The Messenger

No. 150 – December 2012

ESO 50th anniversary celebrations
Allocation of observing programmes
La Silla–QUEST Survey
β Pictoris and RS Puppis

A Milestone for *The Messenger* in ESO's 50th Anniversary Year

Tim de Zeeuw[1]

[1] ESO

In May 1974, Adriaan Blaauw launched *The Messenger*. He stated the goal explicitly: "*To promote the participation of ESO staff in what goes on in the Organisation, especially at places of duty other than our own. Moreover,* The Messenger *may serve to give the world outside some impression of what happens inside ESO.*" Today *The Messenger* is known the world over, and has reached a major milestone with the publication of the current issue, number 150. It has certainly achieved its goal: the entire collection gives a very interesting inside view of the development of ESO over much of its history (see also the article by Claus Madsen on p. 74).

Coincidentally, this milestone occurs in the year of the 50th anniversary of ESO's founding. On 5 October 1962, following many years of discussion and preparation, a group of astronomers from Belgium, France, Germany, the Netherlands and Sweden signed an international convention that created ESO. The aim of the Organisation was to build a large telescope in the southern hemisphere and to foster collaboration in astronomy. This led to the construction of the La Silla Observatory in Chile with first light on the 3.6-metre telescope obtained in 1976. The early issues of *The Messenger* record the last steps leading to this achievement.

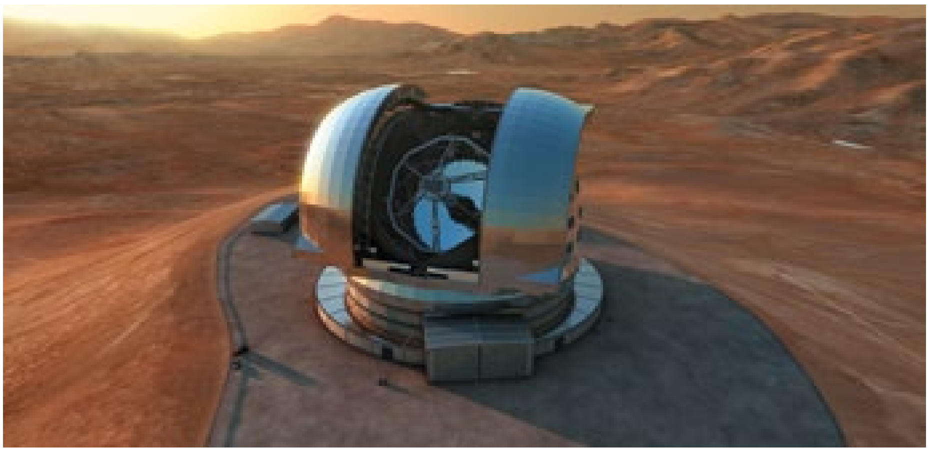
In the years since, *The Messenger* has faithfully chronicled how ESO's programme expanded tremendously beyond the vision of the founding fathers. The build-up of La Silla was followed by the construction of the Paranal Observatory, hosting the Very Large Telescope (VLT), the VLT Interferometer and the survey telescopes VISTA and VST. The Atacama Pathfinder Experiment (APEX) partnership operating a 12-metre submillimetre antenna on Chajnantor was a precursor to the intercontinental partnership that is constructing the world's largest radio telescope, the Atacama Large Millimeter/submillimeter Array (ALMA), on the same site and with initial operations already started. The next giant step is the imminent launch of the construction of the 39.3-metre diameter European Extremely Large Telescope on Cerro Armazones with a projected start of operations in about ten years' time. Meanwhile, the number of Member States has increased to 14, with Brazil poised to join as the first from outside Europe as soon as the Accession Agreement is ratified.

ESO's mission is to design, construct and operate powerful ground-based observing facilities which enable astronomers to make important scientific discoveries and to play a leading role in promoting and organising cooperation in astronomical research. The achievement of these goals would not have been possible without the dedication and engagement of many individuals over the years, in particular the motivated and highly skilled ESO staff members carrying out in-house science, engineering and support activities, matched by effort in technical and scientific institutes and in industry in the Member States, all of it strongly supported by the governments of the Member States and of that of Chile which hosts the Observatories.

Fifty years is a good anniversary at which to take stock — to look back with pride on what has been achieved, to contemplate some of the detail on how it all came to pass, and to learn from the past while forging ahead into the future. The anniversary has been celebrated in a variety of ways — including a scientific workshop (ESO@50, see the report on p. 64), a book by Claus Madsen (*The Jewel on the Mountaintop*) covering nearly all of ESO's history, a richly illustrated book by Govert Schilling and Lars Christensen (*Europe to the Stars*), many additional images on the ESO website, exhibitions and competitions, one of the latter with, as a prize, the opportunity to observe at Paranal, and a gala event for representatives of the Member States and key contributors to ESO's development, past and present (see the report on p. 7, with copies of the speeches). In this special issue, four former Directors General also contribute their reflections on the significance of the 50th anniversary: Lodewijk Woltjer (1975–1987), Harry van der Laan (1988–1992), Riccardo Giacconi (1993–1999) and Catherine Cesarsky (1999–2007).

The need for good internal communication over so many sites, together with the need to ensure that the community in the Member States remains well informed about ESO, is as valid a mission as it was in 1974, and maybe more so. While many new channels of information exchange are now used routinely, *The Messenger* continues to have an important role. The layout and the content have evolved over the years and the fraction of scientific and technical articles has increased, somewhat at the expense of the more informal and sometimes anecdotal contributions in the early issues, no doubt caused by the increased size and complexity of the Organisation. I am convinced that *The Messenger* will continue to have an important role, and I strongly recommend this special edition to your attention.

Artist's impression of the E-ELT on Armazones.



ESO/L. Calçada

Reflections from Past Directors General

Three Threads through Time

Lodewijk Woltjer

The celebration of 50 years of ESO recalls early discussions about the purpose of ESO. Was this only to construct a 3.6-metre telescope to explore the southern Milky Way, or was ESO part of the European revival in science and technology and, more generally, an attempt to restore its independence? When I came to ESO the latter aspect would gradually assume a dominant importance. Three lines of evolution of ESO were started at that time, and it is interesting to see that, during the last decade, this long-term ambition has more or less been completed. The three lines involved the transformation of ESO from a limited association of the six founding countries into a pan-West-European organisation, the expansion of the wavelength region covered by ESO and the development of a strong European centre for astronomical science and technology.

With the accession of Italy and Switzerland thirty years ago, the representativeness of ESO in the European context was much improved and the successful incorporation of these countries made possible the subsequent further growth of the organisation to fourteen members. Since the ESO budget is based on net national income (NNI), this growth also implied a strengthening of the financial capacity to undertake more challenging projects. The recent agreement with Brazil further adds to the weight of the organisation. Of course, ESO becomes less European, but the cultural closeness between Latin America and Europe does not make this a very important issue. Moreover, relations with Chile have developed very favourably; although the Chilean contribution consisted mainly of sites, Chilean scientists rapidly became *de facto* members of the broader ESO community.

The agreement between Sweden, Germany and ESO made it possible twenty-five years ago for ESO to become part of the millimetre/submillimetre community that studies the cold Universe. This thread became more fully developed with the Atacama Large Millimeter/submillimeter Array (ALMA) project.

The third thread in ESO's evolution began with some instrumentation projects. This activity became more extensive with the development of the New Technology Telescope, begun after the accession of Italy and Switzerland. The subsequent VLT approval in 1987 sealed ESO's entry into the field of major telescope technology, which has now allowed it to plan for the 39-metre telescope. In addition, the new instrumentation projects for the VLT interferometer and for the Unit Telescopes of the VLT have made ESO the envy of the world and increased its science productivity by factors unimaginable three decades ago. The model of shared instrumentation development between ESO and its Member States, as planned in the original VLT proposal, has been a full success for both. The technological capabilities of the institutes are infinitely superior to those of only thirty years ago.

ESO has demonstrated that European cooperation works. The sum of its member countries is much larger than a simple addition would suggest. But ESO's long-term future depends not only on factual successes. As in the past, a common ideology will remain necessary. Undoubtedly the current economic problems will pass after a shorter or longer time. Far more serious is the risk of the loss of the European ideals so visible in different places. In this respect it is essential that ESO take care not to lose Member States due to temporary economic problems. ESO activities, including the vital Fellowship programme, should continue to unite the young scientists of the continent towards a common future.

ESO/H. H. Heyer

La Silla Observatory at twilight.

ESO from Age Fifty to Ninety

Harry van der Laan

In 2002 three Directors General wrote their reflections on the state of the organisation to mark ESO's fortieth birthday. Now we stand a decade later, and wiser (?), with the Editor's request to once more reflect on our institution's prospects. I here look ahead another fifteen years to 2027 and then peer into the misty era between 2027 and 2052. ESO as a ninety year old? I dare not presume that I could say anything credible about 2062, the one hundredth birthday.

The period from 2002 until now is clear: Claus Madsen has brilliantly written about its substance in *The Jewel on the Mountaintop*, Govert Schilling and Lars Lindberg Christensen have aptly illustrated the glory of the *Jewel's* success in *Europe to the Stars*. Both books also anticipate the excitement of the Atacama Large Millimeter/submillimeter Array (ALMA) to come.

In the next fifteen years we may expect a whole lot of ALMA discoveries: there is so much unexplored parameter space now coming within reach.

The above-mentioned authors pay ample attention to the European Extremely Large Telescope (E-ELT), a telescope whose engineering and instrumentation design are far along. In this note I presume that the go-ahead light for humankind's biggest eye destined for Cerro Armazones will jump from amber to green.

With the survey telescopes VISTA and the VST, as well as ALMA data analysis, prompting urgent needs for optical–infrared information, the four VLT Unit Telescopes will see their coveted observing time allocated in a very ambitious, competitive environment, with a user community facing high oversubscription factors. Astrochemistry will flourish, attracting a new breed of chemistry students to astronomy graduate work. There will be more laboratory astrochemistry to unravel the molecular mysteries hidden in ALMA's data. Astrophysics and cosmology developments will increase the pressure for VLT Interferometer observing as well, by then streamlined for technically unspecialised observers.

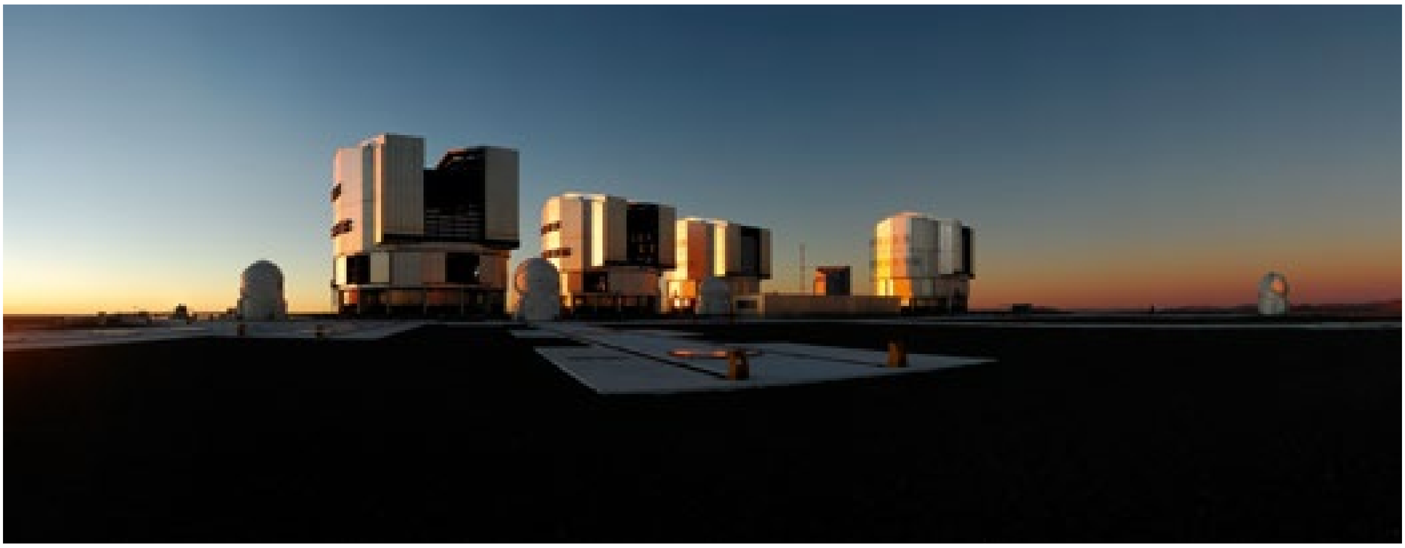
During all this time, we trust that the *finesse* of the E-ELT's design will be transformed into the construction of this unprecedented machine by Member State industries, while the first generation suite of instruments is realised in the — by now — well-tested collaboration between the user community and ESO. By 2027 all the power of the 40-metre-class telescope, based on its built-in informatics and technological ingenuity, should be fully unfolding: the new era for astronomy that is expected to begin with the E-ELT and the James Webb Space Telescope has arrived.

2027, the sixty-five-year-old ESO: what could be the overview?

Our beloved La Silla Observatory may well still have two or three highly specialised and stably operated telescopes. (Remember that the Hale 5-metre telescope on Mount Palomar is nearly sixty-five years old today). The whole of La Silla is an opportunity for a Chilean Maecenas to preserve this splendid place as an interactive cultural/educational scientific/technological monument.

At the Paranal Observatory I expect the VLT to be exploited to the hilt, with instruments not yet conceived, but probably with a greater emphasis on high-precision spectro-polarimetry. On nearby Armazones the E-ELT will be the world's outstanding telescope, as the VLT is today. On Chajnantor the amazing submillimetre array will have many observing modes in numerous (sub)configurations to satisfy ALMA's worldwide community. So the prospects for the 65-year-old ESO are breathtaking, the opportunities for ESO-community astronomers abundant, the challenges for ESO staff fascinating.

There must be a catch …



ESO/F. Kamphues

Paranal Observatory at sunset.

Humankind from 2027 till 2052

ESO is an organisation owned and supported by its Member States for its user community. Continuity requires the commitment of governments, and the engagement of civil servants in Council and the Finance Committee. The dedication of users we can practically take for granted. Will all this hold then even in an additional twenty-five years?

Switch to another level of aggregation. In 2012 the confidence within many of our Member States is eroding. There is no political consensus about the optimum location on the scale — if there is such a one-dimensional choice, it is one that we do not want to make — between *shareholders capitalism* and *compassionate social democracy*. The former rules resource flows in the process of *globalisation*; the latter strives for small-scale uniqueness, preservation of local character and values in the process of "*glocalisation*". The stability of holding to both is highly uncertain and therewith the cohesion and even long-term viability of a European Union. Will it be resilient and prosperous enough to maintain explorative adventures, of which ESO is a prime example? In parallel there is the support for pure scientific research and education in the universities of our Member States. The inflow of future generations of ESO users depends on their vigorous pursuit.

Over all these questions looms the habitability of Planet Earth for the projected nine thousand million people. There is an unmistakable change of climate occurring, tangible on the timescale of a single human lifetime, explosive on a geophysical one. Before the middle of the century, countless millions of humans, now living in coastal areas and continental regions bordering on deserts, may be on the move. Humankind's greatest achievement, the rule of law, may be in jeopardy. I appeal to fellow astronomers, while we so ardently hunt down other planets and search for signs of life, to heed the signals threatening our own.

Riccardo Giacconi

On the 50th anniversary of its foundation it is a pleasure to see ESO striving to achieve and maintain a leadership role in ground-based astronomy in the world. *Arete* is the ancient Greek term meaning "to be the best one can be", and I hope it will be the motto of ESO.

I was Director General of ESO for only seven years from 1992 to 1999. I was lucky that they were the years in which the dream of the VLT, first proposed by Lodewijk Woltjer and initiated by Harry van der Laan, was translated into reality, and I consider those years among the more interesting in my scientific and managerial life.

The undertaking of such an ambitious project (costing some six times the yearly organisational budget) required the technical and scientific preparation of the ESO staff and a rearrangement of the organisational structure to carry it out successfully. The most important aspects of this rearrangement were those required to fully engage the interest and sense of ownership of the project by the staff. They included building up a sense of unity in all institutional activities, and a great deal of communication both vertically and horizontally to best share knowledge, experience and mutual help.

The personnel policies were changed to ensure recognition of performance and the opening up of opportunities to some of the ablest and youngest of the staff. The rather autocratic style of management that had prevailed for many years was slowly turned into a participative management approach where decisions were discussed openly and reached by consensus, whenever possible.

It was fun to turn La Silla into a technically up to date and scientifically productive observatory, while using it also as a test bed for instruments and software, and while building, together with other institutions, a superb set of instruments for the VLT. It was rewarding to ensure that even the hotel for the resident staff of Paranal was up to the same standard of excellence. The satisfaction of working at this high level of competence was an indispensable driver for the achievement of our goals.

I hope this enthusiasm will continue in the future as ESO undertakes more and more ambitious projects. *Arete!*

Perspective on ESO's 50 Years

Catherine Cesarsky

When my husband and I decided to settle in Europe in 1974, after a few years at Caltech, we immediately made contact with ESO, as some of our close friends were working there. ESO was then a young organisation, growing under the wing of its elder sibling, CERN, and it did not even yet own a 4-metre-class telescope; the ESO 3.6-metre only started operations in 1977. But soon, ESO acquired its own headquarters, near Munich, and, more importantly, new member countries, Italy and Switzerland, and new ideas and techniques. The design and construction of the New

Technology Telescope (NTT) was the first turning point, and served as basis for the VLT decision in 1987, even before the glorious first light of the NTT. After a few years of preparation, the VLT construction went on the right path, with a solid methodology inspired by space developments.

I was lucky to take the helm just after the inauguration of the first VLT telescope, and could oversee the end of the deployment of the telescopes, of the first generation of instruments, and of much of the interferometry. During those years ESO took the lead among astronomical observatories in the world, so that it was, as is fitting, in full adulthood for its 40th birthday. It was time for new adventures, and this required an enlarged budget, which was obtained by attracting new Member States. The successive entry of Portugal, United Kingdom and Finland made possible the launch of the Atacama Large Millimeter/submillimeter Array (ALMA) on an equal partnership with the United States; soon after, Japan, associated to Taiwan, joined in. With the ALMA construction, ESO has extended its wavelength range and the breadth of its science, and has learnt to participate successfully in a truly worldwide project. I am looking forward to the ALMA inauguration next March, while enjoying the magnificent results obtained during the early science phase that is still ongoing.

By 2004, ESO and its Council had reflected upon the future of ESO, and had established the following strategic principles: retain European astronomical leadership into the era of Extremely Large Telescopes (ELTs); ensure completion of ALMA, and efficiently exploit its superb scientific capabilities; maintain VLT in a world-leading position for another 10–15 years by continued upgrades; exploit the unique capabilities of the VLTI; lead in the construction of an ELT on a competitive timescale.

These principles guided the last years of my mandate, and I am pleased to see that they remain in practice today, with Tim de Zeeuw. To ensure the competitiveness of the VLT, the construction of a set of highly sophisticated second generation instruments, both for regular observations and for interferometry, has been launched; they have begun to be installed. The Adaptive Optics Facility will transform one of the 8-metre telescopes into an adaptive telescope, by replacing the secondary mirror with an adaptive one, and adding a laser launch facility with four beams, and will strongly enhance the performance of present instruments, such as HAWK-I and future instruments such as MUSE. On the VLTI, MATISSE will fully exploit the power of four telescopes and GRAVITY will probe spacetime close to the event horizon of the black hole in the centre of the Milky Way.

The ESO strategic principles do not mention the future of the La Silla Observatory, which was united with Paranal and has been devoted increasingly to large programmes, and that is still yielding first class science, such as the recent discovery of an Earth-sized planet around α Centauri b, nor the installation in Paranal of two survey telescopes, which fill a gap in ESO's programme.

As for the ELT, the community approved the innovative design proposed by Delabre. The joining of two new Member States, Spain and the Czech Republic, helped to fund a thorough study, now completed. With the help of Austria, which joined ESO in 2009, and Brazil which signed an accession agreement in 2010, the programme is ready to be launched. At 50, ESO is a mature organisation, brimming with expertise, enthusiasm and efficiency; I can only wish it a bright future.

ALMA (ESO/NAOJ/NRAO) and J. Guarda (ALMA)

ALMA antennas and the technical building on Chajnantor.

ESO 50th Anniversary Gala Dinner

Rowena Sirey[1]

[1] ESO

To formally mark the 50th anniversary of the signing of the ESO Convention, a gala dinner was held in the Munich Residenz. A brief report of the event is presented and the speeches are reproduced. The speakers were the President of the Council, Xavier Barcons; the German Minister for Education and Research, Prof. Dr Annette Schavan; the Bavarian State Minister for Science, Research and the Arts, Dr Wolfgang Heubisch; physics Nobel Laureate, Brian Schmidt; the current Director General, Tim de Zeeuw and the Chilean Minister of Foreign Affairs, Alfredo Moreno Charme.

Figure 1. (Top) Guests seated in the Kaisersaal of the Munich Residenz.

Figure 2. (Bottom) The fellows and students together with Tim de Zeeuw.

The signing of the ESO Convention by the five founding members, Belgium, France, Germany, the Netherlands and Sweden, took place on 5 October 1962. The anniversary day itself was marked by a press release and an image of the Wolf–Rayet nebula NGC 2359 taken with FORS2. The nebula was observed by Brigitte Bailleul, a French freelance aerospace writer and journalist, who, as prize winner of an ESO competition, became the first member of the public to observe at Paranal.

The anniversary gala event was held the following week, on Thursday 11 October 2012, in the Kaisersaal of the Munich Residenz, seat of the former kings of Bavaria in the centre of Munich. The Residenz dates back to the beginning of the 16th century and the Kaisersaal was first built in the 17th century as a large entertainment room.

Eighteen months in the planning, the gala was an impressive occasion that managed to capture both the warmth and spirit of ESO, celebrating not only the history of the organisation but also those who have contributed to its present success. The guests represented four decades of ESO history, including three former Directors General: Lo Woltjer (1975–1987), Harry van der Laan (1988–1992) and Catherine Cesarsky (1999–2007) and current senior representatives from all the Member States, Brazil and Chile. Many former and present members of ESO committees also attended, together with prominent retired staff, former senior staff members and a selection of the current staff from Garching. ESO Fellows and Students, acting as guides, represented the current and future generation of astronomers.

Welcomes

A welcome cocktail and canapés gave everyone a chance to catch up with old friends and colleagues before they took their seats and the compère for the evening, Jochen Liske (Dr J) outlined the order of proceedings. The current President of the Council, Xavier Barcons, welcomed the guests. He stressed the four ingredients of ESO: astronomy, courage, cooperation and excellence. Courage was shown by the visionary astronomers from those five founding states and later by others of the remaining nine that have since followed. Cooperation is one of the pillars that have enabled these valiant astronomical ventures both within Europe and with Chile.

Excellence in technology, the telescopes and instruments built within the Member States and the competitive science produced by the telescopes have distinguished ESO and are reflected by the excellence of its staff. The next step in the development of ESO will be the building of the planned European Extremely Large Telescope (E-ELT) for which funding is being secured by the Member States.

The opening was followed by a welcome speech by the Headquarters' host and Member State, Germany, presented by the Federal Minister for Education and Research, Professor Annette Schavan. She congratulated ESO on its many achievements and expressed her pride that Germany could play a special role by hosting ESO's Headquarters. Prof. Schavan recently visited the Paranal Observatory and had been deeply impressed by the VLT operations. She emphasised the dual roles of science and technology that were central to ESO's success and for the extension of the European research area as outlined in the Horizon 2020 programme.

The address by the host state of Bavaria was given by Dr Wolfgang Heubisch, the State Minister for Science, Research and the Arts. He welcomed the attendees to Munich and praised the fine images that ESO produces. He emphasised that success lies in the combination of world-class technology and excellent scientists and that Bavaria has developed a range of facilities to make it into a world location for such activities. He closed by encouraging visitors to come again to Munich to celebrate its many treasures, including the Oktoberfest.


M. McCaughrean (ESA)/ESO

Figure 3. Xavier Barcons giving his welcome address.


M. McCaughrean (ESA)/ESO

Figure 4. Annette Schavan conveying her welcome remarks.

Speech by a young astronomer

After a first course had been served, there was a short video of ESO facilities followed by a presentation by Nadine Neumayer, staff astronomer in the User Support Department. She described her travels on the long road to fulfilling her dream of becoming an astronomer. Entitled “Reaching for the Stars”, she related childhood memories of lying out under the stars in her home in Baden-Württemberg looking up at the sky. She particularly remembers the release of the Hubble Deep Field taken by the Hubble Space Telescope of a tiny region in the constellation of Ursa Majoris in December 1995 as being a defining moment. After unsuccessfully trying for an internship at ESO while still at school, she visited the observatory at La Silla when travelling through Chile after finishing school. She studied at Heidelberg University and the University of Cambridge and received her PhD from the Max-Planck-Institute for Astronomy in Heidelberg. Her thesis topic was the study of the black hole in the nearby galaxy Centaurus A and its influence on the elliptical host galaxy NGC 5128. She took the data for this study at the ESO Very Large Telescope. Nadine, a Fellow at ESO before becoming a staff member, is also the mother of three children and her first child was born during her PhD years. She described how challenging this combination was. She praised the support of her family and colleagues and the assistance she received through organised childcare, from employers, and especially by the Christiane Nüsslein-Volhard-Foundation. Nadine ended her presentation by emphasising how important it was to feel the trust of the people around her, and appealed to the audience to give their support and trust to students and colleagues facing challenging situations.

Keynote speeches

After the main course had been served, Brian Schmidt who, with Saul Perlmutter and Adam Reiss, shared the 2011 Nobel Prize for their discovery of an accelerated expansion to the local Universe, recalled other cultural icons that also began in 1962. From early views that astronomy is not fostered by the level of international co-operation practiced by ESO, he described how, from his astronomical experience, ESO had progressed and how his perspective had changed. He recalled the roles of the New Technology Tele-

M. McCaughrean (ESA)/ESO

Figure 5. Brian Schmidt presenting his keynote speech.

scope (NTT), and later the VLT, and the role of two ESO staff members, Bruno Leibundgut and Jason Spyromilio, in the collection of the crucial data on the acceleration of the expansion of the Universe for the High-*z* Supernova Search team. These data eventually contributed to the award of the Nobel Prize. He closed by commending the governments that have invested in ESO, enabling it to achieve its current place at the peak of world astronomy.

While observing that 50 years is minute in terms of astronomical timescales, the current Director General, Tim de Zeeuw, celebrated the enormous developments since the founding of ESO. He paid tribute to the previous Directors General, and all the staff in bringing about these changes; and to the very supportive role of Chile in hosting the observatories. He noted that next year adds another 50th anniversary, that of the presence of ESO in Chile. While collaboration has allowed so much to be achieved, we should not forget that a spirit of competition still drives our scientific ventures. Even if the mysteries of dark matter and dark energy were to be solved soon, other great challenges lie in wait and extrasolar planets will remain an abiding topic. Looking to the future and to the critical importance for the future of mankind of society continuing to value science, Professor de Zeeuw quoted the Dutch astronomer Christiaan Huygens on the need to pay attention to wider issues and how the recent invention of the telescope can expand our vision.

Closing ceremonies

The official delegates of all the Member States then signed the surface of an E-ELT mirror blank that had been brought to the Residenz for the occasion. Their signatures have since been engraved into the mirror blank as a remembrance of the gala event and the 50 years it celebrated. The Minister of Foreign Affairs for Chile, Alfredo Moreno, than expressed his appreciation of the wonderful science being done under the Chilean skies. Alfredo Moreno has been closely associated with ESO for more than 15 years and was involved in the resolution of land dispute on Cerro Paranal in 1995–6, and his engagement illustrates the supportive environment referred to by the Director General in his speech.

Finally Xavier Barcons wound up with some closing remarks. He exhorted all the Ministers and representatives of the ESO Member States present to be the proud ambassadors of ESO and its activities. He closed by wishing ESO a most successful next 50 years.

Figure 6. Group photograph of all the official representatives of the ESO Member States, the host nation Chile and the Director General.

Texts of Speeches

Welcome

Xavier Barcons, President of ESO Council

Dear Ministers and dignitaries, dear Guests, Colleagues and Friends,

Welcome to this event that marks 50 years of ESO, the European Organisation for Astronomical Research in the Southern Hemisphere. Today we celebrate together a number of things. To start with, we celebrate astronomy, perhaps the most ancient of the sciences and surely among the most captivating ones. We also celebrate recent achievements in astronomy, made with the help of ESO:

- Knowledge of hundreds of planets orbiting stars far from our Solar System, which only two decades ago belonged to the realm of science fiction.
- Progress made during the last 50 years towards our understanding on how stars, planetary systems and galaxies form and evolve.
- A serious hiccup in the widely accepted cosmological model that occurred in the last 15 years when astronomers found that the Universe is expanding faster and faster as time goes by.

These and many other discoveries, as well as the many questions that astronomical investigations have raised, continue to be at the focus of intellectual interest of our society. The response of ESO's Member States to this quest has been to build and operate world-class astronomical observatories and to foster cooperation in astronomical research.

A little more than five decades ago, a group of visionary European astronomers succeeded in promoting the idea of building a 3-metre-class telescope in a new observatory to be placed in the southern hemisphere. The governments of Belgium, France, Germany, the Netherlands and Sweden were brave enough to sign the Convention establishing a European Organisation for Astronomical Research in the Southern Hemisphere. ESO soon after signed the first agreement with the Republic of Chile to establish its observatories in that country, opening a long-lasting and successful collaboration.

Courage

Today we celebrate the courage of those visionary astronomers, of the five governments that started ESO and of the remaining nine that have joined since: Denmark, Italy, Switzerland, Portugal, the United Kingdom, Finland, Spain, the Czech Republic and Austria. In addition we all encourage the efforts of the Brazilian government towards successful conclusion of the ratification process, after which Brazil will become ESO's 15th Member State.

ESO has experienced huge changes during those 50 years, and they are particularly evident during the last couple of decades. Almost two decades ago, and with La Silla firmly established as ESO's observatory in Chile with its 3.6-metre telescope among others, came the building and deployment of the Very Large Telescope, the VLT, the most powerful optical observatory in the world; later the VLTI interferometer — a unique facility — and more recently the survey telescopes VST and VISTA, all of them on Cerro Paranal. ESO's Paranal Observatory is undisputedly the world's most powerful astronomical observatory in the optical and near-infrared. About one decade ago, ESO took a crucial step forward by going into radio astronomy with APEX and ALMA. Today, with ALMA fully integrated into the programme and with North American and East Asian partners, ESO has consolidated its leadership in ground-based astronomy, by expanding on its wavelength coverage, from the classical optical domain into the infrared and now into millimetre and submillimetre radio astronomy.

The next development is the European Extrmely Large Telescope (E-ELT) to which I will return later.

There is no doubt that ESO is a success, and there is plenty of evidence for it, in particular:

- ESO delivers the highest-quality astronomical data to astronomers, who bid in fierce competition for observing time.
- ESO's facilities offer the most advanced instrumentation, largely built in cooperation with institutions from Member States.
- ESO is the European forum where important decisions on ground-based astronomy can not only be discussed, but adopted and eventually implemented.

Cooperation

Cooperation is certainly one of the main pillars upon which ESO's success rests, and a major reason for our celebration today:

- Cooperation amongst ESO Member States is probably best seen at ESO Council. Delegations have made continuous progress together during the last 50 years, often putting aside national interests for the benefit of the full ESO.
- ESO's Member States today encompass the vast majority of European astronomers, who, through cooperation with ESO, devote the best of their efforts to secure a most advanced suite of instruments for our telescopes and the best possible science output of the facilities.
- The same spirit of cooperation was also the driving force behind the signature in November 1963 of the first site agreement between ESO and Chile, which allowed ESO's telescopes to be deployed there.
- Cooperation is also behind the ALMA agreements between ESO and its ALMA partners in North America and East Asia. Let us not forget that ALMA is the very first global ground-based infrastructure of its size without a leading partner. We are well aware that we are being carefully watched by large projects in other areas which are coming next.

Excellence

Looking for excellence is the guiding principle in the way that ESO works, something more to celebrate today:

- ESO's telescopes are amongst the most advanced in the world and placed in some of the best sites for astronomical observing.
- ESO's telescopes are highly demanded by the scientists; typically they request five times more observing time than is actually available. The choice of those projects that actually make it to the telescopes is based on scientific excellence. This has resulted in the astronomical researchers in all our Member States becoming more competitive, leading to the best possible science return from ESO's sophisticated and expensive infrastructures.
- The way ESO handles industrial return, and consequently the generation of R&D-based activity in the Member States, is also largely based in excellence criteria. Of course, a healthy industrial geo-return is also actively pursued by ESO management and carefully monitored by ESO's Finance Committee and Council.
- ESO also looks for excellence when it comes to hiring its staff. It is ESO's obligation to target the best professionals, so the mission charged to the Organisation by the governments of the Member States, can be successfully accomplished. Here, we must be proud of the success of ESO, which has a fully dedicated, professional and engaged staff complement.

Astronomy, courage, cooperation and excellence: these are the perfect ingredients to build the most successful future for ESO.

Several years ago, ESO Council approved how the principles stated in the Convention would need to be realised during the first quarter of the 21st century. This consists of three elements:

- Keeping Paranal at the forefront of optical and infrared ground-based astronomy through the next decade. The VLT is the most powerful observatory in the world, and this needs to be preserved by keeping it operational and with state-of-the-art instruments.
- Building and exploiting ALMA together with ESO's international partners. ALMA construction is not yet over, but we can see it coming closer. In March next year, ALMA will be inaugurated by Chilean President Sebastián Piñera, along with ministers and dignitaries of ESO's Member States and of our North American and East Asian partners. In the meantime, Early Science observations with a reduced version of ALMA are showing astonishing results and giving a glimpse of what a fully developed array with 66 ALMA antennas will bring.
- The third element is to build an Extremely Large Telescope that will keep Europe at the forefront of optical ground-based astronomy in the 2020s and beyond.

ESO, together with European industry, has produced a solid detailed design of the most powerful, and yet affordable, E-ELT. A number of reviews have shown that ESO is technically and programmatically ready to start the construction of this 39-metre giant telescope, provided that the funds are available.

At the moment, seven of our Member States have solidly committed to the project, and this needs to be recognised and appreciated. But the target is to have all ESO Member States joining the E-ELT, including Brazil as ESO's 15th Member State. I am well aware that all ESO Member States are working hard to be able to participate in the E-ELT, despite the current financial environment. But, the E-ELT is a project that will produce, in the short term, R&D activity in the industries of the Member States, a much-needed ingredient to overcome the current financial crisis. In the long term, it will ensure that ESO's Member States will remain at the forefront of astronomy. Together, we can make it happen.

Dear Ministers and dignitaries, dear guests. Thank you very much for coming and joining the big ESO family tonight. And now, enjoy the celebrations.

Welcome Remarks

Annette Schavan, German Federal Minister for Education and Research

Dear Guests, Excellencies, Ambassadors, Mr President, dear Colleagues, Ladies and Gentlemen,

Welcome to Germany. It is a great pleasure for me to have you here for this very special anniversary. It is almost 50 years to the day since the establishment of the European Southern Observatory marked the beginning of the present success story. The five founding states of ESO, have meanwhile grown to 14 and, as we are deeply convinced, 15, on the accession of Brazil. Today ESO is a world-leading and certainly most productive institution for ground-based astronomical research. We are all pleased about this outstanding scientific development, which is a confirmation of the excellent productivity of this partnership.

A few days ago I visited one of the unique observation locations — the observatory of Cerro Paranal in Chile. I was deeply impressed, and with the Director General and the German delegation it was a great pleasure to witness this special place. I was deeply impressed by my visit to the Very Large Telescope there. It is no coincidence that the VLT is an optical telescope with the best performance worldwide. It stands for the international importance of the entire organisation. All three locations of ESO in Chile are operating equipment which is one of a kind, and is greatly in demand by astronomers from all over the world.

The most recent Nobel Prize for Physics, which was awarded for the discovery of the accelerating expansion of the Universe, was based on data obtained from ESO. I believe the Nobel Laureate Prof. Brian Schmidt will tell us about this special theme for scientists — since Monday a very special week for us all, for scientists and for science politicians. He will tell us more about this great research success. Welcome, and we are looking forward to hearing you.

We in Germany are proud to be among the ESO Member States. We are also fully involved with our special responsibility as host country and have greatly contributed to the Headquarters extension building in Garching. We support the ambitious but very realistic objective that research conducted at ESO is at world-class level. We want it to stay that way.

We realise that the construction of the European Extremely Large Telescope will be decisive in maintaining European leadership role in this field. We need the European leadership role. The performance of the E-ELT will be revolutionary and will provide answers to some of the most pressing questions in astrophysics. Let’s jointly make sure that these important findings are European findings. European astronomy has resumed its leadership position on a sound base of cooperation. In particular in the challenging times we face in Europe, ESO’s achievements remind us of what we can achieve jointly.

Cooperation in science and research points the way to Europe’s continued success in the future.

Research in science is, I am deeply convinced, the sole basis for the future of our society. Europe’s real wealth lies in the skills and intellectual potential of its people. That is very important for the further development of the European Research Area (ERA) and to understand it, not only as an instrument of research, but quite specifically as part of the European process of integration.

In addition to the prize ERA initiatives since 2008, the European research Framework Programme has also brought this process forward. Scientists from all over Europe are cooperating in the most diverse projects, sometimes even with researchers in Asia and America. The financial crisis shows us that we must make further efforts for Europe to stay successful in the future. This is the major issue in the context of Horizon 2020. Germany has tried to translate the German high-tech strategy to the European-wide Horizon 2020 in order to focus on the entire information chain, as we have been doing in Germany since 2006. This will distinguish the new research Framework Programme from the former ones. The close network of science, research and innovation is a key to both economic success and social coherence: the bold way to provide young people in Europe with a positive argument for the future. In the 21st century the European Union must become a union of innovation — that will be our great wish for the scope of Horizon 2020. This also provides the opportunity to build new bridges between people in Europe on the topics of education and science, research and development. We must bear in mind the words of John Lee, “We don’t unite states — we unite people.”

The integration of research and innovation with nationality has been remarkably successful in ESO, making it a model for the burgeoning European science community, which actively contributes to the process of integration.

On this 50th anniversary of its founding I would like to congratulate the European Southern Observatory for all its achievements to date. I would like to thank your staff, your partners and the scientists who have always made sure that ESO users are able to work at a high level and at the cutting-edge of astronomical research and will continue to do so by designing, building and operating telescopes and instrumentation. I would like also to thank our international partners who laid the foundations of this success story together. Let’s continue along these lines together.

So once more welcome to Germany and congratulations to ESO.

Welcome Remarks

Wolfgang Heubisch, Bavarian State Minister for Science, Research and the Arts

Dear Professors Schavan, Barcons and de Zeeuw, Vice Minister Wilhelm, State Secretary Dell’Ambrogio, your Excellencies, Ladies and Gentlemen,

On behalf of the Bavarian State Ministry for Science, Research and the Arts, it is my pleasure to welcome you to the Munich Residenz. Together, we want to celebrate the 50th anniversary of ESO. The Prime Minister of Bavaria, Horst Seehofer, regrets that he is not able to join us tonight and sends his best regards.

Curiosity is at the basis of research. It is the driving force for discoveries and inventions. [The Mars Science Laboratory *Curiosity*: demonstrates what curious scientists and researchers can achieve and provides us with fascinating colour images of the red planet.] The success of ESO is due to the far-sighted decision to let an alliance of countries work together in order to further progress. Fourteen — and soon fifteen — countries from Europe and beyond are joining their efforts to realise unique and pioneering projects in astronomy.

Today, ESO is the foremost intergovernmental astronomy organisation in the world. It operates three world-class observing sites in Chile. Its powerful facilities give astronomers the necessary instruments to make discoveries which lead to new insights and a deeper understanding of the Universe. It is no wonder that the discovery of the accelerating expansion of the Universe was based in part on data taken with ESO telescopes. For this breakthrough finding, the Nobel Prize for Physics was awarded to Saul Perlmutter, Brian Schmidt, and Adam Riess in 2011. Two ESO staff members (Bruno Leibundgut and Jason Spyromilio) worked in the team of Schmidt and Riess. Once again we see that success lies in the combination of both world-class technology and excellent scientists.

This is also why Bavaria has developed into a first-rate international location for science and research. Bavaria’s fertile research landscape is based on a sophisticated network of state-of-the-art facilities including nine state universities, seventeen state universities of applied sciences, thirteen Max Planck Institutes, five research facilities of the Leibniz Society, several institutes of the Fraunhofer Society and many other renowned non-university research facilities.

Within this rich research landscape, ESO is an outstanding and precious landmark. It contributes to Bavaria’s reputation as an important site for science and it attracts a large number of top scientists from around the globe. They enrich research in Bavaria with their expertise and excellence. Bavaria also benefits from ESO because a good part of the ESO budget is invested in Garching: about 30 million euros per year. Moreover, within the last ten years ESO concluded contracts in the high-tech sector in Bavaria and Germany amounting to 100 million euros.

As an international research organisation, ESO knows about the importance of EU research programmes and funding. In 2011, the organisation participated in seven EU 7th Framework Programme projects. Bavaria also profits greatly from EU research funds. In the last few years, the Bavarian universities alone received the remarkable amount of more than 70 million euros per year.

Research and innovation are at the core of the Europe 2020 strategy and its flagship initiative, Innovation Union, because research and innovation help to create new jobs and prosperity, and to turn ideas into social progress. The next framework programme — Horizon 2020 — goes in the same direction. It is expected to start in 2014 and to have a budget of 80 billion euros to fund research and innovation over a span of seven years. One of the priorities that Horizon 2020 will focus on is excellence. It is my firm belief that to secure Europe's long-term competitiveness, we need to raise and strengthen the level of excellence.

Dear ESO staff,
Fifty years of working together to uncover the mysteries and secrets of our Universe: I congratulate you on that. With courage, passion and perseverance you make it possible to further astronomical research. Your excellent work also strengthens Bavaria as a key location for science and industry. Thank you very much for your dedication and commitment. Keep on being curious and contributing to new and groundbreaking discoveries.

I am looking forward to an interesting evening and wish all of us a fruitful exchange of ideas and views. And for those guests who have come from far away: I hope that you also find some time in the next few days to discover and enjoy the natural and cultural gems that Bavaria has to offer. Enjoy your dinner!

Keynote Speech

Brian Schmidt, Physics Nobel Prize Laureate, 2011

Meine Damen und Herren, Senoras y Senores, Hyvät naiset ja herrat, Dames en heren, Dámy a pánové, Signore e signori, Mine damer og herrer, Senhoras e senhores, Mina damer och herrar, Mesdames et Messieurs, Ladies and Gentlemen.

While ESO is an institution of many languages, it is the place where people from around the world come together to speak astronomy.

On 5 October 1962, the Beatles released their first single, *Love Me Do*. *Dr No* premiered on this same day, starting the James Bond franchise and helping make all of us order our Martinis "shaken not stirred". But it is the birth of the European Southern Observatory that we celebrate today — a scientific organisation whose discoveries will ensure that it is the longest remembered of these cultural icons born on that faithful and rather remarkable Sunday in 1962.

That is — as big a Beatles fan that I am (I have owned all the albums since I was a kid), and as much as I am looking forward to *SkyFall*, the next James Bond film (and yes, I have seen every James Bond film — the good and the bad), I am sure that the discovery, for example, of the supermassive black hole in our Galaxy's centre will outlast them both. And so I say ESO is a great cultural icon — because astronomy is more than just science — it is an expression of humanity to understand our place in the Universe — an understanding which is shared across the world, and a science which dates back to the beginnings of civilisation — and probably before.

Astronomy is ultimately empowered by telescopes, and the technology behind them. To make progress, it is necessary to marry good ideas with cutting-edge equipment — equipment that can exceed the ability of a single nation to afford. The sky has no owners and no measurable bounds — and as such, astronomers are born to collaborate. Conceived in 1954, born in 1962, ESO was an approach for five countries to be able to better do astronomy — by combining together the resources and ideas of many into a much greater whole. Although this was a new way of doing things in astronomy, it was not a new way of doing things in Europe, as ESO was clearly born out of the ideas surrounding CERN — ESO's highly successful scientific sibling.

As someone who grew up in the United States, the European way of doing things was a bit foreign — and not just to me, but to my entire country. Why would anyone wish to go through the effort to bring together so many cultures through the complexity of an inter-governmental treaty? Why not just go out and do it, one piece and one country at a time? These were my attitudes to ESO when I started my PhD in 1989. I had failed to understand that ESO was not built around a single era of telescope, living a golden age and then fading into obscurity. Rather it was an observatory always with one foot in the present and one foot in the future.

My first glimpse of what was possible came with the New Technology Telescope — the NTT — which, true to its name, employed all sorts of new technology to help the telescope obtain higher quality data. Starting in 1990, we began seeing press reports that talked about phenomenal image quality — too good to be true, we thought; it cannot possibly be that good — there must be a catch. But it was that image quality that both made possible the discovery of the black hole in the centre of the Milky Way, and as it turns out, saved the High-z Supernova Search Team.

In 1994, my colleagues and I formed the High-z Supernova Search Team — a collection of astronomers interested in supernovae — wanting to take advantage of the opportunity to use Type Ia supernovae to measure the change in the expansion rate of the Universe. We took our first data in 1995, but finding supernovae was not as easy a task as I had hoped, made even harder by my foolish decision to try to orchestrate a search from Australia with virgin software through an internet connection that was one character per second.

When all seemed lost and it seemed that our project would fizzle without finding a single exploding star, we found an object at the last possible moment. This object — it looked like a supernova on our images — but the all-important confirming spectrum evaded us. Our last chance was with Bruno Leibundgut and Jason Spyromilio on the NTT, and through the great image quality of the telescope and the amazing persistence of these two astronomers, a spectrum was obtained, revealing this as the most distant supernova then detected. The High-z team was saved. ESO facilities continued to play a pivotal role in our programme up to and well beyond the discovery of acceleration in 1998 with these supernovae.

Today ESO is no longer dismissed as some irrelevant European organisation by anyone in the world. Rather it is often referred to as "Gold Plated" or "The Observatory that God would have built, if only He or She had enough money". I had the chance on my way to this celebration to visit Paranal for the first time. What I saw was not decadence, except possibly for a few fake rocks put in place for the last James Bond movie. Instead, what I saw gave me far more than a quantum of solace that ESO's resources were being well deployed. I saw an amazing observatory — one with a scale that enables efficiencies of operations that make other observatories envious. I saw a vigorous investment in the future, with new instruments being brought online unlike anywhere else in the world. After all, a telescope is only as good as the instruments on it, and it only makes sense to ensure a constant supply of cutting-edge instrumentation on your flagship facilities.

This strategic ability to plan is at the core of ESO's ascension to the pinnacle of world observatories, and this same structure enables ESO to run its first generation facilities on La Silla more efficiently and cheaper than any other comparable observatory. The ESO structure has also allowed forays into new exciting areas — like the ALMA telescope, currently being deployed. Despite millimetre-wavelength astronomy being previously largely foreign to ESO, ESO, by engaging with industrial partners, and the vast array of European universities and research institutes, has managed to quickly catch up. Using its ability to plan, it already has a second generation instrument in the works for this newest of its telescopes. While this planning may have surprised its partners, it is only sensible to plan upgrades to ALMA so that the initial capital investment in the telescope will pay healthy scientific dividends into the future.

ESO is now embarking on its most ambitious project yet — the European Extremely Large Telescope (E-ELT). A project that is no longer just in step with the rest of the world, but rather a step ahead. Although the E-ELT is the most formidable of the next generation of telescopes, its design is already the most technically advanced. I have no doubt it will be a success. There is no doubt that as the E-ELT nears completion in the future, ESO will be able to plan the next big thing — be it another optical telescope, next generation gravity-wave telescope, or a huge radio telescope — it is uniquely able to formulate a portfolio of facilities for its members. It is for this reason that the Australian astronomical community, in our latest report to our government, have advocated that Australia join ESO with its highest priority. Of course we still have the challenging task of convincing our government that it should invest in ESO, as well as ensuring that ESO itself would like us as a member. But as I contemplate the future of astronomy — I do not just see that the future of astronomy is bright at ESO, instead, I see that the future of astronomy is ESO.

So on that note, I would like to commend the governments that have invested in ESO. Your investment has enabled the staff of ESO, and the broader community it serves, to achieve an impressive rise over the last 50 years to its current magnificent state at the top of world astronomy. ESO is poised to continue to thrive into the future, providing the world with an exciting and wonderful look into our Universe. Happy 50th Birthday!

Keynote Speech

Tim de Zeeuw, ESO Director General

ESO's Past, Present and Future

Your Excellencies, Delegates, former Directors General, other luminaries, colleagues and friends,

It is a great pleasure and privilege to be at the helm of ESO and to be able to address you on this special occasion.

Since the founding of ESO, the Earth has been 50 times around the Sun, Jupiter only four times, and Saturn a little over 1.5 times. The Sun itself has covered one-fifth of one millionth of its orbit around the centre of the Milky Way. So fifty years is a tiny period on cosmic scales, yet astronomy has progressed at an unprecedented pace. ESO can be proud to be an integral part of the many discoveries that clearly fascinate young and old across the world.

Over these fifty years, ESO has expanded far beyond the dreams of its founding fathers. This has been made possible by the strong support of the Member States and Chile, by the previous Directors General and by the motivated and highly skilled staff.

The DGs Otto Heckmann and Adriaan Blaauw laid the foundations of ESO and built La Silla. Unfortunately they are no longer with us, although Adriaan visited La Silla and Paranal two and a half years ago, at age 95. I am very pleased that Lo Woltjer, Harry van der Laan and Catherine Cesarsky are here. Riccardo Giacconi has sent warm congratulations. Lo had the vision of the Very Large Telescope and Harry and Riccardo oversaw its construction. Catherine developed ESO's role in ALMA, and managed the early planning for what is going to be the E-ELT. In the process ESO grew to 14 Member States, with Brazil poised to be the fifteenth. Together these countries represent 30% of the world's astronomers. What a change!

This entire development is captured in two excellent books commissioned for this special year. *Europe to the Stars* by Govert Schilling and Lars Christensen, and *The Jewel on the Mountaintop* by Claus Madsen. They contain beautiful images, as well as many of the stories, and some of the legends, that made ESO what it is today.

I want to emphasise the key role of Chile. After the initial idea to go to Namibia or South Africa, the clear skies of Chile quickly became irresistible, and I am pleased to note that next year we will not only inaugurate ALMA with our intercontinental partners on 13 March, but also, in early November, celebrate 50 years of ESO's presence in Chile. The government of Chile has been very supportive of ESO, and it is a singular honour that the Foreign Minister, Chancellor Alfredo Moreno, is with us today. He had a personal hand in valuing the Paranal property during a difficult episode in the mid-1990s, and he was instrumental in the generous gift by Chile one year ago to extend the Paranal property to the east, to contain Cerro Armazones, where the E-ELT will be constructed soon.

ESO is an excellent example of the benefits of collaboration, but we should not forget the advantages of healthy competition. Examples include the discovery of the accelerating Universe, the search for exoplanets and the irrefutable evidence for a giant black hole in the centre of our Milky Way. In all cases there has been intense but fruitful competition between teams using different ground-based telescopes and instruments. This allowed the teams to get to the scientific results sooner and to have their conclusions accepted by the community, and was also very beneficial for pushing the observatories to stay at the leading edge. For these reasons it is my firm belief that ESO should not become a "world lab" where a few giant teams work on a small number of focused experiments.

And this brings me to the future. Much of the truly tremendous progress in our field has come from the huge developments over a wide range of technologies. Astronomy has very happily taken advantage of these, and sometimes pushed them, all with the goal to build better and better telescopes. We should continue to do so, in close collaboration with high-tech industry.

I am convinced that new scientific questions will continue to emerge. Fifty years ago we had no inkling that we would find that the expansion of the Universe was speeding up — as Brian just described. Although finding evidence for planets orbiting other stars was a dream for centuries, the technology to find them didn't become available until the 1990s. Arguing by analogy, there will no doubt be big surprises and probably major paradigm shifts. As the Greek philosopher Heraclitus stated 2500 years ago: *If you do not expect the unexpected, you will not find it.*

I hope we can crack the problem of dark matter and dark energy. The excitement in the exoplanet field is only just starting and will no doubt continue for decades. This new field addresses questions that transcend astronomy and even science, as it connects with the bigger question of the origin of biological activity and the presence of life elsewhere in the Universe. As Dire Straits put it: *So many different worlds, so many different Suns.* The E-ELT has a big role to play here!

Looking further ahead, it is critical that our society remains interested in science. I am always pleased to see people being excited about their latest app which allows them to see what's happening in the sky. But few realise this application requires an astronomer and a skilled software engineer to make it work. If we stop doing science and only watch reality shows, our society is doomed. This is why ESO and many other scientific institutions have active outreach programmes to inspire young people and emphasise the importance of fundamental science for society.

To conclude, let me quote: *No doubt many will say that I am overly fascinated by matters which barely touch us, while there is so much else to investigate closer to home.* You might think this is a recent quote from a spokesperson of a ministry of economic affairs only interested in short term results with immediate financial advantage. In fact, it is taken from the dedication of Christiaan Huygens' book on the Saturnian System, in 1659, presented to Prince Leopold of Tuscany, and written in difficult financial times.

Huygens goes on to say: *Few seem to realise that the study of the heavens surpasses all other endeavours. If we think that what is far away is not important for us, then our mind is without any doubt unworthy of the enlightenment provided by the pure reasoning that transcends even the immensity of the Universe. And we also do not deserve to take advantage of the invaluable invention of the means to improve our vision to be able to reach the realm of the stars.*

I hope I have convinced you that Huygens' words of 350 years ago are as true as ever. This bodes well for ESO's future. Thank you.

Speech of Thanks

Alfredo Moreno Charme, Chilean Minister of Foreign Affairs

As mentioned before, almost 20 years ago I was called by the then Chilean Foreign Minister because there was a serious problem. Chile had donated to ESO a very large piece of land to build the Paranal Observatory. In fact, the observatory was already being built. But there was a Chilean family claiming this piece of land saying that there had been a mistake. The Chilean government commissioned a tribunal to determine who the legitimate owner of that land was and determine its value for the Observatory.

Both the family and the government agreed to set a price for Paranal and I was chosen to determine that price. I don't know why but they chose me to decide the price for the Paranal site. Whatever price I set would have to be the price that the government would pay to the family. Since I was an economist, I had to learn a lot about astronomy. I went to Paranal to see what they were doing there and I talked with many astronomers to find out the price for the site to build an observatory. To make a long story short, I finally came to the conclusion that the Chilean skies were unique. The only competition for Paranal was a small peak nearby called Armazones. In my final report to the Chilean Senate, I stated the probability of having a very large observatory on that mountain peak in a few years. That was in 1995. The Chilean Senate approved unanimously the high price to be paid for Paranal. This price was related to the enormous value of the site. In the near future on that little peak of Armazones the E-ELT will be built.

Thanks to those unique Chilean skies, today I have the opportunity to be part of this ceremony commemorating the 50th anniversary of the foundation of ESO. I am proud to represent the country where all ESO's astronomical sites are located. By the way, referring to Brian Schmidt's speech mentioning James Bond, some scenes from the recent film *Quantum of Solace* were shot at Paranal.

The work carried out by ESO over the last 50 years in the design of structures and the operation of the most important astronomical projects has been of paramount importance to Chile. We have had an opportunity of being part of some of the most important discoveries in astronomy.

As you may all know, our country has received and will continue to receive most of the world's investment in astronomy. In a few more years, Chile will be home to more than 68 percent of the world's largest optical and radio telescopes. ESO will be part of the E-ELT, the largest optical telescope, and part of ALMA, the largest radio telescope in the world, both in Chile. We are fully aware of the opportunities and challenges that these observatories bring to us. We will continue to work with you in the scientific field but also collaborate with the engineering, innovative and technological challenges ahead.

We are also aware that astronomy can be a great way to attract children to science. To this end, we are working jointly with ESO in the creation of a national astronomical network open to all citizens. This is a new step towards making astronomy an essential part of Chile's track record. This is also why we issue so many press releases on this matter and encourage people to visit Paranal.

We really appreciate the work you have carried out in our country and we want people to know that we are doing things together. To set an example, only a few months ago Chile, Mexico, Colombia and Peru signed — in Paranal — the Agreement for the Pacific Alliance. Let me once again extend my appreciation to Massimo Tarenghi and the Director of the Observatory for their warm hospitality.

I would like to propose a toast — not to the last 50 years, but to the coming 50 years. I am sure that the next 50 years will provide us with many more incredible things, new discoveries, not only for Chile but also fantastic developments for all mankind.

Closing Remarks

Xavier Barcons, President of ESO Council

Dear Ministers, Dignitaries and Guests

I'm fully confident that you have enjoyed tonight's celebration of the fiftieth anniversary of ESO. The delightful talks by ESO astronomer Nadine Neumayer, by Nobel Laureate Brian Schmidt and by ESO Director General Tim de Zeeuw have surely promoted a most enjoyable dinner.

I also hope that this night has, in addition, served the purpose of explaining better how ESO works, what are its main achievements and what are the plans for the immediate future of the Organisation. These plans have been put together by delegations from the Member States in ESO's Governing bodies. It is now up to the governments of the Member States to secure these plans, including the E-ELT programme, by applying and extending the principles of cooperation and excellence that have been at the root of ESO's successful 50-year history. I'm fully confident that we, all together, will achieve this.

But before you leave, I have one very important request for all of you, and most especially for the ministers and authorities that represent ESO's Member States: Be proud of ESO!

ESO is your achievement. It is part of your R&D systems, which happens to be in the form of an Intergovernmental Organisation, which has reached far beyond than which would be conceivable for a single country. Spread the word and be the proud ambassadors of ESO. Tell people in your ministries, tell other ministers in your governments, tell your prime ministers, tell your heads of state and tell all the citizens in your countries:

- that ESO builds and operates the most powerful astronomical observatories in the world;
- how ESO enables astronomical research in your country and fosters scientific cooperation with others; and
- explain to them how ESO promotes R&D in institutions and industries in your home country.

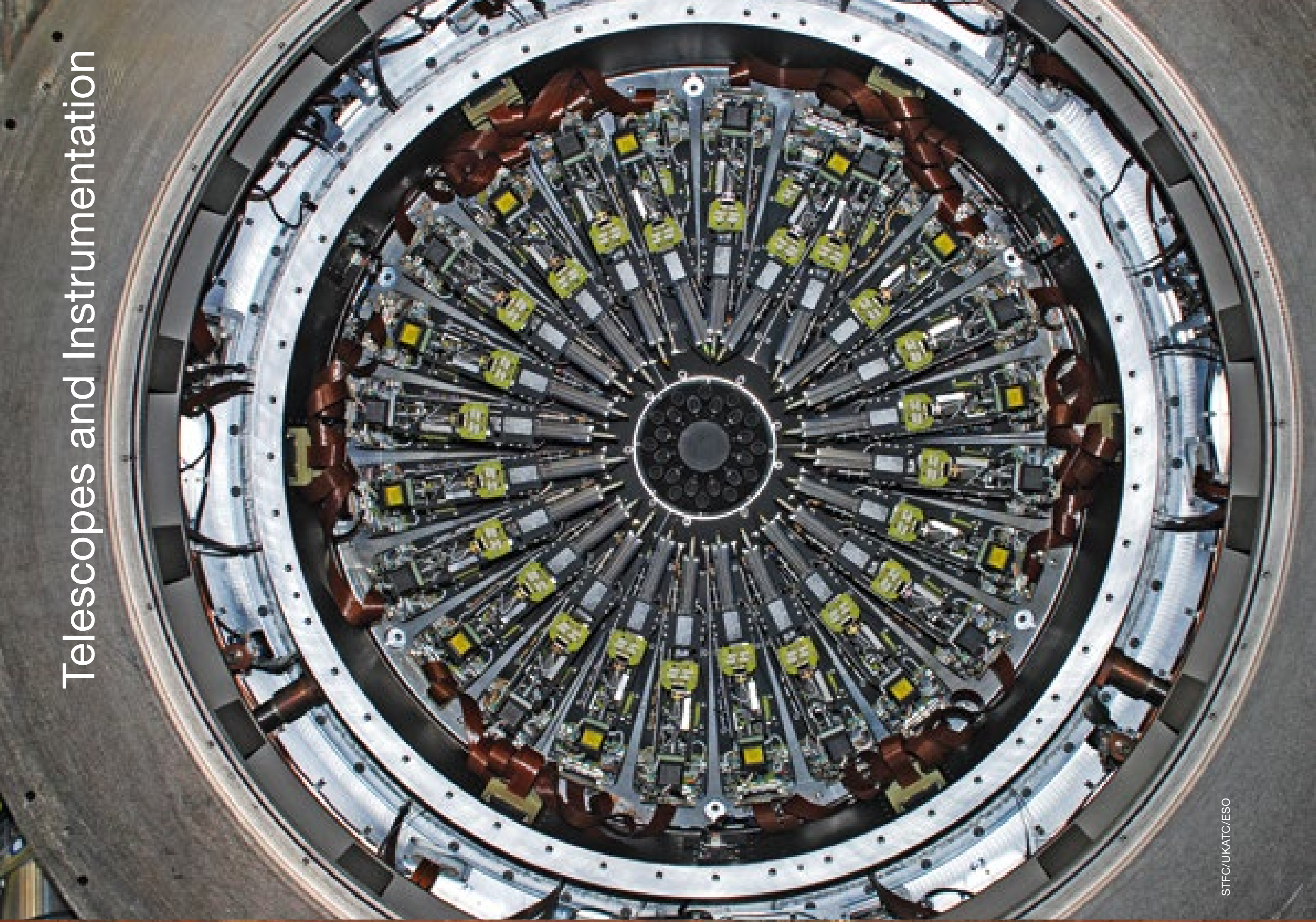
And now, please join me in wishing a most successful next 50 years to ESO. To ESO!

Thank you very much for your continued support, for having been here tonight and for being part of the big ESO family.


M. McCaughrean (ESA)/ESO

Figure 7. The E-ELT prototype mirror segment after signing by the ESO Member State representatives.

Telescopes and Instrumentation



STFC/UKATC/ESO

J. L. Dauvergne & G. Hüdepohl/ESO

Upper: A view inside the dewar of the *K*-band Multi Object Spectrometer (KMOS) showing the 24 robotic arms. KMOS is currently being commissioned at the Very Large Telescope (VLT) Unit Telescope 1. See Sharples et al., 2010, *The Messenger*, 139, 24 and Announcement ann12071 for more details.

Lower: An aerial view of the VLT platform on Cerro Paranal taken in 2010.

Growth of Observing Programmes at ESO

Ferdinando Patat[1]
Gaitee Hussain[1]

[1] ESO

There has been a continuous growth in applications for ESO telescopes from the first calls for proposals in the late 1960s. Typically one thousand applications are now received per semester involving over 3000 astronomers worldwide. A brief history of the evolution of the allocation process is presented and a snapshot of the current procedures is given.

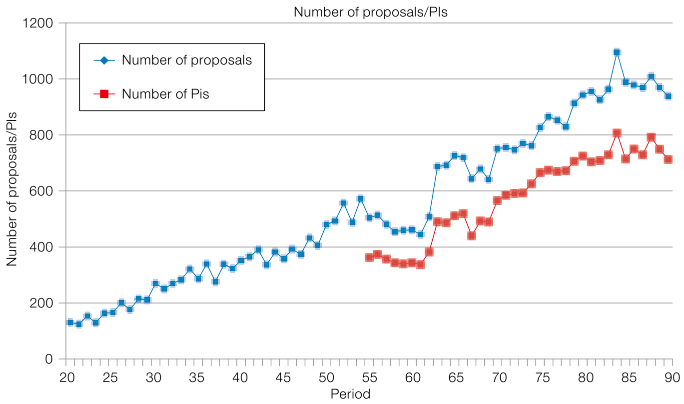


Figure 1. Number of distinct proposals received by ESO from P20 (1977) to P90 (2012). This is also known as the Breysacher plot, after ESO astronomer Jaques Breysacher, who produced the first version of the diagram (Breysacher & Waelkens, 2001). The number of distinct principal investigators is also plotted since P55. The peak observed in P84 coincides with the start of X-shooter operations.

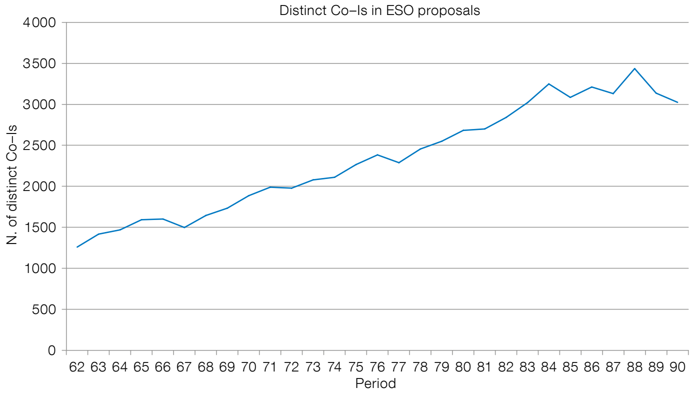


Figure 2. The growth in the number of distinct investigators (Co-Is) in ESO proposals is shown from the start of VLT operations (P62, October 1998) to P90 (October 2012).

Introduction

The history of the European Southern Observatory (ESO) is marked by steady growth, from a few small telescopes at La Silla in the late 1960s, the expansion to 4-metre-class telescopes in the 1970s and 80s, to the opening of the Very Large Telescope (VLT) on Paranal in 1998. Today, on La Silla, ESO operates the MPG/ESO 2.2-metre, the 3.6-metre and 3.58-metre New Technology Telescope (NTT) with five instruments permanently mounted (two each on the 3.6-metre and the NTT). Cerro Paranal is equipped with the four VLT Unit Telescopes (UTs), the 4.1-metre Visible and Infrared Survey Telescope for Astronomy (VISTA), the 2.6-metre VLT Survey Telescope (VST), and the four 1.8-metre auxiliary telescopes of the VLT Interferometer (VLTI). Each of the UTs features three foci (two Nasmyth platforms and one Cassegrain focus), so that up to twelve instruments can be simultaneously offered and easily switched during the night. Currently eleven instruments are offered for normal operations at the VLT and three at the VLTI. ESO is also part an international collaboration involving the Max-Planck-Institut für Radioastronomie (MPIfR) and Onsala Space Observatory (OSO) for the Atacama Pathfinder Experiment (APEX) and 25 % of the observing time is allocated to ESO.

The history of the number of proposals submitted to ESO (per semester [six months], called a Period) over the last 35 years is shown in Figure 1. In the pre-VLT era (i.e., before Period 63 [P63]), the number of proposals kept growing, eventually stabilising at around 500. The start of VLT operations was marked by a rapid increase, bringing the number of proposal submissions above ~ 700, followed by steady growth to today's ~ 950 proposals per semester, submitted by about 700 distinct Principal Investigators (PIs). The total time request averaged over the last four years is about 3170 nights per semester (about 65 % for Paranal only), of which about 1070 nights are scheduled for execution.

The overall observatory pressure (defined here as the ratio between the submitted and the scheduled time) is ~ 3.0. However, at some telescopes (and particularly at some instruments, e.g., FORS2, X-shooter and HARPS), this exceeds 5.0. The increase in the number of investigators on ESO proposals from the start of VLT operations is shown in Figure 2, which presents the evolution of the number of distinct co-investigators (Co-Is). The current number is around 3000 individual users.

The distribution of the number of submitted proposals and requested time by site since the beginning of VLT operations is presented in Figure 3 (left and right respectively). Despite the expected decrease in demand for observing time at La Silla following the reduced number of telescopes offered at this site and the increasing instrumentation contingent at Paranal, it is still in demand. The time request for La Silla averaged over the last three years is about 900 nights/semester, to be compared with the ~ 1450 nights/semester during the first three years of VLT operations. The NTT and the 3.6-metre telescope remain in high demand, and the tendency is to request the time through Large Programmes (LPs; proposals requesting over 100 hours of telescope time that can be distributed up to four consecutive years on La Silla or two consecutive years on Paranal). This is reflected in the time allocation: in P90 at the 3.6-metre telescope ~ 73 % of the time was allotted to LPs, 18 % to Normal Programmes and 9 % to Guaranteed Time Observations. With the deployment

Figure 3. Number of proposals (all types) by site (left) and number of requested nights (right) plotted as a function of time since the beginning of VLT operations.

of the PESSTO public spectroscopic survey (which has an allocation of 90 nights/year), the NTT is moving towards a very similar configuration.

Proposal types

In parallel with the increased availability and demand for observing time, there has been an evolution in the types of observing proposals in order to adequately encompass the wide range of science programmes. In the current implementation, there are six different types of proposals:

1. Normal: Programmes that require less than 100 hours and span one semester.
2. Large: Programmes that require more than 100 hours and can span one or more semesters (up to four for Paranal and up to eight for La Silla). A Large Programme typically has the potential to lead to a major advance or breakthrough in a field and includes a plan for data reduction and analysis by a dedicated team.
3. Target of Opportunity (ToO): Up to 5 % of the available general observing time may be used for ToO proposals. Within this framework it is also possible to apply for the Rapid Response Mode (RRM) implemented at the VLT. This mode allows users to trigger observations with a very fast reaction time (a few minutes).
4. Guaranteed Time Observations (GTO): These arise from contractual obligations of ESO to the consortia who have built ESO instruments. This time is only accessible to the GTO consortia.
5. Calibration: This type of proposal was introduced to allow users to complement the existing calibration of ESO instruments and to fill any gaps that might exist in the calibration plan.
6. Director's Discretionary Time (DDT): Up to 5 % of the available general observing time may be used for DDT proposals in a current period. As opposed to the other proposal types described above, DDTs can be submitted at any time during the semester.

A new programme type, dubbed Monitoring Programmes, is also being implemented. This serves projects requesting small amounts of time (of the order of tens of hours) spanning several periods, and is meant to secure continuity to programmes aiming at time, for instance, coverage of slowly varying targets.

Most of the proposals received are for Normal Programmes. Typically 15 to 20 Large Programme proposals are received each semester. The other proposal categories (ToO and Calibration) only involve a few percent of the total proposal pool.

Observing modes

Since the beginning of VLT operations, time on ESO telescopes can be requested either in Visitor Mode (VM) or in Service Mode (SM). While VM allows the observer to take on-the-fly decisions and to make use of non-standard modes, SM enables the exploitation of the best atmospheric conditions or repeated short visits to the same target during a semester. VM is the classical observing mode, in which the observations are carried out by a visiting astronomer selected by the proposing team. SM observing runs are executed by observatory staff following an established priority order. For each telescope SM runs are grouped into three queues,

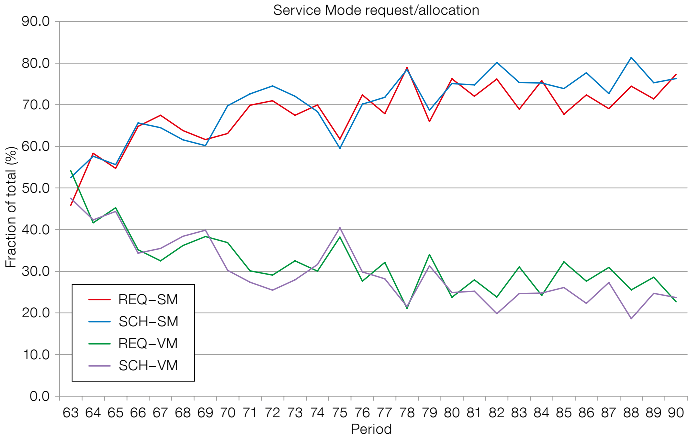


Figure 4. Time evolution of the fraction of VLT requested and scheduled time in SM (upper curves) and VM (lower curves) since the beginning of VLT operations. Statistics refer only to Normal and ToO programmes, excluding Large Programmes and GTO proposals.

which reflect their scientific ranking (see Silva, 2001). The rank classes are defined as follows:

Class A: All possible efforts will be made to execute all observations corresponding to the runs in the requested observing period.
Class B: These runs will be executed in the requested observing period on a best-effort basis.
Class C: Filler runs. Observations will only be executed if the observing conditions do not permit observations for runs within classes A and B.

Although the original plan had foreseen a 50/50 distribution between the two modes, the popularity of SM steadily increased during the first five years of VLT operations. This is very clearly demonstrated by the evolution of the time request for the two modes (see Figure 4). From an almost equal 50 % fraction recorded in the first semester, the share has evolved to the current situation, in which about 75 % of the time is requested in SM. Rather than enforcing the original operations plan, ESO has followed the demand from the community. In the current schema SM is not offered for La Silla telescopes, which are operated in VM only.

Observing Programmes Committee and Proposal Review

Telescope time at ESO is allocated following the recommendations of the Observing Programmes Committee (OPC). It is the function of the OPC to review, evaluate and rank all the proposals submitted in response to the call on scientific merit. From this review process, the committee advises the Director General (DG) on the distribution of observing time, taking into account ESO's scientific policy. The OPC includes 13 panels to cover the four science categories:

A: Cosmology (three panels);
B: Galaxies and galactic nuclei (two panels);
C: Interstellar medium (ISM), star formation and planetary systems (four panels);
D: Stellar evolution (four panels).

The varying number of panels within each category is due to the different numbers of proposals which these categories receive each period. Interestingly, this number has evolved significantly since the beginning of VLT operations, when the proposals were evenly distributed across the four categories. The data covering the last twelve years of operations (see Figure 5) clearly show an increase of the number of proposals in category D (stellar evolution) and especially C (ISM, star formation and planetary systems). The growth in the latter is related to the expansion of the exoplanet field.

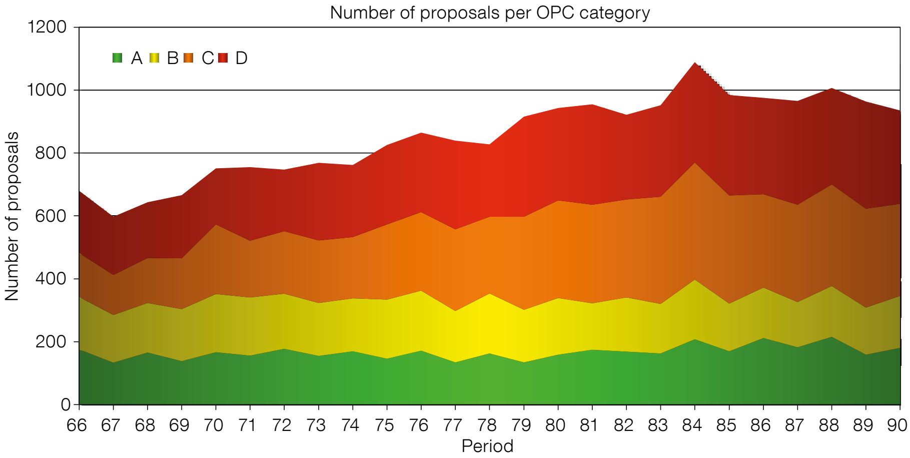


Figure 5. Distribution of submitted proposals by scientific category is shown for the last twelve years (A: Cosmology; B: Galaxies and galactic nuclei; C: ISM, star formation and planetary systems; D: Stellar evolution).

Each panel has six members, including one panel Chair and one co-Chair. Apart from the individual panels, the advisory committee, the OPC, is composed of the 13 panel Chairs, three panel co-Chairs (one in category A, two in B), and the OPC Chair, who is not a panel member. This corresponds to a total of 17 OPC members, and with 72 panel members, a total of 89 scientists.

The OPC and panel members are selected on the basis of their scientific competence. During the selection, some allowance is made for gender balance and for distribution across ESO member states, but these aspects are not rigidly enforced. The candidates are proposed by the OPC Nominating Committee. This board is advisory to the DG and is composed of the Director for Science, the Head of the Observing Programmes Office (OPO), the former OPC Chair and two members of notable accomplishment in astronomy.

OPC members serve for two years (four ESO periods), while panel members serve for one year (two ESO Periods). A fraction of the panel members are invited to serve an extended, second one-year term, to ensure sufficient continuity in the review process. The high turnover ensures that, with time, a significant fraction of the community gains experience in the process from the inside.

ESO facilitates the OPC process, but does not take active part in the scientific evaluation of the proposals. ESO time allocation is carried out by implementing the OPC recommendations while accounting for any technical and scheduling constraints. A full description of the OPC process and an overview of the software scheduling tools used by OPO to facilitate the allocation of OPC prioritised proposals on the telescopes can be found in Patat & Hussain (2012).

Director's Discretionary Time

DDT proposals can be submitted any time. A DDT proposal must necessarily belong to one of the following categories:

- proposals of ToO nature requiring the immediate observation of a sudden and unexpected astronomical event;
- proposals requesting observations on a topical and highly competitive scientific issue;

- proposals seeking follow-up observations of a programme recently conducted from ground-based and/or space facilities, where rapid implementation should provide breakthrough results;
- proposals of a somewhat risky nature, requesting a small amount of observing time to test the feasibility of a programme.

The DDT proposals are reviewed by an ESO internal standing board, the DDT Committee (DDTC), which is chaired by the Head of OPO and includes ESO Faculty astronomers, the Director for Science and the VLT Programme Scientist. The DDTC is advisory to the DG, who takes the final decision based on a recommendation prepared by the Chair. Further details of the allocation process are presented in Patat & Hussain (2012).

Typically 50 to 60 DDT proposals are received per semester (at an average rate of two per week), with requests that range from tens of minutes to a few hours. Since DDT proposals can only be carried out in Service Mode, they are normally considered for Paranal telescopes only. Successful DDT applicants are asked to submit a report within four weeks from the completion of the observations.

Perspectives

As is apparent from this overview, the ESO allocation and scheduling process has evolved to accommodate the varying needs of its community and to ensure the optimal use of observing time on all the telescopes. The present system is not without its weak points and the following article (Brinks et al., p. 21) summarises the findings of the OPC working group that recently reported (Brinks & Leibundgut, 2012). OPO is also studying the implementation of a new proposal submission system, which will feature a more integrated and user-friendly approach. On a longer term and in view of the forthcoming E-ELT era, ESO is also considering a more radical evolution to the next generation system. The operational scenario for the E-ELT is based on a full adoption of the Paranal schema that is operational at that time. This includes time allocation with the E-ELT considered as another telescope of the observatory. With more than a decade before first light for the E-ELT, there is ample time to discuss and debate with the community the most appropriate methodology and philosophy for the time allocation. The process of consultation will start soon after the start of construction.

Acknowledgements

The authors are grateful to Gautier Mathys, former head of the OPO, for his fundamental input on the time allocation procedures and policies.

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ESO/S. Brunier

360 degree view of the sky from Paranal showing the disc of the Milky Way extending across the sky. See Picture of the Week 11 June 2012 for an explanation.

Report of the ESO OPC Working Group

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With over 1000 proposals per semester for ESO telescopes, the community is facing the problem of fair and robust selection of observing programmes. We report here on a working group to investigate the current selection process and procedures and identify possible improvements. The working group report summarises the current process, based on peer review, that has been in use for many years at ESO and other comparable ground- and space-based observatories, and presents an inventory of the changes and approaches that may be considered to make the process more manageable and less time-consuming, while at the same time preserving its integrity. The working group presented several recommendations, which have been discussed with ESO committees and analysed by the operational groups at ESO.

Introduction: Identification of the problem

Over the past two decades, the number of proposals submitted every six months to ESO has been increasing almost linearly, reaching over 1000 proposals for the first time in 2009, followed by a slight decrease over the past three semesters. This large volume of proposals is due to a combination of additional ESO Member States joining, an increase in the number of active astronomers and the many facilities on offer. The increase is correlated with the number of Principal Investigators (PIs). For a description of the current Observing Programmes Committee (OPC) process see the accompanying article by Patat & Hussain (p. 17).

The process employed by ESO to select the best projects and award time on one of its telescopes is a classical peer review system. The ESO Director General (DG) allocates the observing time and customarily follows the scientific recommendations of the OPC and its panels. Very few official complaints, less than half a dozen, are lodged per semester once the outcome is made public, which is a testament to the dedication of the panel and OPC members and to the general acceptance of the process by the community.

The large number of proposals has started to make the review process increasingly onerous, both for astronomers serving on the OPC and its panels, as well as for the Observing Programmes Office (OPO). At the current level of proposals, 13 panels with six members each are needed in order to review the proposals and keep the number of proposals per panel member to a manageable limit. The time spent by panel members refereeing proposals, plus the time involved in the face-to-face meeting, represents a considerable in-kind contribution. The current work load on panel and OPC members is very high and any further increase in the number of proposals will stress the current review process even more.

The situation is exacerbated by the substantial oversubscription rates of three to five (see Patat & Hussain, p. 17). Once applications on a telescope/instrument combination reach a tipping point, many good proposals will not make it to the telescope. As there is nothing fundamentally wrong with those proposals, their Principal Investigator (PI) will likely resubmit them with minor changes, adding to the already substantial oversubscription. The large oversubscription leads to frustrated users, as good proposals are not allocated time. Similarly, serving as a panel member can become an exasperating experience as many good proposals end up being marked as not good enough to be scheduled. Even when proposals are basically fine and nothing much can be mentioned to improve them, users expect to receive feedback.

In a sense, ESO is in danger of becoming the victim of its own success. Although OPO can still manage the number of proposals submitted in each semester, it is causing a workload that is becoming increasingly demanding for OPC panel members. This was the reason for setting up the OPC Working Group (OPC-WG). The members of the working group were Jacqueline Bergeron (IAP, France), Elias Brinks (Chair, University of Hertfordshire, UK), Fernando Comerón (ESO), Simon Garrington (Jodrell Bank Observatory, UK), Bruno Leibundgut (ESO), Gautier Mathys (ESO, now at the Joint ALMA Observatory), Michael R. Merrifield (University of Nottingham, UK), I. Neill Reid (Space Telescope Science Institute, USA) and Letizia Stanghellini (National Optical Astronomy Observatory [NOAO], USA). The OPC-WG was charged to examine the current processes and present recommendations for improvements.

The current OPC process

The ESO process to rank proposals for telescope time is similar in philosophy to that employed at several other ground-based (e.g., NOAO) and space-based (e.g., Hubble Space Telescope [HST] and Spitzer) observatories. There are several proposal categories: Normal, Large, Guaranteed Time (GTO), Calibration and Target of Opportunity (ToO). The category of short proposals has been discontinued (see below). Director's Discretionary Time (DDT) proposals are handled in a separate process and were not discussed by the working group. For definitions of these categories the reader is referred to the ESO web pages[1] or one of the recent ESO Calls for Proposals. The process is divided into Phase 1 (proposal) and Phase 2 (detailed scheduling preparation). Technical feasibility is judged after Phase 1 and before Phase 2.

On average a panel deals with 70–80 proposals, to be reviewed usually within four weeks. Within each panel, all members are required to assign a pre-OPC grade to each of the proposals. Each panel member is first referee on 12–15 proposals which (s)he will need to present in the panel meeting and for which a comment will have to be provided after the meeting.

ESO applies a triage based on the pre-OPC grades, i.e., the lowest 30 % of the ranked proposals on the basis of the pre-OPC grades are eliminated from discussion at the meeting. Panel members can still request to discuss a triaged proposal, if they think it merits it. Figure 1

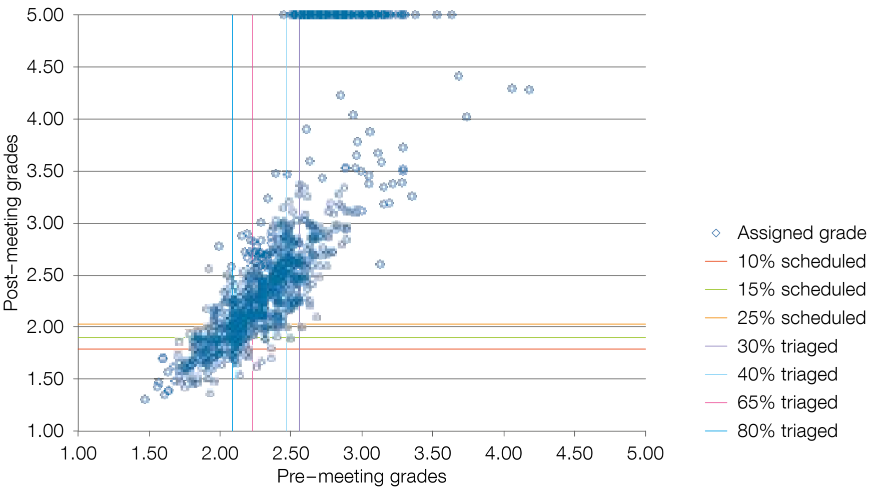

Figure 1. To illustrate the effect that triage has on the selection process, the grades from before and after the panel meetings are shown for the proposals for ESO Period 86. The three horizontal lines show the top 10%, 15% and 25% of the final ranking (lower grades are assigned to better proposals) and are indicative of the oversubscription. The vertical lines illustrate triage at the 30%, 40%, 65% and 80% level. At a 30% triage threshold, it is unlikely that any triaged proposal would have been unfairly excluded from the panel discussion. Proposals with a post-meeting grade of 5.0 were rejected; they include those that were triaged based on their pre-meetings grade, which did not qualify for scheduling.

shows a comparison of the effect of triage for proposals from Period 86 with grades before and after the panel meetings. All other (*viz*. non-triaged) proposals are discussed during the panel meetings. Figure 2 shows plots of the grade and rank of proposals from Period 86, Panel B2 (Galaxies and galactic nuclei: Unresolved and resolved stellar populations) both pre-OPC and after panel discussion, showing generally good agreement, with a significant narrowing of the dispersion following the panel meeting. Scheduling is based on the grades assigned through the panel discussions. The OPC proper mostly focuses on the discussion of LPs and a sub-panel of the OPC deals with the ToO requests based on the grades given by the panels.

Large proposals (LPs) are discussed in joint panels, i.e., within the four broad science categories. A digest of this discussion and recommendation is fed to the OPC, which in turn votes which LPs are accepted. Calibration proposals are few and are only discussed in the OPC. See Patat & Hussain, p. 17 for more details.

Validity of peer review

Peer review has become the gold standard for ranking proposals. It clearly has the trust of the community. In a report on peer review by the Royal Society (1995) it is stated that:

"Peer review is to the running of the scientific enterprise what democracy is to the running of the country. It may not be the most efficient system but it is the least susceptible to corruption. The concept of peer review, in spite of all its difficulties, retains the confidence of most working scientists."

As mentioned, peer review enjoys the trust of the community. Those with experience of peer review, either as member of a time allocation committee or as PI or Co-I of a proposal, will gladly admit that there is a measure of randomness in the process. There is a consensus, largely unsubstantiated (see Figure 2), that the process is repeatable for the top 10–20% of proposals. In other words, the really outstanding proposals are recognised. Similarly, it is argued that there is broad agreement on the bottom quartile. Implicit in this view is that, for all remaining proposals, the outcome is determined more by external circumstances than by intrinsic merit of the proposal.

The WG has found just one paper, by Hodgson (1997, and references therein), that comes closest to a situation where two independent panels ranked the same set of proposals. The author concludes that the results of the two independent panels are correlated, but with a considerable random variation. There was no perceptible decrease in this variation near the top or bottom end of the distribution (see also the example in Figure 2).

Clearly, it is important for this or similar tests of the classical peer review process to be performed in order to quantify its reproducibility. The working group suggested that ESO could use the fact that each scientific category has several panels to test the reproducibility of the rankings by submitting a subset of the proposals to more than one panel. This would be done "blind" for the panel members and would therefore provide ESO with a means to measure to what extent the results are reproducible. The additional workload per referee was considered to be tolerable.

Evolutionary changes

The basic criteria for a better system are fairly straightforward: an ideal system produces a better quality outcome at a lower cost in terms of community investment. Many evolutionary changes were considered: to the way the review panels work, to the frequency at which the review is carried out, and to ways to restrict the number of proposals. In its deliberations, the OPC-WG was guided by the principle that for any proposed change, the process should:

1. be driven by scientific excellence;
2. be fair (as perceived by the community);
3. be robust against conflicts of interest;
4. be robust against abuse/cheating;
5. preserve confidentiality;
6. result in an acceptable/manageable workload for the community;
7. provide useful feedback;
8. be adaptable to changing circumstances;
9. be as manageable for ESO as the current system.

The OPC-WG recommended a rationalisation of the large variety of proposal types. The OPC-WG supports the combination of the application forms for Normal and Short proposals and restricting the length of the scientific justification to one page. This has already been implemented from Period 87 (2010).

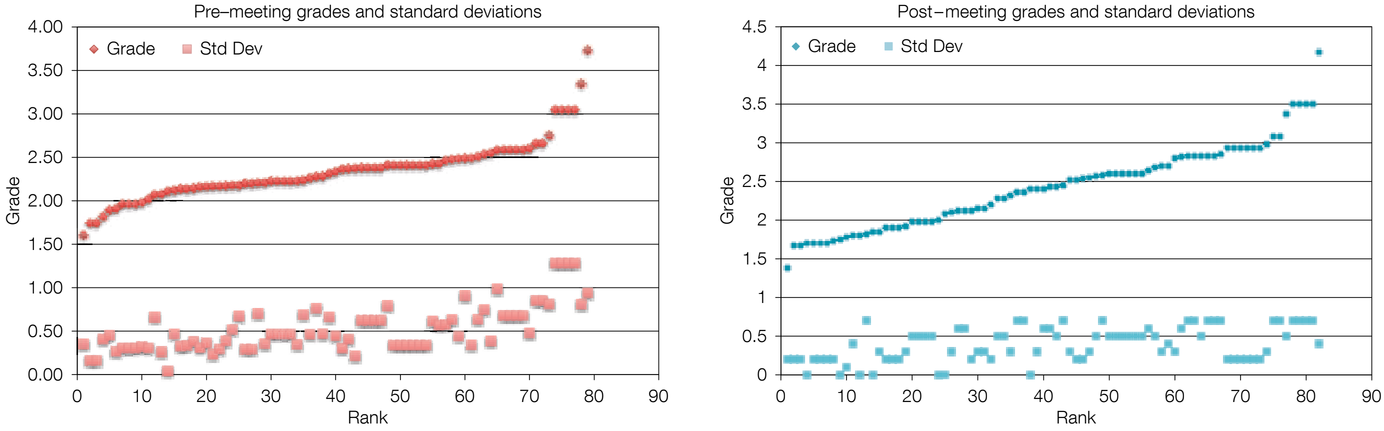

Figure 2. Average grade and standard deviation against run rank is shown based on the preliminary (left) and final (right) grades of the members of Panel B2 in Period 86.

Among the many changes considered, only those where the advantages clearly outweigh the disadvantages are presented here. A first suggestion was to split the selection according to telescope or groups of telescopes. For example, one could imagine a review process exclusively for the VLT Unit Telescopes (UTs) on Paranal (including VLTI), and others for the 4-metre telescopes on La Silla, and a separate one for the Atacama Pathfinder Experiment (APEX). Few projects request the use of telescopes on more than one site and the large majority are for Paranal (see Patat & Hussain, p. 17), and hence there is not much to be gained with such a procedure.

To decrease the load one could increase the panel size. To avoid even larger OPC meetings and contain the costs, one could imagine a system in which only half the panel members were assigned as primary referees and participated in the meeting while the other half provided only written comments and pre-OPC grades. A clear drawback is that this would require more or less doubling the number of referees.

Changing the frequency of OPC meetings was also discussed. A one-year cycle would not result in a doubling of the number of proposals, but rather result in an increase estimated at approximately 30 %, because many proposals are resubmissions (as a result of the substantial oversubscription rate) and quite a few exploit the right ascension overlap regions between semesters. No obvious detrimental impact on the science is expected.

A reduction in the number of submitted proposals could also be achieved through the creation of a new category of monitoring proposals. These are for projects which in any given period lay only a limited claim on telescope resources, but run for many periods, if not years, and therefore guarantee the success of long-term monitoring campaigns. The total time would in general be less than for LPs and the number of semesters might go beyond the LP limit. Because LPs and monitoring proposals are less time critical, they could be discussed in alternating periods. The proposed change would thus be to schedule LPs, monitoring proposals, and proposals for La Silla on a yearly basis, the LPs for example in even-numbered periods, the other two sets in the odd-numbered periods.

The WG also looked into how the number of proposals submitted could be influenced. One way of doing this is to base future allocations on past performance. It should be remembered that there might be a good reason why data are not published (e.g., lack of adequate data, disappointing result, rejection by a journal, etc.). Sometimes at the Phase 2 stage, PIs realise that their original time estimate was wrong (usually too low and frequently due to underestimating the time required for overheads). This then forces them to either reduce the time on target or reduce the number of targets. This could render the original goals of the proposal unattainable and, if the OPC knew this, could result in the proposal being downgraded.

Revolutionary changes

The working group considered fundamental changes to the classical peer review system with potentially major effects for the community or ESO.

One could imagine setting a substantial lower limit on the number of hours or nights per semester for a proposal to be considered. This would force the community to form consortia and, depending on the lower limit set, would result in fewer proposals. There would then be no need for panels, the decision process being limited to the OPC. This would seriously reduce the workload. Also, proposals would likely attack “big questions” and propose coherent work packages. In such a scenario ESO would be outsourcing a large fraction of the decision-making process to the community. The OPC-WG saw many disadvantages to such an approach:

1. Powerful individuals or groups could monopolise certain areas.
2. Instead of the decision on the merit of a proposal being taken in a non-partisan way by referees who have no conflict of interest, decisions are effectively devolved to the consortia. Depending on how a consortium is organised and decisions taken, excellent science might lose out.
3. Small time requests for prime science will not be eligible unless repackaged as part of a larger application by a consortium.

4. Unique and singular objects (e.g., Galactic Centre, SN 1987A, etc.) will be at a disadvantage.

Several observatories have opted for this mode of operation, usually for a substantial fraction of available observing time. Examples are e-MERLIN Legacy projects, Herschel Open Time Key projects, James Clerk Maxwell Telescope (JCMT) Legacy proposals, Hubble Space Telescope (HST) Legacy and Treasury proposals, Spitzer Legacy proposals and proposals for future instruments like ASKAP and MeerKAT, at least for the initial years of their operation. To some extent ESO has followed a similar route by implementing public surveys on the survey telescopes VISTA and the VST, and more recently also at the New Technology Telecope (NTT; PESSTO) and with the Gaia–ESO survey with UVES and FLAMES on UT2. ESO might consider extending such surveys with La Silla and Paranal telescopes when the European Extremely Large Telescope (E-ELT) is built. It was not clear to the OPC-WG how much is gained by having a mix of these mega-requests and normal proposals.

A radical departure from classical peer review is the method of distributed peer review as described by Merrifield & Saari (2009). For reasons inherent to that method, it is not possible to extract what result distributed peer review would have produced, or how well it compares with classical peer review, by analysing the outcome of the latter. In order to do a proper assessment, a full trial would need to be designed.

OPC Working Group conclusions

The conclusions of the OPC-WG are as follows:

- There are small changes that can be applied to the current system that would reduce the workload without affecting in any major way the widely accepted peer review method. These are:
  - Implement a new category of monitoring proposals; these proposals can be long-term, but ask for modest amounts of time per semester. Open up the Call for this type of proposal once a year, e.g., during odd-numbered Periods;
  - Review La Silla proposals only once a year, also in odd-numbered Periods;
  - Limit the Call for Proposals for Large Proposals to once per year as well, for even-numbered Periods.
- A more substantial change would be to change the frequency of the Call for Proposals to once per year. Although the number of proposals will likely increase, it will not double. The reduction in agility could, in cases where this is justified, be made up for by DDT.
- Most other considered changes, either in the way panels deal with the proposals, or by attempting to limit the number of proposals, carry disadvantages that outweigh their advantages.
- Peer review is broadly supported by the community. There is a preconception that top proposals will be recognised with little dispersion in their grades or ranking. Likewise with poor proposals. In other words, peer review is thought to deliver reproducible results. It is accepted that the grades or ranking of all remaining proposals is less clear cut and that some considerable dispersion might be expected. The OPC-WG tried to confirm this picture but came to recognise that precious little in terms of data exists that underpins the validity of this model of peer review. If anything, the few tests available to the WG showed that a large dispersion exists even for proposals in the top and bottom quartiles.
- The WG recommends that the reproducibility of peer review is further investigated. One method that was suggested would be that some 10 % of the proposals in any Category (A, B, C and D), be seen by more than one panel. For those proposals that are seen by two panels, it is decided in advance which grade will be taken for the final ranking. This would be done “blind” for the panel members and would therefore provide ESO with a means to measure to what extent the results are reproducible.
- The WG is concerned about the fact that there are substantial differences between the Phase 1 and Phase 2 time requests. Although the amount of time on the telescope in the end is broadly compatible with that of the Phase 1 request, this implies that either fewer targets are observed, or that less time is spent per target. Either of these outcomes could cause a panel to give a highly ranked proposal a lower grade, which would mean that it should not have been scheduled in the first place. The WG recommends that if the time requests differ by more than what can be considered reasonable (to be judged alongside the technical feasibility), the proposal should not be scheduled.
- Discussion on how the E-ELT can be implemented in the ESO proposal selection process was limited. The E-ELT will likely match or exceed the oversubscription rate of the most popular VLT UT. E-ELT proposals could simply be accommodated within the existing process provided that the science policies for the E-ELT and other ESO facilities remain aligned. Alternatively the E-ELT could be made available to consortia only, setting a lower limit to the number of nights that can be bid for and letting the community organise themselves into larger collaborations. In the opinion of the WG not all telescope time should be allocated in that way as there is a risk that the field becomes dominated by a small number of PIs, blocking access to individuals or small groups who, for whatever reason, lack access to these larger consortia. Also, small projects, in terms of telescope time, with a potentially high impact would never be scheduled on their own merit but would have to be incorporated within a larger time request.
- The OPC-WG ran a test with the distributed review method proposed by Merrifield and Saari. The test was useful in pointing out several issues that the user community would probably raise if it were to be introduced. Most obviously, the user community would need to be thoroughly educated about this method. Also, sufficient trust would need to be built up before this, or any other revolutionary approach, will be accepted. The OPC-WG encourages ESO to perform a larger scale experiment, more closely linked to the observing proposal process, to explore distributed peer review as an alternative method.

Given the current paucity of data on the effectiveness of peer review, the changing landscape, and the unpredictable effects of alterations to such a complex process, it is important to recognise that this report cannot represent a final conclusion on the right way forward.

Follow-up

The report by the working group was presented to the OPC, the Scientific Technical Committee (STC) and the Users Committee (UC). There was general support for the introduction of monitoring programmes and ESO has started developing this type of observing programme to begin in Period 92. The OPC discussed whether ESO should move to a one-year cycle for LPs and proposals for La Silla. There was a small majority for a one-year cycle for La Silla proposals, but clear discomfort about evaluating LPs only once per year. The UC also recommended ESO to stay with the half-yearly cadence for proposal submissions of all telescopes and types. ESO will hence not change the frequency of calls for observing proposals.

The ESO operations groups evaluated the impact of a move to a one-year cycle for all proposals in the current operation setup. They concluded that within the current support scheme a significant increase in effort would be needed. The work load would very strongly peak around the scheduling and Phase 2 as more proposals would have to be processed within the same time span to provide a full schedule at the beginning of the period. The impact for the execution of the observations is not as significant, but the cycle between proposal submission and data delivery could increase to more than one year, which was considered by the OPC-WG and the OPC itself as a possible disadvantage. Offsetting these delays for scientific programmes by an increased Director's Discretionary Time allocation was not considered sufficient. For the time being no change regarding the ESO periods is planned.

The OPC was strongly opposed to adding to the work load by increasing the evaluation of proposals. In particular, it did not like the idea of a parallel evaluation of some proposals to establish the validity of the peer review process. The position by ESO that the proposal selection process should not be used for a "social experiment" to investigate the effectiveness of peer review was supported by the OPC as well. The ESO database should allow an investigation into this question *post facto* and ESO should analyse the available data. The evaluation of the LPs is done in all subpanels in parallel and this could be used as a (limited) dataset for such an investigation. The OPC requested that no panel member should be asked to referee more than 70 proposals in a given selection round.

The OPC-WG was already very sceptical about forcing the community into large collaborations to reduce the number of submitted proposals. The ESO committees (OPC, STC and UC) concurred with this assessment and this will not be regarded beyond the current scheme of Public Surveys. ESO has implemented these surveys to make optimal use of the two survey telescopes and also to allow the community to establish a leading position in a specific subfield. The recent workshop on surveys (see the report by Rejkuba & Arnaboldi, p. 67) has demonstrated the success of this approach. Such surveys are followed by a special review panel to guarantee that the large investment of observing time results in a corresponding return to the community. ESO and its community will need to assess in a few years the balance between regular proposals, requesting a few nights, compared to surveys, with hundreds of nights. The OPC-WG will have a role in this assessment as well.

Changes between Phase 1 and Phase 2 for a given proposal will be handled more strictly in the future. The procedures are available and will be enforced. There is a clear imbalance between the numbers of proposals in the different scientific subcategories. A measure to better distribute the load between the different panels is to redefine the subcategories, with the goal of reaching a more even distribution across the OPC panels. This investigation has started and will be presented to the ESO committees in due course. In the mean time, the number of proposals has been decreasing over the past few periods to currently about 900 proposals per semester. This has the positive effect that the load on the OPC and its panels has decreased (by about 10 %).

The OPC-WG suggested that it would be beneficial to re-visit the proposal selection process regularly, perhaps every few years. The composition of the OPC-WG was originally chosen to combine the expertise residing within several international observatories with high proposal pressures. The exchanges within the OPC-WG were very informative and allowed the members to have a fresh look at the processes involved in selecting the best science for a given facility. ALMA has just finished the proposal selection for Cycle 1 and already is dealing with more than 1000 proposals per cycle. Other observatories are faced with this problem as well and all working group members were interested in returning to these questions in a few years.

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Links

[1] ESO telescope time allocation: http://www.eso.org/sci/observing/teles-alloc.html

Holographic Imaging: A Versatile Tool for High Angular Resolution Imaging

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Speckle holography can be used to reconstruct high angular resolution images from long series of short exposures if the point spread function (PSF) from each frame can be measured reliably. We show that through use of multiple reference stars and iterative PSF subtraction, we can obtain highly accurate PSFs. The technique is optimised for crowded fields and results in images with excellent cosmetics and high Strehl ratio from the optical to the mid-infrared regimes. With examples from NACO, VISIR, and HAWK-I we show that holography opens up novel and unforeseen possibilities and can be an attractive alternative to adaptive optics.

In the past decade adaptive optics (AO) assisted observations have become the standard for obtaining images near the diffraction limit of large ground-based telescopes. At the ESO Very Large Telescope (VLT), the AO-assisted near-infrared (NIR) camera NAOS/CONICA (NACO) has been in operation since 2002 with spectacular success (see e.g., Lenzen et al., 2003; Rousset et al., 2003; Girard et al., 2010). Its AO capability can improve the angular resolution in the NIR (*viz.* 1–5 μm), which is typically limited by atmospheric turbulence, from the seeing, in the range 0.3–2.0 arcseconds, to 0.03–0.15 arcseconds depending on the wavelength.

Despite its immense advantages, AO is not a universal solution to the problem of diffraction-limited imaging through the Earth's atmosphere. AO systems need either a bright natural guide star, which seriously limits sky coverage, or a laser guide star (LGS), which entails some additional image degradation because of the cone effect (i.e. the finite distance of the LGS reference from the source) and tip-tilt anisoplanatism (elongation of the PSF when the faint tip-tilt star is off-axis). The field of view (FoV) with AO is also limited: the change of the incoming wavefront as a function of the line of sight leads to a rapid deterioration in the image quality at distances from the guide star larger than the isoplanatic angle (nominally around 15 arcseconds at 2.2 μm, the *K*-band). These anisoplanatic effects can be partially compensated for by the use of multi-conjugated AO (MCAO) systems and the use of multiple (laser) guide stars, but at great cost in instrumental as well as operational complexity. In addition to, and independent of, these effects, various technical limitations make it difficult to calibrate the AO PSF (Sivaramakrishnan et al., 2003; Lacour et al., 2011). Here, we show that holography can in many situations offer an attractive alternative to AO. It leads to high quality images, works with very faint (infrared) reference stars, and can compensate anisoplanatic effects in crowded fields. Details on the experiments described here, as well as more analysis and discussion can be found in Schödel et al. (2012).

Speckle imaging

Before the maturity of AO, speckle imaging was widely used to obtain diffraction-limited images. It played, for example, a key role in determining the proper motions and orbits of stars near the massive black hole at the centre of the Milky Way, Sagittarius A* (e.g., Eckart & Genzel, 1996). Speckle imaging is based on recording series of hundreds or thousands of images with exposure times around 0.1 seconds. In these frames stars appear as interference patterns or speckle clouds (see Figure 1, left). Image reconstruction is performed *a posteriori*, for example with the simple shift-and-add (SSA) algorithm: a different shift is applied to each frame so that the brightest speckle of the reference star always comes to lie at the reference pixel. Finally, the shifted frames are averaged. The PSF of the reconstructed image (Figure 1, middle) appears like a diffraction-limited core superposed on a broad seeing halo.

SSA was widely used because it is easy to implement, fast and robust. However, the achieved Strehl ratio is typically only around 10 % in the *K*-band with an 8-metre telescope. The Strehl (ratio) is a measure of the image quality and is defined as the ratio between the peak pixel in the normalised PSF and its theoretical maximum value. It is 100 % for a perfect image and ~ 1% for a seeing-limited image. Since turbulence is a statistical process, higher Strehl ratios can be reached by selecting only the frames with the most compact, high signal-to-noise PSFs. In recent years, this technique, termed lucky imaging, has become popular at optical wavelengths, where AO is still challenging. Lucky imaging suffers, however, from large overheads because typically a large fraction of the data (frequently > 90 %) must be discarded in the process. Since the number of speckles increases approximately with the square of the telescope aperture, lucky imaging becomes extremely inefficient for telescopes with apertures of more than a few metres.

Holography

A more complex, but more efficient, algorithm than SSA is speckle holography, which makes use of the information and flux content of the entire speckle cloud of each frame, not just of the brightest speckle. This results in higher Strehl ratios and sensitivity. Efficiency is boosted because frame selection becomes (largely) unnecessary. Holography allows one to reconstruct the best estimate (in the least squares sense) of the astronomical object's Fourier transform: $O = \langle I_m P^*_m \rangle / \langle |P_m|^2 \rangle$ where O, I_m and P_m are the Fourier transforms of the astronomical object, of the m-th frame of the observed image and its instantaneous PSF, respectively (Primot et al., 1990). The brackets denote the mean over the total number of frames and the asterisk the complex conjugate. The final reconstructed image is obtained after multiplication of O with the telescope transfer function (TTF), followed by an inverse Fourier transform. The TTF is usually an Airy function. The main difficulty in the application of holography lies in obtaining reliable estimates of the P_m. In the ideal case, the field contains a single, bright, isolated reference star, whose speckle cloud can be used to estimate the P_m, similar to the role of the guide star in AO. This situation is, however, very rare and can be dealt with efficiently by AO.

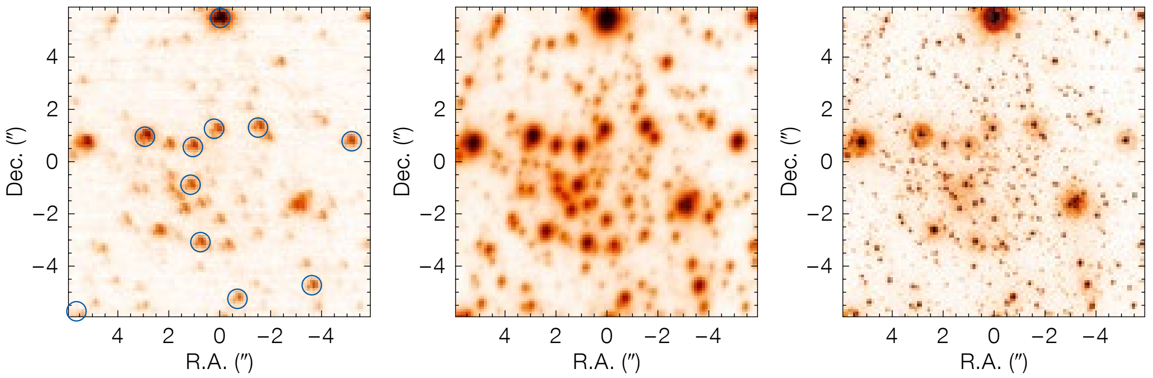

Figure 1. Speckle imaging of the Galactic Centre with NACO. Left: Individual short exposure. Middle: Simple shift and add (SSA) reconstruction. Right: Holographic reconstruction. The 11 reference stars have 7 ≤ *Ks* ≤ 10 mag and are marked by circles in the left panel.

Therefore holography has rarely been used in practice.

Here we present a novel, game-changing approach that allows us to use holography even with faint guide stars in extremely crowded fields. It is based on: (a) iterative improvement of the PSF; and (b) the (optional) use of multiple reference stars. Relative fluxes and positions of stars in the observed field can initially be obtained from an SSA image (or from a previous holographic reconstruction). Subsequently, preliminary PSF estimates can be obtained for each frame from the median superposition of multiple reference stars, whose relative positions are now known with sub-pixel precision. Then, the preliminary PSFs can be used to subtract all secondary sources near the reference stars that were detected in the SSA image. Finally, high accuracy values of P_m are obtained from a median superposition of the reference sources from the cleaned frames.

We use speckle data of the Galactic Centre (GC) obtained with NACO's cube mode on 7 August 2011 to demonstrate the effectiveness of this algorithm (*Ks*-band, S27 camera, 12 500 frames, Detector Integration Time [DIT] = 0.15 s, DIMM seeing ~ 0.5 arcseconds, coherence time τ_0 = 2–3 ms). Figure 1 shows a speckle frame as well as an SSA and a holographic image reconstruction. While the Strehl of the SSA image is only ~ 9 %, the holographic image has a Strehl of ~ 82 % and also excellent PSF cosmetics.

High quality images

A comparison between AO and holographic imaging of a small region around Sagittarius A* is shown in Figure 2. Ideally, the comparison has to be done between contemporary data taken under similar conditions. In the absence of such data, we try to stay on the conservative side and use one of the highest quality NACO GC datasets ever taken (31 March 2009, DIMM seeing ≤ 0.5 arcseconds, $\tau_0 \approx 47$ ms). The comparison underlines the extraordinary image quality obtained with the holography technique. In addition, also in Figure 2, we show a holographic image reconstruction that has been obtained by using only the faintest stars (*Ks* ~ 13) as reference stars. Those stars are barely visible in the individual frames. Nevertheless, a high Strehl (~ 45%) could be obtained by using a large number of them (24 in this case).

Sensitivity is, however, one aspect where AO clearly wins out over holography, where it is fundamentally limited by the readout noise of the detector electronics. The point source detection limit is about 1.5 magnitudes deeper in the AO image (*Ks* ~ 20.5) than in the holography image (*Ks* ~ 19). This cannot be seen in Figure 2 because the region shown is completely dominated by crowding. However, due to the high PSF quality, holography can deliver smaller astrometric and photometric uncertainties on bright sources than AO.

Although holography is closely related to deconvolution techniques like Wiener filtering or Lucy–Richardson deconvolution, it does not suffer the typical problems of those methods, like ringing, photometric biases, difficulties in dealing with extended emission, or creation of spurious sources. Holography is an entirely linear process, leads to well-behaved noise properties in the reconstructed images, and provides reliable photometry.

A highly flexible technique

As we have shown above, holographic imaging works with rather faint reference stars. Moreover, an arbitrary number of

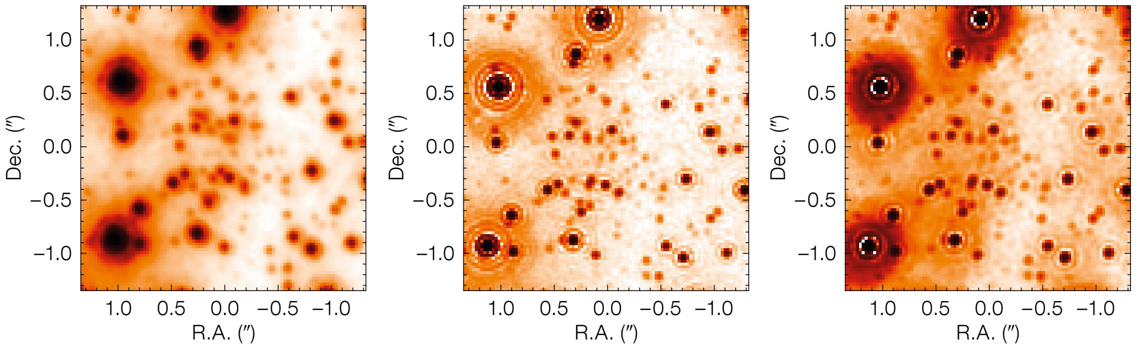

Figure 2. Comparison of speckle holography and AO. Left: AO image of the immediate environment of Sagittarius A*. Middle: Image reconstructed from speckle data via the holography technique, using ten reference stars of 7 ≤ *Ks* ≤ 11. Right: Holographic reconstruction using 24 *Ks* ~ 13 reference stars.

them can be combined, a possibility that lies beyond the capabilities of current AO systems. Therefore, holography can free us from many constraints imposed by classical, single conjugate AO. Holography is thus naturally suited to imaging highly embedded fields, for example in the Galactic Bulge or near the Galactic Centre, that have so far never been possible to observe at high angular resolution from the ground because of the absence of suitable natural guide stars or tip-tilt reference stars for (LGS) AO.

Anisoplanatic effects are among the most adverse problems encountered in AO imaging. In holography, we can deal with these effects if the density of reference stars is sufficiently high. The latter constraint is probably fulfilled for most fields in the Galactic Plane, taking into account that stars of *K* = 12–13 mag can serve as a reference. The image can then be sliced into overlapping subfields that are corrected separately and subsequently stitched together again. Thus, holography can work like an efficient “poor man’s MCAO”.

For different wavelength regimes, we tested the performance of holography successfully in the *J*-band (with NACO on the core of NGC 3603, see Figure 3) and *I*-band (FastCam at the Nordic Optical Telescope on the core of the globular cluster M15), achieving Strehl ratios of ~ 40 % and ~ 18 %, respectively. We have also successfully tested holography with NACO in the L′-band, with excellent results.

The short integration times necessary for speckle imaging can make it necessary to window NACO’s detector to 512 × 514 pixels. Longer DITs are desirable in order to use the full detector array. This was tested using DITs of 0.4 seconds (≫ 10 times longer than the atmospheric coherence time). The diffraction limit was reached, albeit at low Strehl (~ 10 %).

Holography with VISIR and HAWK-I

The primary aim of our experiment with the VLT’s wide-field NIR imager HAWK-I was to test whether holography can also serve to improve the image quality of cameras that undersample the diffraction limit, but significantly oversample atmospheric seeing. A very brief series of 128 frames was taken in *Ks*–band during twilight on the core of the globular cluster M30 (in *Ks*-band, DIMM seeing ~ 0.9 arcseconds). Figure 4 compares a standard long exposure (simple average of all frames) with a holographically reconstructed image. As can be easily appreciated, the holographic image is of superb quality (a Gaussian of 0.27 arcseconds full width at half maximum [FWHM] was used as TTF). Although the total integration time was only 28 seconds, stars as faint as *Ks* ~ 20 are detected at 5σ. The high sensitivity is due to the fact that more photons are collected in each pixel than when the diffraction limit is sampled. This means that in one hour of integration time, stars of *Ks* ~ 22 should become accessible to the holography technique with HAWK-I.

Although, for technical reasons, we only show a small field in Figure 4, we note that the FoV of HAWK-I with the exposure time used (DIT = 0.2 secsonds) is 2048 × 512 pixels, or roughly 3.25 arcminutes squared. We believe that even longer integration times and thus larger FoVs, up to 2048 × 1024 pixels (~ 6.5 arcminutes squared) are feasible. We note that stars as faint as *K* ~ 16 can be identified on the speckle frames. Since the density of such stars is relatively high over the entire sky this means that it is a realistic hope to be able to correct HAWK-I’s large FoV with the holography technique.

On account of the necessarily short exposure times, the mid-infrared (MIR) is a natural regime for speckle techniques. This was recognised at ESO many years ago with the implementation of VISIR’s burst mode. This allows VISIR observers to significantly improve the image quality compared to a standard long exposure (Doucet et al., 2006). We tested holography with VISIR on data obtained in May 2007 when the seeing was as bad as 2–3 arcseconds. A fully diffraction-limited, high Strehl image could be reconstructed. A comparison between a tip-tilt corrected long exposure and the holography image is shown in Figure 5.

This experiment demonstrates that holography can enable astronomers to obtain MIR images of the highest quality even under the most adverse seeing conditions. Additionally, it shows that extended sources can be used as a PSF reference as long as they contain a point-like object. The bright star IRS 3, which sits atop extended, diffuse emission, served as reference source (see Figure 5). When extracting the PSFs from the speckle frames, the diffuse emission was suppressed by flux thresholding. Thus, the holography technique may be very useful for the study of objects such as active galactic nuclei or details of the interstellar medium in star-forming regions. Unfortunately, with VISIR’s current detector the reference source (or sources) must be relatively bright, at least 1 Jy (strongly dependent on seeing conditions), but we hope that significantly fainter point sources can be used with the new and more sensitive AQUARIUS detector currently being installed.

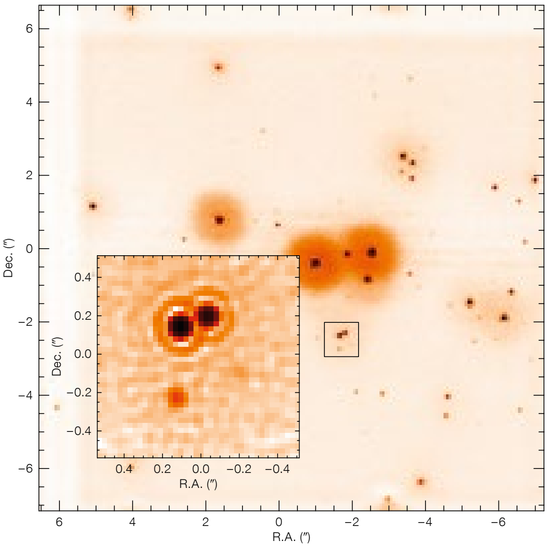

Figure 3. Holographic image of the core of NGC 3603 with NACO in the *J*-band (about 5000 frames, DIT = 0.11 seconds). The inset shows a zoom onto the region marked by the black box: the two closely spaced stars have *J* = 12.0 and 12.6 mag and a separation of 0.078 arcseconds.

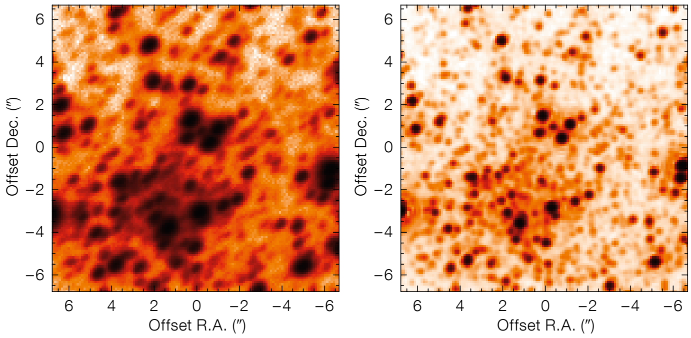

Figure 4. Holographic imaging of the core of the globular cluster M30 with HAWK-I. Left: Standard long exposure. Right: Holographic reconstruction.

When to use holography

Requirements for the use of holography on the instrumental side are a sufficiently fine spatial sampling of the detector plane and the capability of rapid readout and data storage. On the target side, one or several reference stars bright enough to be detected in individual frames are necessary. Crowded fields are ideal. Holographic imaging can be used with the ESO VLT facility instruments VISIR, NACO and HAWK-I, and with the guest instrument AstraLux Sur.

Holography cannot replace AO. Particularly when the targets are faint (most extragalactic observations) or when specialised techniques like spectroscopy or coronagraphy are used, there is no alternative to AO. Also, holography is not a good choice when the target and reference star coincide, as in the search for faint companions or discs around isolated bright stars. In the latter case, extreme AO and techniques like sparse aperture masking (Lacour et al., 2011) or apodising phase plates (Kenworthy et al., 2010) should be used. However there exist a broad range of situations in which holography can provide unique advantages over (single-conjugated) AO:
– necessity for a homogeneous PSF and good PSF cosmetic quality over the FoV;
– demand for a large FoV;
– need for high dynamic range in a field that contains bright stars that would saturate with AO;
– observations of fields devoid of AO guide stars and of suitable tip-tilt reference stars for LGS AO;
– backup when the AO fails to close the loop on a target;
– high angular resolution imaging with an instrument that is not equipped with AO;
– minimisation of systematic errors in photometry and astrometry of bright stars;
– unstable AO correction with highly variable PSF.

In the latter case, holography can also be applied to AO imaging data when the correction is unstable. By combining the advantages of both techniques, holography can enable fainter targets to be reached and considerably boost the performance of AO at short wavelengths, with faint guide stars, or when conditions are adverse. Note, however, that use of AO will freeze anisoplanatic effects into the imaging data.

Holography thus offers a broad range of novel observing possibilities for instruments at ESO's (and other observatories') telescopes. Our work shows how important it is to implement and optimise fast readout modes on imaging instruments. ESO's next generation high angular resolution imager, ERIS, which has just successfully passed its Phase A study, should provide full support for fast readout while maintaining good detector cosmetics. In addition, the novel "zero-noise" infrared and optical detectors under development are very attractive for speckle techniques because they will boost sensitivity both for guide stars and in the reconstructed image, by the order of 2–3 magnitudes (Finger et al., 2010).

A dedicated speckle camera can be very low cost, weight, and complexity, while providing a large field of view. Holography is thus an attractive possibility to equip any telescope with MCAO-like capabilities within a short time. The low weight of a speckle camera minimises flexure, and the lack of complicated optics may make it a well-suited instrument for astrometry (and also polarimetry).

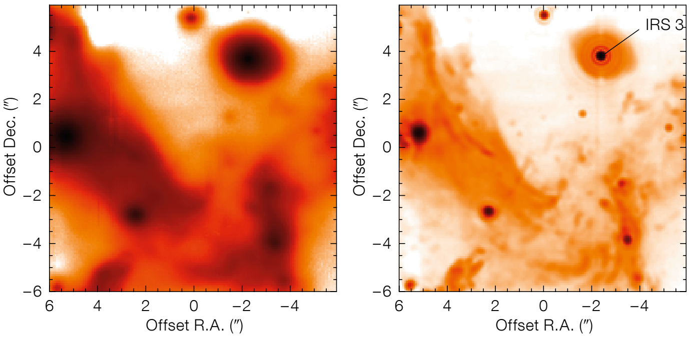

Figure 5. VISIR 8.6 μm observations of the Galactic Centre, taken in May 2007. Left: Tip-tilt corrected long exposure, PSF FWHM ~ 1 arcsecond. Right: Holographic reconstruction with a PSF FWHM ~ 0.25 arcseconds. The brightest source in this image, IRS 3, was used as reference source for the image reconstruction. The vertical line running through IRS 3 is a detector or electronics artefact. Sagittarius A* is located at the origin.

Finally, we note that holography opens up the possibility for optical imaging near the diffraction limit of telescopes of 8 metres and larger class, where lucky imaging is too inefficient. Sensitivity can be adjusted by an optimised trade-off with spatial resolution, to enable the technique to work with relatively faint reference stars. Holography may also be our best chance to quickly realise sub-0.1 arcsecond resolution optical imaging with the future European Extremely Large Telescope (E-ELT).

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The ESO 3D Visualisation Tool

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The ESO 3D visualisation tool provides the capability for visualisation and basic scientific exploitation of 3D spectroscopic datasets obtained with VLT integral field unit instrumentation, including MUSE. The tool was implemented as part of the ALMA CASA software viewer and as such provides the opportunity to view ALMA data as well as VLT 3D data within the same tool. Recently, the first version of the visualisation tool, featuring optical and near-infrared spectroscopic capabilities, has been completed and we describe the released software which is available for Mac OS X and Linux systems.

Introduction

The majority of present and future ESO facilities — the Very Large Telescope (VLT), the Atacama Large Millimeter/submillimeter Array (ALMA), and of course the European Extremely Large Telescope (E-ELT) — feature (presently or in their plans) instruments which produce datacubes (i.e., data with two spatial axes plus one wavelength/frequency axis). In this context, the need for an ESO-based visualisation tool capable of handling datacubes was raised and discussed. A project was set up to deliver a 3D visualisation tool to be used by the ESO community for the visualisation and basic scientific exploitation of (large) 3D datasets.

The development of the tool was focused on the requirements for the Multi Unit Spectroscopic Explorer (MUSE), a VLT second generation instrument (see Bacon et al., 2006, 2012), but it includes the capability of visualising data from other, single-field integral field units (IFUs) operated at the VLT. In many respects, MUSE datacubes provide a challenge to the viewer, not least because of their sheer size (2.9 Gigabytes ~ 300 × 300 × 3600 pixels) both for science and error data.

Given the limited manpower and timeframe available to the project, it was decided that extending the capabilities of one of the already existing visualisation software platforms was the most practical solution. Several possibilities were explored and the viewer of the ALMA CASA software package was selected. The major motivations for this choice were the potential for developing synergies between ALMA and VLT and the long-term maintenance aspects.

The resulting ESO 3D visualisation tool aims at providing the typical astronomer in the ESO community and also ESO operations staff with the means for visualising and performing *basic* scientific analysis of fully calibrated and reduced VLT datacubes of single fields. The tool allows the novice IFU user to obtain a first evaluation of his/her data, as well as the more experienced IFU user to assess data quality in more detail.

Input data

With the exception of the second generation VLT instrument SPHERE (Beuzit et al., 2006; Kasper et al., 2012), all currently operational and almost completed VLT 3D instruments record spatial and wavelength information in a way that can be conveniently re-sampled into a linear 3D grid (i.e., a datacube with uniform *dx*, *dy* and *dz*). As such, the viewer requires cubes to be linearly sampled in all three axes and the data to be properly described according to the FITS standard (Calabretta & Greisen, 2002; Greisen et al., 2006). The main difference with SPHERE is that it records spatial information via hexagonal lenslets projected onto the sky and maintains the wavelength as recorded on the detector (to avoid resampling). The SPHERE data reduction pipeline, however, will also produce a linearly re-sampled cube for visualisation.

Starting with the second generation VLT instruments, error arrays are commonly provided by the data reduction pipelines. Owing to the lack of a pre-existing FITS standard describing the format of error extensions, ESO has defined a new, internal FITS format (ESO, 2012). This format describes how science data, errors and data quality information should be stored in separate extensions of the same FITS file, and how the relationship between them is handled via FITS header keywords. The ESO 3D visualisation tool not only has the capability of displaying the errors, but also the facilities to use them in internal calculations or analysis procedures. This functionality sets the tool apart from similar software available elsewhere. The existence of error and quality information is desirable but not mandatory; the viewer can therefore also be used with 3D data without error information.

As part of the ESO 3D visualisation tool project, all ESO data reduction pipelines for instruments with 3D capabilities were upgraded to produce output files compliant with this new format.

The viewer display panel

The prime purpose of any 3D viewer is to visualise a datacube in a convenient and user controlled, interactive manner. The CASA viewer application consists of a number of graphical user interface (GUI) windows that respond to mouse and keyboard input. In the standard configuration, the viewer display panel (see Figure 1) shows one slice (or channel) of a given datacube in the main image viewer (Figure 1, (a)) and allows the user to move through the slices with the animator panel (Figure 1, (b)). Crucial information on the mouse position in world coordinates as well as pixel-based systems is provided in the position tracker panel (Figure 1, (c)).

In the main image viewer one can define regions (point, rectangle, ellipse or polygon) from which the mean, median or summed spectrum is displayed in the spectral profiler window (see Figure 2). Information on the selected region is given in the regions panel (Figure 1, (d)). The viewer display panel is highly configurable, giving access to all important display options such as colour tables, data display ranges and scalings, and the axis labels. It also allows the user to select any two of the three axes of the datacube to be displayed (e.g., right ascension versus wavelength). Visualisation of non-orthogonal projections is not incorporated, but more specialised tools are available in the public domain (e.g., Campbell, Kjær & Amico, 2012). High quality images of

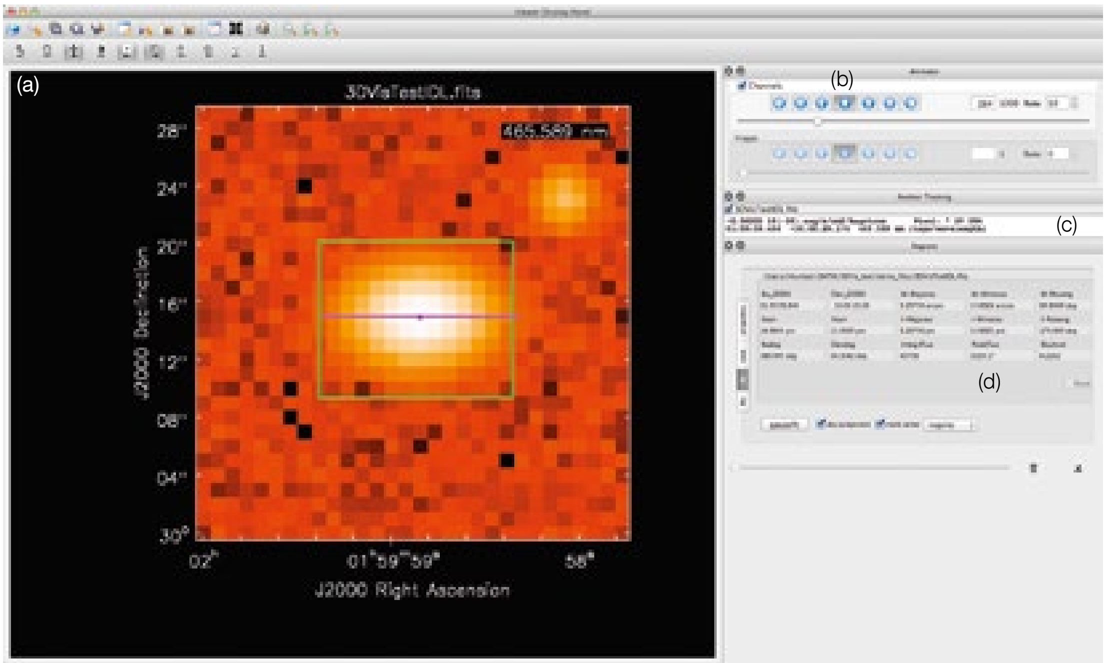

Figure 1. Screenshot of the main viewer panel showing one channel or slice (#284) of a simulated test datacube at 465.589 nm. The locations of the main image viewer (a), the animator panel (b) and the position tracker panel (c) are indicated on the screenshot. The spectrum within the green rectangular region marked in the image viewer panel (a) is displayed in the spectral profiler (see Figure 2). The position tracker panel provides crucial information on the current cursor position such as data value, coordinates in pixels and world coordinate system (WCS) format. In this example, a two-dimensional Gaussian fit to the highlighted emission region has been made. The centre and position angle is given by the magenta line and cross, respectively, and the numeric fit values are shown in the regions subpanel (d).

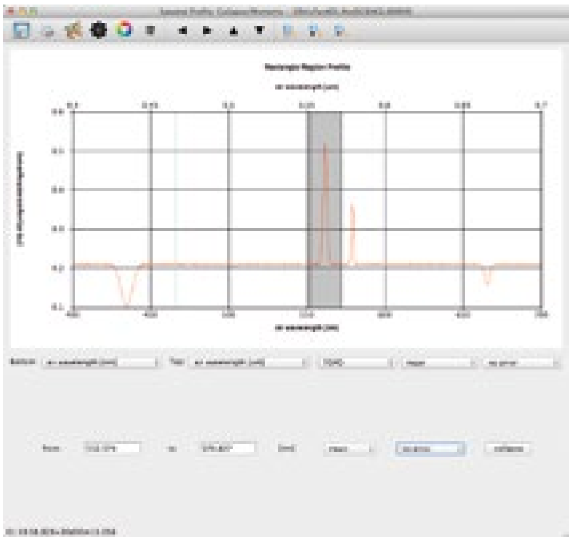

Figure 2. Screenshot of the spectral profiler showing the mean spectrum of the rectangular region (green) marked in Figure 1. A blue line indicates the wavelength of the slice shown in the main viewer panel. In this example a spectral range (grey shaded area) is marked by cursor interaction, which can then be used to collapse the cube and reconstruct an image over this wavelength range (in this case 552.574–570.827 nm).

what is displayed in the main viewer can be saved in all commonly used formats such as FITS, pdf, jpg or png. The spectral unit used for the display can also be interactively chosen (e.g., nm, Ångström, GHz), and, provided a rest frequency or wavelength is specified, can be converted into units of velocity (e.g., km/s).

Beyond the basic visualisation capabilities of the viewer a number of analysis tools are offered. Examples are provided in the following.

Analysis tool examples

It is often convenient to collapse a number of datacube slices along the wavelength direction to, e.g., increase the signal-to-noise level in the resulting "reconstructed image" or sum over an emission line. This action is initiated from the viewer display panel, opening the spectral profiler where a region can be interactively marked with the cursor or provided by numeric values (see Figure 2). In the example shown, a selected region showing a distinct emission feature was chosen. After image reconstruction (a choice between mean, median and sum algorithms is available) the image is displayed in the image viewer (not shown in Figure 1) and can be, e.g., "blinked" with other slices of the cube. Error estimates, derived from the data themselves, can be optionally calculated and stored together with the reconstructed image.

An often-requested application for imaging data is the ability to fit a simple 2D Gaussian to an object in the field of view in order to obtain estimates on the object position, extent and orientation. The viewer provides this capability as part of the *regions* functionality. In Figure 1 we show an example: a rectangular region around a bright emission knot is marked and a 2D Gaussian fit made. The peak is automatically found, and the fit results are shown graphically (magenta line and cross) and numerically (in the regions panel in both pixel and world coordinate systems; see Figure 1).

1D Gaussian fits can also be performed on the spectrum in order to determine, for example, the central wavelength for an emission/absorption line. We show an example of this application in Figure 3. For the fit, a wavelength region is selected

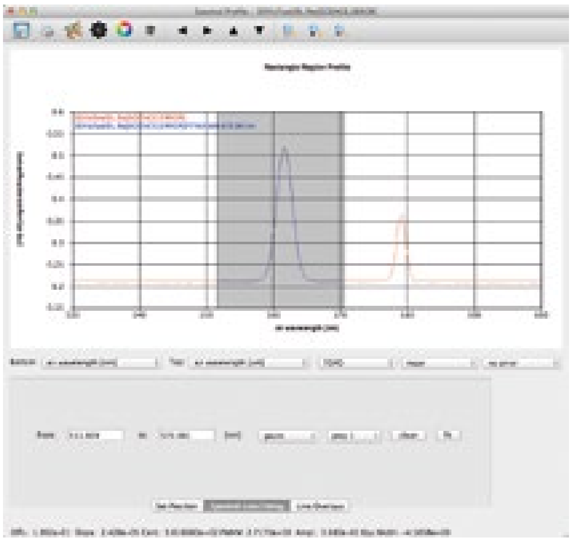

Figure 3. Example of Gaussian emission line fit plus continuum ("poly1") which is applied over the region marked by the grey shaded area. The fit is shown in blue, and the results are shown in the status bar at the bottom of the window.

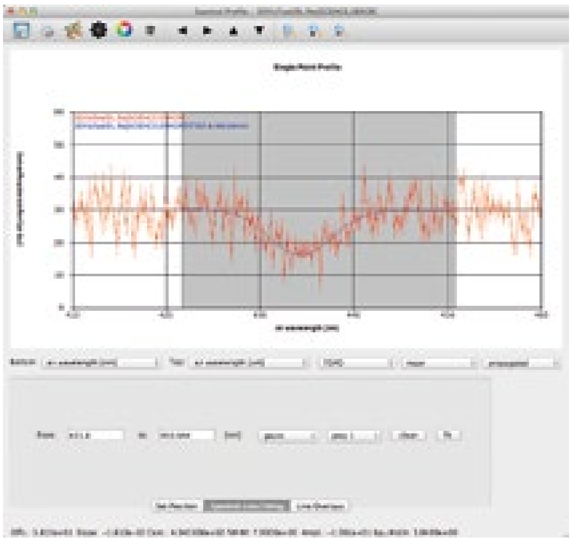

Figure 4. Example of spectrum visualisation with errors. A Gaussian fit (blue line) is applied to an absorption line in the grey-shaded region, including error estimates for each data point; numerical results of the fit are given at the bottom of the window.

either by cursor interaction or numerical input. A range of fitting options, such as the inclusion of a first order continuum is available. Then with a click of a button, a fit is carried out in the specified region and the result shown graphically (blue solid line in Figure 3) and numerically — the fit results with estimated errors are provided at the bottom of the spectral profiler window and on the command line.

The visualisation of data errors, where available, was a requirement for the development of the viewer. In Figure 4 we show an example of a spectrum where the error estimates given in the dataset are displayed for each data point. Not only can one use the errors for visualisation, but they are also used, for example, in Gaussian line fitting, if they are displayed (see Figure 4). When no external error estimates are provided or an independent estimate is desired, the tool will optionally provide error estimates derived from internal data statistics, e.g., for spectra averaged over a user-defined region.

Software download and documentation

The ESO 3D viewer for optical/near-infrared data originating from the VLT is not distributed separately but incorporated into the standard ALMA CASA software viewer. From CASA version 4.0 onwards, the features described in this article will be available as part of the CASA viewer. The CASA software is freely available[1] and full installation is required to make use of the viewer. CASA is also part of the ESO Scisoft software collection[2].

A user manual for the viewer, particularly targeted at users with optical/near-infrared data, has been produced as part of the project. Additionally, for the somewhat less patient users, we provide a "cookbook" with five simple step-by-step examples on how to use the relevant functionality of the viewer. This includes examples ranging from basic tasks such as loading a cube and displaying a spectrum, to obtaining a 2D fit in the image plane. The manual and cookbook are available[3].

Use of the 3D visualisation tool

The ESO 3D viewer provides a way of visualising VLT integral field unit data products conveniently. An effort has been made to harmonise the output of the VLT data reduction pipelines and the interface to the viewer. If error estimates are available in the data products — particularly relevant for second generation VLT instrumentation — the viewer can display the extra information and make use of errors in the internal calculations.

Feedback and problem reports concerning optical/near-infrared data for the viewer are provided by ESO via the user portal or by email[4]. General support for the CASA software is also available[5]. Users who make use of this tool for analysis of their optical/near-infrared 3D data are kindly requested to refer to this article in any publications.

Acknowledgements

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Links

[1] CASA software available: http://casa.nrao.edu/
[2] ESO Scisoft collection: http://www.eso.org/sci/software/scisoft/
[3] ESO 3D viewer manual and cookbook available from: http://www.eso.org/pipelines/
[4] Email for help on 3D viewer: usd-help@eso.org
[5] Help on CASA software available from: http://almascience.eso.org/

ESO/INAF–VST/OmegaCAM. Acknowledgement: OmegaCen/Astro-WISE/Kapteyn Institute

The central core of the nearby Hercules galaxy cluster (Abell 2251) is shown in this VLT Survey Telescope (VST) colour image. The Hercules cluster has a projected size of about 1.7 by 0.8 degrees, but the image is only 20 by 29 arcminutes; the distance to the cluster is about 160 Mpc. OmegaCAM images in *g*-, *r*- and *i*-bands were combined and more details can be found in Release eso1211.

The La Silla–QUEST Southern Hemisphere Variability Survey

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In 2009, the ESO 1.0-metre Schmidt telescope at La Silla was awakened from an 11-year slumber. The telescope had been decommissioned in 1998 after completing a photographic survey of the southern hemisphere. It has now been given a new life with the installation of Yale University's 160-megapixel QUEST camera consisting of a 112-CCD mosaic covering 10 square degrees. The control system for the telescope was also upgraded to allow fully autonomous observing. With the new system, Yale is conducting the La Silla–QUEST (LSQ) Variability Survey in the Southern Hemisphere to detect low-redshift supernovae, RR Lyrae variable stars, Kuiper Belt Objects (KBOs), and other unusual transients. The LSQ variability survey has already covered most of the southern hemisphere multiple times at cadences ranging from hours to years and to a depth ranging from *R* magnitudes 20.5 to 21.5. To date the survey has detected more than 65 new KBOs and thousands of new RR Lyrae stars. The detection of hundreds of supernovae will lead to an improved measurement of the accelerated expansion rate of the Universe.

The motivation for undertaking the new Schmidt surveys stems from the Yale University's broad interests in understanding Solar System evolution, the structure of the Milky Way and the accelerated expansion of the Universe. A variability survey that repeatedly covers large areas of sky at cadences ranging from hours to days to years serves these goals in several ways. On hourly timescales, the survey exposes the motion of objects in the distant Solar System (Kuiper Belt Objects or KBOs), which are remnant bodies from the time of planet formation. Physical observations of these primitive objects reveal the composition of the early Solar System (Barucci et al., 2008). Also imprinted in the orbital distribution of the KBOs is a record of the early gravitational interactions that scattered planetesimals outward from the inner Solar System (Morbidelli, Levison & Gomes, 2008).

On daily timescales, a variability survey exposes the distinctive brightness oscillations of RR Lyrae stars. These remarkable stars serve as precise distance markers, capable of revealing tidal streams and other large-scale structures in the halo of the Milky Way resulting from past collisions with other galaxies (Vivas et al., 2008). Daily observations also reveal the spectacular outbursts of supernovae in nearby galaxies and other high-luminosity transients (Hadjiyska et al., 2012). These are interesting not only for the extraordinary high-energy phenomena they exhibit, but also because the Type Ia supernovae serve as cosmological distance standards. Measurements of their luminosity versus redshift provided the first evidence of a mysterious dark energy accelerating the expansion of the Universe (Riess et al., 1998; Perlmutter et al., 1999). Future observations of Type Ia supernovae are capable of probing the historical expansion rate of the Universe and thereby constraining the nature of this mysterious force.

The QUEST camera was installed on the ESO Schmidt telescope in 2009 after previously completing a five-year, northern hemisphere variability survey in 2008 using the 1.2-metre Oschin Schmidt telescope at Palomar. At Palomar, this camera was the discovery engine for the Supernova Factory, leading to the measurement of more than 200 spectrophotometric light curves of Type Ia supernovae (Kerschhaggl et al., 2011). It was also used to discover the new dwarf planets in the Kuiper Belt (Brown, 2008; Rabinowitz et al., 2012), to characterise the variability of quasars and to measure the effect of gravitational lensing on quasar variability (Bauer et al., 2012). This article describes the installation of the QUEST camera on the ESO Schmidt and the new surveys being conducted with the instrument.

The telescope upgrade

With the termination of the Palomar KBO and transient surveys in 2008, it was natural to look for an appropriate telescope in the south to complete an all-sky survey for the largest KBOs and to continue the search for supernovae, variable stars and other transients. The ideal telescope would have a Schmidt design, like the Oschin telescope, since the QUEST

Figure 1. The 1.0-metre ESO Schmidt telescope inside the dome. The QUEST camera is inside the telescope mounted at the prime focus. The camera electronics are visible on the underside of the telescope tube with cabling running up the yoke and around the declination axis.

camera was specifically designed for this configuration. Fortunately, the ESO 1.0-metre Schmidt was available (Figure 1). The telescope is one of the largest Schmidt configurations in the southern hemisphere, situated at an ideal site, and has the same optical configuration as the Palomar Schmidt (but smaller entrance aperture). The QUEST camera could be installed without any changes to its front-end optics. ESO provided Yale with the opportunity to use this telescope with the expectation that Yale would update the control system for automated operation, replace the plate holder at the prime focus with the 160-megapixel QUEST camera, and establish an independent internet connection for transfer of the image data to Yale. Yale began to implement these changes in early 2009, and was ready for remote and automated operation of the ESO Schmidt by August 2009.

Since the original control system for the ESO Schmidt was over 30 years old and no longer usable, the entire system had to be upgraded. This required a complete replacement of the control electronics for both telescope axes and the focus mechanism, including servo amplifiers, encoders, the controlling computer and control software. With the new system it is possible to run the telescope in a fully robotic mode with no one at the telescope. In typical operation, observing scripts are prepared at Yale during the day and transmitted to a computer at the telescope. At night a master scheduling program automatically sequences telescope pointing, dome rotation, focus sequences and camera exposures. This automation is essential for running the survey every clear night of the year. The operator of the ESO 3.6-metre telescope, sitting in the main control room at La Silla, can monitor and control the opening and closing of the Schmidt dome via a web interface to ensure that it is closed in case of inclement weather.

Because LSQ must process each night of survey data at Yale the day after acquisition, they require a communication link to La Silla that can handle ~ 50 Gbytes per night (after compression). Unfortunately, no such link was available at La Silla. Yale therefore installed a private, high-speed radio link between La Silla and Cerro Tololo, where there is direct 100-kilometre line of sight (Figure 2). Programmable radios connected to 2-metre-diameter antennas were installed with experimental software developed for long-distance links in developing countries. The radio link achieves a bit rate of ~ 20 Mbits/sec, sufficient to transmit the survey data to Yale as fast as they are acquired. The receiving antenna at Cerro Tololo connects to a high-speed internet backbone that is linked to the US mainland.

Figure 2. Installation of a 2-metre-diameter radio antenna on the La Silla weather tower. A matching antenna at Cerro Tololo receives the LSQ image data and transmits them to Yale over a high-speed internet link with the USA.

The QUEST camera

The 160-megapixel QUEST camera (Figure 3) was designed and fabricated at Yale University in collaboration with a group from Indiana University for initial operation at the Oschin Schmidt telescope at Palomar (Baltay et al., 2007). It was installed on the ESO Schmidt without any changes to the CCD array or the camera dewar. The focal plane consists of 112 CCDs fabricated by Sarnoff Labs. Each is a thinned, back-illuminated device with 600 × 2400 13 μm pixels with a peak quantum efficiency of 95 % at 600 nm. The array covers 3.6 × 4.6 degrees, with an active area of 9.6 degrees^2 and a pixel scale of 0.87 arcseconds.

The focal plane is cooled with a pair of 60 Watt cryo-refrigerators. Each unit transfers heat using a Gifford–McMahon cycle, where compressed helium at room temperature drives the motion of a piston, thereby drawing thermal energy from the cold head at the end of the piston

Figure 3. The 10-square-degree QUEST camera. The focal plane of the 161-megapixel camera consists of 112 CCD devices arranged in four rows with 28 CCDs each. The array spans 3.6 × 4.6 degrees with an active area of 9.6 square degrees.

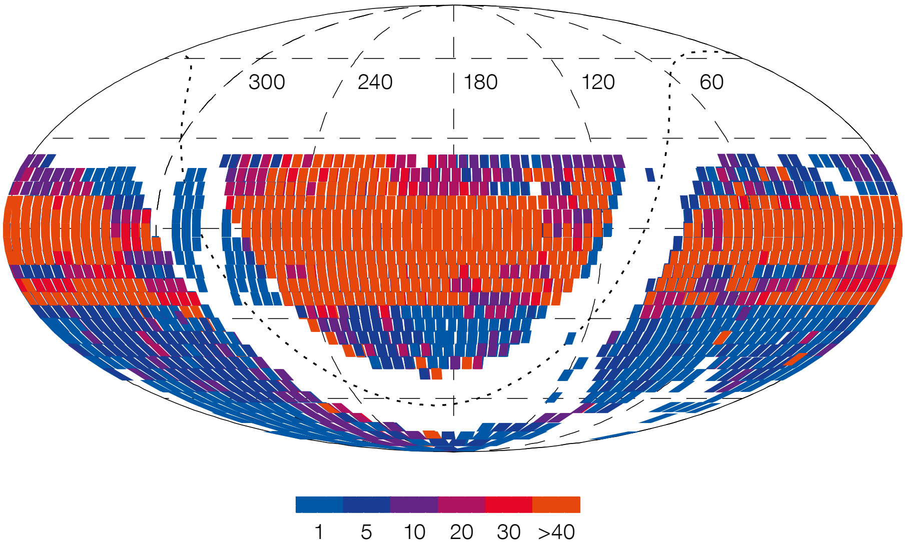

Figure 4. Survey areas covered to date by La Silla–QUEST survey are shown. The colour codes the number of visits per field. Blue areas have been covered at least three times per night for the KBO survey; red areas have been covered extensively for the supernova and RR Lyrae surveys in addition to the KBO survey.

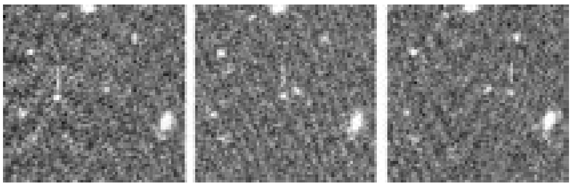

Figure 5. The discovery images of the distant KBO 2010 WG9 with magnitude $R \sim 20.5$. In each square panel north is up, east to the left, the image size is 88 by 88 arcseconds and the position of the source is indicated by a white line. The time interval is ~ 2 hours between exposures.

cylinder. Two large helium compressors sit on the dome floor beneath the telescope, connected by long, flexible high-pressure lines to the piston heads. Recirculated water cools each compressor, with the heat dissipated outside the dome by air/water heat exchangers. To minimise vibration of the focal plane induced by the piston cycling, the two cryo-refrigerators are firmly bolted to the stiff spider vanes supporting the focus hub of the telescope. Because the units mechanically connect to the camera head only by flexible copper straps and flexible vacuum housings, their vibrational energy is almost completely absorbed by the large mass of the telescope. There is no detectable influence from the vibration on image quality.

For all current surveys LSQ uses a single wideband filter covering the 400 to 700 nm range. The red cutoff eliminates fringing in the images due to strong atmospheric emission lines at red wavelengths. The blue cutoff reduces the background from moonlight. Other filter sets are available, including a single plate of Schott glass RG610, and sets that combine four different filters (Johnson *U,B,R,I* or Gunn *g,r,i,z*), each covering a different row of CCDs in the array.

System performance

In the first three years of operation the telescope and camera have performed well given that all exposures are unguided and unmonitored during the night. Typical seeing is 1.6 arcseconds for 60 s exposures and 2.0 arcseconds for 180 s exposures. Pointing repeatability is ~ 10 arcseconds night-to-night. Photometric precision is ~ 1.5 % for field stars observed repeatedly over many nights. The only serious instrumental problem was a failure of the support wheels for the dome owing to the aging of rubber components. This has now been fixed by a complete replacement of the old wheels with new bogies designed by G. Ihle.

The search for KBOs

In recent years, surveys for KBOs conducted with the QUEST camera have exposed a new population of dwarf planets with sizes close to that of Pluto, ultimately leading to the new definition of a planet that excluded Pluto from the list of major planets. Earlier surveys covering much smaller areas to fainter limits had already detected hundreds of fainter KBOs and established that Pluto follows a typical Kuiper Belt orbit. But the much larger size and brightness of Pluto relative to its dynamical cousins had preserved its place among the planetary pantheon. Only with the discovery at Palomar of other bodies like Pluto, massive enough to gravitationally retain a surface rich in volatile ices, did it become clear that Pluto was not unique. But of more importance to our understanding of the origin and evolution of the Solar System, the discovery of the dwarf planets has led to a new understanding of KBO composition and structure, volatile retention, collisional dynamics, surface weathering and dynamical evolution.

The LSQ survey further explores the population of large KBOs. It is intended to cover the entire sky south of the ecliptic to magnitude limit $R \sim 21.5$, including areas not accessible to, or not completely searched by, previous northern hemisphere searches. To date, no other KBO surveys of comparable scale and sensitivity have been conducted in the south. Based on the discovery rate of large KBOs at Palomar and their wide-ranging latitudes, at least a few similar-sized KBOs likely remain undiscovered in the south.

The sky coverage of the KBO survey is shown in Figure 4. Each survey area has been covered at least three times per night for the KBO search. More than 65 new KBOs have been detected, including redetections of the dwarf planets Eris and Sedna. However, no new objects larger than ~ 500 kilometres have yet been discovered. One of the most interesting new objects is 2010 WG9, a distant body with an inclination exceeding 70 degrees and a perihelion near the orbit of Uranus. The discovery images are shown in Figure 5. Only two other bodies are known with similarly high inclinations and distant perihelia. As with long-period comets, commonly observed when they pass into the inner Solar System, 2010 WG9 is likely a returning member of the Oort Cloud. However, it has somehow managed to follow an unusual path allowing Uranus or Neptune to capture the orbit and prevent a closer passage. As such, it may be one of the few observed bodies from the Oort Cloud unaltered by a close passage to the Sun. Observations to determine its physical properties are in progress.

The Supernova Survey

Type Ia supernovae have recently received much attention as calibratable standard candles in cosmological studies, particularly for the role they play in the discovery of the acceleration of the expansion of our Universe. In order to carry these studies to an increased level of precision, a number of surveys have gathered samples of relatively high redshift supernovae. Additional high redshift surveys are being planned, including the Large Synoptic Survey Telescope (LSST) and the space mission WFIRST. As the detections at high redshift become numerous, there is new scientific motivation to carry out a large-scale survey for low-redshift supernovae. In particular, the low-redshift sample anchors the Hubble Diagram at the most recent epoch of expansion. Measurements of the nearby supernovae are necessary to reduce the error obtained on the resulting cosmological parameters. Also, detailed physical studies of the low-redshift supernovae improve our understanding of their ensemble properties and their use as distance indicators.

In order to detect supernova, the LSQ survey covers a given set of fields repeatedly, usually with a two-day cadence (set A is covered on the first night, set B on the second, repeat set A on the third, repeat set B on the fourth, and so on). Similar to other surveys, LSQ uses a rolling search, repeating observations of most of the fields in these two sets for several months. Once a particular field has been observed multiple times in good conditions, a reference image of the field can be made. Subsequent observations of the field can then be sent through the LSQ subtraction pipeline, which subtracts the reference image from each new image and detects transients by identifying the residual sources in the subtracted images.

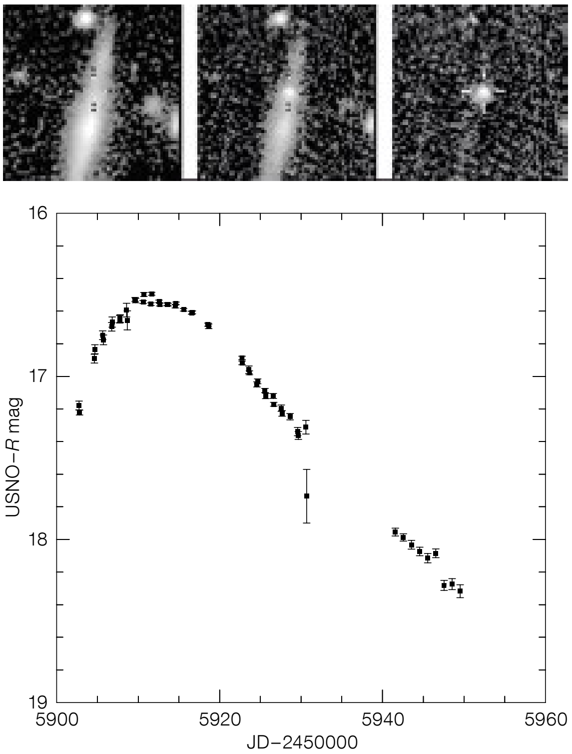

Figure 6. Discovery subimages for the Type Ia supernova LSQ11ot, redshift 0.026, showing the reference, new and subtracted images (left to right, upper panel). The subimages are each 0.94 by 0.94 arcminutes. The host-subtracted light curve for the Type Ia supernova LSQ11bk, redshift 0.03, is shown (lower panel).

On a given night, typically ~ 1000 potential transients are detected and must be visually scanned to remove noise artefacts. Of the remaining candidates, those that appear near or on top of galaxies and have historical variability inconsistent with variable stars are scheduled for spectroscopic follow-up. Figure 6 shows LSQ discovery images for one Type Ia supernova and a light curve of a second one, both discovered at low redshift.

The area covered to date by the supernova survey is shown in Figure 4 (red areas). The search has been concentrated between −25 and +25 degrees declination to allow follow-up by both northern and southern observers. Most of this area has been covered in excess of 40 times in the last three years. Several hundred supernovae have been discovered. More than 100 have been followed up and confirmed spectroscopically by collaborators, including the Public ESO Spectroscopic Survey of Transient Objects (PESSTO) which uses the EFOSC spectrometer on the ESO New Technology Telescope (NTT), located just a few hundred metres from the ESO Schmidt.

The study of RR Lyrae variables

The properties of the halo of our galaxy and how they may be explained in the broader context of galaxy evolution has been an active area of research for many years. Early models assumed a smooth uniform distribution of stars in a halo formed during the early stage of collapse of our galaxy. Recent studies however suggest that accretion of satellite galaxies has played a major role in the formation of the Halo, leaving significant structure inside the Halo. RR Lyrae are periodic variable stars with uniform intrinsic luminosities, hence they make excellent standard candles for probing the structure of the Galactic Halo. LSQ has been used to gather a large sample of RR Lyrae stars, providing sensitivity to remnants of galaxy mergers in the Halo. In a search of 1300 square degrees, a total of about 2000 RR Lyrae variables were found with magnitudes between 14.5 and 20.5, corresponding to distances from 6 to 100 kiloparsecs. Figure 7 shows a few representative light curves.

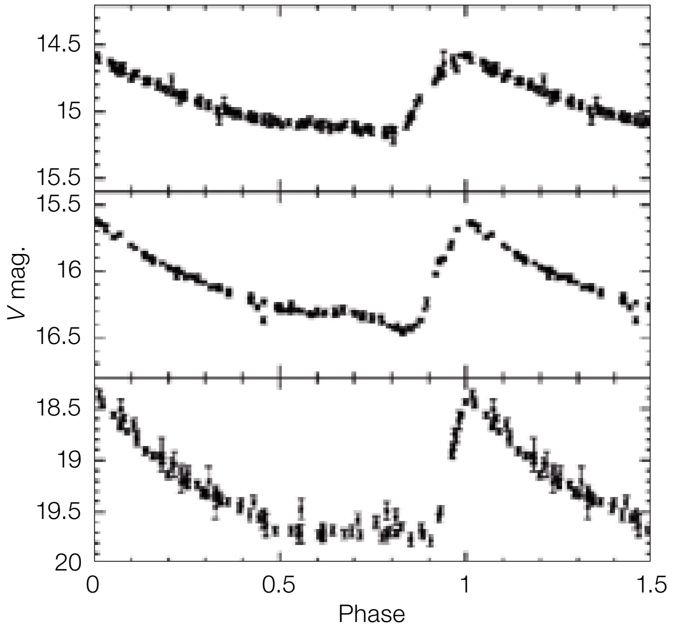

Figure 7. LSQ light curve measurements of a few typical RR Lyrae variable stars. The observations are phased by the light-curve period and photometrically calibrated using Sloan Digital Sky Survey field stars.

Future plans

In collaboration with other institutions in the United States and PESSTO, Yale University plans to continue the LSQ supernova survey for several more years. A new survey for high-inclination KBOs is also planned, with the search area concentrated near the ecliptic pole and pushed to fainter magnitudes in order to find more unusual bodies, like 2010 WG9. The cooperative working relationship between Yale University and ESO staff at La Silla has been extremely fruitful, leading to a revitalised observing programme with the ESO Schmidt. The collaboration promises to yield many exciting discoveries in the years to come, spanning the range from planetismals to exploding stars.

Acknowledgements

We thank Andreas Kaufer for his cooperation in making the La Silla–QUEST project possible. We also thank Gerardo Ihle and the technical staff at the La Silla Observatory for their outstanding efforts both during the installation and the operation of this survey. We are also grateful to Hans-Werner Braun, Jim Hale, and Sam Leffler for their help in the design and implementation of the radio link from La Silla to Cerro Tololo. Many other unnamed friends and colleagues generously contributed their time to make LSQ possible. The work was supported by the US Department of Energy and NASA. The National Energy Research Scientific Computing Center provided staff and computational resources.

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A photograph of the 1-metre Schmidt telescope on La Silla taken in 1971 during its first test period is shown. Otto Heckmann, the first ESO Director General, is standing in front of the telescope.

β Pictoris, a Laboratory for Planetary Formation Studies

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Shortly after its discovery in 1984, the Beta Pictoris disc was recognised as a possible site of past, ongoing or future planet formation. It has since been observed extensively, from the X-ray domain to centimetre wavelengths by many ground- and space-based telescopes. The disc has become a remote laboratory to study the physical and chemical characteristics of debris discs. Recently, we were able to detect a companion orbiting the star at a distance comparable to that of Saturn in our Solar System. The β Pic system thus offers a unique opportunity to study giant planet properties and planet/disc interactions. We present a short — and necessarily incomplete — review of the main discoveries made in this fascinating system over three decades of observations, a number of which were achieved with ESO telescopes.

The debris disc, its gas and kilometre-sized bodies

One of the most challenging topics in astronomy today is certainly to understand how planetary systems, with all their complexity (planets, comets, dust and gas) form and evolve. Even though sketches of the formation of the Solar System have been developed and simulated since the late 1960s, additional examples of planetary systems were lacking to explore their possible variety. The discovery of infrared (IR) excesses associated with T Tauri stars and then with main sequence stars were the first steps in the study of star and planet formation. In 1984, IRAS measured IR excesses associated with a few main sequence stars that were attributed to cold dust, perhaps related to planet formation (Aumann, 1984). Shortly after, Smith & Terrile (1984) imaged the dust around one such star, a young (12^{+8}_{-4} Myr) and close (19.3 ± 0.2 pc) A5V star β Pic (note that at that time, its age was rather estimated to be 200 Myr, and its distance 16 pc). The dust distribution revealed a flat, edge-on disc, detected between 100 and 400 astronomical units (au) from the star. The β Pic disc became a prototype of the debris discs that contain substantial amounts of grains, short-lived against destructive (collisions) or removal (radiation pressure, Poynting–Robertson drag) processes and therefore needing replenishment through collisional cascade or evaporation from large, kilometre-sized bodies down to micrometre-sized grains.

Debris discs trace the stages of planetary system evolution where solid bodies significantly larger than primordial dust are present (see Lagrange et al. [2000] for an early review). Since 1984, the β Pic disc has been extensively observed from optical to millimetre wavelengths (see Figure 1). Briefly, optical and near-IR observations have provided high spatial resolution, scattered light images tracing small grains; thermal data provided by medium resolution images have demonstrated the presence of hotter dust, while (sub-)millimetre images have traced larger grains, and consequently, the parent bodies as well. Thanks to all these observations, we now have a schematic view of the disc (Augereau et al., 2001; Wilner et al., 2012), in which the parent kilometre-sized bodies are mainly located in a narrow (10–20 au) wide ring at about 90–100 au (planetesimal disc). Collisional cascades produce small grains detected out to several hundreds of au because of the radiation pressure of the star, while an additional component of hotter dust is also needed to account for the IR data.

Shortly after the discovery by dust imaging, circumstellar gas was detected in absorption using high spectral resolution optical spectrographs and in the ultraviolet with the International Ultraviolet Explorer (IUE) satellite. The first optical data were obtained in late 1984 with the high resolution Coudé Echelle Spectrograph (CES) at the Coudé Auxiliary Telescope (CAT) on the ESO 3.6-metre telescope at La Silla (Hobbs et al., 1985; Vidal-Madjar et al., 1986, see Figure 2a). Repeated observations with CES and IUE revealed important infalls of high velocity ionised gas (a few tens to a few hundreds of km/s), packed in clumpy structures with sizes smaller than that of the star (e.g., Lagrange et al.,1988), attributed to evaporating comets grazing the star. Intensive monitoring of these gaseous infall events in the late eighties/early nineties as well as detailed modelling

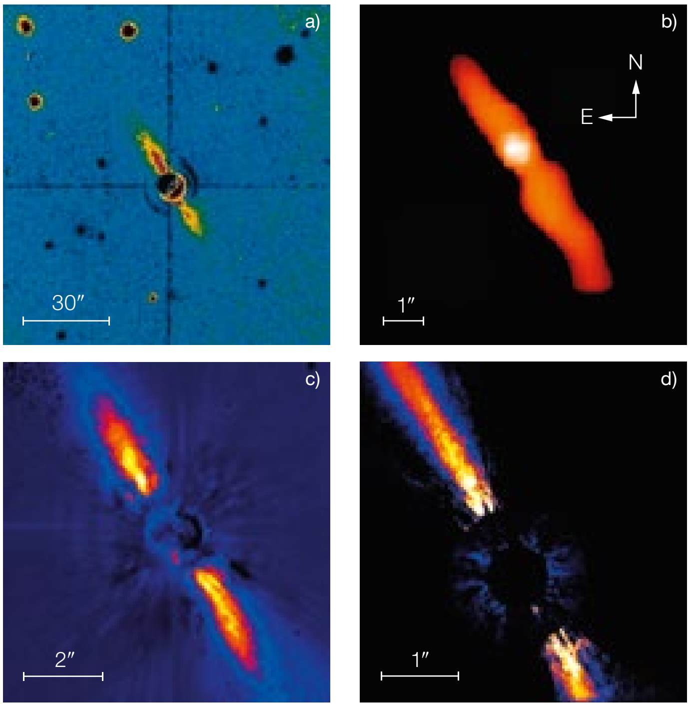

Figure 1. Images of the β Pic disc at various wavelengths: a) optical observations with Las Campanas 2.5-metre at 890 nm obtained in April 1984 (from Smith & Terrile, 1984); b) mid-infrared observations at 12 μm with the ESO 3.6-metre and TIMMI (from Lagage & Pantin, 1994); c) near-infrared coronagraphic imaging in *J*-band with ESO 3.6-metre and the Adonis instrument (from Mouillet et al., 1997); d) near-infrared *Ks*-band images with VLT and NACO (Lagrange et al., 2012a).

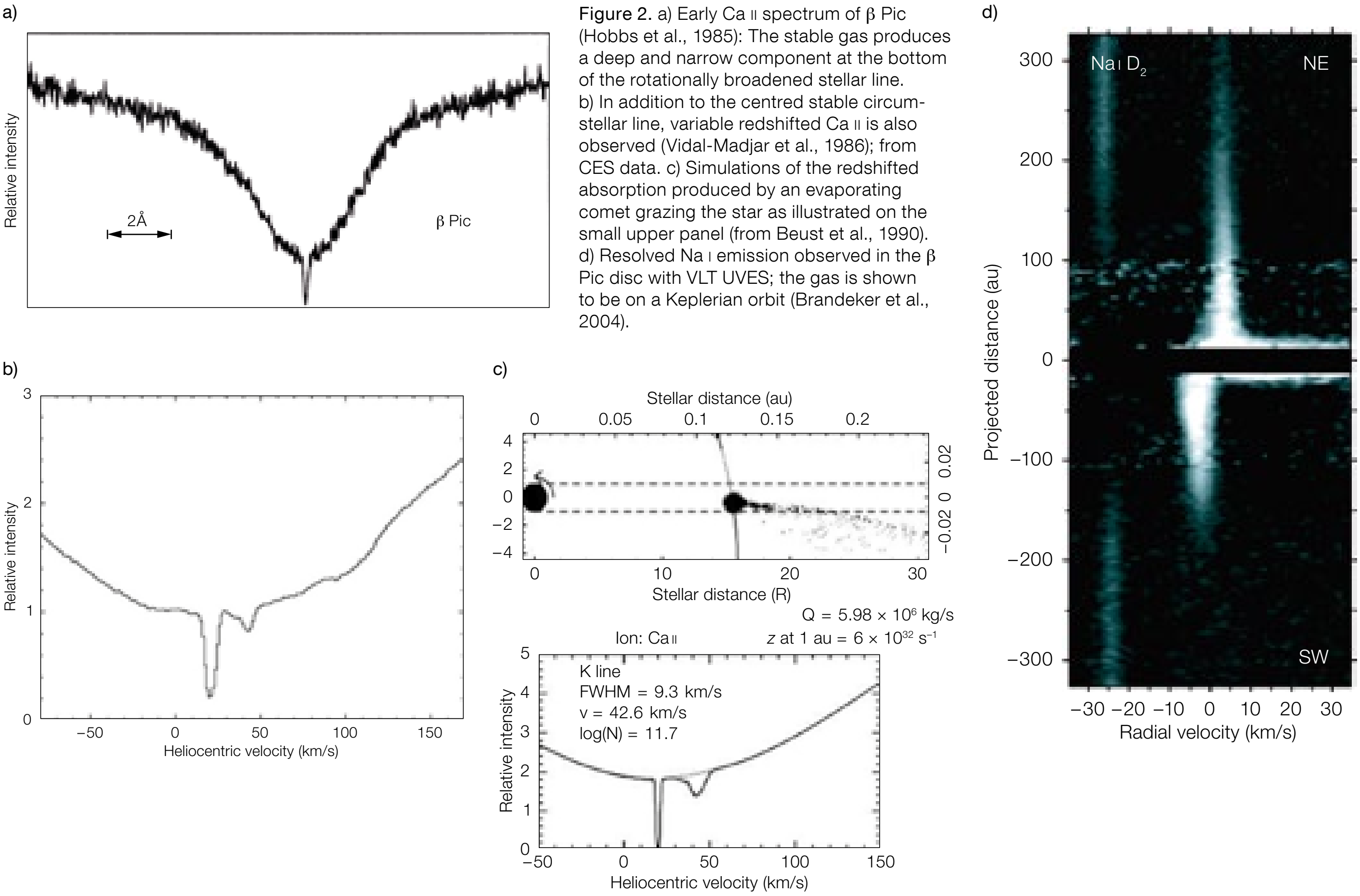

Figure 2. a) Early Ca II spectrum of β Pic (Hobbs et al., 1985): The stable gas produces a deep and narrow component at the bottom of the rotationally broadened stellar line. b) In addition to the centred stable circumstellar line, variable redshifted Ca II is also observed (Vidal-Madjar et al., 1986); from CES data. c) Simulations of the redshifted absorption produced by an evaporating comet grazing the star as illustrated on the small upper panel (from Beust et al., 1990). d) Resolved Na I emission observed in the β Pic disc with VLT UVES; the gas is shown to be on a Keplerian orbit (Brandeker et al., 2004).

(e.g., Beust et al, 1990, see Figure 2c) strengthened the "falling evaporating bodies" (FEB) scenario which still holds after more than 20 years of observations. On the contrary, there is still no consensus concerning the explanation for the stable gas around the star, seen either in absorption or in emission, in particular species that are expected to be very short-lived because of photodissociation, photoionisation or radiation pressure, such as CO, CI, etc (Lagrange et al., 1998; Roberge et al., 2000; Brandeker et al., 2004; Nilsson et al., 2012; see Figure 2d). In any case, the total amount of gas in the β Pic system is significantly smaller than that around younger (a few Myr) systems such as Herbig stars or T Tauri stars, in agreement with the estimations of primordial disc dissipation timescales of about 3–6 Myr.

Early indications of planets in the β Pic system

The presence of planets in the β Pic disc had been suspected since the 1990s from several independent considerations:

- The mere presence of short-lived dust, produced by destruction (collision, evaporation) of kilometre-sized bodies indicated that at least the building blocks of planets were already present in the system. The gravitational perturbation of a giant planet on cometary-like bodies was found to be the best explanation for the observed rate of comet infall. Dedicated simulations concluded that such a planet (a giant planet) should be located within 10 au of the star (Beust & Morbidelli, 2000).
- The presence of a relative void of material in the inner parts of the disc was also attributed to the sweeping up of material by planets. This generic mechanism has also been invoked in other instances, but no dedicated modelling has been done to our knowledge for the β Pic disc.
- Photometric data recorded at the Swiss telescope in the early eighties on β Pic (which used to be regarded as a photometric standard) were re-analysed in the nineties and revealed that intriguing variations had occurred on 10 November 1981. Explanations involving either a multiple giant cometary tail or a transiting planet were proposed to account for the observed variations (Lecavelier et al. [1997] and references therein);
- Thermal infrared data show inhomogeneities in the disc: belt-like structures or clumps that could be due to sculpting by planets located in the gaps (see Freistetter [2007] for more detail). In particular, the latter, a 2–5 Jupiter mass planet at about 10 au, was proposed by Freistetter (2007);
- In the late 1990s the Hubble Space Telescope (HST) and ESO 3.6-metre Adonis adaptive optics high spatial resolution data at optical/near-IR wave-

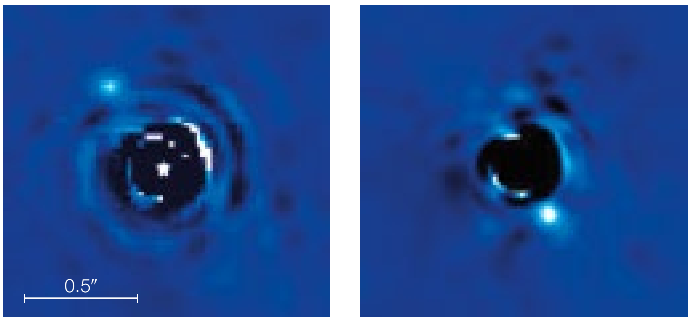

Figure 3. NACO L'-band images of β Pic b are shown: in 2003 (left) with star-planet separation ~ 400 milliarcseconds; in 2009 (right) with separation ~ 300 milliarcseconds. From Lagrange et al. (2009; 2010).

lengths revealed the presence of an inner warp in the scattered-light images, extending up to a few tens of au (Burrows et al., 1995; Mouillet et al., 1997). Dynamical simulations allowed us to show that a massive companion on a slightly inclined orbit with respect to the outer disc midplane could explain the warp, provided its mass (*M*) and separation (*a*) fulfilled a constraint on $M \times a^2$ (Mouillet et al., 1997; Augereau et al., 2001).

None of these considerations proved that planets were indeed present, however altogether they formed a very indicative set of clues.

A giant planet at about 9 au

Using NACO on the VLT, we detected a faint source about 0.4 arcseconds northeast from the star, roughly along the disc direction, in data taken in November 2003 (Lagrange et al., 2009, see Figure 3). Its apparent magnitude of $L' \approx 11.2$ indicated that, if bound to the star, it had a temperature of ~ 1500 K and a mass of about 8 $M_{Jupiter}$ according to the hot-start planet models from the Lyon group (Baraffe, 2003). We had to wait until autumn 2009 to see this object again, this time 0.3 arcseconds southwest from the star and to confirm that it was indeed bound to the star (Lagrange et al., 2010). In the meantime, the companion had travelled about half an orbit behind the star. Subsequent NACO monitoring allowed us to resolve the orbit of β Pic b (Chauvin et al., 2012) and constrain the semi-major axis of the planetary orbit to the range 8–12 au, most probably at 8–9 au, that is within the orbit of Saturn in the Solar System (Figure 4). β Pic b is then located in the region where, according to current formation models, and given the star age and mass, giant planets can have formed *in situ* by core accretion, like the giant planets of the

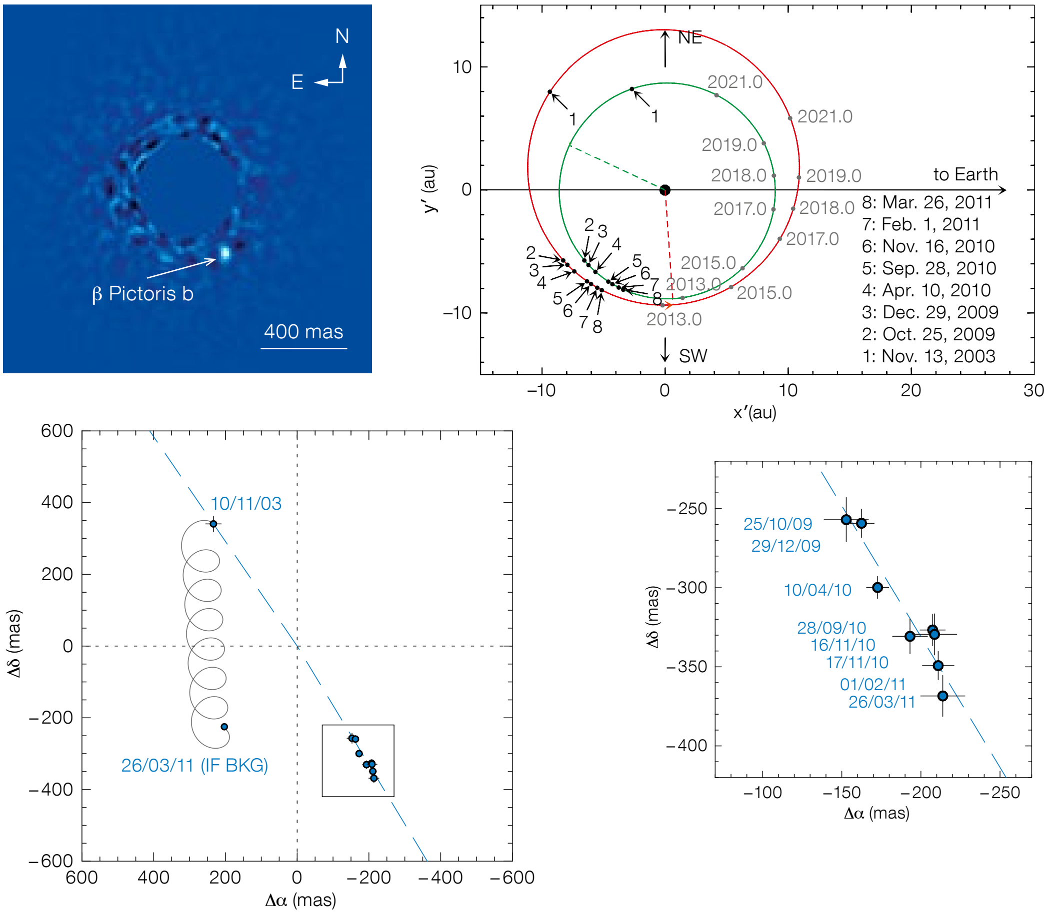

Figure 4. *Ks*-band Image of β Pic b in April 2010 (from Bonnefoy et al., 2011) is shown (upper left). The astrometric monitoring of β Pic b relative to β Pic is reported in the lower plots. The predictions for the position of β Pic b in case of a background source are reported in gray from 10 November 2003 to 26 March 2011 (lower left). A zoomed view of the most recent astrometric observations over 2010 and 2011 is presented at lower right. At upper right, details of the orbit of β Pic b from Chauvin et al. (2012) for two possible solutions of low ($e = 0$ in green) and slightly higher eccentricity ($e = 0.16$ in red) are illustrated.

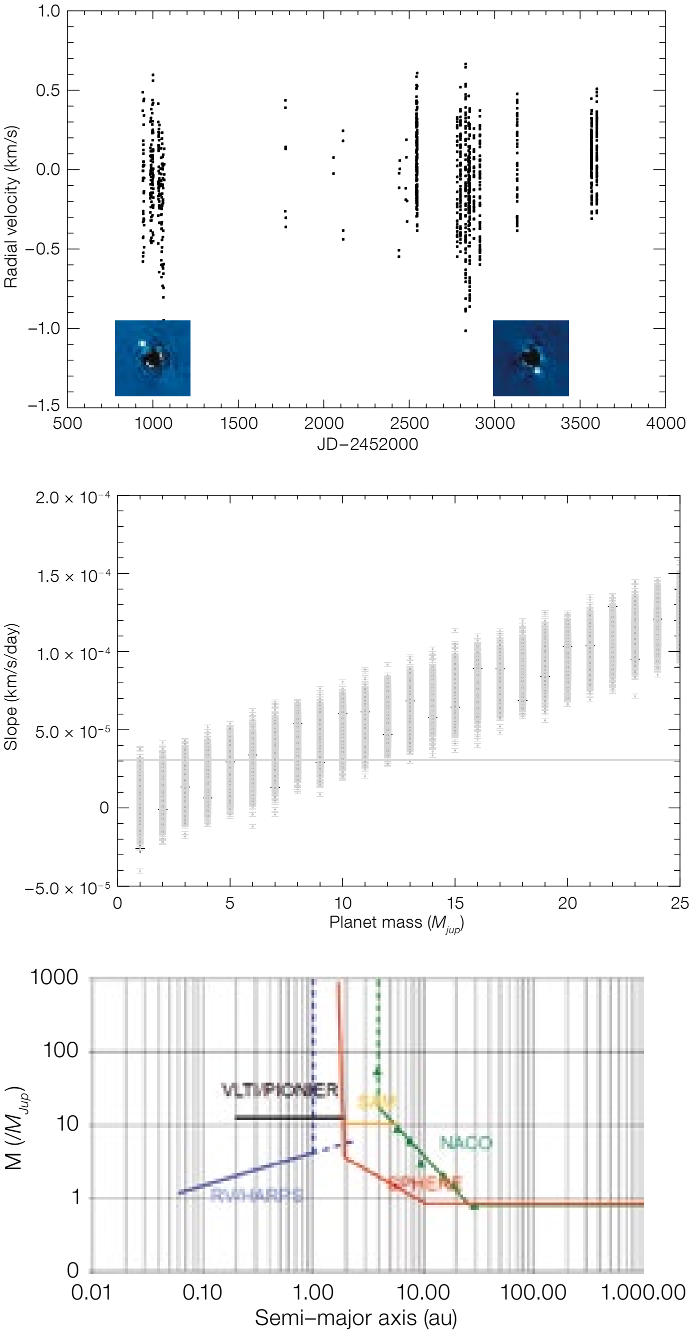

Figure 5. Upper: Radial velocity variations of β Pic (from Lagrange et al., 2012a) observed with ESO 3.6-metre and HARPS are plotted together with the NACO images of β Pic b. Centre: Slope of the radial velocity induced by a planet of different masses with a 7400-day period, similar to that of β Pic b, when using the available data sampling; the horizontal lines indicate the upper level of the slope (3 σ) derived from β Pic radial velocity data. For each mass, the various points correspond to different noise realisations. Lower: Current detection limits in the β Pic system, coupling data from different instruments, especially HARPS, VLT adaptive optics and VLTI Pionier, and showing the potential role of the forthcoming VLT instrument SPHERE.

Solar System, rather than by disc gravitational instability (the latter mechanism being rather inefficient at a few au).

Further imaging at *Ks* (Bonnefoy et al., 2011; see Figure 4) and at 4.0 μm (Quanz et al., 2010) led to mass estimates for β Pic b similar to those deduced from *L´*-band data, again using the hot-start models (Baraffe, 2003). It has to be stressed that the mass determination of β Pic b, as well as those of all other imaged planets, relies on model-dependent brightness–mass relationships. So far, the hot-start models have been used; they assume that the giant planet is formed by the collapse of a gaseous cloud and that the energy released from accretion is entirely converted into heat. The young planet is therefore still quite hot during its first 100 Myr, and within the reach of detection by current/forthcoming imagers, whereas more mature (and colder) counterparts would not be so easily detected. Whether these hot-start models could apply to planets formed by core accretion is obviously questionable.

A first attempt to model core accretion was made by Marley et al. (2007), assuming significant loss of energy during the accretion shock of the gas onto the planet core. This resulted in initial internal entropies much lower than assumed so far and, consequently cooler young giant planets, much less luminous at young ages. However, according to this model, all 12-Myr-old giant planets would be much fainter than β Pic b. Recent, more detailed studies (Mordasini et al., 2012; priv. com.) indicate that the observed luminosity of β Pic b could be compatible with a planet formed with small energy loss during this gas accretion shock. Clearly, current evolutionary models to predict the properties of giant planets still need some tuning; they also need calibrations, i.e. measurements of planet fluxes and independent (astrometric, velocimetric) measurements of their masses. To possibly constrain the mass of β Pic b, we analysed high precision HARPS data collected over eight years since 2003 (Figure 5, top panel) and found that the dynamical mass of β Pic b is less than 10, 12 and 15.5 M_{Jup} if orbiting at 8, 9 and 10 au respectively (Lagrange et al., 2012a). These results illustrate how crucial the combination of radial velocity data and direct imaging might be.

Disc–planet interaction

A subsequent question is whether the β Pic b planet can explain the characteristics of the disc morphology and, in particular, its inner warp. Using the constraints derived from our 2001 dynamical studies, and taking into account the updated mass and age of the system, we found that indeed it could, provided it orbited on a slightly inclined orbit. We recorded new data in which the disc and the planet could be seen simultaneously (to minimise astrometric uncertainties) and that allowed us to conclude that the planet is not orbiting in the plane of the outer disc, but most probably in the warped part of the disc (Lagrange et al., 2012b). Finally, order of scale considerations show that β Pic b could also be responsible for the FEBs at the origin of the replenishment of the disc gas phase, but new modelling is still needed to ascertain this point.

Future work

An unprecedented set of data has been gathered on the β Pic system over some 28 years and remains unique in several aspects. The disc provides the opportunity to study, in great detail, the physical and chemical characteristics of sites of ongoing, or recently completed, planetary formation. Knowledge of the system has improved a lot, but at the same time many questions are still unanswered. What is the origin of the stable gas in the system? What do the dust and gas tell us about planet formation? In that context, a very valuable piece of information is also expected from ALMA, as indicated by the spectacular (yet uncalibrated) test image. How did β Pic b form? Are there other planets in the system, as expected if the observed dust rings/clumps are indeed due to planets? Our exploration of the planet content will significantly improve in the future thanks to forthcoming VLT/SPHERE and Gemini/Gemini Planet Imager high resolution instruments, and to the combination of the results with radial velocity or astrometric data (see Figure 5, bottom panel).

β Pic among other debris discs

β Pic is, so far, the most studied example of the debris discs. Such discs are favourable places to search for planets, especially those around young stars, such as β Pic, as the planets are expected to be brighter than their older counterparts and, unlike younger systems, most of the primordial material has been expelled, or has accreted into planets, and therefore does not set a limit on planet detection. Discs with peculiar structures such as rings with sharp edges or asymmetries and spirals, possibly shaped by planets, are thought to be even more interesting targets, even though we know that other physical effects not involving planets can also lead to the formation of such structures (Takeuchi & Artymowicz, 2001; Lyra & Kuchner, 2012). It is remarkable however that all the stars (as yet only three examples are known) around which relatively close (≤ 120 au) planets have been imaged are surrounded by debris discs: Fomalhaut (Kalas et al., 2008); HR8799 (Marois et al., 2010) and β Pictoris. Thanks to instruments offering increased spatial resolution and/or sensitivities (VLT/SPHERE, the European Extremely Large Telescope and the James Webb Space Telescope), planet searches will become possible for an increasing number of targets, allowing a wider exploration of the diversity of planetary systems and their formation processes.

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Image of the Galactic H II region Sharpless 2-292 (also known as RCW 2 and Gum 1) taken with the MPG/ESO 2.2-metre telecope and the Wide Field Imager. The main source of ionisation of the nebula is the central bright Be star HD 53367. The ionised gas is visible in Hα emission and other filters of this composite image were *B*, *V* and *R*. Further details can be found in Release eso1237.

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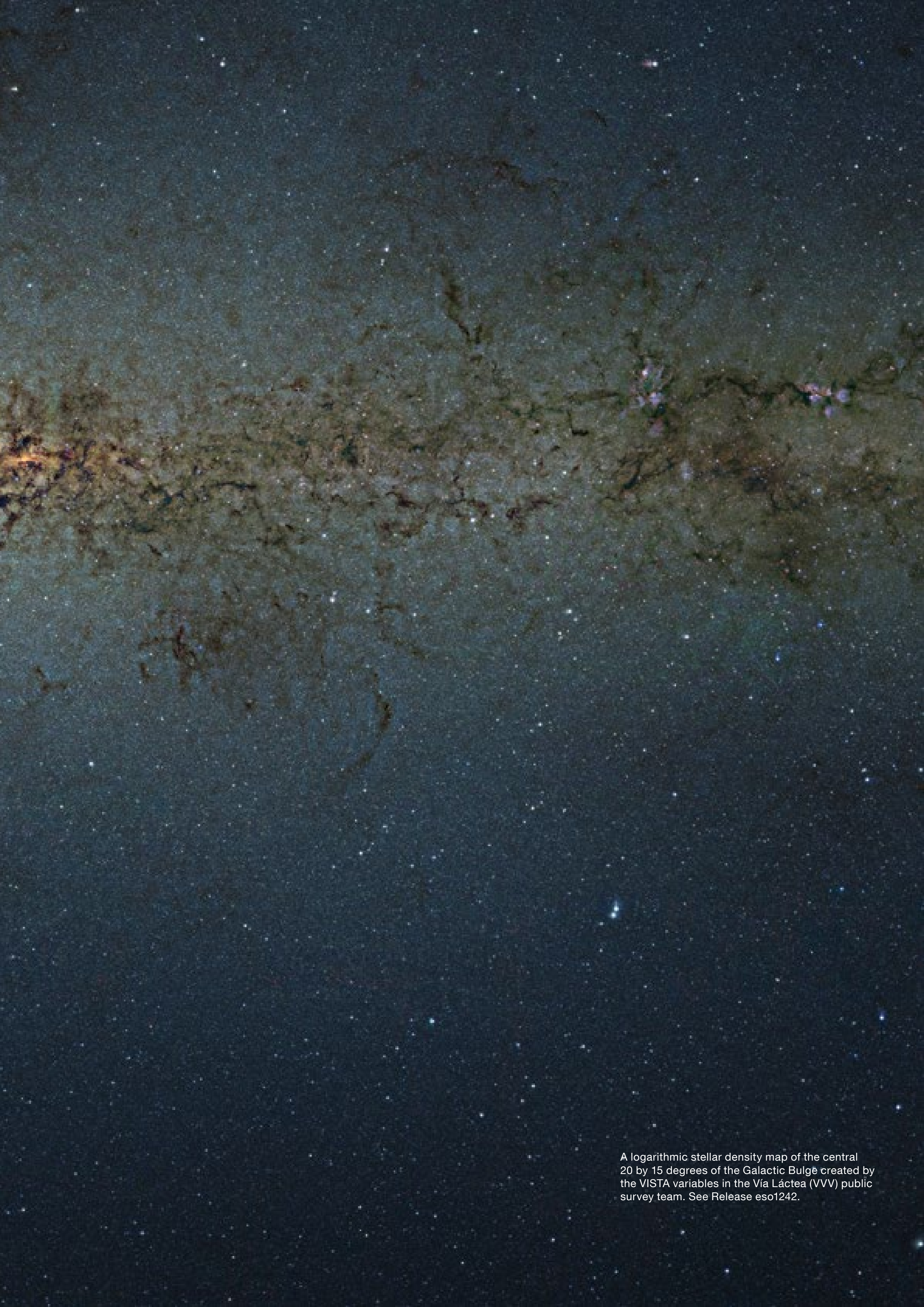

A logarithmic stellar density map of the central 20 by 15 degrees of the Galactic Bulge created by the VISTA variables in the Vía Láctea (VVV) public survey team. See Release eso1242.

RS Puppis: A Unique Cepheid Embedded in an Interstellar Dust Cloud

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The long-period Cepheid RS Pup illuminates its circumstellar dust cloud with a variable flux, and creates spectacular light echoes. Through photometric observations of this phenomenon with NTT/EMMI, and polarimetric imaging with VLT/FORS, we have derived the geometric distribution of the scattering dust and the total mass of the nebula. We conclude that the dust was not created by mass loss from the Cepheid, but is most probably a remnant of the interstellar material from which the Cepheid formed.

Light echoes: a stimulating geometrical puzzle

Cepheids are historically the most important class of variable stars, thanks to the relation between their pulsation period and absolute luminosity; that relation played a key role in the discovery of the expansion of the Universe. In particular, long-period Cepheids are so bright that they can be observed in very distant galaxies, and act as standard candles to measure their distances. With its 41.4-day pulsation period, RS Pup is one of the brightest known long-period Cepheids in the Galaxy. But this star also stands out as the only known example of the intimate association of a Cepheid with a dust cloud (Figure 1, left). The discoverer of the nebula of RS Pup, Bengt Westerlund (Westerlund, 1961), has already remarked that "the nebula may be large enough to permit the detection of possible variations in its intensity distribution due to the light variations of the star". The existence of this "light echo" phenomenon, created by the propagation of the luminosity variations of the star in the nebula, was subsequently confirmed by Havlen (1972).

The geometrical configuration of the light echo phenomenon is somewhat counter-intuitive, as its morphology depends both on the three-dimensional distribution of the scattering material, and the position of the observer (see, e.g., Sugerman [2003] for details). Figure 2 shows a schematic view of the propagation of the maximum light wavefronts emitted by RS Pup into space. The geometrical shape of these wavefronts is almost a paraboloid (rigorously, they are very elongated ellipsoids). Their intersection with a thin light-scattering dust layer produces "light rings", such as those visible in Figure 1 (right). For the nebula of RS Pup, the irregular distribution of the dust results in imperfectly circular rings.

Light echoes are particularly interesting as they may provide a means of measuring the geometrical distance to the central star. For a Cepheid like RS Pup, such an independent distance measurement is of great interest for the calibration of the Period–Luminosity relation. From imaging of the light echoes with the ESO Multi-Mode Instrument on the New Technology Telescope (NTT/EMMI), Kervella et al. (2008) derived its distance based on the assumption that the observed nebular features are located close to the plane of the sky. However, as argued by Bond & Sparks (2009), this simplifying assumption could lead to a significant bias on the determined distance. To derive the distance of RS Pup unambiguously using its light echoes, we therefore need first to determine the three-dimensional geometry of the dust nebula.

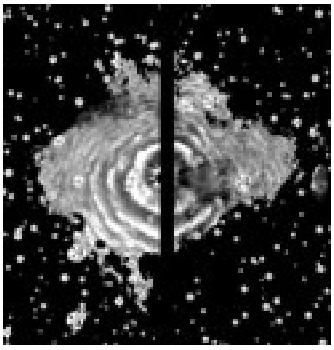

Figure 1. Left: Three-colour *BVR* composite image of the nebula of RS Pup obtained using the NTT/EMMI instrument. Upper: Ratio of two images obtained a few days apart, showing the light echoes (from Kervella et al., 2008).

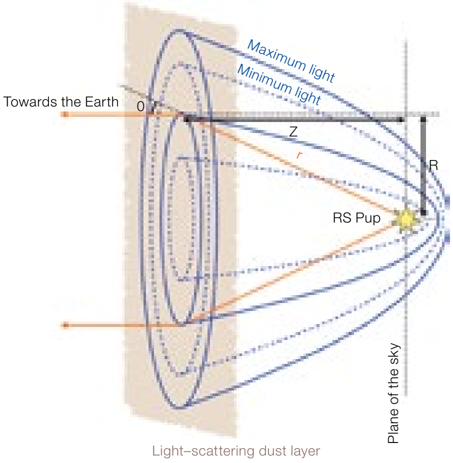

Figure 2. Geometry of the propagation of the maximum and minimum light wavefronts in space, for an observer located to the left of the figure.

The first piece of information on the dust geometry is provided by the high contrast of the light echoes in the nebula. The relative amplitude of the photometric variation on any part of the nebula is comparable to the variation of the central star itself. As shown in Figure 3, the amplitude of the luminosity variation of RS Pup is relatively large, particularly in the *B*-band (there is almost a factor of five between the minimum and maximum luminosity). The fact that this high amplitude is preserved in the scattered light indicates that the dust is confined in a geometrically thin veil, as a thick layer would result in the out-of-phase superposition of different wavefronts, and therefore the disappearance of the echoes.

To determine the spatial shape of this dust layer, we used the particular linear polarisation signature of the scattering of light by dust grains. The degree of linear polarisation ρ of the scattered light is linked to the scattering angle θ, i.e., the angle between the incident and emergent directions of the photon (see Figure 2). The maximum polarisation is ~ 50% for a scattering angle of $\theta = 90°$, i.e. for scattering material located in the plane of the sky, and a zero polarisation degree is obtained for forward or backward scattering ($\theta = 0$ or $180°$). We used the empirical calibration of the $\rho(\theta)$ relation obtained by Sparks et al. (2008) from the light echo of the cataclysmic variable star V838 Mon. This relation is very close to the theoretical scattering law for very small dust grains (Rayleigh scattering). From a measurement of ρ, we can therefore retrieve the scattering angle θ.

The projected angular separation R is directly measured in the images, and by combining R and θ, we can estimate the altitude of the scattering material $Z = R/\tan(\theta)$ above the plane of the sky (i.e. the imaginary plane orthogonal to the line of sight, located at the distance of RS Pup). It should be noted that backward scattering is much less efficient than forward scattering, and we therefore observe essentially the material located between RS Pup and us, while the dust located behind RS Pup will be very much fainter.

To measure θ for each point of the nebula, we took advantage of the polarimetric imaging mode of the FORS spectrograph on the Very Large Telescope (VLT/FORS; Kervella et al., 2012). The resulting polarimetric images allowed us to derive a map of the degree of linear polarisation over the nebula (Figure 4, upper right). The altitude Z of the dust layer relative to the plane of the sky is obtained in the same physical units as the projected distance R. As a consequence, to obtain the altitude in absolute linear units, we have to assume the distance of the star to be 1.8 ± 0.1 kpc (estimated from indirect techniques). The resulting altitude map is presented in Figure 4 (lower left).

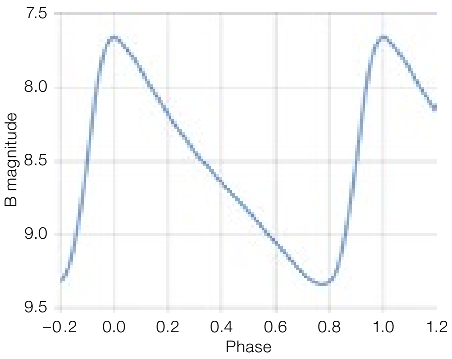

Figure 3. The light curve of RS Pup in the *B*-band (data from Berdnikov et al. [2009]).

The light-scattering material surrounding RS Pup appears to be spread over an irregular surface, with no well-defined central symmetry relative to the Cepheid. The visual shape of the nebula (Figure 4, upper left) appears more symmetric, due to the higher efficiency of forward

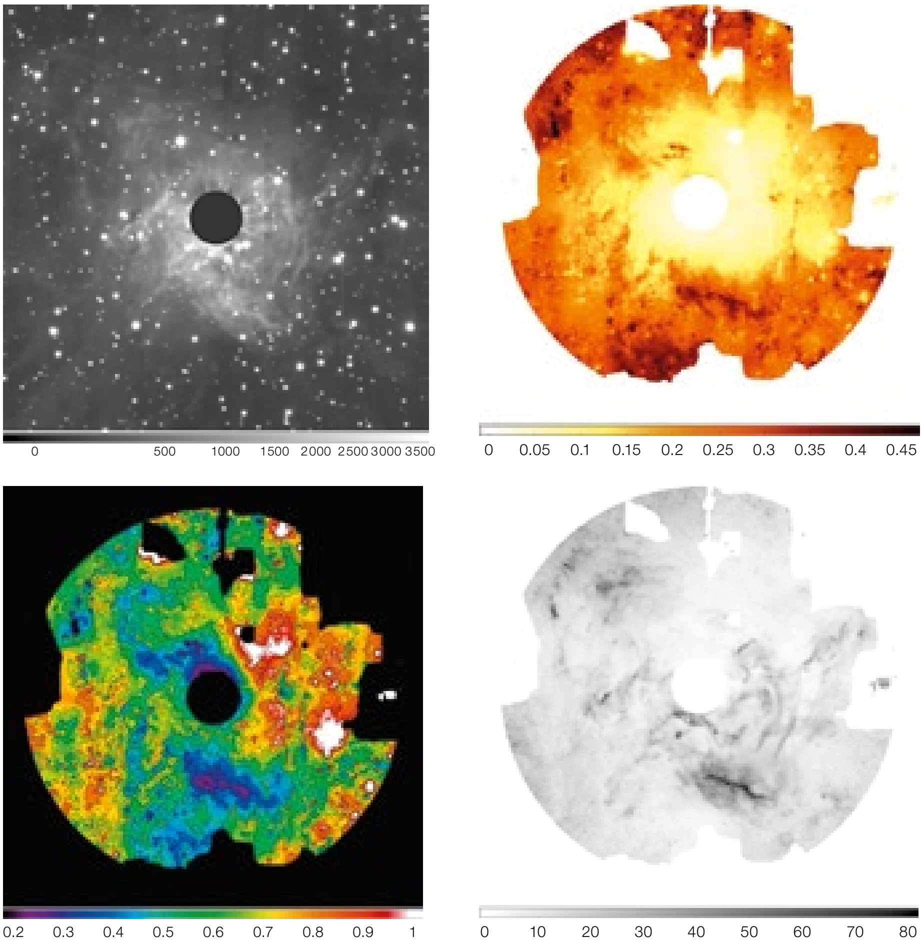

Figure 4. Upper left: FORS+EMMI combined intensity image of the nebula of RS Pup in the *V*-band (field of view 4 by 4 arcminutes). Upper right: Map of the degree of linear polarisation measured with FORS. Lower left: Altitude of the light-scattering dust layer in front of RS Pup, relative to the plane of the sky (in parsec). Lower right: Density of the scattering material (in units of 10^{54} H atoms per square arcsecond, i.e. the equivalent number of hydrogen nucleons in the scattering material). From Kervella et al. (2012).

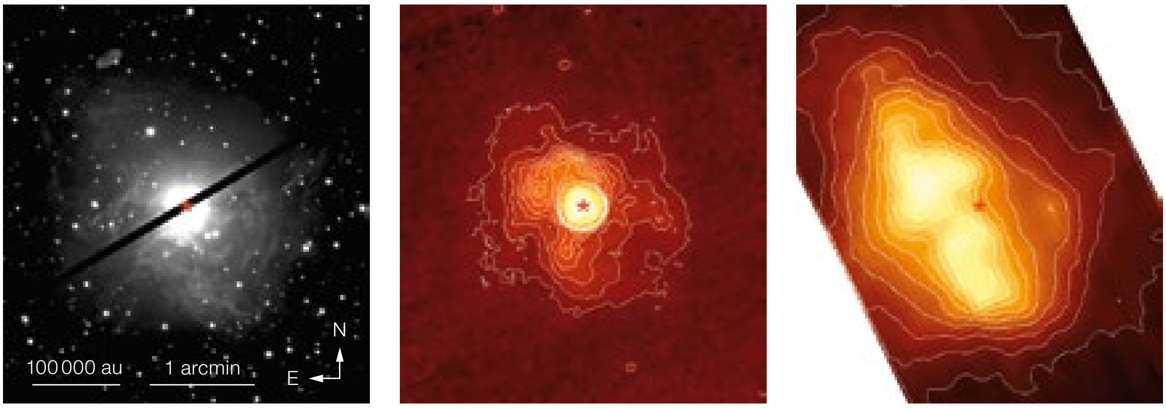

Figure 5. Images of the nebula surrounding RS Pup in the *V*-band (EMMI, left), and Spitzer infrared images at 24 μm (middle) and at 70 μm (right), on the same spatial scale. The position of the Cepheid is marked with a star symbol (from Kervella et al., 2009).

scattering that tends to emphasise the material located close to the line of sight. High degrees of linear polarisation (~ 50 %) are observed for several nebular knots, showing that their position is close to the plane of the sky (represented in blue in Figure 4, lower left).

Origin of the dust nebula

As we have determined the geometry of the dust layer, it is now possible to compute the physical distance *r* between each point in the nebula and the Cepheid ($r^2 = Z^2 + R^2$, Figure 2). Knowing *r* and the scattered light flux, we can deduce the local density of the scattering material at any location on the nebula. Figure 4 (lower right panel) shows the resulting density map.

Compared to Figure 4 (upper left), the highest densities do not generally correspond to the brightest parts of the nebula. This is easy to understand as the scattered light flux depends both on the scattering angle θ and the linear distance *r* between the star and the dust. A particularly prominent feature is the “ridge” structure visible south of RS Pup. This filamentary dust cloud is located close to the plane of the sky, with a slight inclination, as shown in Figure 4 (lower left).

From the density map, assuming standard interstellar dust properties, we estimate the total mass of the light-scattering dust to be 2.9 ± 0.9 $M_\odot$. This value should be regarded as a lower limit to the true mass of the nebula, as we sample only the material in front of RS Pup, while dust is likely to be present also behind the plane of the sky. In addition, we include in this figure only the material that is illuminated by RS Pup within 1.8 arcminutes from the star. FORS and EMMI long exposures show faint nebular extensions far beyond this region, at least up to a radius of 3 arcminutes. These distant parts are too faint to measure their degree of linear polarisation.

This determined mass corresponds only to the light-scattering dust, but does not include the gaseous component, that is transparent to light. The typical gas-to-dust mass ratio in the Galaxy is ~ 100. The total mass of the nebula, including the gas, is therefore approximately 300 solar masses. Such a high mass is clearly incompatible with the scenario that RS Pup created the nebula through mass loss (the mass of the Cepheid itself is estimated to be ~ 13 $M_\odot$). Most of the dust observed in scattered light therefore appears to be of interstellar origin. The higher density dusty environment in which RS Pup is presently located could either be the remnant of the molecular cloud from which the star formed, or unrelated interstellar material into which RS Pup is temporarily embedded, due to its motion in the Galaxy. The thin veil geometry of the dust layer is probably created by the radiation pressure from the extremely bright Cepheid (~ 17 000 $L_\odot$), that sweeps the interstellar dust away from the star.

Prospects

Thanks to our EMMI and FORS observations, we have established that RS Pup did not create the nebula in which it is currently embedded. This peculiar configuration provides a natural explanation to the scarcity of similar Cepheid–nebula associations, and also confirms that the presence of such nebulae is probably not a significant source of photometric bias for the calibration of the Cepheid Period–Luminosity relation. Our determination of the three-dimensional distribution of the dust will also allow us to use the phase of the light echoes to determine unambiguously the distance of RS Pup. This is a particularly important piece of information for this rare, long-period Cepheid, which is a typical example of the stars used to determine extragalactic distances.

As RS Pup illuminates the nebula, part of its radiation is absorbed by the dust, which warms up and emits radiation by itself. As the dust is still rather cold (~ 40–60 K; Barmby et al., 2011), this emission occurs in the infrared domain, but it is clearly observable in the Spitzer images presented in Figure 5. With observations of both the scattered light in the visible, and the thermal emission in the mid-infrared domain, together with the three-dimensional map of the dust distribution, RS Pup is a particularly promising test case for the study of interstellar dust properties.

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COSMOGRAIL: Measuring Time Delays of Gravitationally Lensed Quasars to Constrain Cosmology

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COSMOGRAIL is a long-term programme for the photometric monitoring of gravitationally lensed quasars. It makes use of several medium-size telescopes to derive long and well-sampled light curves of lensed quasars, in order to measure the time delays between the quasar images. These delays directly relate to the Hubble constant H_0, without any need for secondary distance calibrations. COSMOGRAIL was initiated in 2004, and has now secured almost a decade of data, resulting in cosmological constraints that are very complementary to other cosmological probes.

We live in a golden age for observational cosmology, where the Universe seems fairly well described by the Big Bang theory. This concordance model comes at the price of evoking the existence of the still poorly known dark matter and even more mysterious dark energy, but has the advantage of describing the large-scale Universe using only a handful of parameters. Determining these parameters, and testing our assumptions underlying the concordance model, requires cosmological probes — observations that are sensitive tests to the metrics, content and history of the Universe. They include standard candles like Cepheid variable stars or Type Ia supernovae, standard rulers like baryonic acoustic oscillations, or involve the measurement of the cosmic microwave background as well as weak gravitational lensing over large areas of sky, to name just a few.

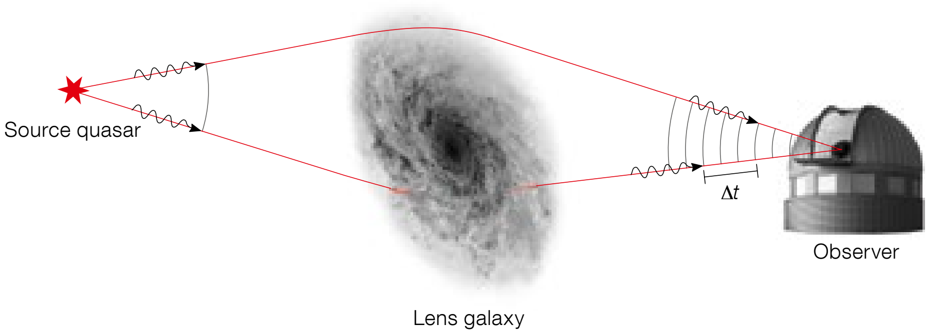
In practice, these probes are all sensitive to different combinations of cosmological parameters, hence making it mandatory to combine them together in the best possible way. Comparisons of different cosmological probes also test their consistency, and allow us to check for systematic errors in the measurements. Strong gravitational lensing time delays offer one of these cosmological probes, whose strength has so far been underestimated due to the lack of adequate data and tools.

Strong lensing time delays

Gravitational lensing describes the deflection of light by a gravitational field. In the case of a particularly deep potential well, the phenomenon can be spectacular: a luminous source in the background of a massive galaxy (the gravitational lens) can be "multiply imaged" and several distorted images of it are seen around this galaxy. This phenomenon is known as "strong gravitational lensing" and has several interesting cosmological applications. One of them uses the measurement of the "time delays" between the multiple images of a gravitationally lensed source.

As illustrated in Figure 1, the different optical paths to the multiple images of a gravitationally lensed source differ in length. In addition, the photons propagate through different depths of the potential well of the lensing galaxy. As a consequence, the time it takes a photon to reach the observer along each path is different. If the lensed source is photometrically variable, like a quasar, the light curves measured for the lensed image will appear shifted in time by some amount called the time delay. This delay is directly related to the size of the gravitational lens system, which essentially depends on the expansion rate of the Universe, that is, the Hubble constant H_0 (Figure 1). This straightforward "time

Large Universe, low H_0, large time delay



Small Universe, high H_0, small time delay

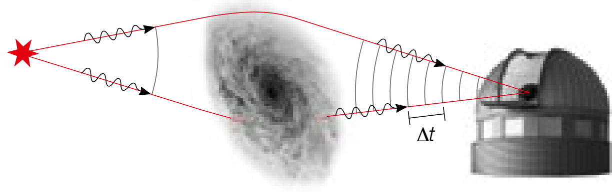


Figure 1. Schematic showing how the time delay Δt between two images of a gravitationally lensed source depends on the scale of the gravitational lens system, and hence on H_0. Illustration inspired by Narayan & Bartelmann (1996).

delay method" to constrain H_0 had already been proposed by Sjur Refsdal in 1964 (Refsdal 1964), well before the first strongly lensed quasar was even discovered by Walsh, Carswell and Weymann in 1979 (Walsh et al., 1979).

The COSMOGRAIL monitoring programme

Obtaining accurate measurements of time delays is challenging, but has recently proved possible. The COSMOGRAIL programme (COSmological MOnitoring of GRAvItational Lenses) is a long-term photometric monitoring programme designed to reach this goal. Initiated and led by the Laboratory of Astrophysics of the École Polytechnique Fédérale de Lausanne, it combines the strengths of medium-size telescopes available for long periods of time, with the collecting power and spatial resolution of the ESO Very Large Telescope (VLT) and the Hubble Space Telescope (HST). The medium-size telescopes are needed continuously over several years in order to measure the time delays, while the VLT and HST are needed punctually to obtain deep and sharp observations in order to constrain the lens models. Indeed, the measured time delays can only be turned into cosmological inference given accurate lens mass models.

COSMOGRAIL uses several medium-size telescopes to carry out a long-term optical photometric monitoring of selected lensed quasars. Our set of monitoring telescopes includes the Swiss 1.2-metre Leonhard Euler Telescope at the ESO La Silla Observatory (shown in Figure 2), the 2-metre Himalayan Chandra Telescope (HCT) in India, the 1.5-metre telescope of the Maidanak Observatory (Uzbekistan), and, with a smaller contribution, the 1.2-metre Mercator telescope on La Palma (Canary Islands, Spain). In 2010, COSMOGRAIL joined forces with the group of Christopher S. Kochanek (Ohio State University, USA) who employs the 1.3-metre Small & Moderate Aperture Research Telescope System (SMARTS) at the Cerro Tololo Inter-American Observatory in Chile. The resulting collaboration is now the largest quasar lens monitoring programme worldwide.

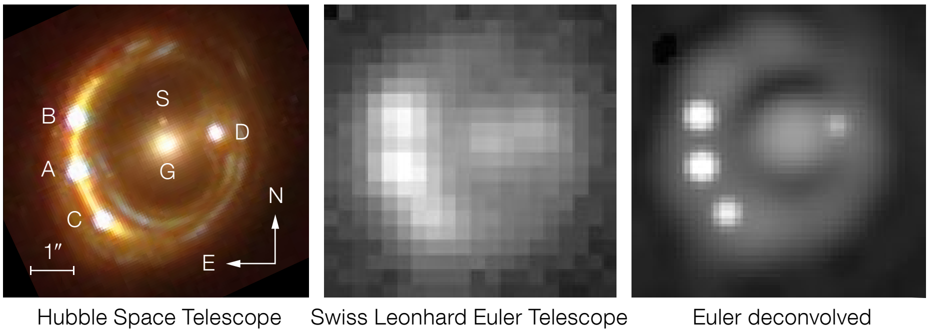
Figure 2. The Swiss 1.2-metre Leonhard Euler Telescope at the La Silla Observatory, used for several long-term observational programmes, from exoplanets to cosmology. Euler is the main telescope of the COSMOGRAIL collaboration.

Light curves and time delay measurement

With these telescopes, we have gathered almost a decade of photometric data with a temporal sampling of between two and five days depending on the targets. As the lensed images of a typical quasar have angular separations on the order of an arcsecond, our reduction pipeline involves an image deconvolution algorithm that can carry out photon-noise limited photometry of heavily blended point sources (e.g., Magain et al., 1998). Figure 3 shows an example of such a deconvolution, in the case of the quadruply lensed quasar RX J1131–1231. The quasar is at a redshift of $z = 0.658$ whilst the lensing galaxy is at $z = 0.295$. Photometry of the deconvolved images allows the use of data spanning a broad range of quality, from 0.8 to 2.0 arcseconds for point source full width at half maximum (Tewes et al., 2012b).

The light curves for the four lensed images of RX J1131–1231 are presented in Figure 4, where a time delay of image D of about 100 days is striking. With a closer look, however, the curves do not perfectly overlap, even when shifted by the appropriate delays. Some of the mismatches are conspicuous, on time scales of a few weeks to several years. These discrepancies result from quasar micro-

Figure 3. The quadruply lensed quasar RX J1131–1231, seen from space with HST in a colour composite (left; from Claeskens et al., 2006) and from the ground in the *R*-band with the Swiss 1.2-metre Leonhard Euler telescope at La Silla (middle). The right panel shows the deconvolution of the Euler data, as used for our photometry.



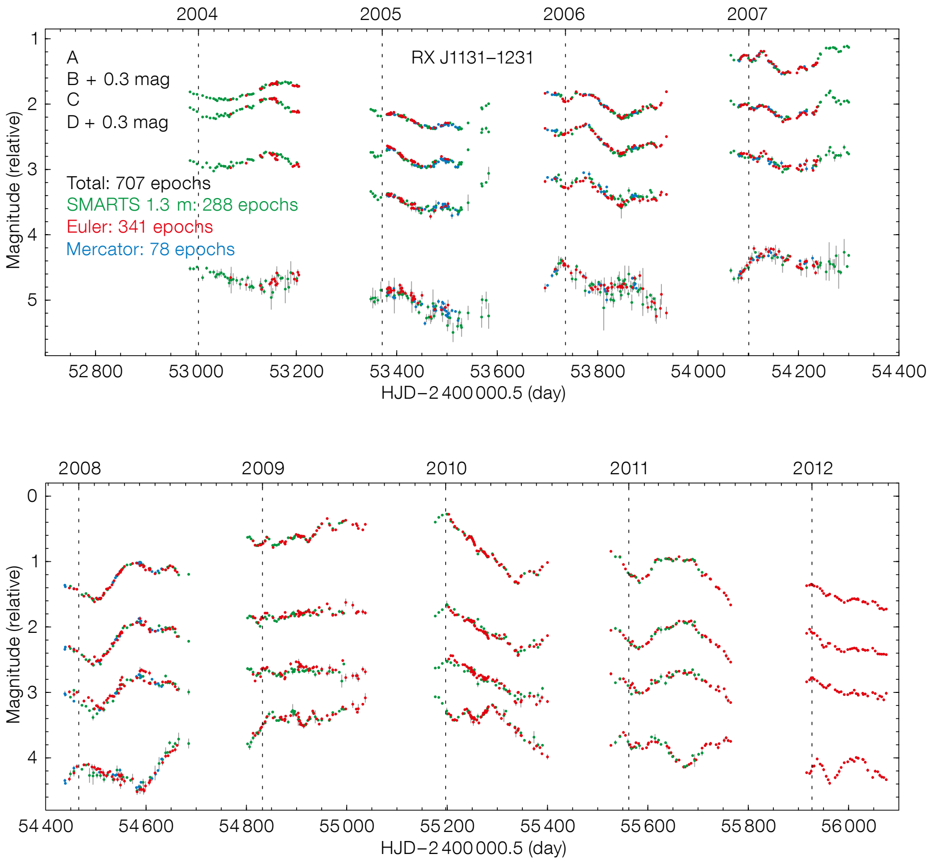


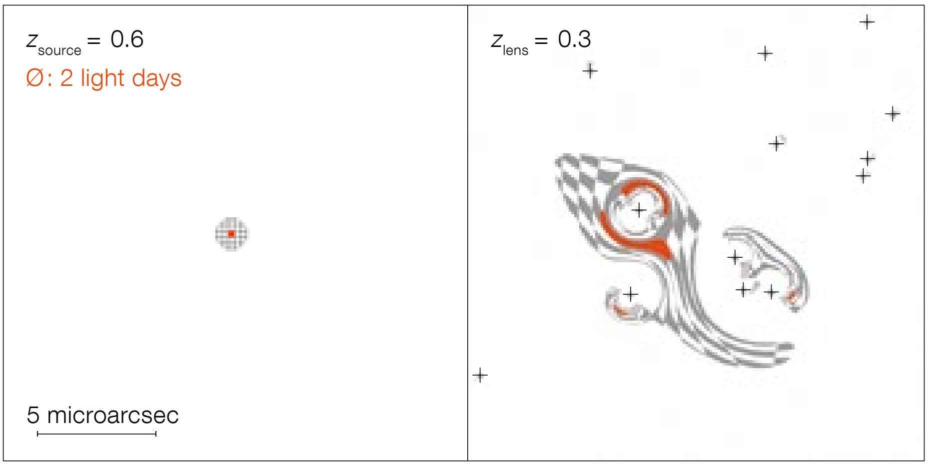
Figure 4. *R*-band light curves for the four lensed images of the $z = 0.658$ quasar RX J1131–1231. The photometry for the 707 epochs is obtained from deconvolution photometry. The three colours used to display the data points correspond to four different instruments/telescopes.

lensing: individual stars of the lensing galaxy, in the foreground of a given quasar image, act as additional gravitational lenses and further distort and magnify the latter. This effect is illustrated in Figure 5. While the image distortions remain undetectable even at high spatial resolution, the apparent increase in size (magnification) yields a change in total flux, since gravitational lensing conserves surface brightness. The stars move relative to the line of sight on orbits within the galaxy and the resulting fluctuating magnifications significantly perturb the light curves of the quasar images. The microlensing perturbations seen in each light curve are uncorrelated, as each quasar image is magnified by different stars of the lensing galaxy.

While quasar microlensing is highly interesting on its own and can be used as a natural telescope to zoom into the inner parts of quasar accretion discs (for a review, see, e.g., Schmidt & Wambsganss, 2010; Eigenbrod et al., 2008; and also ESO Release eso0847[1]), it also perturbs the time delay measurement. We have therefore devised a set of new numerical techniques to measure the time delays and to accurately estimate their uncertainties, even in the presence of microlensing variability (Tewes et al., 2012a). Applying these techniques to RX J1131–1231, the delays between the three close images A, B and C are compatible with being zero, and we measure the delay of image D to be 91 days, with a fractional uncertainty of only 1.5 % (1σ), including systematic errors (Tewes et al., 2012b). Our monitoring data, deconvolution photometry technique and "curve shifting" methods are now all sufficiently tested and accurate that the uncertainties in the time delay measurements no longer dominate the total error budget of the cosmological inferences, as has long been the case.

Follow-up observations for accurate lens models

While medium-size telescopes are used to measure the delays, VLT spectroscopy of the lensing galaxy and of other massive intervening galaxies along the line of sight is a key step in building the models needed to interpret the delays. In parallel,



Unlensed quasar

Macro & microlensed image

Figure 5. Toy model of quasar microlensing by stars of a galaxy at $z = 0.3$, which acts as a gravitational lens on a quasar at $z = 0.6$. The represented field of view is only 20 micro-arcseconds on a side. At such a huge spatial resolution, we clearly see the original quasar image (left) distorted and magnified by microlensing due to solar-mass stars, represented by the + symbols (right). With real observations, we can only observe the integrated flux of this scene.

deep HST or ground-based adaptive optics imaging is crucial to reveal the Einstein rings formed by the host galaxies of the lensed quasars. These highly distorted extended images, if bright enough, strongly constrain the radial mass profile of the lensing galaxy, and therefore are a key ingredient in linking the delay measurements to cosmology.

By building a state-of-the-art lens model of RX J1131–1231, Suyu et al. (2012) show that our delays of the single lens RX J1131–1231 already lead to impressive constraints. The resulting cosmological parameter inference depends on the assumed cosmological model. For the case of a spatially flat universe in which the behaviour of dark energy is parametrised by its equation-of-state parameter, w, the combination of RX J1131–1231 with the WMAP7 dataset gives: $H_0 = 80.0^{+5.8}_{-5.7}$ km s^{-1} Mpc^{-1}, $\Omega_{de} = 0.79 \pm 0.03$, and $w = -1.25^{+0.17}_{-0.21}$. Interestingly, this analysis was carried out with a purposely "blind" approach. The absolute inferred values of the cosmological parameters were revealed only once all members of our collaboration were satisfied with their part of the data analysis, and these results were then published without any further modification. The combination of RX J1131–1231 with only one other quasar lens — also performed in Suyu et al. (2012) — further reduces these uncertainties, as all known systematic errors are under control.

Prospects

COSMOGRAIL illustrates very well the complementarity between astronomical facilities and combines many techniques of optical astronomy: (1) medium-size telescopes to carry out the long-term photometric monitoring; (2) HST or VLT with adaptive optics to constrain the lens models using high resolution imaging; (3) deep VLT spectroscopy to measure redshifts and to constrain the dynamical mass model. In the future, JWST and the E-ELT will allow the 2D velocity field of the lensing galaxies to be mapped and Einstein rings to be imaged with exquisite quality, especially using image deconvolution techniques.

With the large number of lensed quasars that remain to be discovered in forthcoming surveys, notably in the southern hemisphere, the time delay technique has a promising future in providing stringent and independent constraints on cosmology. In the mean time, the ~ 20 currently monitored COSMOGRAIL targets and their follow-up with present-day facilities will already lead to results that are highly competitive with much more expensive cosmological probes.

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Links

[1] ESO release on microlensing in the Einstein Cross: http://www.eso.org/public/news/eso0847/

ESO/P. Grosbol

Near-infrared representative colour image of the nearby prototypical barred spiral galaxy NGC 1300 taken with HAWK-I on the VLT. The filters used were *Y* (shown here in dark blue), *J* (in light blue), *H* (in green), and *K* (in red). This galaxy of type SB is at a distance of about 19 Mpc, has a central supermassive black hole and the spiral arms show many young clusters. The image size is about 6.4 arcminutes. More details can be found in Release eso1042.

Breaking Cosmic Dawn: The Faintest Galaxy Detected by the VLT

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Astronomers have been debating the origin of galaxies for centuries and the timeline of the evolution is now well established. However, despite the success of galaxy formation models, some questions remain largely unanswered. Chief among them is how the first galaxies formed. When the Universe was in a highly opaque state, these first galaxies most likely cleared the cosmic fog and broke the cosmic dawn. However, there are large uncertainties as to how this transition occurred and what the exact role of the first galaxies was. Using galaxy clusters as cosmic telescopes that magnify background objects, we were able to detect hydrogen emission from a galaxy at a redshift of $z = 6.740 \pm 0.003$ using FORS2 on the VLT. To date, this is the faintest galaxy with a successfully measured spectrum and as such an important beacon for cosmic dawn.

Cosmic dawn through cosmic telescopes

The cosmic Dark Ages are thought to have ended around 500 million years after the Big Bang when early light sources produced enough energetic photons to ionise the neutral hydrogen, making the Universe transparent to visible light. This era is referred to as reionisation and is also the era of the formation of the first galaxies. But when exactly did reionisation occur and how long did it last? What were the sources responsible for ionising the neutral gas? Was it the first galaxies? Now, for the first time, we can peer far enough into space to detect these galaxies spectroscopically and answer these questions.

Observations of galaxies at these early times are challenging, not only due to the large distance to these objects, but also due to their lower luminosity (galaxies had fewer stars when they first formed). The quest to discover the most distant (i.e., first) galaxies has advanced rapidly in the last decade. With the help of a galaxy cluster acting as a cosmic telescope and magnifying the background Universe, we have observed the faintest galaxy ever detected spectroscopically at these extremely large distances. It was detected using the FORS2 spectrograph on the Very Large Telescope (VLT). With an extremely long exposure time (16 hours on a mask, a total of 22 hours of observing time) and assisted by nature's own telescope (The Bullet Cluster) we were able to push to the limits of the light-gathering power of the VLT which allowed us to detect Lyman-α emission from this "normal" (i.e., not ultraluminous) galaxy (Bradač et al., 2012).

Beyond simple counting

Detection of high-redshift galaxies is performed by searching for the redshifted Lyman break using broadband photometry (Steidel et al., 1996). These so-called Lyman Break Galaxies (LBGs, see e.g., Vanzella et al., 2009) are the best studied and the largest sample of galaxies at redshifts $z > \sim 5$. One can identify $z \approx 5$ objects by their non-detection in the *V*-band and blueward: such objects are referred to as *V*-band dropouts. Similarly, objects at $z \approx 6$ are associated with *i*-band non-detection, $z \approx 7$–8 with *z*-band, and $z > \sim 8$ objects would be observed as *J*-band dropouts. Substantial progress has been made in detecting $z > \sim 7$ galaxies using the dropout technique (Steidel et al., 1996), both in blank fields (the Hubble Ultra-Deep Field [HUDF] and the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey [CANDELS]; e.g., Bouwens et al., 2012), and behind galaxy clusters (e.g., Hall et al., 2012). One of the most obvious limitations of the dropout technique, however, is that unambiguously confirming the object's redshift usually requires spectroscopic follow-up. This is hard to do for the typically faint high-*z* sources.

However much more important than the redshift confirmation, spectroscopy provides information on properties of the interstellar and intergalactic media (ISM and IGM). In particular, Lyman-α emission from sources close to the reionisation era is a valuable diagnostic, given that it is easily erased by neutral gas within and around galaxies. The observed strength of Ly-α in distant galaxies is a gauge of the time when reionisation was completed (Robertson et al., 2010). Furthermore, we expect Ly-α Emitters (LAEs) to be predominantly dust-free galaxies; hence their numbers should increase with redshift until the state of the IGM becomes neutral, at which point their numbers should decline.

A powerful way to detect emission lines from faint sources is to use galaxy clusters as cosmic telescopes (e.g., Treu, [2010] for a recent review). Gravitational lensing magnifies solid angles while preserving colours and surface brightness. Thus, sources appear brighter than in the absence of lensing. The advantages of cosmic telescopes are that we can probe deeper (due to magnification), sources are practically always enlarged and identification is further eased if sources are multiply imaged. Typically, one can gain several magnitudes of magnification, thus enabling the study of intrinsically lower luminosity galaxies that we would otherwise not be able to detect with even the largest of current telescopes.

The combined power of VLT and the "Silver Bullet"

Our targets were selected from deep Advanced Camera for Surveys (ACS) and Wide Field Camera 3 (WFC3) data, both on the Hubble Space Telescope (HST). Ten z-band dropouts were found by Hall et al. (2012). The aim of the VLT programme 088.A-0542 (PI Bradač) was to target all these extraordinary targets with the FORS2 spectrograph. Ordinarily the hope of detecting any of these sources even with a programme of 22 hours would be impossible, as their intrinsic magnitudes are $H > 27$ AB mag. However with the help of magnification from the Bullet Cluster, which is one of the best cosmic telescopes (due to its large mass and elongation, the magnifications are large), the observed magnitudes of these ten sources are $H = 25$–27 AB mag. Of course, this does not make the observing easy *per se*!

Out of the ten z-band dropout candidates targeted, we detected an emission line at 9412 Å with 5σ significance (see Figure 1) in one target. The line is detected in two different FORS2 masks and is broader than cosmic rays or residuals due to sky subtraction; hence we are confident that the line is not an artefact (see Figure 2). No other emission lines are detected in the spectrum (7700–10000 Å); if the object were at lower redshift one would have expected detections of several lines. Based on this lack of other lines and on the spectral energy distribution fit using imaging, we exclude other alternative explanations and conclude that the line is most likely Ly-α at $z = 6.740 \pm 0.003$.

Breaking cosmic dawn

While this work presents only a single spectroscopic detection at $z > 6.5$, it nonetheless probes a very important region of parameter space. The intrinsic (unlensed) line flux of this object is ~ 2–3 times fainter than the, until now, faintest spectroscopic detection of an LAE at $z \sim 7$ (Schenker et al., 2012). Its intrinsic H(160W)-band magnitude is $m^{\mathrm{int}}_{H(160W)} = 27.57 \pm 0.17$, corresponding to an intrinsic luminosity of 0.5 L^* at this redshift (see Table 1).

But more important than the record breaking is the fact that these sources are excellent beacons of cosmic

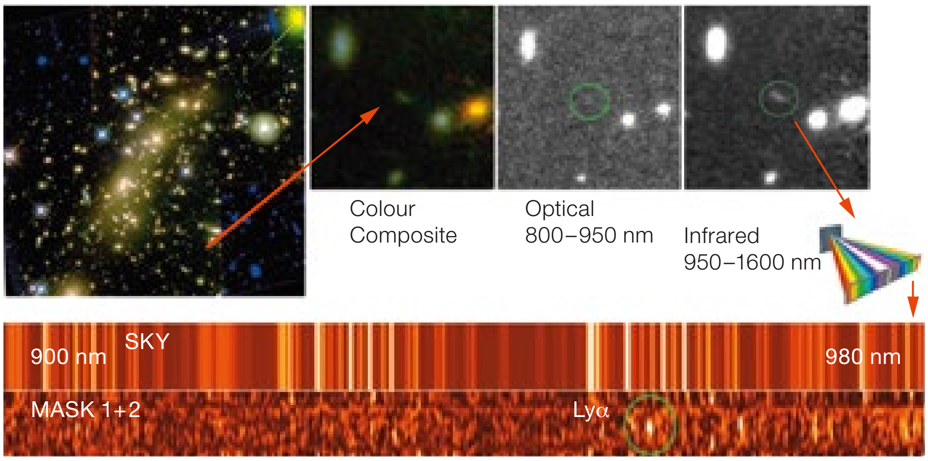

Figure 1. A distant source observed from when the Universe was less than 10% of its current age. The object was found behind the Bullet Cluster. The top row shows an image of the cluster (from HST and WFC3), and a zoom-in on the source in a colour composite from an optical image and an infrared image. The bottom row shows a confirmation spectrum (from FORS2) of the object (sky emission above, object spectrum with Ly-α emission below).

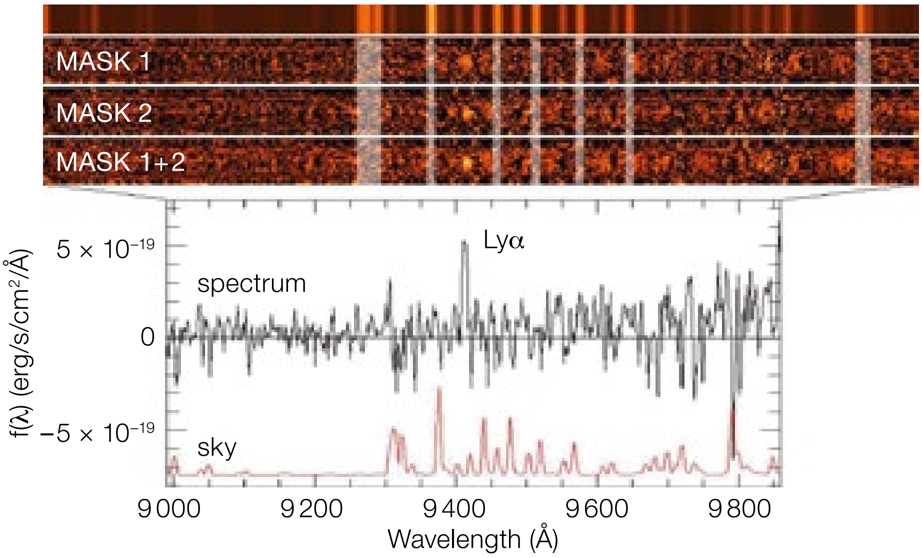

Figure 2. Upper: 2-D spectrum of the dropout galaxy (sky emission above, spectra from individual masks below). Lower: 1-D spectrum of the object. The sky spectrum has been rescaled by a factor of 300 and offset for display purposes, and the regions where skylines are more intense have been marked with transparent vertical bars. Strong residuals in the sky subtraction are evident and correspond to the more intense sky lines. Note that the detected line is broader than residuals of sky subtraction, confirming the reality of the feature.

reionisation. Measuring the rest frame equivalent width (EW) distribution of LAEs as a function of redshift and luminosity is a powerful tool to study reionisation. The EW distribution changes with redshift and source luminosity. Simulations suggest that reionisation is the key factor driving this trend (Dayal & Ferrara, 2012), because, unlike continuum photons, the Ly-α photons that escape the galactic environment are attenuated by the neutral hydrogen in the IGM. With a measurement of the EW distribution in LAEs we can therefore help distinguish between effects of ISM dust and neutral IGM and study the epoch of reionisation (see also Treu et al., 2012).

R.A.	104.63015
Dec.	−55.970482
m_{H160W}	26.37 ± 0.16
m_{J110W}	26.5 ± 0.3
$(J_{110W} - H_{160W})$	0.10 ± 0.15
$(z_{850LP} - J_{110W})$	1.57 ± 0.68
$m_{V606}{}^{a}$	> 28.75 ($t_{exp} = 2336$s)
m_{i775W}	> 28.60 ($t_{exp} = 10150$s)
m_{I814W}	> 29.00 ($t_{exp} = 4480$s)
m_{K_s}	> 26.65 ($t_{exp} = 3.75$hr)
μ	3.0 ± 0.2
$m^{int}_{H(160W)}$	$27.57^{+0.17}_{-0.17}$
λ	9412 Å
z	6.740 ± 0.003
f^{b}	$(0.7 \pm 0.1 \pm 0.3) \times 10^{-17}$ erg/s/cm^2
$f_{\lambda,c}$	$3.3^{+1.0}_{-0.8} \times 10^{-20}$ erg/s/cm^2/Å
f^{int}	$(0.23 \pm 0.03 \pm 0.10 \pm 0.02) \times 10^{-17}$ erg/s/cm^2
$f^{int}_{\lambda,c}$	$1.1^{+0.4}_{-0.3} \times 10^{-20}$ erg/s/cm^2/Å
W_{rest}(Ly-α)	30^{+12}_{-21} Å

Table 1. Imaging and spectroscopic properties of z_{850}-band dropout #10 from Hall et al. (2012).

Our source is the faintest (in line flux) detected thus far and is only the second firm spectroscopic detection of a sub-L^* source at $z > 6.5$ (the other example is also a lensed galaxy at $z = 7.045$ discovered by Schenker et al. [2012]).

Future is made bright by gravitational lensing

With future observations of dropout objects magnified by cosmic telescopes we will further increase the sample. As noted above, measuring the EW distribution of LAEs as a function of redshift and luminosity is a very powerful tool to study reionisation, because the latter is likely to be the key factor driving the trend of EW and luminosity. The main missing observational ingredient is a measurement of the EW distribution for both luminous and sub-L^* galaxies at the redshifts of reionisation; future surveys and facilities will achieve exactly that (e.g., X-shooter on VLT and the new spectrograph MOSFIRE on Keck; see McLean et al., 2010).

Perhaps even more importantly, however, we will also add the wavelength coverage to the observations. A first major improvement will be performed with deep Spitzer observations. There is a large Exploration Science programme approved for Spitzer Cycle 9. The programme (Spitzer UltRaFaint SUrvey - SURF'S Up: Cluster Lensing and Spitzer Extreme Imaging Reaching Out to $z > \sim 7$) will open up new parameter space and will allow us to study the properties (e.g., star formation rates and stellar masses) of a large number of galaxies at $z \sim 7$ for the first time. The presence (or absence) of an established stellar population will be measured in the targets and these findings will allow us to identify the dominant sources of the bulk of ionising photons necessary to drive reionisation.

Furthermore, in the local Universe, star formation is associated with molecular gas, and therefore to understand star formation properties we would like to trace molecules in the cold ISM of high redshift galaxies. ALMA is opening a new window for this endeavour. It is designed to trace molecular gas in galaxies up to $z \sim 5$ in the brightest cases. With the assistance of gravitational lensing, however, these limits can be pushed to the redshifts near reionisation. ALMA's incredible resolution can also be further improved with lensing, giving us access to the sub-kpc regime. This will allow us to characterise the spatial distribution and kinematics of the cold ISM in these extremely high redshift, but not ultra-luminous galaxies, something that would not have been possible without the help of gravitational lensing.

Acknowledgements

Support for this work was provided by NASA through HST-GO-10200, HST-GO-10863, and HST-GO-11099 from STScI, from ASI–INAF, from the NSF, Sloan and Packard Foundations as well as KITP.

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Early ALMA Science Verification Observations of Obscured Galaxy Formation at Redshift 4.7

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Roughly half the star formation in the young Universe is thought to have been heavily obscured by dust and molecular gas. A new suite of facilities and experiments operating at submillimetre through to centimetre wavelengths is providing astronomers with the ability to study galaxies whose star formation and AGN activity would be partially invisible to optical telescopes. The most sensitive of these new instruments is ALMA. Even with only a subset of the final number of 12-metre antennas operational, the first ALMA observations are providing sensitive, unobscured images of the formation of massive galaxies. Observations of BR1202-0725 at $z = 4.7$ are described as an example.

Understanding how galaxies acquire their gas and convert that gas into stars at high redshift represents one of the outstanding problems in galaxy formation. Studies of atomic hydrogen emission at long radio wavelengths are limited to the very nearby Universe, while cold molecular gas may be probed at millimetre and centimetre wavelengths through observations of redshifted CO line emission out to the epoch of reionisation (e.g., Wang et al., 2010). Major advances in our understanding of the cold gas content in the most distant galaxies can be attributed to interferometers like the Plateau de Bure Interferometer (PdBI), the Combined Array for Research in Millimeter-wave Astronomy (CARMA) and the Jansky Very Large Array (JVLA). The Atacama Large Millimeter/submillimeter Array (ALMA) complements these facilities by providing an order of magnitude increase in shorter submillimetre wavelength sensitivity to cold gas and dust in galaxies over a broad range in redshift. Interferometric observations at these higher frequencies are necessary to resolve spatial variations in the cold dust properties and characteristics of atomic and molecular gas in young galaxies, which will ultimately shed light on how they formed their stars early on.

The first single-dish, submillimetre wavelength continuum observations of cold dust in high-redshift quasars and massive starburst galaxies demonstrated that the formation of these objects can be accompanied by large quantities of dust that may be heated by star formation and/or active galactic nucleus (AGN) activity, leading to high far-infrared luminosities for the most extreme objects (e.g., Omont et al., 1996). These early studies helped to motivate the need for higher spatial resolution imaging with facilities like ALMA, which will be used to constrain the source of the dust heating. Fuelled by high molecular gas fractions (Daddi et al., 2010; Tacconi et al., 2010), star formation in young galaxies is also accompanied by strong emission in far-infrared lines like the 157.7 μm [C II] line. This emission is believed to trace photon-dominated regions and the cold neutral medium, and has now been studied by the Infrared Space Observatory (ISO) and Herschel in large samples of star-forming galaxies and AGN in the nearby Universe (e.g., Genzel & Cezarsky, 2000; Sargsyan et al., 2012) to provide an unobscured probe of star formation activity. [C II] line emission is being detected in high-redshift galaxies between $z \sim 1$ and 7 (e.g., Venemans et al., 2012), confirming its usefulness as a tool to study star formation and the kinematics of distant galaxies.

ALMA commissioning observations

Located at an elevation of 5000 metres in the Chilean Atacama Desert, ALMA is the largest submillimetre and millimetre wavelength telescope in the world. Part of the commissioning and science verification phase involves demonstrating the efficacy of various calibration-related properties of the array by repeating observations made with other facilities (Hills et al., in prep.). One of the top-level science goals for ALMA is to detect far-infrared (FIR) line emission from ionised gas in star-forming galaxies redshifted to submillimetre wavelengths, and so in order to demonstrate that this is possible we observed the [C II] line and dust continuum emission in BR1202-0725 at $z = 4.7$.

BR1202-0725 had previously been observed with the Submillimeter Array (SMA) on Mauna Kea (Iono et al., 2006), and is composed of two intrinsically luminous and (presumably) massive galaxies, both rich in molecular gas and dust (Omont et al., 1996). One of the pair is an optically luminous quasar, while the other shows no signs of AGN activity and is undetected in sensitive optical and infrared images. At $z = 4.7$, the [C II] line is redshifted into the 340 GHz (Band 7) receiver window where ALMA provides a unique increase in sensitivity over other telescopes, even with only the sixteen 12-metre antennas that were typically available early in 2012. The previous SMA observations of [C II] line emission represented the only resolved observations of weak and broad, high redshift line and dust continuum emission at these frequencies, making this a unique target for ALMA science verification. These and other commissioning data have been made public to the community who are encouraged to use them for training or scientific purposes[1].

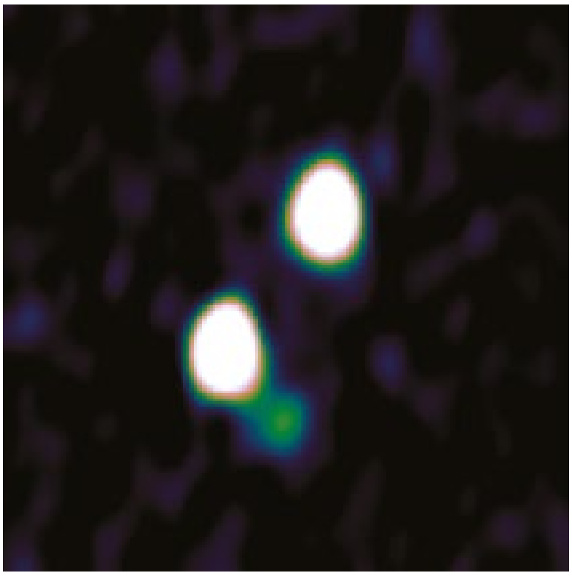

Figure 1. 10 by 10 arcsecond ALMA 340 GHz (Band 7) image of thermal dust continuum emission in BR1202-0725, a system composed of at least two FIR luminous galaxies (a quasar host galaxy and a heavily obscured starburst) that existed 1.3 billion years after the Big Bang. The faint submillimetre source below and to the right of BR1202-0725 South may also be part of the same group of galaxies. The synthesised beam size is 0.9 by 1.3 arcseconds.

Gas and dust in BR1202-0725

Band 7 ALMA observations toward BR1202-0725 were made in January 2012 using seventeen 12-metre diameter ALMA antennas for 25 minutes of total on-source observing time (Wagg et al., 2012). The 340 GHz continuum image with a synthesised beam size of 1.3 × 0.9 arcseconds is shown in Figure 1, and even with such a short integration time this map is already an order of magnitude more sensitive than the previous SMA observations. The northern and southern components of BR1202-0725 are separated by ~ 4 arcseconds, which roughly corresponds to 25 kpc at this redshift, while the positions of the sources in the ALMA map are consistent with SMA and PdBI observations (Omont et al., 1996; Iono et al., 2006; Salomé et al., 2012). These ALMA data reveal a third faint submillimetre counterpart, whose redshift is uncertain, but which may be associated with a Lyman-α emitter at the same redshift as the BR1202-0725 system (Hu et al., 1996). If all three objects lie at the same redshift and are in the process of a dynamical interaction, then it is likely that they will evolve into a massive galaxy with a stellar mass that could grow to 10^{11} $M_{\odot}$.

We also detect the [C II] line emission with high significance in the two brightest members of the BR1202-0725 system (Figure 2). These are some of the most sensitive spectra of this line obtained in high redshift galaxies, and the line profile for the quasar is even suggestive of the presence of an outflow of ionised carbon. Such outflows of gas from the central AGN can potentially quench star formation in the interstellar medium of galaxies and have been observed in a quasar host galaxy that existed about 850 million years after the Big Bang (Maiolino et al., 2012). The large width of the [C II] line emission in the northern component is similar to what was observed with

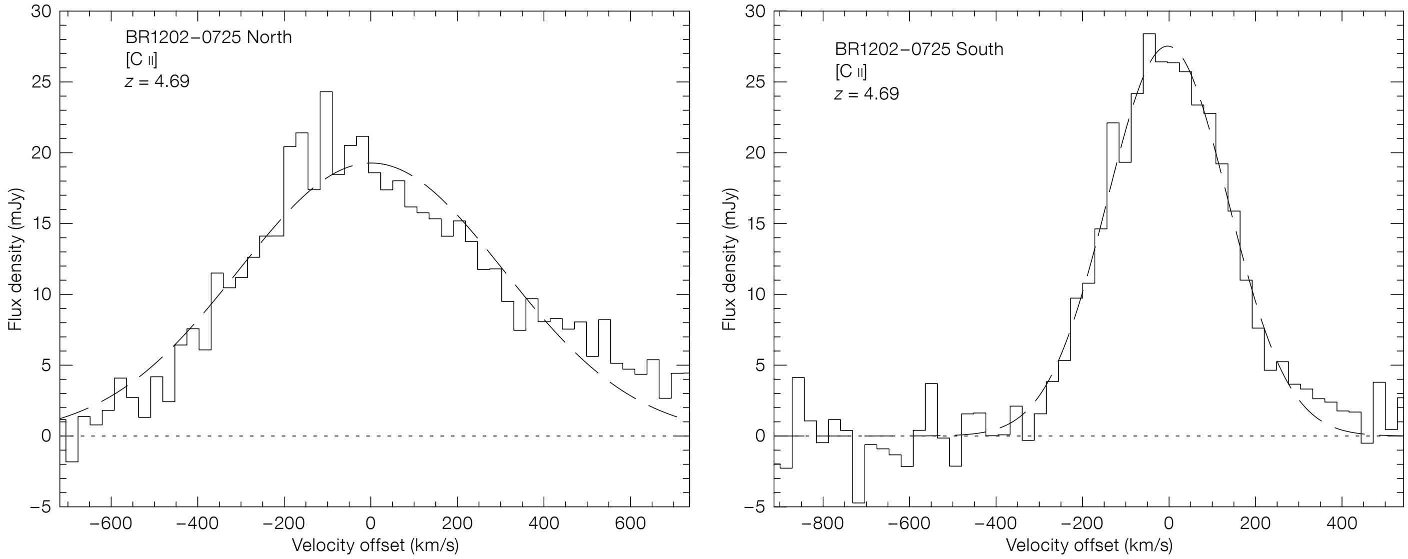

Figure 2. [C II] line emission in BR1202-0725 North and South at $z = 4.69$ after subtraction of the continuum emission. The spectra have a typical rms of ~ 2 mJy per ~ 28 km/s channel. The high signal-to-noise of these spectra reveal how the starburst galaxy to the north has a larger [C II] line luminosity than the quasar host galaxy, while both have similar FIR luminosities. Figures from Wagg et al. (2012).

the SMA, while the small [C II]-to-FIR luminosity ratio is lower in the quasar than the starburst, which is consistent with what is observed in AGN and starbursts in the nearby Universe and $z \sim 1$ (Stacey et al., 2010; Sargsyan et al., 2012).

Recent observations of high-J CO lines and millimetre wavelength dust continuum emission from the PdBI confirm the complex nature of the BR1202-0725 system (Salomé et al., 2012). The CO data agree with the ALMA [C II] observations in that the starburst galaxy exhibits broader linewidths in both species than those observed in the quasar. The CO emission appears to be extended from the quasar, but is not coincident with the faint 340 GHz continuum source detected by ALMA, and all of the data are consistent with this system representing a merger of gas-rich galaxies that existed 1.3 billion years after the Big Bang.

Prospects

These science verification observations with ALMA demonstrate the ability to detect weak line emission from high redshift galaxies at submillimetre wavelengths. Higher spatial resolution ALMA [C II] line observations will inevitably reveal the dynamical structure of the BR1202-0725 galaxy merger, and determine if the third continuum source is at the same redshift as the two more luminous members. Further observations of redshifted FIR line emission in massive galaxies have now been conducted as part of the early-science operations phase and both [C II] and the weaker [N II] 205 μm line emission have been detected (Nagao et al., 2012; Swinbank et al., 2012; de Breuck et al., in prep.). Taken together, the early results from ALMA provide a preview of how this enormous increase in submillimetre wavelength sensitivity will lead to a transformation in our understanding of the gas content of high-redshift galaxies.

The results presented here are due to the hard work and dedication of many people from around the world, and we are grateful to everyone who has made ALMA a reality.

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Links

[1] Access to ALMA Verification data: http://almascience.eso.org/alma-data/science-veification

ALMA (ESO/NAOJ/NRAO); ESO/Y. Beletsky

ALMA Band 3 Science Verification image of the nearby galaxy Centaurus A (NGC 5128) in CO(1-0) emission overlaid on an NTT/SOFI near-infrared image. The CO emission is colour coded by the radial velocity of the molecular gas showing evidence for rotation of the disc around the centre of the galaxy. The galaxy nucleus, visible in the SOFI image, hosts a central massive black hole. See Release eso1222 for more details.

Science Verification Datasets on the ALMA Science Portal

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We summarise the ALMA Science Verification datasets released over the past year, the ALMA capabilities that were demonstrated and how the ALMA results compare with previous observations. Some new scientific results that have been produced using the public Science Verification datasets are summarised and an overview of the capabilities that will be demonstrated with future Science Verification observations is provided.

ALMA Science Verification (SV) is the process used to demonstrate that ALMA is capable of producing data of the quality required for scientific analysis. The SV process is part of the Commissioning and Science Verification (CSV) effort within ALMA and is carried out by the ALMA CSV team with data reduction support from the ALMA Regional Centres. ALMA Science Verification data are made publicly available on the ALMA Science Portal as soon as satisfactory observations and data reduction are achieved. The community is encouraged to use these datasets to familiarise themselves with the ALMA capabilities and data reduction procedures, as well as to publish interesting new science results that they may obtain from analysing the datasets. Detailed information on the ALMA SV process can be found on the Science Portal SV page[1].

About a year ago, we provided an initial account of the status of ALMA SV in Testi & Zwaan (2011). At that time, few initial datasets demonstrating single-field interferometry with a small set of antennas had been fully processed and released. Now, a broad range of datasets is available on the ALMA Science Portal[2]. The datasets cover a variety of science targets and ALMA modes, including mosaics, high frequency observing and spectral survey. All data releases are accompanied by data reduction scripts and a set of sample images or datacubes. For some of the SV data releases, detailed data reduction guides have been made available to explain the data reduction procedures for the various modes step by step. Here, we illustrate some of the released datasets and invite interested users to visit the Science Portal webpages to download the datasets in which they may be interested.

Molecular gas in galaxies

The radio-quiet quasar BR1202-0725, at a redshift $z = 4.69$, was one of the earliest detections of molecular gas at very high redshift ($z > 2$). Previous interferometric observations detected CO(5-4) emission and dust continuum in two compact sources separated by ~ 4 arcseconds (Omont, 1996). This turned out not to be due to gravitational lensing, and instead the southern component has been established to be associated with a quasar, whilst the northern component is an optically faint submillimetre galaxy (SMG). In ALMA Band 7 SV data on this field, [C II] 158 μm emission is clearly detected from both components. The brightness of [C II] makes this line ideal for tracing the kinematics of galaxies and for identifying possible outflows. The fact that ALMA SV observations detect this line at such high significance in only 25 minutes on-source integration time, using only 17 main array antennas, clearly demonstrates the power of ALMA for the study of line emission from high-redshift objects. A study using these SV data on BR1202-0725 was published by Wagg et al. (2012); see also the article on p. 56.

Centaurus A is a massive elliptical galaxy and is one of the best-studied, as well as the nearest (~ 3.8 Mpc), radio galaxies in the sky. It is characterised by a strong dust lane seen in visible light, oriented along the galaxy minor axis, which harbours ~ $4 \times 10^8 M_\odot$ of molecular gas. This feature, together with the strong radio emission, indicates that Centaurus A is the result of a collision between a giant elliptical galaxy and a smaller gas-rich spiral galaxy. High spectral resolution ALMA SV data were taken in Band 6 in order to map the extended CO(2-1) emission along the dust lane. Previously, the inner one square arcminute was mapped in the CO(2-1) line by Espada et al. (2009) using the Submillimeter Array (SMA). With ALMA, a large mosaic of pointings was used to map the three-dimensional structure of the gas disc. The CO(2-1) velocity field overlaid on a near-infrared image produced by the NTT is shown in the figure on p. 58.

Another large mosaic was taken in Band 3 to map the CO(1-0) gas in the grand-design, nearly face-on spiral galaxy M100 in the Virgo cluster, at a distance of ~ 16 Mpc. Molecular gas in this galaxy is abundant in the centre and along the spiral arms. The entire gas disc was previously mapped at 6-arcsecond resolution using the Berkeley–Illinois–Maryland Association (BIMA) millimetre interferometer (Helfer et al., 2003). The ALMA SV observations consisted of 47 pointings and cover a region of 5 by 5 arcminutes, with an angular resolution of 3 arcseconds. The CO map recovers all the structures seen by Helfer et al. (2003). Furthermore, ALMA detects continuum emission at the centre of the galaxy, which was not found in previous observations. Figure 1 shows the impressive spiral structure seen in CO by ALMA.

The Galactic Centre

The Galactic Centre, Sagittarius A* (Sgr A*), is a very interesting ALMA target for the purpose of studying the interaction between a supermassive black hole and its surrounding environment. ALMA SV data were taken towards Sgr A* both in Band 3 and Band 6 with the aim of imaging the hydrogen recombination line emission. The Band 6 data were taken in a seven-point mosaic, while the Band 3 observations consisted of a single pointing. The mini-spiral structure is clearly visible in both recombination line maps (Figure 2), and these maps agree very well with the Combined Array for Research in Millimeter-wave Astronomy (CARMA; H41α; Shukla et al., 2004) and SMA (H30α; Zhao et al., 2011) observations.

Star-forming regions

The study of protoplanetary discs is one of the main science goals of ALMA and

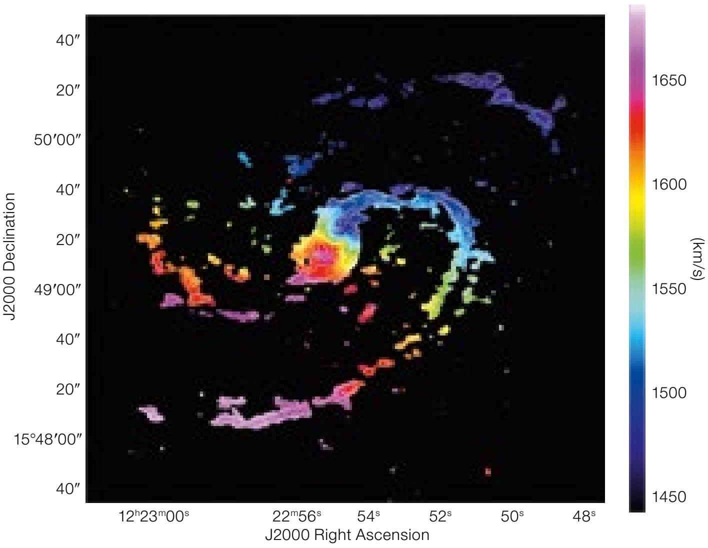

Figure 1. Intensity-weighted CO(1-0) velocity field of the grand-design spiral galaxy M100, with total intensity contours overlaid.

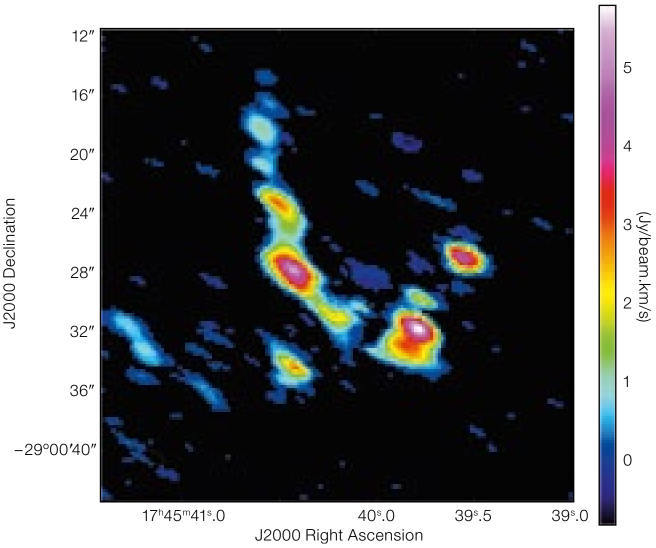

Figure 2. Hydrogen recombination line emission toward SgrA*. The map shows the integrated emission map of the H30α line seen in the inner 30 square arcsecond region of the Galactic Centre.

we had foreseen from the beginning a large number of external users wishing to obtain data on these objects. SV data on two very well-known protoplanetary discs — TW Hya and HD163296 — have been released. TW Hya datasets have already been presented in Testi & Zwaan (2011). HD163296 is a young intermediate-mass star known to host a protoplanetary disc and has been extensively studied at millimetre wavelengths (Mannings & Sargent, 1997; Isella et al., 2007; Qi et al., 2011). SV observations demonstrated one of the basic multi-spectral resolution ALMA capabilities, where lines and continuum can be observed using a combination of four separate spectral windows with different bandwidth and spectral resolution. The released ALMA Band 6 and Band 7 observations cover the continuum at 1.3 and 0.85 mm as well as several emission lines from the isotopes of CO and HCO$^+$. A few examples are shown in Figure 3.

The low-mass multiple protostar and hot corino IRAS16293 (Ceccarelli et al., 1998; Jorgensen et al., 2011) was observed as part of the SV process of demonstrating very high spectral resolution in a near-line confusion condition in Band 6 and to demonstrate high-frequency observations at Band 9. A small mosaic was performed at Band 9 to properly cover the two main components of the multiple system. This was the first ALMA Band 9 dataset to be publicly released and is accompanied by an extensive data reduction guide. The data have been used by separate groups to study the gas kinematics around the protostars (Pineda et al., 2012) and to detect, for the first time, in a solar-mass protostellar system, a simple form of sugar, glycolaldehyde. This is a key pre-biotic molecule which is found to be present in the disc surrounding the young protostars and infalling onto the planet formation regions of the disc (see Figure 4, Jorgensen et al., 2012 and ESO release eso1234).

The Orion KL hot core was observed in Band 6 as a spectral survey. This region, extensively studied at all wavelengths, including the millimetre and submillimetre, was the obvious choice for such an SV observation, due to the bright and numerous lines and plenty of comparison data to check against (see Zapata et al. [2011] for a recent study). The ALMA SV data surveys the lower two thirds of Band 6, from 214 through 246 GHz, at a spectral resolution of approximately 0.7 km/s. In spite of this being one of the best-studied regions of the sky, the ALMA SV data, even with only the 16 antennas available at the time of the observations, is of such a high quality that five separate studies based on these data have already been published (Fortman et al., 2012; Galvan-Madrid et al., 2012; Hirota et al., 2012; Niederhofer et al., 2012; and Zapata et al., 2012). The results span the range of topics from comparison with laboratory spectra, to the study of water masers, SiO isotopologues in the outflow and radio hydrogen recombination line emission.

Future SV observations

At the time of writing, ALMA SV is now moving into demonstrating the capabilities for Cycle 1 and beyond. The details of the planning and the targets for SV are discussed in detail on the Science Portal SV page[2]. Here, we provide a summary of the areas that will be the subject of SV in the near future and for which external users may expect release of SV data in the coming months.

High angular resolution

The longest baselines for Cycle 1 will be ~ 1 kilometre compared with ~ 400 metres in Cycle 0. It is necessary to verify that coherence is maintained and that the calibration techniques, particularly phase correction, are working properly on these longer baselines. Bright compact sources will be used for this purpose. It is

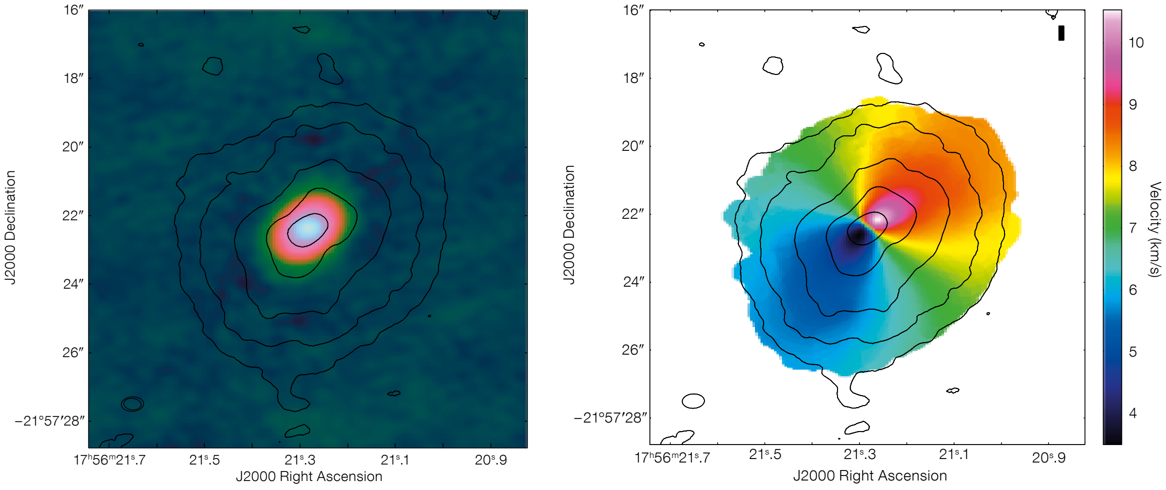

Figure 3. ALMA SV Band 7 data on the protoplanetary disc HD 163296. Left: contours of the CO(3-2) integrated line emission are shown on top of the continuum image. Right: The same CO(3-2) integrated intensity contours are overplotted on the mean velocity map for the same line. In both plots the ellipse in the bottom left corner shows the angular resolution.

expected that ALMA will be in a position to start these observations at the end of 2012.

Ephemeris

One critical goal is also to demonstrate that the special steps required to observe and reduce the data on objects that move in right ascension, declination and radial velocity (Doppler tracking) work correctly in all cases, including both those objects that use the built-in ephemeris, e.g., planets and major moons, and those for which a special ephemeris has to be uploaded, e.g., comets. Dynamical selection of phase calibrators is also required since the objects move on the sky during the possible scheduling period, so this is an additional observatory mode (normally transparent to the users) that an SV project in this area will verify.

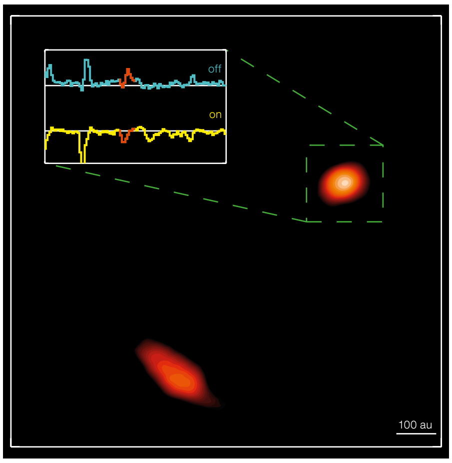

Figure 4. ALMA SV Band 9 690 GHz continuum image of IRAS 16293-2422. Jorgensen et al. (2012) have identified 13 transitions of the simplest sugar, glycolaldehyde, a basic building block of biological molecules, along with many other complex organic molecules, toward the two components of this binary system. The green box around one of the sources in the image measures 270 au on the side; the spatial resolution of the ALMA observations are 0.2 arcseconds (25 au at the distance of the Ophiuchus cloud). The insert shows spectra toward the continuum peak of the source ("on"), where the lines typically are seen as redshifted absorption lines indicative of infall, and toward a position offset from this by about 25 au ("off"), where the lines are seen in emission. One of the 13 identified glycolaldehyde lines is indicated in red.

Spectral modes

Cycle 1 capabilities include cases where the different basebands are used with different spectral modes (time/frequency domain mode; TDM/FDM) or different resolutions. The end-to-end process is more complicated than in Cycle 0, involving changes to the Observing Tool, the control of observations and the data reduction. An important additional capability is the use of spectral averaging, which will make the data volume much smaller in many cases, but again introduces many additional steps in the end-to-end observing process, which need to be verified.

Imaging extended structure

This is the most critical and complicated of the new capabilities for Cycle 1. ALMA has to take well-matched data with the Atacama Compact Array (ACA) and the 12-metre array and then combine these with the correct scaling and weighting into a single cube. When single-dish measurements are made with total power antennas, data have to be taken and reduced in a different way compared to the interferometric data. The three datasets, 12-metre array, ACA and total power, then need to be combined together. Band 9 will be particularly challenging because, in addition to the usual problems of getting good quality data at such high frequencies, the single-dish data requires a special observing technique to separate the signals from the two sidebands.

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Links

[1] ALMA Science Portal SV page: http://wikis.alma.cl/bin/view/ScienceVerification/ScienceVerificationNoticeboard?cover=print

[2] ALMA Science Portal: http://almascience.eso.org/alma-data/science-verification

The group photograph for the workshop ESO@50 The First 50 Years of ESO taken at the entry to the drive of ESO Headquarters. See the workshop report by Walsh et al. on p. 64.

Massimo Tarenghi, ESO Representative in Chile, was recently granted Chilean nationality by special grace, in recognition of his contribution to the development of astronomy in Europe and Chile. Massimo, with hat, is shown celebrating his award. See Announcement ann12079.

Switzerland Celebrates 30 Years of ESO Membership

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This year Switzerland celebrated the 30th anniversary of its accession to ESO. The Swiss contributions to ESO are briefly summarised and a half-day symposium to mark this anniversary is reported.

This year is rich in astronomical celebrations: as well as the 50th anniversary, on 5 October 1962, of Belgium, France, Germany, the Netherlands, and Sweden pooling their resources and ambitions under the flag of ESO, the 30th anniversary of the membership of Switzerland to ESO, through the completion of the accession process on 1 March 1982, is also being commemorated.

During these last five decades, the (currently 14) Member States of ESO have advanced European astrophysical activities to the level of excellence they enjoy today. The role of ESO as the world leader in ground-based astronomy is confirmed by some recent decisions by the ESO Council in relation to the construction the European Extremely Large Telescope (E-ELT). The Swiss membership of ESO has made a strong impact in instrumentation and observational astrophysics, covering many fields from the search for extrasolar planets to the most distant galaxies.

In order to acknowledge the manifold contributions of the Swiss people to all activities related to astrophysics, the Swiss Commission for Astronomy, a board of the Swiss Academy of Sciences, organised a small symposium, which was hosted in the Federal Capital by the University of Bern, on the afternoon of 5 October 2012. The general theme was: Astronomy in Switzerland: The Quest for Summits! Nearly 150 participants attended this event, among them numerous members of the Swiss academic and federal governing bodies, along with astronomers from all the Swiss universities and institutions involved in astrophysics. The event was organised and chaired by G. Meylan from EPFL, who is also the Chair of the Swiss Commission for Astronomy and science delegate for Switzerland on the ESO Council. The oral presentations were split into two groups, first political, then scientific, but in both cases past achievements and future challenges were described.

The welcome address, by T. Courvoisier, from the University of Geneva, who is also President of the Swiss Academy of Sciences, emphasised the essential benefits of Swiss participation in ESO, in the past and the future. L. Woltjer, former ESO Director General and "father" of the Very Large Telescope (VLT), followed with a presentation on the theme of Europe and ESO. Then, M. Steinacher, from the State Secretariat for Education and Research, and also head of the Swiss delegation to the ESO Council, presented the path of Switzerland into ESO, the main highlights of the Swiss participation and the major phases of the development of ESO, with the observatories at La Silla, Cerro Paranal, Chajnantor, and Cerro Armazones as major cornerstones.

Three scientific reviews summarised the activities of Switzerland in three scientific areas where numerous recent discoveries have been achieved. S. Udry, from the University of Geneva (UniGE), summarised the activities related to the search for extrasolar planets with ESO telescopes. The excellent synergy between the universities of Geneva, Bern (UniBE) and the Eidgenössische Technische Hochschule Zurich (ETHZ) is the best way to maintain and develop the leadership established by UniGE during the last 20 years. M. Carollo, from ETHZ, presented the intense research activities in the field of galaxy formation and evolution undertaken at ETHZ, UniGE, Univeristät Zurich, and EPFL, from the points of view of observations and numerical simulations. B. Leibundgut, Director for Science at ESO, and incidentally the highest ranked Swiss staff member at ESO, presented the impact of ESO telescopes on recent progress in cosmology, e.g., through the direct contribution to the discovery of the accelerated expansion of the Universe, which was awarded the 2011 Nobel Prize in Physics.

THE MESSENGER

EL MENSAJERO

Switzerland, Member of ESO . . .

. . . and Italy will Follow Soon

The ESO Scientific and Technical Committee

All three speakers emphasised past Swiss participation in the instrumentation related to the New Technology Telescope (NTT) and the VLT/VLT Interferometer (VLTI), and, hopefully, in the future to the E-ELT. The complementarity between these ESO facilities and some of the NASA/ESA satellites (HST and JWST) and ESA satellites (CHEOPS, EUCLID) was also emphasised, allowing astrophysicists in Switzerland to acquire both ground-based and space-borne observations, a key component in maintaining Swiss activities at the forefront of astrophysical research.

An aperitif allowed everybody to discuss further the future of astronomy and astrophysics in Switzerland through the ESO and ESA projects, with some grateful thoughts for our Swiss predecessors who pushed for direct participation of Switzerland in these outstanding international organisations.

Acknowledgements

We are extremely grateful to Chantal Taçoy (UniGE) for her very efficient organisation in all aspects of this meeting. Our thanks also to Mirjam Kaufmann (UniBE) and Claire Schatzmann (EPFL) for their help.

Report on the Workshop

ESO@50 — The First 50 Years of ESO

held at ESO Headquarters, Garching, Germany, 3–7 September 2012

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In recognition of the 50th anniversary of the signing of the ESO Convention, a special science workshop was held at ESO Headquarters in Garching to focus on the main scientific topics where ESO has made important contributions, from Solar System astronomy to fundamental physics, and to provide a perspective for future scientific challenges. The workshop is summarised.

The five-day workshop ambitiously covered a vast range of topics in optical, infrared and millimetre/submillimetre astronomy on which ESO telescopes have concentrated over the last 50 years. Topics ranged from the planets and moons of the Solar System, extrasolar planets, stellar evolution, star clusters, the Galactic Centre, Galactic structure to nearby galaxies, dwarf and giant, to quasars and active galactic nuclei to galaxy surveys and the distant Universe. As well as focussed contributed talks (21) and poster papers (15), there were invited reviews (25) covering a broader range and five plenary talks putting ESO astronomy in the widest context. As befits the celebratory tone, there were many and diverse social activities, from a welcome reception at ESO on the evening of the first afternoon of the workshop, an informal dinner in a Biergarten in Munich, a more formal workshop dinner in a restaurant in Garching, “beer and brezen” in the auditorium on the penultimate evening and a farewell lunch on the Friday following the last session. A photograph of the participants is shown on p. 62.

The contributions are available (in PDF) on the conference website[1]. For the first time at ESO the proceedings were webcast and the recordings of each presentation are also available on the website. We present a brief summary of the topics covered in the plenary and invited talks.

Young stars and planets

ESO’s next major milestone, the Atacama Large Millimeter/submillimeter Array (ALMA) featured strongly in the first few talks. Some of the first Cycle 0 results in young stars and star-forming regions were presented by Leonardo Testi (ESO) where the high spatial resolution and sensitivity of ALMA will bring many advances. The field of astrochemistry was covered by Ewine van Dishoeck (Leiden), concentrating on very high spectral resolution, including some ALMA spectra from protoplanetary discs, demonstrating the potential for finding new species (up to 50 % of lines are unidentified). High-mass star formation in clusters was presented by Guido Garay (Universidad de Chile) who highlighted the contributions of the Swedish ESO Submillimetre Telescope (SEST) and more recently the ATLASGAL survey with the Large Bolometer Camera (LABOCA) on the Atacama Pathfinder Experiment (APEX).

Two invited talks were devoted to the Solar System, one on the planets and moons by Bruno Sicardy (IAP) and one on small bodies by Pierre Vernazza (ESO). Occultations play an important role in determining the structure of Solar System bodies by exploiting fast readout modes and also adaptive optics imaging with NACO. ESO telescopes have been instrumental in the detection and characterisation of small bodies — comets, asteroids and trans-Neptunian objects (TNOs).

Stephane Udry (Geneva) reported there were 777 extrasolar planet candidates at the time of the meeting, of which 715 had been detected by the radial velocity technique. The large HARPS allocation (100 nights/year over five years) has been crucial, with a variety of programmes targeting stars of different types (early- and late-type, giants and dwarfs, young and older stars). Francois Bouchy (IAP) followed with a talk on transiting planets; many detected with the CoRoT satellite have been followed up with ESO telescopes and instruments.

Transients

Steven Smartt (Belfast) summarised detection and follow-up surveys for bright transients which have recently begun at La Silla Observatory. The La Silla–QUEST survey (see Baltay et al., p. 34) produces transient alerts within days and these are followed up spectroscopically by the Public ESO Survey of Transient Objects (PESSTO) with EFOSC on the New Technology Telescope (NTT).

The Very Large Telescope (VLT) was very well timed for the beginning of the era of observations of gamma-ray burst afterglows. The seminal object 1998bw, a supernova (SN) associated with a weak gamma-ray burst and extensively observed by ESO telescopes, began the exploration of the now fruitful SN–gamma-ray connection, as reported by Johan Fynbo (Niels Bohr Institute).

The Milky Way

The major role that ESO facilities have played in studies of the Milky Way was covered by Marina Rejkuba (ESO), ranging from large surveys with high resolution spectroscopy dating back to the 1980s to the current imaging surveys with the survey telescopes VISTA (VVV) and the VST (VPHAS+) and the Gaia–ESO spectroscopic survey. Pavel Kroupa (Bonn) covered the evidence for systematic variations of the stellar initial mass function, demonstrating that ESO facilities have made many essential contributions. Giampaolo Piotto (Padova) showed how the old paradigm of a globular cluster as a single population of co-eval stars has been overturned in favour of globular clusters as an assembly of multiple populations showing an Na–O (and Mg–Al) anticorrelation. FLAMES in its Medusa modes (130 simultaneous single-object spectra) has revolutionised the field and enabled chemical abundances in many clusters to be measured. Reinhard Genzel (MPE) described two decades of high precision infrared imaging and astrometry on the Galactic Centre. One of the highlights was the observation of a complete orbit for the star S2 from 1992–2012 as it travels around the central black hole, encompassing many NTT and VLT astrometric measurements.

Nearby galaxies

Dwarf galaxies of the Milky Way and the Local Group were discussed by Eline Tolstoy (Groningen). GIRAFFE and UVES have provided important data on the chemical evolution timescales for these galaxies and detailed spectroscopy of more distant dwarf galaxies will be achievable with the European Extremely Large Telescope (E-ELT). The Magellanic Clouds have naturally proved a rich pasture for ESO telescopes and they have explored many of the objects that act as astrophysical probes in these, the nearest, and lower metallicity galaxies, as shown by Carme Gallart (IAC).

Francoise Combes (Observatoire de Paris) discussed observational approaches to understanding the triggering and regularisation of star formation in galaxies. Although H_2 is key for star formation it is very difficult to observe directly, so CO is the favoured tracer. ALMA is set to bring CO and other molecular tracers in normal galaxies at high redshift within the realm of study.

Distant galaxies and clusters

The great impact of the VLT on large-scale redshift surveys was summarised by Simon Lily (ETH Zurich) who noted that of the ~ 100 000 spectroscopic redshifts to $z > \sim 1$ about two thirds are from the VLT. We are currently in a golden age for the exploration of the distant Universe. Linda Tacconi (MPE) showed how ESO is perfectly tuned to answer many of the big questions in cosmic star formation history and ALMA will open up the field of mapping the rotation curves of disc galaxies at $z \sim 1$. Active galactic nuclei (AGN) have been known from around the time of the signing of the ESO convention and, as Carlos de Breuck (ESO) showed, their increased numbers and luminosities at higher z made them ideal targets with which to investigate galaxies. Natascha Förster-Schreiber (MPE) described spatially resolved studies of the kinematics and structure of early galaxies. Integral field spectroscopy (IFS) with SINFONI at the VLT with adaptive optics has enabled the kinematics and structure at 1–2 kpc scales of the star-forming regions to be studied. Many more targets will become accessible with KMOS, currently being commissioned on the VLT and in the longer term by E-ELT IFS instruments.

Yannick Mellier (IAP) provided an overview of gravitational lensing studies, noting that the first quadruple gravitationally lensed galaxy was detected by the MPG/ESO 2.2-metre telescope in 1988 and the redshift determination of the large arc in the galaxy cluster A370 with the 3.6-metre. From 1990–1997 ESO supported the EROS microlensing survey with the 1.0-metre MarLy telescope at La Silla and from 2002–2012 the PLANET consortium using the Danish 1.54-metre. Marijn Franx (Leiden) treated ESO's role in the study of galaxy evolution at high redshift, highlighting the early influential surveys COMBO-17, a 17-filter imaging programme with the MPG/ESO 2.2-metre telescope and the wide-field imager (WFI), and the K20 survey of extremely red objects with FORS on the VLT.

Cosmology

The talk by Mark Sullivan (Oxford) on supernova cosmology began with an historical overview of the first ESO surveys of SN Type Ia as cosmological distance probes, dating from the late 1980s. More recently VLT observations have contributed to refining the value of the cosmological equation of state parameter, w, whose value seems to be very close to -1 (Einstein's cosmological constant). Absorption lines arising in the diffuse intergalactic medium and dense interstellar medium along the line of sight to quasars were considered by Patrick Petitjean (IAP). The spectrum of the first quasar was obtained in 1962, but it was not until the commissioning of UVES on the VLT in 1998 that extensive surveys of quasar absorption lines took off at ESO. Michael Murphy (Swinburne) considered the astronomical evidence that the fundamental constants (in particular the fine structure constant α) are varying throughout the Universe. Based on high-resolution spectra with UVES (153 absorbers) and HIRES on Keck (142 absorbers) of quasars using the many-multiplet method, the two datasets show evidence for a dipole in the sky distribution of $\Delta\alpha/\alpha$ at 4.1σ level.

Instrumentation

Guy Monnet (CRAL) presented a historical outline of ESO's contributions and innovations in instrumentation. Sandro D'Odorico (ESO) then went through the development of instrumentation at ESO, following his close involvement from 1981 to his emeritus appointment in 2010. The instrumentation plan for the VLT was defined with the community at an early stage and for the E-ELT the paradigm was significantly extended, with ESO coordinating 11 studies for instruments and adaptive optics modules, of which two concepts were accepted as first-light instruments (a diffraction-limited near-infrared imager and a single-field near-infrared wide-band integral-field spectrograph).

Plenary talks

Alvio Renzini (Padova) presented a personal view on ESO's important influence on astronomy in Europe, noting that approval of the VLT was seen as a turning point from small to big science. Large Guaranteed Time Observing (GTO) allocations to instrument consortia, Large Programmes and most recently Public Surveys, have led to progress on major problems and areas of astrophysics. These large programmes typically produce a larger impact per night, in terms of papers and citations, compared to small programmes.

Massimo Tarenghi (ESO) gave an enthusiastic talk on the history of the ESO observatories from the 3.6-metre to the NTT (for which he was Project Manager) at La Silla, to the VLT (where Massimo was the first Director) and onwards to ALMA (where he also served as Director).

Richard Ellis (Caltech) presented a talk on the global impact of ESO. In its formative years (1962–1986) ESO showed a strong diversity of high performance instrumentation including the infrared, pioneered by the late Alan Moorwood. The NTT era

(1986–1996) was based not only on the success of this innovative new telescope, but also planning of the VLT and expansion of instrumentation at La Silla including the SEST, which initiated ESO's route into the submillimetre. For the VLT era (1998–present), he compared some of the science cases in 1997 with those achieved with the VLT and demonstrated that new telescopes achieve far more than their original science cases. He closed by looking forward to the Extremely Large Telescope era with the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT) and the E-ELT.

Bruno Leibundgut (ESO) examined the synergies between ground- and space-based observatories. Examples of the relative advantages of ground versus space measurements were made and the example of SN1987A was used to show how a multi-wavelength approach is essential to arrive at a fuller picture of the many features of the evolving supernova remnant. The presence of the Space Telescope European Co-ordinating Facility, which was hosted by ESO from 1984 to 2010, provided many synergistic benefits with Hubble Space Telescope practice and operations, such as operations models and the science archive. In addition, the link with the European Space Agency improved coordination of ground and space missions, such as ground-based support for the Rosetta and Gaia missions.

Roberto Gilmozzi presented a white paper, for discussion, on Paranal in the era of the E-ELT, seeking community input to the two questions:
- Is the VLT operations model suitable for the E-ELT?
- What is the future of the VLT in the next decade 2020–2030?

He sketched the facilities considered to be available circa 2025, the instruments still operating on the VLT and what the extant scientific questions might be. A range of tactical and strategic options were presented. The initial ideas have been presented to the ESO committees — the Scientific Technical Committee (STC) and Council — and internally to ESO astronomers. The aim is to incorporate feedback in a white paper to be subsequently iterated in the next six months, leading to a community-wide workshop in 2013 with the aim to finalise the white paper by end of 2013.

Figure 1. The Director General, Tim de Zeeuw, outlining future perspectives for ESO at the conference.

Closing remarks

Tim de Zeeuw summarised ESO's mission and accomplishments during the past half century in developing and operating world-class observing facilities for astronomical research and organising collaborations (see Figure 1). He then provided a perspective for the next 10–15 years:
- keep Paranal as a leading observatory with an integrated system of VLT, VLTI, VST and VISTA;
- maintain and upgrade instruments and replace them with second generation instruments;
- add the E-ELT into this system;
- further develop ALMA;
- continue the fruitful partnership with the community such as, for example, hosting experiments on La Silla, building instruments and providing studentships and fellowships.

The Director General tried to envision astronomy 50 years from now, emphasising that surely new questions will arise and paradigm shifts will occur in the way astronomy is done in the future, but most likely the exoplanet field will continue to be a high priority one. Technology developments should be harnessed to improve and extend the capability of instruments. This assumes, of course, that society continues to be interested in scientific advancement; outreach has a role to play here. ESO operates within a world astronomical community and a degree of competition in the optical/infrared field is healthy for future progress.

Strategically some moderate further growth by the addition of new ESO Member States was advocated, and will bring added value without leading to over-dominance (ESO currently involves about 30% of the world astronomical community). ESO's successful operational model should be retained with a mix of multi-purpose telescopes and experiments, in combination with strong national programmes and strong connections between the Observatory and the astronomers in the Member States (through community involvement and a mix of visitor/service observing modes). Around the end of the decade a new telescope project could be perhaps contemplated in close connection with space observatories and other ground-based astronomy developments.

Links

[1] ESO@50 workshop programme: http://www.eso.org/sci/meetings/2012/ESOat50/program.html

Report on the Workshop

Science from the Next Generation Imaging and Spectroscopic Surveys

held at ESO Headquarters, Garching, Germany, 15–18 October 2012

Marina Rejkuba[1]
Magda Arnaboldi[1]

[1] ESO

Over 100 participants gathered to present and discuss the first exciting results from the eleven ESO public survey programmes in the context of current and planned major ground- and space-based surveys. The VISTA and VST public surveys presented a wide range of new scientific results. Presentations of other current or planned large ground- and space-based projects provided a benchmark for the ESO public surveys and their relevance worldwide.

Figure 1. The conference photograph on the stairs of the entrance hall of ESO Headquarters.

Introduction

ESO and European astronomy have firmly entered the era of large public surveys with the addition of the VLT Infrared Survey Telescope (VISTA) and the VLT Survey Telescope (VST) to the Paranal telescope suite and the start of the first spectroscopic public surveys. The official start of VISTA operations was in April 2010, and the six VISTA imaging public surveys have collected over 2.5 years worth of data; the opening day of the workshop coincided with the first anniversary of VST operations. Since January 2012, two public spectroscopic surveys have been collecting data, at the VLT Unit Telescope (UT2) and the New Technology Telescope (NTT). The main aims of the workshop were the presentation of the goals of the ESO public surveys and their first scientific results. The global context of ESO surveys was provided by presentations of other current and planned large ground- and space-based surveys.

ESO public survey science covers a wide range of topics. In only three and a half days, more than 50 talks showed exciting new results in the fields of star formation and the structure of our own Galaxy, the nearby Universe and all the way out to high-redshift studies with both very deep and wide surveys. In addition to the oral contributions, 20 poster presentations covered similar topics, and provided details on survey facility operations and data mining challenges. The presentations are available from the conference web page[1].

The ESO Director General, Tim de Zeeuw, opened the workshop, outlining the key role that surveys play in astronomical research. They provide an inventory of the Universe, allowing astronomers to find rare objects, and, on account of large number statistics, allow measurements of key parameters in cosmology. The scale of current surveys changes the way astronomical research is done by supporting the formation of very large teams and by providing the astronomical community with public data at a high level of processing, for further scientific analysis.

Survey facilities from ground and space were the topic of the first session. M. Capaccioli, the Principal Investigator (PI) of VST, and J. Emerson, the PI of VISTA, described the two latest imaging survey facilities on Paranal, presenting their characteristics and capabilities, together with a short summary of the ESO public imaging surveys (see also Arnaboldi et al., 2007). The European Space Agency Euclid project was presented by Y. Mellier: this imaging and spectroscopic facility, to be launched in 2020, will carry out a survey for 5.5 years, and produce about 10 Pbyte of processed data by 2028. Mellier emphasised the need for complementary ground-based photometric and spectroscopic observations for the ultimate goal of the mission: understanding the Universe's accelerating expansion by deriving the properties and nature of the dark energy and testing the law of gravity on large scales.

A. Connolly presented the scientific potential of the Large Synoptic Survey Telescope (LSST) and its scientific drivers: dark matter, dark energy, cosmology, time-domain astrophysics, structure of the Solar System and Milky Way structure. These drivers motivate a uniform cadence for multi-epoch observations and 90% of the southern hemisphere accessible from Cerro Tololo observatory will be covered every 3–4 nights. The final survey will accumulate, over ten years, 1000 visits in *ugrizy*-bands to reach $r \sim 27.5$ mag (36 nJy) and ~100 Pbytes of data. This unique facility is in its design and development phase, with expected commissioning in late 2020.

The year 2013 will be a decisive one for the next generation of large spectroscopic survey instruments at ESO. M. Cirasuolo and R. de Jong presented the two competing projects: MOONS and 4MOST (Multi-Object Optical and Near-infrared Spectrograph and 4-metre

Multi-Object Spectroscopic Telescope; see also Ramsay et al., 2011). These two spectrographs are quite complementary, the former being designed for the VLT and working in the near-infrared (NIR) with 1000 fibres (Cirasuolo et al., 2011), while the latter expects to go to VISTA and work primarily in the optical with 2400 fibres (de Jong, 2011). Their science cases include Galactic archaeology, galaxy evolution and cosmology, and have strong synergies with the ongoing imaging public surveys.

The core of the workshop programme consisted of invited talks by the 11 ESO public survey PIs. The VISTA Deep Extragalactic Observations (VIDEO) PI, M. Jarvis, described the 12-square-degree survey covering the XMM-Newton Large-Scale Structure (XMMLSS), Chandra Deep Field-South (CDFS) and European Large-Area Infrared Space Observatory (ELAIS-S1) fields, with the aim of tracing the formation and evolution of galaxies over a large range of redshifts, and over a survey area large enough that the impact of environmental effects can be studied.

The Milky Way galaxy and local Universe

The second session began with an overview of the VISTA and VST imaging surveys of the Milky Way. D. Minniti presented the status and the first results from the VISTA Variables in the *Via Lactea* (VVV) Survey. His talk was followed by several contributions describing the search for RR Lyrae stars (by I. Dekany) and the search for the young star clusters (by J. Borissova) in the VVV area. R. Saito presented the 84-million-star colour–magnitude diagram of the Galactic Bulge: this large dataset can now be analysed in the same way as an external galaxy! The large-scale extinction and metallicity maps for the Milky Way were presented by M. Rejkuba.

The PI of the optical Galactic survey VPHAS+, J. Drew, described how it will be combined with the northern hemisphere Galaxy surveys IPAS and UVEX surveys to contribute to European Galactic Plane Surveys. The northern hemisphere surveys started in 2003, and now VPHAS+ is filling up the 1800 square degrees of the southern Galactic Plane with ~ 2000 VST/OmegaCAM fields observed in *ugri* and $\mathrm{H}\alpha$ filters. This survey will provide a 3D extinction map and the census of the Galactic Disc, enabling detailed study of star clusters and star-forming regions in the Galaxy.

The latest addition to the ESO public surveys exploring the Galaxy is the Gaia–ESO spectroscopic survey led by G. Gilmore and S. Randich. This survey addresses key open issues in the formation and evolution of the Milky Way and its stellar components based on accurate radial velocities and abundances from VLT FLAMES spectra, to complement Gaia observations in the coming years. The science drivers require uniform analysis, resulting in yearly advanced data releases as described by Randich. The Gaia–ESO survey started in January 2012, but the nearly completed RAVE (Radial Velocity Experiment) survey, presented by M. Steinmetz, has already collected more than 500 000 stellar spectra. These are analysed for kinematical tomography of the Galactic Discs and study of the presence of substructure and tidal debris, and large-scale deviations from axial symmetry.

The Local Universe session started with an invited talk on the VISTA Magellanic Cloud (VMC) survey by M.-R. Cioni. The *Y*, *J* and *Ks* filters are used to obtain a deep picture of the Large and the Small Magellanic Clouds as well as of the Bridge and Stream regions. This survey is unique because of its depth and multi-epoch data (12 epochs) that are used to determine the 3D structure of the Magellanic Clouds with Cepheids and RR Lyrae variable stars. Following on, L. Girardi presented the main driver of the survey: the determination of the spatially resolved star formation history of the Magellanic Clouds.

G. Battaglia summarised the main results from the Dwarf galaxies Abundances & Radial velocities Team (DART) VLT/FLAMES spectroscopic survey of dwarf spheroidal galaxies. She concluded that it is necessary to look at many stars in order to derive velocity and metallicity gradients as well as to explore the significance of the multiple kinematic components in these small galaxies. This survey has implications for the current models of galaxy formation since its results show that it is difficult to make the whole Milky Way halo out of low luminosity dwarf spheroidals.

High-*z* Universe, galaxy evolution and cosmology

The high-redshift Universe session started with the Ultra-VISTA survey results presented by H. J. McCracken. The wide part of the survey covers 1.5 square degrees in the Cosmic Evolution Survey (COSMOS) field, and is now completed. The deep and the narrowband (using the NB118 filter) survey components are still ongoing. The narrowband part of this survey is designed to find $z \sim 7$ Lyman-break galaxies and $z = 8.8$ Lyman-alpha emitters, and has already identified four robust sources with mean redshift 6.98 ± 0.05. At the same time the deep NIR Ultra-VISTA data has uncovered the real nature of several other luminous sources that were originally claimed to be at $z > 7$, but turned out to be at much lower redshifts ("only" $z = 2$–4) instead. Another source of contaminants for these high-redshift objects are T-dwarf stars — a treasure trove for low-mass star formation studies.

The VISTA Hemisphere Survey (VHS) and the VST ATLAS survey were presented by their PIs, R. McMahon and T. Shanks respectively. These are wide-area surveys that will enable studies of rare sources at all redshifts, from nearby L-dwarfs to highly obscured broad line quasars at $z = 2$, as well as very rare luminous quasars up to $z \sim 7$. These two surveys will be used to determine the dark energy equation of state by detecting "baryon wiggles" in the power spectrum of about half a million galaxies.

The Kilo-Degree (KIDS) and VISTA Kilo-degree Infrared Galaxy (VIKING) surveys, presented by PIs K. Kuijken and W. Sutherland, respectively, constitute another pair of complementary VST and VISTA public surveys. The combination of optical and NIR photometry enables a clear separation of galaxies from stars, hence creating highly complete galaxy samples that are useful for weak lensing studies. Since the image quality of the VST is about a factor two better than the

Sloan Digital Sky Survey (SDSS), these surveys provide a detailed picture of the structure of galactic halos as function of galaxy type and environment. KIDS and VIKING have already uncovered quasars at $z > 6.5$, with three candidates spectroscopically confirmed (talk by B. Venemans).

S. Smartt presented PESSTO, the spectroscopic public survey aimed at exploring the physics of supernova explosions and a detailed study of transients, unusual, and currently unknown, types of variable sources. The targets for this survey come primarily from the La Silla–QUEST variability survey described by C. Baltay (see the article on p. 34).

Pipelines, data mining and survey data products

The last session of the workshop was dedicated to pipelines, data products and data mining. The KIDS team with Astro-WISE has an integrated data handling system presented by G. Verdoes-Kleijn, while R. Smareglia presented the data handling and archiving system of PESSTO. The six ESO public surveys with VISTA rely on the data processing carried out in the UK centres, Cambridge Astronomical Survey Unit (CASU) and the Wide Field Astronomy Unit (WFAU) in Edinburgh, and the latter was presented by N. Cross. The workshop closed with the presentation of M. Romaniello on the ESO Phase 3 process for the reception, validation and publication of data products from ESO public surveys and large programmes (see also Arnaboldi et al., 2011), and a live demo by J. Retzlaff of the new ESO catalogue query interface, now deployed in the ESO Science Archive Facility.

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Links

[1] Conference web page: http://www.eso.org/sci/meetings/2012/surveys2012.html

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Retirement of Preben Grosbøl

Dietrich Baade[1]

[1] ESO

On 31 October, exactly half a year after Klaus Banse's retirement (Ballester & Péron, 2012), Preben Grosbøl, the other father of ESO's former MIDAS image processing system, retired, marking the end of an era. Preben's contributions to develop and promote MIDAS, ranging from specialised numerical algorithms to fundamental over-arching concepts, were central to the success of MIDAS (and its predecessor IHAP). However, his lifetime achievements go far beyond that. The third of a century of his affiliation with ESO was devoted to the support of many other initiatives to serve optimally the community's needs for efficient, reliable and versatile data reduction capabilities.

Figure 1. Preben Grosbøl at his retirement party at ESO Headquarters receiving a framed photograph from the Director General Tim de Zeeuw.

Preben was born in Denmark and obtained his PhD from the University of Copenhagen in 1977. For his thesis, he worked closely with George Contopoulos in Thessaloniki, Greece, where he also met his wife Barbara. Throughout his scientific career, Preben studied the properties of spiral galaxies: structure, dynamics, star formation and evolution. He combined careful optical and infrared observations with detailed theoretical model calculations; the results have materialised in several dozen refereed publications. After his retirement, Preben plans to further focus on unravelling the spiral and central bar pattern of the Milky Way, thereby continuing the scientific restlessness that already drove him well before enrolling at university.

Preben was one of ESO's first postdoctoral fellows and for one year (1979/1980) was still based in Geneva, where ESO was hosted by CERN. He has been Head of the Image Processing Group, the Science Data Analysis Group, and the Data Pipeline Group. For several years, he was Deputy Head of the Data Management Division, and eventually even moved to submillimetre wavelengths and the ALMA Division in Garching. He chaired the OPTICON Network 3.6 on Future Astronomical Software Environments and the IAU FITS Working Group. Preben was a member of numerous ESO internal working groups, often as chair, always as one of the most active and knowledgeable players: the Computer Coordination Group, VLT User Software Advisory Group, VLT Data Flow System Working Group, Data Interface Control Board to name just a few that have laid the foundation for ESO's leading position today in supporting users of complex ground-based observing facilities.

As a highlight, he was one of the recipients of the 21st Century Achievement Award from the Computerworld Honors Program presented to ESO (2005). Preben also showed remarkable judgment in anticipating major technological developments in the IT markets: database systems, operating systems and hardware for astronomical data processing. His pioneering efforts to introduce new working concepts such as configuration control, object-oriented programming, software modelling tools, etc. further consolidated the results. Although Preben's knowledge in these matters was hardly rivalled, he always approached new themes in a team-based fashion and in an open and cooperative spirit. This combination earned him the deep respect of everyone working with him and made him an effective leader.

As in the instrumentation area (D'Odorico et al., 1991), Preben was one of the first to realise that ESO would maximise its efficiency not by doing everything in-house but by serving as a catalyst and focus of community-based efforts. Among other initiatives, this was achieved through a series of well-attended ESO/ST-ECF Data Analysis Workshops and the infrastructure enabling VLT/I instrument consortia to deliver software modules suitable for integration with ESO's data flow system, which ultimately aims at the delivery of science-ready data products.

A farewell party was held at ESO Headquarters on 30 October 2012, where, on the one hand, many people expressed their regret at Preben's departure but, on the other, convinced themselves that he is leaving full of energy for new undertakings, not just scientific and technical ones. Many words of warm personal and professional appreciation accompany Preben Grosbøl.

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Announcement of the

ESO Public Survey Catalogue for Ultra-VISTA available from the Science Archive Facility

The Ultra-VISTA[1] survey, targeting a sub-area of the COSMOS field, represents the deepest of the six near-infrared ESO public imaging surveys, which are currently being executed at the Visible and Infrared Survey Telescope for Astronomy (VISTA). The first release of the new infrared source catalogue in the COSMOS field is now accessible from the ESO Science Archive Facility through a new powerful user interface for querying and data download.

The Ultra-VISTA *Ks*-selected [5σ limit *Ks* = 23.7 AB mag] matched source catalogue contains 331 077 sources observed in *Y*-, *J*-, *H*- and *Ks*-bands over the full "deep" survey area of 1.8 square degrees, with narrow-band NB118 observations covering the "ultra-deep stripes" area.

The catalogue was prepared by the Ultra-VISTA team for the first catalogue release (DR1) and delivered through the ESO Phase 3 system[2] for publication to the ESO community. It is now accessible from the Science Archive Facility through a new dedicated user interface with powerful search options and download capabilities[3]. The ESO Catalogue Facility complements the existing functionality by adding the possibility to query catalogues by content using positional and non-positional constraints. To this end the catalogue data is stored in a dedicated data-base system from which the data are extracted on request, according to the constraints and output format specified by the user.

Additional Phase 3 catalogue data, which are being submitted by VISTA public survey teams, will soon be made available through the ESO Catalogue Facility.

Links

[1] Ultra-VISTA survey homepage: http://www.ultravista.org/
[2] ESO Phase 3 data releases: http://www.eso.org/sci/observing/phase3/data_releases.html
[3] ESO catalogue facility query interface: http://www.eso.org/qi

Staff at ESO

Peter Gray

Returning to ESO after an absence of eleven years feels very much like coming home. The ESO I knew from those heady days of the VLT construction and the birth of the Paranal Observatory still feels very much the same. There are many familiar faces from those days, my Garching colleagues and the many co-workers with whom I shared the excitement of building the VLT and setting up Paranal Engineering. Equally as enjoyable is the chance to meet so many new faces, many young people along with experienced older new-hands. ESO has certainly grown, both in numbers of people, but also in the depth and breadth of the experience and expertise of its staff, but it retains the same look and feel of ESO as "the" place of technical and scientific excellence in astronomy, telescopes and instrumentation engineering. After nearly thirty years of working in engineering at many of the world's major observatories, it really does feel like coming home.

How I ended up working as an engineer in astronomy is an interesting story. I started out at the University of Sydney in Australia studying physics, then mechanical engineering. As part of the engineering degree it was necessary to spend time working in industry. My first choice at the time was working for a large hydro-electricity company, since it sounded fun to travel around to remote places, looking after dams and pumps. However as fate would have it, I didn't get the job and was forced to take my second choice, working at the Anglo–Australian Observatory (AAO) in Sydney and some exciting months up at the 4-metre Anglo Australian Telescope at Coonabarabran. Those were the days when 4-metre telescopes were state of the art, when programming meant punched cards and everyone was happy to have 3-arcsecond images.

I ended up liking it so much that after graduation I started working at the AAO as a young mechanical engineer, helping build instruments and improving telescope performance. During this time I helped pioneer the technique of multi-object spectroscopy using optical fibres, which has now been extensively exploited by the AAO and other major observatories. After ten years at the AAO, learning my trade, I launched my career as an astronomical engineer and spent the next twenty years moving around internationally among most of the major observatories in the world, working in instrumentation, engineering operations support and large telescope projects.

Peter Gray

When I first left Australia in 1992, I worked for five years at Steward Observatory in Tucson, Arizona on a variety of projects including mirror casting and polishing in the Mirror Lab, the Multi-Mirror Telescope (MMT) telescope 6.5-metre upgrade, the Large Binocular Telescope and various other instrumentation projects. That was an exciting time, working for Roger Angel and other people at the Mirror Lab, audaciously casting and polishing big mirrors in the basement of the University of Arizona football stadium.

In 1997 I started work for ESO in Chile as the Assembly, Integration and Verification (AIV) manager for the VLT project. I was responsible for the organisation, coordination and execution of the AIV work up until first light of the four VLT telescopes. This work began with the first telescope in 1997 when Paranal existed as a construction site. As each VLT was finished, we continued to provide engineering support to Commissioning, and then Science, Operations. As Paranal transitioned from construction to operations, my position became one of Head of the Engineering Department. The infrastructure, staffing and engineering processes were gradually built up into the successful engineering support team at Paranal, which has continued to the present day.

At the end of 2001, after five years of the most exciting time of my life at Paranal, I was on the look-out for new challenges. I decided to switch wavelengths and try my hand at radio astronomy engineering so I left Paranal to take up a position with the National Radio Astronomy Observatory (NRAO) in the US ALMA project office in Charlottesville, Virginia. During this time I worked closely with many of the ALMA project staff, both at NRAO and ESO, and became familiar with the techniques, technologies and instrumentation of millimetre-wave astronomy. I left the ALMA project at the end of 2002 and moved on to the Gemini Observatory as Associate Director of Engineering.

For the next five years I worked as the Head of Engineering at Gemini Observatory where I built up the operational engineering support to transition the Gemini telescopes from commissioning to routine science operations and used my Paranal experience to implement a similar set of engineering operations systems and procedures. During this time I led the Gemini engineering team through a number of advanced developments including low emissivity silver coatings and laser guide star adaptive optics systems.

During the last four years I have worked as the Assistant Project Manager at the

Thirty Meter Telescope (TMT) Project Office in Pasadena, California. I worked on a number of tasks, including the design and planning of the telescope enclosure and structure, project assistance to the TMT–Japan project offices, the investigation and planning of the on-site construction phase and the detailed long-term operations planning for the observatory.

Now back at ESO once again as the Project Engineer for the European Extremely Large Telescope (E-ELT) project, I'm using these accumulated experiences of the last 20–30 years of my working life in big projects and astronomical organisations to help ESO deliver the largest and most technologically advanced telescope so far.

In between times, those who know me, know that I'm seldom idle outside of work on weekends.

Over the years, whatever the remote location of the observatory, I'm always out and about, whether it be paragliding in Tucson, mountain biking at Paranal, windsurfing in Antofagasta, or kiteboarding in La Serena and Hawaii. Road cycling is my current passion, which is how I met my wife, Leslie. Although Californian, Leslie has actually spent most of her life in northern Montana as a cowgirl, backcountry horse riding, skiing, hiking and road cycling. Leslie and I now have a combined "stable" of twelve bicycles, including several beloved Pinarellos. As well as sharing her passion for road bikes, Leslie shares with me our grown-up son Hunter, a young entrepreneur living back in Pasadena, whom we proudly boast is a successful small-business owner employing several people and helping to kick start the US economy.

Fellows at ESO

Noé Kains

Looking back, my path to becoming an astronomer is perhaps a slightly unconventional one. Like most other astronomers, I have early memories of being interested in space and rockets. I also remember being entranced by the night sky during summer family holidays — I was lucky to spend entire summers sailing around the North Sea, and I particularly enjoyed sailing at night, which gave me plenty of opportunities to get away from light pollution and see the night sky in all its glory.

I was born and raised in Brussels, and moved to London when I was 17 to begin an undergraduate degree in physics at Imperial College, because I enjoyed physics and maths at school, but also because I had decided very early on that I wanted to go and see other things than the small country in which I grew up. Apart from my long-standing obsession with London, there was another reason that I wanted to move to the UK in particular. Since the age of six, I had been studying the piano and I knew that the more flexible education system in the UK would allow me to pursue both interests. During my undergraduate physics degree, I was lucky enough to be supported by scholarships that enabled me to continue my musical education in parallel; something that would have been very difficult in Belgium. After working on an astronomy project for my Master's thesis, I decided to apply for a PhD in astrophysics, which I started at the University of St Andrews in Scotland in 2006. Again, throughout my PhD I kept up a busy musical parallel life, which I think made the PhD experience much easier. I was lucky to have a supervisor who fully supported this, even when I disappeared for weeks at a time on concert tours! During almost four years in Scotland, my love for astronomy developed further and the fun I had working on my PhD convinced me that this was the career I wanted to pursue.


Noé Kains

My first observing trip, in 2007, was a 23-night run on the 1.54-metre Danish telescope at La Silla. If 23 long winter nights did not dent my fascination for observing, clearly my commitment to this was no fluke! Every day I was amazed to wake up in this strange place in the middle of nowhere, and every night I spent hours marvelling at the splendour of the Chilean night sky, running outside between two exposures of the Galactic Bulge to look at the bright trail of the Milky Way and the Magellanic Clouds. Two (thankfully slightly shorter) further observing runs in La Silla only strengthened my attachment to the place, so ESO was a natural place for me to consider when it came to looking for my first postdoctoral position.

Working at ESO is such a privilege — to be surrounded by the people who run the world's most important observatory, particularly seeing the engineering and political sides of it, which is something that most scientists easily forget. The sheer number of talks, seminars and colloquia is a testament to this. Most astronomers come through ESO at some point or another, which means that, being here, we get to hear and meet many of today's brightest astronomers. During my Fellowship I have continued my work on exoplanet hunting using gravitational microlensing, and have started new collaborations, leading me to apply my work to areas of astronomy that I would not necessarily have considered before. There is definitely a sense of being lucky to be here at ESO and wanting to make the most of it amongst the community of young researchers. Of course, being an astronomer is a privilege in general: we are essentially employed to think, and get to visit many of the world's most incredible places for observing trips, conferences or collaborations. Another advantage of being here is that ESO is in the news a lot. It may seem trivial, but it is a nice feeling when your family and friends have a vague idea of what you do as an astronomer, thanks to the amount of media exposure ESO receives as a world-leading observatory.

On the music side — well, of course I don't spend as much time practicing the piano or performing as I once did, but the first "piece of furniture" I bought when I moved to Munich was a piano — before even buying a bed! I still find that the balance in my life between music and my "job" is essential. When struggling with a science problem I can come home, practice for a few hours and "reorganise" my brain. It really works!

After two great years at ESO, it's unfortunately already time to start looking for my next job. Wherever I go, I know that the experience and contacts I am gaining here will be a major asset, both on a personal and professional level.


Roberto Galván-Madrid

Roberto Galván-Madrid

Looking at it in retrospect, I don't know how I got here, but I'm very happy that it came to be. I was born in the southeast of Mexico, in the "small" city (with about a hundred thousand inhabitants) of Chetumal, in the Yucatan Peninsula. People there just do not become scientists. The natural path within my extended family would have been to become a merchant, a bureaucrat, or a politician. Luckily, my parents always motivated my brothers and me to educate ourselves, perhaps because they didn't have the chance to finish professional degrees, and there were many lectures at home on which to spend some afternoons after school. I remember my excitement when I was a kid and discovered some books that explained things about particle physics, space travel or the Solar System.

When I finished high school in 2000 I convinced my parents that "I had to leave" my home town to study physics. Then I moved to Monterrey to start my college degree, a completely different, accelerated, heavily industrialised city of four million people in the north of Mexico. I remember those years as a period of discovery where I dived into so much knowledge, made some of my best friends in life, and realised that making contributions to science was within reach. Five years later, after discarding the idea of postgraduate studies in some other areas of physics, or taking a second degree in philosophy — good decision! — I started my masters in astronomy at the Center for Radioastronomy and Astrophysics of the National University of Mexico (UNAM). There I learned a lot from my advisor Luis F. Rodríguez and several other staff members. In 2007, I was lucky enough to be admitted to the predoctoral programme of the Smithsonian Institution, and moved to the Center for Astrophysics in Cambridge, Massachussetts, to conduct my doctoral research working with the Submillimeter Array (SMA) group. Those years in "the geekiest town on Earth", with all their ups and downs, have a very special place in my memory. Toward the end of my thesis, I also spent a dreamy season in Taipei, Taiwan, eating yummy Chinese food.

In September 2011 I moved to Munich and started my ESO Fellowship. I wanted to learn about the European way of doing things and gain expertise with ALMA, and what better place than at the flagship astronomical institution on this continent. So far I am loving both the scientific opportunities and life in Germany, including beer fests and trying to learn to pile up words as locals do. I envision myself in the future going back to Mexico and helping a little bit to the development of my country — but one never knows! — while at the same time strengthening ties with all the great institutions in which I have worked all over the world. Owning a dog and publishing some fiction are also in my plans.

Presenting the ESO Story: One Hundred and Fifty Messengers

Claus Madsen[1]

[1] ESO

Since 1974, *The ESO Messenger* has been one of ESO's primary communication channels to the outside world in particular. It has provided a window not only onto the organisation, its projects and people, but also onto the research carried out by ESO's ever-growing user community. Last but not least, today it constitutes a fascinating historical source, documenting the life and evolution of ESO over the last 38 years.

"With this issue, we launch *The ESO Messenger* in its orbit and wish it a fruitful mission." Such were the opening remarks by ESO Director General Adriaan Blaauw, when the first six-page issue of ESO's new in-house magazine appeared in May 1974. The new publication was supposed to serve two purposes: a) "to promote the participation of ESO staff in what goes on in the Organisation, especially at places of duty other than our own"; and b) "to give the world outside some impression of what happens inside ESO.

At the time, the need for internal communication had become pronounced. In 1974, ESO had ongoing operations at four sites: the Headquarters in Hamburg; the CERN premises which housed the ESO Telescope Project Division; Santiago-de-Chile with its administrative and technical staff; and, of course, the La Silla Observatory with its growing number of telescopes. Two decades before the worldwide web came into being and e-mails became the standard communication tool, maintaining proper communication and ensuring that staff was duly informed and motivated was an immense task, even if the ESO staff complement was much smaller than today.

The new magazine therefore reflected a very real need, contributing to the coherence of the organisation at a time when it was thinly spread and struggling under the burden of completing the 3.6-metre telescope project. Reaching out beyond the ESO staff was equally important. With four telescopes in operation (including the 40-centimetre Grand Prism Objectif), in addition to two national telescopes, ESO had an active user community. During that year, 178 observing runs were carried out with the ESO telescopes. Furthermore, 14 runs were undertaken under ESO time with the national telescopes. Perhaps more importantly, the user community was preparing itself and eagerly looking forward to the advent of the 3.6-metre telescope.

The Messenger was not the first publication by ESO. Aside from the Annual Reports, ESO had published the *ESO Bulletin*, the first issue appearing in November 1966 and the last, No. 12, published in June 1975. The *Bulletin's* intended readership were astronomers and decision makers, but despite this, it had been a more modest undertaking than *The Messenger* as regards size and frequency, and it clearly covered a much more restricted range of topics in the area of science and technology. The presentation style of the *Bulletin* was formal, rather different from the more relaxed ways of the new magazine. However, as *The Messenger* changed its character, the *ESO Bulletin* became redundant and the articles that would have appeared in this publication were now published in the new magazine.

Finding its feet

The first issue of *The Messenger*, edited by Francis Walsh, was rather small, with just six pages. Written in English, selected texts were also reproduced in Spanish, mainly for the benefit of the local staff in Chile. The print run was 1100 copies (Kjär, 2000), printed in letter-press, as was the custom of those days. Even with six pages, the magazine included a wide range of "stories" from the "preparation of a conference on Research Programmes for the New Large Telescopes", progress reports regarding the 3.6-metre telescope project, the ESO Sky Survey, etc. to a short article about the ESO Christmas party, held in the [Santiago] Guesthouse garden. The writing style and the choice of topics were reminiscent of a newspaper — or a newsletter, which was precisely its intended role. To ensure adequate coverage, the editor was assisted by "local correspondents" in Geneva and Santiago. Interestingly, astronomy was absent, at least as a science. This would soon change.

With the publication of issue No. 4, astronomy entered the pages of *The Messenger*. Intended to appear on a quarterly basis, this issue was published in March 1976, after an interruption of one year. In the meantime, the editorship had passed to Richard West. In 1975 a new Director General (DG), Lodewijk Woltjer, had taken over from Blaauw. Woltjer was intent on strengthening the scientific aspects of ESO including building up a group of active scientists at ESO. The editorial changes that may have seemed to begin rather subtly with issue No. 4 fitted well within the overall direction of ESO under the new DG. West was based in Geneva and thus embedded in the growing technical and scientific environment, rather than in the ESO administration, still based in Hamburg. As early as the following issue, astronomy had become the dominant topic, clearly demonstrated by the fact that for the first time, the cover page contained an astronomical picture of the globular cluster NGC 1851. The issue also featured articles by astronomers describing their research. This was originally meant to motivate the non-astronomical staff at ESO.

Newsletter-style reporting continued, especially regarding the 3.6-metre telescope, which was rapidly approaching first light, but elaborate descriptions of staff barbecues, presentations of staff representatives and the like disappeared. Even so, the editor tried to balance the scientific or technical articles with light and easy-to-read stories of general interest. In the early years, *The Messenger* even published letters to the editor, such as the following in the December 1979 issue, allegedly from a certain "H.D.": "Since *The Messenger* is evolving in the direction of serious journals, one should consider the problem of quoting articles in lists of references. The other day I found the reference: 'ESO Mess' — which is perhaps not the best compliment to the otherwise fine organisation…."

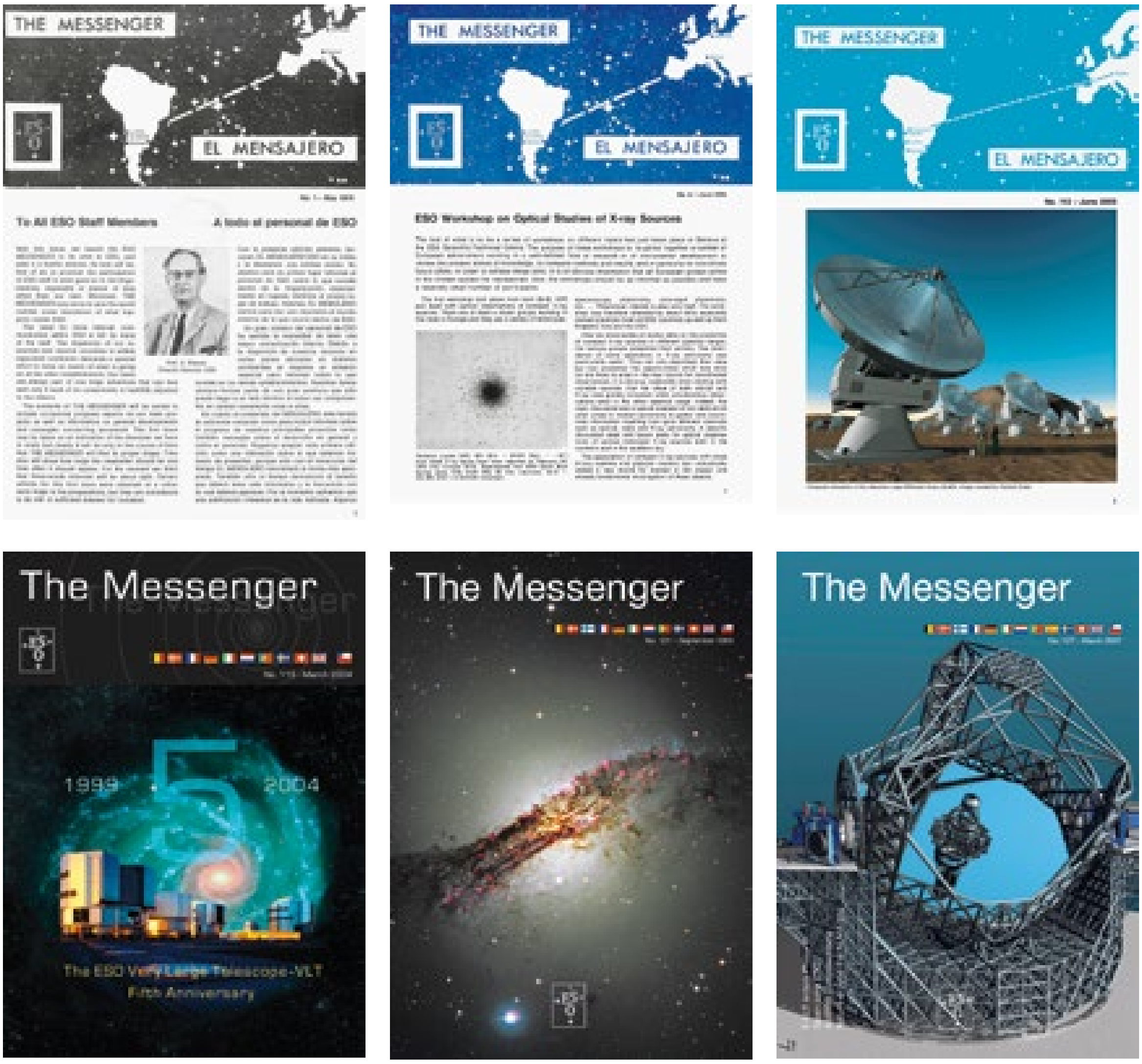

Figure 1. The changing face of *The Messenger* – from a modest black and white version to the current appearance.

A particularly amusing article, written by the editor and also published in December 1979, discussed the transformation of observing, from the classical style with the astronomer glued to the eyepiece, patiently guiding his telescope for an hour or more, to the modern automated (as it was described) mode of observation. Reading this dark-humoured preview of the times to come is strongly recommended, perhaps especially for young astronomers.

The editor also allowed space for the occasional cartoon, in most cases provided by gifted ESO staff, but also from professionals. Perhaps most famous of the first category was the cartoon of the overcrowded La Silla Observatory, created by Karen Humby (No. 12); an example of the latter was a drawing by the iconic Danish cartoonist Robert Storm Petersen, published in issue No. 47. With police officers crowding an observatory dome, the text explains that "the police now collaborate with the astronomers to determine the exact time when bicycle lights must be lit".

The change of editor was also visible in other ways. From issue No. 4, the banner on the cover, designed by Bernard Dumoulin and featuring a stylised map of Europe and South America transposed on a starry sky, was printed in colour. Since colour printing was expensive, this was the only use of colour and, modesty prevailing, the header used one colour only. Unsurprisingly, it was blue, intended to match the official colour of the organisation (although it never really did).

In terms of preparing the publication, West formed a strong partnership with Kurt Kjär, who as technical editor oversaw the layout, typesetting and general interaction with the printers as well as the distribution. Kjär remained as technical editor until his retirement in 2003 (the last issue on his watch was No. 111). West's influence on the magazine was also visible when it came to its size, occasionally reaching 40 pages during his first term. (In 1980, West was succeeded as editor by Philippe Véron, only to return again between 1986 and 1993 after finishing his term as IAU Secretary General). The growth in the number of pages reflected the increase in activities at ESO and within the scientific community. It is therefore not surprising that *The Messenger* would also continue to grow, reaching a peak of 88 pages in December 1992.

History, current affairs and preview of the future

Among the many pages, thousands by today, it is difficult to pinpoint articles of particular importance, but it is hard to overlook the series of papers that appeared in Nos. 15 and 16 (December 1978 and March 1979) under the common heading "Ten nights at the VLT". Here prominent astronomers offered their views and expectations as regards Europe's next generation telescope, the Very Large Telescope (VLT), at the time barely more than a dream. This was a year after the seminal ESO conference at CERN about the large telescopes of the future, which in many ways started the thinking about the VLT. This shows a different aspect of *The Messenger* that gradually began to evolve – beyond newspaper-style reporting and educational articles about astronomical research to the use of the magazine as a strategic communication tool, supporting the overall future goals of the organisation. This is visible again in the use of colour printing, until December 1982 restricted to the banner on the cover page. In the December 1982 issue, which celebrated the 20th anniversary of ESO, *The Messenger* featured the first tri-colour composite images based on ESO Schmidt plates as well as early CCD images in colour.

One year later, in December 1983 (No. 34), the cover page had a large picture with an artist's impression of the VLT, created by Jean Leclercqz. The particular picture bears relatively little resemblance to the VLT as we know it today, but it stirred the imagination of the readers, following the crucial meeting in Cargèse, in which the project began to take shape with the support and enthusiasm of the astronomical community. The same issue carried an article by Daniel Enard and Jean-Pierre Swings about the project.

Perhaps an article of similar importance to the VLT "dreams" of the 1970s was the article in March 1998 by the Director General of the time, Riccardo Giacconi, entitled "The Role of ESO in European Astronomy", in which he laid down the rationale for the organisation within the European astronomical landscape, setting the course for future projects. But the use of *The Messenger* as a strategic communication tool was perhaps most clearly enunciated in No. 100, published in June 2000, which fittingly presented the 100-metre Overwhelmingly Large Telescope (OWL) conceptual study to the audience of readers and helped to prepare the ground for the coming ELT generation of telescopes. On the cover page of the anniversary issue, just above the OWL paper, the editor presented *The Messenger* as "one channel of ESO's multimedia approach to providing information about its activities and achievements".

This shift in approach did not mean that *The Messenger* no longer maintained its mixture of articles, including institutional developments, new instruments and current observation programmes. It was sometimes even used for fast presentation of new research results, although without a peer-review system it never aspired to become a formal scientific journal. One strength of *The Messenger* was the short production time. An example of this was a 16-page section with early ESO observations of SN 1987A, appearing only three weeks after its discovery in February 1987.

The Messenger also gave space to retrospective articles. Best known, perhaps, is the series of articles written by Adriaan Blaauw and published in 1990–91 about ESO's early history, which he defined as the period between 1953 and 1975. These articles were subsequently compiled into a book that has become the reference historical description of ESO during that epoch (Blaauw, 1991). But others provided informative articles and brief notes about ESO's history as well, such as Daniel Enard's "The VLT – genesis of a project" in issue No. 50, Woltjer's article on the "Discovery of Paranal" (No. 64), Alan Moorwood's article on the evolution of infrared instrumentation at ESO over 30 years, appearing in the same issue as Hans Dekker's paper on optical spectrographs (No. 136), Gero Rupprecht's summary of 20 years of FORS operations (No. 140), and indeed many others.

Since the early days, *The Messenger* had brought articles about new telescopes and instruments, and it could be said that these articles stand out as the strongest contemporary asset of the publication. This is hardly a coincidence. The strong engineering tradition is one of the hallmarks of ESO and undoubtedly a key source behind its success.

In September 1993, Marie-Hélène Ulrich took over as editor of *The Messenger*. The change of editorship brought a tightening of the editorial policies, with an introduction of fixed sections on Telescopes and Instrumentation, Reports from Observers and Other Astronomical News and finally, Announcements. This change enforced the move towards a publication for technically or scientifically oriented readers. The more rigid approach, manifested in the new format, was maintained by Ulrich's successor, Peter Shaver, who assumed the task in June 2002. At the time, opening up *The Messenger* to cover non-ESO related astronomical news was considered, but in the end, *The Messenger* continued on the path it had followed so far — as an in-house publication appealing to a broad external readership. This readership was sizeable. From the original print run of little more than a thousand copies, in the 1980–90s the circulation grew to 3–5000, with an estimated readership clearly exceeding that number since it included many institute and public libraries.

Changing appearance

Looking back, the editorial changes can largely be seen as adjustments to the early concept, although compared to the first issues there is little resemblance between then and now. This also applies to the graphical appearance, even though for almost 30 years, practically no visible changes occurred. On the technical side much had happened. Thus, from issue No. 6, offset printing was used and from issue No. 79 (March 1995), desktop publishing was introduced. By March 2003, however, the new technical editor, Henri Boffin, had given the magazine a face-lift. The first change was the introduction of full-size cover pictures (i.e. with no text other than a caption). A year later, the traditional banner at the top of the cover disappeared, seeing instead the introduction of the row of flags of ESO's member states.

When Boffin moved to other tasks at ESO in March 2005, Jutta Boxheimer replaced him as technical editor. Boxheimer brought with her the skills of a very successful, professional graphic designer with additional solid experience in scientific publishing. She naturally played a central role in developing the new ESO "corporate design" which encompassed everything from letterheads and business cards to the ESO website – and, of course, *The Messenger*. From then on, ESO's communication efforts, including the graphical design, were seen as a whole, establishing *The Messenger* in its present look and feel and supporting its image of a mature, up-to-date, serious scientific publication with high quality content.

The current external circulation, of 4100 copies, is testimony to the continued interest that readers take in ESO and its activities. In the recent years, *The Messenger* has also been accessible online and so even new readers have access to past issues, from the very first issue until today. In that sense, one of the two aims for the magazine when it was launched 38 years ago – to provide a window onto ESO for the outside world — has undoubtedly been reached.
The other aim, to support internal communication (although it was phrased slightly differently) can be said to have been reached as well, inasmuch as the publication contains a wealth of information about what goes on at ESO at the technical level. Providing space for the members of the science faculty to present themselves has added an important human dimension, too. Nonetheless, the relaxed newsletter, as it was originally conceived, has disappeared. So has the Spanish summary, which was discontinued in March 1988, although two articles, in much abbreviated versions, appeared slightly later. The last one, with the title, "Mi Visita a La Silla", fittingly described a visit to the observatory by André Muller, the ESO Superintendent in Chile of the early years. This article was published in December 1988.

The Messenger has over the years served several purposes: as a tool for internal communication as well as providing information to the user community at large and other interested parties, such as many amateur astronomers. Perhaps unwittingly, however, it has fulfilled an additional role as a highly valuable source of information about ESO's history and, to the extent that it mirrors at least some main developments and trends in the general history of European astronomy, it remains an incredibly rich treasure to explore and to enjoy. Happy Anniversary, *Messenger*!

Acknowledgements

The author wishes to thank Kurt Kjär and Richard M. West for informative discussions in connection with the preparation of this article.

	Editors	Technical Editors
1974–1975	Francis Walsh	Kurt Kjär
1976–1980	Richard West	Kurt Kjär
1980–1986	Philippe Véron	Kurt Kjär
1986–1993	Richard West	Kurt Kjär
1993–2002	Marie-Hélène Ulrich	Kurt Kjär
2002–2006	Peter Shaver	Kurt Kjär Henri Boffin (from 2003) Jutta Boxheimer (from 2005)
2007–	Jeremy Walsh	Jutta Boxheimer

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Blaauw, A. 1991, *ESO's Early History — The European Southern Observatory from Concept to Reality*. ESO, Garching, Germany
Kjär, K. 2000, The Messenger, 100, 53

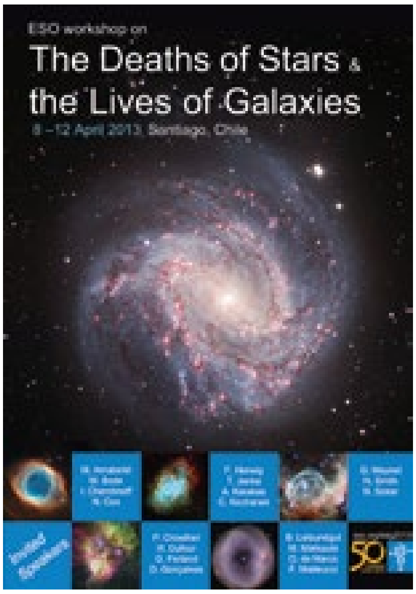

Credit: ESO/IDA/Danish 1.5 m/R. Gendler and C. Thöne

A colour image of the nearby barred spiral galaxy NGC 4945, in the Centaurus A group of galaxies, obtained with the 1.5-metre Danish telescope at La Silla. Images in three filters (*B*-, *V*- and *R*-bands) were combined and emphasise the dust clouds and H II regions of the disc. In the centre of the galaxy there is a heavily obscured Seyfert 2 active galactic nucleus. More details can be found in Picture of the Week 15 February 2010.

Announcement of the ESO Workshop

The Deaths of Stars and the Lives of Galaxies

8–12 April 2013, ESO Vitacura, Santiago, Chile



Too often in astronomy, experts from various fields do not interact, making progress slower than it could be. This is why it is sometimes useful to come together in a workshop that embraces a larger scope than traditional ones. This ESO workshop will do precisely that, bringing together astronomers working on the final stages of stellar evolution and how their demise affects their immediate surroundings and their host galaxies.

The conference is organised along three broad themes: channels of stellar death, products of stellar death, and stellar death in an extragalactic context. It will address questions such as:

- Which stars become planetary nebulae?
- What are under-energetic supernovae?
- Where is the dust in the Universe coming from?
- What is the source of carbon in the Universe?
- What are the Type Ia supernova progenitors?

A remarkable panel of invited speakers will provide extensive reviews of the three themes, while still leaving plenty of time available for contributed talks and discussions.

The deadline for abstract submission is 31 January 2013 and registration will be open until 28 February 2013, or until we have reached the maximum number of participants.

Details are available at:
http://www.eso.org/dslg2013/
or by e-mail: dslg2013@eso.org

Personnel Movements

Arrivals (1 October–31 December 2012)

Europe	
Geier, Stephan (D)	Fellow
Gibson, Neale (GB)	Fellow
Grunhut, Jason Harley (CDN)	Fellow
Huckvale, Leo (GB)	Student
Inno, Laura (I)	Student
Lagos Urbina, Claudia del Pilar (RCH)	Fellow
Rahoui, Farid (F)	Fellow
Urrutia-Viscarra, Paula Maria Fernanda (RCH)	Student
Wang, Ke (VR)	Fellow
Woillez, Julien (F)	Instrument Scientist
Yan, Fei (VR)	Student

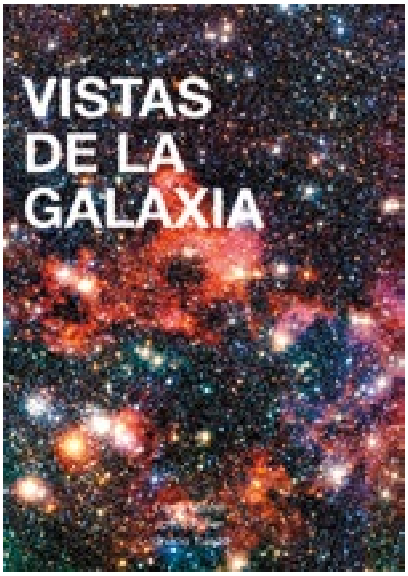
Chile	
Aladro, Rebeca (E)	Fellow
Blanchard, Israel (RCH)	Telescope Operator
Breitfelder, Joanne (F)	Student
Dias, Bruno (BR)	Student
Elliott, Paul (GB)	Student
Gonzalez Garcia, Oscar Alberto (RCH)	Fellow
Grellmann, Rebekka (D)	Fellow
Krogager, Jens-Kristian (DK)	Student
Milli, Julien (F)	Student
Wahhaj, Zahed (BD)	Operations Astronomer

Departures (1 October–31 December 2012)

Europe	
Aspinall, Gareth (GB)	Project Planner
Clare, Richard (GB)	Physicist
Grosbøl, Preben (DK)	Systems Scientist
Heyer, Hans Hermann (D)	Photographer
Krüger, Anna (D)	Adminstrative Assistant
Maury, Anaelle (F)	Fellow
Meuss, Holger (D)	Software Engineer
Montagnier, Guillaume (F)	Fellow
Vernazza, Pierre (F)	Fellow
Zinsmeyer, William (USA)	Software Engineer

Chile	
Camuri, Massimiliano (I)	Lead Electrical Engineer
Fulla Marsa, Daniel (E)	ALMA Commissioning Scientist
Gourgeot, Florian (F)	Student
Jones, Matias (RCH)	Student
Kim, Taehyun (ROK)	Student
Macchino, Agustin (RCH)	Electronics Engineer
Marti Canales, Javier (E)	Lead System Engineer
Pizarro, Manuel (RCH)	Telescope Instruments Operator

Vistas de la Galaxia



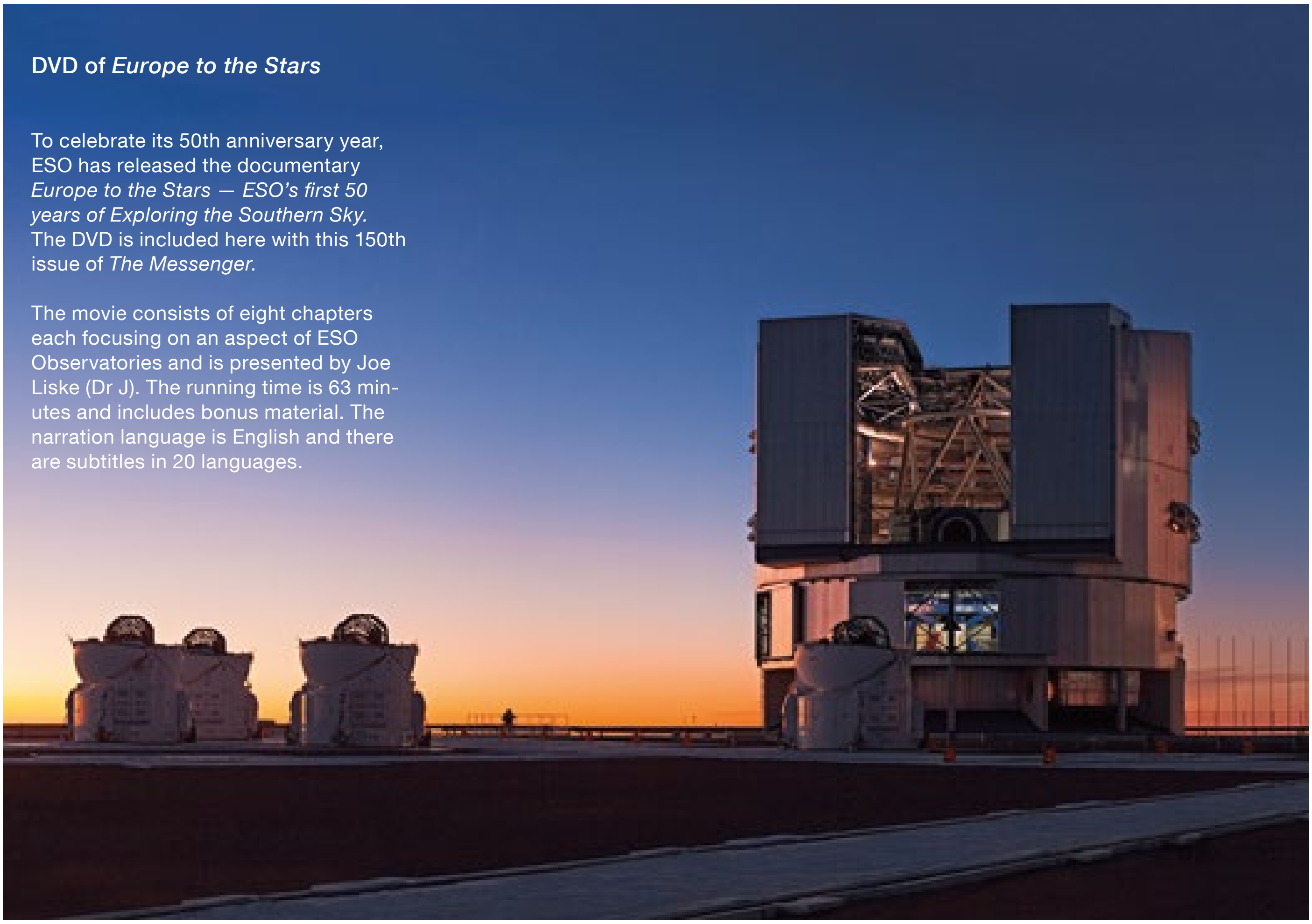
Pontificia Universidad Católica de Chile/ESO

The recently released book *Vistas de la Galaxia* (Vistas of the Galaxy) by Dante Minniti, Joyce Pullen and Ignacio Toledo describes some of the discoveries of the VISTA Variables in the *Via Lactea* (VVV) public survey being conducted with the Visible and Infrared Survey Telescope for Astronomy (VISTA).

VVV is a near-infrared survey of the Galactic Bulge, including the monitoring of many variable stars, to determine the structure and properties of the central 520 square degrees of the Galaxy. The PI is Dante Minniti of Pontificia Universidad Católica de Chile. The survey was described in Saito et al. (2010). One of the recent results from this survey (Saito et al., 2012) is the 84-million-star colour–magnitude diagram and density map of the central ~ 315 square degrees of the Galaxy, featured on p. 44–45 and in Release eso1242.

References

Minniti, D., Pullen, J. & Toledo, I. 2012, *Vistas de la Galaxia*, Ograma Impresores, Santiago
Saito, R. K. et al. 2010, The Messenger, 141, 24
Saito, R. K. et al. 2012, A&A, 544, 147



DVD of *Europe to the Stars*

To celebrate its 50th anniversary year, ESO has released the documentary *Europe to the Stars — ESO's first 50 years of Exploring the Southern Sky.* The DVD is included here with this 150th issue of *The Messenger.*

The movie consists of eight chapters each focusing on an aspect of ESO Observatories and is presented by Joe Liske (Dr J). The running time is 63 minutes and includes bonus material. The narration language is English and there are subtitles in 20 languages.

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It is supported by 15 countries: Austria, Belgium, Brazil, the Czech Republic, Denmark, France, Finland, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, Switzerland and the United Kingdom. ESO's programme is focused on the design, construction and operation of powerful ground-based observing facilities. ESO operates three observatories in Chile: at La Silla, at Paranal, site of the Very Large Telescope, and at Llano de Chajnantor. ESO is the European partner in the Atacama Large Millimeter/submillimeter Array (ALMA) under construction at Chajnantor. Currently ESO is engaged in the design of the European Extremely Large Telescope.

The Messenger is published, in hardcopy and electronic form, four times a year: in March, June, September and December. ESO produces and distributes a wide variety of media connected to its activities. For further information, including postal subscription to The Messenger, contact the ESO education and Public Outreach Department at the following address:

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Contents

ESO 50th Anniversary

Telescopes and Instrumentation

Astronomical Science

Astronomical News

Front cover: The Wolf–Rayet Nebula NGC 2359, known as the Thor's Helmet Nebula, is shown in a colour image from VLT FORS2 exposures in *B*-, *V*- and *R*-bands. This image was released on 5 October 2012 for the 50th anniversary of the founding of ESO and was taken with the help of a member of the general public, Brigitte Bailleul — winner of the competition *Tweet Your Way to the VLT!*. The nitrogen-rich nebular bubble surrounds the WN4 star HD 56925 and is blown by the prodigious mass loss of this Wolf–Rayet star. The wind from the star is interacting with an ambient cloud to the east and south, driving shock fronts into the cloud giving rise to molecular emission. More details can be found in Release eso1238.