Director General of ESO effective as of 1 September 2007, when the current Director General, Catherine Cesarsky, will complete her mandate.

Tim de Zeeuw has an excellent record, both as a highly respected scientist and as a leader of an internationally recognised science institute in the Netherlands. He is Scientific Director of the Leiden Observatory, a research institute in the College of Mathematics and Natural Sciences of Leiden University. Tim de Zeeuw also has considerable experience as regards science policy issues. "The ESO Council is very pleased that Professor de Zeeuw has accepted the task as its next Director General. He has played a key role over the last few years in developing a strategic vision for ESO, and I have every confidence that he will now lead the organisation in the realisation of that exciting vision" announced Richard Wade, the President of the ESO Council.

Catherine Cesarsky, ESO's current Director General, commented: "Over the recent years, ESO has developed considerably with more activities and new member states, and with its ambitious project portfolio, ESO is clearly facing an exciting future. I shall be delighted to pass the baton to Tim de Zeeuw, who as a recent Council member is very familiar with our Organisation."

"It is a great honour and an exciting challenge to lead this world-class organisation in the years to come in support of one of the most dynamic areas of science today" said de Zeeuw. "I look forward to overseeing the continued upgrading of the Very Large Telescope with the second-generation instrumentation and the completion of the ALMA project, and in particular to help developing the future European Extremely Large Telescope."

Tim de Zeeuw's main research interests embrace the formation, structure and dynamics of galaxies, including our own Milky Way galaxy. A second area of research is the study of the origin, structure, and evolution of associations of young, massive stars in the Solar Neighbourhood. He obtained his PhD from the University of Leiden in 1980, moving on to work at the Institute for Advanced Study in Princeton, and subsequently at Caltech in Pasadena before returning to the Netherlands. He has received several honours and awards and is the author of a large number of research papers.

In 1993, he became the founding director of NOVA, the Netherlands Research School for Astronomy, which coordinates the graduate education and astronomical research at the five university astronomy institutes in the Netherlands. NOVA has contributed to strongly increasing the international visibility of Dutch astronomy and has enabled intensified Dutch participation in ESO activities. He is also the co-founder of the Lorentz Center, an international centre for Astronomy, Mathematics and Physics in Leiden.

Tim de Zeeuw regularly advises NWO, the Netherlands Organisation for Scientific Research. He has served on many committees including the Time Allocation Committee for the NASA/ESA Hubble Space Telescope, and, since 2003, as the Chairman of the Space Telescope Institute Council in Baltimore. He also serves on the AURA Board of Directors, and on the ESA Space Science Advisory Committee, and leads the development of a Science Vision for European Astronomy as part of the EU ASTRONET initiative.

For three years Tim de Zeeuw served as the Dutch national astronomy delegate to the ESO Council. As a member of the ESO Council he participated in the work of the Council Scientific Strategy Working Group, which resulted in the Council resolution of December 2004 outlining ESO's strategic goals. More recently, as Chair of this Working Group, he has been elaborating various scenarios for ESO's future role in European astronomy.

Tim de Zeeuw, who is 50, is married to Dutch astronomer Ewine van Dishoeck.

(Based on ESO Press Release 03/07)

Photo: C. Ödman

Prof. Tim de Zeeuw, ESO's next Director General.

Astronomy in Spain

Xavier Barcons (Instituto de Física de Cantabria (CSIC-UC), Santander, and Ministry of Education and Science, Spain)

Spanish astronomy has grown in a spectacular way over the last few decades. Spain hosts world-class astronomical facilities, and its astronomers publish over 5 % of all papers in this discipline. As an ESO member, Spain joins forces to pursue the most ambitious projects in European ground-based astronomy.

Some history

What best defines the current state of astronomy in Spain is its rapid development over the last three decades. By the end of the 1970s, there were only a handful of astronomers in Spain who were active in research, and only a few places with some activity in astronomy. The Jesuits had some observatories in Spain: the Carthusian Observatory in Granada; the Ebro Observatory; and the Fabra Observatory in Barcelona which combined, and still continues, studies in meteorology, geophysics and astronomy. These observatories were founded at the beginning of the twentieth century. The Naval Astronomical Observatory in San Fernando (Cádiz) was created over 250 years ago to train naval officers in navigation techniques. One of their driving tasks was to prepare the Nautical Almanac and, together with the National Astronomical Observatory, they provided the official time in Spain. Today, the Navy's Royal Institute and Observatory in San Fernando runs, among other projects, the Carlsberg meridian telescope. Finally, the National Astronomical Observatory (OAN) in Madrid, which is part of the National Geographical Institute (founded in 1786 by King Charles III) was also active in optical astronomy. Today, OAN is a reference for Spanish, European and world-wide radio astronomy. In addition to these institutes, a few universities (Madrid, Barcelona, Santiago de Compostela, Zaragoza, Valencia) had astronomy professorships, often engaged in the more mathematical branches of astronomy and in charge of teaching positional astronomy to scientists and engineers.

The big leap forward

The late 1970s were the key period for the large and spectacular development of astronomy in Spain. Beyond doubt, the international agreements promoting and regulating the use of the observatories in the Canary Islands were the main driver. This enabled internationally competitive facilities to be installed on Spanish land, with a reward of observing time to Spanish astronomers. In addition, the fact that Spain was a founding member of the European Space Agency (ESA) triggered early on the involvement of Spanish scientists in the construction, use and scientific exploitation of space-borne astronomical observatories and exploratory missions in the Solar System. The creation of the Spanish-German Astronomical Centre, with its observatory in Calar Alto (near Almería, in the southeast of Spain), the deployment of the 30-m IRAM dish in Pico Veleta, the establishment of ESA's Villafranca Satellite Tracking Station near Madrid (now converted to the European Space Astronomy Centre – ESAC) and specifically the founding of ESA's International Ultraviolet Explorer Science Operations Centre there, were all of them instrumental in forming new generations of astronomers in regular contact with international partners. Soon afterwards, in the 1980s and 1990s, the universities began to create new permanent positions in the field of astronomy and astrophysics. Many of those posts, as well as those in the Research Centres, were filled with young and talented people who had often entered astronomy through these international enterprises and had then followed their professional career in internationally recognised research institutions abroad.

The current workforce

The Spanish R&D system now contains over 500 professional astronomers, including PhD students. Of these, well over 350 have their PhDs completed and conduct independent research. About one half of these PhD astronomers have permanent positions in universities and research centres. They are assisted by about 150 technical people totally devoted to astronomy. They work in about 30 different places spread around all over Spain. University departments, where research is conducted along with teaching, and research centres share the astronomical workforce in approximately equal halves.

In recent years the training of new PhD students in astronomy has proceeded vigorously. About 25 new PhDs in astronomy are obtained every year, and this number may be growing. At the moment, the Ministry of Education and Science alone is funding 20–25 PhD fellowships in astronomy and space science, to which other fellowships provided by the regional governments, universities and research centres can be added.

Astronomical research in all fields is pursued to some degree. A study conducted in 2002[1] for the Spanish Astronomical Society (SEA)[2] showed that relative to other European countries, Spain is fractionally stronger in studies of stars and the Galaxy, and fractionally weaker in extragalactic astronomy and cosmology as well as in Solar System science (planets and interplanetary medium). Concerning the tools used by Spanish astronomers, not surprisingly, the use of optical observations is fractionally stronger than in other European countries. A counterpart to this is the relative weakness of high-energy (X-ray and Gamma-ray) and laboratory astrophysics.

Overall Spain has about 12 professional astronomers per million inhabitants, a number which is smaller than the one claimed for countries like France and Germany (about 16 to 18) and a factor of two lower than that claimed for the United Kingdom. The expectations recently raised by a very substantial yearly increase of the budget dedicated to R&D by the Spanish government are that, in the following decade, Spain should grow much closer to average European numbers.

[1] This document can be accessed through *http://sea.am.ub.es/TWiki/pub/Main/InformacionSea/Informe2002.zip* (in Spanish only).
[2] The Spanish Astronomical Society (*http://sea.am.ub.es*) was constituted in 1992 as a society of professional astronomers. It is associated to the European Astronomical Society (EAS) and was the main promoter of the Confederation of Scientific Societies (COSCE, *http://www.cosce.org*) in Spain.

Astronomical centres

The largest astronomy centre is the Instituto de Astrofísica de Canarias (IAC). Formally founded in 1975, the IAC is a consortium with participation by the Spanish Government through the Ministry of Education and Science (MEC) and the Spanish Council for Scientific Research (CSIC), the local government (*cabildo*) of Tenerife and the University of La Laguna, one of the oldest in Spain. About 25 % of all researchers in astronomy in Spain work at the IAC, but this share is indeed much higher when technical staff are included. The IAC owns the observatories of Roque de Los Muchachos in the island of La Palma and Teide in Tenerife, where national and international facilities are based.

Whilst there is activity in all fields of astronomy at the IAC (cosmology, extragalactic astronomy, interstellar medium, stars and their evolution), it is in solar physics and optical and infrared astronomy (including instrumentation in both cases) where IAC is clearly a reference both nationally and internationally.

In 1975 the CSIC also founded the Instituto de Astrofísica de Andalucía (IAA) in Granada. The IAA has largely expanded from its moderate initial size to a truly multi-disciplinary research centre. Astronomers at the IAA conduct investigations on radio astronomy and Galactic structure, Solar System, stars and extragalactic astrophysics. IAA is the flagship of CSIC in the astronomy domain and a reference for the development of instrumentation aboard Solar System space missions and its scientific exploitation. The IAA owns the Observatorio de Sierra Nevada and the Spanish-German Astronomical Centre of Calar Alto in conjunction with the Max-Planck-Gesellschaft.

The CSIC also has other astronomical research units in other places in Spain. A very active Department of Molecular and Infrared Astrophysics is now operational in Madrid, where important R&D activities around ALMA, Herschel and the James Webb Space Telescope instrument MIRI take place. The Instituto de Física de Cantabria, a joint venture of CSIC with the University of Cantabria, is the reference centre for X-ray astronomy in Spain and for microwave background experiments in space, through participation in the ESA missions Planck and XMM-Newton. The Institute for Space Science (ICE), located in Barcelona, is very active in theoretical and observational astrophysics of stars, cosmology (for example, through participation in the Dark Energy Survey (DES) project) and gravitational waves.

The Department of Astronomy and Meteorology of the University of Barcelona is one of the largest and with the longest tradition among astronomy departments in Spain. The research topics covered include galaxy formation, astrometry and the Milky Way, micro-quasars, star formation, supernovae, robotic astronomy and space weather. Similarly, the University of Valencia (UV) also hosts an ample set of astronomers, working on numerical astrophysics, theoretical and observational cosmology and radio interferometry. A further group heavily dedicated to space activities is also very active in Gamma-ray astronomy both from the scientific and instrumental point of view.

The National Astronomical Observatory (OAN), belonging to the National Geographical Institute, one of the classical sites of astronomy in Spain, is now dedicated almost in full to radio-astronomy. Its headquarters are in Alcalá de Henares, near Madrid, and its own observatory is in the Centro Astronómico de Yebes (CAY), province of Guadalajara. Besides its research in star formation, evolved stars and galaxies, the OAN technological work in High Electron Mobility Transistor (HEMT) amplifiers is internationally recognised.

The Universities Complutense (UCM) and Autonomous (UAM) of Madrid encompass also an important number of active researchers. The projects cover a wide range of topics such as observational, theoretical and numerical cosmology, extragalactic astrophysics, star formation, active stars and exo-planets. The two universities, along with other research centres in the area, are collectively engaged in the training of new researchers through a joint PhD programme.

Madrid also hosts the Laboratory of Space Astrophysics and Fundamental Physics (LAEFF), belonging to the National Institute of Aerospace Technologies (INTA), which hosts a number of astronomers conducting research in many topics. Thanks to the INTA premises and support, LAEFF has led an instrument on-board ESA's INTEGRAL mission (the Optical Monitor Camera, shown in Figure 1). LAEFF is the chief node of the Spanish Virtual Observatory and will host the Gran Telescopio Canarias data centre. INTA also shares with CSIC the newly-created Centre for Astrobiology, with growing activity in the fields of exoplanets and exobiology. INTA hosts one of the most important teams of technicians dedicated to building instrumentation for space science payloads.

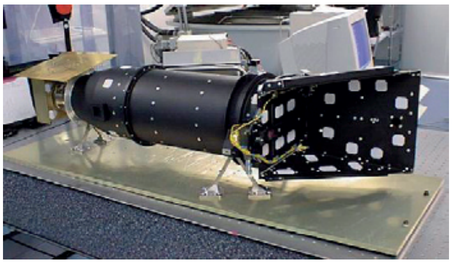


Figure 1: The Optical Monitor Camera (OMC), an instrument led by Spain now on-board ESA's INTEGRAL mission. See *http://www.laeff.inta.es* for details.

Many other places are important for their unique contributions to astronomy. To mention a few (and the list is not complete): the University of the Basque Country hosts a very active group in Planetary Atmospheres; the University of Granada has a group in galactic magnetism and stellar astrophysics; the Polytechnical University of Catalonia group works on white dwarfs and supernovae; the University of Alicante on the physics of collapsed objects and active stars; the historical naval Royal Institute and Observatory is dedicated to astrometric surveys; the University of Santiago de Compostela conducts studies on binary stars; and the University of Alcalá de Henares hosts a group working on solar-terrestrial physics.

Astroparticle physics is another field with growing impact in Spain. In terms of infrastructure (for example, in the construction and operation of the MAGIC Cerenkov telescope), groups traditionally engaged in high energy physics have taken the lead. The exploitation of these facilities benefits a much wider community, including some active groups in high energy astrophysics. A similar scheme applies to the growing field of gravity waves, where much of the initial effort is being provided by groups traditionally working on relativity theory.

Observatories and facilities

Owing to its privileged geographical situation and to a number of other factors, Spain is home to a number of astronomical observatories where both Spain and other international partners operate their facilities. A list of the most prominent observational facilities is given in Table 1.

The Canary Islands are amongst the best sites around the world for optical ground-based observing. Through international agreements, around 60 institutions from 17 different countries operate their facilities either in the Observatorio del Roque de los Muchachos (ORM) on the island of La Palma (see Figure 2) or at the Observatorio del Teide (OT) on the island of Tenerife (Figure 3). These agreements have been instrumental in the development of astronomy in Spain, since a fraction of the observing time is reserved for Spanish astronomers and a further 5% is devoted to international cooperative programmes.

Table 1: Main observing facilities at Spanish observatories. Those marked with an asterisk are joint national participations with Spain.

Observatory	Facility
ORM	10.4-m Gran Telescopio Canarias*
ORM	4.2-m William Herschel Telescope*
ORM	3.5-m Telescopio Nazionale Galileo
ORM	2.6-m Nordic Optical Telescope
ORM	2.5-m Isaac Newton Telescope*
ORM	2.0-m Liverpool JMU Telescope
ORM	1.2-m Mercator Telescope
ORM	0.18-m Carlsberg Meridian Telescope*
ORM	1.0-m Swedish Solar Tower
ORM	0.45-m Dutch Open Telescope (Solar)
ORM	MAGIC, Gamma-Ray Cerenkov*
OT	1.5-m Telescopio Carlos Sánchez*
OT	0.8-m IAC80*
OT	0.9-m THEMIS (Solar)
OT	0.7-m Vacuum Tower Telescope (Solar)
OT	1.5-m GREGOR
OT	Solar Laboratory*
CAHA	3.5-m Telescope*
CAHA	2.2-m Telescope*
CAHA	1.23-m Telescope*
CAHA	1.52-m Telescope* (OAN)
OSN	1.5-m Telescope*
OSN	0.9-m Telescope*
Yebes	14-m Antenna*
Yebes	40-m Antenna*
Pico Veleta	30-m IRAM Antenna*

Figure 2: Panoramic view of the Observatorio del Roque de los Muchachos (ORM) in the island of La Palma.

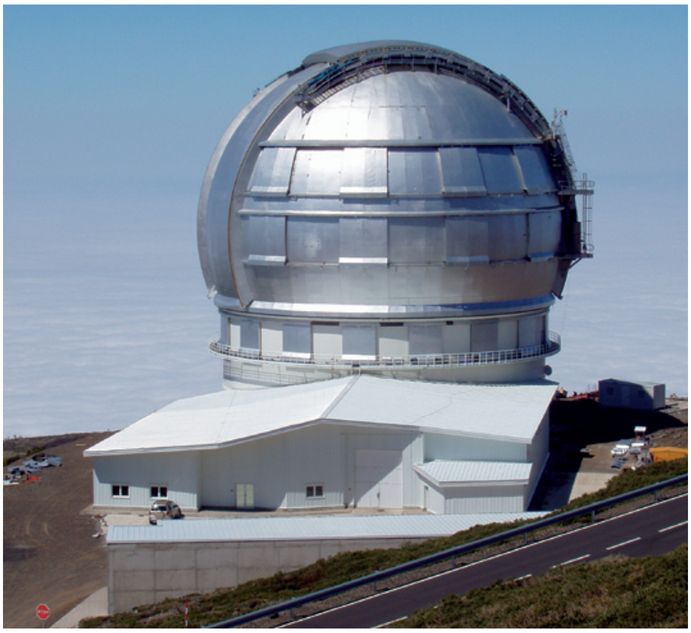
Figure 3: The Observatorio del Teide (OT) with the Solar Telescopes THEMIS (right) and VTT (centre) in the foreground.

The ORM has been, and continues to be, a primary destination for international observational facilities in Europe. The ORM hosts a number of night-time facilities operated by several countries, often through international consortia or ad-hoc agreements. The Very High Energy Gamma-ray Cerenkov facility (MAGIC) is also operational in the ORM (see Figure 4). The Teide Observatory is mostly dedicated to solar observations, but also hosts two experiments to observe the structure of the Cosmic Microwave Background from the ground. A support sea-level facility, the CCALP (Common Centre for Astrophysics in La Palma) has recently opened in La Palma.

The ORM is also the home of Spain's top national astronomical facility, and biggest challenge, the Gran Telescopio Canarias (GTC), shown in Figure 5. This is a 10.4-m segmented telescope being built by a public enterprise called GRANTECAN, S.A. (co-sponsored by the Spanish and Canarian governments) on behalf of Spain and its partners: Mexico (through the Instituto Nacional de Astronomía Óptica y Electrónica and Universidad Nacional Autónoma de México) and the University of Florida. The construction of the GTC is at present in its final stages. GTC is preparing for the first pointing on the sky (first light) with the first six segments of the primary mirror (Figure 6); the secondary (shown in Figure 7) and

Figure 4: The MAGIC Cerenkov ultra-high energy gamma-ray telescope in the ORM. See *http://magic.ifae.es* for more details.

Figure 5: External view of the Gran Telescopio Canarias (GTC) dome.



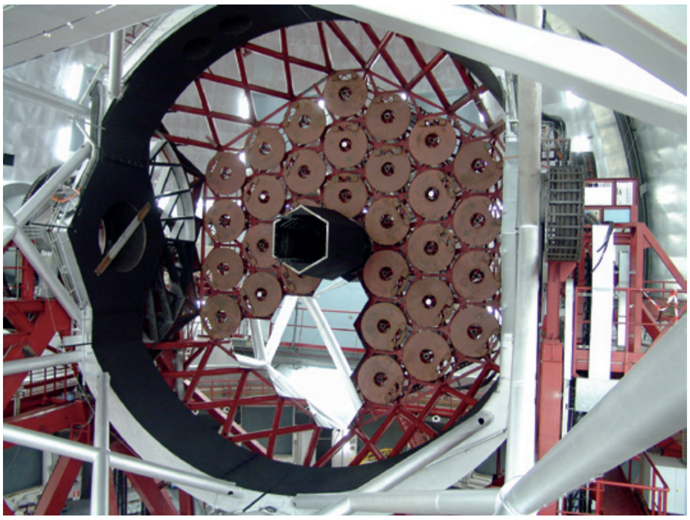


Figure 6: The primary mirror of the GTC with the first six segments already mounted.

Figure 7: The secondary mirror of the GTC, fully aluminised and mounted.

Figure 8: The Centro Astronómico Hispano-Alemán (CAHA) in Calar Alto, jointly owned and operated by the MPG and the CSIC. From left to right: the 2.2-m, 1.23-m (no longer offered), the 3.5-m and the Schmidt (not offered) telescopes. See *http://www.caha.es* for details.

tertiary mirrors are already mounted. First light will be followed by a one-year commissioning of the telescope and the two Day 1 instruments – OSIRIS, an optical instrument led by Spain, and CanariCam a thermal infrared instrument built by the University of Florida – before the start of normal science operations.

The GTC is the first segmented telescope built in Europe. Important high-technology components have been contracted to Spanish and other European industries. This has placed Spain and Europe at the forefront in the capacity to build large segmented telescopes, specifically in some key technologies. Spain is proud that part of the in-kind contribution for the accession to ESO has been agreed in the area of scientific and technological programmes at the GTC. From the technological viewpoint, this will be an important tool for the design and eventual construction of a European Extremely Large Telescope.

The Spanish-German Astronomy Centre (CAHA) is another major asset in terms of infrastructure for Spanish astronomy, and is shown in Figure 8. The agreement for the installation of German telescopes in Calar Alto was signed in 1972, with the first operations carried out in 1976. After years of development from the German side and modest participation by Spain, a new agreement was signed in 2004 between the Max-Planck-Gesellschaft (Germany) and the CSIC (Spain) to share costs, responsibilities and property of the CAHA on a fifty-fifty basis. There are currently two fully operational telescopes with apertures of 2.2 m and 3.5 m, along with other instrumentation. Nearby the IAA also operates an observatory in Sierra Nevada (OSN) where 0.9-m and 1.5-m telescopes are located.

The Centro Astronómico de Yebes (CAY), near Guadalajara, is the home for the OAN's radio telescopes. The currently operating 14-m antenna will soon be joined by a fully Spanish designed and built 40-m antenna (Figure 9). Operations of this new facility are expected to start early in 2007. OAN is also the Spanish partner in IRAM (along with France and Germany). Besides the millimetric interferometer in Plateau de Bure, IRAM also operates a 30-m antenna in Pico Veleta, not far from Calar Alto and Sierra Nevada, shown in Figure 10.

There are other facilities that have played a very important role in the development of Spanish astronomy. Among others are, the Deep Space Network antennas of NASA at Robledo de Chavela near Madrid (partly used for VLBI radio observations, and available to Spain in a small fraction) and ESA's Villafranca Satellite Tracking Station (popularly VILSPA, now renamed ESAC), which will host the Science Operations Centres of all the new ESA astronomy and Solar System missions.

Computing is also another pressing need in modern astronomy and astrophysics, for which the Barcelona Supercomputing Centre (hosting the Mare Nostrum super computer) is an important asset that devotes a part of its scientific service to astronomy projects. This and other smaller facilities have lent support to increasing activity in numerical astrophysics.

Figure 9: The 40-m antenna being installed in the Centro Atronómico de Yebes (CAY), near Guadalajara. See *http://www.oan.es*.

Figure 10: The IRAM 30-m millimetre antenna in Pico Veleta. *http://www.iram.fr/IRAMES/index.htm*

Funding

The main national funding resource for research teams in Spain stems from the National Plan for Research, Development and Innovation, a four-year plan whose current version will expire in 2007[3]. There are a number of programmes devoted to specific R&D areas. The Astronomy & Astrophysics Programme was created in 2000, its main objectives being:
– Basic research in astronomy and astrophysics
– Design and development of astronomical instrumentation
– Exploitation of available facilities
– R&D in astronomy-related technologies

This Programme is complemented by the Space Programme, where an important ingredient is the development of scientific payloads for astronomy and Solar System missions, and their scientific exploitation.

The National Plan has a number of tools, which range from provision of funding for direct research costs, provision of PhD fellowships and technical trainee contracts, postdoctoral contracts at various levels, and many others. An important tool is funding to 3–5 year projects, which often provides the largest financial contribution to astronomy groups. Project funding is assigned following strict peer-review evaluation and an overall rank decided by a national programme board.

Infrastructures, and particularly what are currently called 'singular scientific infrastructures' (which for astronomy means telescopes or similar), are funded through independent channels and budgeted separately. An Advisory Committee on Singular Infrastructures proposes, evaluates and oversees these at national level.

[3] More information under *http://www.mec.es/ciencia/jsp/plantilla.jsp?area=plan_idi&id=3*.

Productivity

Scientific productivity[4] in astronomy in Spain reflects very closely the development of the discipline. In the 1970s, before the big leap forward, less than 10 papers per year were published in the field. In the first half of the 1980s, the publication rate stabilised at some 40–60 papers per year. It is instructive to see that many of today's main centres of Spanish astronomy are contributing to this success (Calar Alto, Yebes, and several universities), but most remarkable is the contribution from the ESA Villafranca station (and specifically the International Ultraviolet Explorer data). The IAC and the IAA started to dominate the scene in that epoch.

In the second half of the 1980s the publication rate started to increase dramatically. This rise has not stopped and if anything, is growing even faster since 2000. In 2005 the number of publications in astronomy and astrophysics exceeded 600, which is well above 5 % of the total number of publications in this field from around the world. Astronomy and astrophysics is the discipline where Spanish scientists have made their largest contribution, which is on average around 3 %. A direct count of all papers shows that the fraction of papers in the field of astronomy and astrophysics among all scientific production in Spain has gone up from well below 0.1 % in the 1970s to close to 0.2 % in the last decade or so.

Another important product of astronomical research is technological development, through contributions to instrumentation. There is a long tradition in Spain of contributions to ESA's space science missions, in part due to full ESA membership since its foundation and to the existence of a Space Programme, which dates back longer than the Astronomy & Astrophysics Programme. Indeed, a variety of research centres and university departments have contributed, and are contributing, to virtually all important ESA astronomy and Solar System science missions. These are complemented by participation in ESA's Earth observation programme, as well as the Exploration programme, along with some contributions to NASA and other agencies.

In terms of ground-based astronomical activities, the Gran Telescopio Canarias is indeed the greatest technological challenge faced by Spain. Besides the construction and operations of the whole facility, Spain is leading two of the main instruments: OSIRIS, a Day 1 optical multi-object spectrometer equipped with tunable filters; EMIR, a second-generation multi-object near-infrared spectrometer. In addition, ELMER, a back-up first-light optical instrument, has also been built by GRANTECAN. Vigorous activity is now building up to secure a full second-generation instrument complement for GTC.

On a more modest scale, other optical and infrared instruments have been built and are operational in some other facilities. The optical spectrometers ALBIREO on the 1.5-m telescope in IAA's Sierra Nevada Observatory, ALFOSC on the 2.5-m NOT and the infrared instrument LIRIS on the 4.2-m WHT are examples of these developments.

Radio astronomy has also been an active field of instrumental development in Spain. The OAN is currently finishing the 40-m antenna at its Yebes observatory (Figure 9), which is fully designed and built in Spain and will start operations by early 2007. The antenna will be part of the European VLBI Network, where Spanish astronomers had an active role even before this important instrumental contribution was planned. In a collaborative effort between CSIC and OAN, along with other partners, Spain is providing some important items to ALMA, a project that Spain joined prior to the accession to ESO.

The future

Spain has a glowing future in astronomy which is fostered by its accession to ESO. Activity does not appear to stop growing, and, if anything, is growing faster. The most important asset of Spanish astronomy – its human resources – appears to be in good shape, as new generations of highly skilled and enthusiastic astronomers are being recruited. Consolidating these new generations in the R&D system is now one of the major challenges.

Operating, maintaining and exploiting the GTC will continue to be a top priority in Spain. There are plenty of ideas for second-generation scientific instruments accompanying EMIR, which will be the first operational near-infrared multi-object spectrometer. Among them, FRIDA, making full use of the adaptive-optics facility to be implemented at the GTC, is high on the list. We will make sure that GTC stands up as a top-class facility well within the era of the ELTs.

In parallel to the GTC, smaller aperture optical telescopes will play a crucial role in a balanced development. These facilities are far more efficient than larger aperture telescopes in conducting some types of observing programmes and will need to be equipped with the correct instrumentation. Fortunately, Spain shares, or has access to, a number of these 2–4-m-class telescopes (particularly in Calar Alto and La Palma).

The frontier infrastructures for ground-based astronomy after the current epoch are clearly on the scale of a billion Euros. In joining ESO, Spain confirms its full participation in the ALMA project and will work vigorously towards making the European ELT a reality. Spain brings experience from the construction of the GTC and other facilities to this enterprise. It also brings the possibility of placing this E-ELT in our best observatory – the ORM in La Palma. The other key international facility under study, the Square Kilometre Array (SKA), is also a target for Spain.

Acknowledgements

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[4] All data related to publications has been obtained through ISI's Web of Science, thanks to a subscription funded by the Spanish Ministry of Education and Science and the Spanish Foundation for Science and Technology.

The VLTI AMBER instrument undergoing adjustment.

Photo: H. H. Heyer, ESO

The European Extremely Large Telescope (E-ELT)

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(ESO)

The ESO Council has authorised the E-ELT project to move to Phase B and approved the budget for the further design of the telescope and its instrumentation. In this article we present the activities and design concepts considered in the past year leading up to the decision of Council.

In the March 2006 Messenger the path towards a basic reference design for a European Extremely Large telescope was presented. The plan involved extensive community consultation through five working groups, established by the Director General of ESO, on the topics of science, site, adaptive optics, instrumentation and telescope. The conclusions of the ELT Scientific and Engineering (ESE) Working Group panels were combined into a toolbox which was used as a guide by the ESO ELT Project Office towards determining a Basic Reference Design to be presented to the community and the committees of ESO. The basic premise underlying these activities is the strategic resolution of the ESO Council that requires that the organisation develop a facility that will address the exciting science awaiting us in the coming decade and will be competitive in timescale and performance with similar facilities planned elsewhere.

The toolbox generated very specific goals to be addressed in the design phase. The telescope to be built should have a primary mirror of order 40 m in diameter (42 m was thought to be a good compromise between ambition and timeliness), should not be based on spherical mirrors, should have adaptive optics built into it and deliver a science field of view of at least five arcminutes diameter with a strong preference for larger fields. Furthermore the telescope was to provide multiple stable observing platforms while maintaining a focal ratio that would be favourable to instrumentation.

Additional inputs to the design of the telescope came from the conclusions of the OWL review held in November 2005. While that review concluded that the ELT project could advance into the next phase, the panel recommended that certain high-risk items be avoided in the next iteration of the design. Double segmentation (on OWL the primary and secondary were both segmented) and the high complexity of the adaptive mirror (in OWL the sixth mirror combined field stabilisation and adaptive corrections in a single unit) were considered risks that would delay or jeopardise the project. The fast focal ratio of the telescope (f/6) and the absence of gravity invariant focal stations were also on the hit list of things to be avoided in the redesign.

The ELT Project Office at ESO worked during 2006 to determine whether a telescope that can meet these requirements can be designed and constructed within reasonable timescales and for plausible costs. Some work has been performed in-house at ESO, while some activities have been contracted to industry. In parallel to these pre-design activities, many cost estimates have been received from industrial suppliers.

The optical design

In the process of evaluating the options for the European ELT, two candidate designs were recommended by the ESE working groups to be considered in more detail. A classical Gregorian design and a novel five-mirror design were submitted to detailed trade-off analyses (see Figure 1). The design process has been followed by the ESE subcommittee of the STC and within that framework, meetings with the telescope, science and instrumentation working groups have been held.

Both telescopes are based on 42-m diameter aspheric primary mirrors, on the elliptical side of the parabola, and to be assembled using more than 900 hexagonal segments (petals are also an option but not in the current baseline), each approximately 1.45 m peak-to-peak in size. The Gregorian design has a 4.8-m concave secondary and can either exploit the beam at a deep Cassegrain location or, using a tertiary 5-m flat, redirect the beam to a Nasmyth focus. In the five-mirror design, an active convex 6-m secondary mirror is followed by a concave, mildly aspheric, tertiary mirror located within the central obstruction of the primary. Two flat mirrors relay the beam to the Nasmyth foci of the telescope. Both optical designs deliver a 10 arcminute diameter, f/15 beam at the Nasmyth focus. In the Gregorian the field is limited by the size of the tertiary, while in the five-mirror design the size of the hole in the quaternary mirror defines the field and the central obstruction.

Before we delve into the details of the design and the trade-offs, the primary mirror

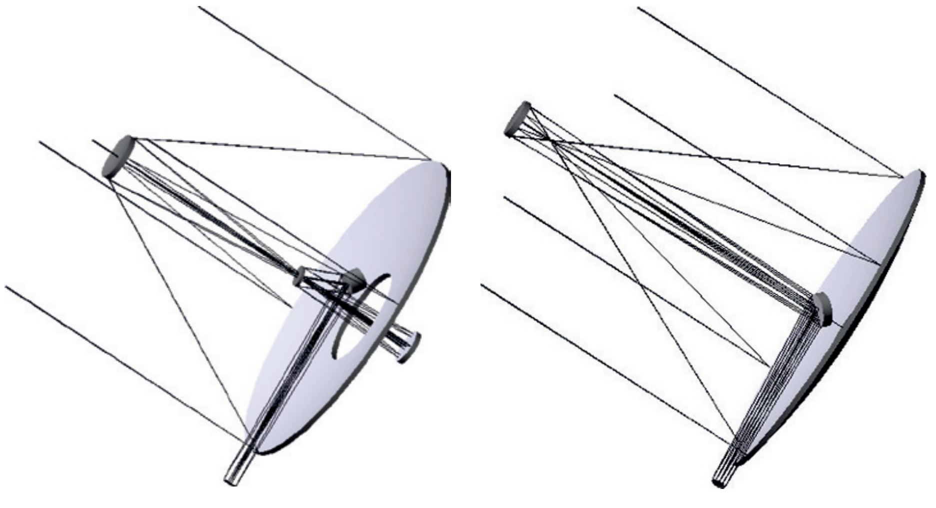


Figure 1: The two optical designs considered during the Basic Reference Design development: five-mirror (left) and Gregorian (right).

of the telescope deserves some attention. The primary of the E-ELT will need to be phased and, to this purpose, we have been working within the FP6 ELT Design Study programme, and within the Project Office, to develop both a phasing methodology and the requisite sensors. The active phasing experiment will test different phasing sensors on a small segmented mirror. It is to be mounted at the visitor focus of the VLT and in this way we expect that the telescope's ability to produce (as well as cancel) aberrations on demand can be used to optimise the process of phasing. Sophisticated sensors and actuators are under development in industry as part of the FP6 programme. At ESO we recognise that we have almost no experience in matters associated with segmented mirrors. The entry of Spain into ESO will bring this expertise into the organisation and, with a number of technical nights available to ESO on the GTC, we hope to greatly expand our knowledge base.

To build adaptive optics into the telescope, as recommended by the ESE working groups, a convenient location for an adaptive mirror is required. In the Gregorian design, the deformable mirror is the secondary that is naturally conjugated to the ground layer. That deformable mirror will also need to look after the tip-tilt component of the wavefront error. In the five-mirror design the deformable mirror is the quaternary, also conjugated to the ground layer, while the fifth mirror in the optical train provides for tip-tilt compensation.

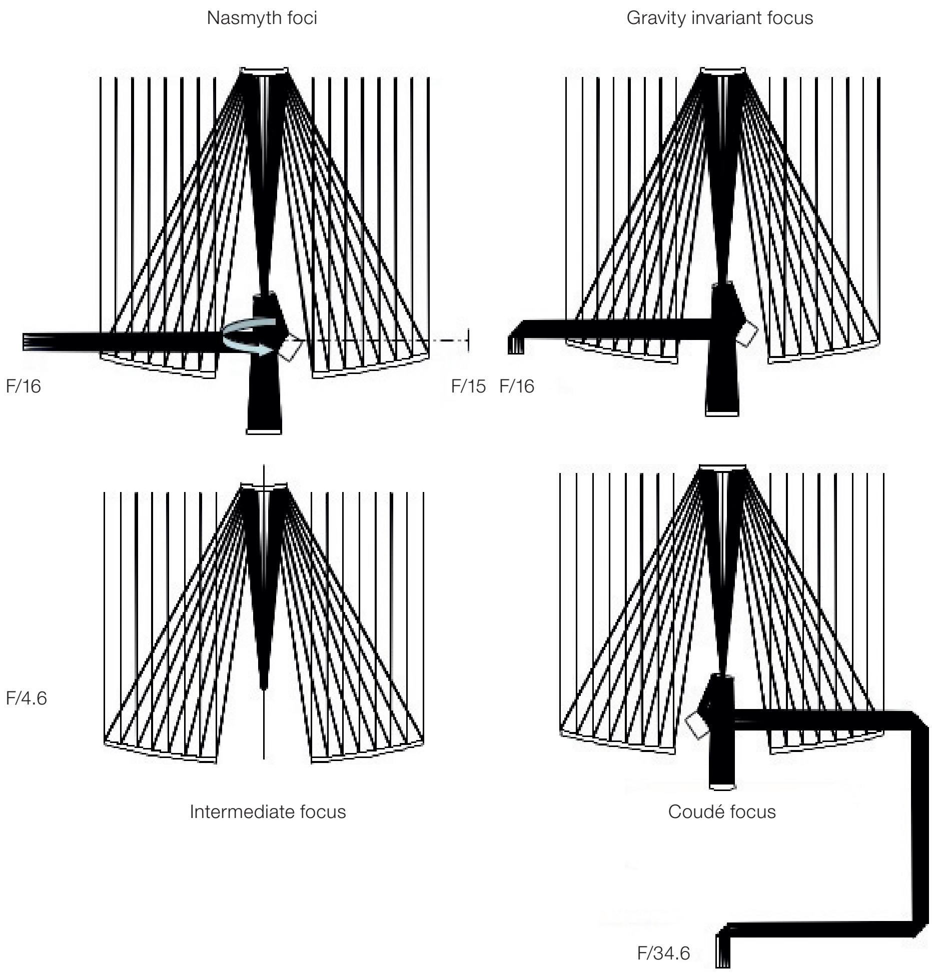


Figure 2: Different foci can be supported by changing the focal length of the telescope. In the five-mirror design, shown here, this is achieved by moving the tertiary mirror along the telescope axis. An intermediate, two-reflection focus can also be provided.

The five-mirror design

The simplicity and elegance of the Gregorian design would make it a front-runner. The minimum number of mirrors is necessary to relay the beam and it provides a prime focus, particularly useful when wishing to calibrate the adaptive mirror. Furthermore concave mirrors that are easier to polish. So why study an alternative? The issue at hand is that large telescopes are very difficult to build and a natural question is: "Is there a better solution to the traditional telescope?"

What is so challenging about large telescopes? It is hard to find any single area where the increased size of the telescope makes things easier. The simplification made by segmenting the primary mirror is easily compensated by our wish to have the primary as large as possible.

Both the Gregorian and the five-mirror designs provide excellent image quality across the field of view. The Gregorian has field aberrations increasing with distance from the centre of the field of view, but their contribution to the image quality will be limited to well below any reasonable expectation for the natural seeing. With three powered mirrors, the five-mirror design delivers nearly perfect image quality across the entire field of view.

Furthermore, big telescopes have awkward focal planes. The linear dimensions of the ten-arcminute field of view of the E-ELT are similar to those of the VLT at Nasmyth. However, only one ninth of the area of the sky is imaged. The plate scale and its matching to any detector system or slit are serious challenges for instrumentation, while at the same time a faster focal ratio would severely limit the working volume for the construction of instruments. Another problem is how to provide for a relatively flat focal plane for the instruments. Classical designs of telescopes, such as the Ritchey-Chrétien or the Gregorian, have significant field curvature (for an E-ELT with the Gregorian solution, the radius of curvature at the focal plane is of the order of 4 m) and rely upon field flattening lenses or mirrors in the instruments to generate the field flatness. This solution is economical in optical surfaces, as often some optics would be required in any case for the window of a cryostat and giving it the right properties to compensate for field curvature does not overcomplicate the instrument. This, however, places very strict alignment requirements on the instrument relative to the telescope.

For the Gregorian design a further complication arises as the direction towards the centre of the field curvature is inverted, relative to the direction of the chief ray from the telescope, at any particular location in the field. While as mentioned above, field flatteners are common-place, for the field of view of an E-ELT they need to be segmented and off-axis. Doing without this complication certainly helps.

With three powered mirrors, the five-mirror design delivers a focal plane that is largely un-aberrated at all field locations and the chief ray and the axis of the very limited field curvature (radius of 36 m and convex as seen from the instrument) are parallel. To all intents and purposes it does not matter where in the focal plane you mount your instrument. The focal plane properties are uniformly excellent in the five-mirror design.

The mechanical structure

The next stage in the design process is to create a mechanical concept that meets: the needs of the optics to be kept in place; the needs of the instrumentation for accessible foci; and the needs of maintenance to be able to reach the optics. Of course all of this has to be done for the lowest possible cost while providing the maximum possible performance.

The basic mechanical design of the E-ELT baseline is an altitude over azimuth mount, with a grid-like structure made of multiple identical components. The result looks boxy but is light and designed to be easy to manufacture and transport. There are very few large elements in the telescope. The azimuth platform rests on four concentric hydrostatic tracks providing axial support to the telescope, while the radial direction is constrained using a central bearing. The elevation structure is supported by four cradles that transfer the loads directly through to the same azimuth bearings. Here again hydrostatic bearings are envisaged. The cradles of the altitude extend above the level of the primary mirror in order to provide sufficient support to the telescope to reach the horizon pointing location. Direct drive motors (as are used in the VLT) are foreseen to move the telescope. The mechanical structure is very similar for both the Gregorian and five-mirror designs. The structure supporting the secondary mirror is a three pier system located at 120 degree intervals around the primary mirror. At the top of the three towers, the spider of the telescope supports the secondary unit while at the same time minimising the obstruction of the beam. The current design avoids the use of 'ropes' that would provide additional stiffness but cause extra diffraction patterns in the PSF. This is regarded as an advantage by the extrasolar planet-searching community who hope to go beyond searching and into studying the planets themselves. The project hopes to be able to maintain such a configuration in the final telescope.

The telescope is mounted on a central concrete pier that ensures a minimum clearance of 10 m above the ground is maintained throughout the operational range of down to 30 degrees above the horizon. An enclosure/dome is foreseen to protect the telescope from the elements. The enclosure studies are ongoing through the FP6 ELT studies and activities within the ELT Project Office. Various options exist for an enclosure for the telescope. As is described below, the size and design of the enclosure becomes a critical issue when considering the effects of the wind on the telescope structure.

Controlling the telescope

One of the biggest challenges of a large telescope is to provide for the stability of the images. Large telescopes tend to shake in the wind. As a result the images will also shake and possibly be distorted as the optics may become ever

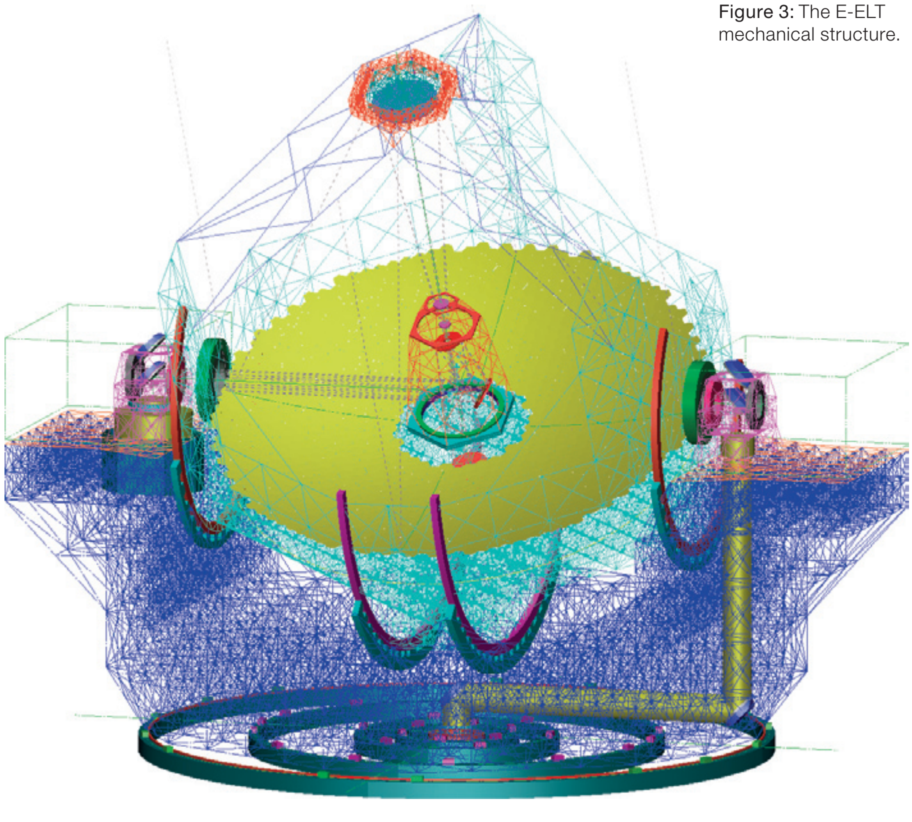


Figure 3: The E-ELT mechanical structure.

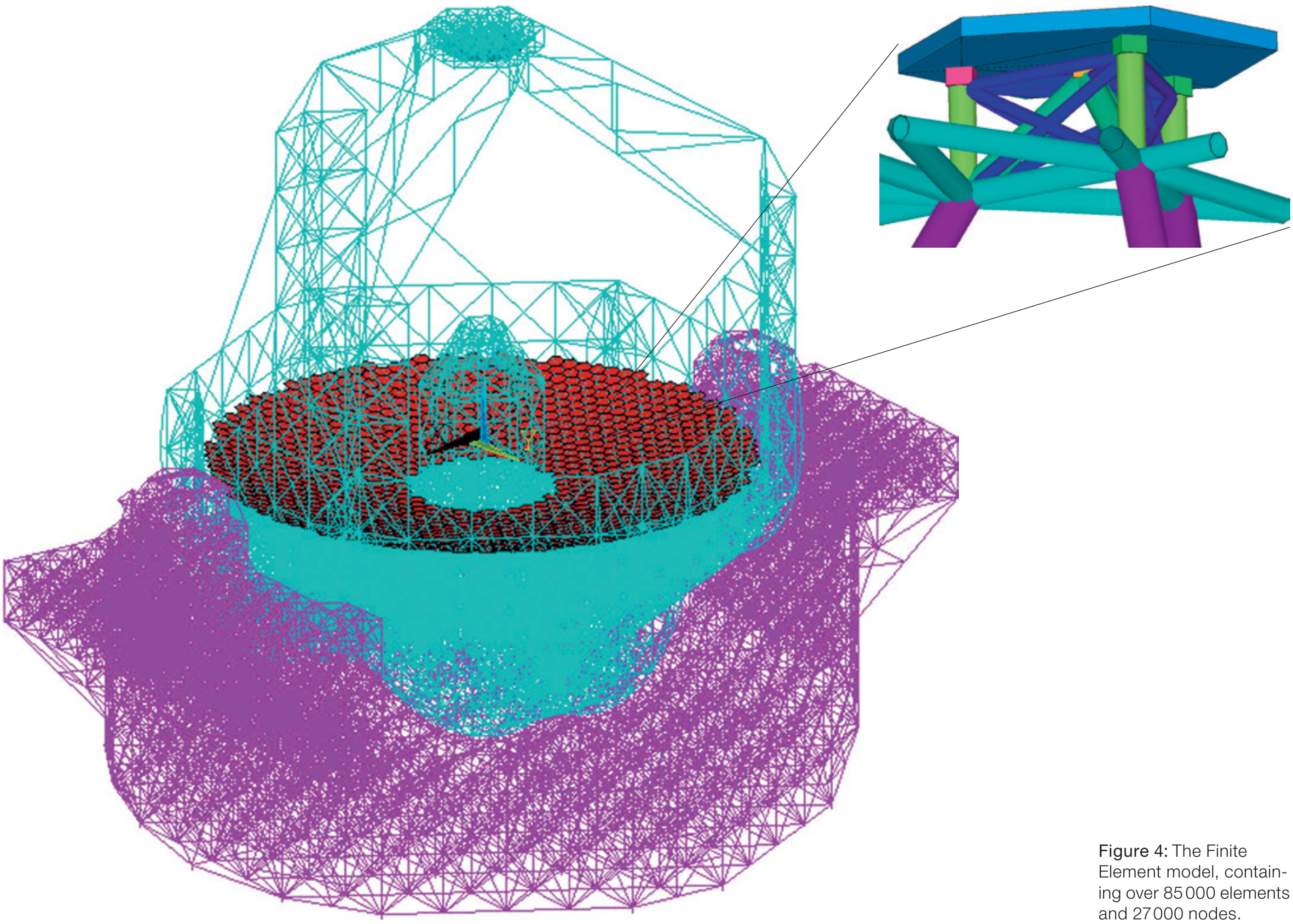


Figure 4: The Finite Element model, containing over 85000 elements and 27000 nodes.

so slightly misaligned. This is not a new problem and in fact the tradition of enormous domes protecting the telescopes has, to a large extent, been the first defence against the wind. Large domes however had a negative effect, detected in many of the 4-m-class telescopes, namely dome seeing. In the evolution of telescope-system design a critical step was the open structure of the MMT – a solution later adopted also for the ESO NTT. Exposing those telescopes to the wind provided, on the one hand, clean air, but required that the mechanical structures were stiff enough to withstand the effects of the wind. With 4-m-class telescopes and alt-azimuth designs, it has been possible to achieve eigenfrequencies of well above 10 Hz (an order of magnitude higher than the equatorial mounts of the 1970's).

For the 8–10-m class telescopes, the mechanical structures were even larger and the eigenfrequencies lower. For example the VLT Unit telescopes start at a very respectable 8 Hz. To combat the effects of the wind on the 8-m telescopes, rather than employing enormous domes another choice was available, viz. field stabilisation, the rapid correction of the effects of wind shake with a fast steerable mirror, located somewhere conveniently close to the pupil of the telescope. The deployment of such mirrors in UTs, and also in the Gemini 8-m telescopes, has permitted very compact enclosures and excellent ventilation. As a side benefit, exceptional tracking performance is delivered by the telescope systems at the focal plane. The telescope may well be all over the place (figuratively speaking) but the focal plane stays put.

As we move to the large telescopes of the future the challenge of the wind shake returns. Before we decide how to address this issue we need first to establish its scale. To do this, a fairly sophisticated finite element model of the telescope is required, with of course the subsequent analysis, comprising models of the servo systems, the impact of mechanical deflections on the optical performance, etc. A number of iterations around this loop are needed before something plausible can be extracted for a design/performance trade-off.

For the E-ELT we have iterated our design against the requirements using a Finite Element model with over 85000 elements and 27000 nodes that was constructed for both the Gregorian and the five-mirror optical designs. The first eigenfrequencies of the mechanical design are around

2.5 Hz, almost irrespective of optical design. These are decently high for a 5 500-ton structure that carries a telescope 'tube' that is just under and just over 40 m long for the five-mirror and Gregorian solutions respectively. It is interesting to note that the five-mirror design makes for a telescope that is wider than it is long. The size of the dome will be dictated by the Nasmyth platforms, rather than the telescope 'tube'. The static analysis of the structure shows us that we can build it without resorting to exotic materials and only in few locations may need to employ anything but the most normal of steel. The analysis also shows that the structural design is in principle compatible with sites with high earthquake risks, although again certain locations may need reinforcement. Of some concern are the large accelerations that the secondary units of both designs are subjected to in case of earthquake.

Irrespective of the optical design, one challenge for the telescope will be to maintain collimation. The static deflections of the secondary mirror relative to the primary are large and cannot easily be accommodated within a classical NTT-like system of re-alignment during operations. Maintaining a decent wavefront from the telescope will not be easy.

The impact of the wind

Having a structure that can support the optics, we now discuss the impact of the wind. Various wind loading assumptions have been made. Open air has been used as the benchmark. A VLT-like box-style, tightly fitting, enclosure provides limited protection from the wind and even in some cases shifts some the wind power to higher frequencies, something that is not favourable. A TMT-like calotte design was also considered as it provides for a much better damping of the wind, partly by restricting the opening to the wind and partly by having a dome somewhat larger than absolutely required by the telescope.

In either case, the analysis made for the 42-m telescope clearly indicates that making the telescope deliver good images in a passive mode and under reasonable wind loads is going to be very difficult without a field stabilisation stage. In short, the tip-tilt component of the wavefront, attributable to the telescope under relatively strong winds, is expected to be on the order of 0.8 arcseconds rms, irrespective of optical design. A smaller telescope with a bigger dome could reduce this to below 0.2 arcseconds and possibly even lower. However, we should recall that, thanks to the recommendation that the telescope be adaptive, we already have a tip-tilt capable mirror in our optical train.

The issue at hand is how to address a 0.8-arcsecond tip-tilt component with a large (2.5- or 4.8-m mirror). The edge of the mirror will be moving by a number of 100's of microns, if it is to provide for the required tip (or tilt), and it will need to do so at frequencies of some tens of Hz.

The Project Office contracted design studies to a number of industrial firms to develop a solution to this problem. The studies were embedded within a more complete package of providing conceptual designs for the entire adaptive optics system, for either or both of the Gregorian and five-mirror optical designs. Two industrial firms provided solutions for the 4.8-m Gregorian mirror. The tip-tilt capability of the mirror is to be achieved by segmenting the support structure of the mirror (and the front face) and providing a tip-tilt capability in each of the segments. Synchronously tip-tilting as many as 18 segments (in phase) provides for a global tip-tilt. The number of segments and details of the technology differ depending on the supplier, but the underlying principle, of a thin face sheet of glass being supported by actuators mounted on a support structure, is the same[1] for both designs.

In the case of the five-mirror design three options for the field stabilisation stage were provided in our consultation with industry. As in the five-mirror design, since the fifth mirror is 'only' 2.7-m in size segmentation has not been seen as necessary and, although some novel ideas are being considered, we believe that this is a tractable problem.

An adaptive telescope

An adaptive telescope is the natural evolution of the active telescope that ESO pioneered with the NTT. There are many reasons why active optics was a great advance in telescope design and it is worth elaborating somewhat on them here. In order to deliver good images, a telescope not only has to be at a good site, but also has to be a good telescope. More than just having the right optics, the optics has to be properly aligned and kept that way. In the past century, colossal advances were made in optical materials that allowed the mirrors to maintain their polished surfaces to the correct prescription. With the use of the Serrurier truss, classical telescopes maintained their collimation to the accuracy needed for arcsecond and even sub-arcsecond images. Much, if not all of this, was pioneered on the 200-inch at Palomar. However, it is worth noting that a number of the 4-m telescopes were found to have the wrong prescription polished into some of their mirrors or not to be correctly aligned. Exceptional images from the CFHT and the NTT changed the expectations of astronomers.

A number of innovations were tested at the NTT, but we shall concentrate here on the active optics. The collimation of the telescope (rolling the M2 about the coma-free point during observations to align it with M1) was critical for the performance of the telescope. The active support of the primary to compensate for gravitational deformation was not absolutely necessary in the NTT, as the primary was conservatively made thick enough to be able to operate without it. However, it worked remarkably well and the success of the active deformation ensured that we could make thin meniscus mirrors for the VLT within reasonable schedules and costs. The unit telescopes of the VLT run in closed-loop active optics at all times and have done so since the first star was detected in April of 1998. Millions of corrections have now been made and this operational mode has been critical to the high efficiency of

[1] Each segment of the large deformable mirror is similar in size and complexity to the current generation of large deformable mirrors, such as those deployed at the MMT, in the process of deployment at the LBT and in manufacturing for the VLT and Magellan telescopes.

the observatory, as no time is ever wasted focusing or checking the telescope performance.

This rather lengthy aside leads us to the reasons adaptive optics should be part of the telescope of the future. With exacting requirements on image quality, an E-ELT will need to keep objects with good PSFs in very precise positions on the focal plane. In addition to the instruments requiring excellent images, the wavefront sensors also benefit from this good image quality. The distortions of the wavefront, whether from the telescope or the atmosphere, need to be taken into account. Active optics can handle slow variations, and for the VLT the residual is pure tip-tilt which can in that case be taken out at the secondary. For an E-ELT the residual is more than just tip-tilt and therefore other low-order aberrations will need to be corrected. If you fix them in the telescope, you need not do it in the instruments. An alternative design choice would be to fix the telescope aberrations in each instrument. For the E-ELT, we believe that we will need this capability anyway for each instrument and therefore we do better to fix this problem once and for all. The penalty of doing it once is that you do it for the entire field, rather than the special needs of any given instrument.

As telescopes become increasingly large, it is not immediately obvious how one goes about building instruments for them without breaking the budget. Long focal lengths are needed to provide sufficiently large back focal distances and reasonably powered mirrors in the telescopes. However, slow optics also imply pixel scales that are less favourable for seeing-limited observations. Big telescopes do not allow for big pixels in the cameras. Small pixels not only mean that many more of them will be needed to cover some patch of sky, but also that the sensitivity of the system depends greatly on the image quality of the telescope. The bottom line is that if the telescope is adaptive then making the instruments for it is easier. Critics are likely to argue that the global problem may be harder to solve. We hope to address this during the design phase of the telescope.

The adaptive mirrors

The adaptive mirror will of course correct for the atmospheric wavefront errors. This challenge can be relatively straightforwardly (an unfair choice of words given the enormous task that underlies this statement) translated into a requirement of spatial and temporal flexibility of the glass. The spatial requirement is typically expressed with two numbers: the pitch of the actuators (or inter-actuator spacing) and their stroke. The temporal requirement is exactly that: namely, how fast can an actuator get to the required position and with what accuracy.

When the actuator spacing, as projected on the primary of the telescope, is small, then the actuators map better on to the atmospheric turbulence scale-length and the resulting correction is better. The stroke has to be sufficient to correct the low-order aberrations and the temporal issue is relatively simple: faster is better. Stroke, pitch and actuator rise times are all technological issues. As mentioned above, the Project Office contracted industrial partners to evaluate the requirements and the specifications for the adaptive optics systems of the two designs for the E-ELT.

Over the past years and in the context of both the past ELT studies at ESO and the FP6 framework, very sophisticated simulations have been used to derive performance requirements for adaptive mirrors to be used in ELTs. Within the E-ELT Project Office we are using this simulation environment to validate the various design options and make choices.

During the selection of the baseline reference design, we investigated the adaptive capabilities of the two designs. This is very much technology-driven. For example, starting from a 30-mm actuator pitch on the Gregorian 4.8-m mirror we would have over 20 000 actuators projected on to the primary, the equivalent of a 20-cm pitch there. The same 30-mm actuator pitch on the 2.5-m quaternary mirror of the five-mirror design only provides 5 000 actuators and a 50-cm pitch on the primary. It is clear that the Gregorian adaptive mirror would deliver better AO performance thanks to the higher number of actuators.

Artificial guide stars

Another part of the adaptive optics puzzle are the laser guide stars to be used to provide the high number of photons required to make fast corrections. Natural guide stars will also be needed to correct for low-order aberrations. Telescopes are focused at infinity, while laser guide stars are images at the sodium layer at a distance of 90 to 160 km from the telescope. The laser guide star images at the telescope focal plane appear significantly aberrated, defocus being the obvious aberration. The in-focus images of the laser guide stars appear as much as 5 m behind (i.e. away from) the telescope focal plane. The extent of the defocus is such that the footprint of the lasers, at the location of the natural guide star adapter, is of the order of a fifth of the total field of view.

While in theory a dichroic could separate off the sodium light and send it in a direction perpendicular to that of the light from the telescope, this solution cannot possibly cover the entire linear field of view of the telescope at the Nasmyth focus, unless the dichroic were also to be segmented. Additionally, going through dichroics introduced non-common path errors for the adaptive optics to handle.

To solve this problem we propose to have a separate adapter for the laser guide stars that will receive the beam from close to the focal plane of the telescope by reflection. The differential focus, as the distance to the sodium layer changes, will be accommodated using relatively simple zoom optics within the laser guide probe systems.

Defocus unfortunately is not the only aberration to be handled. Aberrations in the laser guide stars can of course be handled if they are static. However, they change with the changing distance to the sodium layer. The five-mirror design in this respect has a big advantage over the more classical designs. With three powered mirrors the residual aberrations of the laser guide stars are of the order of 0.3 waves, while for the Gregorian the equivalent is of the order of 4 waves.

Another issue for E-ELTs is the spot elongation of the laser guide stars when

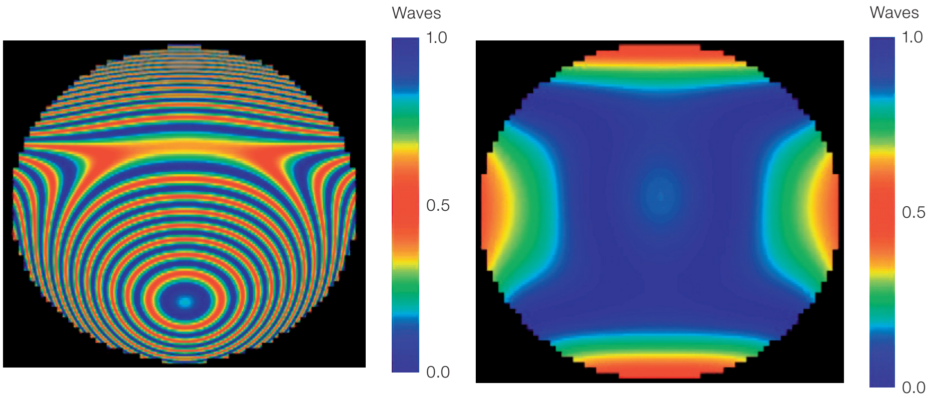


Figure 5: Wavefront aberrations in the laser guide stars. The five-mirror design (right) has a clear advantage over the Gregorian (left).

viewed off-axis. To work efficiently with the laser guide stars we will need to develop new generations of sensors that will allow us to centroid 'stars' that may be a number of arcseconds long. A number of programmes are under way both in Europe and the US to deal with this elongation. Potentially using pulsed lasers, rather than the current generation of continuous wave systems, may provide a very attractive way forward.

Even before the beam arrives at the post-focal adaptive optics systems, the E-ELT, as currently designed, will be able to deliver ground-layer adaptive optics corrections using as many as six laser guide stars and a number of natural guide stars. Ground-layer adaptive optics performance is expected to deliver an improvement of a factor of two or three in the encircled energy within 50 mas for objects within the inner five to seven arcminute field of view. Simulations show that beyond 10 arcminutes, no significant global improvement of the image quality can be expected. Beyond 10 arcminutes ground layer corrections no longer fix very much. Ground-layer correction may also feed more sophisticated post focal AO systems (e.g. multi-object adaptive optics). Laser tomography adaptive optics would also be available from the telescope systems.

Field of view

More field is always nice to have but only if it can be used effectively. As an excellent correction cannot be made across a large field of view, there is a break point where a smaller field telescope with better image quality will beat a larger field of view with poorer image quality. This is a complicated optimisation process that will require the details of the instrumentation to be folded into the design of the global systems. For the time being we are taking the recommendations of the ESE working groups and we retain the 10 arcminute field of view.

Instrument platforms

The E-ELT irrespective of design will have two Nasmyth foci and a Coudé focus. As some of the proposed instruments are expected to be rather large and complex, a gravity stable focus is to be provided even at the Nasmyth. Using a flat mirror and redirecting the beam downwards, an instrument can be installed at a location where it can rotate about the vertical axis and maintain a fixed angle with respect to gravity. To do this the telescope has to be able to change its focal length by relatively small amounts. This is routinely done at the VLT where the exchange from the true Ritchey-Chrétien f/15 focus at Nasmyth to the Cassegrain f/13.6 is performed without exchanging the secondary mirror, but rather by modifying the conic constant of the primary (using the active optics actuators) and refocusing the telescope. For the E-ELT, both the Gregorian and the five-mirror designs can support such a change of focal length. For the Gregorian design we would require that the secondary segments be re-aligned to modify the focal length of the telescope. In the five-mirror solution a natural zoom mode is offered by moving the tertiary mirror in the direction of the secondary. A wide-field Coudé focus can also be provided using this same zoom mode. However, as no requirement for a wide-field Coudé currently exists, a lens relay system is envisaged.

Hosting some of these enormous instruments requires a Nasmyth platform of considerable size. The recommendations of the ESE instrumentation working group have been taken into account and instruments weighing in at over 20 tons and with dimensions as large as 16 m on a side can be accommodated at the focus. More than one of these can be present on the platform at any given time.

Operational requirements

When considering such a large telescope, due attention needs to be paid to the various activities to be undertaken during operations. Exchanging more than one segment per day is likely and with only one E-ELT we will need to facilitate instrument exchanges. During 2006 the instrumentation team, in conjunction with the telescope and dome designers, has worked hard to find an elegant solution for the exchange of instruments. The proposed implementation involves a rail system and instruments that move on pallets. This is very much the same system as is used for the Nasmyth instruments at the VLT although there the pallet is used to carry the cable derotator and support the instrument during maintenance, while on the E-ELT it is expected that the pallet will be used at all times to support the instrument. To remove an instrument from the Nasmyth platform, a hydraulic elevator located in the dome lifts a Nasmyth extension with a matching rail system upon which the instrument can be moved and then lowered to the ground floor. Positions either side of each of the two Nasmyth platforms can be reached by rotating the azimuth of the telescope. Moreover, for the five-mirror design the same elevator can be used to access the secondary mirror for maintenance activities.

One of the prominent science cases calls for a high-resolution extremely stable spectrograph for radial velocity work. The E-ELT is the only one of the major ELT projects to provide a fully fledged Coudé focus. In lieu of the classical Cassegrain focus, the five-mirror design provides an intermediate focus that can be accessed by relatively small instruments to work in the thermal infrared. The implementation of this focus is not simple, as locating a full wavefront sensing capability at the side of the adaptive optics relay unit would be complicated. We envisage an open loop operation with the wavefront sensing performed at the Nasmyth focus. Such a solution will require much further analysis during the design phase of the project.

Although it is not seen as a requirement for the project, the idea of a full-field Atmospheric Dispersion compensator is very attractive for some science cases. The separating prisms solution, employed with great success for the FORS instruments at the Cassegrain foci of two of the Unit telescopes of the VLT, is a solution we are keen to redeploy. However, at the Nasmyth foci it is not possible to combine this solution while simultaneously limiting the introduced aberrations and decentre to sensible values. With a linear field of view of almost 2 m in diameter, a full-field ADC with a rotating prisms solution is also not plausible. The corrected field of view would be limited to the central five arcminutes. Somewhat more seriously the mechanisms for the ADC are likely to obstruct some of the field from where guide stars would need to be picked. In the five-mirror solution, a convenient location for the ADC can be found above the quaternary mirror where the beam is neither too slow nor too fast (f/4) and, with the deformable mirror to follow any introduced aberrations, can be corrected before the beam reaches the focal plane.

Trade-off between optical designs

A detailed trade-off between the Gregorian and the five-mirror design has been performed and presented to the ESO committees and in somewhat abbreviated form to the European community at the Marseille conference in December (see the article by Monnet, page 24). The industrial studies revealed that for a 42-m telescope the complexity, cost and schedule risk of a Gregorian deformable secondary mirror would seriously endanger the project. The deformable mirror of the five-mirror design is anything but straightforward. However, industrial proposals for its construction place it far from the critical path and a number of alternative solutions are available to the project. At 2.5 m in diameter, the quaternary is more than twice the linear size of the biggest deformable mirror currently under manufacture (the VLT deformable secondary mirror) and it would have at least five times, and possibly 10 times, the number of actuators. The 2.7-m field stabilisation mirror (M5) is also far from simple and in the next phase of the project significant attention is likely to be focused on both of the 'adaptive' mirrors. Another major challenge for the five-mirror design is the meniscus secondary mirror. Polishing such a mirror (actually the testing rather than the polishing) requires some innovative approaches. The Project Office has contracted with industry to investigate the matter and a solution, that would have the mirror ready within the timeframe for construction, has been proposed. The complexity of this mirror is comparable to that of the very large flat tertiary mirror of a classical design. A lot of emphasis will be placed on the mechanical support of this mirror and its behaviour in case of earthquakes during the Phase B design.

The advantages of the five-mirror design – in separating the field stabilisation function from the adaptive mirror, providing an instrument friendly focal plane and being laser friendly – make it a very attractive design. The two additional reflections of the five-mirror design are not expected to contribute dramatically to the total mirror count before the photons arrive at the instrumentation detectors. The Project Office will be looking into novel coatings currently under development that can further mitigate the effect of more reflections. Another significant advantage of the five-mirror design is that given the reasonable development timescales for the deformable mirrors, the telescope is well configured to take advantage of future enhancements in the technology of these systems. The cost of an upgrade of the deformable mirror of the five-mirror design to have a higher density of actuators, when this becomes available, would be comparable to that of a novel instrument and could be deployed in a similar or even shorter timescale. In the Gregorian case the cost and schedule of such an upgrade could be prohibitive.

The selection of the five-mirror design as the baseline does not exclude the evolution of many of the design choices. A reader with access to old copies of *The Messenger* may choose to search for the early ideas on the VLT and compare with the as-built observatory.

The ESO Council resolved that we should proceed into Phase B and we have already started our three-year design effort. During this phase we shall investigate the solutions that are in the baseline proposal and other concepts that may arise. Together with industry and institutes, we will fully develop the project with the aim to have a proposal for construction ready to be submitted to the ESO Council in late 2009 or early 2010. A seven-year construction timescale is foreseen.

During the Phase B, the FP6 ELT design study activities will be concluded. That work is expected to provide input on system aspects, control simulations, phasing methods, wind effects, dome designs, edge sensors, instrumentation, operations and other critical areas. The ELT Project Office is working closely with the FP6 programme to, as much as possible, avoid duplications. Within the FP6 programme, there is a site characterisation activity that we expect will start providing additional data on possible locations for the telescope. Currently no site is selected and therefore the project is evaluating the design for a variety of conditions.

Performance

A legitimate question that can be asked, when considering the performance of the E-ELT, is whether a smaller telescope using the same AO technology, e.g. the same number of actuators, would perform better since it could achieve higher Strehl ratios and correction at shorter wavelengths. We have analysed the trade-offs between collecting area and AO per-

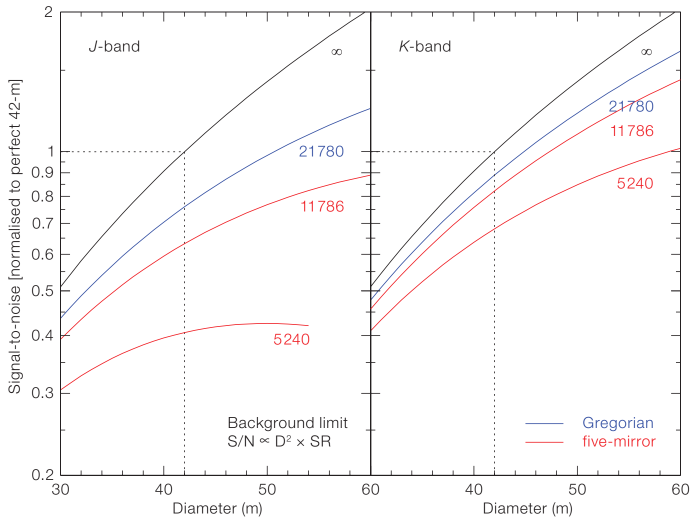


Figure 6: Signal-to-noise *versus* telescope diameter as a function of adaptive optics technology. The numbers of actuators for the options studied are indicated (from top to bottom): perfect AO; 30-mm pitch at the Gregorian secondary; 20- and 30-mm pitch at the five-mirror quaternary.

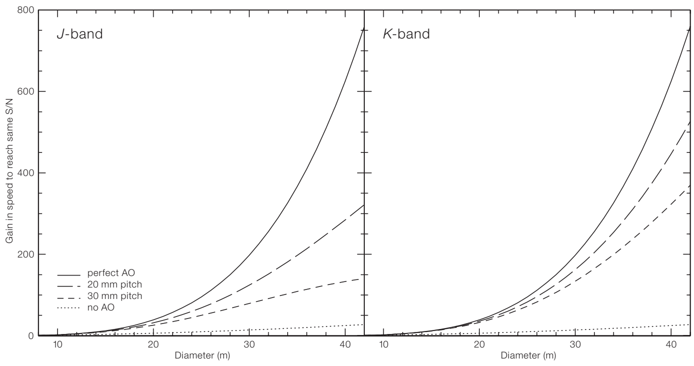


Figure 7: Gain in speed to achieve the same S/N compared with an 8-m telescope. The total number of actuators available at each diameter is kept constant and equal to the two technologies studied for the five-mirror solution.

formance based on the technology options explored by our industrial partners (see Figure 6). We find that in terms of sensitivity at near-infrared wavelengths, the gain in telescope diameter overcomes the loss of Strehl between e.g. 30 and 42 m. At around 50 m, the diameter gain in the *J*-band stops overcoming the loss of Strehl in the case of the lower actuator density technology. (Of course in terms of spatial resolution a larger telescope is always better). As pointed out above, the Gregorian has a better AO performance due to the higher number of actuators that can be accommodated by its larger adaptive mirror.

At shorter wavelengths there may indeed be an advantage of smaller telescopes that is more or less pronounced depending on the actuator technology considered. However, as explained above, the five-mirror design has a clear upgrade path to higher actuator density mirrors that will make the disadvantage a short-term one. Moreover, the requirements to perform AO at short wavelengths do not affect only the number of actuators, but also many other parameters, e.g. the bandwidth of the corrections and the power of the lasers to provide brighter guide stars. So it is not immediately obvious that a smaller telescope with the same number of actuators would be able to perform corrections at, say, optical wavelengths at the time E-ELT will start observing. For these reasons we conclude that the performance of a larger telescope in the range of interest is always superior.

Another way to look at performance is the 'speed', or the time necessary to achieve the same S/N on the same object for telescopes of different diameters. Even at 'constant' number of actuators, the gain of a 42-m telescope with respect to an 8-m telescope is enormous, achieving a value of more than 350 in the *K*-band even for the lower end of the actuator technology (see Figure 7). Although one could interpret this to mean that it would be possible to perform in one 42-m night the observations that take one year at an 8-m telescope (disregarding overheads and assuming identical instrumental configuration), the converse is not true, and the real power of a larger telescope is of course in the ability to detect fainter objects with better spatial resolution. It is also worth noting how much better the gain with diameter is when using AO compared with the gains in the seeing limit.

Acknowledgements

The authors take full responsibility for what is written here, especially for what turns out to be wrong, but the credit for anything that turns out, after the design and construction, to have been a smart idea can be attributed to one or more of: Enzo Brunetto, Mark Casali, Fernando Comeron, Bernard Delabre, Philippe Dierickx, Martin Dimmler, Sandro D'Odorico, Toomas Erm, Christophe Frank, Norbert Hubin, Franz Koch, Max Kraus, Miska Lelouarn, Guy Monnet, Michael Müller, Lothar Noethe, Marco Quattri, Michael Schneermann, Babak Sedghi, Arek Swat, Christophe Verinaud, Elise Vernet, Natalia Yaitskova, Filippo Zerbi; any of the ESO staff that we may have missed; all the scientists and engineers who contributed to the ESE working group; the scientists and engineers at all the industries and institutes that are part of the FP6 ELT Design Studies; and the people that worked with the Project Office during the baseline definition stage.

Reports on the Conference

Towards the European Extremely Large Telescope

held in Marseille, France, 27 November–1 December 2006

As a prelude to the decision by the ESO Council to approve the detailed studies (Phase B) for the European Extremely Large Telescope (E-ELT) project, a meeting was held in Marseille to comprehensively present and discuss the extensive planning for this exciting project. The conference was attended by 250 astronomers and engineers (see the conference photograph in Figure 1). The strong support, together with detailed considerations and feedback from the community provided by this meeting were instrumental in the ESO Council decision a few days later. They will be further harnessed in the years to come. There were three sessions, devoted to science (1.5 days), the telescope design (1.5 days) and instrumentation (1 day). In the following articles, a summary of each session and the list of speakers and posters is presented, by the chairs of the three sessions: Isobel Hook, Guy Monnet and Jean-Gabriel Cuby.

A general discussion was held on the Thursday morning on various aspects on the project, including the need for flagship science cases, telescope design trade-offs (size, image quality), instrumentation priorities, operating modes and synergies and complementarities with other facilities. The discussion closed with the ELT Standing Review Committee (ESRC) view presented by Roger Davies and the conclusions by the ESO Director General Catherine Cesarsky. The conference web page is at *http://www.elt2006.org* where most of the presentations are accessible.

Photo: J.-P. Goudal, OAMP

Figure 1: Conference photograph taken outside the venue – Le Palais du Pharo – overlooking the Vieux Port of Marseille.

Summary of Science Sessions

Isobel Hook
(University of Oxford, United Kingdom)

The meeting began with sessions dedicated to the science drivers for the European ELT project. Many ELT science themes are already well developed through the work of the OPTICON network (see summary in Hook 2005a and the full science case in Hook 2005b), the OWL science case (see *http://www.eso.org/projects/owl*) and more recently by the ELT Science Working Group (see *http://www.eso.org/projects/e-elt/*). During the 1.5 days of science talks at this meeting these themes were developed and new ideas also emerged.

Extremely Large Questions – and how the ELT will answer

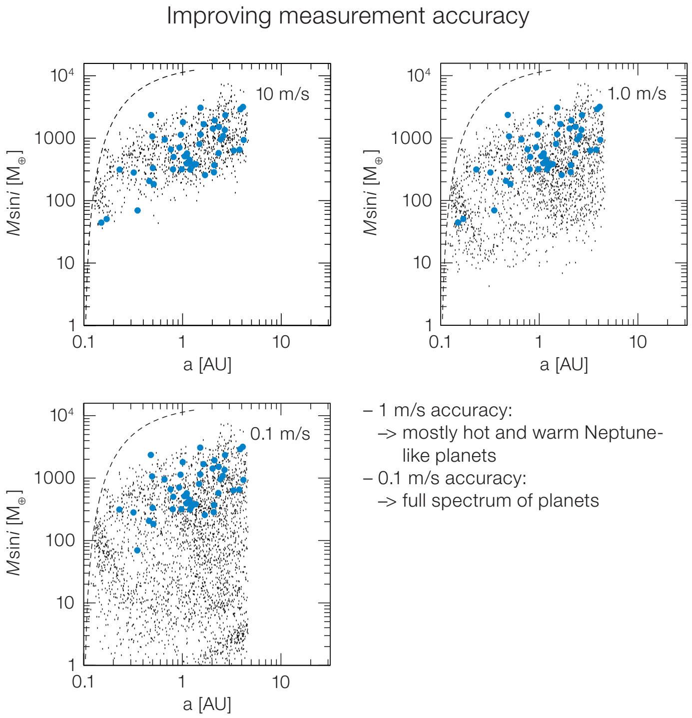
Many of the speakers discussed the current 'big questions' in astronomy and the ways in which an ELT will provide answers. Some showed the results of simulations or calculations made using the ELT exposure time calculator (described and demonstrated at this meeting by Markus Kissler-Patig). In the summary below the names of the speakers are given in brackets.

Exoplanets and discs

Some big questions:
- *What is the formation mechanism for planetary systems?*
- *What is the impact of feedback on star formation?*
- *What is the origin of stellar masses and the Initial Mass Function?*

The radial velocity technique – an indirect method for detecting planets via the Doppler wobble that they produce on their parent stars – was highlighted as a very powerful method for studying low-mass planets, and an ELT has the possibility to even reach down to Earth mass planets (Pepe and Chabrier). Improving the accuracy of radial velocity measurements to 0.1 m/s would reveal the entire

Figure 1: Gilles Chabrier in his presentation showed this schematic of the advances in terms of number of exo-planet detections expected from an increase in radial velocity accuracy from 10 ms^{-1} through 1 ms^{-1} to 0.1 ms^{-1}. The individual plots for the mass-distance diagram of exo-planets are from theoretical predictions by Mordasini et al. (2007) based on a theoretical formation model by Alibert et al. (2005). The black dots are the expected detections and the blue circles a comparable subset of known exoplanets. The sharp cutoff at about 5 AU is due to an assumed duration of ten years for the radial velocity survey.



underlying planet population, of which only about 10 % are accessible with current instruments (see Figure 1). This method will provide mass estimates for planets discovered by future transit searches such as COROT and KEPLER.

The ELT's collecting area and spatial resolution will also give it the key ability to directly detect exoplanets, as has been discussed previously (Hook 2005a, 2005b). Among the wealth of physical information provided by direct detection, Chabrier highlighted the use of direct luminosity measurements of the planet to provide key evidence for the initial conditions of the planet formation process. ELT thermal-IR spectroscopy may allow us to distinguish between brown dwarfs and exoplanets via the CO line (although the expected signatures are still not well known).

Direct imaging with an ELT (and JWST, plus astrometric observations, e.g. from GAIA) can extend the search for planets around white dwarfs 4–5 magnitudes deeper than currently possible, bringing new targets into view and allowing detection of planets with masses in the range ~1–3 M_{Jup}. This will tell us about the late evolution of planetary systems (Burleigh).

In the area of star formation the complementarity with other facilities (particularly ALMA and JWST) is very important. The superb spatial resolution of an ELT is a particular strength that will allow it to carry out a census of binary stars in clusters, which provides a probe of their formation mechanism. For example the ELT will be able to measure dynamical masses of brown dwarf binaries via astrometry (McCaughrean).

Superb spatial resolution will also allow the ELT to study dust agglomeration and processing in proto-planetary discs (via mid-IR imaging and spectroscopy, combined with ALMA). The tell-tale signs of planet formation – such as gap formation and disc warping – should be visible via near- and mid-IR imaging in dust and debris discs (McCaughrean). Indeed new simulations (Wolf) show that an ELT could detect local heating of the disc by a planet. The ELT's sensitivity to large dynamic range makes it ideal for studying the outer planet-forming region of the disc, complimentary to interferometry with VLTI for studying the inner regions (Wolf). With an ELT it would also be possible to map out the magnetic field strength in the discs of T-Tauri stars in nearby star-forming regions, as well as the field

Science Session – Talks	
Exoplanets and discs	
Gilles Chabrier	Invited review: Exoplanets
Mark McCaughrean	Invited review: Star formation
Sebastian Wolf	The formation of planets and planetary systems – science case for the ELT
João Alves	Towards pan-star formation
Matt Burleigh	Searching for ancient Solar System planets around white dwarfs
Francesco Pepe	Exoplanets by high-precision radial velocities with ELTs
Galaxy Formation	
Piercarlo Bonifacio	Invited review: Stellar populations
Livia Ogiglia	Near IR spectrosocopy: a powerful tool to trace resolved and integrated stellar populations
Renato Falomo	Probing the stellar population of galaxies with ELT
Simon White	Invited review: Physics and evolution of galaxies
Andrew Bunker	Invited review: First galaxies and reionisation
Matthew Lehnert	The physics of galaxy assembly
Mathieu Puech	Mapping the galaxy mass assembling with ELTs
Steffen Mieske	Cosmic flow studies with the ELT: how far can we reach with the SBF method
Emmanuel Rollinde	The IGM at high-*z*: the UV part of the spectrum

Frontiers of Physics	
Hans-Walter Rix	Invited review: Black holes
Peter Schneider	Invited review: Fundamental constants and cosmological parameters
Jochen Liske	The Cosmic Dynamics Experiment
Paolo Molaro	Varying fundamental constants @ ELT
Rhaana Starling	The highest redshift stars – gamma-ray bursts
Isobel Hook	Simulated observations of distant galaxies (and supernovae) with ELT AO systems

Science Session – Posters	
Philippe Amram	Rotation curves at high redshifts
Masanori Iye	Discovery of a galaxy at z=6.964 and its implication
Markus Kissler-Patig	The E-ELT Exposure Time Calculator
Simona Mei	Evolution of galaxy clusters at $z \sim 1$
Claudia Mendes de Oliveira	The low surface brightness and ultra-compact dwarf population in nearby groups
Paola Merluzzi	Pushing frontiers of galaxy evolution in clusters
Norbert Przybilla	Blue Supergiants beyond the Local Group
Hans Zinnecker	Magnetic fields in young stellar objects and star forming regions: a polarimetric ELT science case

topology over the stellar surface using polarimetry techniques such as Zeeman-Doppler imaging (poster by Zinnecker).

Galaxy formation

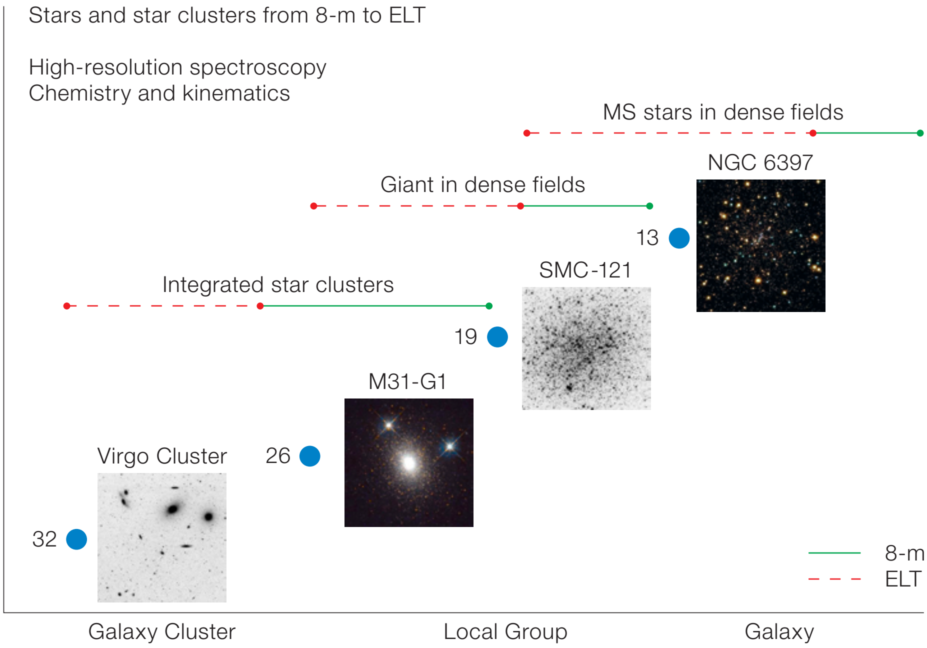
Some big questions:

- *What is the distribution of baryonic and dark matter in galaxies?*
- *How does the distribution evolve with redshift?*
- *When and how did galaxy halos form?*
- *What is the assembly sequence of the major components of galaxies?*
- *What is the role of internal versus external processes in building galaxies?*
- *Where did all the angular momentum come from? (observations show significantly more angular momentum than is predicted by galaxy formation simulations).*
- *How and when was the Universe reionised?*
- *How do the heavy elements cycle between galaxy components and the IGM?*

The spatial resolution of an ELT makes observations of individual stars in galaxies beyond our Local Group possible. Falomo highlighted the use of imaging to produce colour-magnitude diagrams (CMDs) – he presented a method of counting stars in regions of near-IR CMDs which, with an ELT, could be used to obtain basic star-formation histories of several galaxies as distant as the Virgo cluster.

An ELT would also be a very powerful spectroscopic tool for the study of stellar populations (Figure 2) – indeed a 42-m ELT would allow spectroscopic measurements about four magnitudes fainter than the JWST in the IR because it could resolve stars in significantly more crowded regions (Origlia). These measurements will tell us about the age of the stellar populations and hence the merger history of the galaxy. This in turn will allow us to understand the location and role of dark matter in the formation process. By using the ultraviolet (UV) parts of the spectrum we can study hot and metal-poor stars (Bonifacio) while in the infrared we can study cool and metal-rich stars, for example using Fe, and CNO as indicators (Origlia). A poster by Przybilla described

Figure 2: Schematic diagram showing the distance to which various stellar populations can be studied spectroscopically with current 8-m telescopes (green lines) and with a future 40-m ELT (dashed, red lines). The blue circles with associated number indicate the distance moduli of the representative targets (from presentation by Livia Origlia).



improvements in the theoretical interpretation of IR spectra of blue supergiants and the prospects for observing these luminous stars to large distances with an ELT.

ELTs will be capable of studying the very first galaxies, and the partnership of ELTs and JWST (which will be particularly powerful for finding the galaxies) will be crucial in this area (Bunker). Very high redshift galaxies can be found using narrow-band imaging techniques (as demonstrated by the discovery of a $z \sim 7$ galaxy – see the poster by Iye et al.) with JWST or possibly the ELT itself, and their physical properties investigated with ELT spectroscopy. The ELT will have spatial resolution matched to the size of individual H II regions at high redshift (Bunker). Another possibility for finding early galaxies is to locate the host galaxies of Gamma Ray Bursts (Starling). The ELT will also chart the evolution of metal enrichment in the intergalactic medium (Bunker) with spectroscopy of distant 'background' sources such as QSOs and GRBs (Rollinde and Starling).

With an ELT we will be able to study large samples of distant galaxies and measure motions of gas, star-formation rates and chemical abundances at many locations within each galaxy, shedding light on the physical processes at work and the role of dark matter in galaxy formation (Lehnert, Puech, posters by Merluzzi and Amram). The impressive maps of velocity fields in galaxies at $z \sim 2$–3 recently made using integral field spectrographs on the VLT (Forster-Schreiber et al., 2006; Genzel et al. 2006; Nesvadba et al. 2006), are very promising but still allow a range of interpretation because of limited spatial resolution (Lehnert). An ELT will allow higher spatial resolution observations at higher signal-to-noise – for example Puech showed simulated observations of rotation curves at $z \sim 1.6$ and dynamical classification of galaxies to $z \sim 4$ that could be made using an IFU fed by multi-object adaptive optics on an ELT.

In these ways (and combined with what we will learn about black hole formation – see the next section) an ELT will test our understanding of galaxy formation by making detailed comparisons with the predictions of galaxy formation simulations (White).

Frontiers of Physics

Peacock and Schneider (2006) provide a concise overview of this extensive field.

Some big questions:

- *What is the physics of black hole growth?*

– *Can we quantitatively chart new relativistic effects near black holes?*
– *What is the dark matter?*
– *What is the dark energy?*
– *Did inflation happen?*
– *Is standard cosmology based on the correct physics? Are features such as dark energy artifacts of a different law of gravity, perhaps associated with extra dimensions? Could fundamental constants actually vary?*

The extremely high spatial resolution of an ELT will allow us to probe the "sphere of influence" of black holes at large distances from us, and hence measure the abundance of black holes and their masses. Synergy with VLTI (for high angular resolution) and JWST (for surface brightness sensitivity) were pointed out as particularly important (Rix).

Astronomy is uniquely placed to study the effects of dark energy and inflation, and can also make significant contributions to understanding dark matter and the laws of physics (in combination with laboratory experiments). The ELT's collecting area will allow it to make significant advances, for example it will be able to study Type Ia supernovae well beyond the current limits, possibly out to redshifts of around four, allowing us to measure the expansion history of the Universe and hence the effects of dark energy (Hook). With a very high resolution, high-stability spectrograph (such as the CODEX concept) – it will be possible to observe the expansion of the Universe in "real time" over a period of a decade or two (Liske). This direct, dynamical measurement of the expansion of the Universe should match geometrical measurements such as those provided by supernovae – this is a fundamental test of our model of the Universe and the framework of general relativity on which it relies.

An extremely stable, high-resolution spectrograph would also be capable of measuring changes in fundamental constants such as the fine structure constant (α) to much greater accuracy – two orders of magnitude better – than currently possible. Such a measurement is fundamentally important – variation in α would point to extra dimensions in the Universe as predicted by string theory. It would also distinguish between dynamical models for dark energy and Einstein's cosmological constant. Only astronomy can probe the value of these constants in remote regions of space-time (Molaro).

Absorption in the spectra of distant sources caused by intervening clouds of neutral hydrogen provides information about the structure of the Universe on the smallest scales (Rollinde). This can be used to test the model of inflation when combined with measurements on much larger scales (e.g. from Cosmic Microwave Background measurements).

What's New?

At this meeting we obtained a refreshing new perspective on the science case for an ELT. One area given increased emphasis compared to previous science case studies is the UV part of the spectrum. UV spectroscopy of metal-poor stars can be used to understand the discrepancy in Lithium abundances compared to the predictions of the Big Bang Nucleosynthesis model (Bonifacio). The potential use of Berylium and Uranium as age indicators was also highlighted. The UV is also beneficial for the study of QSO absorption lines enabling (for example) the measurement of the non-Euclidean geometry of the Universe which is revealed in a difference in structure evolution observed in angle versus along the line-of-sight (the Alcock Paczynski test, Rollinde).

In addition to 'new' science, some previously-studied cases were given increased emphasis – the radial velocity technique for planet detection is one such case. Improving the accuracy of radial velocity measurements to ~ 1 m/s would reveal mostly hot and warm Neptune-like planets. Improving the accuracy to 0.1 m/s would reveal the entire underlying planet population, of which only about 10 % are accessible with current instruments (Chabrier, Pepe). This requires a very high-stability spectrograph (e.g. CODEX) but also sufficient photons – the ELT will bring a larger sample of stars within reach of this technique.

Mieske introduced the subject of Surface Brightness fluctuation measurements with an ELT – this could potentially allow measurement of the distance scale to 10–15 % out to redshift ~ 0.1, which would dramatically improve the overlap with Type Ia supernovae in the measurement of the extragalactic distance ladder. However, the technique is sensitive to PSF variations across the field and this effect needs to be simulated. The case for using distant Type Ia supernovae to measure the effects of Dark Energy was also given higher prominence at this meeting (Hook).

The velocity field measurements with VLT integral-field instruments show promise for future ELT multi-IFU instruments in the study of the physics of galaxies (as described in talks by Lehnert and Peuch and poster by Amram).

Finally

Throughout this meeting the importance of complementarity with other facilities was a recurring theme. In many cases, future ELT science will be greatly enhanced with data from (for example) COROT, KEPLER, VLTI, ALMA, GAIA and JWST. In some cases contemporary observations are needed, requiring that the ELT is built rapidly so as to be operating at the same time as JWST.

And finally, after hearing about a wonderful range of science that an ELT can do, we should not forget that some of the ELT's most exciting future discoveries were not mentioned at all at this meeting – the ELT will almost certainly reveal surprises in the Universe that we cannot even imagine now!

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Summary of Extremely Large Telescope Session

Guy Monnet (ESO)

E-ELT (ESO) Session: The E-ELT Programme	
Catherine Cesarsky	ESO, Europe and the World Scene
Roberto Gilmozzi	Overview of the Programme including ELT-DS
Establishing the basic E-ELT Concepts	
Marijn Franx	Science WG Conclusions
Colin Cunningham	Instrumentation WG Conclusions
Gérad Rousset	Adaptive Optics WG Conclusions
Roland Gredel	Site Evaluation WG Conclusions
Daniel Enard	Telescope Design WG Conclusions
Daniel Enard	E-ELT Top-level Requirements
Towards the E-ELT Basic Reference Design	
Jason Spyromilio	Telescope Design Overview
Arne Ardeberg	Aspects of Combined Gregorian/Nasmyth Design
Sandro D'Odorico	Instrumentation Aspects
Fernando Comerón	Operational Aspects
Jason Spyromilio	BRD Close-out and Discussion
General Discussion on the E-ELT Programme	

The one and a half day ELT Session started on Wednesday, 29 November with presentations of the facility high-level goals. The Basic Reference Design (BRD) of the E-ELT project had been established during the first nine months of 2006 with the help of and for the ESO community. The session mirrored the Basic Reference Design (BRD) process, starting with the final reports from the five topical community-ESO Working Groups (Science, Instrumentation, Adaptive Optics, Site Evaluation and Telescope Design) and followed by the E-ELT top-level requirements, distilled by the ELT Science & Engineering (ESE) Working Group. The BRD of the facility (Telescope, Instruments & Operation) was then presented by the ESO ELT Project Offices, with, in addition, an in-depth presentation of an alternative basic telescope design – the Gregorian option by the Euro50 team.

E-ELT high-level goals

The ESO goal is to provide an ELT for and to the community, with continuous feedback during the process and full involvement of research institutes and high-tech industries. The decision time was immediately after the meeting, with the objective to start operation of the facility no later than 2018.

E-ELT top-level requirements

The full ELT 'toolbox', created in the first four months of 2006 by the five topical ESE Working Groups is accessible from *http://www.eso.org/projects/e-elt/publications.html* and the five chairs presented a comprehensive summary of their respective Working Group conclusions during the conference. The top-level requirements distilled by ESE call for an instrumentation-friendly visible to mid-infrared collector with a superb image quality, a built-in adaptive optics corrector and a working field of up to 10 arcmin diameter. Special emphasis is put on getting a general-use facility with fast all-sky access and a fully flexible scheduling capability. Attention should be given to synergies with ALMA, VLT and JWST.

E-ELT Basic Reference Design (BRD)

The BRD has been developed by the then (1 June 2006) newly created ESO E-ELT Project Office, still in close connection with the ESO community. It is in charge of the project and is getting advice from the ESE subcommittee established by the ESO STC. Furthermore, the ESO Council has established the ELT Standing Review Committee (ESRC) to oversee the whole project.

Two basic optical designs have been carefully explored. Each holds a 42-m f/1 aspheric primary mirror, covers a 10 arcmin diameter field and offers multiple foci for instrumentation. One, analogous to Euro50, features a three-mirror combination with a concave (Gregorian) secondary mirror. The other is a five-mirror combination with a convex (Cassegrain) secondary mirror. The two designs are shown in Figure 1 of Roberto Gilmozzi and Jason Spyromilio's article on the E-ELT in this issue (page 11).

Detailed mechanical models for both approaches were developed and iteratively optimised. Their pointing performances were established under closed-loop operation. Detailed feasibility, costing and schedule for all critical components – especially the large internal deformable mirror – were obtained. Choosing between these two alternatives provoked lively debates within the Working Groups, especially the Telescope Design one, with ESE and ESRC, and finally during the conference. The final consensus was to take the five-mirror design as the baseline choice henceforth, with the three-mirror option as a backup to be further explored in the next years. Overall feasibility of the project has now been well established, with excellent performance, a global facility preliminary cost around 850 M€ (for a 42-m primary) and a ~ 10 year design and construction schedule.

General Discussion and Conclusions

Following the conference discussions, and given the ESO Council decision, to start immediately the full design phase (Phase B) of the European ELT project, a very large consensus was reached on the following actions:
- develop in parallel with community help an in-depth scientific Design Reference Mission (DRM), identifying in particular flagship science cases (extra-solar planets, physics of galaxies at all redshifts, foundations of physics);
- establish from the DRM the expected scientific performance versus telescope diameter to permit an early decision (June 2007) on that crucial design and cost/timeline parameter;
- put forward, together with the community, a long-term instrumentation plan, scientifically optimised through the DRM, but also featuring a simple instrument ready from Day 1;
- keep the VLT dual operation model (service and classical) with a mix of individual, large and legacy programmes and, when the facility enters into operation, let it evolve with the market;
- establish a high level of collaboration with the other ELT projects, in particular on enabling technology programmes, site selection and cooperation, e.g. plan for complementary instruments with reciprocal access.

Summary of Instrument Sessions

Jean-Gabriel Cuby
(Laboratoire d'Astrophysique de Marseille)

The conference week ended with the instrumentation session on Thursday afternoon and Friday morning (see tables for lists of talks and posters). Instrumentation aspects had been introduced earlier in the week by D'Odorico who presented preliminary designs of the telescope instrument interface and future plans for instrument studies and development. The first part of the instrumentation session on Thursday afternoon was dedicated to presentations of instrument conceptual studies performed in the context of the ELT Design Study (DS), a technology development programme supported by the Sixth Framework Programme (FP6) of the European Commission and coordinated by ESO. Some of these instrument studies were initiated in 2005 in the context of the ESO 100-m OWL telescope and were further elaborated in the framework of the ELT Design Study. Cunningham gave an overview of the eight instruments that would be described later, stressing the main outcomes of these studies and the future plans, and providing a comprehensive overview of the technology developments that will be required. Some of these developments are already being carried out as part of the FP6 OPTICON and ELT DS programmes.

Brandl began the series of instrument talks presenting MIDIR, a mid-IR imager and spectrograph concept for the E-ELT. This is a high visibility, multi-purpose instrument to study in particular planet formation, the Galactic Centre, the environment of black holes, etc. A poster by Lenzen described a VLT instrument concept that could serve as a prototype of MIDIR on the E-ELT, and a poster by Venema detailed some of the technical solutions to be implemented on MIDIR. Dent then presented HISPEC, a high spectral resolution (R ~ 150 000) near-IR spectrograph concept covering a wide range of scientific applications, from the radial velocity detection of low mass exoplanets, the characterisation of exoplanet atmospheres, to the study of the IGM at high redshift.

Two instruments, MOMSI and WFSPEC, looking somewhat similar at first sight, were presented by Evans and Moretto respectively. However, the instruments are aimed at rather different – but both highlight – science cases. MOMSI is a near-IR multi-IFU instrument designed for resolving stars in nearby galaxies – out to Virgo for the brightest populations. WFSPEC is designed for the study of the first objects in the Universe and the study of the physical processes at work in galaxy

Instrumentation Session – Talks

Small Studies	
Colin Cunningham	Overview of the FP6 ELT Instrumentation Programme and Technology Challenges for ELT Instruments
Bernhard Brandl	MIDIR, the Thermal/Mid-IR Instrument for the E-ELT
Bill Dent	HISPEC, the Case for High-resolution Near-IR Spectroscopy on the ELT
Chris Evans	MOMSI: A Multi-object, Multi-field Spectrometer and Imager for the European ELT
Gil Moretto	Wide-field Spectrograph Concepts for the European Extremely Large Telescope
Christophe Verinaud	Imaging and Characterising Exoplanets with the E-ELT: the Challenges of EPICS
Luca Pasquini	CODEX: an High-resolution Visual Spectrograph for the E-ELT
Michael Redfern	HITRI, the High-time Resolution Instrument for the E-ELT
Other concepts and detectors	
Mark Casali	Near-IR Imager for the ELT
Gavin Dalton	IR Detectors
Francisco Garzón	SMART-MOS: a NIR Imager-MOS for the ELT
Eric Prieto	A Target Selection System for ELT Multi-object Instruments: System and Trade-off Analysis
High-contrast imaging	
Anthony Boccaletti	Comparison of Coronagraphs for Exoplanet Imaging with ELTs
Niranjan Thatte	High-contrast Imaging Spectroscopy of Extrasolar-planets with an Integral-field Spectrograph
Wide-field Imaging and Spectroscopy	
Benoît Epinat	Wide-field Spectro-imaging and High-*z* Galaxies: Merit Factor for Several Concepts
Eric Gendron	Multi-object AO System for the E-ELT – Strategy and first results
Roberto Ragazzoni	Wide and Very Wide Field Imaging as a New Challenge for E-ELT Adaptive Optics
Hans Ulrich Käufl	Quantitative Analysis of Infrared Sensitivities for High Altitude Sites

Instrumentation, Adaptive Optics and Site Testing Posters

Bill Dent	SCELT – a wide-field submillimetre camera for the ELT
Denis Fappani	Deformable MS-VLT THIN Shell manufacturing
Marco Ferrari	New active optics techniques for large off-axis segments manufacturing
Olivier Hernandez	Improved 3D spectrograph for ELTs: applications of new technologies
Olivier Hernandez	3DSiS: 3D spectrograph improved simulator for ELTs
Florian Kerber	Calibration of ELT instruments
Rainer Lenzen	An AO-supported Mid-IR facility as a second-generation instrument for the VLT, prototyping the E-ELT
Noria Lorente	SPECSIM: the IFU Spectrometer Simulator
Fabrice Madec	Active beam steering mirror concept for multi-IFU
Patrice Martinez	Optimisation of Apodized Lyot Coronographs for ELTs
Vincent Minier	ArTeMiS: Wide-field submillimetre imager for next-generation telescopes
Iciar Montilla	Monolithic Integral Field Unit Spectrograph for the E-ELT
Hernán Muriel	Site Testing in the North-West of Argentina
Mamadou N'Diaye	Coronagraph feasibility studies on FRIDA
Guy Perrin	Diffraction-limited high dynamic range imaging with the E-ELT from the visible to the infrared
Didier Rabaud	New concept of Real Time Computer based on bi-Xeon cluster ATCA Infiniband for next-generation OA (1000–10000 actuators)
Didier Rabaud	Electronics drive for new generation OA (1000–10000 actuators)
Raymond Sharples	Novel Technologies for Imaging and Spectroscopy
El Arbi Siher	Aerosol index map over North Africa ELT sites
Christian Surace	Towards a new kind of processing software, a FASE prototype
Samantha Thompson	Developments in large adaptive carbon-fibre composite mirrors for ELTs
Lars Venema	MIDIR – technical solutions for the thermal/mid-IR Instrument for the E-ELT
Jean Vernin	Present status of Dome C site testing – Implication for an ELT
Arthur Vigan	ZEUS, a cophasing sensor for the future ELTs
Sébastien Vivès	Innovative Global Approach for High-performance Low-cost Integral-field Unit (IFU)
Frederic Zamkotsian	MOEMS devices for ELT instrumentation

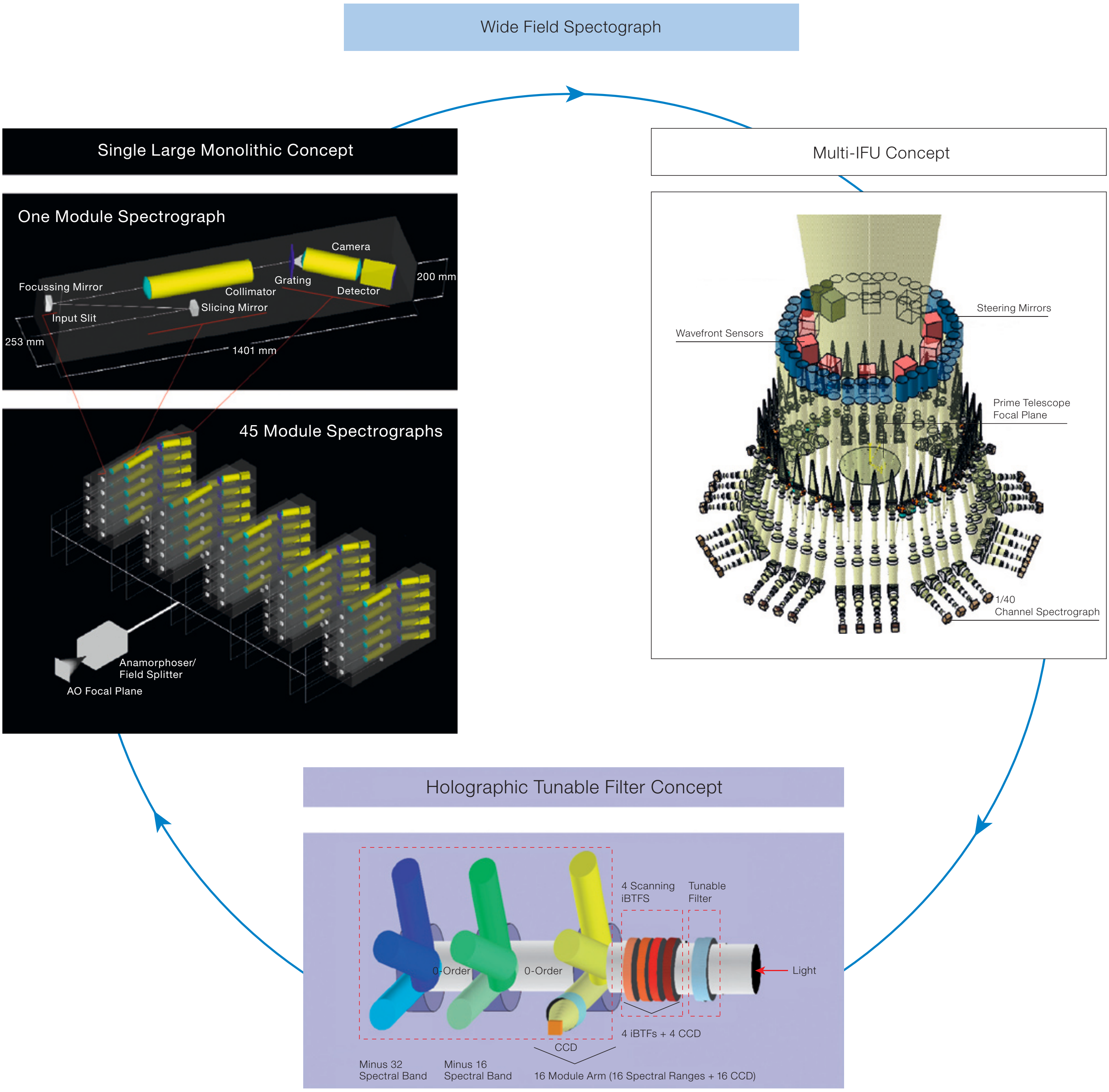

Figure 1: Instrument concept studies were performed as part of the FP6 ELT Design Study. Their aim was to define the global concepts, identify the requirements on telescope and site, and to elaborate roadmaps, but not to perform detailed designs (the interface to the telescope was not available since the E-ELT Basic Reference Design was proceeding in parallel). Here is illustrated the case of a wide-field spectrograph, for which three different concepts were investigated.

formation and evolution across cosmic times. The differences between MOMSI and WFSPEC lie in spatial and spectral resolution requirements. A series of posters described alternative concepts to WFSPEC (Montilla, Hernandez) and detailed aspects of WFSPEC subsystems (Madec, Vives).

The following talks presented what are probably the two most challenging instruments for some of the most fascinating 'extreme' E-ELT science cases. The instrument for detection and characterisation of planets in outer planetary systems (EPICS) was presented by Verinaud. Studies at the frontiers of physics, such as the direct measurement of the differential expansion of the Universe and the universality of the physical constants (the CODEX instrument) was presented by Pasquini. EPICS is one of the most demanding instruments in terms of telescope and Adaptive Optics performance, while CODEX requires innovative instrumental concepts to achieve the required instrument stability.

The day concluded with Redfern stressing the importance of designing E-ELT instruments with detectors providing high-time resolution capabilities that could open up a variety of science cases dealing with rapid phenomena in stars, close binaries, pulsars and AGNs. The last instrument presented which formed part of the ELT Design Study, SCELT, is a submillimetre instrument and a nice complement to ALMA, if the E-ELT was to be located on a very high altitude site (poster by Dent).

Starting the last day of the conference, Casali presented two near-IR imager concepts for the E-ELT, a Narrow-Field MCAO imager and a Wide-Field (~ 7 arcmin) Imager for which various AO options can be contemplated. Some flavour of this instrument is likely to be the first science instrument on the E-ELT. The instrument presented by Garzón relies on MOEMS (MicroOptoElectroMechanical Systems) for a 2 arcmin field of view near IR Multi-Object Spectrograph, using a micro-mirror array. A poster by Zamkotsian provided further details on MOEMS micro-slit and micro-deformable mirror technology and characterisation.

The second part of the instrumentation session concentrated on specific aspects of the instruments or on adaptive optics. Dalton defended the case for an innovative approach to IR detector development and procurement. Indeed, procurement of the many (> 100) 2 k × 2 k IR detectors, ideally required for the complete E-ELT instrumentation plan, would represent one of the highest single cost items of the whole project, not mentioning the risks associated with reliance on a single source procurement. Prieto presented a system and trade-off analysis of a target selection system based on pick-off and beam steering mirrors, including parameters related to the telescope interface. This target selection system can be used to feed a multi-channel instrument, or a multi-purpose instrument facility.

Two talks dealt with methods under consideration for the direct detection of exoplanets. Boccaletti presented a system analysis of various types of coronographs, concluding that the Apodized Lyot coronograph, detailed in a poster by Martinez, was the most promising candidate. Thatte gave a fairly convincing talk on the promise of integral-field spectroscopy illustrated by real data obtained at the VLT with SINFONI on AB Dor.

The relative merits of various instrument concepts (multi-IFU, single-IFU and a scanning system) were illustrated by Epinat for two types of high-redshift galaxy observation: when the position of the sources are known; and for blind searches of line-emitting objects. Gendron presented the challenges of Multi-Object Adaptive Optics (MOAO) with preliminary results from simulations and laboratory measurements, and a roadmap to MOAO, including technology developments and demonstration experiments. Ragazzoni gave as usual a very lively talk, presenting his latest thoughts on the merits of natural and laser guide stars and their impact on the performance of wide (and even very wide!) imaging on an ELT. No doubt this discussion will go on for some time yet. The final talk was by Käufl who presented an interesting model for simulating the atmospheric radiance and transmission in the near-IR, up to five microns, allowing quantification of the gains to be achieved in this thermal IR regime by going to high altitude (and cold) sites. The meeting was brought to a conclusion by Gilmozzi who summarised the many paths that led to the E-ELT design that were presented during the conference in Marseille.

The conference was a timely opportunity to revisit all the instruments that had been in the air, either for OWL or as part of the ELT Design Study effort, and to enter into the details of some of them. It is however clear that the initial suite of the E-ELT instruments will have significantly fewer instruments in total, and/or will require some combinations of those proposed. The process by which these instruments will be selected, studied and procured will be elaborated in the next months, as the whole project proceeds to Phase B. The E-ELT Marseille Conference will be remembered as the place and time where and when the first part of the road to the E-ELT was paved.

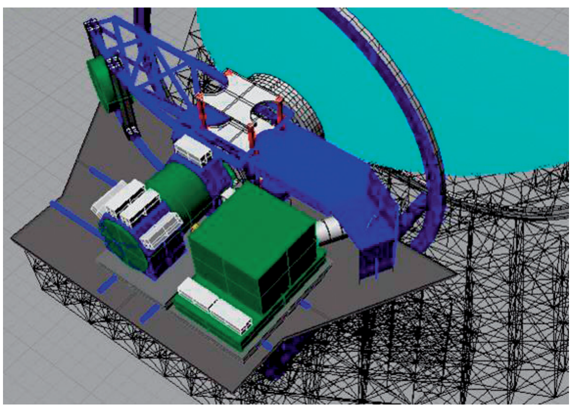

Figure 2: A schematic view of a planned E-ELT Nasmyth platform is shown, with two science instruments in place on the platform and a test camera (green box to upper left).

ESO Public Surveys with the VST and VISTA

The ESO Survey team:
Magda Arnaboldi, Mark J. Neeser, Laura C. Parker, Piero Rosati, Marco Lombardi, Jörg P. Dietrich, Wolfgang Hummel

A new chapter for European astronomy will soon begin with dedicated survey telescopes in the optical and near-infrared. The intent of this article is to illustrate the ESO policies for managing Public Surveys (PS) and validating their advanced data products, to introduce the VST and VISTA telescopes along with their wide-field instruments, and to provide a brief summary of the planned public surveys.

ESO policies for Public Surveys and their implementation

The large collaborative surveys selected for VST and VISTA within Europe target many of the fundamental questions in astrophysics today, ranging from the nature of dark energy to the universality of the stellar initial mass function (see *http://www.eso.org/observing/webone.html* for more details of ESO Public Surveys). In the following, we illustrate briefly the mechanisms that ESO has set in place to manage the survey projects, to ensure their legacy value and their usefulness for the astronomical community at large.

The Survey Management Plan

The Principal Investigators (PIs) whose public survey proposals have been reviewed by the Public Survey Panel (PSP) and recommended by the Observing Programme Committee (OPC) are then asked to submit a Survey Management Plan (SMP). The ESO Guidelines for the preparation of the SMP are available at *http://www.eso.org/observing/ps/Guidelines_SMP.pdf*

The SMP represents an additional form requested from the PIs and it is an integral part of ESO's appraisal of the proposal. The SMP aims at collecting the necessary information to carry out PS in Service Mode (SM), and allows for an efficient and timely planning of Phase 2 and telescope operations. The SMP must illustrate the observing strategy, the survey data calibration needs, the data reduction process, the manpower and hardware capabilities, the data quality assessment process, and the data product delivery to the Virtual Observatory. During the SMP process, the iterations with the Survey Consortia for the definition of the observing strategy will ensure that at no time are there ever more than two active PS covering the same RA range or similar observing conditions (dark time, excellent seeing, etc.).

The ESO survey team

The ESO survey team (EST) follows the implementation of the ESO policies for PS. The EST members are Magda Arnaboldi (team leader), Jörg Dietrich, Wolfgang Hummel, Mark Neeser, Laura Parker, and Piero Rosati. In the framework set by the current policies, the EST has a role which is similar to that of an audit group. We will support the teams during their observations with the survey instruments and telescopes (VST and VISTA), monitor the progress of the surveys, and referee the data quality of the PS products submitted for ingestion into the ESO archive, based on the quality control parameters and technical reports provided by the survey consortia.

Monitoring of the survey progress

The PSP is asked to serve as independent referee of the progress and achievements of the PS. The Chair of the PSP will receive a yearly report by the EST with the information on the basic monitoring of the progress for each PS. The first progress review will be carried out one year after the surveys have started, and then once per year, until the completion of each survey. The EST leader, after consultation with the PSP Chair, will report to the OPC on the status and progress of each PS. Furthermore, any time required for additional survey related observations (e.g. spectroscopic follow-up) at other ESO telescopes must be applied for.

Survey data products

What makes these surveys particularly unique is that while they are facilitated and archived by ESO, the Principal Investigator (PI) of each survey is ultimately responsible for the higher level data products. The surveys are simply too large and diverse to all be carried out by ESO and having PIs with a vested interest in the data will ensure the best data products for the community at large.

Raw data

In Figure 1 we show a comparison of the total monthly output of the current VLT instruments, and that expected from OmegaCAM and VIRCAM. The values for the survey instruments are based on image sizes and the data rates expected from the PS, and this plot clearly shows the challenge and efforts to carry out PS! The raw data from the PS with OmegaCAM and VIRCAM will be immediately made public worldwide from the ESO archive, with public users being able to download limited volumes.

Advanced data products

Advanced data products from the ESO PS (instrumentally corrected-stacked frames, weight maps and objects catalogues) will be available from the ESO archive. For the VISTA PS, a copy of the advanced data products will be available also from the Wide Field Astronomy Unit at the Royal Observatory Edinburgh (*http://www.roe.ac.uk/ifa/wfau/*). The accuracy/uniformity of the advanced data products from the PS must be validated before their acceptance and ingestion into the ESO archive, and the EST has issued guidelines which describe the required reports and tests supplied by the survey consortia in order to verify the declared data quality. They also include information on data formats and metadata to be delivered to ESO which will publish them in the archive in compliance with Virtual Observatory standards. These guidelines are available at *http://www.eso.org/observing/ps/VOS-RRD.pdf.* Nonetheless, the ultimate responsibility for the quality of the delivered data products rests on the teams proposing and processing the surveys.

The VLT Survey Telescope (VST)

The VLT Survey Telescope (VST) is a 2.6-m optical telescope that will be fitted with a large camera (OmegaCAM) comprised of 32 separate CCD chips (280 Megapixels). This enormous camera has a field of view of one square degree with a pixel scale of 0.2 arcseconds: in Figure 2 we show a real image from the OmegaCAM laboratory tests. The large field of view is ideally suited for surveying large areas. The camera will be equipped with five broadband filters (u′, g′, r′, i′, z′) as well as an Hα filter, Strömgren v, Johnson *B* and *V* and a four-segment u′g′r′i′-filter for photometric monitoring. More information can be found at the relevant web sites: for the VST telescope at *http://twg.na.astro.it/vst/vst_homepage_twg.html* and for the OmegaCAM camera at *http://www.astro.rug.nl/~omegacam/*

There are three VST PS in the process of final approval by the ESO Director General, and they are described below. In Figure 3 we show the sky coverage of the three VST PS, overlaid on a 2MASS image of the southern hemisphere. It is anticipated that the surveys will take approximately five years to carry out and they are scheduled to begin data acquisition in 2008. The VST survey details are summarised in Table 1. The VST and OmegaCAM have been discussed in previous Messenger articles (Capaccioli et al. 2005; Cappellaro 2005).

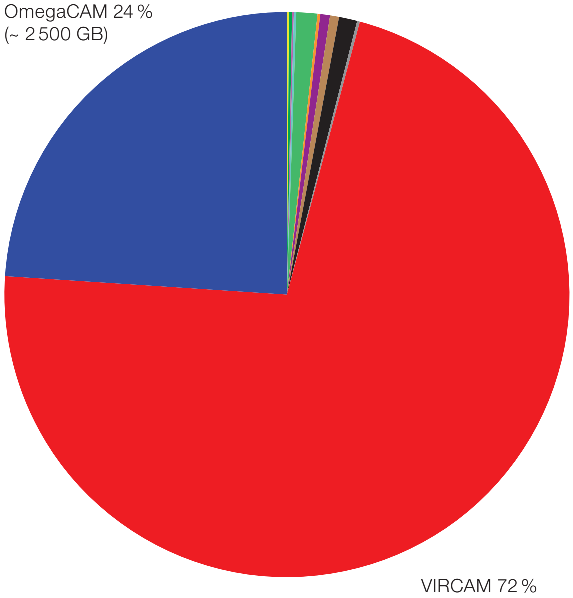

Figure 1: A comparison of the total monthly output (raw calibration and raw science frames) of the VLT instruments, and that expected from OmegaCAM and VIRCAM. The statistics for the current Paranal instruments are based on the monthly average for all 2006, while the values for the survey instruments are based on image sizes and the data rates expected from the Public Serveys.

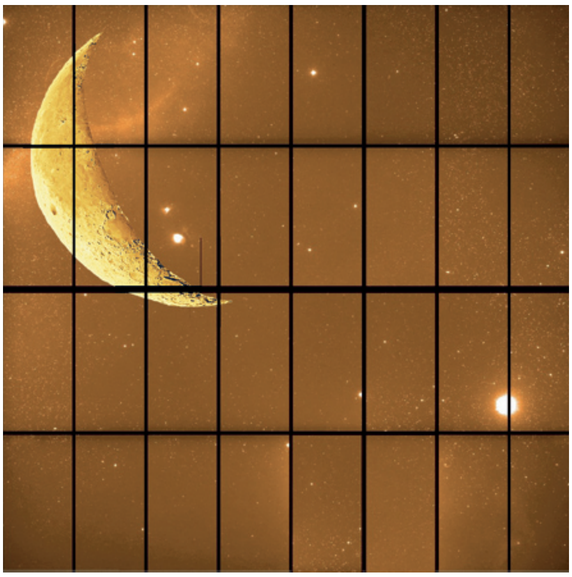

Figure 2: A real image from the OmegaCAM laboratory tests. The field of view is demonstrated by superposition of an image of the Moon.

1. KIDS – The Kilo-Degree Survey
PI Konrad Kuijken (Leiden Observatory)

This survey aims to image 1500 square degrees in four bands (to be complemented in the near-infrared with data from the VISTA VIKING survey). The survey aims to cover this large area to a depth 2.5 magnitudes deeper than the Sloan Digital Sky Survey (SDSS), with considerably better image quality. The primary science driver for the design of this project has been weak gravitational lensing. The science goals of the KIDS project are numerous, including studying dark matter halos and dark energy with weak lensing, investigating galaxy evolution, searching for galaxy clusters, and looking for high-redshift quasars. The KIDS project fills an important niche in lensing surveys between smaller, slightly deeper surveys, such as the CFHT Legacy Survey, and larger, shallower surveys like the SDSS.

2. The VST ATLAS
PI Tom Shanks (University of Durham)

This survey is targeting 4500 square degrees of the Southern Sky in five filters to depths comparable to the SDSS. This survey will also be complemented with near-infrared data from the VHS VISTA survey. The primary science driver is to determine the dark energy equation of state by examining the ‘baryon wiggles’ in the matter power spectrum, via surveys of luminous red galaxies using both photometric and spectroscopic redshifts. This survey will also provide the imaging base for many other future spectroscopic surveys, both at the VLT and also via wide-field fibre spectrographs such as the new AAOmega instrument at the Anglo-Australian Observatory. For example, the VST ATLAS will be valuable in the hunt for high-redshift galaxies and quasars.

3. VPHAS+ – The VST Photometric Hα Survey of the Southern Galactic Plane
PI Janet Drew (Imperial College London)

This survey will combine Hα and broadband u′g′r′i′ imaging over an area of 1800 square degrees capturing the whole of the Southern Galactic Plane within the latitude range |b| < 5 degrees. VPHAS+ will facilitate detailed extinction mapping of the Galactic Plane, and can be used to map the structure of the Galactic disc and its star-formation history. The survey will yield a catalogue of around 500 million objects, which will include greatly enhanced samples of rare evolved massive stars, Be stars, Herbig and T Tau stars, post-AGB stars, compact nebulae, white dwarfs and interacting binaries. This survey is complementary to IPHAS, a survey of the Northern Galactic Plane nearing completion, but VPHAS+ will include more filters and will achieve better image quality.

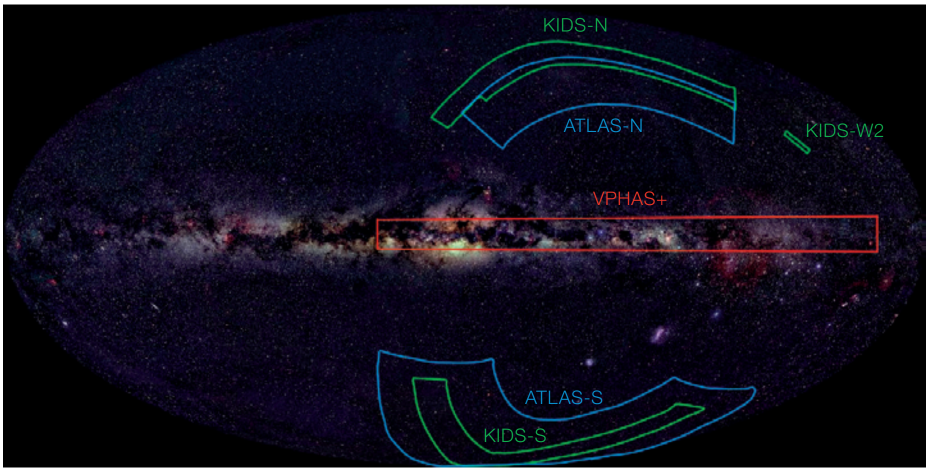

Figure 3: The sky coverage of the three VST Public Surveys, overlaid on a 2MASS image of the southern hemisphere.

Survey	Area [deg_2]	Filter	Magnitude limit	Depth Measure
KIDS	1500	u′	24.1	10σ (AB)
		g′	24.6	
		r′	24.4	
		i′	23.4	
ATLAS	4500	u′	22.0	10σ (AB)
		g′	22.2	
		r′	22.2	
		i′	21,3	
		z′	20.5	
VPHAS+	1800	u′	21.8	10σ (AB)
		g′	22.5	
		Hα	21.6	
		r′	22.5	
		i′	21.8	

Table 1: Summary of the VST Public Surveys based on their Survey Management Plans.

VISTA

The Visible and Infrared Survey Telescope for Astronomy (VISTA) is a 4-m near-infrared optimised telescope that will be equipped with a large array of 16 infrared detectors that will fill a 1.5 square degree field (after stepping to fill in the gaps between the detectors). In Figure 4 we show the VIRCAM field of view, with the moon superimposed for scale. The VISTA filter set includes *Z*, *Y*, *J*, *H*, K_s and a narrowband filter at 1.18 microns. Each exposure will contain 67 Megapixels, and a typical observing night will see the collection of 300 GB of data. This enormous data volume will require very efficient processing and considerable resources.

At present there are six VISTA PS that have been recommended by the VISTA Public Survey Panel and endorsed by the OPC. They are currently in the process of submission of their SMP, and their final approval awaits acceptance of the SMPs (planned for early 2007). They are listed below according to the priority for their implementation given by the VISTA Public Survey Panel, and in Figure 5 we show their sky coverage. The VISTA PS are scheduled to begin data acquisition sometime in late 2007 and to have a duration of five years. The basic VISTA survey properties are summarised in Table 2. The progress of the VISTA project was recently reviewed in *The Messenger* (Emerson et al. 2006), and more information is available from the VISTA web page (*http://www.vista.ac.uk*).

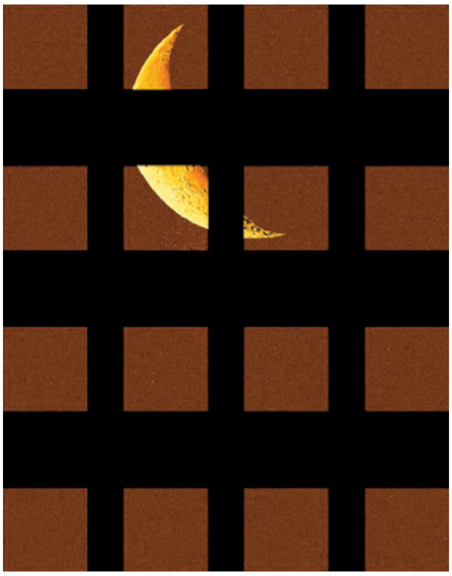

Figure 4: The VIRCAM detector plane, with the Moon superimposed for scale.

1. Ultra-VISTA
   PIs Jim Dunlop (University of Edinburgh); Marijn Franx (Leiden Observatory); Johan Fynbo (University of Copenhagen); Olivier LeFèvre (Laboratoire d'Astrophysique de Marseille)

Ultra-VISTA aims to image one patch of the sky (the COSMOS field) over and over again to unprecedented depths. The survey will use the *Y*, *J*, *H*, and K_s broadband filters along with one narrowband filter specifically designed to study Lyman-α emitters at redshift 8.8, of which ~ 30 are expected to be found with this survey. The science goals of Ultra-VISTA include studying the first galaxies, the stellar mass build-up during the peak epoch of star-formation activity, and dust obscured star formation.

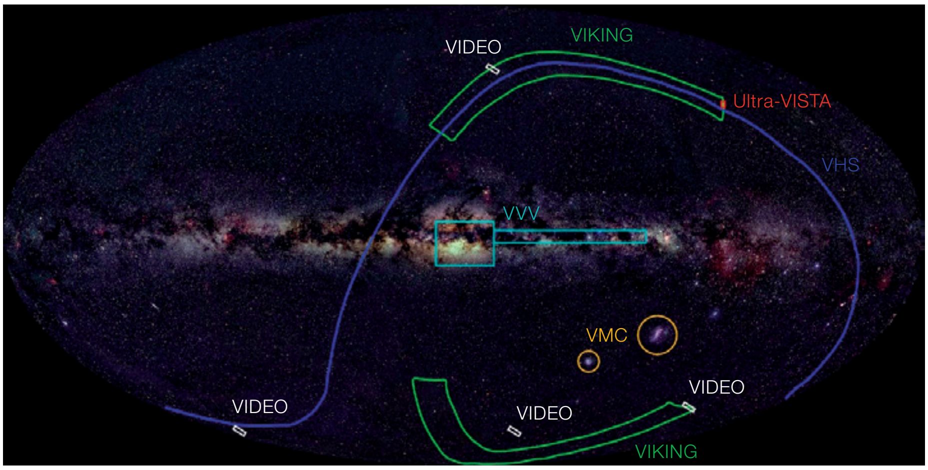

Figure 5: Sky Coverage of VISTA surveys, overlaid on a 2MASS image of the southern hemisphere.

Survey	Area [deg_2]	Filter	Magnitude limit	Limit Measure
Ultra-VISTA	0.73 (ultra-deep)	*Y*	26.7	5σ (AB)
		J	26.6	
		H	26.1	
		K_s	25.6	
		NB	24.1	
VHS	20000	*Y*	21.2	5σ (AB)
		J	21.1	
		H	20.6	
		K_s	20.0	
VIDEO	15	*Z*	25.7	5σ (AB)
		Y	24.6	
		J	24.5	
		H	24.0	
		K_s	23.5	
VVV	520	*Z*	21.9	5σ (Vega)
		Y	21.2	
		J	20.2	
		H	18.2	
		K_s	18.1	
VIKING	1500	*Z*	23.1	5σ (AB)
		Y	22.3	
		J	22.1	
		H	21.5	
		K_s	21.2	
VMC	184	*Y*	21.9	10σ (Vega)
		J	21.4	
		K_s	20.3	

Table 2: Summary of VISTA Public Surveys as described in the submitted proposals.

2. VHS – VISTA Hemisphere Survey
   PI Richard McMahon (University of Cambridge)

The VHS will image the entire Southern Sky, with the exception of the areas already covered by the VIKING and VVV surveys, in *J* and K_s. The resulting data will be about four magnitudes deeper than 2MASS and DENIS. The 5000 square degrees covered by the Dark Energy Survey (DES), another imaging survey scheduled to begin in 2010 at the CTIO 4-m Blanco telescope, will also be observed in *H*-band. The area around both of the Galactic Caps will also be observed in *Y*- and *H*-band by the VHS, to be combined with the data from the VST ATLAS survey. The main science drivers of the VHS include examining low-mass and nearby stars, studying the merger history of the Galaxy, measuring the properties of Dark Energy through the examination of large-scale structure to a redshift of ~1, and searches for high-redshift quasars.

3. VIDEO – VISTA Deep Extragalactic Observations Survey
   PI Matt Jarvis (University of Hertfordshire)

VIDEO is a 15 square degree, *Z*, *Y*, *J*, *H*, K_s survey of AGN, galaxy cluster evolution and very massive galaxies to study galaxy evolution as a function of epoch and environment to a redshift of ~ 4. Three fields of the original four described in the proposal have been recommended by the VISTA PSP: the Chandra Deep Field South; 4.5 square degrees of the XMM-Newton Large-Scale Structure Survey; and a field of the European Large-Area ISO Survey. The width and area of VIDEO are intermediate between the wide, but relatively shallow, VIKING survey and the small, but very deep, Ultra-VISTA.

4. VVV – VISTA Variables in the Via Lactea
   PI Dante Minniti (Universidad Católica)

The VVV survey will target the Galactic Bulge and a region of the adjacent plane in *Z*, *Y*, *J*, *H*, and K_s. The total area of this survey is 520 square degrees and contains 355 open and 33 globular clusters. The VVV is multi-epoch in nature in order to detect a large number of variable objects and will provide > 100 carefully spaced observations for each tile. A catalogue with ~ 10^9 point sources including 10^6 variable objects is expected. These will be used to create a three-dimensional map of the Bulge using well-understood distance indicators such as RR Lyrae stars. High-proper-motion objects will be detected and other science drivers include the ages of stellar populations, globular cluster evolution, as well as the stellar initial mass function.

5. VIKING – VISTA Kilo-Degree Infrared Galaxy Survey
PI Will Sutherland (University of Cambridge)

The VIKING survey provides an important complement to the optical KIDS project. The VISTA PSP has recommended that VIKING shall cover the KIDS 1500 square degrees of the sky in *Z*, and few hundreds square degrees in *Y*, *J*, *H*, and K_s at a limiting magnitude 2 to 2.4 mag deeper than the northern hemisphere UKIDSS Large Area Survey. The near-infrared data will be used in the determination of very accurate photometric redshifts, especially at $z > 1$, and is crucial for the weak lensing analysis and the observation of baryon acoustic oscillations. Other science drivers include the hunt for high-redshift quasars, galaxy clusters, and the study of galaxy stellar masses.

6. VMC – VISTA Magellanic Survey
PI Maria-Rosa Cioni (University of Edinburgh)

This survey will image 184 square degrees of the Magellanic System, i.e., the Large Magellanic Cloud, the Small Magellanic Cloud, the Bridge, and the Magellanic Stream in the *Y*, *J*, and K_s wavebands. Multi-epoch observations will constrain the mean magnitude of short-period variables. The survey will be used to study resolved stellar populations, the star-formation history of the system as well as to trace its three-dimensional structure.

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Photo: H. H. Heyer, ESO

Comet McNaught imaged from Paranal. In the foreground are one of the VLT Unit Telescope domes and two Auxiliary Telescopes. Picture taken on 18 January 2007 (see ESO PR 05/07 for more images).

AMBER, the Near-Infrared Instrument of the VLTI

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The AMBER instrument, installed at the Very Large Telescope (VLT), combines three light beams from as many telescopes to produce spectrally dispersed fringes from milliarcsecond angular scale. Two years after installation, the first astrophysical results are flourishing.

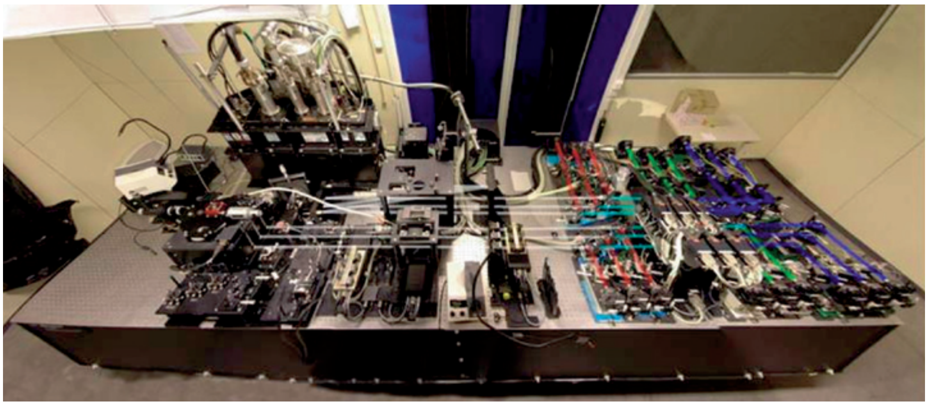

Figure 1: The VLTI instrument AMBER, which is the near-infrared instrument to combine and spectrally analyse the light caught by three of the telescope apertures (either UT's or AT's), is shown. The incoming beams have been superimposed on the photograph.

Progress in astronomy needs instrumental developments in several important directions: larger collecting area to observe fainter, more distant and therefore more ancient sources closer to the birth of the Universe; larger spectral coverage to probe different physical processes; and finally finer observations to investigate the physics in peculiar and extreme situations, such as the vicinity of putative black holes, or to find hidden details, such as extrasolar planets overwhelmed in the dazzle of their parent sun. Long baseline interferometry is the difficult but unique way to gain orders of magnitude in spatial resolution.

To achieve this goal down to the milliarcsecond scale, ESO has equipped its Very Large Telescope (VLT) with an interferometric mode (VLTI) combining giant telescopes spread over hundreds of metres in an exceptional site. At the focus of the VLTI, the near infrared Astronomical Multiple BEam Recombiner AMBER (Petrov et al. 2007), which coherently merges the light of three telescopes, has been installed; the instrument is shown in Figure 1. The resulting interference fringes in many spectral channels are analysed simultaneously, with low (35) and – for the first time – medium (1500) and high (12 000) spectral resolution. By merging three giant apertures into a single telescope, AMBER makes the VLTI the largest existing optical telescope both in collecting power and in angular resolution.

The consortium team[1] installed AMBER on the VLT in March 2004 and, although we are still in the test and commissioning process, we have obtained a wealth of original results about the close environment of a variety of stars. By using the amplitude and the phase information, and most of all their dependence with wavelength, we are able to constrain not only the size and geometry of these sources but also the relative morphology between the continuum and lines. In the following article, we describe the science results which have been obtained and which are published in a special issue of the journal *Astronomy & Astrophysics* (vol. 464, issue March II, 2007).

Science drivers and specifications

The specifications of AMBER have been defined as giving the highest priority to three key astrophysical programmes: young stellar objects; active galactic nuclei; and hot giant extrasolar planets. The first programme was considered as the minimum objective and the third one as an ambitious goal at the very edge of what could be achieved with the technology and VLTI infrastructure expected when AMBER was to be installed.

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We used the experience gained with IOTA, PTI, GI2T, and single-aperture speckle interferometry on high-angular-resolution instrumentation to define a certain number of strategic choices:
- operation in the near-infrared domain (1–2.5 μm)
- spectrally dispersed observations
- spatial filtering for high-accuracy absolute visibility
- very high-accuracy differential visibility and phase
- imaging information from closure phase
- high flux sensitivity

Table 1 lists the intersection between these strategic choices (columns) and the needs set by the scientific objectives (lines), as described in Petrov et al. (2007). Specifications in blue correspond to the most demanding ones.

AMBER concept

The optical principle and the data reduction are described in much greater details in other papers in the special A&A issue (respectively Robbe-Dubois et al. 2007; Tatulli et al. 2007). In addition, a summary and a brief justification of the fundamental choices made in the design of AMBER and its data processing can be found in Petrov et al. (2007). The selection of the concept is the result of an iteration between scientific specifications, performance, and complexity estimates in the context of some preferences set by previous experience with interferometric instruments.

Scientific topic	Spectral coverage	Spectral resolution[a]	Minimum *K*-band magnitude	Maximum visibility error[b]	Imaging (closure phase)
Key programmes					
Young stellar objects	*J*, *H*, *K*, lines	medium	9	10^{-2}	yes
AGN dust tori	*K*	low	11	10^{-2}	yes
Extrasolar planets	*J* + *H* + *K*	low	5	10^{-4}	no[c]
General programmes					
Stellar structure	lines	high	2	10^{-4}	yes
Circumstellar envelopes	*J*, *H*, *K*	medium	4	10^{-2}	yes
Binary stars	*K*	low	9	10^{-3}	yes
QSO and AGN BLR	*J*, *H*, *K*, lines	medium	11	10^{-2}	no

Table 1: Summary of the initial scientific requirements and top level specifications for AMBER. From Petrov et al. (2007).

[a] At the time when it was specified, low spectral resolution meant about 35, medium resolution about 1000 and high resolution at least 10 000.
[b] Error on either visibility amplitude (in normalised visibility units) or differential phase (in radians).
[c] It was found that after the initial specification, closure phase is likely to be more critical for exoplanets than simultaneous *J*+*H*+*K* observations.

AMBER was designed following the concept of multi-axial beam combination, namely an optical configuration similar to the Young's slits experiment, which overlaps images of the sources from different telescopes. A set of collimated and mutually parallel beams are focused by a common optical element in a common Airy pattern that contains fringes. The output baselines are in a non-redundant set-up, i.e. the spacing between the beams is selected in order that the Fourier transform of the fringe pattern shows separated fringe peaks at all wavelengths. The Airy disk needs to be sampled by many pixels in the baseline direction (an average of four pixels in the narrowest fringe, i.e. at least 12 pixels in the output baseline direction), while in the other direction a single pixel is sufficient. To minimise detector noise, each spectral channel is concentrated in a single column of pixels by cylindrical optics. This multi-axial beam combiner has been selected because it allows an easy and modular evolution from two to three telescopes and because it simplifies the design of the interface to the spectrograph and of the spectrograph itself.

Figure 2 summarises the key elements of the AMBER concept. First, each beam is spatially filtered by a single-mode optical fibre. After each fibre, the beams are collimated so that the spacing between the output pupils is non redundant. The multi-axial recombination consists of common optics that merges the three output beams in a common Airy disc containing Young's fringes. Thanks to a cylindrical optics anamorphoser, this fringed Airy disc is fed into the input slit of a spectrograph. In the focal plane of the spectrograph, each column (in the figure, but in reality each line) of the detector contains a monochromatic image of the slit with three photometric (P1, P2, P3) zones and one interferogram (IF). In this figure, the detector image contains a view, rotated by 90°, of the AMBER real-time display showing three telescope fringes, in medium resolution between 2 090 and 2 200 nm, on the bright Be star α Arae. The three superimposed fringe patterns form a clear Moiré figure because, in that particular case, the three optical path differences were substantially different from zero during the recording. Note the vertical brighter line indicating the Brγ emission line.

Figure 3 displays the raw detector image from AMBER obtained in the three-telescope low-resolution mode on the star τ Bootis in April 2006. The stellar signal is spectrally dispersed in the vertical direction and each (pair of) detector lines contains a spectral channel. The rows of *K*-band and *H*-band occupy respectively the upper and the lower half of the screen. From left to right, the first, second, and fourth columns represent the photometric beams for each one of the three telescopes, while the third column contains the interferometric signal, with the three superimposed fringe systems.

AMBER observables

During the observation, we record exposures of several frames, each exposed during the detector integration time. Typically a calibrated point is made of five exposures of 1000 frames of 20 to 100 ms. For each baseline and in each spectral channel, we obtain a measure of the intensity and of the visibility amplitude and phase used to derive the various AMBER observables.

Spectrum of the source

Each one of the photometric beams yields a spectrum of the source within the chosen spectral window. The spectrum is a crucial element of AMBER model fitting. Simultaneous observations of high-resolution infrared spectra, for example with the ISAAC instrument, have often been found to be very useful.

Absolute visibility per spectral channel

The absolute visibility[2] in each spectral channel is the direct result of the data processing. The absolute visibility mainly depends on the equivalent size of the source in the direction of the baseline. Visibility alone does not allow axisymmetric and non-axisymmetric solutions to be disentangled (except with a very good u-v coverage), and will be of little use if the structure of the object is completely unknown.

Differential visibility

The differential (or relative) visibility is the source visibility in a spectral channel, often called work channel, calibrated by

[2] The measured absolute visibility is affected by the piston jitter within one frame. This jitter should be frozen by VLTI fringe tracking or measured when the flux per frame is high enough. Currently this correction is impossible because the vibrations in the Unit Telescopes produce a piston variation between consecutive frames that is almost always larger than the wavelength.

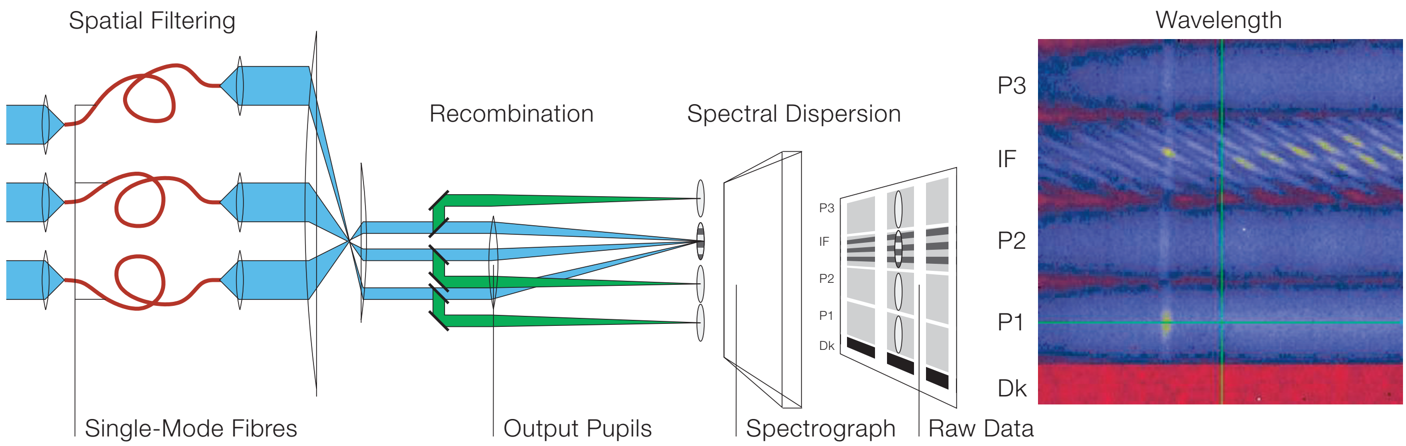

Figure 2 (above): The basic concept of AMBER (see text for details).

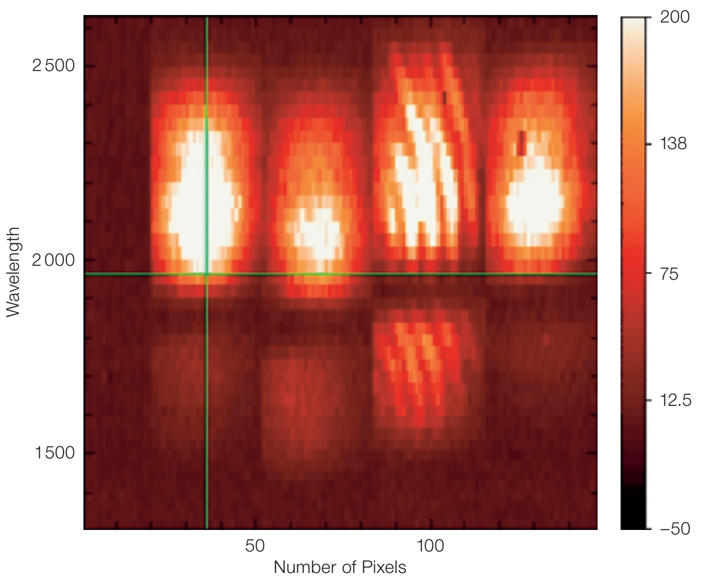

Figure 3: Raw detector image from AMBER obtained in the three-telescope low-resolution mode on the star τ Bootis in April 2006.

the average visibility of a reference channel. The differential visibility is independent of most of the systematic effects affecting the absolute visibility, and it does not need the use of a calibrator star. The relative visibility basically yields the same physical information as the spectrally-resolved absolute visibility, but it is much better calibrated, at the cost of losing information on the reference channel.

Differential phase

In optical, as well as in radio astronomy, source phase information refers to the phase of its complex visibility. In a single-mode interferogram, the phase is related to the position of the fringes, and in the absence of nanometer accuracy metrology, the measured phase is affected by an unknown instrumental term linked to the VLTI+AMBER differential piston and to the instantaneous atmospheric piston between the beams of the baseline. A remarkable feature of the differential phase is that, for non resolved sources, it is proportional to the variation of the photocentre of the source. Given sufficient signal-to-noise ratio, the photocentre variation with wavelength can be measured on very unresolved sources with many very rich astrophysical applications.

Closure phase

The closure phase between baselines is the phase of the average 'bispectral product' of the coherent fluxes. It is independent of any terms affecting individual beams including the achromatic piston and the chromatic optical path difference. For any triplet of baselines, the closure phase is zero for an axisymmetric object. For non-axisymmetric candidates, the closure phase varies with the third power of the object angular size when it becomes unresolved. Then, a non-zero closure phase is a strong indication of a source with an interferometrically resolved non-axisymmetric feature.

AMBER operation

AMBER is working within the standard Science Operations framework in use for the VLT instruments. The VLTI Science Operations is described in Rantakyrö et al. (2004). The AMBER general user can concentrate on the scientific objectives of the run rather than on details of the telescopes, VLTI, and AMBER operations. In this framework, the user's main, if not single, concern is to make certain that the proper calibration procedures are used.

The main calibration required is the interferometric calibration of the instrument which is specific to the observing mode. This calibration can be modified by any change in the spectrograph set-up, and the operating procedure will force the observer to measure a new calibration for any new set-up, prior to science observations. The observer must choose between a standard-accuracy calibration, to be within the specifications of AMBER, and a high-accuracy one, to try to approach the goals of highest accuracy.

All interferometric observables, including the differential and the closure phases, are affected by systematic effects that can be removed or reduced using a calibrator star with known complex visibility. An important task for the observer is to choose good calibrators. Ideally a calibrator is a point source; however, finding strictly non-resolved and bright-enough stars is a real problem. A good calibrator is then a single, non-variable star, which can be considered as a uniform disk with a known diameter.

Observing is performed through the VLT control system using the standard tool P2PP (Phase 2 Preparation Package) to create observation blocks. These blocks contain several templates, to set up the instrument, to point the interferometer, optimise the beam injection into AMBER, search for fringes, and acquire observation data. The observation block is executed through BOB (Breaker of Observing Blocks). Some of the templates are executed in parallel, such as the injection of light into the AMBER fibres for each telescope.

AMBER performance

The knowledge of the full VLTI environment (including vibrations, adaptive optics correction, fringe tracker, tunnel turbulence, etc.; see review by Bonnet et al. 2006) is still too preliminary to enable us to predict what would be the ultimate performance of AMBER on the VLTI. Therefore the reader should be guided by the performance given here, which has been secured for the various calls for proposals, but follow the improvements either in *The Messenger* or in the calls for proposals.

In the present state[3], the transmission measured on AMBER and the VLTI shows that the current coherent limiting magnitude on the UTs is K ~ 7 and K ~ 5 on the ATs. This limit can be pushed by up to a magnitude using non-standard DITs and allowing a lower selection of frames with SNR higher than two.

With the ATs, the VLTI+atmosphere fringe contrast already ranges from 0.5 to 0.9.

[3] With a VLTI and atmosphere fringe contrast of 0.12 without frame selection and before any improvement in the vibrations of the UTs.

In present conditions with AMBER taking the full advantage of the FINITO performance, all spectral resolution modes will be accessible on the AT for K ~ 3 in average conditions and K ~ 5 in the 20 % best conditions, with enormous possibilities in stellar physics.

With the UTs, without reducing too much the total throughput, the level of vibration can probably be brought down into the range 150 to 200 nm rms. The contrast, integrating all effects like the atmosphere and residuals from the VLTI, can then reach values higher than 0.6, a performance which is currently obtained on the ATs. Then AMBER on the UTs could reach a coherent limiting magnitude as high as K = 11 in the very best conditions, i.e. routinely K ~ 9 in the future.

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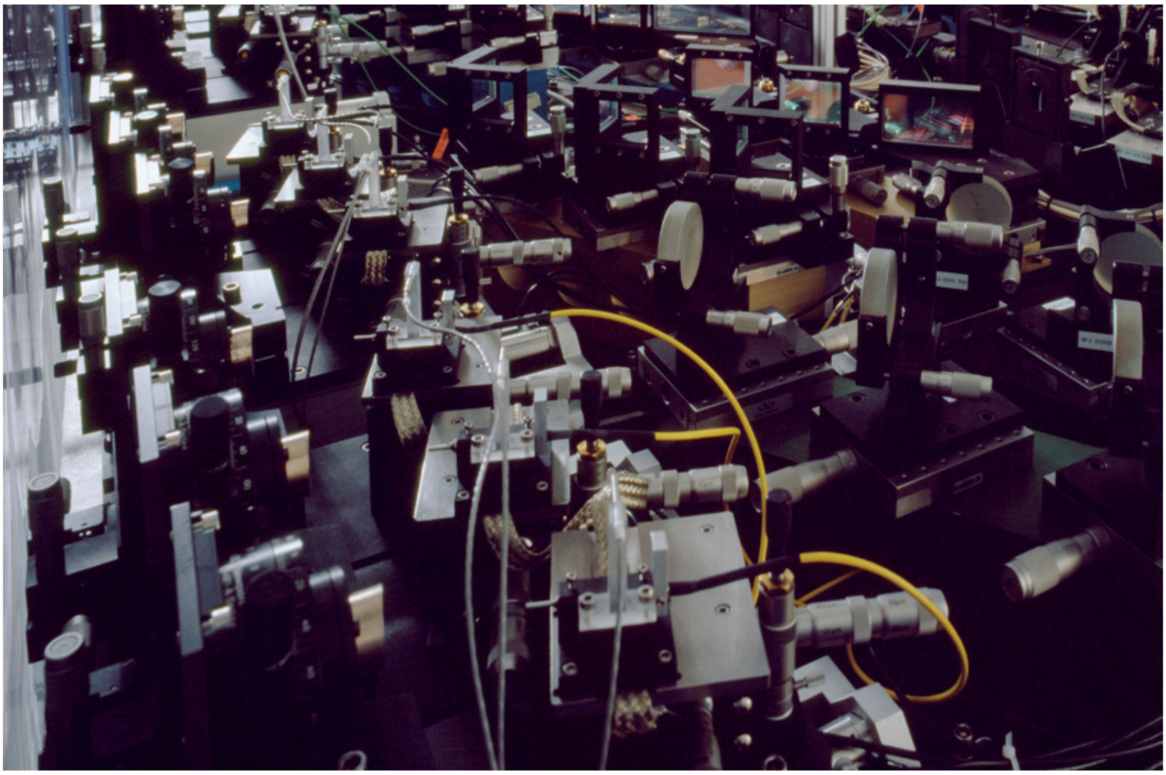
Photo: H. H. Heyer, ESO



The AMBER instrument in the VLTI laboratory at Paranal.

First AMBER/VLTI Science

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The AMBER instrument installed at the Very Large Telescope (VLT) combines the beams from three telescopes to produce spectrally dispersed interference fringes with milli-arcsecond angular scales in the near infrared. Three years after installation, first scientific observations have been carried out mostly during the Science Demonstration Time and the Guaranteed Time. The first science has mainly focused on the environment of various types of stars. Because AMBER has dramatically increased the number of measures per baseline, this instrument brings strong constraints on morphology and models.

AMBER is one of the two science instruments of the Very Large Telescope Interferometer (VLTI) described in Petrov et al. (2007). AMBER is an interferometric beam combiner for the VLTI working in the near-infrared *J*-, *H*-, and *K*-bands and able to simultaneously mix three beams coming from three identical telescopes. AMBER interferograms are spectrally dispersed with a resolution of about 35, 1500, or 12000. Therefore the instrument can measure visibilities and a closure phase in a few hundred different spectral channels. The spectral coverage, the spectral resolution, and the better sensitivity compared to small-aperture interferometers give access to many new astrophysical fields that we describe in this paper.

Discs and winds in young stars

The young stellar object MWC 297 is an embedded Herbig Be star exhibiting strong hydrogen emission lines and a strong near-infrared continuum excess. MWC 297 was observed with AMBER during its first commissioning run (Malbet et al. 2007). MWC 297 has been spatially resolved in the continuum as well as in the Brγ emission line where the visibility decreases to a lower value (see Figure 1). The interpretation of this result is that the gas emitting the Brγ emission line is located in a region larger than the disc from which the dust continuum emission arises. A picture emerges in which MWC 297 is surrounded by an equatorial, optically thick disc, that is possibly still accreting, and by an outflowing wind located just above it. AMBER's unique capability to measure spectral visibilities allowed Malbet et al. (2007), for the first time, to compare the apparent geometry of a wind with the disc structure in a young stellar system.

A lower-mass, less active system, the Herbig Ae system HD104237, was also observed with AMBER (Tatulli et al. 2007). The central emission line star is surrounded by a circumstellar disc that causes the infrared excess emission and that drives a jet. The visibility of this object measured by AMBER does not vary between the continuum and the Brγ line region, even though the line is strongly detected in the spectrum. This result demonstrates that the line and continuum emission have similar size scales. Assuming that the *K*-band continuum excess originates in a puffed-up inner rim of the circumstellar disc, Tatulli et al. (2007) conclude that this emission most likely arises from a compact disc wind very close to the inner rim location.

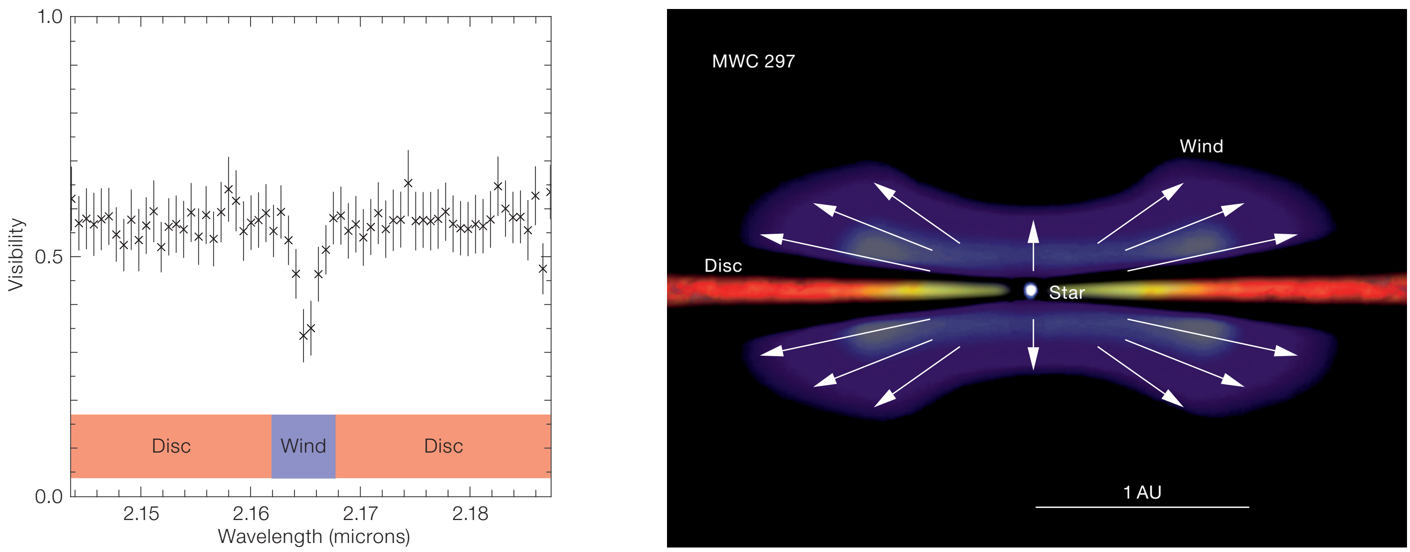
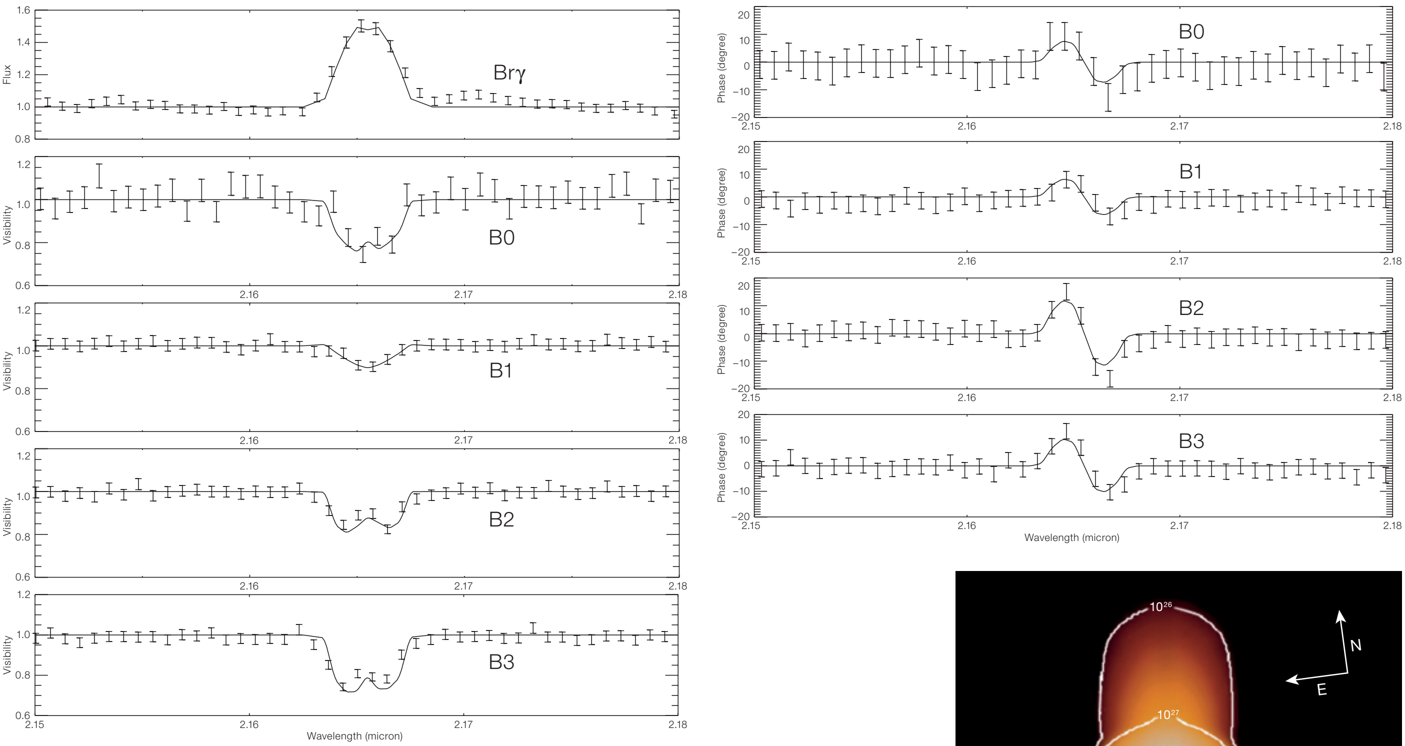


Figure 1: **Left:** Spectral dependence of the visibility as measured with AMBER for MWC297 around the Brγ line. **Right:** Edge-on view of the model including an equatorial optically thick disc (in red/yellow) and an outflowing wind (in blue). The wind geometry has been computed to both fit the visibility drop in the Brγ line and reproduce the object spectrum. The apparent size of the wind is larger than the apparent size of the disc. From Malbet et al. (2007).



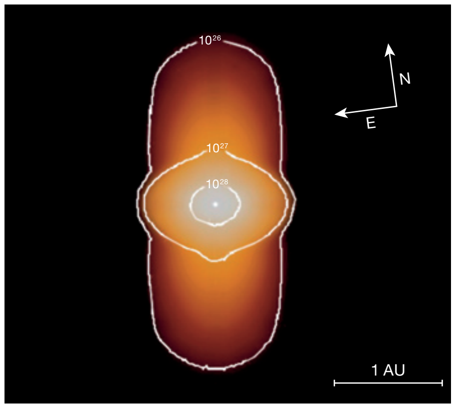


Figure 2: Relative visibility (left plot) and differential phases (right plot) of α Arae across the Brγ line profile for several VLTI baselines. The upper left subpanel is the Brγ line profile. The plain lines are the fits we obtain with the best model, whereas the VLTI/AMBER data are the points with error bars. **Bottom right figure:** intensity map in the continuum at 2.15 μm obtained with the best model parameters of α Arae.

These two results show that AMBER on the VLTI is going to be a major tool for understanding the very close environment of young stars and will disentangle the regions of emission of dust and gas, especially those coming from the disc and the wind.

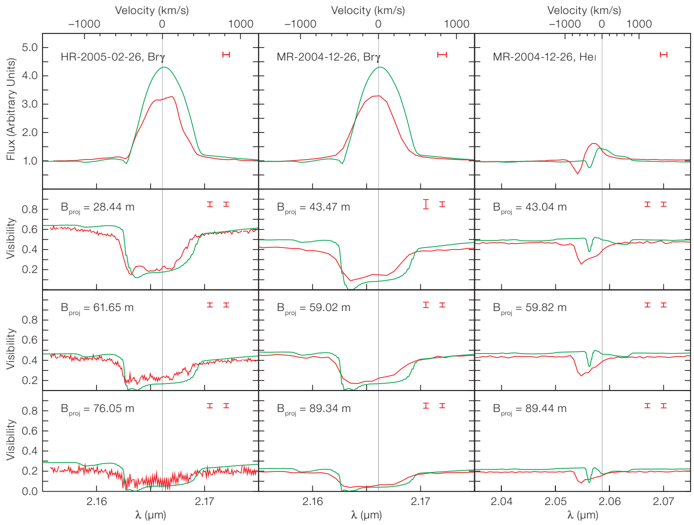
Rotating gas envelopes around hot active stars

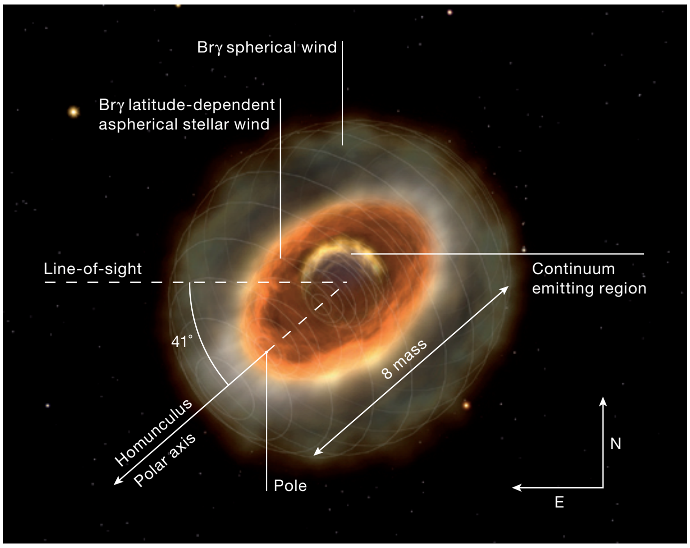
Several emission-line stars have been scrutinised by AMBER: two Be stars, α Arae, one of the closest Be stars (Meilland et al. 2007b) and κ Canis Majoris, one of the brightest ones (Meilland et al. 2007a), and one B[e] supergiant star, CPD-57°2874, which is one of the rare hot stars showing forbidden lines and IR emission from dust (Domiciano de Souza et al. 2007).

The AMBER instrument, when operating in the *K*-band, provides a gain in spatial resolution of a factor of five compared to previous VLTI/MIDI observations of α Arae. Moreover, high angular resolution is combined with medium spectral resolution which allows the kinematics of the gas envelope inner part to be studied and its rotation law to be estimated (see Figure 2). Meilland et al. (2007b) obtained, for the first time, direct evidence that the gas envelope is in Keplerian rotation, answering a question that has existed since the discovery of the first Be star, γ Cassiopae, by Father Secchi in 1866. The envelope around α Arae is compatible with dense equatorial matter confined in the central region, whereas a polar wind is outflowing along the rotational axis of the central star. Between these two regions the density must be low enough to reproduce the large visibility amplitudes obtained for two of the four VLTI baselines.

Using differential visibility amplitudes and phases across the Brγ line, Meilland et al. (2007a) detected an asymmetry in the circumstellar structure around κ Canis Majoris. However, this star is difficult to fit within the classical scenario for Be stars, i.e., fast rotating B star close to its breakup velocity surrounded by a Keplerian circumstellar gas envelope with a strong polar wind. We found that κ CMa does not seem to be a critical rotator, the rotation law within the envelope is not Keplerian, and the detected asymmetry seems to be hardly explained within the one-armed viscous disc framework.

The first high spatial and medium spectral observations of the circumstellar envelope of a B[e] supergiant, CPD-57°2874, were performed with the VLTI using both the AMBER and MIDI instruments. Thanks to these observations Domiciano de Souza et al. (2007) estimated the size and geometry of the circumstellar regions re-





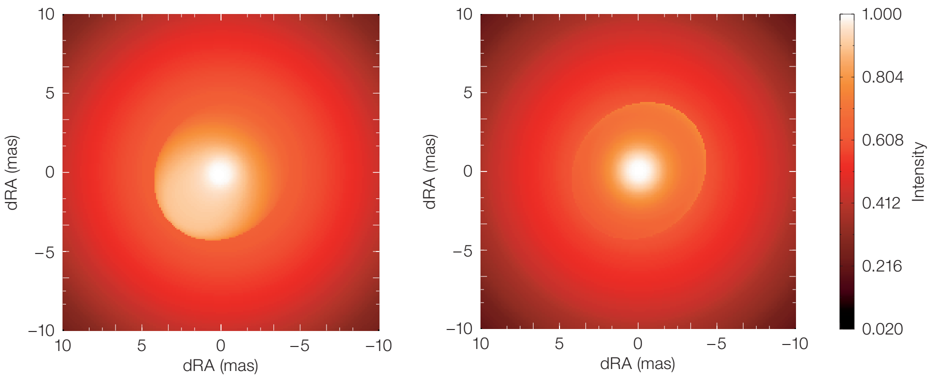


Figure 3: Left panel: η Car's AMBER visibilities (red lines) compared to model predictions (green lines) in the spectral regions of the Brγ and HeI emission lines (from left to right: Brγ, high spectral resolution 12 000; Brγ, medium spectral resolution 1 500; and HeI, medium spectral resolution 1 500). The figure shows the spectra (upper row) and the wavelength dependence of the visibilities (lower three rows; three different projected baseline lengths). Upper right panel: Illustration of the components of the geometric model for an optically thick, latitude-dependent wind (for the weak aspherical wind component, we draw the lines of latitudes to illustrate the 3D-orientation of the ellipsoid). Bottom right panels: for two representative wavelengths, the total brightness distribution of the model including the aspherical wind component and the contributions from the two spherical constituents. From Weigelt et al. (2007).

sponsible for the mid-IR emission (mostly coming from dust) and for the near-IR emission (probably resulting from a complex interplay among the radiation from the central star, the tail of hot-dust emission as well as free-free and free-bound radiation from the fast polar wind and the disc-wind interaction). By adopting elliptical Gaussian models with wavelength-dependent diameters, typical angular sizes of the major-axes derived are 3.4 mas (8.5 AU adopting a distance of 2.5 kpc) in the continuum at 2.2 µm, 5.2 mas (13 AU) in the Brγ emission line, and 15 mas (38 AU) in the continuum at 12 µm. These spectro-interferometric VLTI results provide direct evidence for a multi-component environment around B[e] supergiant stars supporting the non-spherical, gaseous, and dusty circumstellar envelope paradigm for these complex objects.

Mass loss from massive stars

One of the most luminous, most massive, and unstable Luminous Blue Variable stars, η Carinae, is suffering from an extremely high mass-loss rate. A variety of observations suggest that the central source of this object is a binary, even if it is still a matter of debate. η Car was observed with AMBER (Weigelt et al. 2007) at two different epochs using three Unit Telescopes and both medium and high spectral resolutions in the spectral regions around the HeI and Brγ emission lines.

The visibility measurements revealed and resolved the η Car's optically thick wind region (see left part of Figure 3). Comparing the AMBER continuum visibilities with recent NLTE radiative transfer models, a very good agreement is found. In both the Brγ and the HeI emission lines, non-zero differential phases and non-zero closure phases were measured, indicating a complex and asymmetric object structure. Weigelt et al. (2007) developed a model which shows that the asymmetries measured within the wings of the Brγ line with differential and closure phases are consistent with the geometry expected for an aspherical, latitude-dependent stellar wind (see right part of Figure 3).

Colliding wind binary in late stellar evolution

The Wolf-Rayet (WR) and O star binary system γ^2 Velorum was observed using AMBER in medium-resolution mode (Millour et al. 2007). Signals strongly varying through the broad Wolf-Rayet (WR) emission lines were observed and interpreted in the framework of a simple model that consists of two unresolved sources, whose flux ratio (close to one) is strongly wavelength dependent due to the strong emission of WR lines. Millour et al. (2007) demonstrated that the combination of differential visibility, differential phase and closure phase, as a function of the wavelength, allows both the angular separation of the binary components to be retrieved and their respective spectra to be extracted, leading to a direct measure of the distance of the system. It is found to be significantly larger than the Hipparcos-determined distance, placing the target in the Vela OB association. One of the by-products is a direct and model-independent measurement of the spectrum of the WR component, improving the modelling of this star. Furthermore, the signature of the circumstellar material is revealed in tens of spectral channels by a 5 to 10σ residual between the AMBER measurements and the binary model. These significant residuals allow speculations on the nature of the corresponding emission, probably associated with the wind-wind collision zone that contributes both to the emission lines and to the free-free continuum.

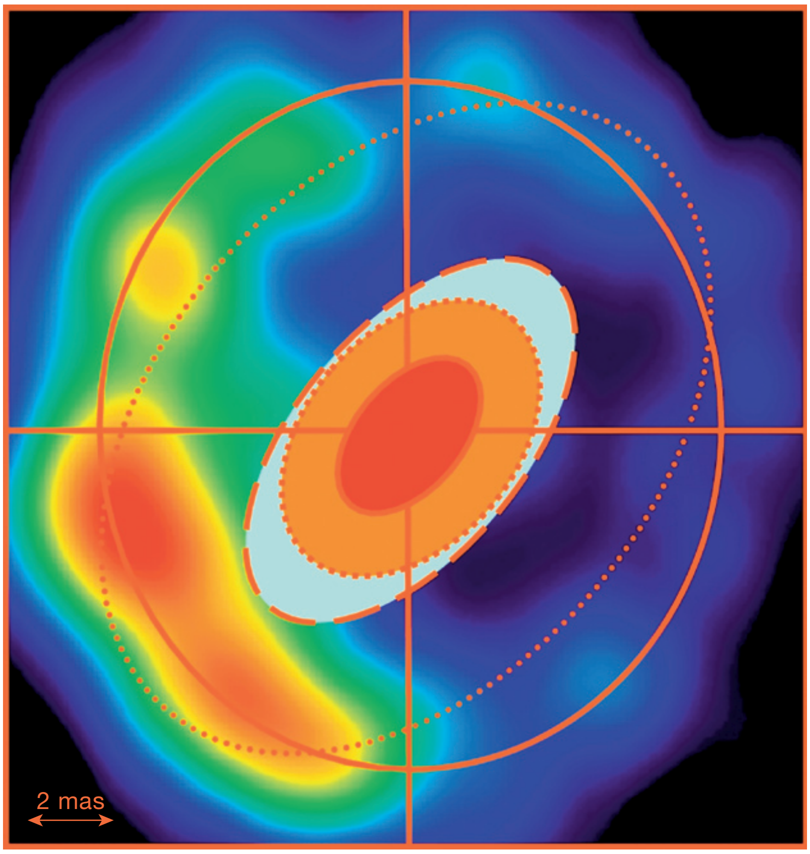


Figure 4: Sketch of the fitted elliptical extension in the near-IR for RS Oph nova at t = 5.5 d compared with the radio structure observed at t = 13.8 d (thick extended ring). The continuum ellipse is delimited by the solid line, the ellipse that corresponds to the core of Brγ by the dotted line and the one corresponding to the core of He I by the dashed line. The outer small dotted line delimits the Brγ ellipse scaled at t = 13.8 d. North is up, East left. From Chesneau et al. (2007).

The outburst of the recurrent nova RS Oph

The famous recurrent nova RS Ophiuci exploded on 12 February 2006, an event expected since the previous outburst that occurred only 21 years ago. The extension of the expanding milliarcsecond-scale emission was measured by AMBER only five days after the discovery using three telescopes and the medium spectral resolution in the *K*-band continuum, the Brγ 2.17 μm line and the He I 2.06 μm line (Chesneau et al. 2007). Unfortunately, the 200 km s^{-1} spectral resolution was unsufficient to get a deep insight into the kinematics of the outflowing material ejected at high velocities. The low visibilities in the lines, compared to their values in the nearby continuum, are consistent with extended line-forming regions, the He I emission being formed in the fastest ejecta, close to the shock front. Both the continuum and the line emissions are highly flattened, sharing apparently the same global geometry, at different scales (see Figure 4). In addition, two radial velocity fields were detected in the Brγ line: a *slow* (~ 1800 km s^{-1}) expanding ring-like structure and a *fast* (~ 3000 km s^{-1}) structure extended in the East-West direction, a direction that coincides with the jet-like structure seen in the radio domain. These results demonstrate the capabilities of the VLTI to study the geometry and the kinematics of the earliest stages of nearby, i.e. few kiloparsec distant, recurrent or classical nova explosions.

Acknowledgements

We are grateful to the AMBER consortium and to the ESO staff for their help in making such observations possible.

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ULTRASPEC: High-speed Spectroscopy with Zero Read-out Noise

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The commissioning of a spectroscopic version of the high-speed CCD camera ULTRACAM is described. This visitor instrument, ULTRASPEC, uses an electron-multiplying CCD for fast and low-noise read-out and was tested with the EFOSC2 spectrograph on the ESO 3.6-m.

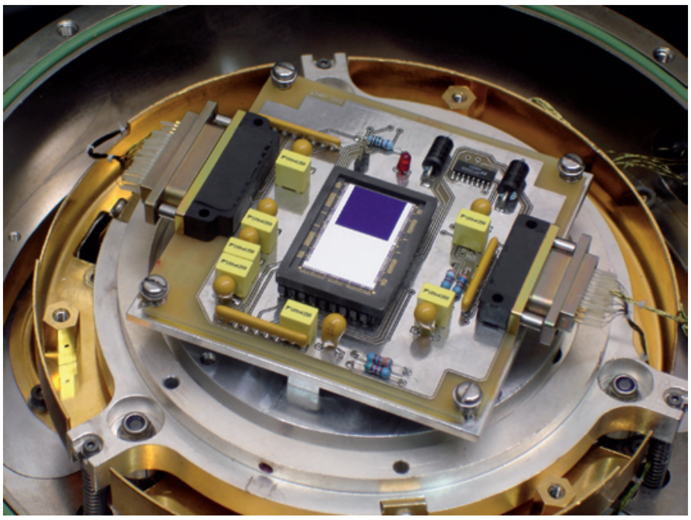
Conventional CCD detectors suffer from two major weaknesses: they are slow to read out and they suffer from detector noise. These weaknesses combine to make high-speed astronomical spectroscopy of faint targets the most demanding of observations, where by 'high-speed' is meant timescales of tens of seconds and below.

It is possible to overcome the problem of slow speed by using *frame-transfer CCDs* and detector-limited data acquisition systems. Such an approach has been adopted by ULTRACAM, the high-speed, triple-beam CCD imager which was recently commissioned on the VLT (see *The Messenger* 121, 46). Reducing read-out noise in CCDs to negligible levels is more difficult, and has only recently been solved by the development of *electron-multiplying CCDs* (EMCCDs). These are conventional CCDs, but with an extended serial register to which a higher-than-usual voltage is applied. Secondary electrons are produced as the photon-generated electrons are clocked through it, resulting in a signal amplification which dwarfs the read-out noise, rendering it negligible.

EMCCDs have generated a lot of interest in the high spatial-resolution community, but have received much less attention for other astronomical applications. To address this problem, a consortium from the Universities of Sheffield, Warwick, the UK Astronomy Technology Centre and ESO, were awarded funding under OPTICON Joint Research Activity 3: *Fast read-out, high-performance optical detectors* to investigate the use of EMCCDs for high-speed spectroscopy. The resulting camera that has been developed is called *ULTRASPEC*, since it is essentially a spectroscopic version of ULTRACAM.

At the heart of ULTRASPEC is an EMCCD – we chose to use an E2V CCD201-20 detector, which has an imaging area of 1024 × 1024 pixels (each of 13 microns). The CCD201 is also a frame-transfer device, thereby offering high frame rates (up to hundreds of Hertz) with negligible dead time, as well as essentially zero read-out noise. The chip is mounted in a standard (old-style) ESO cryostat, cooled by liquid nitrogen and temperature-regulated by a Lakeshore controller (see Figure 1a). The chip read-out is controlled by a San Diego State University (SDSU) Generation III CCD controller, which incorporates a custom-made, high-voltage clock board to power the serial gain register (shown in Figure 1b). The SDSU controller is hosted by a rack-mounted dual-processor PC running Linux patched with Real Time Application Interface (RTAI) extensions. The use of RTAI allows one processor to be strictly controlled so as to obtain accurate timestamps from the GPS antenna located outside the dome and connected to the PC via a serial port. The data acquisition, instrument control and user interfaces are all virtually identical to the tried and tested hardware/software used in ULTRACAM.

Building a new spectrograph to test ULTRASPEC would have been prohibitively expensive and time consuming, and is unnecessary as so many excellent spectrographs with external foci able to accept visiting cryostats already exist. We identified the EFOSC2 spectrograph on the ESO 3.6-m telescope as ideal for our purposes, and the Director of the La Silla Paranal Observatory awarded us four nights of technical time in December 2006 to commission and test ULTRASPEC on the sky.



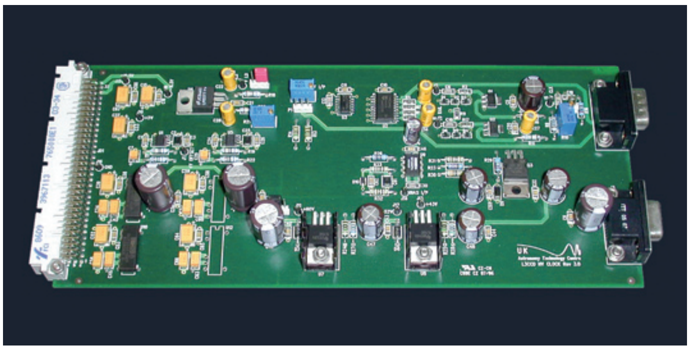


Figure 1a (left): The frame-transfer EMCCD chip mounted in the ESO cryostat.

Figure 1b (above): The third and final version of the high-voltage clock board that was developed for the SDSU controller.

Figure 2a: View inside the Cassegrain cage of the ESO 3.6-m telescope, showing ULTRASPEC mounted on EFOSC2. The gold-coloured cryostat containing the EMCCD is visible at the bottom of EFOSC2. Close to this is the SDSU controller, mounted at the bottom of the red frame. The ULTRASPEC electronics rack containing the Lakeshore and PC is the unit on the left with a square black sticker on its door.

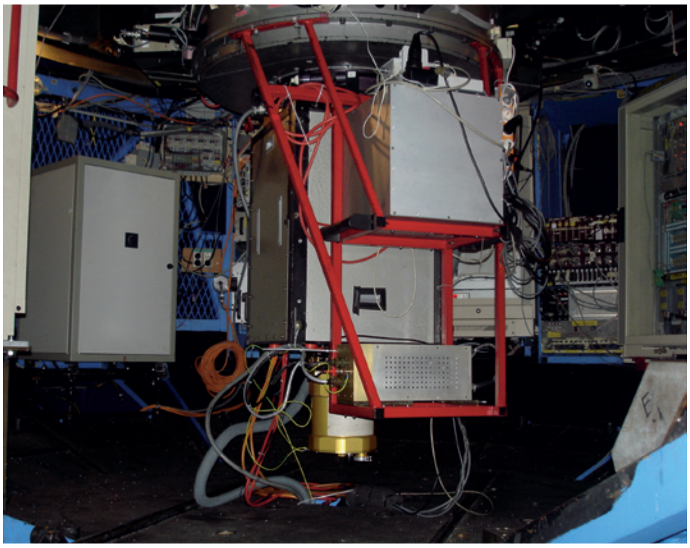


Figure 2b: The ULTRASPEC commissioning team. From left to right: Emilio Barrios (ESO), Naidu Bezawada (UKATC), Kieran O'Brien (ESO, standing), Vik Dhillon (Sheffield), Chris Copperwheat (Warwick), Tom Marsh (Warwick), Andy Vick (UKATC, standing).

The ULTRASPEC commissioning run was a great success. Installation, integration and alignment proceeded without problems, no telescope time was lost due to technical problems with ULTRASPEC, and the characterisation of the EMCCD chip was completed with a spectrograph on the sky. This latter task was the main aim of the run, and the main deliverable of our OPTICON-funded project, and was achieved by observing a series of standard stars ranging from magnitude 13 to 19 with different avalanche gains and exposure times (from hundredths of a second to hundreds of seconds). As an added bonus, we were also able to observe some demonstration science objects, which will serve as useful examples to the community of the power of EMCCDs for astronomical spectroscopy (see Figure 3). The results, which show that EMCCDs are likely to revolutionise certain types of (i.e. read-out-noise-limited) astronomical spectroscopy, will shortly be submitted for publication in a refereed journal.

With ULTRASPEC successfully commissioned, we are now keen to start using it to do science and are planning a science run on the ESO 3.6-m during Periods 80/81. There is little additional work to be done on ULTRASPEC in preparation for this proposed run, although we would like to purchase new VPH-based grisms for EFOSC2, providing higher resolutions and better-matched central wavelengths for ULTRASPEC's smaller CCD. In the longer term, we are also investigating the possibility of procuring a larger-format, multi-output EMCCD designed specifically for astronomical spectroscopy and using this in combination with the new Generation IV SDSU controller.

Any readers interested in using ULTRASPEC on a shared-risks, collaborative basis during Periods 80/81 are encouraged to contact Vik Dhillon (*vik.dhillon@sheffield.ac.uk*) or Tom Marsh (*t.marsh@warwick.ac.uk*). Users of SDSU controllers who are interested in adopting our high-voltage clock-driver board to control EMCCDs should contact Derek Ives (*dji@roe.ac.uk*).

Acknowledgements

This project would not have been possible without the support of the past and present Director of the La Silla Paranal Observatory – Jason Spyromilio and Andreas Kaufer – who authorised the use of technical time for this project and gave us unfettered access to an ESO cryostat and the EFOSC2 spectrograph. We are also indebted to Peter Sinclaire, Emilio Barrios and the other members of ESO staff on La Silla who provided expert assistance prior to and during the commissioning run.

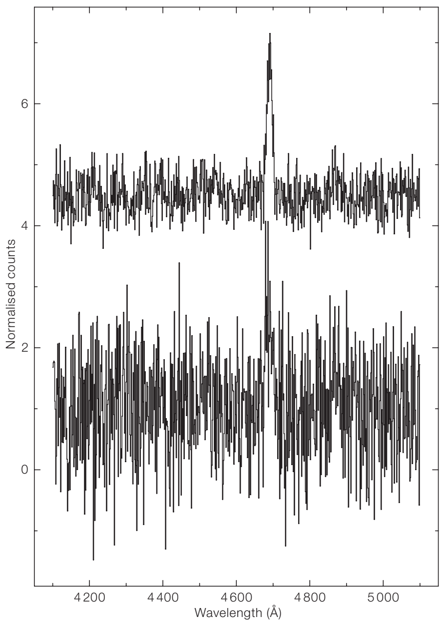


Figure 3: ULTRASPEC spectra of the AM CVn-star ES Cet, a binary of magnitude V ~ 17 consisting of two helium-rich white dwarfs in a very close 10-minute orbit. One of the white dwarfs is filling its Roche lobe and transferring material to its companion, producing the strong He II emission at 4686 Ångstroms visible in its spectrum. Top: A 10-second spectrum using the avalanche output of ULTRASPEC. Bottom: A 10-second spectrum taken using the normal output of ULTRASPEC. The latter is identical to what would be obtained using a conventional CCD. The gain in signal-to-noise is approximately a factor of three. Given that these are read-out-noise-limited observations, using an EMCCD on the ESO 3.6-m is therefore equivalent to using a conventional CCD on a 6.3-m telescope! The gain is even greater if the negligible dead time of the frame-transfer EMCCD (~ 10 milliseconds) compared to a conventional CCD (~ 10 seconds) is also taken into account.

Region of the Large Magellanic Cloud centred on SN 1987A (from ESO PR 50/06).

Twenty Years of Supernova 1987A

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The unique supernova SN 1987A has been a bonanza for astrophysicists. It provided several observational 'firsts', like the detection of neutrinos from the core collapse, the observation of the progenitor star on archival photographic plates, the signatures of a non-spherical explosion and mixing in the ejecta, the direct observation of supernova nucleosynthesis, including accurate masses of ^{56}Ni, ^{57}Ni and ^{44}Ti, observation of the formation of dust in the supernova, as well as the detection of circumstellar and interstellar material. Now, after 20 years, it continues to be an extremely exciting object as we will be able to observe the supernova shock interacting with the circumstellar ring in real time.

Entering with a bang

When the first signs of Supernova 1987A, the first supernova of the year 1987, were noticed early on 24 February 1987, it was clear that this would be an unusual event. It was discovered by naked eye and on a panoramic photographic plate taken with a 10-inch astrograph on Las Campanas in Chile by Oscar Duhalde and Ian Shelton, respectively. A few hours earlier, still on 23 February, two large underground proton-decay detectors registered the passage of high-energy neutrinos. Unlike the optical detections the localisation of the source was not so easy for the total of 20 neutrinos detected within about 13 seconds. Since SN 1987A exploded in the Large Magellanic Cloud (LMC), the detectors on the northern hemisphere measured the neutrinos after passage through the Earth. In recognition for this first detection of neutrinos from a celestial object other than the Sun, Masatoshi Koshiba was awarded the Nobel Prize in 2002 (shared with Riccardo Giacconi for X-ray astronomy and Raymond Davis Jr. for solar neutrinos). The most important implication of the neutrinos was that it confirmed the hydrodynamic core collapse, releasing about 3×10^{53} ergs of gravitational energy, mainly in neutrinos of all kinds. This confirmed the predictions by Colgate, Arnett and others from the 1960s. Among many other results, the few neutrinos showed that the electron-neutrino mass has to be rather small ($m_{\nu_e} \leq$ 20 eV, superseded in the meantime by direct experiments) as no time-delay effects could be measured. Also, the fact that there is no structure in the neutrino burst indicates that they came from the collapse to the neutron star, but no further collapse to a black hole occurred. At the same time these neutrinos gave an unprecedented accuracy of better than a minute (the reason the accuracy is not better had to do with the time keeping at the neutrino detectors) for the time of explosion, which optical observations cannot provide, as the photons emerge from the shock breakout on the surface of the exploding star, which can occur several hours later. The neutrinos were the direct signal from the collapse of the core of Sanduleak –69° 202 to a neutron star.

A historical irony has it that this very star was on the target list of an ESO observing programme looking at blue supergiants in the LMC with the 3.6-m telescope in December 1986. Unfortunately, it was not observed and hence we do not have a high-resolution spectrum of it. Pre-explosion images show a rather unspectacular blue supergiant. The earliest optical observations of the supernova – some of them were pre-discovery plates – pieced together from observations in Australia and South America, showed a steep luminosity increase of about six magnitudes in less than half a day. Since the discovery was only made in the morning in Chile, the first spectrum of SN 1987A was obtained in South Africa. From then on, the supernova was on the observing programme of every major southern or active space observatory, in particular IUE. Ironically, it was too bright for the state-of-the-art 4-m telescopes and many of them had to be stopped down, e.g. by half-closed telescope covers. Some of the smaller telescopes took their chance. The 61-cm Bochum telescope on La Silla was used, on a nearly daily basis for more than a year, to measure optical spectroscopy with photometric accuracy. Since the LMC is circumpolar for most southern observatories, this also meant that we have an uninterrupted record of the photometry and spectroscopy; else we would have missed part of the peak phase, which lasted into May of 1987. By July, the first conference on SN 1987A had already taken place at ESO in Garching (Danziger 1987) to be followed by several others during that year and following years. Among the many excellent reviews of different aspects of SN 1987A we note Arnett et al. (1989), Chevalier (1997), and McCray (1993, 2005).

An unusual supernova

The optical light curve of SN 1987A was rather different from the one of previously observed core-collapse supernovae. Progenitor stars were normally assumed to be red supergiants with extended envelopes, which would produce long plateau phases in the light curve. Not so SN 1987A, which started out as an extremely blue object only to turn into the reddest supernova ever observed. The reason for this was that the supernova was discovered so early that the early cooling phase, when the supernova ejecta cool down from the shock passage, could be observed. But SN 1987A did not become as luminous as expected. The compact nature of the blue supergiant meant that the adiabatic cooling was stronger, producing a fainter object than usual. About four weeks after the explosion, the supernova light curve was powered by the radioactive decay of freshly synthesised ^{56}Ni. Unlike any supernova before, it was possible to construct a bolometric light curve of SN 1987A, which was extremely useful for the physical interpretation of the event. The absence of a significant plateau phase was understood in the context of the nature of the progenitor star and the extent to which the ejecta of the supernova were mixed. It turned out that helium was mixed into the hydrogen layer and hydrogen further down into the ejecta. This was also apparent from the early appearance of X-rays, originating from the ^{56}Co decay. Further confirmation for the strong mixing of the layers in SN 1987A came from the line shapes of the infrared lines. The old models of spherical explosions had to be revised, and density inhomogeneities in the stellar structure were recognised as responsible for turbulent mixing when the shock moved across such boundaries.

The next surprise was revealed by high-spatial resolution observations with speckle cameras at the AAT and the CTIO 4-m telescopes. They independently found a 'mystery' spot close to the supernova. The nature of this phenomenon remains unclear, but it was a strong indication of broken symmetry. The asymmetry was also detected in polarisation observations of SN 1987A.

The spectroscopic evolution provided further evidence for asymmetries in the explosion. The 'Bochum event' was a rapid change in the P Cygni profile of the Hα line observed with the Bochum telescope on La Silla (shown in Figure 2). It is the signature of a radioactive blob rising from the inner ejecta to the surface. The picture emerging from the observations of the first several weeks was certainly more complex than what had ever been assumed of supernovae before.

Once SN 1987A entered the radioactive decline, one could have expected that it would become less exciting. Far from it! IUE observations started to detect an increase in flux of several high-excitation lines, like N V, N IV], N III], C V, C III], He II, mirrored by similar behaviour of [O III] and Hα in the optical at about 80 days after explosion. These lines could not possibly come from the fast moving ejecta and were quickly recognised as originating from material outside the supernova, ionised by the soft X-rays from the shock breakout. From the high ionisation of these lines, a temperature of ~ 10^6 K at the shock breakout could be inferred.

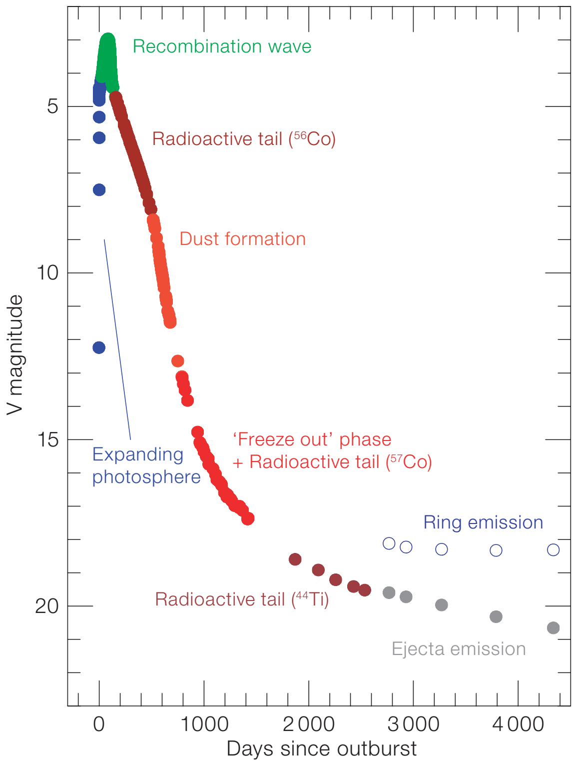


Figure 1: Light curve of SN 1987A over the first 12 years. The figure marks some of the most important events in the history of the supernova (from Leibundgut and Suntzeff 2003).

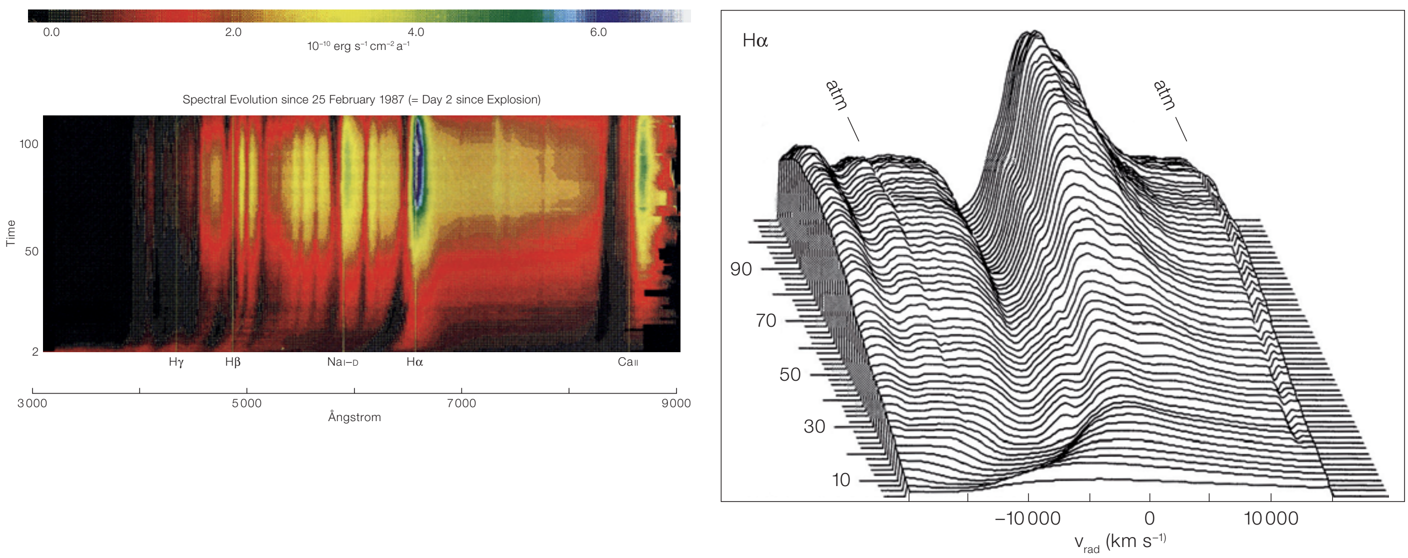


Figure 2: Spectral evolution of SN 1987A as observed with the Bochum telescope (Hanuschik and Thimm 1990). Important lines are marked at the bottom. The evolution covers the first 120 days and the redshifting of all lines is easily visible. The Bochum event is shown in the right panel displaying the Hα evolution as the blueshifted excess.

The circumstellar material had to be from the progenitor star itself due to the high N/C ratio, indicating CNO processing (Fransson et al. 1989). This was, of course, emission from the inner circumstellar ring around SN 1987A, which was first imaged with the NTT. Later HST images provided the linear dimensions of the ring. In combination with the rise time for the narrow circumstellar lines, this provided a purely geometric distance to SN 1987A (Panagia et al. 1991). With the LMC being the first rung in the distance ladder to determine the Hubble constant, SN 1987A provided a very solid stepping stone.

Of molecules, radioactivity and freeze-out

At just about the same time as the appearance of the UV lines, the supernova ejecta were presenting another surprise. Infrared spectroscopy about 100 days after explosion showed CO and SiO molecular signatures indicating substantial masses (about 10^{-3} $M_{\odot}$). The presence of the molecules within the ejecta was difficult to explain. The formation of molecules required that they be protected from the UV and X-rays in the harsh environment of the ejecta. This also contrasted with the observations of the characteristic γ-rays at 847 keV and 1.238 MeV from the ^{56}Co decay, observed with KVANT on MIR. The characteristic decay lines could be observed for the first time ever in a supernova, confirming the radioactive energy source. The X-rays are from Compton scattering of the γ-ray rays and their emission peaked after about 200 days and slowly declined thereafter as the number of ^{56}Co nuclei decayed away. The presence of molecules was a clear sign that there were regions in SN 1987A which could cool down significantly, while at the same time the radioactive material from the core had to be transported towards the surface to become observable.

Infrared wavelengths gained in importance as more and more radiation was emitted at longer wavelengths. The bolometric light curve very quickly started to become dominated by long-wavelength radiation and the inclusion of this spectral range became more and more important. ESO and CTIO collaborated for several years in providing this vital ingredient to measure the bolometric light curve. The decline of the light curve remained constant at the rate of decay of ^{56}Co and allowed the measurement of the mass of ^{56}Ni (0.07 $M_{\odot}$) produced in the explosion. The Ni→Co→Fe decay chain could be observed directly in the changing line ratios of the near-infrared Co and Fe lines. The bolometric light curve was also the first indicator that something else was happening about 500 days after explosion. The light curve started to drop below the expected decline rate due to dust formation in the ejecta. At the same time the near-infrared [Fe II] lines dropped dramatically as the ejecta cooled below the temperature to excite these lines, a signature of the infrared catastrophe predicted by modellers (Spyromilio and Graham 1992). Macroscopic dust grains which partially covered the ejecta, and hence blocked some of the light, had formed. The radiation was absorbed in the optical spectrum and shifted to the far infrared, where it was detected by the Kuiper airborne observatory. Line shifts towards shorter wavelengths of the infrared emission lines coming from the ejecta were a signature of the same phenomenon. Again, the explanation was that the distant part of the object is blocked by intervening dust (Lucy et al. 1992).

The light curve had one more unexpected deviation in store. After about 1200 days the decline started to slow down. First interpretations were that the slower decays of ^{57}Co were starting to dominate the light curve, but this would have required unreasonably high isotope ratios, which were inconsistent with the expected nucleosynthetic yields or the known abundances. This interpretation was also incompatible with the observed decline of the infrared Co lines compared to the Fe line, which allowed the amount of ^{57}Co to be deduced. The explanation here was that the time scale for recombination and cooling in the supernova envelope became comparable to the expansion time scale, i.e. some of the 'stored' energy was finally released. This was termed "freeze-out" as the ejecta were no longer in thermal equilibrium and detailed time-dependent calculations had to be performed. The light curve did flatten later because of the ^{57}Co (mass 0.001 $M_{\odot}$) and now is powered mostly by ^{44}Ti (~ 10^{-4} $M_{\odot}$) (Fransson and Kozma 2002). These three radioactive isotopes all formed during the first seconds of the explosion and the masses of these together contribute some very strong constraints on the explosion models. Besides the determination of the radioactive isotopes, the masses of the most abundant elements formed in the progenitor star and in the explosion could also be determined. These included such important elements as carbon, nitrogen, oxygen, manganese and silicon. For the first time one could determine reliable masses of these elements directly.

'Napoleon's hat' and other circumstellar matters

Narrowband imaging with the NTT about three years after the explosion revealed a circumstellar structure around SN 1987A which was supposed to resemble the triangular hat which Napoleon would have worn. Napoleon's hat gave the first opportunity for a three-dimensional view of SN 1987A. This image, together with the detection of extended narrow emission from the He I 1083 nm line and the IUE observations of the circumstellar gas, were the first indications that there was more to come with this supernova. HST revealed first the inner ring and then later confirmed the outer rings (Figure 3). The NTT was used to measure the density and other properties of the outer rings. The HST images also showed the fading supernova ejecta in the middle. The ring on the other hand had been fading extremely slowly and hence after about ten years it started to outshine the ejecta (cf. Figures 1 and 3). The circular ring is inclined by about 43° with the northern part closer to us. It is essentially stationary with an expansion velocity of about 10 km s^{-1}.

The existence of the ring presents an unsolved puzzle for SN 1987A. It is obviously the remnant of the stellar mass-loss history of the progenitor star, but how did it become concentrated into a ring and not be distributed spherically? With the two outer rings there appears to be an hour-glass-shaped structure enveloping the supernova itself. Even though it is not clear how to construct such a ring, it is likely that the progenitor system of SN 1987A had to be a binary (e.g., Morris

Figure 3: NTT image of the circumstellar environment of SN 1987A (left; Wampler et al. 1990) and the ring in 2003 as observed by HST (right).

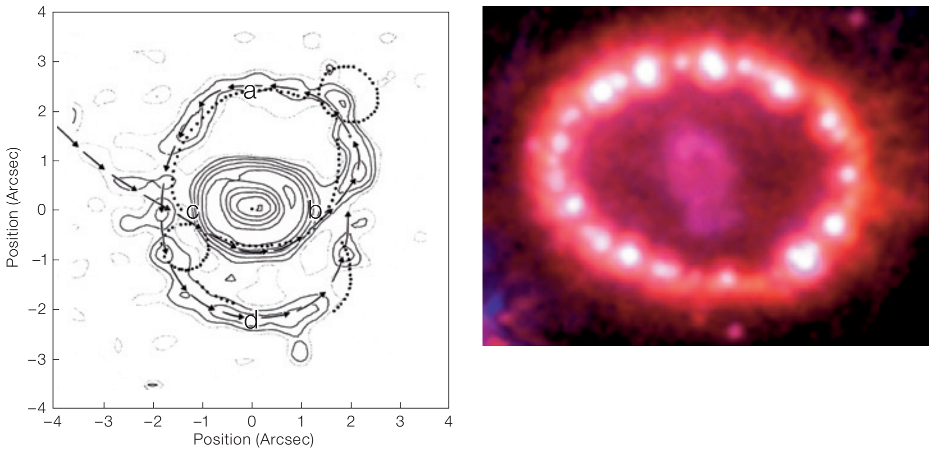
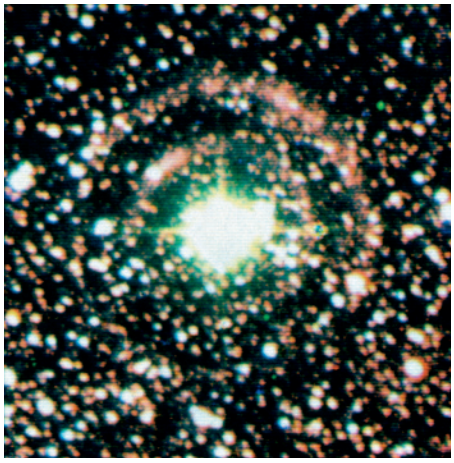


Figure 4: Expanding light echoes around SN 1987A. (ESO PR Photo 08d/07)



and Podsiadlowski 2005). What happened to the companion is unclear and no trace of it – other than the rings – has been detected. Some theories surmise that the progenitor of SN 1987A was a merger, a star that had swallowed its companion.

The prediction that the stationary ring would be reached by the supernova shock was made early on, but the exact date was debated. The radio flux of SN 1987A – after an initial short emission of a few weeks – started to increase again after about 1200 days (Manchester et al. 2002). This brightening has continued since then and was the first signal of the interaction of the supernova shock with the circumstellar environment.

Similarly, the X-ray flux started to increase, and has continued to increase almost exponentially (Park et al. 2006, Haberl et al. 2006). Finally, after 10 years, a spot of optical emission appeared toward the North-East of the ring. And again this was a surprise: rather than having the shock reach a smooth ring more or less simultaneously, the ring appears to be more like spokes on a wheel with inward intrusions. Also, the expansion of the supernova shock may not be uniform but faster in some directions than others. The asymmetries in the explosion could be reflected in this interaction as well. Over the past few years the ring has continued to be lit up in various places and now resembles a pearl necklace (Figure 3 right). The interaction is now observable at all wavelengths from the X-rays (Chandra and XMM), the optical and infrared (all major southern observatories VLT and Gemini, HST), as well as the far infrared (Spitzer) and radio (ATCA), and a rich data set is being assembled.

Several echoes, the integrated light from the peak phase reflected off interstellar sheets between the supernova and us, have been observed over the years around the supernova (see Figure 4). They have been monitored with several telescopes and have been used to map the interstellar material in the LMC near the supernova.

The supernova ejecta themselves are now difficult to observe due to their faintness and the increasing brightness of the inner ring, but it is becoming clear that they display an asymmetric shape. The details will have to be worked out from HST imaging and adaptive-optics observations from the ground.

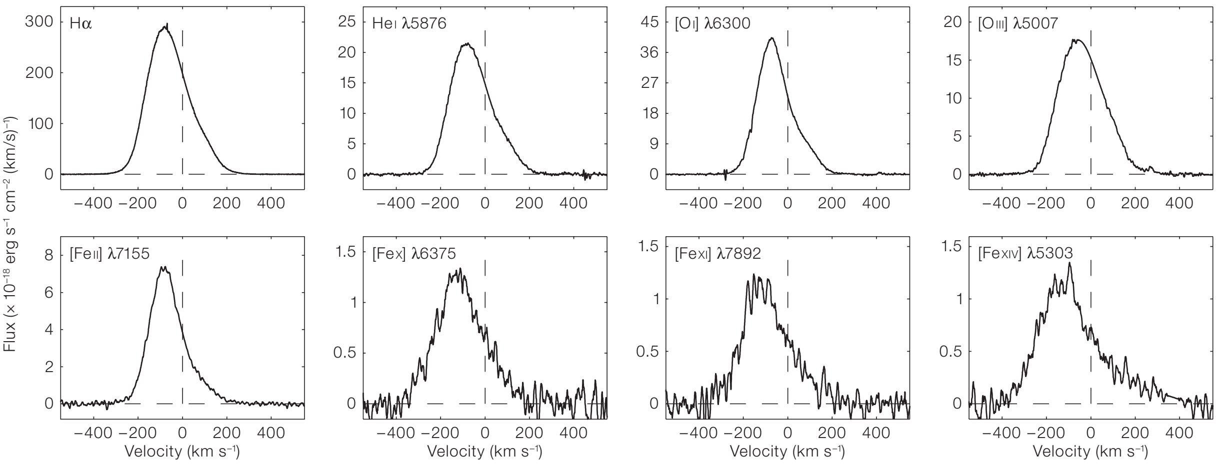
SN 1987A at twenty

Right now SN 1987A is undergoing another transition from the supernova emission to the supernova shock interaction with the circumstellar material. The 'three-ring circus' of SN 1987A has become an emblematic picture of modern astronomy. The supernova shock has now reached the inner ring and we can observe in real time how it will work its way through the ring.

At optical/near-IR wavelengths we can now distinguish five emission sites in SN 1987A: (1) the ejecta in the centre with a typical velocity structure of 3000 km s^{-1}; (2) the stationary extended ring with 10 km s^{-1} expansion; (3) the shocked material in the ring, visible in the hot spots and with velocities of about 300–500 km s^{-1}; (4) the reverse shock moving back into the supernova ejecta with a velocity of up to 15000 km s^{-1}. In addition, the X-rays show evidence of shocked gas with a temperature of $\geq 10^8$ K, which has not had time to cool down enough to be seen in the optical (Zhekov et al. 2006). We have observed these various components in the optical with high-resolution spectroscopy with UVES (Gröningsson et al. 2006) and in the near-IR with ISAAC and – spatially resolved – with SINFONI (Kjær et al., in preparation). The UVES spectra show asymmetric line shapes for several coronal lines, which are produced by the same shocked gas that is responsible for the soft X-rays (Figure 5). Our SINFONI data for the first time allow us to measure the velocity distribution around the ring, indicating how the shocks are accelerating ring material (Figure 6). At the same time, the X-ray observations show a rich line spectrum complementing the optical/IR observations. The radio light curve is increasing, reflecting the production of non-thermal electrons, and probably also cosmic rays, in the shock. Hot dust emission is seen by Spitzer, as well as by VISIR and Gemini (Bouchet et al. 2006).

The future

The coming years will provide exciting times (indeed!) and SN 1987A will remain the focus of observations with many telescopes. The destruction of the inner ring will take many years and maybe it will



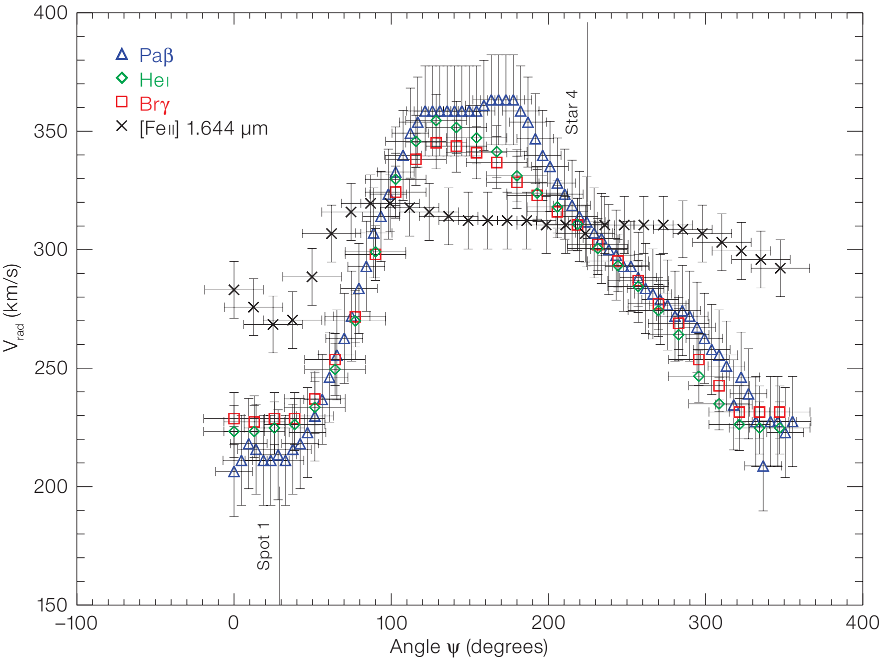


Figure 5 (above): Intermediate-velocity emission components from the cooling, shocked material from the inner ring, showing a range of ionisation stages, including highly ionised coronal lines from gas at ~ 2×10^6 K (from Gröningsson et al. 2006).

Figure 6 (left): The azimuthal velocity distribution of the inner ring is shown from different near-infrared emission lines (from Kjær et al., in prep.).

hold a clue to its origin. The X-rays may also help in illuminating any material outside the ionised ring which arises from a possible red supergiant stage. The circumstellar ring of SN 1987A will be a bright source at all wavelengths for several years.

The compact remnant in the centre has so far remained elusive. The neutrinos indicate that such a compact object should exist, but it remains deeply embedded in the ejecta. The very low limits to both the optical (Graves et al. 2005) and X-ray luminosity (Park et al. 2006) may be explained by either gas or dust absorption. In this case, however, the radiation should emerge in some waveband, possibly the far-IR. Other possibilities to explain the apparent absence of a neutron star include a weak magnetic field, slow rotation or that a black hole may have formed, possibly as a result of fall-back of material onto the newborn neutron star.

SN 1987A was full of surprises and it remains unique amongst the known supernovae. Not only was it the closest supernova for several centuries, it was also very peculiar, coming from a blue supergiant progenitor, with a circumstellar environment unlike any other supernova known. We will continue to monitor its evolution towards a supernova remnant.

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SN 1987A at La Silla: The Early Days

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We first try to capture some of the response at ESO La Silla to the announcement of a bright supernova in the LMC – the excitement, the planning, and the discussion. Some of this was a result of the growing realisation that we were confronted with a unique event whose special aspects we describe. We conclude with very brief descriptions of the role of ESO astronomers in trying to unravel some of the mysteries in competition and collaboration with other observatories.

First news of a bright supernova

When astronomers at La Silla arrived for the ritual afternoon tea at 4 p.m. on 24 February 1987 after the previous night's clear observing, they were greeted by the news that a supernova had been detected in the LMC the previous night by Shelton at the neighbouring Las Campanas Observatory. This news, conveyed to La Silla by a telephone call from Mark Phillips at Cerro Tololo at tea-time, was met with only a fleeting skepticism because the source was recognised as impeccable. The tea-time ritual of groggy astronomers quietly sipping their tea and gazing out the windows to judge the prospects for the coming night by the quality of the sky was transformed, to be succeeded by flurries of excited, but still to some extent uncoordinated, planning. Nobody doubted for one second that the sky would be clear and there would be excitement galore in the days and nights ahead. And indeed there was!

Now on such occasions a large observatory such as La Silla can be considered like a naval fleet consisting of many ships of the line from torpedo boats to cruisers and even aircraft carriers. La Silla had them all. Fortunately, also present was the Admiral of the Fleet Lo Woltjer, otherwise known as the DG of ESO. An admiral has the ultimate power to define battle tactics, and therefore the roles of the various ships under his command, while leaving his individual captains the flexibility of initiative and manœuvre; and this was the course followed by our Admiral. All observers were encouraged to plan for observing SN 1987A by whatever means at their disposal. This was understood to mean abandoning scheduled observing plans. In fact there were even judicious changes of instruments, one being the immediate installation of IR equipment on the 1-m telescope, the rewards for which can be seen in the long history of IR photometry and low-resolution spectroscopy emanating from La Silla and its importance in determining the bolometric light curve, among other things.

There were also remarkable sociological effects witnessed at La Silla during this initial period. Although even after the first night astronomers were talking to one another at afternoon tea more than ever before, it was decided after the third night to have regular meetings of all observers at 4 p.m., naturally with the tea and cakes, but in a room in the 'Atacama Hilton' ample enough to accommodate both the sipping and munching and, more importantly, a lively report and discussion of what had transpired the previous night. Our Admiral was always present ready to give judgment on various delicate questions such as who should co-author the various papers that would inevitably appear and could this include collaborating colleagues (named in their original proposals) back in Europe. Not much room for Solomonic judgements there.

To add to all this excitement we began to receive advice on the internet on what to observe and how, and even offers to take responsibility in some yet to be constructed archive of all the data flowing in, not just from La Silla but from the other southern observatories as well. Separation by intercontinental distances made handling these matters relatively easy.

The observations commence

Spectral observations at the 3.6-m telescope were complicated because the supernova was too bright, not too faint. This necessitated the insertion of neutral density filters involving added calibration problems and very short exposures. It left little time for us to stand outside and admire the supernova with the naked eye. Appreciating by now that this was an historic occasion, we did however sneak outside occasionally to satisfy ourselves that it had not been an optical illusion. No breaks that night however for midnight lunch at least at the 3.6-m.

In the meanwhile the internet had been flowing with speculations about what type of supernova it might be even after spectra had been taken. There was in fact misinformation. Some of this speculation was undoubtedly biased by the knowledge, among supernova *aficionados*, that a Type II supernova had until that time never been recorded in a Magellanic-type irregular galaxy. Moreover in flux uncalibrated spectra – those you are likely to see first as a spectral observation is completed – the nature of P-Cygni profile of Hα does not exactly stand out particularly for an observer inexperienced in such matters. We soon knew that poor statistics had been responsible for any bias.

For these reasons, and for the more important reason of informing the community about observed facts and some measurable quantities, an *ESO communiqué* was sent in the form of IAU Circular No. 4326 agreeing with the classification of Type II made earlier in IAUC No. 4317 from Las Campanas and IAUC No. 4318 from CTIO. Identification and temporal behaviour of various lines were given. What was not remarked was how the velocity of the photosphere was decreasing so rapidly in the early stages as the photosphere receded into the ejecta that it could be seen online with each successive spectrum.

A somewhat tense atmosphere surrounded activity at the 1-m telescope because, as mentioned above, the removal of a spectro-polarimeter to be replaced with IR InSB photometer had been approved by our Admiral. There was worry whether this change could be accomplished rapidly enough to allow observations before SN 1987A reached a high enough air mass to impede a sufficiently accurate beam switching. Accurate optical alignment was also a major point of concern to establish the throw amplitude for the chopping in the complicated dense field of 30 Doradus. The final outcome, predicated on the strong signal from the supernova, was that the 1-m IR equipment was kept in place and scheduled, even for daytime, months ahead.

To add to this excitement (and tension) during that initial period was the news, informally propagating at that stage, but soon officially revealed in IAUC. Nos. 4323, 4338, 4340 that neutrino bursts had been detected, providing observational evidence that theory was on the right track, but also giving a precise time for the collapse of the core after the physicists had clarified which reported events were real. These neutrinos certainly played a part in giving an extra incentive push that we were on to something special, just as they may have provided a push to force the envelope off the collapsed core.

Uniqueness of the event

It is worth recalling just how unique this SN 1987A proved to be. Much of this uniqueness, though not all, was appreciated within the first week or ten days after the discovery and ESO observers played a part in elaborating some of those. Here we list some but probably not all. One general aspect, not listed but certainly unique, was the extent to which it has triggered a huge upsurge in studies of supernovae of all types, and the extent to which it, as a single object, has been studied over the past 20 years. Virtually all of these unique characteristics stem from its proximity in the LMC and of course were helped by the availability of modern instrumentation, eager observers and theoretical insight.

SN 1987A is the only naked eye supernova for 383 years. It was the first Type II recorded in a Magellanic type irregular galaxy. It was the first supernova whose progenitor was identified. It is the only supernovae from which neutrinos have been detected (marking the core collapse). It was the first supernova to be detected in gamma-rays, both line and continuum emission. The prompt intrinsically faint radio burst was the first of its kind. (Stronger radio emission started later at about the same time as X-ray emission.)

There was evidence of asymmetries in the expansion and shape revealed by means of the Bochum event, polarisation and later structures in emission line profiles. While spectral synthesis of both UV and optical photospheric spectra using Monte Carlo methods satisfactorily explained the main features, the enhanced lines of s-process elements identified at CTIO and later modelled at ESO proved something of a surprise.

And somewhat later direct observations of the masses of ^{56}Co and ^{57}Co were both confirmed by entirely independent methods. Also, with greater uncertainty, a determination of the increased mass of Fe albeit before all the ^{56}Co had decayed. The first light echoes from a supernova were detected. The unambiguous detection of dust formation in the expanding ejecta was also a major feature.

As a separate issue SN 1987A in the first days was bright enough that it acted as a background source observable at very high spectral resolution revealing interstellar lines and bands never before detected in the LMC.

As a further separate issue of uniqueness one might suspect that the increase in cost of IAUC telegrams announced in IAUC No. 4344 was a case of demand inflation whose immediate cause was SN 1987A.

The role of ESO in some of this

1. The progenitor. Astronomers were quick to identify the culprit as Sanduleak –69° 202, a blue supergiant, and ESO was well up in this competition with IAUC No. 4319. These results were later elaborated with a careful evaluation of the astrometry (West) in one of a series of papers to appear as a volume of A&A Letters, as were most of the other early results from ESO.

2. A long series of optical photometry was obtained with various filter systems at various smaller telescopes. These included *U*, *B*, *V* broad bands, the Walraven system and the Geneva system. In general the *U*, *B*, *V* observations were used (in combination with the IR) for defining the bolometric light curve. The most accurate proved to be the Geneva system photometry (Rufener) in which, to this day, one wonders about the reality or otherwise of small glitches seen occasionally, particularly in the *UV* band. With time, account had to be taken of the contamination from two neighbouring stars.

3. Broad-band IR photometry covering from *J* to *Q* bands was essential for establishing the bolometric light curve and therefore the energy budget of SN 1987A as a function of time (Bouchet). It had and has special relevance to the study of dust. It also had special relevance in demonstrating how much gamma-ray deposition occurred and therefore how much outward mixing of radioactive Cobalt was required in the models to reproduce the observations. An intriguing result of these observations has been the occurrence of an IR excess beyond two microns starting near day 40. There is still not complete agreement concerning its origin – early dust in the ejecta, heated dust in the circumstellar environment, free-free emission from the ionised gas in or around the ejecta. This photometry has now extended with unavoidable gaps over 20 years (Bouchet) and still produces new insights, as can be seen in Figure 1.

4. Early reports of measurements of polarisation were given by other observatories in IAUC Nos. 4328 and 4337 neither of which demonstrated that there was a component intrinsic to SN 1987A. With IAUC No. 4339 from ESO, it was established that polarisation varied strongly across PCyg features thus establishing an intrinsic component. Subsequent observations (Schwarz) have shown that with time the polarisation increased.

5. The early low resolution optical spectroscopy from ESO provided, as did most other spectroscopy, a means of measuring the expansion rate of the envelope (Danziger). The availability of IUE spectra allowed the creation of a

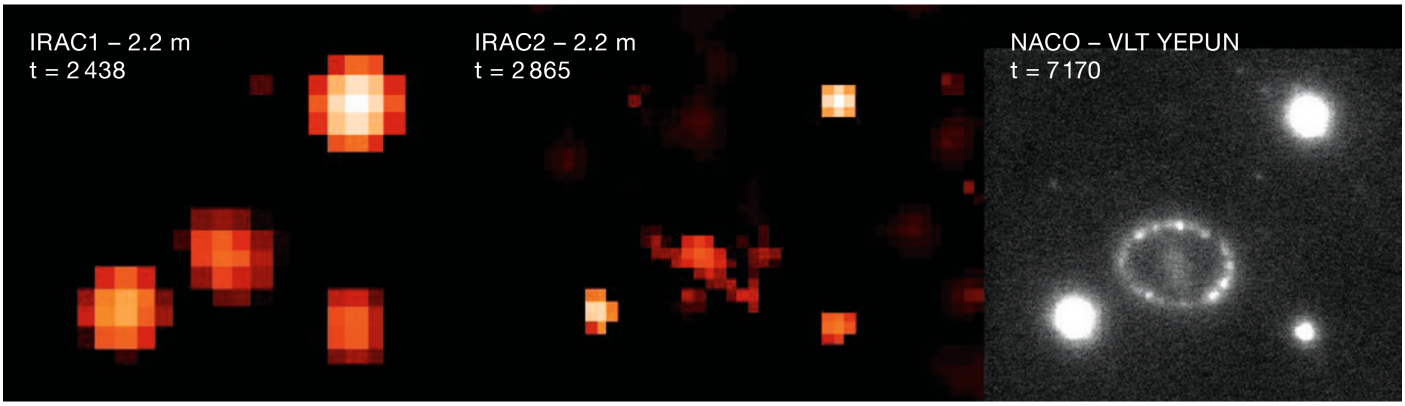

Figure 1: Then – first IR images obtained at the 2.2-m with IRAC1 on 26 October 1993 (left) and IRAC2 on 27 December 1994 (middle). And now – with NACO at the VLT Yantun on 9 October 2006 (right). All images have been acquired through the *H* filter.

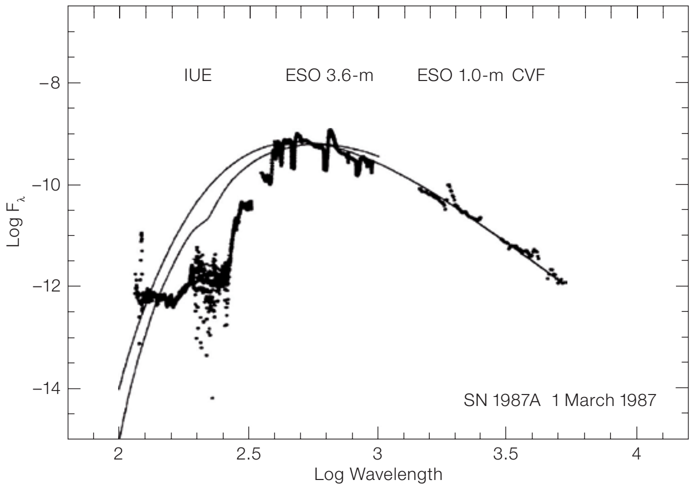

Figure 2: A combination of the UV, optical and infrared spectra for 1 March 1987. The axes are logarithmic in units of erg cm^{-2} s^{-1} nm^{-1}. Overplotted is a 6000 K black-body, both unabsorbed and with an extinction corresponding to E(B–V) = 0.22, all normalised to 550 nm.

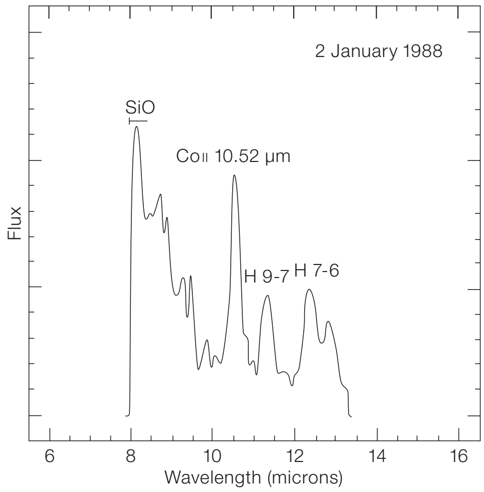

Figure 3: CVF Spectrum obtained at the 1-m on day 314.

composite spectrum from 1500 Ångstroms to 5 microns for 1 March 1987 observations shown in Figure 2. But its ready availability at ESO provided the means of spectrophotometric modelling using Monte Carlo techniques (Lucy). Arguably the best reproduction up to that time of a SN spectrum virtually from first principles, this modelling helped to establish the identity of major absorption features in the early spectra (Fosbury). Early IUE UV spectra were also well reproduced at ESO, immediately allowing one to identify the main sources of opacity in the UV. The Bochum event was seen in the beautiful regularly spaced low-resolution spectra taken with the scanner on the Bochum telescope at La Silla (Hanuschik). It can be described as a structural bump appearing after 15 March 1987 and growing in contrast on the blue wing of the Hα emission and gradually decreasing in velocity. Another bump appears on the red side of Hα perhaps a bit later. There seems no way of avoiding an asymmetry near the line-forming region to adequately account for this. Such effects, though less well documented have appeared in spectra of subsequent supernovae.

6. Low-resolution IR spectra were obtained with the CVF starting very early. As the supernova expanded it gradually became optically thin at various wavelengths in various lines. Apart from the more conventional lines of hydrogen being present and detected, the less conventional molecular emission bands of CO (fundamental and first overtone) and silicon monoxide (SiO) (fundamental only half visible owing to atmospheric cutoff) were identified (Bouchet). Subsequent higher-resolution spectra obtained with IRSPEC led to the first estimate of the mass of CO (Oliva) not so different from later more sophisticated modelling of this emission. Probably the most important result of this IR spectroscopy has been the detection and temporal variation of the fine structure line of CoII at 10.52 microns. This line is insensitive to temperature, most of the Co was singly ionised, and the line was in a clear atmospheric window without serious blending. Simple nebular theory, after it became optically thin, has

therefore led to the most direct determination of the mass of Cobalt in SN 1987A. Its temporal behaviour was also consistent with the radioactive decay of ^{56}Co, but leaving at later times a residual that could be safely ascribed to 57Co whose decay rate is much longer (Danziger). Figure 3 shows a CVF spectrum with the prominent [Co II] 10.52-micron line. Observations from space and the bolometric light curve are entirely consistent with these conclusions. One can add to this story that the estimate of the mass of Fe determined with IRSPEC spectra (Oliva) suggested an increase consistent, within the uncertainties, with what would be expected from the Cobalt decay.

7. Echoes were expected if one reads the literature. In fact the first report of echoes appeared in IAUC No. 4561, March 1988. Here we refer to optical echoes and not the dubiously named IR echoes. However a close inspection of Schmidt plates taken at ESO revealed the presence of echoes as early as 16 August 1987. An analysis of spectra showed that the reflecting medium lay at two discrete distances on the near side of the supernova reflecting light emitted near maximum (Gouiffes).

8. Interstellar lines of Ca II and Na I at high spectral resolution were detected with the CES at La Silla during the first week when the supernova acted as a bright background source (Vidal-Madjar). The forest of Ca II absorption lines showed a complex interstellar structure in the LMC, while the Na I/Ca II ratios were different in the LMC from those in the halo. The presence of diffuse interstellar bands in the LMC (the first in an external galaxy) was also reported and elaborated on later (Vladilo). This work was nicely complemented by detection of hot coronal gas in the LMC, the [Fe X]6375 Ångstrom line in absorption, using the same instrument early on, and supplemented with AAT data (D'Odorico). All of these results suggest, but do not prove, that SN 1987A could hardly lie on the near side of the LMC. After some misleading starts, all of the relevant high-resolution spectra were combined to provide a stringent upper limit on the strength of the interstellar lithium line near 6 708 Ångstroms (Baade).

9. Other observations included attempts to detect a central pulsar presumed to have formed at the time of core collapse. All attempts at ESO, both early and later, have failed to demonstrate a convincing detection (Ogelman).

This account of the early period of observational results from ESO is by its nature highly biased. This is shown not only through the selection of topics but through our method of referencing results, namely by quoting only the name of the first author of any paper that we have used to write this. We hope that all those who contributed to the enterprise of observing and understanding SN 1987A, including the Chilean staff, will understand and be tolerant of this relaxed style.

Photographic image of the Large Magellanic Cloud, before (left) and after (right) the explosion of SN 1987A. The supernova is visible on the right image just below the Tarantula nebula, in the upper part of the irregular galaxy. (ESO PR Photo 08b/07)

Integral-field Spectroscopy of Galactic Planetary Nebulae with VLT FLAMES

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Results from the first dedicated observations of three Galactic planetary nebulae (NGC 5882, 6153 and 7009) made with VLT FLAMES and the Giraffe/Argus integral-field unit are discussed. The unique capabilities of the Giraffe/Argus spectrograph allowed construction of two-dimensional spectral maps of one nebula and of large portions of the other two, and to record in exquisite detail the weak optical recombination lines emitted from carbon, oxygen and nitrogen ions.

A long-standing problem

Planetary nebulae are superb laboratories for the study of the late evolutionary stages of low- and intermediate-mass stars, and of stellar nucleosynthesis, and can be used to probe the chemical history of galaxies as they trace a stellar population that was born earlier (up to several billion years). Their rich emission-line spectra, now observable even to distances beyond the Local Group, offer us the possibility to use them also as test beds of atomic data delivered by the latest theoretical calculations, plus working with planetary nebulae proves to be an inspiration for much other astrophysical work. Here we pursue a physicochemical analysis of three representative nebulae belonging to the Galactic disc population. The traditional forbidden-line methods (based on the bright, collisionally-excited lines) and metallic recombination lines have been used to map the nebular plasma temperature and density, as well as the abundances of various ions and elements relative to hydrogen. We specifically investigated in detail the occurrence of the 'abundance discrepancy problem', whereby abundances in planetary nebulae of elements of the second row of the periodic table (such as carbon, nitrogen, oxygen and neon) when derived from their recombination lines are *much higher* than abundances of the same elements derived from their forbidden lines (e.g. [O III] 495.9 nm) – by as much as factors of 30 for oxygen. The resolution of this problem is important, since knowing which diagnostics to trust and how to interpret complex nebular spectra is vital if we want to have accurate information on the properties of these fascinating objects; we can then safely use them as tools for other work.

Previous studies with smaller telescopes, such as the now decommissioned ESO 1.52-m, relying on 'one-dimensional' long-slit spectroscopy had revealed the presence of large 'abundance discrepancy factors' in the targets (*adfs*; that is, the ratio of abundances from the two categories of spectral line), ranging between two and ten. In total about 100 nebulae have now been surveyed, the majority by long-slit spectroscopy, and most of them show *adfs* larger than two (Liu 2006). The most likely explanation for this spectroscopic anomaly was judged to be the presence of cold plasma regions embedded in the nebular gas in the form of relatively dense, hydrogen-poor condensations – clumps or filaments (Liu et al. 2000; Tsamis et al. 2004). Due to their elevated content in heavy elements (several times Solar), this plasma would have cooled down much faster than the ambient 'normal' composition gas by emitting far-infrared lines, the primary nebular thermostat in relatively low plasma temperatures. Since the emissivity of metallic recombination lines is enhanced at lower temperatures, while at the same time that of the classical forbidden lines is diminished, the hydrogen-poor, metal-rich clumps would emit metallic recombination lines profusely, yielding a truer estimate of the heavy element content of these regions. Whereas the large long-slit survey yielded concrete evidence for elevated recombination-line abundances, the temperature of the suspect metal-rich clumps was tougher to determine since the diagnostic lines involved are faint and often suffer from blends in lower-resolution spectra. Nevertheless, there was some evidence deduced from those studies for temperatures lower by several thousand K than the typical temperatures of photoionised nebulae. This is one aspect of the proposed 'dual abundance model' solution that renders it self-consistent, something rather lacking from alternative propositions which do not invoke metal-rich plasma to explain the discrepancies, such as small-scale temperature fluctuations in a chemically homogeneous medium (e.g. Peimbert et al. 2004). A major unresolved issue remains the, as yet, unknown origin of the high abundance plasma.

The current study

Metallic recombination lines in nebulae can be a thousand times fainter, or even more, than hydrogen recombination lines, in sharp contrast to the luminous forbidden lines emitted by the same heavy ions. The VLT with its light-collecting power, coupled with the ability to make spatially resolved spectral maps across the face of the nebulae, settled the choice of the VLT FLAMES instrument and the Giraffe spectrograph with the Argus integral-field unit, mounted on UT2/Kueyen, for our study. The target sample comprised three nebulae belonging to the Galactic disc population: we used the large Argus unit (12 × 7 $arcsec^2$) to observe NGC 5882, NGC 7009 and NGC 6153 in the 396–508 nm range at a spatial resolution of 0.52 arcsec per spatial pixel (*spaxel*), as well as the small 6.6 × 4.2 $arcsec^2$ field of view to observe a portion of NGC 7009 in the 419–439 nm and 454–476 nm ranges at 0.30 arcsec per spaxel. The small field spectra of NGC 7009 were taken in high-resolution mode (R = 32 500) allowing us to measure gas velocities to an accuracy of a few km/s, while the remaining spectra had a resolution of 25–30 km/s comparable to the typical expansion velocity of a planetary nebula and thus optimal for the detection of faint recombination lines. Our main goals were to map: (i) the spatial distributions of metallic recombination lines from heavy ions (e.g. C II, O II, N II);

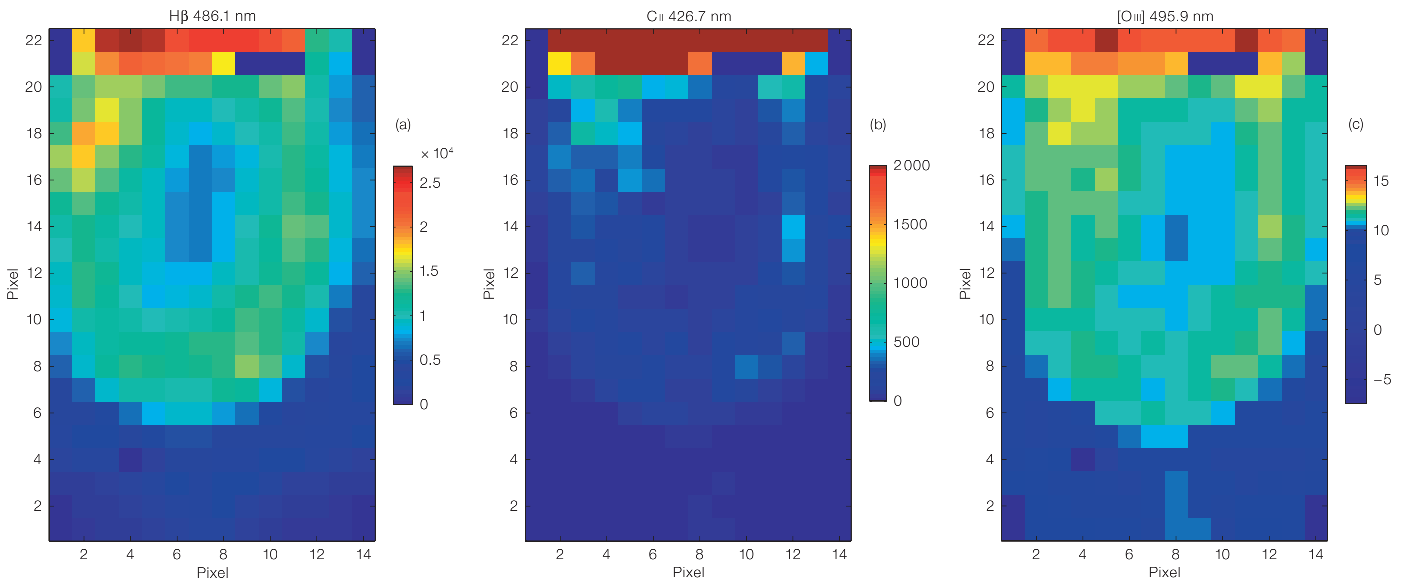

Figure 1: Narrowband emission line maps of NGC 5882 taken with the 12 × 7 arcsec^2 Argus unit in the light (a) of Hβ, (b) the C II 426.7 nm recombination line, and (c) the [O III] 495.9 nm forbidden line (the log is shown). The blank corner spaxels correspond to sky-fibres, and three blank spaxels in the second row from top correspond to dead fibres.

(ii) the corresponding two-dimensional chemical abundance distributions from both recombination lines and forbidden lines; and (iii) to investigate the resulting pattern of *adfs*, temperatures and densities derived from recombination lines in order to probe the physical properties of the posited super-metal-rich component. The high spectral resolution data of NGC 7009 were aimed at revealing whether there is any *kinematical* evidence for the existence of hydrogen-poor regions embedded in the nebula with velocities different from the bulk velocity of the normal gas component.

The spectra were reduced with the dedicated girBLDRS pipeline provided by the Geneva Observatory and were flux-calibrated within IRAF. Custom-made routines allowed us then to convert the row by row stacked CCD nebular spectrum to a 'data cube', this in the terminology of integral-field spectroscopy denoting a three-dimensional array incorporating the two spatial dimensions, and the astrophysical flux as a function of wavelength in the third dimension (hence the term '3D spectroscopy' for this kind of observations). The emission-line spectra in each spaxel of the data cubes were fitted by Gaussians using a dedicated tool which also allows interactive fitting for individual spaxels, such as those over the central star. Maps of the emission in each line species were then constructed from the Gaussian fits. The maps were corrected for interstellar extinction using the c(Hβ) extinction constants derived from a comparison of the observed and predicted relative intensities of H I recombination lines (the Balmer decrement). In Figure 1 we show maps of NGC 5882 outlining the bright shell of the nebula in the light of the hydrogen Balmer recombination line Hβ, the metallic recombination line C II 426.7 nm (emitted when C^{2+} ions recombine with free electrons), and the forbidden line [O III] 495.9 nm (emitted following electron-impact excitation of O^{2+} ions). C II 426.7 nm is typically the strongest heavy ion optical recombination line emitted from planetary nebulae and H II regions (up to a few per cent of Hβ 486.1 nm). Observations of this line in the early 1980s first exposed the nebular abundance anomaly when comparisons were made between the high carbon abundance measured from it *versus* that from the collisionally-excited C III] 190.8 nm line, which had just become accessible with the International Ultraviolet Explorer (e.g. Barker 1982). In Figure 2 we show a representative spectrogram of NGC 6153 registered by a *single* 0.52^2 arcsec^2 spaxel, highlighting the superb quality of the FLAMES Giraffe data and the prominent high signal-to-noise metallic recombination lines of CNONe ions: all these are useful abundance indicators provided that appropriate recombination coefficients are used for their interpretation. The spectrum has been smoothed using a five-point average; even so, almost all features seen down to the noise limit are nebular emission lines.

A strange nebular phase: very high metal abundance, low-temperature gas

We proceeded by investigating the nebular physical conditions; plasma temperatures and densities were first derived from the dereddened forbidden-line ratios [O III] 436.3 nm/495.9 nm and [Ar IV] 471.1 nm/474.0 nm respectively. These were subsequently adopted for the calculation of nebular abundances: forbidden-line abundances relative to hydrogen depend strongly on the adopted temperature via an exponential factor (being higher when temperatures are lower and vice versa), whereas metallic recombination line abundances have a much weaker temperature dependence (a shallow, inverse power law).

In Figure 3a we show a temperature map of the south-eastern quadrant of NGC 6153. The temperature which has a mean value of 9 400 ± 145 K shows a shallow positive gradient averaging about 1000 K from the outer to the inner regions (top to bottom) – the central star is at spaxel (9, 3). This gradient reflects

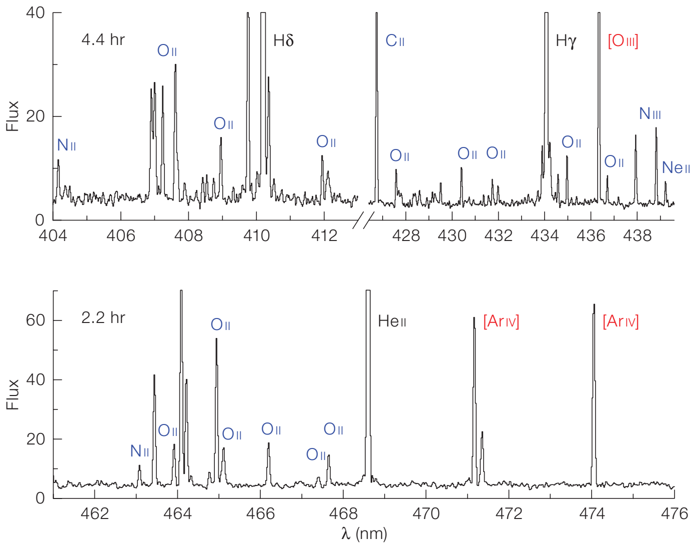

Figure 2: Single spaxel spectrum of NGC 6153 showing the prominent recombination lines of CNONe ions. The metallic recombination lines are marked in blue and the collisionally excited lines are marked in red.

directly on the O^{2+}/H^{+} abundance ratio derived from the forbidden 495.9 nm line, which shows a rough trend in the opposite direction, with a mean value very close to the Solar abundance of oxygen (Figure 3b). On the other hand, the same abundance ratio derived from the recombination line 464.9 nm is highest in the inner nebular regions, peaking close to the central star (Figure 3c), and the resulting abundance of oxygen there (even without taking into account other ionic stages) is at least 10 times Solar. In this sense the recombination- and forbidden-line abundances of doubly-ionised oxygen increase in opposite directions. The ratio of the two (the *adf*) thus becomes smaller for increasing radial distance from the central star and has a mean value of 16 in a 2.4 $arcsec^2$ area centred on the nucleus of NGC 6153. This can be better seen in Figure 4 where we respectively plot the radial variation of the oxygen *adf* for NGC 6153 by binning the spaxels at successive radial increments, weighting them by the total number of non-zero signal spaxels at each radius.

The oxygen abundance discrepancy thus correlates with distance from the planetary nebula nucleus. The carbon abundance derived from the C II 426.7 nm line also behaves in a similar manner (displaying values several times higher than Solar throughout the nebulae). It is not yet clear what the reasons for this is, though one possibility could be that the *adf* is caused by metal-rich, clumped plasma ejected from the central star during its post-AGB evolution, becoming more 'dilute' as it progressively mixes with the 'normal' nebular component further out in the nebula. If this picture is true then the highest concentration of high-abundance gas will be found close to the central star. On the other hand, the two different O II lines used to compute the *adf* in the upper and lower panels of Figure 4 show slightly different radial trends. The exact trends depend also on the temperatures and densities adopted as representative for the emitting regions of these lines – here the plasma conditions corresponding to the hot gas were used (from forbidden-line ratios). These nebular parameters, as we show later, are probably not appropriate. But just what are the physical conditions of the postulated clumps, other than their obvious metal-rich nature, and how do we get a handle on them?

The weak temperature sensitivity of the emissivities of O II recombination lines can be used to provide a temperature estimate via the O II 408.9 nm/464.9 nm ratio. We have used this diagnostic cou-

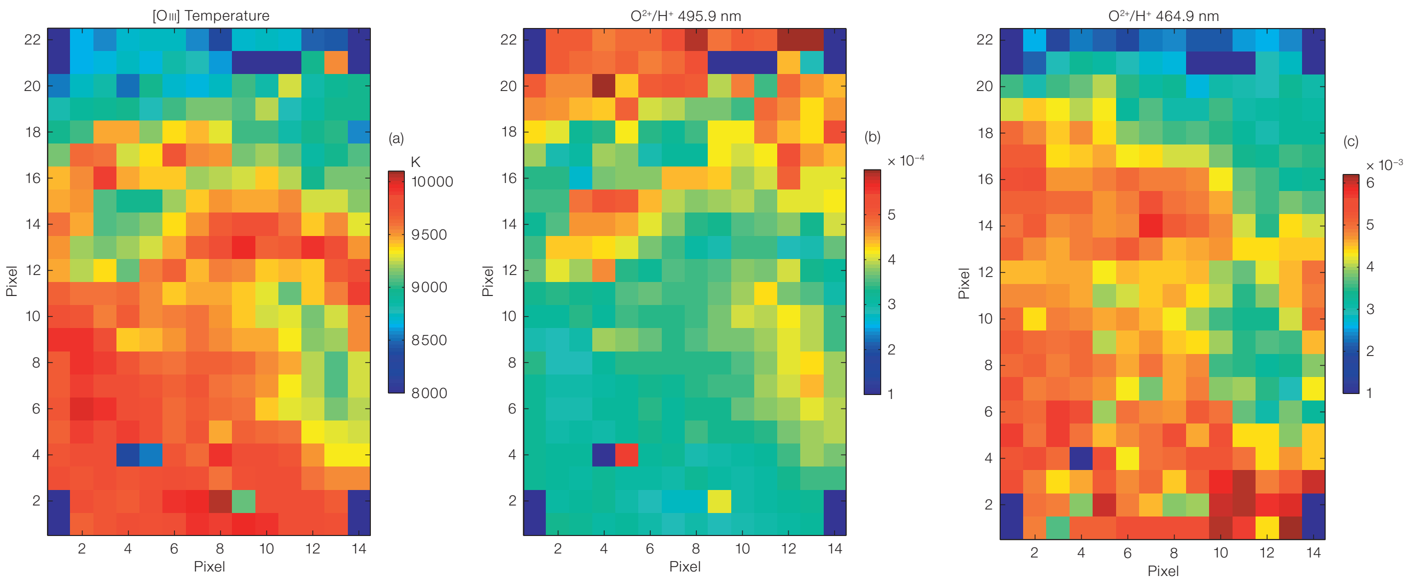

Figure 3: Physical properties across the south-eastern quadrant of NGC 6153: (a) The electron temperature measured from the forbidden line ratio [O III] 436.3 nm/495.9 nm; (b) The O^{2+}/H^{+} abundance ratio derived from [O III] 495.9 nm, and (c) The same abundance ratio derived from the O II 464.9 nm recombination line.

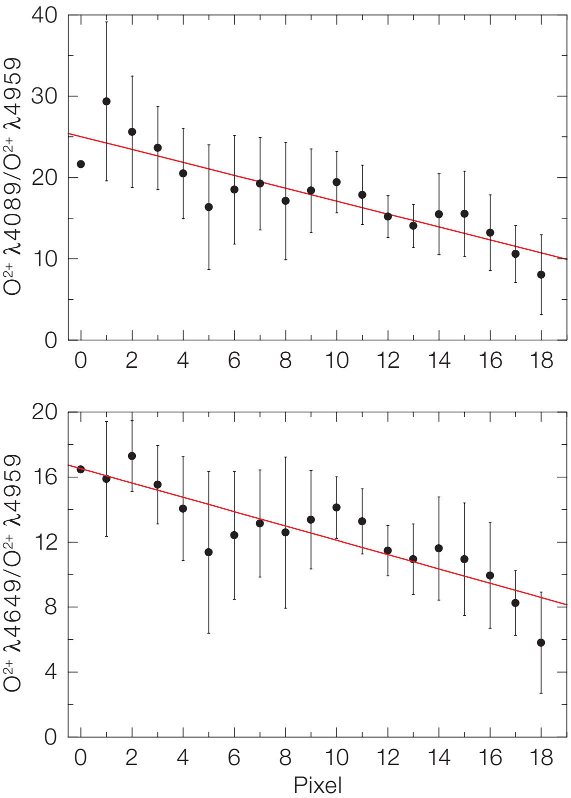

Figure 4: The radial profile of the O^{2+} abundance discrepancy factor for NGC 6153.

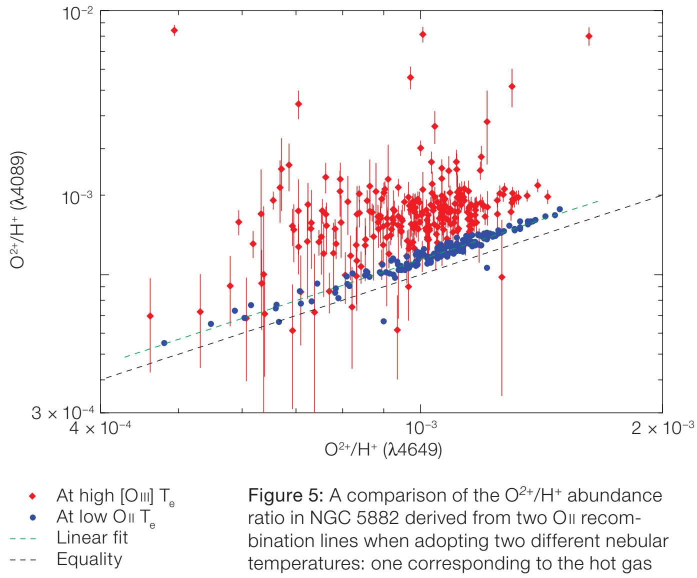

Figure 5: A comparison of the O^{2+}/H^{+} abundance ratio in NGC 5882 derived from two O II recombination lines when adopting two different nebular temperatures: one corresponding to the hot gas component, and another corresponding to the cold O II gas component.

pled with the latest theoretical O II recombination coefficients and found mean temperatures as low as about 5 300 K for NGC 6153, 2 400 K for NGC 5882, and 2 500 K for NGC 7009; importantly these appear to be even lower near the central stars. The associated errors are quite large but, assuming that the O II diagnostic ratio is a valid thermometer, there seems to be good evidence for the existence of a cold plasma phase at temperatures several thousand K lower than the normal nebular component. We stress again the self-consistency of this component being *both* cold *and* metal-rich (hydrogen-deficient). Another piece of evidence supporting this point is shown in Figure 5; there we compare the spaxel to spaxel variation of the O^{2+}/H^{+} abundance ratio derived from the 408.9 and 464.9 nm lines (both emitted by the same ions) for NGC 5882: when the high temperatures derived from the classical [O III] diagnostic (mean of 9160 K) are adopted for the computation, the scatter of the data is very large. In contrast, when the much lower O II ratio temperatures are adopted (mean of 2 400 K), the two lines yield almost exactly equal abundances with minimal scatter. Thus the O II lines cannot be compatible with an emitting region of high temperature. Importantly, it seems that this is true even for NGC 5882 which is our 'control' object, and a nebula previously known, from long-slit spectra, to exhibit a mild abundance discrepancy of a factor of two.

In order to add more weight to the above discussion we show in Figure 6 the spectrum of a 0.9 × 0.9 arcsec^2 region in NGC 7009 straddling the interface between the bright inner nebular shell and the fainter outer envelope. This spectrum was taken with the small Argus unit in high spectral resolution mode (32 500) and covers several C III and O II recombination lines near 465.0 nm. At this resolution each line is split into three components with central wavelengths at about −93, −60 and −28 km/sec, probably corresponding to the edge of the inner nebular shell (central peak) and the expanding outer shell (peaks on either side). In the upper panel the observed (red) and synthetic (green) spectra are shown. Also overplotted are the intrinsic synthetic spectra, before convolution with the instrumental profile, of C III (orange) and O II (blue). We specifically wanted to compare the widths of the metallic recombination lines to those of the forbidden [O III] 436.3 nm line to uncover any evidence of different temperature nebular phases in this way. The synthetic O II line profiles were thus replaced by the profile of [O III] 436.3 nm and in the bottom panel the difference between the observed and synthetic spectra is shown: this yielded large residuals, especially for the central O II peak, meaning that the O II lines have significantly narrower thermal widths than [O III] 436.3 nm. This indicates that, even though they are emitted from the same O^{2+} ion, the O II spectrum and [O III] 436.3 nm cannot originate from material of identical physical properties. This constitutes extra evidence for lower temperature gas associated with the metallic recombination lines.

All these results are strongly in favour of the dual abundance model for planetary nebulae, whereby a portion of the gas that has distinctly different properties from the gas emitting the collisionally excited lines, predominantly emits the metallic recombination lines. At the time of writing we are investigating the possibility of using the relative intensities of

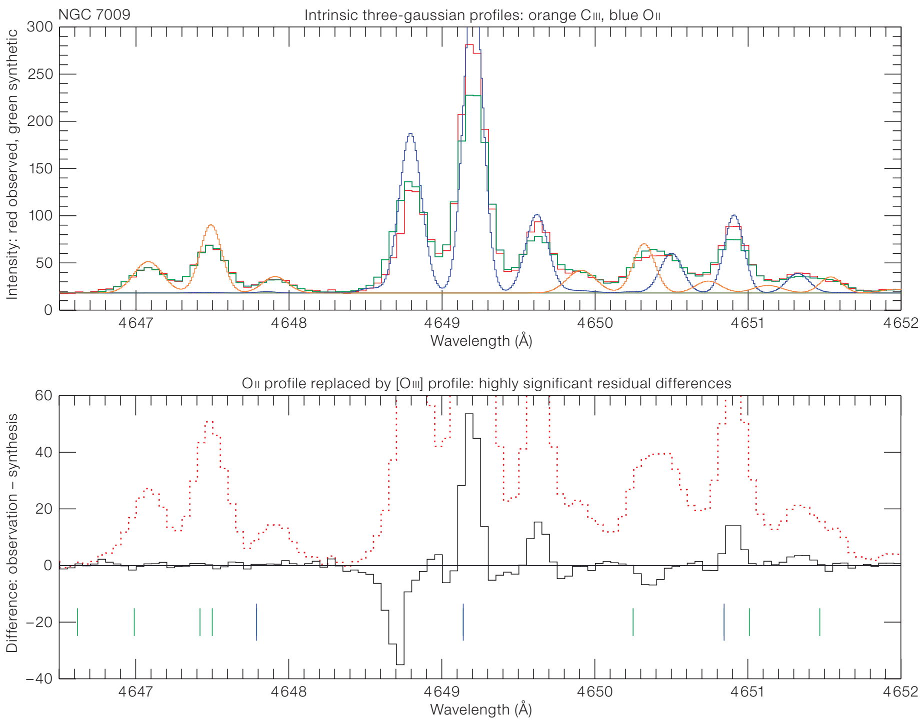

Figure 6: High-resolution spectrum of NGC 7009 in the 465.0 nm region showing in the top panel the observed profiles of C III and O II recombination lines split into three components (red line), and overlaid a synthetic spectrum (green line). Synthetic spectra associated with C III (orange) and O II (blue) are also shown. In the bottom panel the difference between the observed (red) and synthetic (green) spectra is shown.

certain O II lines as a probe of the density of their emitting regions: such lines can be found in the 465.0 nm spectral region (see bottom panel of Figure 2) and a group of some seven lines belonging to the V1 multiplet are a sensitive density diagnostic (Tsamis et al. 2003; Bastin and Storey 2006). Once the density and temperature of the region emitting the O II spectra is measured, the mass of the strange nebular phase can be safely estimated and we shall know what fraction of the total mass in a given nebula was 'hidden' from view in this way. Photoionisation modelling studies have to this date indicated that the H-poor gas constitutes only a few per cent of the total *ionised* mass in a nebula (Péquignot et al. 2002). If instead the cold component is found to have significant mass this will have important implications, as the heretofore 'established' average abundances of important heavy elements in planetary nebulae will only be lower limits, with repercussions on the study of the whole class of these objects.

The obscure origin of the hidden nebular phase and further work

We mentioned that one scenario that has been put forward to explain the origins of the cold component is mass ejection from the planetary nebula nucleus. This may happen during the thermally pulsing AGB stage or even after this has terminated in the form of a late thermal pulse that could result in a hydrogen-poor stellar atmosphere and parallel ejection of hydrogen-deficient clumped gas in the nebula. There is precedent for this in the class of objects such as Abell 30, which possess hydrogen-poor knots embedded near the centres of their nebulae emitting carbon and oxygen recombination lines. *HST* has imaged the optically resolved knots of Abell 30 and Abell 78 (Borkowski et al. 1993), but as yet no such features have been recorded in run of the mill nebulae like the ones in our sample. However, from the long-slit survey of a large sample it has emerged that when one compares the abundance ratio of heavy elements (e.g. C/O, Ne/O) measured from one type of emission line with that obtained from the other type of line, the ratios are often quite similar, showing that the nucleosynthetic histories of the posited H-poor clumps and the normal nebular component may not be very different, as if the whole nebula was born out of similarly processed gas. When the C/O ratio for several nebulae measured from recombination lines is less than unity, it points towards an oxygen-rich nature for the ejected clumps (Tsamis 2002; Ercolano et al. 2004), something contrary to the expectations of standard scenarios for late thermal pulses which result in central stars with carbon-rich atmospheres. Other hypotheses include the evaporation of planetary bodies predating the formation of the nebula (Liu 2003), or of cometary-knot complexes (Tsamis et al. 2004) such as those originally observed in the planetary nebula nearest to us – NGC 7293 (the Helix) – but now shown to be a common occurrence in many more objects. The Argus data are of sufficient quality to allow us to investigate in detail the relative abundance ratios of carbon, oxygen, nitrogen, and neon from recombination lines across the face of the targets and can shed more light on the chemical history of the mysterious nebular component, and its likely origin. Finally, the high-resolution kinematical data of NGC 7009 have yet to be examined in detail. It's no exaggeration therefore to say that VLT FLAMES has afforded us a truly rare view of planetary nebulae and their well-hidden secrets have started to unravel.

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View of the 5000-m high Llano de Chajnantor towards Cerro Toco.

Photo: H. H. Heyer, ESO

Nature Around the ALMA Site – Part 1

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The natural environment around the ALMA site, its flora, fauna and landscape morphology, are presented and interpreted in terms of combined geological and climatic evolution with, in parallel, the necessary biological adaptions.

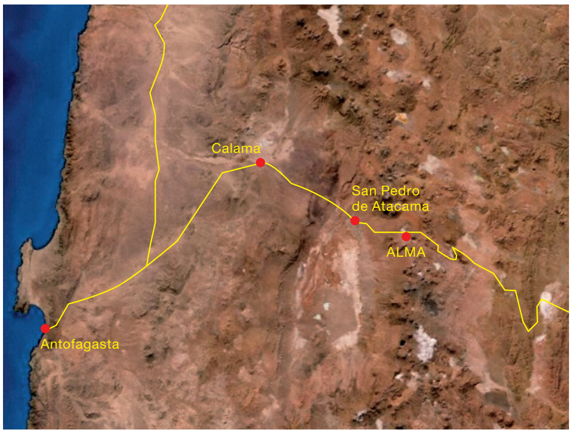

Figure 1: ALMA is located inside the high volcanic range in the Central Andes, east of San Pedro de Atacama, close to the road to Argentina through the Jama Pass.

The ALMA site morphology results from the long-term evolution of the Andes, governed by plate tectonics. The associated volcanic activity, the climate evolution and oscillations, the erosion by ice, water and wind, are factors which converge to build up the exceptional landscape as we may observe it now, adequate to host the ALMA installations.

The present-day vegetation pattern and composition, the plant adaptations to various, and often extreme, conditions, and the local fauna, are testimonies and, by the way, key indicators of the complex past history of this singular site. After a summary of the geological history of the area, representative examples of life adaptations around the site will be given, mainly in the field of geobotany which is by far the most sensitive approach, having the highest spatial resolution to reveal tiny macro- and microclimatic effects.

The local altiplano history

A striking feature of the landscape at ALMA is the presence of a nearly flat surface, made of pale yellow to pink material, culminating at about 5100 m, capped with several volcanic cones and structures, reddish to black, depending on their origin, age and chemistry.

These structures are direct consequences of the peculiar volcanic activity prevailing in the Central Andes. The whole area is being uplifted due to the compression by two tectonic plates, a continental one, the South-American plate, moving westwards, a distant response to the slow opening of the South Atlantic Ocean, and an oceanic one, at the west, the Nazca plate, moving towards South America at the highest known velocity in tectonics 10.4 cm/yr. The Nazca plate is subducted in the Pacific trench, about 80–100 km west of the Atacama coast, with a depth of 8064 m in front of Antofagasta. The subducted material, oceanic crust and sediments, travels along an inclined plane. It is metamorphosed when the partial melting point is reached, at a depth of about 200 km. Carbonates turn into silicates, CO_2 is restored to the atmosphere through volcanos, together with other volatiles as H_2O, SO_2 and salts such as NaCl, plus rarer ones involving Lithium and Boron.

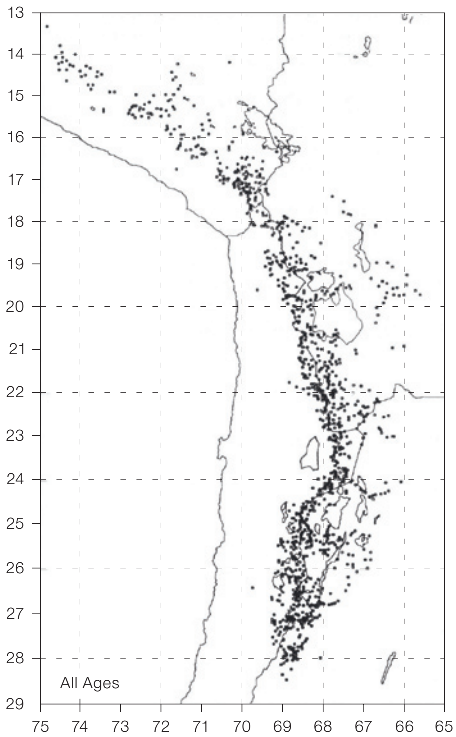

Figure 2: The distribution of 1113 late Tertiary and Quaternary volcanoes in the Andes. The distance between the volcanoes and the coast is maximum at the Chajnantor latitude (23S) (from de Silva and Francis 1991).

Lavas emitted in this context, the andesitic basalts, are richer in SiO_2 than those issued directly from the Earth's mantle, such as the Galapagos or Hawaiian lavas. A higher content in SiO_2 dramatically increases the lava viscosity, leading to a very explosive volcanism. The Lascar volcano, about 40 km south-east of the ALMA site, is a well-known example of such behaviour.

The volcanic activity is impressive with 1113 volcanoes active or extinct between latitudes 14S to 28S, as counted from Landsat satellite images (Figure 2). The amount of emitted material has been enormous, raising the Andes to very high altitudes (the altitude difference between the Pacific trench and the Cerro Llullaillaco volcano is no less than 14.8 km!).

The Central Andes area, at ALMA latitude, is characterised by major silicic volcanic systems, at the origin of paroxysmal explosions in the past. The injection of pyroclastic material, as incandescent ash clouds, up to the stratosphere is followed by its deposit on the ground, filling all landscape depressions such as valleys or even gorges. If close enough to the emission centre, ashes are hot enough (above 600 °C) to glue as a compact rock, the tuff, also called ignimbrite.

Ignimbrite deposits constitute the flat basement of the ALMA site. Around ALMA, major emission centres are Cerro Pastos Grandes, Cerro Guacha and La Pacana.

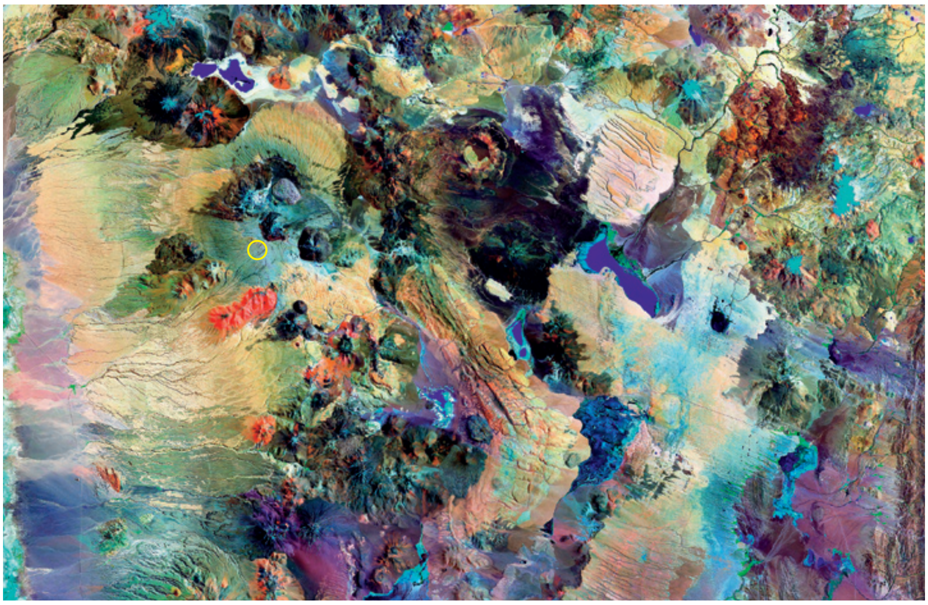

Figure 3: Satellite image showing the area around ALMA (yellow circle). Surfaces covered by ignimbrites are yellowish. Fresh lava is brown to black. Hills with hydrothermal alteration appear orange-red because of the presence of iron oxydes. Alluvions are grey, turning to bluish, pink or purple depending on the amount of Mn and Fe in minerals. Snow appears as turquoise, as does the salt in the Atacama Salar (left side). Some volcanic structures are very recent, such as the Licancabur, 5916 m, close to the twin Laguna Verde, capped with snow (upper left corner), showing recent fluid lava flows over the ignimbrite. In the image centre lies the faulted zone of the Cerro La Pacana caldera (Landsat, S-19-20 2000).

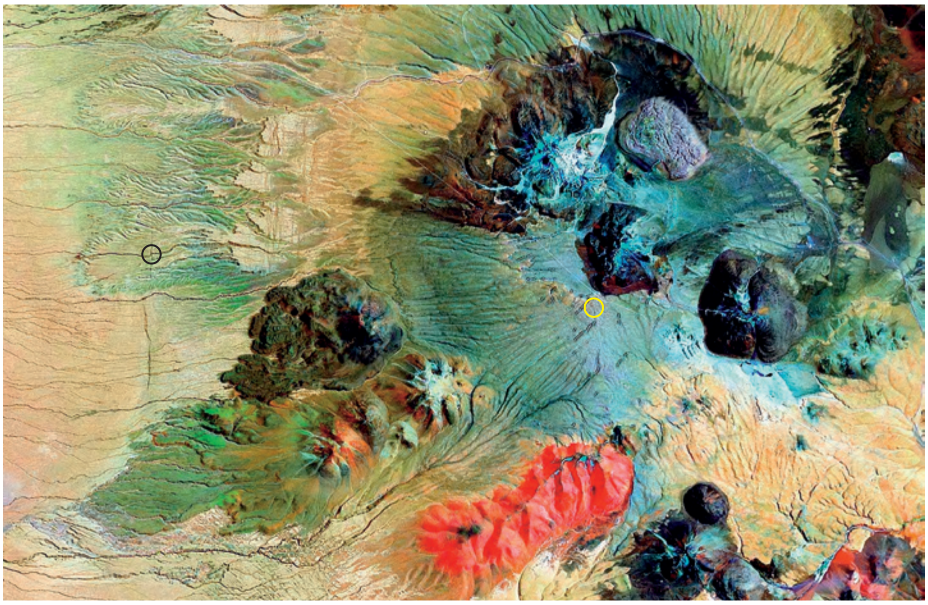

Figure 4: The ALMA site is located on an ignimbritic dome, the Purico ignimbrite. The crested edge of terraces at the upper left corner marks the limit between two consecutive deposit layers. ALMA is surrounded by a wide variety of volcanic structures. Immediately N and E of ALMA, two young volcanoes, made of black and viscous lava, show flow ridges (ogives) rapidly solidified. The grey structure to the north is a silicic dome, with a wavy 'elephant skin' texture, the terrestrial counterpart of the 'pancakes' discovered on Venus. North of ALMA, the old volcano Toco Toco shows whitish flows due to sulfur exploitation around the summit. To the south, in red, are hills with soil alteration by hydrothermal circulation. Thin NS lines to the west reveal a network of tectonic faults. One of them has recently shifted a river bed (black circle), an indication that deformations are still going on. (Landsat, S-19-20 2000).

Plinean eruptions occur when a volcanic system is mature, i.e. reaching an altitude above the ground level such that the next magmatic rising will be unable to find its path across the cone. Tensions accumulate until the whole structure explodes, cutting at minimum the upper part of the volcano. Truncated volcanoes are locally named *Descabezado*, the decapitated. When the magmatic chamber shrinks, it leaves an ellipsoidal depression, a caldera. Calderas around ALMA are among the largest in the world. La Pacana caldera, immediately East of ALMA, has an extent of 70 × 35 km, with ejecta covering about 17000 square km. The volume emitted in the last 5.6 Myr is about 3000 km^3.

The last Ice Age and after

During the last Ice Age, the Würm, the climate was altered not only at high latitudes, but also in the intertropical zone. In the Atacama, the alternation of a warm and dry climate during the interglacial episodes, such as the present one, with a colder and more humid climate, as during the glaciations, started at the Lower Pleistocene epoch, about 2.4 Myr ago. The present climate on the Chilean side of the Andes is characterised by an extreme aridity, nearly the most extreme reached up to the present.

During the last glacial maximum, about 22000 Before Present (BP), precipitations around ALMA were more intense by at least a factor of two. The increased cloudiness, combined with a fall of temperature by 6–7 °C, allowed a significant extension of the local glaciers. In the El Tatio area, NW of ALMA, most summits were ice covered with glacial tongues going down to 4300–4200 m. The volcanoes, not active since the ice retreat, show conspicuous glacial features as lateral and front moraines (Figure 5). The snowline was lowered by about 1000 m, as in parallel the altitude of the vegetation belts. Today's high mountain plants could have expanded over wide areas, forming nearly continuous populations. Now, all of that zone, including that of the high Cerro Llullaillaco (6739 m), is totally devoid of ice.

Nowadays, volcanic spring waters and meteoric waters accumulate in closed depressions. Waters are saturated in salts, crystallising on the shores and at the bottom of the so-called *salares*. The residual lake sizes are self-regulated, a result of a balance between water accumulation and evaporation. During Ice Ages, the water supply was sufficient to fill nearly all basins with fresh water and salts emitted by the volcanoes were removed continuously by the rivers.

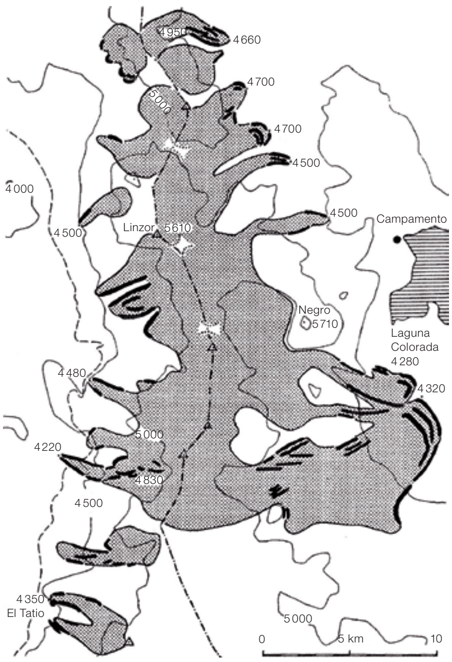

Figure 5: At the maximum extent of the Würm glaciation, 22000 years ago, all areas in grey were covered by ice. The old front and lateral moraines (thick lines) are still conspicuous in the landscape (from Graf 1991).

The precipitation regime

The ALMA climate is quite distinct from that of the coast where precipitation occurs mainly during the southern winter, in phase with, or just preceding major El Niño events. The occurrence of rainfall is irregular; rains are separated by long-duration droughts reaching typically 5–8–12 years, thus the scarce vegetation, if any, has to develop highly specialised adaptations.

Around ALMA, precipitation is much more regular, in phase with the Bolivian winter, with an interannual variability not exceeding ~ 65 %. The amount of precipitation depends strongly on the local landscape morphology. The compact mountain ranges extending NS and reaching nearly 6000 m such as the Linzor (5610 m)-Sairecabur (5971 m) range, NW of ALMA, and the Miñiques (5913 m) range S of ALMA, act as barriers and convection centres, where the humid air pumped over the Pacific as a sea breeze, heated over the Atacama desert, reaches the dew point at about 6100 m. The resulting thunderstorm activity produces fine grain hail in amounts sufficient to cover the whole landscape, as shown in Figure 7. Due to the very low air humidity and temperature in the morning, the hail turns into vapour, the sublimation process leaving little liquid water to moisten the soil and plants.

On the west side of the Andes, the amount of precipitation increases quadratically with altitude: 10 mm/year at 2100 m, 50 at 3300 m, 200 at 4300 m, 350 at 5000 m. On the contrary, the evapotranspiration – the water layer evap-

Figure 6: Laguna Leija, south of ALMA, with the Lascar volcano (5641 m) at left and Aguas Calientes (5924 m) at the centre, is a typical example of an altitude lake saturated by salts of volcanic origin. Its brackish waters host one of the highest colonies of Chilean flamingos. By the end of the afternoon, strong SW winds form balls of foam, rolling over the waves, up to the shore (Source, see footnote).

Figure 7: The road to ALMA after a thunderstorm in mid-December 1993. At left, the Licancabur (5930 m), at right the Juriques (5704 m).

Note: all pictures are from the author, except where specifically indicated.

orated per year from a surface maintained at 100% humidity – decreases with altitude, e.g. from 2200 mm/year at 3000 m, to 1400 mm at 5000 m. In all cases, the water deficit is huge.

The high evapotranspiration rate is due to very high insolation, low air humidity and moderate to high wind velocity. The combination of precipitation and transpiration effects leads to an increase of biodiversity with altitude, from the Atacama Salar level up to 3500–4000 m, where the maximum richness is observed (~ 45 different plant species), followed by a slow decline down to zero around 5000–5100 m, the local vegetation limit. Above 5350 m, the soil is permanently frozen to 50 cm depth.

Winter storms provoke snowfalls lasting several days. Strong winds associated with the transit of cold air masses may accumulate snow in ground depressions and at the lee side of mountain crests. Through melting-freezing cycles, the snow hardens and forms compact *névés* with a uniform surface. During spring, thanks to an erosion/sublimation process by the wind and the solar radiation, the surface becomes wavy, showing depressions like bowls. The dust brought by the wind accumulates in the depressions. Around the summer solstice, the solar radiation is maximum: the dust absorbs the radiation more efficiently than the crests and the snow sublimates faster in the holes. In deep holes, the higher water vapour pressure allows melting, whereas on the crests the sublimation alone is active. Since sublimation requires eight times more energy than melting, daily snow losses are eight times larger in the holes which deepen and finally reach the dark ground as shown in Figure 9, leaving a field of ice blades, the so-called ‘Ice Penitents’ or ‘White Penitents’ in memory of the ‘White Penitents’ procession during Holy Week, prior to Easter. From sunrise to sunset, solar rays draw an inclined plane aligned East-West, pointing to the Sun position at noon. The crest shadow prevents the sublimation of the adjacent ice in the EW direction, the alignment direction of penitents. At Chajnantor at the summer solstice, the Sun is close to the zenith at noon, penitents are thus vertical. Around Ojos del Salado, east of Copiapo, the penitent inclination towards the North reaches about four degrees. Penitents may be used as a natural compass providing the latitude of the site in addition to the EW direction.

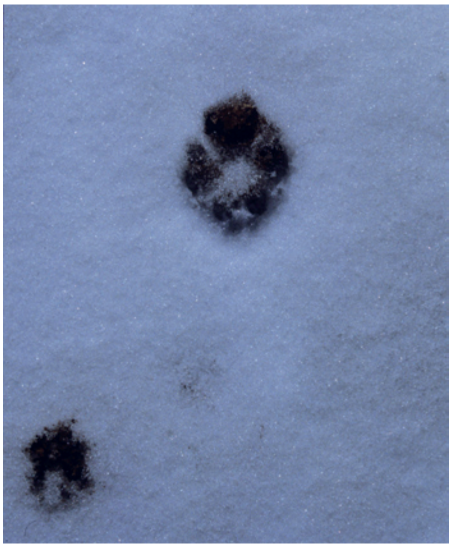

Figure 8: Hail may reveal the most discrete wild life presence, such as the puma footprint on the way to ALMA, NW of Cerro Toco-Toco.

The wind and temperature regimes

The ALMA area is under the influence of two wind regimes: an upper wind, blowing continuously from the west, above 4500 m during the night and 5200–5500 m during the day. This zonal circulation is driven by the South-East Pacific anticyclone, fed by high altitude air brought by the Hadley circulation from the intertropical convergence zone (ITCZ). This air, travelling at the lower limit of the stratosphere, is nearly free from water vapour and aerosol particles.

During the day, a convective boundary layer, driven by the intense solar radiation on the west flank of the Andes, travels across the Atacama desert, in a NE direction. Its thickness increases from about 600 m east of the Coastal Cordillera, to 1.5 km above the Atacama Salar. This anabatic wind (blowing uphill) reaches its maximum velocity, about 12 m/s at 5800 m, in late afternoon and stops around 10 p.m. in summer. The relative humidity follows a similar pattern and peaks between 7 and 8 p.m. at about 70% at 5800 m and 100% at 6200 m.

Because of the very low vapour content above 5000 m, and of the reduction of the column density of CO_2 by a factor of two at 5200 m, the greenhouse effect is extremly low by night at high altitude. The ground surface cools down rapidly through unblocked radiation towards space. At Sairecabur (5820 m), at ground level, the temperature may reach +40 °C in the early afternoon, fall below freezing point around 4 p.m. and reach –15 °C before midnight. The thermal amplitude at the ground surface is huge, 39 °C in July, 52 °C in January (Schmidt 1999). Such amplitudes put enormous stress on the vegetation, which has to develop highly specialised strategies to survive. If we notice that the yearly 0 °C isotherm is located at 4850 m, we can easily understand that very few species may develop above 5000 m outside well-protected biotopes.

During the night, the air layer in contact with the ground, which is colder and denser, flows down by gravity, giving birth to a katabatic wind (blowing downhill), a land breeze, blowing towards the SW until about 8 a.m. when the solar heating restarts the convection.

West winds, zonal and anabatic, fall as cascades on the east flank of the mountains immediately at the back of the ALMA site. The air compression lowers the relative humidity and provides an extraordinary dessicating power to this Föhn-like wind (Figure 11).

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Part 2 of this article, on flora, fauna and animal life in the ALMA area, will appear in the next issue of *The Messenger*.

Figure 9: Field of white penitents at 4500 m above Laguna Verde, east of Copiapo, in December 1992.

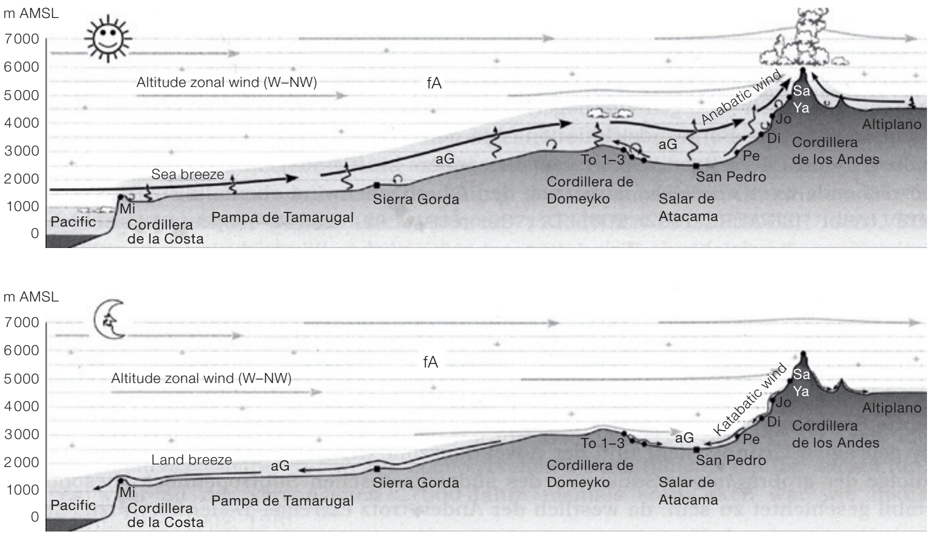

Figure 10: The air motions in the lower troposphere at the ALMA latitude. The sea breeze (day) and the land breeze (night) develop under an altitude zonal wind, blowing from the west. Above massive mountain ranges, the boundary layer associated with the sea breeze forms convective clouds, leading to thunderstorm activity in summer. In between the high mountain ranges, the boundary layer merges with the zonal wind and flows towards the east side of the Andes. During the night, the boundary layer disappears and a slower katabatic wind flows down to the sea, jumping over the Paranal site (from Schmidt 1999).

Figure 11: To the east of ALMA, strong katabatic winds generate ripples, amplified by the vegetation which traps blown soil parcels. A graminaceous herb is the only plant able to survive in this harsh environment, forming vegetal dunes, linear or half-moon shaped.

Research Project "Safety and Health in High-altitude Observatories"

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Goal of the research project

Modern astrophysics is characterised by the world wide strategy to develop extremely large optical-IR collectors with exquisite image quality (European Extremely Large Telescope, Giant Magellan Telescope, and Thirty Meter Telescope) as well as innovative ground-based submillimetre astronomy observatories like the Atacama Large Millimeter/submillimeter Array (ALMA) or projects like the Atacama Pathfinder Experiment (APEX).

To guarantee the best observation conditions the atmosphere above the observation sites must be transparent. Therefore, the astronomical community tries to take advantage of the natural conditions of dry, high-altitude sites. But, working at high altitude does have a major impact on safety, health and performance of staff.

On the basis of the enhanced developments in ground-based astronomy, an increasing number of people will be exposed to high-altitude conditions. Therefore, measures to improve work conditions and organisation at high altitude must be developed. A research project is being initiated which will consider particularly those people who, within the next years, will be required to work above 5 050 m altitude at the Llano de Chajnantor (ALMA, APEX), district of San Pedro de Atacama, and at 2 635 m altitude at Cerro Paranal, Taltal district in Chile. The goal of this project is to create and promote knowledge in the field of human activities in high-altitude observatories, which will then be offered for utilisation in work organisation. While we know a lot about biomedical changes at high altitude, relatively few studies focus on psychological changes, for example with respect to mental task performance, consciousness and emotionality. Both, biomedical and psychological changes, are relevant factors in occupational safety and health.

Problem and scope

Workers whose itineraries take them above an altitude of about 2 400 m should be aware of the risk of altitude illness and potentially impaired mental performance. While the individual response to high altitude can vary, all people are at risk of altitude illness above about 3 000 m altitude.

Therefore, the negative influence of high altitude is present especially at ESO's very high-altitude sites of APEX and ALMA (5 050 m at the observation site and about 2 500 m to 3 000 m at operation control site, offices and lodging). The current ESO internal medical statistics suggest that certain demographics, like age, sex or physical condition, do not correlate with the susceptibility to altitude sickness. Some people suffer from it and some people do not, and some people are more susceptible than others.

The conditions in the high-altitude environment also have a negative impact on human physiology and psychology. They affect nearly all biological processes, particularly rhythms, including sleep. Due to the reduced adjustment of the body at high altitude, the person concerned has to work against the demands of his or her body. Finally, the low oxygen (hypoxic) stress of altitude can impair work efficiency, performance and best practice mainly due to maladaptive behaviour, distorted consciousness, impaired biomedical functioning, and reduced sleep quality.

The final scope of the research project is the provision of practical recommendations to maintain work efficiency at high altitude. This will be done by gathering and disseminating knowledge about high-altitude work considering both, psychology and physiology. Thus, more adequate risk estimations during work are supported with further practical benefits for ESO and ALMA in:
- accident prevention and emergency process optimisation, and
- work organisation (shift work, daily working hours, operational safety procedures, etc.).

In addition, the project will support work organisation by providing further input to staff selection and training. Figure 1 summarises the rationale of the research project. A proper strategy of Technical, Organisational and Personnel measures adapted to the high altitude environment will positively affect the human and the organisation. The research will provide an input in finding and developing an adequate way.

Furthermore, the project results and data will be used to improve the scientific data base about people working at high-altitude workplaces and to enhance, by this means, the integral understanding of the interactions of human beings with their natural surroundings.

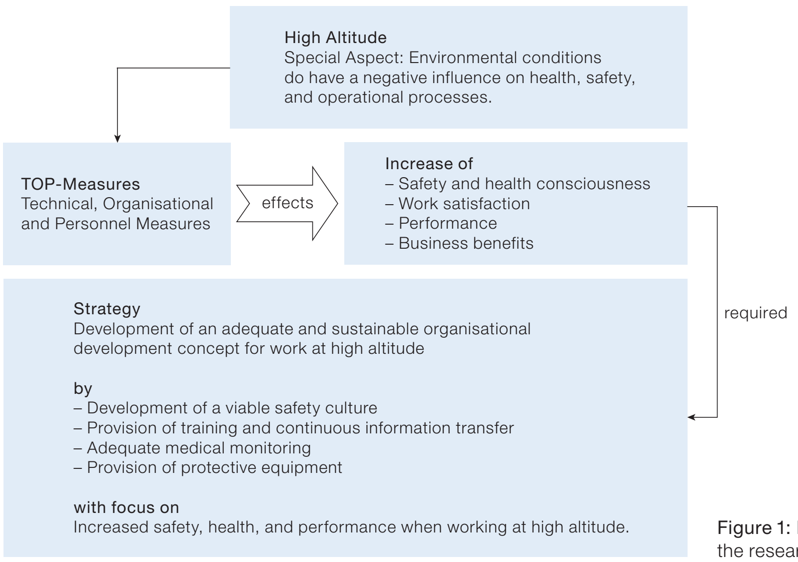

Figure 1: Rationale of the research project.

The research approach

The target group within the research project mainly consists of volunteers, as there are local and international ESO staff members working at La Silla Paranal Observatory, ESO Staff members from Garching travelling to ESO high-altitude sites, staff working at APEX and ALMA, ALMA partners, scientists and contractors. All these people will be asked to volunteer for biomedical, questionnaire, and interview investigations.

These investigations deal with the following main research fields:
– Stress and strain when working in shifts
– Susceptibility to shift work
– Optimisation of daily working hours
– Consequences for work performance,
– Long-term influence on human body
– Effectiveness of supplementation with antioxidants.

To be able to analyse the above-mentioned main research areas, the data collection needs to be multidisciplinary considering medical, physiological, psychological and economic approaches:

Medical and physiological issues (responsible: University of Antofagasta, University of Chile, already started at ALMA)
– Monitoring of cardiovascular, respiratory, oxymetric[1] and polysomnographic[2] (EEG[3], EOG[4], EMG[5]) data through small portable devices
– Measurement of hormone levels
– Application of psychometric tests
– Analysis of circadian rhythms and the relationship with mental and physical functions
– Questionnaire to obtain information on current habits (nutrition, exercise, etc.) and personal background (perinatal data, diseases, etc.).

Psychological and work organisation issues (responsible: University of Copenhagen)
– Questionnaire about shift work and breaks
– Questionnaire about stress and strain during daily work, work satisfaction, performance drivers and obstacles.

Business benefits (responsible: University of Copenhagen)
– Monitoring of economic benefit and strategic impact of occupational safety and health measures.

Data-base evaluation
– Data collection through networks, data bases and collaborations.

The informed consent of participants, data protection, confidentiality, and anonymous data handling shall be a main concern in the project to support a smooth and trustworthy process. Particularly, a high number of participants will guarantee the anonymity and validity of the results.

Current research project

Currently, a research concept is being developed which will be used to apply for funds from external third parties. The research partners intend to evaluate existing data provided by the observatories. Therefore, a close cooperation with the paramedics at the high-altitude sites is sought.

In addition, there will be a small pre-study to support the validity of the research concept. The results will have a major impact to obtain external monetary support. So far, five staff members of an ALMA contractor already agreed to participate in such a pre-study. In addition, two ESO international staff members with duty station at ESO headquarters in Garching also volunteered to provide personal data when visiting the observatories. The data collection in the field study will be done with minimum effort for employees (about one hour per working week), by using very small devices which will not interfere with the test persons' work. The data collection involves mainly filling out a questionnaire and providing data (O_2 saturation and heart rate).

Generally, close cooperation and coordination with ALMA and ESO as well as anonymous data collection are essential and self-evident. To get data directly from ESO/ALMA personnel, the research group will formally request approval by the respective organisations. It is recommended to involve the Ethical Committee of the Faculty of Medicine of the University of Chile. Provision of detailed information to the management as well as staff concerned, staff association and other interested groups is also self-evident.

Bilateral agreements and start-up status

Bilateral letters of intent between ALMA and the research partners have been established. The bilateral letter of intent between ESO and the research partners is in preparation.

The University of Antofagasta and the University of Chile have already started to collect biomedical data from ALMA, APEX and the Paranal site. The University of Copenhagen will start with the evalua-tion as soon as the bilateral letter of intent between ESO and the University of Copenhagen has been finalised.

Research team (in alphabetical order)

Prof. Dr. Claus Behn (Chairman of the research group; Laboratory of Extreme Environments, Programme of Physiology and Biophysics, Institute of Biomedical Sciences (ICBM), Faculty of Medicine, University of Chile, Chile)
Michael Böcker (Project leader for ESO research; ESO Safety Manager/ALMA European Executive Safety Representative, ESO)
Jody Bolyard (NRAO Safety Manager/ALMA North American Executive Safety Representative, National Radio Astronomy Observatory, USA)
Jacques Lassalle (Project leader for ALMA research; ALMA Safety Manager)
Ohta Masahiko (ALMA-Japan Project Office, National Astronomical Observatory of Japan, National Institutes of Natural Sciences, Japan)
Dr. Juan Silva Urra (University of Antofagasta, Chile)
Assoc. Prof. Dr. phil. Joachim Vogt (Department of Psychology, University of Copenhagen, Denmark)
Prof. Dr. med. Hans-Christian Gunga (Zentrum für Weltraummedizin Berlin, c/o Institut für Physiologie, Charité – Universitätsmedizin Berlin)

[1] Measurement of systolic arterial blood pressure using a pulse oximeter.
[2] Polysomnography is the evaluation of a broad range of sleep disorders.
[3] A graphic record of the electrical activity of the brain as recorded by an electroencephalograph; abbreviated to EEG and also called encephalogram.
[4] The electroencephalographic tracings made while moving the eyes a constant distance between two fixation points, inducing a deflection of fairly constant amplitude; abbreviated to EOG and also called electro-oculogram.
[5] A graphic record of the electrical activity of a muscle as recorded by an electromyography; abbreviated to EMG and also called electromyogram.

First Report on

The 2007 ESO Instrument Calibration Workshop

held at ESO Headquarters, Garching, Germany, 23–26 January 2007

Andreas Kaufer, Florian Kerber, Reinhard Hanuschik, Ferdinando Patat, Michele Peron, Martino Romaniello, Michael Sterzik, Lowell E. Tacconi-Garman (ESO)

The first ESO Instrument Calibration Workshop took place from 23–26 January 2007 at the ESO Headquarters in Garching, Germany. It attracted more than 120 participants (Figure 1) with a good representation of the diverse ESO user community and ESO operations groups.

Photo: L. Calçada, ESO

Figure 1: The participants of the 2007 ESO Instrument Calibration Workshop just behind the Headquarters building in wintry Garching.

The La Silla Paranal Observatory is currently operating 19 optical, NIR, and MIR instruments (9 VLT, 2 VLTI, 8 La Silla). Successful scientific operation of such an instrument suite is a complex task. To monitor and calibrate both the performance of each of these instruments and the quality of the data they deliver, ESO executes dedicated calibration plans. The calibration plans describe – for each instrument – systematic measurements that are routinely performed in order to aid in the calibration of data from science programmes, at least to specified levels of accuracy.

This scheme of orchestrating our instruments using a detailed plan based on a combination of scientific and operational requirements is invoked in the poster of the workshop (cf. Figure 2). In the case of a concert or other musical performance on stage, the contact between the audience and the artist is very direct and the feedback is given in an immediate, audible and usually unmistakable manner. This is not always true in the case of an observatory and its user community, even more so when many programmes are performed in service mode and observers do not meet observatory staff in person.

Figure 2: The La Silla Paranal orchestra.

The first ESO/ST-ECF workshop "Calibrating and understanding HST and ESO instruments" was held in 1995 to review the calibration strategies of HST and ESO La Silla instruments and to prepare for the start of operation of the VLT.

We felt that after more than seven years of science operation with the innovative, complex, and still growing instrumentation suite at the VLT, it was timely to review the achievements and limitations of the established instrument calibration plans together with the ESO user community.

Hence the goals of the workshop can be summarised as:
– to foster the sharing of information, experience and techniques between observers, instrument developers, and instrument operation teams,
– to review the actual precisions and limitations of the applied instrument calibration plans,
– to collect the current and future requirements from the ESO users.

We tried to cover a large variety of aspects through a series of overview talks given by observatory staff, invited talks, contributed talks and posters. A total of 11 sessions highlighted the various instruments: Optical Spectro-Imagers; Optical Multiobject Spectrographs; NIR and MIR Spectro-Imagers; High-Resolution Spectrographs; Integral Field Spectrographs; Adaptive Optics Instruments; Polarimetric Instruments; Wide-field Imagers; Interferometric Instruments; as well as other crucial aspects such as data flow, quality control, data reduction software and atmospheric effects. In all sessions an overview talk given by a member of the Instrument Operation Team (IOT) described the status quo including the calibration plan, followed by invited talks by expert users. Almost all talks are available in pdf format by clicking on the corresponding links on the workshop programme page at *http://www.eso.org/cal07/agenda.html*

Immediately after the workshop a group of about 15 ESO Instrument Scientists and experts met for a retreat, starting the process of analysing the feedback and discussing the next steps. Based on the valuable feedback from the community provided during the workshop and, in order to carry over the momentum created by it, we compiled a first list of topics that deserve further attention:
– Calibration Proposals at ESO
– Role of Instrument Operations Teams and Instrument Scientists
– Closing the loop between Science Requirements and Calibration Plans
– Interaction with user community
– Pipelines (modular, robust, error handling, science ready products, feedback to engineering calibration, flat fielding, sky subtraction)
– How to achieve high precision in photometry and spectrophotometry

– How to achieve the highest S/N ratios
– Quality Control (interaction with science pipeline, trending analysis)
– Archive (access to calibration data)
– Refined exposure time calculators
– Instrument modelling (bottom-up and top-down approaches combined)
– Calibration Reference Data (traceable to laboratory standards)
– Facilitate the use of VLTI and address its specific calibration needs
– Support for polarimetry
– Availability and use of standard stars
– Characterisation and calibration of the atmosphere
– Radiometric calibration of AO data
– Detector fringing
– Instruments (pre-construction simulation, performance monitoring, active compensation).

As mentioned, we very much consider this a process and further input is highly welcome. One easy way to send your suggestions will be to fill in the feedback form at: *http://www.eso.org/cal07/feedback.html*

Our next steps are to consolidate the input and topics in a concise document that will contain recommendations for improving calibration procedures at ESO. We will attempt to assess the effort required for each recommendation and will assign priorities based on scientific merit, but also practical considerations. We will then make a detailed plan and schedule to implement the improved calibration procedures in a timely manner.

While the above is clearly work in progress, Dietrich Baade already offered his personal summary of the workshop in an excellent and stimulating summary talk from which we extracted some quotes for future reference (see text box).

As Gianni Marconi put it during the workshop: "Calibration is a life-long learning process". One obvious lesson from the workshop is to ensure good communication between the observatory and the end user. In this spirit we hope to make progress on the above points together and we plan to soon report back to the community.

Acknowledgements

We would like to thank the following individuals who have helped in making the Calibration workshop a success: Konstantina Boutsia, Günther Dremel and his crew from General Services, Ed Janssen, Simon Lowery, Mariya Lyubenova, Steffen Mieske, Silvia Pedicelli, Francesco Saitta, Erich Siml, and Britt Sjöberg. Finally, a special "Thank you" goes to Christina Stoffer for her exquisite support.

Selected Quotes

– Calibration cannot make up for poorly prepared observations. (Piercarlo Bonifacio)
– Artifacts are removed most effectively by multiple re-sampling. (Eric Emsellem)
– Prenatal modelling is better than postmortem calibration. (Michael Rosa)
– False matches can confirm expectations most beautifully. (Carlo Izzo)
– NIR polarimetry is a last-minute add-on for enthusiasts. (Nancy Ageorges, Hans Martin Schmid)
– ESO should accept and support calibration proposals. (Eric Emsellem and the Calibrated Majority)
– The best quality check is a logarithmically scaled three-colour image. (Mike Irwin)
– Thou shalt not have parallel pipelines. (Several)
– No calibration – no astronomy. (Dietrich Baade)
– The sky is the limit. (Many, referring to the Earth's atmosphere)

Report on the

Fourth Advanced Chilean School of Astrophysics: Interferometry in the Epoch of ALMA and VLTI

Felipe Barrientos[1]
Neil Nagar[2]
Felix Mirabel[3]

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[2] Grupo de Astronomía, Universidad de Concepción, Chile
[3] ESO

The interferometry school in the epoch of ALMA and VLTI (*www.astro.puc.cl/school*) was held at the campus of the Universidad Católica de Chile, in Santiago, during 4–8 December 2006. This FONDAP Center for Astrophysics school was organised jointly by Pontificia Universidad Católica de Chile, Universidad de Concepción, ESO, ALMA, the National Radio Astronomy Observatory (NRAO), the U.S. Naval Research Laboratory (NRL) and the U.S. Office of Naval Research Global (ONRG).

The school was organised to provide young Chilean and Latin American researchers and students with the fundamentals of interferometry in the radio and in the optical, and to introduce current and future instrumentation, techniques and results. The experts also discussed the impact of interferometry techniques on studies of star-forming regions, galaxies and the high-*z* Universe. The students were also informed of the near-future opportunities with ALMA and the VLTI.

The invited lecturers were: Tom Armstrong (NRL), Dave Mozurkevich (Seabrook Engineering), Juan Uson (NRAO), Paul Van den Bout (NRAO), Al Wootten (ALMA), Robert Laing (ESO), Massimo Tarenghi (ALMA), Tony Beasley (ALMA), Ricardo Bustos (CBI), Paulo Cortes (University de Chile), Christian Hummel (ESO), Kotaro Kohno (University of Tokyo), and Markus Schöller (ESO). Additionally there was a wide range of topics presented in the poster session. The lectures can be found in the school web page.

The school was financially supported by the FONDAP Center for Astrophysics, the ALMA-CONICYT committee, Sociedad Chilena de Astronomía, Fundación Andes, NRAO, ESO, ONRG and AFORS. There were nearly 150 registered participants from Argentina, Brazil, Peru, Venezuela, Mexico and Chile. The funding allowed full or partial support for all the students attending the school. The school participants enjoyed a lively talk on "The Genesis of ALMA" by Paul Van den Bout at the school dinner at the Hacienda Santa Martina, and also visited the facilities of the Universidad Católica Observatory.

Participants and lecturers at the summer school pose in the sun at the Unviersidad Católica de Chile.

Report on the

Third Advanced Chilean School of Astrophysics

held at the Universidad de Concepción, Chile, 8–12 January 2007

Wolfgang Gieren[1]
Manuela Zoccali[2]
Ivo Saviane[3]
René Méndez[4]
Grzegorz Pietrzynski[1]

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[2] Pontificia Universidad Católica de Chile, Santiago de Chile
[3] ESO
[4] Universidad de Chile, Santiago de Chile

During the second week of January 2007, the third Chilean Advanced School of Astrophysics was held at the Universidad de Concepción, the third-largest university in Chile, on "Insights into Galaxy Evolution from Resolved Stellar Populations". This school, targeted at Ph.D. students mainly from Chile and South America, but also open to students from other countries, was organised in the framework of the Chilean FONDAP Center of Astrophysics which includes astronomers of the two largest universities in Santiago and the Universidad de Concepción. The school focused on a field of research which is very well represented in the Center. Additional support was kindly offered by the ALMA Committee, ESO Chile, the Católica and Concepción universities, and the Sociedad Chilena de Astronomía.

During one week, five mini-courses were delivered to the students, each with an frequency of one hour per day and ample time for discussion, which were complemented by a series of contributed talks, mostly given by the students. Most of the students had also brought a poster describing their Ph.D. research project. The lecturers and the topics of their courses were the following:
– Carme Gallart, Instituto de Astrofísica de Canarias: The history of the Local Group (and beyond) through the analysis of colour-magnitude diagrams.
– Laura Greggio, INAF Osservatorio di Padova: Local dwarfs and giant ellipticals.
– Rolf Peter Kudritzki, Institute of Astronomy, Hawaii: Hot massive stars in the Local Group and beyond.
– Barry Madore, Carnegie Observatories: Stars as distance indicators.
– Eline Tolstoy, Kapteyn Astronomical Institute: Abundances and kinematics from high-resolution spectroscopic surveys.

We were very pleased to host about 110 enthusiastic students from Chile, Argentina, Brazil, Uruguay, Colombia, Venezuela, Peru, Honduras, Italy, Spain, the Netherlands and the United Kingdom (see Figure 1). They all manifested strong interest in the nicely complementary lectures our invited scientists had prepared for them, together providing a comprehensive introduction to this very active field of research. The lectures can be found at the school website at *http://www.astro-udec.cl/phd_school_2007*. We were all lucky enough to enjoy a sunny week in Concepción of which the participants of the school could take advantage during the outdoor coffee and lunch breaks, and during the long summer evenings. Many participants were also impressed by the beauty of the campus of the Universidad de Concepción. During the week, many new friendships and working contacts were created among the students, and there was a lively interaction with the lecturers and organisers of the school. The social highlight was the conference dinner which took place in the Canto de Luna restaurant on the shore of the Laguna Chica de San Pedro, a beautiful lake on the southern side of the Bio Bio river which divides Concepción into a northern and southern part. The dancing party extended to well beyond midnight, and several of our invited lecturers showed unexpected skills in this activity as well.

Figure 1: Group photograph of the Advanced School of Astrophysics at the Universidad de Concepción.

The organisers of the school were Wolfgang Gieren (Chair), Manuela Zoccali (Co-chair), Rene Méndez, Grzegorz Pietrzynski and Ivo Saviane. They were very effectively assisted by Andrea Lagarini who took care of the logistical aspects of the School and helped to make this a week everybody will like to remember.

ESO at the AAS, the AAAS and in Dublin

Henri Boffin, Claus Madsen (ESO)

The great variety of new distribution methods and tools available does not replace face-to-face communication, which remains a most valuable activity in presenting ESO and its future needs. Face-to-face communication, in turn, takes many forms ranging from formal lectures and speeches, through less formal and informal meetings and briefings, e.g. with decision makers or media representatives, to information stands at fairs and conferences. Information stands often provide a physical basis for important personal encounters. In 2006, ESO's Public Affairs Department organised or participated in more than 20 events, involving exhibitions, briefings and VIP visits. This constitutes a marked increase over the previous years, on the one hand reflecting the growing importance and visibility of ESO, and, on the other hand, a necessity, given the need to enlist wide support for ESO's ambitious future projects.

This year for the first time, ESO was present at the 209th Winter Meeting of the American Astronomical Society (AAS) which took place in early January in Seattle, USA. The meeting, which was held jointly with the Annual Meeting of the American Association of Physics Teachers, gathered over five days about 3000 astronomers and hundreds of teachers, and also attracted many journalists. On account of its shear size, the AAS Winter Meeting is one of the astronomical events of the year, especially for years in which there is no IAU General Assembly, and it is thus no surprise that ESO decided to be present with an exhibition stand, featuring a VLT model. ESO's presence was very much appreciated and many astronomers and teachers came by to get the latest information on the most recent developments. In particular interest was high in the Laser Guide Star project, ALMA and, of course, the E-ELT. ALMA was also represented at the AAS meeting on the NRAO stand, our colleagues in this global project. In addition to the exhibition, ESO was present at some of the press briefings, including the one on the discovery of the first triple quasar (see

Photo: H. H. Heyer, ESO

Young Japanese scientists at the ESO stand at the AAS.

ESO PR 02/07) and on results from the COSMOS survey. This, in turn, resulted in an enhanced presence of ESO in the media, ironically also on the European scene. ESO's first participation in the Winter Meeting of the AAS appeared therefore well justified and we look forward to attending next year's event in Austin, Texas.

From Seattle, the exhibition stand of ESO was then transferred a little bit further south, to San Francisco, where from 15 to 19 February, the AAAS meeting took place. The participation of ESO in the Annual Meeting of the American Association for the Advancement of Science, arguably the largest gathering of its kind worldwide, was not in this case a premiere, as ESO was already present at last year's meeting. In addition to the European Commission, another EIROforum member participated, namely the European Molecular Biology Laboratory (EMBL). With an estimated 10 000 participants and visitors, it is a privileged place for exchanges between American

Photo: E. Janssen, ESO

The AAAS Family Science Days drew the attention of a large number of youngsters and students who showed a great interest in the information provided at the ESO stand.

Photo: H. H. Heyer, ESO

The Lord Mayor of Dublin gets information on ESO's VLT.

and European scientists and science policy makers, as well as an opportunity to get in touch with a large number of science journalists in a very short timespan.

With its 30 m^2 information stand at these two major events, ESO and its ambitious projects have been well represented across the Atlantic. In Europe, ESO was the key exhibitor at the Astro-Expo 2006 event in Dublin in December. Organised by Astronomy and Space Magazine at the Dublin City University (DCU), the event was opened by the Lord Mayor of Dublin, Councillor Vincent Jackson. With the exhibition and a public talk, ESO had a first chance to present itself to a broader audience in Ireland and there was clearly a strong interest in learning more about the organisation and its current and future projects.

Announcement of the ESO Workshop on

12 Questions on Star and Massive Star Cluster Formation

3–6 July 2007, ESO Headquarters, Garching, Germany

The goal is to bring together two communitites: one working on star formation (mostly Galactic) and the other working on the formation of young massive clusters (mostly extragalactic). We will link Galactic with extragalactic work, optical/NIR techniques with sub-mm/mm/radio ones, the formation of stars with that of massive star clusters and observations with theory. Views will be exchanged on topics such as the earliest phases of star and star cluster formation, ultracompact and ultradense H II regions, embedded massive stars and star clusters, stages at which stars and clusters emerge in the NIR and the optical, and culminating with young massive clusters observed in starbursts.

The format is bold and new, aiming to focus attention on 12 critical questions in this area. Each of the 12 questions will be addressed in a dedicated session by all speakers. The session will include an introduction, several short contributions as well as a general discussion (with accompanying posters). The community was requested to propose the 12 questions. We have received over 30 proposals of which 12 have been selected to be discussed at the workshop.

The programme can be found at *http://www.eso.org/star07*

Organisers: Markus Kissler-Patig and Tom Wilson

Announcement of

ONTHEFRINGE: The Very Large Telescope Interferometer Training Schools

Circumstellar discs and planets at very high angular resolution
28 May–8 June 2007, Porto, Portugal

Active Galactic Nuclei
27 August–7 September 2007, Torun, Poland

Optical interferometry is a new technology enabling observations at visible and infrared wavelengths with an angular resolution an order of magnitude larger than that achieved by the largest single telescopes currently available. Europe has achieved world leadership in this field with the ESO Very Large Telescope Interferometer (VLTI). This science machine will pay a central role in understanding the lifecycles of stars in the Milky Way; the discovery and characterisation of planets orbiting stars in the Solar Neighbourhood, and the understanding of the energy conversion mechanisms in Active Galactic Nuclei (AGN).

ONTHEFRINGE is a set of four schools on optical interferometry and related science financed by the Marie Curie programme. The goal of the schools is to train young astronomers in the use of the VLTI, therefore optimising the scientific return of the VLTI investment. Two of the schools are on data reduction. The first, on AMBER and MIDI, took place in Goutelas, France, in June 2006. A second one, on PRIMA and imaging, is planned for June 2008 in Hungary.

This year, two schools with a strong emphasis on science will take place. One on circumstellar discs and planets and another on AGNs. The goals of these schools are to present:
a) an extensive introduction to the scientific field;
b) place optical interferometry in context by presenting other techniques such as adaptive optics and mm-interferometry;
c) teach interferometry basics in order to facilitate preparation of successful observational proposals for the VLTI.

In addition all schools have a complementary skills pack dealing with:
a) presentation skills;
b) topics in scientific written communication;
c) professional ethics;
d) career development; and
e) opportunities in FP7 for young researchers.

To maximise interaction and learning the schools are open to only 50 students, and the vast majority have their participation (travel and living) fully financed by the Marie Curie programme.

For further information, including application procedures and rules for financing, please have a look at the ONTHEFRINGE site *http://www.vlti.org*

ESO Studentship Programme

The ESO research student programme aims at providing opportunities to enhance the Ph.D. programmes of ESO member-state universities. Its goal is to bring young scientists into close contact with the activities and people at one of the world's foremost observatories. For more information about ESO's astronomical research activities please consult *http://www.eso.org/science/*

The ESO studentship programme is shared between the ESO headquarters in Garching (Germany) and the ESO offices in Santiago (Chile). These positions are open to students enrolled in a Ph.D. programme at a university in an ESO member state or, exceptionally, at an institution outside ESO member states.

Students in the programme work on their doctoral project under the formal supervision of their home university. They come to either Garching or Santiago for a stay of normally between one and two years to conduct part of their studies under the co-supervision of an ESO staff astronomer. Candidates and their home institute supervisors should agree on a research project together with the ESO local supervisor. A list of potential ESO supervisors and their research interests can be found at *http://www.eso.org/science/personnel/index.html* and *http://www.sc.eso.org/santiago/science/person.html.* A list of current Ph.D. projects offered by ESO staff is available at *http://www.eso.org/science/thesis-topics/*. It is highly recommended that the applicants start their Ph.D. studies at their home institute before continuing their Ph.D. work and developing observational expertise at ESO.

In addition, the students in Chile have the opportunity to volunteer for as many as 40 days/nights work per year at the La Silla Paranal Observatory. These duties are decided on a trimester by trimester basis, aiming at giving the student insight into the observatory operations and shall not interfere with the research project of the student in Santiago.

Students who already enrolled in a Ph.D. programme in the Munich area (e.g. the International Max-Planck Research School on Astrophysics or a Munich University) and wish to apply for an ESO studentship in Garching, should provide compelling justification for their application.

The outline of the terms of service for students (*http://www.eso.org/gen-fac/adm/pers/student.html*) provides some more details on employment conditions and benefits.

The closing date for applications is 15 June 2007.

Please apply by:

(1) filling the form available at *http://www.eso.org/gen-fac/adm/pers/forms/student07-form.pdf*

(2) and attaching to your application:

- a Curriculum Vitae (including a list of publications, if any), with a copy of the transcript of university certificate(s)/diploma(s);
- a summary of the master thesis project (if applicable) and ongoing projects indicating the title and the supervisor (maximum half a page), as well as an outline of the Ph.D. project highlighting the advantages of coming to ESO (recommended one page, maximum two pages);
- two letters of reference, one from the home institute supervisor/advisor and one from the ESO local supervisor;
- and a letter from the home institution that: (i) guarantees the financial support for the remaining Ph.D. period after the termination of the ESO studentship; (ii) indicates whether the requirements to obtain the Ph.D. degree at the home institute are already fulfilled.

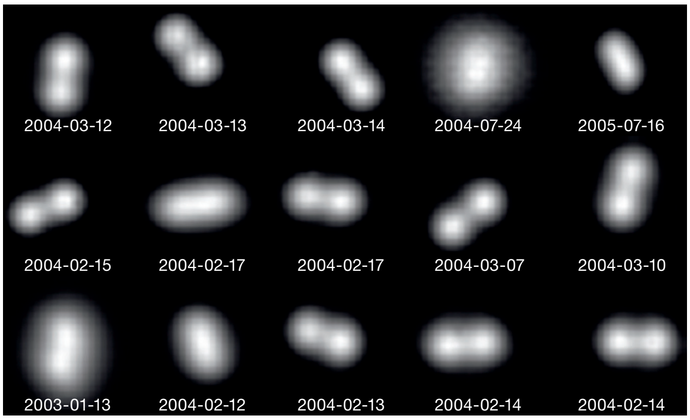
All documents should be typed in English (but no translation is required for the certificates and diplomas).

The application material should be posted to:
ESO Studentship Programme
Karl-Schwarzschild-Straße 2
85748 Garching bei München
Germany

All material, including the recommendation letters, must reach ESO by the deadline (15 June 2007); applications arriving after the deadline or incomplete applications will not be considered!

Candidates will be notified of the results of the selection process in July 2007. Studentships typically begin between August and December of the year in which they are awarded. In well-justified cases, starting dates in the year following the application can be negotiated.

For further information contact Christina Stoffer (*cstoffer@eso.org*).



Series of VLT adaptive optics images of the double asteroid (90) Antiope taken in 2003–2005 with the NACO instrument. The two components have an orbital period of 16.5 hours and the use of adaptive optics allowed the separation of the binary pair to be measured as 171 km. Further details of this study can be found in ESO Press Release 18/07.

Fellows at ESO

Photo: G. Dremel, ESO

Andrés Jordán

Andrés Jordán

I studied physics at the Universidad de Chile in Santiago, where I was born and raised. I then moved to Rutgers University in the US, where I obtained my Ph.D. under the supervision of Pat Côté. During this period I started working on the ACS Virgo Cluster Survey, a project in which I have been deeply involved since.

After finishing my Ph.D. in 2004, I moved across the pond to take up my fellowship at ESO Garching. At ESO I have continued and expanded the work I started during my Ph.D. I am now concentrating my efforts on the ACS Fornax Cluster Survey, a project which I lead and which extends our Virgo HST observations to the Fornax cluster of galaxies. I am currently particularly interested in the the properties of the inner regions of galaxies, which are teeming with supermassive black holes and nuclear star clusters.

While at ESO I have had the experience of working in a very stimulating environment. I have witnessed the development of the ELT with all its intricate dependence on scientific and political issues. In passing, I have also learned to value things in a new ESO currency: an ELT mirror segment. During the last few years I have had the opportunity to work closely with students, fellows and staff, and to teach at the NEON school. It is seldom that in one place one can experience such a broad array of aspects of life as an astronomer, from teaching to the development of the next large European astronomical project.

My days at ESO are sadly coming to an end, and in September I will move to the Harvard-Smithsonian Center for Astrophysics to take up a Clay fellowship. One more summer for Biergärten!

Paul Lynam

Midway through a Chile-based fellowship, I share my time between Paranal Science Operations and trying to understand the environments and properties of giant galaxy formation.

Aged seven, I witnessed a spectacular green fireball roll above the evening twilight horizon, dropping sparks and swinging flickering shadows silently across the ground. While trying to learn about this event, I became enchanted by the images of nebulae and galaxies and it became my ambition to be a regularly observing 'Gentleman Astronomer', like the Irish Earls of Rosse.

The local astronomical society fostered my interest until university studies in observational astronomy and applied physics, followed by a space science master's thesis assessing the danger of meteoroids to spacecraft.

En route to a Ph.D, I performed sensitive photometry of giant elliptical galaxies in an all-sky survey of ROSAT-selected clusters at various worldwide observatories. The resulting measurements are used as motion indicators in 'peculiar velocity surveys'. Any coherent motions of these objects are called 'cosmic flows' and potentially reveal huge mass concentrations, 'great attractors', which must gravitationally induce the flow. If detected, large-scale flows challenge modern cosmology and confuse our current idea of an accelerating Universe.

My interest in observing the populations of galaxy clusters continued while based at the Max-Planck Institute (MPE) in Garching, before developing software for the ESO Imaging Survey at the neighbouring ESO headquarters.

With the opportunity to work at Paranal, my childhood ambition was fulfilled: like the Earls of Rosse, I regularly observe with the most advanced telescope of the age. The forefront science, the scale of operation, the team maintaining the elegant nocturnal ballets of this engineering masterpiece in a hostile environment, all contribute to Paranal's special appeal.

Paul Lynam

ESO

European Organisation for Astronomical Research in the Southern Hemisphere

ESO is opening the following positions of

Engineer for Cryogenic Systems

in the Integration and Cryo/Vacuum Department of the Instrumentation Division at the ESO Headquarters in Garching near Munich, Germany. The successful candidate will work in the Integration and Cryo/Vacuum Department on the cryogenic and vacuum systems used to cool the instrument optics and/or detectors (typically CCDs or infrared arrays operating at temperatures down to ~ 5 K). Further specific tasks will include the design of vacuum vessels and cooling systems using liquid nitrogen or closed-cycle coolers, pulse tubes etc., the supervision of the manufacture of cryo/vacuum systems, the performance or supervision of system testing, the integration and commissioning of cryo/vacuum systems in instruments before and after shipping to the observatory, the support to R&D activities e.g testing new cooling concepts and devices as well as the monitoring and reviewing the development of cryo/vacuum systems for ESO by external consortia of scientific institutes.

Because the Department is relatively small she/he will be expected to take individual projects from the concept stage to commissioning at the telescope. Technical support will be provided by other INS staff, a small workshop plus engineers and technical staff from the Technology Division.

The position requires a University Degree in Engineering or equivalent. The successful candidate shall have a sound knowledge and understanding of the design and several years experience in the development of cryogenic and vacuum systems. Additional knowledge and experience of instrument design and thermal analysis would be a great asset. A good written and spoken command of the English language, good communication skills and a strong sense of team spirit are essential.

System Engineer

The successful candidate will work in the Instrumentation Division (INS) which comprises about 40 astronomers, physicists, engineers and technicians responsible for the design, development, installation and commissioning of advanced optical and infrared instruments for ESO telescopes. The latter include the Very Large Telescope (an array of four 8-m-diameter plus several smaller telescopes) on Mount Paranal in Northern Chile plus the future 30–60-m-diameter European Extremely Large Telescope (E-ELT) now undergoing its Phase B design study. Specific tasks will include the definition and preliminary design of interfaces between the European Extremely Large Telescope and its suite of up to six optical and infrared instruments, the system engineering support to specific E-ELT instrument design studies, the system engineering support to one or more second-generation VLT instruments as well as the monitoring and reviewing of instrument designs performed for ESO by external consortia of scientific institutes. Furthermore, she/he will generally work in a team comprising staff from the Instrumentation, Telescope Systems, Technology and Software Development Divisions of ESO.

The position requires a University Degree in Engineering or equivalent. A sound knowledge and understanding of astronomical instruments or comparable systems and direct experience with their design and construction as well as mechanical design skills are necessary and at least a basic knowledge of optics design would be a valuable asset. A good written and spoken command of the English language, good communication skills and a strong sense of team spirit are essential.

For details and to download an application form, please consult our homepage: *http://www.eso.org*. If you are interested in working in areas of frontline technology and in a stimulating international environment please send your application in English to:

ESO Personnel Department, Karl-Schwarzschild-Straße 2
85748 Garching near Munich, Germany
e-mail: vacancy@eso.org

ESO is an equal opportunity employer. Qualified female candidates are invited to apply.

ESO. Astronomy made in Europe

Personnel Movements

1 January–31 March 2007

Arrivals

Europe

Correia Nunes, Paulo (P)	Software Engineer
Pedicelli, Silvia (I)	Student
Stoehr, Felix (D)	Software Engineer
Marx, Beate (D)	Database Administrator
Madec, Pierre-Yves (F)	Optical Engineer
Dinkel, Andrea (D)	Secretary
Jolley, Paul (GB)	Mechanical Engineer
Sierra González, María del Mar (ES)	Software Engineer
Hewitson, Jennifer (D)	Secretary
Sahlmann, Johannes (D)	Student

Chile

Cerda, Claudia Silvina (RCH)	Accounting Clerk
Lira, Luis Felipe (RCH)	Chilean Affairs Officer
Celedon, Karina (RCH)	Logistics Assistant
Figueroa, José (RCH	Mechanical Technician
Avanti, Juan Carlo (RCH)	Accountant
Adriazola, Patricia (RCH)	Administrative Assistant
Rodriguez, Paula Valentina (RCH)	Public Relations Officer

Departures

Europe

Nilsson, Kim (S)	Student
Verinaud, Christophe (F)	General Engineer
Lapeyre, Pascal (F)	Antenna Production Engineer
Wirenstrand, Krister (S)	Head of Control & Instrument Software
Scales, Kevin (USA)	Optical Engineer
Donino, Gabriele (I)	Software Engineer
Szasz, Gabriel (SK)	Student

Chile

Horst, Hannes (D)	Student
Bagnulo, Stefano (I)	Operations Astronomer
Depagne, Eric (F)	Fellow
Stefanon, Mauro (I)	Operations Scientist
Araya, Alejandra (RCH)	Administrative Assistant
Edmunds, Ann (RCH)	Administrative Assistant

List of Proceedings from the ESO Astrophysics Symposia

Volume	Title	Editors
2007	Exploring the Cosmic Frontier: Astrophysical Instruments for the 21st Century	Andrei P. Lobanov, J. Anton Zensus, Catherine Cesarsky, Phillip J. Diamond
2006	Chemical Abundances and Mixing in Stars in the Milky Way and its Satellites	Sofia Randich, Luca Pasquini
2006	Planetary Nebulae Beyond the Milky Way	Letizia Stanghellini, Jeremy R. Walsh, Nigel G. Douglas
2005	Growing Black Holes: Accretion in a Cosmological Context	Andrea Merloni, Sergei Nayakshin, Rashid A. Sunyaev
2005	High Resolution Infrared Spectroscopy in Astronomy	Hans-Ulrich Käufl, Ralf Siebenmorgen, Alan F. M. Moorwood
2005	Multiwavelength Mapping of Galaxy Formation and Evolution	Alvio Renzini, Ralf Bender
2005	Science with Adaptive Optics	Wolfgang Brandner, Markus Kasper
16/2003	Astronomy, Cosmology and Fundamental Physics	Peter A. Shaver, Luigi Di Lella, Alvaro Giménez
15/2004	Toward an International Virtual Observatory	Peter J. Quinn, Krzysztof M. Górski
14/2003	Extragalactic Globular Cluster Systems	Markus Kissler-Patig
13/2003	From Twilight to Highlight: The Physics of Supernovae	Wolfgang Hillebrandt, Bruno Leibundgut
12/2003	The Mass of Galaxies at Low and High Redshift	Ralf Bender, Alvio Renzini
11/2003	Lighthouses of the Universe: The Most Luminous Celestial Objects and Their Use for Cosmology	Marat Gilfanov, Rashid A. Sunyaev, Eugene Churazov
10/2003	Scientific Drivers for ESO Future VLT/VLTI Instrumentation	Jacqueline Bergeron, Guy Monnet

New Editor

It is an honour and a challenge to take up the editorship of the Messenger at this time of ESO's expanding role in European and worldwide astronomy. In order to mark the change, we have made a few adjustments to the appearance without departing from the overall style that Peter Shaver had evolved during his term as editor. I would like to thank Peter for gently coaching me into the position and Jutta Boxheimer, the technical editor, for the high quality of the layout.

Jeremy R. Walsh

Annual Index 2006 (Nos. 123–126)

Subject Index

Telescopes and Instrumentation

Reports from Observers

Other Astronomical News

Announcements

Author Index

A

B

C

D

E

F

G

H

ESO is the European Organisation for Astronomical Research in the Southern Hemisphere. Whilst the Headquarters (comprising the scientific, technical and administrative centre of the organisation) are located in Garching near Munich, Germany, ESO operates three observational sites in the Chilean Atacama desert. The Very Large Telescope (VLT), is located on Paranal, a 2 600 m high mountain south of Antofagasta. At La Silla, 600 km north of Santiago de Chile at 2 400 m altitude, ESO operates several medium-sized optical telescopes. The third site is the 5 000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a new submillimetre telescope (APEX) is in operation, and a giant array of 12-m submillimetre antennas (ALMA) is under development. Over 1600 proposals are made each year for the use of the ESO telescopes.

The ESO Messenger is published four times a year: normally in March, June, September and December. ESO also publishes Conference Proceedings and other material connected to its activities. Press Releases inform the media about particular events. For further information, contact the ESO Public Affairs Department at the following address:

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Contents

Front Cover Picture: The European Extremely Large Telescope (Artist’s Impression by Herbert Zodet, ESO PR Photo 46/06)