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The ASTRONET Infrastructure Roadmap: A Twenty Year Strategy for European Astronomy

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Figure 1. The broad coverage of the ASTRONET Infrastructure Roadmap.

The process followed by ASTRONET to build a long-term strategy for European astronomy is presented. The main conclusions and priorities given in the recently unveiled report on the Infrastructure Roadmap for the next 20 years, following the establishment of a Science Vision last year, are summarised. These reports together hopefully represent a blueprint for a bright future for European astronomy.

Astronomy is experiencing a golden era, with recent epochal discoveries from the identification of the first exoplanets to the hunt for the still-unidentified dark matter and the enigmatic dark energy. Europe is presently at the forefront of astronomy in essentially all areas, a quite recent achievement that has been largely gained by learning to cooperate on a multilateral basis, especially through ESA and ESO, although the backbone of European astronomy remains the scientists and research programmes at the national level. Addressing the scientific challenges of the future now requires a much higher cooperation level, based on a long-term strategy underpinned by vibrant national communities; in short a true European Research Area in astronomy. In view of fierce, worldwide competition, it is also a must for Europe to be a strong international partner in large global projects.

To meet this challenge, a group of European funding agencies created ASTRONET *(http://www.astronet-eu.org)*, a 2005–2009 programme funded by the European Commission to create a comprehensive long-term plan for European astronomy. The now much-enlarged consortium comprises 29 agencies, representing most of the astronomical resources across Europe. The ASTRONET playing field is equally broad, covering both ground- and space-based facilities and the whole astronomical domain from the Sun, and Sun–Earth connection, to the primordial Universe, with every conceivable observational means (photons, astroparticles and gravitational waves).

The strategic planning activity was conducted in two successive steps. The first was the development with the community of an integrated Science Vision, which identifies the key astronomical questions that may be answered in the next 20 years or so by a combination of observations, simulations, laboratory experiments, interpretation and theory. This step was concluded in September 2007 with the public release of the Science Vision *(http://www.astronet-eu.org/-Science-Vision-)*, as reported in Monnet et al. (The Messenger, 130, 2, 2007). The next step was to construct a Roadmap that defines the required infrastructures and technological developments, leading to a long-term implementation plan. This is now being concluded with the public release of the final Infrastructure Roadmap at the end of November 2008 *(http://www.astronet-eu.org/-Infrastructure-Roadmap-)*. This article presents the process leading to the release of the Roadmap and its main results and concludes with a rough sketch of the implementation steps ahead.

The Infrastructure Roadmap process

The process started in late 2006, led by Michael Bode, with the help of Maria Cruz (then at Liverpool John Moores University) and Frank Molster (Leiden University). It built on the Science Vision input, an analysis of the main scientific questions, addressed under four broad headings: (1) Do we understand the extremes of the Universe?; (2) How do galaxies form and evolve? (3) What is the origin and evolution of stars? (4) How do we fit in? In doing so, the Science Vision identified generic types of research infrastructures required to answer key questions under each heading. The aim of the Infrastructure Roadmap was to define and prioritise the specific developments needed to get the required observing capabilities and to set up a realistic plan to reach these goals, taking into account the expected human and material resources. The ASTRONET Roadmap thus complements the European Strategy Forum on Research Infrastructures (ESFRI) selection of a number of infrastructure flagships over all sciences, but goes one step further by tracing the future astronomical landscape — adding smaller-scale, but still much-needed, facilities, identifying promising research and development (R&D) areas and addressing the hard facts of implementation.

In a rather similar way to the Science Vision, the Roadmap was developed primarily on scientific grounds by five specialist panels, supervised by a working group appointed by the ASTRONET board. The first three Panels covered observational domains: high energy astrophysics, astroparticle astrophysics, and gravitational waves (Panel A); ultraviolet, optical, infrared and radio/mm astronomy (Panel B); solar telescopes, Solar System missions and laboratory studies (Panel C). Two other Panels considered respectively the parallel needs regarding theory, computing facilities, networks and virtual observatories (Panel D); and the human resources including education, recruitment and training, public outreach and industrial impact (Panel E). Overall, over 60 European scientists were directly involved in this effort.

The Working Group and Panels took into account existing national and international European strategic plans, including those of ESFRI, ESA and ESO. They also considered the worldwide context and, in particular, the plans of our major intercontinental partners. Close contacts were maintained with the astrophysical FP6 infrastructure networks (OPTICON, RadioNet, EuroPlanet, and ILIAS) and with our astroparticle "sister-net", the AStroParticle ERAnet, ASPERA.

Feedback from the community

In preparation for the Infrastructure Roadmap symposium in June 2008, a first draft of the Roadmap document was put online at the beginning of May 2008, shortly followed by the opening of a web-based discussion forum to get grassroots community feedback. By the time the forum had closed on 4 July 2008, around 50 astronomers had contributed, often with extensive and multiple comments, to the building of the Roadmap. Their input has been taken into account by the Panels and the Working Group, first in preparation for the symposium, then in the writing of the final document.

The symposium was held on 16–19 June in Liverpool, United Kingdom. About 300 participants from 34 countries (22 EU member states, eight other European states, four non-European states) came for this crucial steering process. General presentations on the status of European Infrastructure analyses by ESFRI, ASTRONET and ASPERA, and on the similar US decadal process, were presented on the Monday afternoon. After the Tuesday morning presentation of preliminary conclusions from the five panels, each participant enrolled in one of the panels for parallel intense discussions during the following day and a half. This essential feedback ended with a 90 minute plenary discussion on Wednesday afternoon. Revised Panel conclusions were presented on Thursday morning, followed by concluding remarks from Johannes Andersen, the ASTRONET chair. For more information, please look at the symposium pages *(http://www.astro.ljmu.ac.uk/~airs2008/Process.html)*, which, in particular, feature the detailed programme and all presentations.

The Roadmap: ground-based projects

Among ground-based infrastructure projects, two emerged as clear top priorities due to their potential for fundamental breakthroughs in a very wide range of scientific fields, from planetary systems (including our own) to cosmology:

- The European Extremely Large Telescope (E-ELT), a 42 m optical–infrared telescope being developed by ESO as a European-led project, with a decision on construction planned for 2010.
- The Square Kilometre Array (SKA), a low frequency radio telescope being developed by a global consortium with an intended European share of up to 40 %, to be built starting in 2012 in phases of increasing size, area and scientific power.

It was concluded that, although the E-ELT and the SKA are very ambitious projects requiring large human and financial resources, they can both be delivered via an appropriately phased plan.

Three other outstanding projects, but with narrower fields and lower budgets, were grouped together on a separate list and are, in descending order of priority: (1) the 4 m European Solar Telescope (EST) to be built in the Canary Islands; (2) the Cherenkov Telescope Array (CTA), a "true" high energy gamma-ray observatory; and (3) the proposed underwater neutrino detector, KM3NeT. In addition, a working group is being set up to study the case for a wide-field spectrograph for massive surveys with an 8 m-class optical telescope. Finally the report stresses the need to enhance support for laboratory astrophysics — including curation of Solar System material returned by space missions.

The Roadmap: space missions

The Working Group and Panels independently agreed with ESA's initial selection of Cosmic Vision missions, all recognised to be of high scientific value. The final choice of missions by the standard ESA procedure, which tracks changes in mission scope and cost and possible mergers with, or replacement by, other European or international projects, is therefore broadly supported. Within this framework, Roadmap priorities, including some non-ESA missions, are as follows:

- Among the large-scale missions, the gravitational-wave observatory, the Laser Interferometer Space Antenna (LISA) and the International X-ray Observatory (XEUS/IXO) were ranked together at the top. Next were the proposed Titan and Enceladus Mission (TandEM) and LAPLACE missions to the planets Saturn and Jupiter and their satellites. One of these will likely be selected in early 2009; it will then compete with IXO or LISA for the next L-mission slot. ExoMars was ranked highly as well, just below TandEM/LAPLACE, but does not compete directly with the other science missions as it belongs to a different programme (Aurora). The longer-term missions, Darwin (search for life on "other Earths"), the Far InfraRed Interferometer (FIRI; formation and evolution of planets, stars and galaxies), and the Probing Heliospheric Origins with an Inner Boundary Observing Spacecraft (PHOIBOS; a close-up study of the solar surface) were also deemed very important. However, they still require lengthy technological development, so it was regarded as premature to assign detailed rankings to them at this stage.

– Among medium-scale investments, science analysis and exploitation for the approved Horizon 2000 Plus astrometric mission GAIA was judged most important. Among proposed new projects in this category, the dark energy mission EUCLID and the Solar Orbiter were ranked highest. Next, with equal rank but different maturity, are Cross-Scale (magnetosphere), Simbol-X (a non-ESA X-ray project), the PLAnetary Transits and Oscillations of Stars mission (PLATO; exoplanet transits) and SPICA (far-infrared observatory). Below these is Marco Polo (near-Earth asteroid sample return).

The Roadmap: role of existing facilities

In space, several current missions are so successful that an extension of their operational lifetimes beyond those already approved is richly justified on scientific grounds. In a constrained environment, however, the selection of the missions that can be extended within available funds should be based on the scientific productivity of the mission and, for ESA-supported missions, the overall balance in the ESA programme.

On the ground, the existing set of small to medium-size optical telescopes is a heterogeneous mix of national and common-user instruments, equipped and operated without overall coordination. This is inefficient in the era of 8–10 m telescopes and ASTRONET has therefore appointed a committee to review the future role, organisation and funding of the European 2–4 m optical telescopes within the context of the Roadmap, and to report by September 2009. Reviews of Europe's existing mm–sub-mm and radio telescopes will be undertaken shortly after, followed later by a review focusing on the optimum exploitation of our access to 8–10 m class optical telescopes as we enter the era of the E-ELT. These reviews will help Europe to establish a coherent, cost-effective complement of medium-size facilities.

The Roadmap: theory, computing and data archiving

The development of theory and computing capacity must go hand-in-hand with that of observational facilities. Systematic archiving of properly calibrated observational data in standardised, internationally recognised formats will preserve this precious information obtained with public funds for future use by other researchers, creating a Virtual Observatory. The Virtual Observatory will enable new kinds of multi-wavelength science and present new challenges to the way that results of theoretical models are presented and compared with real data. Along with other initiatives, the Roadmap proposes that a "virtual" European Astrophysical Software Laboratory, (a centre without walls), be created to accelerate developments in this entire area on a broad front.

The Roadmap: education, recruitment and outreach

Ultimately, the deployment of skilled people determines what scientific facilities can be built and operated as well as the scientific returns that are derived from them. Recruiting and training the future generation of Europeans with advanced scientific and technological skills is therefore a key aspect of any realistic roadmap for the future.

Astronomy is a proven and effective vehicle for attracting young people into scientific and technical careers, with benefits for society as a whole, far beyond astronomy itself. The Roadmap identifies several initiatives to stimulate European scientific literacy and provide European science with the human resources it needs for a healthy future, drawing on the full 500-million-strong population of the new Europe.

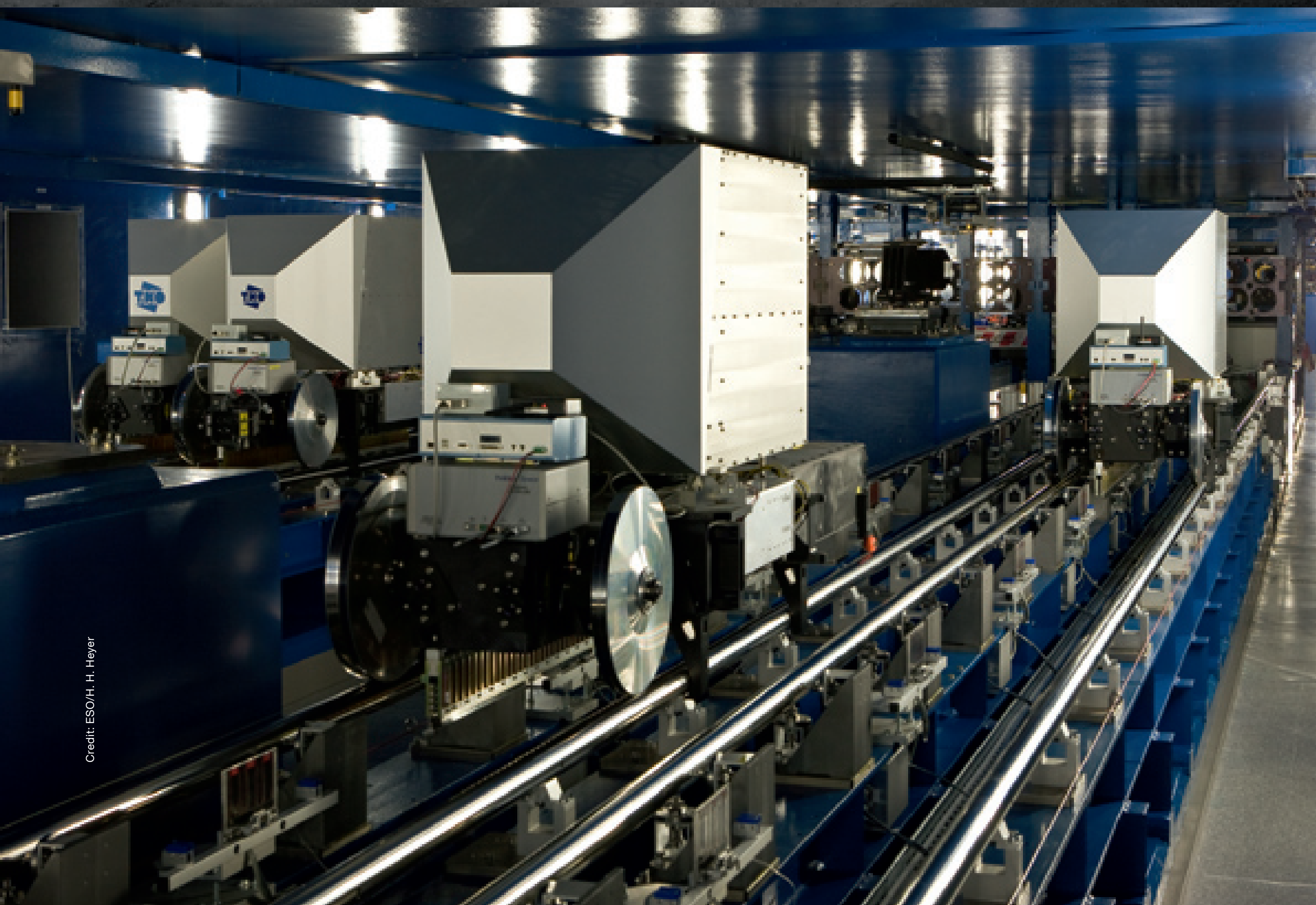
The Roadmap: technology development

Technological readiness, along with funding, is a significant limiting factor for many of the proposed projects, in space or on the ground, and key areas for development are identified in each case. However, astronomy also drives high technology in areas such as optics and informatics. Maintaining and strengthening a vigorous and well-coordinated technological R&D programme centred on promising future facilities and in concert with industry is therefore an important priority across all areas of the Roadmap.

Conclusions and perspective for the future

The Roadmap's aim is to represent a community-based comprehensive plan that addresses the great majority of the Science Vision goals. Its implementation will maintain and strengthen the role of Europe in global astronomy, as well as providing a much-needed tool in negotiating international partnerships for the largest projects. In order to achieve this in a timely manner, given the stiff international competition, a budget increase of order 20 % over the next decade will be required, a somewhat tall order, but also a very cost-effective investment for Europe.

The context of the Roadmap has kept evolving while it was being developed, and will continue to do so. ASTRONET, in concert with ESFRI, will monitor progress on implementing the proposals of the Roadmap over the next 2–3 years, whether small or large in financial terms. Finally, we foresee that a fully updated Roadmap will be needed on a timescale of 5–10 years. Whether the Science Vision then needs to be updated as well will depend on scientific and financial developments on the international scene in the meantime.



Two contrasting images of a section of the VLTI interferometric tunnel. Upper: as it appeared ten years ago. Lower: as it appears today filled by four of the Delay Lines.

Credit: ESO/H. H. Heyer

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The Phase Referenced Imaging and Microarcsecond Astrometry (PRIMA) instrument was recently delivered to the summit of Cerro Paranal and installed as part of the Very Large Telescope Interferometer (VLTI) infrastructure. PRIMA is designed to (i) provide phase-referenced interferometric imaging at milliarcsecond scales, (ii) enable faint star science several magnitudes fainter than the current atmospheric limits of the VLTI, and (iii) provide astrometric measurements at the tens of micro-arcsecond level. PRIMA has successfully seen first fringes and is currently (as of late 2008) undergoing initial commissioning tests.

The PRIMA Big Bang and first fringes

The thirty-plus crates of optics, electronics, mechanics, and other assorted hardware and software of the Phase Referenced Imaging and Microarcsecond Astrometry (PRIMA) instrument arrived at Cerro Paranal in mid-July from ESO Garching, and the PRIMA Big Bang was underway. PRIMA's assembly, integration and verification phase — better known simply as "the Big Bang" — spanned the following seven weeks. Teams of engineers and scientists from ESO Garching and ESO Paranal split into multiple shifts and worked literally around the clock to assemble the complex instrument, carefully rationing out the limited resources of lab space, subsystem availability and sky time. Basically, we were just trying not to step on each other's toes. Two weeks after the first shipment, a further 18 crates arrived from our PRIMA partners at the Geneva Observatory, along with staff from Geneva and MPIA Heidelberg. In the end, over 30 individuals participated directly in a delicately choreographed dance of optical instrumentation in a space no larger than ESO Garching's lobby. An underlying sense of purpose and *esprit de corps* kept our efforts afloat as we worked long days and nights, playing out the endgame of more than eight years of PRIMA development.

As of the beginning of September 2008, individual subsystems had been unboxed, installed and taken through their paces, but the larger question of system integration was beginning to be considered. In the waning days of the PRIMA Big Bang, two of the VLTI's auxiliary telescopes (ATs) were trained skywards (Figure 1), and the 1.8 m apertures were used to thread light from a single star through the optical beam trains, delay lines, and into one of PRIMA's fringe sensor units (FSUs). On 3 September 2008 — a few days ahead of the ambitious Big Bang schedule — twin beams of starlight from HD 19349 (spectral type K0 III; $V = 5.2$; $K = 0.4$) were recombined in FSU A, and

Figure 1. Nicola Di Lieto (ESO) working to configure a PRIMA Star Separator out at AT4 during the PRIMA Big Bang.

the telltale wiggle of interfering light was seen as the delay lines swept through the position of equal path length for each aperture (Figure 2). Within a few days, this core element of the PRIMA system was not only sensing fringes on far dimmer stars, but achieving the more difficult task of locking onto the fringes and actively tracking them (Figure 3). Independently, the PRIMA laser metrology system was also successfully operated over an optical path of length 300 m, from the interferometry laboratory to two ATs and back.

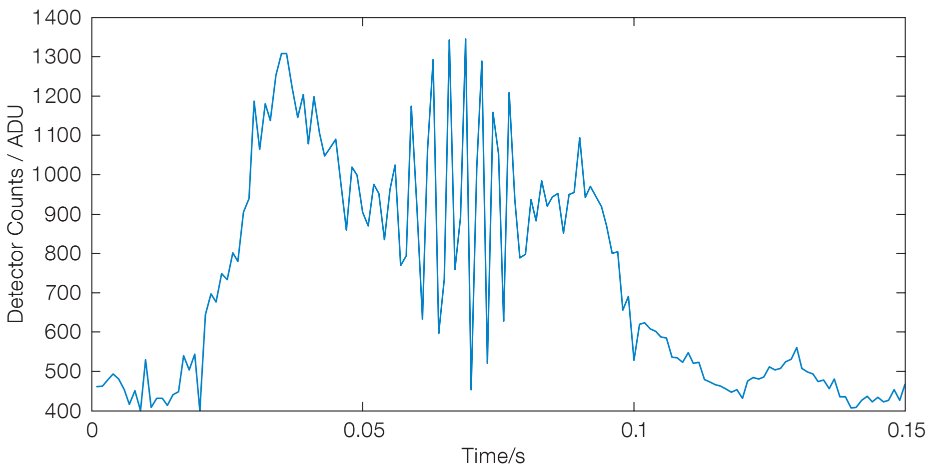

Figure 2. First fringes for PRIMA, obtained on Fringe Sensor Unit A on 3 September 2008, observing the star HD 19349 with two ATs separated by 32 m at VLTI stations G0 and G2.

What is PRIMA?

PRIMA is the last of the first generation of VLTI instruments, although its complexity and spot in the queue as the last of the first lend it a flavour of being VLTI generation 1.5; expanded technical details on PRIMA beyond the scope of this article can be found in Delplancke et al. (2008).

PRIMA is, put simply, two astronomical interferometers in one. It is able to collect starlight in each of two telescopes from not just one source but two, and simultaneously send these pairs of starlight beams to the interferometer backend. The *K*-band (2.2 μm) starlight from the first source is recombined in the VLTI laboratory to form interference fringes, while fringes are collected simultaneously on the second source.

However, PRIMA is also much more than two interferometers that just happen to cohabit the same lab. At the telescopes, star separator (STS) units take the field observed by each telescope and split it, sending one source down one PRIMA beam path and a second source down the parallel one. A secondary interferometric delay line, the differential delay line (DDL, built by the ESPRI consortium), accounts for small pathlength differences between the two sources due to their slightly different positions on the sky, and allows fringes to be obtained simultaneously from both sources. Each beam combiner contains a laser metrology gauge (PRIMET) that is injected at the point of combination, travels backwards through the system to the STSs, and is retroreflected back from that point, monitoring the pairs of telescope feeds and tying them together at the nanometre level. These additional subsystems take PRIMA out of the realm of simply achieving contemporaneous fringes and empowers it with three unique capabilities (see Figure 4).

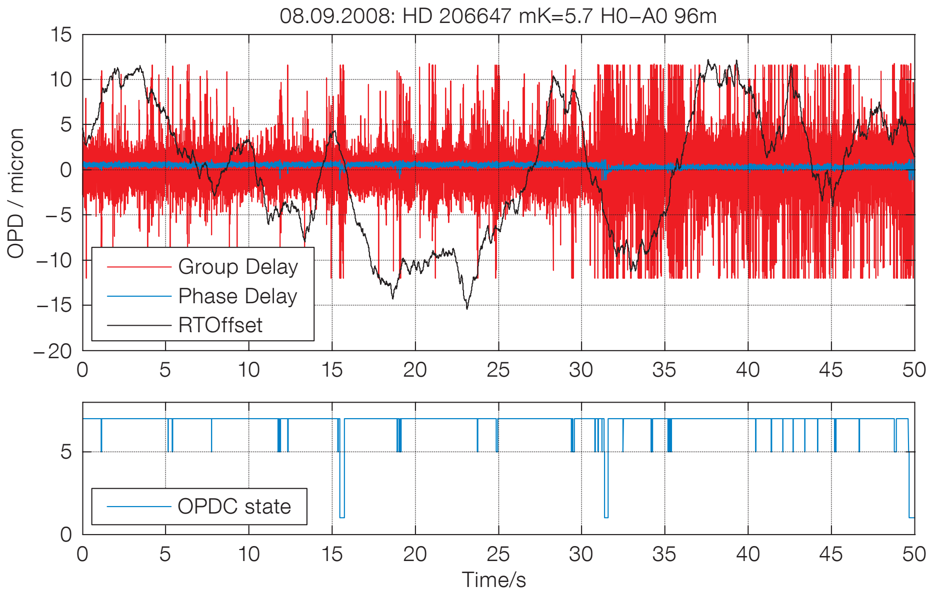

Figure 3. By the end of the PRIMA Big Bang, fringes from stars with *K* ~ 6 were not only being detected, but actively tracked. The upper panel shows the phase delay (blue), group delay (red) and delay line offset (black) in microns of optical path delay as a function of time for star HD 206647 with ATs at VLTI stations A0 and H0 for a separation of 96 m. The lower panel shows the optical path delay controller (OPDC) state during this time, with a high state (7) indicating fringe lock, low (1) a fringe search state, and a middle state (5) reflecting a minor loss being waited out.

The first of these capabilities is PRIMA's ability to measure astrometric angles between two sources. When using an astronomical interferometer, knowledge of the geometry of the separation between two telescopes (the "baseline") combined with a measurement of the

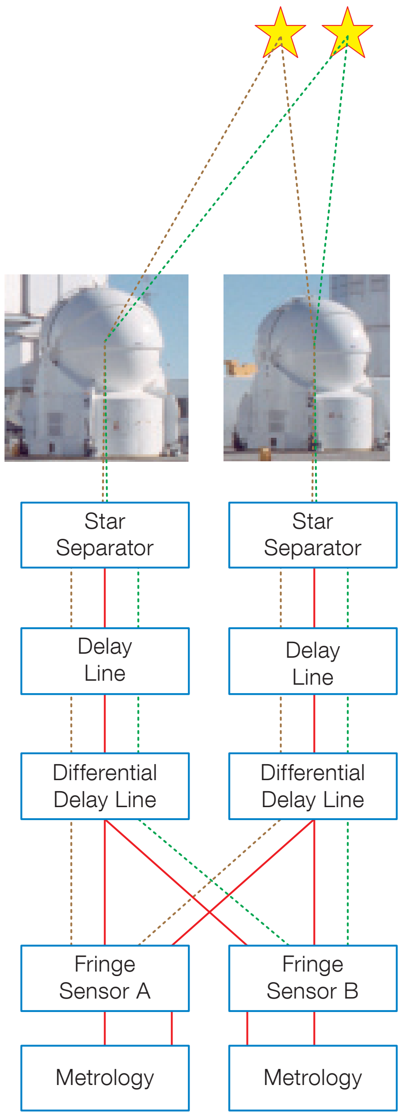

Figure 4. Schematic of the PRIMA system for the VLTI, highlighting the major subsystems along the optical paths of the facility.

delay line setting can be used to establish a position on the sky of the observed source. This is typically limited by the atmosphere and, more importantly, the instabilities of the optical system, which, for a widely distributed system like an interferometer, are considerable. However, by observing two sources simultaneously, and in particular, the instantaneous delay line settings for these two sources, this measurement may be done in a differential sense. Many of the dominant error terms become common mode and drop out when using this approach, allowing unprecedented levels of precision to be attained in measuring the astrometric angle between two sources. This technique was predicted to be useful by Shao & Colavita (1992) and demonstrated on an engineering basis by the Palomar Testbed Interferometer (PTI; Lane & Colavita, 2000); PRIMA will be the first instrument to offer this capability to the general astronomical community on a routine basis.

Secondly, PRIMA can leverage the twin-interferometer setup to observe sources significantly dimmer than previously possible with single-source interferometers. By observing a bright source in one of the two channels of the system, PRIMA can use this source not only to track the atmospheric disturbances for the bright source itself, but to feed-forward the error correction signals to the secondary channel. The secondary channel can then be steered off to a nearby, dim source, and interferometric observations can be carried out without the atmosphere obfuscating the interference fringes. In this fashion, PRIMA operates as an interferometric analogue to single-aperture natural guide star adaptive optics: the bright source in this case is not only being used to take out the "corrugations" in the wavefronts of the individual apertures, but is also used to remove pathlength errors that are introduced by the fluctuating atmosphere (commonly referred to as "piston" or "fringe jitter"). To track the fringes, the bright source is limited to observations no longer in duration than an atmospheric coherence time; however, the error signals from the bright source tracking can then be used to create a synthetic coherence time for the secondary source that is significantly longer. The second channel can then stare coherently at a significantly dimmer source and record useful data. Again, this was demonstrated by the PTI (Lane & Colavita, 2003) and again, PRIMA will be the first instrument to routinely offer this functionality to all. In addition to feeding one of the two FSUs with a dim source, PRIMA has been designed to provide off-axis dim source tracking to the existing VLTI instruments AMBER and MIDI.

Thirdly, the dual-object nature of the interferometer can be used to construct high resolution images of objects upon the sky using "phase referenced imaging". Atmospheric turbulence corrupts the phase information relevant to the Fourier transform of the object image — without such corruption, it would be possible for a single-object interferometer to construct, point by point, the full Fourier components of the object image, and allow full image reconstruction. PRIMA is able to make object image phase measurements by observing a science object simultaneously with a reference star; the reference star in this case being selected to have a null phase (i.e., be centro-symmetric). By making multiple observations over the course of a night, and with multiple baselines on different nights, many Fourier phase components for a science object can be built up, and an image can be reconstructed. This technique can be applied to faint targets as described in the previous paragraph.

These three capabilities make PRIMA extraordinarily special and an exciting development for astronomical interferometry with either the ATs or the Unit Telescopes (UTs). Its astrometric capability is a unique new tool, and its faint source capabilities will allow astronomers to reach past the barrier of sensitivity that has plagued interferometers and examine faint targets with high angular resolution.

Expected performance and limitations of PRIMA

As PRIMA operates, there are two major limitations familiar to all astronomers: the atmosphere, and the instrument itself. The atmosphere limits PRIMA in a number of ways. As mentioned above, the atmospheric coherence time is the maximum time span allowed for attempting to detect and track fringes on the brighter of the two sources. This value is typically about 10 ms for Paranal, which will limit the system (accounting for beam transmission losses, detector QE, and other system pitfalls) to sources of roughly $K = 8$ on the auxiliary telescopes (and correspondingly dimmer for UT observations, roughly $K = 11$).

For the second, fainter source, the tracking of PRIMA on the bright source allows a longer, synthetic coherence time to be provided, but only if the atmospheric corrections are common mode. This limits the second source to a sky location that is near the bright primary source — specifically within one isoplanatic angle. For Paranal, the size of this angle in the *K*-band for an evening of median seeing is roughly 10–20 arcseconds. As one might expect, as the primary–secondary on-sky angle decreases, the system performance improves, particularly in the area of determination of the astrometric angle. Astrometric precision also benefits from having a bright secondary source, but likelihood of finding a secondary source for use as an astrometric reference increases as one searches deeper. Unfortunately, it becomes increasingly difficult to find dim sources next to bright ones from existing surveys, due to saturation limitations. For example, sources at $K = 6$ in the 2MASS and DENIS surveys tend to wash out all dimmer sources out to 30 arcseconds, unfortunately making these surveys unsuited for selecting bright–dim pairs (although it is still quite useful for at least identifying the bright sources).

The instrumental limitations are many, which is unsurprising in an instrument of this complexity. Of these, one that is foremost in many people's minds is that of system vibration, which serves to smear out interference fringes by introducing variations in system pathlength that are too fast and/or large to be followed by the fringe tracker's observations of starlight fringes. The PRIMET metrology system will operate to mitigate these effects by monitoring the pathlengths through most the system, coherently preserving the precious starlight for the fringe tracker.

A second thorny instrumental issue is that of baseline knowledge. For astrometry at the 10–30 microarcsecond (µas) level, the geometry of the two telescopes relative to each other needs to be known to an accuracy of roughly 50 µm over separations of 100–200 metres. This problem separates out into two components: the wide-angle baseline, which is the average separation between the two telescopes during the observation, and the narrow-angle baseline, which is the differences in wide-angle baseline seen by the primary and secondary sources due to residual non-common paths and mechanical imperfections in the system. The wide-angle baseline can be established to the required accuracy by observations of stars with well known astrometric positions, such as Hipparcos targets. The narrow-angle baseline is determined through monitoring of the system mechanical structure, and is a primary motivation for the PRIMET subsystem. However, PRIMET is unable to monitor all of the beampath, in particular the telescope Coudé trains. Establishing a full solution for the narrow-angle baseline problem remains an outlying challenge for the PRIMA team. Fortunately, while this particular problem is an issue for PRIMA's astrometric performance, it does not impact the faint star science.

Working within these limitations, we expect to be able to reach magnitudes of $K = 8$ on the bright source in reasonable seeing conditions with the ATs, and push at least five magnitudes deeper with the companion faint source when a bright source is phasing up the system. Synthetic coherence times at the PTI experiment of 1–2 seconds — some 100–200 times longer than the atmospheric coherence time — bear this expectation out as a reasonable one. Anecdotal evidence from early FINITO operations that even longer synthetic coherence times are possible under excellent seeing conditions will be explored to establish the full sensitivity envelope of the system. Initial astrometric performance of the system, pending a solution to the narrow-angle baseline problem, will be limited to the 50–100 µas level (an expectation also supported by the previous work on the topic). The fully operational system will have an ultimate limit of 10–20 µas, although this will require not only near-perfect operations, but also almost unrealistically well-suited pairs of bright sources with almost similarly bright secondary astrometric reference sources situated well within an isoplanatic angle (of which there are no known examples in the southern hemisphere). Our expectation is that, for a reasonable science programme with a sample size of at least ten, the median performance limit of the system (accounting for instrument, good but not great atmospheric conditions, realistic source brightnesses, and realistic observing times) will be 30–40 µas.

Clearly, our goals are to push beyond these limits. However, even at these limits, the capabilities offered by PRIMA are exciting and enable unique science.

Science case for PRIMA

The general science case that motivated the development of PRIMA is discussed in Delplancke et al. (2003). A primary driver for the astrometric aspect of PRIMA's functionality is the detection and characterisation of extrasolar planets. At a distance of 10 parsecs, a star with spectral type G2 orbited by a Jupiter-mass object in a Jupiter-like orbit shows an astrometric signal of about 1000 µas (Figure 5) — clearly within the reach of even PRIMA's initial capabilities. These objects are, by design, particularly well suited for PRIMA, since the star of interest is nearby and will have a significant apparent brightness, providing PRIMA's bright channel with a strong signal upon which to fringe track.

Many of the extrasolar planets that are nearby have already been detected through the efforts of teams using the radial velocity (RV) technique. While this could be considered by some to be a "scoop" of PRIMA's opportunity to discover new worlds, it in fact greatly expedites PRIMA's ability to contribute significant astrophysical knowledge to the field. A major limitation of the RV technique is the uncertainty in planetary mass due to the lack of knowledge of orbital inclination: RV is essentially a one-dimensional technique and has this limitation built-in. PRIMA's astrometry, by contrast, is an inherently two-dimensional approach that has no such restrictions. As the field of extrasolar planetary science progresses from the discovery phase to the more detailed characterisation phase, specific knowledge of the planetary masses will help open up the considerations of planetary composition and structure that are now being pondered. The RV detections made to date provide a roadmap for PRIMA to provide contributions to the field rapidly, while it begins the more lengthy process of exploring its own unique discovery space (Launhardt et al., 2008).

It should be noted that recent results probing the limits of large single-aperture telescope astrometry are starting to push

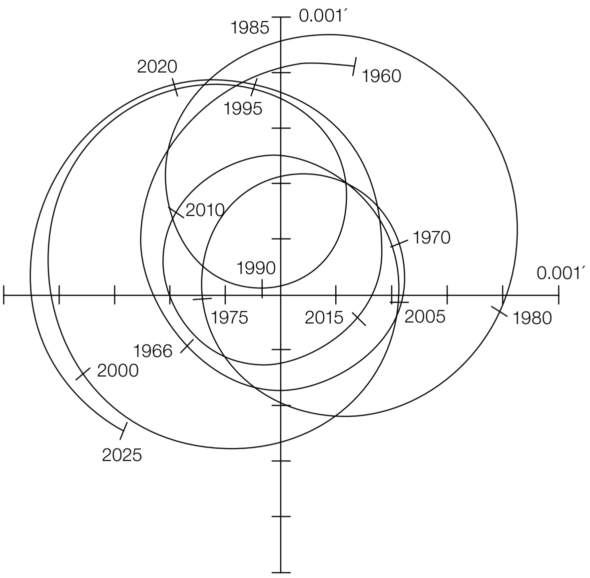

Figure 5. Apparent astrometric signature of our Sun as a function of time at a distance of 10 parsecs, exhibiting the astrometric reflex motion associated with all of the Solar System planets. Jupiter dominates, followed by Saturn and the other two gas giants. Earth's signature is masked by the plot line width at the ≤1 µas level.

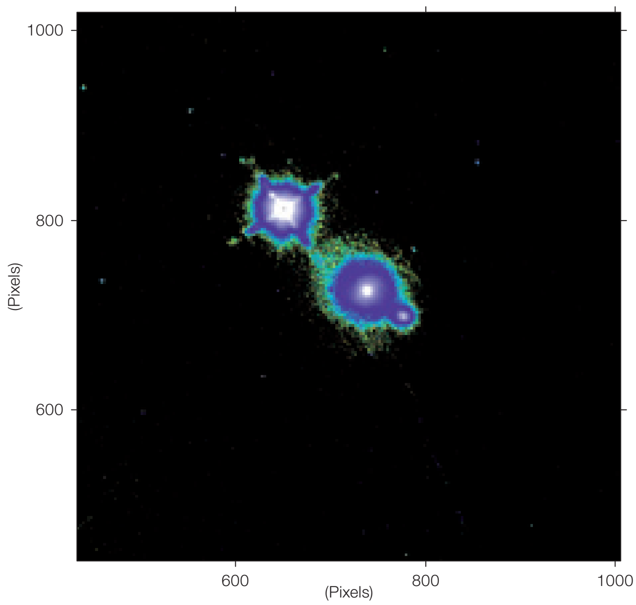

Figure 6. Example faint source for observation with PRIMA. NTT/SOFI image of ESO 548-81. The object is a Seyfert 1 galaxy, too dim for direct fringe tracking at $K \geq 10.5$, but nearby there is a bright source (HD 23134, $K = 6.02$) that can be used to phase-up the interferometer.

into the slightly coarser 100–200 µas regime (Lazorenko et al., 2007). However, these experiments are limited to dense fields of stars of similar brightness, limiting their utility, particularly for extrasolar planetary investigations (although they are exciting new tools for exploring globular clusters and other sufficiently dense regions of the sky).

Many other astrometric applications exist for PRIMA beyond just extrasolar planets. Determination of parallax is possible with proper selection of the secondary reference star; deflection of starlight due to general relativistic effects could be explored (e.g., as Jupiter passes close to one of two stars being fed into PRIMA); orbits of small Solar System bodies could be tracked with unprecedented accuracy with PRIMA; dynamics of objects near the Galactic Centre could be tracked with accuracy beyond existing studies and additional applications surely exist that have not yet been considered.

For faint object and phased-referenced imaging science, PRIMA opens up a realm of phase space that, up until now, had been off-limits to optical interferometry. Galactic cores constitute an obvious class of objects that is of considerable interest for high resolution observations. Fringe-tracking limitations have, until now, limited such work to sources that could be self-referenced, serving as their own fringe tracking source, but PRIMA will be able to sidestep this limitation through use of its faint source channel. The need for a nearby bright soure for fringe tracking is its own limitation, but a quick survey of the appropriate catalogues shows it to be far less of a one than the previous limits (van Belle et al., 2008; see example in Figure 6). Other object classes include young stellar objects (especially those that are deeply embedded in dusty shells), asteroid shape mapping and density determination, imaging of evolved stars, and possibly brown dwarf angular diameters. As with the astrometric possibilities, many of the applications of PRIMA faint object mode await the creativity of the ESO community to exploit it in new and unexpected ways.

Description of the system

The PRIMA instrument has a sufficiently expansive footprint upon the VLTI infrastructure that we consider it to be more of a facility than merely an instrument. A significant component of PRIMA is the existing infrastructure, including the ATs, UTs, standard delay lines (DLs), telescope visible-light tip-tilt tracking system (STRAP), Multi-Application Curvature Adaptive Optics (MACAO) on the UTs, interferometer infrared tip-tilt tracking system (IRIS), variable curvature mirrors (VCMs) on the delay lines and now also part of the new star separator subsystem, the DL alignment subsystem, and when PRIMA is used with the UTs, vibration control.

Significant upgrades to the VLTI infrastructure that benefit the existing instruments are a new, improved alignment source MARCEL (which replaces the previous unit, Leonardo), and a new reflective memory network (RMN) that features improved throughput and reduced latency times.

PRIMA-specific subsystems that arrived *en masse* during and in advance of the PRIMA Big Bang began with the Star Separators (STSs). The STSs separate the light of two astronomical objects with separations 1–60 arcseconds and feed it into two parallel VLTI optical beam trains. The STS compensates for field rotation, stabilises the beam tip-tilt and adjusts the lateral and axial alignment of the pupil. Chopping and/or counter-chopping on the bright or faint source has also been implemented in the STS design; two units specific to the ATs and one for each of the UTs have been built (Nijenhuis et al., 2008).

The Differential Delay Lines (DDLs) were provided by the ESPRI Consortium and are responsible for providing slight delay offsets between the primary and secondary sources. The DDLs consist of high quality cat's eyes in vacuum, displaced on parallel beam-mechanics by means of two-stage actuation, with a precision of 5 nm over a stroke length of 70 mm. Over the full range, a bandwidth of about 400 Hz is achieved (Pepe et al., 2008).

The Fringe Sensor Units (FSUs) are designed to provide high precision fringe phase measurements with a goal of 1 nm rms (corresponding to $\lambda/2\,000$). To achieve this, careful calibration procedures were developed, with special attention given to the achieved measurement linearity and repeatability. The quality of the FSU calibration is crucial in order to achieve the ultimate astrometric accuracy (Sahlmann et al., 2008).

Central to successful FSU calibration is the PRIMA metrology subsystem (PRIMET, Leveque et al., 2003), designed by ESO and the Institute of Microtechnology of Neuchâtel (IMT). The PRIMET source, based upon a frequency-stabilised Nd–Yag laser, provided by IMT and calibrated with the help of the Max-Planck-Institut für Quantenoptik, allows nanometre-level pathlength measurements to be attempted with an imperfectly stable interferometer. The overall complexity of PRIMA is carefully being addressed from software standpoint with comprehensive operations software and astrometric data reduction software (Elias et al., 2008; Tubbs et al., 2008) as well.

A further significant effort in support of PRIMA that has now been retired, but bears special mention, is the Fringe Tracking Testbed that was employed extensively over the past two years to test the FSU and PRIMET subsystems and remove the risk associated with them (Sahlmann et al., 2008). This testbed facility was built at MPE laboratories in Garching with the aim of simulating the VLTI and included FSUs, an optical path delay controller, PRIMET and in-house-built delay lines.

Who is PRIMA?

More than the collection of hardware and software mentioned in the previous section, PRIMA is a partnership working towards the goal and rewards of dual-beam interferometry. PRIMA includes significant contributions from both ESO Garching and ESO Paranal, and ESPRI partners the Geneva Observatory, the Max-Planck-Institut für Astronomie in Heidelberg, and the Landessternwarte Heidelberg; PRIMA also includes contributions from Leiden University, the Ecole Polytechnique Fédérale de Lausanne, the Institute of Microtechnology of Neuchâtel and MPE Garching; industrial partners on the PRIMA project include TNO and Thales Alenia Space.

Schedule for PRIMA

Commissioning of PRIMA is scheduled to occur throughout Period 82, covering four runs of roughly ten days each; P82 observing will concentrate on simple system operations involving feeding only a single star into the system. Optimisation of fringe-tracking algorithms will lead to fundamental system characterisation, including night-to-night repeatability, absolute visibility amplitude tests and measurements of limiting magnitude. Period 83 will have a similar set of commissioning runs, but will expand testing to full dual-star operations, with initial tests of the astrometric observing mode. If successful, science verification observations will soon follow and PRIMA astrometry will be released to the community thereafter.

Future of PRIMA and phase-referenced imaging

Already there are plans to expand the scope of dual-beam interferometry at the VLTI. In particular, the second generation VLTI instrument GRAVITY (General Relativity Analysis via VLT InterferometrY; Eisenhauer et al., 2008) is specifically designed to operate in a PRIMA-like fashion, but using not just two, but all four UTs simultaneously to achieve 10 µas astrometry on six baselines on faint ($K \geq 15$) sources at the Galactic Centre. Such observations have the potential to probe highly relativistic motions of matter close to the event horizon of Sgr A*, the massive black hole at the centre of the Milky Way.

For PRIMA itself, exciting discoveries lie ahead in the more immediate future. The new capabilities it provides to the VLTI for both astrometry and faint object science open up wide new frontiers in astronomical interferometry. Experience has shown that in such circumstances, the most interesting results come from unexpected quarters.

Useful PRIMA Jargon

Term	Description
ADRS	Astrometric Data Reduction Software
DDL	Differential Delay Line
ESPRI	Exoplanet Search with PRIma
FSU	Fringe Sensor Unit
PRIMET	PRIMA Metrology
µas	micro-arcsecond
STS	Star Separator

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News on the Commissioning of X-shooter

Sandro D'Odorico
ESO

X-shooter is the high efficiency, single target (slit or mini-integral field unit [IFU]), intermediate resolution, high efficiency spectrograph built for the Cassegrain focus of one of the UTs of the VLT (see Vernet et al., 2007). The instrument consists of three spectroscopic arms that allow, in a single exposure, the spectral range 310–2400 nm to be covered. X-shooter is the first of the second generation VLT instruments to go to Paranal. SPHERE, KMOS and MUSE will follow between 2010 and 2012.

The instrument was built by a consortium of institutes in Denmark, France, Italy, the Netherlands and by ESO. The co-principal investigators are P. Kjaergaard Rasmussen (Copenhagen), F. Hammer (Paris), L.Kaper (Amsterdam–NOVA), R. Pallavicini (INAF) and S. D'Odorico (ESO).

In the first commissioning, the instrument was mounted at the telescope with the UV-Blue (UV-B) and Visual-Red (V-R) arms. The near-IR arm is still being optimised in Garching and will be brought to the telescope in the first quarter of 2009. The instrument was attached to the telescope for the first time on 9 November. Observations began on the same night and continued for a further ten nights. Over the whole run, a total of only about seven hours of observing time was lost: four hours due to strong winds and three hours for telescope–instrument software interface problems. The many observations have been used to test the functionalities of the instrument at the telescope and to obtain sky data for instrument calibration. The observations will also be used to assess the performance of the instrument and its data reduction pipeline — quickly, during the commissioning time on Paranal, and more systematically in the next few weeks. Preliminary results indicate that the instrument meets most crucial specifications (and exceeds a few). It will be offered as of Period 84 (deadline for application 1 April 2009).

The successful X-shooter commissioning team on Paranal was composed of:
- H. Dekker (Project Manager and System Engineer), S. D'Odorico (ESO co-PI), M. Downing, J. L. Lizon, F. Kerber, C. Lucuix, A. Modigliani, V. Mainieri and J. Vernet (Instrument Scientist) from ESO Garching;
- R. Castillo, E. La Pena, E. Mason (Paranal Instrument Scientist) and A. de Ugarte Postigo from ESO Paranal;
- P. Santin and M. Vidali from INAF Trieste for the control software.

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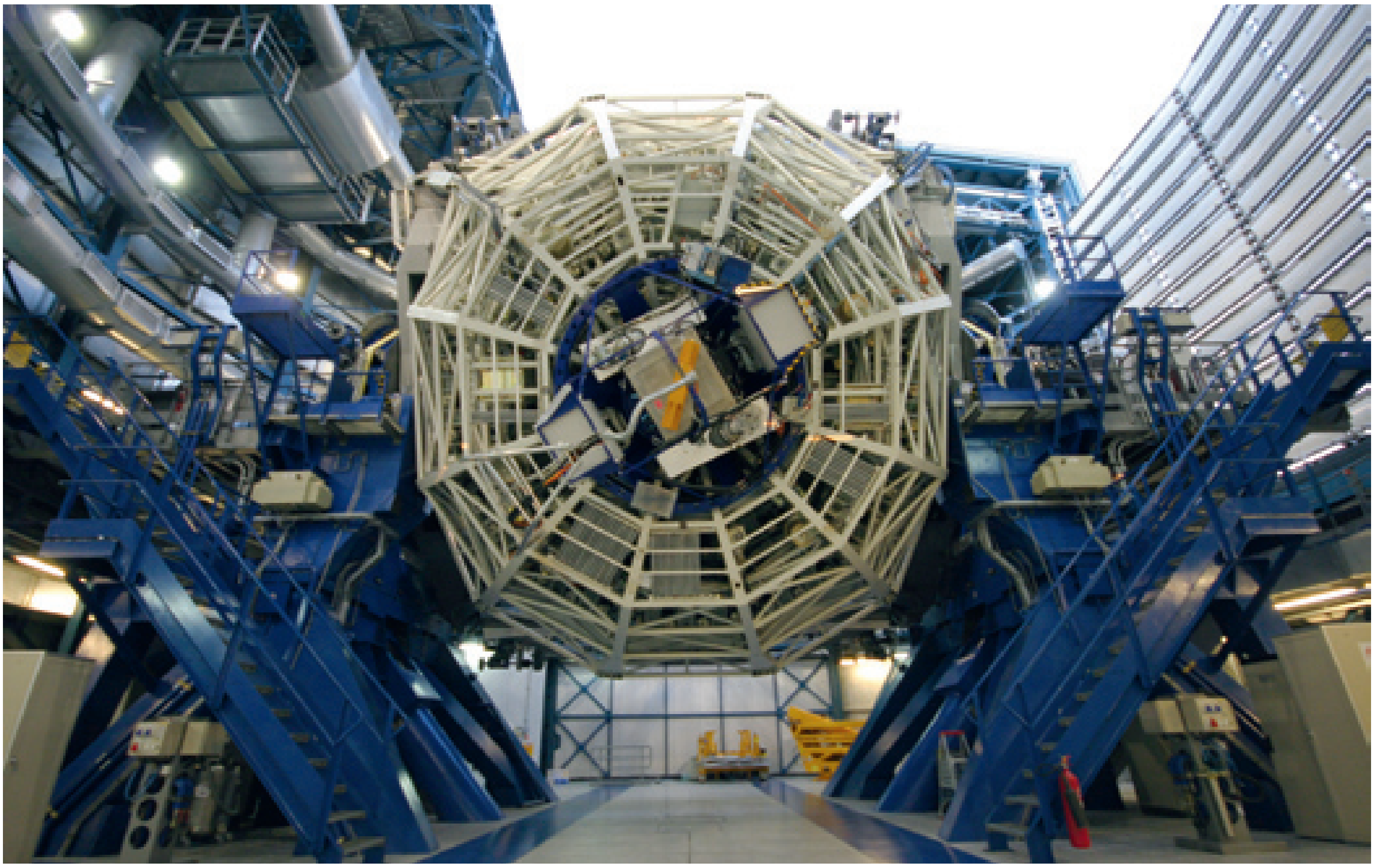


Credit: A. de Ugarte Postigo/ESO

Figure 1. A view of X-shooter at the centre of the M1 cell of UT3 (Melipal). The UV-B and V-R spectrographs and CCD cryostats are visible on the sides of the central backbone. The yellow counterweight is substituting for the near-IR spectrograph that will be installed in the first quarter of 2009.

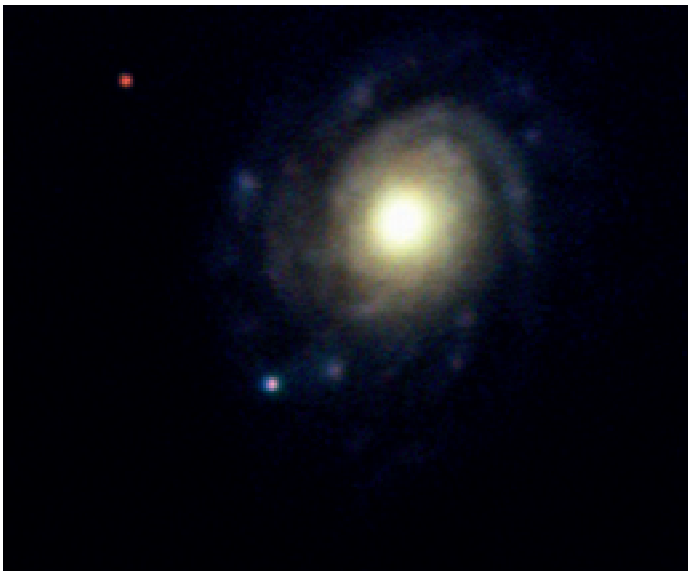


Figure 2. Composite of *B*-, *V*- and *R*-band images of the supernova SN2008hg in the spiral galaxy IC 1720 taken with the X-shooter acquisition camera.

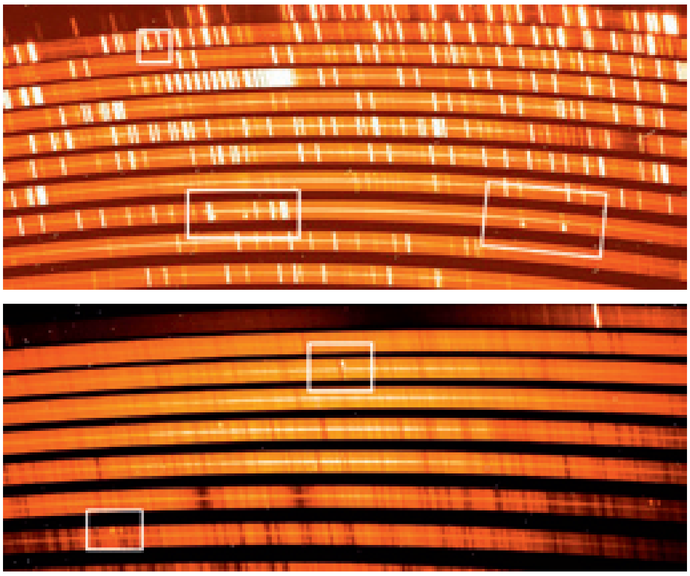
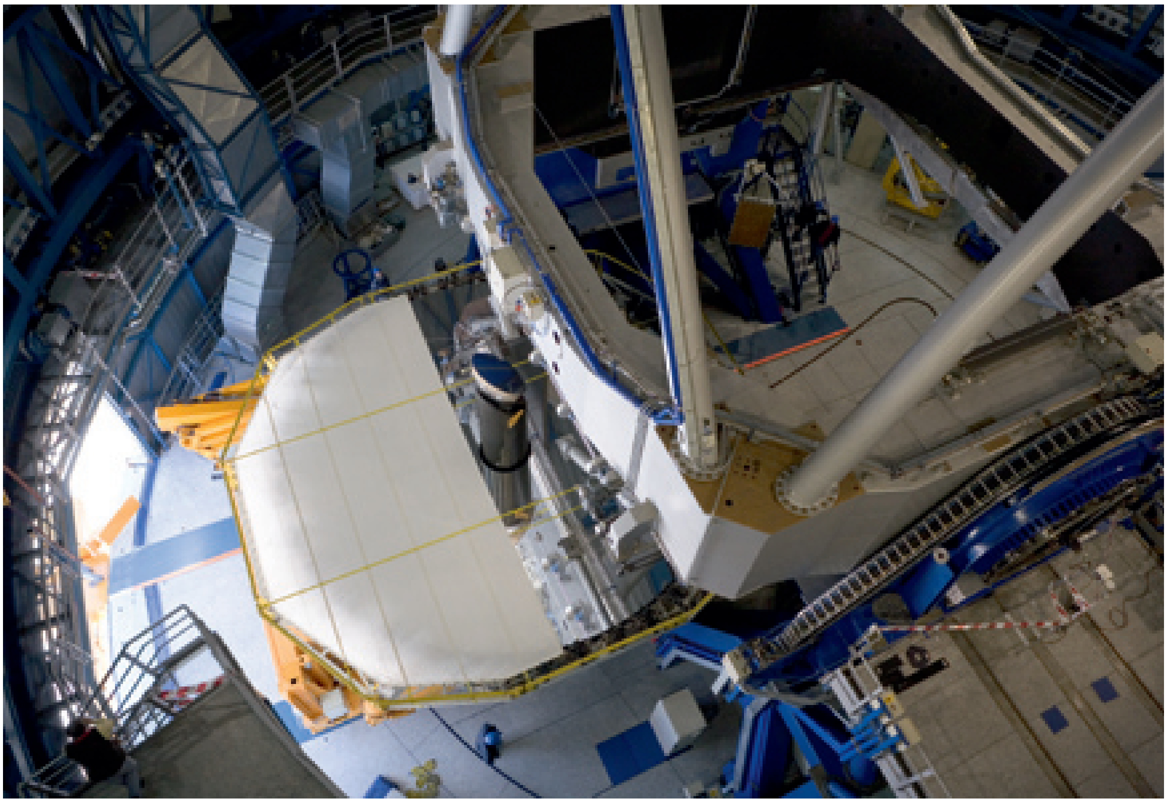


Figure 3. This 20-minute exposure of SN2008hg ($m_V \approx 17.5$) taken at full Moon gives a hint of the capability of X-shooter. V-R and UV-B spectra of the SN with emission lines of the nearby H II region (with the brightest highlighted in boxes) cover the range from 310 to 1 000 nm. The spectra were taken with slit widths of 1.2 and 1.3 arcseconds in the V-R and UV-B ranges respectively in 1.4 arcsecond seeing. The resolving powers are 6 000 and 4 000 approximately. Using narrow slits, the instrument can reach resolutions of 14 000 and 9 000 in the V-R and UV-B bands respectively.



Delicate manoeuvres in the daylight. The 8.2 m primary mirror of VLT Antu (UT1) being removed prior to aluminization in December 2005. The white screen covering half of the mirror prevents direct sunlight from the open dome door falling onto the mirror during removal from the telescope.

Report on the JENAM 2008 Meeting Symposium Science with the E-ELT

Guy Monnet
ESO

The symposium "Science with the E-ELT" was held at the Joint European and National Astronomy Meeting (JENAM) 2008 meeting. It featured presentations on the development of a comprehensive E-ELT science case and how it is driving the detailed design of the facility, followed by talks addressing topical observational domains in which the E-ELT should have a major scientific impact. All presentations can be accessed at *http://www.eso.org/sci/facilities/eelt/science/meeting/jenam08/EELT_JENAM08_Programme.pdf*.

The European Extremely Large Telescope (E-ELT) project is presently in the midst of its three-year (2007–2009) detailed Phase B design phase. This effort covers the whole observing facility (infrastructure, enclosure, telescope) including feasibility studies within the ESO community for focal instruments and adaptive optics modules (see Spyromilio et al., 2008, for details). This phase will be concluded with a number of internal and external reviews in the first semester of 2010. The proposal for a decision on the subsequent construction phase is planned to be presented to the ESO Council in June 2010.

By mid-2008, the time was just ripe for this Symposium to discuss and assess the main science goals for this major observing facility. JENAM 2008, as a gathering of a significant fraction of European astronomers, was a fitting location for such an event and we are grateful to its organisers for their offer and continuous support in organising the meeting. Our prime goals were to inform the community of the scientific perspectives opened up by such a facility and to elicit its feedback on the science goals and requirements, with the aim of making the E-ELT a powerful scientific tool for European astronomy in the coming decades.

The event

The 2008 JENAM was held on 8–12 September 2008 at the University of Vienna, Austria. The unifying theme of this year's meeting was to explore "New Challenges to European Astronomy". Quite naturally within this framework, ESO and Opticon jointly organised one of the nine JENAM 2008 symposia, namely Symposium #1 on "Science with the E-ELT". The Symposium was conducted in three sessions, on the afternoons of 8 and 9 September, and in the morning of 10 September. Despite heavy competition from other topical Symposia being held in parallel, attendance was good, with close to a hundred participants.

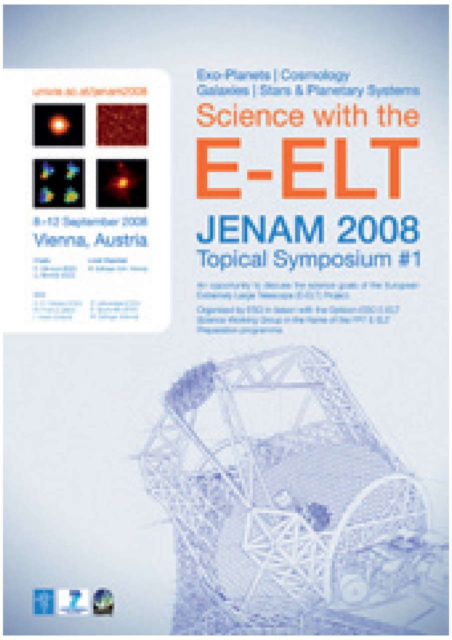


Figure 1. Poster for the Science with the E-ELT Symposium.

A total of 22 presentations were delivered at the Symposium. Six addressed the project status, and the remaining 16 its scientific potential, either covering a science domain and the potential impact of the E-ELT when equipped with suitable instrumentation, or alternatively focusing on one instrument presently under study and covering its most important scientific uses. In that way, most scientific aspects relevant to the E-ELT were covered in depth. All presentations can be accessed on the web (*http://www.eso.org/sci/facilities/eelt/science/meeting/jenam08/EELT_JENAM08_Programme.pdf*). Here follows a short summary in session number order covering the scope and main conclusions of the presentations.

Session #1: E-ELT programme

Roberto Gilmozzi (ESO), the E-ELT Principal Investigator, presented the status of the present detailed design (Phase B) of the facility. He first addressed all ELT projects worldwide in the global context of planned space- and ground-based large facilities. This was followed with a summary status of the main aspects of the present project (site characterisation, infrastructure, enclosure, telescope mount, optics, control, maintenance and operations). He then discussed the most critical science drivers for the E-ELT (exoplanets, stellar archaeology, cosmology and the unknown) and the corresponding technical challenges, in particular how to achieve superb image quality, down to the diffraction-limit of the 42 m aperture of the telescope, through wind and atmospheric turbulence correction, based on adaptive optics (AO), over the full working field of the facility.

The status of the Design Reference Mission (DRM) was presented by Isobel Hook (Oxford University), who is responsible for the DRM. This development is driven by the Opticon–ESO Science Working Group (SWG) with the help of the community. The goal is to produce a set of science proposals, with accompanying simulations of the observing results taking into account the whole facility, including adaptive optics systems and instrumentation, leading to a quantitative assessment of the expected science output. This significant effort, covering nine prominent science cases, involves a total of 17 proposals to be analysed in depth and four cases are well advanced at this time. Preliminary conclusions point to a broad E-ELT science case with such highlights as direct detection of super-Earths, watching galaxies form, real-time observation of the accelerating Universe, plus a strong discovery potential for new science. Details on the DRM can be found at *http://www.eso.org/sci/facilities/eelt/science/*.

Markus Kissler-Patig (ESO), E-ELT Project Scientist, showed how the science requirements are driving the project. This started as a generic process, with the publication of the 2005 Opticon–ELT science cases (Hook, 2005), and the Opticon–ESO SWG then focused on the

E-ELT. The resulting report on the science case and requirements released in May 2006 established, in particular, the need for a multi-purpose facility with a large field-of-view and a built-in adaptive optics capability. The SWG is now leading the project Design Reference Mission (see previous presentation description). The ESO E-ELT Science Office is in charge of injecting the science requirements assembled by the SWG and the ten instrument science teams into the design phase. To enlarge the E-ELT scientific base, the community is presently being asked to help build a Design Reference Science Plan (DRSP) by providing additional science cases through a web interface at *http://www.eso.org/sci/facilities/eelt/science/drsp*.

Mark Casali, on behalf of Sandro D'Odorico, who is responsible for the ESO E-ELT instrumentation, covered the status of the current instrumentation feasibility studies. Eight instruments and two post-focal adaptive optics modules are presently being studied by 36 research institutes across Europe with the goal of delivering full science cases, detailed instrument requirements (including telescope/observatory interfaces), consistent and feasible concepts, costs and construction schedules. The complete list of studies is given in Table 1 of Spyromilio et al., 2008. This huge community effort is on track to provide, by the first quarter of 2010, thoroughly studied, scientifically powerful and technically feasible options for the E-ELT first generation instrumentation, which form an essential input for the mid-2010 evaluation process and anticipated decision to build the facility.

Finally, Florian Kerber (ESO), E-ELT Calibration Scientist, described the objectives and methods pursued by ESO, with the help of external partners, to ensure that all E-ELT instrument observational data will be properly calibrated and that adequate pipelines will be available to transform raw data into measurable and accurate quantities expressed in physical units. He stressed the importance of physical modelling of the instruments to minimise the statistical and systematic uncertainties associated with the measuring process. It is equally important to build a set of calibration reference data such as accurately known wavelength calibrators and faint spectrophotometric standards, especially for the near-infrared (near-IR).

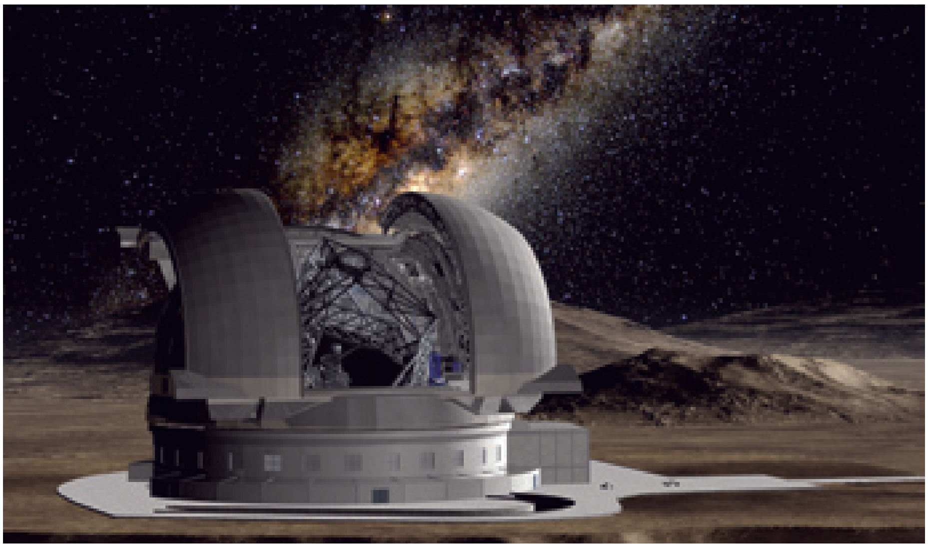
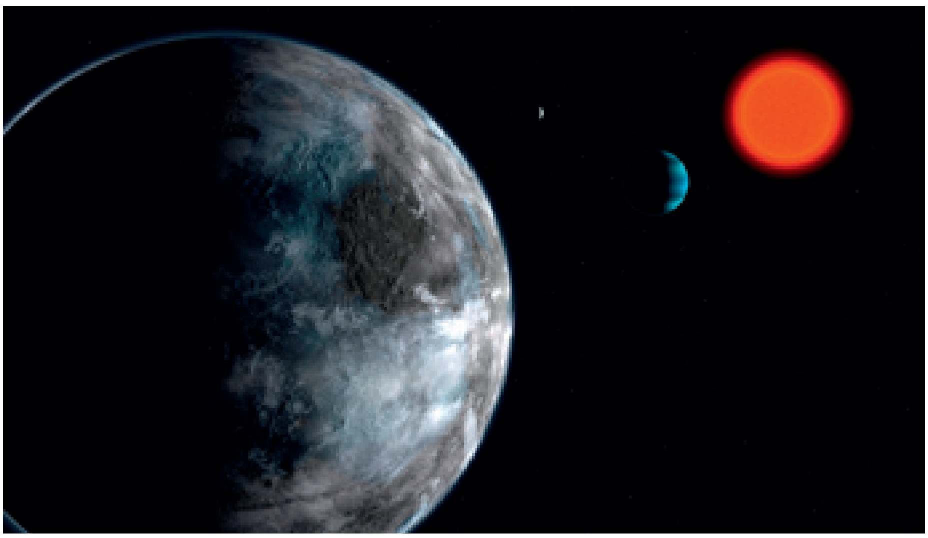


Figure 2. An artist's impression of the E-ELT during observations.

Session #2: Planetary systems and stellar formation

The science case for EPICS, the E-ELT planet finder, was put forward by Markus Kasper (ESO) and Rafaele Gratton (INAF–OAP, Italy) on behalf of the consortium. The fundamental characteristics of the instrument were briefly discussed as well as the hardware, software and observational strategies envisioned to achieve the extreme contrast required to make large scientific inroads into the highly competitive field of exoplanet direct detection. EPICS is a near-IR, extreme contrast, spectral and polarimetric imager with the potential to detect a substantial number of self-luminous exoplanets, especially around hundreds of young stars, and including nearby giant planets down to the mass of Neptune, as well as dozens of nearby rocky planets. The present feasibility study, including the instrument development plan, should be concluded by early 2010.

Figure 3. An artist's rendering of the three-planet system around Gliese 581, as found from highly precise radial velocity measurements with the ESO 3.6 m HARPS spectrograph.



Hans Zinnecker (AIP–Potsdam, Germany) with Fernando Comeron (ESO) and Mark McCaughrean (Exeter University, UK) covered infrared investigations of massive star formation with the E-ELT through diffraction-limited imaging and three-dimensional (3-D) spectroscopy. Observing in the *K*-band and beyond up to 12 μm is essential to observe the early stages of cluster formation, penetrating as much as 200 magnitudes of visual extinction. A combination of high definition imaging, astrometry and spatially resolved radial velocities is required to probe these extremely active dynamical phases. As a complement to observations from the Atacama Large Millimeter/submillimeter Array (ALMA), the E-ELT has the potential to provide clear scientific breakthroughs in the field of massive star formation in dense environments.

Session #3: The stellar component

Rafael Rebolo (IAC, Tenerife, Spain) showed the "unique and fascinating" impact of the E-ELT on the understanding of the origin and evolution of stars and planets. The main research thrust aims at: determining the initial stellar mass function, including multiplicity; studying protoplanetary systems; establishing exoplanet demography and characterising their global physical properties. The E-ELT will also be a powerful tool for investigating a large variety of objects (planets, moons and comets) in our Solar System. All these programmes will require: (a) ultra-stable high resolution spectroscopy in the optical (the CODEX instrument) and near-IR (SIMPLE instrument) wavelength domains for indirect detection of companions and planets; and (b) a fully AO-equipped ELT providing 1–20 μm imaging and spectroscopy at high angular resolution and high contrast (to be provided by the EPICS, HARMONI and METIS instruments) for direct planet detection and physical assessment.

Ernesto Oliva (INAF–Arcetri, Italy) presented the status of the study of the E-ELT high spectral resolution, near-IR diffraction-limited spectrograph (SIMPLE) on behalf of a recently assembled consortium. The project features a wide wavelength coverage (0.8–2.5 μm), high efficiency and radial velocity accuracy, with a minimum 10^5 spectral resolution. He emphasised the unique science within reach with such an instrument, including kinematics and metal content of Lyman-α absorbers, early chemical nucleo-synthesis and chemical enrichment in the inner Galaxy, spectro-astrometry of inner stellar discs within ~ 1 AU, and detection of atmospheric absorption features of Earth-like planets around low mass stars from transit observations.

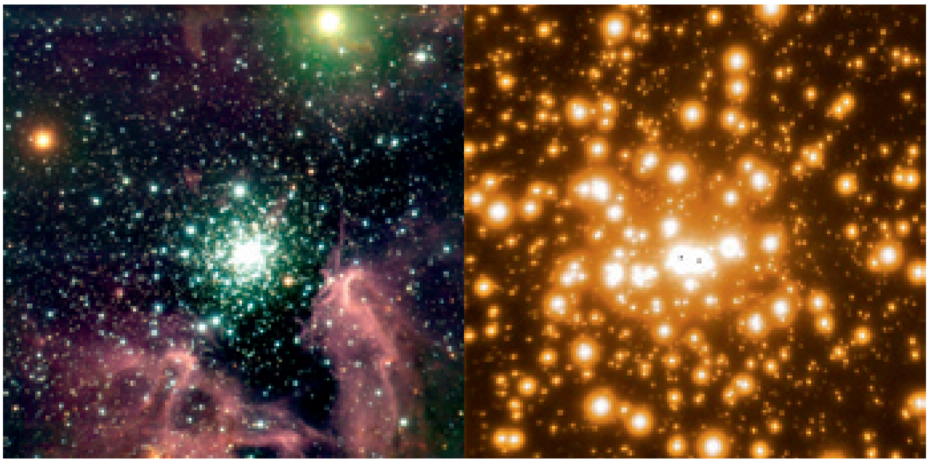


Figure 4. Near-IR images of the Galactic starburst region NGC 3603 at the VLT. Left: 0.4" seeing-limited *J, H,* K_s composite image taken with ISAAC. Right: Diffraction-limited *K*-band image obtained with the MAD adaptive optics demonstrator.

Norbert Przybilla (Sternwarte Bamberg, Germany) addressed the role of blue supergiants (BSGs) as tracers for the cosmic cycle of matter. BSGs emerge as powerful tools for studying: (a) stellar atmosphere physics; (b) metallicity effects on stellar evolution; (c) abundance gradients in field, group and cluster galaxies; and (d) the cosmic distance scale. Quantitative studies of extragalactic BSGs with an ELT require diffraction-limited, near-IR spectra at intermediate resolution. The role of the VLT's Cryogenic high-Resolution Infrared Echelle Spectrograph (CRIRES) as a preparatory tool for ELT science, through observations of Galactic BSGs in order to test stellar atmosphere models and analysis methodology, was strongly emphasised.

Maria Fernanda Nieva (MPA, Garching, Germany) and collaborators made the case for near-IR high resolution spectroscopy of OB stars with CRIRES at the VLT as a pilot study for an ELT science case. Their aim is to determine accurate atmospheric parameters and chemical abundances of Galactic OB stars from identification of metal lines with CRIRES to compare with optical data. Beyond obtaining more accurate models, a very useful by-product of these observations will be the establishment of a set of telluric line standards. Direct application to an ELT includes high precision determination of the chemical composition of massive stars in the Local Group in diverse environments (star formation regions, field stars, the Galactic Centre, etc.).

Chris Evans (UKATC, UK) presented the case for spectroscopy of stellar populations with EAGLE, a near-IR spectrograph with deployable integral field units, currently under phase A study for the E-ELT. The stellar science case spans spectroscopic studies of obscured stellar clusters and resolved stellar populations in and beyond the Local Group (galaxy archaeology), including the central regions of our Galaxy. The primary instrument requirements imposed by the stellar cases are the inclusion of a high (R ~ 10 000) spectral-resolving-power mode, and the extension of the wavelength coverage bluewards of 1 μm to include the calcium triplet region. The unprecedented primary aperture of the E-ELT, combined with a large patrol field, modest multiplexing and excellent AO correction, will yield huge gains in sensitivity and efficiency over current facilities, leading to unique advances in studies of stellar populations.

Giuseppe Bono (INAF–OAR, Italy) and collaborators presented recent results on crowded stellar photometry in Galactic globular clusters with the VLT's Multi-conjugate Adaptive optics (MCAO) Demonstrator (MAD). Deep J and K_s images of NGC 3201 were obtained over the 2' x 2' field with a spatial resolution (full width at half maximum) of 70–100 milliarcseconds. Simultaneous reduction of these near-IR images and Hubble Space Telescope (HST) optical images were performed with "classical" reduction packages. This gave a precise Colour Magnitude Diagram (CMD) down to 2 magnitudes below the main sequence turnoff. Stars down to 0.1 $M_\odot$ have been detected in the Galactic starburst NGC 3603 from K_s-band images. The discovery space with an E-ELT looks wide open, provided extensive J-H-K calibrations down to ~ 19 magnitude are obtained (see report on presentation by Kerber, above) together with a vigorous effort to improve theoretical models and stellar diagnostics.

Paolo Ciliegi (INAF–OAB, Italy) presented the Multi-conjugate Adaptive Optics RelaY (MAORY) for the E-ELT on behalf of the consortium. High system performance, in particular in terms of differential photometric precision and relative astrometric accuracy, is required to enable prominent E-ELT science cases, such as deep CMDs of resolved stellar populations (see report on previous presentation), in conjunction with the near-IR MICADO imager (see next reported presentation), to be achieved. These two critical performance requirements are being evaluated by the MAORY consortium with simulated, field-variable point spread functions and simulated globular cluster images. Final conclusions are expected by the end of 2009.

The science case for the E-ELT MCAO Imaging Camera for Deep Observations (MICADO), was presented by Renato Falomo (INAF–OAP, Italy) on behalf of the consortium. An advanced exposure time calculator produces realistic simulated sky images on which data analysis algorithms are tested. Science cases cover a rather wide range, from stellar dynamics around the Galactic Centre, through 100 microarcseconds astrometry, to photometric evidence for supermassive black holes in the centres of galaxies and the physical structure of high redshift galaxies. Two cases were presented in detail in the talk, namely resolved stellar populations in galaxies up to the Virgo cluster distance and QSO hosts and environments at high redshift. A report with a comprehensive scientific analysis is expected soon.

Session #4: The Universe fabric

Klaus Strassmeier (AIP, Potsdam, Germany) presented the ubiquitous role of magnetic fields with examples of the Sun–Earth magnetic connection and its exoplanet version, stellar magnetic fields during core collapse, main sequence and planetary nebula phases, and the still open case of an Intergalactic Magnetic Field (IGMF) as a possible primordial seed. For the last example, the proposed breakthrough with the E-ELT would be to obtain high spectral resolution optical and near-IR linear spectropolarimetry of background quasars in order to measure the Faraday rotation due to the IGMF. This observation requires polarimetric modulation at the E-ELT intermediate focus, comparable to the upcoming PEPSI instrument at the Large Binocular Telescope (LBT). Feeding an optical and a near-IR spectrograph simultaneously would permit access to a wealth of objects from Solar System and extra-Solar System bodies to bright quasars. More discussion of this topic will take place at the IAU Symposium 259 (Cosmic Magnetic Fields: from Planets, to Stars and Galaxies) in November 2008.

One prominent E-ELT science case in the DRM is the determination of the physics and mass assembly of galaxies up to z ~ 6 from a survey of ~ 1000 galaxies with a multi-object integral field spectrograph (see report on the presentation by Evans above). Mathieu Puech (ESO) presented in detail the simulation pipeline developed to assess quantitatively the potential of the E-ELT for this case. This pipeline includes distant galaxy modelling and evaluation of the effects of the point spread function, thermal background and noise sources. From these detailed simulations, the impact of telescope size, site (thermal background and seeing) and instrument characteristics (AO correction, pixel scale and spectral resolution) are being assessed. Finally, a provisional strategy for an optimal survey able to succeed in this science case was unveiled.

Malcolm Bremer (Bristol University, UK) presented the state-of-the-art observations and the impact of the future astronomical large facilities on the exploration of the early Universe during its first gigayear. The James Webb Space Telescope (JWST) will probably be the first to identify the sources of reionisation, but full spectroscopic confirmation will probably require an ELT equipped with an efficient spectrometer working at a spectral resolution of ~ 10^4 to explore the z ~ 6 intergalactic medium (IGM) seen against

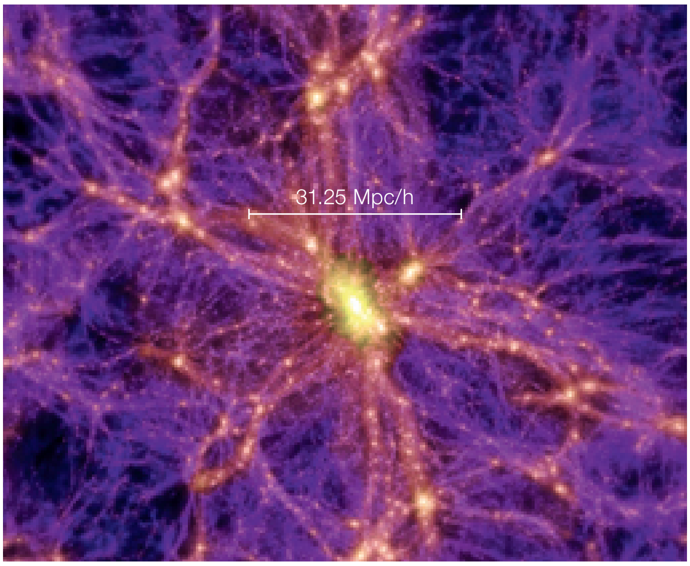


Figure 5. The cosmic tapestry at z = 0 (from the Millennium Simulation).

'bright' background sources. ELTs will be a key component in elucidating the detailed properties of the earliest galaxies, in particular when used along with complementary facilities such as ALMA and the extended Very Large Array (EVLA). The ELT requirement is for spatially resolved, diffraction-limited spectroscopy to achieve ~ 100 pc spatial resolution, a capability that should, in principle, be offered by the current planned instrumentation.

Andreas Kelz (AIP, Potsdam, Germany) discussed the need for ELT optical spectroscopic follow-up of space- and ground-based imaging surveys. He presented the highly promising observing potential of seeing-limited, modular, high-multiplex spectrometers as the most cost-effective and currently feasible approach. Astrophysical examples from the PMAS instrument at the 3.5 m Calar Alto telescope. and from the VLT MUSE and the Hobby–Eberly Telescope (HET) VIRUS 3-D spectrometers under construction, were given. For the E-ELT, the proposed concept features a modular design built from seeing-matched, deployable, fibre integral field units and multiple, replicable, small-size spectrometers. Optionally, photonic components such as fibre Bragg OH suppressors, integrated photonic spectrographs, etc. (see Bland Hawthorn et al., 2006) can be incorporated. Such advanced photonic technologies are amongst the concepts for the proposed ERASMUS instrument study for the E-ELT.

Joe Liske (ESO) presented the E-ELT COsmological Dynamics EXperiment (CODEX) on behalf of the team. The aim of the instrument is to probe the acceleration of the expansion of the Universe directly, one of the most fundamental problems in cutting-edge physics, not only astrophysics. This requires a high resolution optical spectrograph with exceptional radial velocity (*viz.* wavelength) stability of the order of 1 cm/s to detect the so-called redshift drift in the Lyman-α forest spectra of ~ eighteen $2 < z < 5$ QSOs over a 15–20 year period (Liske et al., 2008). The availability of key instrument subsystems, in particular a laser frequency comb to provide the required ultra-stable wavelength calibration, was assessed. A successful detection of the redshift drift on the 42 m E-ELT requires a total of about 4 000 hours of observing time spread over two decades.

Figure 6. The ever-growing progress of the ELT science case under the Opticon aegis, from Marseille in 2003, to Florence in 2004 and back to Marseille in 2006.

Wolfram Freudling (ESO), with Eric Emsellem (CRAL–Lyon, France) and A. Küpcü Yoldaş (MPE, Garching, Germany) investigated the potential E-ELT scientific impact on dynamical mass estimates of supermassive black holes (SMBH). Present day knowledge of these objects was summarised, followed by detailed simulations of potential observations with the E-ELT. Advances in this scientific field require a diffraction-limited 3-D spectrometer at a spectral resolution of ~ 1000–3 000. Preliminary results show that detection of relatively low mass SMBHs in Virgo should require only ~ 15 minutes integration with 5–10 hours required for the most massive SMBHs to z ~ 0.3. ELTs clearly have the potential to open a new era for SMBH research, and in particular to understand the processes of their formation and evolution better.

Session #4: Conclusions

Gerry Gilmore (IoA, Cambridge, UK), Opticon chairman, summarised the history of European involvement in ELTs and delineated the role played by Opticon since 2002 in bringing out a united pan-European effort, first towards the design-independent FP6 ELT Design Study, then rallying around the E-ELT Project. Opticon has played a major role in developing, in close collaboration with the community, a comprehensive science case for the E-ELT, including its first top level science requirements. The importance of the three "big questions" — the physical meaning of dark energy, the nature of dark matter and the ubiquity of life — and the potential E-ELT role in attacking these problems were emphasised in the talk. He concluded: "The E-ELT is an excellent and realistic project, enjoying a strong and wide community support that the ESO design team must retain. The community must continue active involvement and work for national agency support, to raise the funds and approval by mid-2010."

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The spiral galaxy Messier 83 (NGC 5236) from a Wide Field Imager colour composite. Exposures in B, V, R and Hα filters were combined; see ESO PR 25/08 for details.

Credit: ESO/Davide De Martine

From the Dynamics of Cepheids to the Milky Way Rotation and the Calibration of the Distance Scale

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High precision spectroscopic measurements of ten southern Galactic Cepheid stars with the High Accuracy Radial velocity Planet Searcher (HARPS) on the 3.6 m telescope at La Silla has allowed detailed analysis of the dynamical structure of their atmospheres and close environment. The results have consequences for the calibration of the cosmic distance scale, and show that the rotation of the Milky Way is probably simpler than previously thought. However, a full understanding of the effect of spectral line asymmetries still requires the development of dedicated models.

Since Henrietta Leavitt's discovery of their unique properties in 1908 (Leavitt, 1908), the Cepheid class of pulsating supergiants has been used as a distance indicator to probe the structure of our Galaxy (Shapley, 1918) and to measure the expansion of the Universe (Hubble, 1929). When combined with velocity measurements, the properties of Cepheids are also an extremely valuable tool in investigations of just how our Galaxy, the Milky Way, rotates (Joy, 1939). Recently, the HST Key Project on the Extragalactic Distance Scale totally relied on Cepheids to calibrate far-reaching methods of distance measurement and to determine the Hubble constant (Freedman et al., 2000). However, the major uncertainty in the use of Cepheids as standard candles continues to be the accurate determination of the distance to the Large Magellanic Cloud (LMC). This distance provides the fiducial Cepheid period–luminosity relation and constitutes the largest source of uncertainty in the whole process of constructing the cosmic distance ladder.

Studying the dynamical structure of the atmospheres of Cepheids, together with their close environment, is one of the most fundamental ways to obtain constraints on the rotation of the Milky Way and to improve the distance scale ladder. In order to achieve these goals, high signal-to-noise (S/N), high spectral resolution and multi-epoch spectrographic observations of Cepheids are required.

Probing the dynamical structure of the atmospheres of Cepheids

In total, we have obtained 300 measurements using the HARPS optical spectrograph. Eight stars were observed with very high spectral and time resolution, combined with a high S/N ratio (around 300). In order to provide a dynamical picture of the pulsating atmospheres of the Cepheids, we carefully selected 17 spectral lines that are formed at different layers in the atmosphere.

The spectral line profile, in particular its asymmetry, is critically affected by how the Cepheid atmosphere pulsates and by the many phenomena involved: limb-darkening; velocity gradients within the line-forming region; turbulence; rotation; and the relative motion of the line-forming region with respect to the corresponding mass elements. When the line-forming region moves relative to the background atmospheric structure, it will also move with respect to the background velocity field. All these physical effects are also variable over the pulsation cycle.

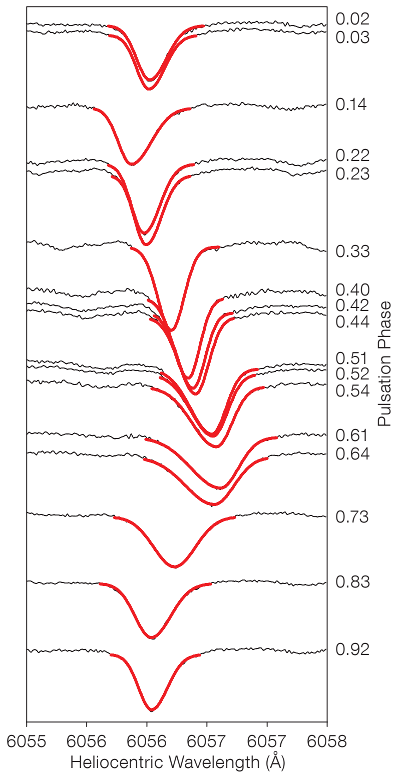
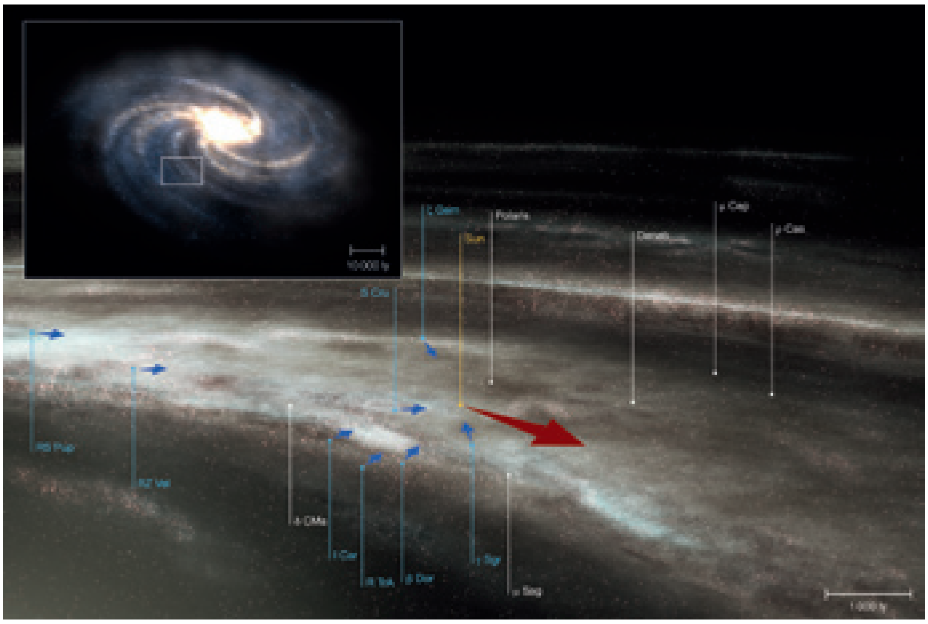


Figure 1. HARPS spectral line profiles of ß Dor (spectral resolution ≃ 120 000) together with an analytic bi-gaussian (in red) at different pulsation phases.

We extracted radial velocity and line asymmetry curves for all selected lines of all stars. Concerning the radial velocity, the best method to use — when the S/N ratio allows it — is the first moment of the spectral line profile. The radial velocity curve derived from this method is absolutely *independent* of the spectral line width and the rotation. This property is extremely valuable for comparing the behaviour of different spectral lines of different Cepheids. We also derived the spectral line asymmetries with a very high precision, using a new estimator that we called the bi-Gaussian: two analytic semi-Gaussians are actually fitted to the blue and red part of the spectral line profile respectively. The amount of asymmetry (as a percentage) is then given by the comparison of the half-width at half-maximum of each semi-Gaussian. This definition was well suited to the data quality (see Figure 1). The last very important tool we considered was the correlation curves between the radial velocities and the spectral line asymmetries (Nardetto et al., 2006).

Figure 2. Artist's impression of the local neighbourhood of the Sun and its setting within our Galaxy, the Milky Way. The figure shows the positions of the eight Cepheid stars used in the investigation. After the rotation of the Milky Way had been accounted for, it seemed that the Cepheids were all 'falling' towards the Sun. New, very precise measurements with the HARPS instrument have shown that this apparent 'fall' is due to effects within the Cepheids themselves and is not related to the way the Milky Way rotates.



The rotation of the Galaxy

The motion of Milky Way Cepheids is confusing and has led to disagreement in the literature. If an axisymmetric rotation of the Galaxy is taken into account, Cepheids appear to 'fall' towards the Sun with a mean velocity of about 2 km/s (Figure 2). This residual velocity shift has been dubbed the "K-term", and was first estimated by Joy (1939) to be −3.8 km/s. Since then, the sample of stars has increased, as well as the precision of the measurements, but the problem has persisted.

A debate has raged for decades as to whether this phenomenon was truly related to the actual motion of the Cepheids and, consequently, to a complicated rotating pattern of our Galaxy, or if it was the result of effects within the atmospheres of the Cepheids.

The latest results by Pont et al. (1994) are based on an N-body simulation for the Galaxy. They ran a simulation of over 300 000 particles orbiting non-axisymmetrically about the centre of a galaxy and computed what the observed radial velocities would be from the Sun. They found a residual velocity shift of −2.1 km/s.

The measured radial velocity of a Cepheid reflects its motion in the Galaxy plus the motion of its pulsating atmosphere. The centre of mass velocity, or γ-velocity, defined as an average value of the radial velocity curve, is generally used to determine the apparent velocity of the star along the line-of-sight. While the cross-correlation method is generally used to derive the γ-velocity, we measured it independently for each spectral line of each star in our sample. Following the same definition, we measured the average values of the corresponding asymmetry curves, which we called the γ-asymmetries (Figures 3a and 3b). Interestingly, for each Cepheid in our sample, we found a linear relation between the γ-velocities of the various spectral lines and their corresponding γ-asymmetries. This result is actually easily understandable: the more asymmetric the line, the larger the first moment of the spectral line (as an absolute value). It also shows that the residual γ-velocities stem from the intrinsic properties of Cepheids.

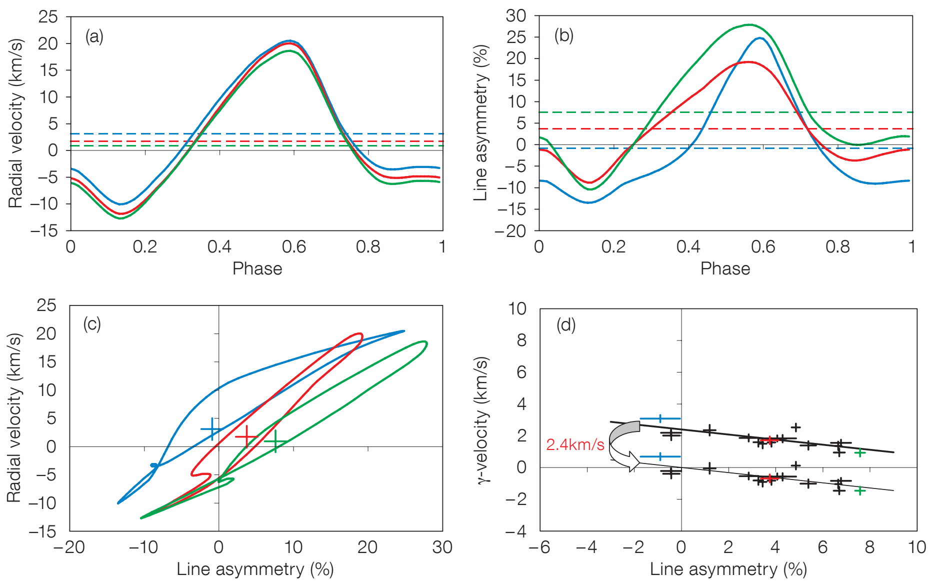


Figure 3. Radial velocities (a) and line asymmetries (b) are presented as a function of the pulsation phase for three spectral lines for the case of ß Dor: (Fe I 489.6 nm [blue line]; Fe I 537.3 nm [red line]; Fe I 602.4 nm [green line]). Horizontal dashed lines correspond to the average values of the interpolated curves, respectively. In (c) velocity as a function of the line asymmetry, and the corresponding (γ-asymmetry, γ-velocity) average values (crosses) are shown for the three different lines. In (d) a generalisation of diagram (c) is shown for all spectral lines. The velocity-versus-asymmetry plots are not included for clarity. The upper values are without any correction except for the Galactic Cepheid Database γ-velocity. The origin of the plot is then used as a physical reference for all spectral line γ-velocities of the star (lower values). We find a correction of −2.4 km/s for ß Dor that is consistent with the K-term value.

Using these linear relations, we can provide a physical reference to derive the centre of mass velocity of our stars: it should be zero when the γ-asymmetry is zero (Figures 3c and 3d). The corrections we found between our 'calibrated' velocities and the ones found in the literature (from the Galactic Cepheid Database[1]), range from −0.2 to −3.6 km/s. The average value (over the eight Cepheids) is −1.8 ± 0.2 km/s, which is consistent with the K-term value.

Our observations show that this apparent motion towards us almost certainly stems from an intrinsic property of Cepheids.

This result, if generalised to all Cepheids, implies that the rotation of the Milky Way is simpler than previously thought, and is certainly axisymmetric (Nardetto et al., 2008a).

The γ-asymmetries of spectral lines also show a trend with the period of the star. We investigated several physical explanations for these non-zero γ-asymmetries, such as velocity gradients or the relative motion of the line-forming region compared to the corresponding mass elements. However, none of these hypotheses seems to be entirely satisfactory to explain the observations. Further numerical investigations are required.

The distance scale calibration

Two methods have recently been used to calibrate the period–luminosity relationship for determining the distance of Cepheids (see, e.g., Kervella et al., 2004): the infrared surface brightness method (IRSB); and the interferometric Baade-Wesselink (IBW) method. The basic principle behind these two methods is to compare the linear and angular size variation amplitudes of a pulsating star to derive its distance through a simple division. The *caveat* is that interferometric or photometric measurements in the continuum lead to angular diameters corresponding to the photospheric layer, while the linear stellar radius variation is deduced from spectroscopy, i.e., it is based on line-forming regions that are formed at high altitudes above the photosphere. Thus, radial velocities V_{rad}, which are derived from line profiles, include the integration in two directions: over the stellar surface (weighted by the limb-darkening effect), and over the atmospheric layers (through velocity gradients in the thickness of the atmosphere). All these phenomena are currently merged into one parameter, generally considered as constant with time: the projection factor p, defined as $V_{puls} = pV_{rad}$, where V_{puls} is defined as the photospheric pulsation velocity. Then V_{puls} is integrated with time to derive the photospheric radius variation. The precision in the distance currently obtained with the IBW and IRSB methods is a few percent; however, they remain strongly dependent on the projection factor.

Based on hydrodynamical models for δ Cep and *l* Car, we devised a new spectroscopic method of determining the projection factor. This method was then applied to the stars observed with the HARPS spectrometer. We divide the projection factor into three sub-concepts: (1) a geometrical effect; (2) the velocity gradient within the atmosphere; and (3) the relative motion of the 'optical' pulsating photosphere compared to the corresponding mass elements. Both (1) and (3) are deduced from geometrical and hydrodynamical models, respectively, while (2) is derived directly from spectroscopic observations by considering different lines that are formed at different layers in the atmosphere, allowing us to measure velocity gradients. We found, for the first time, a period–projection factor relation P_p (Figure 4). This P_p relation is an important tool for removing a bias in the calibration of the period–luminosity relation of Cepheids. We emphasise that if a constant projection factor is used (generally p = 1.36 for all stars) to derive the period–luminosity relation, errors of 0.10 on the slope and 0.03 magnitude on the zero-point of the period–luminosity relation can be introduced (Nardetto et al., 2007). Our semi-theoretical P_p relation has been confirmed by Hubble Space Telescope (HST) observations (Mérand et al., 2005; Fouqué et al., 2007).

Using this P_p relation in the IBW and IRSB methods of distance determination, as well as HST parallaxes, Fouqué et al. (2007) showed that the slope of the Galactic and LMC period–luminosity relations are similar. This result shows that applying the well-determined LMC slopes

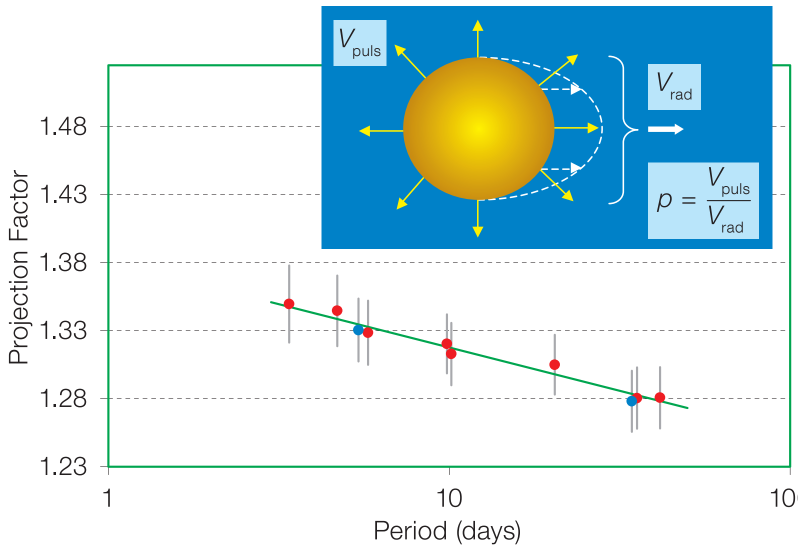


Figure 4. The projection factor (p) used in the interferometric Baade-Wesselink (IBW) and infrared surface brightness (IRSB) methods for determining the distance of Cepheids includes a geometrical effect (see inset box), a velocity gradient within the atmosphere and the relative motion of the line-forming region with respect to the corresponding mass elements. A relation was found between the projection factor and the logarithm of the period. Red points are semi-theoretical (including the HARPS determination of velocity gradients), while blue points are from hydrodynamical models.

[1] *http://www.astro.utoronto.ca/DDO/research/cepheids/*

to distant galaxies of different metallicities is warranted. However, metallicity effects are not excluded concerning the zero-point of the period–luminosity relations, which still prevents us from determining the distance to the LMC directly. Using the IBW and IRSB methods, our group expects to determine the distance of 20 Galactic Cepheids with a precision of 2 % in the near future, and to calibrate the Galactic period–luminosity relation with an error of less than 0.01 magnitude. Work in progress shows that a good precision can be also obtained on the distance of LMC Cepheids using the IRSB method. An accuracy on the distance modulus of the LMC of 0.01 magnitude and 5 % on the Hubble constant are now conceivable.

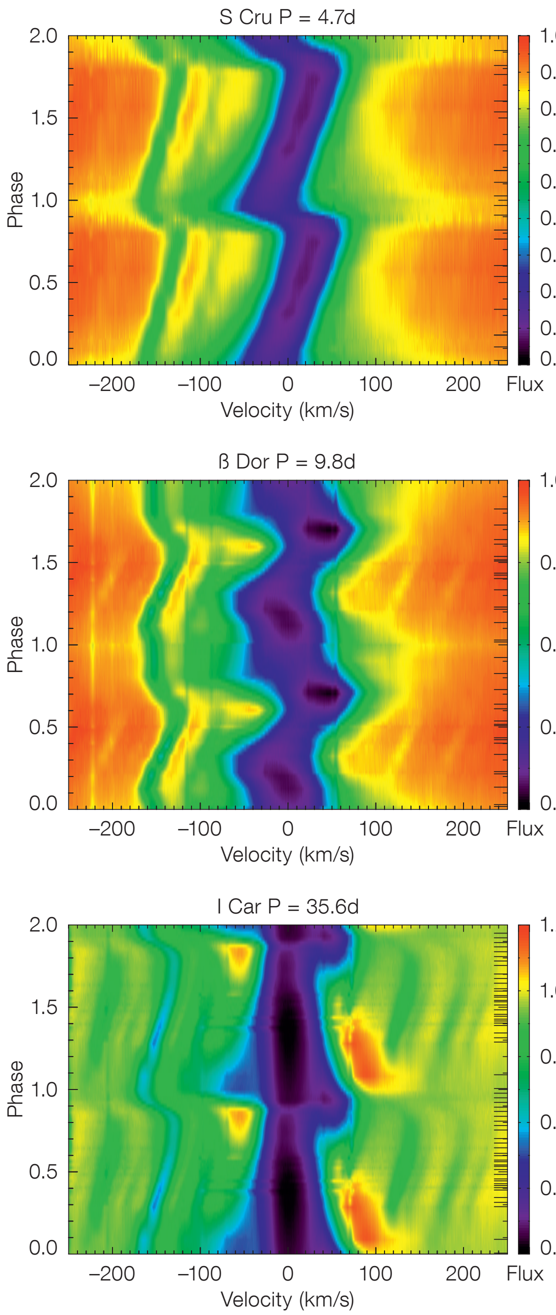


Figure 5. Hα line profiles of short, medium and long period Cepheids. Time series of HARPS spectra are interpolated to provide a two-dimensional map of the Hα profile in the [–250, 250] km/s velocity range. Diagrams are given in the stellar rest frame with positive velocities corresponding to receding motion (red-shifted). The pulsation phase is indicated on the left edge of each panel and on the right we quote the pulsation phases corresponding to our observations (data are duplicated over two pulsation cycles for clarity). For each star the colour bar indicates the continuum-normalised flux.

The close environment of Cepheids

Another possible bias in the IBW and IRSB methods of determining the distance of Cepheids is the presence of a circumstellar envelope, which has been recently discovered by Kervella et al. (2006) and Mérand et al. (2007). Such envelopes have a signature in the Hα line profiles.

The Hα line profiles were described for all stars using a 2-D (wavelength versus pulsation phase) representation. For each star, an average spectral line profile was derived, together with its first moment (γ-velocity) and its asymmetry (γ-asymmetry). Short period Cepheids show Hα line profiles which closely follow the pulsating envelope of the star, while long period Cepheids show very complex line profiles and, in particular, large asymmetries (Figure 5). We also confirmed a dominant absorption component with a constant, almost-zero velocity in the stellar rest frame for *l* Car. This component is attributed to the presence of a circumstellar envelope. For other Cepheids, the central component is certainly too faint to be observed in our spectra.

Interestingly, we found a new relationship between the period of Cepheids and their Hα γ-velocities and γ-asymmetries. However, regarding the metallic lines, the γ-asymmetries of metallic lines are a few percent and show a decrease with the period of the Cepheid. In comparison, γ-asymmetries measured for the Hα line profiles increase with the period and reach about 20 % for long period Cepheids. Therefore, we suggest that γ-asymmetries (or γ-velocities) corresponding to metallic and Hα lines are the result of different physical mechanisms. Even if the γ-velocities of Hα line profiles might be partially due to the dynamical structure of the Cepheid atmosphere, it seems reasonable to also invoke some possible mass loss from Cepheids with typical velocities projected on the line of sight up to –20 km/s (Nardetto et al., 2008b). The most spectacular example of circumstellar material around a Cepheid is the large light-scattering nebula of the long period Cepheid RS Pup (Kervella et al., 2008). Moreover, strong pulsational compression of atmospheric layers and shock waves have been observed in the short period Cepheid X Sgr (Mathias et al., 2006), a star that is also part of our HARPS sample, as well as RS Pup.

Prospects

While we found that the rotation of the Milky Way is likely to be simpler than previously thought, the dynamical structure of a Cepheid atmosphere is conversely much more complex than their radial pulsation would indicate. For a better understanding of the γ-asymmetries, we gathered high resolution infrared spectra with VLT/CRIRES in order to sample different line-forming regions in the Cepheid atmospheres. Another very promising instrument is VEGA: a visible spetrograph and polarimeter mounted on the Center for High Angular Resolution Astronomy (CHARA) interferometer. As it combines very high spectral resolution (R = 30 000) and high angular resolution (sub-milliarcsecond) at visible wavelengths, VEGA will provide novel geometrical constraints on the dynamics of Cepheids. Further insights into the link between γ-asymmetries and atmosphere dynamics will also come from the application of our data analysis techniques to other classes of pulsating stars (such as RR Lyr, δ Scu, etc.).

Although the hydrodynamical code for pulsating stars that we are using (Fokin, 1991) reproduces the atmospheric velocity gradients extremely well and provides spectroscopic and spectro-interferometric observables, it is not capable of describing very subtle and second order physical behaviour, like γ-asymmetries. Therefore, further numerical studies are required to investigate the effect of convective flows and complex radiative transport on the atmospheres of Cepheids. These phenomena, as well as mass loss, the circumstellar envelope, and the exact evolutionary state of the star, have to be incorporated simultaneously and consistently into dedicated numerical models to reproduce the observed spectral line profiles in detail.

A better understanding of the atmospheric dynamics of Cepheids has already given us a better understanding of the rotation of our Galaxy. It represents key progress towards a truly accurate calibration of their distance scale. Exactly a century after the discovery of the period–luminosity relation (Leavitt, 1908), the pulsation mechanism of Cepheids is still a challenge to understand today, and high resolution spectra are certainly part of the key.

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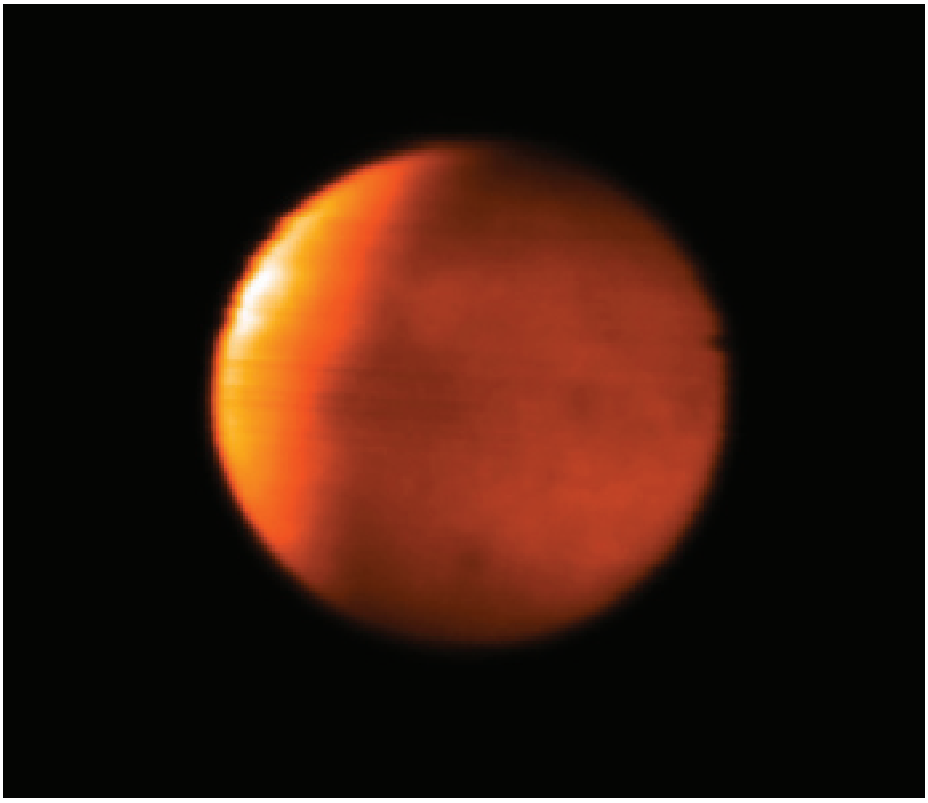

The Moon at 3 mm wavelength. The data used to produce this image were taken with the European ALMA prototype antenna as part of a test of the continuum raster map observing mode at the ALMA Test Facility in August 2008. The data acquisition and reduction were all performed with the ALMA software that is being prepared for use next year for commissioning of the real ALMA hardware in Chile.

STRESS Counting Supernovae

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The rate of occurrence of supernovae (SNe) is linked to some of the basic ingredients of galaxy evolution, such as the star formation rate, the chemical enrichment and feedback processes. SN rates at intermediate redshift and their dependence on specific galaxy properties have been investigated in the Southern inTermediate Redshift ESO Supernova Search (STRESS). The rate of core collapse SNe (CC SNe) at a redshift of around 0.25 is found to be a factor two higher than the local value, whereas the SNe Ia rate remains almost constant. SN rates in red and blue galaxies were also measured and it was found that the SNe Ia rate seems to be constant in galaxies of different colour, whereas the CC SN rate seems to peak in blue galaxies, as in the local Universe.

Why count SNe?

A complete and coherent picture of the formation and evolution of galaxies is a fundamental objective of observational astronomy. Star formation (SF) is one of the main processes driving the evolution of galaxies. Individual young stars are unresolved in almost all nearby galaxies even with the Hubble Space Telescope, but the integrated luminosity in the ultraviolet (UV) continuum, nebular emission lines such as Hα or [O II] and the infrared (IR) continuum provides a direct, sensitive probe of these young massive star population in the galaxies. Integrated light measurements in these wavelength ranges scale linearly with the current star formation rate (SFR) and are used to investigate the SF properties of galaxies. An alternative and complementary approach to trace the SFR is based on direct observation of the death of some stars through SNe.

There are two distinct types of explosion: core-collapse-induced explosion of short-lived massive stars (CC SNe) and thermonuclear explosion of long-lived low mass stars (SNe Ia). Stellar evolution theory predicts that all stars more massive than eight to ten solar masses complete their nuclear burning and develop an iron core that cannot be supported by any further nuclear fusion reactions, or by electron degenerate pressure. The subsequent collapse of the iron core results in the formation of a compact object, a neutron star or a black hole, accompanied by the high velocity ejection of a large fraction of the progenitor mass. Due to the short lifetime of progenitor stars (from a few tenths of a million to several tens of millions of years), the CC SN rate is directly proportional to the current SFR. Poor statistics is a major limiting factor for using the CC SN rate as a tracer of the SFR both at low redshift, due the difficulty of sampling large volumes, and at high redshift, due to the difficulty of detecting and typing faint SNe. Moreover a significant fraction of CC SNe are missed by SN searches, since they are embedded in dusty spiral arms or galactic nuclei, and this fraction may change with redshift, if the amount and the average properties of dust in galaxies evolve with time. As a consequence an appropriate correction is required to estimate the intrinsic SN rate from the number of discovered CC SNe.

SNe Ia are widely believed to originate from the thermonuclear explosion of a carbon and oxygen white dwarf (WD) in a binary system, but the nature and evolution of the binary system remain poorly constrained. Progenitor models are broadly classified as either: single degenerate (SD) in which a WD, accreting from a main sequence or red giant companion, grows in mass until it reaches a critical limit and explodes; or double degenerate (DD), in which a close double WD system merges after orbital shrinking due to the emission of gravitational wave radiation. The time elapsed from the birth of the binary system to the SN explosion (delay-time) spans a wide range, from tens of millions of years to ten billion years or more. As a consequence the SN Ia rate reflects the star formation history (SFH) of a galaxy according to the distribution of the delay times.

SNe Ia can act as standard candles due to their significant intrinsic brightness, ubiquity and homogeneity, and have provided the first evidence for an acceleration of the expansion of the Universe. Understanding the mechanism that is responsible for this accelerating expansion, i.e., the nature and amount of dark energy, is one of the crucial next steps for observational cosmology and requires new searches for SNe Ia. Given the importance of SNe Ia as cosmological probes, the questions whether SNe Ia are a homogeneous class of stellar explosion and whether their properties evolve with redshift require answers. In particular the investigation of the nature of the progenitor star has become a critical issue. The analysis of the SN Ia rate as a function of redshift, galaxy morphological type and colour is a powerful tool for investigating the nature of the progenitor stars, their possible evolution with redshift and their connection with the environment.

Why STRESS?

Progress in using the CC SN rate as a SFR tracer and in investigating the nature of SN Ia progenitors requires accurate measurements of SN rates at various cosmic epochs. To reduce the uncertainty in the estimates of SN rates, a statistically significant SN sample and strict control of systematic effects, in particular

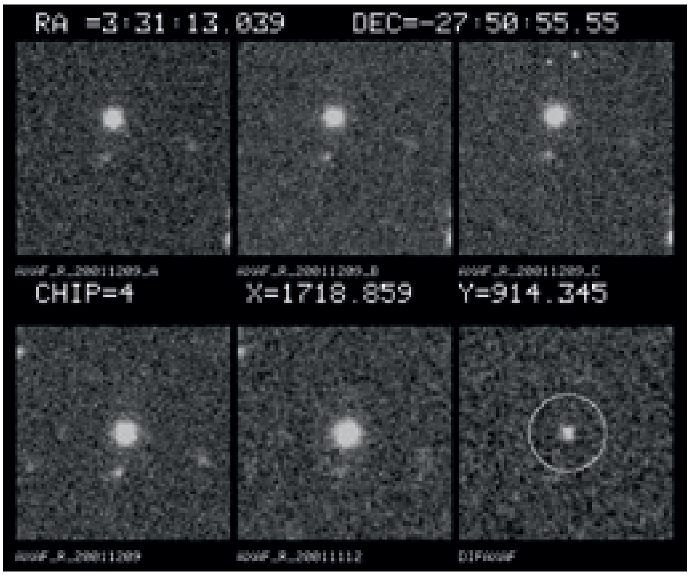

Figure 1. An example of a SN candidate discovered in the *R*-band. At the top are images of the same sky field acquired with a small offset of the telescope pointing (jittered images). These images are acquired to allow a better removal of cosmetic defects, cosmic rays, satellite tracks and fast moving objects. At the bottom left and centre are two images acquired at different epochs (obtained stacking the jittered images), with the difference image to the right. The variable source appears projected on a galaxy and shows a point-source-like profile in the difference image.

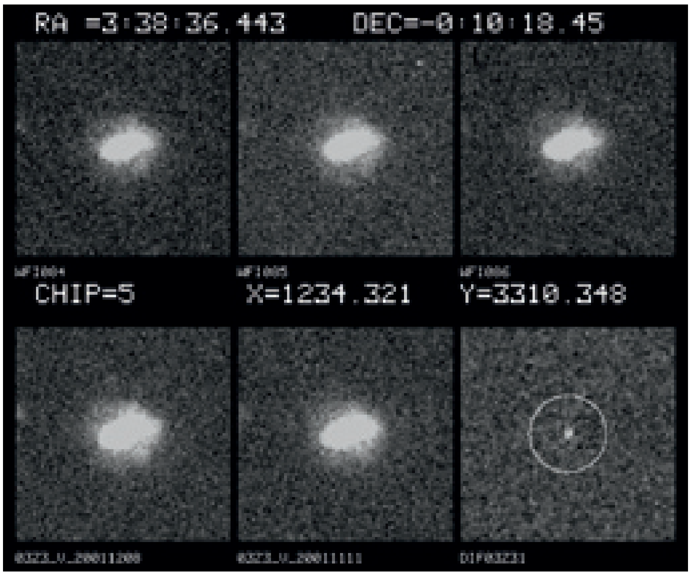

Figure 2. An example of a SNorAGN candidate discovered in the *V*-band (layout of images as in Figure 1). The variable source occurs near the galaxy nucleus. This candidate is actually an AGN and was also discovered by the Sloan Digital Sky Survey.

concerning dust attenuation, are necessary. Since SNe are rare and transient events, deep observations of a large sky field with a suitable time interval are required to maximise the number of SNe discovered. Early SN searches based on visual observations of nearby galaxies or photographic surveys with Schmidt telescopes were confined to the local Universe. Collecting data from five nearby SN searches (137 discovered SNe) and adopting an empirical correction for dust attenuation, based on the morphological type and inclination of SN host galaxies, it has been possible to estimate the SN rates in the local Universe as a function of both galaxy morphological type and colours (Cappellaro et al., 1999).

Nowadays, by using panoramic detector arrays mounted on medium-size telescopes, it has become possible to monitor large sky fields and to sample an adequate volume of the Universe with a reasonable amount of telescope time. The Wide Field Imager (WFI), a mosaic camera consisting of eight CCDs with a field of view of 0.5 square degrees mounted at the 2.2 m MPG/ESO telescope, is an excellent example of this type of instrumental setup. New technological capabilities have allowed the SN sample to be greatly enlarged, leading to the discovery of SNe up to redshifts greater than one. Despite this progress, measurements of SN rates are still scant (in particular for CC SNe) and uncertain (for both SN types). The main goal of almost all SN surveys performed in the last few years has been to investigate the expansion of the Universe and the properties of the dark energy using SNe Ia as standard candles. The observing strategy of these searches was tuned to identify *bona fide* SN Ia candidates before maximum light and confirm spectroscopic type only for these candidates. As a consequence the SN sample collected by these surveys is seriously incomplete, so that the measurement of the rate for SNe Ia is troublesome and for CC SNe nearly impossible.

STRESS was devised to improve SN rate determinations (Botticella et al., 2008). The observing strategy was specifically designed to measure both CC SN and SN Ia rates at intermediate redshift, and the SN detection and classification processes were tuned to collect an unbiased and homogeneous sample of both SN types. In addition, we aimed to investigate the evolution of SN rates by comparing our estimates with those obtained in the local Universe and to relate the SN events to SF in the parent galaxies by collecting detailed information on the galaxy sample including their photometric properties and dust content. In order to preserve the link between SNe and their parent galaxies, we measured SN rates by counting the events discovered in a selected galaxy sample, rather than those detected in a given volume. This approach involved the following steps: the selection of the galaxy sample and its characterisation; the detection and classification of SN candidates; the measurement of SN rates; the analysis of their dependence on the colour of the host galaxy; and their evolution with redshift.

How to handle STRESS

STRESS is a multi-year project (from 2000 to 2005) consisting of two related observing programmes: an imaging programme, intended both to search for SN candidates and to obtain colour information for the monitored galaxies, and a spectroscopic programme to type SN candidates and measure their redshift. The imaging programme was carried out with the 2.2 m MPG/ESO telescope equipped with WFI in the *V*-band over the first four years (Cappellaro et al., 2005), and in the *R*-band, targeting SNe at higher redshifts in the last year (Botticella

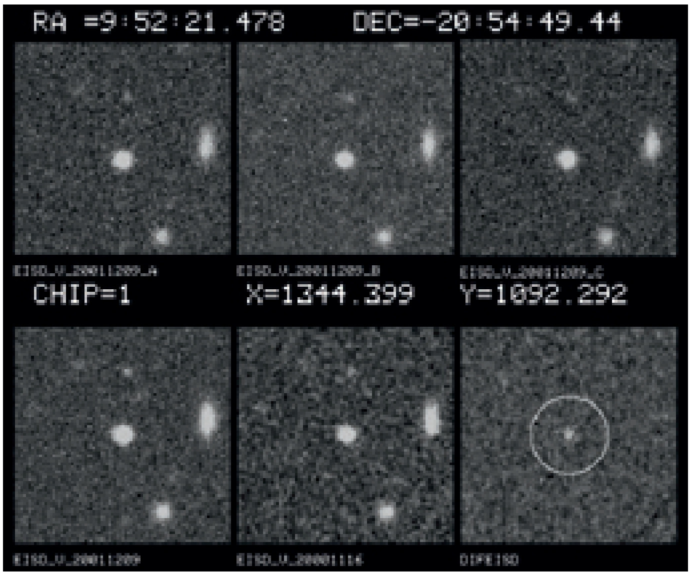

Figure 3. An example of a variable star discovered in the *V*-band (layout of images as in Figure 1). The source shows a stellar profile on all images.

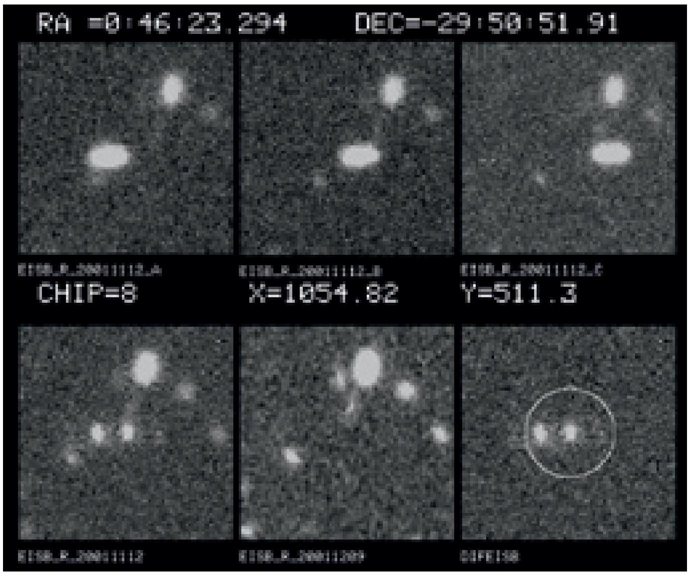

Figure 4. An example of an asteroid discovered in the *R*-band (layout of images as Figure 1). The source shows up at a different position on the jittered images and thus as an irregular shape in the stacked image. No source was visible in the image acquired one month before.

et al., 2008). Spectra were acquired with the Very Large Telescope (VLT) equipped with the FOcal Reducer and low dispersion Spectrograph (FORS1 and FORS2). Sixteen sky fields were imaged on average once every four months and spectroscopic observations were scheduled about one week after imaging observations to secure SN candidate typing.

SN candidates were identified by subtracting images acquired at different epochs using the Optimal Image Subtraction code (OIS) in the Alard (2000) package. The resulting image was searched for variable sources (SN candidates — Figure 1; variable Active Galactic Nuclei (AGNs) — Figure 2; variable stars — Figure 3; and asteroids — Figure 4) using a source detection code (SExtractor, Bertin & Arnouts, 1996). There were often spurious sources on the difference images due to imperfect removal of bright stars, cosmic rays and hot or dead CCD pixels. To reject these artefacts and to obtain a first classification of actual variable sources we used a custom-made ranking program that assigns a score to each source based on several parameters (magnitude, shape, position) measured by SExtractor. The score was tuned using a training dataset of known events and extensive simulations. The final selection of *bona fide* SN candidates, about ten per image, was made by visual inspection. We classified as SN candidates those sources with a stellar profile in the difference image that appeared projected on a galaxy (see Figure 1), and as SNorAGN candidates all those sources detected within a radius of 0.5 arcsec from the host galaxy nucleus (Figure 2).

We developed a database of information about each detected variable source with a search engine to identify independent detections of the same source at different epochs and in different filters. SN and SNorAGN candidates were cross-checked with all sources in the database before spectroscopic typing. This allowed us to clear the SNorAGN sample, identifying AGNs by their long-term, irregular variability.

Spectroscopic observations were planned for all SN candidates and the remaining SNorAGN, but we could classify only 40 % of the candidates because of limited telescope time allocation. At the end of STRESS we re-analysed all variable sources in the database to obtain a final classification. We also carried out a new spectroscopic programme using FORS2 to obtain the redshift and to check for signs of the presence of AGN in the host galaxies of those candidates without spectroscopic typing. Combining information from the long-term variability, direct and host galaxy spectroscopy, we found that 50 % of the variable sources originally classified as SNorAGN were actually AGN. Our final SN sample consists of 25 SNe (9 SNe Ia and 16 CC SNe), 33 SN candidates and 28 SNorAGN candidates.

For the selection of the galaxy sample and the measurement of galaxy properties (colours, redshift, absolute luminosity) we used multi-band (*BVRI*) images obtained during the SN search programme. To produce a catalogue of the monitored galaxies we selected all images with the best seeing and sky transparency for each field and band, stacked them, detected all sources on the resulting deep images and selected galaxies (43 283 in total) using the SExtractor classifier. The galaxy colours have been estimated by measuring flux in the same physical region (adaptively scaled to the galaxy dimensions) in all bands. The galaxy redshift and the absolute *B*-band luminosity were obtained by comparing observed and predicted galaxy colours as a function of redshift with a spectral energy distribution template fitting technique.

The results of STRESS

Three basic ingredients are required to estimate the SN rate in a galaxy sample: the number and type of SNe discovered; the time of effective surveillance of the sample in order to relate the detection frequency to the intrinsic SN rate (control time); and a physical parameter, proportional to the stellar content of each galaxy, to normalise the rate.

The control time is defined as the time during which a SN occurring in a given galaxy can be detected by the search, and depends on the shape of the SN light curve, distance and dust extinction of the galaxy, instrumental setup, observing strategy and detection technique of the SN search. The effect of dust attenuation on the control time has been estimated by modelling SN and dust distributions in galaxies. In short, following the method described in Riello & Patat (2005), we performed Monte Carlo simulations where artificial SNe were generated with a predefined spatial distribution function, and were viewed from random lines of sight. Integrating the dust column density along the line of sight for each SN, we derived the total optical depth and the relative attenuation. Repeating a number of simulations, we obtained the expected distribution of SN absorption. We considered three possible scenarios for the amount of dust in a galaxy assuming different total optical depths along the galaxy rotation axis ($\tau = 0$ — no extinction, $\tau = 1$ — standard extinction, $\tau = 5$ — high extinction). For CC SNe the control time was estimated for each extinction scenario. For SNe Ia we did not consider the high extinction scenario, since it is expected to occur, on average, in environments with a smaller amount of dust. Monte Carlo simulations also allowed us to probe the most relevant parameters affecting the SN detection efficiency. In each simulation, artificial SNe of different magnitudes were added to an image that was then searched for variable sources using the same software as in the actual search. The detection efficiency at a given magnitude was computed as the ratio between the number of discovered and injected artificial sources.

The normalisation parameter for SN rates can be the galaxy mass or a mass tracer, e.g., the blue luminosity, in which case the rate is expressed in SN per unit galaxy mass (SNuM = $1 SN/10^{10} M_B$ /century), or in terms of galaxy luminosity (SNu = $1 SN/10^{10} L_B$ /century), respectively. Since the estimate of the galaxy mass is uncertain (and makes use of the galaxy luminosity as a mass tracer anyway), we chose to determine the rate in SNu.

The SN rate at a given redshift is computed as the ratio between the number of discovered SNe and the control time of the monitored galaxies at the given redshift. Since our SN sample spans a wide redshift range (0.06–0.6), we can obtain some constraints on the evolution of the rate. We adopted a power law parameterisation for the redshift dependence of the SN rate with two free parameters: the rate at the weighted average of the galaxy redshifts, with weights given by the respective control time; and an evolution index. The best-fit values of the free parameters were obtained by comparing the observed SN redshift distribution with the expected one.

Our results indicate that the SN Ia rate appears almost constant up to redshift $z = 0.3$, whereas the SN CC rate has already increased by a factor of two by redshift $z = 0.2$. The different evolutionary behaviour of CC SN and SN Ia rates implies that their ratio increases by a factor of two from the local Universe to redshift $z = 0.25$ (about three billion years ago), thereby requiring that a significant fraction of SN Ia progenitors have a lifetime longer than three billion years. The estimate of the SN rate evolution depends on the correction applied for dust extinction. For instance, the ratio between the CC SN rate at redshift $z = 0.2$ and that in the local Universe varies from 1.6 to 2.8, depending whether a no extinction or a high extinction scenario is assumed. However, the fact that the CC SN rate increases faster than the SN Ia rate appears to be a robust result.

We also investigated the dependence of SN rates on galaxy colour, an indicator of the stellar population and SFR. We split our galaxy sample and the local galaxy sample by Cappellaro et al. (1999) into blue and red sub samples, according to the observed *B-V* colour and adopting the rest frame *B-V* colour of an Sa galaxy (*B-V* = 0.45) as a reference. The SN Ia rate appears almost constant in galaxies with different *B-V* colour, whereas the CC SN rate strongly increases from red to blue galaxies, both at redshift $z = 0.25$ and in the local Universe.

Finally we compared the observed evolution of SN rates with the behaviour predicted by the cosmic SFH, assuming various SN progenitor models and different extinction scenarios. This comparison provides interesting clues about the reliability of SN progenitor models and the adequacy of the dust extinction correction of SN rates. We collected published measurements of SN rates at intermediate and high redshifts that are in units of co-moving volume. To convert our measurements from SNu to volumetric units, we multiplied the rates by the total blue luminosity density at the redshift of our estimated rates. Since the blue luminosity density increases with redshift, the volumetric SN rates evolve faster than the rates in SNu. We found an increase of a factor two at redshift $z = 0.3$ for SNe Ia, and a factor of about three at redshift $z = 0.2$ for CC SNe (see Figures 5 and 6).

The CC SN rate expected for a given SFH depends on the mass range of the progenitors, on the initial mass function (IMF) describing the distribution of the stellar masses and on the correction due to dust extinction. We assumed that the mass of CC SN progenitors ranges from 8 to 50 $M_\odot$ and that the IMF has a Salpeter slope, with a turnover below 0.5 solar masses. Since there is a large scatter between the measurements obtained with different SFR indicators, it is difficult to obtain a consistent picture of the SFH. We selected two representative prescriptions for the SFH in the literature: the piecewise linear fit of SFR measurements from different tracers (Hopkins & Beacom, 2006) and the linear fit to the SFR measurements from the Hα emission line (Hippelein et al., 2003). The measurements of CC SN rate confirm the steep increase with redshift expected with both SFHs (Figure 5). The evolution predicted from the SFH based on Hα fits the CC SN rate measurements very well, while the SFH by Hopkins & Beacom requires higher CC SN rates both in the local Universe and at high redshift.

If we correct our measurements and the local CC SN rate measurements according to the high extinction scenario, we obtain an acceptable agreement between the data and the predictions of the Hopkins & Beacom SFH. However, this correction requires an extremely high dust content in galaxies, which needs to be confirmed with new accurate measurements in nearby and distant galaxies, and also requires a better estimate of the fraction of obscured CC SNe that are missed in optical SN searches.

Alternatively we may consider the possibility of a narrower range for the CC SN progenitor masses: in particular, a lower limit of 10–12 $M_\odot$ would bring the observed CC SN rates into agreement with the SFH by Hopkins & Beacom. On the other hand, estimates of the progenitor mass from the detections of stars in pre-explosion images seem to favour a lower limit of about 8–10 $M_\odot$ (Smartt et al., 2008). This result illustrates that it is necessary to reduce the uncertainties in the cosmic SFH and to apply a consistent dust extinction correction both to SF and to CC SN rates in order to constrain the mass range of CC SN progenitors. A comparison of the CC SN rate with other SFR tracers in the same galaxy sample could shed light on these issues.

The cosmic evolution of the SN Ia rate is modulated by two critical ingredients: the SFH and the delay time distribution (DTD). Different SFHs give different evolutionary paths (Blanc & Greggio, 2008), but we have considered only the SFH by Hopkins & Beacom. We estimated the evolution of SN Ia rate by convolving this SFH with different formulations of the DTD: three distributions related to different SN Ia progenitor models and described by the analytical formulation of Greggio (2005); the parameterisation by Mannucci et al. (2006), designed to address some specific observational constraints, regardless of the correspondence with a specific progenitor scenario. All DTDs appear to predict a SN Ia rate evolution consistent with the observations, with the exception of the 'wide' DD model, which appears too flat (see Figure 6). At the same time, with the adopted SFH none of the explored DTD functions are able to reproduce both the rapid increase from redshift $z = 0$ to $z = 0.5$ and the decline at redshift greater than one, suggested by some measurements. With the current data on the rate evolution, it is difficult to discriminate first between different DTDs and then between different SN Ia progenitor models. Measurements of the SN Ia rate in star-forming and passively evolving galaxies over a wide range of redshifts can provide more significant evidence about the progenitor models.

Future wide-field SN surveys at ESO telescopes, such as SUDARE on the VLT Survey Telescope (VST) equipped with OmegaCam, will be able to discover thousands of SNe and will enable accurate measurements of the SN rates, providing an unbiased census of the host galaxies. A different observing strategy that consists of the frequent, long-term monitoring of a few selected sky fields (rolling search), will allow us to detect SN candidates and obtain their light curves in different bands at the same time. Photometric typing, based on the shape of the light curve and colour evolution, for all SN candidates will reduce the uncertainty due to the lack of spectroscopic classification of SN candidates.

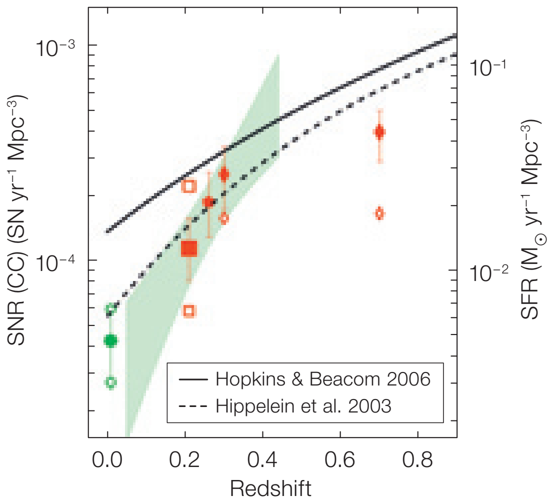

Figure 5. Comparison between the core collapse (CC) SN and the SF rate evolution. Lines are selected star formation histories from the literature. The shaded area represents the 1σ confidence level of our estimate of CC SN rate evolution as deduced from the likelihood fit. Circles show local measurements by Cappellaro et al. (1999); squares are measurements by Botticella et al. (2008); the pentagon is the measurement by Cappellaro et al. (2005), and the rhombi the measurements by Dalhen et al. (2004). Filled symbols are measurements obtained assuming a standard extinction correction. The lower open symbols are measurements not corrected for extinction while the upper open symbols are measurements obtained adopting a high extinction correction.

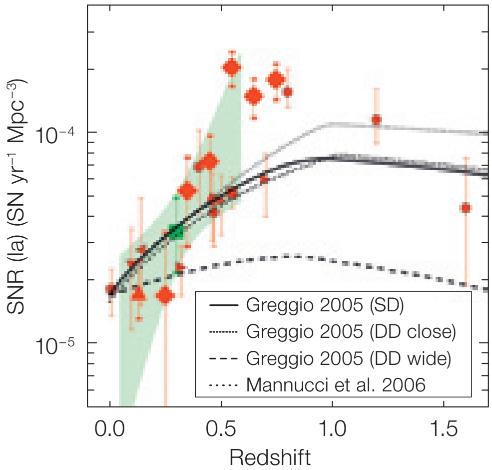

Figure 6. SN Ia rate measurements in the literature and predictions obtained by convolving the SFH of Hopkins & Beacom with various delay time distribution functions. The predicted paths are plotted as lines with different types (see inset box for key). The shaded area represents the 1σ confidence level of our estimate of SN Ia rate evolution as deduced from the likelihood fit. The circle is the measurement of Cappellaro et al. (1999); the inverted triangle from Madgwick et al. (2003); the leftward triangle for Hardin et al. (2000); the triangle for Blanc et al. (2004); the rightward triangles for Neill et al. (2007); the green square for Botticella et al. (2008); the rhombi for Barris & Tonry (2006); the small rhombus for Tonry et al. (2003); the pentagon for Neill et al. (2006); the red square from Pain et al. (2002); and the hexagons for Dahlen et al. (2004).

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Swift, VLT and Gamma–Ray Bursts: The Richness and Beauty of the Global View

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In this paper we emphasise the role of ESO in the optical follow-up of gamma-ray burst light curves and the importance of early observations via rapid response mode. We describe some of the best short gamma-ray burst observations ever and illustrate the need for spectroscopic data. Specifically, we show how the exceptional dataset collected for the naked-eye burst GRB 080319B, the brightest burst ever, has proved very challenging for current theoretical models. The final aim is the understanding of the physical processes that make such phenomena the true beacons at the edge of the Universe.

How it happened

Heritage, know-how, creativity and organisation. Our previous experience with BeppoSAX and the related optical follow-up from the ground, taught us that we needed a very fast re-pointing of the spacecraft, multi-wavelength coverage and high sensitivity instruments. These goals were achieved in the design of the Swift satellite (Gehrels et al., 2004), where on-board decision-making successfully substituted for human intervention. But all of this would be completely useless without a fast and efficient communication system, able to deliver data and information all over the world. A gamma-ray burst (GRB) explodes: in a few seconds the Swift team has provided the astronomical community with the accurate position of the event, allowing ground-based telescopes to collect photons coming from the remote corner of the Universe where a giant explosion has just occurred. From the very first Swift meetings we realised that to achieve very fast Very Large Telescope (VLT) pointing, we needed not only a letter of intent from the ESO Director General (DG), but also a strategy. The Rapid Response Mode (RRM) was born: in this mode a VLT instrument is able to set on the target and start acquiring data less than seven minutes after an alert. This is a fantastic technical and organisational achievement by ESO. Essential for obtaining early data of objects characterised by a rapidly declining luminosity, the RRM gives the community the potential to understand the early physics of these events, with the final aim of using GRBs as beacons at the edge of the Universe. The primary need was to secure GRB redshifts, a task that has been fulfilled effectively by the various European teams with ESO as lead player on the scene (45–50 % of GRB redshifts have been obtained with ESO observations, see, e.g., Fynbo et al., 2007).

Figure 1. Organisation of GRB follow-up: ASI Science Data Center (ASDC) staff are involved in GRB science while the Malindi ground station is responsible for satellite duties and for the Swift-XRT (X-Ray Telescope) data analysis software. MISTICI (Multiwavelength Italian Swift Team with International Co-Investigators) and CIBO (Consorzio Italiano Burst Ottici) are the optical follow-up groups. Economic support comes mainly from ASI (Agenzia Spaziale Italiana) and MIUR (Ministero dell'Istruzione Università e Ricerca). The unique architecture of the ESO follow-up related to the Swift Mission was organised also thanks to the collaboration of the Directors General Riccardo Giacconi and Catherine Cesarsky and the unique technical contribution of Roberto Gilmozzi and Jason Spyromillio.

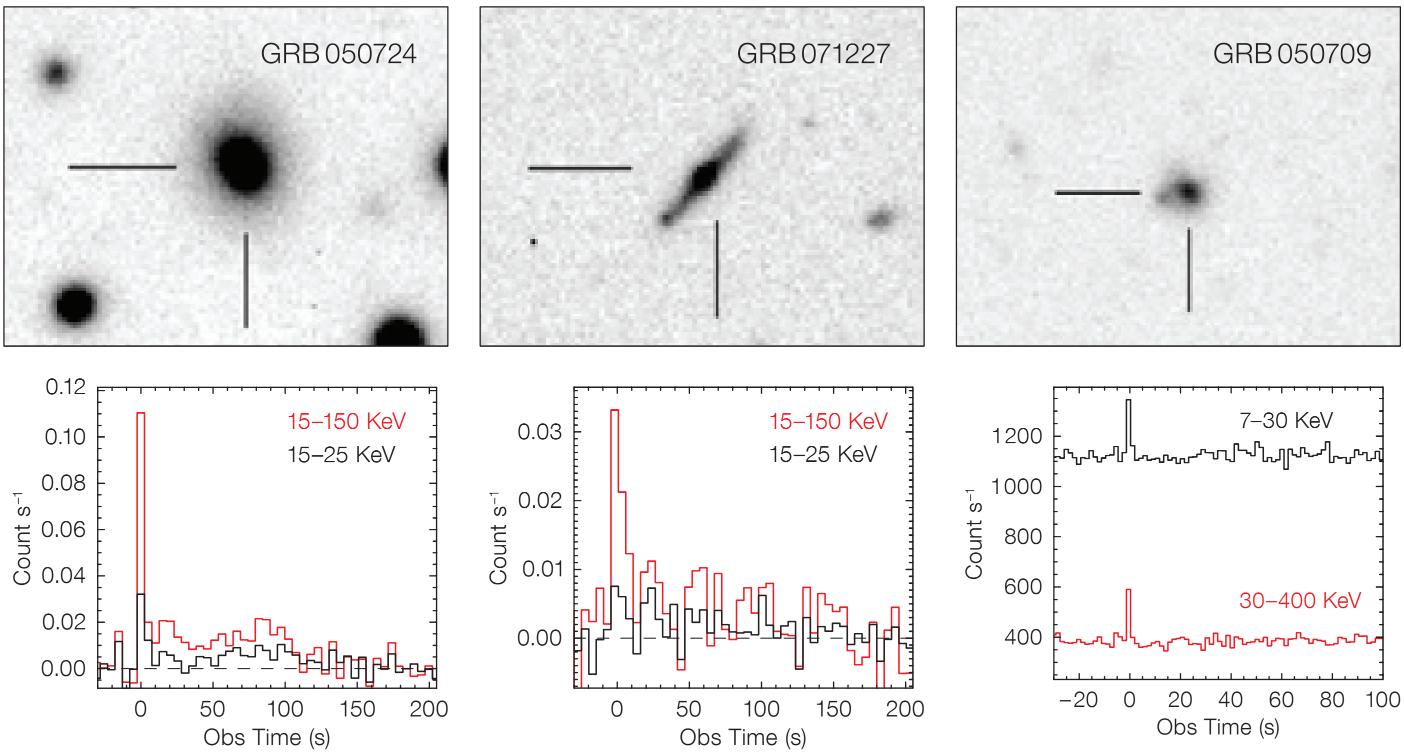

Figure 2. Top panels, from left to right: VLT observations of the host galaxies of the short GRBs, GRB 050724, GRB 071227, and GRB 050709. Bottom panels: prompt high energy emission coming from the same bursts; note the broad soft bump following the early short spike. GRB 050709 is a HETE (High Energy Transient Explorer) burst, the other two come from Swift.

But there was another requirement: the Swift UVOT (Ultra-Violet/Optical Telescope) instrument is not sensitive to wavelengths longer than 650 nm, and we considered it crucial to have observations reaching out to the near-infrared. Following some in-house discussions and early interactions with Catherine Cesarsky, the then ESO DG, we decided on a new concept for a robotic telescope in Chile on the ESO territory: the REM (Rapid Eye Mount) was born. Funded by the Italian MIUR, this telescope provided the opportunity to collect unprecedentedly early information on GRBs. Later a symbiotic telescope, the TORTORA (Telescopio Ottimizzato per la Ricerca di Transienti Ottici Rapidi) was added to this unit. This telescope — the result of a Russian–Italian collaboration — may be limited in sensitivity, but has the advantage of a very large field-of-view and of spectacular time resolution. The latter was of great advantage for the "naked eye burst", GRB 080319B.

This short account gives a feel for how organised and synchronised the Swift and the Italian teams are. For a full appreciation of what we believe is a unique model of working collaboration and management, we show the follow-up organisation in Figure 1. This organisation, and the will to make it work, is what made and currently makes the research successful. In the following we will only discuss a few open issues and concentrate on a few results among many.

Morphology and progenitors

Morphology in any species, class of objects or natural phenomena is the result of heritage and of the mechanisms generating them. As in other cosmic objects, GRB morphology (GRBs are classified into long [LGRB] and short [SGRB] types according to the duration of the high energy initial event) is a consequence of the different progenitors, host galaxies and various physical mechanisms at work. LGRBs are likely due to the collapse of very massive stars ($M > 20M_{\odot}$), as testified by their association with core collapse supernovae (SN). No SN explosion has ever been observed in connection with SGRBs, which are believed to originate from the merging of compact objects (neutron stars or black holes, see, e.g., Nakar, 2007). LGRBs occur in late-type galaxies, but never in early-type galaxies. The prototype host of an LGRB is a young, blue, metal-poor and subluminous (about 0.1 L*) galaxy, with high specific star formation rate, but low mass. In contrast, SGRBs seem to span galaxies of various morphologies (see Figure 2); the model in this case is that of a hot and dense torus of 0.01–0.3 $M_{\odot}$ that is accreted onto a stellar mass black hole (BH). The high energy involved, (10^{46}–10^{50} erg after correcting for the jet opening angle) implies rather large accretion rates that call for an equally efficient cooling mechanism: neutrino cooling is the first candidate. While the occurrence of the jet is likely related to the asymmetry of the model, it still remains unclear how and if the late engine activity, testified by the presence of flares, might be related to the duration of the primary burst and to the viscous and gravitational instabilities of the disc.

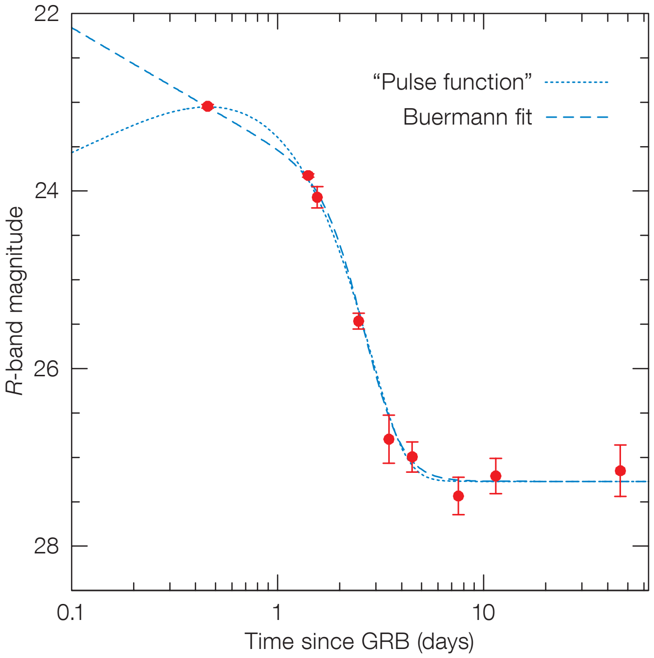

Figure 3. *R*-band light curve of the short GRB 070707 afterglow. Either a smoothly joined broken power law (dashed line) or a pulse function (dotted line) gives an equally acceptable fit. After ten days the flux levels off at the host galaxy contribution.

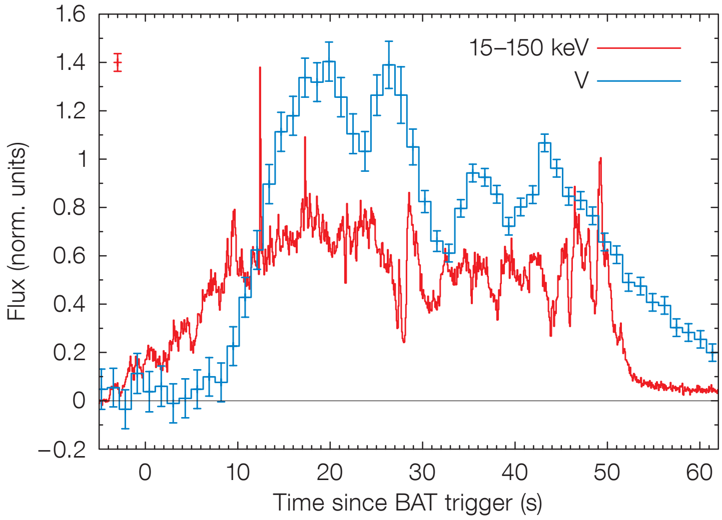

Figure 4. The GRB 080319B prompt emission is shown. In blue, the optical data collected by TORTORA; in red, the gamma-ray component (15–150 KeV) detected by Swift BAT (Burst Alert Telescope).

Nature does not fit into any particular classification scheme. In particular, the simple long–short dichotomy hides a more complex reality: how do we account for the broad and soft emission following, in some cases (see, e.g., Figure 2), the primary short pulse? This pattern requires a rather long-lasting activity of the central engine, a different progenitor model and perhaps a new classification scheme. What we do know is that in all these cases — and for SGRBs in particular — optical observations are fundamental. Such observations enable direct information to be gained on the host galaxy (HG) morphology, on the interstellar medium properties and the progenitor parent population; then indirectly we constrain the jet structure and the physical mechanisms at work, with the final aim of understanding the nature of the central source that powers these explosions. This raises the question of whether we really need the VLT and the RRM?

The answer is unequivocally, yes, since we have no optical spectrum of an SGRB to date. Moreover, we need high resolution spectroscopy, fast photometry and polarisation information: fast reaction from an 8–10 m telescope is therefore crucial. The best-sampled SGRB afterglow optical light curve comes from GRB 070707, from ESO–VLT observations (Piranomonte et al., 2008): the light curve displays an initial slow decay that becomes significantly steeper, beginning one to two days after the explosion, and later levelling off at $R = 27.3$ (see Figure 3). This is most likely the HG emission level, the faintest yet detected for an SGRB. Unfortunately, due to the low signal-to-noise ratio, spectroscopic observations did not reveal any line feature or edge able to constrain the redshift, so that only an upper limit ($z < 3.6$) can be inferred from the lack of Lyman limit suppression down to 420 nm.

As with a number of other SGRBs, the nearly unconstrained redshift of GRB 070707 remains an important handicap. These strong limitations bias and constrain our knowledge: not only do we not know clearly the nature of the progenitors and of the physical processes at work, but we are still unable to say whether these merging events originate in galaxies or in extragalactic globular clusters. The SGRB research field is currently one of the most intriguing; progress can only come by setting on the target with large optical telescopes as soon as possible after the burst, and then following the light curve evolution with multicolour observations down to the limits of the telescope sensitivity.

The naked eye burst GRB 080319B

"The simplicity offers us the possibility to enter a rich field of physical processes and to challenge our understanding, leading us to a beautiful variety of observable effects." R. Sunyaev

The extremely bright GRB 080319B is a showcase for the role of follow-up observations. The data from the ESO facilities provide an example of the key observations of this burst, while the international collaboration demonstrated how sharing data, ideas and expertise often leads to unique and rapid results. The Italian robotic telescope REM was pointing at GRB 080319A at the time it received the alert for GRB 080319B. It automatically started slewing to the new target, but TORTORA with its wide field of view and high time resolution, happened to be imaging the burst location from before the time of explosion. This observation, the first of this quality since GRBs were discovered, revealed that the optical flux was too bright to be the extrapolation of the high energy (0.3 keV–1.16 MeV) tail.

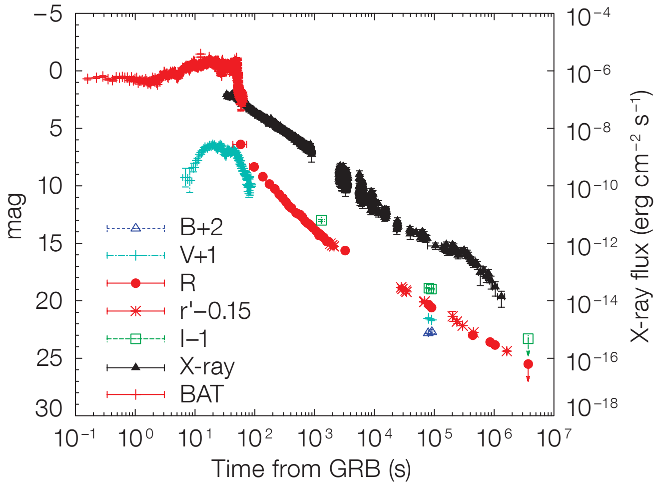

Figure 5. Broadband light curve of GRB 080319B, including radio, NIR, optical, UV, X-ray and gamma-ray flux densities. Data have been renormalised for graphical purposes.

The observations also showed some temporal coincidence of the bright optical flash and the gamma-ray emission. The prompt optical flux profile is broadly correlated with the gamma rays, sharing a comparable duration, rise and decay times, with the first half brighter than the second. A visual inspection of Figure 4 suggests a delay of a few seconds in the arrival times of the optical photons with respect to the gamma rays. A possible interpretation invokes the former being produced by synchrotron radiation, which is initially self-absorbed (thus explaining the later rise of the optical flux), while the latter are up-scattered photons via synchrotron self-Compton (SSC). But there is an aspect missing: relativistic electrons up-scatter the low energy photons turning them into gamma-ray photons (first inverse-Compton, IC) while the same electrons will further scatter these high energy photons, kicking them into the TeV range (second IC). This emission could be detected by Cherenkov ground-based telescopes (e.g. MAGIC) or, at lower energies, by the Fermi satellite.

Following the first phases, REM and TORTORA had to hand the baton on to larger telescopes and in particular to the VLT, which then allowed the community to follow the event down to very faint magnitudes. The Swift X-ray telescope (XRT) was gathering data at the same time. As is apparent from Figure 5, this burst shows a completely different behaviour in the optical and the X-ray ranges, suggesting that they must stem from different emitting regions. A possible explanation requires the action of a two-component jet: a, highly relativistic jet with a very narrow opening angle (0.2 degrees) pointing to the observer that is responsible for the prompt gamma emission via internal shocks, and coaxial with a wider jet (opening angle 4 degrees). In this picture the afterglow is the result of the forward and reverse shocks from both the narrow and wide components. While this model is not unique and has a few caveats, it is the most likely interpretation — a product of the joint efforts of a worldwide collaboration (Racusin et al., 2008).

The power of the VLT/UVES (Ultraviolet and Visual Echelle Spectrograph) rapid response mode has also been fully exploited for the observation of this GRB (D'Elia et al., 2008). We were able to observe the spectrum just 8 minutes 30 seconds after the trigger, at a time when the magnitude was R ~ 12, obtaining the best ever signal-to-noise, high resolution spectrum of a GRB afterglow. We caught the absorbing gas in a highly excited state producing the strongest Fe II absorption line ever observed. More to the point, we witnessed the local effects caused by the GRB explosion, enabling the study of the evolution of the interstellar medium (ISM) parameters. A few hours later the optical depth of the lines was reduced by factors of 4–20 and the optical UV flux by a factor of ~ 60.

GRB 080319B does not show any kind of plateau or flares in either the X-ray or the optical light-curves. While affecting about half of the GRB X-ray light-curves, flares seem to be sporadic events at optical wavelengths, a spectral range where statistics are currently lacking, especially at later times. The power of multi-wavelength observations is testified by GRB 060418 and GRB 060607A for which we have contemporary REM near-infrared (NIR) and XRT X-ray data. The early X-ray light curves of both events show several, intense flares superimposed on a smooth power-law decaying continuum. On the other hand, the flaring activity, if any, is much weaker at NIR frequencies: the NIR curve is very smooth with peaks at 153 s and 180 s for GRB 060418 and GRB 060607A respectively. This implies an initial bulk Lorentz factor of 400, confirming the highly relativistic nature of GRB fireballs. From our multicolour observations we were able to firmly establish that late engine activity, as exemplified by the X-ray flares, does not affect the optical light curve in the same way: at 800 s after GRB, when both the NIR and X-ray light curves are decaying regularly, the spectral energy distribution is described by a synchrotron spectrum, so no SSC need be invoked.

Multi-wavelength follow-up is therefore crucial both at early and late times.

Towards new challenges

Wavelength coverage and spectral resolution are key ingredients for understanding the different aspects of an astrophysical process. At the same time, an accurate temporal analysis of the GRB light curves represents a powerful tool for obtaining a deeper insight into the physics underlying these explosions. The fireball model is able to account for the vast majority of the observations, but other models are not ruled out. In particular, we would like to stress that the magnetar model, where the jet is Poynting flux dominated and the small baryon loading is naturally explained, has not yet been fully investigated (Lyutikov & Blandford, 2004). The determination of the relevant time scales in different wavelength ranges could help in distinguishing between competitive models, while the accurate study of the time variability could reveal particularly interesting information on the source that powers this

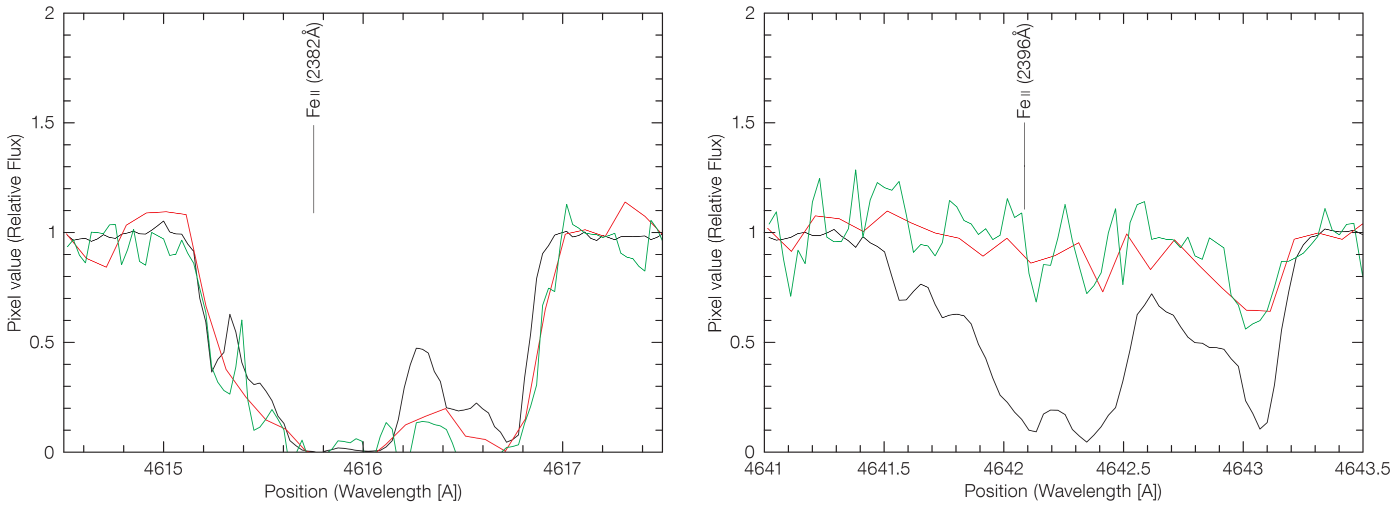

Figure 6. UVES spectra of GRB 080319B around the Fe II 2374 Å (left panel), and Fe II 2396 Å (right panel) transitions. Black lines refer to the first epoch spectrum (8 minutes 30 seconds after the Swift trigger); red lines refer to the second epoch spectrum (1.9 hours after the GRB event); green lines refer to the third epoch spectrum (2.9 hours after the GRB onset).

kind of explosion. More specifically, the details of the time structure are invaluable footprints of the original mechanism at work, being determined by a combination of intrinsic properties (cooling mechanism, jet profile, energisation, etc.) and of extrinsic properties (viewing angle effects, intervening absorption). Investigation of these details calls for high time resolution, multi-wavelength observations.

GRBs are aperiodic short-term events, with a temporal structure that represents a challenge for standard temporal analysis techniques: while a fraction (about 15 %) of the gamma-ray prompt emission consists of a single smooth pulse, the vast majority appear to be the result of the random superposition of a number of emission episodes. A pulse decomposition of the entire light curve is often difficult and in bright bursts the pulses are often blended, while in most dimmer bursts the low signal-to-noise prevents any kind of pulse-by-pulse study. For this reason we decided to develop a completely different kind of analysis.

A modified version of power spectrum analysis in the time domain, formerly developed by Li (2001), has been applied to the prompt and afterglow emission of GRBs: unlike the Fourier transform, this technique is suitable for studying the root-mean-squared (rms) variations of a completely aperiodic signal at different time scales. This method has the advantage of being completely model-independent. GRB 080319B is a showcase for the application of this technique to the prompt gamma-ray emission and the study of GRB 080319B high energy data shows the evolution of the characteristic time scale of variability from 0.1 s at the beginning of the emission up to 1 s at the end of the prompt event. Moreover, an energy-resolved analysis reveals that the variability time is strongly energy dependent. The same kind of analysis could be applied to high time resolution optical data. GRB 080319B showed the extraordinary importance of high time resolution multi-wavelength observations: it was the simultaneity of high time resolution optical and gamma-ray observations that gave us the unprecedented opportunity to study the underlying emission mechanism in detail. High time resolution optical observations, able to record the flickering behaviour of the light curve, are therefore of primary importance. This was understood even at the time of the REM design; however, contrary to earlier expectations, most afterglows are already faint a few minutes after the explosion, so that we soon realised that it would be very difficult to collect good quality data (except of course for GRB 080319B-like events, where brightness and luck played a major role). The implications are that large area robotic telescopes are fundamental.

Prospects

We have described a few of the many interesting results obtained for GRBs. The final goal — the real source that powers the bursts — is still elusive. The new Fermi mission will certainly add a wealth of information, owing to the spectacular high energy coverage. The coupling with Swift will provide unique broadband spectroscopic information, settling the long-lasting question about the mechanism for the prompt radiation (synchrotron or SSC). Furthermore, within a few years, LIGO (Laser Interferometer Gravitational Wave Observatory), Virgo and other facilities will open up the new observational window of gravitational waves. Their detection will constitute the real proof of the collapse of massive stars, SNe and the merging of relativistic objects. In the meanwhile VLT and the other extremely large telescopes will drive human knowledge on towards new challenges.

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The zCOSMOS Data Release 2: the "zCOSMOS-bright 10k-sample" and structure in the Universe out to redshifts of order unity

Simon Lilly (ETH Zurich, Switzerland) and the zCOSMOS team*

The global COSMOS project is aimed at understanding the evolution of galaxies and active galactic nuclei, and in particular the role of the galactic environment in that evolution. It is built around observations of a single equatorial 1.7 deg^2 field corresponding to transverse dimensions of 100 x 100 Mpc^2 at high redshift. The COSMOS field is emerging as the premier extragalactic survey field, and is currently the object of study of large observational programmes on most of the major observational facilities around the world. The zCOSMOS programme on the VLT is securing spectroscopic redshifts for a very large number of galaxies and quasars over the whole redshift range $0 < z < 3.5$, using the VIMOS spectrograph. This allows the environment of galaxies to be characterised on all scales from that of the immediate group environment, 100 kpc, up to the 100 Mpc scales of the cosmic web. The second public data release, DR2, of approximately 10 000 zCOSMOS spectra, took place via the ESO Science Data Archive in October 2008. This article describes the current status of the project and in particular of this so-called "10k-sample", and our reconstruction of large-scale structure in the Universe out to $z \sim 1$.

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There are many reasons to suspect that the environment plays a major role in driving the evolution of galaxies and active galactic nuclei (AGN). In the local, present-day Universe, clear trends are seen between many galaxy properties, such as their star formation rates and structural morphologies, and different measures of the environment of galaxies. These were first quantified over twenty years ago by Alan Dressler, and have now been seen clearly in the large-scale local surveys of the Sloan Digital Sky Survey (SDSS). Broadly speaking, galaxies in higher density environments are, today, less actively forming stars and more often have spheroidal 'early-type' structures rather than 'late-type' disc-dominated morphologies, than galaxies in lower density parts of the Universe. The actual physical cause of these effects is however far from clear, and the basic question of the relative importance of 'nature' and 'nurture' in controlling galactic development is far from settled.

There is no shortage of plausible mechanisms whereby the galactic environment could influence the evolution of a particular galaxy: on the one hand, the accumulation of material via the hierarchical assembly of dark matter haloes and the accretion of gas, whether through cooling of shock-heated gas or through cold mass flows out of the cosmic web, must depend on the immediate environment of the system in question; on the other hand, the effects of interactions with the surrounding intergalactic medium (IGM) through starburst-driven winds or from energy injection from AGN, may provide a feedback onto the properties of the galaxies. Major mergers of galaxies, which almost certainly play a very large role in the morphological transformation of galaxies, and possibly also in the control of their star formation rates, will occur at very different rates in different environments because of the different number densities and velocity dispersions of the galaxies. Even a purely internal rearrangement of material within galaxies through dynamical instabilities may have been triggered by nearby neighbours. In the richest environments, the intracluster medium may strip out material from galaxies, while close, high speed 'fly-bys' may also have transformational consequences, even in the absence of mergers. Finally, the overall time scale for the growth of large-scale structure in the Universe via gravitational instability is set by the amplitude of the density field on large scales. No doubt all of these processes play a role, but their relative importance is not known. Even in the present-day Universe, there is controversy as to the scale on which the environmental signature is present — solely on the scales below 1 Mpc characteristic of a single dark matter halo, or also on larger scales indicating a role also for the larger cosmic web of structure.

Looking to larger distances, and thus observing the Universe at earlier epochs directly, and establishing when and how these observed relations are established should go a long way to resolving these questions. For many of the physical processes listed above, it is the environment on the scale of galaxy groups that is suspected of being most relevant. In the standard ΛCDM (Lambda Cold Dark Matter) paradigm for cosmological structure formation, these environments have undergone strong evolution since redshifts $z \sim 2$ and environmentally-driven evolution may plausibly therefore be the cause of the dramatic decline in galactic activity over this same period.

Unfortunately, environmental information on distant galaxies has been very limited up until now. This is mostly because of limited sample sizes, and the small size and sparse sampling of the deep extragalactic survey fields. The COSMOS survey (Scoville et al., 2007) was designed to remedy both of these, by bringing to bear on a single large field all of the techniques, that have been developed over the last decade or more, to study distant galaxies over a wide range of redshifts. The COSMOS field is about 600 times larger than the famous Hubble Deep Fields, and about thirty times larger than each of the two Great Observatories Origins Deep Survey (GOODS) fields. In addition to the initial imaging with the Hubble Space Telescope (HST), COSMOS is now also quite unique in the breadth and depth of the imaging data that have been assembled using large amounts of observing time on the X-ray satellite observatories XMM-Newton and Chandra, with the ultraviolet Galaxy Evolution Explorer (GALEX) and infrared Spitzer space telescope, and, on the ground, with the Subaru, the Canada France Hawaii Telescope (CFHT) and the UK Infrared Telescope (UKIRT) optical/infrared telescopes. At longer wavelengths, the Very Large Array (VLA) radio telescope and various millimetre-wave facilities have also observed the field. In the future, the COSMOS field will be the major focus of the very deep UltraVISTA infrared imaging survey at ESO.

zCOSMOS provides the crucial 'third-dimension' to COSMOS by measuring accurate redshifts for large numbers of galaxies in the COSMOS field.

zCOSMOS at the VLT

zCOSMOS is a major project (ESO Large Program 175.A-0839) that is using 600 hours of observing time with the VIMOS spectrograph on the VLT UT3, spread over five observing seasons 2005–2009. It consists of two parts (see Lilly et al., 2007, for details): The first, "zCOSMOS-bright", obtains spectra of about 20 000 galaxies selected to have $I_{AB} < 22.5$ across the full 1.7 deg^2 of the COSMOS field. zCOSMOS-bright was designed to yield a high and fairly uniform sampling rate (about 70%), with a high success rate in measuring redshifts (approaching 100% at $0.5 < z < 0.8$), and with sufficient velocity accuracy (about 100 km/s) to efficiently map the environments of galaxies down to the scale of galaxy groups out to redshifts $z \sim 1$. The second part, zCOSMOS-deep, will consist of about 10 000 spectra of higher redshift galaxies, colour-selected to have redshifts in the $1.4 < z < 3.0$ range, and lying in the central 1 deg^2 region of the COSMOS field.

After the first two zCOSMOS observing seasons in 2005 and 2006, about a half of the zCOSMOS-bright observations had been completed, yielding a total of over 10 500 spectra from which redshift measurements have been made, or attempted — the so-called "10k-sample" (Lilly et al., 2008). This sample was released, with the help of the ESO External Data Products Group, to the wider science community via the ESO Science Archive (*http://archive.eso.org/cms/eso-data/data-packages/zcosmos-data-release-dr2/*) on 1 October 2008. It is being used by the zCOSMOS team for a number of science investigations that are now at various stages of the publication process.

In the meantime, further observations have taken zCOSMOS-bright almost to completion, with only a handful of the 180 spectroscopic masks remaining to be observed at the start of next year. We therefore anticipate constructing the final "20k sample" after these observations are completed in 2009. Observations of zCOSMOS-deep were phased later in the programme, but are now over 50% complete. Hopefully, observations for this part of the survey should also be completed by the end of the 2009 observing season.

The zCOSMOS-bright 10k-sample

A great deal of effort by the team has gone into ensuring the high quality of the zCOSMOS data products. In particular, a redshift survey like zCOSMOS produces redshift identifications with a range of reliabilities, simply because of the faintness of the galaxies and because we are pushing the limits of what is possible. The vast majority of redshifts are, of course, very secure, but some are unavoidably less reliable, and a few are little better than guesses. For some, we cannot offer even a tentative redshift identification. To get the best science out of such a large and well-defined sample, and to enable their use by others, it is essential to characterise the reliability of the redshifts, and to understand any biases present in the set of objects for which usable redshifts are secured — failures cannot be simply thrown away. To deal with this, every redshift measurement is assigned its own individual 'Confidence Class'. This is already the result of 'reconciling' two independent reductions of the observational data at two (of the six) zCOSMOS institutes. This duplication catches most of the potential problems in the reduction process. The Confidence Class scale varies from Class 0 (no redshift) up to Class 4 (very secure), with an additional Class 9 which designates 'one-line' redshifts, with various additional modifiers to reflect details such as whether the target is an AGN, or whether it was observed serendipitously in a slit targeted at another object (see Lilly et al., 2008, or the DR2 release notes for details). We then need to quantify the reliability of each of these classes. Our team has approached this in two ways.

First, repeat spectra for over 600 objects have been taken through a variety of different pathways. These repeat spectra are processed blind to the first reduction, providing an invaluable check as to whether the same redshift is found the second time around. With the simplifying assumption that the chance of getting the same wrong redshift twice is negligible, we can construct a simple probabilistic measure of the reliability. Our most secure Class 3 and 4 redshifts, which form the bulk of the sample, are indeed highly repeatable, > 99.8%. With the lower reliabilities, we find that generally we were conservative: Class 2, intended to be only 75% reliable is in fact confirmed 92% of the time, and even our Class 1 'guesses' are correct in 70% of cases. The repeat spectra also yield an empirical measure of the velocity accuracy of our redshifts, which comes out to be 110 km/s or $\Delta z = 0.00036\,(1 + z)$.

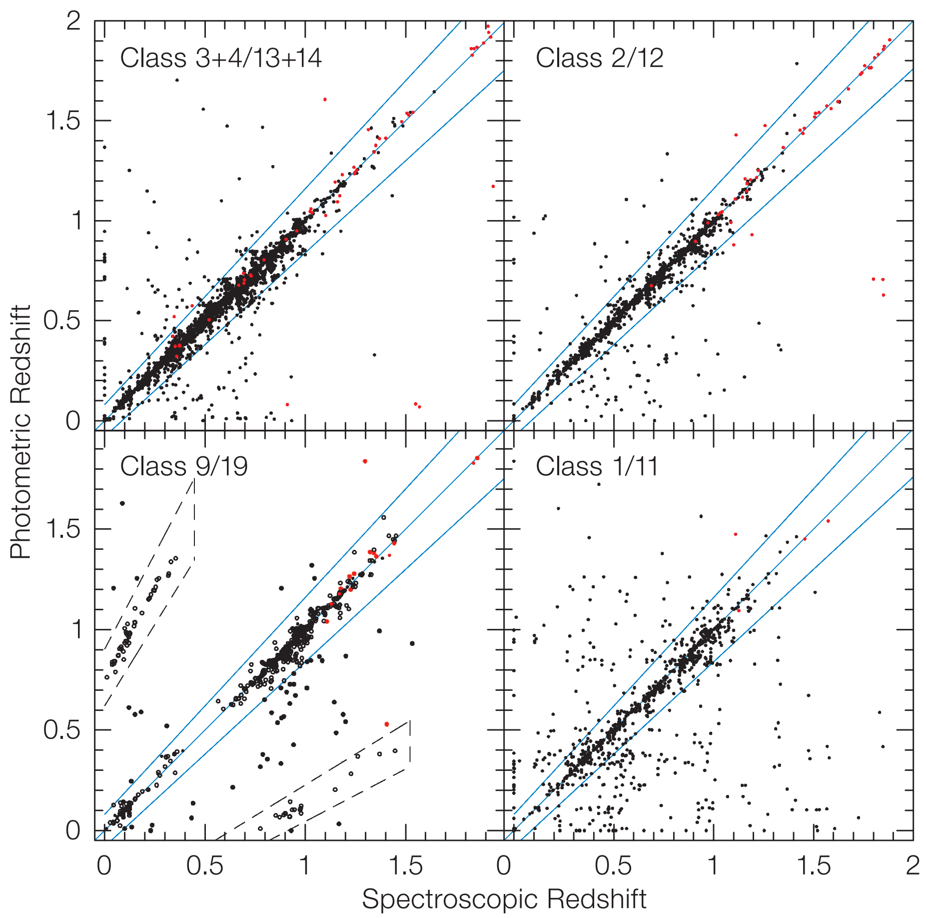


Figure 1. Comparison of photometric and spectroscopic redshifts of zCOSMOS-bright galaxies, as described in the text. Note that Class 9 redshifts are those based on a single emission line, which therefore have two alternative redshifts based on either a [O II] 3727 Å or Hα 6563 Å identification. A "1" preceding the Class (e.g. 4 → 14) indicates a broad line AGN, indicated by red points on the figure.

Secondly, we also use independent redshifts that are estimated solely from the colours of the galaxies, (photo-*z*). These are based on the unparalleled richness of the photometric data available in the COSMOS field. We examine the consistency with our spectroscopically estimated redshifts, which is shown in Figure 1, and find that there is generally a very good consistency: Comparison with our most reliable redshifts shows that there is a floor of about 3% photo-*z* 'failures', but otherwise an impressively small statistical dispersion of about $\Delta z = 0.01\ (1 + z)$ in redshift (Ilbert et al., 2008). The failures can probably be traced to unavoidable problems with the photometry, such as close pairs of galaxies or areas of the sky close to bright stars. However, as we then look at our less reliable redshifts, we see an excellent correspondence between the spectroscopic confirmation rate described in the previous paragraph and the consistency with the photo-*z* to within $\Delta z = 0.08\ (1 + z)$. As well as confirming the empirical calibration of our spectroscopic reliability, this suggests three things: first, we can use the photo-*z* to indicate which of our less reliable redshifts are very probably right and which are probably wrong — information that we capture as a further decimal place modifier to the Confidence Class of individual redshifts; second, we can use the photo-*z* themselves to estimate the redshifts of those galaxies for which we have failed to measure the redshift, thereby quantifying the biases in the final spectroscopic sample — this is shown in Figure 2; finally, we could, though we haven't yet done this, go back to the spectra of these failures and search again for a new spectroscopic redshift identification in the narrow redshift range indicated by the photo-*z*.

This powerful two-way complementarity between spectroscopic and photometric redshifts is a unique feature of COSMOS and zCOSMOS, and allows us to produce a spectroscopic catalogue with high accuracy redshifts and very high fidelity. Figure 3 shows the distribution of redshifts in the 10k-sample. The richness of the redshift structure in the distant Universe is immediately apparent, with structures spanning the range from about 100 km/s, up to the 20 000 km/s ($\Delta z \sim 0.05$) for the largest voids and overdensities.

Reconstruction of the density field to $z \sim 1$

We further exploit the complementarity of spectroscopic and photometric redshifts when we construct the overall galaxy density field in the COSMOS field out to redshifts $z \sim 1$. This is central to our scientific goal to determine the role of the environment in driving galaxy evolution and is already being used as the basis of several papers in an advanced state of preparation.

The density field, presumably a continuous distribution of dark matter, must be reconstructed using the discrete locations of relatively sparse galaxies, which inevitably introduces a smoothing into any reconstruction of the density field. The minimum physical scale of this smoothing depends on the number density of the tracer galaxies. There are of course many more galaxies with only a photo-*z* measurement than galaxies with a much more accurate spectroscopic redshift. Currently only one galaxy in three with $I_{AB} < 22.5$ has been observed in zCOSMOS-bright, and this will not get much above 60% even when the full survey is finished. Recognising that these photo-*z* galaxies nevertheless have very accurately determined locations in the (x,y) plane of the sky, we have developed a new algorithm (ZADE, see Kovac et al., 2008, for details) which seeks to combine the redshift accuracy of the spectroscopic redshifts with the increased numbers, leading to greater spatial 'resolution' in the density field, of a photo-*z* sample. This is done by modifying the probabilistic redshift distribution P(*z*) for each of the individual photo-*z* using the spectroscopic redshifts of nearby galaxies, making use of the fact that galaxies are clustered in the Universe.

One advantage of the new approach is that the complex selection function of the 10k sample, especially the currently, highly non-uniform, spatial sampling on the sky, is automatically taken into account. Extensive tests of the algorithm have been made against mock catalogues that have been generated from large-scale cosmological simulations (Kitzbichler et al., 2007), and on which we impose the different zCOSMOS selection functions. These tests have shown that the ZADE approach allows a much better reconstruction of the density field than traditional weighting methods, with very little systematic bias and with improved statistical accuracy. By using this new approach of combining spectroscopic and photometric redshifts, plus the use of a smoothing scale that is adapted to the local density of galaxies, we can achieve a spatial resolution in the density field that extends down to 1 h^{-1}Mpc, or below, even at the highest redshifts.

Figure 4 shows the resulting density field throughout the COSMOS cone out to a comoving distance of 2 400 h^{-1}Mpc (corresponding to $z = 1$), giving us a unique view of large-scale structure in the distant Universe. The density field has been normalised to the average density of galaxies to show the over-density δ, and the different cones in Figure 4 show iso-density surfaces for four different values of δ. Again a rich hierarchy of structure is revealed, showing variations on scales up to at least $\Delta z = 0.05$.

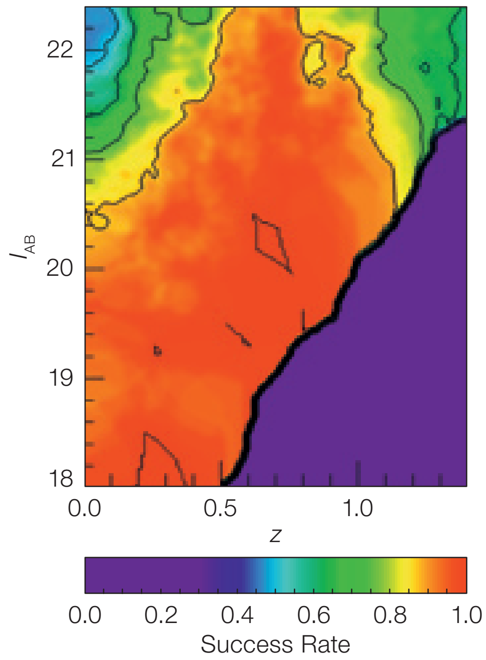
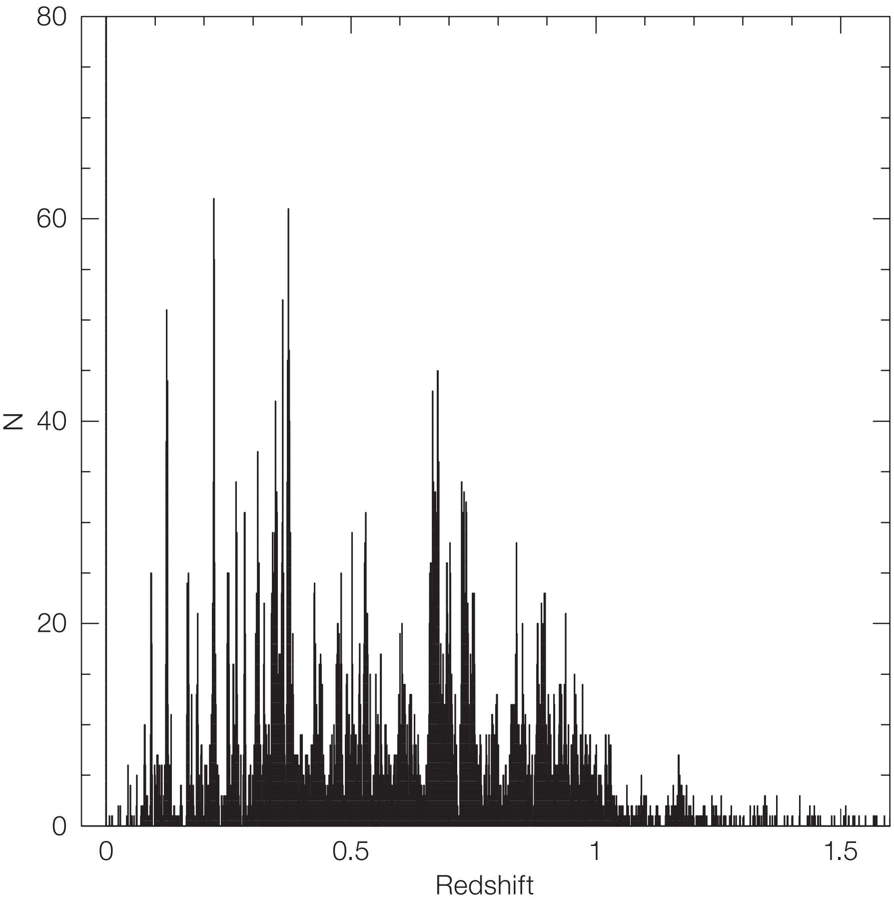


Figure 2. (Left) Fraction of spectra yielding a successful spectroscopic redshift measurement as a function of redshift (derived from the photo-*z* for the remainder) and I_{AB} magnitude. Notice how the success rate stays high in the key redshift range $0.5 < z < 0.8$ all the way to the limiting depth of the survey.

Figure 3. (Below) Redshift distribution of extragalactic objects in the zCOSMOS-bright 10k sample with secure redshifts, binned in intervals $\Delta z = 0.001$, which is larger than the redshift uncertainty by a factor of three at $z = 0$ and of two at $z \sim 1$. Despite the large transverse dimension of the survey, the redshift distribution shows structure on all scales from the velocity resolution up to $\Delta z \sim 0.05$.



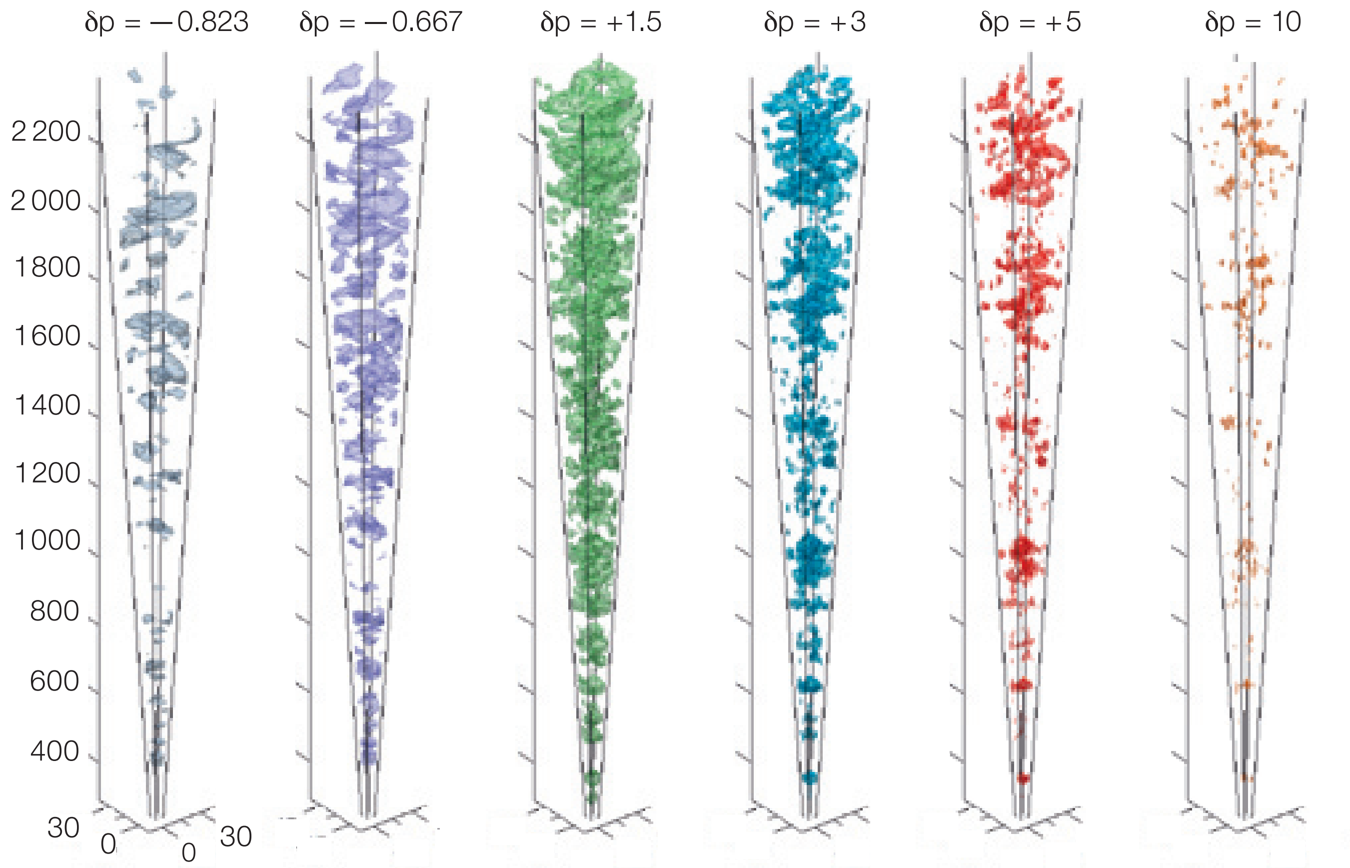


Figure 4. The galaxy density field reconstructed from the zCOSMOS 10k sample using the ZADE algorithm to include about 30 000 galaxies with photometrically estimated redshifts. The maximum comoving distance of 2 400 Mpc corresponds to a redshift $z = 1$. The cones show, from left to right, iso-density surfaces corresponding to underdensities of $\delta p = -0.823$, $\delta p = -0.667$ and overdensities of $\delta p = +1.5$, 3, 5 and 10 respectively. Because the density field is locally projected to avoid the effects of peculiar motions, the equivalent physical overdensities are significantly higher, approximately $\delta \sim 3$, 7, 13 and 35 for the four rightmost cones.

There are many detailed choices for exactly how to construct a density field, and different ones may be best suited to some particular science applications. Accordingly, we have generated many such density reconstructions, each with different choices of tracer galaxies (flux- or volume-limited samples of galaxies), of smoothing kernels of different geometries (cylindrical or spherical) and scales (fixed size or adaptive), and of how the tracer galaxies are weighted (by straight number, by luminosity or by stellar mass). These are all described in detail in Kovac et al. (2008) and will soon be released at *http://www.exp-astro.ethz.ch/COSMOS.*

A large catalogue of galaxy groups to z ~ 1

The density field described above is inevitably on rather large scales, above one comoving Mpc. We may also be interested in the smaller-scale structure of individual galaxy groups — which we define to be galaxies moving within the gravitational potential well of a single virialised dark matter halo. zCOSMOS is well suited to this, having a relatively high sampling rate compared with other surveys (this will be especially true of the final 20k sample).

Numerous algorithms have been developed in the literature to identify galaxy groups in redshift surveys. We have extensively tested these against the zCOSMOS mock catalogues, which reproduce the complex selection function of the actual survey, and for which we know the host dark matter halo for each and every galaxy. By optimising against these very realistic mock catalogues, we have a very good idea of the statistical properties of our group catalogue, in terms of 'purity' and 'completeness' — the probabilities that our detected groups are real and that a given real group is detected, respectively — and the analogous 'interloper fraction' and 'completeness' for individual galaxy members of the groups. Compared with previous practices in the literature, we find that we can improve the fidelity of the group catalogue by introducing a multipass scheme in which we progressively alter the group-finding parameters to optimally find smaller and smaller groups, and by comparing and combining two

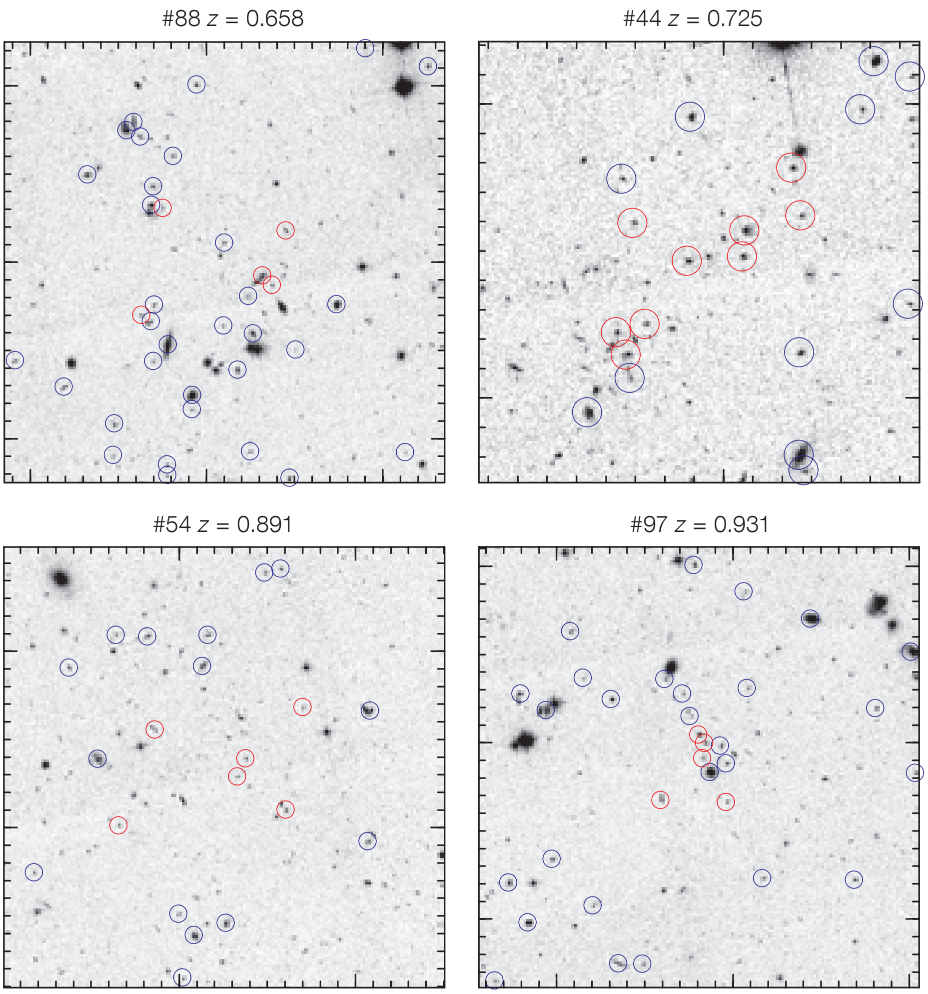


Figure 4. Four representative zCOSMOS groups at $0.6 < z < 1$. In the complete 10k sample there are 151 groups with four or more members and another 649 with two or three members. Group members are circled in red. Other galaxies with spectroscopic redshifts that are not in the group are circled in blue.

different approaches — the linking length based "friends-of-friends" method and a Voronoi–Delauney tessellation approach.

Already with the 10k sample, we have been able, with these improvements, to achieve, despite the currently quite inhomogeneous sampling, an impressively high fidelity in our group catalogue — significantly better than others in the literature at these redshifts. The group catalogue will continue to improve with the doubling of the number of spectroscopic redshifts that will be in the future 20k sample. Already we have identified 151 groups with four or more spectroscopically confirmed members and a further 649 groups with two or three member 'groups'. The zCOSMOS group catalogue is already one of the largest, and certainly the best defined, catalogues of galaxy groups at high redshift.

At low redshifts, $z \sim 0.3$, about a third of the galaxies in the 10k sample can be assigned to a group. This falls to about 15% at redshift $z \sim 0.8$, partly because the higher redshift galaxies are brighter, and therefore only intrinsically richer groups will be detected as a group, and also because there are fewer groups even at a fixed richness, because of the hierarchical growth of structure on these scales. Figure 5 shows a selection of a few of these groups at redshift $z > 0.5$. The zCOSMOS group catalogue is described in detail in Knobel et al. (2008) and will soon be released (see *http://www.exp-astro.ethz.ch/zCOSMOS*).

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Two pictures taken at Paranal during the filming of the recently-released James Bond film *Quantum of Solace*. Upper: film crew on the roof of the Residencia. Lower: the director of the film Marc Forster (centre) flanked by Daniel Craig (James Bond) and Mathieu Amalric (Dominic Greene).

Preparing for the ESO Public Surveys with VISTA and VST: New Tools for Phase 2 and a Workshop with the Survey PIs

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New Phase 2 tools are described to support service mode operations for large public surveys. A workshop was held with the principal investigators and selected team members of the VISTA and VST surveys to introduce the new tools.

Outline

Observational astronomy is in an era of surveys, with the Sloan Digital Sky Survey (SDSS), UKIRT Infrared Deep Sky Survey (UKIDSS), Panoramic Survey Telescope & Rapid Response System (Pan-STARRS), SkyMapper and the Large Synoptic Survey Telescope (LSST) to name only a few of the major projects. All of these are large investments in survey *systems*, ranging from dedicated telescopes and instruments to data distribution. The goal common to all these projects is to target new science in a vast variety of fields and serving broad communities. The VISTA and VST public surveys are ESO's response to these new demands.

In the scheme of ESO service mode operations, the public surveys represent a challenge because they require the definition of several thousands of observing blocks that need to be managed, scheduled and executed in the most efficient way. In this article we present the new Phase 2 tools being developed to support the service mode operations for public surveys, and report on the ESO workshop with the survey principal investigators (PIs) as an example of ESO's commitment to the support of the first survey Phase 2.

Challenge of Phase 2 for public surveys

The ESO public surveys on the near-infrared 4 m telescope VISTA (Emerson et al., 2006) and the optical 2.6 m telescope VST (Capaccioli et al., 2005) are ambitious projects that range from those with very wide area coverage with short exposures, like the Vista Hemisphere Survey (VHS) survey that aims to cover the whole southern hemisphere, to deep surveys concentrating on small areas, but going very deep. Typical examples of the latter are the UltraVISTA and the VISTA Deep Extragalactic Observations (VIDEO) survey; for an overview of the six VISTA and the three VST public surveys see Arnaboldi et al. (2007). Both wide and deep surveys are similar in terms of the total amount of observing time, although their observing requirements, e.g., seeing, sky transparency, moon illumination and RA range, may be complementary. The size of survey projects has a strong influence on their operations.

The unit observation at ESO telescopes is called the Observing Block (OB), and the total execution time of an OB is limited to one hour. The current number of OBs prepared, submitted and scheduled in service mode annually for all the VLT instruments on the 4 Unit Telescopes (UTs), including carry-over and large programmes, is shown in Figure 1.

In VLT service mode operations we currently schedule 3 000–5 000 OBs per year per telescope on average. Based on the Public Survey Management Plans submitted by the survey PIs, the expected number of OBs estimated by the ESO Survey Team (EST) is three to five times larger. Furthermore, since there are only six programmes on the VISTA telescope, then for Phase 2 each survey team must prepare more than 1 000 OBs per semester. Clearly the current manual editing of parameters in each OB is not up to this task, and therefore ESO and the VISTA consortium have developed new tools to support the survey Phase 2.

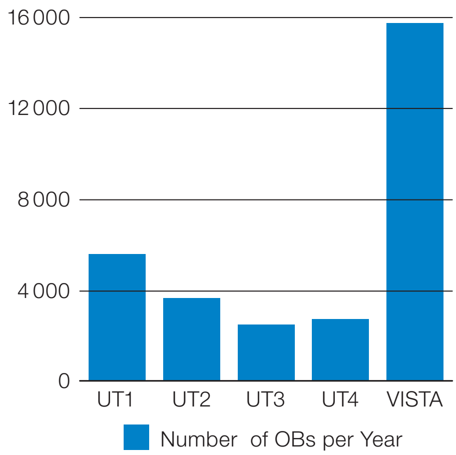


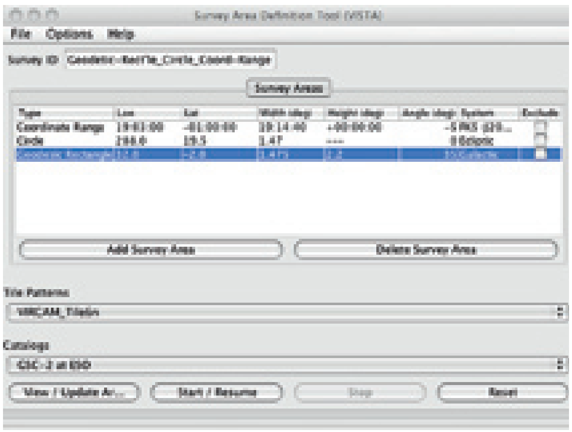
Figure 1. Average number of OBs scheduled in service mode per year over the last two years (including carry-overs and large programmes) on the 4 UTs and the comparison with the estimated average number of VISTA OBs in one year. The histogram does not include the VST OBs.

Phase 2 tools

The generation of thousands of OBs can be simplified when we separate the geometry of the surveys, i.e., where to point on the sky, from the observation strategy, e.g., how many filters, epochs and their order of execution. Both ESO and the VISTA consortium have been developing the necessary new capabilities within the ESO P2PP (Phase 2 Proposal Preparation tool) and the SADT (Survey Area Definition Tool) specifically for the preparation and support of the ESO public surveys. These survey preparation tools are currently being optimised for VISTA operations, expected to start in early 2009. Subsequently they will be upgraded to support VST operations.

In preparing observations for public surveys, users will have to define the geometry of the survey areas using SADT. The output from SADT will then be imported into the new P2PP for surveys, version 3.1, to prepare valid OBs.

SADT: The Survey Area Definition Tool is a utility developed by the VISTA Consortium that allows users to define areas to be covered by surveys executed with either VIRCAM at VISTA or OmegaCam at the VST according to a number of criteria. SADT determines the central coordinates of the different pointings required



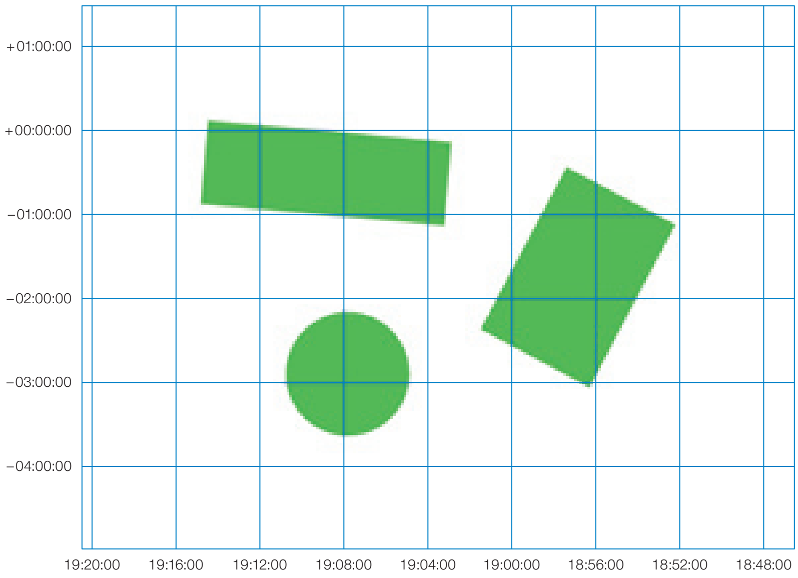


Figure 2a. **Left:** Survey Area Definition Tool (SADT) command GUI window displaying the definition of a survey with three areas. **Right:** View of the survey area.

to cover the field according to the specifications, as well as ancillary guide star information to allow acquisition and guiding. The output of SADT is a file to be ingested by P2PP that contains all the target information needed for the preparation of the OBs with which the survey will be executed.

The IR detectors in the VISTA focal plane are not contiguous, so a single sky exposure has large gaps between the areas covered by the detectors, also known as "pawprints". To make an image without gaps several (minimum six) pawprints with position offsets must be combined so as to cover the gaps and form a filled "tile". In order to survey a given area, the positions of the tiles that VISTA should observe must be defined and for each pawprint in each tile suitable candidate guide stars and active optics (aO) stars must be pre-selected, ready for use when the observation is made. This procedure ensures that the survey speed is not limited by frequent operator intervention.

In Figures 2a and 2b, we show the SADT command GUI and reproduce an image of the plot window, showing the three areas defined for a given survey. Figure 2b shows the pawprints and the tiles defined for this survey.

P2PP: The Phase 2 Proposal Preparation tool has been in use with ESO telescopes since 1997 and has evolved since then to adapt to both operational and user-friendliness needs, as they have been identified, and to provide enhanced functionality. P2PP development continues, and it is currently focused on specific requirements set by the ESO public survey programmes with the survey telescopes, VST and VISTA on Paranal. However, most of these new functionalities and enhancements to P2PP will be of use for all service mode users of ESO telescopes, including those conducting normal programmes. The use of the new P2PP for surveys will be extended to normal programmes on the VLT and other telescopes in the future.

To prepare observation blocks for VISTA and VST surveys, the survey definition generated by SADT is given as input to P2PP. Then P2PP combines the survey definition with 'parent' OBs, i.e., OBs where exposure times, filters, dithering patterns and observing constraints are set, but which lack pointing information. The parent OBs can be a single OB, or mulitple OBs, which are then structured

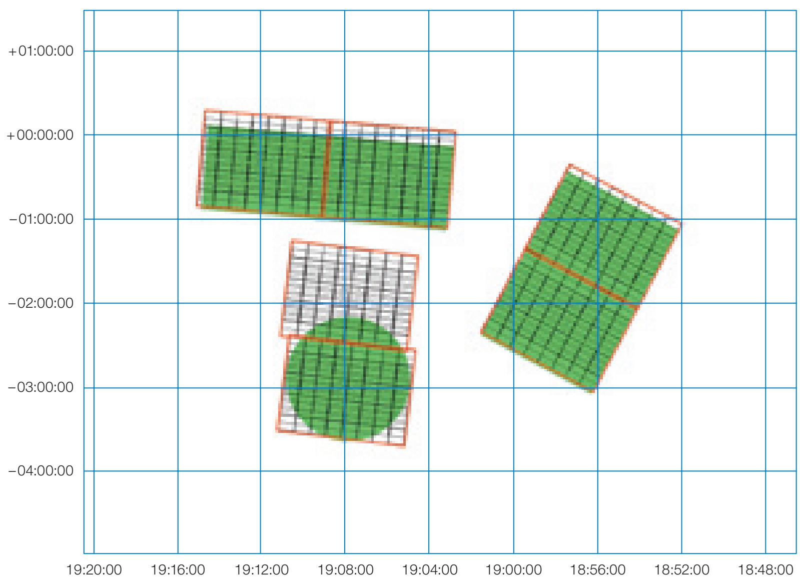


Figure 2b. Pawprints (black contours) and tiles (red squares) computed for the survey area defined in Figure 2a.

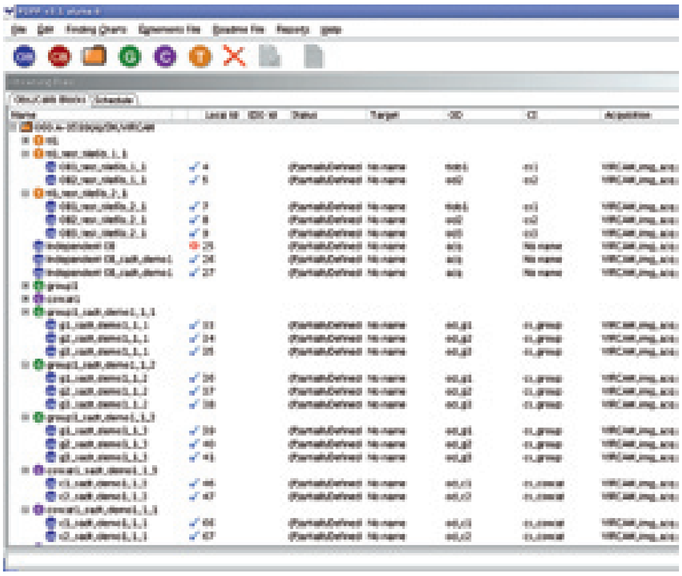


Figure 3. The main P2PP GUI showing the view for Obs/Calib blocks.

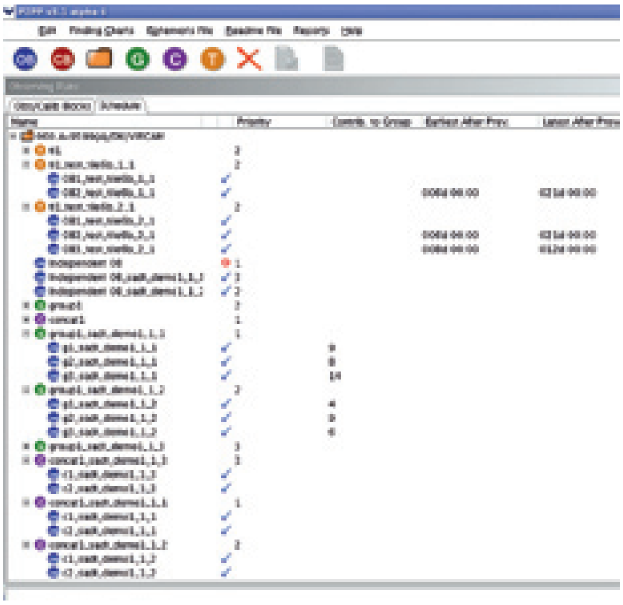


Figure 4. The main P2PP GUI showing the Schedule view.

into an observing strategy. The observing strategy may require grouping OBs with different priorities, chains of OBs, or a time sequence of OBs. The new version of P2PP allows the implementation of these different observing strategies via the scheduling containers defined as time-links, concatenations and groups of OBs. In Figure 3 we show the P2PP main GUI and describe the scheduling containers.

– *Time-linking of OBs:* It may be a requirement that certain OBs must be executed within precise time windows, rather than any time when the external conditions (phase of the Moon, seeing, transparency, etc.) would allow their execution. The following types of time-dependencies can be recognised: absolute time constraints, e.g., an OB must be executed at specific dates that can be predetermined (an example is the observation of a binary star at a precise phase of its period), or relative time links, implying that an OB must be executed within a time interval after the execution of a previous OB, but not necessarily at a fixed date. Examples of this latter are monitoring observations of a variable source at roughly constant intervals.

– *Concatenation of OBs:* In some cases the OBs should be executed consecutively, with no other observations in between. This has been implemented in the P2PP for surveys within the new 'concatenation' container. The concatenation container consists of two or more OBs that must be executed back-to-back without breaks, regardless of the order of execution. In a concatenation, once an OB fails, the whole concatenation must be repeated.

– *Definition of groups of OBs:* At present it is possible to assign an execution priority to each OB, so that the operator is aware of those with a higher scientific importance, when the time comes to decide which observations to execute for a given programme. It has, nevertheless, been recognised that such a simple priority scheme is sometimes insufficient to define the observing strategy of a more complex programme. This is especially true for surveys containing large numbers of target fields observed in a number of instrumental setups. In such cases the need for a prioritisation scheme, at a level above the individual OB, which can take into account the past execution history of the programme, becomes clear. One can consider, for instance, the case of a survey of several target fields to be observed through several different filters, with each field and filter specified in a single OB. Depending on the science goals of the programme it may be desirable to complete the observations of a given field in all filters before proceeding to the next field or, conversely, to observe all fields in a given filter before proceeding to the next filter. The group scheduling container allows any such strategies to be implemented.

In Figure 4 we show the P2PP GUI where the user can set group priorities and time-link constraints. Once the parent OBs are defined in P2PP, the user can import the target fields produced by SADT and then the parent OBs are replicated and combined with each tile (or pawprint) defined in the survey area. The result will be a large series of OBs stored in the ESO OB repository and made available for execution.

Workshop with the survey PIs

The Phase 2 tools for public surveys were presented to the survey teams during a two and a half day workshop held at

ESO, Garching on 15–17 September, 2008. The PIs of the ESO public surveys were invited to attend the workshop, together with two additional team members who would then be in charge of the preparation of the Phase 2 submission. More than 30 astronomers from both VST and VISTA survey teams attended the Phase 2 workshop.

During the workshop, each team was trained with the new survey Phase 2 tools installed on ESO computers, and invited to prepare OBs for the Phase 2 submission, equivalent to the first year of survey observations. Given the overlap in scientific goals and the connection between the VISTA and the VST public surveys, the three VST PIs were also invited to join the corresponding VISTA teams for the Phase 2 preparation exercise.

The Survey Phase 2 workshop included a presentation of the VST and VISTA status, an overview of the survey telescope operations and the presentation of the Phase 2 tools. The second day was devoted to a demonstration of the Phase 2 tools, SADT and P2PP, followed by tutorials organised by the ESO Survey Team (EST). This interaction allowed a fruitful exchange and feedback for further optimisation of the tools. On the third day the programme for VISTA science verification was presented to the survey teams, followed by a discussion on the science goals of the surveys and the readiness of the individual survey teams for the start of these challenging projects.

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Announcement of the Workshop

The E-ELT Design Reference Mission and Science Plan

26–28 May 2009, ESO Garching, Germany

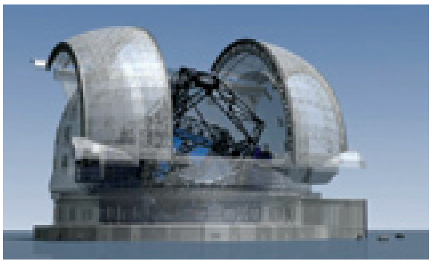
As part of the FP7 funded "E-ELT Preparatory Phase" programme, ESO will host a three day workshop on the E-ELT Design Reference Mission (DRM) and the Design Reference Science Plan (DRSP). The aim is to bring together members of the community, various instrument study teams, members of the E-ELT Science Working Group and the E-ELT Science Office at ESO to present and discuss the results of the DRM simulations. Details and first results of the DRSP will also be presented and discussed.

For further details and registration please refer to *http://www.eso.org/sci/facilities/eelt/science/drm/workshop09/.*

Announcement of the Workshop

Imaging at the E-ELT

29 May 2009, ESO Garching, Germany



Also as part of the FP7 funded "E-ELT Preparatory Phase" programme, ESO will host a one day workshop on the specific topic of "Imaging at the E-ELT". The aim is to bring together members of the community currently working on wide field imagers on 4–8 m-class telescopes and on topics related to imaging at the ELT. The goal is to explore synergies with and alternatives for wide field imaging at the E-ELT. This workshop will take place immediately after the workshop on the E-ELT Design Reference Mission and Science Plan (see above).

For further details please contact Dr. Magda Arnaboldi (*marnabol@eso.org*).

The ESA–ESO Working Group on Galactic Populations, Chemistry and Dynamics

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ESA and ESO initiated a series of Working Groups to explore synergies between space- and ground-based instrumentation. The work of the fourth of these Working Groups, described in this article, focuses on Galactic stellar populations, their chemistry and dynamics, and identifies a set of top questions that future missions and/or ground-based facilities will help to answer. Its mandate was to focus on Gaia/ground synergies in the domain of Galactic science. The major recommendations are for ESA to guarantee the expected tremendous capabilities of Gaia, for ESO to consider the construction of highly multiplexed spectrographs for follow-up and complementary observations of selected Gaia targets, and for ESA and ESO to consider jointly ways to give European astronomers a lead in the exploitation of the Gaia catalogue.

As part of the bilateral cooperation between the two organisations, the Executives of ESO and ESA decided "to identify potential synergies within their future projects". ESA and ESO therefore initiated a series of Working Groups (WGs) to explore synergies between space- and ground-based instrumentation in some key scientific areas of astronomy. The first three Working Groups dealt with Extrasolar Planets (Perryman et al., 2005), the Herschel–ALMA Synergies (Wilson & Elbaz, 2006) and Fundamental Cosmology (Peacock et al., 2006). The fourth Working Group, whose report is presented in this article, was decided during the third ESA–ESO bilateral meeting that took place on 25–26 October 2006 at ESO, with the mandate to focus on Gaia/ground synergies in the domain of Galactic science. The Working Group was constituted in April 2007 and is composed of Catherine Turon (Chair), Francesca Primas (Co-Chair), James Binney, Cristina Chiappini, Janet Drew, Amina Helmi, Annie Robin and Sean G. Ryan. A few colleagues also made some further contributions to the report. Three meetings were held in Garching with the efficient support of the ST-ECF, particularly Wolfram Freudling, Bob Fosbury and Britt Sjoeberg. The beautiful cover was designed by the ESO Education and Public Outreach Department, based on the painting *Origine della Via Lattea* by Jacopo Tintoretto (1518–1594) and an artist's impression of the Milky Way (from a NASA/JPL–Caltech press release).

Since the original motivation for this report was a desire on the part of ESO and ESA to consider projects that would complement the Gaia mission in the domain of Galactic science, the panel's expertise is based primarily in stellar and dynamical astronomy and the WG mostly concentrated on Galactic stellar components and on optical observations. The main goal of Galactic science is to understand the formation and further evolution of our Galaxy, and to identify the processes that have shaped, and which continue to shape, its stellar populations and gas content. This implies obtaining a consistent picture of the structure, the dynamics and the chemical characteristics of the different Galactic populations and, when possible, the comparison with the observations made on nearby galaxies in the Local Group, where mean chemical characteristics are different from those in our own Galaxy.

This work was especially timely given the planning currently being undertaken for Gaia by ESA, with a launch foreseen by the end of 2011, and the impending first-light of dedicated survey telescopes in the optical and near-infrared by ESO (VISTA by the end of 2008 and VST in 2009). Moreover, in the future E-ELT era, new utilisation of 4- and 8-metre telescopes and instrumentation can be envisaged.

The context

In this context, a few remarks should be highlighted:

- the volume and quality of data that Gaia will provide will revolutionise the study of the Galaxy even more than Hipparcos revolutionised the study of the Solar Neighbourhood;
- there is a need for very large statistically-significant samples to undertake many of the dynamical, kinematic and compositional studies of the Galaxy, and surveys are ideal tools in this respect;
- it will be important to develop the capabilities to cover what Gaia will not, such as high resolution spectroscopic follow-up for a large number of targets selected from Gaia data, medium resolution spectroscopy for a large number of selected faint stars for which no spectroscopic data will be obtained from Gaia, or achieving wide wavelength coverage in photometry and spectroscopy;
- advances in infrared (IR) astronomy will allow us to tap the benefits of infrared wavelengths for astrometric, spectroscopic and photometric observations of the obscured Galactic Bulge and the central region of the Galaxy;
- stellar population science needs access to visible (including blue) spectra of stars in the Galaxy, and not just to the infrared (IR) that is favoured for much cosmological work;
- proper interpretation of such a huge mass of data demands significant improvements to underlying theory, modelling and analysis techniques.

The top questions in Galactic science

Much has been learned about the various components of the Galaxy since the early 1940s when Walter Baade introduced the concept of stellar populations, but we still have a fragmentary picture of how the Galaxy was assembled and subsequently evolved. Only the concomitant availability of high quality data on distances, kinematics, ages, physical parameters and element abundances for sufficiently large samples of stars from each of the Galaxy components would have a profound impact on our views of how the Galaxy formed and evolved. It is, in particular, crucial to obtain observations at various distances from the Galactic Centre and various distances from the Galactic Plane, from the Galactic Bulge out to the external parts of the Disc and the halo, including stars in all kinds of substructures such as OB clusters and associations, globular clusters and streams.

The first and main task of the Working Group has been to review the state-of-the-art knowledge of the Milky Way galaxy, to identify the future challenges, and to propose which tools (in terms of facilities, infrastructures, instruments, science policies) would be needed to successfully tackle and solve the remaining open questions. In Section 3 of the report we examine the current state of our knowledge in Galactic science: the main structures of the Galaxy; the continuing process of star formation that strongly shapes its present-day properties; the dynamics of stars that are the clue to determining the mass distribution in the Galaxy, connecting the kinematics of each population with its spatial distribution and relating the present orbits of stars to the orbits on which they were born; the basic astrophysical parameters (ages, kinematics and chemical abundances) from which stellar evolution can be inferred. Finally, at the end of Section 3 we sketch the current picture of how the Galaxy was assembled from its building blocks.

In Section 4 of the report we describe how the Galaxy can be used as a laboratory in which to study the processes that shape galaxies, and to constrain theoretical models of galaxy formation and evolution. In the course of Sections 3 and 4, we identify a number of limits on our current knowledge, and hint at future work that would overcome these. These issues are brought into sharp focus in Section 5, where we identify the top remaining questions, and suggest how possible solutions might be provided by investment in new facilities, planned and yet to be planned. In that section, we first identify the eight top global questions, related to the Galaxy as a whole: Which stars form and have been formed where? What is the mass distribution throughout the Galaxy? What is the spiral structure of our Galaxy? How is mass cycled through the Galaxy? How universal is the initial mass function? What is the impact of metal-free stars on Galaxy evolution? What is the merging history of the Galaxy? Is the Galaxy consistent with ΛCDM? Then we consider the top open questions for each of the main components of the Galaxy. In Section 6 we review ground- and space-based facilities that have played and/or will play a major role in achieving our scientific goals. Detailed recommendations of the Working Group are drawn together in Section 7.

Figure 1. The front cover to the 4th ESA–ESO Working Group Report, designed by the ESO Education and Public Outreach group, is shown. A detail from the painting of Jacopo Tintoretto is blended with an artist's impression of the Galaxy. Jacopo Tintoretto (1518–1594) was a Venetian painter of the Italian Renaissance, renowned for his dramatic use of light, shadows and bright colours. The painting is the *Origine della Via Lattea* showing how the Milky Way was created from the milk of Hera. Zeus, wishing to immortalise his baby Heracles, born from a mortal woman, Alcmene, held him to the breast of Hera, who was sleeping. She suddenly awoke and pushed away the unknown infant. The milk spurting towards heaven became the Milky Way, while some drops fell downwards giving rise to lilies. The painting is currently located in the National Gallery, London. The artist's impression of the Galaxy was designed to illustrate new observations from NASA's Spitzer Space Telescope revealing that the Galaxy might have only two major arms of stars rather than four as was previously believed (see *http://www.spitzer.caltech.edu*).

Recommendations

Europe has led the way in Galactic research as regards astrometry and spectroscopy and is on the brink of taking the lead in photometry: ESA's Hipparcos mission pioneered space astrometry and paved the way for the ambitious Gaia mission, which will perform the first parallax survey down to magnitude $V = 20$ in parallel with a complete characterisation of each observed object; ESO's innovative telescopes (NTT and VLT) coupled to leading capabilities in the construction of multi-object spectrographs have yielded detailed stellar abundances of faint stars; ESO is about to start massive programmes of optical/near-IR photometry with two dedicated survey telescopes (VISTA and VST). This observational work is backed by unique European expertise in modelling stars and galaxies (stellar atmospheres, stellar and galactic evolution, population synthesis, dynamics, etc.).

The opportunities for European science are tremendous if we make strenuous efforts to capitalise fully on these assets. This involves taking both full advantage of the instrumentation that we have and planning new facilities. Particular attention has to be paid to the optimisation of synergies between Gaia and ground-based observations, especially with the present or potential ESO instruments.

The major recommendations from this Working Group are as follows:

1. For ESA to make maximum effort to guarantee the expected tremendous capabilities of Gaia (accuracies and limiting magnitudes for the astrometric, photometric and spectroscopic aspects of the mission). Only if these requirements are fulfilled can the satellite provide the promised revolution in our knowledge of the Galaxy by unveiling populations through the study of chemistry and dynamics.

2. For ESO to consider facilities (construction of new highly multiplexed wide field spectrographs or improvement of the capabilities of existing instruments) for medium to high resolution spectroscopic observations of a large number (40 000–100 000) of particularly interesting stars selected from Gaia observations. There are two aspects to this recommendation:

– Follow-up observations. Gaia will be a fantastic tool to select well-defined and unbiased samples of targeted stellar populations. High resolution spectroscopy (in the blue for the halo and thick disc stars, in the red and with more fibres for the thin disc and Bulge) will provide detailed abundances.

– Complementary observations. Medium resolution spectral observations will provide radial velocities and metallicities for selected samples of stars fainter than $V = 16.5$, not measured by the Radial Velocity Spectrometer (RVS) on-board Gaia.

The recommended instruments are as follows:

a) Blue multiplexed spectrograph on a 4 or 8 m-class telescope, with more than 100 fibres, high blue sensitivity (signal-to-noise, S/N ~ 30–40) and high resolving power (20 000–30 000), to measure detailed abundances in 20 000–50 000 halo, thick-disc and outer thin-disc stars. This could be either on a dedicated 8 m-class telescope with field of view (FOV) ~ 0.5 deg^2, or on a dedicated 4 m telescope with FOV ~ 2.5 deg^2.

b) Infrared highly multiplexed spectrograph to be placed on a dedicated 4 m-class telescope, with AO correction, massive multiplexing (> 500 fibres), S/N ~ 20–30, high resolving power (20 000–30 000) and large field of view. This instrument would obtain detailed abundances and radial velocities for 20 000–50 000 obscured Bulge, thin-disc stars. A lower resolution mode (R ~ 4 000) would also be perfect for fainter targets, not observed by the RVS on board Gaia. ESO may also consider collaboration with teams starting the development of such instruments (APOGEE in the USA; WINERED in Japan; UKIDNA or HERMES in Australia).

c) Infrared multiplexed spectrograph on an 8 m-class telescope. ESO should consider improving the capabilities of current VLT multiplexed spectrographs for a larger field of view and at IR wavelengths.

3. For ESA and ESO jointly:

– Calibration of Gaia instruments. ESA and ESO should jointly facilitate observations with ESO telescopes that are required for the calibration of Gaia instruments.

– European leadership in the exploitation of Gaia data. ESA and ESO should jointly consider ways to give European astronomers a lead in the exploitation of the Gaia catalogue and facilitate follow-up observations on a "targets to be specified later" basis.

Other recommendations

1. For ESA:

– Prepare for the future of astrometry.

a) Infrared astrometry would be the ideal complement to Gaia, which is not able to observe deeply in the Galactic Centre, the Bulge and parts of the Disc because of heavy extinction and crowding. The ideal instrument would achieve an astrometric accuracy of 10 μas down to magnitude 17 in the 0.9 μm z-band. A first step in this direction might be a collaboration with the Japanese project JASMINE (10 μas astrometric accuracy for stars brighter than $z = 14$).

b) Microarcsecond accuracy astrometry in the optical (better than 4 μas). This is the requirement for resolving the internal motions of the outer globular clusters and dwarf galaxies of the Local Group, for which Gaia will provide only mean motions. This capability would also enable us to obtain direct distances to extragalactic stellar candles.

– Asteroseismology. This is a major tool to complement Gaia with respect to age determination. ESA should encourage the community to prepare for a next-generation mission, which would sample all stellar populations of the Galaxy.

– UV spectroscopy. UV wavelengths are now only accessible through the Hubble Space Telescope (HST). ESA should support the longevity of Hubble, with a substantial share of its observing time being devoted to UV instruments, and support the use of COS, the new UV spectrograph to be installed on HST during the fourth Servicing Mission.

2. For ESO:

– Spectrograph on the E-ELT. ESO should consider a spectrograph with very high resolving power (40 000–70 000) on the E-ELT to observe abundances of stars (Population II and III stars, F- and G- dwarfs, etc.) across the whole disc and far from the Solar vicinity (Bulge, outer Halo).

– Near-IR photometric survey. It would be very valuable for the Southern Galactic Plane area as well the innermost regions of the Galaxy to have full near-IR coverage. The different VISTA surveys will be an important first step in this direction, but their final goals might be different. ESO should closely follow the sky and wavelength coverage of these surveys, and eventually invest extra observational efforts to ensure total coverage.

3. For ESA and ESO jointly:

– Observation of the fine structure of the ISM. Support proposals to use ALMA/Herschel observations to study the fine structure of the interstellar medium (ISM).

– Enhance the European scientific return from large Galactic surveys by sponsoring actions that would optimise the performance of the European astronomical community in mining these data:

a) Workshops on modelling and theory for stellar interiors and atmospheres; stellar evolution including that of massive stars and binaries; stellar population synthesis; galactic dynamics and specific models of Galactic populations; the interstellar medium and the distribution of dust and gas in the Galaxy.

b) Fellowships, aimed at both improving the underlying theory and modelling and developing high performance analysis techniques.

– Further ESA–ESO Working Groups:

a) Star formation in various environments. This topic will have a strong impetus with the start of the ESO public surveys of the Galactic Plane, the launch of Herschel, and the progressive and massive enhancement of sub-mm observations with ALMA.

b) Galaxy formation. The diverse instruments considered for the E-ELT are in their definition phases and it is appropriate to explore fully the possible synergies between E-ELT and JWST instruments in order to explore in detail the whole Galaxy and its outskirts, in particular the *Terra Incognita* behind the Galactic Centre.

As a conclusion, ESA and ESO are providing European astronomers with unique instruments, opening the way to extremely high accuracy space astrometry and innovative ground-based telescopes, equipped in particular with first-class spectrographs. The main recommendation of this report is for the two organisations jointly to organise vigorously the exploitation of synergies between Gaia and ground-based observations, and consider ways to give European astronomers a lead in the exploitation of the Gaia catalogue.

References

Peacock, J. A. et al. 2006, ESA–ESO Working Group Report on Fundamental Cosmology
Perryman, M. et al. 2005, ESA–ESO Working Group Report on Extrasolar Planets
Wilson, T. L. & Elbaz, D. 2006, ESA–ESO Working Group Report on The Herschel–ALMA Synergies

Links

Spitzer release: *http://www.spitzer.caltech.edu/Media/releases/ssc2008-10/release.shtml*
Working Group Report: *http://www.stecf.org/coordination/eso-esa/galpops.php*

To request a printed copy of the report, please contact Britt Sjoeberg (*bsjoeber@eso.org*).

L'Harmonie des Spheres
CD of Organ Music for IYA2009

Music of the Spheres is the title of a CD by the French astrophysicist Dominique Proust. As well as being a regular observer at La Silla and Paranal he has given organ concerts at Santiago, Valparaiso, La Serena as well as at La Silla.

The CD contains 12 organ pieces directly inspired by astronomy, including the planetary harmonic scale of the *Harmonices Mundi* from Joannes Kepler, a *Dialogo* from Vicenze Galilei (father of the astronomer), a fugue by the famous astronomer William Herschel, *Jupiter* from Gustav Holst's *The Planets*, variations on the chorale *How bright is the morning star* from Johann Sebastian Bach and other pieces. The CD has been produced with the support of the AMA2009 (Année Mondial de l'Astronomie) committee and is available on request from Dominique Proust (*dominique.proust@obspm.fr*). Benefits will be donated to a charitable association.

Report on the Workshop

Interstellar Medium and Star Formation with ALMA: Looking to the Future. A Workshop to Honour Tom Wilson

held at Consejo Superior de Investigaciones Científicas, Madrid, Spain, 16–17 June 2008

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In June 2008, a group of friends and colleagues of Tom Wilson gathered in Madrid to honour his scientific career in a workshop on ALMA organised by three of his PhD students. The workshop was devoted to reviewing recent progress in our understanding of the main topics of research that Tom has pursued during his career: the physics and chemistry of the interstellar medium and how stars form. Specific topics included H II regions, molecular clouds, clumps, cores, outflows and masers in Galactic and extragalactic environments, mainly from an observational perspective.

Introduction

Last December our colleague and friend Tom Wilson celebrated his 65th birthday. During his fruitful career he has made important contributions to the understanding of the physical and chemical properties of the interstellar medium and the processes leading to star formation. In the last five years, while at ESO, Tom has helped to realise the Atacama Large Millimeter/submillimeter Array (ALMA). To honour him, his former students Christian Henkel (Max-Planck-Institut für Radiostronomie, MPIfR), Jesus Martin-Pintado (Consejo Superior de Investigaciones Científicas, CSIC) and Rainer Mauersberger (ESO) organised a two day workshop entitled "Interstellar Medium and Star Formation with ALMA: Looking to the Future". The workshop was organised by the Departamento de Astrofisica Molecular (DAMIR) and held on 16–17 June on the campus of the CSIC in Madrid. Support for the workshop was provided by CSIC, ESO and RadioNet.

Scientific programme and attendance

Sixty people attended the workshop. Most of the attendees were Tom's friends, colleagues and former PhD students. Unfortunately, not all of those invited could come; many were prominently mentioned by Tom and others in their presentations. A significant number of those mentioned were PhD students and postdocs, who are Tom's scientific grandchildren.

Following Tom's suggestion, the emphasis was on the future of molecular astrophysics, rather than a review of his career. Thus most of the programme was devoted to future studies of interstellar matter and star formation in the Milky Way and in external galaxies. The organisers also decided that Tom's students would act as chairpersons of the sessions to give short introductions, recounting anecdotes and personal experiences from their professional or personal relationship with Tom. The presentations from the workshop, which are available online at *http://www.damir.iem.csic.es* included two kinds of talks. The first were given by Tom's old friends and colleagues, who looked back on Tom's life, relating anecdotes and also presenting their view of future areas of research to be done with ALMA. The second kind were given by the younger generation of students, many of them Tom's scientific grandchildren; these were mainly concerned with providing perspectives on ALMA's contribution to their research area.

The after-dinner speech on 16 June was given by Professor Robert Rood, who gave an extended talk about Tom Wilson's career.

Tom's scientific career

The workshop started with a summary of Tom's career by Professor Bernard F. Burke, Tom's thesis adviser. He described the first steps in Tom's career as a PhD student in MIT, when he had also just arrived at MIT. He mentioned three of Tom's main virtues: persistence, change and transition, all of which are fundamental to success in astronomy and astrophysics; he noted that Tom has shown the ability to handle all of them. Tom started his thesis by surveying a catalogue of H II regions in the northern sky in recombination lines with the Green Bank 140-foot telescope. Tom also joined Peter Mezger in an extension of this project to survey recombination lines from southern H II regions with the Parkes 210-foot radio telescope. Both surveys were great successes. The Parkes work constituted the main body of his thesis.

Tom then moved to MPIfR and started to work with the new 100 m radio telescope at Effelsberg in Germany. Using the 100 m telescope Tom made the transition from studying H II regions to observing molecular clouds, mainly in the centimetre wavelength lines of ammonia and formaldehyde. Most of Tom's students were basically trained on molecular line observations related to the field of star formation. Tom continued working on recombination lines from H II regions and one of the most innovative works in this field was the venture with Robert Rood (the dinner speaker, Tom Bania and later Dana Balser) to detect the hyperfine line of ionized ^{3}He.

Bernard Burke stressed that big radio telescopes became Tom's *métier* and he was involved in the commissioning of big radio telescopes operating from centimetre to short sub-millimetre wavelengths: the 100 m telescope at Effelsberg (Germany), the Institut de Radio Astronomie Millimetrique (IRAM) 30 m at Pico Veleta (Spain) and the 10 m Heinrich Hertz telescope at Mt. Graham (Arizona, USA). All of Tom's students will always remember him as ready to go at any time to observe or commission receivers and backends at the 100 m telescope. His typical response in these cases was, "We will take the telescope time, please sign up for the Dienstwagen to go to Effelsberg."

In recent years, Tom has been heavily involved in the realisation of the ALMA through key positions at ESO (European ALMA Project Scientist and Deputy Director). The workshop continued with technical and scientific presentations on the potential of ALMA.

Status of ALMA and the synergy with Herschel

The anticipated performance of ALMA and the current status of the project were described by Richard Hills, the ALMA Project Scientist. At the time of the workshop eight antennas were already at the Operations Support Facility; these will be delivered to ALMA after a series of tests. As one can imagine, the activity is frantic, with equipment being delivered and tested. In addition to the antennas, the two antenna transporters were also undergoing testing. Pere Planesas presented a visual tour of ALMA and the site. He showed a number of beautiful pictures of the landscape and the current status of construction. The synergies between the Herschel Observatory and ALMA were discussed by José Cernicharo.

The molecular interstellar medium

Studies of the chemical complexity and the structure of the molecular interstellar medium (ISM) will play a central role in ALMA. John Bieging described the role of large-scale mapping of the structure of the molecular clouds to understand the impact of massive stars and their evolution. The large-scale, very high angular resolution images of dust and line emission will allow scientists to study the origin and the role of turbulence in the fragmentation of molecular clouds.

Alain Baudry showed the great potential of the ALMA correlator in searching for new molecules in the ISM. Molecular abundances vary with evolutionary state, as different species appear and disappear, for example by depletion onto dust grains. A plethora of molecular species can be used as tracers of the complex physics and chemistry and the ability to model these processes with high spatial resolution was identified as an essential complement to ALMA observations. Eric Herbst reviewed chemical models, showing how molecular abundances vary with the evolutionary state of star formation in molecular clouds. Aina Palau discussed the intriguing behaviour of nitrogen-bearing molecules in molecular clouds with intermediate mass star formation. Finally Javier Rodriguez-Goicoechea presented the chemical effects observed in photodissociation regions generated by UV radiation from massive stars.

Low mass star and planet formation

Turning to low mass star formation it was noted that the processes leading from molecular clouds to stars cannot be followed in detail at present. Progress depends on new instrumentation, especially ALMA. Stars form in the central cores of molecular clouds by accreting material onto protostellar cores. However, we do not understand in detail the kinematics and dynamics of this process; neither the formation and collimation of outflows nor the eventual evolution of circumstellar discs to form planetary systems, asteroids and comets. Presumably magnetic fields play an important role, but this is not understood at present.

Frédéric Gueth presented recent results of molecular outflow observations with high angular resolution obtained with the IRAM interferometer and argued that ALMA will be able to see central regions in young stellar objects, providing images of the complex structure and kinematics of the outflowing and accreting material. Stephane Guilloteau presented the potential of ALMA for understanding the formation and evolution of circumstellar discs. ALMA will provide a complete view of the physical conditions, the kinematics and the chemical evolution of circumstellar discs by imaging with very high angular resolution several lines of a large number of molecules. The gaps predicted to occur in circumstellar discs as a result of planet formation can be imaged directly by ALMA. Josep Miquel Girart discussed the expected role of magnetic fields in star formation. He presented images of dust polarisation obtained with the Sub-mm Array (SMA) and compared the results of low mass versus high mass star formation. The expected hourglass shape of the magnetic field is found in both cases.


Credit: Sergio Martin (CfA)

Figure 1. Workshop participants collected around Tom Wilson (jacket and tie in the front row, 6th from the right).

Massive star formation: masers, star clusters and H II regions

Massive star formation has been one of the central themes in Tom's career and ALMA will provide images with the required angular resolution and sensitivity to study the formation of stellar clusters and also the individual stars in clusters. There were a number of talks covering topics from molecular excitation in massive star-forming regions to the properties of hot cores associated with intermediate mass protostars in clusters. Karl Menten summarised the results obtained from imaging maser emission from different molecular species in massive star-forming regions. Al Wootten also reported the results of high angular resolution imaging of water masers and thermal emission from other molecules. Both stressed the importance of the longest baselines in ALMA to use maser emission to trace the smallest scale structures in these regions.

Mayra Osorio presented model predictions for dust and molecular emission from high mass protostars and Carlos Carrasco Gonzalez showed recent inteferometric (VLA and Combined Array for Research in Millimeter-wave Astronomy, CARMA) images of the molecular outflows and discs in the stellar cluster of NGC 2071. Izaskun Jimenez-Serra presented high angular resolution images of the

Cep A HW2 region and showed that a cluster of intermediate mass stars is being formed.

Studies of H II regions were presented by Dan Jaffe and James Moran. Dan presented observations of the kinematics in compact and ultracompact H II regions using the [Ne II] emission line at 12.8 μm. The kinematics are inconsistent with the predictions that the exciting stars are moving with high velocities; a disc geometry explains the evolution of very young H II regions better. Jim Moran presented the results of SMA observations of the recombination line maser in MWC 349. The kinetics of the disc around this young massive star is not fully consistent with Keplerian rotation. Although MWC 349 is far in the north, ALMA can provide images with enough resolution to discriminate between kinematical disturbances produced by gas spiralling toward the star from gas ejected from the disc of this source.

Extragalactic molecular astrophysics

ALMA will enable a series of advances in the field of galaxy formation and evolution, particularly at early epochs. Galaxy number counts will be extended to the faintest sources in every ALMA band. The spatial and redshift distribution of these sources, as well as their luminosity functions, will become measurable, as ALMA will not be confusion-limited in any of its bands. It will excel as a follow-up instrument for large-area surveys with bolometer arrays, both in resolving continuum emission and in measuring redshifts from molecular lines. In this context, Pierre Cox presented the new results of the molecular emission at high redshift and Paola Andreani discussed the star formation at high redshifts in obscured sources detected by the Spitzer satellite, stressing the potential of ALMA for understanding the nature of the power sources. Dennis Downes presented recent high angular resolution imaging of the continuum of the ultraluminous galaxy Arp 220 and concluded that active galactic nuclei (AGN) activity dominates the output, in contrast with previous models that favoured star formation as the dominant mechanism.

Sergio Martin and Daniel Espada argued that detailed chemistry of star formation in nearby galaxies and in the Galactic Centre will be a major topic for ALMA, as will be the relationship between the chemical complexity and the dominating activity in galactic nuclei (AGN or starbursts). Based on a model of molecular emission, Sergio proposed that the power source in Arp 220 could be due to a burst of massive star formation (now in the protostar phase), similar to the hot core phase in Galactic star-forming regions.

Links

Workshop contributions:
http://www.damir.iem.csis.es/alma2008/
http://www.astro.virginia.edu/~rtr/photos/tlwfest/

Award of the Ioannes Marcus Marci Medal to Tom Wilson, Associate Director for ALMA

Tom Wilson, who has been at ESO since 2004, first as ALMA Project Scientist and, after 2006, as ESO Deputy Director, was awarded the renowned Ioannes Marcus Marci Medal of the Czechoslovak Spectroscopic Society at a ceremony in Prague. Previous medallists include T. W. Hänsch, the 2005 Nobel Laureate in Physics.

Ioannes Marcus Marci was born in 1595 in Lanškroun, on the border of the former provinces of Bohemia and Moravia, currently in the Czech Republic. In 1627 he was appointed Professor of Medicine at Charles University, Prague, later Dean of the Faculty of Medicine and Rector of Charles University. He was also a private physician to the Emperor Ferdinand III. The results of his research activity have been collected in 16 scientific books. His most important contributions in the field of physics were his studies of the refraction of sunlight by a prism and the explanation of the origin of the rainbow, collected in his work, *Thaumantias. Liber de arcu coelesti deque collorum apparentium natura ortu et causis*. I. M. Marci died in Prague in 1667.

Since 1977, the I. M. Marci Medal for outstanding achievements in the field of spectroscopy has been awarded annually by the Spectroscopic Society of Ioannes Marcus Marci. This is a non-profit organisation for scientific, educational and technical workers with the aims of promoting and fostering advancement in the field of spectroscopy.

The ceremony took place on 3 September 2008 in the Prague City Hall Auditorium, a historic lecture hall in central Prague. Tom presented a lecture on the "Current Status and Scientific Potential of the Atacama Large Millimeter/submillimeter Array" and he and Terry A. Miller (Ohio State University) were awarded the Ioannes Marcus Marci Medal for their contributions to different areas of spectroscopy.

Report on the Conference

Optical Turbulence — Astronomy meets Meteorology

held at Nymphes Bay, Alghero, Sardinia, Italy, 15–18 September 2008

Elena Masciadri
INAF, Osservatorio Astrofisico di Arcetri, Florence, Italy

"A European boost to a strategic research field on which the success of the ELTs relies."

The spatial resolution of current and future ground-based telescopes is limited by the optical turbulence of the atmosphere. An interdisciplinary conference of astronomers, meteorologists and atmospheric physicists to consider the study, characterisation and correction of atmospheric turbulence is reported.

An international conference, "Optical Turbulence — Astronomy meets Meteorology" (see *http://forot.arcetri.astro.it/otam-08)* was held at Nymphes Bay, Alghero in Sardinia to bring together researchers from different fields, including astronomers, physicists and meteorologists, to discuss the consequences of the new era of ground-based astronomy from the point of view of optical turbulence, taking account of the main challenges and critical points. The meeting was an experiment, with the aim of fostering new types of collaborations that enhanced interdisciplinary and cross-field interactions.

Optical turbulence (OT) is one of the main causes limiting the spatial resolution attainable in ground-based visible and infrared astronomical observatories. It is certainly one of the principal obstacles to be overcome in achieving the potential performance of the next generation of ground-based astronomy facilities, the Extremely Large Telescopes (ELTs). The success of these facilities strongly depends on our ability to:

1. Characterise optical turbulence at astronomical sites from a qualitative as well as a quantitative point of view.
2. Improve our knowledge of the mechanisms that produce and develop optical turbulence.
3. Predict 3D maps of optical turbulence to optimise flexible scheduling of scientific programmes and instruments.
4. Correct wavefront perturbations produced by atmospheric turbulence.

Many of the most challenging scientific programmes to be carried out with ground-based telescopes and aiming to enhance our understanding of the Universe require excellent turbulent conditions to be successful. The competitiveness of ground-based astronomy with respect to space-based astronomy is strictly related to our ability to identify and predict temporal windows of favourable atmospheric conditions in the most accurate way. New and sophisticated Adaptive Optics (AO) techniques, assisted by either natural or laser guide stars (such as Multi-Conjugate AO [MCAO], Ground-Layer AO [GLAO] and Laser Tomographic AO [LTAO]), are intended to optimise the correction of perturbed wavefronts over different fields of view, but, to achieve this optimisation of efficiency, they will also require a detailed knowledge of the vertical distribution of the OT (and not simply integrated values). This new generation of AO requires a detailed understanding of the connections between the turbulence spectrum and the shape of the point-spread function (PSF) over the entire field of view. Some specific topics, such as the precise nature and role played by the spatial coherence outer scale in high angular resolution (HAR) techniques and the turbulence spectrum features in non-Kolmogorov regimes, are still active research topics at the frontiers of the theory in this field.

From the meteorological side, Operational Numerical Weather Prediction (NWP) systems at medium and mesoscale range might play an important role for ground-based astronomy over the next few decades. 4D-Var Assimilation Data[1] employing satellite measurements has greatly improved the quality of medium range weather forecasts recently. A new challenge for meteorology recently appeared on the horizon: Mesoscale Data Assimilation. This consists of a network of surface stations and an assimilation system with a resolution of a few kilometres. Such a system is mandatory to improve the ability of mesoscale models in reconstructing the unresolved physical parameters (such as the OT) evolving at spatial and temporal scales smaller than the resolution of the General Circulation Model[2] and to improve the accuracy of meteorological weather forecast models that extend over limited surface areas. How this can be set up in remote regions of the Earth, such as those that are typically of interest to astronomers, is an important question.

This international conference was aimed at all these topics. The meeting was promoted and organised by Elena Masciadri, Team Leader of the ForOT Project[3], and was a milestone in a long-timescale programme begun a few years ago. ForOT is actively involved in studies relating to turbulence characterisation for astronomical applications, employing measurements as well simulations with mesoscale atmospheric models (Masciadri, 2006). The conference was sponsored by the European Community, which contributed most of the funding through the ForOT Project, but additional contributions were provided by ESO and INAF (Italy).

The original intention of the conference was to attempt to link the two communities of astronomers and meteorologists. This step is fundamental to guaranteeing the success of dedicated systems conceived for the prediction of the optical turbulence (seeing and related integrated astroclimatic parameters, such as isoplanatic angle, wavefront coherence time, etc.) above astronomical sites using mesoscale atmospheric models. The reason is simple. We need to apply an investigative tool developed in meteorology (atmospheric models) to do science (the

[1] In meteorology, Assimilation Data is the procedure that provides the distribution in space and time of the status of a set of variables supposed to describe the atmosphere in a given volume. The accuracy of this description depends on the nature and density of the observations (such as radio-soundings, satellites, etc.) and is fundamental for better description of the initialisation of a model.

[2] General Circulation Models (GCMs) are models that extend over the whole Earth and are used for weather forecasting.

[3] The ForOT Project (see *http://forot.arcetri.astro.it*) is funded by a Marie Curie Excellence Grant (FP6 Programme) — MEXT-CT-2005-023878.

characterisation of optical turbulence) in the astronomical field. This is a classic example of problem solving by a multidisciplinary approach between disciplines that use different languages, different strategic approaches and investigative tools.

The challenge for astronomers is to be aware just how much the success of the next generation of ground-based astronomy facilities will depend on numerical predictions of the atmosphere. This is a discipline that requires long timescales, so it is important not to ask the impossible of the current models and to optimise the work of astronomers and meteorologists to make clear the achievable challenges and to work together to attain them in the shortest time and most efficient way. As a first step in this direction, on the last day of the conference, a special session was dedicated to an open discussion moderated by the scientists managing some of most powerful current astronomical ground-based facilities, those leading operational forecasting systems and members of research groups developing atmospheric models and data assimilation systems.

Around 60 specialists (from instrumentation, atmospheric modelling and theory, AO simulations and systems) met in Sardinia to highlight their new results with around 45 oral presentations and 10–15 posters. A considerable number of meteorologists attended the event (with a strong participation from the Centre National de Recherches Meteorologiques (CNRM), Meteo France, Toulouse) with presentations covering all the key topics related to the numerical prediction of the atmosphere. The conference proceedings will be published by Imperial College Press and edited by E. Masciadri and M. Sarazin.

Main conference results

The conference started with a general introduction by two Emeritus Professors. Jacques Beckers introduced the topic of optical turbulence in high angular resolution techniques, and Rene Racine provided a personal and provocative vision of the problem of turbulence characterisation in astronomy.

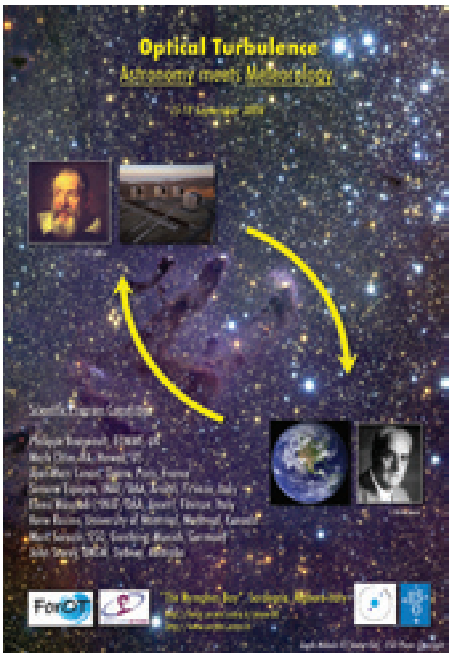

Figure 1. Conference Poster.

Subsequent sessions were dedicated to the characterisation of turbulence from measurements. The number and type of optical instruments to measure the vertical distribution (vertical profilers) has suddenly increased in recent years and many of them are conceived to monitor dedicated regions of the troposphere. One of the most interesting developments is the proliferation of vertical profilers dedicated to measuring and characterising the OT with high vertical resolution near the surface. From a typical resolution of the order of 1 km (typical of Generalised Scidar [GS]), we have moved on to resolving thinner vertical slabs of up to a few tens of metres. Concepts on which the instruments are based, and/or results obtained in first site-testing campaigns were presented for the solar and lunar scintillometers called SHABAR (solar SHAdow BAnd Ranger) by Beckers, for a lunar scintillometer by Paul Hickson, for SLODAR (SLOpe Detection And Ranging) by Richard Wilson and Tim Butterley; HVR–GS (High Vertical Resolution — Generalised SCIDAR) and LOLAS (LOw LAyer SCIDAR) were presented by Masciadri and Remy Avila, representing two different ways of improving the resolution of GS near the surface. A version of SODAR (SOnic Detection and Ranging) at high vertical resolution, called SNODAR, (Colin Bonner) and even a vertical profiler based on the measurements of the wavefront angle-of-arrival statistic (Julien Borgnino) were also discussed. Most of these instruments have been employed in recent years to characterise the first kilometre above several astronomical sites (Mt. Graham, Mauna Kea, Paranal, Cerro Tololo), providing fundamental results for the optimisation of many of the GLAO systems that are under feasibility study for existing facilities.

On the topic of surveys, we highlight the conclusions of the extended site-testing campaigns made by the Thirty Meter Telescope (TMT) group on a set of preselected sites around the world (Matthias Schoeck) and the presentation of preliminary results of a cross-correlation analysis between the results of many different optical instruments performed, at Paranal in December 2007 as part of the FP6 ELT Design Study (Marc Sarazin). Once more, the spatial coherence outer scale was confirmed to be a key astroclimatic parameter for astronomical sites (Aziz Ziad).

On the meteorological side, a very comprehensive description of a couple of European mesoscale atmospheric models, such as Meso-Nh (Non-hydrostatic Mesoscale atmospheric model) and AROME (Applications of Research to Operations at MEsoscale) were presented by Christine Lac, as well as the American Weather Research and Forecasting (WRF) model (Jordan Powers). A highlight was the description (Pierre Brousseau) of the state of the art of the Data Assimilation systems employed for mesoscale models. As explained previously, the performance of such models strongly depends on our ability to set the initial conditions in the most detailed way possible (that is, on the Assimilation Data).

Concerning the dynamical and optical turbulence simulations, considerable progress has been made in the last ten years. A key role in this section has been played by the ForOT activities (Masciadri). ForOT aims to continue the path undertaken by Elena Masciadri several years ago that led her to achieve many relevant results in this discipline and, in particular, to prove that a mesoscale model can reconstruct the optical turbulence above an astronomical site with an accuracy that is not worse than that achievable with measurements. Among the activities of this group, the interesting first simulations of the turbulence parameter C_N^2 above Antarctica, with good reliability of the model in statistical terms (Franck Lascaux), are highlighted. The main goal for this research group is to be a reference and support for observatories in developing turbulence prediction systems above astronomical sites. It is worth noting the creation of the Mauna Kea Weather Center, where astronomers hired meteorologists to make an operational forecasting system of the atmosphere above the Mauna Kea summit (Steven Businger). The general impression was that this research field is gaining interest among astronomers and this, once more, supports the thesis that it is time to boost actions to support benchmark site-testing campaigns, expressly conceived to validate the atmospheric model above astronomical sites, as proposed by the ForOT group.

There were several contributions aimed at the study of the correlation between OT and the meteorological parameters that frequently provide valuable inputs on the OT characteristics. On the topic of AO and interferometry, we report a few results concerning the implications for the turbulence constraints. In the field of MCAO, a detailed investigation of the limits of the validity of the Taylor hypothesis would provide useful insights on ways to improve the sensitivity of MCAO with natural guide stars (Roberto Ragazzoni). For GLAO systems, if the vertical structure of the turbulence decays sufficiently sharply above an astronomical site, GLAO systems in the visible can be applied over an extremely large field of view (Olivier Lai). We also discovered that new wavefront sensor concepts, such as the Differentiation Wavefront Sensor (WS), reported on by Eric Gendron, might be used to characterise the turbulence in a more efficient way than a Shack Hartmann. An exhaustive overview (Peter Wizinovich) depicted the main turbulence constraints as they depended on the type of astronomical target (Galactic, extragalactic and solar) and the observational technique.

Credit: P. Anio

Figure 2. Conference group picture taken in front of Capo Caccia, Porto Conte, Alghero, Sardinia beside a robotic Differential Image Motion Monitor (DIMM) automatic mount.

The final session was dedicated to science operations. The studies related to OT do have a direct impact on the implementation of the science operation models that make extensive use of queue scheduling or service observing. Several 8–10-m class telescopes currently implement one of two approaches:

1. Application of a singly administered queue mode observing system (as for ESO).

2. Application of a 'partner' queue mode observing system (as for the Large Binocular Telescope, LBT).

It is evident that the selection of the strategy is widely influenced by organisational issues (the single European agency in the former case, a consortium of a few institutes in the latter) and for this reason the absolute efficiency of a telescope is not the only criterion in selecting a given strategy. However it is certainly useful to quantify these efficiencies so as to be aware of what might be lost or gained through alternative solutions. On this topic Fernando Comeron noted that, currently at the VLT, a sizeable fraction of observations (~ 20 %) have to be repeated, because conditions strayed outside constraints during execution; this is an important, hidden source of inefficiency. It is therefore obvious that a tool for the prediction of the state of the atmosphere would definitely be a major step towards increasing the efficiency of the service mode at the VLT. Thus it appears evident that the goal of OT prediction on the timescale of a few hours in advance remains an important objective for observatory operations.

The closing discussion session evinced the success of the first step towards a productive collaboration between astronomers and meteorologists. The most evident feature of such a constructive interaction was the decision, promoted by the Principal Investigator (PI) of the E-ELT (Roberto Gilmozzi), to prepare a detailed document outlining the main steps necessary to prepare an efficient site-testing campaign benchmark test expressly conceived for the validation of mesoscale atmospheric models for application to astronomy. We are all confident that this document will represent the first step on a path that this conference has definitively and unequivocally charted.

References

Masciadri, E. 2006, SPIE Orlando, 62671C

Links

Conference programme and presentations:
http://forot.arcetri.astro.it/otam-08
ForOT website:
http://forot.arcetri.astro.it

Report on the Conference

Future Ground-based Solar System Research: Synergies with Space Probes and Space Telescopes

held at Portoferraio, Elba, Italy, 8-12 September 2008

Hans Ulrich Käufl[1]
Gian Paolo Tozzi[2]

[1] ESO
[2] INAF–Osservatorio Astrofisico di Arcetri, Firenze, Italy

An interdisciplinary workshop bringing together Solar System researchers, space mission engineers and scientists, ground- and space-based observers and theoreticians is summarised. The broad scope of the meeting covered current and future space missions, planned ground-based facilities and their closer interaction.

Figure 1. The workshop took place in the historic centre of the city of Portoferraio, dominated by the Renaissance fortifications erected in the 16th century under the reign of Cosimo I de Medici. The venue, near the centre of the photograph, is flanked to the left by a building of reddish ochre colour, to the right by a small church tower, and was originally commissioned as a barracks. It later became a monastery, but serves now as a cultural and congress centre (named after Cesare De Laugier), as well as a picture gallery (Pinacoteca Foresiana) and the city library (Biblioteca Comunale).

In a previous issue of *The Messenger* (Käufl & Sterken, 2006) there was a report of a dedicated workshop, co-sponsored by ESO and held in Brussels, in the context of NASA's Deep Impact space mission to comet 9P/Tempel 1. This comet had been the focus of an unprecedented worldwide long-term multi-wavelength observation campaign. Many participants at this workshop, looked beyond their direct involvement in the Deep Impact experiment, and frequently noted how useful it was to hold interdisciplinary workshops, which bring together Solar System researchers, those involved in spacecraft experiments, ground- and space-based remote observers and theoreticians. The idea of a similar meeting was born. Part of the programme of the Brussels workshop was a joint excursion to the battlefield at Waterloo, close to the conference venue. Standing at the monument there, some participants remarked how incredible it was that this battle took place only 100 days after Napoleon's escape from the island of Elba, and how difficult it often is these days to get anything going within a few months. Somehow this sparked the idea of the "Route Napoleon Reverse" that is to say, the next such workshop should happen on the island of Elba. Needless to say, it took us more than 100 days to organise it!

Fundamentally new observing platforms and space probes will become available for Solar System research in the coming decades. The Elba 2008 workshop provided a forum to discuss the use of these future facilities, and especially how to optimise the scientific returns and to establish synergies. It was particularly interesting to identify, or at least start the process of identifying, the potentially paradigm-shifting observations that will become possible with the next generation of large ground-based telescopes and their advanced instrumentation.

Among the various goals of the workshop, the fostering of collaborations between ground and space projects, such as those between ESO (ground) and ESA (space), was the primary goal. In general we sought to create synergies between research programmes at different wavebands into Solar System objects. For the ground-based projects the aims were to define the Extremely Large Telescope (ELT), and in particular the European ELT (E-ELT), science cases for the Solar System science and to refine the science case for the Atacama Large Millimeter/submillimeter Array (ALMA).

The topics that were specifically addressed during the meeting fall under the two headings of ground-based support for existing or planned space missions and new facilities for remote observations. There are missions to comets and asteroids (e.g., Rosetta, Dawn, Deep Impact and Stardust Wrap-up), to the outer Solar System planets and moons (e.g., Cassini–Huygens and New Horizons), to terrestrial planets and the Moon (e.g., Mars and Venus Express, Messenger and BepiColombo). In the ESA Cosmic Vision 2015–20 programme there are also expected to be a number of planetary missions. In the area of new facilities for remote observations the planned ELTs (E-ELT, Thirty Meter telescope [TMT] and Giant Magellan telescope [GMT]) were considered, as well as ALMA.

Following a first series of reviews and status reports on the major observing facilities, topical sessions were held on main belt asteroids, the giant planets, including their moons and magnetospheres, Trans-Neptunian Objects (TNOs), including Pluto, comets and the formation of the Solar System. A bridge was made from the study of our Solar System to the relatively new field of extrasolar planetary systems. We are starting to consider our Solar System as one of many possible planetary systems, or alternatively, our Solar System to be in range of extrapolation of current theories of star and planetary system formation. Our Solar System is also the yardstick that will define the characteristic observables when direct observations of extrasolar planets become feasible, with future facilities such as the E-ELT.

The detailed scientific programme of the meeting is available at *http://www.arcetri.astro.it/elba2008/*. The scientific scope ranged from the detection of the tenuous sodium atmospheres of Mercury and our Moon to the bio-signatures of extrasolar planets. The proceedings will be published in a special edition of *Earth, Moon and Planets*, with a target publication date in the first half of 2009.

In the conference summary, provided by Hermann Boehnhard, the following main conclusions were reached and agreed:

– Even the most advanced and sophisticated space missions that provide for *in situ* data need the complement of remote sensing data to place the observations in their wider scientific context.

– The Solar System inventory is far from complete and there is a strong need for more surveys. For the faintest objects a serendipitous occultation mode (e.g., involving telescope acquisition cameras) shows great promise.

– For the inventory of asteroid and cometary nuclei, systematic statistical studies of shapes, sizes, albedos and rotation will depend critically on ground-based telescopes as well as the James Webb Space telescope (JWST). The same conclusion holds for the study of their surface chemistry.

– Paradigm-changing observations can, for example, be expected in the field of planetary atmospheres. Currently the long-term stability of planetary atmospheres against erosion by solar UV radiation and particle flux is not understood; high resolution spectral and spatial observations may provide for fundamentally improved insights into the relevant processes.

– In order to achieve a synthesis between the observations and theory of extrasolar protoplanetary discs and our Solar System, more mineralogical data (e.g., mid-infrared low resolution spectroscopy) for primitive bodies in our Solar System are mandatory.

– European astronomers will be in the front seat for these research programmes, thanks to participation in ALMA and the instrumentation suite under study for the E-ELT (D'Odorico et al., 2008). For Solar System studies, the METIS instrument (Mid-infrared Imager and Spectrograph with Adaptive Optics) and EPICS (the Planet Imager and Spectrograph with extreme adaptive optics) are most relevant.

In a splinter session, some 20 participants also convened to form the kernel of a working group to complement the Science Case of the E-ELT with a special Solar System section. Follow-up activities of this group are being planned soon[1].

References

D'Odorico, S. et al. 2008, SPIE, 7014, 70141
Käufl, H.U. & Sterken, C. 2006, The Messenger, 126, 48

[1] Anyone wishing to join this group can contact either of the authors by e-mail: *hukaufl@eso.org* or *tozzi@arcetri.astro.it*

Report on the ALMA Workshop

Simulations for ALMA

held at IRAM, Grenoble, France, 8–10 September 2008

Bojan Nikolic[1]
John Richer[1]
Frédéric Gueth[2]
Robert Laing[3]

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[3] ESO

A workshop on Simulations for ALMA was held on 8–10 September 2008 at IRAM. About 40 participants from Europe, North America and Japan attended, and discussed many aspects of ALMA imaging: topics included detailed scientific simulations of astronomical observations together with more technical simulations of instrumental and atmospheric effects and the strategies for their correction. The workshop web page contains the presentations made at the meeting and is available from http:*//www.mrao.cam.ac.uk*.

Construction of the Atacama Large Millimeter/submillimeter Array (ALMA) in northern Chile is proceeding rapidly. The majority of the hardware design is complete, and in many cases full production is underway. Eleven antennas have already been delivered to the mid-level site, the Operations Support Facility (OSF), near San Pedro de Atacama. With interferometric fringes expected next year, now is a good time to revisit in detail the plans for ALMA data analysis to ensure that ALMA scientists have the necessary tools both to develop their scientific observing programmes with ALMA and produce the best possible datasets for scientific analysis.

Extensive work is being done in many of the ALMA partner countries to develop

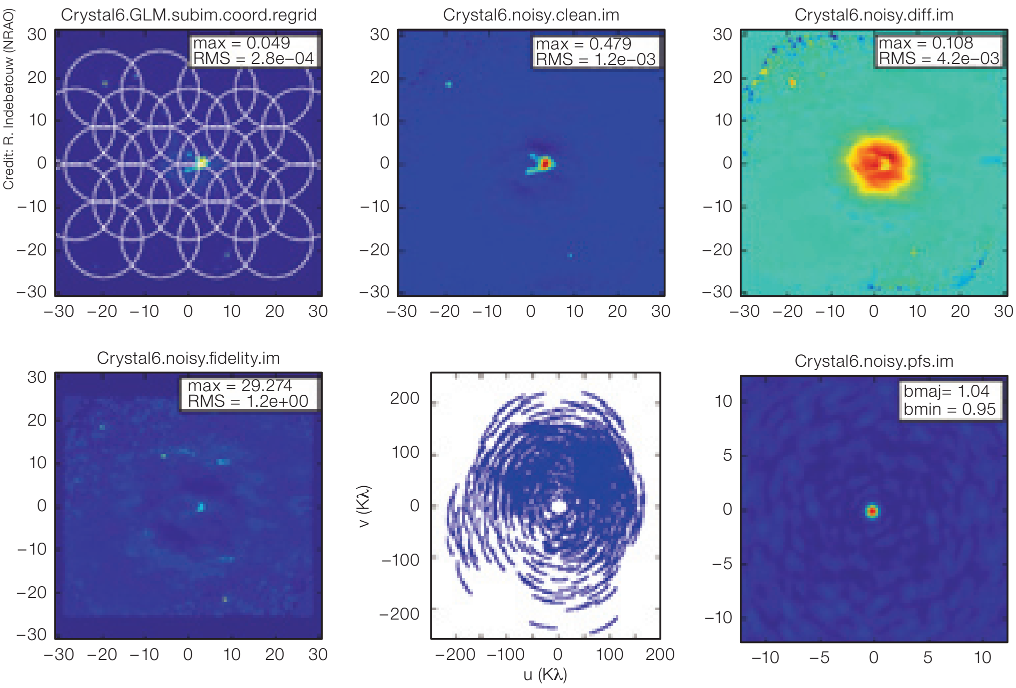

Figure 1. An example diagnostic output produced by *almasimmos* (the CASA simulator for ALMA) for a mosaic ALMA observation in one of the compact configurations at the frequency of 345 GHz.

the software required for data taking, data analysis and simulation. In the absence of a working ALMA interferometer, simulations play an important role in understanding how to optimise ALMA's performance. For example, simulations allow us to quantify the effects of errors caused by the atmosphere, by pointing errors or antenna surface errors. They also help us develop techniques for calibrating and imaging ALMA data. In addition, the realistic simulation of models of astrophysical objects — for example protoplanetary discs and high redshift galaxies — allows the scientific community to develop observing programmes for ALMA.

ALMA is an interferometer with many unique features. Its 66 antennas come in two sizes, 12 m or 7 m in diameter, and can be moved to any of the 200-plus pads on Chajnantor. They work at very high frequencies, so that the primary beams are imperfect, and the atmospheric phase errors are large. Pointing errors caused, for example, by wind shake can be significant at times. As expected, a great deal of effort has gone into simulations, especially in the early design years of the project, to ensure that the technical specifications of ALMA are good enough to meet the ambitious scientific goals.

The focus for this year's workshop, held at the headquarters of the Institut de Radio Astronomie Millimétrique (IRAM) in Grenoble was to bring together all the different groups worldwide working on different aspects of ALMA simulation software, to assess recent progress and help plan future software developments. The meeting was generously supported by Radionet and by IRAM.

Four of the major packages used for ALMA simulations were presented at the meeting. The CASA simulator for ALMA (*almasimmos*) was presented by R. Indebetouw of NRAO. The simulation capabilities of GILDAS were presented by F. Gueth of IRAM. F. Viallefond of LERMA presented the simulator that he has been designing in collaboration with J. Pardo; and M. Wright of Berkeley presented the simulation capabilities of the MIRIAD package.

Of the four, the package most targeted toward non-expert users is *almasimmos*, which also has the advantage of being a part of the official ALMA offline data reduction tool (CASA). A sample screenshot of *almasimmos* output is shown in Figure 1, illustrating the simulation of a mosaic ALMA observation. In common with CASA, *almasimmos* is still under active development and in a beta-testing stage only. With this *caveat* it is, however, available for use and testing by the entire community as part of the CASA beta release, which may be downloaded at *http://casa.nrao.edu*.

Also in the session on simulators, there were presentations by A. Richards from the University of Manchester on integration of simulations with the Virtual Observatory (VO) and by R. Lucas from the Joint ALMA Office, who presented the ALMA Shared Simulator, which is designed to simulate the detailed online operation of ALMA as a system.

In the session on science simulations, S. Takakuwa of ASIAA presented simulations of low mass star-forming regions and debris discs, illustrating the improvement in imaging fidelity provided by the ALMA Compact Array (ACA). M. Wyatt from the University of Cambridge presented exciting simulations based on physical models of debris discs as observed with ALMA at high resolution. E. van Kampen of the University of Innsbruck presented large-scale galaxy formation simulations and discussed their relevance to ALMA observations. I. Heywood from the University of Oxford also presented large-scale semi-empirical simulations designed primarily for the

Square Kilometer Array (SKA), but including both mm-wavelength spectral lines and radio continuum.

We also had a session on algorithms and the use of simulations to optimise these. M. Wright discussed the degradation in image fidelity due to deviations of antenna primary beams from their canonical shape and on the technique to correct this effect by deconvolution of the measured primary beam shape. N. Rodriguez Fernandez from IRAM presented the progress of the work being done under EU Framework Programme 6 (FP6) to develop on-the-fly interferometric observations for ALMA. The subject of combining interferometric and single dish data was analysed by Y. Kurono from the University of Tokyo and he presented simulations based on data from the Nobeyama Millimetre Array and the 45 m single dish telescope. Lastly, B. Nikolic presented some work done under FP6 at the University of Cambridge on simulations of atmospheric phase errors and their correction by a combination of fast-switching and water-vapour radiometry.

The final session at the workshop was on the configurations of ALMA and the impact of having 50 rather than 64 antennas in the main array. M. Holdaway (formerly at NRAO, and now running Kalimba Magic) discussed the effects of the antenna number reduction on calibration techniques (and also gave an impromptu kalimba performance). R. Reid of NRAO then presented his investigation of proposed improvements to ALMA's intermediate configurations (those with baselines about 4–10 km in length). This was followed by an open discussion on the scientific impact of the suggested configuration changes.

No proceedings of the workshop will be published, but all of the presentations are available at *http://www.mrao.cam.ac.uk*.

Links

Workshop webpage:
http://www.mrao.cam.ac.uk/~bn204/almasim08/
CASA beta release:
http://casa.nrao.edu/betarelease.shtml
Workshop presentations:
http://www.mrao.cam.ac.uk/~bn204/almasim08/presentations2008.html

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Report on the Conference

400 Years of Astronomical Telescopes

held at ESTEC, Noordwijk, the Netherlands, 29 September–2 October 2008

Bernhard Brandl
Remko Stuik
Leiden Observatory, the Netherlands

Four hundred years ago, on 25 September 1608, the Dutch lens maker Hans Lipperhey from Middelburg traveled to The Hague to apply for a patent for his invention: the "spyglass". The Commander in Chief of the Dutch armed forces, Prince Maurice of Nassau, was quite impressed. However, since the instrument could be easily copied, Lipperhey was not granted the patent. Nevertheless, he was generously rewarded and two more copies of his invention were ordered. Lipperhey's spyglass constitutes the basis for the development of astronomical telescopes.

To celebrate this event and the resulting developments, Leiden Observatory, in cooperation with ESTEC, recently organised an international meeting entitled "400 Years of Astronomical Telescopes". The meeting took place from 29 September–2 October 2008 at the ESTEC conference centre.

The goal of the meeting was to present a comprehensive coverage of the history, science and technology of 400 years of astronomical telescopes in a wider sense, provided exclusively as review talks by invited speakers. Although the classical telescope was an optical instrument, the topics covered the entire electromagnetic spectrum. The audience of about 130 participants — who were noticeably more senior than at most topical science meetings — included many key players in the creation of the current generation of telescopes (see Figure 1). Many of them contributed their own memories and perspectives to the meeting, frequently leading to very interesting coffee and dinner table discussions.

The meeting started with the historical development of optical telescopes, from the beginnings in Middelburg via Galilei, Newton, Herschel and Lord Rosse to the great refractors of the 19th century, and the big reflectors of the 20th century. After a review of optical astronomical instruments the focus shifted to longer wavelengths, covering the history of infrared and radio telescopes.

The second day was — apart from an intermezzo on solar telescopes — dedicated to non-optical telescopes, from Riccardo Giacconi's talk on X-ray telescopes to reviews of gamma-ray and imaging TeV telescopes and neutrino detectors. Miscellaneous aspects, like the history of astronomical discoveries, the improvement of astrometric accuracy, the capabilities of amateur telescopes, and the history of the Hubble Space Telescope by Robert O'Dell, followed. The second day was concluded by Reinhard Genzel's talk, illustrating the feedback between technological developments and scientific discoveries relating to the Galactic Centre.

The third day started with the key enabling technologies for optical telescopes, from mirror casting and polishing, active optics and telescope design considerations to adaptive optics and interferometric techniques. The second part reviewed the technological developments that enabled submillimetre and radio astronomy, and the realisation of X-ray and gamma-ray telescopes. The session was complemented by a poster session and a visit to the Herschel Space Telescope. The interplay between technological developments, society and politics was highlighted in the next session, which included Lo Woltjer's talk on "ESO's Past and Future" and a stimulating plan to use telescopes to harvest solar energy by Roger Angel.

How embedded in, and dependent on, their surrounding infrastructure astronomical observatories really are became obvious on the last day of the conference, during the talks on the "Sacred Mountains", Mount Graham and Mauna Kea, on the increasing problem of light pollution, and on the role of observatories in underdeveloped countries. Talks on measures of the impact of publications, "very big science", the history of NASA's Great Observatories and perspectives for future technologies completed the programme of the last day. The meeting was concluded by Tim de Zeeuw's talk on "Challenges and Perspectives for Future Telescopes".

The social programme included three events: a welcome reception at ESA's Space Expo, a visit to the impressive collection of historical telescopes at the Museum Boerhaave in Leiden, and a dinner cruise along the Dutch canals. Certainly one of the most memorable and unique events was the get-together of five of the former and present ESO Directors General: Adriaan Blaauw, Lodewijk Woltjer, Harry van der Laan, Riccardo Giacconi and Tim de Zeeuw (see Figure 2). Being present throughout the meeting they contributed heavily to the discussion, in particular after Lo Woltjer's talk on the history of ESO.

The proceedings of the conference will be published in a hardcover book by Springer in early 2009, and will be a great memory for those who attended the meeting, as well as a great resource for all those who missed this unique event. More details on the meeting can be found at *http://www.strw.leidenuniv.nl/400years/*.

Credit: Carolina Ödman (Leiden Observatory)

Figure 1. Participants at the conference, 400 Years of Astronomical Telescopes.

Credit: Carolina Ödman (Leiden Observatory)

Figure 2. Five ESO Directors General at the conference. From right to left: Tim de Zeeuw (2007–present); Adriaan Blaauw (1970–1974); Riccardo Giacconi (1993–1999); Lodewijk Woltjer (1975–1987); and Harry van der Laan (1988–1992). The VLT background was provided by Fred Kamphues (TNO).

Announcement of the ESO–Porto Conference

Towards Other Earths: Perspectives and Limitations in the ELT Era

19–23 October 2009, University of Porto, Portugal

The conference on the theme of the search for extrasolar planets is being jointly organised by the Center for Astrophysics, the University of Porto (CAUP) and ESO. To enable the discovery of other Earths, a new generation of instruments and telescopes is now being conceived and built by different teams around the world. This includes a new generation of Extremely Large Telescopes (ELTs). Thanks to the diameter of their primary mirrors, the detection of Earth-mass planets is expected to be within reach of these ELTs.

In parallel, a new generation of instruments for the current 8–10 m class facilities is being planned. This new cutting-edge suite of instruments includes high angular resolution adaptive optics (AO) imagers, microarcsecond astrometry with interferometers and ultra-stable spectrographs at the cm/s level. The synergy of these facilities with space-based observatories will play a key role in the discovery of Earth-mass planets.

What are the requirements that this instrumentation will have to match to allow us to find other Earths? Do we know how to calibrate the instruments to achieve such a precision and stability? Equally important are the limitations imposed by intrinsic astrophysical phenomena such as stellar activity, granulation or oscillations. Are we preparing ourselves to deal with and to correct for these effects? What are the ultimate limitations of the different techniques mounted on ground- or space-based facilities? We want to gather together the community of planetary astronomers and instrumentalists working on the field to:

- review the current status of the search for telluric exoplanets, and present our understanding of their formation;
- discuss the implications of their main physical properties at the detection limits of different techniques;
- draw a coherent picture of the technical and physical issues that we have to solve in this fabulous endeavour of finding and characterising other Earths.

The conference will give particular emphasis to the contributions from the upcoming generation of ELTs to this task of finding and characterising other Earths. In addition to invited talks, contributed papers (oral or poster) can be presented. The SOC will select a limited number of contributions for oral presentation on the basis of the submitted abstracts.

The conference will take place in the town of Porto (Oporto in English), which is the second largest town in Portugal. It is located on the estuary of the River Douro, facing the Atlantic. The city is about 300 km north of the capital (Lisbon), and is renowned for its famous Port (Porto) wine. The beauty of this area is acclaimed and it is a UNESCO World Heritage Patrimony Site. Porto's historic centre was classified by UNESCO as a World Cultural Heritage site in December 1996.

Registration will open in January 2009. More details are available at *http://www.astro.up.pt/investigacao/conferencias/toe2009* or by sending an e-mail to *toe2009@astro.up.pt.*

Announcement of the

EIROforum School of Instrumentation (ESI)

11–15 May 2009, CERN, Geneva, Switzerland

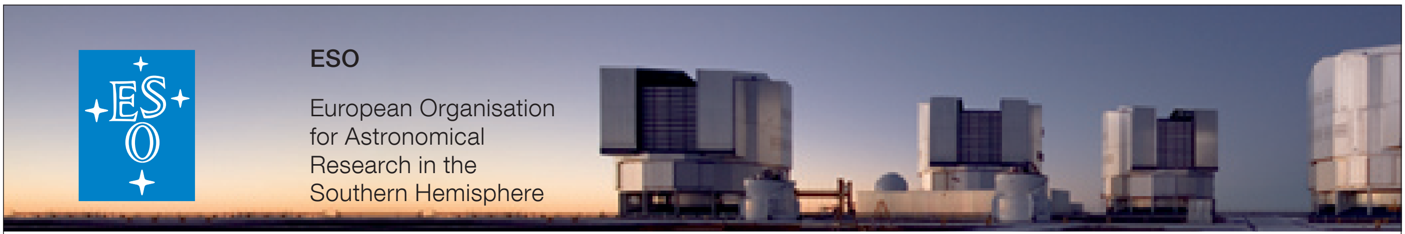
The EIROforum Schools on Instrumentation are held bi-annually and are jointly organised by the seven EIROforum organisations. The scientific programme of ESI addresses all aspects of instrumentation related to the missions of EIROforum.

The main objective of ESI is to teach the basic principles of instrumentation to young researchers, scientists and engineers, mainly from the EIROforum organisations. A fraction of the places will be reserved for particularly talented PhD students not directly connected with EIROforum who work on instrumentation topics.

The school covers the following topics:

- Principles of radiation detection and detector technologies
- Introduction to detector electronics and data acquisition
- Detector systems and techniques for high energy physics
- Experimental setups, optics and detectors for neutrons and synchrotron radiation applications
- Space- and ground-based instrumentation for astronomy
- Control, dosimetry and detection in fusion experiments
- Radiation hardness of detection systems and electronics

For further details please visit the web page *http://www.cern.ch/eiro-school.*



ESO ALMA Fellowship Programme

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 between young astronomers and the activities and staff at one of the world's foremost observatories.

With ALMA becoming operational in a few years, ESO offers additional ALMA Fellowships — funded by the Marie-Curie COFUND Programme of the European Community — to complement its regular fellowship programme. Applications by young astronomers with expertise in mm/sub-mm astronomy are encouraged.

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 2009. Young scientists from all astrophysical fields are welcome to apply.

The selected candidates may choose to work at one of the European institutes hosting an ALMA Regional Centre node (Bologna, Bonn, Grenoble, Leiden, Mancester, Onsala) or at ESO in Garching.

Fellowships start with an initial contract of one year followed by a two year extension (three years in total). In addition to the excellent scientific environment that will allow them to develop their scientific skills, as part of the diverse training ESO offers, Fellows are encouraged to participate 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.

The closing date for applications is 31 January 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 (refereed) publications;

– your proposed research plan (maximum 2 pages);

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

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

Please also read our list of FAQs regarding fellowship applications.

Questions not answered by the above FAQ page can be sent to:
Paola Andreani, Tel +49 89 320 06-576, Fax +49 89 320 06-898, e-mail: *pandrean@eso.org*

Daniel Enard 1939–2008

Martin Cullum
ESO

Daniel Enard died in Paris on 2 August 2008 at the age of 68 following a serious illness. He made a major contribution to ESO over the many years he served the Organisation and is considered by many as the technical father of the Very Large Telescope project.

Daniel graduated at the École Supérieure d'Optique in Paris in 1963 and completed his doctoral thesis in 1965. After spending eight years working for the Optical Division of Matra, he joined the ESO Telescope Division in Geneva as an Optical Engineer in the Ray Wilson's group in February 1975. Although the 3.6 m telescope was well advanced at that time, the instrumentation programme was seriously delayed. So after the arrival of Lo Woltjer as Director General, Daniel contributed to an updated instrumentation plan for the 3.6 m telescope and the Coudé Auxilliary Telescope (CAT). In the following years he played a key role in the development and commissioning of the Coudé Echelle Spectrometer (CES), which remained the only high dispersion instrument of this facility.

After ESO moved into the new headquarters building in Garching in September 1980, Daniel took over the leadership of the Instrumentation Group and initiated the development of several new instruments for the 3.6 m telescope. These included CASPEC, IRSPEC, OPTOPUS and EFOSC, which were all highly innovative instruments at that time. IRSPEC was ESO's first cooled-grating infrared spectrograph and OPTOPUS used fibre optics to enable a classical slit spectrograph to be used for multiple-object spectrometry. EFOSC was a very efficient multi-mode instrument that employed refractive optics. Daniel was among the first to recognise that new optical glasses enabled refractive solutions that were far more compact, more efficient and also cheaper than conventional Schmidt camera systems.

In June 1983, a VLT Project Group was set up under Daniel's leadership. In this role, his broad understanding of optics and general engineering disciplines enabled him to steer the VLT project through its difficult conception phase, in which the many different wishes from the ESO community were weighed and evaluated, toward the pioneering, but solid engineering, concept that was finally approved by the ESO Council in 1987. Fundamental to the whole VLT concept was the application of the active optics that Ray Wilson had so successfully applied to the NTT, but in a much more extreme form. This was a bold decision, which proved to be fully justified after the implementation by Lothar Noethe and colleagues.

In June 1996 Daniel was seconded to the VIRGO gravitational wave detector project at Cascina near Pisa where he served as Technical Manager. After the creation of the European Gravitational Observatory (EGO) in December 2000, Daniel became the Deputy Director of this organisation. Daniel retired from EGO at the end of December 2003, shortly after the project had been successfully inaugurated.

However, this was not the end of Daniel's involvement with ESO. After the 100 m OWL telescope concept design review in November 2005, Daniel was appointed Chair of the ELT Design Working Group and later, in March 2006, he chaired the ELT Science and Engineering Committee (ESE) that advises the ESO Council on the E-ELT project and now oversees Phase B of the programme. As for the VLT project some 25 years earlier, this was a critical period for the E-ELT due to the diversity of views within the European astronomical community on which concept should be selected. Daniel's broad experience and calm approach was fundamental to the eventual adoption of the novel five-mirror concept at the European ELT Workshop that was held in Marseille in November 2006. He continued chairing the ESE committee until the beginning of 2008 when illness prevented him from continuing.

Daniel will be missed and remembered by many friends and colleagues at ESO, not only for his technical knowledge and insight, but also for his open and generous personality that was greatly appreciated by all who worked with him.

He leaves a widow, two daughters and five grandchildren.

New Staff at ESO

Rodrigo Parra

Rodrigo Parra

As a young boy I was mystified by those enigmatic and persistent "clouds" in the night sky of my beloved Valparaiso. I will neither forget, nor be able to describe, the striking feeling I had while reading about the real nature of the Magellanic Clouds in the very first astronomy book I ever owned (*Astronomia* by José Comas Solá). My interest in astronomy grew at a steady rate. Many years passed. During a visit to La Silla while studying electrical engineering, I saw a long-haired (and bearded) astronomer walking barefoot towards a small white dome. I remember thinking to myself something like, "Wow, what a cool job!"

I graduated and started working in industry. After one year, I decided to obtain an MSc in digital/microwave communications in Chalmers, Sweden. Just as I was writing my master's thesis, I had the opportunity to meet John Conway and work with him on a thesis about interstellar masers (disguised as a telecommunications thesis). I was assigned to a small office at the Onsala Rymdobservatorium, which eventually became my second home for about five years, until I received a PhD in radio astronomy under John's supervision.

I am deeply interested in the study of the possible evolutionary connections between AGN and starburst activity. One of the questions guiding my research is whether or not the 100-parsec-sized regions of starburst activity we see in external galaxies are scaled-up versions of Galactic star-forming regions. If not, what makes them different? I have studied star formation and AGN activity using cm-wavelength VLBI observations of large samples of galaxies, as well as deep cm- and mm-wavelength interferometry of single objects. Over the years I have gathered much experience in both the theoretical and practical aspects of the interferometric techniques that are my principal research tools.

In 2007 I returned to Chile as a postdoc at Pontificia Universidad Catolica. I taught a radio astronomy course and gave a few theoretical seminars about interferometry. Additionally, I worked in parallel as the CONICYT support astronomer for the APEX telescope where my main duties were to plan and conduct the observations of Chilean projects. In this position, I was lucky enough to have a free "test-drive" of the job before joining ESO as an APEX staff astronomer. I must say I completely fell in love with the Sequitor base and the overwhelming beauty of the "white lady" (our VERTEX dish) dancing against the immaculate sky of Chajnantor. I must say also that the operation of the APEX telescope is particularly challenging (and tricky), due to the experimental nature of the project itself. But the reward is priceless: the assortment of installed instruments combined with the outstanding site allows discoveries to be made almost every day.

Faviola Molina

Not feeling totally a foreigner in Chile, I arrived in this exciting country in March 2006, when I started postgraduate studies at the Pontificia Universidad Catolica de Chile. As student I enjoyed my first two and a half years in Chile, sharing great experiences with the people I worked and studied with.

When I was a five years old my big brother began to encourage me to watch astronomical TV programmes. I was surprised about how many things can be found 'outside', and how they work. I was born in Mérida, Venezuela. I studied physics at the Universidad de Los Andes, situated in the same beautiful city where I was born. At the end of my undergraduate studies, I joined the Centro de Investigaciones de Astronomía (CIDA) to start my thesis project. The subject was modelling the emission line spectra of star-forming galaxies.

I have been always interested in observational astronomy. So, at the same time as I was developing my undergraduate thesis, I started to work as a service mode observer at the Observatorio Nacional Llano del Hato, the observatory closest to the equator, and managed by CIDA.

After I obtained a BSc in physics, I moved to Chile and obtained an MSc in astronomy and astrophysics from the Pontificia Universidad Catolica de Chile. My thesis there was about modelling the mass-luminosity ratio and chemical enrichment in galaxies, considering the impact of the integrated stellar IMF.

I joined ESO in September 2008 and work as a support astronomer at La Silla.

Faviola Molina

Fellows at ESO

Daniel Kubas

Daniel Kubas

My journey to the Atacama desert started quite a while ago. When I learned from my parents that what I was referring to as the "big lamp", was a celestial companion called "the Moon" and was not in fact shining itself, but only reflecting the light from the "truly big lamp", the Sun, I became more curious about what was going on up there in the skies above Berlin. Thanks to the supply of books from Jules Vernes, television shows from Carl Sagan and films in which the Earth stood still, or featuring people from a planet called Vulcan, I held on to this curiosity. Eventually I started studying physics at the Technical University of Berlin, spending a year (1998) at the University of Melbourne and finishing at the University of Potsdam (2005).

Finally, in March 2006, I had the privilege of joining the ESO team serving the astronomical community as support astronomer in Paranal. I had spent a lot of nights before on telescopes, but none as clear and long as the ones in the Martian-like Atacama desert. Apart from being an out-of-this-world place, what strikes me most, is the dedication and enthusiasm of the people working there. No matter the time of the day you always find a helping hand with a smile. However ESO is much more than an observatory. The science life at ESO Vitacura — last, but not least, thanks to new impulses given by the recently arrived Head of Science Michael West — offers an attractive mix of talks ranging from passing high profile experts from all fields, to specialised seminars organised by local staff, fellows and students.

So my decision to spend my last off-duty fellow year (starting in March 2009) outside ESO was certainly not easy, but the temptation to exchange the starry lights for the city lights of the Institute d'Astrophysique de Paris, where a strong team in my favourite field of research (the hunt for exoplanets using microlensing) is forming, was too big. However I will surely stay in contact with my ESO colleagues and friends and, who knows, may be back some day or some night.

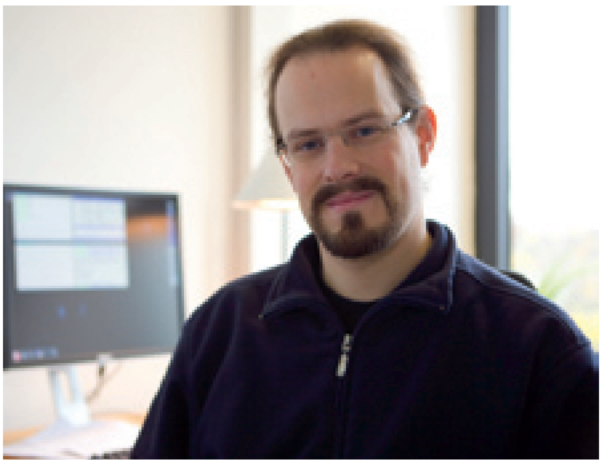
Jörg Dietrich

I am one of those astronomers who became enchanted with astronomy very early in their lives. My parents tell me that shortly after my fascination with astronomy started, at the age of five, I declared that I wanted to become an astronomer, a goal I have pursued ever since.

I studied physics and astronomy at the University of Bonn and the University of Tennessee, Knoxville, and obtained a masters degree in physics in Bonn in 2002. After that I joined ESO for the first time, working for the ESO Imaging Survey for one year. I then returned to Bonn to work on my PhD, which I obtained in 2006, two months before starting my ESO fellowship.

My work focuses on studying galaxy clusters, the cosmic web, and the determination of cosmological parameters. My tool of choice is weak gravitational lensing, a technique that has fascinated me ever since I first heard about it in a lecture course in 2000. During my fellowship I have mostly worked on comparing weak-lensing mass estimates of galaxy clusters to those obtained with other methods, and developing new statistics to constrain cosmological parameters with upcoming imaging surveys. Garching, with its unique conglomeration of astronomical institutes, is a near-perfect environment for my science and some of my projects could not have been realised without the close collaborations of colleagues at ESO's neighbouring Max-Planck Institutes.

For my functional work at ESO I joined the ESO Survey Team, which oversees the preparation and, eventually, the execution of ESO public surveys with the upcoming VISTA and VST facilities. Since my research is based on large imaging surveys, my functional work is a perfect match to my science interests.



Jörg Dietrich

ESO at the European City of Science

Henri Boffin, Ed Janssen and
Hännes Heyer
ESO

Credit: Pascal Blondé (OBSPM)

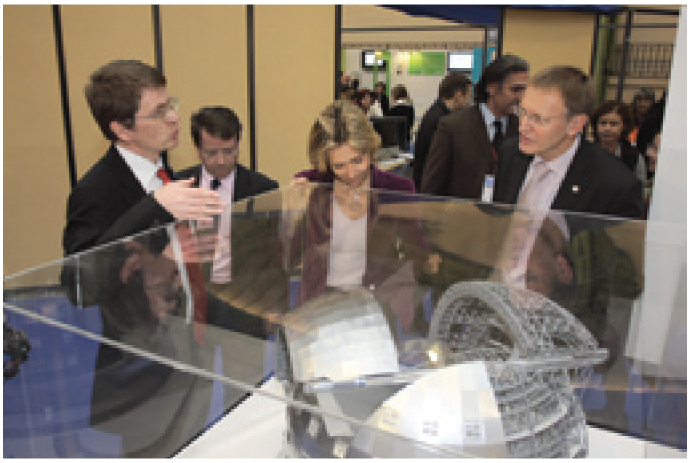


Figure 1. Henri Boffin from ESO (left) explaining the model of the dome for the European Extremely Large Telescope to Valérie Pécresse, the French Minister of Higher Education and Research (centre) and Janez Potočnik, the European Commissioner for Science and Research (right).

To mark the French Presidency of the Council of the European Union, the French Ministry of Higher Education and Research decided to create a European City of Science in one of most magnificent historical buildings in Paris, the Grand Palais, on 14–16 November.

In this impressive setting, the European City of Science paid host to more than 42 000 visitors — some queuing for up to two hours to enter — all taking the opportunity to learn how the European Research Area does its work. Not only schoolchildren of all ages, but also adults, could learn about scientific and technical culture with the help of guides taking them to meet research scientists from every country in Europe. The scientific and technological perspectives were presented through the outcomes and inventions produced by the research.

The scientific community had enthusiastically rallied round the realisation of the European City of Science. Over 200 organisations (80 from countries in the European Union other than France) expressed their interest in taking part in this event by answering a call for project proposals issued by the ministry. A scientific committee selected the final 80 proposals (including 20 from other countries in the European Union) that were presented.

ESO was present, in a joint venture with several French research partners: CEA Service d'Astrophysique; Observatoire de Paris; Institut d'Astrophysique de Paris; Laboratoire d'Astrophysique de Marseille and the Centre de Recherche Astrophysique de Lyon.

The stand occupied by ESO and its partners was a 130 m^2 'astronomy dome', entitled "From the VLT to the E-ELT: Europe, a Window on the Universe". It showcased most current astronomical themes, from life in the Universe to black holes and dark energy, as well as the crucial role played by Europe in these areas, with particular emphasis on ESO's Very Large Telescope (VLT) and its plan to build the biggest 'eye' on Earth, the 42-metre European Extremely Large Telescope (E-ELT).

Numerous short presentations on a wide variety of topics made by astronomers from our partner institutes were an important component of the stand. These presentations drew a very large crowd throughout the three days. ESO's presence at the European City was very much appreciated both by the public and the media, and the E-ELT was showcased in the special Euronews report on the event. Moreover, we had the pleasure of welcoming the French Minister of Higher Education and Research, Valérie Pécresse, together with the European Commissioner for Science and Research, Janez Potočnik. If there is a building that can compete with the magnificent Grand Palais, it is the planned E-ELT!

ESO and the International Year of Astronomy 2009

Douglas Pierce-Price, Pedro Russo and
Lars Lindberg Christensen
ESO

As many readers already know, the International Astronomical Union (IAU) launched 2009 as the International Year of Astronomy (IYA2009) under the theme "The Universe, Yours to Discover". IYA2009 marks the 400th anniversary of the first astronomical observations through a telescope, by Galileo Galilei. After many years of preparation, we are ready for an amazing year full of discovery and wonder. ESO has played a major role in this project since planning began in 2003.

ESO is hosting the IAU's IYA 2009 Secretariat, which coordinates the Year globally. ESO is also one of the Organisational Associates of IYA2009, and was closely involved in the resolution submitted to the United Nations by Italy, which led to the UN's 62nd General Assembly proclaiming 2009 the International Year of Astronomy.

ESO IYA2009 projects and activities

There will be a range of ESO-specific activities throughout the year, some of which are described here.

"In search of our Cosmic Origins" is a planetarium show about ALMA. The show is being produced by ESO and the Association of French Language Planetariums in collaboration with the Planetarium of Augsburg.

In collaboration with the IAU, ESO has produced a book and DVD movie celebrating the 400th anniversary of the telescope. "Eyes on the Skies" explores the story of the telescope — its history, scientific and technical advances, and the people behind this ground-breaking invention.

A wide range of activities and projects for IYA2009 in Chile is planned, including a planisphere, "Science Cafés", a night-sky photo book, a network of schools revisiting classical science experiments, a permanent astronomical exhibition at the Museum of the Desert in Antofagasta, and an Open House at Paranal, La Silla, and APEX/ALMA.

ESO will also participate in a number of activities at its headquarters in Garching, Germany, including the Open House day on the Garching campus, planned for 24 October 2009.

ESO will be featured at several exhibitions during IYA2009, including the global IYA2009 opening ceremony at UNESCO in Paris, and the German IYA2009 opening event in Berlin.

IYA2009 Global Cornerstone Projects at ESO

In addition to its ESO-specific activities, ESO is involved in many of the IYA2009 Global Cornerstone Projects, and is playing a leading role in three of them.

"100 Hours of Astronomy" (2–5 April 2009) is a worldwide event bringing together star parties, webcasts, and more. ESO is coordinating a 24-hour webcast from research observatories around the world.

In "Cosmic Diary", professional scientists will put a human face on astronomy through blogs. The project is coordinated from the IYA2009 Secretariat at ESO, and 16 of our researchers are participating in the project's ESO blog.

The "Portal to the Universe" seeks to provide a global, one-stop portal for online astronomy content, for content providers, laypeople, press, educators, decision-makers and scientists. ESO, together with ESA/Hubble, is providing the portal infrastructure.

For more about ESO in IYA2009, visit: *http://www.astronomy2009.eu/* or contact *information@eso.org*.
For IYA2009 in general visit: *http://www.astronomy2009.org/* or contact the IYA2009 coordinator, Pedro Russo (*prusso@eso.org*)

Personnel Movements

Arrivals (1 October–30 December 2008)

Europe	
Dall, Thomas (DK)	User Support Astronomer
Suarez Valles, Marcos (ES)	Software Engineer
Jeanmart, Kristel (BE)	Administrative Assistant
Dinjens-D'Lazarus, Mary (NL)	Administrative Assistant
Wild, Wolfgang (DE)	European Project Manager ALMA
van Kampen, Eelco (NL)	Applied Scientist
Schmid, Christian (DE)	Physicist
Saint-Hilaire, Valérie (FR)	Administrative Assistant
Todorovic, Mirko (BA)	Electronics Technician
Venemans, Bram (NL)	Fellow
Teixeira, Paula Stella (PT)	Fellow
Klaassen, Pamela (NL)	Fellow
Béchet, Clémentine (FR)	Optical Engineer
Meil, Betül (DE)	HR Officer
Villegas Mansilla, Daniela (CL)	Astronomer
Schneller, Dominik (DE)	General Engineer
Geeraert, Patrick (BE)	Head of Administration
Jaffe Ribbi, Yara Lorena (VE)	Student
Frank, Matthias (DE)	Student
Seemann, Ulf (DE)	Student

Chile	
Smoker, Jonathan (GB)	Operations Astronomer
Dent, William (GB)	Systems Astronomer
Cabrera, Claudio (CL)	Civil Engineer
Serrano, Guido (CL)	Procurement Officer
Thomas, Alexis (CL)	Network Specialist
Abadie, Sergio (CL)	Maintenance Technician
Leon, Gino (CL)	Telescope Instruments Operator
Moerchen, Margaret (USA)	Fellow
Huertas-Company, Marc (ES)	Fellow
Lombardi, Gianluca (IT)	Optical Engineer
Montenegro-Montes, Francisco M. (ES)	Operations Astronomer
Zorotovic, Monica (CL)	Student
Gallenne, Alexandre (FR)	Student

Departures (1 October–30 December 2008)

Europe	
Haggouchi, Karim (FR)	Software Engineer
Pangole, Eric (FR)	System Engineer
Rudolf, Hans (DE)	System Engineer
Mengel, Sabine (DE)	User Support Astronomer
Gustafsson, Birger (SE)	Software Engineer
Sivertsen, Beatrice (DE)	Secretary/Assistant
Toft, Sune (DK)	Fellow
Felber, Nina (DE)	Paid Associate
Araujo Hauck, Constanza (CL)	Optical Engineer
Wilson, Thomas (USA)	Director for ALMA
Malapert, Jean-Christophe (FR)	Software Engineer
Correia Nunes, Paulo (PT)	Software Engineer
Sommariva, Veronica (IT)	Student
Brogaard, Karsten (DK)	Student
Shen, Zhixia (CN)	Student
Gobat, Raphael (CH)	Student
Karovicova, Iva (CZ)	Student

Chile	
Durand, Yves (FR)	Head of Engineering Department
Arenas, Eduardo (PE)	Procurement Officer
Nuñez, Herman (CL)	Technical Drawer
Gonzalez, Domingo (CL)	Waiter
Garnica, Sonia (CL)	Guesthouse Supervisor
Risacher, Christophe (FR)	Instrument Scientist
Cesetti, Mary (IT)	Student
Pinto Moreira, Olga (PT)	Student
Salinas, Ricardo (CL)	Student

ESO is the European Organisation for Astronomical Research in the Southern Hemisphere. Whilst the Headquarters (comprising the scientific, technical and administrative centre of the organisation) are located in Garching near Munich, Germany, ESO operates three observational sites in the Chilean Atacama desert. The Very Large Telescope (VLT), is located on Paranal, a 2 600 m high mountain south of Antofagasta. At La Silla, 600 km north of Santiago de Chile at 2 400 m altitude, ESO operates several medium-sized optical telescopes. The third site is the 5 000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a new submillimetre telescope (APEX) is in operation, and a giant array of submillimetre antennas (ALMA) is under development. 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: Colour image of the H II region and active star-forming region NGC 2264 (commonly called the Cone Nebula) formed from images in different filters (B, V, R and Hα) with the Wide Field Imager at the Max-Planck/ESO 2.2 m telescope.