The Messenger

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400 Years of the Telescope - special feature
New Generation detector Controller
Chemistry of the Galactic Bulge
ESO Distant Cluster Sample

ESO

400 Years of the Telescope:
Special Feature on History and Development of ESO Telescopes and Instrumentation

The International Year of Astronomy 2009 celebrates the 400th anniversary of Galileo Galilei's construction of a telescope and the cascade of discoveries that have resulted since he first pointed it to the sky.

This special feature celebrates that anniversary with some reminiscences of developments in ESO telescopes and instrumentation.

This feature is produced in conjunction with a special issue of GeminiFocus that celebrates the history of the Gemini telescopes and the people who shaped them.

The Editor

ESO's Telescopes
In memoriam Daniel Enard

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The contributions of ESO to the art of telescope-making have come a long way since the early years, placing it, by the turn of the millennium, among the acknowledged leaders in the field. In this article I will give a brief history of what are, in my view, the highlights among these developments, from the 3.6-metre telescope through the NTT and VLT/I to the E-ELT.

Bridging the gap

In the years after the Second World War it became evident that astronomy and particle physics in Europe had fallen behind the US. In both cases, intergovernmental cooperation was identified as a solution. The European Organization for Nuclear Research (CERN) was conceived in 1949 and created in 1954, followed by ESO, conceived in 1954 and created in 1962. Since then, both organisations have grown to become significant players and even leaders in their field.

ESO's beginnings were not very spectacular. The design of the 3-metre telescope, a goal explicitly set out in the ESO convention, suffered from lack of expertise, especially concerning the mechanics. Patterned originally on the 3-metre Lick telescope, its diameter was increased to 3.5 m to accommodate a more spacious prime focus cage (much to the delight of the rotunder astronomers!). The final diameter of 3.6 m was reached because the blank size allowed it.

The design was a modified Ritchey–Chrétien with exchangeable secondary mirrors and envisaged three foci, as recommended by the Instrumentation Committee: an F/3 prime, an F/8 Cassegrain and an F/30 Coudé. The mirror cell was designed to compensate passively for the deformations of the primary that, even with a thickness of 50 cm, was not stiff enough to avoid flexure due to the changing gravity load during observations: it included thirty independent concentric axial supports (astatic levers) with three pads and a system of air cushions providing the lateral support. Polishing of the mirror and manufacturing of the cell were carried out by the same company, allowing the mirror and cell to be tested as a single unit.

Meanwhile, the pre-design of the mechanics, an interesting mix of horseshoe and fork mountings, resembling the Lassell mount of a century earlier, was progressing fairly slowly, due mostly to the rather understaffed design team. This led to a number of options being considered, including outsourcing the design to some large firms (which was discarded as no firms with the appropriate experience existed) and collaboration with other scientific organisations with experience in managing large projects. Contacts were made with CERN and the European Space Research Organisation (ESRO), and in late 1969 a proposal to collaborate with CERN was submitted to Council. In June 1970, the ESO Council endorsed the creation of a Telescope Development Group, an increase in staff, and the start of the collaboration with CERN. The latter was approved by the CERN Council a week later, and in September a formal agreement was signed. In October the newly named Telescope Project Division moved to Geneva. The collaboration proved extremely positive for the project, and by the end of 1972 the first contracts for the construction of the 3.6-metre telescope were awarded to industry. Four years later, on 7 November 1976, the telescope achieved first light at La Silla (see an example image in Figure 1). The gap with the "competition" had begun to close, although it took until the end of the 1990s to align the telescope properly, and the arrival of a new secondary mirror unit in 2004 to achieve its intrinsic image quality.

An active development

Léon Foucault, he of the famed pendulum, not only invented the modern reflecting telescope around 1857 (using metallised glass mirrors, which he polished hyperbolic so as to compensate for the aberrations of the eyepiece), but also introduced a rudimentary pneumatic support of the primary mirror using support vessels that could be inflated or deflated to allow the mirror to reach its optimal figure. His 80-cm telescope is on display at the Observatoire de Marseille, France.

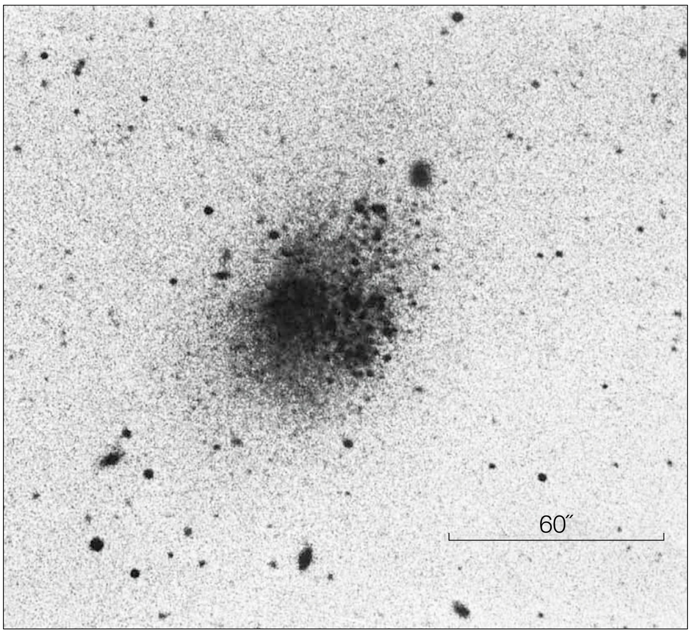

Figure 1. One of the first images obtained at the ESO 3.6-metre telescope prime focus: the Sculptor dwarf galaxy (120-minute exposure on IIIa-J emulsion and taken on 11 November 1976).

It took another 120 years for this concept to mature into one of the most important ESO contributions to the development of the telescope: active optics. The brainchild of Ray Wilson, active optics allows the telescope to monitor its own image quality, correcting automatically for any errors introduced by thermal or gravity deformations. Equally importantly, the technique also allows some of the tolerances of the mirror production to be relaxed without impairing its performance, which in turn allows diameters beyond the 4–5-metre class to be seriously contemplated. The principle of active optics is based on an image analyser that measures the aberrations introduced by any deformations, and then applying compensating forces to the back of the mirror via a series of computer-controlled actuators so that the mirror returns to its optical prescription (while the focus and collimation are corrected by moving the secondary mirror). This happens continuously during an observation without disturbing it. Corrections are applied every few minutes in closed loop. This technique was certified with a 1-metre prototype, and the New Technology Telescope (NTT) mirror has proved to be one of the best ever built (on a par, if not superior, to the Hubble Space Telescope (HST) primary, although both suffered from spherical aberration, but that is much easier to correct with active optics!).

Conceived as a test bed to explore solutions for a future very large telescope (and to ease the demand on the 3.6-metre telescope), the initial specifications for the 3.5-metre NTT were defined in 1980, the year ESO moved from Geneva to Garching (losing many of its technical staff in the process). Following the entry of Switzerland (1981) and Italy (1982) into ESO, the NTT became a "real" project, with a budget about one third that of the 3.6-metre. Its main characteristics were compact design and low weight, to be achieved through a thin, fast F/2.2 primary (40% of the thickness of the 3.6-metre primary) controlled by active optics; altazimuth mounting; a single focus (F/11 Nasmyth, at two locations); and a compact co-rotating building without a classical dome. It also included modular ("maintenance-friendly") electronics. The optical design is of the Ritchey- Chrétien type. Many of these characteristics were later included in the design of the Very Large Telescope (VLT).

The experience gained from the design and construction of the 3.6-metre telescope (as well as a number of smaller ones, e.g. the MPG/ESO 2.2-metre telescope, where remote observing was tested in 1986) reinforced by an increase in technical staff, enabled the project to progress more smoothly, first under the direction of Ray Wilson and later, from 1984, of Massimo Tarenghi. The NTT telescope was fully assembled and functionally tested in Europe before being shipped to La Silla in the spring of 1988. Erection of the enclosure was already advanced by then, the telescope was integrated and testing started later that year. The NTT achieved first light on 22 March 1989, with an image quality of only 0.33 arcseconds.

That the NTT image quality was indeed outstanding I learned from personal experience. In December 1989 I was at La Silla to search for the suspected ring around SN 1987A using the 2.2-metre telescope with an instrument developed at the Space Telescope Science Institute, where I was working at the time. The instrument had a photon counting array that provided the position and time of arrival of each photon, and the idea was to try to reconstruct a high spatial resolution image from this information (a sort of *post facto* speckle imaging). The night before my run I was invited by Massimo Tarenghi to visit the NTT control room during a commissioning run. A short observation of SN 1987A was taken "in my honour", and to my great astonishment as the image appeared on the screen, the ring was clearly visible in the 0.4 arcsecond picture (see Figure 2). My observing programme became obsolete then and there, but this was more than compensated for by the spectacular confirmation of the existence of the ring!

The NTT was not a milestone towards the realisation of the VLT in technical terms only. In 1993, on the advice of an *ad hoc* committee, it was decided to upgrade it to achieve its full potential. In what was called the "NTT Big Bang", an activity led initially by Dietrich Baade and then by Jason Spyromilio, the upgrade included replacing the old control system by the VLT one. This allowed the VLT control system to be brought up to full functional status well before the start of VLT commissioning, which represented an enormous advantage both in terms of the understanding and experience that were gained, and of time.

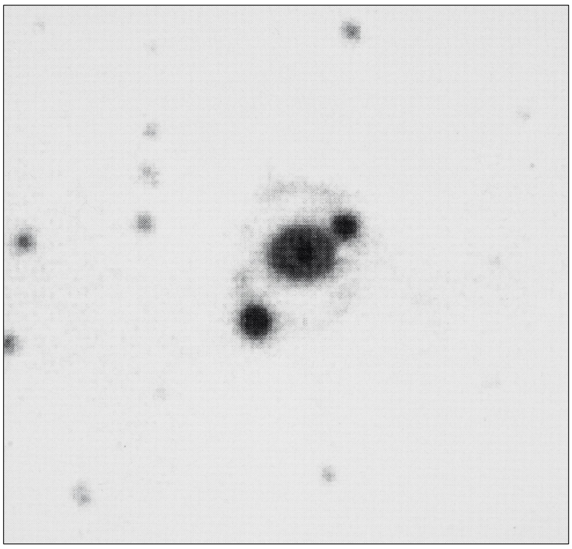

Figure 2. One of the images of SN 1987A taken at the NTT with EFOSC2 on 18 December 1989 (see Wampler et al., 1990).

The science machine

As early as 1978, well before the NTT had even been conceived, ESO started thinking about a Very Large Telescope. The solutions contemplated by the working group, chaired by Wolfgang Richter, included a single 16-metre telescope and arrays of four 8-metre and sixteen 4-metre telescopes. A second working group, chaired first by Ray Wilson and later by Jean-Pierre Swings when Ray took over the NTT project, was appointed in 1981. Its work concluded with the Cargèse workshop in 1983 where the preferred option (among the three proposed by the first working group, plus that of a multi-mirror (MMT-like) telescope) was presented: an array of four 8-metre telescopes. This had been the favourite since mid-1982 (and indeed the reference for the decision of proposing the NTT as a prototype for active optics) on the basis of its scientific advantages, including the potential for inteferometric combination (albeit dependent on the as-yet not well-established use of adaptive optics). The workshop endorsed the choice, and a project group was set up at ESO under the leadership of Daniel Enard. An external committee chaired by Jean-Pierre Swings provided supervision.

The project group started by looking at the same options again, but now from an engineering point of view. Although both the segmented single telescope and the MMT options were considered attractive, the 8-metre array design proved superior to both because it built on the experience ESO was developing in active optics and because it was more flexible (construction could be timed to reflect the current resources, each telescope could be offered to the community as it was completed, and the interferometric combination could be implemented when the appropriate technology became available). Interaction with industry and the community quickly determined that an 8-metre monolithic, thin (hence active) mirror was feasible and that a low cost enclosure concept and an efficient beam combination could be developed. This led to the "linear array" concept that became the baseline for the VLT (see Enard, 1987).

Setting the example currently being followed in the European Extremely Large Telescope (E-ELT) Phase B, a number of competitive design/feasibility contracts were placed with industry (with others carried out in-house). This allowed different solutions to be explored and accurate cost estimates to be obtained, advancing the project considerably. In 1986 it was presented at a dedicated conference in Venice, achieving a large consensus. By early 1987 a proposal for construction had been prepared and distributed to the ESO governing bodies.

On 8 December 1987 the ESO Council gave the green light to the start of the project. The Council decision was courageous, displaying both forward-looking vision and trust in the executive (the NTT was still more than one year from first light at that time!).

Thus began the great adventure of the construction of the VLT. Each Unit Telescope is a Ritchey–Chrétien with an F/1.8 primary and equipped with four foci (F/13.4 Cassegrain, two F/15 Nasmyth and F/47.3 Coudé). Each primary takes full advantage of active optics, and, with a thickness of 175 mm, is some 40 times more flexible than the NTT mirror (which was conservatively sized so as also to be able to function in passive mode). In particular, this flexibility allows the focus to be switched between Cassegrain and Nasmyth by changing the conic constant of the primary. The secondary is a lightweight beryllium mirror with five degrees of freedom and is used for many functions: to focus and collimate the telescope as part of the active optics control loop; to maintain the pointing of the telescope; to field stabilise the focal plane, thus rejecting vibrations induced by wind and motors; as well as to chop and nod when observing in the infrared.

Contracts began to be placed with industry for the long-lead items (e.g., the primaries) while options were still being explored for other subsystems (e.g., the dome, whose design was selected in 1991, the year the top of Paranal was flattened to create the necessary area). Some technical problems occurred with some of the contracts (e.g., the secondary mirror), but the project, from 1987 under the leadership of Massimo Tarenghi, with a brief tenure by Joachim Becker in 1991, progressed at a healthy pace. The interferometric infrastructure was being redefined, increasing the number of delay lines and auxiliary telescopes to allow phase closure, thanks also to special contributions by France and Germany (later supplemented by Belgium, Italy and Switzerland for the production of a fourth Auxiliary Telescope). The final location of the Unit Telescopes (UTs) on the Paranal "platform" was defined so that when used as an interferometer the best coverage of the uv plane could be achieved (within the constraint of mutual vignetting by the domes). Civil works, lead by Joerg Eshway, progressed steadily on the mountain, notwithstanding the "La Torre family incident" in 1994.

Figure 3. VLT FORS image of the spiral galaxy NGC 1232 taken during commissioning on 21 September 1998. This image was voted amongst the ten most inspiring images of the century (Sky and Telescope, January 2000).

By 1996 all primary mirror blanks had been delivered, and the Observatory was beginning to take shape: the erection of the main structure of UT1 had started at Paranal, while a complete UT had been installed and tested functionally in Europe. The first secondary mirror blank had been completed, and the first enclosure was nearly complete.

First light of UT1 was achieved on 25 May 1998, after the heroic efforts of the Acceptance, Integration and Verification (AIV) team lead by Peter Gray had succeeded in fully integrating the telescope. Commissioning of the telescope under the leadership of Jason Spyromilio came next, while I started defining the science operations scenario for the Observatory: in this capacity I was privileged to witness first light, and to share in the excitement of that memorable event (see Tarenghi et al., 1998). By April 1999 the telescope and its two first instruments FORS1 and ISAAC had been commissioned, and operations of UT1 started. The following years saw the completion of the other telescopes and of the interferometer infrastructure. By September 2000 all telescopes had seen first light, and in March 2001 the first fringes had been detected by the interferometer combining the light from two small siderostats.

The VLT represents the crowning achievement of ESO in the field of telescope-making. Thousand of man-years of effort by ESO and its contractors were invested in this success, and today the Paranal observatory — with its four 8-metre telescopes, four 1.8-metre ATs, the almost complete VLT Interferometer (VLTI) and the VLT Survey Telescope (VST) and the VLT Infrared Survey Telescope for Astronomy (VISTA) telescopes soon to enter service — is the leading astronomical facility in the world, serving more than 4500 astronomers and producing an average of two refereed papers per day, the highest scientific output of any observatory anywhere.

This success is due, in my opinion, to a number of factors, among which I would like to emphasise the tight collaboration with industry, the professional management methods, the professionalism and enthusiasm of the staff and the integrated system design that includes an end-to-end scientific approach for its operations. The VLT was designed to be a proper interferometer, and new results will start appearing after the current commissioning of the PRIMA facility concludes. With its low technical downtime and high scientific efficiency, the VLT can truly be considered a science machine!

The future

In 1998 ESO began analysing the concept of an extremely large telescope, a 100-metre behemoth called OWL (for the eponymous bird's keen night vision and for being OverWhelmingly Large, a marvellous name coined by the project manager of the OWL studies, Philippe Dierickx). The OWL was based on a spherical primary that allowed the advantages of mass production to contain costs, but at the expense of a complex optical design to correct for the enormous spherical aberration introduced by the primary. The OWL had a Phase A review by an international panel in November 2005. The review panel judged the project feasible, but identified some technical risks that might affect the schedule and the budget and recommended that the project proceed to Phase B, but that a smaller size be considered to mitigate the risks and to contain the budget.

What followed was the definition of a European Extremely Large Telescope that involved extensive community consultation through five panels established by the ESO Director General in late December

2005 on the topics of science, site, adaptive optics, instrumentation and telescope. The conclusions of the ELT Science and Engineering Working Group (composed of chairs and co-chairs of the panels and chaired by Daniel Enard) was a toolbox to be used as a guide for the ESO ELT Project Office (created 1 June 2006) for the definition of a basic reference design that could be presented to the community and the committees of ESO. The premise underlying these activities was the December 2004 strategic resolution of the ESO Council that requires that the organisation develop a facility that will address the exciting science awaiting us in the coming decade and will be competitive in timescale and performance with similar facilities planned elsewhere.

The work by the ESE panels and the Working Group represents a remarkable success of the community. This, not only for having been able to produce the toolbox (consisting of several hundred pages of reports) in just a few months, but above all for demonstrating the ability to converge to a unified set of requirements and to a unified concept. The specific goals to be addressed in the design were that the E-ELT should have a primary mirror of 42 m in diameter (considered a good compromise between ambition and timeliness), the primary should preferably not be spherical, the telescope should have adaptive optics built into it, and should deliver a science field of view of at least five arcminutes in diameter with a strong preference for larger fields. Furthermore the telescope was to provide multiple stable observing platforms and have a focal ratio favourable to instrumentation.

Additional inputs to the design of the telescope came from the conclusions of the OWL review. The panel had recommended that certain high risk items present in the OWL design should be avoided in the next iteration of the design. Double segmentation (on OWL the primary and secondary were both segmented) and the high complexity of the adaptive mirror (in OWL the 6th mirror combined field stabilisation and adaptive corrections in a single unit) were considered risks that would delay or jeopardise the project. The fast focal ratio of the telescope (F/6), the absence of gravity invariant focal stations, and the concept

Figure 4. Simulated E-ELT image (bottom) compared with the same view by HST (top) and by an 8-metre diffraction-limited telescope (centre).

of open-air operation were also on the list of things to be avoided in the redesign.

On the advice of the ESE working group, during 2006 the ELT project office at ESO analysed two designs of a fully adaptive telescope — a Gregorian and a novel five-mirror design proposed by Bernard Delabre (an on-axis three mirror anastigmat with two additional flat mirrors conveniently located to serve as adaptive optics and field stabilisation mirrors). The anastigmat design provides excellent image quality (diffraction limited over the full 10-arcminute field of view), is almost free of field curvature, has the exit pupil concentric with the focal plane, can adapt its focal length to the different foci in a way similar to the VLT's, and introduces minimal aberrations in the wavefront from laser guide stars.

Eventually, the notion of an adaptive telescope may one day be seen as a natural evolution of telescope design. As size increases, so does the potential resolution, and atmospheric turbulence becomes just one more error source (admittedly a major one) the telescope must deal with. Indeed, with the E-ELT the boundary between adaptive and active optics becomes blurred, if there at all.

A detailed trade-off between the two designs was performed and presented to the ESO committees and to the European community at the Marseille conference in December 2006 (Hook, 2007; Monnet, 2007; Cuby 2007). On the basis of the industrial studies it appeared that the complexity, cost and schedule risk of a 4.8-metre Gregorian deformable secondary mirror would seriously endanger the project. While the 2.6-metre deformable mirror of the five-mirror design is anything but straightforward, the industrial proposals for its construction placed it far from the critical path with a number of alternative solutions. The 3-metre field stabilisation mirror (M5) is also far from simple. Another major challenge for the five-mirror design is the 5.7-metre secondary mirror. Polishing such a convex mirror (actually it is the testing rather than the polishing) requires some innovative approaches, but industrial suppliers have confirmed that it can be achieved.

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

The ESO committees and the community unanimously supported the choice of the five-mirror design, and of the 42-metre size, and recommended the start of the detailed design phase.

In December 2006 the ESO Council resolved that ESO should proceed into Phase B with the aim of having a proposal for construction ready to be submitted to the ESO Council in late 2009 or early 2010. The resources allocated to Phase B are 57.2 M€ including manpower costs.

During Phase B, contracts have been placed with industry for the advancement to preliminary design status for all major subsystems. Contracts are in place for the development of the main structure, the dome, the adaptive mirrors, the tip-tilt unit and the primary mirror support. Several prototype mirror segments are being procured and polished to the specifications of the project. Integrated modelling, development of concepts for the control system, the mirror cells and the adaptor rotators (now called pre-focal stations) are ongoing, as is the design of the secondary unit. For critical subsystems where more than one technology exists or where more than one approach is possible, multiple contracts have been placed. At the present time, more than 90% of the Phase B budget has been committed. See Spyromilio et al. (2008) for details.

Phase B is supported by the EC-sponsored (Framework Programme 6) ELT-Design Study (DS) work that started in 2005 as a pan-European design independent R&D activity, but was aligned to the E-ELT design at the end of 2006. Many of the ELT-DS results have been folded into the Phase B activity. Further supporting activities are being carried out under an FP7-sponsored "preparation for construction" activity.

Supervision for the project is provided by the E-ELT Science and Engineering subcommittee of the Scientific Technical Committee (STC) chaired by Tom Herbst, by the STC itself, and by the ESO Council's ELT Standing Review Committee chaired by Roger Davies. A Site Selection Advisory Committee will advise the Director General about the site choice, to be made within a year.

Phase B has just passed its mid-term review after a number of internal reviews consolidated the baseline reference design, and is on track for submitting a construction proposal to the ESO committees and Council by autumn 2010 after a construction review that will take place in September 2010.

Acknowledgements

During the past 40 years ESO has regained a competitive level for European ground-based observational astronomy, has pioneered new technologies and new operational solutions, and is poised to take the lead in the design and construction of an extremely large telescope. This has been made possible by the combined efforts of its staff members. Acknowledging all who have contributed would require the whole ESO organigram during the past 40 years to be reproduced!

Daniel Enard, who contributed so much to the development of the VLT and to helping us set the course for the E-ELT, passed away on 2 August 2008. He is sorely missed. An obituary can be found in Messenger 134 (Cullum, 2008).

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30 Years of Infrared Instrumentation at ESO: Some Personal Recollections

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This is a brief account of the development of infrared instrumentation at ESO from the first single pixel photometers, built in the optically dominated late 1970s, through the revolution ushered in by the development of panoramic infrared detectors and the VLT, to a tiny glimpse of the 42-metre E-ELT, whose instruments will probably operate predominantly in the infrared, with the aid of adaptive optics. In support of my personal memories, I have combed *The Messenger* for facts and include here the most accurate timeline I could construct, together with references for those who wish to read more, and by way of acknowledging some of those who contributed to this story.

Early Days at Geneva and La Silla

When I joined ESO as an Infrared Staff Astronomer in Geneva in October 1978 the infrared (IR) instruments on offer at the 1-metre telescope on La Silla were a 1–5 μm near-IR photometer from the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn and the Kapteyn Institute 2–30 μm photometer from Groningen. Almost state of the art at the time, the first was equipped with a single InSb detector cooled with liquid nitrogen and the second with a liquid helium cooled germanium bolometer. Filters had to be changed manually while listening, like a safe breaker, for the wheel to catch in the detents. Detector signals were monitored on a strip chart recorder and recorded on ½ inch magnetic tapes. Eyepieces were provided for acquisition and guiding. Observing was carried out day and night, as I discovered to my cost when awarded three weeks observing in one run in July, when it is also pretty cold at night in the 1-metre dome.

In those days, chopping secondaries and the skill and bravery required to fill cryostats safely with liquid nitrogen and liquid helium (still not easy) classified infrared astronomy as a dark art that most ESO staff doubted would ever catch on. In Geneva, however, plans agreed by the external Instrumentation Committee were already afoot for the provision of both more advanced IR spectrophotometers for the 3.6-metre telescope and an undersized, F/35, chopping secondary for performing sky subtraction at up to 30 Hz, plus upgraded instrumentation for an unspecified smaller telescope. A recommendation to follow the new spectrophotometers with a medium resolution near-IR grating spectrograph had also been made at an ESO Workshop on Infrared Astronomy (in which I participated on the Swedish island of Utö in June 1978, shortly before taking up duty) and was later endorsed by the Instrumentation Committee. At the time, this proposal was received with little enthusiasm by most of ESO's astronomers, who were almost exclusively working at visible wavelengths and had their hearts set on another long slit spectrograph. Maybe it all worked out for the best, however, as the ESO Multi Mode Instrument (EMMI) was subsequently developed for the ESO New Technology Telescope (NTT), which had not even been conceived at that time. The telescope engineers also used some questionable language in describing what they thought about the new IR top end and using the 3.6-metre in daytime. Nevertheless, the near- and mid-IR spectrophotometers (equipped with ~1%

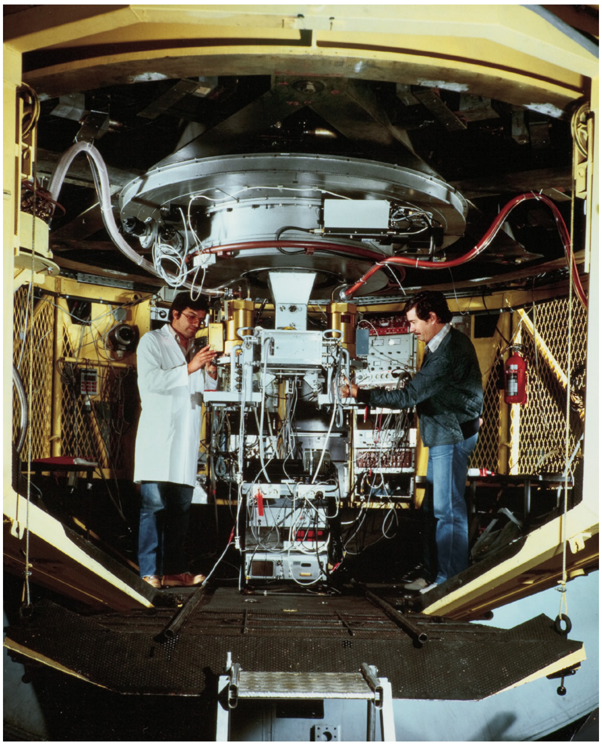
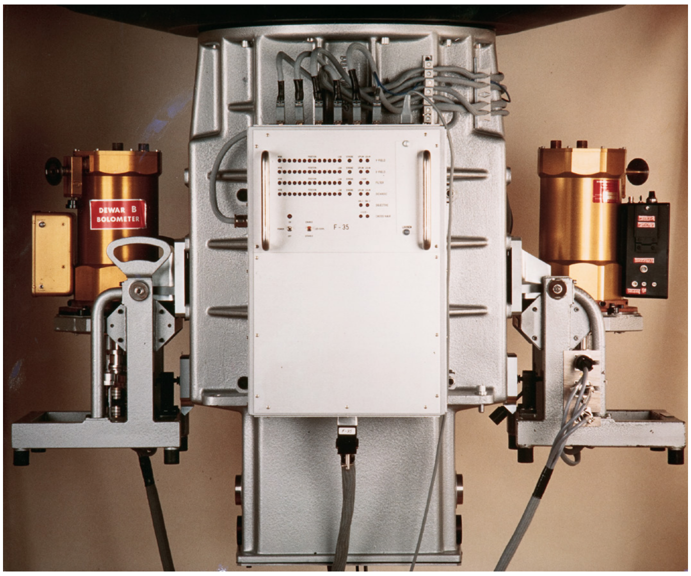


Figure 1. (Left) Installation of the first infrared spectrophotometers at the F/8 focus of the 3.6-metre telescope.

Figure 2. (Right) F/35 chopping secondary mirror on the 3.6-metre telescope.



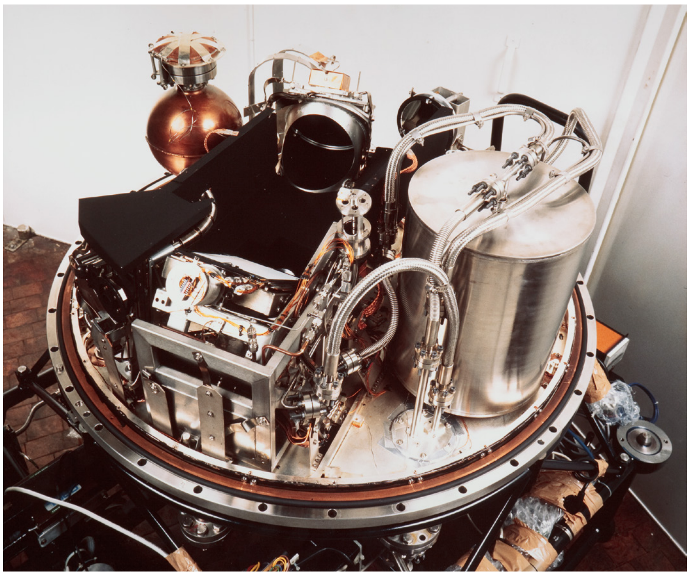


Figure 3. F/35 infrared spectrophotometers on the 3.6-metre telescope. The righthand dewar contains a liquid/solid nitrogen cooled InSb diode for 1–5 μm photometry and the lefthand one a liquid helium cooled bolometer for 8–25 μm photometery through broadband and narrowband circular variable filters. The support unit contains dichroic mirrors and a novel acquisition and guiding system using visible and IR TV cameras and a 2D tilting pupil mirror to explore the field.

circular variable filters) were produced (in a caravan on the CERN site at Geneva), installed (involving a lot of walking around on the primary mirror cover looking for laser beams) and used initially at F/8 with a focal plane chopper until the infamous F/35 was ready (see Figures 1–3). A similar system was built for the 1-metre and, later, the 2.2-metre, which was also equipped with an F/35 chopping secondary built by the Max-Planck-Institut für Astronomie (MPIA) in Heidelberg. In 1985 the 3.6-metre was also provided with a linear scanned IR speckle detector built by the Observatoire de Lyon. All of these systems were productive, but eventually rendered obsolete following the miraculous development of 2D panoramic IR array detectors in the mid-to-late 1980s.

Before the first cameras were finished we had already built the IRSPEC near-IR cryogenic grating spectrograph, shown in Figure 4, which was conceived on Utö and equipped with a linear diode array.

Figure 4. IRSPEC used for medium resolution 1–5 μm spectroscopy at the 3.6-metre and NTT telescopes. Its novel design includes the use of a warm bench to support all the optical units that are cryogenically cooled by a continuous flow of liquid nitrogen from the internal tank on the right. It was also the first infrared spectrograph equipped with a monolithic infrared array detector — initially a 1 x 32 linear array of InSb diodes (cooled by liquid/solid nitrogen in the small copper dewar) and later a 2D 58 x 62 InSb array (cooled by the first mechanical closed cycle cooler used at ESO). In operation, the instrument was enclosed by a dome-shaped cover and evacuated.

When installed on the 3.6-metre in 1985, it was one of the first, and certainly the largest of its type, and the first equipped with a monolithic array (initially the 1 x 32 InSb Cincinnati charge injection device (CID) array and later the famous 58 x 62 Santa Barbara Research Center (SBRC) tank buster InSb array). Its large size also pushed us to develop its unique continuous flow liquid nitrogen cooling system, which has influenced many subsequent cooling systems at ESO. In 1990 IRSPEC was transferred to the NTT and replaced in 1998 by SOFI (Son of ISAAC). Before that, ESO's first imager had been IRAC1 for the 2.2-metre telescope (Figure 5), which was a good camera and the first to provide narrowband imaging with a circular variable filter (CVF). Due to US export restrictions, however, it had to be initially equipped with a 32 x 32 pixel Hg:Cd:Te array bonded to a CCD readout, which sort of worked in the thermal IR, but suffered low efficiency due to a threshold problem in the low background

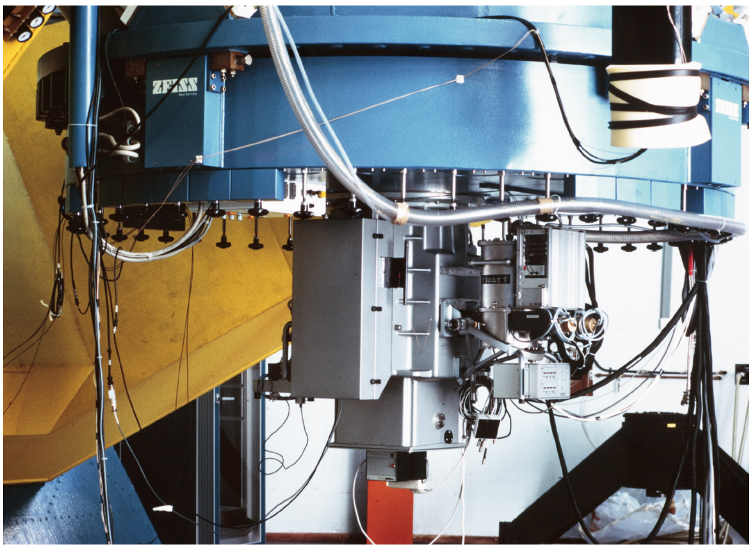


Figure 5. The F/35 IRAC1 camera mounted at the MPG/ESO 2.2-metre telescope.

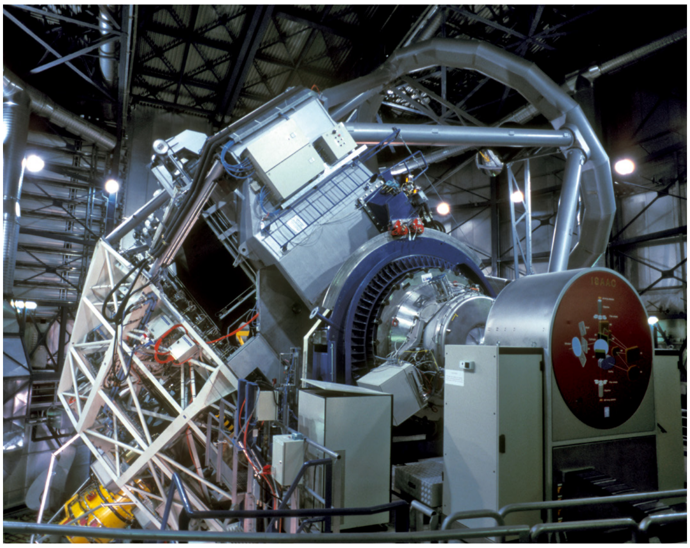


Figure 6. ISAAC at the VLT (UT1). This multimode 1–5 μm imager/spectrometer/polarimeter built by ESO was the first infrared instrument installed on the VLT in 1998 and is still operational and in high user demand. The box attached to the vacuum vessel houses the detector electronics and can be compared with the size of the amplifiers used on the early photometers in Figure 1. The unit in the foreground is the co-rotator needed to avoid tangling the large number of cables and high pressure He hoses for the closed cycle coolers, as the instrument itself rotates at the Nasmyth focus. On its rear is a diagram of the optical layout inside the vacuum vessel.

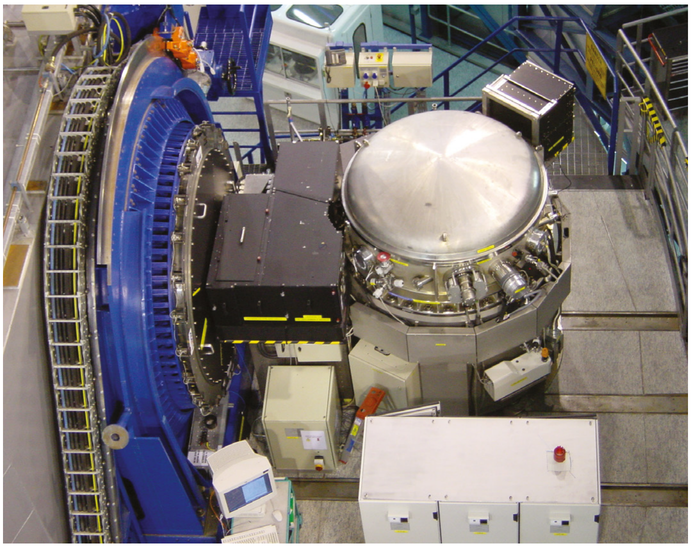


Figure 7. CRIRES, last of the first generation instruments on the VLT (UT1). The black box to the left houses the adaptive optics system and the vacuum vessel contains the 1–5 μm, R = 100000, cryogenically cooled echelle spectrograph.

near-IR. Coupled with poor cosmetics, this detector lacked popularity and was replaced eventually with an improved 64 x 64 pixel Hg:Cd:Te array and finally a 58 x 62 pixel SBRC array in 1994. In the meantime, IRAC2 was built by ESO and equipped with a scanning Fabry Perot and one of the first of the famous Rockwell 256 x 256 Hg:Cd:Te NICMOS3 arrays that were a spin-off from the Hubble Space Telescope NICMOS development. In 1998, SOFI replaced IRSPEC at the 3.5-metre NTT — it is still there and in high demand for 1–2.5 μm imaging, polarimetry and grism spectroscopy with its 1k x 1k Hawaii 1 Hg:Cd:Te array.

Partly in parallel with the above, the 3.6-metre F/35 focus was increasingly used for mid-IR imaging and spectroscopy, first with the *N*-band (10 μm) TIMMI camera, built by the CEA around a 64 x 64 Ga:Si array evolved from the smaller one flown on the ISO satellite and, later, TIMMI2 developed by the University of Jena and ESO and equipped with a Raytheon 240 x 320 As:Si array. The F/8 focus of the 3.6-metre was also used for the pioneering efforts in adaptive optics with COME-ON and COME-ON+/ADONIS developed with ONERA, Observatoire de Meudon and others which have paved the way for the current VLT systems.

In case it has not yet become apparent, it is worth mentioning here that in striving to offer the best available detectors, ESO's infrared detector group has also evolved into a major asset, which has achieved worldwide recognition through its fundamental research and characterisation work, performed in addition to just providing detector systems (including the latest in acquisition electronics/software). By providing much appreciated technical feedback it has also established a positive working relationship with manufacturers over the years, which has resulted in improved detectors with additional features for the whole community. It has also paid off in ensuring that the VLT has been equipped with state-of-the-art detectors from the start and continues to be upgraded as new devices become available. ESO is now responsible for most of the detector systems at, or planned for, the VLT.

The VLT

The VLT was a revolution! Infrared array detectors had continued to get bigger — requiring even larger optics and hence mechanisms and surrounding cryogenic systems — even before taking into account the increases needed to adapt to the larger 8-metre telescopes. We were suddenly talking about instruments weighing tons rather than kg, rotating at the Nasmyth foci and with lots of control and detector electronics, compressors, cooling pipes — you name it, we had it. It turned out we actually had to write down the specifications to remember them, use advanced design and failure mode and effects analysis software, have project plans and meetings and even reviews to check where we were. It was our equivalent of NASA going to the Moon.

ISAAC (Infrared Spectrometer And Array Cameras) was the first VLT IR instrument and was developed completely at ESO, along with some of the standards to be used in later instruments. Its installation on UT1 (Figure 6) was challenging under the pioneering conditions existing on Paranal at that time (missing doors, windows, floors, lots of dust, etc). Nevertheless, after 10 years and more than 500 refereed papers since the start of science operations, and following a certain amount of surgery, it remains in high demand for 1–2.5 μm and 2.5–5 μm imaging, polarimetry and spectroscopy

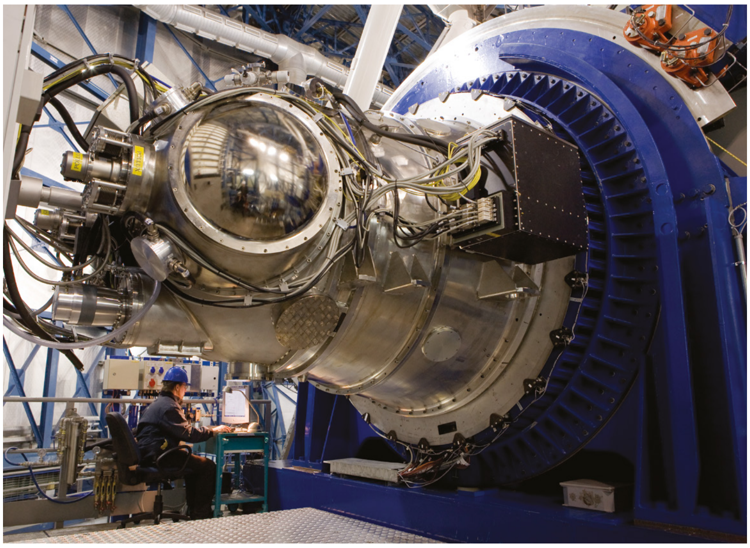


Figure 8. HAWK-I on the VLT (UT4). This near-infrared camera is equipped with four 2k x 2k Hawaii 2 Rockwell/Teledyne arrays. Although employing mirror optics to image its large 7.5 x 7.5 arcminute field of view with maximum optical efficiency it appears overly large here due to the artistic choices of lens and viewing angle.

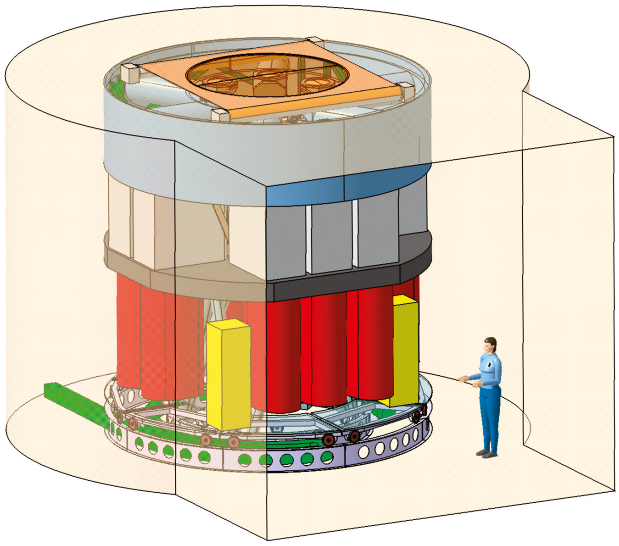


Figure 9. One concept for a multi-object infrared spectrometer at the E-ELT.

with its two arms equipped with 1k x 1k Hg:Cd:Te and InSb arrays. In order of installation it was followed by NACO (comprising the NAOS adaptive optics system developed by a consortium comprising ONERA, Observatoire de Paris and Laboratoire d'Astrophysique de l'Observatoire de Grenoble (LAOG) and CONICA, a near-IR camera/spectrometer/polarimeter/coronagraph built by the MPIA and Max-Planck-Institut für Extraterrestrische Physik (MPE)); VISIR (8–28 μm imager/spectrometer built by a consortium including the CEA, Kapteyn Institut and ASTRON); SINFONI (1–2.5 μm integral field spectrograph built by MPE and fed by an adaptive optics (AO) system provided by ESO); CRIRES (1–5 μm, AO-assisted, high resolution, spectrograph built by ESO, see Figure 7); HAWK-I (wide-field 1–2.5 μm camera shown in Figure 8, built by ESO and equipped with four 2k x 2k Rockwell/Teledyne Hg:Cd:Te arrays and designed to benefit in future from the Ground Layer Adaptive Optics provided by the Adaptive Optics Facility on UT4). Here it is worth pausing to remember that the first IR instruments offered by ESO had one pixel at the focus of a 1-metre telescope with an effective resolution of a few arcseconds. NACO and SINFONI provide resolutions down to the diffraction limit of an 8-metre telescope and HAWK-I has 16 million pixels and a resolution ~0.1 arcseconds over a field of view of 7.5 x 7.5 arcminutes. The VLTI mode in which the UTs and the 1.8-metre diameter ATs can be interferometrically combined also operates in the near- and mid-IR with its AMBER (French/German/Italian consortium) and MIDI (German/Dutch/French consortium) instruments. Also, not far from the VLT, the VISTA 4.2-metre infrared survey telescope and its VIRCAM camera (which deploys 16 2k x 2k arrays covering the equivalent of a 40 x 40 arcminute field) are currently being commissioned.

We are also now developing new second generation VLT/I IR instruments. Recently commissioned, X-shooter is the first to be finished and is the first combined visible-infrared instrument. Built by an ESO-led collaboration with institutes in Denmark, Netherlands, Italy and France it delivers spectra covering the UV, visible and IR (out to 2.5 μm) spectral ranges simultaneously; KMOS (multi-object, integral field, near-IR spectroscopy using cryogenic deployable pick-off arms built by a UK–German consortium) and SPHERE, being developed with a French-led consortium in collaboration with ESO and designed for exoplanet studies using extreme adaptive optics and a variety of polarimetric, coronographic and differential spectroscopic high contrast modes; GRAVITY (built by a German led consortium for *K*-band astrometry) and MATISSE (built by a French-led consortium for 3–15 μm interferometric imaging and spectroscopy).

Into the future, the E-ELT

If it was difficult to match instruments to 8-metre telescopes, how about going to 42 m! Indeed some of the instruments being designed now are looking pretty big and could weigh several tens of tons (see Figure 9). They would have been even larger if it were not for the growing maturity of adaptive optics, which will assist essentially all IR instruments, thus allowing them to utilise efficiently small pixels and the high intrinsic spatial resolution of the telescope. Even so, feeding many millions of pixels with resolutions down to a few milliarcseconds could also pose its own challenges! It is also foreseen that the larger instruments will be fixed relative to gravity, thus avoiding the potential flexure problems faced by VLT instruments at its rotating Nasmyth foci. Much of the complexity has also moved to the various flavours of adaptive optics systems and the laser guide stars required to use them efficiently. Overall, however, these future systems look rather exotic, complex and expensive to somebody who observed at the 1-metre telescope on La Silla around 30 years ago!

First light	Instrument	Capabilities	Telescope	*Messenger* reference
1975?	Mid-IR Kapteyn photometer	2–30 µm single pixel (bolometer) photometry	1-metre	
1976	Near-IR Bonn photometer	1–5 µm single InSb pixel photometry	1-metre	Wamsteker, W. 1976, 5, 6
1980	Near- and mid-infrared (spectro) photometers	1–30 µm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	3.6-metre F/8	Moorwood, A. 1982, 27, 11
1982	Near- and mid-infrared (spectro) photometers	1–30 µm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	1-metre	
Nov 1984	F/35 chopping secondary system and infrared (spectro)photometers	1–30 µm photometry + 1% Circular Variable Filter (CVF) spectrophotometry.	3.6-metre F/35	Moorwood, A. & van Dijsseldonk, A. 1985, 39, 1
Oct 1985	Lyon Specklegraph	1–5 µm broad and CVF linear scanning speckle interferometry	3.6-metre F/35	Perrier, C. 1986, 45, 29
Nov 1985	IRSPEC	1–5 µm spectroscopy at R ~ 1000–2500 with a 1 x 32 pixel array	3.6-metre F/8	Moorwood, A. et al. 1986, 44, 19
Mar 1987	F/35 + (spectro)photometers (with MPIA)	1–30 µm photometry and CVF spectrophotometry	2.2-metre F/35	van Dijsseldonk, A., Moorwood, A. & Lemke D. 1987, 48, 50
Jul 1988	IRAC	1–5 µm imaging and CVF with 32 x 32 and 64 x 64 pixel arrays	2.2-metre F/35	Moorwood, A., Finger, G. & Moneti, A. 1988, 54, 56
Apr 1990	COME-ON	3–5 µm high spatial resolution AO imaging	3.6-metre	Merkle, F. et al. 1990, 60, 9
Nov 1990/ Feb 1991	IRSPEC Transfer/upgrade	1–5 µm spectroscopy at R ~ 1500–3000 with 58 x 62 SBRC InSb array	NTT	Moorwood, A., Moneti, A. & Gredel, R. 1991, 63, 77
May 1992	IRAC2	1–2.5 µm imaging and Fabry-Perot spectroscopy with 256 x 256 NICMOS array	2.2-metre F/35	Moorwood, A. et al. 1992, 69, 61
Jul 1992	TIMMI	5–15 µm imaging and long slit spectroscopy with a 64 x 64 Ga:Si array	3.6-metre F/35	Käufl, U. et al. 1992, 70, 67
Dec 1992	COME-ON+	3–5 µm high spatial resolution AO imaging	3.6-metre F/35	Hubin et al. SPIE, 1780, 850
Dec 1997	SOFI	1–2.5 µm imaging, polarimetry and grism spectroscopy with 1k x 1k Hawaii 1 array	NTT	Moorwood, A., Cuby, J.-G. & Lidman, C. 1998, 91, 9
Nov 1998	ISAAC	1–5 µm imaging, medium resolution spectroscopy and polarimetry	UT1	Moorwood, A. et al. 1999, 95, 1
Oct 2000	TIMMI2	2–28 µm imaging, grism spectroscopy and polarimetry with 340 x 260 As:Si array.	3.6-metre F/35	Käufl, U. et al. 2000, 102, 4
Nov 2001	NACO	AO assisted 1–5 µm imaging, spectroscopy, polarimetry, coronography	UT4	Brandner, W. 2002, 107, 1
Oct 2001	VLTI	Interferometry with UTs or 1.8-metre diameter ATs		Glindemann, A. 2001, 106, 1
Dec 2002	MIDI	Mid-IR imaging and spectroscopy	VLTI	2003, 111, 40
Mar 2004	AMBER	Near-infrared imaging and spectroscopy	VLTI	Richichi, A. & Petrov, R. 2004, 116, 2
May 2004	VISIR	Mid-IR (*N*- and *Q*-bands) imaging and low, medium and high resolution spectroscopy	UT3	Lagage, P.O. 2004, 117, 12
May 2004	SINFONI	Near-infrared, AO assisted, integral field spectroscopy	UT4	Bonnet, H. et al. 2004, 117, 17
Jun 2006	CRIRES	1–5 µm, AO assisted, R = 10^5 spectrometer	UT1	Käufl, U. et al. 2006, 126, 32
Jul 2007	HAWK-I	0.8-2.5 µm imaging	UT4	Kissler-Patig, M. et al. 2008, 132, 7
Nov 2008	X-shooter	Simultaneous UV–IR (2.5 µm) spectroscopy		Vernet, J. et al. 2007, 130, 5
2011?	KMOS	0.8–2.5 µm MOS with 24 deployable IFUs over a 7-arcminute field	UT1	Sharples, R. 2005, 122, 2
2011?	SPHERE	Visible and near-IR observations of exoplanets using extreme adaptive optics	UT3	Beuzit, J.-L. 2006, 125, 29
2012?	MUSE	Visible integral field spectroscopy	UT4	Bacon, R. 2006, 124, 5
2013?	GRAVITY	*K*-band astrometry	VLTI	
2014?	MATISSE	Mid-IR imaging and spectroscopy	VLTI	

Table 1. ESO Infrared Instrument Timeline

Acknowledgements

I would like to particularly thank Lo Woltjer for his support of the early IR instrumentation developments when he was Director General and my colleagues in Geneva — Piero Salinari, Anton van Dijsseldonk, Bernard Delabre and, on La Silla, Daniel Hofstadt, the late Willem Wamsteker and Patrice Bouchet — for some truly pioneering efforts. Although too many people to name here have subsequently contributed to the development and amazing growth and sophistication of the IR programme in the Garching era, I would also like to single out for mention Jean-Louis Lizon and Gert Finger who have met most of our IR-specific cryogenic and detector challenges for more than 25 years now. I would also like to acknowledge the contribution made over the years by several visitor instruments that could not be mentioned here for lack of space.

Evolution of Optical Spectrograph Design at ESO

Hans Dekker[1]

[1] ESO

The evolution of optical spectrograph design and its implementation at ESO since 1980 is sketched out from the point of view of the instrumentation with which I have been closely involved. The instruments range from the early days of EFOSC, EMMI, UVES, GIRAFFE to the present-day X-shooter and important optical design features, such as the use of focal reducers and the white light pupil principle, are highlighted.

This is an account of developments in optical instrument design at ESO from 1981, when I joined ESO, until now. I began to write this article just as I was preparing for the 4th commissioning period of X-shooter and concluded it just after my return from Paranal, one day before the deadline. Because of the lack of time, I will focus on the projects in which I have been most involved, whether wearing the hat of system engineer, project manager, or both.

EFOSC

Before my arrival at ESO I worked for five years in the development of military infrared instruments at Philips in the Netherlands. My first project at ESO was the ESO Faint Object Spectrograph and Camera (EFOSC), which saw first light in 1984. Surprisingly, instrumentation techniques and technologies at Philips and at ESO were then not that much different. The concept of EFOSC was developed under the late Daniel Enard, then head of optical instrumentation. CCDs had recently become a viable option for astronomical instruments. At first light, EFOSC was equipped with an RCA chip of about 300 x 500 pixels and a readout noise of 30 electrons! The instrument is a focal reducer: because of the small physical size of the detector, to get any useful angular field and not oversample the seeing, it was necessary to “reduce” the telescope image plane to match the size of the chip, and also to not spread the photons over any more pixels than necessary, in view of the high readout noise. This entailed speeding up the telescope F/8 beam to F/2.5 at the detector. The innovative twist was the creation of a parallel beam space between the collimator and the camera, which allows a host of optical components, like filters, grisms, and Wollaston prisms to be inserted. The instrument had just three moving functions: a slit wheel (also used for multi-object and other masks), a filter wheel and a grism wheel. Although conceptually very simple, it could be used in eight different modes: direct imaging, long slit spectroscopy, slitless spectroscopy, echelle spectroscopy, imaging polarimetry, spectropolarimetry, coronography and multiple object spectroscopy (MOS).

EFOSC used a lens camera instead of the more traditional catadioptric (mixed lens and mirror) systems used in Schmidt cameras. This choice eliminates the central obstruction present in catadioptric cameras, which can easily cause a light loss of 30–40%. For good image quality over the complete spectral range of EFOSC (350–1000 nm) we had to use the anomalous dispersion glasses that had recently been developed by Schott and which allowed a much better colour correction than the traditional crown/flint combinations. The field lens unit of the camera acted as a vacuum window and was the only part of the detector assembly that had to be customised to interface with the instrument-specific camera optics. As detectors have grown larger in size, this has proved to be a wise decision and has allowed a standard detector cryostat to be used on most instruments, without the need to develop a new cryostat for every new instrument.

The wide spectral bandwidth of EFOSC only permitted the use of single-layer anti-reflection coatings, which caused a light loss of up to 2% per surface at the extremes of the wavelength range. So, wherever possible, lenses were cemented to reduce reflection losses. This was problematic because of the big differences in the thermal expansion coefficients of the glasses used, and so we embarked on a programme to qualify flexible cements with good UV transmission. Finally, we found a suitable candidate: silicone potting cement that had been originally developed to protect printed circuit boards against the hardships of humidity and launching accelerations. It had excellent UV transmission down to 300 nm, was flexible and had good adherence and image quality even when used in thick layers.

The focal reducer concept has been extremely influential in the design of astronomical instruments. It is the basis of the design of many ESO instruments: EFOSC2, the Danish Faint Object Spectrograph and Camera (DFOSC), the FOcal Reducer/low dispersion Spectrographs (FORS1/2), the VIsible MultiObject Spectrograph (VIMOS) and the Multi Unit Spectroscopic Explorer (MUSE), as well as numerous non-ESO instruments and those planned for Extremely Large Telescopes. It is a versatile concept that can be adapted to new detector developments: compared to the first-light detector of EFOSC with 150 thousand pixels, MUSE with its 24 channels, each with a 4k x 4k chip, has 380 million pixels, an increase of a factor of more than 2500!

EMMI

The ESO 3.6-metre telescope had a suite of instruments for imaging, multi-object spectroscopy, long slit and echelle spectroscopy. These were mounted at the Cassegrain focus according to a pre-agreed exchange schedule. These frequent exchanges were detrimental to reliability. It was also not possible to change observing mode quickly when the meteorological conditions changed. In parallel with the construction of the New Technology Telescope (NTT), ESO started to consider alternative observing strategies to maximise the scientific return and minimise maintenance — remote and service observing became buzzwords. The NTT was designed to deliver exceptional image quality. But its concept allowed only two Nasmyth foci, there was no prime focus cage and no Cassegrain focus.

The telescope designers had really got their way this time (and rightly so, as the success of the NTT proved).

This is the framework within which the concept of EMMI (ESO Multi Mode Instrument) was developed in the mid-1980s, for the most part under the leadership of Sandro D'Odorico. We realised that compared to EFOSC, we could increase the peak throughput and extend the ultraviolet coverage by using two focal reducers, each optimised for the ultraviolet and visible spectral ranges, with dedicated glasses, coatings and detectors. The versatility of EFOSC already went a long way towards providing multimode capability in a single instrument. To increase the spectral resolution capability (limited to a few 1000 with grisms), two medium resolution arms were added. Each had a reflection grating turret, and could feed the focal reducers with a long slit by inserting or retracting some flat mirrors. With this addition it was possible to reach a resolution of 20 000, and by replacing the first-order grating by an echelle, it was possible to reach 70 000 in a cross-dispersed echelle format.

Bavarian engineers, when you ask them to design multifunctional machines, will curse you — usually under their breath — and tell you that you are asking for an "eierlegende Wollmilchsau" (egg-laying woolmilkpig). They will then continue to build their beautiful machines — like BMW motor cars — that are good at only one thing and not much else. Well, in 1989 the NTT acquired its version of this mythical animal — EMMI — which was a real workhorse and stayed in operation until 2008.

EMMI was the first ESO instrument that used the "Pupille Blanche" principle, a term coined in the early 1970s by André Baranne for a novel spectrograph concept, where the beam dispersed by the grating is re-collected by the collimator optics to produce an image of the grating (the white pupil — white because here all the dispersed beams overlap again), where the camera or cross-disperser is placed. The second pass through the collimator may be thought to be a waste of photons, but compared to more traditional designs, the overall efficiency is actually improved, because the camera mouth can be placed very close to the second pupil, which eliminates vignetting. The concept also allows the grating to be used with a small angle between incident and diffracted beams, which maximises the diffraction efficiency. There is also the additional design freedom to tune the diameter of the white pupil. While the primary beam size in EMMI was 120 mm, the secondary beam had a diameter of only 50 mm (with a correspondingly larger angular field), which led to light and affordable spectrograph cameras.

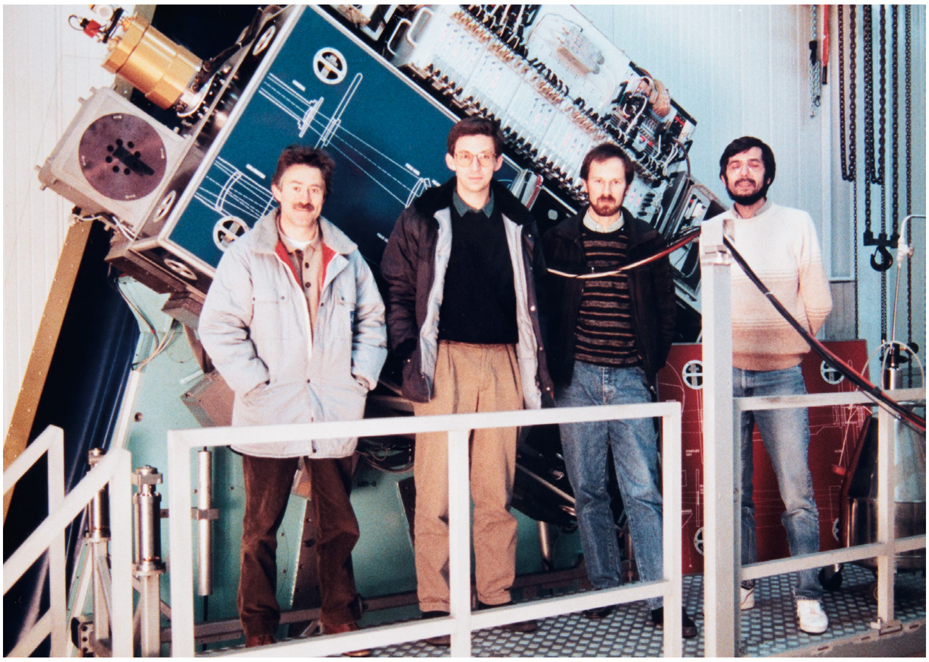
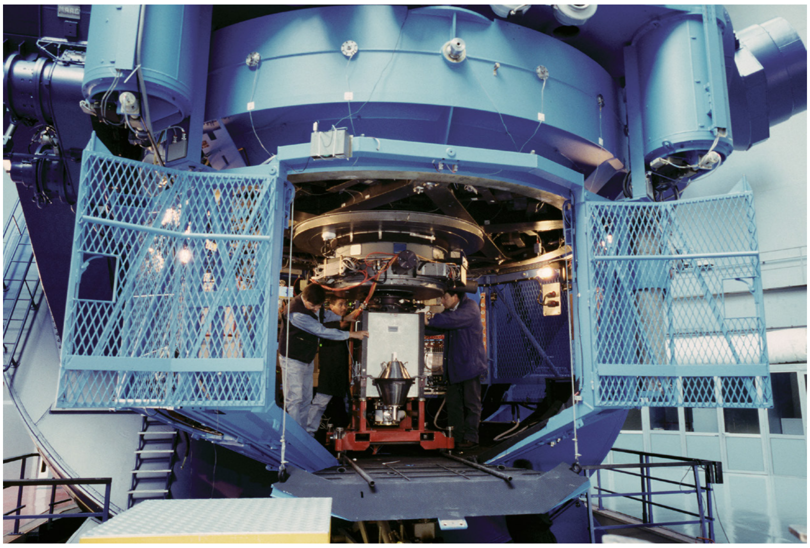


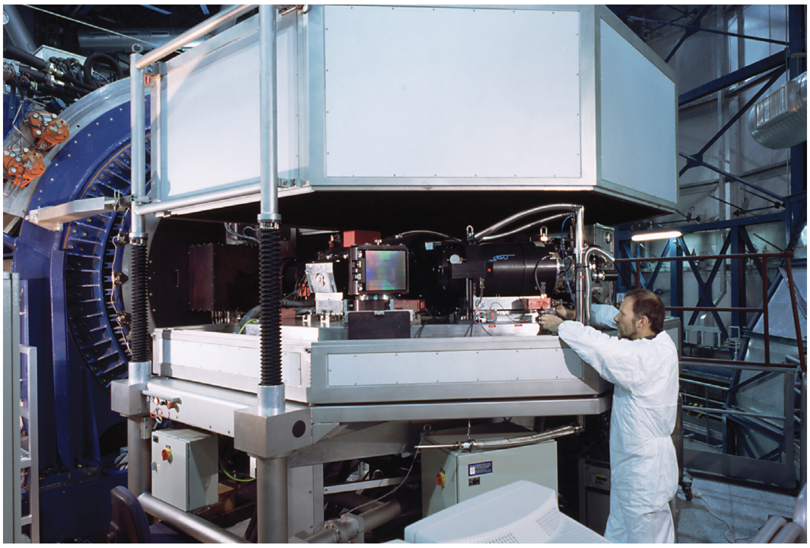
Figure 1. The ESO multimode instrument (EMMI) at the NTT; photo from 1991. Shown from left to right are Sandro d'Odorico, Hans Dekker, Jean-Louis Lizon and Gianni Raffi. All are still with ESO.

UVES

The study and design of UVES, the UV–Visible Echelle Spectrograph for the VLT, started around 1990. The instrument combines many of the features that had been tested and implemented successfully in the EFOSC and EMMI designs: dioptric cameras and a dual-arm design, and a white pupil arrangement with a grating cross-disperser.

UVES was to have a spectral resolution of 40 000 with a one arcsecond slit. Spectral resolution depends only on grating depth — not on collimated beam diameter — and to reach R = 40 000 we needed a grating with a path length difference of 1.6 m (i.e. the optical path difference [OPD] between the wavefronts striking the first and last groove of the ruled surface). We realised that by using very steep "R4" gratings (that for maximum efficiency are to be used at 76 degrees, the "blaze angle") we could achieve this large depth with a collimated beam size of only 20 cm, making for a compact instrument. But for various reasons (low efficiency, the introduction of anamorphosis effects and a strong change of sampling along the orders), R4 gratings were reputed to be unsuitable for use in astronomical spectrographs After some study we realised that while this was true for R4s used in traditional arrangements, which require angles of 6–8 degrees between the incident and diffracted beams, these effects become tolerable at small angles — another point in favour of the white pupil concept, which





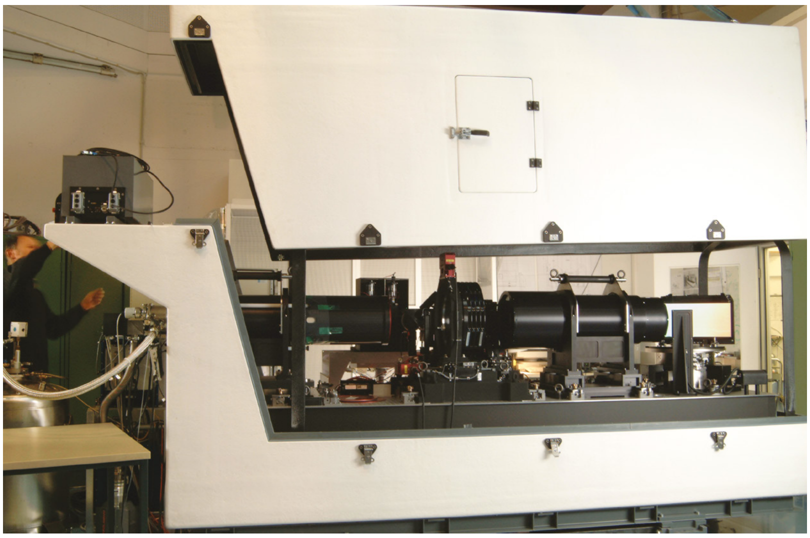


Figure 2. Composite image of some of the instruments mentioned in this article — EFOSC, UVES, GIRAFFE (left, top to bottom) and X-shooter (top right).

allows angles as small as 2 degrees. The UVES echelles would need a ruled area of 22 x 85 cm. New master rulings were ruled under ESO contract by the Richardson Grating Laboratory (RGL). Since the ruling engine limited the ruled length of the grating masters to 16 inches (410 mm) we decided to use a mosaic. Under the same contract, RGL developed a technique to copy (replicate) two identical and precisely aligned submasters onto a common substrate. This resulted in a mosaic grating with a wavefront stability identical to that of monolithic gratings. UVES was commissioned on UT2 (Kueyen) in 1999 as the second VLT instrument.

The white pupil concept is especially well-suited for use in high resolution spectrographs, and after some initial scepticism, especially overseas, the concept has proved as influential in high resolution spectrograph design as the focal reducer. (Our optical designer Bernard Delabre is good at many things, except at tooting his own horn, which is why this statement is here). The concept is used in the Fibre-fed, Extended Range, Échelle Spectrograph (FEROS) at the MPG/ESO 2.2-metre telescope, in the High Accuracy Radial Velocity Planetary Searcher (HARPS) at the ESO 3.6-metre, and for example in the High Dispersion Spectrograph (HDS) at Subaru, SARG at the Telescopio Nazionale Galileo (TNG) and the High Resolution Spectrographs for the Hobby-Eberly Telescope (HET) and South African Large Telescope (SALT).

GIRAFFE

Unlike the previous instruments, which were all built by ESO, the GIRAFFE spectrograph of the multi-fibre FLAMES facility was designed and built by the Paris–Meudon and Geneva observatories. Final system integration and testing were done at ESO in 2001–2002, and the instrument was released in 2003. GIRAFFE is a medium-high resolution (R = 7500–30 000) spectrograph for the visible range, aimed at carrying out spectroscopy of Galactic and extragalactic objects with a high spatial density. The name is no acronym, but was inspired by the first optical design plots, where the spectro-graph was planned to be set standing vertically to minimise its footprint size on the Nasmyth A platform of UT2. During the mechanical design process it was decided to lay it horizontal on an optical table, and any resemblance to that gracious animal was lost (it now looks more like a stranded white whale, actually). GIRAFFE is fed by the robotic fibre positioner (OzPoz) developed by the Anglo-Australian Observatory, which I will not describe here.

GIRAFFE is equipped with two gratings for high and low resolution, working in orders 2–5 (low resolution) and 5–15 (high resolution). The spectral format is linear. Since the gratings work in higher orders, sorting filters are needed. The fibre slit consists of 130 fibres and is about 80 mm high. Only a lens collimator could provide the necessary field, while at the same time being fast enough to capture all the light coming from the fibres in an F/5 collecting aperture. As the attentive reader will be anticipating by now, it is a white pupil instrument, and the optical designers used that fact to create a relatively small and cheap camera.

Except for a single folding mirror, GIRAFFE is completely lens-based. This leads to a focus that is dependent on the temperature. For this reason, the fibre slit is placed on a focusing carriage, the position of which is automatically adjusted according to the temperature of the optics, in a way that is transparent to the user.

X-shooter

X-shooter is ESO's new high efficiency, single-object, cross-dispersed echelle, point-and-shoot spectrograph with a resolution (1 arcsecond slit) of 4500 (for ultraviolet–blue and near-infrared ranges) and 7000 (visible range). It has three arms, each with its own detector, and covers, in one shot, the spectral range 0.3–2.5 μm. X-shooter is the 14th VLT instrument and replaces the first, FORS1, which has recently been mothballed. The instrument subsystems were developed and built by a consortium consisting of ten institutes in the Netherlands, Denmark, Italy and France, while ESO delivered the detector systems and was responsible for the system engineering, system integration and commissioning.

The instrument marks the current evolutionary stage of the design process that started more than 25 years ago, and combines many of the features found in the instruments previously described: dioptric cameras with apertures much smaller than the collimated beam on the grating; white pupil; efficiency optimisation by judicious splitting of the spectral range (the crossover wavelengths of the dichroics are placed at sky line features at 557 and 1020 nm). Novel optical design features in X-shooter are the use of prism cross-dispersers that are by their nature more efficient than gratings or grisms, and techniques to correct for chromaticism in the camera, that allow the number of air/glass interfaces in the cameras to be reduced to just six. As a result, X-shooter is probably one of the most efficient cross-dispersed echelle spectrographs worldwide, with a measured efficiency (top of the atmosphere to detected photo-electrons) that is larger than 30% in *B*-, *V*- and *H*-bands. Another new design feature worth mentioning is active flexure compensation: after the telescope has slewed to a new object, the instrument will align its three slits on the sky to better than 40 milliarcseconds within zenith distance 0–60 degrees, while at the same time the telescope is performing its active optics correction. X-shooter will be available in P84 on UT2 Kueyen.

Why UT2 is special

When looking back, some people tend to become sentimental. I'm sure it was just a coincidence that ESO decided to place all the VLT instruments with which I have been involved on UT2: UVES, GIRAFFE, and now X-shooter. When entering the UT2 dome, I feel a bit like I do when meeting old friends — ageing, but still going strong.

Acknowledgements

This has been a very personal account of the proverbial 1% inspiration that went into the conceptual design of some of the optical VLT instruments. The 99% perspiration aspect is not described: the toil of designing optical, mechanical, electronic and software subsystems; rejecting; redesigning; reviewing; building; testing; commissioning; and adapting them to the operational environment. Yet these aspects, to a very large extent, determine reliability, ease of maintenance and user satisfaction. I cannot begin to name all the colleagues — inside and outside ESO — who have been involved in this process. So I will not. But thank you. You know who you are.

Aerial view of the La Silla Observatory which has just celebrated its 40th anniversary. See news release ESO 12/09.

Credit: ESO/C. Madsen

La Silla 2010+

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From October 2009, the La Silla Observatory will begin a new phase in its history, following implementation of a new operations model. We describe here the upcoming changes, how the visiting astronomers will interact with the Observatory and how they will carry out their observations from October 2009 (ESO Period 84).

Motivation

ESO is fully committed to maximising the scientific return of its highly competitive facilities, and it has to make sure that its next generation telescopes and future projects will extend its European leadership in ground-based astronomy further. Therefore ESO resources have to be administered in a judicious way. Priorities have to be established, and the La Silla Observatory (LSO) has to cope with this reality. But at the same time, LSO facilities are still delivering excellent data (accounting for *ca*. 40% of publications based on all ESO instruments[1]). In this framework, in June 2007 a plan was endorsed by the ESO Council that envisages operating and maintaining the LSO site centred on its core activities and with reduced costs. The new scheme would first be fully operative after 2009, so it was called "LS2010+".

The new operations scheme allows La Silla to remain part of the La Silla Paranal Observatory, and therefore fully maintains the ability to support regular science projects, as well as national telescope projects — visitor instruments, tests of novel Instrumentation and scientific experiments — for the ESO community. The core activities are defined as supporting, at minimum, the 3.6-metre telescope with the High Accuracy Radial velocity Planet Searcher (HARPS), and the New Technology Telescope (NTT) with the ESO Faint Object Spectrograph and Camera 2 (EFOSC2) instrument at the Nasmyth B focal station and a free Nasmyth A focal station for visitor instruments.

Soon after the Council resolution a working group was formed, which defined the practical implementation of the plan, according to the general scheme of Site Operations. Responsibilities and task descriptions, together with the profiles for core staff positions, were defined in the different areas, as well as the activity frequencies and the support requirements.

New operations model

In the new model, the La Silla Site Operations Department within the La Silla Paranal Observatory division will be in charge of maintenance, science operations, engineering and logistics. In addition to the two telescopes owned by ESO, the 2.2-metre telescope will also be fully supported, thanks to a new four-year agreement between ESO and the German Max-Planck-Gesellschaft (MPG), in effect from April 2009. In preparation for the new operations model, the instrument suite offered has been simplified in particular to minimise the number of instrument changes. The complex EMMI instrument has been decommissioned after 18 years of operation at the NTT. Since April 2008 EFOSC2 has been offered at the Nasmyth B focus of the NTT, after its transfer from the 3.6-metre telescope. Presently the Nasmyth A focus feeds the cryogenic near-infrared instrument SOFI, which will be offered as an ESO facility instrument for as long as it can be maintained technically. Both focal stations of the NTT are also offered for visitor instruments. HARPS remains the only instrument at the 3.6-metre telescope. However, visitor instruments requiring a Cassegrain focus will be considered at the 3.6-metre telescope.

The new operations model implies that all observations are carried out in classical Visitor Mode. Already, as of Period 81, Service Mode observations have been discontinued at La Silla. At the same time a minimum run length of three nights is requested for La Silla proposals to reduce the turnover of visitors at the telescopes. Long and dedicated observing runs at La Silla are further encouraged through the possibility to apply for Large Programmes with a duration of up to four years.

What are the implications of the new model for the user community? Since HARPS and EFOSC2 are both instruments that are relatively simple to operate, they do not require the presence of dedicated scientific support staff on-site. Instead, the system engineers (SEs) and Telescope Instrument Operators (TIOs) will take an even more active role in the future to support visiting astronomers.

New procedures for visiting astronomers

In order to prepare LSO visiting astronomers for the new operational scheme, all useful information is being collected on our web server[2]. Besides the usual manuals and web pages, videos and screencasts are being prepared, as well as cookbooks that encapsulate the support astronomer's experience. Furthermore a contact scientist will be available for each programme, so visitors will be able to clarify any queries before arriving on the mountain, using the well-known e-mail entry point lasilla@eso.org. In the following paragraphs an outline of a typical observing run is given.

When the visitor arrives at LSO, (s)he will receive the usual welcome package, and (s)he will be met by the SE. Note that in the new compact configuration of the Observatory with the control room being located in the operations building (the former administration building) close to the hotel and the living quarters, visitors will no longer need a car to commute to the telescope or control room. Visits to the telescopes will be coordinated with the SE. The SE is the main interface between the Observatory and visiting astronomers, and (s)he will guide them through the next steps of the visit. For EFOSC2 observations, in particular, the instrument setup will be defined. An office in the operations building will be assigned, with the understanding that access to the control room outside observing time will be regulated, and must be agreed with the SE. Typically, this can happen the night before starting the observations, so as to understand better how the system works. Finally, day calibrations will be performed in the

Credit: Pablo Rodriguez Gil

Figure 1. A view of the La Silla Observatory before dawn, taken from the dome of the ESO 3.6-metre telescope.

morning, according to the calibration plan of each instrument. Calibration Observing Blocks (OBs) for the most common instrument modes will be available at the console; so visitors will have the opportunity to perform their own, additional, calibrations in the afternoon. On the first day, the OBs provided by the user will be transferred from the user account (or from the user's laptop) to the data handling computer, and will be imported into p2pp.

During observations, visitors will mainly interact with TIOs. To cope with this requirement, TIOs are going through substantial training in astronomical techniques and basic data reduction. The courses are given in the form of lectures by ESO fellows and staff astronomers. Moreover, the training includes most of the system components, such as the VLT software and templates, the data flow system including pipelines, optical and infrared detectors, optics, etc. In general, all groups at LSO will maintain a close relationship with their counterparts in Paranal, which will ensure the proper functioning and success of La Silla. This is particularly true for software and IT support, which are complex areas where TIOs might not always be able to intervene directly, but where remote support can be easily obtained from Paranal colleagues.

A critical area of the new model is to guarantee astronomical data quality control, which will be accomplished by both remote monitoring of the instrument parameters and by a few dedicated shifts of support astronomers during reserved technical and calibration nights. For this reason, standard ESO pipelines are being ported from Paranal instruments to their La Silla cousins, and by the start of P84 all LSO instruments will be supported. In this way TIOs and visitors will have an easy way to monitor the instrument health.

In terms of simplifying logistics, the common control room will be moved from the old location next to the NTT dome to the administration building in July 2009. It will occupy the space that once hosted the La Silla library. All personnel offices will be located in the same building, and visiting astronomers will also have offices available to them. In this way the interactions among the various groups on site, and with the visitors, will be optimised. The reduction in the number of staff also allows them to be lodged in those dormitories closest to the hotel, and visiting astronomers will mainly be accommodated in the hotel.

These changes will also benefit the environment, as the need for cars on-site, and for commuting, will be greatly reduced. Transport to and from LSO will be optimised by a shift schedule of Monday–Monday or Monday–Friday for support staff, and a Wednesday–Wednesday shift for TIOs. In this way visiting astronomers can to travel to the site on three days of the week, which is flexible enough to accommodate observing runs of various lengths, allowing for between one and three days run preparation on site. In general, long runs are appreciated for the LSO. Since 2007 the minimum observing duration for a visitor mode run at LSO has been three nights, and Large Programmes up to four years can be considered! The trips of visiting astronomers, from their home institution to LSO via the Santiago Guesthouse and back, will continue to be organised fully by ESO.

There is no doubt that this new operations model represents a major change for the community of observers that rely on LSO to carry out their science programmes. However we are convinced that this is the most sensible way to keep a valuable site operating efficiently and with a long-term perspective. The La Silla Observatory will offer a fully-fledged VLT environment and impeccably supported instruments where students and young astronomers will have the chance to be trained by their supervisors in a modern facility. In addition, all focal stations at the ESO operated telescopes are available for visitor instruments, thereby offering an arena for innovative experiments and ideas that might be difficult to implement and test otherwise. All the technical information that is needed to interface an instrument with the LSO telescopes is gathered in a single document[3].

We could not end this short description of LS2010+ without stressing that this big change at LSO is a work in progress — improvements and adjustments to the procedures to optimise the science return will rely on constructive feedback from visiting astronomers.

Links

[1] Instrument publication statistics: http://www.eso.org/sci/libraries/edocs/ESO/ESOstats.pdf
[2] La Silla Observatory web page: http://www.eso.org/sci/facilities/lasilla/sciops/
[3] Visitor instruments guide: http://www.eso.org/sci/facilities/lasilla/instruments/visitor/VisitorFocus.pdf

NGC — ESO's New General Detector Controller

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As the replacement for ESO's standard infrared and optical detector controllers, IRACE and FIERA respectively, ESO has developed a new controller — the New General detector Controller — that will be the default detector controller for all new La Silla Paranal instruments in the next decade. The basics of its design and functionality are described, and first performance examples are given.

The invisibility challenge

In an era when professional astronomers have long abandoned the naked eye and photographic plates as scientific detectors, many users of La Silla Paranal (LSP) instruments may no longer know what happens exactly between the arrival of the photons at the detector and the first inspection of the new observation – and there should be no need to, as this process should be fully transparent to them. On the other hand, this transparency can be achieved only if the corresponding process is very robust and does not imprint signatures of its own on the data. Since this final step of any modern observation is quite complex, and should be completed quickly, there are many potential failure points, and so this largely invisible step requires much care and effort. The detector may have to be cleaned of the residue of a previous exposure, voltages need to be applied to keep the electrons generated where the photons hit the detector, a shutter may have to be opened, the exposure time must be accurately kept, a shutter may have to be closed, and a sequencer has to generate time-dependent voltage patterns to drive the accumulated electrons to the amplifier, or to address each pixel amplifier sequentially. After amplification, the charges are converted to voltages and digitised, and the resulting number must be inserted at the right location in the data block, and important ancillary information must be written to the FITS header, without which the data block would not form an image that can be processed further and scientifically interpreted.

The requirements on the precision, repeatability and invisibility of this process are quite tough: the shutter timings must be accurate to 1 millisecond; voltages specific to each detector must be repeatable at the 10-mV level; the proper shaping of readout signals requires 10-nanosecond resolution, and is different for all detector models; the analogue electronics should, at most, minimally degrade the photon noise, even of the faintest signals; and analogue-to-digital converters must oversample this system noise. This latter task is more easily appreciated if it is realised that most present-day detectors generate voltages as tiny as a few microvolts per photoelectron. In order to speed up data transfer, parallel output channels are used, but none should generate an echo of its own signal in any of the other channels. At any one moment, software and hardware-embedded firmware must keep tight control over all steps and give status reports to the higher-level control software. If something does go wrong, due to the failure of some general utility such as electrical power or computer networks, the user wants to be given a meaningful error message, which is a much less trivial task than it first appears.

The present past: FIERA and IRACE

Almost all current infrared LSP instruments employ IRACE (InfraRed Array Control Electronics; Meyer et al., 1998) to execute the above (and more) tasks, while all optical instruments use FIERA (Fast Imager Electronic Readout Assembly; Beletic et al., 1998). They are the VLT standard detector controllers. Following IRAQ (cf. Finger et al., 1987) and ACE (Reiss, 1994), they were the first standard detector controllers developed at ESO. A recent analysis has shown their downtime-weighted reliability in the first decade of operation of the VLT to have reached a level of 99.85%. The contribution of the detector systems to the total observatory downtime is thus only about one-tenth.

Why not, then, use IRACE and FIERA forever? The answer is twofold and simple: the electronics of both FIERA and IRACE include an increasing number of electronic components that are no longer manufactured and cannot be replaced by other parts. In addition, some detectors, and especially those for advanced applications such as adaptive optics and interferometry, have requirements exceeding the specifications and capabilities of FIERA and IRACE. Therefore, successors are needed. Interestingly, the first ESO instrument to bridge the conventional gap at 1 micron between optical and infrared instruments, X-shooter, took delivery of the last IRACE as well as the last FIERA systems.

The present future: NGC

After some initial debate, and successful tests of a CCD with IRACE, it became clear that it would probably not take two separate systems to replace FIERA and IRACE and that the development of a unified, wavelength-independent controller should be attempted, known as the New General detector Controller (NGC). A dedicated NGC team was formed from staff at ESO's two detector departments, namely the Infrared Detector Department and the Optical Detector Team. The strengths and weaknesses of FIERA and IRACE were analysed, requirements for future detectors and applications were solicited, taking note also of the practical needs of the LSP Observatory, and four generations of prototypes were produced and carefully tested. First deliveries have been made to the MUSE prototype, to KMOS, SPHERE and soon also to ZIMPOL, so that it is timely to present this new "invisible box" to the LSP community.

NGC architecture

Apart from the critical performance parameters, other strong design goals of the front-end electronics included modularity, scalability and compactness. While both FIERA and IRACE boxes still host a

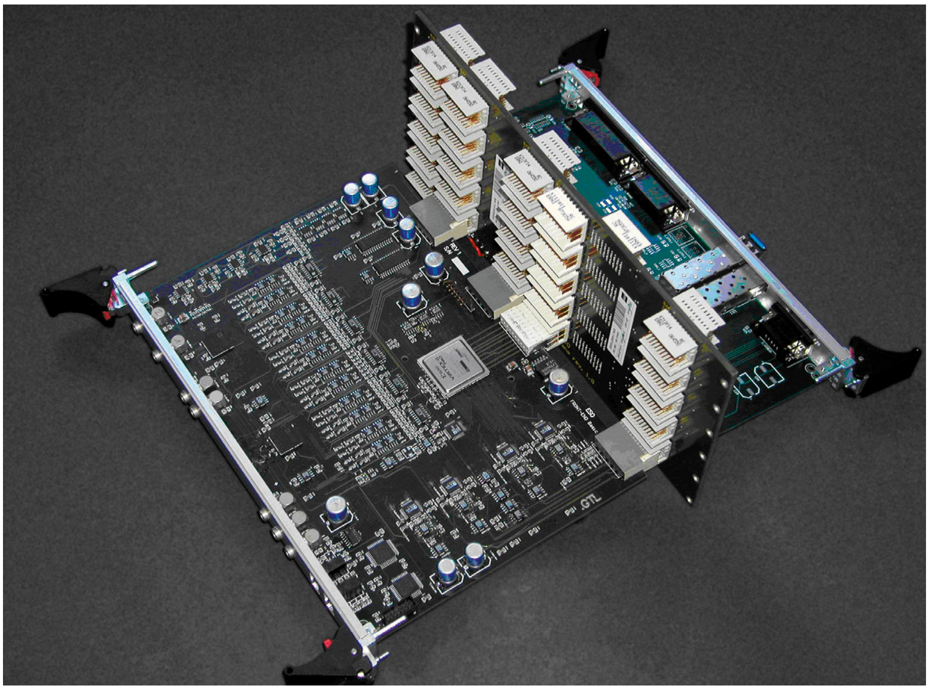
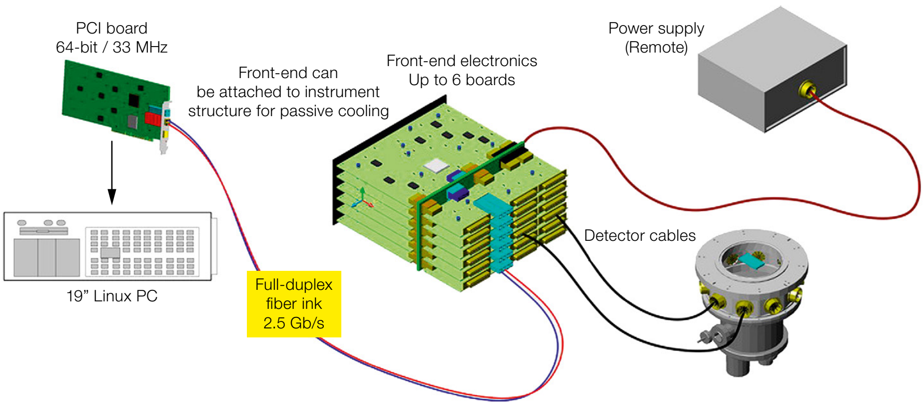


Figure 1. Minimal-configuration NGC system consisting of Basic Board (left), associated Transition Board (right), and backplane (middle).

handful of different electronic boards, this diversity is much reduced in NGC. The simplest NGC system (Figure 1) consists of one so-called Basic Board, which can handle up to four video input channels and provides 18 clocks and 20 biases. For multi-channel detectors, a 32-channel Acquisition Board is available. There must always be at least one Basic Board, but otherwise both types of boards can be combined in arbitrary quantities to form an NGC system. The heart of each board is a Xilinx Virtex Pro II Field-Programmable Gate Array (FPGA) running firmware programmed in VHDL (VHSIC Hardware Description Language, where VHSIC is the acronym for Very High Speed Integrated Circuit). Multiple boards are daisy-chained through direct FPGA-to-FPGA high-speed serial links, i.e., there is no parallel bus. Commands are passed on through the chain until they reach the FPGA to which they are addressed. Most connections with other parts of an NGC system are through two types of Transition Boards, which complement each Basic and 32-channel Acquisition Board, respectively.

Figure 2. Top-level diagram of a scientific NGC system (schematic).



Initially, FIERA and IRACE systems featured UltraSPARC-based Logical Control Units (LCUs), called SLCUs, running the low-level software required to prepare the electronics and the detector for an observation, to acquire the readout data and pre-process them in more advanced readout schemes, assemble them into FITS data blocks, possibly post-process the latter, and transfer the resulting images to the instrument workstation for subsequent inspection, online reduction, and archiving. Following successful tests, notably with IRACE, the role of the SLCUs is, in NGC systems, now taken over by PCs from the Dell PowerEdge family. They are known as LLCUs because they employ the Linux operating system. A dedicated 64-bit 33-MHz PCI interface card handles the data ingestion. Up to two PCI (Peripheral Computer Interconnect) boards can be used per LLCU, which can therefore support up to two NGC front-ends, whereas applications with very high data rates may require more than one back-end per front-end. The fibre link between front-end electronics and back-end LLCU may be up to 2 km long. A top-level system diagram of the NGC is shown in Figure 2.

For the NGC control software, there was a strong request from VLT control software engineers that the interfaces be as close as possible to the ones for FIERA and IRACE. Since interfaces for FIERA and IRACE are very different, obviously only half of this request could be fulfilled if the interface for NGC were to be homogeneous. Because the NGC hardware concept has inherited more from IRACE than from FIERA, the IRACE interface was a natural starting point. In fact, VLT infrared (IR) instrument software developers will not see much of a difference between IRACE and NGC.

Functionally, the NGC control software is divided into three parts. One of them is also the lowest layer, which handles all interactions with the NGC electronics and is used by all NGC applications. But the next layer has to pay tribute to the fact that an observation in the optical typically consists of one integration with one readout while in the infrared most observations comprise many exposures, each of which may be read out multiple times. The optical case seemingly boils down to the most trivial infrared case, although invariably requiring the use of a shutter. However, the details of the atomic readout process proper are very different. Not only can IR detectors be read out non-destructively, but they permit the build-up of the signal with the number of readouts to be fitted separately for each pixel, thereby drastically improving the data homogeneity. In CCDs, individual pixels cannot be addressed, and full images are shifted line-by-line to the horizontal or readout register, where the charge shifting continues in the orthogonal direction and pixel-by-pixel. Moreover, the different states of a CCD exposure require different voltages to be applied. Last but not least, the much higher background signal in IR data requires very different, coupled operating strategies for detector, instrument and telescope. Therefore, it is more effective to develop two separate software branches. The infrared one is again very similar to the IRACE software. By contrast, the optical part, while trying to benefit maximally from the experience with FIERA, is an all-new development. Therefore, there was freedom to test software concepts that had not previously played a major role in the VLT environment. The approach chosen is the one of a state machine, to which the various states of an optical detector controller (wiping, integrating, reading, etc.) map very well. In addition, the code for a state machine can be very effectively restructured if necessary. This is an asset not to be underestimated. The NGC project was fortunate that a state-machine approach had just been introduced to the VLT control software (the so-called Workstation Software Framework — Andolfato & Karban, 2008).

The NGC control software is an integral part of the VLT control software and, as such, participates in the annual release scheme following thorough test cycles, for which a comprehensive suite of dedicated automatic tools was developed.

Ancillary functions and peripheral devices

The three fundamental on-detector steps that eventually lead to the formation of an image are charge generation (by the incident photons), charge confinement and transport (in CCDs), and the measurement of the voltage corresponding to the accumulated charge. They are accomplished by the application of a set of time-dependent voltages, in part with a resolution of 10 ns. These so-called readout patterns are encapsulated in NGC-specific parameter files. While for exact fine-tuning a normal text editor is mostly a good choice, rapid prototyping and checking for possible conflicts is done much more effectively with a graphical editor. The tool for the latter is the Java-based BlueWave package. Since BlueWave is not directly embedded into the VLT operation it is not part of the NGC control software, but is distributed with it.

The original signals provided by the detectors themselves are so feeble that they must be pre-amplified as early as possible so that they do not get mixed with parasitic signals (pick-up noise) emitted by other devices or the electrical mains. In infrared systems, cryo-proof Complementary Metal-Oxide Semiconductor (CMOS)-based pre-amplifers are integrated along with the detectors into the cryostat heads while for the optical pre-amplifiers are located within 2 m of the respective heads. Synchronisation with external activities such as M2 chopping is supported.

Since detectors are delicate devices and, in science-grade quality, very expensive, the Transition Boards of the Basic Boards carry a sensitive, rapid-response protection circuitry to prevent overvoltage causing any damage. Likewise, failures of the input power or overheating within the NGC housing lead to automatic preventative shutdowns, which can be reported to the LSP Central Alarm System (CAS).

The NGC front-end electronics is accommodated in a custom-built housing (Figure 3). Each board and its associated transition board are plugged back-to-back into

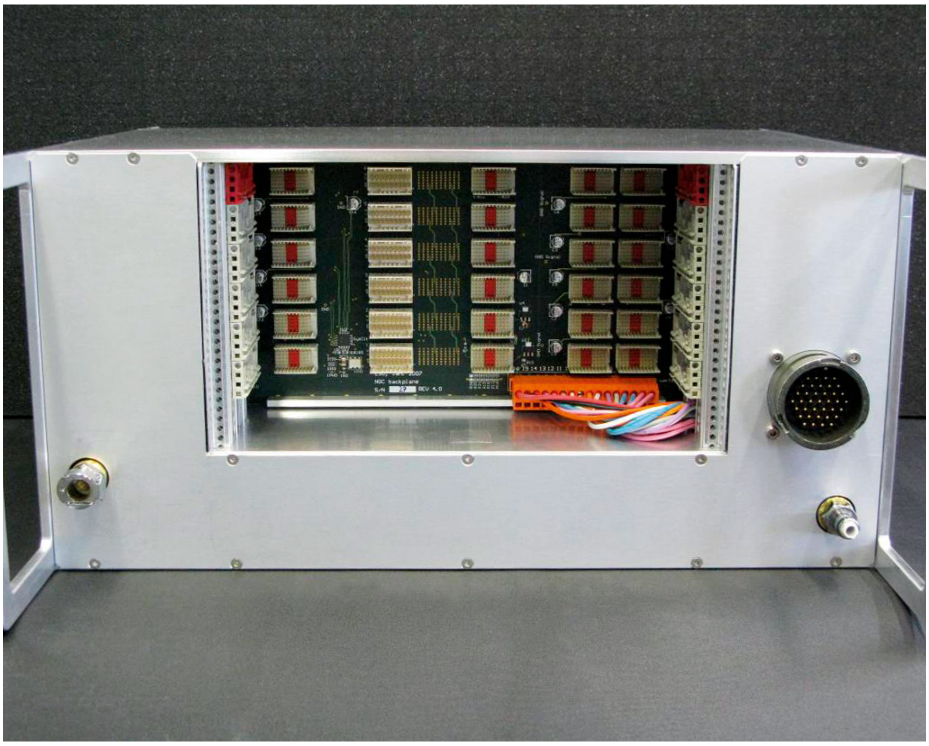


Figure 3. Rear side of an NGC housing with connectors for power cable and cooling-liquid hoses. The width is about 440 mm; depending on application, all surfaces can be anodised. Also visible are the backplane and, on both sides, rails to guide and hold the boards, of which there may be up to six.

the backplane (cf. Figure 1), which forms the core of the housing. A liquid-based heat exchanger provides active cooling. Although the heat dissipation per Basic Board (32-channel Acquisition Board) is only about 15 W (20 W), this is necessary in order to meet the tight VLT environmental specifications on the surface temperatures of equipment installed at the Unit Telescopes (UTs). Taking into account the baseline dimensions implied by these specifications, the number of slots was fixed to six, i.e., one Basic Board and up to five more boards with their associated Transition Boards can be stacked. For many laboratory applications, a simple passively cooled two-slot housing is used.

Each NGC front-end electronics unit needs its own power supply. The initial default is a separate one-size-fits-all housing. Because of the low, and still decreasing, intrinsic noise levels of modern scientific detectors, it is filled with a number of commercial linear power supplies, although their lower efficiency results in roughly doubling the mass (and volume). These unit power supplies must be different for optical and IR detectors. Further application-specific diversification is under discussion.

FIERA-controlled optical detector systems include a general-purpose housekeeping unit, PULPO, for shutter and temperature control and pressure monitoring. However, quite a few of its components are no longer available. In NGC, the shutter control is implemented on the Basic Board. The MUSE project has developed "TeePee", which is based on the commercial Jumo Imago 500 multichannel process controller; as the name indicates it is used to handle TEmperaturE and PrEssurE. Other optical detector systems may use suitable adaptations but TeePee is not part of the NGC project. The much higher demands on temperature control of IR detectors (or ultra-stable instruments such as needed for exoplanet searches) can be met with commercial LakeShore controllers, which reach an accuracy of a few milliKelvin.

NGC-AO: NGC for adaptive optics

The NGC described so far is also called Scientific NGC as it is used to control detectors for the recording of scientific data. Another important application of digital detectors at modern observatories is signal sensing, most notably for autoguiding, active optics and adaptive optics. Since the first two applications rarely require frame rates above 1 Hz and the interface to the Telescope Control System is not too demanding, commercial detector controllers are more economical than any customised development. This is not (yet) so for adaptive optics (and interferometry) applications, where frame rates of order 1000 Hz quickly become supra-commercial when combined with the requirement of negligible read and system noise.

An agreement was concluded between ESO and e2v technologies for the custom development of an L3 Vision split frame-transfer CCD with 240 x 240 pixels and eight channels. This CCD 220 (Downing et al., 2006) will be the standard detector for the forthcoming VLT adaptive optics (AO) wavefront sensors such as GALACSI (MUSE), GRAAL (HAWK-I) or SAXO (SPHERE) and generate data rates of well above 10 Mbyte/s. In a parallel effort, the observatories in Marseille, Grenoble, and Haute Provence are developing a test controller (OCam; Gach et al., 2006). The analogue part of the OCam electronics is being integrated with a specially customised part of the digital electronics of NGC to form NGC-AO. A considerable extra challenge associated with the high data rates is that the sequencer must run at subnanosecond resolution and that the controller must be within centimetres of the detector, where the constraints on volume, mass and heat dissipation are very tight. After readout, the data is directly and continuously transmitted via serial Front Panel Data Port (FPDP) to ESO's AO real-time computer system SPARTA (Fedrigo et al., 2006).

Performance and other qualities

NGC prototypes were extensively tested at all phases and with various optical and IR detectors. Not surprisingly, each hard- and software release has required some bug fixes. But in no case was a significant redesign necessary. It was very gratifying that the combination of two sets of expertise did not partly annihilate one another and cause previously unknown problems, as has been the experience with many industry-scale cooperations or mergers. A particularly welcome early observation was that images read out with NGC do not show those suspicious wavy patterns, which mostly add little to the effective overall noise, but are visually quite irritating.

Very comprehensive tests were run with the first science-grade detector for KMOS, a Hawaii-2RG device from Teledyne Imaging Sensors. The noise histogram in Figure 4 demonstrates a read noise of 6.9 e- root mean square (rms), which was achieved with simple double-correlated sampling and is the lowest noise ever reported for such a detector (cf. Finger et al., 2009). Detailed tests were also performed with the prototype detector system for MUSE, which employs a 4k x 4k CCD 231-84 device from e2v. At 50 kpix/s, a read noise as low as 2.8 e- was achieved. Using all four ports, the entire array can be read within 45 seconds and at a read noise of 3 e-. An excellent (non-)linearity of 0.3% was measured.

While system noise is the most decisive figure of merit for any detector controller, there are many more advantages to the NGC system:

- Signals can be sampled once or several times, in the analogue as well as digital domain.
- Much higher bias voltages are supported than for FIERA. This is important as it permits fully depleted CCDs, that are made of very thick silicon, to be operated, leading to the achievement of a much improved near-IR sensitivity. (Silicon becomes increasingly more transparent with wavelengths into the near-IR.)
- Gain and bandwidth of the optical preamplifier are both programmable in 16 steps, permitting sensitive matching of NGC to various types of CCDs and readout modes.
- An NGC system can go online within just 3 seconds (longer if more configuration checks are performed), and detector engineers appreciate that, in

the laboratory, they can make a warm start after having changed voltages so that test sequences can be executed with high time efficiency.

– While a FIERA front-end with four video channels comprises 5373 electronic components, of which 286 are different, these numbers are 1697 and 91, respectively, for NGC so that parts procurement and stock-keeping are much simplified.

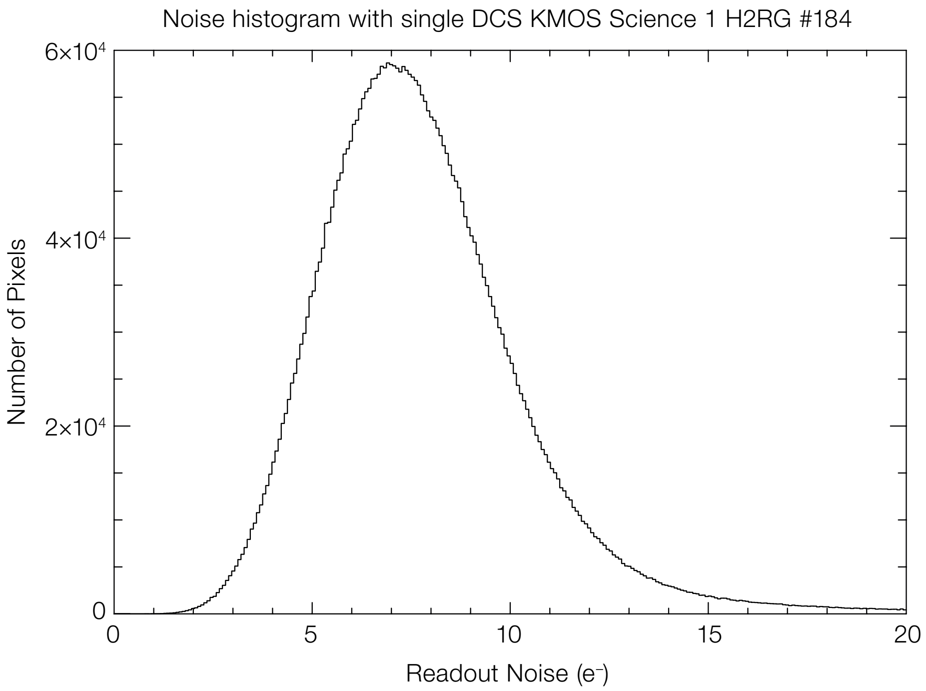


Figure 4. Noise histogram for single double-correlated readout of a 2K x 2K HgCdTe substrate-removed λ_c = 2.5 μm Hawaii-2RG array (KMOS science-grade array #1). The noise distribution peaks at 6.9 electrons (rms).

Outlook

NGC will be the standard detector controller for future LSP instruments, regardless of wavelength. For the existing instruments, FIERA and IRACE fulfil all requirements, and there are enough spare parts to sustain the unrestricted functioning of all systems throughout the lifetimes of their host instruments. Like FIERA and IRACE, NGC will be a line-replaceable unit at the observatory. Because of the increasingly specialised demands from both new detectors and new applications, NGC will develop into a toolkit, which permits ambitious projects to be realised on one common platform, but with a minimum number of actually-used variants. For instance, new 3-MHz analogue-to-digital converters (ADCs) are being tested for their suitability to replace the current default 1-MHz ADCs for higher-speed applications. A special high speed (10 MHz) development is also underway. Software for standardised low-level post-processing of data (e.g., averaging of frames or bias correction) on the LLCU is under development. NGC will continue to serve as the basis for close collaborations between the Infrared Detector Department and the Optical Detector Team, and a joint NGC production line has been set up. Extrapolation from the experience with FIERA and IRACE suggests that, in all probability, a full-blown second generation NGC will be needed to support the E-ELT operations due to start in 2018. By then many detectors may come with their own on- or near-chip controllers (ASICs — application-specific integrated circuits). But they will need a common E-ELT umbrella to interface to the overall E-ELT control system and operations paradigm.

Additional technical information including numerous downloadable documents is available on the NGC home page[1]. The section "General" contains pdf versions of a number of detailed presentations about various aspects of NGC (design, production, testing, performance). The NGC Team welcomes your enquiries and feedback at ngc@eso.org.

Acknowledgements

We thank Stefan Hötzl for much laboratory support, and Iris Bronnert and Stefan Hötzl for the compilation and execution of endless procurement lists. BlueWave was developed by Alessandro Bortolussi. Mark Downing and Roland Reiss helped with useful requirements and feedback. Roland Reiss is the lead engineer for the development of TeePee; he also provided some of the performance measurements with CCDs. Luigi Andolfato gave generously of his experience with state machines built up with the development of the VLT Workstation Software Framework (WSF). Sebastian Deiries and Eric Müller prepared the CCD test bench of the Optical Detector Team for NGC and executed quite a number of CCD tests. The database for the reliability analysis of FIERA and IRACE was established by Nicolas Haddad.

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On-sky Testing of the Active Phasing Experiment

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The Active Phasing Experiment (APE) has been used by ESO to gain experience in controlling segmented primary mirrors in preparation for the European Extremely Large Telescope. The experiment tested various phasing techniques and explored their advantages and limitations. Four optical phasing sensors were developed using different techniques — a curvature sensor, a pyramid sensor, a Shack–Hartmann sensor and a sensor based on a modified Mach–Zehnder interferometer. The design of the APE instrument is described. APE was installed at the VLT visitor focus for on-sky testing and a brief summary of the results of the experiment is given.

Alignment of the mirrors of a segmented primary mirror

Some of the next generation of giant optical telescopes will be equipped with segmented primary mirrors composed of hundreds of hexagonal segments. It is necessary to operate at the diffraction limit of such telescopes if the telescope is to use adaptive optics and be a science driver, and this can only be achieved if the segments are well-aligned both in height, called from now on "piston", and in tip and tilt. The fast control of the rigid-body positions of the segments will be based on measurements made with edge sensors. These, however, can only measure differential movements between adjacent segments and therefore have to be supplied with reference values for the absolute measurements of the piston steps at the intra-segment borders. At the moment, such reference values can only be obtained with a precision of the order of a few nanometres by optical measurements, preferably using the light of a star in the field of the telescope.

The optical phasing sensor (OPS) of the first large segmented telescope, the Keck telescope with 36 segments, is based on the Shack–Hartmann principle, which is also widely used in active and adaptive optics applications. The phasing at the Keck telescopes (Chanan, 1998) is undertaken at intervals of around four weeks, using relatively bright guide stars, and takes between half an hour and two hours. For the rest of the time the control of the segment positions, also called phasing, relies on the stability of the edge sensors.

In the Shack–Hartmann method small lenslets must be positioned in the strongly reduced image of the primary mirror such that the corresponding subapertures cover an area with a diameter of approximately 100 mm centred on the border between two segments, with a projected error of less than 10 mm. In extremely large telescopes with potential distortions of the pupil this may be difficult to achieve. Other types of sensors working directly with pupil, images may not suffer from the effects of pupil distortions and misalignments. Furthermore, a phasing sensor that could work with fainter stars would give the option to perform optical phasing measurements during operation and therefore deliver continuous closed-loop updates of the reference values of the edge sensors.

The Active Phasing Experiment (APE) tests various phasing techniques, explores their advantages and limitations and also allows the participating institutes and ESO to gain experience in the field of phasing. The project started at the end of 2004. It has been carried out by a consortium of three European institutes — Instituto de Astrofisica de Canarias (IAC), Osservatorio Astrofisico de Arcetri, Instituto Nazionale d'Astrofisica (INAF) and Laboratoire d'Astrophysique de Marseille (LAM) — one industrial company (Fogale Nanotech) and ESO. Four optical phasing sensors have been designed and fabricated, all based on technologies that have been used in active and adaptive optics systems during the last 20 years: a pyramid sensor (PYPS) developed by INAF; a curvature sensor, called DIPSI (Diffraction Image Phase Sensing Instrument), developed by IAC; a sensor based on Mach–Zehnder interferometry with a combination of phase and spatial filtering, called ZEUS (ZErnike Unit for Segment phasing), developed by LAM; and finally a Shack–Hartmann phasing sensor, called SHAPS, developed by ESO. APE had its first light in the laboratory during the spring of 2008 and its first light on-sky on the 6 December 2008. The project will end in June 2009, when the instrument will be dismounted from the visitor focus on Melipal (UT3). This experiment has been supported by the FP6 research programme of the European Union.

Goals of APE

The basic idea behind APE is to simulate a segmented VLT, with segment diameters and gaps between the segments similar to the ones in real segmented telescopes. The telescope pupil is imaged onto a small Active Segmented Mirror (ASM; Dupuy et al., 2008 and Gonté et al., 2007) to test the phasing techniques both in the laboratory and in an observatory environment. To make comparative tests and make efficient use of the telescope time, APE had to be capable of measuring with all phasing sensors in parallel. This meant that the beam had to be split into four with identical intensities. Furthermore, the precision of the control of the individual segments of the ASM had to be better than 5 nm root mean square (rms). An internal metrology

(IM) system was developed to support the positioning control for the segments and as an independent reference system for the OPSs.

The goals for the OPSs were to measure piston, tip and tilt errors of the segments and to use these for closed-loop corrections and demonstrate their functionality on-sky under various perturbations, for example, variable seeing conditions, limited star brightness and aberrations generated by the telescope. When possible the OPSs should also be able to measure the wavefront errors generated by the telescope, the figure errors of the segments and the lateral displacements, as well as the distortions, of the pupil.

Design of APE

APE has been designed as a modular system on a 3 m by 2 m optical bench. The main subsystems are a turbulence generator (called MAPS), the ASM, the IM, four optical phasing sensors and the junction boxes. Three electronics cabinets contain the amplifiers, the analogue-to-digital converter cards, the controllers and the nine central processing units required for the control of the electronic components of APE (six CCDs, five translation stages, twelve rotating stages, two fast steering mirrors and the 183 actuators of the 61 segments incorporated in the ASM). The cabinets are linked to the bench via the junction boxes. Figure 1 shows a top view of APE with its two independent optical paths. The path in pink that includes a reflection of the ASM, feeds the OPSs, with the light coming from either the telescope focus or from MAPS. The path shown in green is the one used by the IM to measure the position of the ASM segments. In total there are 42 optical surfaces (lenses, filters, mirrors, beam splitters, etc.) between the focus of the telescope and the entrance foci of the phasing sensors. The quality of the wavefront delivered to the phasing sensors is better than $\lambda/2$ peak-to-valley across the segmented pupil. APE operates at wavelengths between 500 nm and 920 nm, with the bandpass between 820 nm and 880 nm reserved for the IM. The sensor units, fixed to the bench by kinematic interfaces, the optics and the other subsystems are aligned with a precision better than 100 μm.

The ASM, shown in Figure 2 after its installation on the bench, is a flat mirror composed of 61 hexagonal segments, made of Zerodur with a reflective coating of aluminium. The wavefront quality of the segments is better than 15 nm rms. They can be positioned in piston, tip and tilt by three piezo-actuators with strokes of 30 μm and a resolution of 0.5 nm. The segments have inner diameters of 17 mm with gaps between them of the order of 100 μm. The inner and outer diameters of the pupil of the ASM are 139 mm and 154 mm, respectively. Projecting the segments onto the primary mirror of the VLT, the telescope with a meniscus primary mirror appears transformed into a segmented telescope with 61 segments of 1.05 m diameter, with gaps between the segments of 4 mm and with the capability of correcting piston, tip and tilt with a precision of 0.5 nm.

The heart of APE is the ASM, but its pacemaker is the IM developed by Fogale Nanotech (Wilhelm et al., 2008). It is a dual wavelength (835 and 860 nm) phase shifting interferometer with two optical arms with lengths of 2.5 m each. The first arm located inside the IM unit serves as the reference. The second arm goes back and forth between the IM and the ASM via an off-axis parabola. The IM measures the position of each segment of the ASM with respect to the central segment at a frequency of 8 Hz with a precision better than 0.3 nm. Like any other interferometer, the system is sensitive to environmental disturbances like vibrations of the bench and air turbulence due to temperature inhomogeneities or wind, all creating noise in the measurement and consequently a loss of resolution in the control loop between the ASM and the IM. In the laboratory the APE bench was placed on a pneumatic support to filter the vibrations coming from the ground. In addition, the temperature was controlled. The IM resolution obtained in the laboratory for the positioning of the segments relative to the central one was better than 0.4 nm rms.

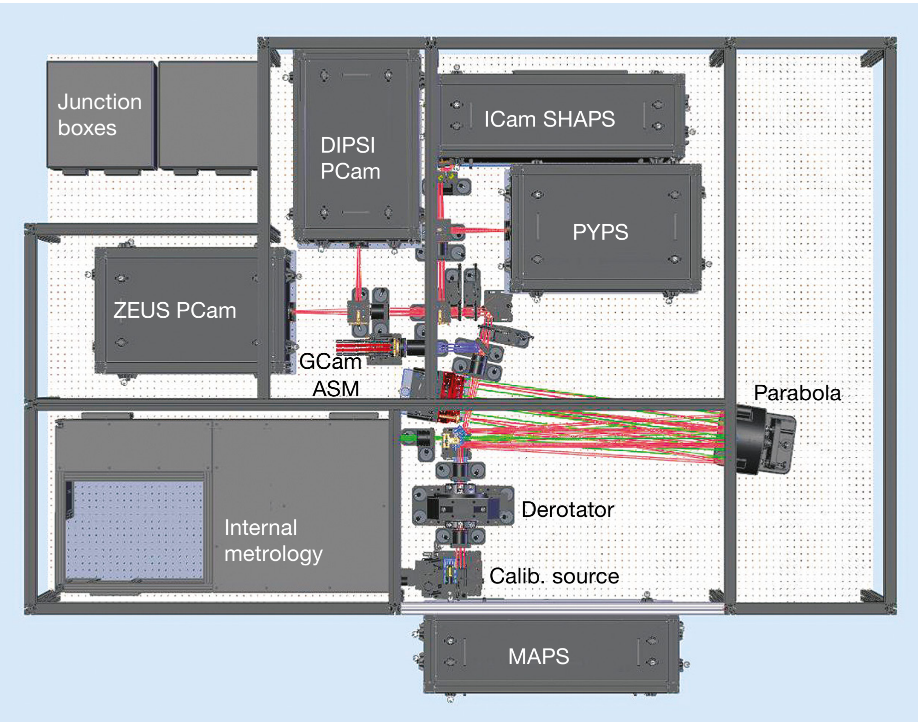


Figure 1. Top view of the model of the APE opto-mechanical bench showing the four optical phasing sensors (DIPSI, PYPS, ZEUS and SHAPS) and the pupil cameras (PCam) and imaging cameras (ICam).

Credit: ESO/H. Heyer

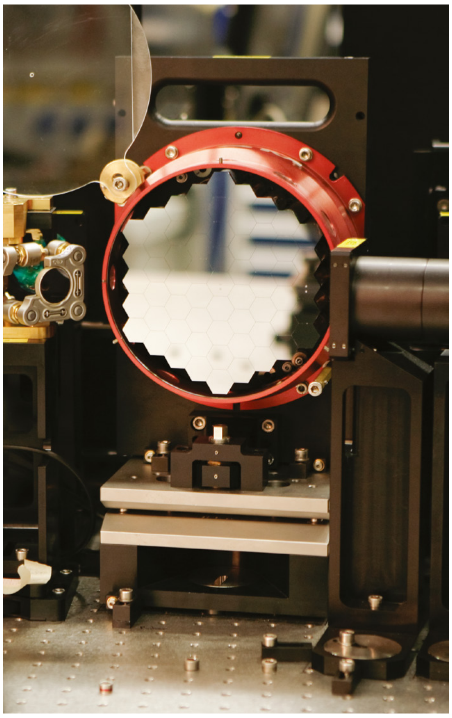


Figure 2. The active segmented mirror assembled on the opto-mechanical bench.

Approximately 50% of the manpower dedicated to APE has been spent on the development of the VLT-compliant software, covering a variety of tasks ranging from the control of the motors to the archiving of the data gathered by APE and its phasing sensors. The complexity of the software is due, on the one hand, to the need for high flexibility in the configuration and execution of the experiment and, on the other hand, to the elaborate algorithms used for the analyses of the data delivered by the four phasing sensors.

The four optical phasing sensors

Four different types of OPSs were built and tested.

DIPSI (Chueca et al., 2008) is a curvature sensor analysing defocused images of the pupil. For low order wavefront errors the signal is approximately proportional to the second derivative of the wavefront and is easily interpreted using geometrical optical theory. For sharp discontinuities generated by phase steps at segment borders, the explanation of the signal requires Fresnel diffraction theory. The amplitude of the signal has been used as the estimator for the piston step.

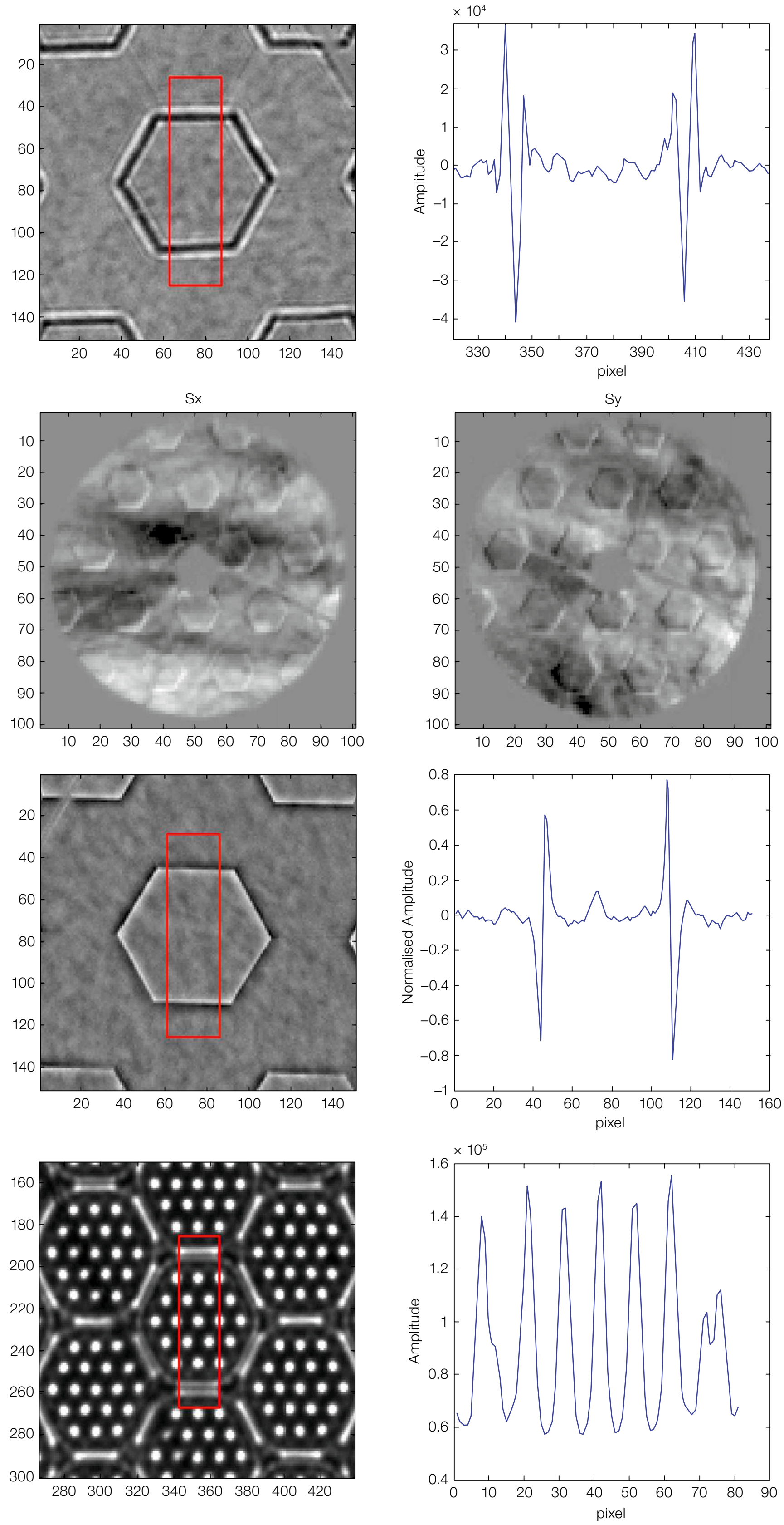
PYPS (Pinna et al., 2008) is based on the pyramid sensor technology, originally developed for adaptive optics. PYPS produces an optical signal by splitting the image in a focal plane by a pyramid with four faces. This is equivalent to a simultaneous knife-edge test on two orthogonal axes. The signal is constructed from the intensities in the four pupil images and, broadly speaking, is proportional to the first derivative of the local wavefront. A simulated or measured interaction matrix is then used to retrieve the piston, tip and tilt errors of each segment. To determine the interaction matrix a record of the signal for each degree of freedom of the segmented mirror is made and the pseudo-inverse of the matrix is generated. The interaction matrix depends on the number of modes to be corrected. This approach has the advantage that it captures all parameters that affect the signal. The disadvantage is that interaction matrices have to be determined for a variety of parameters like the seeing conditions and the number of modes to be corrected. The modified feature of PYPS, compared to other pyramid sensors, such as the one used in the Multi-conjugate Adaptive Optics Demonstrator (MAD, see Marchetti et al., 2007), is that the focus on the pyramid is modulated by a fast steering mirror to increase the sensitivity of the sensor.

SHAPS (Mazzoleni et al., 2008) is based on the Shack–Hartmann technology that has been used in active and adaptive optics for a long time. It is also the standard method used on the Keck telescopes to measure the positions of the segments. The lenslets are aligned so that the centres of the corresponding subapertures lie on the borders between two segments. The signals are the diffraction patterns of the lenslets. Although the piston step affects the position as well as the shape of the signal, only the shape is used as an estimator for the piston steps. SHAPS uses cylindrical lenslets covering the full border between two segments that provides the flexibility to average the signal along any fraction of the border and therefore measure the piston step along the whole border. The lenslet array also supplies 19 lenslets inside each segment subaperture for the measurement of the segment aberrations.

ZEUS (Surdej et al., 2008) is based on the modified Mach–Zehnder interferometer phasing sensor developed at LAM (Yaitskova et al., 2005). A phase and spatial filter is installed at the focus of the telescope to filter out low spatial frequencies in the wavefront, such as the ones generated by the atmosphere, thereby increasing the contrast for high frequency errors such as those due to segment piston errors. The optimum size of the mask is approximately equal to the diameter of the seeing disc. However, three different masks are sufficient to cover seeing conditions ranging from 0.4” to 2”. The normalised signal is constructed from three images: a signal taken with the filter; an image of the pupil taken without the filter; and a dark image. The piston steps are then estimated by fitting a theoretical expression to the signal. A simpler, but less accurate, method is to use only the amplitude as the estimator for the piston step.

All OPSs suffer from the same limitation. Using monochromatic light with a wavelength, λ, the range of the measurable phase difference is limited to $(-\lambda/2, \lambda/2)$ and the signals are identical for piston steps differing by integral multiples of λ. The ambiguity can be resolved, and the capture range increased, if multiple measurements are performed with a small set of narrowband optical filters. This method, conventionally called the multi-λ technique, allows a capture range of the order of a few µm, following which only a small number of iterations are necessary in closed loop to reduce the piston steps to values well within the $(-\lambda/2, \lambda/2)$-range. Another approach to resolve the ambiguity, usually called the coherence method, is to move adjacent segments with respect to each other over a large range of piston values. Using a broadband filter a signal will only appear if the piston step is sufficiently small.

In principle, for all sensors, the highest precision will be obtained with narrowband optical filter measurements, provided that the sources are sufficiently



bright. However, sufficient precision with faint stars can only be achieved with broadband optical filter measurements. Figure 3 shows typical signals obtained by the four OPSs.

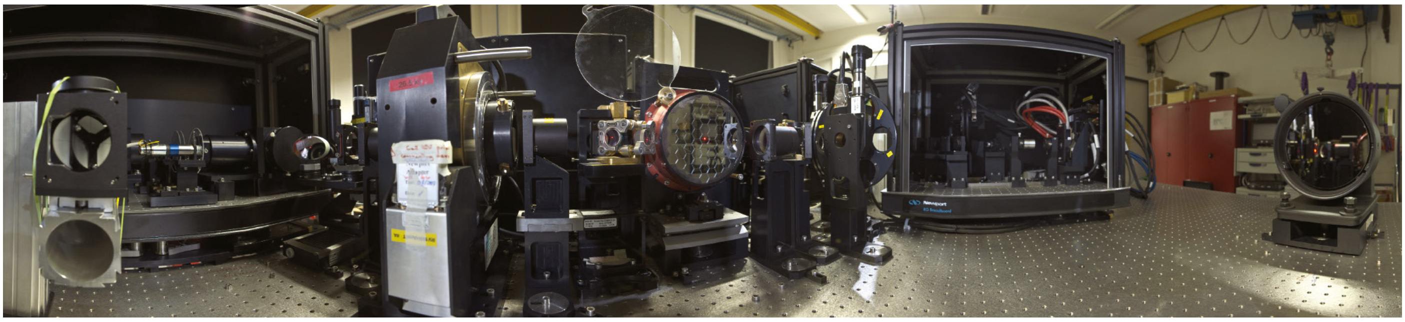
Tests in the laboratory

Figure 4 shows the fully integrated optical bench with all its subsystems and optics, but without the cover, on its pneumatic support in the laboratory. The tests performed in the laboratory differ in many ways from the tests at the telescope. Some of the features of the telescope and the atmosphere that affect the wavefront cannot be simulated sufficiently realistically or at all. The list includes variations in the optical quality of the telescope, pointing, tracking, vibrations generated by the wind or by the motors, rotation of the obstruction by the spider, field or pupil rotation, variations in the spectra of the guide stars, often rapid variation of the seeing, variations of the heights and characteristics of the turbulence layers, etc. On the other hand, the tests in the more controlled and stable laboratory environment allow for a much more accurate determination of the dependence of the results on specific parameters, such as the light intensity, the algorithm and the choice of the estimator.

The fully functional APE was tested for three months during the summer of 2008 with three weeks dedicated to each OPS. The measurements demonstrated the capability of all OPSs to measure the piston steps with narrowband, broadband and multi-λ techniques using diffraction-limited wavefronts, as well as wavefronts distorted by atmospheric seeing up to 0.8 arcsec. PYPS and SHAPS also showed that they could measure the tip and tilt errors of the segments. In addition, all sensors were tested with different light intensities equivalent to star magnitudes up to 16.

Figure 3. Typical images and signal cross-sections through active segments obtained with the four optical phasing sensors (DIPSI, PYPS, ZEUS and SHAPS, shown top to bottom) during on-sky observations with a wavefront piston step of 150 nm (except SHAPS with steps of 150 nm and 300 nm) and seeing conditions between 0.8" and 1.2". All image units are pixels.

Credit: ESO/H. Heyer



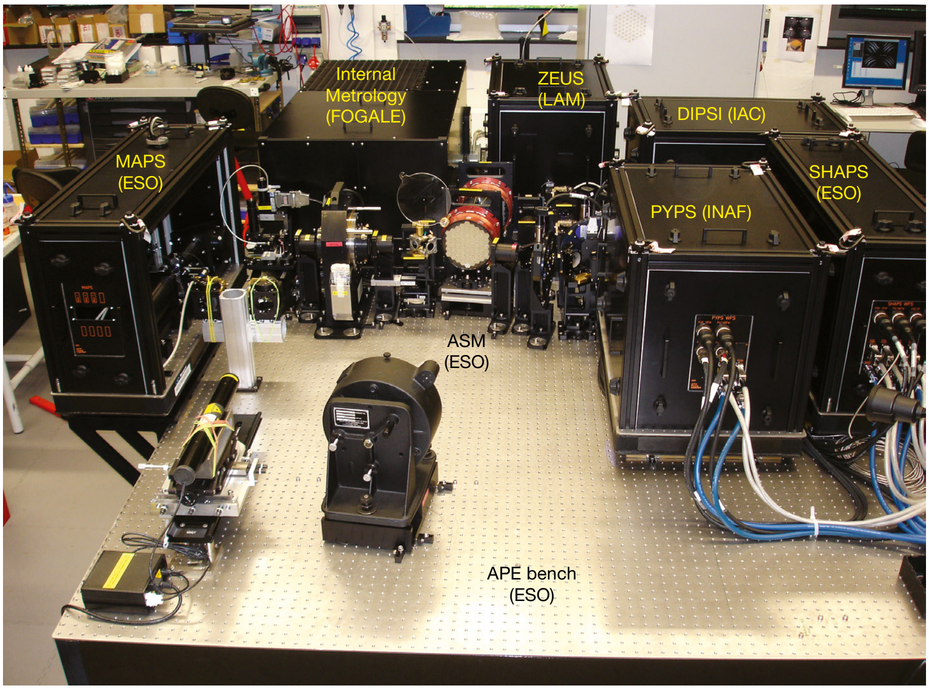


Figure 4. A 360-degree view of the APE bench (top). The APE bench in the laboratory, with its main subsystems indicated, before the cover was installed (left).

Integration on Paranal

APE was dismounted in Garching at the end of September 2008. A total of 22 crates with a volume of 50 cubic metres and a weight of 9 tons were shipped to Paranal. The re-assembly, including the support structure and the cooling interfaces, in the integration hall, located in the VLT control building took three weeks. After two weeks of tests and verifications, APE was installed as a complete unit at the visitor focus on the Nasmyth A platform of Melipal. A few days were required to align the APE bench with the telescope. Figure 5 shows APE fully assembled on its support structure, with some scaffolding around it for easier access and two of the three electronics cabinets on the right. APE was ready for its first light on 6 December 2008.

On the telescope, APE, as expected, was confronted with perturbations that did not occur in the laboratory environment. A pneumatic support structure could not be used since it would not have allowed for a proper alignment of the bench with respect to the telescope. Therefore, all the electronics cabinets that are equipped with fans generating vibrations were isolated from the Nasmyth platform by damping devices. Another source of vibrations was the movement of the telescope itself. To minimise the transfer of telescope vibrations to the bench, the system had been designed such that the lowest eigenfrequency was as high as possible. During the on-sky measurements, the most important sources of noise turned out to be the wind forces on APE and temperature gradients inside APE. This noise was strongly reduced by protecting the IM–ASM optical path by an additional internal enclosure. Nevertheless, the resolution was always better than 5 nm rms and even fell below 3 nm rms during the second half of the night.

First light and preliminary results

The first light images of the four optical phasing sensors obtained on the 6 December 2008 are shown in Figure 6. After the commissioning run, APE had three more runs with a total of 23 nights. Two types of measurements were obtained. The first type did not involve closed-loop corrections of piston, tip and tilt of the segments. This included measurements, performed in parallel by all sensors, on the dependence of the signals on parameters like the piston steps, tip and tilt of the segments and specifically measurements with telescope aberrations, as well as the test of the coherence method. For some sensors it produced calibration data required for the second type of measurements with closed-loop corrections. In this case the ASM was controlled by one sensor whereas the other sensors were just measuring the wavefront errors. The results reported below were all obtained with closed-loop measurements.

Based on narrowband measurements by the OPSs with bright stars under seeing conditions better than 1”, the closed loop corrections of the piston steps achieved precisions between 6 and 18 nm wavefront rms. Less than five loops were usually sufficient to converge to the final residual error. This is illustrated in

Credit: Gerhard Hudepohl

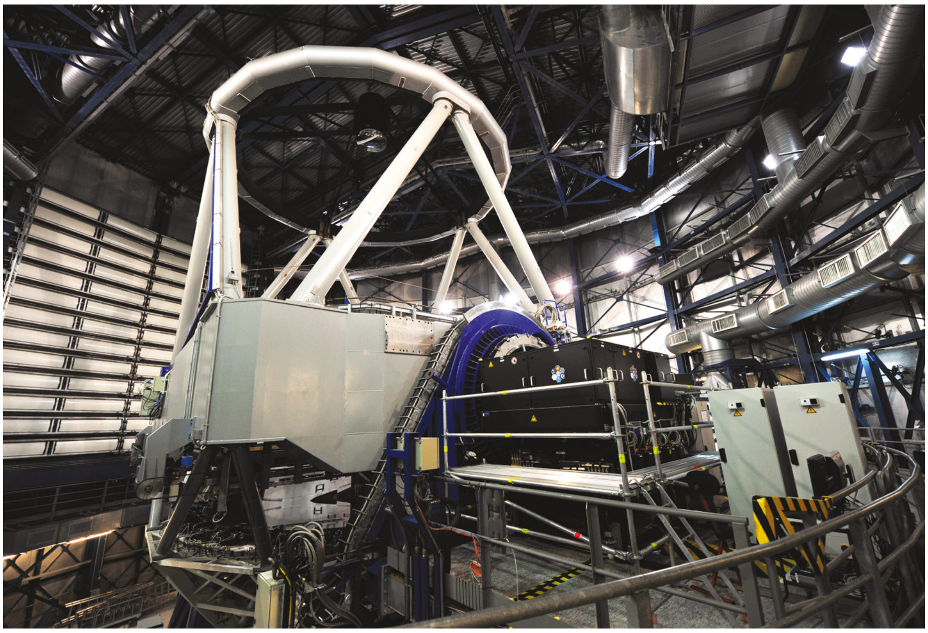


Figure 5. APE fully assembled on the visitor focus of Melipal (UT3).

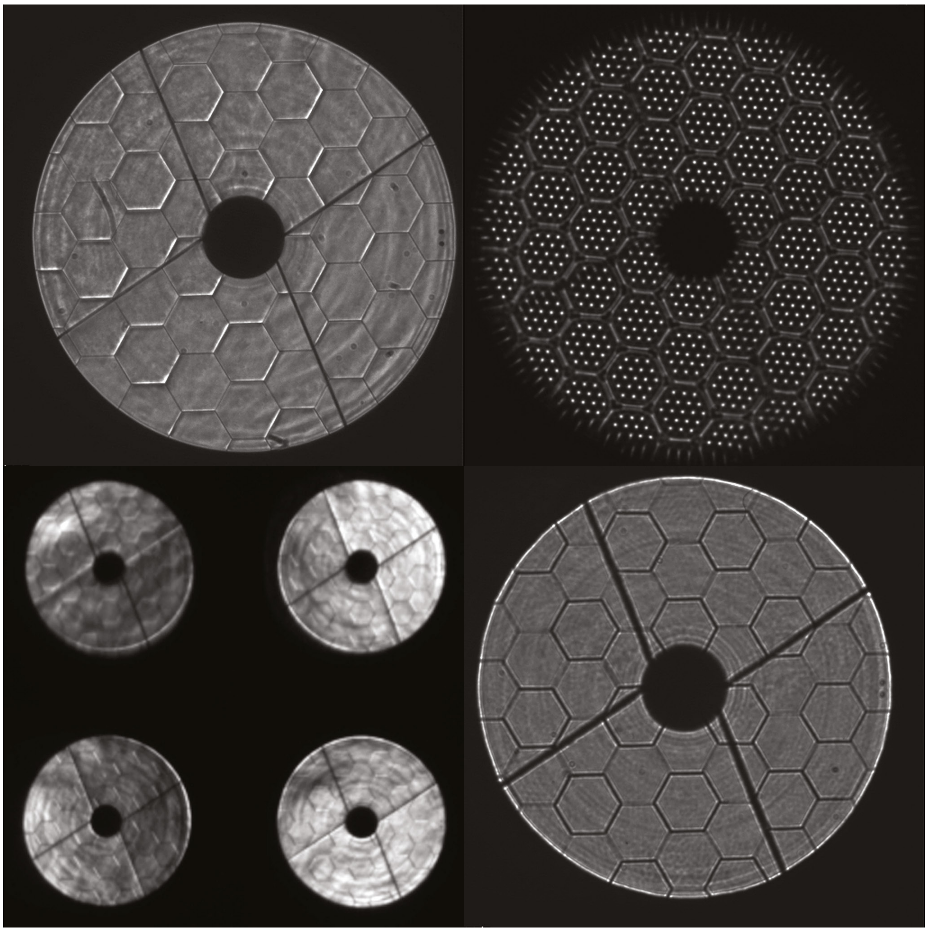


Figure 7c with SHAPS being the master sensor. Clearly, the seeing has an impact on the final residual error of each OPS. However, ZEUS, owing to the presence of the mask adapted to the seeing and filtering out, in particular, the low spatial frequency modes dominating the aberrations generated by the atmosphere, seems to be the most robust sensor with respect to this perturbation.

For each OPS with a broadband filter, the limiting star magnitudes for which the closed loop corrections would still converge have been determined. The convergence has been obtained with magnitudes between 14 and 18 depending on the sensor. The PYPS measurement is shown in Figure 7b. Starting from an initial configuration with 45 nm rms piston wavefront error, the loop converged with a final precision of 23 nm rms. With the multi-λ technique, most sensors were capable of extending the capture range typically to a few µm. Figure 7a shows a closed-loop correction with DIPSI using a set of four optical filters. After seven iterations, the initial random wavefront piston error of 550 nm (rms) was reduced to 30 nm. Three sensors were also able to close the loop for the correction of segment tip and tilt errors. Figure 7d shows a typical sequence obtained with ZEUS achieving a final precision better than 0.4 arcsec rms. This is equivalent to a residual error at the borders of the segments of 16 nm wavefront rms.

So far, only a fraction of the data gathered at the telescope has been analysed. In addition, the teams working with the four sensors used different methods to estimate the piston steps. A better understanding and comparison of the sensors requires a thorough analysis of all the data.

APE conclusions

With tests in the laboratory and on-sky at the VLT, APE demonstrated that the four tested optical phasing sensors, all based on different technologies, are capable of phasing a segmented primary mirror. In particular, they supplied sufficient ranges

Figure 6. Raw first light signals of the “segmented” primary mirror of the VLT obtained by the four optical phasing sensors. Top row: ZEUS, SHAPS; bottom row: PYPS, DIPSI.

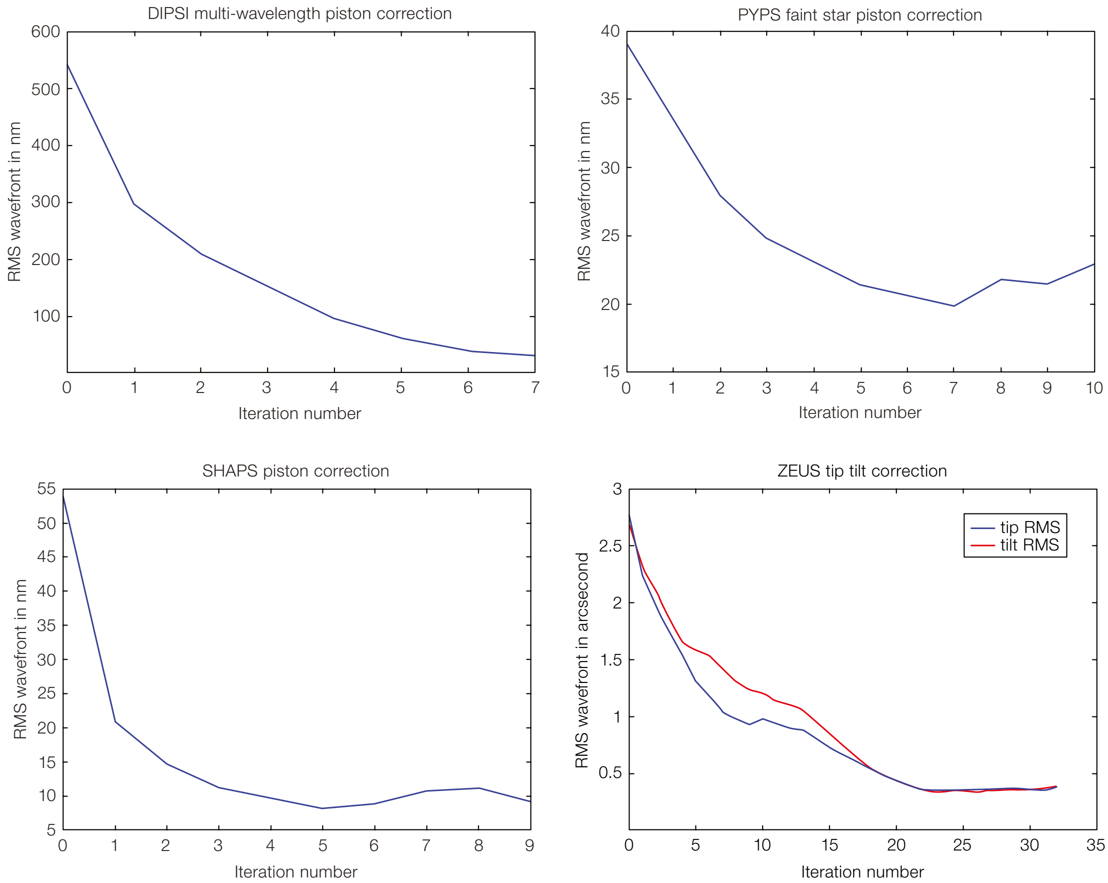


Figure 7. The resulting rms error on closed-loop corrections for the four OPSs: (a) DIPSI, piston correction using multi-λ technique; (b) PYPS, piston correction with a faint star (magnitude 18); (c) SHAPS, piston correction with a bright star; (d) ZEUS, tip and tilt correction.

for the capture of large piston errors. In addition, for the correction of piston steps, precisions of the order of 6 nm wavefront rms could be reached with bright stars and precisions of the order of 23 nm with stars as faint as magnitude 18. A thorough analysis of all the data during the next few months will further improve our understanding of the capabilities of the four optical phasing sensors. The success of this experiment has also been the result of a good cooperation among the partners of the consortium, shown in Figure 8 at first light.

Credit: Arthur Vigan

Figure 8. The APE team after First Light.

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ALMA Receivers Invading Chile

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The ALMA Project has moved into the production phase, perhaps most notably for the advanced receiver systems, or Front Ends that are required by the project. This article provides a summary of the technical and production status of the various Front End subassemblies and some of their recent deliveries. The first complete Front End has been delivered by the European Front End Integration Centre to the ALMA Observatory in Chile.

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), in North America by the US National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA. The recent status and progress of the project was reported by Haupt & Rykaczewski (2007).

Since the previous article in 2004 dedicated to the ALMA receivers and published in this magazine (Tan et al., 2004), major progress has been made. In the past five years the baseline design has been largely completed, a pre-production phase of crucial Front End subassemblies has been successfully achieved and the project has now embarked on the final production run of receiver systems. The other noteworthy news is that the scope of this essential ALMA subproject has been substantially expanded with the entrance of Japan into the ALMA Project. This important event has allowed a further expansion of the Front Ends by the addition of another three receiver cartridges for Bands 4 (125–169 GHz), 8 (38–500 GHz) and 10 (787–950 GHz) in addition to the four baseline receiver bands. Funding has also been made available by the European Commission under the 6th Framework Programme for the development and pre-production (six units) of Band 5 (163–211 GHz) receivers as part of the project for the Enhancement of ALMA Early Science. The design and construction of the cold cartridges, including superconductor insulator semiconductor (SIS) mixers and intermediate frequency (IF) amplifiers, has been undertaken by Chalmers University in Gothenburg, Sweden. The matching local oscillator needed for this heterodyne receiver is being designed and built by the Rutherford Appleton Laboratory in the UK. Programme and system management of this activity is undertaken by the Front End Integrated Product Team (FE IPT) within the ALMA Division at ESO.

ALMA receiver status

The performance goals initially set by the project for the ALMA receivers were considered as challenging and at the very edge of what had so far been demonstrated (Tan et al., 2004). Over the past few years all groups involved in the development and construction of these receivers have worked very hard and demonstrated that it is possible to achieve this performance. It is also very rewarding to note that, for example, a key performance parameter like receiver temperature, a fundamental measure of the sensitivity of the receiver, is maintained over a broad frequency range and is repeatable from one receiver system to another (Barkhof et al., 2009), as shown in Figure 1. Table 1 provides a summary of the ALMA receiver bands, including achieved sensitivity performance (values in parentheses) where available.

Table 1 also shows that work is ongoing on four additional frequency bands as well as to the four baseline bands — Bands 3, 6, 7 and 9 — with which the bilateral project started. NAOJ took responsibility for Bands 4, 8 and the most recently approved in 2008, Band 10. The European Community has funded the development and preproduction of six units for the Band 5 receivers. More recently, informal discussions between various institutes in the ALMA partner regions have started on a collaboration for the development and production of the ALMA Band 1 receivers.

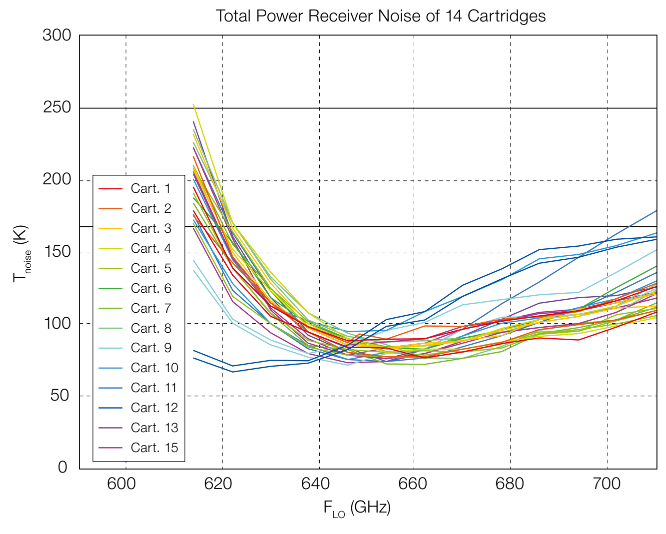

Figure 1. Receiver noise performance as a function of frequency as measured on 14 different Band 9 cartridges. The two blue curves deviating from the other curves, for Cartridge#12, are due to the use of a different type of SIS junction.

ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Supplier
		T_{rx} over 80% of the RF band	T_{rx} at any RF frequency		
1	31.3–45 GHz	17 K	28 K	USB	Not assigned
2	67–90 GHz	30 K	50 K	LSB	Not assigned
3	84–116 GHz	37 K (40K)	62 K (50K)	2SB	Hertzberg Institute of Astrophysics
4	125–169 GHz	51 K (45K)	85 K (55K)	2SB	National Astronomy Observatory of Japan
5	163–211 GHz	65 K	108 K	2SB	Onsala Space Observatory**
6	211–275 GHz	83 K (40K)	138 K (60K)	2SB	National Radio Astronomy Observatory
7	275–373 GHz*	147 K (75K)	221 K (100K)	2SB	Institut de Radio Astronomie Millimétrique
8	385–500 GHz	196 K (160K)	294 K (270K)	2SB	National Astronomy Observatory of Japan
9	602–720 GHz	175 K (120K)	263 K (150K)	DSB	Netherlands Research School for Astronomy (NOVA)
10	787–950 GHz	230 K	345 K	DSB	National Astronomy Observatory of Japan

* Between 370 – 373 GHz T_{rx} is less than 300 K

** Limited to 6 units, funded by the EC under FP6

Table 1. ALMA frequency bands and associated noise performance requirements. The values within brackets indicate actual measured performance. In column 5, USB = Upper Sideband, LSB = Lower Sideband, 2SB = Sideband separating and DSB = Double Sideband.

For all of the four baseline receiver cartridges, the design, after successfully passing a Critical Design Review (CDR), went into preproduction phase, and eight units have been completed. The final production phase of these baseline receivers has started and covers the production and delivery of another 65 units to equip the whole ALMA array and provides sufficient spare units (Jackson et al., 2009b).

Amplitude Calibration Device

One of the important science requirements for the ALMA instrument is that it should be able to measure the strength of the incoming astronomical signal accurately. The objective is to achieve an accuracy of better than 3% below 300 GHz and better than 5% above this frequency. In order to enable this high precision in power measurements each antenna, including all ACA antennas, will be equipped with a so-called Amplitude Calibration Device (ACD). This ACD consists of two loads, both blackbody radiators, which have different accurately known physical and radiometric temperatures, and which are used as a power reference (see Murk et al., 2008). One load is at an ambient temperature of about 293 K, while the other is actively kept at a well-stabilised temperature of between approximately 343 K and 353 K. By inserting the loads in front of one of the receiver inputs, the amplitude scale of each receiver can be calibrated. The loads are moved by a robotic arm in front of one of the ten receiver inputs (see Figure 2).

In addition to these calibration loads, the ACD can carry two so-called “widgets”. One of these widgets is a solar filter enabling observations of the Sun. This is basically a broadband attenuator, operating across the 30 to 950 GHz range, which reduces the radio frequency (RF) signal from the Sun, which has a brightness temperature of approximately 6000 K, to a lower level that does not saturate the sensitive ALMA receivers. The other widget consists of an optional Quarter Wave Plate (QWP), optimised for operation in Band 7 (275–373 GHz). This device converts an incoming circularly polarised signal into a linearly polarised signal very accurately. The QWP might be required to enhance high fidelity observations of polarised sources. The ACD concept using the robotic arm was conceived by Matt Carter from the Institut de Radio Astronomie Millimétrique (IRAM) in Grenoble. The actual design has been done through a collaboration between ESO, IRAM, the Institute of Applied Physics (IAP) at the University of Bern, STFC/RAL in the UK and NTE SA near Barcelona.

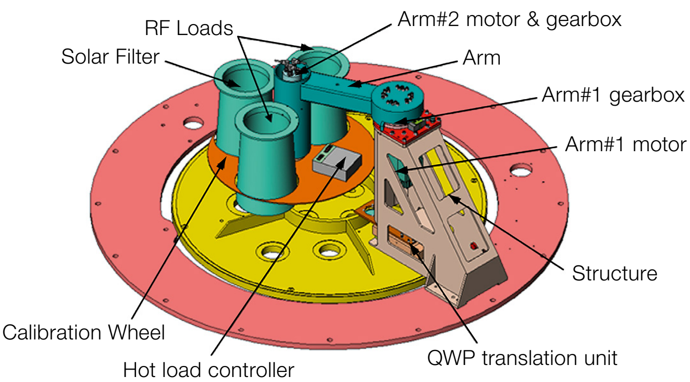

Figure 2. CAD overview drawing of the Amplitude Calibration Device.

In 2008 the development activities led to the completion of two prototype ACDs. In August 2008 the first prototype ACD, #1, successfully passed the Test Readiness Review and Preliminary Acceptance In-house (PAI) at ESO Garching. Subsequently the unit was shipped to the Operations Support Facility (OSF) in Chile where it passed the Provisional Acceptance on-Site (PAS) in mid-September 2008. A support team from the ALMA Division at ESO travelled to the OSF to assist the local Assembly, Integration and

Figure 3. ACD#1 during installation in the antenna receiver cabin.

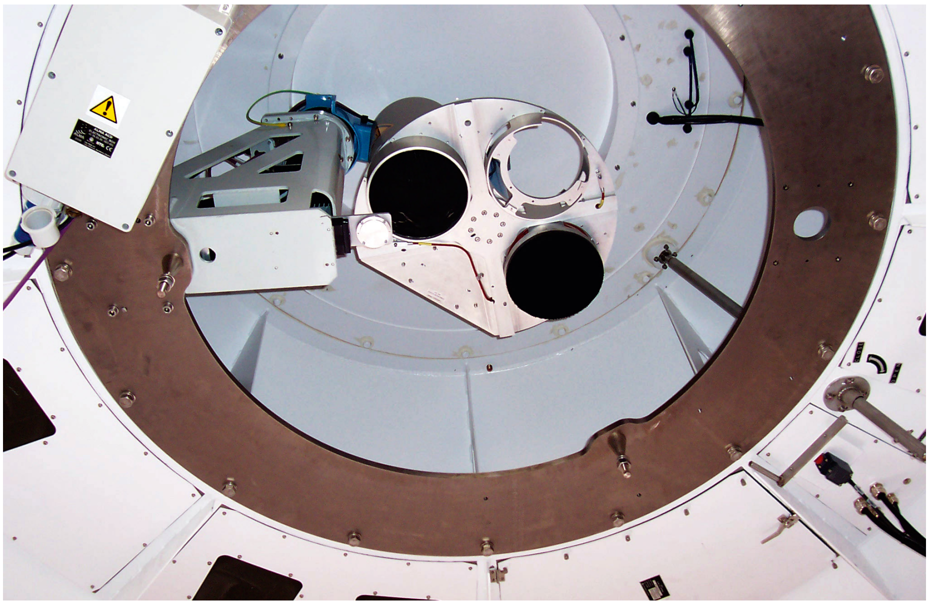

Figure 4. ACD#1 installed in a MELCO antenna.

Verification (AIV) team with these activities, as well as for the first installation of the ALMA calibration device into a 12-metre antenna, manufactured by Mitsubishi Electrical Company (MELCO), on 29 September 2008. Figure 3 shows the ACD mounted on an *xy*-translation stage during installation in the receiver cabin. The installation equipment was designed by the ESO team, who also provided the procedure for a safe and smooth installation. Figure 4 shows ACD#1 after installation in the MELCO antenna. The calibration device itself is installed on top of an annular ring, the Front End Support Structure (FESS), which acts as the mechanical interface between the antenna and the Front End subassemblies. Below the FESS, a box containing the control and power electronics for the ACD is mounted.

The second prototype, ACD#2, passed PAI in November 2008 and was shipped to the OSF. ESO assisted the AIV team with the PAS in February 2009. The calibration device was installed in a Vertex 12-metre antenna shortly afterwards. Following the successful delivery of these two prototype ACDs a preproduction run of five units, still using loads based on an interim design, has started. ACD#3 and #4 passed PAI on 8 April 2009. Figure 5 shows ACD#3, with the calibration wheel and interim calibration loads, during PAI testing in the ESO ALMA Laboratory. Final production of the robotic arms was contracted to NTE AS in Spain. These will be initially integrated into complete ACDs by the ALMA Division at ESO. Development of the final load design, meeting all the demanding technical requirements, is still underway at ESO with support from IAP, University of Bern and industry, and is scheduled to be completed by summer 2009.

Figure 5. ACD#3 during PAI testing in the ESO ALMA laboratory.

European Front End Integration Centre

The ALMA European Front End Integration Centre (EU FEIC) is located at the Rutherford Appleton Laboratory within the Space Science and Technology Department (SSTD). The Centre is nearing completion of its Phase 1 infrastructure preparation and much of the receiver assembly and test equipment is in place, and a key item — the receiver tilt-table (Figure 6) —was recently installed and commissioned. The

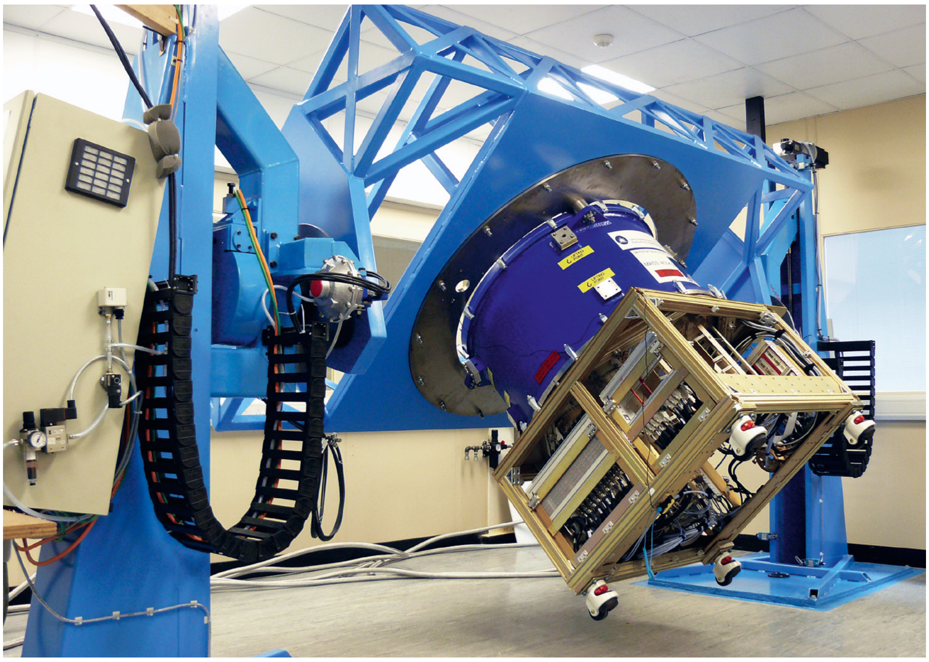

Figure 6. Receiver tilt-table installed at the European Front End Integration Centre. The table emulates an ALMA antenna interface.

remaining test infrastructure, particularly the critical millimetre and submillimetre wave beam scanner, is at an advanced stage of development and the EU FEIC is able to perform essential tests on receiver Front Ends that demonstrate receiver functionality and operation. By the end of 2009, the EU FEIC will be completely ready for the full integration and verification of ALMA Front Ends when the Operational Readiness Review (ORR) will be held. This ORR is a formal validation by the ALMA Project that a Front End Integration Centre meets the requirements to perform its tasks as defined by the project. At this ORR, not only a technical evaluation of the test equipment and integration tools will be made, but also much attention will be paid to aspects related to product assurance, to assure that the integration and verification activities are performed in a consistent and controlled manner. This ORR is held for all three ALMA FEICs and ensures that the Front Ends delivered, irrespective where they have been integrated and verified, are built in an identical way and fulfil the same project requirements.

In fact, the state of readiness is such that the European ALMA Executive recommended to the Joint ALMA Office management that the first European integrated Front End, as a partially qualified engineering model, should be shipped to the project in spring 2009 — some six months earlier than originally anticipated for a first fully qualified Front End. The ALMA management accepted this recommendation and plans were initiated at ESO and RAL to bring forward the delivery schedule. Technical and administrative teams at RAL and ESO — and with the support of groups within the ESO member states, especially the Band 7 and 9 cartridge groups from IRAM and the Netherlands Research School for Astronomy (NOVA), North America and East Asia — worked hard to provide appropriate subassemblies, perform integration, and complete testing, all in the required timescale. The fully assembled and verified receiver system, a first for an FEIC, was duly dispatched from RAL in March 2009 and successfully completed its journey to the OSF in Chile, where it arrived on 2 April (Figure 7). Since then it has successfully undergone PAS verification, performed by a joint team from the ALMA Observatory, ESO, NOVA, NRAO and RAL (see Figure 8), and currently preparations for deployment on one of the ALMA antennas are underway.

The delivery of this receiver represents a major milestone, not only for the European element of ALMA, but also the ALMA observatory itself, as once the receiver is installed on a telescope then interferometry becomes possible. In addition, a pioneering step was taken with regard to the methodology of shipping that demonstrated the feasibility of safe delivery of a single fully integrated system to Chile — this improves the efficiency of delivery and substantially eases the test and installation process at the observatory. This success was also appreciated by the

Figure 7. Arrival of the first ALMA Front End from the European Front End Integration Centre at the temporary assembly integration and verification laboratory at the ALMA Operations Support Facility.

Joint ALMA Observatory, which now would also like to apply this shipment method to the other two FEICs in East Asia and North America.

Water Vapour Radiometer

Another important milestone for the ALMA Project has recently been achieved with the delivery and successful provisional acceptance of the project's first Water Vapour Radiometer (WVR) system at the OSF. When fully commissioned, the WVR will provide near real-time measurements of the brightness temperature of the atmosphere at the Array Operations Site (AOS). These data will enable subsequent delay correction of the astronomical signal received by each antenna that is impaired by the continually fluctuating water vapour conditions present within the Earth's atmosphere (Nikolic et al., 2008). This delay correction procedure is important in achieving the overall performance specification for obtaining high dynamic range maps with the ALMA system. Each 12-metre diameter ALMA antenna, including the four so-called total power antennas within the ALMA Compact Array (ACA), will therefore be provided with its own dedicated WVR, operating as a passive receiver system at submillimetre frequencies, to monitor the sky temperature along each antenna's boresight. The smaller 7-metre diameter antennas within the ACA are grouped closely together, within a circle of diameter less than 300 m, and are thus less affected by the water vapour variations in the atmosphere above the site. For this reason these 7-metre antennas are not equipped with WVRs.

The WVR has been designed to an exacting and demanding technical specification that necessarily takes into account the harsh climatic and environmental conditions that exist at an altitude above 5000 m. The WVR has also been designed to operate continuously for extended periods in the field without routine maintenance. The design of the WVRs is based on an uncooled heterodyne receiver and incorporates precision quasi-optical mirror assemblies and RF components designed for operation at a centre frequency of 183 GHz, where one of the water emission lines is located. This RF signal is subsequently down-converted and filtered into four IF frequency bands from 0.5–8 GHz and the atmospheric water vapour content can be determined by comparing the power level in the four IF channels to each other. The WVR system design is based on a "Dicke-switched" radiometer configuration that includes a rotating chopper wheel subsystem and also features two highly accurate and thermally regulated blackbody internal calibration loads. The WVR system also includes sophisticated thermal management electronics, precision mechanical components and embedded monitoring and control software, all packaged and contained within a relatively lightweight and compact structure. Each WVR is then integrated and mounted into the antenna cabin alongside other ALMA subsystems.

Figure 8. The first ALMA Front End from the European Front End Integration Centre undergoing Provisional Acceptance on-Site verification with a subgroup of the international team supporting the delivery.

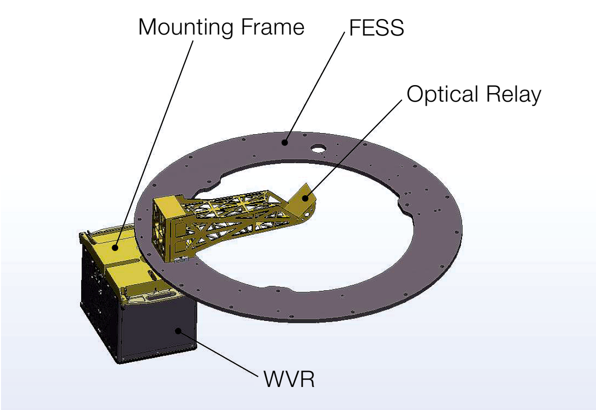

Figure 9. CAD overview drawing of the 183 GHz water vapour radiometer.

The first production water vapour radiometer was delivered to the OSF on the 1 April 2009 and underwent a successful on-site provisional acceptance test. This period of testing was followed by an initial installation check and sky-temperature test with the WVR integrated into a Vertex 12-metre antenna. This testing was accomplished smoothly and successfully, which bodes extremely well for future integration testing and operations at the AOS.

The WVR is a complex, multidisciplinary project that has been system-designed and developed by Omnisys Instruments AB based in Goteborg, Sweden. Omnisys AB has given serious attention to developing a receiver that can be effectively manufactured for series production and optimised for efficient operational use. This latter aim is achieved by avoiding the use of any cryogenic components, since the cooling system would need regular maintenance. It is easy to handle by maintenance staff because of the low mass and small size. See Emrich et al. (2008, 2009) for a description of the system. Omnisys AB has also provided personnel and extensive technical support to the WVR acceptance trial, carried out with close liaison and interaction between the ALMA AIV team, ESO Front End and science IPT personnel.

The WVR work package is managed and has been procured for ALMA by the ESO FE IPT of the ALMA Division in Garching and complements a range of Front End systems being procured and provided to the ALMA Project.

Successful delivery and acceptance of the first WVR is a fitting tribute to the dedication and work of all the personnel involved in this project, including staff and personnel from Omnisys AB, ESO and ALMA, as well as other supporting teams and organisations.

Acknowledgements

We would like to thank all our collaborators spread around many organisations within the three ALMA partner regions for supporting the work described in this article.

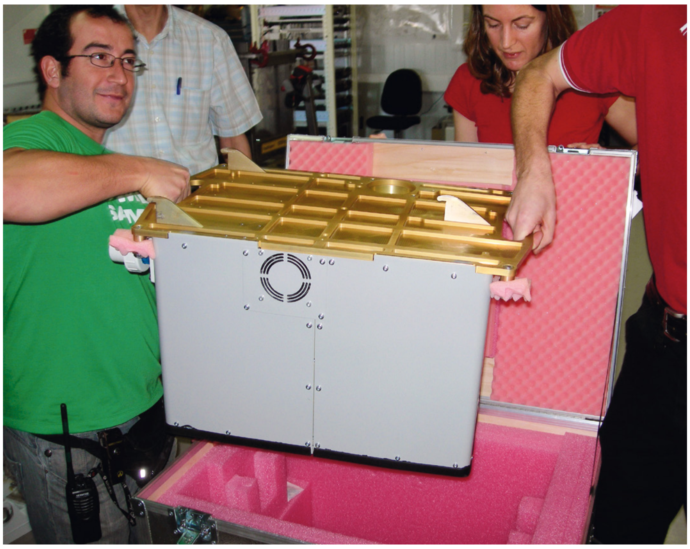

Figure 10. First production water vapour radiometer being unpacked after arrival at the ALMA Operations Support Facility.

Figure 11. First production water vapour radiometer mounted inside an ALMA antenna.

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The nearby (~3.5 Mpc) barred spiral galaxy NGC 253 is shown in an MPG/ESO 2.2-metre WFI colour image formed from broadband exposures in *V* and *R* and narrowband images in [O III] and Hα. The image size is 20 x 29 arcminutes. The galaxy is undergoing a nuclear starburst that was imaged by VLT NACO (see ESO 02/09 for more details).

The UVES M Dwarf Planet Search Programme

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We present results from our search programme for extrasolar planets around M dwarfs carried out with UVES between 2000 and 2007 and enjoying ESO Large Programme status from April 2004 to March 2006. In our sample of 41 stars we have found one "brown dwarf desert" companion candidate, but no planetary mass companions. We have determined upper limits to the mass of possible companions, which, in the habitable zones of our better observed stars, reach the regime of a few Earth masses. Significant periodic variability observed in Barnard's star is attributed to stellar activity.

There are now first indications that M dwarf stars provide a less efficient environment for the formation of Jupiter-type planets than G–K main sequence stars, whereas Neptune-mass planets and planets with a few Earth masses ("Super-Earths") could be numerous around M dwarfs. It has also become clear that the striking paucity of brown dwarf companions orbiting G–K stars at separations of a few astronomical units (known as the "brown dwarf desert") extends into the M dwarf regime.

High precision differential radial velocity (RV) measurements of stellar reflex motions, induced by an orbiting companion, have so far been the most successful method of discovering extrasolar planets and characterising their orbital properties. Originally, RV planet search programmes mostly concentrated on main sequence stars of spectral types F7 through K with masses in the range 0.7–1.2 $M_{\odot}$. M dwarfs have only been included in search programmes in the last few years, because of their faintness requiring large telescopes and/or a substantial amount of observing time to perform RV measurements with a precision of the order of a few ms^{-1}. Among the more than 300 known extrasolar planets currently known, only thirteen planets accompanying eight different M dwarfs have orbits determined by RV measurements.

Table 1 lists all planets around M dwarfs so far discovered with the RV method. Masses are the minimum masses that correspond to the RV effect observable when viewing in the plane of the orbit. Since the RV method does not allow the determination of all parameters of the orientation of the orbit, only minimum masses are obtained. As can be shown, a viewpoint from within the plane of the orbit is the most probable case, so that these minimum masses are also the most probable masses. For two of the M dwarf planets, GJ 436b and GJ 876b, the true masses could be obtained. GJ 436b is observed to transit in front of its host star, thereby slightly dimming the star light, and confirming that we are really viewing from close to the orbital plane. For GJ 876b the astrometric displacement on the sky could be measured, which allows for the complete determination of the orientation of the orbit on the sky.

In this article we report on our RV monitoring programme of 41 M dwarfs carried out with the UVES spectrograph at UT2 on Paranal between 2000 and 2007 and enjoying ESO Large Programme status from April 2004 to March 2006 (Kürster et al., 2006). This programme was designed to search for terrestrial planets in the habitable zone of M dwarfs. The first brown dwarf desert companion object around an "early-type" M dwarf (spectral types M0–M5) was found in this programme, but the small sample did not reveal any planetary companions. This is consistent with the small number (only 13 planets orbiting eight different M dwarfs) found to date by other RV surveys that are observing several hundred stars. In our sample we can exclude the presence of Jupiter-mass planets for a wide range of orbital periods. We did however find significant variability in Barnard's star that we attribute to stellar activity, thus indicating that this star may have non-solar surface convection patterns.

Why M dwarfs?

For an understanding of the formation and abundance of extrasolar planets, it is of utmost importance to determine the presence and orbital characteristics of planets around stars of as many different types as possible, and especially around the most abundant type of star, the M dwarfs. It is currently estimated that M dwarfs make up 70–75% of the stars in the Solar Neighbourhood and probably a similar figure holds for the fraction of M dwarfs in the Galaxy as a whole. M dwarfs have smaller masses than Solar-type stars. Dwarf stars of spectral types M0, M3 and M6 have, respectively, 0.5, 0.29 and 0.2 solar masses. The smaller the stellar mass the greater is its reflex motion induced by a planet. Given a sensitivity to find RV signals of a certain amplitude lower mass

Star	Components				Reference
	b	c	d	e	
GJ 876	**2.53 M_{Jup}**	0.79 M_{Jup}	7.53 $M_{\oplus}$		Delfosse et al. (1998), Marcy et al. (1998), Rivera et al. (2005)
GJ 581	15.7 $M_{\oplus}$	5.4 $M_{\oplus}$	7.1 $M_{\oplus}$	1.94 $M_{\oplus}$	Mayor et al. (2009), Bonfils et al. (2005), Udry et al. (2007)
GJ 436	**21 $M_{\oplus}$**				Butler et al. (2004)
GJ 317	0.71 M_{Jup}				Johnson et al. (2007)
GJ 674	11.1 $M_{\oplus}$				Bonfils et al. (2007)
GJ 849	0.82 M_{Jup}				Butler et al. (2006)
GJ 176	8.4 $M_{\oplus}$				Forveille et al. (2009)
GJ 832	0.64 M_{Jup}				Bailey et al. (2009)

Table 1. Masses of the RV-discovered planets around M dwarfs. Values in bold face are true masses (see text). All other values are minimum masses.

planets can be found around M dwarfs, and terrestrial planets of just a few Earth masses are within the reach of state-of-the-art spectrographs.

Another interesting characteristic of M dwarfs is that the potentially life-bearing region around it, called the "habitable zone", is much closer to the star than it is for Solar-type stars. Depending on the spectral subtype, the habitable zone corresponds to orbital periods from a few days to several weeks. This is a consequence of the low luminosity of M dwarfs. In the visual a dwarf star of spectral type M0, M3 or M6 is, respectively, 4.2, 6.9 or 11.8 magnitudes fainter than the Sun; their total luminosities reach just 6%, 3% or 0.5%, respectively, of the Solar value.

The habitable zone

The habitable zone is defined as that region around a star where liquid water can exist on a rocky planet with a suitable CO_2/ H_2O /N_2 atmosphere (Kasting et al., 1993). Here the key term is "suitable", which means that quite a number of atmospheric parameters need to have the right values. Overall, the term habitable zone is not a very well defined concept and it may well be that it will have to be expanded should life be found in more exotic environments.

M dwarfs and Jupiter-mass planets

Due to the low masses of M dwarfs, Jovian planets in orbits up to a few astronomical units (AUs) would be relatively easy to find with current precision RV surveys. To date only five such companions to M dwarfs have been found orbiting four different stars (see Table 1). First analyses indicate that the frequency of Jovian planets around M dwarfs is relatively low. Endl et al. (2006) have shown that it is below 1.27% for orbital separations up to one AU. This value is considerably higher around G–K main sequence stars, of which 2.5% are known to harbour Jovian planets within AU.

The UVES sample

Target selection for our UVES search programme was based on the following criteria. Since high resolution spectrographs strongly disperse the light and are therefore hungry for photons, all stars had to be brighter than V = 12 mag to achieve the necessary high RV measurement precision. With the exception of one misclassified M giant that had an erroneous distance entry in the catalogue of nearby stars, all stars are closer than 37 parsec.

The sample stars were also selected for small X-ray luminosity as an indicator of low levels of activity. To meet this criterion a star must either not have been detected in the ROSAT X-ray satellite all-sky survey or have an X-ray luminosity below 10^{27} $ergs^{-1}$ (Hünsch et al., 1999). Two exceptions to this rule are the known flare star Proxima Cen, which was included, since it is the star nearest to us, and the star GJ 229, which was known to have a wide brown dwarf companion at a separation of at least 44 AU (Nakajima et al., 1995). We initially selected 21 stars, but added another 20 when the survey became an ESO Large Programme in April 2004.

Achievable RV precision and allocated time

To achieve high RV measurement precision, the UVES spectrograph was used,

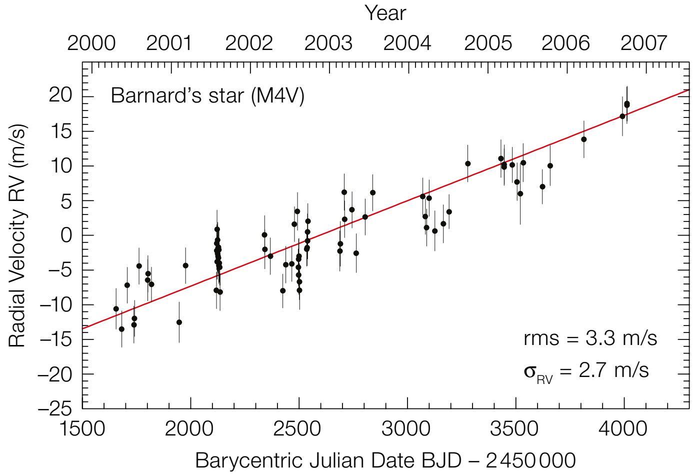

Figure 1. Time series of UVES differential RV measurements of Barnard's star. The solid line represents the predicted RV secular acceleration. The scatter of the data around this line (rms) and the RV measurement error (σ_{RV}) are listed in the plot.

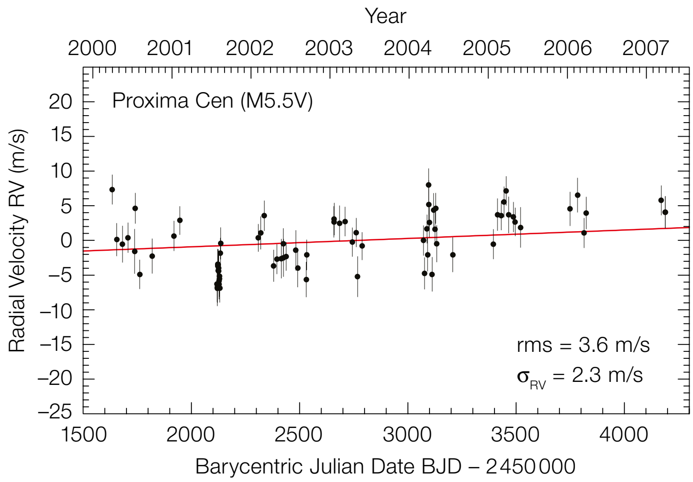

Figure 2. Same as Figure 1, but for Proxima Cen.

together with its iodine gas absorption cell, a self-calibrating device that corrects for instabilities of the instrument over time. The RV precision achievable in long exposures (i.e., with high signal-to-noise ratios) is 2 ms^{-1}, which corresponds to determining the position of the stellar spectrum on the CCD detectors to within 1/700 of a pixel, or 22 nm.

In order to make the best use of the time available time for our sample of stars, we decided to sacrifice some of the achievable RV precision and work at typical values of 2.5–4 ms^{-1}. The observing time allocated to our survey was 160 h for the four-semester Large Programme phase plus 280 h for nine single-semester normal programmes.

RV time series

The 41 stars in our sample were observed with different frequencies. The number of visits per star ranged from just two visits, for two of our stars (that were immediately identified as double-lined spectroscopic binaries and not followed up any further), up to 75 and 76 visits, respectively, for our best observed targets — Barnard's star and Proxima Centauri. On average we have 20 measurements per star and no more than one visit for any given star was made in a single night.

The RV time series for our best-observed stars are shown in Figure 1 (Barnard's star) and Figure 2 (Proxima Cen; see also Endl & Kürster, 2008). The data are shown together with a solid line corresponding to the predicted change in the RV of these nearby stars resulting from their movement on the sky, called the "RV secular acceleration". The RV can be defined as the change in distance of a star from us. When a star passes by us its RV is first negative, reaches zero at the point of closest approach and becomes positive afterwards. RV secular acceleration is thus an ever-increasing effect (see Kürster et al., 2003).

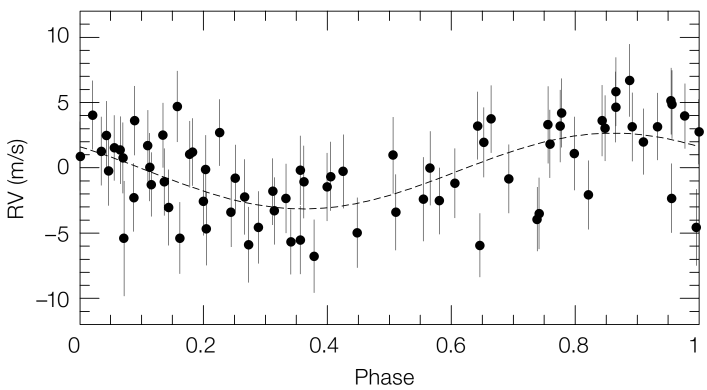

Figure 3. Differential RV data for Barnard's star phase-folded with a period of 44.9 d. The dashed line corresponds to the best-fitting sinusoidal variation.

RVs *v.* activity in Barnard's star

If this purely geometric effect is subtracted from the data, the data can then be subjected to period analysis in an attempt to find periodic signals that would be indicative of an orbiting companion. In the case of Barnard's star we find a significant signal with a period of 44.9 d and an RV amplitude of ± 2.9 ms^{-1} (Zechmeister et al., 2009; Kürster et al. 2003). Figure 3 shows the RV data phase-folded with this period. If this signal could be attributed to an orbiting companion, this object would be a Super-Earth with a minimum mass of 4.7 $M_{\oplus}$. It would orbit somewhat outside of the habitable zone of Barnard's star.

However, there are reasons to believe that the signal is produced by the star itself, i.e. by its surface activity and its influence on the convective motions that carry the heat transport from the interior to the outer regions of a low-mass star. When examining the line strength of the Hα line one finds the same 44.9 d periodicity. The Hα line originates in the stellar photosphere as an absorption line, but it has superimposed emission components generated in localised, so called "plage", regions in the chromosphere, a higher and hotter layer of the stellar atmosphere.

Examining in detail how the behaviour of the Hα line strength is correlated with our RV measurements we find evidence that the convection must be locally disturbed by the magnetic fields of active regions. While this is a well-known effect in Solar-type stars, where it causes a net blueshift of the stellar absorption lines, it appears that in Barnard's star a net redshift is produced, pointing at fundamental differences in the underlying behaviour of the surface convection of Solar-type stars and this M4 dwarf (see Kürster et al., 2003, for details).

Mass upper limits

Faced with the lack of a signal from an orbiting planet one can determine which types of planets can be excluded around a given star, because their signals would have been found. This kind of analysis requires detailed simulations in which signals of hypothetical planets are added to the observed data, and the modified data are subjected to the same tests that are employed to discover signals.

Figures 4 and 5 show the results of such simulations for Barnard's star and Proxima Cen, respectively (from Zechmeister et al., 2009). Upper limits to the mass of planets that would have been found are shown. They are plotted as a function of orbital distance of the planet from the star and of orbital period. In both figures vertical dashed lines delimit the habitable zone. In both cases planets with more than five Earth masses can be excluded from the habitable zone. Note again that these values correspond to the most probable viewing direction from within the orbital plane, so that a lower mass planet could still be hidden in our data, if the viewing angle were

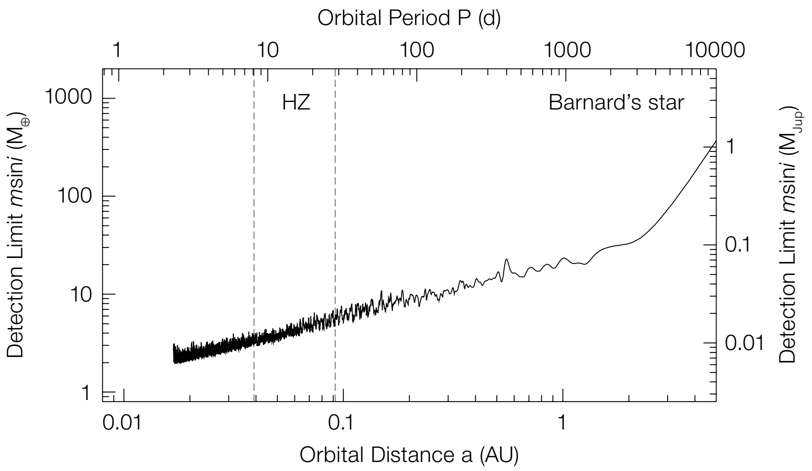

Figure 4. Upper limits to the projected mass *m*sin*i* of hypothetical planets around Barnard's star as a function of separation (lower *x*-axis) and orbital period (upper *x*-axis). Planets above the solid line would have been detected. Vertical dashed lines delimit the habitable zone (HZ).

grossly different. At 1 AU we exclude Neptune-mass (17 $M_\oplus$) planets, whereas Jupiter-mass (318 $M_\oplus$) planets should have been found at 5 AU.

For the majority of our stars for which we could not secure as many measurements as for Barnard's star and Proxima Cen, the same type of simulations lets us exclude planets with masses in the range between the masses of Neptune (17 $M_\oplus$) and Saturn (95 $M_\oplus$) from the habitable zone around the star.

Note that the necessary sensitivity to discover a given planetary signal depends very much on the phase of the signal with respect to the temporal measurement window. Data taken near the maxima and minima of the signal carry much more information than data taken at intermediate phases. In order to exclude a planet with a given mass, we must consider all possible phases, also those for which we are least sensitive. Therefore, our upper limits are relatively conservative. A lower-mass planet could still be discovered, if its RV signal has a favourable phase. If it corresponded to a planet, the 44.9-d signal in Barnard's star (Figure 3) would be an example.

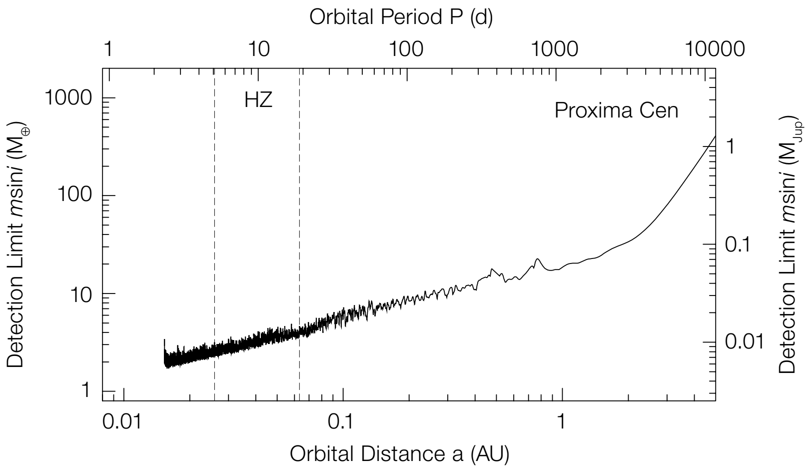

Figure 5. Same as Figure 4, but for Proxima Cen.

An oasis in the brown dwarf desert

So far no brown dwarfs in orbits up to a few AU around their host star ("brown dwarf desert" objects) have been found around M dwarfs of spectral types M0–M5. Our survey has now found the first such object, a companion to the M2.5 dwarf star GJ 1046 (Kürster et al., 2008). Figure 6 shows the RV time series along with the best-fitting Keplerian orbit with a period of 169 d and an eccentricity of 0.28. The star-companion separation is 0.42 AU.

From the RVs we determine a minimum mass of 26.9 Jupiter masses. Considering all possible orbital orientations we find

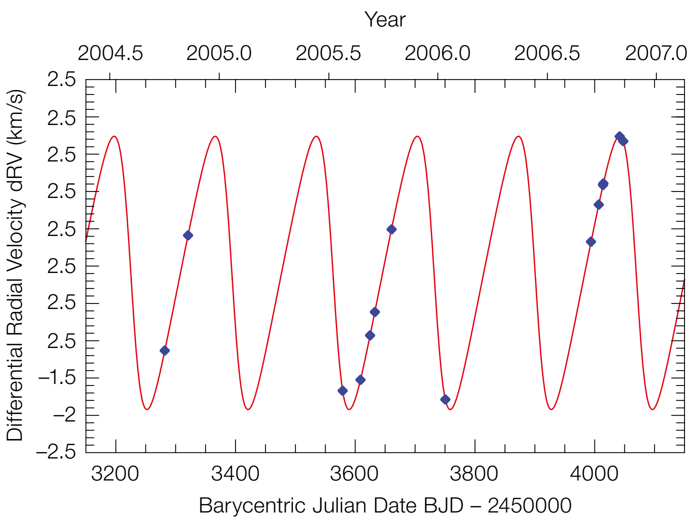

Figure 6. Time series of UVES differential RV measurements of GJ 1046 along with the best-fitting Keplerian orbit corresponding to a brown dwarf desert candidate.

a chance probability of 6.2% that the companion mass exceeds the mass threshold of 80 Jupiter masses between brown dwarfs and stars. When combining our RV data with the astrometric measurements made by the Hipparcos satellite (using the new reduction by van Leeuwen, 2007), we can place an upper limit to the companion mass of 112 Jupiter masses and narrow down the chance probability that the companion is a star to just 2.9%. Most likely, it is a genuine brown dwarf.

Astrometric follow-up

To determine the true mass of the companion to GJ 1046, and thereby its nature, we have begun an astrometric follow-up study with the NACO adaptive optics system and infrared camera at UT4 (Meyer & Kürster, 2008). We aim to measure the orbital reflex motion of GJ 1046 relative to a background star separated by just 30” on the sky. This chance encounter makes precise astrometric measurements possible, from which the orientation of the orbit, and hence the true mass of the companion, can be derived.

From our RV measurements we can predict that the astrometric signal is at least 3.7 milliarcseconds (peak-to-peak) corresponding to 14% of an image pixel in the employed NACO S27 camera, but, depending on the orientation of the orbit, the true signal may be considerably larger.

Acknowledgements

We thank the ESO Observing Programmes Committee and the Director’s Discretionary Time Committee for generous allocation of observing time. We are also grateful to all of ESO staff who helped with the preparation of the service mode observations, carried them out, or processed, verified and distributed the data. A number of people have contributed in many ways to make this survey happen. Our thanks go to Stéphane Brillant, William D. Cochran, Sebastian Els, Artie P. Hatzes, Thomas Henning, Andreas Kaufer, Sabine Reffert, Florian Rodler, Frédéric Rouesnel and Steve S. Saar.

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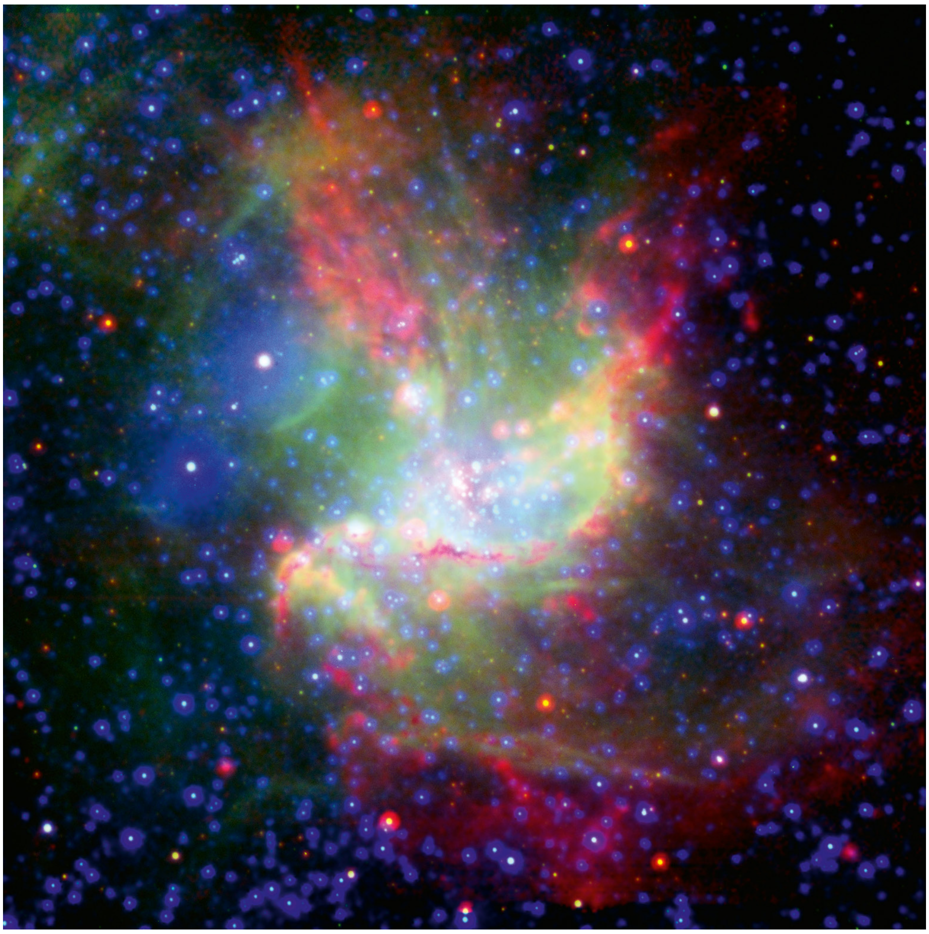

The star forming region NGC 346 in the Small Magellanic Cloud is shown in this colour composite image. The picture combines images from the infrared (NASA Spitzer Space Telescope, in red), the visible (ESO NTT, in green) and the X-ray (ESA XMM, in blue) to reveal the multi-component structure of dust, stars and hot gas. See ESO PR 55/07 for more details.

Tracing the Dynamic Orbit of the Young, Massive High-eccentricity Binary System θ^1 Orionis C. First results from VLTI aperture-synthesis imaging and ESO 3.6-metre visual speckle interferometry

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Located in the Orion Trapezium Cluster, θ^1 Ori C is one of the youngest and nearest high-mass stars known. Besides its unique properties as an oblique magnetic rotator, the star happens to be a close (~20 milliarcseconds) binary system, which makes it an ideal laboratory to determine the fundamental parameters of young hot stars. In this article, we report on our 11-year interferometric monitoring campaign, which covers nearly the full dynamic orbit of the system and resulted in the first interferometric images obtained with the VLT interferometer (VLTI) in the infrared (~20 μm) and diffraction-limited bispectrum speckle interferometry at the ESO 3.6-metre telescope at visual (440 nm) wavelengths.

The formation and early evolution of high-mass stars is still a matter of ongoing debate. In particular, for young O-type stars, stellar evolutionary models are still highly uncertain and require further empirical verification. In order to test and refine these models, perhaps the most important parameter is the stellar mass, which, together with the chemical composition and the angular momentum, determines the entire stellar evolution. Thus, direct and unbiased mass estimates, such as those provided by the dynamical masses accessible in binary systems, are very important to advance our knowledge about the earliest phases of stellar evolution.

Due to its relative proximity at just ~400 pc, the Orion Nebula Cluster (ONC) is the best-studied star-forming region where high-mass stars are forming. θ^1 Ori C in the Orion Trapezium is the brightest and most massive (~40 $M_\odot$) of the ONC members and has been the target of numerous studies. With an age of less than one million years, this O7V-type star is also one of the youngest O-type stars known in the sky, and its strong Lyman radiation dominates the whole Orion Nebula. θ^1 Ori C also illuminates the proplyds and shapes its environment by strong stellar winds. Furthermore, θ^1 Ori C is one of only two O-stars with a detected magnetic field (the other one being the much more evolved object HD 191612). The strong magnetic field (1.1 ± 0.1 kG, Donati et al., 2002) might also channel the radiation-driven winds from both hemispheres along the magnetic field lines to the equatorial plane, where the winds collide at high velocity, forming a thin, nearly stationary shock region in the equatorial plane. This "magnetically confined wind shock" (MCWS) model (Babel & Montmerle, 1997) can explain not only the hard X-ray emission from θ^1 Ori C, but also the periodic variability of the Hα line, several UV spectral lines, the X-ray flux, as well as the magnetic field (see Stahl et al., 2008, for a brief review).

In 1997, near-infrared bispectrum speckle observations obtained with the Russian BTA 6-metre telescope revealed a visual companion around θ^1 Ori C (Weigelt et al., 1999), contributing about 30% of the total flux at visual to near-infrared wavelengths. The discovery of this very close companion star situated at 33 milliarcsecond (mas) offset is important, since the observation of orbital motion allows one to derive direct constraints on the stellar masses as well as the dynamical distance to the Orion Trapezium Cluster. While stellar mass measurements are urgently required for the calibration of stellar evolutionary models of O-type stars, distance estimates are of general importance for all studies on the ONC star-forming region. An interesting aspect of the dynamical history of the ONC was presented by Tan (2004), who proposed that the Becklin–Neugebauer (BN) object, which is located 45" northwest of the Trapezium stars, might be a runaway B star ejected from the θ^1 Ori C multiple system about 4000 years ago. Although still a matter of ongoing debate, this scenario is based on proper motion measurements, which show that the BN object and θ^1 Ori C recoil roughly in opposite directions. Therefore, a high-precision orbit measurement of θ^1 Ori C might offer the fascinating possibility of recovering the dynamical details of this recent stellar ejection.

Diffraction-limited imaging at 440 nm

Bispectrum speckle interferometry is a powerful technique to overcome atmospheric perturbations and to reach the diffraction-limited resolution of ground-based telescopes. In contrast to adaptive optics, which currently only provides a good Strehl ratio at near-infrared wavelengths, bispectrum speckle interferometry can provide diffraction-limited images even at visual wavelengths. Since the discovery of the θ^1 Ori C companion in 1997, we have employed the BTA 6-metre telescope to trace the orbital motion of the system at near-infrared (*J*-, *H*- and *K*-bands) and visual wavelengths (*V*-band). In January 2008, we also used our visitor speckle camera at the ESO 3.6-metre telescope on La Silla and obtained diffraction-limited images of θ^1 Ori C even at a wavelength of 440 nm (*B*-band; see Figure 4). In spite of the small binary separation of 20 mas, the astrometry could be measured with an accuracy of better than 3 mas, which is approximately a factor of ten smaller than the diffraction-limited resolution of the 3.6-metre primary mirror at this wavelength. With 3.6-metre-class telescopes such as the ESO 3.6-metre or the NTT, this technique allows one to obtain diffraction-limited images of targets brighter than K ~ 14 mag or V ~ 17 mag, with a typical observing time of 1 hour per target/calibrator pair (including overheads). Given these favourable characteristics, bispectrum speckle interferometry is also a very promising technique for 8-metre-class telescopes such as the VLT, likely enabling diffraction-limited imaging with an angular resolution down to ~ 11 mas (*B*-band).

VLTI/AMBER high accuracy astrometry

Of course, even higher angular resolution can be achieved with long-baseline interferometry. Combining the light of separate apertures, infrared interferometers, such as the VLTI, can now provide a resolution corresponding to the separation of the individual apertures in an array of telescopes. The VLTI near-infrared beam combination instrument AMBER (Petrov et al., 2007) combines this revolutionary technique with spectral capabilities, allowing the measurement of the interferometric observables (visibility and closure phase) as a function of wavelength.

Adding the spectral information can open up unique new science applications (for instance, by performing long-baseline interferometry in spectral lines) and can also increase the observing efficiency by sampling radial tracks of the Fourier plane (uv-plane) with each observation. This effect is illustrated in Figure 1, where we show the uv-coverage of a single AMBER observation taken in low spectral resolution mode (LR-mode, $\lambda/\Delta\lambda = 35$) together with the expected wavelength-differential visibility and closure phase signatures of a binary star. In Figure 2 we show actual VLTI measurements obtained on θ^1 Ori C, revealing the expected wavelength-differential signatures. These wavelength-differential signatures can then be fitted to geometric models, which allowed us to derive the binary astrometry with a very high precision of ~ 0.5 mas. As a matter of fact, the astrometric precision achievable with AMBER's LR-mode is currently not limited by the interferometric constraints, but by the precision with which the instrument wavelength calibration can be performed.

Model-independent VLTI aperture-synthesis imaging

To date, model-fitting, as described above, represents the most commonly applied approach to extract scientific information from infrared interferometric data. Of course, this approach requires some *a priori* knowledge about the source structure, which allows the astronomer to choose an appropriate geometric or physical model. In many cases, this information might not be available (or could potentially be biased), which makes it highly desirable to enable optical interferometers, such as VLTI/AMBER, to directly recover the source brightness distribution without any model assumptions. Although the principles of interferometric imaging through closure phases are practically identical to the ones routinely applied in radio interferometry, optical interferometry faces additional challenges, which are mainly related to the very small number of telescopes combined in current-generation optical interferometers and in the resulting poor uv-plane coverage.

Given that our VLTI/AMBER observations on θ^1 Ori C (including 18 measurements on one Unit Telescope triplet and three Auxiliary Telescope (AT) triplet configurations) provide a relatively good coverage of the uv-plane, we applied our image reconstruction algorithm (Building Block Mapping; Hofmann & Weigelt, 1993) to reconstruct a model-independent aperture-synthesis image. The reconstructed image (Figure 3) shows the θ^1 Ori C system with a resolution of ~ 2 mas and independently confirms the binary astrometry determined by model-fitting.

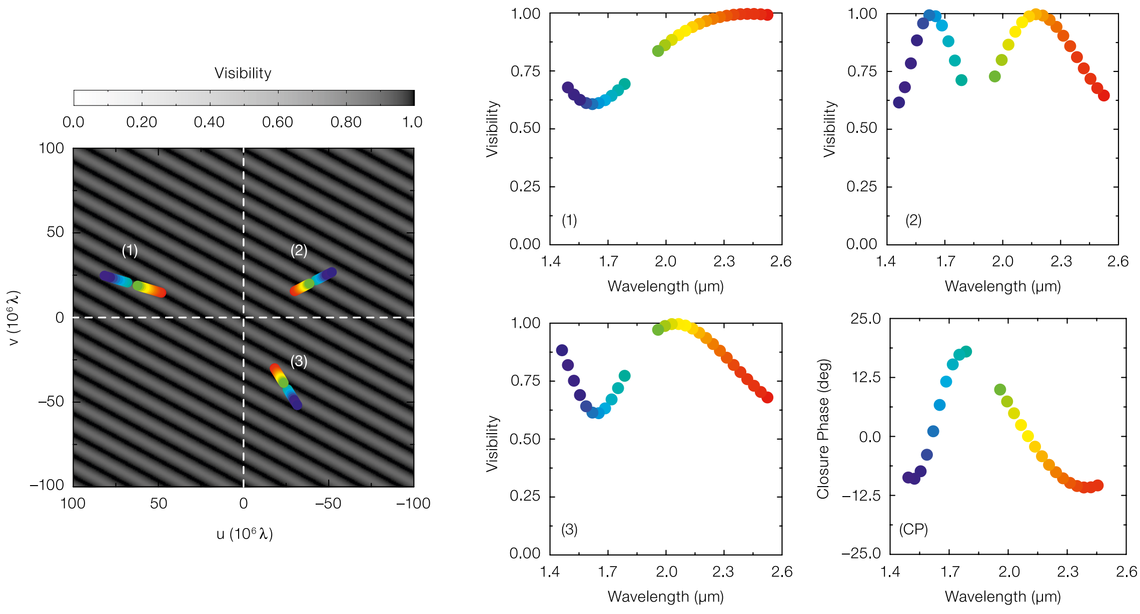

Figure 1. VLTI/AMBER three-telescope spectro-interferometry allows one to cover simultaneously the *H*- and *K*-band spectral window, resulting in radial tracks in the uv-plane (left). These radial tracks allow one to sample the sinusoidal visibility and closure phase modulation expected for a binary star, such as θ^1 Ori C with a single AMBER observation (middle and right columns).

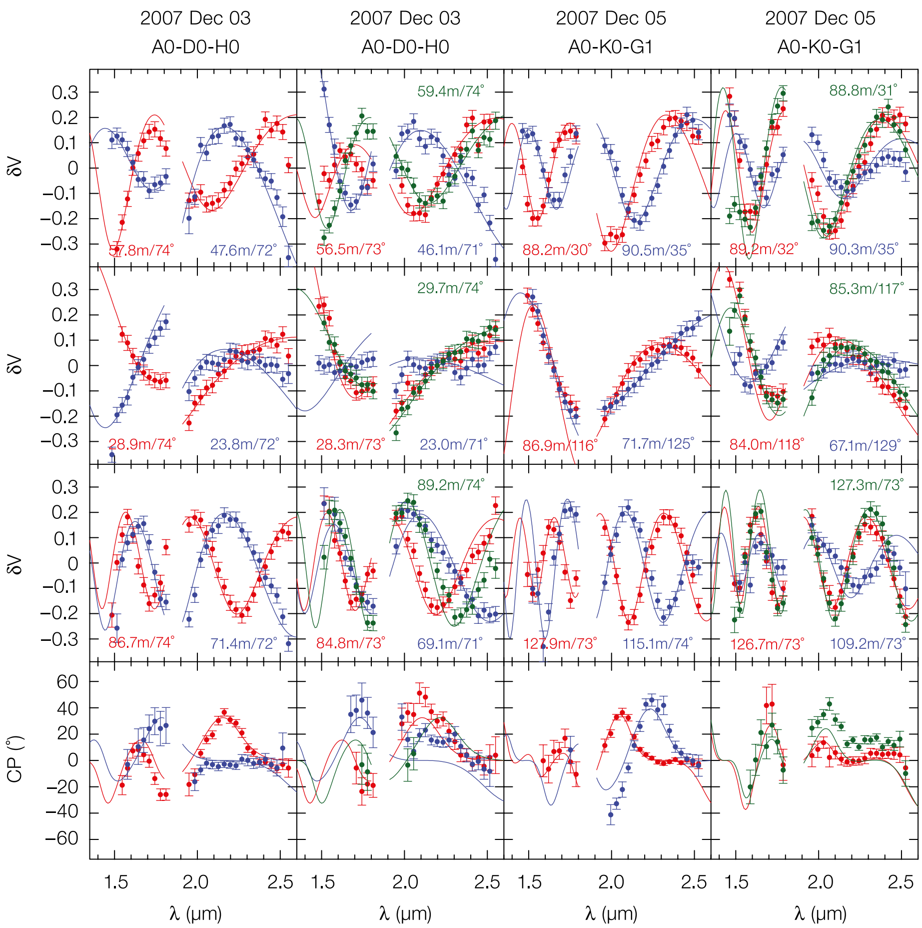

Figure 2. VLTI/AMBER data obtained on θ^1 Ori C during two half-nights in December 2007 (points), overlaid with our best-fit binary model. The upper three rows show wavelength-differential visibilities, while the bottom row shows the recorded closure phases.

The dynamic orbit of the θ^1 Ori C system

Including earlier astrometric measurements obtained with bispectrum speckle interferometry (Weigelt et al., 1999; Schertl et al., 2003; Kraus et al., 2007) as well as IOTA (Kraus et al., 2007) and NPOI (Patience et al., 2008), the available data covers the period from 1997 to 2008 and shows that since its discovery, the binary system has nearly completed a full orbit cycle (Figure 4). The good orbital coverage allows us to solve for the astrometric orbit of the system, yielding a short-period (P ~ 11.2 yrs), high-eccentricity (e ~ 0.6) orbit. According to this orbit solution, the physical separation between the two high-mass stars varies between ~ 7 AU at periastron passage and 28 AU at apastron. From the orbital elements, we derived constraints on the system mass ($M1 + M2 = 47 \pm 4\ M_\odot$) and on the distance to the ONC (410 ± 20 pc; see Kraus et al. [2009] for a description of the applied methods). Our distance estimate is in excellent agreement with recent trigonometric parallax measurements of some Orion non-thermal radio emitters, which yielded a distance of 414 ± 7 pc (Menten et al., 2007).

Various earlier spectroscopic studies also measured the radial velocity of θ^1 Ori C, revealing long-term radial velocity variations (Stahl et al., 2008). Combined with our solution for the astrometric orbit, these radial velocity measurements can be used to constrain the mass ratio of the two stars to $M2/M1 = 0.23 \pm 0.05$. Accordingly, the individual stellar masses are ~ 39 $M_\odot$ and ~ 8 $M_\odot$, corresponding to spectral types of O5.5 and B2, respectively.

Future science prospects

Being well suited to high-accuracy mass estimates, the θ^1 Ori C binary system represents an important benchmark for evolutionary models of young massive stars. Interferometric as well as spectroscopic observations over the next few years will be important to tighten the observational constraints further, in particular as the system is approaching the next periastron passage around 2013.9.

Other very exciting science could perhaps be achieved in the immediate future using AMBER's higher spectral resolution modes ($\lambda/\Delta\lambda$ = 1500 or 12 000). These modes will allow one to spatially resolve the distribution of the line-emitting gas in the inner few stellar radii around the θ^1 Ori C primary star. According to the MCWS model, this line emission traces the magnetically channelled stellar winds, providing unique insights into the mass-loss mechanism and the dramatic magnetohydrodynamic effects around this intriguing young hot star.

Our successful aperture-synthesis imaging of the θ^1 Ori C system demonstrates the capabilities of the VLTI/AMBER facility for high quality interferometric imaging. Considering the large number of exciting upcoming science applications which rely on model-independent imaging, these capabilities will be of utmost importance not only for AMBER but, in particular, for the second generation VLTI instruments. Given the large demand for observing time and the relatively small number of AT stations offered, interferometric imaging with the 3-telescope beam-combiner AMBER currently remains a challenging task. The second generation instruments GRAVITY, MATISSE and VSI will simultaneously combine four and more apertures, which should significantly increase the imaging efficiency and ultimately push interferometric imaging into mainstream astronomy.

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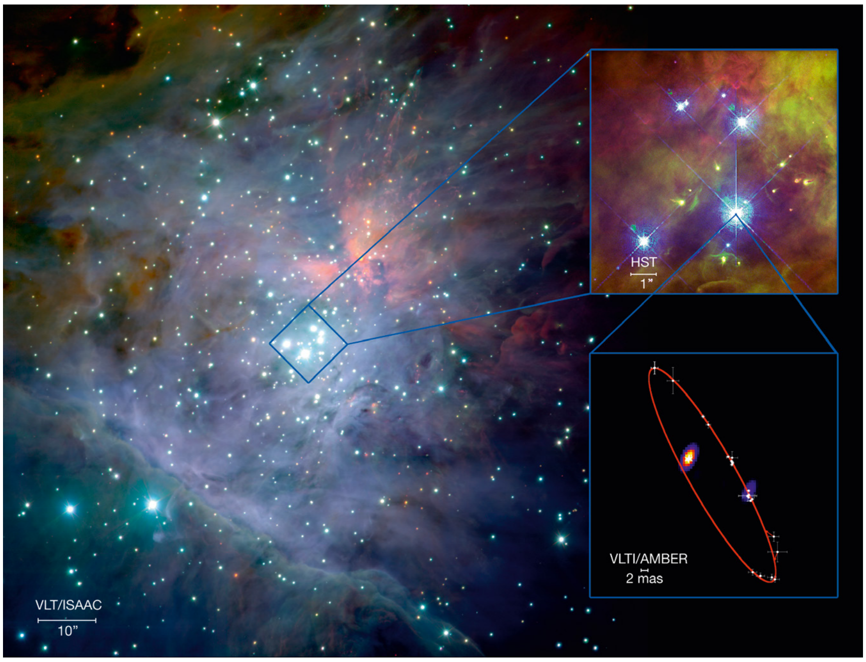

Figure 3. Mosaic showing the Orion Trapezium Cluster, as seen with VLT/ISAAC (left, from ESO/Mark McCaughrean) and with the HST (upper, from NASA/John Bally). The inset to the lower right shows our θ^1 Ori C VLTI/AMBER aperture-synthesis image (*K*-band, epoch 2007.9) and the derived orbit solution. At the given epoch (2007.9), the companion (flux ratio 1:4) had a separation of 19.07 ± 0.05 mas and was located towards position angle 241.2 ± 1°. The elongation of the stars reflects the limitations in the achieved uv-plane coverage.

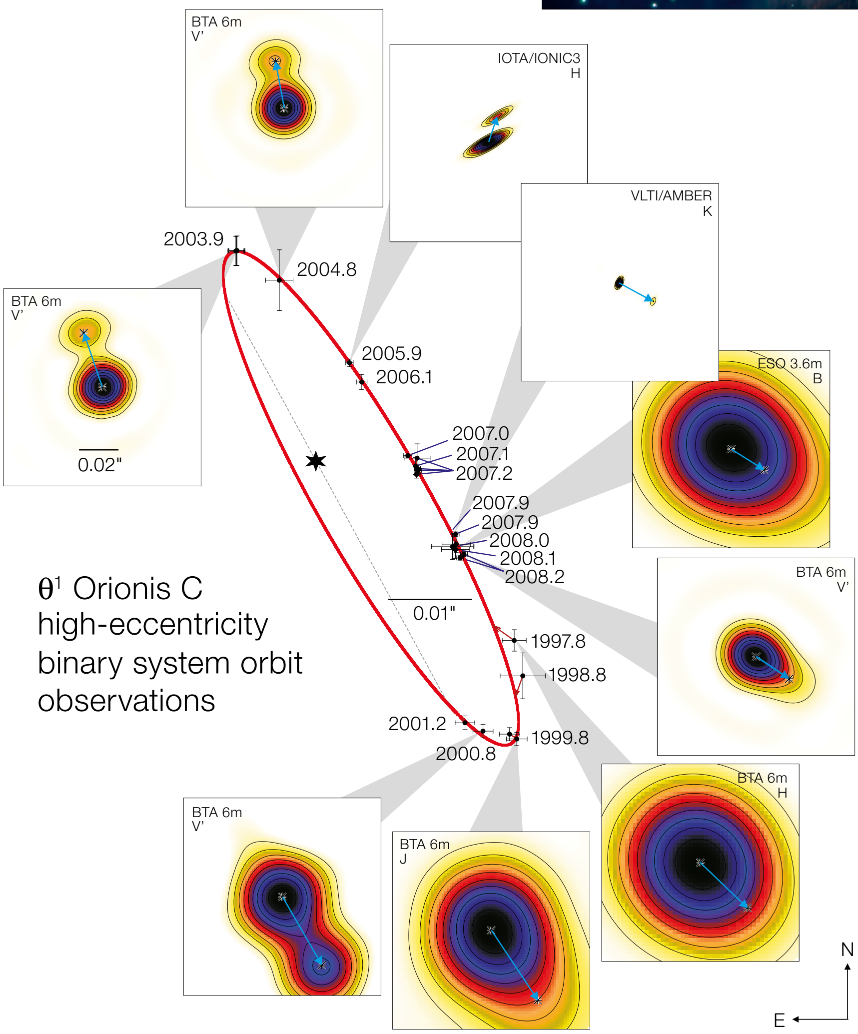

Figure 4. Dynamical orbit of the high-eccentricity binary system θ^1 Ori C, as derived from the interferometric monitoring campaign, covering the period 1997 to 2008.

Chemistry of the Galactic Bulge: New Results

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VLT–FLAMES observations provide by far the largest sample of high dispersion spectra of Bulge red giants available. Five years of work on these 900 spectra have yielded the abundances of different elements in the Milky Way Bulge, and new results on its formation. The results so far include the Bulge metallicity distribution, the Bulge metallicity gradient, the metallicity dependence on kinematics, the history of enrichment with alpha-elements, as well as the lithium abundance. The evidence collected on Milky Way Bulge chemical enrichment supports a rapid early formation scenario, and the metallicity gradient argues against formation via secular bar evolution.

Introduction to the Milky Way Bulge: a complex evolution?

The central part of our Milky Way galaxy is called the Bulge, and it is the region that contains the densest concentration of baryonic matter. We live in the Galactic disc, a relatively calm place in comparison with the Bulge, which might have had a very complex formation and evolution. Unravelling the whole history of the evolution of the Milky Way Bulge is a very difficult task, but we hope to be able to understand the major events, or establish an approximate sequence for its development, aided by the study of Bulge chemical evolution. We have learned relatively recently how to interpret the chemical composition of different stellar populations as a result of enrichment by different supernovae and asymptotic giant branch stars. The abundances of different elements act for astronomers as ancient bones do for palaeontologists; they can be used to establish a sequence of generations of stars from past times.

Since high resolution spectroscopy of a large number of stars is prohibitive in terms of observing time, in the past the metallicity distribution was determined via low resolution spectra for a few hundred stars and sometimes obtaining high resolution spectra only for a few dozen stars, used as calibrators (McWilliam & Rich, 1994). All agreed that the Galactic Bulge was metal-rich, but there was contradictory evidence regarding the mean, spread and shape of the distribution. The Bulge metallicity is far from that of a simple stellar population like a globular cluster, and therefore a large number of stars needed to be measured to sample the whole metallicity range.

The main obstacles to reliable metallicity determination are: the distance and line of sight depth to the Bulge; large and variable reddening; field crowding; and the composite nature of the stellar population. The large mean distance to the Bulge (8 kpc) makes the stars faint, and the non-negligible depth along the line of sight makes it difficult to determine the absolute stellar luminosities accurately. The large reddening makes stars fainter and redder, and its spatial variation adds a significant uncertainty to the conversion between colour and effective temperature. Field crowding is a real issue, because it is always difficult to determine whether the spectrum we are looking at has been emitted by one star, or represents the superposition of several. The composite nature of the stellar population is due not only to the fact that we have to look throughout the Galactic disc, but also to the possible presence of disc as well as halo stars *in situ*. When measuring chemical compositions, it is difficult to tell if we are looking at a true Bulge star, and we would have to resort to other evidence (such as photometry and kinematics).

Our brave team of astronomers was not daunted by these difficulties, and decided to undertake the major enterprise of measuring elements for Bulge red giants. In this *tour de force* we measured hundreds of Bulge stars, which is a sample size more than an order of magnitude larger than earlier studies. While we have not found all the answers, we are extremely pleased with the progress made using ESO telescopes. This is our story and the major results.

Data for Bulge red giants

Target selection

In the colour-magnitude diagram illustrated in Figure 1, the target stars are located on the red giant branch (RGB), roughly one magnitude above the red clump. The astrometry and the V, I photometry come from OGLE and ESO Wide Field Imager (WFI) observations. Cross-identification with the 2MASS point source catalogue (Carpenter et al., 2001) allowed us to obtain V, I, J, H and K magnitudes for each of the target stars. Some of the fields contain a globular cluster, namely NGC 6528 and NGC 6522 in Baade's Window, NGC 6558 in the b = −6° field, and NGC 6553 in the eponymous field. Member stars of these clusters are the subject of other dedicated papers (see Barbuy et al., 2007, for NGC 6558). Also, in order to avoid strong biases in the resulting iron distribution function (IDF), we included targets spanning the whole colour range of the RGB at that magnitude.

Observations with FLAMES

Spectra for a sample of K giants in four Bulge fields have been collected at the VLT-UT2 with the FLAMES–GIRAFFE spectrograph, at resolution R ~ 20 000. A total wavelength range of about 760 Å has been covered through the setup combinations HR 13 + HR 14 + HR 15 (programme 071.B-0617), and HR 11 + HR 13 + HR 15 (programme 073.B-0074) for different

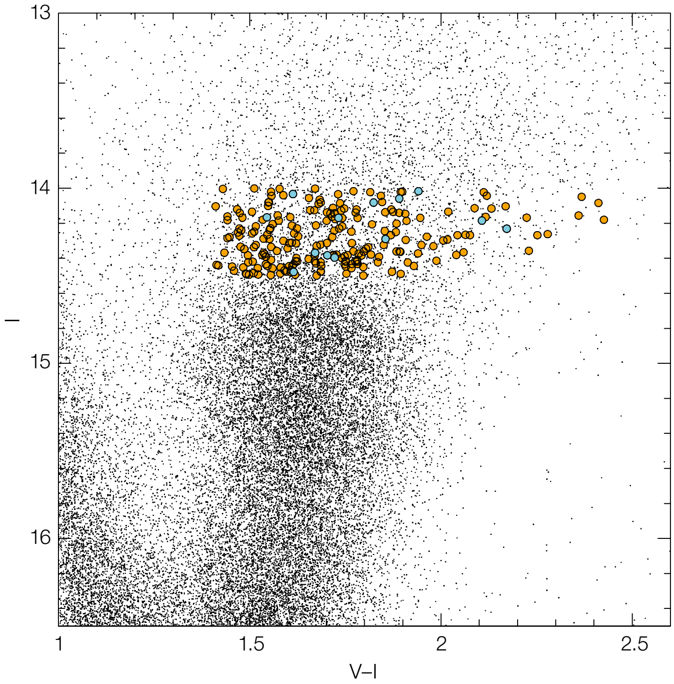

Figure 1. The location of target stars in the colour-magnitude diagram of the field at b = −6°. GIRAFFE targets are marked in orange, UVES ones in cyan. The broad vertical sequence is the Bulge red giant branch, with the red clump just below our targets. Partially visible as a vertical sequence on the left is the disc main sequence, spread along the line of sight.

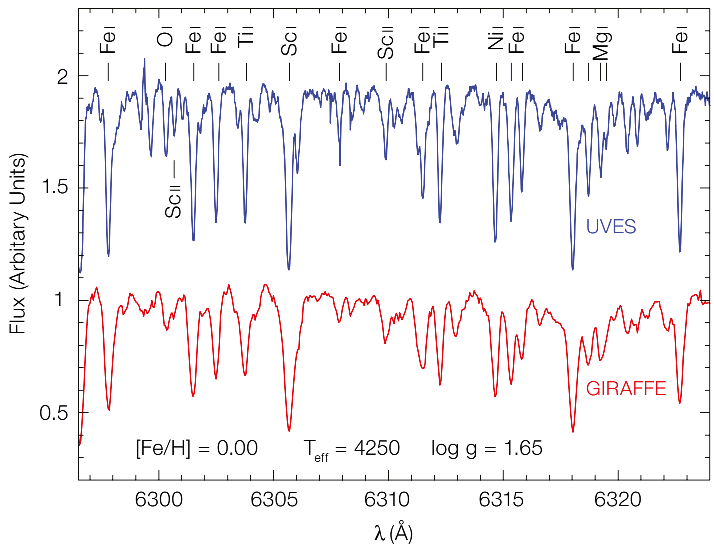

Figure 2. The spectrum of a typical star of our sample, as observed with UVES (top) and GIRAFFE (bottom). The oxygen line at 6300 Å and the magnesium triplet at 6318 Å are marked, together with all the other identified lines. The high density of spectral lines is evident, complicating the location of the stellar continuum.

fields. A portion of a typical star spectrum observed with both the GIRAFE and UVES modes is shown in Figure 2. The characteristics of the observed fields, together with the number of target stars contained in each, are listed in Table 1. The total exposure time varied from about 1 hour to almost 5 hours, depending on the setup and on the star luminosity (targets have been divided into a bright and a faint group) in order to ensure that the final signal-to-noise (S/N) of each co-added spectrum is around 60.

In fact, the actual S/N is not identical among the targets of a given field. Simultaneous to the GIRAFFE observations we collected UVES spectra for around 50 stars, in common with the GIRAFFE sample. These higher resolution spectra (R ~ 45 000) are useful for more precise determinations of element abundances and a check for systematic errors in the GIRAFFE (R ~ 22 000) measurements.

Individual spectra were reduced with the GIRBLDRS pipeline provided by the FLAMES consortium, including bias, flatfield, extraction and wavelength calibration. All the spectra for each star (a number between 1 and 5, depending on the field) were then registered in wavelength to correct for heliocentric radial velocity and co-added to a single spectrum per setup, per star. In each plate, about 20 GIRAFFE fibres were allocated to empty sky regions. These sky spectra were visually inspected to reject the few that might have evident stellar flux, and then co-added to a single sky spectrum. The latter was then subtracted from the spectrum of each target star. The equivalent widths (EWs) for selected iron lines were measured using the automatic code DAOSPEC (Stetson & Pancino, 2008).

Analysis of abundances and errors

The V–I colour was used to obtain photometric temperatures, based on the infrared flux method. As an additional indicator of the star temperature we measured the strength of the TiO band using an index defined between 6190–6250 Å (band) and 6120–6155 Å (continuum region). Finally, it is worth emphasising that the photometric temperature has only been used as an initial first guess. The final adopted temperature is the spectroscopic one, derived imposing excitation equilibrium on a sample of around 60 Fe I lines.

Photometric gravity was calculated from the mass and the radius, the latter derived from the Stefan–Boltzman law, relating the total flux (absolute bolometric magnitude), the temperature and the radius of a blackbody. For this calculation we have adopted a mean distance of 8 kpc for

Nr.	Identification	*l*	*b*	R_{GC} (pc)	*E(B–V)*	N_{stars}
1	Baade's Window	1.14	−4.18	604	0.55	204 (+ 205)
2	b = −6° field	0.21	−6.02	850	0.48	213
3	b = −12° field	0.00	−12.0	1663	0.20	104
4	NGC 6553 field	5.25	−3.02	844	0.70	201

Table 1. Characteristics of the four Bulge fields. In column 5 R_{GC} is the offset distance from the Galactic Centre.

the Bulge, $T_{\odot} = 5770$ K, $\log g_{\odot} = 4.44$, $M_{\odot,bol} = 4.75$ and $M^* = 0.85\ M_{\odot}$. Note that, at each step of the iterative process used to converge on the stellar parameters and metallicity, described below, the photometric gravity was re-calculated using the appropriate (spectroscopic) temperature and metallicity.

Local Thermodynamic Equilibrium (LTE) abundance analysis was performed using standard procedures and the new MARCS spherical models. Excitation equilibrium was imposed on Fe I lines in order to refine the photometric T_{eff}, while photometric gravity was imposed, even if ionisation equilibrium was not fulfilled. The microturbulence velocity (V_T) was found by imposing a constant [Fe/H] for lines of different expected strengths (predicted EWs for a given stellar model). Finally, once converged on the best stellar parameters, we calculated the [Fe/H] of each star as a weighted mean of the line-by-line measurements. The weight associated with each line is given by the inverse square of its abundance error, as derived from the error in the measured EWs.

There are three independent estimates of the internal errors: i) via repeated and independent analysis; ii) by comparison with the UVES results; and iii) using globular cluster stars. These indicate $\sigma_{[Fe/H]} = 0.09$, 0.16, and 0.12 dex, respectively. Figure 3 shows a comparison between GIRAFFE and UVES iron abundances for stars observed with both setups. All those estimates include the smaller (< 0.06 dex) statistical error due to line-to-line dispersion, but each of them includes only a subset of all the possible causes of errors. Putting together the different tests, and considering that some of the systematics (non-LTE effects, uncertainties in the model atmospheres themselves, etc.) have not been taken into account here, we can conclude that ± 0.2 dex is a conservative estimate of our uncertainty on the metallicity of an individual star, including both the effect of statistics and systematics.

Results: the detailed Bulge chemical abundances

The contamination due to disc and halo

Before analysing the abundances, we boldly estimated the contamination in the survey fields coming from the Galactic thin disc, thick disc and halo using an updated version of the Besancon Galaxy model (Robin et al., 2003). Simulated colour-magnitude diagrams (CMDs) have been constructed for the three fields along the Bulge minor axis. Minor adjustments were made in the assumed reddening law to ensure that the simulated red clump would coincide in colour and magnitude with the observed one. The model CMDs reproduce well many characteristics of the observed CMDs, although some differences, especially in the colour spread (likely due to differential reddening), are evident.

Contaminating foreground thin disc stars are estimated to be giant stars (not dwarfs as one might naively expect) located mostly between 2 and 5 kpc from the Sun. The contamination from the halo population turns out to be between zero and 2% in all the fields, and hence it can be safely neglected.

Finally, note that our knowledge of the disc properties far from the Sun is still extremely poor. The Besancon model predicts many thick disc stars in the central region of our Galaxy. However, there is certainly a hole in the H I and CO distribution inside ~3 kpc, and we know that in most barred galaxies disc stars are cleaned up in the central region. We do not know if the real thick disc follows the thin disc and gas distribution, or whether it keeps growing towards the centre. Thus, the relative contributions of the various Galactic components in fields so close to the Galactic Centre need to be handled with caution.

The Bulge metallicity gradient

Based on the metallicity distribution obtained from high dispersion spectroscopy of hundreds of stars in different Bulge fields, we confirm that the Bulge is predominantly metal-rich, with a metallicity dispersion much larger than the errors.

The iron distribution functions (IDFs) obtained in the three fields along the Bulge minor axis are shown in Figure 4. We do not show the IDF for the field around NGC 6553 here as this field has the strongest differential reddening, and none of the reddest stars were included in our target list. In addition, the separation between cluster and field stars is very difficult to establish in this field because the cluster shares the mean

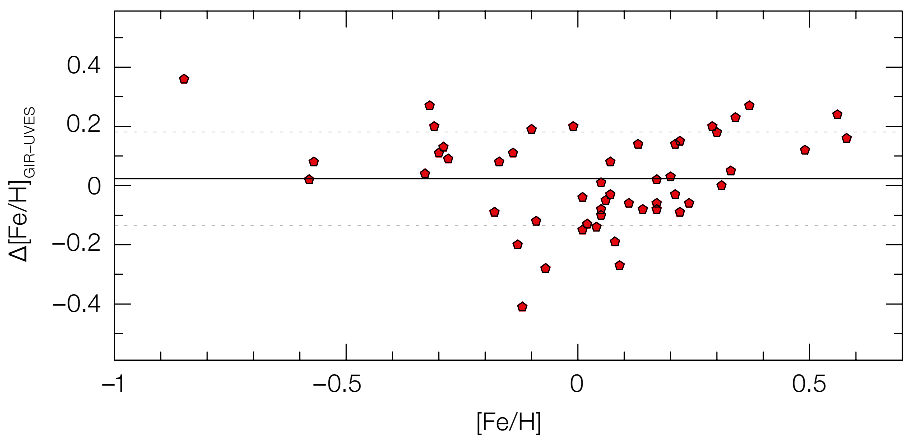

Figure 3. Difference between the [Fe/H] abundance ratio measured in the GIRAFFE and in the UVES spectra for the same stars. The mean difference between the two (solid line) is consistent with zero on average, and, in particular, around [Fe/H] = 0 where most of our stars are located. The spread of the distribution (dotted lines) is $\sigma = 0.16$ dex, included in our conservative error estimate of $\sigma_{[Fe/H]} = \pm\ 0.2$ dex, for the GIRAFFE spectra.

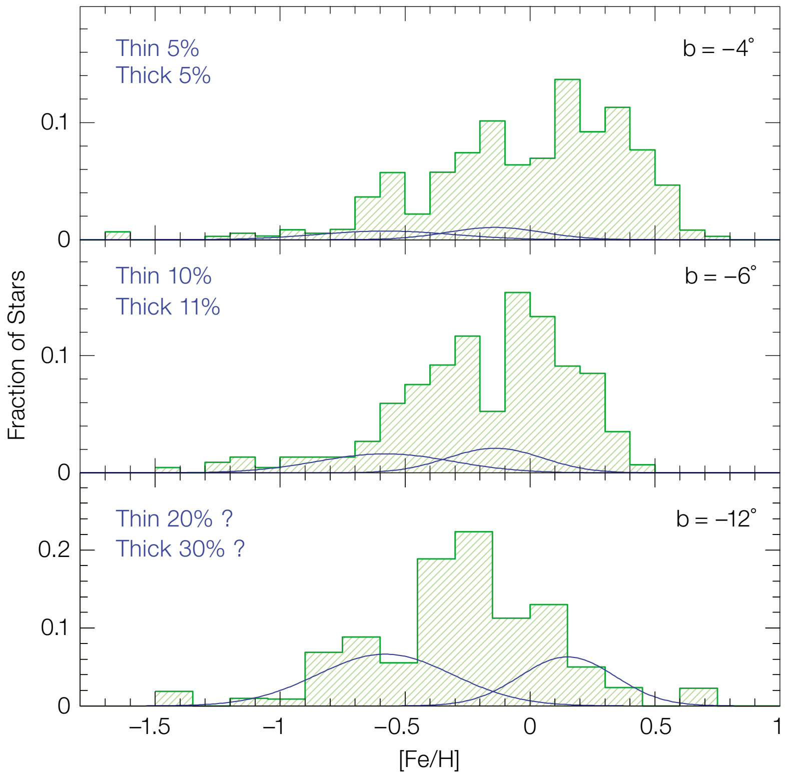

Figure 4. Iron Distribution Function (IDF) in the three fields along the Bulge minor axis. The innermost field (upper), at Galactic latitude b = −4° (Baade's Window) contains 409 target stars, with mean metallicity <[Fe/H]> = +0.03. The intermediate field (middle) at b = −6° includes 213 target stars, with <[Fe/H]> = −0.17. The outermost field (lower) at latitude b = −12°, includes 104 target stars, with <[Fe/H]> = −0.28. The blue Gaussians qualitatively show the percentage of target stars estimated to belong to the Galactic thin and thick disc, and their approximate IDF, assuming it is similar to the thin/thick disc IDF in the Solar Neighbourhood.

metallicity and radial velocity of Bulge stars. Figure 4 clearly shows a difference in the mean metallicity of the three fields, with the inner one being on average more metal-rich than the intermediate and outer one. Two Gaussians are plotted over the metallicity distribution of Bulge stars (histograms) showing the estimated percentage contamination by thick and thin discs. The Gaussians do have the mean and sigma values characteristic of the thick (Reddy et al., 2006) and thin disc (Nordström et al., 2004) IDF, in the Solar Neighbourhood. According to the model, the contaminating disc stars are closer to the Bulge than to us, but the inner disc radial gradient for intermediate-age and old stars has never been measured, hence where exactly these Gaussians would lie is not very well known.

The Baade's Window IDF has been derived from the combination of our data, plus a very similar set of spectra for red clump stars, obtained within the GTO programme and reduced in a consistently way (cf. Lecureur et al., 2009, in preparation). In spite of the uncertainty on the mean metallicity of the contaminating disc stars, it is clear that their number is negligible in this field. The IDF of the field at b = −6° has been derived from 213 giant stars and shows a hint of bimodality, unlike the other fields. Again, the relative disc contamination is low in this field, and would not have a significant impact on the shape of the derived Bulge IDF. The field at b = −12° has the lowest metallicity, but also the highest field contamination (due to a very rapid decrease of the Bulge density with respect to the disc one), thus the highest uncertainty in the true Bulge IDF. However even if we consider only the innermost two fields, there is a radial metallicity gradient, with the IDF mean value going from <[Fe/H]> = +0.03 at b = −4° to <[Fe/H]> = −0.12 at b = −6°. More specifically, it seems that rather than a solid shift towards more metal-poor mean values, it is the metal-rich stars that gradually disappear, while the metal-poor ones are always roughly in the same position.

Metallicity dependence on kinematics

We studied the dependence of the radial velocities versus metallicity for Bulge field stars in the three fields. First, as expected, the velocity dispersion (σ_{RV}) goes down along the Bulge minor axis, from σ_{RV} = 105 km/s in Baade's Window, σ_{RV} = 84 km/s in the b = −6° field, and σ_{RV} = 80 km/s in the field at b = −12°. The latter would be further reduced to σ_{RV} = 60 km/s if the five stars with absolute velocity $|V_{RV}|$ > 150 km/s are rejected (e.g., if they are halo stars).

Second, the velocity dispersion of the metal-rich tail is very different in the three fields along the minor axis, being hotter than the metal-poor one in the innermost field, about the same in the intermediate one, and extremely cold in the outermost field. The outermost field is contaminated with disc stars, and we propose that the metal-rich tail is in fact made up of thin disc stars. On the other hand, the two innermost fields have negligible disc contamination, and the interpretation of the different kinematics of the metal-rich component with respect to the metal-poor one is not straightforward (Babusiaux et al., 2009, in preparation).

The important light elements O, Mg, Na and Al in the Bulge

We measured oxygen, magnesium, sodium and aluminum in the 50 K-giants observed through the FLAMES simultaneous fibre link to UVES. These have [Fe/H] covering a wide metallicity range, from −0.8 to + 0.3 (Zoccali et al., 2006; Lecureur et al., 2007). The result is shown in Figure 5, where it is evident that Bulge stars have larger [O/Fe] and [Mg/Fe] than both thin and thick disc stars. This is the signature of a chemical enrichment by massive stars, progenitors of Type 2 Supernovae (SN II), with little or no contribution from SN Ia, and thus of a shorter formation timescale of the Bulge with respect to both disc components. In this sense, the Bulge (including its globular

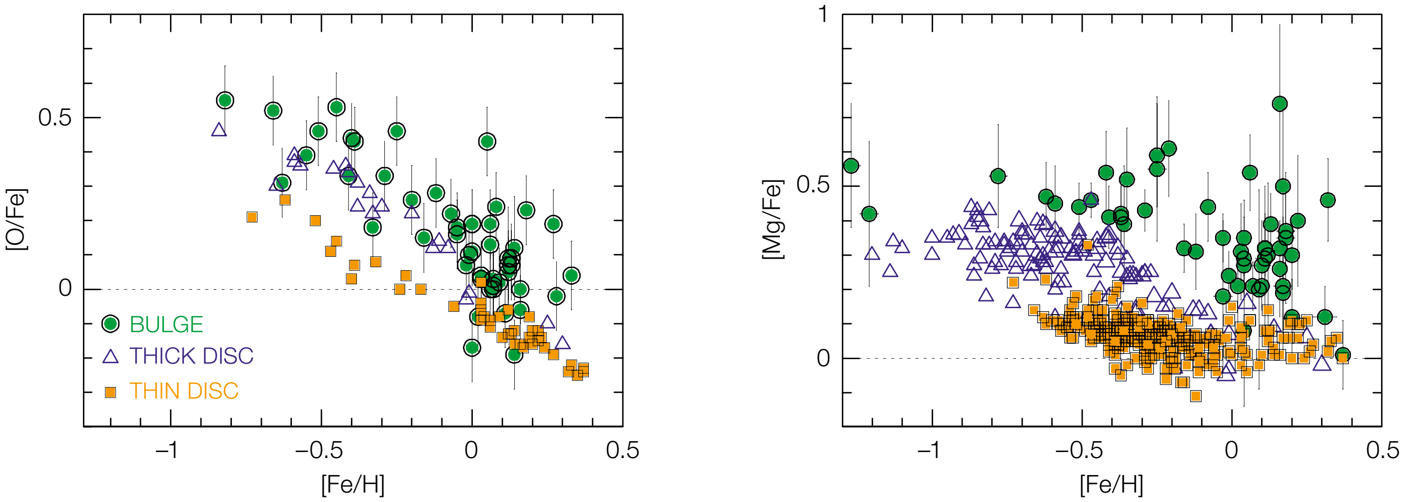

Figure 5. Oxygen to iron (left) and magnesium to iron (right) ratios for Bulge stars, as determined in the present analysis, compared with the same quantities available in the literature for thin and thick disc stars. It is evident that both [O/Fe] and [Mg/Fe] are higher in the Bulge than in the thin and thick disc.

clusters) is the most extreme Galactic population. This result is in agreement with previous studies of a smaller number of stars (10–15) covering a narrower metallicity range (e.g., McWilliam et al., 2003; Rich & Origlia, 2005; Cuhna et al., 2006) and has been confirmed by Fulbright et al. (2007). However, Melendez et al. (2008) found similar [O/Fe] ratios in Bulge and thick disc stars, due to a new abundance analysis of thick disc giants, showing higher oxygen content (while Bulge giants have abundances consistent with the present ones).

Lithium in the Bulge: a scarce element

Lithium, due to its fragility, is expected to be strongly diluted in giants. In marked contrast with this expectation, several Li-rich red giants have been found to date. Very intriguingly, no difference has yet been found between Li-rich stars and those showing normal Li abundance.

The spectra of about 400 K giants, in Baade's Window and the b = –6° fields, including the region around the Li line at 6767.18 Å, were observed. Only 13 of them have a detectable Li line, with six of them having logarithmic abundances A(Li) > 1.5 (González et al., 2009). No clear correlation was found between the Li abundance and those of other elements. Except for the two most Li-rich stars, the others follow a fairly tight A(Li)–T_{eff} correlation. We conclude that there must be a Li production phase during the RGB, acting either on a very short timescale, or selectively only in some stars. The proposed Li production phase associated with the RGB bump cannot be excluded, although our targets are significantly brighter than the predicted RGB bump magnitude for a population at 8 kpc.

What this all means: the formation of the Galactic Bulge

Zoccali et al. (2003) have shown that a simulated CMD with an age of 13 Gyr (which includes the Bulge metallicity distribution) gives a good match to the Bulge CMD. This match includes the luminosity difference between the horizontal branch and the main sequence turnoff, a classical age indicator. However, due to metallicity, reddening, and distance dispersion, the Bulge turnoff cannot be located to better than 0.2–0.3 mag, corresponding to an age uncertainty of ~2–3 Gyr. Conservatively, we take the age of the bulk of Bulge stars to be in excess of 10 Gyr. This limit is confirmed by the recent analysis of a Bulge CMD that was cleaned of foreground disc contamination via proper motions (Clarkson et al., 2008). Such an age limit implies that star formation and chemical enrichment had to be confined within a time interval that is definitely shorter than the age of the Universe at a lookback time of 10 Gyr, or ~3.7 Gyr according to the current concordance cosmology. If the bulk of Bulge stars formed in the cosmic time interval corresponding to a redshift between 3 and 2, then star formation cannot have taken much more than approximately 1 Gyr. Thus, the main uncertainty affecting the duration of the star formation in the Bulge comes from the uncertainty in its age: the older it is, the shorter the star formation era.

The second constraint on the formation timescale of the Bulge comes from the measured alpha-element enhancement (Barbuy et al., 2006; Zoccali et al., 2004, 2006; Lecureur et al., 2007). This is interpreted as a result of the interplay of the fast delivery of iron-poor nucleosynthesis products of massive stars by SN II, with the slow delivery of iron-rich products by SN Ia. A star formation timescale of approximately 1 Gyr is generally derived from chemical evolution models, which typically assume a distribution of SN Ia delay times. Thus, the derived timescale is modulo the adopted distribution of SN Ia delay times. Other equally plausible distributions would have given somewhat shorter or longer timescales. Thus, until the actual mix of SN Ia progenitors is fully identified, we shall remain with this uncertainty on how to translate an alpha-element overabundance into a star formation timescale. All in all, combining the age and the alpha-element enhancement constraints, we conclude that the formation of the Bulge cannot have taken much longer than approximately 1 Gyr.

In addition, the radial metallicity gradient found here would argue against the formation via secular evolution of the bar, because obviously the vertical heating that transforms a bar into a pseudo-bulge would not act preferentially on metal-poor stars. However, combining our result with previous ones on the inner Bulge, at the moment there is evidence of a flat metallicity distribution inside ~600 pc, and a radial gradient outside. Should those findings be confirmed, they might indicate the presence of a double-component Bulge, an inner pseudo-bulge, and an outer classical one, as already found by Peletier et al. (2007) within the SAURON survey of galaxy bulges.

Finally, concerning the Bulge chemical evolution, from the IDF we conclude that the Bulge must have accreted primordial gas, due to the lack of metal-poor stars with respect to the simple model prediction (the so-called G dwarf problem, solved with the inclusion of some infall in the model) and must have ejected a substantial fraction of the iron it produced (outflow). In addition, from the overabundance of alpha-elements quoted above, we can conclude that the Bulge cannot have accreted stars already significantly enriched by SNIa products, such as disc stars, or stars born in the surviving satellite galaxies in the Local Group.

We are currently completing the analysis by measuring the alpha-elements in the complete GIRAFFE sample. The different abundances of these elements in Bulge and disc stars will allow us to pose a stronger constraint on the fractional disc contamination in the IDFs of Figure 4. In addition, we will measure other heavier elements, adding independent constraints on the chemical enrichment history, thus the formation timescale. We look forward to the E-ELT: its fantastic collecting power, coupled with the high spectral resolution of one of the proposed instruments (the near-IR spectrograph SIMPLE, at R ~ 100 000), will allow us to measure abundances in Bulge main sequence stars. These are hotter, thus have cleaner continua, and are unevolved, i.e., they maintain on their surface the exact chemical pattern of the gas from which they were born.

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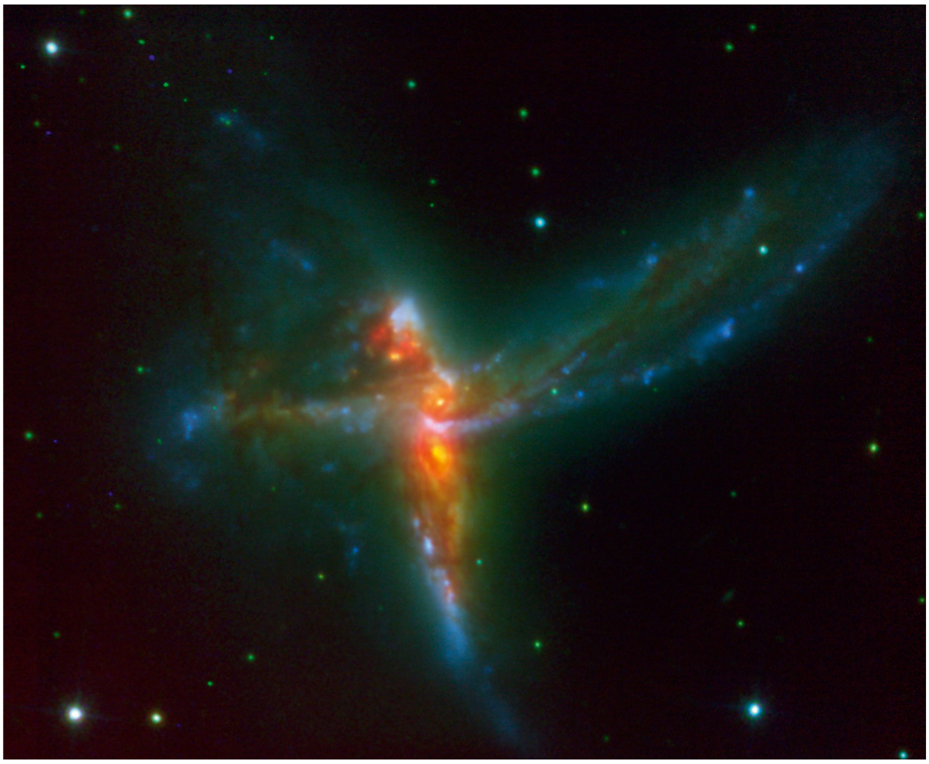

A VLT/NACO *K*-band exposure was combined with HST/ACS B and *I*-band images to form this colour image of the interacting galaxy system ESO 593-IG 008 (IRAS 19115-2124), dubbed "The Cosmic Bird". The three components are a barred spiral, an irregular galaxy and an irregular luminous infrared galaxy (the head of the Bird) with a very high rate of star formation (~ $200 M_{\odot}$/year). See ESO PR 39/08 for details.

The ESO Distant Cluster Sample: Galaxy Evolution and Environment out to $z = 1$

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The ESO Distant Cluster Survey (EDisCS, P.I. Simon D.M. White, LP 166.A-0162) is an ESO Large Programme aimed at studying clusters and cluster galaxies at $z = 0.4–1$. How different is the evolution of the star formation activity in clusters, in groups and in the field? Does it depend on cluster mass and/or the local galaxy density? How relevant are starburst and post-starburst galaxies in the different environments? Is there an evolution in the galaxies' structures, and if so, is this related to the changes in their star formation activity? These are some of the main questions that have been investigated using the EDisCS dataset.

There is no shortage of evidence that galaxy properties vary systematically with the environment where the galaxy resides. The distributions of star formation histories, morphologies and masses, all strongly depend on galaxy location at all redshifts probed so far. For large statistical studies, there are two main complementary ways to "measure" environment: the local galaxy number density (the number of galaxies per unit volume or projected area around the galaxy of interest), and the virial mass of the cluster or group in which the galaxy of interest may reside, usually derived from the velocity dispersion of the system.

Traditionally, studies of the dependence of galaxy evolution on environment were largely based on cluster studies, and their comparison with the "field". Recently, understanding the role of environment has become a major theme of all deep galaxy redshift surveys. Fully characterising environment is a challenging task even for the largest field surveys, but great advances have been made in studying the local galaxy density as well as significant samples of groups at high-z. Even the widest area field surveys, however, include only a few distant massive systems. Pointed surveys are the only ones able to probe galaxy clusters and massive groups, and to reach the high end of the local density distribution. Studies of galaxy clusters have traditionally opened the way to some of the major discoveries of galaxy evolution, such as: the first recognition of the strong decline of star formation activity occurring in clusters in the last 7 Gyr; the existence of a relation between local galaxy density and the distribution of morphological types; the completion of both the star formation activity and mass assembly in massive ellipticals at high redshift; and the observed evolution of galaxy morphologies. Today, it is now possible to study galaxy evolution across a wide range of environments (in clusters, groups, poor groups and the field), using optically-selected cluster fields. Here we present one such cluster survey.

The survey

The ESO Distant Cluster Survey is a multiwavelength survey of galaxies in 20 fields containing galaxy clusters at $z = 0.4–1$ based on an ESO Large Programme approved in Period 66.

Candidate clusters were chosen from among the brightest objects identified in the Las Campanas Distant Cluster Survey (Gonzales et al., 2001). They were confirmed by identifying the red sequence in moderately deep two-colour data from FORS2 on the VLT (White et al., 2005). For all 20 fields, EDisCS assembled deep three-band optical photometry with FORS2 (Figure 1, see White et al., 2005), near-IR photometry in one or two bands with SOFI on the NTT (Aragón-Salamanca et al., in prep.), deep multi-slit spectroscopy with FORS2 (Halliday et al., 2004; Milvang-Jensen et al., 2008), and wide-field three-band imaging with MPG/ESO 2.2-metre telescope and Wide Field Imager (WFI), as well as Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) mosaic imaging of ten of the highest redshift clusters (Desai et al., 2007). Other follow-up programmes have included XMM-Newton X-ray observations (Johnson et al., 2006), Spitzer IRAC and MIPS imaging (Finn et al., in prep.), and Hα narrow-band imaging (Finn et al., 2005). Photometric redshifts were

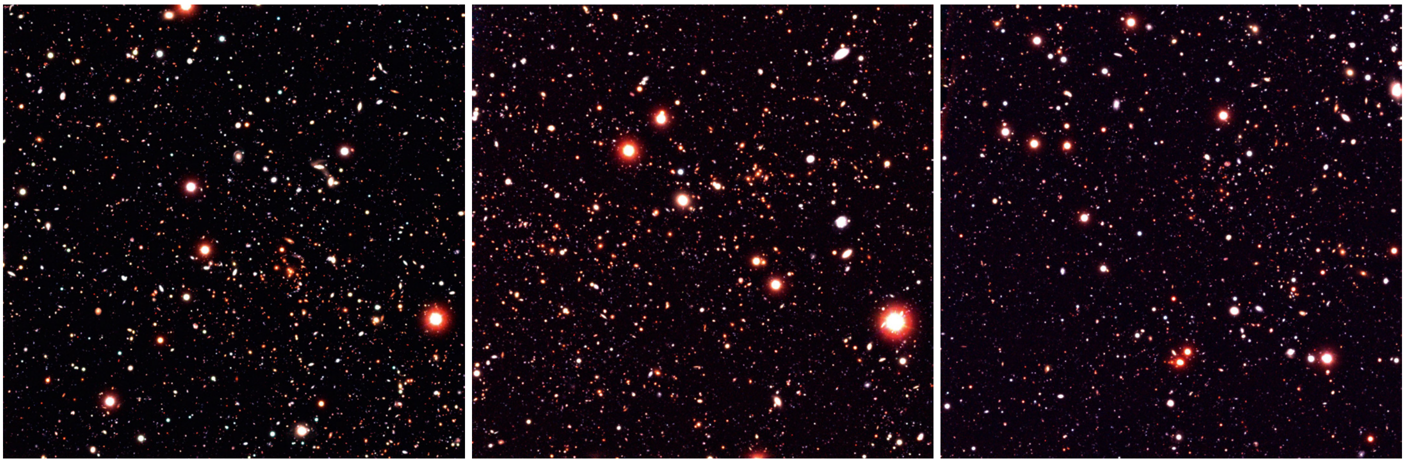


Figure 1. Examples of EDisCS clusters: Colour composite (VRI) FORS2 images of Cl 1216 (z = 0.79, velocity dispersion σ = 1018 km/s, left), Cl 1054-11 (z = 0.70, σ = 589 km/s, centre) and Cl 1103 (z = 0.96, 0.70, 0.63, σ = 534, 252, 336 km/s, right).

derived by combining optical and near-IR imaging using two independent codes (Pello et al., 2009).

The EDisCS dataset has allowed galaxies to be studied in a wide range of environments using homogeneous data. The EDisCS fields contain 16 clusters with velocity dispersion greater than 400 km/s, ten groups with at least eight spectroscopically-confirmed members, for which a velocity dispersion between 150 and 400 km/s could be measured, as well as comparison samples of poor groups (galaxy associations of three to six galaxies) and of "field" galaxies not belonging to any cluster, group or poor group. One of the most valuable characteristics of this dataset has proved to be the large range of velocity dispersions, and thus masses, of the cluster sample (see Figure 2). The quality of the cluster mass estimates based on VLT spectroscopy has been confirmed by weak lensing (Clowe et al., 2005) and X-ray (Johnson et al., 2006) estimates. EDisCS is thus the first distant cluster sample that can be used to assess how the evolution of galaxy properties depends on their host mass, providing a sample of high-z clusters that will evolve into a wide range of cluster masses today.

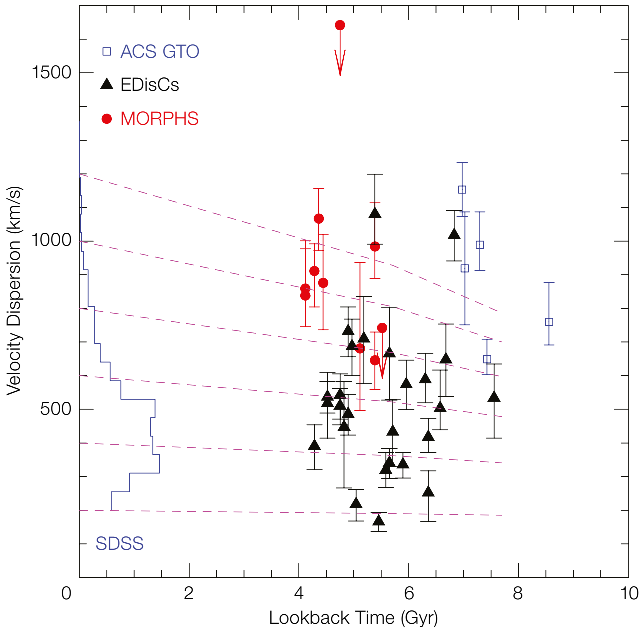
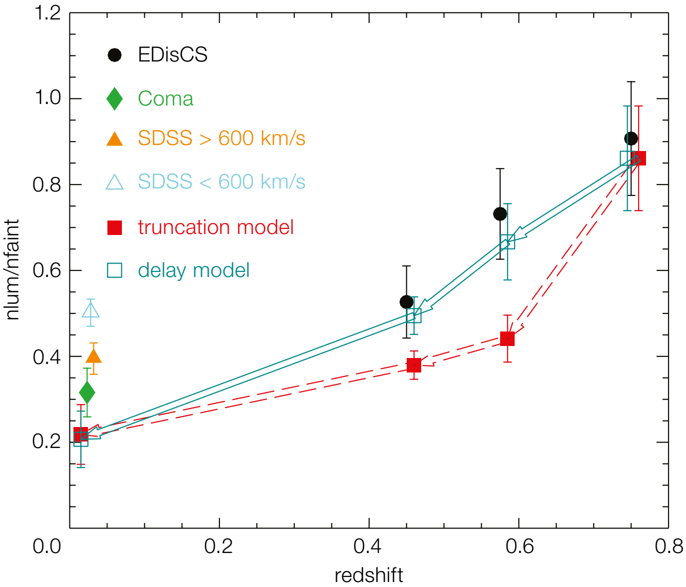


Figure 2. The distribution of velocity dispersion *v.* lookback time for EDisCS (black points) and for two other well-studied cluster samples at similar redshifts (red and blue points), as well as for a well-studied local sample (histogram). Dashed lines show how the velocity dispersion is expected to evolve with time. From this plot it is apparent that: a) EDisCS clusters span a wide range of velocity dispersions, and hence masses; and b) the majority of EDisCS clusters can be progenitors of "typical" low redshift clusters. From Milvang-Jensen et al. (2008).

Galaxy evolution: from star-forming to passively evolving...

Early-type galaxies in clusters exhibit a well-defined relation between colour and luminosity, the so-called red sequence. Distinct red sequences have been observed for clusters up to z = 1.5, indicating the existence of significant numbers of passively evolving galaxies whose star formation activity terminated well before the observation epoch. However, not all today's red sequence galaxies have been red and passive since high-z. There is solid evidence of a downsizing effect in the red sequence build-up in clusters: on average, the most massive/luminous galaxies stopped forming stars, and therefore were already on the red sequence, at an earlier epoch than the less massive and less luminous ones. This has been demonstrated using EDisCS data in various independent ways. The evolution in the number ratio of luminous-to-faint red galaxies clearly shows a deficit of faint, red galaxies in distant clusters compared to local clusters (Figure 3 left panel, see also De Lucia et al., 2004; 2007). In agreement with this finding, the luminosity function of red galaxies is consistent with passive evolution at the bright end, but shows a significant build-up at the faint end towards lower redshifts (Figure 3 right



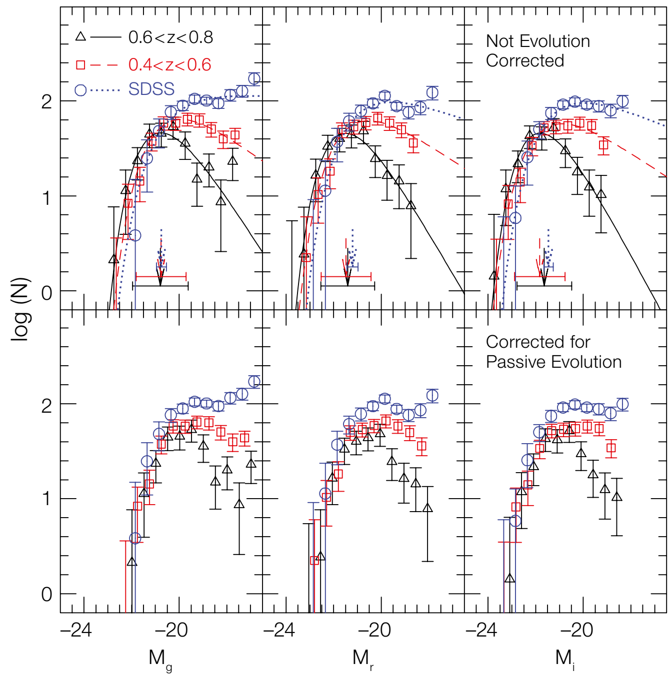


Figure 3. (Left) Ratio by number of luminous to faint red-sequence galaxies as a function of redshift. EDisCS results (black points) are compared with Coma and SDSS clusters at low-*z*. The arrows indicate the expected evolution if star formation is instantaneously or slowly truncated in star-forming galaxies infalling onto clusters (De Lucia et al., 2007). (Right) Composite rest-frame g, r and i luminosity functions of red sequence EDisCS and SDSS cluster galaxies. Luminosities are corrected (bottom panels) or uncorrected (top panels) for passive evolution. From Rudnick et al. (2009).

panel, see Rudnick et al., 2009). Relative to the number of bright red galaxies, the field has more faint red galaxies than clusters at $z = 0.6–0.8$, but fewer at $z = 0.4–0.6$. This variation in evolutionary rate with environment implies that cluster environments are more efficient than the field at adding galaxies to the red sequence at $z < 1$. Finally, an analysis of spectral line indices yielding stellar population ages, metallicities and α-element enhancements confirms that massive red galaxies are well described by passive evolution and high formation redshifts, while less massive galaxies require a more extended star formation history (Sánchez-Blázquez et al., 2009).

The most massive of all galaxies, the Brightest Cluster Galaxies (BCGs), are no exception to the downsizing effect: the evolution of their colour and rest-frame *K*-band luminosity is consistent with stellar populations formed at $z > 2$ and subsequent passive evolution. In contrast with previous findings, BCGs in EDisCS clusters do not show a significant change in stellar mass since $z = 1$ (Whiley et al., 2008). The clusters with large velocity dispersions, and therefore masses, tend to have brighter and more massive BCGs, but this dependency is weak: the stellar mass of the BCG changes only by 70% over a two-order-of-magnitude range in cluster mass.

…in different environments…

By comparing the fraction of emission line galaxies in EDisCS clusters with that in low-*z* clusters, Poggianti et al. (2006) have studied in detail the evolution of the star-forming galaxy fraction as a function of cluster mass. At high-*z*, there is a broad anticorrelation between the star-forming fraction and the system velocity dispersion (Figure 4). Low-*z* clusters have much lower star-forming fractions than clusters at $z = 0.4–0.8$ and, in contrast with the distant clusters, show a plateau for velocity dispersions above ~500 km/s, where the star-forming fraction does not vary systematically with velocity dispersion (Figure 4). Thus, the evolution in the average proportion of star-forming galaxies is strongest in intermediate-mass systems, those with velocity dispersions ~500–600 km/s at $z = 0$.

This evolution in the fraction of star-forming galaxies parallels the strong evolution observed in the galaxy morphological fractions. Visually classifying galaxies into Hubble types on the basis of our HST/ACS images, we have confirmed previous results — from the MORPHS team and others — finding lower S0 and higher spiral fractions in distant clusters compared to nearby ones, suggesting that a large number of distant spirals have turned into (some of the) present day S0s (see Figure 5 and Desai et al., 2007). In contrast, no evidence for evolution in the elliptical fraction is observed out to $z = 1$. The comparison of the stellar population analysis and the morphologies also confirms previous evidence that the timescale for morphological evolution is longer than the timescale over which the star formation activity ceases (Sánchez-Blázquez et al., 2009). EDisCS results demonstrate that cluster morphological fractions plateau beyond $z \sim 0.4$, implying that most of the morphological evolution in luminous galaxies has occurred in the last 5 Gyr (Desai et al., 2007).

Combined with other distant cluster samples, the EDisCS dataset shows a correlation between morphological content and cluster velocity dispersion similar to the relation between star-forming fraction and velocity dispersion described above

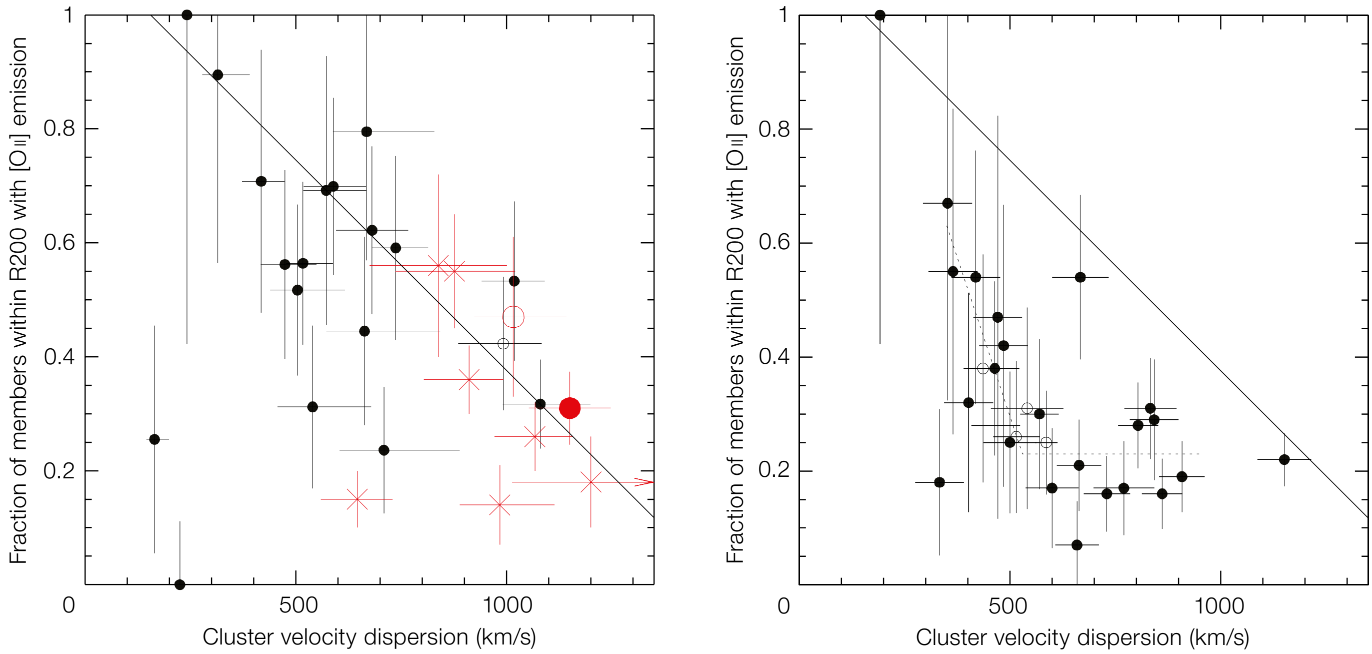


Figure 4. Fraction of star-forming galaxies *v.* cluster velocity dispersion in EDisCS clusters at z = 0.4–0.8 (left) and in a cluster sample selected from Sloan at z = 0.04–0.08 (right) from Poggianti et al., 2006. In the left panel, black points are EDisCS structures, red points are data from the literature. The solid line in both panels show the best fit to the high-z data points.

(Desai et al., 2007). Altogether, these results demonstrate that morphological evolution at $z < 1$ involves a significant fraction of cluster disc galaxies, and it is stronger in lower mass clusters than in the most massive ones, as it is for the changes in star-forming fractions (Poggianti et al., 2009b). Thus, the strongest evolution between $z \sim 1$ and today appears to affect galaxies in intermediate-mass environments, those commonly named low-mass clusters or massive groups.

Disc-dominated galaxies in the EDisCS dataset are also found to have a higher fraction of large-scale bars than bulge-dominated galaxies, in agreement with local studies (Barazza et al., 2009). Samples of disc galaxies selected in clusters and in the field both show similar bar fractions and bar properties, indicating that internal processes are crucial for bar formation. On the other hand, cluster centres are found to be favourable locations for bars, which may suggest that the internal processes responsible for the bar growth are supported by the kinds of interactions often taking place in these environments.

Analysing the proportions of morphological types as a function of local galaxy density, EDisCS galaxies are found to follow a morphology–density relation similar to that observed in previous cluster studies, with ellipticals being more common in high density regions and spirals being more frequent in low density ones. The

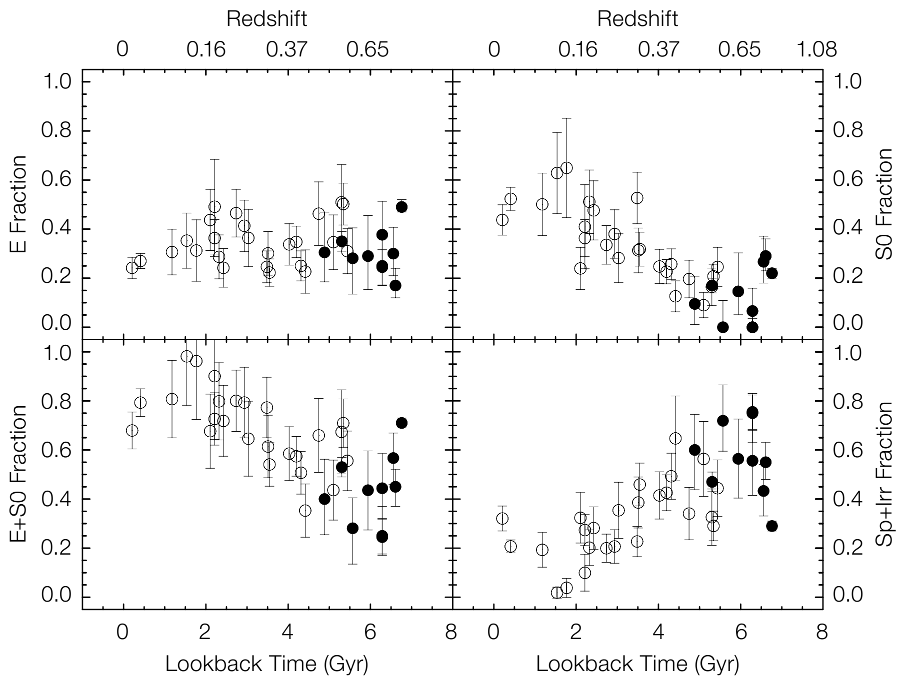


Figure 5. Evolution of the elliptical, S0, early-type (E+S0) and spiral fractions (black points EDisCS, empty points from the literature) is shown as a function of redshift. From Desai et al. (2007).

decline of the spiral fraction with density is entirely driven by galaxies of types Sc or later, while early spirals (Sa's and Sb's) are equally frequent at all densities, similar to S0's (Poggianti et al., 2008). In addition to measuring the morphology–density relation, we have been able to quantify the relation between star formation activity and local density in distant clusters for the first time. The star formation–density relation in EDisCS clusters qualitatively resembles that observed at low-z. In both nearby and distant clusters, higher density regions contain proportionally fewer star-forming galaxies. This is observed using both the [O II] and the $H\alpha$ lines (Poggianti et al., 2008; Finn et al., 2005). Moreover, the average [O II] equivalent width of star-forming galaxies is independent of local density both at high- and low-z. Although this seems to suggest that the star formation in star-forming galaxies is not affected by the local environment, that is not the case: the current average star formation rate in star-forming EDisCS galaxies does depend on the local density, and seems to peak at intermediate densities (15–40 galaxies/Mpc^2), declining at higher densities and also, possibly, at lower densities. So far, no one has studied how the star formation activity in star-forming galaxies varies with local density at low-z, thus our findings await a local comparison.

Finally, for galaxies of a given Hubble type, we see no evidence that star formation properties depend on local environment. In contrast with recent findings at low-z, the star formation–density relation and the morphology–density relation in our distant clusters seem to be fully equivalent, suggesting that neither of the two relations is more fundamental than the other at these redshifts and/or in these environments (Poggianti et al., 2008).

...through a starburst and then a post-starburst phase?

A crucial question is, of course, on what timescale do galaxies turn from blue to red in different environments, as the timescale provides important clues to the physical processes involved. The spectra of post-starburst galaxies (called "E+A" from their similarity to an elliptical galaxy spectrum with strong Balmer lines of A type stars, or called "k+a" from their mixture of K stars and A stars) are characterised by their exceptionally strong Balmer lines in absorption and the lack of emission lines, belong to galaxies in which the star formation activity ended abruptly sometime during the past Gyr. In EDisCS we find that the incidence of k+a galaxies at these redshifts depends strongly on environment (Poggianti et al., 2009a). Galaxies with k+a spectra reside preferentially in clusters and, unexpectedly, in a subset of those groups that have a low fraction of [O II] emitters (Figure 6). In these environments, 20–30% of the star-forming galaxies have had their star formation activity recently and suddenly truncated. In contrast, there are proportionally fewer k+a galaxies in the field, the poor groups and groups with a high [O II] fraction.

The properties of k+a galaxies are consistent with previous suggestions that cluster k+a galaxies are observed in a transition phase: at the moment they are rather massive S0 and Sa galaxies, evolving from star-forming, recently infallen, later types to passively evolving cluster early-type galaxies. The incidence of k+a galaxies correlates with the cluster velocity dispersion: more massive clusters have a higher proportion of k+a galaxies. The correlation between k+a fraction and cluster velocity dispersion supports the hypothesis that k+a galaxies in clusters originate from processes related to the intracluster medium, while the origin of the high k+a frequency in low-[O II] groups is currently an important, but poorly understood, piece of the puzzle.

Spectra of dusty starburst candidates, with strong Balmer absorption and emission lines, present a very different environmental dependence from the post-starburst galaxies. They are numerous in all environments at $z = 0.4$–0.8, but they are especially numerous in all types of groups, favouring the hypothesis that they are triggered by a merger or tidal interaction (Figure 6). Hence, at least from the optical point of view, starbursts do not appear to be triggered by the cluster environment, while they probably do feed the cluster post-starburst population after they have fallen into the clusters.

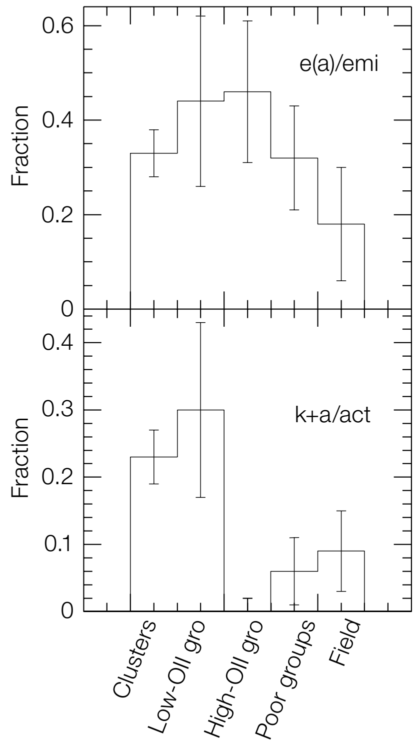


Figure 6. Fraction of candidate dusty starburst galaxies among all emission-line galaxies as a function of environment (upper). Fraction of post-starburst (k+a) galaxies among all galaxies with recent or ongoing star formation activity, in the five different environments: clusters; groups with a low star-forming fraction (low-[O II] groups); groups with a high star-forming fraction (high-[O II] groups); poor groups; and the field (lower). From Poggianti et al. (2009a).

Group bimodality?

One of the unexpected and perhaps more striking results emerging from the EDisCS data is that two types of groups can be identified, with notably distinct galaxy properties, but similar velocity dispersion estimates of 100–400 km/s. There are groups with a star-forming fraction higher than 80% (high-[O II] groups), which consist mostly of morphologically late-type galaxies, with no post-starburst galaxies, and thus are quite similar to the "field" in all their galaxy properties. The other type of groups (low-[O II] groups) have low star-forming fractions (lower than 50%), consist mostly of galaxies with early-type morphologies, and have high proportions of post-starburst galaxies, i.e. their galaxy populations resemble those of the most massive clusters.

It can be argued that this dichotomy may arise simply because the low-[O II] groups are "true" virialised groups, while the high-[O II] groups are just groups in formation or, more generally, unbound galaxy associations. However, this hypothesis is unlikely to explain the observed bimodality since a very large spread in star-forming fraction is also observed among X-ray selected groups, all of which have a hot intra-group medium within a potential well. The very different galaxy populations observed in the two types of groups could be the key to discriminating which physical processes establish the dependence of galaxy properties on environment. The answer will be found in future large (cluster or field) surveys with high quality data.

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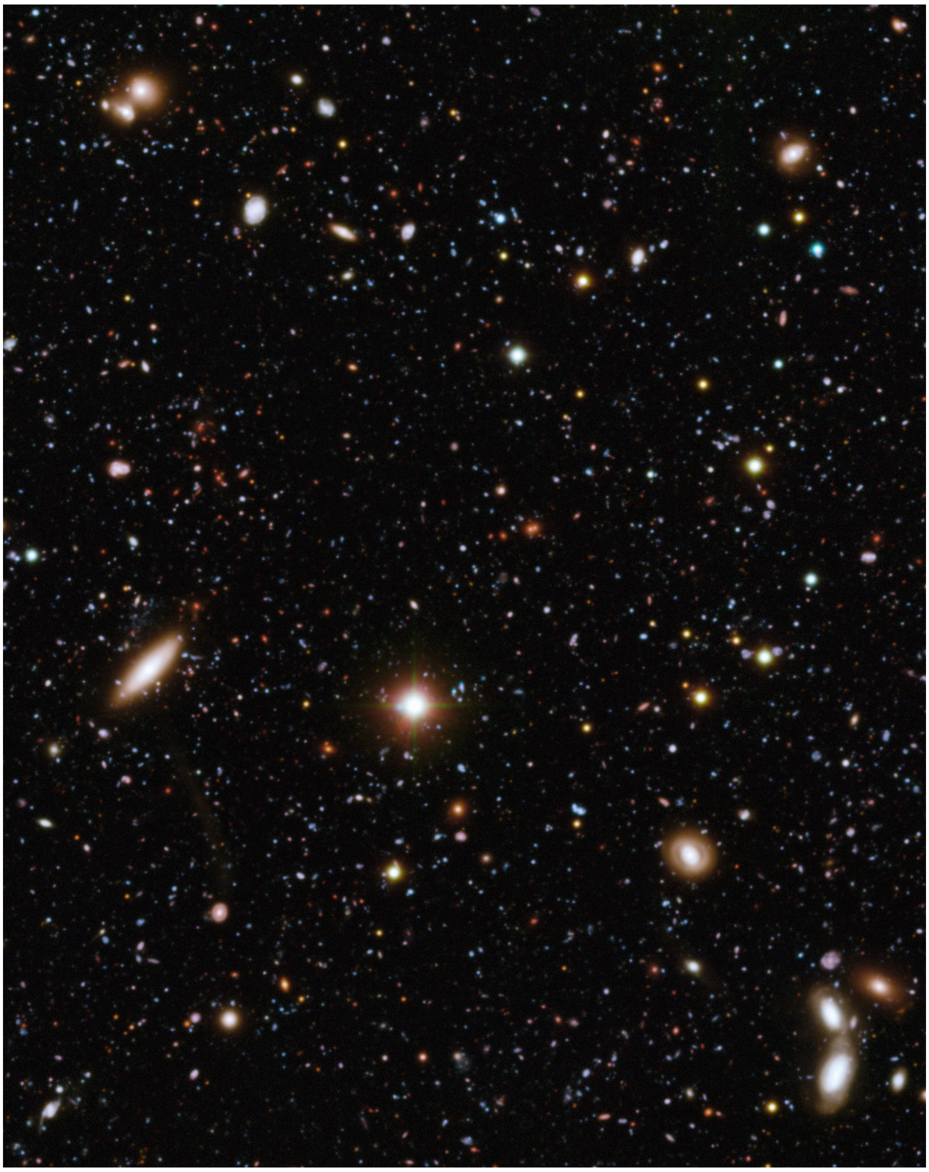

A part of the large (14.1 x 21.6 arcminute) colour composite of the Chandra Deep Field South, observed in the *U*-, *B*-, and *R*-bands as part of GOODS. The VIMOS *U*-band image is the deepest ground-based *U*-band image taken (40 hours exposure). The deep *B*-band image was made with the MPG/ESO 2.2-metre telescope and WFI in the frame of the GaBoDS survey and the 15-hour *R*-band image with VIMOS. More details can be found in ESO Release 39/08.

Two views from the JENAM meeting at Hatfield, UK: Lord Drayson, the British Minister of State for Science and Innovation, takes a closer look at the E-ELT with an explanation of its pivotal role for raising the European scientific, technological and industrial profile by ESO Director General Tim de Zeeuw (upper).

Michel Mayor announces the lowest-mass planet yet found outside the Solar System to the media present at the conference (lower). See Leibundgut et al. page 72.

You and Your Observatory — The ESO Users Committee

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The European Southern Observatory is an international organisation serving a large scientific community. Financed by its member states, its facilities are open to all professional astronomers around the world. ESO and its users form a partnership, aimed at maximising scientific progress: ESO provides the infrastructure and logistical support, and the users carry out the most exciting measurements and publish these in a timely fashion in respectable journals.

The Users Committee (UC) is an advisory body set up to liaise between the users and ESO. Now a well-established institution, its 33rd annual meeting took place on 27 and 28 April 2009 at ESO Headquarters in Garching. It is seen by some as a platform for users to tell ESO what they think of it, but it is also used by ESO to inform users and, increasingly, to ask users for input into some of their initiatives. My personal view is that the role of the UC is to facilitate the collaboration between ESO and its users, where ideally most interaction would take place in a natural way outside the UC.

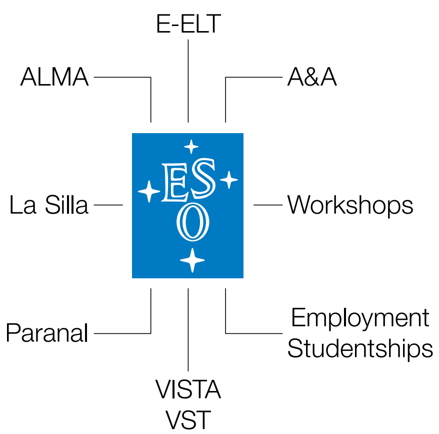

Figure 1. Summary of the services provided by ESO. ESO not only constructs and operates the most powerful telescopes at some of the best sites on Earth, but also provides various other services for the benefit of the scientific community.

Things that have remained the same over the past eight years

Lutz Wisotzki last described the role and functioning of the UC in 2001 (Wisotzki, 2001). Many features remain the same. The UC still has the same remit, to advise ESO of the views of its users, and to help ESO communicate with its users. UC members are appointed by the Director General, and normally serve for four years. Each member state, as well as the host country, Chile, is represented by one UC member. The UC and representatives from ESO meet for two days each year to discuss user feedback reported in end-of-mission forms or made known to the UC in other ways, and to discuss updates on telescope operations and developments, usually through presentations made by ESO staff. Each year there is a special topic, to allow time to go deeper into a more specific issue, for which ESO invites specialist users to that part of the meeting. This year's special topic was "Target of Opportunity and Rapid Response Mode".

There are two important ways in which this meeting becomes effective, and both parties become accountable: firstly, the minutes are made public online[1]; and secondly, the UC proposes, and ESO agrees, on a set of action items and recommendations. Progress on these action items and recommendations are reported at the next meeting.

Things that have evolved over recent years

Over the past decade, ESO has grown enormously. When I returned home from an ESO studentship twelve years ago, the VLT had yet to start operation. Now, Cerro Paranal is a fully mature observatory site, with an increasingly powerful interferometer, ready for its second generation of instrumentation and two wide-field survey telescopes poised for operations. ALMA is on the doorstep, and the E-ELT is becoming a reality. ESO employs more people than ever before and new buildings are planned on the Vitacura and Garching premises.

Importantly, also, new member states have acceded. After the United Kingdom joined early this century, Finland, Spain and the Czech Republic have followed suit, and Austria is being welcomed as the youngest ESO member state. This means that the UC has increased in size, both in terms of the number of its members and the size of the community it directly represents (see Table 1 for a list of the current members). The enlarged ESO user community no doubt contributes to the continuously growing demand on telescope time, presenting both ESO and its users with serious challenges.

The way in which feedback is gathered from users has also evolved. End-of-mission forms are now also solicited from the principal investigators of service mode programmes, and the UC annually polls users through an online questionnaire about two months before their meeting. The UC collects all feedback from each of the representatives and the UC Chairperson sends this to ESO in advance of the meeting, accompanied by a summary of the feedback and users poll.

Likewise, ESO prepares factsheets for the UC, which summarise statistics of telescope demand and usage, etc., and reports on recent developments within the various ESO departments. ESO, as well as the UC, certainly take their roles very seriously — this is reflected not least in the fact that most ESO personnel in charge of relevant divisions participate in the meeting, including the ESO Director

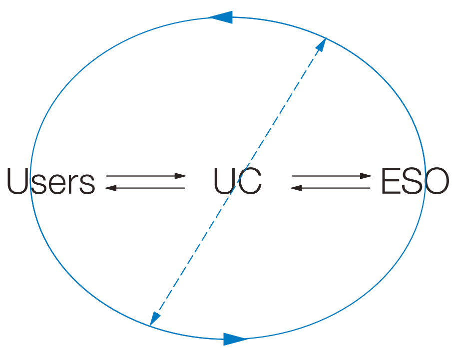

Figure 2. The role of the UC. The ESO Users Committee acts not just as a relay station between the users and ESO, but more importantly as a mechanism for facilitating direct interaction between ESO and its users.

Austria	Werner Zeilinger	werner.zeilinger@univie.ac.at	Vice-Chair
Belgium	Martin Groenewegen	marting@oma.be	
Chile	Manuela Zoccali	mzoccali@astro.puc.cl	
Czech Republic	Jiri Grygar	grygar@fzu.cz	
Denmark	Frank Grundahl	fgj@phys.au.dk	
Finland	Seppo Katajainen	sekataja@utu.fi	
France	Vanessa Hill	Vanessa.Hill@obspm.fr	
Germany	Jochen Heidt	jheidt@lsw.uni-heidelberg.de	(until 2009)
Italy	Bianca Poggianti	bianca.poggianti@oapd.inaf.it	(until 2009)
the Netherlands	Walter Jaffe	jaffe@strw.leidenuniv.nl	(until 2009)
Portugal	Jorge Melendez	jorge@astro.up.pt	
Spain	Ignacio Negueruela	ignacio@dfists.ua.es	
Sweden	Nils Ryde	ryde@astro.uu.se	
Switzerland	Frederic Courbin	Frederic.Courbin@epfl.ch	(until 2009)
United Kingdom	Jacco van Loon	jacco@astro.keele.ac.uk	(Chair)

Table 1. The Users Committee currently has 15 representatives.

General (DG). Users should thus be reassured that their voice is heard and the DG is open to discussion. The ESO DG sets high standards for his employees, and encourages the UC and ESO users in general to set similarly high standards for themselves. This has proved a constructive approach, and matters are being attended to rapidly nowadays.

The UC has assumed an active role in contributing to ESO, in an attempt to transcend the stigma of a complaining and demanding "trade union". I am a strong believer in sharing responsibility. Hence, for the past year the UC has also set action items for itself, for instance to help ESO advertise new features or to solicit input from the community on specific issues. I have also called for a teleconference between the UC and a select number of ESO representatives, offset by half a year from the annual face-to-face meeting. This allows for much more continuous interaction, and has no doubt contributed to the accelerated pace at which action items are being addressed (resulting in the fact that most past action items could be deemed closed at the recent annual meeting).

My predecessor introduced an informal teleconference between the Chairpersons of the UC, Observing Programmes Committee (OPC) and the Head of the Observing Programmes Office (OPO). These now take place shortly before each OPC meeting. They should allow the UC to learn about OPC procedures for that semester, and to inform the OPC Chairperson of user feedback related to the proposal submission and evaluation process. This should increase the sense of "ownership" of the time allocation process, as user feedback sometimes gives the impression that the users are alienated from this process, whereas in actual fact the OPC is composed entirely of ESO users. In that respect, I would urge anyone being asked to serve on the OPC or its subpanels to accept — one learns a lot, besides performing an important task for ESO and ultimately oneself.

Examples of recent and current burning issues

There have been several recurrent items on the UC meeting agenda of late, some of which have now been addressed, whilst others require more resources and setting of priorities.

A recent success story is that of the timely access to service mode data. Previously, principal investigators had to wait until the end of the semester before they received their data, on disc. This delay between the time of the data acquisition and the time when it could be analysed sometimes led to missed opportunities, e.g., to correct observing strategy, to prepare for follow-up observations, or simply to publish rapidly. In particular, users with access to other observatories where data were made accessible within a day or two (or even quicker) could not understand why ESO could not deliver the same service. This was at least in part due to the way the data flow was organised, the way the ESO archive operates, and the fixation on data quality assurance. The recent addition of the User Portal now provides the necessary interface for data exchange between the archive and the user, and initially this made access possible within around ten days, after validation by ESO personnel. For many applications, in particular exploiting the highly successful rapid response mode for the observation of fast transients, this was still far too slow. Less than a year later, ESO is now offering access to unvalidated (raw) data within half an hour or so. Faster access will require a high speed data-link between Paranal and the intercontinental grid. The archive and User Portal interface are also subject to continued development, promising simpler retrieval of associated calibration data and easier access for co-investigators.

Another pertinent item that enjoys continuous attention is the availability of data reduction tools. In the past, ESO developed Midas as a software environment within which it offered recipes for reducing imaging and spectroscopy data obtained with ESO instruments (generic enough to often also be useful for data obtained at other observatories). However Midas has not been the preferred software environment for some time now. Instead, ESO has concentrated on developing data reduction pipelines for its VLT instruments, but for the main purpose of data quality control — not to produce science products. Users have felt left to their own devices when it comes to reducing their data, and this causes not only frustration, but is also a waste of time and resources and has ultimately reduced scientific productivity. That said, it is a huge undertaking to provide dedicated software for each and every mode of the many diverse and advanced instruments that have come into operation at the four VLT telescopes, and priority was given to ensuring the correct operation of these instruments and the requisite quality of the products that enter the ESO archive. Limits to resources continue to play a role, but over the past year ESO has demonstrated a clear intent to provide (or require instrument teams to provide) reduction tools that produce science-grade data products. In some cases this may be in the form of a science-grade pipeline — certainly a prerequisite for reducing the extremely high data flow expected to come from the survey telescopes or from highly multiplex instruments. ESO is also working towards developing recipes that can properly treat the data reduction steps that are standardised in current pipelines. The UC welcomes the electronic forum set up for users to discuss issues with regard to data reduction[2]. This could be a great way for users to provide input and help achieve what they have been asking for.

Challenges and opportunities that lie ahead

There are big challenges lying ahead, but these also present great opportunities, where users can make a real positive difference. Some of these are associated with the changing landscape of observing facilities that ESO can maintain. Therefore, the UC decided to poll the users this year on their views regarding currently available and future telescopes and instrumentation.

The future of La Silla and ESO's support for "small" telescopes has been a worry for a significant fraction of the user community for some time. This has recently been exacerbated by the steep rise in telescope time applications and pressure factors on some telescope/instrument combinations exceeding that of space-borne observatories. It is felt desirable to improve the balance between the pressure on different telescope/instrument combinations (and to avoid as far as possible "unreasonably high" oversubscription rates), and La Silla might be part of a solution of this delicate and not trivial "luxury problem". La Silla is still operated by ESO, and there are no plans for this to change in the foreseeable future. However, a streamlined and, by necessity, more limited operation model has been adopted, and efforts have concentrated on a smaller number of productive telescopes and instruments (see the article by Saviane et al. on page 18). La Silla welcomes large programmes, which can last up to twice as long as large programmes at Paranal, as well as visitor instruments, and it responds kindly to consortia interested in operating some of the remaining telescopes. The UC will continue to work with ESO to look into ways in which users can be offered alternatives to the heavily oversubscribed VLT, and we are currently pursuing the idea of combined programmes for La Silla telescopes, which could overcome the minimum three-night rule by sending a single observer to execute a number of programmes that would otherwise be too small. This could also be an effective way of training novice observers, training the next generation of astronomers surely being part of ESO's directive.

Also with a view towards the new instrumentation choices that will be made for existing and upcoming ESO facilities, we are trying to improve the communication between the user community and the Scientific and Technical Committee (STC). The latter makes recommendations to ESO as to its strategy for telescope and instrument development. To ensure that the STC has all the information it needs, the UC sees a role for itself in providing the STC with the views and expectations of the (prospective) users of ESO facilities. The results of this year's users poll pertaining to the STC's remit have been prepared and will be relayed in an effective format to the STC. One clear general result emerging from this exercise was that the ESO scientific community clearly echoes the cultural diversity of Europe: a certain field of research may dominate the research agenda of one country, but the situation will be very different in another country, and this is often reflected in the popularity of instruments that best suit the respective research requirements.

If only for this reason, it is probably a good thing that ESO's committees generally have one member from each country rather than proportional representation, which would lead to committees dominated by the larger member states. In a similar vein, I am very happy that the representative of the newest ESO member state, Austria, has agreed to serve as Vice-Chairperson on the UC (see Table 1). Lastly, I believe that European (and Chilean) astronomers have good reasons to consider themselves very fortunate to benefit from ESO, and I am confident that they can — and will — help make ESO even better.

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Links

[1] Overview of UC meetings: http://www.eso.org/public/about-eso/committees/;
[2] See the announcement on page 75 and refer to http://www.eso.org/sci/data-processing/forum.html

Report on the ESO workshop on

Wide-Field Spectroscopic Surveys

held at ESO Headquarters, Germany, 10–11 March 2009

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The wide-field imaging surveys to be conducted with ESO VISTA and VST telescopes and with the ESA Gaia satellite demand spectroscopic follow-up. Presentations and discussions on the role of wide-field spectroscopic surveys with ESO telescopes at this dedicated workshop are summarised. The instrument requirements for spectroscopic surveys of large-scale galaxy structure, fundamental cosmology, and the structure of the Milky Way and its neighbourhood are presented.

Ever since the large surveys with the Schmidt telescopes in Chile and Australia, the European astronomical community has been very active in the execution and exploitation of wide-area imaging surveys. This has been reflected in the scientific policies within ESO and in particular has led to the advent of two specialised survey telescopes on Paranal: the 2.4-metre VLT Survey Telescope (VST) for optical surveys and the 4.1-metre Visible and Infrared Survey Telescope for Astronomy (VISTA) for wide-field near-infrared surveys. These telescopes have attracted a very strong interest from the community to propose public surveys with these facilities. A comprehensive set of three large surveys with VST and six public surveys with VISTA, supported by almost 500 astronomers in total, have been allocated more than 2000 nights with these telescopes over a period of five years[1]. To exploit these imaging surveys fully, several programmes will require follow-up spectroscopy, which in turn need proper facilities and policies to be implemented. Thus, the community has been asking ESO to enable wide-field spectroscopic surveys at either the La Silla or Paranal observatories. Besides the follow-up of ESO imaging surveys, the community also anticipates that wide-field spectroscopic survey capabilities at ESO will be needed for future major space missions, like Gaia.

ESO invited the community to present their ideas and requirements at the workshop "Science with the VLT in the ELT Era", where astronomers gathered in Garching in September 2007 to discuss plans for the second generation instruments on the VLT (Moorwood, 2009). Following that conference and the announcement of VIMOS and GIRAFFE upgrades, ESO's Scientific and Technical Committee (STC) issued the following recommendation:

A Short-term Path to Successful Implementation of Spectroscopic Surveys

With the upgrades of GIRAFFE and VIMOS, ESO will provide to the ESO community highly competitive facilities to run wide-field spectroscopic surveys as early as 2009. These instruments will be unique during the next 5 years and will put the ESO community in a strong leading position in the field. STC then requests that a joint STC-ESO workshop be organised as early as possible in order to review the scientific potential of these instruments for public wide-field spectroscopic surveys and to identify potential scientists in the ESO community who would lead these survey efforts. The workshop would also be an opportunity for the community to propose new concepts for the next generation wide field instruments on ESO telescopes consistent with the STC recommendations from STC-67 and STC-68. Depending on the outcome of the workshop, ESO could then call for Large Programmes or Public Surveys in order to begin wide field spectroscopic surveys as soon as the VIMOS upgrade is completed successfully.

Thus, the Wide-Field Spectroscopic Surveys Workshop was organised at very short notice so as to be able to report back to STC at its April 2009 meeting, and start the process to enable large spectroscopic surveys as early as possible. In spite of the short notice, more than 100 astronomers from all over Europe registered for the workshop, again attesting to the strong interest of the community in the subject. Each topic was treated in considerable depth, leading to an extremely pleasurable and informative scientific meeting in spite of its rather technical background.

The core scientific requirements for wide-field spectroscopic surveys were already anticipated by the scheduled ESO public surveys with VST and VISTA. In fact these core themes had been reviewed by the two ESA–ESO Working Groups that focused on optimising the ground/space synergies in these core themes: fundamental cosmology (Peacock et al., 2006) and populations, chemistry and dynamics of the Milky Way (Turon et al., 2008). They were also discussed by the ASTRONET Science Vision working groups (see Bode, Cruz & Molster, 2008) that envisioned an increasing demand for wide-field multiplex spectroscopic facilities over the next few decades.

Fundamental cosmology and the high redshift Universe

This broad heading encompasses not only the quest for the fundamental cosmological constants and related mysteries, such as the nature of dark matter and the origin of cosmic acceleration, but also topics focused on the high-redshift Universe, the mass assembly of galaxies, and the star-formation history of the Universe.

The subject was reviewed by Jordi Miralda-Escude who described the rather large number of ongoing or planned surveys to address the current most fundamental problem in observational cosmology: the nature of dark energy. One of the best techniques to investigate the nature of dark-energy is the so-called Baryon Acoustic Oscillations (BAO — also known as baryon wiggles). These are fluctuations in the galaxy distribution at large spatial scales imprinted in the dark matter distribution by acoustic waves in the early Universe. This translates into a peak in the galaxy power-spectrum that defines a physical scale that can be used as a standard ruler to map the geometry of the Universe a function of redshift. The effect of BAOs is shown in Figure 1 from the Sloan Digital Sky Survey (SDSS) results at low redshift that clearly detect the BAO peak at a scale of about 100 Mpc (from Eisenstein et al., 2005). The challenge, of course, is to detect this peak at higher redshift.

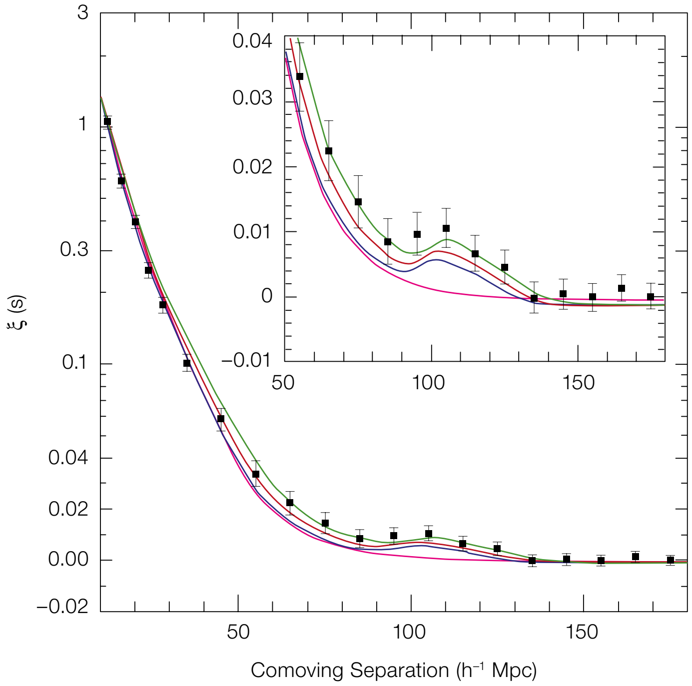

Figure 1. The large-scale redshift-space correlation function of the Sloan Digital Sky Survey Luminous Red Galaxy sample. The different line types show different models, including a pure Cold Dark Matter (CDM) model (i.e. with no dark energy) in magenta, which lacks the acoustic peak. (From Figure 2, Eisenstein et al., 2005).

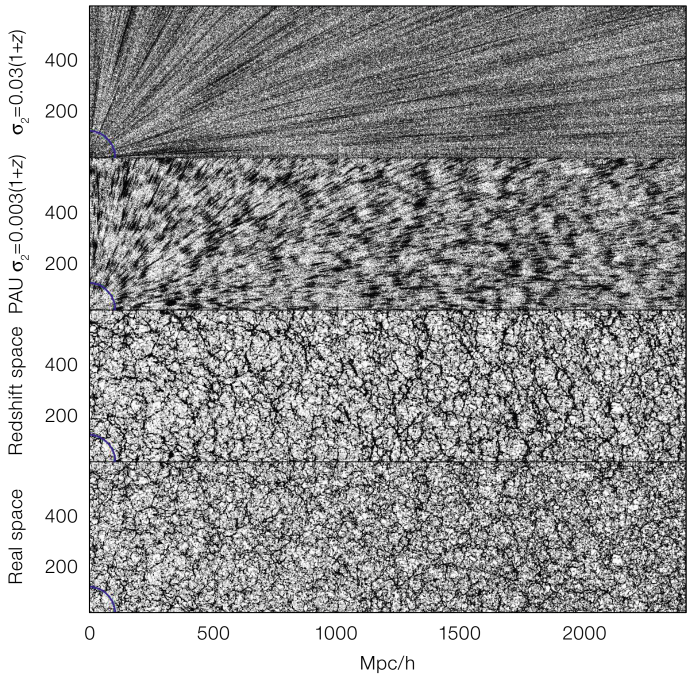

Figure 2. The effect of redshift errors on the observation of large-scale structure. All signal is erased if the error is as little as 0.03(1 + z). (From Figure 2, Benitez et al., 2009).

In his presentation, Tom Shanks proposed focusing on wide-field spectroscopic surveys of Lyman-break galaxies selected from current deep imaging surveys to explore the properties of the BAO peak at $z \sim 3$. Several presenters showed beautiful simulations that clearly illustrate the effect of redshift errors in the observation of the large-scale structure. One example, shown in Figure 2, taken from the presentation of Enrique Gaztañaga, shows that if the errors are larger than about 0.03(1 + z) the structure is completely washed out; to measure the structure, therefore, the redshift accuracy must be better than 0.003(1 + z). While the required accuracy can comfortably (but not trivially) be achieved with spectrographs, Gaztañaga claimed that it could also be achieved photometrically by using about 40 intermediate-band interference filters, as the Physics of the Accelerating Universe (PAU) project is planning to do. But of course a very large number of spectroscopic redshifts will still be required to calibrate the photometric estimates.

Konrad Kuijken reviewed the imaging cosmological surveys that are planned with the VST and VISTA. He showed that the fundamental properties of the Universe outlined above could be investigated using photometric redshifts of 60 million galaxies studied through weak lensing. This requires an accuracy of 3% in the photometric redshifts. Again this requires a large number of spectroscopic redshifts to calibrate the photometric estimates. Figure 3 from Kuijken's presentation shows that with 60 million galaxies and 3% redshifts it will be possible to extract the BAO signal from the weak-lensing potential spectrum illustrating the power of large multicolour broadband imaging surveys.

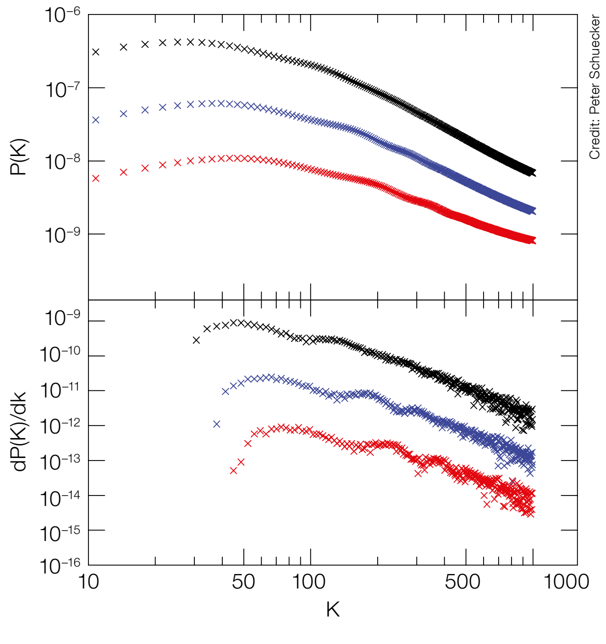

Figure 3. Estimated power spectrum in the galaxy distribution for the KIDS/VIKING surveys for z = 0.6 (black); z = 1.0 (blue); and z = 1.4 (red) based on photometric redshifts accurate to 3% for 60 million galaxies. The bottom panel shows that with this sample it should be possible to detect BAO in the weak-lensing signals.

Another technique that also allows to test the effects of non-standard gravity (e.g., braneworlds) was presented by Luigi Guzzo in his discussion of the VIMOS Public Extragalactic Redshift Survey (VIPERS). The idea is to look for distortions in the two-dimensional galaxy correlation function (in the radial and spatial directions). This so-called Kaiser effect is illustrated in Figure 4 where the distortions from the VIMOS–VLT Deep Survey (VVDS), at a redshift range between 0.6 and 1, are shown (Guzzo et al., 2008). While the distortions are clearly detected, the error bars are much too large to discriminate models and, in particular, to say anything about alternative theories of gravity. Many more galaxies at even higher redshifts are required for this crucial distinction.

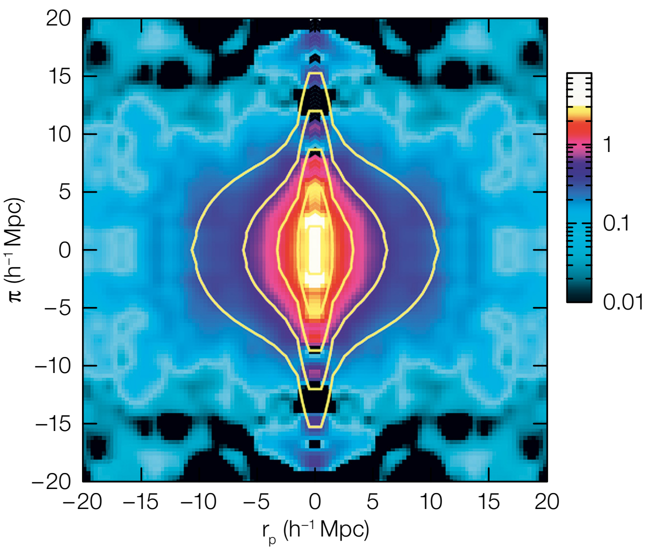

Figure 4. Colour-coded representation of the galaxy correlation function measured using ~6000 galaxy redshifts with $0.6 < z < 1$. The intensity describes the measured degree of correlation as a function of the transverse (r_p) and radial (π) separation of galaxy pairs. The actual measurement is replicated over four quadrants to show the deviations from circular symmetry. Galaxy peculiar velocities combine with the cosmological expansion producing the distorted pattern when the redshift is used as a distance measure. From Guzzo et al. (2008).

Spectral resolution	300 < R < 3000
Wavelength coverage:	350 nm –2.2 microns
Number of objects	$>10^5$ –10^6
Multiplex	200–1000
Depth (continuum S/N 10–30)	$22.5 < I_{AB} < 25.0$
Sky coverage	100–5000 deg^2
Typical number of nights	> 300
Targets	Faint galaxies; QSOs

Table 1. Technical requirements for wide-field cosmological surveys.

The nature of star formation, its evolution with redshift, the role of environment and the intergalactic medium, and the cosmic history of galaxies and haloes are the most pressing issues that were presented by O. Le Fèvre, S. Lilly, A. Renzini and L. Tresse. All present-day spectroscopic samples suffer from incompleteness, poor spatial sampling, or insufficient uniformity, and are still not deep enough to probe with enough statistics large volumes of the very high redshift Universe and the faintest galaxy populations. Beyond redshift ~1.5 the need for near infrared spectra is essential. The presenters were insistent on the increasing demand for large subsamples (~10^5 spectra) in order to unravel biases, selection effects, and the different physical processes at work. There was a consensus that it is of primary importance that new surveys move towards very well-defined spectroscopic subselections per magnitude, colour, and redshift bins, as well as towards extremely faint galaxy and quasar samples ($I_{AB} > 25$), all of which are within the reach of an upgraded VIMOS.

Putting all these science cases together results in the set of instrument requirements summarised in Table 1.

The Galaxy and its neighbourhood

The second day of the workshop started with a review by Amina Helmi of the recommendations of the ESA–ESO Working Group No. 4 on Galactic Populations, Chemistry, and Dynamics. The focus of the report was on the synergy between the Gaia mission and ground-based observations of the Milky Way, since the quality and the sheer volume of the Gaia data will revolutionise the study of the Galaxy. Gaia will provide astrometric information of a complete sample of stars out to distances of 10 kpc and will therefore allow investigating the properties of the major components: thin disc, thick disc, Bulge, spiral structure and halo with unprecedented depth and accuracy. Gaia will thus allow questions such as the initial mass function (IMF) of clusters and associations, the chemical enrichment history, the dynamics of the central region and the influence of the central black hole, among others, to be addressed. The Gaia data will also expand so-called near-field cosmology as it will be possible to map the history of mass assembly of the Galaxy and in particular to address the problem of the missing satellite galaxies predicted by the CDM galaxy-formation scenarios.

A serious problem with the exploitation of the Gaia data will be the incompleteness of the radial velocities. Gaia was conceived from the beginning as an astrometric instrument with the inclusion of a multi-colour photometer and an onboard low dispersion slitless spectrograph. The 1.45 × 0.5 m telescopes onboard Gaia allow radial velocities to be measured for stars brighter than V = 17 mag. At that limit the radial velocity accuracy will be degraded to about 14 km/s, to be compared to the astrometric precision on the transverse velocity which will be about ten times better at that magnitude. In her talk Alejandra Recio-Blanco summarised the situation as shown in Figure 5 that shows that the full exploitation of the Gaia astrometric data for V > 15.5 mag requires deep, high resolution spectroscopic surveys from the ground. In particular, these ground-based complementary observations are required for the Galactic Halo and the Bulge. As several participants pointed out, the HERMES survey on the AAT planned for 2011+ will likely skim some of the cream of the Gaia targets unless something is started at the VLT or La Silla.

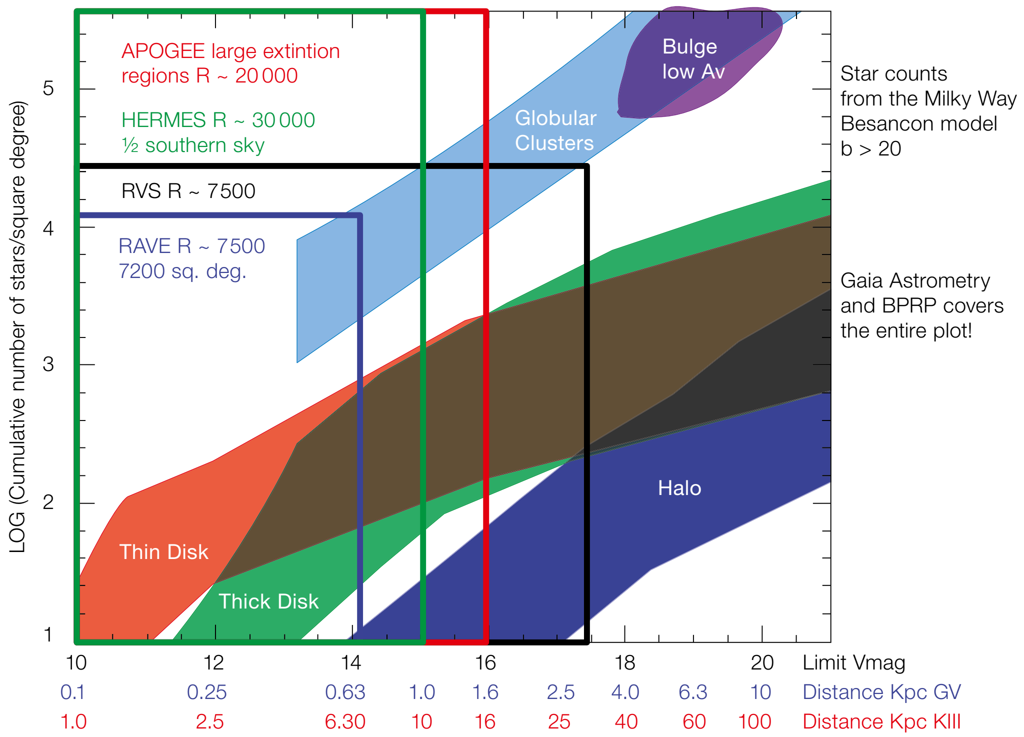

Figure 5. Plot of the number density and locus of different components of the Milky Way *v.* V magnitude and equivalent distance for two spectral types as relevant to the follow-up of stars from Gaia. (From the presentation by Recio-Blanco.) The locus of some other spectroscopic surveys are indicated.

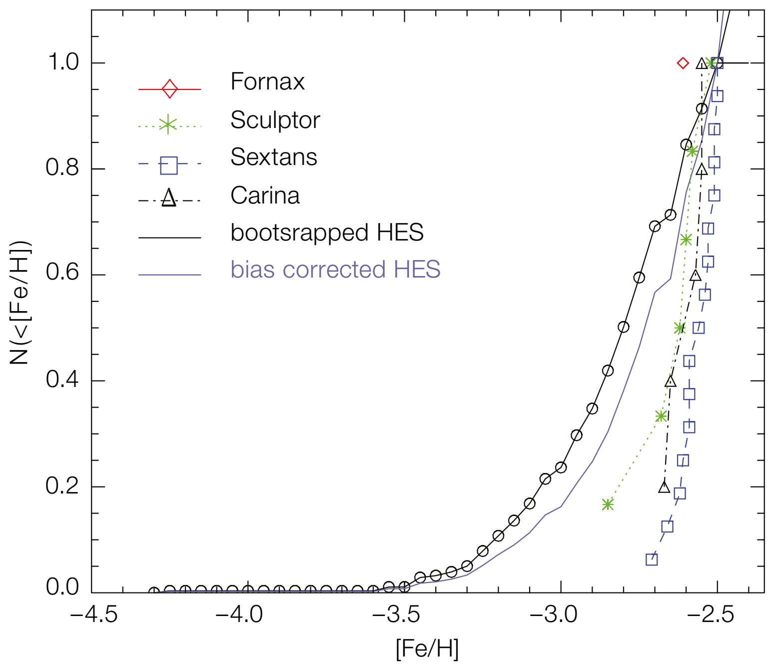

Figure 6. The cumulative metallicity distribution function in the metal-poor satellites of our Galaxy is shown as individual points for different galaxies. The solid black line shows the distribution of metallicities of stars in the Milky Way from the Hamburg–ESO survey and the blue line for the Galactic halo (Figure 10 from Tolstoy et al., 2009).

Similar problems to those investigated by the ESA–ESO Working Group for the Galaxy can also be studied in the nearby dwarf satellites of the Milky Way, and the spectroscopy case was presented by Maria Rosa Cioni and Giuseppina Battaglia at the workshop. For example, Figure 6 shows that the distribution of metallicities in the dwarf satellites of the Milky Way seem to be radically different from the distribution of metallicities in the halo of the Milky Way itself (when suitably scaled). The recently discovered nearby dwarf galaxies with extremely low surface brightness have a metallicity distribution that is substantially lower again.

Janet Drew reviewed the current imaging surveys of the plane of the Galaxy, in particular with UKIRT, and the plans for Galactic surveys with VST and VISTA. She showed that the wide wavelength coverage afforded by the addition of the near IR bands to the optical wavelengths, plus the use of narrowband Hα filters, significantly narrow the gap between photometric and spectroscopic surveys. However, imaging surveys can never replace spectroscopy for kinematics or abundances.

Table 2 summarises the instrument requirements demanded by the follow-up of the surveys by the VST, VISTA and Gaia.

Spectral resolution	5000 < R < 40000
Wavelength coverage:	370 nm –1.2 microns
Number of objects	$>10^5 - 10^6$
Multiplex	200–1000
Depth (continuum S/N 20–100)	$14.0 < I_{AB} < 20.0$
Sky coverage	100–5000 deg^2
Typical number of nights	> 300
Targets	Galaxy: Bulge, bar, spiral structure, clusters, halo streams. Magellanic Clouds. Dwarf satellites.

Table 2. Requirements for Galactic spectroscopic surveys.

Proposals for new instruments

In addition to talks concentrating on the science cases for advanced wide-angle spectroscopic surveys, several talks presented actual proposals for instruments to equip the VLT telescopes with wide-field high-multiplex spectrographs. Tom Shanks presented a very interesting concept of a 3 deg^2 field, 12000-slit spectrograph for VISTA, which could survey more than 80000 $z = 0.7$ galaxies per night. Adriano Fontana discussed a concept for a 5 deg^2 fibre-spectrograph with a multiplex factor of 5000, which is being studied for one of the prime foci of the Large Binocular Telescope (LBT). This instrument could also be suitable for other 8-metre-class telescopes such as the VLT, but it would demand changes of the UT top end. Joss Bland-Hawthorn presented FIREBALL, that would use the OzPoz positioner of FLAMES to feed five spectrographs with hexabundle fibres from 50 deployable Integral Field Units (IFUs). Francoise Roques proposed an instrument called ULTRAPHOT that would investigate the time-variability of different types of sources using the FLAMES positioner to feed up to 100 objects to a very fast CCD camera. Finally, Matt Lehnert presented super-GIRAFFE, a third possible upgrade of FLAMES/GIRAFFE, aimed at expanding the overall multiplex and throughput.

Summary

The primary outcome of the workshop was that there are two instruments at the VLT — VIMOS and FLAMES — that can be immediately used to address some of the most pressing scientific topics discussed at the meeting. The current ESO wide-field multi-object spectrographs can then keep the ESO community at the forefront of the field until 2015, when the next generation worldwide facilities come on line. However, while FLAMES has been recently upgraded (Melo et al., 2008) with the addition of a new detector, VIMOS needs some urgent repairs to reach the survey efficiency required to meet the scientific goals. An upgrade of VIMOS is planned for the coming year and hopefully will result in an enhanced reliability of the instrument. Thus, the workshop participants applaud ESO's plan to upgrade the red-sensitivity of VIMOS (i.e. replace the CCDs) and to solve some of the mechanical problems that have bedevilled operations in the past.

A call for large public surveys to address some of the astrophysics problems described above could place the European community in a favourable situation before instruments with massive multiplexing go into operation at other observatories. This discussion point was brought to the STC for recommendation and advice. A call for large cosmological redshift surveys is timely and would put European astronomy at the forefront of the relevant fields, if these surveys can be completed before 2014. Similarly, ground-based Gaia preparatory surveys would go a long way towards generating the data required to complement Gaia if the surveys begin soon.

Concerning the proposals for new instruments, the outcome of the workshop is to recommend that ESO make a call for wide-field instrument concepts that could either be entirely new instruments, or upgrades of existing instruments, in line with the ideas that were presented at the workshop. To be consistent with a previous recommendation by STC, these concepts must not include modifications to the VLT telescopes that could in any way compromise the VLT interferometric mode. Thus, at the VLT such an instrument could have a maximum field of view of 30 arcminutes, but must still have a large multiplex of 500 or more. The scientific cases require resolutions between R = 1000 and R = 40000, and a very wide wavelength coverage between 350 nm and 2.2 microns.

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Links

[1] http://www.eso.org/sci/observing/policies/PublicSurveys/

Report on the ESO workshop

ALMA and ELTs: A Deeper, Finer View of the Universe

held at ESO Garching, Germany 24–27 March 2009

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Leonardo Testi[1]

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The workshop explored the scientific synergies between ALMA and the extremely large telescopes that are being planned. The main goal of the workshop was to bring the ALMA and ELT communities together, to identify the common science cases and to outline instrumentation/upgrade priorities for the ALMA and ELT facilities. We provide a brief account of the scientific sessions and the wide-ranging discussions held during this very lively four-day meeting.

The workshop on synergies between ALMA (Atacama Large Millimeter/submillimeter Array) and ELTs (Extremely Large Telescopes) was held at the ESO Headquarters in Garching from 24–27 March 2009. It was motivated by a growing interest the ALMA and ELT communities to understand the capabilities of these large infrastructures better, as they will dominate ground-based astronomy for the next two to three decades. The workshop was particularly timely as both ALMA and the ELTs are actively shaping their future in the coming months: investigating possible upgrade paths for the future in the case of ALMA; and consolidating the priorities for their sites, their instrument suites and adaptive optics capabilities in the case of the ELTs.

Close to a hundred participants from all over Europe, North America and East Asia shared their views and ideas on submm and optical/near-infrared astronomy over the four days. The audience was delighted by outstanding reviews and many interesting scientific highlights. The discussion sessions were very lively and productive. All talks can be found online through the programme pages of the workshop[1].

The programme presented an overview of all the facilities under consideration — ALMA, the Giant Magellan Telescope (GMT), the Thirty Metre Telescope (TMT) and the European Extremely Large Telescope (E-ELT) — on the first day. This was followed by two topical science days, with the first dedicated to distant (extragalactic), the second to nearby (the local Universe) research, before wrapping up with some technical talks as well as a summary and final discussion on the last day.

The ESO Director General opened the meeting by reminding all those present of the privileged position of ESO in co-ordinating both the European efforts on ALMA, as well as leading the largest of the ELT projects. The impressive progress over the last year on ALMA construction was reviewed by Richard Hills, Lars-Åke Nyman presented the concepts of Science Operations and Andrew Blain summarised the scientific cases for the ALMA upgrades for the 2020 horizon. The ELT projects were introduced by Pat McCarthy and Steve Shectman (GMT), Paul Hickson (TMT) and Roberto Gilmozzi (E-ELT), who each summarised the exceptional capabilities of their projects and showing all the projects to be at very similar stages, with completion expected for 2018.

Science days

The two science days were organised with four reviews in the morning and science highlights and discussion in the afternoon. The extragalactic day split the reviews into "Fundamental physics, cosmology, relics of the early Universe", presented by Frank Bertoldi and Xiaohui Fan, and "Galaxy and ISM Evolution" presented by Linda Tacconi and Alvio Renzini. The following day, focusing on the local Universe, split into "Star formation from re-ionisation to the present" reviewed by Ewine van Dishoek and Rob Kennicutt, and "Solar Systems near and far" scrutinised by Bryan Butler and Didier Queloz.

The original idea was to hold discussions on the different strategies of approaching a given topic with ALMA or the ELTs and then highlight the synergies in the various science goals between the different facilities. Perhaps surprisingly, one of the clear outcomes of the meeting was that the submillimetre and optical/infrared communities have already approached each other much more than was originally anticipated, leading to a situation where all reviews already included the full wavelength range — not only in the context of future research, but also in the current state-of-the-art! To many, this general overview strengthened further the impression that ALMA and the ELTs cannot be seen as stand-alone facilities, but each must be viewed as an extremely strong complement to the other, allowing us to tackle the most exciting scientific questions in astrophysics and cosmology in the coming decades. Towards the end of the meeting some talks highlighted the synergies with other major facilities of the future, the James Webb Space Telescope (JWST) and the Square Kilometre Array (SKA), demonstrating how modern astrophysics has gone beyond the old compartmentalisation of wavebands and ground- *v.* space-borne facilities.

Some of the highlights of the cosmology reviews that would be tackled by a combination of ALMA and ELTs included: the prospects for studying both molecular and ionised gas in objects at the epoch of reionisation; various tests of the variability of fundamental constants, such as the fine structure constant (see Figure 1), the electron/proton mass ratio, the proton gyromagnetic ratio, as well as of general relativity; several tests on the nature of dark matter; the evolution of the intergalactic medium (IGM) and stellar populations with cosmic time and various ways of measuring the cosmic deceleration. In tackling many aspects of these topics, ALMA and the ELTs will complement each other almost perfectly.

The extragalactic reviews emphasised how the combination of ALMA and the ELTs is ideally suited to the study of early galaxy evolution from high redshifts to today (see Figure 2). Using examples of the synergies that have developed between the VLT and the Institut de Radioastronomie Millimétrique (IRAM), it was shown that the interplay of the giant facilities will answer many questions, such as: what fraction of star formation is due major *v.* minor mergers *v.* steady accretion; how do galaxies get their gas; how do discs evolve and how do bulges form; what drives the internal evolution of high-*z* star-forming galaxies; how important is feedback; how does chemical enrichment proceed; how does the co-evolution of black holes, Active Galactic Nuclei (AGN) and their host galaxies vary with redshift?

The second science day started with reviews on star formation in which the immense power of ALMA in studying the various phases of star and planet formation was emphasised, but also the key role of the ELTs in complementing these studies was stressed, in particular for the understanding of the inner disc regions in protostellar systems (Figure 3). These facilities will straddle the boundaries of Galactic and extragalactic star formation. Targets for ALMA–ELT studies have and will come from unbiased submillimetre and infrared wide-field surveys. We were also reminded that there are many areas where we currently know little or nothing at present, and how important their understanding will become for the full exploitation of ALMA/ELT data. High impact will come from investigations of fundamentals such as the initial mass function (IMF), the CO to HII ratio, the structure of the interstellar medium, the formation of complex molecules and stellar physics.

Finally, the last science session considered our Solar System and exoplanets. Bryan Butler reminded us that the planets in our Solar System are "not just calibrators" — understanding their structure and properties is a very lively research field and a "Rosetta Stone" for our understanding of other planetary systems. Even in an era of *in situ* exploration by space vehicles, ground-based facilities will still play a key role in the study of the Solar System. ALMA and the ELTs will complement each other strongly in the study of planetary atmospheres, as well as in characterising Trans-Neptunian Objects (TNOs) and minor rocky bodies beyond their simple dynamical parameters. This study would open the doors to a full understanding of the formation of planetary systems. Beyond our Solar System, the strength of ALMA is to be able to detect protoplanets forming within protoplanetary discs, while the ELTs will observe young to old planets. Earth-like exoplanets will probably have been found by the advent of the ELTs, but their characterisation and systematic imaging will be the tasks of the new facilities.

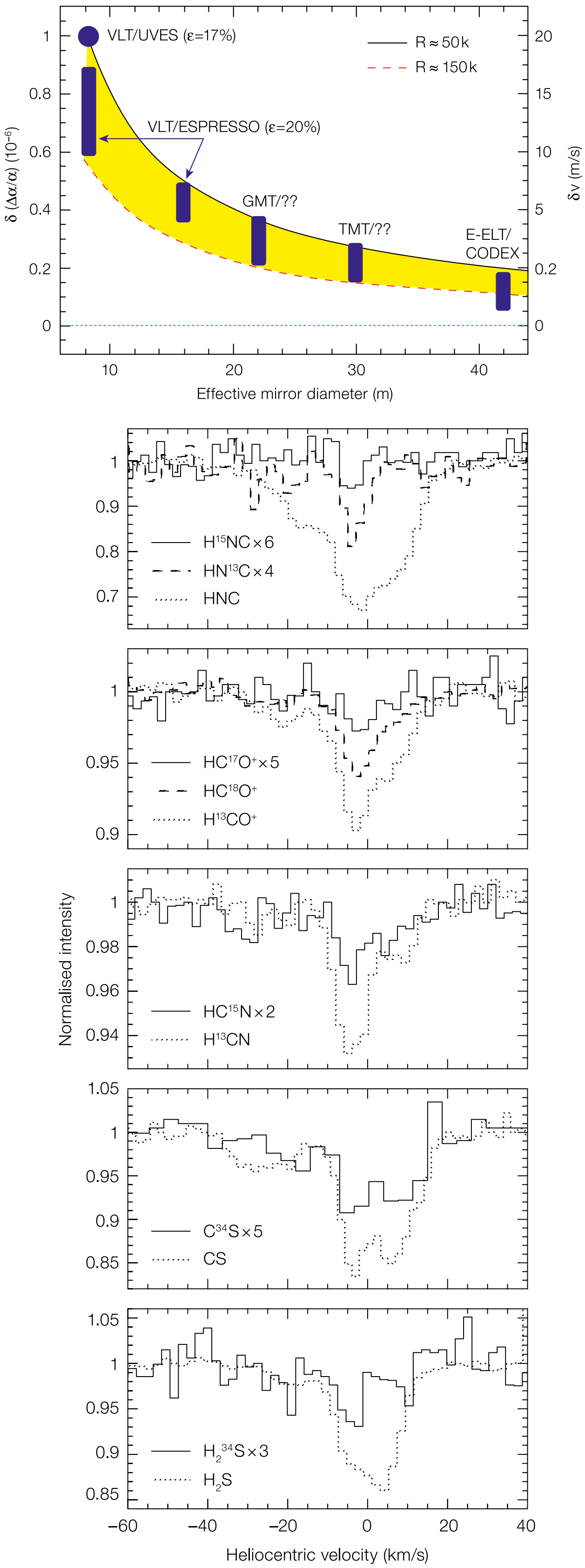

Figure 1. Prospects for measuring the possible cosmic variation of the fine structure constant with current and future high resolution optical spectrographs. The expected precision reachable with high resolution ultra-stable optical spectrographs is shown as a function of the telescope effective diameter (adapted from Murphy). ALMA will be able to provide complementary constraints by measuring the cold narrow molecular lines at extremely high spectral resolution; as an example, the mm absorption line system at $z = 0.89$ along the line of sight to PKS 1830-211 is shown (Muller et al., 2006).

Figure 2. The Antennae galaxy merger, a relatively nearby merger that triggered intense star formation and the production of super star clusters. From left to right images in the optical (Hubble Space Telescope), infrared (Spitzer Space Telescope) and millimetre continuum (Caltech Submillimeter Observatory). ALMA and the ELTs will allow images to be obtained at a comparable level of detail for mergers at high redshift.

Discussions

The discussion session focused on questions such as what are the main synergies between the facilities? Which ELT instruments and/or ALMA upgrades would maximise the synergies? Do the communities of the facilities need to be brought still closer together? Do formal links between the communities/facilities have to be established? Should systematic programmes be established with ALMA to prepare for ELT observations?

All these questions were discussed in the various sessions and picked up in the conference summary presented by James Di Francesco. The overall impression was that very strong synergies existed in all fields of astrophysics and that the community had already identified the vast majority of them and was actively preparing to meet the challenges. Young astronomers are being trained across the wavelength domains and are not waiting for the giant facilities to operate in order to prepare themselves for the optimal use of the data. Yet, further cross-fertilisation activities should be organised to keep up the momentum and institutes should aim at hiring the right mix of researchers from both communities. Top-rated instruments for ELTs that would clearly enhance the synergy with ALMA are high resolution optical and infrared spectrographs and near-/mid-infrared imagers and integral field spectrographs, while ALMA would profit from long baselines and Bands 1 and 5. Formal connections between the projects seem premature at this point, but will certainly be thought of in due time. More importantly, the data from all facilities should be made accessible to the entire community and the reduction/analysis tools should be designed to encourage non-experts to use them.

In summary, the meeting was very well attended and enabled very lively discussions between the communities. It demonstrated, maybe even more strongly than had already been assumed, the huge impact that the combination of ALMA and the ELTs will have on the full breadth of observational astrophysics and cosmology, extending to planetary science and fundamental physics. We are truly looking forward to two most exciting decades in astronomy. A summary of the workshop in the form of a 30-page booklet will appear in the course of 2009.

Acknowledgements

The organisers are most grateful to the SOC and the LOC (in particular to Christina Stoffer for handling the full logistics, and Annalisa Calamida for her help with the workshop pages). The review speakers are also thanked for their excellent job in summarising their fields, and all the speakers for very interesting and enjoyable talks, all of a high standard.

Links

[1] http://www.eso.org/almaelt2009

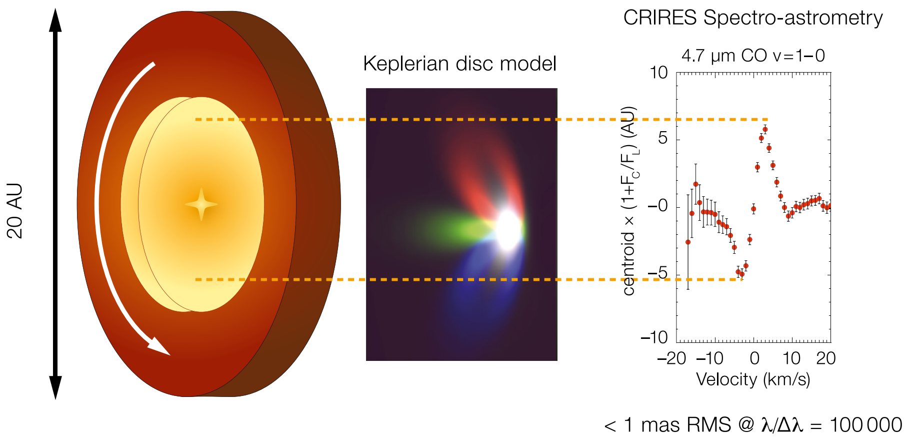

Figure 3. The inner regions of a protoplanetary disc explored with spectroastrometry with CRIRES. The ELTs equipped with high spectral resolution infrared spectrographs will allow a detailed study of the gaseous component of the inner regions of protoplanetary discs, while ALMA will provide a unique view of the processes in the cold outer regions of the systems (adapted from Pontoppidan et al., 2008).

ESO at JENAM 2009

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From 20 to 24 April over 1100 astronomers celebrated the European Week of Astrophysics and Space Science at the University of Hertfordshire in Hatfield, UK. The occasion was the joint meeting of the Royal Astronomical Society (RAS) and the European Astronomical Society (EAS). These meetings are generally known as the National Astronomy Meeting (NAM) for the UK and the Joint European National Astronomy Meeting (JENAM). The scientific programme was divided into plenary sessions in the mornings, followed by parallel sessions during the afternoons and flanked by meetings of the EAS and the RAS.

Francoise Combes (Observatoire de Paris) received the EAS Tycho Brahe prize and gave a lecture on galaxies with decoupled kinematical components. ESO and ESA were each asked to organise one plenary session and to offer several parallel sessions. ESO also hosted a prominent exhibition stand in the main thoroughfare between the lecture halls that became a popular meeting point for astronomers (see Figure 2).

The meeting was opened by Lord Drayson, the British Minister of State for Science and Innovation, who emphasised the importance of astronomy and space science for today's society. Lord Drayson then visited the various exhibitions — including the ESO stand, where he had a long conversation with Tim de Zeeuw, the ESO Director General, and Patrick Roche, the UK member of the ESO Council. Lord Drayson showed great interest in VLT operations, the ALMA construction activities and ESO's plans for the future ELT (see the photograph on the Astronomical News section page).

The ESO plenary session was scheduled for the second day and was opened by Tim de Zeeuw with an overview of ESO's programmes and plans. He was followed by Michel Mayor (Geneva Observatory) who presented a discovery made with data from the 3.6-metre telescope at La Silla — that of the lightest yet known exoplanet, with only 1.9 Earth masses, orbiting Gliese 581. This star harbours a planetary system, now known to have at least four planets, one of which lies within the habitable zone. Linda Tacconi (Max-Planck-Institut für Extraterrestrische Physik) presented exciting results of the kinematics of massive galaxies at redshifts between 1.5 and 3. She demonstrated how the combination of millimetre and infrared observations can shed light on the structure of these distant galaxies and what can be learned about how these galaxies form and evolve.

Five symposia and 26 special sessions were organised in addition to the plenary sessions. These symposia and sessions covered essentially all of astrophysics and many astronomers struggled to decide which talks to attend and what to miss out on. Many exchanges took place between astronomers who were catching up on a missed session. Three of the special sessions concerned specific ESO issues: status reports on the E-ELT study, updates on ALMA's construction and plans for its scientific exploitation, and a session devoted to informing the community on how to make the best use of the existing telescopes on La Silla and Paranal.

The ESO exhibition was centrally placed and many astronomers stopped by to catch up on the latest developments at ESO. In addition, ESO organised two press conferences: a very successful conference to announce the discovery of the exoplanet with the lowest mass yet and another, less visited, to inform the public about the progress in the planning for the E-ELT.

This year's JENAM was one of the largest astronomical meetings in Europe and the organisers should be congratulated for its smooth running and an exciting programme. The pictures from the ESO exhibition reflect the breadth of the ESO activities and the interest taken by astronomers.

Figure 1. The thin VLT mirrors explained to future users.

Figure 2. ESO's exhibition stand was a popular spot at JENAM 2009.

ESO Fellowship Programme 2009/2010

The European Organisation for Astronomical Research in the Southern Hemisphere awards several postdoctoral fellowships each year. The goal of these fellowships is to offer young, outstanding scientists opportunities and facilities to enhance their research programmes by facilitating close contact with the activities and staff at one of the world's foremost observatories.

For all fellowships, scientific excellence is the prime selection criterion. The programme is open to applicants who have earned (or will have earned), their PhD in astronomy, physics or related disciplines before 1 November 2010. Young scientists from all fields of astrophysics are welcome to apply.

In Garching, the fellowships start with an initial contract of one year followed by a two-year extension (three years in total). The fellows spend up to 25% of their time on support or development activities in the area of instrumentation, operations support, archive/virtual observatory, VLTI, ALMA, ELT, public affairs or science operations at the Observatory in Chile.

In Chile, the fellowships are granted for one year initially with an extension of three additional years (four years in total). During the first three years, the fellows are assigned to one of the operations groups on Paranal, ALMA or APEX. Fellows contribute to the operations at a level of 80 nights per year at the Observatory and up to 35 days per year at the Santiago Office. During the fourth year there is little or no functional work and several options are provided. The fellow may be hosted by a Chilean institution (and will thus have access to all telescopes in Chile via the Chilean observing time). Alternatively, she/he may choose to spend the fourth year either at ESO's Astronomy Centre in Santiago, or at the ESO Headquarters in Garching, or at any institute of astronomy/astrophysics in an ESO member state.

In addition to pursuing independent research, all fellows will have ample opportunities for scientific collaboration within ESO, both in Garching and Santiago. For more information about ESO's astronomical research activities and available projects open for collaborations to fellows please consult www.eso.org/sci/activities/ESOfellowship.html. A list of current ESO staff and fellows and their research interests can be found at www.eso.org/sci/activities/personnel.html. ESO Headquarters in Munich, Germany, is situated in the immediate neighbourhood of the Max-Planck-Institutes for Astrophysics and for Extraterrestrial Physics and only a few kilometres away from the Observatory of the Ludwig-Maximilian University. ESO is participating in the newly formed Excellence Cluster on Astrophysics on the Garching campus. In Chile, fellows have the opportunity to collaborate with the rapidly growing Chilean astronomical community as well as with astronomers at other international observatories located in Chile. The anticipated 2010 completion of the new ALMA building next to ESO's Santiago offices will further enhance the stimulating scientific environment available to ESO Chile fellows.

We offer an attractive remuneration package including a competitive salary (tax-free), comprehensive social benefits, and provide financial support for relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added. The Outline of the Terms of Service for Fellows provides some more details on employment conditions/benefits.

Candidates will be notified of the results of the selection process between December 2009 and February 2010. Fellowships begin between April and October of the year in which they are awarded. Selected fellows can join ESO only after the completion of their doctorate.

The closing date for applications is 15 October 2009.

Please apply by filling the web form available at the recruitment page http://jobs.eso.org attaching to your application (preferred format is PDF):

– your Curriculum Vitae including a list of publications (refereed papers only);

– your proposed research plan (maximum two pages); and

– a brief outline of your technical/observational experience (maximum one page).

In addition three letters of reference from people familiar with your scientific work should be sent directly to ESO to vacancy@eso.org by the application deadline.

Please also read our list of FAQs regarding fellowship applications (http://www.eso.org/sci/activities/ESOfellowship-faq.html).

Questions not answered by the above FAQ page can be sent to Marina Rejkuba, Tel. +49 89 320 06-453, Fax +49 89 320 06-898, E-mail: mrejkuba@eso.org

ESO ALMA Fellowship Programme 2009/2010

The European Organisation for Astronomical Research in the Southern Hemisphere awards several postdoctoral fellowships each year. The goal of these fellowships is to offer young outstanding scientists opportunities and facilities to enhance their research programmes by facilitating close contact with the activities and staff at one of the world's foremost observatories.

As ALMA will become operational in a few years, ESO is offering additional ALMA Fellowships — funded by the Marie-Curie COFUND Programme of the European Community (http://cordis.europa.eu/fp7/people/cofund_en.html) — to complement its regular fellowship programme. Applications by young astronomers with expertise in mm/submm astronomy are encouraged.

The programme is open to applicants who have earned (or will have earned), their PhD in astronomy, physics or related disciplines before 1 November 2010. Young scientists from all astrophysical fields are welcome to apply.

For all fellowships, scientific excellence is the prime selection criterion. The selected candidates may choose to work at one of the European institutes hosting an ALMA Regional Centre (ARC) node (Bologna, Bonn, Grenoble, Leiden, Mancester, Onsala) or at ESO in Garching. More information about the ARC nodes can be found at: www.eso.org/sci/facilities/alma/arc/. Following the mobility rules of the Marie-Curie Programme, some restrictions may apply: a fellow cannot be hosted by an institution if he/she has spent more than 12 months in the same country as the selected ARC node over the last three years.

Fellowships last for three years, with an initial contract of one year followed by a two year extension. In addition to the excellent scientific environment, where fellows can develop their scientific skills, fellows are encouraged, as part of the diverse training ESO offers, to take part in some functional work related to ALMA (in instrumentation, operations, public relations, etc.) for up to 25% of their time.

We offer an attractive remuneration package including a competitive salary (tax-free), comprehensive social benefits, and provide financial support for relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added. The Outline of the Terms of Service for Fellows provides some more details on employment conditions/benefits.

Candidates will be notified of the results of the selection process between December 2009 and February 2010. Fellowships begin between April and October of the year in which they are awarded. Selected fellows can join an ARC node only after the completion of their doctorate.

The closing date for applications is 1 November 2009.

Please apply by filling the web form available at the recruitment page http://jobs.eso.org attaching to your application (preferred format is PDF):

- your Curriculum Vitae including a list of publications (only refereed papers);
- your proposed research plan (maximum two pages);
- a brief outline of your technical/observational experience (maximum one page); and
- a list of three ARC nodes, in order of preference, where the fellowship will be taken.

In addition, three letters of reference from people familiar with your scientific work should be sent directly to ESO to vacancy@eso.org by the application deadline.

Please also read our list of FAQs regarding fellowship applications (http://www.eso.org/sci/activities/ESOfellowship-faq.html).

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E-mail: mrejkuba@eso.org

A New Service for the ESO Community: The Science Data Products Forum

ESO supports its telescope users through a wide variety of avenues. At the La Silla Paranal Observatory, night astronomers carry out service observations and assist with observations undertaken by visiting astronomers. In Garching, the User Support Department helps throughout the observing process, starting with Phase I and II proposal preparations. The archive helps to publish finished data products. ESO also distributes calibration data and software to reduce the data.

In addition to the years of direct experience acquired by ESO staff with the telescopes, there is a vast pool of expertise within the ESO community. Many experienced users are willing, or even eager, to share their knowledge and the tools and methods they have developed. However, for general users, it is often difficult to locate the specific knowledge they might need. To help and encourage the sharing of relevant knowhow, ESO has opened a new internet forum that can be used to discuss any issues related to ESO data.

This Science Data Products Forum is intended for:

– discussions of observing strategies that impact on the science output, including alternative or refined methods and non-standard modes;

– discussions of calibration and reduction issues, including methods, algorithms and software;

– sharing home-grown software such as scripts or small packages written by users that are not otherwise distributed;

– sharing calibration data produced by users, including those that apply to special circumstances or non-supported modes;

– discussions of any other topic related to science products from ESO telescopes.

The forum can be used both to request information and to offer and share experience gained in dealing with ESO data.

The forum was established in response to requests by users and its success will depend on the contributions from the ESO community. ESO encourages anybody with relevant experience to look at and post to this forum. To access the forum, simply direct a Java-enabled browser to http://eso.org/sci/data-processing/forum.html.

Announcement of the ESO/MPE/MPA/USM Joint Workshop

From Circumstellar Disks to Planetary Systems

3–6 November 2009, Garching, Germany

The study of circumstellar disks and the formation of planetary systems has made enormous progress in recent years. New and exciting developments range from evidence for grain growth and settling (the first steps in planet formation) as the disks evolve, to the development of gaps and holes in a new set of transition disks, and to the direct detection of (proto-) planets around pre-main sequence stars. New facilities with enormous potential are lining up and are expected to start producing a wealth of new data: the Herschel Space Observatory in 2009 and the Atacama Large Millimeter/submillimeter Array (ALMA) with the opening of early science in 2010. In the more distant future, the topic of protoplanetary disks is also a key theme for the Extremely Large Telescopes.

The goals of the workshop will be to review the status of the field and to discuss transformational programmes that will be made possible with these upcoming facilities. The meeting will bring together communities working with ground-based infrared large telescopes and interferometers, space observatories and millimetre interferometers, as well as theorists.

The main topics to be addressed at the workshop are:

1. Properties of circumstellar disks across the stellar mass spectrum
2. Evolution of protoplanetary disks
3. Chemistry in disks (gas phase and solids)
4. Initial phases of planet formation
5. Young (proto-)planets
6. Planet–disk interactions
7. Debris disks

The deadline for abstract submission is 1 July, and the closing date for registration is 10 September 2009.

Scientific Organising Committee:
Y. Aikawa (Kobe Univ.), M. van den Ancker (ESO), J. C. Augereau (LAOG), A. Burkert (LMU), J. Carpenter (Caltech), F. Comerón (ESO), E. van Dishoeck (Leiden/MPE, co-chair), J. Greaves (St. Andrews), Th. Henning (MPIA), U. Käufl (ESO), F. Malbet (LAOG), L. Testi (ESO, co-chair), and G. Weigelt (MPIfR).

Further information can be found at: http://www.eso.org/sci/meetings/disks2009/

New Staff at ESO

Eric Emsellem

Eric Emsellem

Coming back to ESO, 13 years after my first post here: impressive changes in Garching and Munich, and a large chunk of life on my side, quite a happy bit in fact. So why leave such a beautiful city (Lyon), the French capital of Gastronomy (G's are important), with such a relaxing atmosphere, wondrous surroundings, fine weather...?

Although I can, very probably, claim blood ties to too many wanderers and migrants, including Swiss, Italian, Spanish, Belgian, Maltese, Kabyle, and more relevantly from Visigoths, this is obviously not what led me back to ESO. I am in fact privileged enough that I can today carry out my passion as an astronomer, which took hold of me quite early on, while watching the sky during long summer nights in the countryside of France. For many years, I forgot about that passion, and after maths and physics studies in Paris, I directed my steps towards an Engineering School in Lyon. I soon realised this was a mistake, and took my chance to cross the ocean and spend some time at Cornell University as a Masters student. I have a degree in engineering, but this is clearly not my field: my first self-built piece of instrumentation (a laser-controlled Fabry-Perot) required part of the enclosure to be sawn off to make the instrument fit during commissioning at the IRTF (NASA Infrared Telescope Facility, Hawaii), and well, it didn't work anyway.

I then decided that −20°C was not the best temperature at which to spend my winters, and had the opportunity to head back to Lyon for a PhD, working on all sorts of galactic nuclei (axisymmetric, presumed triaxial, single or double) with the help of the first of a series of integral field units (IFUs), the (in)famous "TIGER" spectrograph. You could then easily remember every pixel of every spectrum, and I certainly knew each individual lens by their nicknames. Glorious days! I then spent more than two years in Leiden as an EARA postdoc, followed by a fellowship at ESO Garching. I was still in the business of galactic dynamics, and contributed to writing, with Niranjan Thatte, the ESO document that got SINFONI accepted by the Scientific and Technical Committee. Of course the IFU now at the VLT does not look at all like the one described in that document.

I finally came back to Lyon as Associate Astronomer at the Centre de Recherche Astrophysique de Lyon (CRAL), and a few years later led the TIGER team, to merge finally with the cosmology group to become GALPAC (Galaxy Physics and Cosmology). I served a few years as French–INSU deputy for Anne-Marie Lagrange and Jean-Marie Hameury, and more briefly as deputy director of CRAL. I became a Full Astronomer in 2006. During these very happy years in Lyon, I always enjoyed standing between the pure modelling and observational sides, and had the chance to witness the evolutionary line from TIGER to OASIS, and then SAURON and now MUSE. But time to move on! To paraphrase many, I cannot think right now of a place better than ESO for astronomy. Staying close to junior and senior researchers, and doing my best to catalyse science activities in Garching, with a strong link to Chile (thanks to Michael West), is both an exciting task and a challenge.

I, of course, had to ponder over a few things though. The first one is my irrepressible taste for fermented grape juice (I was born in Bordeaux). But living in Munich should not prevent me from pursuing this quest — so many vintages to discover, so little time. The second one may be related to the fact that most of my ancestors spent their lives near the sea. An inaccurate translation from German nearly tricked me here: I am a southern person, and I would need more than just an encouragement to dive deep into these Garchinger/Echinger/Starnberger "See" things, even if the Chiemsee is also known as the Bavarian Sea. But apart from that, Munich, with its size, number of inhabitants, rich culture, pork specialties, the nearby Alps, its weather and landscapes, it is probably as close as you can get to Lugdunum on a German-speaking country. I sincerely feel fortunate to live such an experience. I sometimes hear that "Emsellem" means "good star": it is certainly just a lie (a nice one though), but clearly stars and luck have been my best friends for decades.

Francisco Miguel Montenegro Montes

Although I was born and grew up in Madrid, my roots spread further to the southern region of Spain, near the city of Córdoba, where most of my family lives. When I was twelve I won my first telescope in a road safety education contest at school. It was a 5-cm diameter refracting telescope with a poor quality wooden tripod, but enough for me to have my first direct encounter with the craters and valleys on the Moon and the few bright "stars" visible at that time in the skies of Madrid.

To a great extent I was motivated to become a professional astronomer by the fascinating science fiction stories and outreach literature that captured my interest at that time. The library of the local amateur astronomy group (AAM, Agrupación Astronómica de Madrid) was a fantastic place to find such videos and books. I remember the excellent "Cosmos" TV series by Carl Sagan with particular fondness. In one episode he was peacefully walking over his one-year "cosmic calendar" while explaining the history of the Universe in half an hour, in another relating how Erastothenes of

Francisco Miguel Montenegro Montes

Cyrene could manage to measure the circumference of the Earth with remarkable accuracy many centuries ago.

At some point I started studying physics (and lots of mathematics) at the Universidad Complutense de Madrid. Later, I moved to the Canary Islands to complete my studies and there I had the first opportunity to explore the clear Canarian skies with a professional telescope: the IAC-80 at the Teide Observatory in Tenerife. For my PhD I moved to the heart of the province of Emilia-Romagna in Italy. At the Istituto di Radioastronomia in Bologna I started to study the Universe with different "eyes". There I learnt about dishes, interferometers, correlators and day-time (non-solar) observations! In those years I gained experience with the use of several astronomical facilities around the world, like the 100-metre radio telescope in Effelsberg (Germany), the IRAM 30-metre single dish in Granada (Spain) and the VLA and VLBA arrays in the US.

I have been studying the radio emission from an interesting group of quasars, Broad Absorption Line (BAL) quasars. Forty years have passed since their discovery and it is still not clear why about 15% of quasars develop the winds that give rise to the absorption troughs we can see in the optical spectrum of BAL quasars. We have tried to use radio observations to find hints about the orientation and evolutionary status of these distant objects. I am involved in an international collaboration with participation from Italy, Spain, the Netherlands and Chile that aims to study these objects with a multi-wavelength approach.

Since December 2008 I've been working at ESO in the APEX Science Operations group. This is a great new experience for me in various ways. Working in the Atacama desert is sometimes a surprising adventure where I can find wild donkeys in the middle of the ALMA road and thousand-year-old cacti. But it is also one of the driest atmospheres in the world, which makes this prototype a privileged eye at mm and submm wavelengths. Every day I learn something new about the telescope and its many instruments. In my still short stay here, APEX has performed very important observations (see for example, the cover of last issue of *The Messenger*, 135) and I'm pretty sure it will continue like this for several years, successfully scrutinising the dry skies above Chajnantor.

The Integral Field Spectroscopy Wiki

The field of integral field spectroscopy (IFS) is now well developed, with IFS instruments installed on all the main optical telescope facilities around the world. Some of the most sophisticated are available on the VLT. However IFS continues to be avoided by large sections of the astronomical community due to perceived difficulties with data handling, reduction and analysis. There is no doubt that dealing with IFS data is more complicated than simple imaging or long-slit spectroscopy, but many of the problems that arise could easily be avoided by benefiting from the experience and knowledge of others.

In order to facilitate exchange of IFS knowledge, a repository of information, tips, codes, tools, references, etc., accessible and editable by the whole community, has been initiated. The wiki is intended for use by IFS beginners for any questions or issues with IFS data and for more expert users who are invited to contribute tips, experience of particular instrumental quirks, pieces of code, etc.

Topics covered by the wiki are:

- current and future integral field spectrographs;
- observational techniques and planning;
- data reduction, including overview of procedures for different types of IFS;
- more advanced tasks like mosaicing or differential atmospheric refraction (DAR) correction;
- analysis techniques, from visualisation to line fitting and source extraction.

The originators and maintainers of this site are currently Katrina Exter (Katholieke Universiteit Leuven, Belgium) and Mark Westmoquette (University College London, UK). To access the wiki go to: http://ifs.wikidot.com

Fellows at ESO

Carla Gil

Carla Gil

I decided that I wanted to be an astronomer when I first visited the Lisbon Planetarium. I was six years old at the time, and had no clue what astronomy was about! I just remember my school drawings went from being little houses and trees to stars and planets.

I lived in Lisbon until I was 18, and one day I came home and told my parents I was moving to Porto because that was the only place where I could study astrophysics. Portugal is a small country, and as you can imagine astronomy is not one of the most popular careers to pursue. However, my family was always very supportive of my choices and I was lucky to be one of the few people to be given such an opportunity.

I did my undergraduate studies at the University of Porto and after that I moved to Italy where I worked on my master's thesis at the Osservatorio di Capodimonte as part of the European Solar Magnetism Network. I started my PhD shortly after that and this time I moved to Grenoble, France.

I obtained a joint degree from the University Joseph Fourier and the University of Porto. My thesis research consisted of studying interferometry and its application to the study of ejection processes close to pre-main-sequence stars. I worked on the AMBER instrument, the three beam combiner for the VLT, during the time I spent in France. When the instrument was shipped to Paranal I was awarded an ESO studentship in Chile, where I spent two years finishing my PhD and I had the privilege of participating in the assembly, integrations and first light of AMBER.

I joined ESO as a fellow in June 2006. My duties consisted of observing 80 nights per year at the VLTI and being instrument fellow for the AMBER instrument. I am now finishing my third year of a postdoc in Chile and soon will be moving back to Europe. One of the good things about the ESO fellowship in Chile is that it allows us to do a fourth year postdoc devoted full-time to research in any of the ESO member countries. I am moving to Northern Ireland, where I will be kindly hosted by the Armagh Observatory for the next year. After five years in Chile it is now time to start a new adventure in a different place. I am looking forward to the green landscape, but will, for sure, miss the unusual workplace I have had for the last few years where no living species can survive, apart from astronomers!

Thomas Stanke

Looking out of the window I can see buses bringing the workers from the Chajnantor plateau back to their "low-elevation" camp (3000 m above sea level). My "functional duty" work at ESO is to do service observations at the APEX telescope, located right next to the construction site of the ALMA array, at an elevation of 5100 m; if I have written anything that seems stupid, I can easily blame it on the lack of oxygen (I just walked up three steps to measure my blood oxygen, it's 85% of normal, pulse is at 110 bpm, and that's without actually doing anything). Working at APEX is one of the few possible ways to see Chajnantor and the progress of work up here on a regular basis, and yes, there is progress. Every time I come back, there are a few more antennas around, more foundations, construction spreading out, and more speed limit signs on the ALMA road up to Chajnantor!

Working at APEX, i.e., being sort of a radio astronomer, however also means being a bit of a freak within ESO, although the community of freaks (those radio astronomers, just imagine, they also observe during daytime....) is growing, with ALMA nearing the beginning of operations. As my research interests are in the field of star formation, I use observations covering a wide wavelength range, so luckily, I'm only half of a freak, doing a fair fraction of my work at infrared and optical wavelengths.

While I did of course look at the skies as a kid, with binoculars, or without, I never really planned to become an astronomer. First, I wanted to be an archaeologist (well, astronomers and archeologists do pretty much the same — try to find out about the big picture with very little information). But after a while, I became more and more interested in physics, so I studied physics in Würzburg. I always thought that it could be interesting to work in research, either on the small scale (particle hunting), or on the large scale. But it was not until I had to look around for a theme for my diploma thesis that I got hooked up with astronomy, after I had found the way to the Würzburg University Astronomy Department, hidden on the fourth floor of the mathematics building. There, Professor Yorke told me that yes, there may be some things to work on, I should talk to Herr Zinnecker, but NOW, as he was just back from travelling, and would leave for the next trip in two hours, and indeed, Herr Zinnecker found, after some digging, a DAT tape with some 10-μm data of binaries I could work on.

Starting from 10 μm, I then first worked my way to shorter wavelengths, and did my PhD thesis on a *K*-band (not the radio but the infrared one) imaging search for protostellar outflows in Orion, following Herr Zinnecker to Potsdam. The original idea of that project was to use the outflows as pointers to protostars, but as I collected my data at the Calar Alto Observatory (which can be a pretty good site, but in December there's a fair chance of getting stuck in fog for days...), the millimetre guys had time to develop ever larger bolometer arrays, and in the end I started to search for protostars directly, shifting to wavelengths 500 times longer and moving to the

Thomas Stanke

Max-Planck-Institut for Radioastronomie in Bonn. Apart from regular observing trips to the IRAM 30-metre telescope, I also took the opportunity to observe at a real radio telescope in Effelsberg, and found it very impressive that one can indeed observe in pouring rain (those radio astronomers...). During that time, I started to observe my dear outflows also in millimetre CO lines, and envisaged the higher excitation lines, possibly at higher resolution, which led to the next move to the IfA in Hawaii. The main motivation was to use the SMA, but as the IfA has access also to all the other nice things on top of Mauna Kea, I had a lot more toys to play with. And Hawaii is not only nice for doing astronomy. However, it's also a pretty expensive place to live. So, after two years, when I was offered the ESO fellowship, we were among the very few people who are delighted to see that the rents in Munich and surroundings are quite affordable (well, at least if you have the Hawaii experience...).

But now, my fellowship is about to end. I have found ESO a very interesting place to work, having contact with the progress on the next generation of major observatories almost every day. Still, having left Hawaii's beaches and telescopes behind hurts a bit (mostly the beaches, particularly for my family), but we also love the Biergarten in Garching. Maybe you should not be too surprised then, if some day you see an original Bavarian Biergarten on your next observing trip to Hawaii.

Personnel Movements

Arrivals (1 April–30 June 2009)

Europe	
Lange, Uwe (DE)	Software Engineer
Gube, Nikolaj (DE)	Legal Advisor
Schmidt, Sandra (DE)	Secretary/Assistant
Nilsson, Kim (SE)	Astronomer
Santander Vela, Juan de Dios (ES)	Applied Scientist
Justen, Benedikt (DE)	Student
Böhnert, Alex (DE)	Student

Chile	
Martayan, Christophe (FR)	Operations Astronomer
Spille, Christian (DE)	Site Safety Officer
Vanderheyden, Pierre (BE)	Electrical Engineer
Marti Canales, Javier (ES)	Lead System Engineer
Amira, Maria Soledad (CL)	Executive Administration Officer
Rojas, Pascual (CL)	Electrical Maintenance Technician
Gajardo, Gabriela (CL)	Administrative Assistant – Legal
Pretorius, Magaretha (ZA)	Fellow
Lynam, Paul (GB)	Operations Astronomer

Departures (1 April–30 June 2009)

Europe	
Zech, Gabriele (DE)	Software Engineer
Moloney, Catherine (GB)	Student
Spaleniak, Izabela (PL)	Student

Chile	
Lidman, Christopher (AU)	Astronomer
Gutierrez, Adriana (CL)	Administrative Assistant
Scharwächter, Julia (DE)	Fellow
Monaco, Lorenzo (IT)	Fellow
Doherty, Michelle (AU)	Fellow
De Ugarte Postigo, Antonio (ES)	Fellow
Eschwey, Joerg (DE)	European Site Development Manager

ESO is the European Organisation for Astronomical Research in the Southern Hemisphere. Whilst the Headquarters (comprising the scientific, technical and administrative centre of the organisation) are located in Garching near Munich, Germany, ESO operates three observational sites in the Chilean Atacama desert. The Very Large Telescope (VLT), is located on Paranal, a 2 600 m high mountain south of Antofagasta. At La Silla, 600 km north of Santiago de Chile at 2 400 m altitude, ESO operates several medium-sized optical telescopes. The third site is the 5000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a submillimetre telescope (APEX) is in operation, and a giant array of submillimetre antennas (ALMA) is under construction. Over 2 000 proposals are made each year for the use of the ESO telescopes.

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

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Contents

Front Cover: The well-known Helix planetary nebula (NGC 7293) is shown in a colour image taken with the MPG/ESO 2.2-metre telescope and Wide Field Imager. Images in *B*-, *V*- and *R*-band filters with exposures of 12, 9 and 7 minutes respectively were combined. The nebular shell is stronger in low ionisation emission of [N II] and Hα (red), while the central region is brighter in high ionisation [O III] emission (green). Background galaxies can be seen through the low surface brightness nebular emission.