The Messenger

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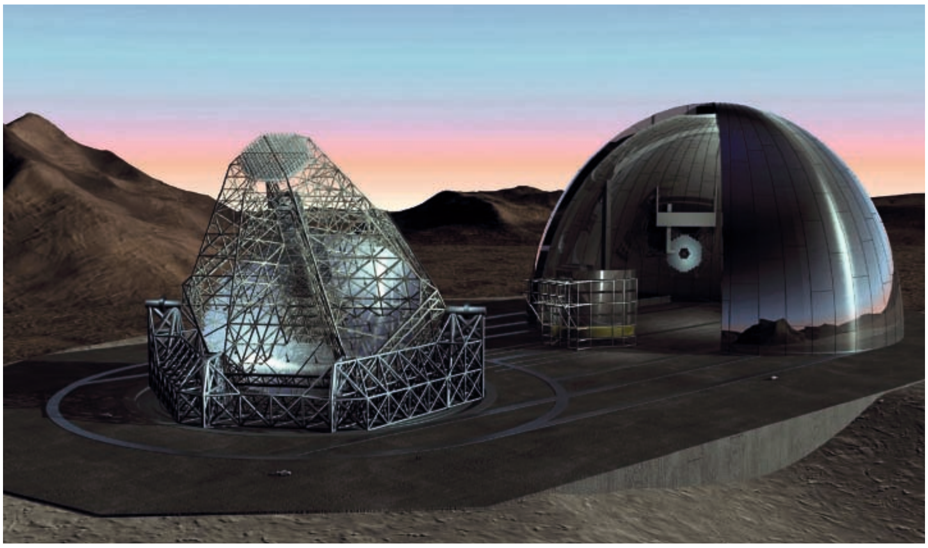
Science with Extremely Large Telescopes



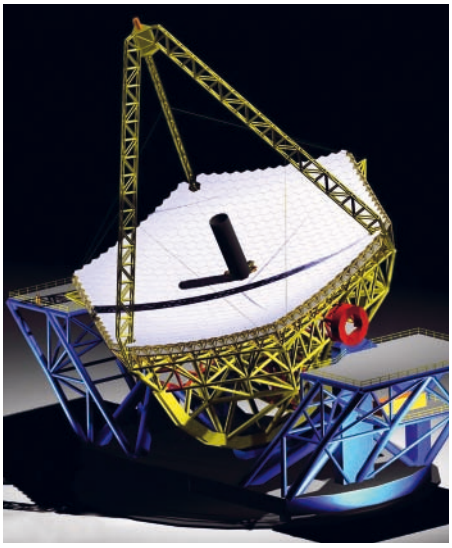


Figure 1: Concepts for 50–100-m ELTs. **Left:** the OWL (Over Whelmingly Large) Telescope, a design for a 100-m-class telescope being developed by ESO (Gilmozzi 2004, Dierickx et al. 2004). **Right:** The Euro-50 concept (Andersen et al., 2003, 2004).

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http://www.astro-opticon.org/networking/elt.html

Astronomers around Europe are gearing up for the next generation of ground-based telescopes to follow on from the success of the VLT and other 6–10-m telescopes. All aspects of astronomy will be dramatically advanced by the enormous improvements attainable in collecting area and angular resolution: major new classes of astronomical objects will become accessible to observation for the first time. In July of this year a book[1] was produced by a group of European astronomers, which describes the science achievable with a telescope of diameter 50–100 m. Here we present some highlights from this science case, ranging from direct observations of Earth-like planets outside our own Solar System to the most distant objects in the Universe.

In the past half-century a new generation of telescopes and instruments allowed remarkable new discoveries: quasars, masers, black holes, gravitational arcs, extra-solar planets, gamma ray-bursts, the cosmic microwave background, dark matter and dark energy have all been discovered through the development of a succession of ever larger and more sophisticated telescopes. This progress poses new, and more fundamental, questions, the answers to some of which will perhaps unite astrophysics with elementary particle physics in a new approach to the nature of matter, while others may give us insights as to the existence (or otherwise) of other life-supporting planets in our Galaxy. As the current generation of telescopes continues to probe the universe and challenge our understanding, the time has come to take the next step.

Several projects are under way around the world to design and construct the next generation of ground-based, Extremely Large Telescopes (ELTs), which will provide astronomers with the ability to address the next generation of scientific questions. Initial studies in the United States and Canada are concentrating on potential designs in the 20–30-m range, such as the proposed Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT). In Europe the focus is on even larger telescopes – preliminary studies indicate that the technology to achieve a quantum leap in telescope size is feasible, and a detailed design study is now under way in Europe (led by ESO) to develop the technology needed to build a 50–100-m telescope (see Figure 1).

A larger telescope is beneficial for two main reasons – firstly, a larger collecting area (proportional to the square of the diameter) allows fainter and more distant objects to be observed. Secondly, the resolution achievable improves in proportion to diameter of the telescope, provided that the telescope is equipped with an adaptive optics system that corrects for the blurring effects of the Earth's atmosphere. Thus a 50-m telescope working at its diffraction limit could in theory produce images over five times sharper than the best images from today's 6–10-m telescopes. These two effects together have a profound effect on the scientific observations that can be made – from the ability to resolve faint planets around other stars, to studying the most distant object in the Universe.

Some examples are given below of the potential scientific breakthroughs achievable with the vast improvement in sensitivity and precision allowed by the next

[1] Hook, I. M. (Ed.), 2005, "The Science Case for the European Extremely Large Telescope: The next step in mankind's quest for the Universe". Printed copies and CDs are available on request from Suzanne Howard (*showard@ast.cam.ac.uk*). PDF files can be downloaded from *http://www.astro-opticon.org/networking/elt.html*

step in technological capabilities, focusing on the science case for a 50–100-m telescope, which is being developed in Europe. Additionally, as we have seen in the past, each new generation of facilities has advanced science by discovering the new and unexpected. Therefore it is likely that the major scientific impact of these new telescopes will be discoveries beyond those we can predict today.

Are we alone? Planets beyond our Solar System

In 1995 the first planet around a normal star other than the Sun was detected, by the Swiss astronomers Mayor and Queloz, using a small French telescope with sophisticated instrumentation. The rate of announcement of new discoveries of extra-solar planets currently exceeds several tens per year, with discoveries dominated by indirect methods: either the motion of the parent star induced by the gravitational pull of the planet, or the light-loss resulting as the planet transits in front of its star, as seen by us. First claims of direct imaging of planets have already been made using 8–10-m telescopes (see Figure 2): it is only a matter of time until several reliable detections are available. Quantitative studies will become possible with advanced adaptive optics, using coronographic techniques to suppress the glare from the planet's parent star. Studies of Earth-like planets, especially via spectroscopy, will however remain impossible.

Extremely Large Telescopes offer spectacular advances in studying planetary systems. In addition to the improved collecting area, needed for observing such faint objects as the smaller extra-solar planets, the improved resolution allows cleaner separation of a planet from the image of its star. As a result, one of the most exciting new opportunities for Extremely Large Telescopes is the ability directly to detect *and to study* large samples of planets in other solar systems.

Planets of course come in a wide range of types, sizes and distances from their parent stars. What sort of planets can be studied with different types of telescope, and how many different planetary systems might one be able to detect? Simula-

Table 1: Highlight science cases for a 50–100-m Extremely Large Telescope.

Are there Terrestrial planets orbiting other stars?	Are we alone? Direct detection of earth-like planets in extra-solar systems and a first search for bio-markers (e.g water and oxygen) becomes feasible.
How typical is our Solar System? What are the planetary environments around other stars?	Direct study of planetary systems during their formation from proto-planetary disks will become possible for many nearby very young stars. In mature planetary systems, detailed spectroscopic analysis of Jupiter-like planets, determining their composition and atmospheres, will be feasible. Imaging of the outer planets and asteroids in our Solar System will complement space missions.
When did galaxies form their stars?	When and where did the stars now in galaxies form? Precision studies of individual stars determine ages and the distribution of the chemical elements, keys to understanding galaxy assembly and evolution. Extension of such analyses to a representative section of the Universe is the next great challenge in understanding galaxies.
How many supermassive black holes exist?	Do all galaxies host monsters? Why are supermassive black holes in the nuclei of galaxies apparently related to the whole galaxy? When and how do they form and evolve? Extreme resolution and sensitivity are needed to extend studies to normal and low-mass galaxies to address these key puzzles.
When and where did the stars and the chemical elements form?	Can we meet the grand challenge, to trace star formation back to the very first star ever formed? By discovering and analysing distant galaxies, gas clouds, and supernovae, the history of star formation, and the creation history of the chemical elements can be quantified.
What were the first objects?	Were stars the first objects to form? Were the first stars the source of the ultraviolet photons which re-ionised the Universe some 200 million years after the Big Bang, and made it transparent? These objects may be visible through their supernovae, or their ionisation zones.
How many types of matter exist? What is dark matter? Where is it?	Most matter is transparent, and is detectable only through its gravitational effect on moving things. By mapping the detailed growth and kinematics of galaxies out to high redshifts, we can observe dark-matter structures in the process of formation.
What is dark energy? Does it evolve? How many types are there?	Direct mapping of space-time, using the most distant possible tracers, is the key to defining the dominant form of energy in the Universe. This is arguably the biggest single question facing physical science.
Extending the age of discovery	In the last decades astronomy has revolutionised our knowledge of the Universe, of its contents, and the nature of existence. The next big step is likely to be remembered for discovering the unimagined new.

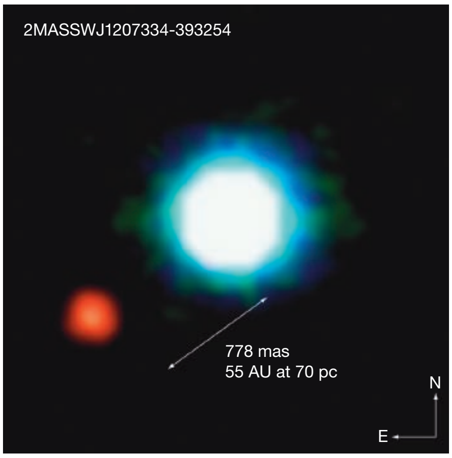
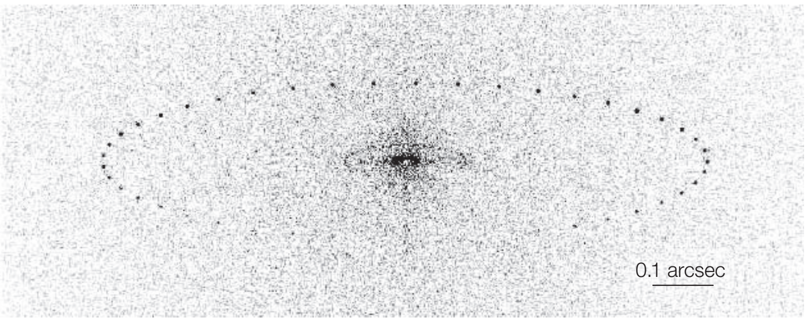


Figure 2: Infrared image obtained with the NACO adaptive optics facility on the VLT of the young (~ 10 Myr) brown dwarf 2M1207 (centre) in the nearby TW Hydrae association (Chauvin et al. 2004). The fainter object seen near it at an angular distance of 778 milliarcsec has recently been confirmed to be gravitationally associated with the brown dwarf. Models suggest that it is a giant exoplanet with a mass about five times that of Jupiter. The source is very young, is still liberating considerable energy as it contracts and cools, and probably formed in a way unlike that of planets in our Solar System. An ELT is essential to image fainter planets like our Earth, particularly as they are likely to be closer to their parent stars.

Figure 3: A simulated time-series image of a solar-system analogue, containing a Jupiter-like and an Earth-like planet at a distance of 10 pc. The system has been "observed" at number of epochs as the planets go around in the 15-degree obliquity orbits to illustrate the phase effect. Each epoch is represented by a 100-ksec exposure in the V-band with the OWL 100-m telescope, based on adaptive-optics simulations. The PSF of the central star has been subtracted from the image. (From Hainaut, Rahoui, & Gilmozzi 2005.)



tions of observations of extra-solar planets show that a 30-m telescope at a "standard" site, equipped with suitably sophisticated adaptive optics instrumentation, should be capable of studying Jupiter-like gas giant planets out to several tens of light years, while only a much larger, 100-m-class, telescope would be capable of detecting and studying a sample of *Earth-like* planets – the key here is the extremely high spatial resolution needed to observe an object that is about 10 billion times fainter than, and very close to its parent star. Earth, for example, would appear only 0.1″ from the sun if the Solar System were observed from a distance of 10 parsecs (~ 30 light years): see the simulation in Figure 3.

The *habitable zone* is the narrow region in a planetary system where water exists in liquid form: this is a prerequisite for life as we know it. Not all stars have planets, and perhaps only a very few will have planets in the habitable zone, so the largest possible sample has to be surveyed if we are to be confident of identifying a true Earth-twin. The number of stars that can be studied is approximately proportional to the spatial resolution to the cube (i.e. to D^3, where D is the telescope diameter). A 100-m telescope can in principle detect an Earth-like planet around a solar-type star out to a distance of 100 light years. This distance limit means that there are about 1000 candidate Sun-like stars to be observed. The corresponding numbers are about 200 stars for a 50-m telescope and 30 stars for a 30-m telescope.

The large telescope collecting area, which is the key to achieving the challenging goal of detection of an Earth-like planet in a habitable zone, will automatically allow substantial extra analysis, beyond 'just' detection: it will characterise planetary surfaces and atmospheres. The search for biomarkers in the planet atmosphere has the potential to discover life beyond our Solar System.

Massive planets

A limitation in studies of our own Solar System is that we have only one example: is what we see typical? unique? transient? It is clear that a telescope and instrumentation which could detect Earth-like planets would with ease detect larger planets, and planets with larger separation from their star. Imaging of entire planetary systems will become possible. Such data will define the outcome of the formation of planetary systems, by discovering and defining the types of systems which form and survive. Basic questions which remain unanswered to date include which stars have which types of planets, what conditions are required to form the various types of planet, what are the special properties, if any, of the parent stars and are there planets around rare types of stars (e.g. white dwarfs, very old halo stars: planets near neutron stars are already known).

By repeated imaging, planets will be followed around their orbits. Variations in their apparent brightness during this process then can be used to determine many properties. For example, their reflectivities (albedo) determine their surface temperatures. For larger planets, rings like those around Saturn, and the presence of moons may be inferred indirectly from the small deviations they produce in brightness, position of the planet and its velocity over time.

Worlds in formation

At least as important as determining the diversity of mature planetary systems is understanding the formation and early evolution processes. Is planet formation ubiquitous but survival unlikely? Or vice-versa? How long does planet formation take? How is it terminated? What happens to a planet after it forms? All these, and many related, questions require detection of the observable effects generated by on going planet formation around young stars. Current models, as yet untested by direct observations, suggest that planets form from condensations in a dusty disc encircling a young star, and subsequently create circular gaps at discrete positions in the disc; Figure 4 shows a simulation of this process. A telescope with sufficient resolving power and a coronagraph to suppress light from the central young star will be able to detect these planetary birthplaces, even at the inner disc locations where habitable planets should form.

A sub-millimetre detection capability on a suitably large telescope would even permit the mapping of the colder, outer regions of protoplanetary systems out to their Kuiper Belts, where the debris of planetary formation is believed to accumulate and survive.

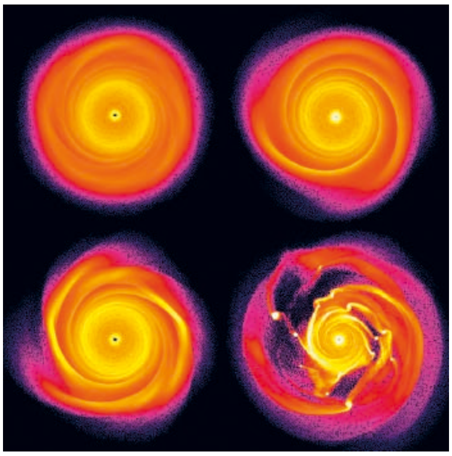


Figure 4: Simulation showing four stages in the formation of gas giant planets via fragmentation of protoplanetary discs (from Mayer et al. 2004). As the planets form, gaps are carved in the disc. An ELT has the potential to detect such gaps.

Solar System astronomy

An Extremely Large Telescope provides a natural and valuable complement to dedicated spacecraft. It would be capable of assembling a unique atlas of the surfaces of hundreds of solar system objects. Of unique value will be an Extremely Large Telescope's ability to make repeated highly-resolved imaging and spectroscopic observations of planets and moons with evolving surfaces and atmospheres. Detailed and continuing observations of this kind cannot otherwise be obtained except by dedicated (single-target) orbiters, none of which have yet been sent to the outer Solar System. Figure 5 shows an image of Jupiter's moon Io taken during a fly-by of the Jupiter orbiter Galileo: a 100-m telescope for example would have a diffraction-limited resolution of about 8 km (at a wavelength of 1µm) at the distance of Io, allowing detailed surface maps to be made and changes to be monitored (such as the volcanic activity shown in Figure 5). Thermal-infrared images at these resolutions have never been secured.

Such a systematic series of imaging and spectroscopic observations would also allow us to follow the seasonal and long-term variability of Titan's dense haze layers, allow studies of the structures generated by the gas geysers on Triton and permit the monitoring of the evolution of the atmosphere of Pluto as it recedes from the sun.

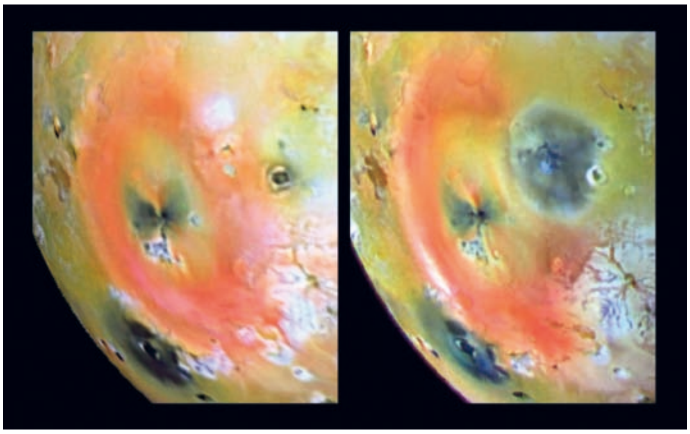


Figure 5: Changes in the surface of Io observed by the Galileo spacecraft. The images were taken on April 4 and September 17 1997. (Credit NASA/JPL). Ground-based ELTs will allow repeated imaging and monitoring of such events.

When and where did the stars form?

When did the stars form? This basic question is a key puzzle in astronomy and is only partly answered: young stars are being born today in our and other galaxies, but at a very low rate. Most stars were formed long ago. But when were the stars that make up the giant elliptical galaxies and the central bulges of spirals like our own Milky Way formed? To answer this we can make use of the fact that massive stars die young. Indeed many explode only a few million years after their birth, in spectacular supernovae explosions, whose flash can outshine whole galaxies. With an Extremely Large Telescope, such supernovae could be seen to vast distances, corresponding to redshifts up to ten in the case of a 100-m telescope (see Figure 6) and possibly to redshift 20 for supernovae from the very first (population III) stars. Redshift ten corresponds to direct observation back to 500 million years after the Big Bang, barely 3 per cent of the present age of the Universe. The frequency of supernovae at different times in the history of the Universe is directly related to the number of stars that formed at that particular cosmic epoch. Measuring the rate of supernova explosions across the Universe can therefore tell us when stars formed and at what rate. Simulations suggest that a 100-m telescope would require about 130 nights both to discover ~ 400 supernovae (using

Figure 6 (below): Hubble diagram, normalised to a cosmological model for an empty Universe, for supernovae out to redshift 20 (from Della Valle et al. 2005). Pink dots are simulated Type Ia SNe, black dots Type II (+Ib/c), blue and green dots are Ia SNe actually discovered by groundbased telescopes (Perlmutter et al. 1998, 1999; Riess et al. 1998; Knop et al. 2003, Tonry et al. 2003) and from HST (Riess et al. 2004). The SNe have been distributed around the track $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ after taking into account the intrinsic dispersion of the peak of the luminosity of Type Ia and II SN populations, while the photometric errors have been derived from the S/N ratio that has been computed for each simulated observation, assuming a 100-m telescope. Red dots represent SNe from Pop III star population. A 100-m ELT could generate such a sample of supernovae in about 130 nights of observing, including crucial measurements of spectroscopic redshifts and determination of the supernova types.

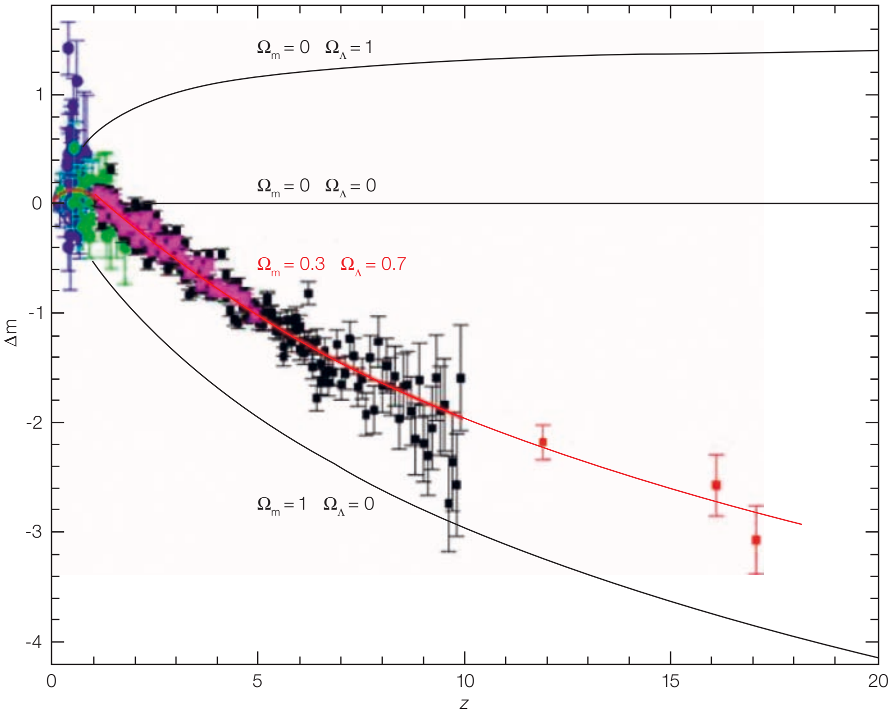
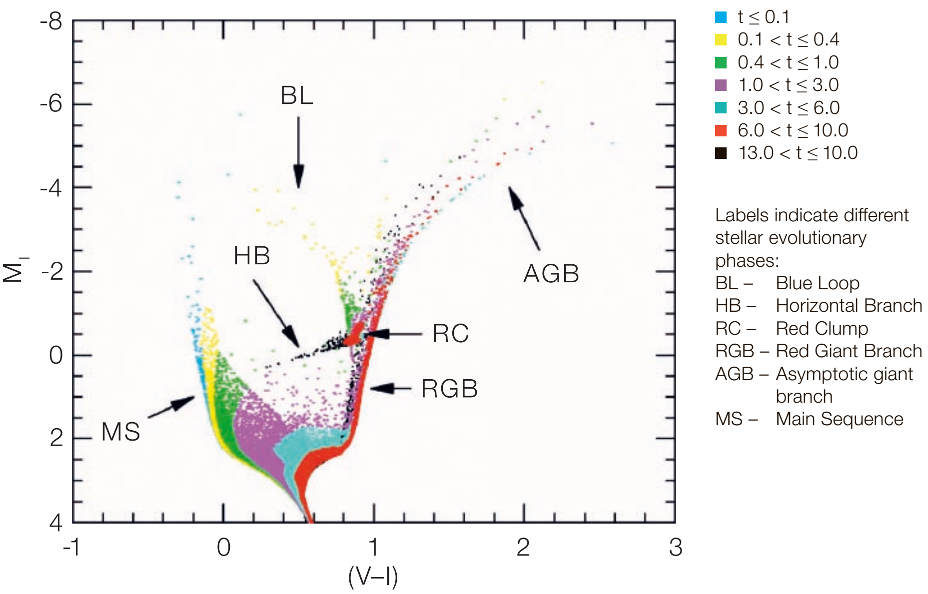


Figure 7: A predicted distribution of stars as a function of magnitude (vertical axis), colour (horizontal axis) and age, for a plausible galaxy model (from Aparicio & Gallart 2004). The colour coding represents stars in different age intervals, with units in billions of years. A 100-m-class ELT would have the resolving power and collecting area needed to place individual stars on such a diagram, and hence measure the age of the stellar populations, in galaxies as distant as the Virgo cluster.



Labels indicate different stellar evolutionary phases:
BL – Blue Loop
HB – Horizontal Branch
RC – Red Clump
RGB – Red Giant Branch
AGB – Asymptotic giant branch
MS – Main Sequence

near-infrared imaging in the *J*-, *H*- and *K*-bands) and to carry out spectroscopy to confirm their nature, redshift and properties. Such a sample will provide a reliable measure of the star-forming history of the Universe back to a time when the Universe was a few per cent of its present age.

When did the stars assemble into today's galaxies?

How did the galaxies that we observe around us come to be formed? This remains one of the outstanding questions in modern astronomy. The current best model suggests that a hierarchical sequence of mergers of smaller component galaxies built up most of the galaxies we see today. Indeed, recent studies of our own Milky Way galaxy have revealed a few small galaxies currently merging into the Milky Way, while similar behaviour is apparent in our neighbour the Andromeda galaxy M31. Detailed analysis of merger events gives clues as to the timing of the main mergers in a galaxy's history and through this, the role of the mysterious dark matter, which must play an important part in galaxy formation through its dominant gravitational effect.

Up until now these studies have been limited to our own Galaxy and its nearest neighbours. But do all galaxy types have similar merger histories? How important is environment? To study a representative section of the Universe requires reaching at least the nearest large galaxy clusters which contain large elliptical galaxies. This means observing galaxies in the Virgo or Fornax clusters at distances of 16 or 20 mega-parsecs respectively. Initial feasibility studies look very promising – simulations show that a 100-m-class telescope should be able to resolve individual stars in galaxies in the Virgo cluster, and obtain sufficiently accurate photometry to determine their ages and composition, even for the oldest, hence faintest, unevolved stars. Spectroscopic observations of the brighter stars will also be possible, allowing measurements of the kinematic motion of the stars and accurate determination of their chemical composition. From these a detailed picture will be derived of the process by which (and, indeed, of the components from which) the target galaxies were assembled, and the role of dark matter in this process.

The physics of galaxy formation

To understand the creation and evolution of galaxies in general we must address what is one of the major goals of future astrophysics: to map the distribution and growth of both the baryonic (normal matter) and dark matter components of galaxies at moderate to high redshift ($z = 1–5$), a key epoch for galaxy formation. Although individual stars cannot be resolved at these cosmological distances, a 50-m to 100-m Extremely Large Telescope will not only resolve the distant galaxies into their luminous components, but will be able to characterise these individual components.

Using techniques such as integral-field spectroscopy, in which spectra are obtained at thousands of locations across a (proto-) galaxy simultaneously, it will be possible to determine the relative star formation rate, the mass of stars and the chemical composition at these different locations within each galaxy. This will shed light on the "feedback" mechanisms believed to affect the formation of galaxies, such as the effects of a newly-formed active galaxy nucleus, or supernova explosions, on surrounding star formation. In addition, the bulk motions of gas and stars inside galaxy could be determined, thus allowing one to map the dark matter content of individual galaxies at a range of redshifts, corresponding to epochs when the galaxies were in the process of assembly. Then, measuring the kinematics of their satellite objects, both internal and relative to their more massive partners, we can estimate the amount of and infer the distribution of the mass present in the galaxy's halo, which is one of the few ways we have of detecting and examining the dark matter and its distribution.

This will provide astronomers with a detailed evolutionary history of the clumping of dark matter (Figure 8). We will "see" galaxy formation in all its glory from formation to maturity, and so directly test our understanding of the basic evolutionary processes in the Universe.

Supermassive black holes

The centres of most, perhaps all, galaxies harbour supermassive black holes. These exotic objects are usually discovered indirectly, as extreme radio- or X-ray-luminous sources, quasars and Active Galactic Nuclei. Direct studies, critical for reliable mass determination, and essential when the hole is not active, are possible only when precision studies of the very local region of the galactic nucleus are feasible: only (relatively) close to a black hole is the gravity of the whole galaxy dominated by the mass of the black hole, so that the black hole's presence can be deduced. The methodology has been proven by observations at ESO over many years proving the existence of a massive (~ $3 \times 10^6\,M_\odot$) black hole in the core of the Milky Way galaxy. Direct measurements of the speed at which stars and gas clouds are orbiting the centre of a galaxy are required. The closer to the centre these can be measured, the more reliable is the evidence for, and the determination of the mass of, the black hole.

For reasons which are not understood, the evolution and mass of the supermassive black holes is apparently very closely related to the properties of the very much larger host galaxy. Understanding this, and determining if it is indeed ubiquitous, would be the first clue relating the nuclei of galaxies to their major parts, and the first link between the exotic and the typical in galaxies. How do the black holes first form? How do they grow, and at what rate? Are growing black holes always active? How does a central black hole "know" the properties of the larger galaxy in which it resides? Does every galaxy have a massive black hole?

All these questions require for progress detailed study of the masses and ubiquity of central black holes. This requires the highest possible spatial resolution and faint-object spectroscopy, attainable only with an extremely large telescope. For example, Figure 9 shows that a 100 m telescope working at its diffraction limit can in principle resolve the sphere of influence of a supermassive ($10^9\,M_\odot$) black hole at all redshifts across the Universe (provided they exist of course!) and even detect the influence of a modest 100 $M_\odot$ black hole in the local Universe, out to about 1 Mpc from us. It will then be possible to carry out a systematic census of black holes as a function of cosmic epoch and begin to understand their formation in relation to the galaxies around them.

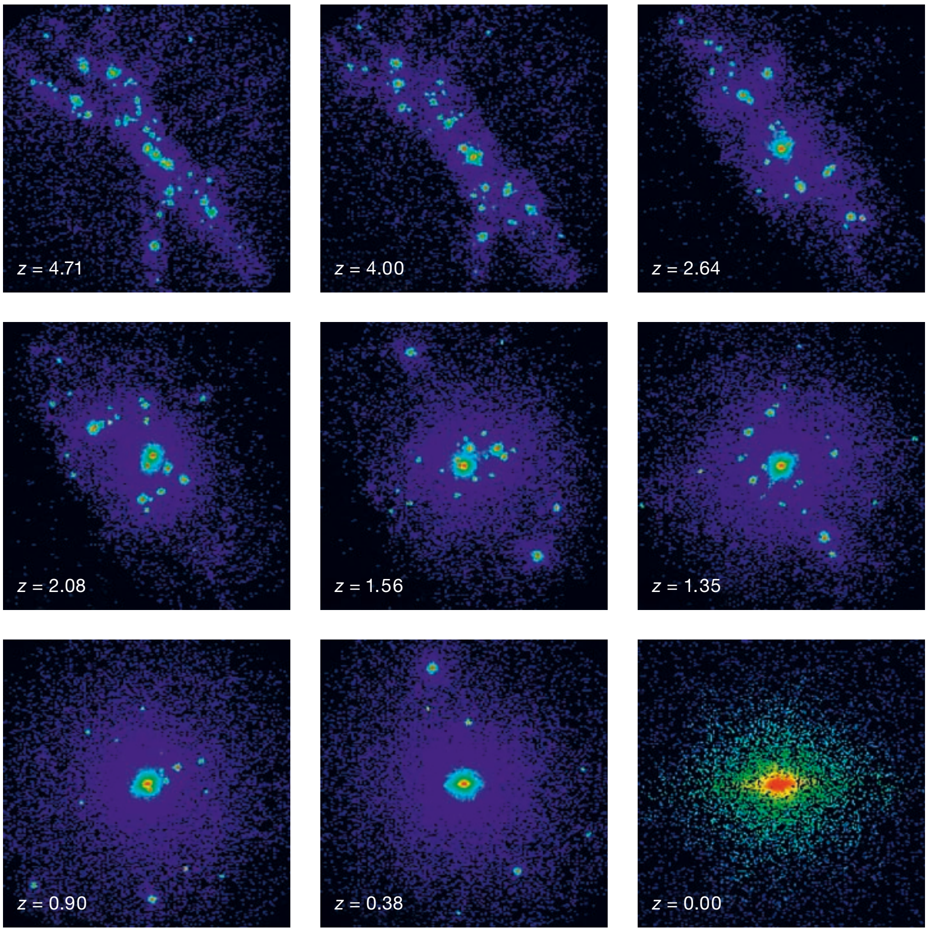


Figure 8: Simulations showing Dark Matter particles within a cube of 320 physical kpc on a side, shown at various redshifts and projected so that the luminous galaxy at $z = 0$ is seen edge-on (from Abadi et al. 2003). The bottom right panel zooms into the innermost 40 kpc of the system. Each particle is coloured according to the logarithm of the local dark matter density using a palette that runs from red to blue: red and blue correspond to ρ_{dm} greater than and less than about $10^{10}\,M_\odot\,\mathrm{kpc}^{-3}$ respectively. An ELT has the potential to observe such galaxy haloes in the process of formation: observations of the motion of the central galaxy and its satellites will provide a measurement of the distribution of dark matter in the extended galaxy halo.

The ionisation of the Universe

The early Universe was hot (ionised) and transparent. With time, the gas cooled. The aftermath of the Big Bang left the early Universe an opaque gas of hydrogen and helium. Some time later, the first objects heated the hydrogen and helium, making it (again) transparent – the "era of (re-)ionisation". A key goal of astrophysics is to understand how and when the first luminous objects in the universe formed from the primordial gas, what they were, and how they contributed to ionising and enriching the gas with heavy elements.

Tantalising questions about the re-ionisation history of the universe are raised by recent results. Those from the Wilkinson-MAP Cosmic Microwave Background satellite probe, when combined with ground-based surveys of the large-scale structure of the Universe today, suggest that the gas was re-ionised by about 180 million years after the Big Bang (redshift ~ 17) while observations of the highest redshift quasars at about 700 million years (redshift ~ 6) demonstrate that enough of the intergalactic medium remained un-ionised at that time to absorb almost completely all radiation bluer than the Lyman α recombination line of HI (Figure 10). What is the solution to this apparent quandary? It may be that there were two re-ionisation epochs, an earlier caused by the first generation of massive stars, followed by cooling, and then one later by the first quasars and galaxies. Alternatively, a slower, highly inhomogeneous re-ionisation process may have occurred over the period between the two epochs.

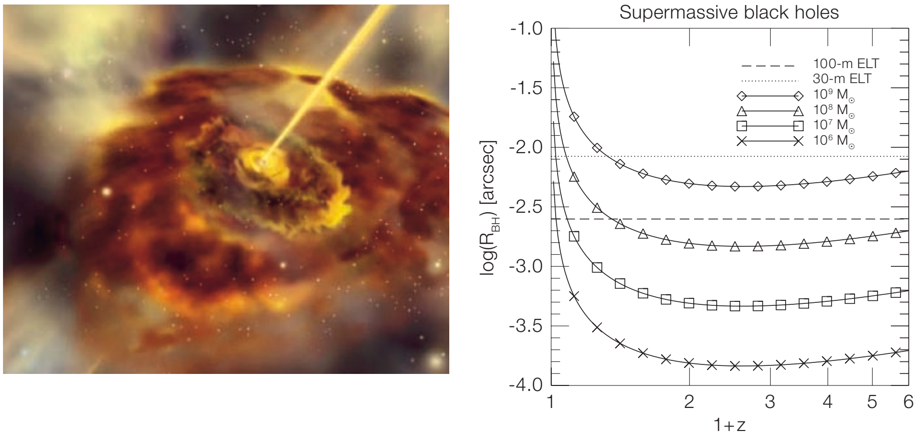


Figure 9: Left: Artist's conception of an AGN with the black hole surrounded by accreting material and ejecting jet at relativistic velocities. **Right:** The impact of a 100-m-class telescope on studies of intermediate and massive black holes would be considerable. Shown here are the distances to which the sphere of influence can be resolved (for comparison, the resolution of a 30-m telescope is also shown). With a 100-m ELT we be able to detect 10^9 $M_\odot$ black holes at all redshifts (where they exist). Here we assume a cosmology of $H_0 = 70$ km $s^{-1}Mpc^{-1}$, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$. The point spread function is given by 1.22 λ/D, where D is 30 m or 100 m and $\lambda = 1$ µm. (Figure credits: Left: GLAST/NASA, Courtesy Aurore Simonnet, Sonoma State University, Right: M. Hughes.)

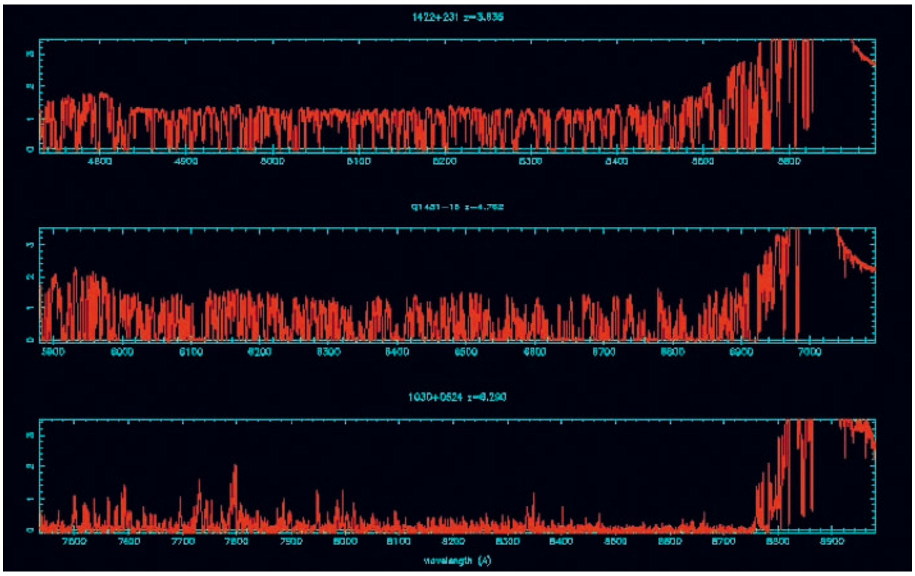


Figure 10: Spectra of quasars of increasing redshift illustrating the increase in absorption due to intervening neutral gas with increasing redshift. At the highest redshifts these show a "Gunn-Peterson" absorption trough – the complete absorption of light at wavelengths shortward of the Lyman α line of atomic hydrogen – implying that the re-ionisation epoch which began at redshift ~ 20 must have continued until redshift ~ 6. An ELT's supreme sensitivity to point sources (such as quasars, gamma ray bursts and supernovae) will allow observations of the ionisation state of the Universe to very high redshift, possibly all the way back to when the re-ionisation process began. (Figure shows observations by W. Sargent & M. Rauch; Tae-Sun Kim; M. Pettini. Compilation by R. Carswell.)

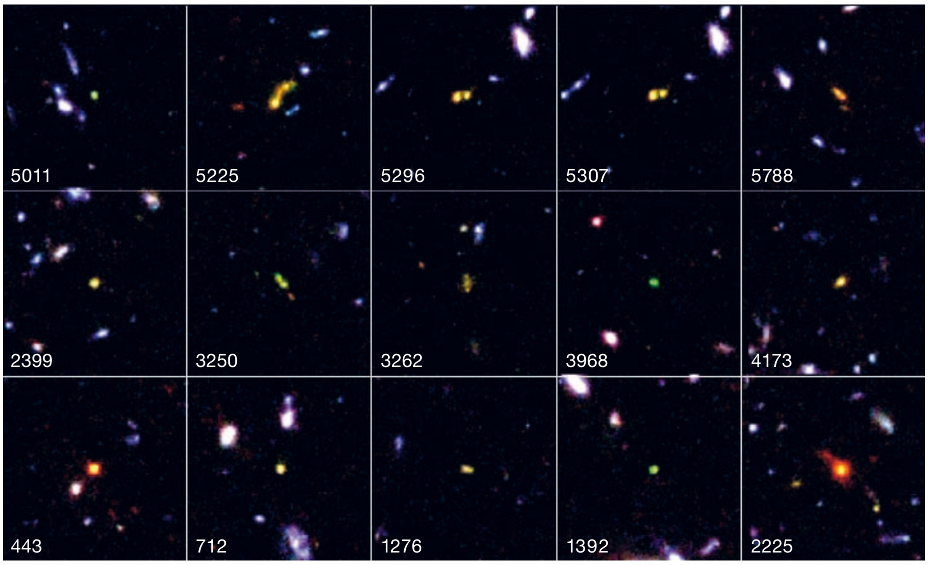
These models, together with other more complex possibilities, could be tested if we can observe the ionisation state of the high-redshift Universe directly: this is feasible, through analysis of the absorption features produced in the spectra of suitably-luminous very distant "background" objects. There are a few populations of sources that could be observed at such very high redshift with an ELT. The short-lived gamma-ray bursts are extremely bright for a short time, so much so that they should be detectable up to redshift ~ 15–20. Supernova explosions of the first stars to form, though not yet detected, would probably be fainter than this, but could still be used to probe the state of the gas at redshifts up to 10. This population of "first supernovae" may well disappear once the local heavy-element enrichment becomes higher than 1/10000 of the solar value. Testing this prediction will itself be a major challenge, and discovery.

Quasars are currently used as powerful background sources, and will continue to be useful in future, if they exist at higher redshift. Although the epoch of first quasar formation remains an open question, the quasars being found at redshifts around 6 are (presumably!) powered by supermassive black holes, so we infer that intermediate-mass black holes (corresponding to quasars of intermediate luminosity) must have existed at earlier epochs, up to at least redshifts of about 10. Probing the physics of the gas in the early Universe requires intermediate/high-resolution spectroscopy of these "background" sources in the near infrared, the natural domain of ground-based Extremely Large Telescopes. Apart from the very rare extreme gamma-ray bursters (and/or bursts caught very early), which could be observed with a 30-m-class telescope, spectroscopic observations of these faint background objects can only be carried out with telescopes of the 60–100-m class.

The first galaxies

The first galaxies, being the places of formation of the first stars (a prediction well worth verifying!) compete with the first quasars for the re-ionisation of the gas in the early Universe. Candidate star-forming galaxies out to redshift about 6 have already been discovered and a few have been confirmed spectroscopically. Equivalent objects are expected to exist out to redshifts greater than 10 for several reasons. Firstly, the analyses of the fluctuations in the Cosmic Microwave Background indicate ionisation of the universe at redshifts > 10, presumably by ultraviolet emission from the first objects. Secondly, SPITZER satellite observations of the higest redshift galaxies known to date show evidence for old stellar populations – indicating that these galaxies formed

Figure 11: HST/ACS images of high-redshift (z ~ 5–6) galaxies from Bremer & Lehnert (2005) showing the small but resolved nature of the galaxies, with typical half-light radii of 0.1–0.2 arcsec (1–2 kpc). A 50 to 100-m ELT will not only measure detailed physical properties of such galaxies but will also be capable of finding and confirming (with spectroscopy) galaxies at significantly higher redshifts (10 and beyond), possibly including the first galaxies to form in the Universe.



much earlier. Very high-redshift star-forming galaxies will probably be detectable in considerable numbers with future spacecraft (James Webb Space Telescope) and ground-based (ALMA) facilities. However a 100-m-class Extremely Large Telescope will be needed to provide the desired diagnostics of the astrophysics of both the gaseous interstellar medium and the early stellar populations in these galaxies.

Furthermore, a sub-millimetre capability on an Extremely Large Telescope, if it were at a suitable site, would allow a large-scale survey (with mapping speed thousands of times faster than ALMA at 850 μm) that would detect the millions of dusty high-redshift galaxies which (probably) contribute the cosmic far-infrared and sub-mm background, resolved down to quite faint levels throughout the Universe. With redshift estimates from sub-mm flux ratios, such a survey would yield a treasure-trove of information on large-scale structure from very early epochs to the recent past.

Dark energy and fundamental physics

The recent discovery of the accelerating expansion of the Universe has led to an urgent need to understand the nature of the mysterious “dark energy” which is driving this expansion. The dark energy is believed to account for about 70 per cent of the energy budget of the Universe (Figure 12, see next page) and yet its nature is completely unknown. One potential candidate is the vacuum energy implied by the “cosmological constant” term in Einstein’s field equations (whose solutions represent global pictures of the Universe). However measurements of the effects of dark energy on cosmological scales constrain its contribution to be many orders of magnitude smaller than the vacuum energy scale predicted by particle physics theories.

The direct measurement of the dynamical expansion history of the Universe via Type Ia supernovae has shown that the dark energy exerts a negative pressure and hence accelerates the universal expansion. Direct analysis of the expansion rates of the Universe across spacetime is needed to investigate this remarkable form of energy. Intriguingly, most of the effects of dark energy are apparent at relatively low redshifts (less than about $z = 1$), although equivalent studies at high redshift, when feasible, may well have their own surprises in store.

An Extremely Large Telescope can determine the expansion history of the Universe using several different and complementary astrophysical objects, thus decreasing any dependency on possibly unknown systematic effects. The well-understood primary distance calibrators, pulsating Cepheid stars, globular clusters, planetary nebulae and novae, could all in principle be observed to cosmological distances where the effect of dark energy is dominant in the Universe. The exquisite sensitivity to point sources of an Extremely Large Telescope with appropriate adaptive optics capability, combined with its impressive collecting area, will allow it to detect Type Ia supernovae to redshift of about 4, and Type II supernovae (which can also be used as distance indicators via the expanding photosphere method) possibly all the way to redshifts of about ten (see Figure 6).

By mapping the geometry of the Universe on the largest scales and accurately determining any variations of the strength of dark energy with time, astronomers can answer the fundamental question of whether dark energy corresponds to Einstein’s cosmological constant or to some “quintessence field” as suggested by modern versions of quantum field theories. The need for these observations is critical and the implications for all of physics and cosmology are vast.

Furthermore, ELTs offer the intriguing possibility of observing the expansion of the Universe directly – by observing the minute increase in redshift of absorption lines in quasar spectra over a period of about 10 years it will be possible to watch the Universe expanding in “real time”! Such detailed and direct measurements will provide an important test of cosmological models and also allow tests for the constancy of fundamental parameters such as the fine structure constant.

Cosmological observations have now become the only way to characterise several of the most promising unexplored sectors beyond the Standard Model of particle physics. The discovery and description of dark energy is possible only with cosmological-scale observations: no small-scale effects are yet known. However, dark energy and dark matter must be part of the process towards understanding the next generation of theory in Physics: they are related to super-symmetric particles, string theory, theories of gravity and quantum gravity, theories of higher dimensions, and the constancies of the fundamental constants. An Extremely Large Telescope is the next big step in direct observation of the nature of the Universe.

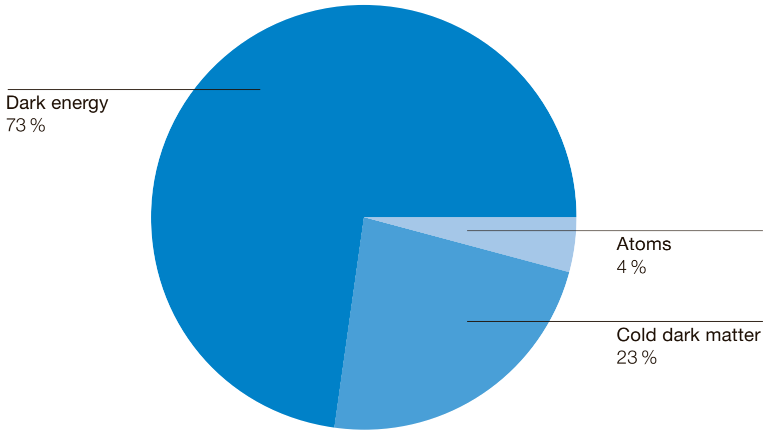


Figure 12: Our current understanding of the mass-energy content of the Universe. All "normal" matter is a minor contribution of only about 4 %. Dark matter, of unknown nature dominates mass. Dark energy, of unknown identities, dominates the Universe. What is it? ELTs can tackle this question by measuring the expansion history of the Universe using a range of independent techniques.

Why an ELT now?

The relatively large apertures which are affordable and technically feasible for groundbased telescopes means that these facilities are the natural means to provide maximal light-gathering power. Natural complementarity exists between these and orbiting observatories which, although considerably more expensive for the same size of telescope, benefit from being clear of the thermal background and the seeing effects of the Earth's atmosphere.

For example, routine images from the Hubble Space Telescope's Advanced Camera for Surveys reveal objects which are so faint the largest existing telescopes are unable to acquire their spectra. Without spectroscopic information we can learn only a limited amount about the basic nature and properties of an astrophysical object. The advent of the James Webb Space Telescope, currently scheduled for launch in 2012, will increase this imbalance. Until the astronomical community acquires complementary groundbased facilities which are much larger than those available at present, the majority of future discoveries will be beyond our spectroscopic reach and detailed understanding. This is a major reason why astronomers are urgently seeking to begin construction of the first groundbased Extremely Large Telescopes.

Space observatories which are designed for observations at wavelengths inaccessible from the ground (because of absorption by the Earth's atmosphere), such as the flagship X-ray facilities XMM-Newton and Chandra, regularly discover sources which are too faint in the wavelength range readily accessible to the ground, the optical and near infrared, to be detected or investigated by existing telescopes. Planned next-generation missions will further increase the need for a major enhancement in the performance of our large optical/near infrared telescopes if the new phenomena which they reveal are to be understood.

New radio and sub-millimetre astronomy groundbased facilities are being built that will also naturally complement an Extremely Large Telescope's optical and infrared capabilities, and will discover sources which will demand further study at other wavelengths. For example the Low-Frequency Array (LOFAR), due for completion in 2008, will operate at long radio wavelengths, and a more ambitious project, the Square Kilometer Array is being proposed to follow as the next-generation radio facility. In the sub-mm bands the Atacama Large Millimeter Array (ALMA), an interferometer currently in the initial stages of construction and a key element of ESO's scientific strategy, will provide very high sensitivity and spatial resolution beyond the limits of current ground-based telescopes. ALMA is due to be fully operational by 2012 and will cover a very wide range of science, detecting both thermal continuum emission from dust and line emission in objects from the nearest star-forming regions to luminous galaxies at very high redshift. Groundbased Extremely Large Telescopes will be ideally matched to provide imaging and spectroscopic follow-up of these sources at optical to mid-infrared wavelengths, with matched angular resolution.

Science Case Development

This summary is based on a full science case document developed at a series of meetings over four years involving over 100 astronomers. The work is sponsored by the EC network OPTICON, and maintained as part of the European Extremely Large Telescope Design Study, funded in part by the EC FP6 programme, by ESO, and by many European national agencies and organisations.

WWW sites for further information:
OPTICON European ELT science case work: *http://www.astro-opticon.org/networking/elt.html*
Euro-50 telescope web site: *http://www.astro.lu.se/~torben/euro50/*
OWL telescope web site: *http://www.eso.org/projects/owl/*

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Deep Impact at ESO Telescopes

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This article is a first summary of the observations done with ESO telescopes and instrumentation in the context of NASA's Deep Impact (DI) space mission. The ESO observers* were part of an extremely active, communicative and thus successful worldwide network of observers. Through this network all information was freely exchanged and highlights are reported here as well.

Comets and the formation of the Planetary System

The most important scientific rationale for studying comets is to obtain information on their origin, on their relationship with interstellar and interplanetary material, and on implications for the formation of the Solar System. The knowledge about comets had been synthesized in the 1950s by Fred Whipple into the "Dirty Snowball" model for cometary nuclei. Today comets are referred to as "icy dirt balls" of the solar system because this is a better reflection of their constitution of frozen volatiles and dust. Comets are known to arrive in the inner planetary system coming from two main reservoirs: the Oort Cloud at several 1000–10 000 AU distance from the Sun, and the Edgeworth-Kuiper Belt at 30–50 AU from the Sun. The latter is considered to be also the birthplace of most of the short-period comets, while the Oort Cloud contains comets originating in general from the region of birth of the major planets in the Solar System.

Gravitational interaction with the outer planets and the immediate and even more distant neighbourhood of the Sun in the Milky Way (passing stars, molecular clouds, galactic centre) has moved and stored these cometary nuclei into the Oort Cloud, now the repository of non-periodic comets. It is the same process, gravitational interaction with stars and molecular clouds passing our Solar System, which is responsible for injecting comet nuclei from their storage place back into the inner Solar System where they can be observed from Earth. Comets then become sometimes spectacular objects, since close to the Sun, the frozen volatiles sublimate, which creates the dust and gas comae. *Coma* is the Latin word for "hair" and thus, comets have been referred to as "hairy stars" by our ancestors.

Since comets stayed inactive most of their lifetime in the cold environment of the outer Solar System, they are believed to be primordial, i.e. representing in a close to original form an important population of minor bodies that agglomerated in the protoplanetary disc from interstellar dust some 4.6 billion years ago. Comets can thus be considered as fossil records from the formation of our Solar System. Of course, any *fossil* on Earth has been subject of some type of "weathering". Similarly cometary nuclei have not survived 4.5 billion years in the Solar System without any changes. Their upper surface layers of a few metres thickness experience evolutionary modifications due to cometary activity, space weathering and collisions with other minor bodies. Hence it is not surprising that comets have very high priority on the target lists of interplanetary missions of the national and international space agencies: triggered by Halley's comet's encounter of a fleet of five spacecraft in 1986, four more comets were explored by man-made scientific instrumentation in fly-by missions up to the last year. At this point, the exploration of comets with ground-based telescopes and fly-by spacecraft had resulted in a cornucopia of many, sometimes fairly sophisticated detailed observations. The most important parameters

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* The ESO observations were the result of a worldwide scientific cooperation involving the following colleagues: Michael A'Hearn (University of Maryland, USA), Claude Arpigny (Université de Liége, Belgium), Anita Cochran (McDonald Observatory USA), Catherine Delahodde (University of Florida, USA), Yanga Fernandez (University of Central Florida, USA), Damien Hutsemekers (Université de Liège, Belgium), Hideyo Kawakita (Gunma Astronomical Observatory, Japan), Jörg Knollenberg (Deutsches Zentrum für Luft und Raumfahrt, Germany), Ludmilla Kolokolova (University of Maryland, USA), Mike Kretlow (Max-Planck-Institut für Sonnensystemforschung, Germany), Michael Küppers (Max-Planck-Institut für Sonnensystemforschung, Germany), Ekkehard Kührt (Deutsches Zentrumfür Luft und Raumfahrt, Germany), Luisa Lara (Instituto de Astrofísica de Canarias, Spain), Javier Licandro (Instituto de Astrofísica de Andalucía, Spain), Casey Lisse (The John Hopkins University/Applied Physics Laboratory, USA), Karen Meech (Universitiy of Hawaii, USA), Rita Schulz (ESTEC, the Netherlands), Gerhard Schwehm (ESTEC, the Netherlands), Michael Sterzik (ESO), Joachim A. Stüwe (Universiteit Leiden, the Netherlands), Isabelle Surdej (Université de Liège, Belgium), Diane Wooden (NASA Ames Research Center, USA) and Jean-Marc Zucconi (Besançon, France).

of a solar-system body, density and thus mass and the tensile strength of surface and interior, however, were the subjects of theoretical conjectures, but remained basically undetermined. It was thus important to take the next logical step: 2005 has seen a new flavour of cometary exploration, Deep Impact, an active experiment with a cometary nucleus.

The Deep Impact mission

On 4 July 2005, NASA's discovery mission Deep Impact (DI) encountered Comet 9P/Tempel 1, releasing a 370 kg copper probe at the comet (A'Hearn 2005). The probe was hit by the comet nucleus at a speed of 10.2 km/s and penetrated into the upper surface layers of the nucleus while the mother spacecraft flew by the nucleus at a distance of about 500 km observing the event with three on-board remote sensing experiments, a wide- and a narrow-field camera (visible wavelength range) and a near-infrared imaging spectrometer (1–5 micron). The target comet, 9P/Tempel 1, is a medium-bright, slowly rotating (41 h), medium-size (> 7.5 km diameter), low-albedo (8 %) short-period comet, most likely originating in the Edgeworth-Kuiper Belt. During the impact the kinetic energy released by the impactor was 19 GigaJoule or 5 300 kWh (this amount of energy is equivalent to the biannual electricity consumption by the author in his apartment for which the local public utility company charges approximately 900 €. Or it is slightly more than the equivalent of an Airbus A380 airplane flying at cruise speed – pick the unit which is more familiar to you!).

Models describing the subsequent crater formation resulting from this experiment gave a wide range of predictions, from the comet swallowing the impactor with virtually no effects, to complete disruption of the nucleus. The most likely models predicted a crater of football stadium size, an impact flash, an ejecta plume with a high probability that pristine material from the inner "original" layers is released during and after impact, when the Sun will illuminate this newly formed active region on the nucleus. Under lucky circumstances even a new long-lasting active region might have been created by the impact. Due to the fly-by nature of the mission, the spacecraft could perform only a short monitoring campaign of the target peaking in an approximately 800 sec long period around close encounter, when the impact area was in direct view of the instruments on board the fly-by spacecraft. Figure 1 shows an example of images taken by the fly-by spacecraft.

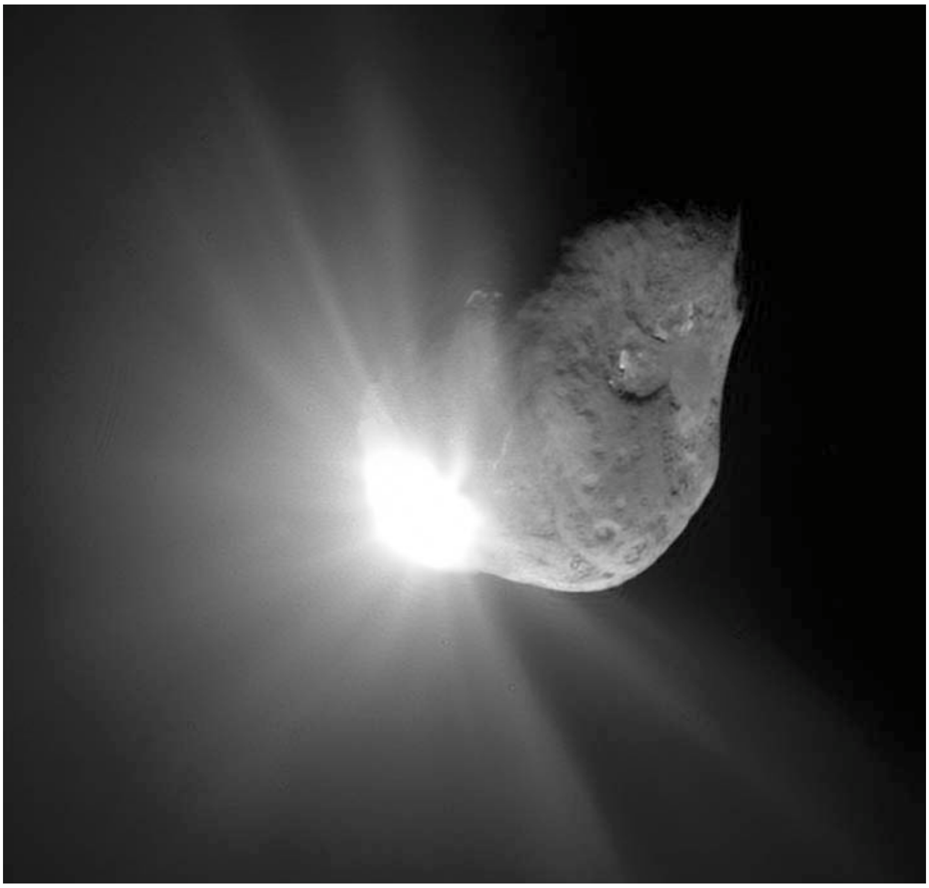

Figure 1: Comet 9P/Tempel 1 imaged 67 seconds after it obliterated Deep Impact's impactor spacecraft. The image was taken by the high-resolution camera on the mission's fly-by spacecraft. The image reveals topographic features, including ridges, scalloped edges and possibly impact craters formed long ago. First light from the impact flash arrived on Earth at 05:52:03.3 UT. For ESO telescopes the comet had just set (see text).
Image credit: NASA/JPL-Caltech/UMD.

Need for earth-based DI science

Given the limited scope of the on-board instrumentation (described in Hampton, 2005) and the short visibility of the impact area from the spacecraft, Earth-based observations were the most important complementary means to guarantee the expected science return and the success of the mission. Hence, they formed an integral part of the DI mission concept and have been coordinated world-wide by a dedicated mission scientist (Karen Meech, University of Hawaii, see Meech 2005). Due to the limitations of man-made interplanetary spacecraft a short-period comet had to be picked for this experiment. The comet should have a perihelion not too far from our Earth's orbit. The encounter could only take place close to a crossing point of the cometary orbit with the orbital plane of the Earth, the Ecliptic. For Comet 9P/Tempel 1, one of the few comets fitting the set of constraints, perihelion passage (July 5, 2005)

Figure 2: The participants of the ESO-Deep-Impact preparatory workshop in February 2004.

was very close to the descending node crossing (July 7, 2005). To have optimum conditions for ground based follow-up, the event should take place during "dark time" (new moon July 6, 2005). These constraints set the date for the experiment. The visibility of the immediate impact event on Earth covered most of the Pacific Ocean region except for the west coast of South America. ESO's role in the scientific follow-up was to study and document the activity of Comet 9P/Tempel 1 until shortly before impact. The comet set for Chile approximately two hours before impact. From the study of spontaneously broken-up comets it was known, that the break-up related phenomena peak in brightness 12–24 hours after the event. For an example we refer to Comet 73P/Schwassmann-Wachmann 3 (c.f. *http://www.eso.org/outreach/press-rel/pr-1996/pr-01-96.html*). In that sense it was considered advantageous, that the comet became visible in Chile 16 hours after impact. Given the light-collecting power and instrumental multiplexing capabilities, the ESO observatories in Chile were considered critical sites for the ground-based observational coverage of the impact event. Moreover, ESO is in the special position of having its telescopes located on two different mountain tops separated far enough geographically that they have different weather. Both sites by themselves are already excellent astronomical sites, but in combination it is highly unlikely that both observatories would be clouded out. For a time critical event such as Deep Impact, this was, of course, an invaluable asset, especially in Chilean winter!

The coordinated ESO DI campaign

For an optimum preparation of the campaign, an impromptu weekend workshop was sponsored and organised at ESO in February 2004, to get the ESO community involved. Many of the participants had been involved in the July 1994 observing campaign for the collision between the fragments of Comet Shoemaker-Levy 9 with Jupiter (SL9, c.f. The Messenger 77, 1994 or *http://www.eso.org/outreach/info-events/sl9/*). In total five proposals received time at ESO telescopes, of which

Table 1: Usage of different observing modes during impact period.

ESO Campaign	Obs. mode	Setup	July 2005 2	3	4	5	6	7	8	9	10	11	Observatory	Telescope	Instrument
Imaging	Small field	NQ-Filters	x	x	x		x	x	x	x	x		VLT/LSO	UT3/3.6-m	VISIR/TIMMI2
	AO	LM-Filters				x	x	x	x	x			VLT	UT4	NACO
	AO	*JHK*-Filters	x	x	(x)	x	x	x	x	x			VLT	UT4	NACO/SINFONI
	Small field	*JHK*-Filters	x	x	x		x	x	x	x			VLT/LSO	NTT/UT1	SOFI/ISAAC
	Small field	BVR-Filters		x	x	x	x	x	x	x	x	x	VLT	UT1/UT2	FORS1/FORS2
	Small field	Comet. Filters	x	x	x		x	x	x	x			LSO	NTT	EMMI
	Wide field	BVRI-Filters	x	x	x		x	x	x	x			LSO	2.2-m	WFI
	Wide field	NB-Filters	x							x			LSO	2.2-m	WFI
Spectroscopy	Low Disp. LSS	*N*-Band	x	x	x	x	x	x	x	x	x		VLT/LSO	UT3/3.6-m	VISIR/TIMMI2
	AO long slit	*L*-Band					x						VLT	UT1/UT4	ISAAC/NACO
	AO IFU/LSS	*JHK*-Band	x	x									VLT	UT4	NACO/SINFONI
	Low Disp. LSS	*JHK*-Band	x	x	x	x	x	x	x	x			LSO	NTT	SOFI
	Low Disp. LSS	370–920 nm	x	x	x	x	x	x	x	x	x	x	VLT/LSO	UT1/UT2/NTT	FORS1/FORS2/EMMI
	High Disp. SSS	304–1040 nm	x	x	x	x	x	x	x	x	x	x	VLT	UT2	UVES
Polarimetry	Imaging linear	*JHK*-Band		x	x	x							LSO	NTT	SOFI
	Imaging linear	NB visible	x						x				VLT	UT2	FORS1
	Spectro. linear	400–900 nm			x	x							VLT	UT2	FORS1
	Spectro. circular	400–900 nm					x						VLT	UT2	FORS1

four were closely coordinated and performed by an international team of cometary experts, experienced observers, data analysts and modelers. Two of the proposals (PIs: Hainaut, Käufl) characterised the pre-impact status of the comet, the other two (PIs: Böhnhardt, Rauer) focused on the observation of the impact event and its aftermath. During the impact period the team used all seven telescopes currently operated by ESO at Paranal and La Silla, i.e. the four 8.2-m unit telescopes of the ESO Very Large Telescope (VLT) and the 3.6-m, the NTT and 2.2-m telescopes at La Silla (LSO). Altogether 11 instruments at these telescopes delivered scientific measurements covering the widest possible wavelength range from 300 nm to 20 micron and exploring almost all possible observing techniques such as seeing and diffraction limited direct imaging through broadband, narrowband, and special cometary filters, spectroscopy using long-slits/low-dispersion, short-slit/high-dispersion and integral field optics as well as imaging and spectro-polarimetry with linear and circular polarisation optics. Table 1 provides an overview of the usage of the different observing modes applied during the impact period at the various ESO telescopes and instruments. In this context it is interesting to note that one of the reference science cases for the VLT was to repeat an observational campaign such as SL9 and indeed, the VLT proved to be perfectly suited for such a unique and unpredictable event.

Paranal and La Silla, part of a world observatory

Even if the Deep Impact spacecraft had missed the comet, the data set would be absolutely unique, as the worldwide campaign to observe Comet 9P/Tempel 1 involved all major observatories and various spacecraft. Hubble Space Telescope, Spitzer Infrared Space Observatory, and Chandra and XMM/Newton in X-rays, to name just the most important observatory type missions observed in parallel and even ESA's Rosetta space-

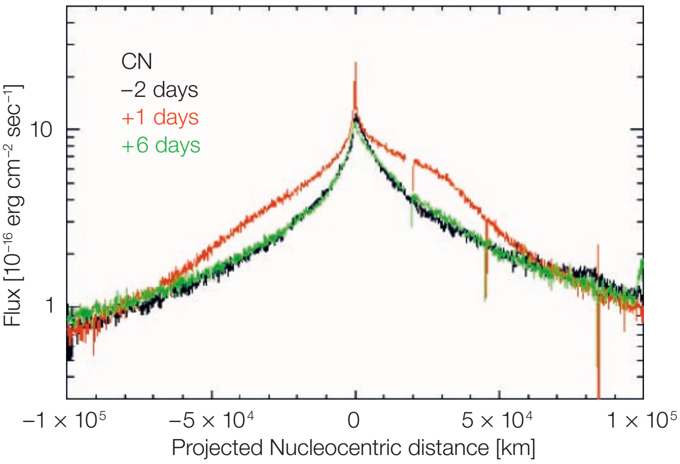

Figure 3 (above): Comparison of the spatial profiles along the slit for the integrated CN emission (at ~ 390 nm) on the nights July 2/3 (black), July 4/5 (red) and July 9/10 (green). The impact plume can be seen in CN and dust, being more extended in the CN than in the dust continuum (not shown here). The distances are positive towards the sun direction (Rauer et al., in preparation).

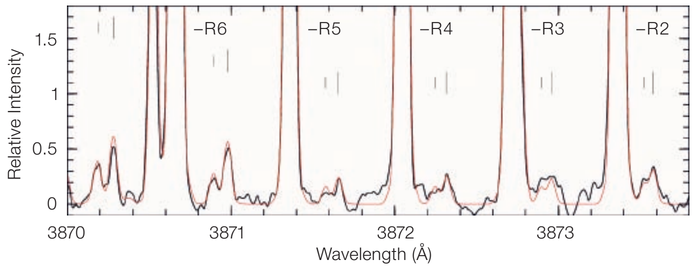

Figure 4 (above): Section of the UVES spectrum of the CN (0,0) band in Comet 9P/Tempel 1. The black *thick line* is the observed spectrum (50 hours); the *thin (red) line* is the best fitting synthetic spectrum of $^{12}C^{14}N$, $^{12}C^{15}N$ and $^{13}C^{14}N$ obtained for an isotopic mixture $^{12}C/^{13}C = (95 \pm 15)$ and $^{14}N/^{15}N = (145 \pm 20)$. The lines of $^{12}C^{15}N$ are identified by the short ticks and those of $^{13}C^{14}N$ by the longer ticks. The quantum numbers of the R lines of $^{12}C^{14}N$ are also indicated. This is only the second time that the C and N ratios have been measured in a Jupiter-family comet. The ratios are the same as in Oort Cloud comets. This will put important and interesting constraints on the formation history of Jupiter-family comets. (Jehin et al., in preparation).

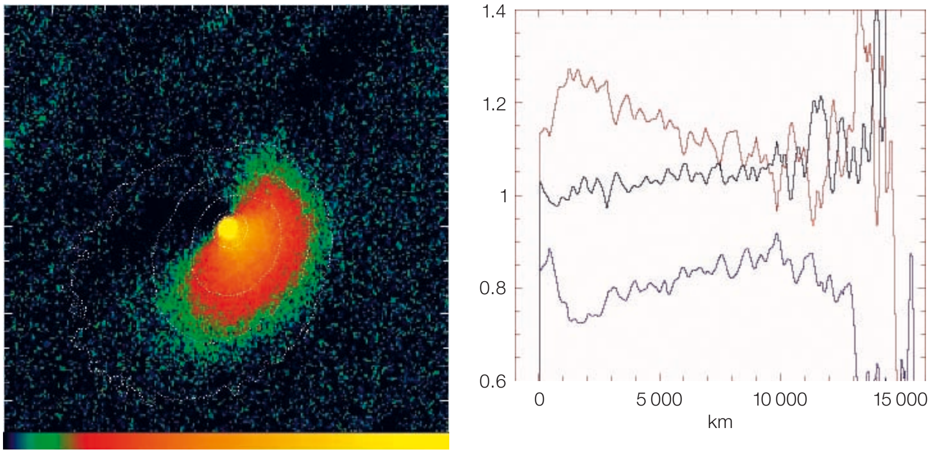

Figure 5 (left): Dust ejecta with SOFI: The left image shows the extra signal after impact ("normal" comet coma subtracted, July 4 – July 2) of the dust ejecta in *J*-band. The differences in the radial profiles of JHK images (right) of the ejecta cloud suggest that heavier dust is concentrated closer to the nucleus than the lighter one, since the *K*-band profile peaks at 2000 km projected nucleus distance while the *J*-band reaches maximum around 10 000 km distance. From the flux enhancement of the ejecta cloud over pre-impact level, we deduce a total dust production by the impact that compares to about 5–10 h of "normal" undisturbed activity of the nucleus at the time of the encounter (this assumes similar dust grain properties and a mean expansion velocity of about 100–200 m/s) (Tozzi et al., in preparation).

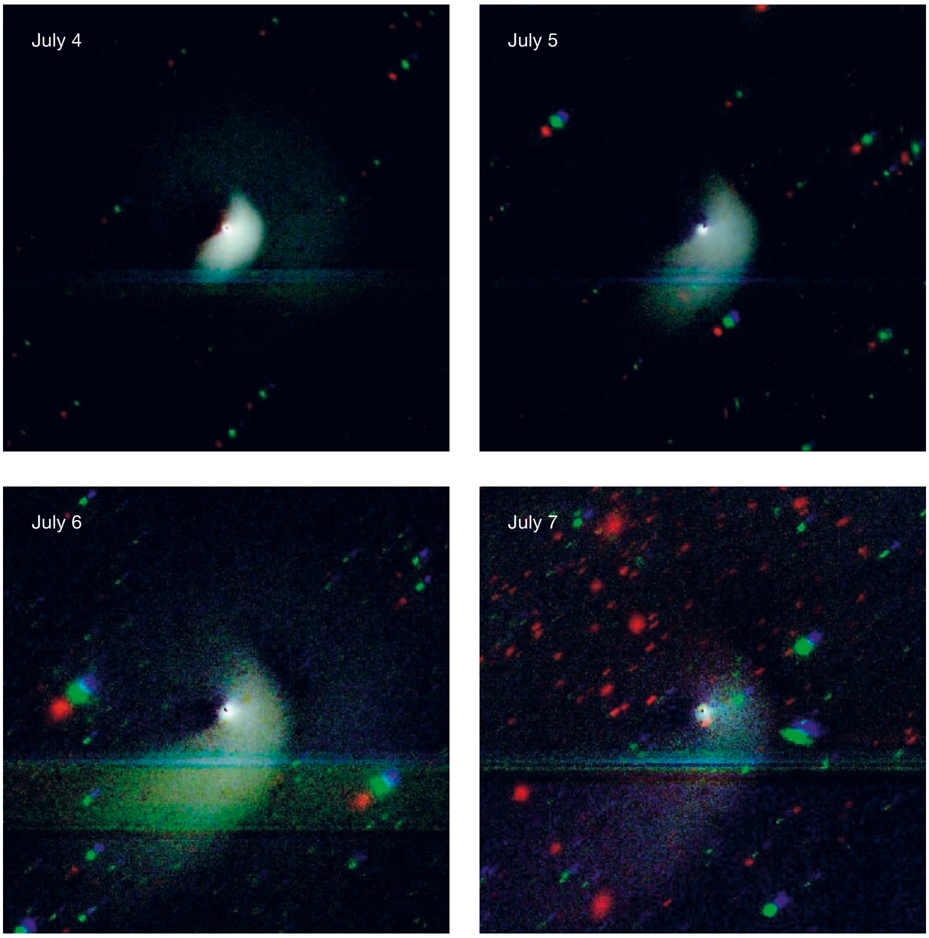

Figure 6: A set of four quasi-true-colour composite images with FORS2. The dust cloud from the impact was detected in broadband and narrowband images until July 8, 2005. On July 4 it had a semi-spherical shape expanding at the front edge with an average speed of about 200 m/s into the south-western coma quadrant (velocity of brightness maximum moved at about 120 m/s). The main axis of the cloud was at position angle (PA) of about 225 deg, which indicates that the impact happened below the orbital plane of the comet. The cloud expansion was slowed by radiation pressure during the subsequent days and reached a maximum expansion in the Sun direction of about 30 000 km. This distance compares to dust grains with a ratio of radiation pressure to gravity $\beta \sim 0.3$ (assuming an initial expansion speed of 200 m/s). Latest as of July 6, 2005, the dust started to be expelled into the tail direction (PA = 111 deg). The sudden drop in surface brightness between July 6 and 7 is yet to be understood.

craft – en route for a rendezvous with Comet 67P/Churyumov-Gerasimenko in January 2014 took part in the scientific observations of the impact event. Thanks to the coordination through Karen Meech at the University of Hawaii and colleagues at the University of Maryland a dedicated web-server was available and a permanent multi-site videoconference moderated from the control room of the NASA-3-m Infrared Telescope Facility (IRTF) on Mauna Kea provided the tools to communicate preliminary results and to have mutual consultation on the observations. Thus very effective observing was possible and duplication of observations minimised.

Observational results

All scientists involved in the ESO campaign met after the observations in Santiago at the ESO-Vitacura premises for a 10-day “conclave”. ESO had made available two conference rooms, and two data servers were set up, so that data reduction could start immediately. At this point nearly all data are reduced in the sense that the instrumental signatures have been removed and the data have been calibrated and converted into physical units. Now the real work has to begin, that is to compare the data to theoretical models and to put them into context with data from the spacecraft and from other observatories. The ESO data set was already partially presented at the IAU Symposium 229, August 7–12, 2005 *Asteroids, Comets, Meteors* (one oral presentation and four posters).

The following results from the spacecraft were reported at the recent IAU Symposium 229:

- the impact did release 1–2 * 10^7 kg of dust with a particle size < 10 µm; particles were pre-existing, i.e. not the result of impact shattering of larger structures
- the nucleus albedo is 4 %
- the crater formation was most likely “gravity controlled”; this implies that the tensile strength of comet material is of order of ~ 100 Pa, very similar to the limits set by the tidal disruption of comet Shoemaker/Levy 9 by Jupiter
- the impact angle was 50–70 deg (measured in the optical convention, from the surface normal)
- the nuclear shape model is not finished, but the size is 3.5 × 5 km (A’Hearn, IAUS 229)
- the infrared spectrum during the first seconds after impact showed: H_2O, HCN, (CH)x, CO_2 (CO_2/H_2O) ~ 0.08, CH_3CN (Sunshine, IAUS 229)

As a selection of ESO results a few spectra and images are presented here. In general one can note that 4–5 days after impact all impact related signatures had disappeared in the “noise” of normal cometary activity.

Dust grain characterisation

The characterisation of the physical and chemical properties of the dust grains was attempted – among others (dynamics, near-IR) – through mid-IR and polarimetric observations of the cometary coma before and after impact.
Mid-IR: By black-body fitting to mid-IR filter photometry of the cometary coma obtained with VISIR (VLT) and TIMMI 2 (LSO), a significant temperature increase of the dust was seen post-impact (330 K). The dust temperature dropped to the pre-impact level (280–290 K) as of July 6, 2005. However, the overall mid-IR flux,

measured in the very inner coma (3–5″), was higher from July 4–7, 2005 and returned to the pre-impact state only thereafter. The *N*-band spectra of the inner coma reveal a silicate emission with different profile shape pre- and post-impact. Preliminary modelling indicates the presence of a large amount of absorbing (carbon-like) material and an enhancement of amorphous and crystalline silicates in the post-impact dust. Furthermore, the post-impact dust seems to be enriched in crystalline silicates and displays a shallower size distribution (indicating larger grains present).

Polarimetry: The linear polarisation of the dust was found to be 7.5 and 0 % (Stokes Q and U, respectively) in the visible wavelength range. The polarisation did not change across the coma within ~ 7000 km projected distance from the nucleus and was found the same on July 3, 2005 (before impact) and July 5, 7, 9, 2005 (after impact). Using spectropolarimetric observations (July 5 + 9, 2005) we could not detect any wavelength dependence of the linear polarisation over the wavelength range ~ 400–850 nm. Moreover, the post-impact dust was found not to be circularly polarised over the wavelength and distance range mentioned above (July 8, 2005).

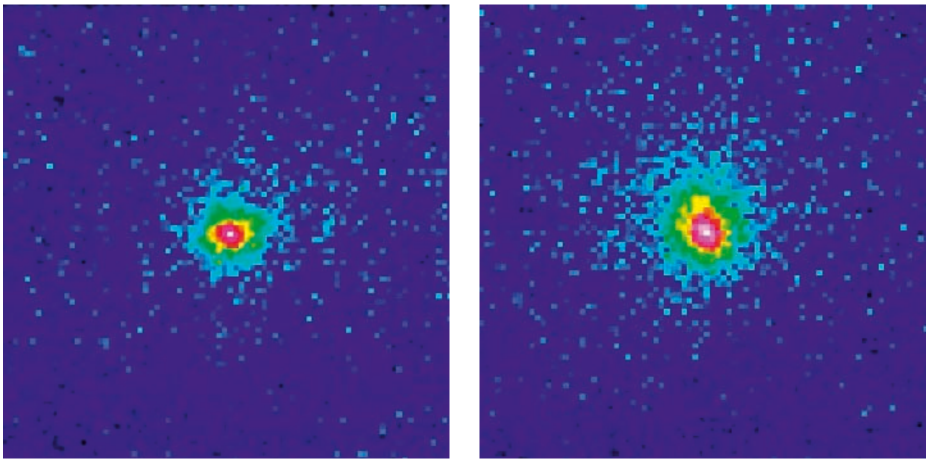

Figure 7: Sample images from TIMMI2 before and after impact: the left image was taken on July 3 00h38 UT while the right image was recorded on July 4 19h38 UT. The filter was the OCLI 11.9 μm filter, showing the strongest variations after the impact. The pixel scale in both cases is 0.2″/pix (130 km at the comet), N up E right. The right image was taken in daytime.

TIMMI2 observations

Thanks to daytime observing, the comet could be observed from La Silla 3–4 hours before Paranal. Indeed the TIMMI2 data are most likely the first data taken after impact with a professional telescope west of Greenwich! While the comet coma appears clearly brighter in the "after-impact" frames it is not entirely clear if this is due to the impact or normal activity. Ground-based mid-IR observations cannot detect a signal for distances exceeding typically ~ 4 arcsec or 2600 km due to sensitivity limitations. Assuming a "canonical" outflow velocity of 200 m/s this in turn implies that ground-based thermal IR observations are sensitive only to material (dust) produced by the comet in an interval of 10–15 000 s before observation. This has to be kept in mind when comparing any mid-IR data set obtained from the ground with optical, near-IR or data obtained by the Spitzer space-based observatory. TIMMI2 data shown here (as well as the VISIR data) thus refer to material which either has been released hours after the impact (fresh material under the impact site?), or is very slowly moving or even gravitational bound to the nucleus. (Käufl et al., in preparation).

Outlook and future work

At this point a series of special publications in Science is under way. Once results of the spacecraft are published in refereed journals we can start to assemble the global picture from all observations. Back during the Jupiter-SL9 event, the analysis of all observational data was severely handicapped as the impact areas were just behind the visible limb of Jupiter. Astronomers thus did not know the physical details of the impact and the viewing geometry was awkward. The DI spacecraft data, however will provide us with the "ground truth" of the impact and the associated physics. This will make the analysis much clearer. However, a synthesis of this unprecedented worldwide multi-wavelength data set is required to uncover synergies.

To that end a dedicated workshop "Deep Impact as a World Observatory Event – Synergies in Space, Time, and Wavelength" will take place August 7–10, 2006 at the Palace of The Royal Academies for Science and the Arts in Brussels (for more information consult *http://www.eso.org/~hukaufl/deepimpact.html*). The workshop will be organized by the Vrije Universiteit Brussels and ESO.

Acknowledgements

On behalf of all scientists involved in the campaign we wish to thank the observatory staff for "a job well done". In spite of all the "extras" asked for by this unusual and demanding campaign we felt a very positive attitude towards this project, including a genuine interest in the results of the observations. We appreciate the outstanding professionalism and dedication of everybody involved: everything worked perfectly for this campaign. After the observations, in Vitacura we found excellent working conditions and a warm hospitality.

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Note: For in-depth reading on the subject, *http://deepimpact.eso.org/* is a good starting point.

A Triple Asteroid System

Artist's impression of the triple asteroid system.

One of the thousands of minor planets orbiting the Sun has been found to have its own mini planetary system. Astronomer Franck Marchis (University of California, Berkeley) and his colleagues at the Observatoire de Paris[1] have discovered the first triple asteroid system – two small asteroids orbiting a larger one known since 1866 as 87 Sylvia[2].

"Since double asteroids seem to be common, people have been looking for multiple asteroid systems for a long time," said Marchis. "I couldn't believe we found one."

The discovery was made with NACO on the VLT. Using the observatory's Service Observing Mode, Marchis and his colleagues obtained images of many asteroids over a six-month period.

One of these asteroids was 87 Sylvia, which has been known to be double since 2001, from observations made by Mike Brown and Jean-Luc Margot with the Keck telescope. The astronomers used NACO to observe Sylvia on 27 occasions, over a two-month period. On each of the images, the known small companion was seen, allowing Marchis and his colleagues to precisely compute its orbit. But on 12 of the images, the astronomers also found a closer and smaller companion. 87 Sylvia is thus not double but triple!

Because 87 Sylvia was named after Rhea Sylvia, the mythical mother of the founders of Rome, Marchis proposed naming the twin moons after those founders: Romulus and Remus. The International Astronomical Union has approved the names.

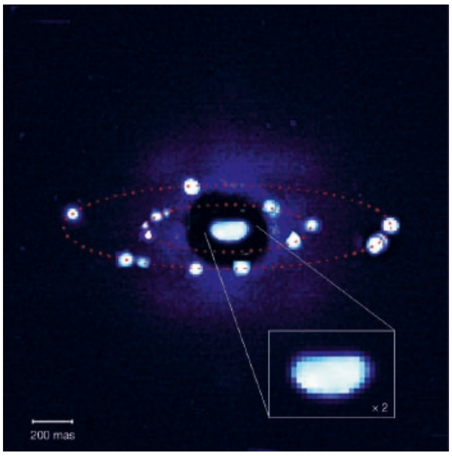
Sylvia's moons are considerably smaller, orbiting in nearly circular orbits and in the same plane and direction. The closest and newly discovered moonlet, orbiting about 710 km from Sylvia, is Remus, a body only 7 km across and circling Sylvia every 33 hours. The second, Romulus, orbits at about 1360 km in 87.6 hours and measures about 18 km across.

The asteroid 87 Sylvia is one of the largest known from the asteroid main belt, and is located about 3.5 times further away from the Sun than the Earth, between the orbits of Mars and Jupiter. The wealth of details provided by the NACO images show that 87 Sylvia is shaped like a lumpy potato, measuring 380 × 260 × 230 km. It is spinning at a rapid rate, once every 5 hours and 11 minutes.

The observations of the moonlets' orbits allow the astronomers to precisely calculate the mass and density of Sylvia. With a density only 20 % higher than the density of water, it is likely composed of water ice and rubble from a primordial asteroid. "It could be up to 60 per cent empty space," said co-discoverer Daniel Hestroffer. "It is most probably a 'rubble-pile' asteroid", Marchis added. These asteroids are loose aggregations of rock, presumably the result of a collision. The new asteroid formed later by accumulation of large fragments while the moonlets are probably debris left over from the collision that were captured by the newly formed asteroid and eventually settled into orbits around it. "Because of the way they form, we expect to see more multiple asteroid systems like this."

Marchis and his colleagues reported their discovery in the August 11 issue of the journal Nature, simultaneously with an announcement that day at the Asteroid Comet Meteor conference in Armação dos Búzios, Rio de Janeiro state, Brazil.

(Based on ESO Press Release 21/05)



A composite image showing the positions of Remus and Romulus around 87 Sylvia on nine different nights as seen on NACO images. It clearly reveals the orbits of the two moonlets. The inset shows the potato shape of 87 Sylvia. The field of view is 2 arcsec. North is up and East is left.

[1] The team is composed of Franck Marchis (University of California, Berkeley, USA) and Pascal Descamps, Daniel Hestroffer, and Jerome Berthier (Observatoire de Paris, France).

[2] 87 Sylvia is the 87th minor planet discovered. It was first observed from the Observatory of Madras (India) on May 16, 1866, by the Government Astronomer Norman R. Pogson. It was common in the early days to assign a name – mostly feminine – from the mythology to newly found asteroids. Pogson selected a name from the list furnished to him by Sir John Herschel.

FLAMES Observations of Old Open Clusters: Constraints on the Evolution of the Galactic Disc and Mixing Processes in Stars

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Open clusters are populous groups of stars whose members have the same age, chemical composition, and distance from the Sun. Hence, they provide homogeneous samples to investigate several important issues related to stellar and Galactic evolution. We present here an overview and preliminary results of a VLT/FLAMES programme aimed at a detailed study of seven old clusters. Our two main goals are the determination of the radial abundance gradients in the Galactic disc and their evolution with age, and the investigation of internal mixing processes in stars similar to our Sun.

Galactic open clusters (OCs) cover large intervals in age (from a few × 10^7 years to several billion years), metallicity (from about five times below to about twice above the solar value), and position in the Galactic disc (up to 22 kpc from the Galactic centre). OCs represent vital laboratories for stellar astronomy because they provide a means to study the individual properties of stars as a function of age, metallicity, and mass. On the other hand, the global properties of old OCs, and in particular their chemical composition, provide reliable information on the status of the disc at early epochs, which is crucial for a better understanding of the overall Galaxy formation and evolution.

In this article we describe a FLAMES project on old Galactic OCs aimed at addressing two distinct issues: namely, i) the formation and evolution of the Galactic disc, and ii) the study of the evolution of lithium abundances and mixing processes in solar analogues. Final results and conclusions require completion of the analysis of our large data set and detailed comparison with both results available in the literature and theoretical models. Here we provide an overview of the project together with a few examples of preliminary results, with the purpose of emphasising the wealth of information that can be achieved with a relatively small amount of observing time with FLAMES.

The astrophysical problems

1. Formation and evolution of the Galactic disc

Various important quantities related to the evolution of the Galaxy, such as star-formation history (SFH), initial mass function (IMF), or gas flows are still not well known. For example, the question of how much chaotic early accretion of dwarf satellites and star-forming clouds, on one side, and a smoother, dissipative gas accretion, on the other side, concurred to build up the Galaxy is currently one of the hottest open issues concerning galaxy formation (Freeman & Bland-Hawthorn 2002). Radial metallicity gradients and their evolution with Galactic age are among the most useful observational constraints that one can put on those processes and, more in general, on Galactic chemical evolution (GCE) models (Tosi 2000). For example, the predicted gradients can flatten or steepen in time, depending on the different model assumptions on the SFH and infall processes (e.g., Portinari & Chiosi 1999). Hence, empirically proving the flattening or steepening of the gradients with time appears crucial. Knowledge of [α/Fe] abundance ratios and their evolution as well represents an important tool to trace a galaxy SFH and IMF, since the timescales of the variations of the abundance ratios depend on both the SFH and the IMF. More specifically, the mass function affects the ratios of elements synthesised by stars of different mass, while the star formation rate regulates the timing of their production.

Several abundance studies exist for the solar neighbourhood, but we still know little about the chemical composition in other parts of the disc. The mean metallicity gradient has been determined based on different spectroscopic studies of a variety of tracers (H II regions, B stars, planetary nebulae (PNe), OCs). However, these samples provide partial results, mainly because they can only sample a limited range of distances and ages. In particular, indicators such as H II regions and B-type stars give independent estimates of the shape and magnitude of the present-day Galactic gradients, while information about the temporal variation of the gradients can be obtained only from PNe and old OCs. Also, uncertainties arise since different classes of objects (and even objects belonging to the same class) are often analysed using different methods, resulting in possible systematic effects in the derived gradients and in discrepant results. There is indeed a hot debate over whether OCs really present a metallicity gradient or rather a discontinuous distribution of metals with Galactocentric distance (Twarog et al. 1997). Finally, very little is known about [α/Fe] ratios, their radial distribution, and evolution with Galactic age (Friel 2005). It thus becomes mandatory to use a large, homogeneous OC sample – like that presented in this paper – in order to shed more light onto the actual behaviour of the metallicity distribution in the disc.

2. Evolution of lithium and mixing in solar-type stars

Lithium (Li) is destroyed by proton capture at the relatively low temperature of 2.5 MK and it is depleted from stellar atmospheres when a mechanism is present that is able to transport surface material down to the deeper stellar interiors where the temperature is high enough for Li burning. Thus, although the absolute abundance of this element is very small (3×10^{-9} in number with respect to hydrogen, at most), measurements of Li abundance in stars are unique tracers of internal mixing mechanisms. With the exception of very low mass, fully convective stars, the physics driving Li depletion in stars is not well understood. Measured Li abundances in stars of different spectral types (from early-F to late-K) and evolutionary stages (from pre-main-sequence – PMS – to evolved clump stars) strongly challenge the prediction of "standard" models of stellar evolution. With this term we refer to those models that include convection, but neglect other transport phenomena such as diffusion, gravity waves, rotation and angular momentum loss.

Focusing on stars similar to our Sun, standard models predict that they should deplete most of their Li while on the PMS, that they should not undergo any depletion on the main sequence (MS), and that stars with the same age, mass, and chemical composition should deplete a similar amount of Li. At variance with these predictions, observations of Li in field and cluster stars carried out during the last 20 years have shown that solar-type stars suffer very little PMS Li depletion, but do deplete Li on the MS. Li depletion is not a monotonic function of age; rather it seems to be bimodal and otherwise similar stars do not deplete the same amount of Li. Our Sun has a very low Li abundance, a factor of about 100 below the meteoritic value which is indicative of the initial solar abundance, but several stars with similar or even older age exist with a much higher Li. A large dispersion in Li abundances is also seen among MS stars in the solar-age, solar-metallicity cluster M 67 (Jones et al. 1999).

This puzzling scenario and, in particular the evidence for MS Li depletion, has motivated theoreticians to introduce non-standard or extra-mixing physics in the models. Several mechanisms have been proposed, together with the suggestion that an additional parameter, besides age, mass, and chemical composition, must affect Li depletion. Stellar rotation and/or rotational history appear as the most likely additional parameters, and rotational mixing is the extra-mixing process that presently receives the largest consensus; nevertheless, this process is not able to explain other observational results (for example beryllium abundances in M 67) and, as a matter of fact, the mechanism driving MS Li depletion in solar-type stars remains elusive (Randich 2005). We also mention that the effects of chemical composition on Li depletion which are predicted by theory are still rather poorly constrained.

Understanding mixing processes at work in Pop. I stars and their dependence on metals is important not only for a better comprehension of stellar structure and evolution; it also provides a key to investigate whether this mechanism may work for metal-poor Pop. II stars and, possibly, to explain the origin of the discrepancy between primordial ^{7}Li abundance predicted by WMAP and Big Bang Nucleosynthesis and the stellar value based on Pop. II star Li abundances (Romano et al. 2003).

The goals and target clusters

Until the advent of multiplex facilities on 8-m-class telescopes, high spectral resolution studies of OCs were very time consuming and limited to small samples of bright stars in the closest clusters. As a consequence, the open issues mentioned above could not be investigated in a comprehensive and systematic way, due to the lack of accurate, homogeneous abundance data sets for large samples of stars in OCs well sampling the age-metallicity-Galactocentric distance parameter space. By exploiting FLAMES capabilities, our project aims at simultaneously acquiring high-quality spectra of significant samples of evolved (7–14 per cluster) and unevolved (100–200 per cluster) members of seven well-selected OCs. Our specific goals are:

- The investigation of the [Fe/H] radial gradient in the disc and its evolution with Galactic age, based on a homogeneous abundance analysis of evolved cluster members;
- The determination of abundances of α and Fe-peak elements and their ratios to Fe, to study their radial distribution and evolution with Galactic age;
- The determination of cluster membership of photometric cluster candidates that will allow us to "clean" colour-magnitude diagrams. This is crucial in order to (re)derive secure and homogeneous cluster parameters (age, distance, reddening);
- The determination of Li abundances in MS and/or TO cluster members, in order to carry out a systematic study of the evolution of Li in solar-type stars and its dependence on chemical composition.

The multiplexing capability of FLAMES and its high efficiency are perfectly suited to our purposes. Radial velocities and Li abundances (from the Li 670.8 nm line) are determined from Giraffe spectra of unevolved cluster stars, while the detailed chemical analysis is obtained from UVES spectra of cluster clump or RGB members.

Giraffe has been used in MEDUSA mode with the high-resolution gratings covering the ranges 630.8–670.1 nm, 660.7–679.7 nm and 647.0–679.0 nm. With UVES CDs covering 476.0–684.0 nm and 660.0–1060.0 nm have been used, allowing us to target, besides several iron lines, the forbidden lines of O around 630.0 nm, Na at 568.2–568.8 nm and 615.4–616.0 nm, Mg and Ca from several lines, Si from lines around 570.0 nm. The O I triplet at 777.4–777.7 nm, the Na lines at 813–819.4 nm, the N ones around 800.0 nm, and the $^{12}C/^{13}C$ isotope from the CN lines around 800.0 nm are included in the red UVES setting.

The sample clusters are listed in Table 1, while in Figure 1 we show, as an example, the colour-magnitude diagram of Berkeley 32, the most metal-poor cluster in our sample. Table 1 shows that the selected clusters span large intervals in age, distance, and metallicity. Our sample will be complemented by a sample of three additional old OCs observed in the context of the Ital-FLAMES Guaranteed Time (GTO) programme (Pallavicini et al. 2005).

Two observing runs were approved for this programme, for a total of about 50 hrs; one of them was performed in Service Mode, while the other one has been carried out in Visitor Mode. The data were reduced using the UVES pipeline within MIDAS and the Giraffe BLDRS pipeline. Examples of extracted UVES spectra of clump stars in NGC 3960 are plotted in Figure 2, while in Figure 3 we show Giraffe spectra of 16 MS stars in NGC 6253 around the Li I 670.8 nm spectral region.

Results: first examples

Cluster membership

In Figure 4 we show the radial velocity histograms obtained from the analysis of Giraffe spectra of 196 and 111 photometric candidate members of NGC 6253 and Be 32 respectively. In both cases the distribution of radial velocities is characterised by a well-defined, narrow peak, implying a small velocity dispersion. Our velocity determination for Be 32 is in good agreement with available velocities for evolved cluster members from the literature. To our knowledge no radial velocity measurements have so far been performed for NGC 6253 and thus our estimate represents the first determination of the cluster velocity. Noticeably, for both clusters the percentage of confirmed members is rather low (slightly above 50 %).

A zoom of the colour-magnitude diagram of Be 32 is shown in Figure 5; radial-velocity members are denoted as red dots. The figure indicates that, when removing

Cluster	Age (Gyr)	[Fe/H]	R_{GC}(kpc)	D (kpc)	E (B-V)
NGC 3960	0.9	–0.34	8.0	1.7	0.29
NGC 2324	0.9	–0.15	11.6	3.6	0.20
NGC 2477	1.0	–0.13	8.9	1.3	0.28
NGC 2660	1.1	–0.18	9.2	2.8	0.31
NGC 6253	3.0	+0.36	7.0	1.5	0.20
Be 29	3.5	–0.44	22.0	14.8	0.16
Be 32	7.2	–0.50	11.3	3.1	0.15

Table 1: Sample clusters in increasing age order. Cluster parameters (age, [Fe/H], Galactocentric distance, distance from the Sun, and reddening) have been retrieved from different sources in the literature. [Fe/H] values for most of the clusters have been derived from low-resolution spectra or photometry and are not on the same scale. One of the goals of the present project is the homogeneous determination of cluster parameters and abundances.

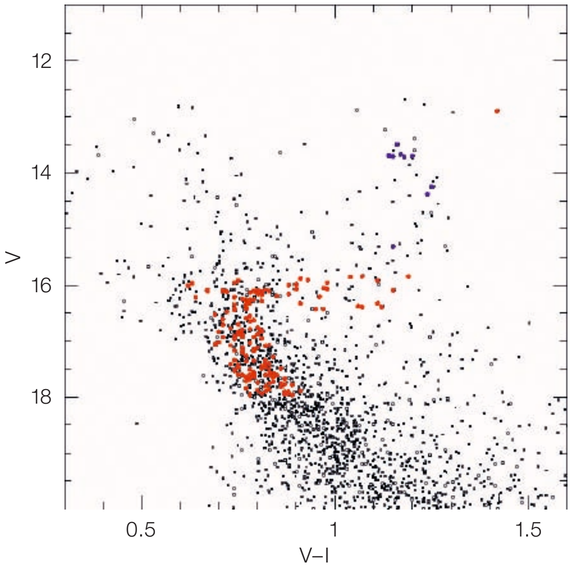


Figure 1: V vs. V-I colour-magnitude diagram of Berkeley 32. Photometry was retrieved from the literature. Two FLAMES pointings on this cluster were obtained and stars observed in both pointings are shown in the figure. UVES targets are denoted as blue symbols, while Giraffe/Medusa targets are indicated as red symbols.

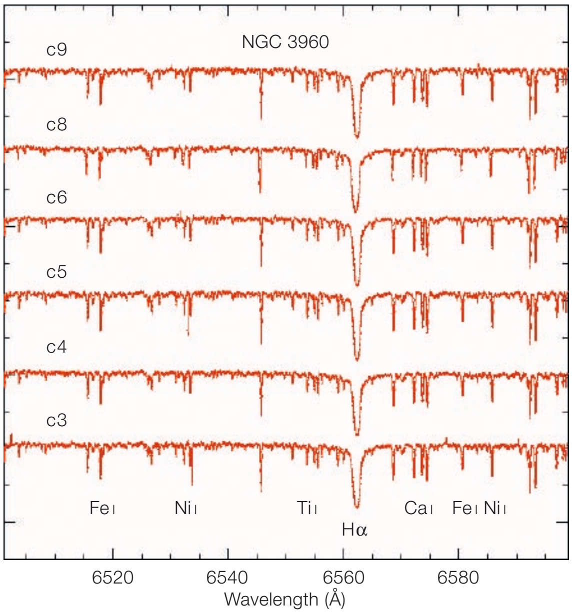


Figure 2: UVES spectra of six clump members of NGC 3960 in a 100 Å wide region around Hα. Besides Hα, a few lines employed for the chemical analysis are indicated. Abundance analysis has been performed using MOOG and Kurucz model atmospheres. The sample stars have magnitudes V ~ 13 and the spectra are the sum of two 45 minute long exposures.

non-members, the cluster sequence of confirmed members remains rather broad. This suggests the presence of a significant fraction of photometric binaries and/or differential reddening. Interestingly, we note that all but one of the stars bluer and brighter than the TO, which were classified as possible blue stragglers belonging to the cluster, are instead non-members.

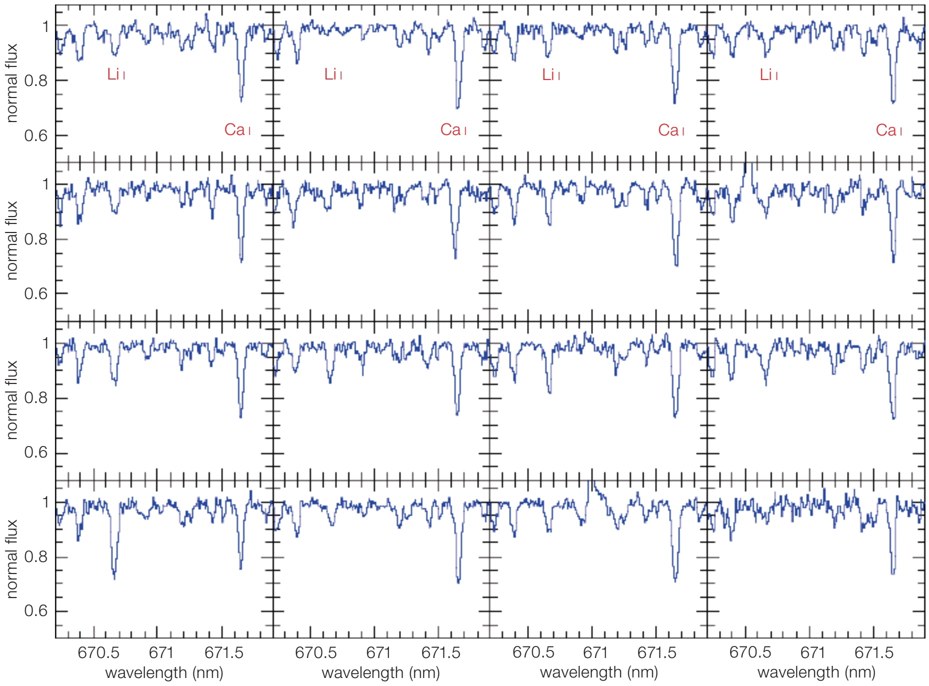
Chemical abundances: NGC 3960

NGC 3960 is one of the youngest and closest clusters in our sample. It hence represents an important extreme for the determination of the radial metallicity gradient and its evolution with Galactic age. A photometric study of this cluster was recently carried out by Prisinzano et al. (2004), who concluded that the cluster has an age between 0.9 and 1.4 Gyr and is characterised by differential reddening. Spectroscopic studies of the cluster are therefore also important to better constrain its parameters.

From the analysis of the UVES spectra of seven clump stars we derive an iron content close to solar ([Fe/H] = −0.02 ± 0.11), at variance with earlier reports of a somewhat lower metallicity ([Fe/H] = −0.34) based on modest-resolution spectra. This result evidences the need for abundance determinations using high-resolution spectra. Also, the previous low-metallicity estimate for NGC 3960 made this cluster one of the most metal-poor ones at its age and Galactocentric distance, significantly contributing to the dispersion in the [Fe/H] vs. age and R_{GC} diagrams at relatively young ages and small distances. This dispersion is considerably reduced when considering the value of [Fe/H] derived by us.

Our [X/Fe] ratios represent the first determinations of these quantities for NGC 3960; we find values close to solar ratios for Mg, Si, Ti, and Ni, while aluminium is slightly underabundant and Na, Ca and Cr appear somewhat enhanced. The mean [α/Fe] ratio is almost solar.

Figure 3: Giraffe spectra of 16 MS members of the metal-rich cluster NGC 6253. The Li I 670.8 nm and Ca I 671.8 nm features are indicated in the upper row. Magnitudes of the sample stars are in the range V = 15.5–16.5 and they were exposed for 45 min. Note the varying strength of the Li feature for stars with similar Ca I line (i.e. of similar spectral type).



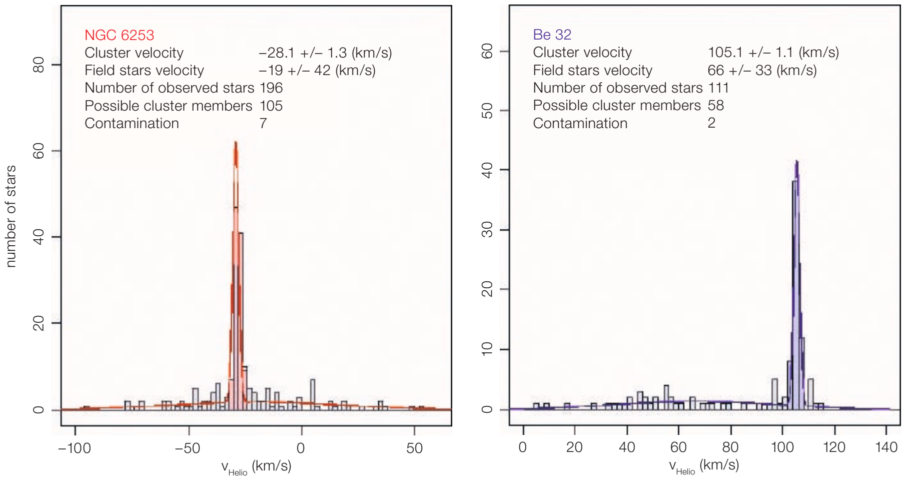


Figure 4: Left: Histogram of heliocentric radial velocities of candidate NGC 6253 members observed with Giraffe. The solid line indicates the best fit of the observed distribution obtained using a maximum likelihood fitting procedure. The resulting mean velocities for the cluster and field stars are indicated, together with their standard deviations, the number of possible cluster members, and expected number of contaminants. Individual radial velocities of cluster stars were determined either with our own procedures within the MIDAS or IRAF[1] contexts or using the appropriate recipe within the BLDRS software. As a by-product, we were able to assess the accuracy of the latter and its dependence on the set-up (or spectral range), the reference templates, and the S/N ratio of the spectrum. **Right:** Same as left-hand panel, but the histogram of radial velocities for Berkeley 32 is shown.

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[1] IRAF is distributed by the National Optical Astronomical Observatory, which is operated by the Association of Universities for Research in Astronomy, under contract with the National Science Foundation.

Lithium in NGC 6253

NGC 6253 is the most metal rich cluster in our sample and provides a good target to better investigate the dependence of Li depletion on metals, which is predicted by both standard and non-standard models. In particular, at the high metallicity of this cluster a larger amount of Li depletion for a given mass is expected.

In Figure 6 we show the canonical plot of Li abundances vs. effective temperature for NGC 6253 MS stars together with the distribution of M 67. Besides the normal trend of decreasing Li abundance with decreasing temperature (mass), two important features are evident in the figure: 1. Li abundances for stars warmer than about 5 800 K are characterised by a small dispersion, much narrower than that observed among M 67 members. On the other hand, cooler stars do show a dispersion comparable to M 67. Together with the results for other old clusters, this suggests that the presence of the scatter and the temperature/mass at which it is seen are related to some (still unknown) characteristics of the cluster, rather than to the cluster age. The complete analysis of the whole Li data set will shed more light on this aspect. 2. Stars in the upper envelope of NGC 6253 are not more Li depleted than stars in the upper envelope of the about a factor of two more metal poor M 67, suggesting that, at variance with model predictions, even a rather large difference in the overall metal content does not affect the rate of Li depletion, at least in the temperature range considered here.

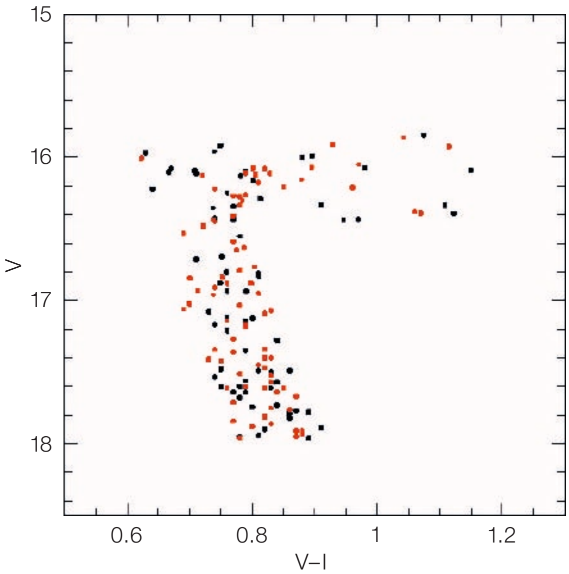

Figure 5: Zoom of the colour-magnitude diagram of Berkeley 32. Only Giraffe targets are plotted. Red and black filled circles indicate confirmed radial-velocity members and stars rejected as members.

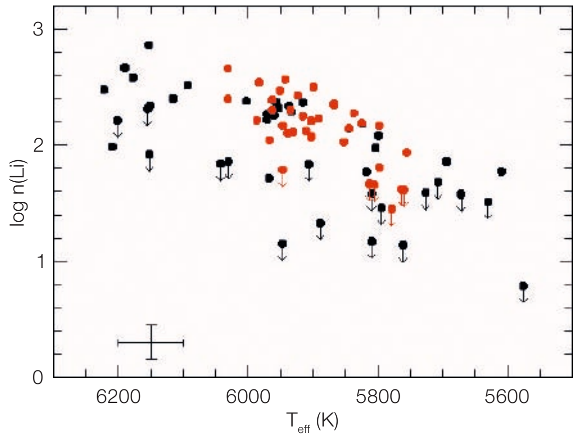

Figure 6: Lithium abundances (log n(Li) = log n(Li)/n(H) + 12) as a function of effective temperature (T_{eff}) for NGC 6253 (red symbols) and M 67 (black symbols). The sample of NGC 6253 includes only stars covered by one of the two pointings on this cluster, that were confirmed as members, and that are fainter than V = 15.5, i.e., are still on the MS and have not undergone any post-MS Li dilution. Data for M 67 were taken from the literature. NGC 6253 Li abundances were determined using the method that we have used in other studies and consistently with M 67.

In summary, the few preliminary results discussed above already attest the strength of our approach. Radial velocity analysis has been completed for all the sample clusters and we are now ready to determine cluster parameters in a homogeneous way using the synthetic colour-magnitude diagram technique developed by us. At the same time, we will complete the analysis of UVES spectra to derive the chemical composition of the whole sample and the analysis of Giraffe spectra for Li determination. Spectra of the clusters observed in the context of the GTO project mentioned above are also being consistently analysed. The final homogeneous data set of cluster parameters and abundances will let us put stringent and robust empirical constraints on models of Galactic disc formation and evolution, as well as on the physics at work in the interiors of solar analogues during the MS phases. Several spin-off scientific topics will also be addressed.

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Measuring Improved Distances to Nearby Galaxies: The Araucaria Project

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An intense use of ESO telescopes over the past years has allowed us to make significant improvements in the characterisation of stellar populations, and in the determination of the distances of nearby galaxies. We report on recent progress on the use of Cepheid variables and blue supergiant stars for the accurate measurement of galaxy distances. This work will finally lead to a significant reduction of the uncertainty on the Hubble constant, which measures the current rate of expansion of the Universe.

Figure 1: The spiral galaxy NGC 55 in the Sculptor Group, one of the target galaxies of the Araucaria Project. The presence of an abundant young stellar population is revealed by the many blue objects concentrated towards the disc of this galaxy.

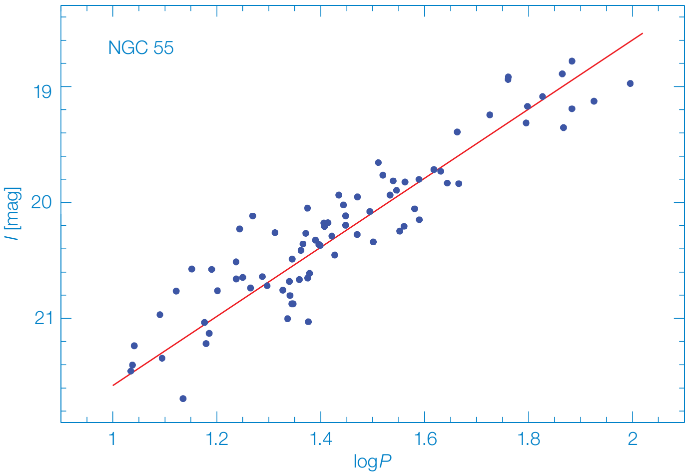
The measurement of distances to astronomical objects is a fundamental problem ever since humanity began to look at the stars. Knowledge of precise distances to galaxies is important for the study of a broad range of astrophysical phenomena, including the true energy outputs of luminous sources; it is also fundamental for establishing accurate cosmological parameters which describe the actual state, and history of the Universe. One parameter of particular interest is the Hubble constant H_0 which measures the current acceleration of the expanding Universe. Some ten years ago, the *HST Key Project on the Extragalactic Distance Scale* (Freedman et al. 2001) set out to measure Cepheid distances to a sample of nearby galaxies in order to calibrate far-reaching secondary methods of distance measurement which could be used to determine the distances to galaxies remote enough to find an unbiased value of H_0. Their very successful work was hampered by the fact that Cepheid variables are not a perfect instrument for distance measurement. Cepheids, like other stellar standard candles, are affected to some degree by the environmental properties of their host galaxies, most notably abundances of the heavy elements, and the ages of the stellar populations. Such effects must be taken into account if truly accurate distances to nearby galaxies are to be measured. With this motivation in mind, our group set out, a few years ago, to thoroughly investigate the environmental dependences of a number of stellar distance indicators, including Cepheids, blue supergiants, RR Lyrae stars, red clump giants, and the tip of the red giant branch (TRGB) magnitude in the *Araucaria Project (http://ifa.hawaii.edu/~bresolin/Araucaria/)*. This project is a necessary complement to the *HST Key Project*. Over the past two years, the Araucaria Project has obtained a *Large Programme* status at ESO, and a number of important scientific results have emerged from the abundant data obtained with ESO telescopes, some of which we will briefly describe in this article. In this progress report, we will focus on two types of distance indicators, the pulsating Cepheid variables, and the extremely luminous blue supergiant stars.

Progress on the Cepheid period-luminosity relation

The radially pulsating and relatively cool Cepheid supergiant stars exhibit a well-known relation between their mean intrinsic luminosity, and their pulsation periods – *the famous period-luminosity* (PL) *relation*, which is normally written in the form $M = a \log P + b$, where M is the mean absolute magnitude (in a given photometric band), and P the period (in days). With the PL relation calibrated, the mean luminosities of Cepheids, and thus their distances, can be inferred from their periods. In order to determine the dependence of the PL relation on metallicity, we have been conducting surveys for Cepheids in a number of spiral and irregular galaxies of widely different metallicities in the Local Group, and in the Sculptor Group. From a comparative study of the PL relations exhibited by the Cepheids in the different galaxies, in a variety of optical and near-infrared photometric bands, we can expect to determine both, the effect of metallicity on the *slope*, and on the *zero point* of the PL relation, and to filter out the most appropriate photometric band for distance work in which the effect is minimised.

So far, we have completed optical (BVI) surveys for Cepheids over the whole spatial extents for the Local Group galaxies NGC 6822 (Pietrzynski et al. 2004), NGC 3109 and WLM; these data complement previous surveys for Cepheids in other Local Group irregular galaxies (LMC, SMC, and IC 1613). In Sculptor, Cepheid surveys have been completed for the spiral galaxies NGC 300 (Gieren et al. 2004), NGC 55, NGC 247, and NGC 7793. The wide-field imaging data used in these surveys were obtained at the ESO 2.2-m telescope and WFI instrument, with a strong complement from the Polish 1.3-m telescope and mosaic camera at Las Campanas Observatory, and the 4-m Blanco telescope and mosaic camera at CTIO. In all Araucaria target galaxies, including those in the Local Group, we were able to very substantially enlarge the number of known Cepheids, and in particular find long-period ones which carry the strongest weight in the distance determinations. In three of the four Sculptor Group spiral galaxies, we have discovered the first Cepheid variables ever. An example is NGC 55 (Figure 1); in this galaxy, we have detected 81 Cepheids with periods in the range 10–100 days which define a tight PL relation (Figure 2). In Figure 3, we show the light curves of two of these variables in the *V*- and *I*-bands, obtained from our mosaic images taken on about 50 different nights. As an example of the improvement on the Cepheid census in the Local Group, we show in Figure 4 (see next page) the PL relation defined by some 100 Cepheids in NGC 3109, most of them discovered in the Araucaria Project from data taken during 80 nights at the Polish 1.3-m telescope on Las Campanas. In contrast to the more massive spiral NGC 55, NGC 3109 does not contain a population of very long-period Cepheids.

Figure 2: The Cepheid period-luminosity relation defined by Cepheid variables in NGC 55, in the *I*-band. The period P is in days. From wide-field images taken on about 50 different nights, we discovered 81 Cepheids with periods longer than 10 days – these are the first Cepheid variables ever discovered in this galaxy. Differential reddening in this rather inclined galaxy is likely to contribute significantly to the observed scatter. This effect should be greatly reduced in the near-infrared PL relations we are currently measuring from VLT/ISAAC images.



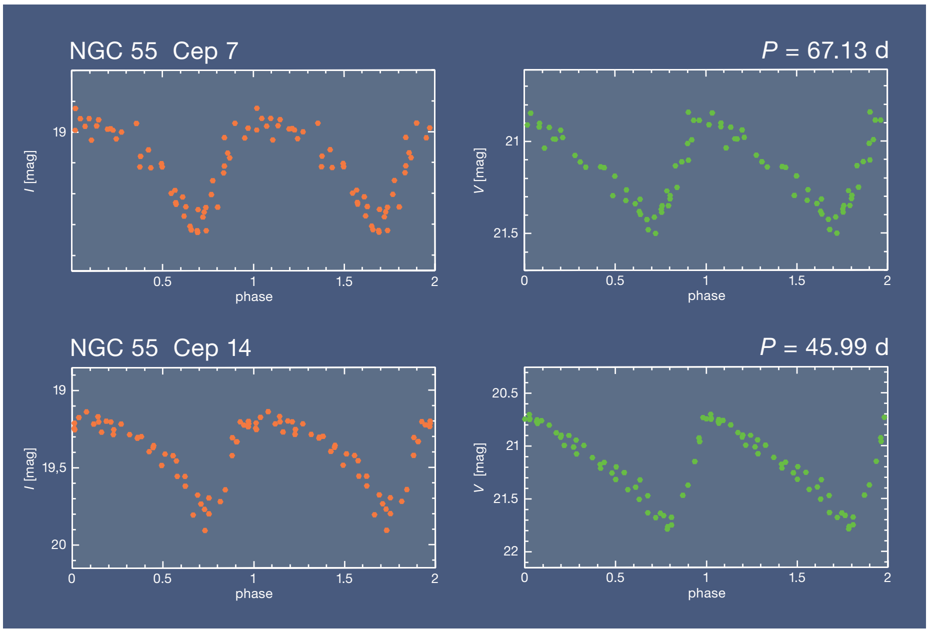


Figure 3: Phased light curves in *V*- and *I*-bands for two of the Cepheids we discovered in NGC 55. The periods are indicated on the plots. Such data lead to a very precise determination of the mean magnitudes of the variables.

One first conclusion from these data is that in the optical V and I bands, the slopes of the PL relations observed in all these different galaxies are consistent with the slopes defined by the LMC Cepheids observed in the OGLE-II Project (Udalski 2000), arguing for a very small metallicity effect (consistent with a null effect) on the PL relation *slope* in the [Fe/H] range from about – 1.0 dex to – 0.3 dex, spanned by the young populations of our target galaxies. Recently, our distance work on LMC and Milky Way Cepheids with the direct Baade-Wesselink-type *infrared surface brightness technique* (Gieren et al. 2005a) has furthermore provided strong evidence that the slope of the PL relation keeps being independent of metallicity up to the solar abundance shown by the Milky Way Cepheids. This is an especially important result since many of the massive spiral galaxies in the HST Key Project have near-solar heavy-element abundances. Application of the LMC Cepheid slopes in V and I to the observed Cepheid PL relations in such

Figure 4: The Cepheid PL relation in the *I*-band for the Local Group galaxy NGC 3109. Most of the Cepheids in this plot were discovered in the Araucaria Project. Note that NGC 3109, in contrast to NGC 55, does not contain truly long-period Cepheids – the longest observed period is 31 days.

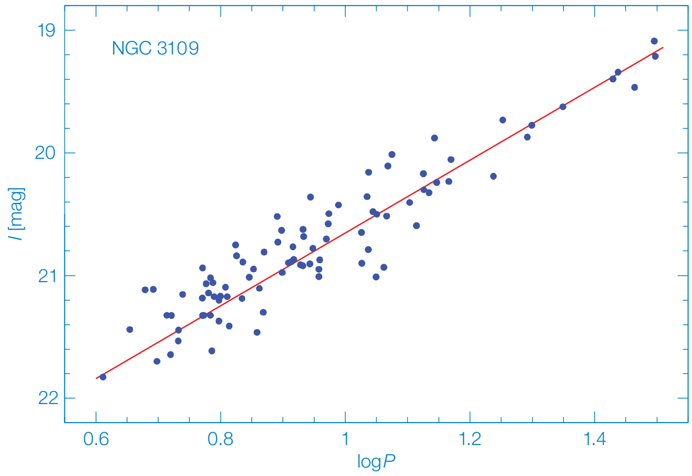
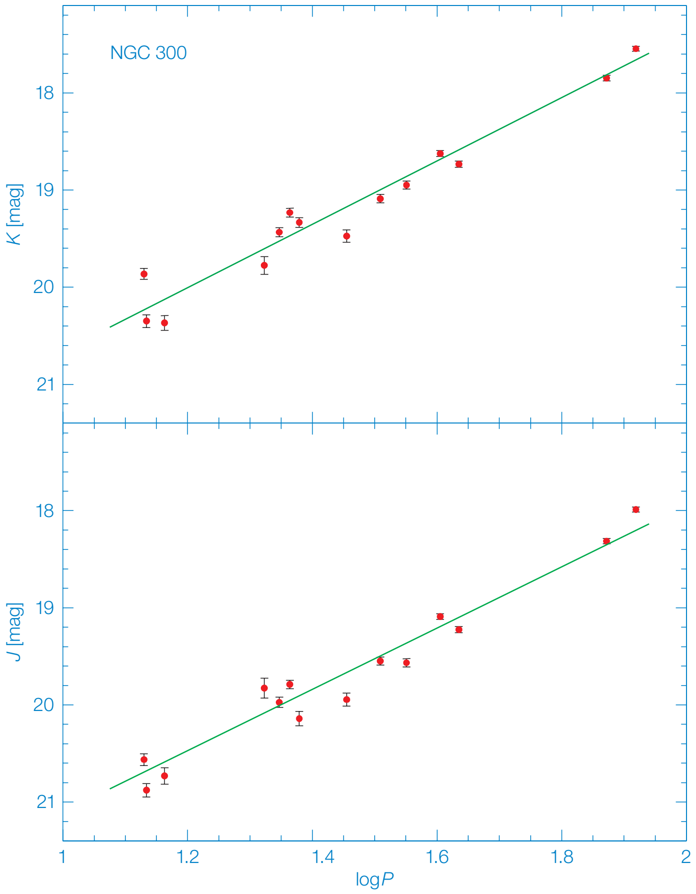


Figure 5: The near-infrared PL relations in *J*- and *K*-bands determined from VLT/ISAAC data for Cepheids in the Sculptor galaxy NGC 300. The variables were previously discovered by Pietrzynski et al. (2002) from wide-field images obtained at the ESO-MPI 2.2-m telescope. Each Cepheid was observed at two different epochs and its mean magnitude determined with the method of Soszynski et al. (2005). The data fit very well the PL relations in *J* and *K* as obtained for the LMC Cepheids by Persson et al. (2004). The slopes of the solid lines were taken from this work.



galaxies should therefore not cause any important systematic problem.

Very recently (Bresolin et al. 2005a), we have been testing the effect *blending* of Cepheids with nearby projected neighbour stars in the crowded images of distant galaxies has, by comparing ground-based photometry of Cepheids in NGC 300 from ESO-WFI data to BVI images of the same Cepheids obtained with the Hubble Space Telescope and ACS. In the case of NGC 300, with its distance of close to 2 Mpc, the systematic effect of blending on the distance derived from the ground-based images is found to be only ~ 2 per cent. The main reason is that long-period Cepheids are intrinsically bright enough to outshine nearly all of the close companions on the images, making their relative contributions to the Cepheid flux measured on ground-based images insignificant in most cases. This is good news for ground-based Cepheid distance work on relatively distant galaxies.

Since the LMC Cepheids are currently providing the fiducial PL relations for the distance determination of other galaxies, owing to the very large number of Cepheids discovered by the OGLE-II and other microlensing projects, it is extremely important to establish the Cepheid PL relations (in different bands) in the LMC with the highest possible accuracy. Since the existing microlensing surveys have not found many long-period Cepheids in the LMC, due to long integration times which overexposed any Cepheids longward of periods of ~ 30 days, we are currently undertaking a “shallow” Cepheid survey in the LMC with the Polish 1.3-m telescope on Las Campanas which is expected to discover a large number of new bright, long-period Cepheids close to the bar. These data, which cover most of the spatial extent of the LMC and which will become available in 2007, will also decide the nagging question of whether the LMC Cepheid PL relation shows a break near 10 days, as claimed by Sandage et al. (2004). Such a departure from a uniform slope over the whole period range, if real, would evidently constitute a serious problem in the use of the Cepheid PL relation for distance work. If the break at 10 days turns out to be real, new fiducial LMC PL relations must be established in the period range longwards of 10 days, which is the relevant range for the measurement of the distances of galaxies beyond about 1 Mpc. Our current “LMC shallow Cepheid survey” is expected to provide a significant improvement of the calibration of the LMC Cepheid PL relation in V and I, and provide a definitive answer about the reality of a period break in the relation.

Cepheid work in the near-infrared

There are at least three substantial advantages when Cepheid distance work is carried out in near-infrared bands. The first obvious advantage is the strong reduction of the effect of dust absorption. A second advantage is that Cepheid light curves in the near-infrared, and particularly in the *K*-band, are more symmetrical than their optical light curves, and have smaller amplitudes. This makes it possible to measure a Cepheid’s mean *K*-band brightness with a very good precision from just one random phase photometric observation, if the star’s optical light curve and period is known (Soszynski et al. 2005). *K*-band PL relations can therefore be determined very economically if the Cepheids of a galaxy have been previously found and characterised in the optical spectral range.

In addition to these important advantages, theoretical studies suggest an even smaller dependence of the PL relation on metallicity in the near-infrared, as compared to optical wavelengths.

For these reasons, we have been undertaking near-infrared follow-up imaging for selected subsamples of long-period Cepheids in most of the target galaxies of our project. We have been obtaining these images using VLT/ISAAC, and the NTT with the SOFI instrument. Superb results are being obtained from these very high-quality data, as recently demonstrated in the case of NGC 300. Figure 5 shows the PL relations in the *J*- and *K*- bands obtained from our VLT images for this galaxy, which have led to a very accurate determination of the distance to NGC 300 by combining the near-infared and optical data for this galaxy (Gieren et al. 2005b; see also a recent August 1, 2005 ESO Press Release). The work on NGC 300 has shown how essential infrared images are to achieve an accurate determination of the reddening of a galaxy, including the contribution coming from dust absorption inside the galaxy. Only in this way can it be hoped to achieve the final goal of the Araucaria Project, which is to measure the distances to nearby galaxies with a precision of at least 5 per cent, or better.

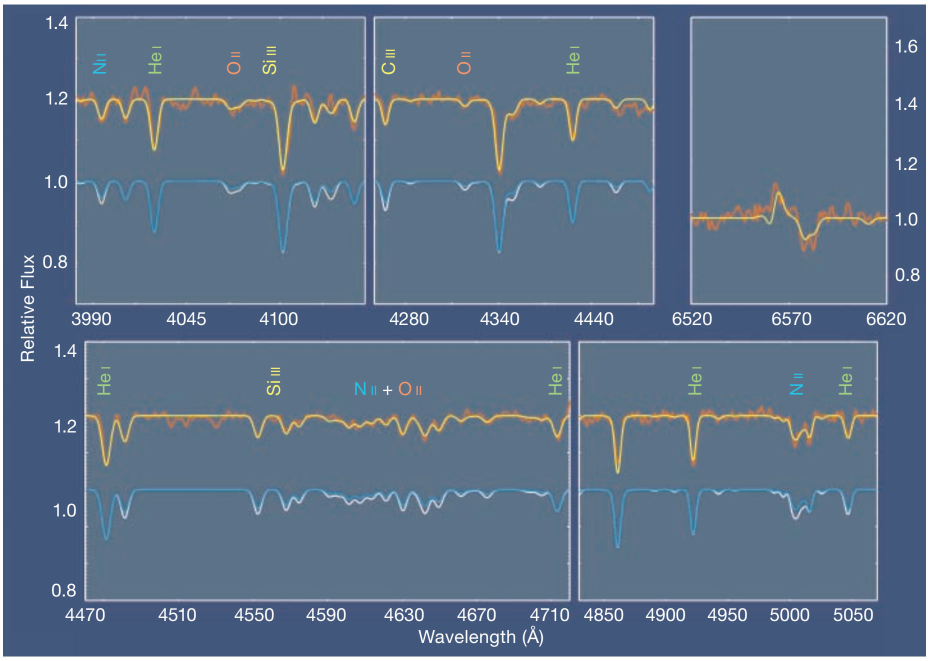


Figure 6: The technique used to measure the abundance of metals of blue supergiants is shown here. With the stellar gravity fixed by fits of model spectra to the high-order Balmer lines and the effective temperature determined from line diagnostics, the abundances of different elements are varied in the models until the best fit (in yellow) to the observed spectrum (orange line) is obtained. The sensitivity to the abundance is indicated in the lower part of the panels, where models differing by ± 0.2 dex relative to the best-fitting model are compared. The effects of strong stellar winds in this B3 supergiant in NGC 300 are visible in the Hα line, which is in emission (upper right).

Blue supergiants

The spectroscopy of blue supergiants, the brightest young stars visible in galaxies, and among the most massive, is an integral part of the Araucaria Project. The goal of our detailed study of these stars is twofold: to measure chemical abundances of heavy elements and to develop and apply a new distance determination technique based on a small set of fundamental stellar parameters.

Gathering information on the metal content of galaxies is essential to obtain accurate distances, since the techniques used, such as the Cepheid PL relation, could significantly depend on metallicity. The chemical abundances in spiral and irregular galaxies are commonly obtained from the spectroscopic analysis of giant H II regions, resulting from the photoionisation of gas clouds by hot stars. There are, however, considerable uncertainties on the gas-phase abundance scale at high metallicity (around the solar value and above), as encountered in the central regions of spiral galaxies (Bresolin et al. 2005b). Stellar abundance studies allow us to circumvent this difficulty, although the chemical analysis in young massive stars is a complex task, due to strong departures from conditions of local thermodynamic equilibrium and to the effects of stellar winds on the atmospheric structure. It is important to note that both the blue supergiants and the H II regions are young (< 10–20 million years) objects, and therefore the galactic chemical abundances derived from them are relevant for the study of young stellar distance indicators, such as Cepheids.

The analysis of the chemical composition of blue supergiants complements the study of H II regions, which is limited mostly to the abundances of oxygen, nitrogen and sulphur, by providing information not only for these elements, but also for additional species, such as magnesium, iron and silicon. Model spectra, calculated accounting for the presence of millions of atomic transitions, are compared to the observed supergiant spectra to measure the abundances of these metals. An example of this procedure is shown in Figure 6, taken from our chemical analysis of early B-type supergiant stars in NGC 300 (Urbaneja et al. 2005). By combining our good-quality data with modern stellar-atmosphere analysis techniques for massive stars we have been able to compare for the first time in a galaxy located outside the Local Group the chemical abundance gradient in its disc obtained independently from the stellar analysis, and from the ionised gas (Figure 7).

The NGC 300 observations were carried out utilising the multi-object spectroscopic capabilities of FORS at the VLT, yielding intermediate-resolution spectra of several dozens of stars in this galaxy (Bresolin et al. 2002). This observing strategy, repeated for all the galaxies included in the Araucaria Project, has allowed us to collect several hundred spectra of blue supergiant candidates (the case of NGC 247 in Sculptor is shown in Figure 8). This represents an unprecedented sample of extragalactic massive star spectra, of

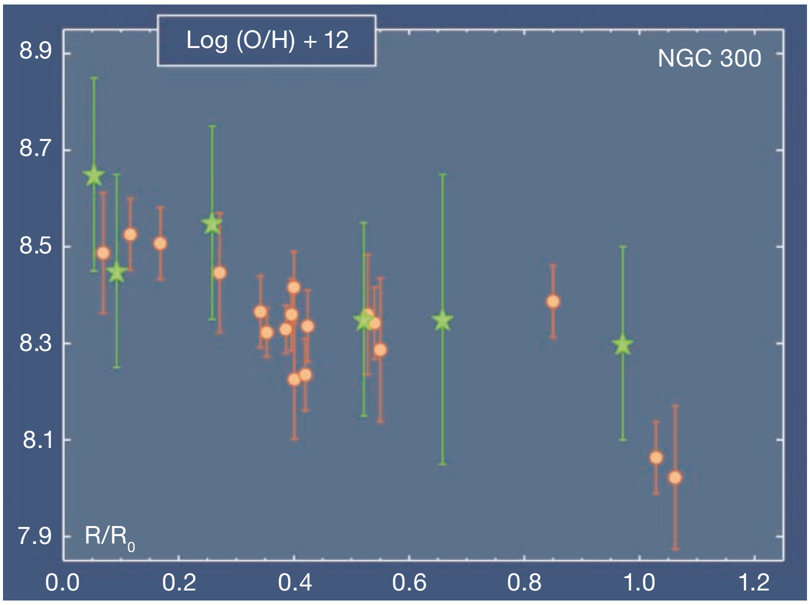
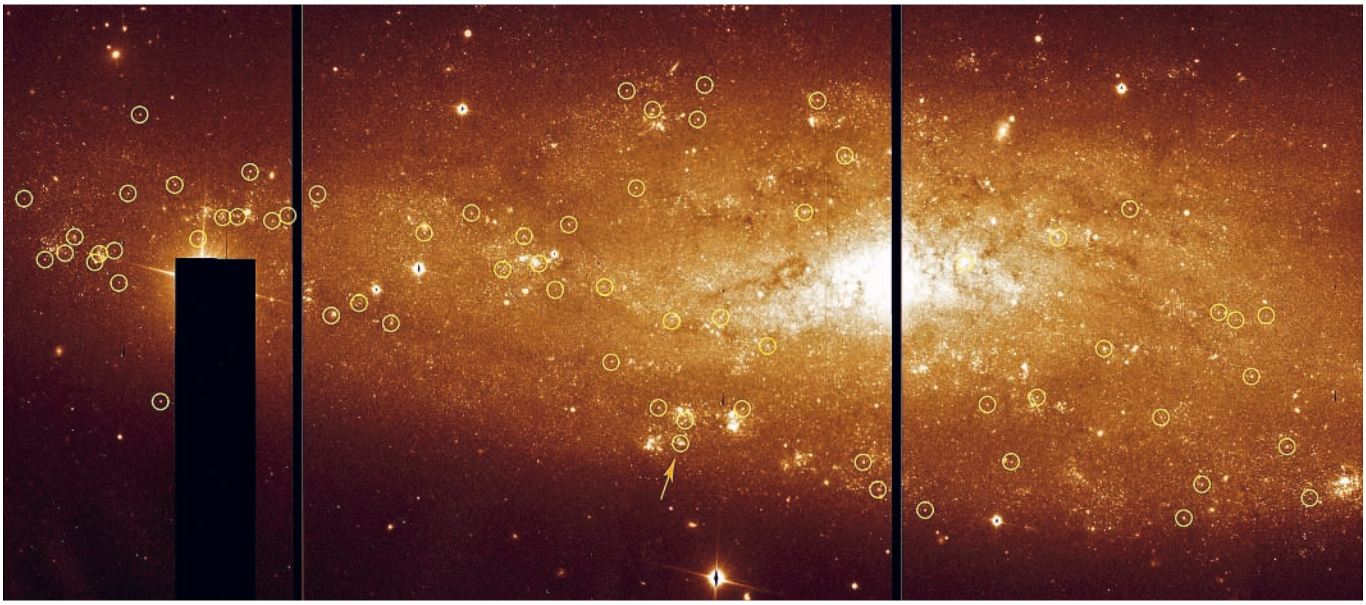


Figure 7 (left): A comparison of the radial oxygen abundance gradient in NGC 300 obtained from the B supergiants (green star symbols) and the H II regions (orange disks). The oxygen abundance is in the 12 + log(O/H) scale, commonly adopted in nebular work (the solar value is ~ 8.7 on this scale), while the horizontal coordinate is the deprojected galactocentric distance in units of the isophotal radius. The nebular abundances have been obtained from the emission line fluxes available in the literature and adopting the Pettini & Pagel (2004) calibration of the R_{23} abundance indicator.

Figure 8 (below): Over 60 blue supergiant candidates have been observed spectroscopically in the Sculptor Group galaxy NGC 247, as indicated here on a mosaic derived from FORS images. The arrow points to the emission line star whose spectrum is shown in Figure 9. Candidates for the FORS/MXU spectroscopic follow-up were selected from colours and magnitudes measured from 2.2-m telescope WFI images.



great value for the immediate needs of the project (abundances and luminosities), and for future research on normal B- and A-type supergiants, as well as on more exotic, rare objects, like the extremely luminous emission-line star we discovered in NGC 247 (Figure 9). A dedicated analysis technique is being developed by our group in order to cope with the large amount of stars for which we are deriving the basic parameters (gravities, temperatures and metallicities).

Thanks to their extreme luminosity in the optical range (with absolute magnitudes in V between –7 and –10), blue supergiants are among the brightest stellar objects observed in galaxies, second only to supernovae. The investigation of their usefulness as extragalactic distance indicators, therefore, is a natural component of the Araucaria Project. A simple but powerful technique was developed by Kudritzki et al. (2003), who found that the *flux-weighted gravity* g/T_{eff}^4 (the gravity g and the effective temperature T_{eff} are both determined from the spectra) is strongly correlated with the intrinsic luminosity of blue supergiants, and appears to be quite insensitive to metallicity variations.

The *Flux-weighted Gravity-Luminosity Relationship* (FGLR) determined from our analysis of blue supergiants (spectral types from early-B to mid-A) in galaxies of the Local Group and in NGC 300 is shown in Figure 10. The calibration we have obtained can be used to measure distances to galaxies where spectra and apparent magnitudes of blue supergiants are available. This independent spectroscopic method, despite the complexities involved in the data analysis, provides simultaneously the luminosities, as well as the chemical abundances of the target stars. In this respect, the FGLR has an

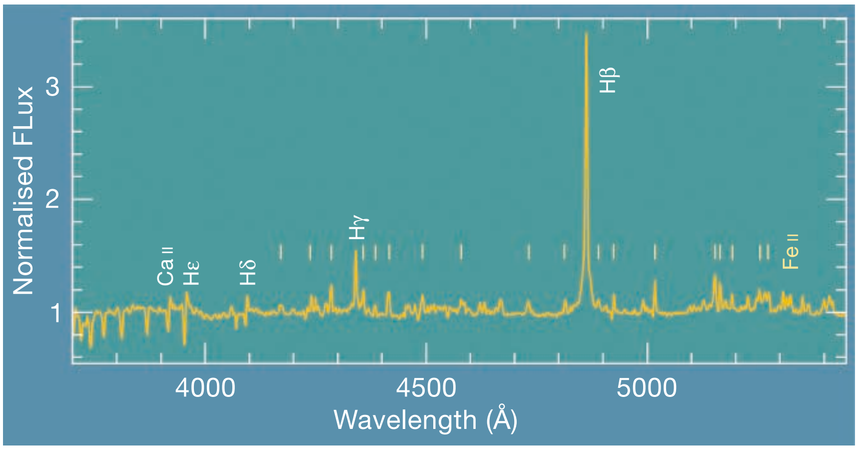


Figure 9: The FORS 2 spectrum of an extremely luminous ($M_V \sim -9.3$) blue supergiant star in NGC 247. A strong stellar wind is responsible for the emission lines visible throughout the spectrum (a nebular component is also present for the Balmer lines), which is reminiscent of the spectra of Luminous Blue Variables. Most of these features are due to Fe II, as identified by the vertical bars.

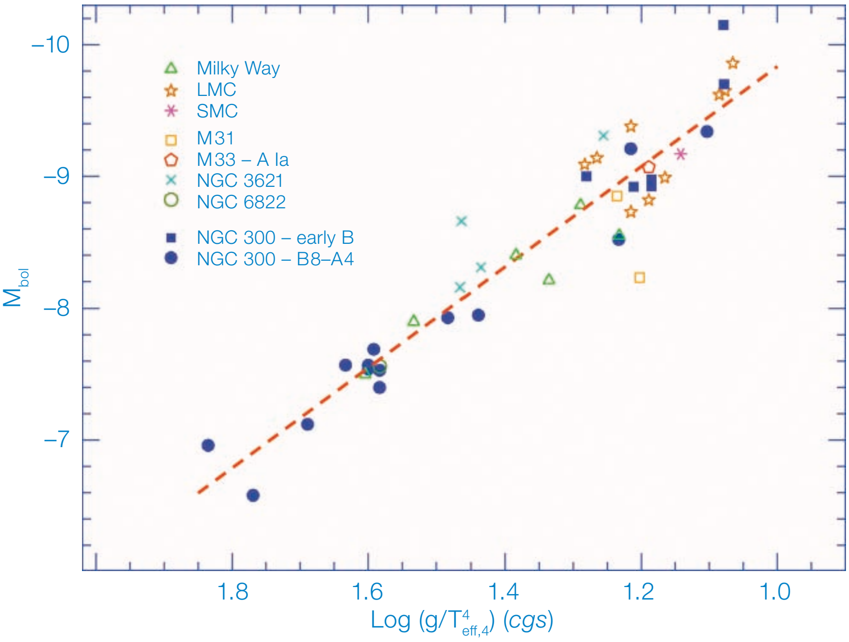


Figure 10: The Flux-weighted Gravity-Luminosity relationship is plotted here for blue supergiants analysed in the Local Group and in NGC 300. The legend shows the meaning of the different symbols used. The data are taken from Kudritzki et al. (2003), except for the early B-type supergiants in NGC 300, which are taken from Urbaneja et al. (2005).

advantage over the photometric methods of distance determination (Cepheids, TRGB, etc.), in that it allows us to account directly for the effects that metallicity has on the distances derived.

Acknowledgements

We thank the ESO Observing Programmes Committee for the generous allocation of observing time to our project. It is a pleasure to thank ESO staff on Paranal and La Silla for their expert collaboration in obtaining those observations which were scheduled in service mode. Wolfgang Gieren, Grzegorz Pietrzynski, and Dante Minniti acknowledge support from the Chilean FONDAP Center for Astrophysics for this research. Last not least, we want to thank the different members of the OGLE Project for helping out with the observations for this programme at the Polish telescope on Las Campanas.

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Early Galaxy Evolution: Report on UVES Studies of a New Class of Quasar Absorbers

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Distant galaxies can be studied using the imprints that their gaseous structures leave in the spectrum of a background quasar. These "quasar absorbers" provide a measure of both the neutral gas and metallicity content of the Universe back to early cosmic times. A newly defined class of quasar absorbers, the sub-Damped Lyman-α Systems, have been studied for the first time using both the ESO archives and new UVES/VLT data. This review presents results from four years of research on these systems and emphasises the scientific role played by the ever-growing ESO science archive.

Tracing the rate at which stars form over cosmological scales still remains a challenging observational task. An indirect way to measure the assembly of galaxies is to probe the rate at which they convert their gas into stars. The neutral H I mass in particular can be estimated from observations of absorbers seen in the spectrum of background quasars. The most remarkable property of these systems is that their detection threshold is essentially redshift independent and only relies on the properties of random luminous background sources (quasars or Gamma-Ray Bursts) observed up to early cosmological times ($z > 6$). Thus, unlike other high-redshift galaxies (such as Ly-α emitters or Lyman Break Galaxies), these objects are selected regardless of their morphologies or intrinsic luminosities but solely on their H I cross-sections (see Figure 1). Therefore, they provide unbiased samples to measure the redshift evolution of $\Omega_{\rm HI}$, the total amount of neutral gas expressed as a fraction of today's critical density.

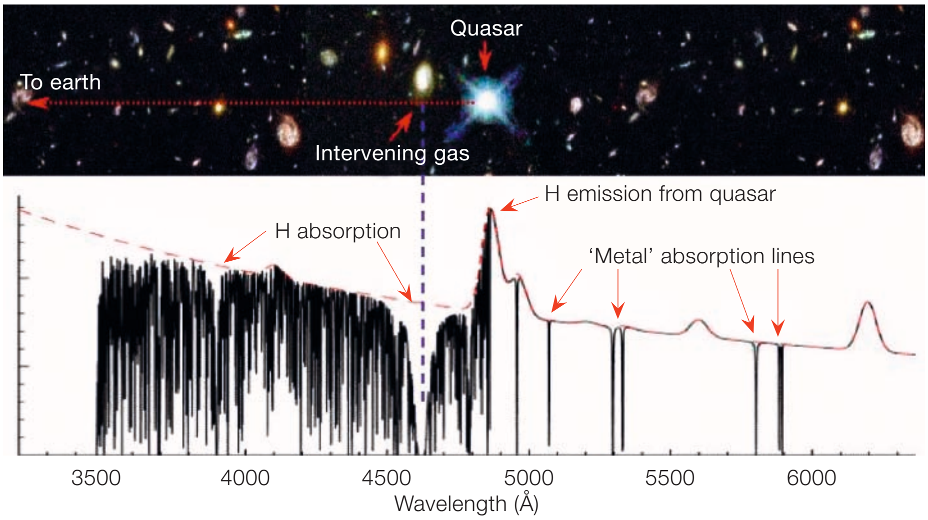


Figure 1: Cartoon illustrating a quasar line of sight along which various objects give rise to absorption features seen in the spectrum of the background quasar. The panel presents a typical quasar spectrum, showing the quasar continuum, emission lines, and the absorption lines produced by galaxies and intergalactic material that lie between the quasar and the observer. The strongest $N_{\rm HI}$ absorption at $\lambda_{\rm obs} \sim 4600$ Å is due to a Damped Lyman-α Absorber at $z \sim 2.79$ (Figure courtesy of John Webb).

Quasar absorbers are also an excellent tool for measuring the abundances of a wide variety of elements over >90 % of the age of the Universe. In addition to providing information on individual objects, they can be used statistically to provide measures of the cosmological evolution of metals in the neutral gas phase. The so-called H I-column density weighted metallicity shows surprising results: contrary to virtually all chemical models, the most recent observations indicate only mild evolution with redshift. Nevertheless, it is wellknown that such analyses are dominated by the main contributors to the H I mass. Therefore, it is important that all the quasar absorbers containing a significant fraction of H I gas are included to get a global metallicity estimate.

A new class of quasar absorbers

Quasar absorbers are sub-divided into classes according to their column density, the number of hydrogen atoms per unit area along the line of sight between the observer and the quasar (commonly expressed in atoms cm^{-2}). Therefore a low column density cloud could either be a small cloud with high density or a large cloud with low density. They are thus believed to probe a variety of physical conditions including halos and discs of both dwarf and normal (proto)galaxies. Damped Lyman-α systems (hereafter DLAs) have $N_{\rm HI} > 2 \times 10^{20}$ atoms cm^{-2} and are the major contributors to the neutral gas $\Omega_{\rm HI}$. Nevertheless, based on a new sample of $z > 4$ quasars (Péroux et al. 2001), we have suggested that some fraction of the H I lies in systems below the traditional DLA definition. We proposed to extend the definition to $N_{\rm HI} > 10^{19}$ atoms cm^{-2} and introduced the terminology " sub-Damped Lyman-α systems" (sub-DLAs) in Péroux et al. 2003a. Such high column density systems are reportedly good tracers of galaxies: looking out through the Milky Way, many lines of sight have $10^{19} < N_{\rm HI} < 2 \times 10^{20}$ atoms cm^{-2}, reminding us that we actually live in a sub-DLA!

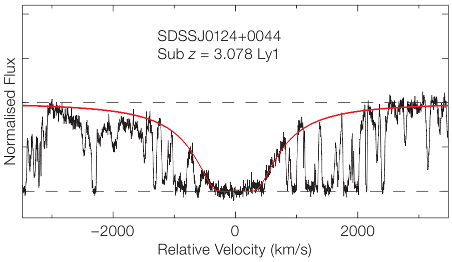
The study of sub-DLAs has been made possible only thanks to the advancement of 8–10-m-class telescope related technologies. Indeed high-resolution spectroscopy is required to study sub-DLAs. The Ultraviolet-Visual Echelle Spectrograph UVES (D'Odorico et al. 2000) mounted on UT2 has played a key role in recent developments of our understanding of quasar absorbers, and sub-DLAs in particular. In 2001, we initiated a programme aimed at building and studying a homogeneous sample of sub-DLAs. The overall goal of this ongoing project is to identify what can be learned about the early stages of galaxy evolution from the study of the systems detected in absorption.

Global metallicity evolution

In a first step towards this aim, we took advantage of the ESO VLT archive to build a sample of sub-DLAs by reducing and analysing UVES archival Echelle quasar spectra available to us on July 2001. This represented a sample of 35 quasars, 22 of which were unbiased for our study. This work led to the discovery of 12 sub-DLAs (Dessauges-Zavadsky et al. 2003). Their chemical abundances were derived using Voigt profile fitting (see Figure 2 for an example) and photoionisation models from the CLOUDY software package in order to determine the ionisation correction. We find that the correction is negligible in systems with $N_{\mathrm{H\,I}} > 3.2 \times 10^{19}$ and lower than 0.3 dex for most elements in systems with $10^{19} < N_{\mathrm{H\,I}} < 3.2 \times 10^{19}$ atoms cm^{-2}. The abundances observed in this sample of sub-DLAs were further used to determine the global metallicity of H I gas in both DLAs and sub-DLAs. We found that the metallicity redshift evolu-tion of absorbers as traced by [Fe/H] shows a slightly more pronounced slope for sub-DLAs ($\alpha = -0.40 \pm 0.22$) than for DLAs ($\alpha = -0.18 \pm 0.12$). In addition, the H I-weighted mean metallicity was computed for DLAs and sub-DLAs. The evolution of $[\langle \mathrm{Fe/H_{DLA}} \rangle]$ might be stronger for sub-DLAs than for DLAs, and absorbers with $N_{\mathrm{H\,I}} > 10^{21}$ atoms cm^{-2} appear to be the less evolved (Figure 3). Observational evidence supports the hypothesis that this different behaviour is not due to the hidden effect of dust (Péroux et al. 2003b).

A study of the metallicity evolution with metal line profile ionisation showed hints of a correlation, whereby higher [Fe/H] ratios are associated with systems with larger widths (Figure 4). This correlation could indicate either a recent activity of star formation (and hence more enrichment) or a higher mass (higher rotational velocity being proportional to the mass of the system). Abundance ratios for [Si/Fe], [O/Fe], [C/Fe] and [Al/Fe] were determined and compared with two different sets of models of the chemical evolution of galaxies. Overall, these appear to resemble abundance ratios observed in DLAs. The first comprehensive sets of measurements of O I and C II in high $N_{\mathrm{H\,I}}$ column density systems were given. Indeed, another advantage is that these elements are well-defined in sub-DLAs while they are almost always saturated in DLAs. These species, unaffected by dust depletion, provide direct indicators of the abundances in quasar absorbers.

Figure 2: Example of a normalised UVES/VLT spectrum of a high-redshift quasar. This velocity scale plot is centred at the sub-DLA position corresponding to $z_{\mathrm{abs}} = 3.078$. The red line represents the Voigt profile model used to determine the quasar absorber column density: $N_{\mathrm{H\,I}} = 1.62 \times 10^{20}$ atoms cm^{-2} (Figure from Péroux et al. 2005).



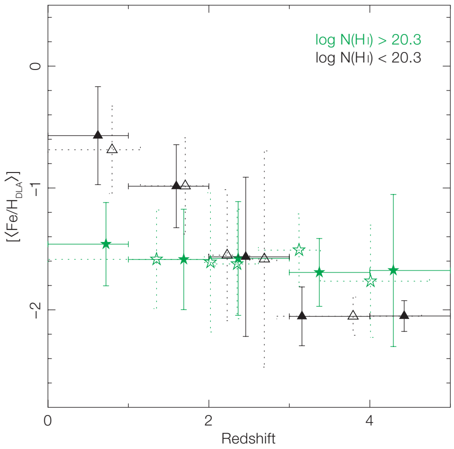


Figure 3: $N_{\mathrm{H\,I}}$ column density-weighted mean metallicities for DLAs (green) and sub-DLAs (black). The dotted bins are for constant $N_{\mathrm{H\,I}}$ intervals and the solid bins are for constant redshift intervals. The evolution of $[\langle \mathrm{Fe/H_{DLA}} \rangle]$ is possibly more pronounced for sub-DLAs than for DLAs (Figure from Péroux et al. 2003b).

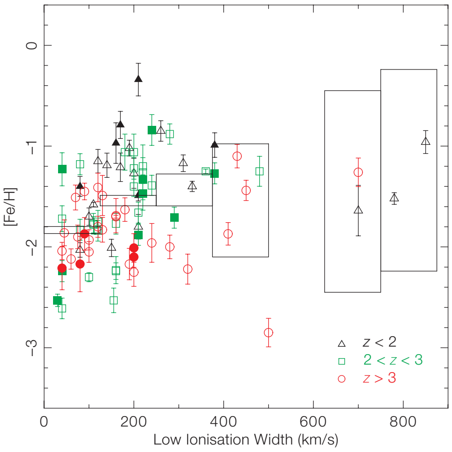


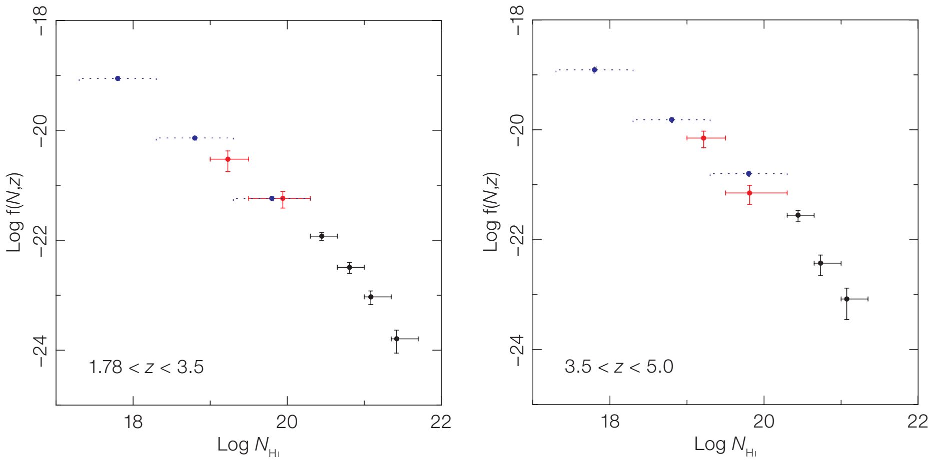
Figure 4: [Fe/H] as a function of the velocity width of the low-ionisation transition. The colours of the symbol depict different redshift ranges. The open sym-bols are for DLAs and the filled symbols are for sub-DLAs. The boxes represent the mean in a given velocity interval with *rms* errors and suggest an increase of metallicity towards larger widths of the low ionisation species. (Figure from Péroux et al. 2003b).

Cosmological evolution of H I gas mass

In order to study the early stages of galaxy evolution, we selected a sample of 17 $z > 4$ quasar lines of sight observed with UVES/VLT (Péroux et al. 2005). The statistical properties of the resulting sample of 21 new sub-DLAs were analysed in combination with the sub-DLAs from the previous ESO archive study. This homogeneous sample allowed us to determine the redshift evolution of the number density of DLAs and sub-DLAs. All these systems seem to be evolving in the redshift range from $z = 5$ to $z \sim 3$. Assuming that all the classes of absorbers arose from the same parent population, estimates of the characteristic radii were provided. R_{*} increases with decreasing column density, and decreases with cosmological time for all systems. The sub-DLA downsizing runs from $R_{*} = 40\ h^{-1}_{100}$ kpc at $z = 4$ to $R_{*} = 30\ h^{-1}_{100}$ kpc at $z = 2$. The redshift evolution of the column density distribution, $f(N,z)$, down to $N_{\mathrm{H\,I}} = 10^{19}$ cm^{-2} was also presented for two different redshift ranges (Figure 5). A departure from the usual power law is observed in the sub-DLA regime.

$f(N,z)$ was further used to determine the total H I gas mass in the Universe at $z > 2$ (Figure 6). The complete sample of sub-DLAs shows that they are important at all redshifts from $z = 5$ to $z = 2$ and that their contribution to the total gas mass $\Omega_{\mathrm{H\,I}}$ is ~ 20 % (or more if compared with the latest Sloan results). It appears that $\Omega_{\mathrm{H\,I}}$ observed in both DLAs and sub-DLAs at high redshift ($z > 2$) is low compared with the mass density observed in stars today, Ω_{*}. The possibility that large numbers of quasar absorbers are missing in optically selected quasar surveys is still hotly debated. While radio surveys looking for DLAs in quasar samples without optical limiting magnitudes (Ellison et al.

Figure 5: Column density distributions for two redshift ranges down to the sub-DLA definition. The horizontal error bars are the bin sizes and the vertical error bars represent the uncertainties. The blue dotted bins are predictions from Péroux et al. (2003a), while the red bins at $10^{19} < N_{\rm H\,I} < 2 \times 10^{20}$ atoms cm^{-2} correspond to the direct observations from the sample of sub-DLAs. The black bins represent DLAs (Figure from Péroux et al. 2005).



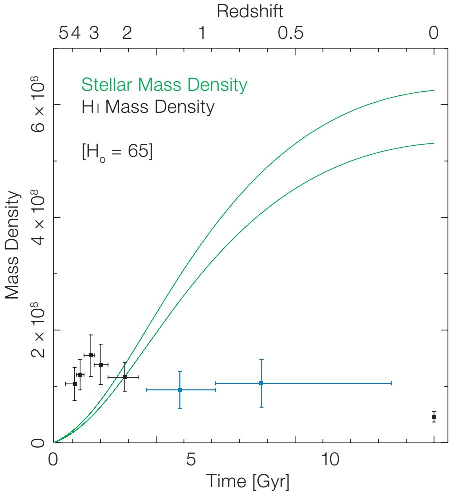


Figure 6: Observable baryons in the Universe as a function of time. The green curve represents the mass density in stars integrated from the Star Formation Rate (SFR). The error bars represent the mass density in H I gas as derived from quasar absorbers deconvolved from the local critical density (Figure from Péroux et al. 2005).

2003) show that there are not a large number of DLAs missing, our expectations are that high-redshift galaxies should be dusty. It should be emphasised however that there are two separate issues: i) what is the dust content of the quasar absorbers we know of today and ii) what fraction of the quasar absorbers are missed because their background quasar is not selected in the first place.

On the nature of sub-DLAs

By assuming that both DLAs and sub-DLAs trace the same underlying parent population, a natural explanation for the nature of sub-DLAs could be that they are the outermost parts of galaxies. This is illustrated by the absorber size calculations where the characteristic radius of sub-DLAs is around 40 h^{-1}_{100} kpc and the one from DLAs is 20 h^{-1}_{100} kpc.

The metallicity of sub-DLAs also seem to differ from the one of classical DLAs. Smoothed particle Hydrodynamics simulations indicate that DLAs have one third solar metallicity at $z = 2.5$ and should be even more metal-rich towards lower redshifts. Indeed there are lines of evidence pointing towards lower column density quasar absorbers like sub-DLAs being more metal-rich at $z < 2$ (Figure 3). This could be explained by classical DLAs being dustier than their sub-DLAs counterparts, hence preventing the selection of their background quasar. If confirmed, this can be explained by the fact that in sub-DLAs, the Zn column density threshold does not combine with the $N_{\rm H\,I}$ threshold $N_{\rm H\,I} > 2 \times 10^{20}$ atoms cm^{-2} that prevents their detection. We therefore propose that sub-DLAs might be associated with the external parts of galaxies which better traces the overall chemical evolution of the Universe.

Future prospects

In order to investigate further this hypothesis, we are currently investigating the metallicity of sub-DLAs at $z > 3$, using 10 of the 17 high-resolution UVES $z > 4$ quasar spectra from our sample for which we have spectral coverage at wavelengths red-wards of the quasar emission lines. These systems will also be modelled with CLOUDY in order to determine the ionisation fraction of the gas.

In parallel, one of us (CP) is working on the UVES ESO VLT archive data with the aim to provide the user community with a uniform data set of pipeline-reduced products. The results will be made available to the public with the hope that it will encourage and facilitate the ESO archive usage. This new data set could be used to search for new sub-DLAs already observed with ESO facilities but so far unstudied. This type of research illustrates the role that the ever-growing ESO archive plays for science.

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A New Einstein Ring

Using the VLT, Rémi Cabanac and colleagues[1] have discovered a new and very impressive Einstein ring. This cosmic mirage, dubbed FOR J0332-3557, is seen towards the southern constellation Fornax (the Furnace), and is remarkable on at least two counts. First, it is a bright, almost complete Einstein ring. Second, it is the farthest of its type ever found.

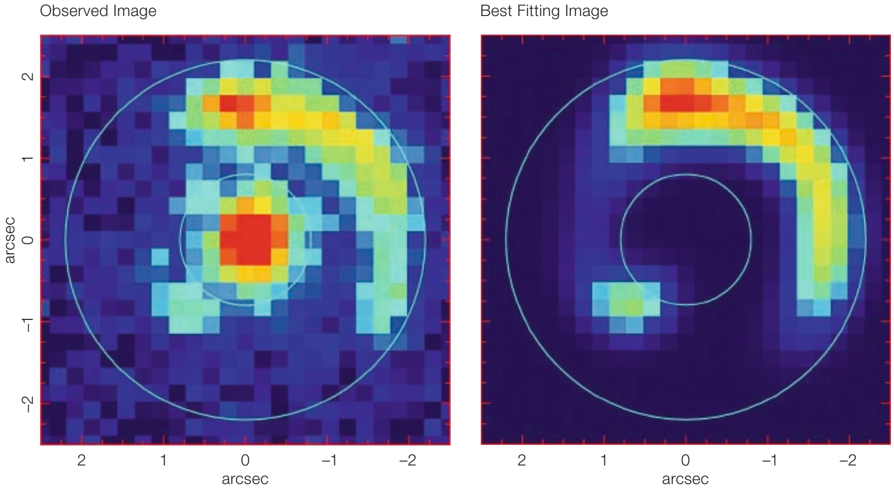
"There are only a very few optical rings or arcs known, and even fewer in which the lens and the source are at large distance, i.e. more than about 7 000 million light years away (or half the present age of the Universe)", says Rémi Cabanac, former ESO Fellow and now working at the Canada-France-Hawaii Telescope. "Moreover, very few are nearly complete", he adds.

The ring image extends to almost 3/4 of a circle. The lensing galaxy is located at a distance of about 8 000 million light years from us, while the source galaxy whose light is distorted, is much farther away, at 12 000 million light years. Thus, we see this galaxy as it was when the universe was only 12 % of its present age. The lens magnifies the source almost 13 times.

The observations reveal the lensing galaxy to be a rather quiet galaxy, 40 000 light years wide, with an old stellar population. The much more distant lensed galaxy, however, is extremely active, having recently experienced bursts of star formation. It is a compact galaxy some 7 000 light years across.

"Because the gravitational pull of matter bends the path of light rays, astronomical objects – stars, galaxies and galaxy clusters – can act like lenses, which magnify and severely distort the images of galaxies behind them, producing weird pictures as in a hall of mirrors", explains Chris Lidman (ESO), co-discoverer of the new cosmic mirage.

Figure 1: Composite image taken in bands B and R with VLT/FORS, which reaches to magnitude 26. A zoom-in on the position of the newly found ring.



Observed Image

Best Fitting Image

Figure 2: The left image is magnified and centred on the newly discovered Einstein ring. The image quality ("seeing") of the *R*-band image is exceptional (0.5″) and the image reveals the lensing system in stunning details. The central feature is the lens, a quiescent massive galaxy that distorts the light emitted by background sources. The large arc surrounding the central lens is part of the Einstein ring created by a background source finely aligned with the lens. The reddish colour indicates that the redshift of the system is very large. FORS2 spectroscopy of the lensing system yielded a redshift close to 1 for the lens (we see the lens as it was when the Universe was half its present size), and a redshift $z = 3.8$ for the ring (a background star-forming galaxy seen as it was when the Universe was only 12 % of its present age. The lensing model indicates that the light of the source is magnified at least 13 times. The right panel shows the reconstructed image based on the model of the lens and the source; the ring is found to extend over 3/4 of a complete circle.

In the most extreme case, where the foreground lensing galaxy and the background galaxy are exactly aligned, the image of the background galaxy is stretched into a perfect ring. Such an image is known as an Einstein ring, because the formula for the bending of light, first described in the early twentieth century by Chwolson and Link, uses Einstein's theory of General Relativity.

Gravitational lensing provides a very useful tool with which to study the Universe. As a "weighing scale", it provides a measure of the mass within the lensing body, and as a "magnifying glass", it allows us to see details in objects which would otherwise be beyond the reach of current telescopes.

From the image, co-worker David Valls-Gabaud (CFHT), using state-of-the-art modelling algorithms, was able to deduce the mass of the galaxy acting as a lens – it is almost one million million solar masses.

(Based on ESO Press Photos 20 b+c/05)

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[1] The paper describing this research has recently been published as a Letter to the Editor in Astronomy and Astrophysics, Volume 436, L21–L25, by Rémi A. Cabanac (CFHT, Hawaii), David Valls-Gabaud (Observatoire Midi-Pyrénées), Andreas Ortmann Jaunsen (ESO Chile), Chris Lidman (ESO), and Helmut Jerjen (Mount Stromlo Observatory, Australia).

Resolved Spectroscopy of a $z = 5$ Gravitationally Lensed Galaxy with the VIMOS IFU

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We have used the VIMOS IFU to spatially resolve and study the star-forming, galactic superwinds and metal-enrichment properties in a highly magnified gravitationally lensed galaxy at $z = 5$ (i.e., seen when the Universe was only ~ 10 % of its current age). These results are allowing us to study galaxy formation and evolution in a level of detail never before possible and provide exciting possibilities for future studies of galaxies at these early times.

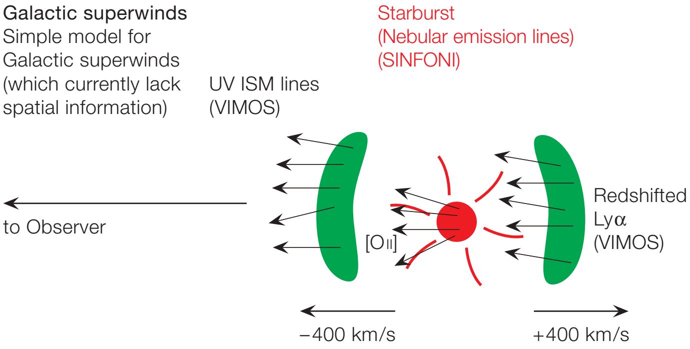


Figure 1: A cartoon of the dynamics of a galaxy with high-velocity superwinds. By observing Ly α emission and ISM lines with VIMOS and the [O II] with SINFONI we will resolve all three components of the galaxy and superwind.

The problem with galaxy-formation models is not to understand why galaxies form (this is due to the cooling and condensing of gas in dark matter halos), but to understand why such a small fraction of baryons cool to form stars. Galaxy-formation models which only include cooling predict that more than 50 % of baryons should form stars, yet a census of the baryons in the local Universe show that less than 10 % are locked up in stars, the rest is in a hot diffuse state, similar to that in the inter-cluster medium (Balogh et al. 2001). To account for this puzzling inefficiency requires some form of feedback – a method of expelling gas from galaxies, preventing them from forming stars, and hence regulating galaxy formation (Bower et al. 2004, Swinbank et al. 2005, Wilman et al. 2005).

Regulating galaxy formation: feedback

The local Universe is a largely inert place, with most activity long over. In order to understand the feedback phenomenon we must therefore look to the first galaxies that formed in the Universe (between 1 and 2 Gyr after the Big Bang, $z = 3$–5). However, since they are very distant these young galaxies are difficult to observe in great detail. Recent deep observations of distant Lyman-break galaxies suggest that, in these young systems, the collective effects of intense star-formation activity (and resulting supernovae) sweep up and drive a shell of material through the galaxy disc, eventually bursting out of the galaxy and accelerating into the ambient intergalactic medium. In these observations the wind ejecta manifests itself through the velocity offset between Lyα emission which traces the outflowing material and the rest-frame optical emission lines (such as Hα and [O II]) which trace the star-forming (H II) regions (Shapley et al. 2003). Indeed, velocity offsets of several hundred km/s have been observed. If the energy of this wind is sufficient, the gas escapes the galaxies' potential and is not recaptured and plays no further role in galaxy formation. But the evidence for this superwind is rather indirect, and based on the assumption that the outflow takes the form of an expanding spherical bubble surrounding the galaxy as illustrated in Figure 1 (the current data are limited to traditional long-slit spectroscopy, and are therefore limited to one spatial dimension). Hence, if the large velocity flow were instead within the galaxy, the wind would be unlikely to escape the gravitational potential. Of course, other interpretations are also possible: the outflow may be collimated and may not inhibit the inflow of gas in other directions; the wind might even stall and fall back onto the galaxy (a more energetic version of the Milky Way's "galactic fountain").

The key to resolving this issue is to identify these features in spatially resolved out-flows around distant protogalaxies. By comparing the velocity field of the outflow with that of the host galaxy the three-dimensional structure of the outflow can be established. However, at these great distances even a massive galaxy only spans 1″ on the sky and therefore obtaining spatially resolved information is extremely difficult.

Gravitational telescopes

Fortunately nature provides us with a natural telescope with which we can study very distant galaxies in great detail. Galaxy clusters magnify the images of distant galaxies that serendipitously lie behind them (Smail et al. 1996, Ellis et al. 2001, Swinbank et al. 2003). This natural magnification causes background galaxies to be strongly amplified and stretched. It provides us with the opportunity of studying young and intrinsically faint galaxies with a spatial resolution that cannot be attained via conventional observations.

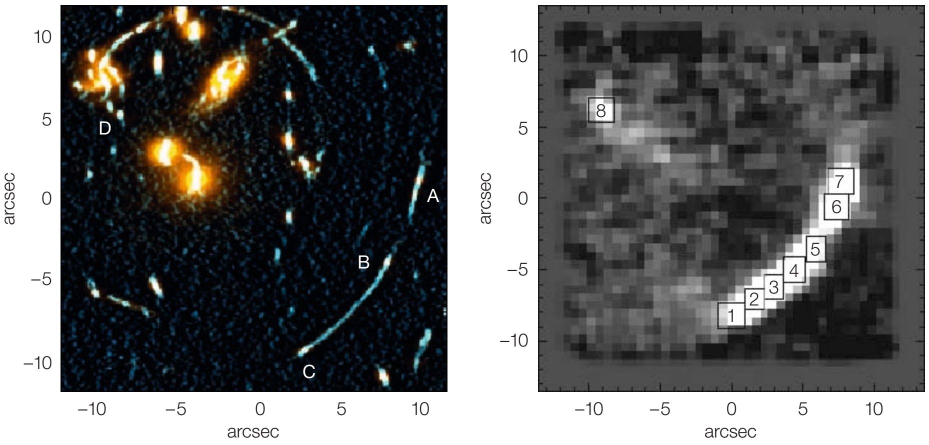
One of the most striking cases of gravitational lensing is the (highly magnified) $z = 4.88$ galaxy behind the rich lensing cluster RCS0224-002 (Gladders et al. 2002). The natural amplification caused by the galaxy cluster has two effects (i) the image of the background galaxy is magnified at a fixed surface brightness (i.e. the total brightness is increased) and, (ii) the galaxy is not simply amplified, it is also stretched, making it possible to spatially resolve components of the galaxy from the ground.

This project

In this article we report on the first results from a VLT VIMOS and SINFONI IFU study of the star-forming and kinematical prop-

Figure 2: Left: HST false colour *VI*-band image of the RCS0224-002 cluster core showing the central cluster galaxies as well as the multiple arcs and arclets. The multiply imaged $z = 4.88$ arc is labelled *A*, *B* and *C*, whilst the radial counter-image is labelled *D* (see text).

Right: Wavelength collapsed (white light) image around the Lyα emission from the $z = 4.88$ arc made by collapsing the datacube between 7138 and 7188 Å. The $z = 4.88$ arc can clearly be seen in the Lyα image. We also note that there appears to be another strong Lyα emitter to the North-East which is the counter image of the arc.



erties in a $z = 4.88$ arc in the core of the lensing cluster RCS0224-002. In the left-hand panel of Figure 2 we show the HST image of the cluster core and mark the components of the arc *A*, *B* and *C*. As can be seen from the HST image, the lensed galaxy (or arc) is over 12″ in length and therefore is an ideal candidate for integral field spectroscopy. The arc is multiply imaged, with component *A* appearing to comprise a dense knot surrounded by a halo of diffuse material (a foreground object is also superposed). The morphology of components *B* and *C* mirror those of *A*.

The arc was observed with the VIMOS IFU on the VLT in December 2004. Although the target was only observed for 2 hours (the remaining 12 hours are due to be completed in the current semester), the data already offer fascinating insight into the nature of the Lyα emission in this galaxy. The VIMOS IFU provides a three-dimensional (x, y, λ) "datacube" from which we can investigate the spatial variations in the Lyα and C IV emission lines and (eventually) UV interstellar absorption features. In turn these allow us to infer the spatial distribution of star formation, metal abundance and to map the dynamics of the system's components.

Early results

In Figure 2 we have projected the datacube in the wavelength between 7138 and 7188 Å so as to map the spatial distribution of the emission. It is clear that the Lyα emission line morphology traces that seen in the imaging, with the densest knots in the HST image being the brightest in Lyα.

By extracting a series of independent spectra from the IFU datacube (Figure 3) we can investigate the dynamics of the galaxy and the nature of any outflowing material. Even the initial dataset, allows us to search for spatial variations in the Lyα emission line. As seen in other young galaxies, the Lyα emission has a characteristic asymmetric (P-Cyni) profile. To examine the structure of the emission line, we compare the emission from the regions marked 1–8 in Figure 2. The structure of the line is remarkably constant from region to region. While there is tentative evidence for structure in the red wing of the line, the blue cut-off occurs at constant wavelength (the variations are less than 30 km/s). This is particularly important: the individual star-forming regions in the underlying galaxy are expected to be moving at relative speeds in excess of 100 km/s (SINFONI observations are scheduled to confirm and map this): if the superwind was localised to these regions, the structure of the Lyα emission would vary significantly. In contrast, the superwind model (Figure 1) predicits that the sharp blue edge of the Lyα emission line (which is formed by resonant absorption in the outflow) will be uncorrelated with the velocity structure of the host galaxy. The lack of structure suggests that the superwind "bubble" is located well outside of the galaxy and is escaping into inter-galactic space.

Other primeval galaxies

We can also scan the datacube for emission lines from other galaxies within the VIMOS IFU field of view. Although the current data are only partially complete, we have already identified at least two other serendipitous sources in the field, including Lyα for $z = 3.66$ and $z = 5.09$ and as well as [O II] from an arc at $z = 1.0$.

Summary

Whilst these results are in their early stages, they are showing the power of coupling integral field spectroscopy with gravitationally lensed galaxies to spatially resolve and study the internal dynamics and star-formation properties of primeval galaxies. The signal-to-noise that we expect from the final set of observations (the remaining 12 hours of observations are expected to be completed in August/September 2005) will allow us to tightly constrain the geometry of the outflowing material and so test the geometry of the superwind ejecta. We will also be able to investigate the dynamics of the interstellar medium (spatially resolved) through the absorption lines and the metallicity of the gas through the C IV/Lyα emission line ratios (continuum and C IV emission are both detected in the first 2 hours of data, but the remaining 12 hours are required to boost the signal-to-noise and draw strong conclusions). Furthermore, by coupling this high-quality data with SINFONI IFU observations (also expected to be taken in August/September 2005) we will probe the [O II] emission from this galaxy (which comes from the star-forming regions and therefore reflects the underlying stellar populations which are responsible for driving the superwind in the galaxy; see Figure 1). These ground-breaking and exciting results will provide valuable and important insights into this important phase of galaxy evolution.

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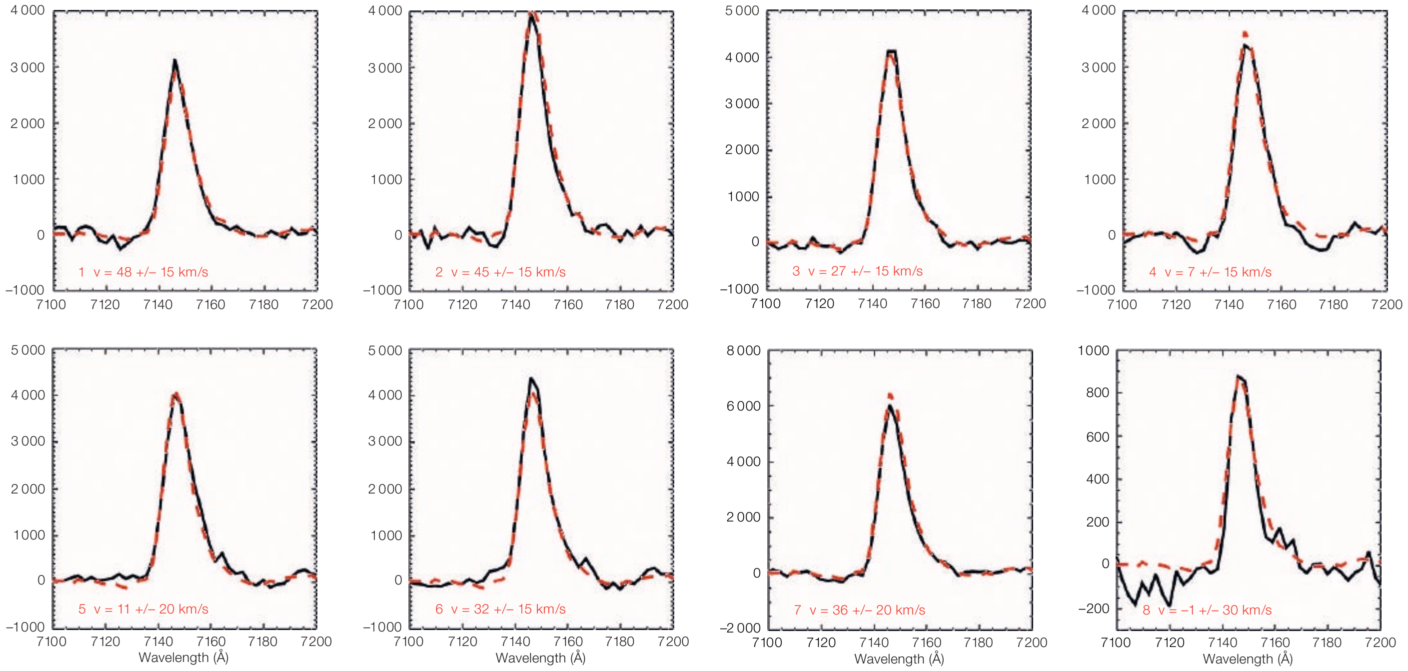
Figure 3: Spectra around the redshifted Lyα emission from the eight components labelled in Figure 2. The red dashed line shows the composite spectra from the arc (scaled in flux). In each independant pixel of the datacube we use the position and shape and intensity of the Lyα emission to study the superwind outflow. By combining these measurements with SINFONI spectroscopy of nebular emission lines we will investigate the star formation and chemical enrichment of this young galaxy.



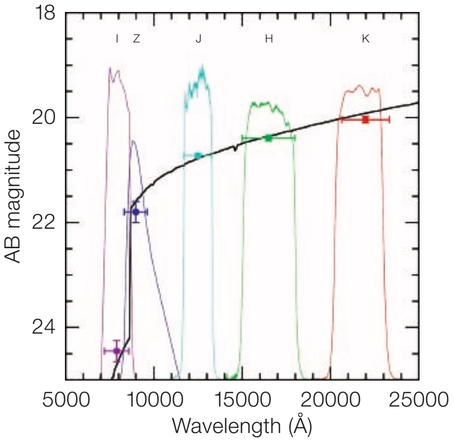
Farthest Known Gamma-Ray Burst

An Italian team of astronomers[1] has used the VLT to observe the afterglow of a Gamma-ray burst that is the farthest known to date with a measured redshift of 6.3. "This also means that it is among the intrinsically brightest Gamma-ray bursts ever observed", said Guido Chincarini from INAF-Osservatorio Astronomico di Brera and University of Milano-Bicocca (Italy) and leader of a team that studied the object with ESO's Very Large Telescope. "Its luminosity is such that within a few minutes it must have released 300 times more energy than the Sun will release during its entire life of 10 000 million years."

Gamma-ray bursts (GRBs) are short flashes of energetic gamma rays lasting from less than a second to several minutes. They release a tremendous quantity of energy in this short time, making them the most powerful events since the Big Bang. It is now widely accepted that the majority of the gamma-ray bursts signal the explosion of very massive, highly evolved stars that collapse into black holes.

The Gamma-ray burst GRB050904 was first detected on September 4, 2005, by the NASA/ASI/PPARC Swift satellite, which is dedicated to the discovery of these powerful explosions. Immediately after this detection, astronomers in observatories worldwide tried to identify the source by searching for the afterglow in the visible and/or near-infrared. The Italian group observed the object in the near-infrared with ISAAC and in the visible with FORS 2 on the VLT. By comparing the brightness of the source in the various observing bands (see Figure), the astronomers were able to deduce its redshift, and hence its distance. "The value we derived has since then been confirmed by spectroscopic observations made by another team using the Subaru telescope", said Angelo Antonelli (Roma Observatory), another member of the team.

(Based on ESO Press Release 22/05)



This figure shows the magnitude of the Gamma-ray burst GRB 050904 as observed with FORS 2 and ISAAC in the various filters. The bandpasses of the ESO filters are overplotted as well as the best-fitting template which allowed the astronomers to measure the photometric redshift. The clear drop of the flux of the object in the *I*-band compared to the others is the telltale signature of a high-redshift object.

[1] The MISTICI collaboration consists of astronomers from Osservatorio Astronomico di Roma (INAF), Osservatorio Astronomico di Brera (INAF), Osservatorio Astronomico di Arcetri (INAF), Università degli Studi di Milano – Bicocca, International School for Advanced Studies (SISSA) and Observatori Astronòmic of Universitat de València (Spain). In particular, Angelo Antonelli, Daniele Malesani, Vincenzo Testa, Paolo D'Avanzo, Stefano Covino, Alberto Fernandez-Soto, Gianpiero Tagliaferri, Guido Chincarini, Sergio Campana, Massimo Della Valle, Felix Mirabel, and Luigi Stella were notably active with the data analysis and observations. Prof. Guido Chincarini is the Italian Principal Investigator of the Italian research on GRBs related to the Swift satellite, which is funded by the Italian Space Agency (ASI).

Photo: G. Hüdepohl, ESO

Surveying the High-Redshift Universe with the VIMOS IFU

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We present results from a new method of exploring the distant Universe. We use 3-D (integral-field) spectroscopy to sample a large cosmological volume at a time when the Universe was less than 3 billion years old to investigate the evolution of star-formation activity in the Universe. Within this study we also discovered an obscured accreting black hole at high redshift which would not have been identified with imaging studies alone. This highlights the crucial role that integral-field spectroscopy may play in surveying the distant Universe in the future.

Hunting for high-redshift galaxies

The way in which galaxies form and evolve, along with the stars they contain, are crucial processes to investigate if we are to understand how the structure we see in the Universe today builds up over cosmic time. For many years this has been the forte of deep multi-colour imaging observations, which have been used to find and investigate galaxies in the distant Universe. This technique utilises the characteristic break in the continuum of a galaxy below the Hydrogen Lyα emission line at 121.6 nm and the Lyman-limit at 91.2 nm. Redward of these characteristic wavelengths, a galaxy will be observed to have a bright continuum, and observing the same patch of sky with a shorter wavelength filter, which lies below the continuum break wavelength, a galaxy will be much fainter and possibly not detected at all. Therefore large samples of candidate high-redshift galaxies can be constructed in this way over large areas. After catalogues of such objects have been built up, follow-up long-slit or multi-object spectroscopy is usually the next step to confirm redshifts and to gain a census of galaxies in the high-redshift Universe.

A further technique which has come to fruition over the past decade, with the onset of 8- and 10-metre-class telescopes, is that of narrow-band imaging. This method selects galaxies with strong emission lines at distinct distances, where the bright emission lines are redshifted into a filter which has a typical width of 5–10 nm. This essentially means that the imaging instrument acts as a very coarse spectrograph with 5–10 nm resolution. There are now many fields which have been targeted with this technique, most notably the deep narrow-band survey to target Lyα emitting galaxies at $z = 3.1$ (Steidel et al. 2000) which went on to find a new class of object – that of giant Lyα nebulae which are not associated with powerful active galactic nuclei. Other important surveys using the narrow-band technique have been those which target powerful radio sources at high redshift. These have yielded the detection of overdensities of Lyα emitting galaxies at redshifts above 2. Blank-field searches have also yielded the detection of large numbers of Lyα emitters at $z = 5.7$ (Ajiki et al. 2003) and one of the highest redshift galaxies known to date at $z = 6.6$ (Hu et al. 2002). However, similar to the multi-colour method highlighted above, this technique also requires follow-up spectroscopy to confirm the Lyα emitting candidates.

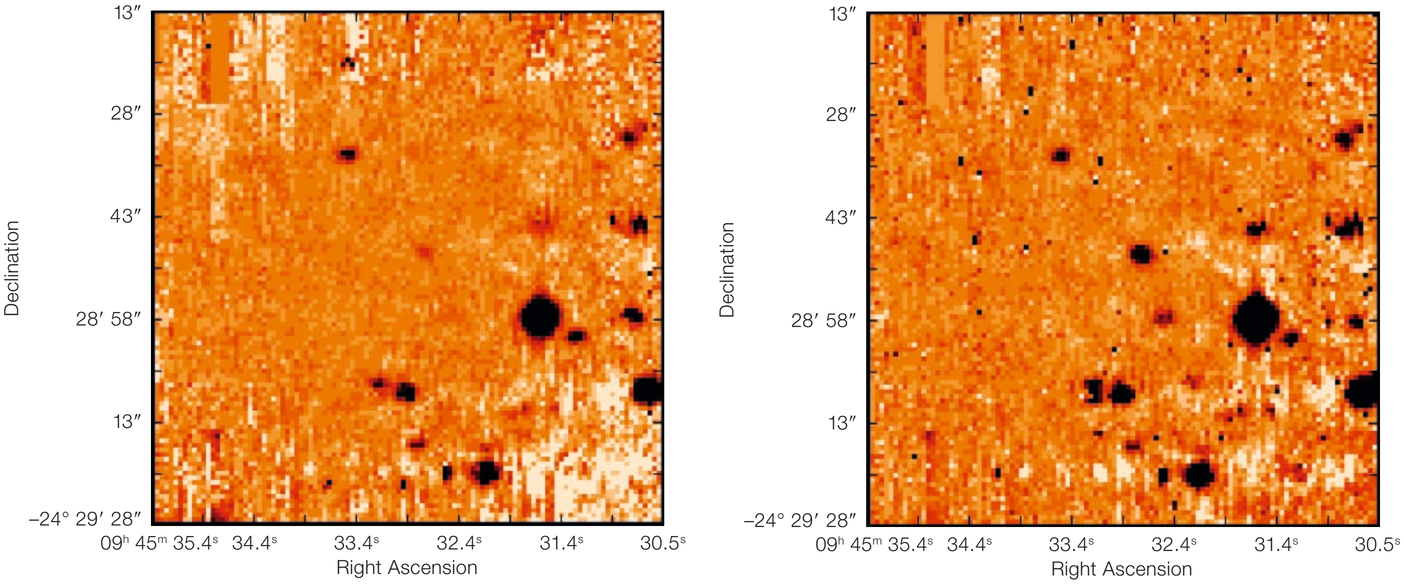
It would obviously be extremely useful if one could combine the imaging and spectroscopy into a single observation, which would not only overcome the various biases inherent to colour selected samples but would also expand on the narrow redshift ranges which one can probe with narrow-band searches. We are now entering an era in astronomy where this is achievable. In this article we describe the first results from a deep, large volume search for emission-line galaxies with the Visible Multi-Object Spectrograph (VIMOS) on the ESO-VLT (*http://www.eso.org/instruments/vimos/*).

As well as being a large multi-object spectrograph, VIMOS can also be used as a "large-area" integral-field unit (IFU). The idea behind an IFU is to obtain continuous coverage of a field in three dimensions, i.e. two spatial dimensions and a third spectral dimension. This is analogous to taking a number of long-slit spectra side-by-side all in one observation. Integral-field observations are therefore able to provide an immediate 3-dimensional view of structure in the Universe. The range of scales these IFUs may probe is from stellar populations in nearby galaxies to the furthest reaches of the observable Universe. In this article we highlight the intriguing possibilities that large-area IFUs offer with respect to volume-limited surveys of the high-redshift Universe.

A deep VIMOS IFU field and the star-formation history of the Universe

We initiated a pilot project with a deep, nine-hour, VIMOS observation centred on the high-redshift radio galaxy MRC0943-242 at a redshift of $z = 2.92$ in April 2003. The aims of this project were to probe the giant-Lyα emitting halo surrounding this source and the distribution of galaxies within the volume probed by the IFU. Figure 1a shows the reconstructed "broad-band" (i.e. with the spectral direction collapsed over all frequencies) image of the radio galaxy field. The central radio galaxy can easily be seen in the centre of the image. However, the only other sources visible in this broad-band representation are all relatively bright. Conversely, as can be seen in Figure 1b, if we now integrate over the spectral region where the Lyα line is seen in the radio galaxy spectrum [i.e. 121.6 nm × $(1 + z)$], the radio galaxy becomes much brighter. This highlights the benefit of the integral-field approach when hunting for galaxies with bright emission lines at all redshifts. If we now split this data set up into finer bins in wavelength then we are able to detect all the galaxies with bright emission lines over the whole volume. For Lyα emission this range is $2.3 < z < 4.6$, and for [O II] emission at a rest-frame wavelength of $\lambda = 372.7$ nm, we probe $0.08 < z < 0.83$. Therefore we can search for emission-line galaxies over a large fraction of cosmic volume along the sightline of the IFU (e.g. for [O II] and Lyα emitters we probe ~ 50 % of cosmic time since the Big Bang over the 1.2 square arcminute field-of-view).

Figure 1: (a) The two-dimensional image of our IFU field of view, integrated from 405–680 nm. (b) The same image integrated from 470–500 nm. The noisier regions in the corners of the images are due to a dither pattern used in the observations to enable accurate sky subtraction and bad pixel rejection, therefore the corners have had slightly less exposure time than the central, least noisy, region.



In order to achieve this we construct a sensitivity map across the whole field and search for peaks in the clean parts of the optical spectrum, i.e. those regions devoid of bright sky lines and also where characteristic problems associated with the optics within the IFU are at a minimum. This is carried out by fitting a polynomial to the spectra at all points over the field and detecting all of those peaks in the spectra which deviate significantly from the noise estimates in each spectrum and each region within that spectrum.

This process enabled us to detect 17 emission-line objects over the volume probed with the IFU. These are predominantly single line objects, and for 14 all of the characteristics point to them being hydrogen Lyα emission-line galaxies (two others are [O II] emitters and the third is the type-II quasar discussed later in this article), we will now concentrate on these Lyα emitters. Lyα emission is produced by massive stars photoionsing hydrogen gas. By using some simple assumptions it is possible to estimate the star-formation rate in galaxies which exhibit Lyα emission by measuring the luminosity of the emission line. Although undoubtedly crude, this does at least produce a lower limit for the star-formation activity in distant galaxies. If we now bin all of the Lyα luminosities in the volume then we are able to construct the Lyα emitter luminosity function, i.e. the number density of emitters at a given luminosity per unit volume. Construction of the luminosity function is a non-trivial task for this type of data because those galaxies with bright emission lines can be seen to much greater distance in the volume covered in our data, thus the volume probed is a strong function of the luminosity of the emission lines. Therefore, the luminosity-dependent volume is measured using the sensitivity function of the data cube.

Figure 2 shows the Lyα luminosity function derived from this study compared to the luminosity function measured from narrow-band studies and multi-colour selection. One can see that our luminosity function, which probes the redshift range $2.3 < z < 4.6$ extends the work of the narrow-band searches to fainter luminosities where the luminosity function keeps the same Schechter function form over redshifts up to $z \sim 6$. This implies that there is little evolution in the star-formation rate density over this redshift range, although small number statistics preclude strong statements regarding any evolution.

As stated above, knowledge of the luminosity of the Lyα emission line in these galaxies gives information on the total star-formation rate. Using typical assumptions of hydrogen recombination the star-formation rate is given by,

$$\mathrm{SFR} = 9.1 \times 10^{-36}\ (L_{(\mathrm{Ly}\alpha)}\ /\ \mathrm{W})\ M_{\odot}\mathrm{year}^{-1}.$$

By integrating over the Lyα luminosity function we are therefore able to measure the star-formation rate at the redshifts covered by our data. This plot, along with the star-formation rate density derived by other methods, is shown in Figure 3, for $0 < z < 6$. Due to the fact that Lyα can be resonantly scattered and absorbed by neutral hydrogen around the source, the measured SFR from studies using Lyα are hard lower limits. Also, the presence of dust preferentially extinguishes the UV continuum emission, therefore even multi-colour searches are prone to biases which work to reduce the estimated SFR. Therefore, we also show the estimated star-formation rate corrected for obscuration. With this correction in place it is apparent that our IFU search is in line with previous studies conducted in a number of different ways. However, the benefit of using the integral-field approach is that we select sources at all redshifts in our volume in precisely the same way, thus reducing the biases involved in comparing studies at different redshifts from different surveys, which may utilise different techniques.

Further it is also worth mentioning that the choice of field, i.e. one containing a powerful radio galaxy at $z = 2.92$, does not bias the results in any way. Our data contains only one Lyα emitter at the redshift of the radio galaxy. This is principally due to the small area probed by the IFU. However we can quantify how many we would expect in our data at this redshift, given the typical overdensities of emitters found in narrow-band searches around powerful radio galaxies. In their study of Lyα emitters around the powerful radio galaxy TN J1338-1942 at $z = 4.1$, Venemans et al. (2002) showed that the overdensity of emitters was a factor of ~ 15 more than one would expect in a blank-field search. Using this fact we would expect to find of order one object within $\Delta z = 0.004$ of the radio galaxy. In the IFU data cube we find one object at a distance of $\Delta z = 0.002$. Thus although in agreement with the expected overdensity for a protocluster, the poor number statistics arising from the relatively small field-of-view of the IFU, precludes any strong statement about the clustering of Lyα emitters around the radio source. However, we do find what seems to be an excess of Lyα emitters at $z \sim 2.5$, where there are three emitters within $\Delta z = 0.04$ of each other. This leads us to believe there may be a probable high-redshift cluster at this redshift, although there is no known powerful AGN in the vicinity. However, deep, wider-field observations are needed to confirm this.

Discovery of a type-II quasar in the IFU deep field

In this section we discuss the way in which our integral-field data has also led to the discovery of two Active Galactic Nuclei (AGN) in the volume probed, in addition to the radio galaxy which was targeted. One of these is a "normal" unobscured type-I quasar with broad emission lines and an unresolved morphology on optical images at a redshift of $z = 1.79$. However, the other AGN exhibits only narrow-emission lines (Figure 4) and has a resolved morphology in the optical image.

From radio surveys we know that there are at least two populations of powerful radio-loud AGN, radio-loud quasars (RLQs) and radio galaxies (RGs). Under the model for the unification of AGN, this difference is dictated solely by the orientation of the AGN with respect to our line-of-sight, where the presence of a dusty torus surrounding an accreting supermassive black hole may obscure our view to the nucleus. RLQs are the unobscured type-I population where our view to the nucleus is through the opening in the torus, and we see the unresolved nucleus and the high-velocity clouds ($v > 2\,000$ km/s) of gas which surround it. Whereas for radio galaxies, the torus lies along our line of sight obscuring our view to the central engine, these are type-II AGN and we only see the low-velocity, narrow forbidden ($v < 2\,000$ km/s) emission lines. Moreover, there is also a population of radio-quiet quasars which outnumber their radio-loud counterparts by a factor of ~ 10. These are relatively easy to find due to the fact they exhibit a characteristically very blue continuum and appear as unresolved point sources in imaging surveys. By simple methodology there should also be a large population of radio-quiet obscured AGN. This can also be inferred from models of the X-ray background, where the universal hard X-ray emission cannot be accounted for unless there is a large population of obscured AGN at high redshift.

These type-II AGNs are relatively difficult to find compared to the type-I counterparts. This is principally due to the fact that type-II AGN look like normal galaxies, and it is only by looking for other signatures of AGN activity, which do not suffer from extinction due to the torus, they can be found, e.g. X-rays from the central engine which penetrate the torus, radio emission from powerful jets or reprocessed dust emission in the mid-infrared from the torus itself. However, with the integral-field approach we are sensitive to the bright narrow-emission lines that are characteristic of an obscured AGN, as we obtain the spectrum of any object in the IFU field immediately.

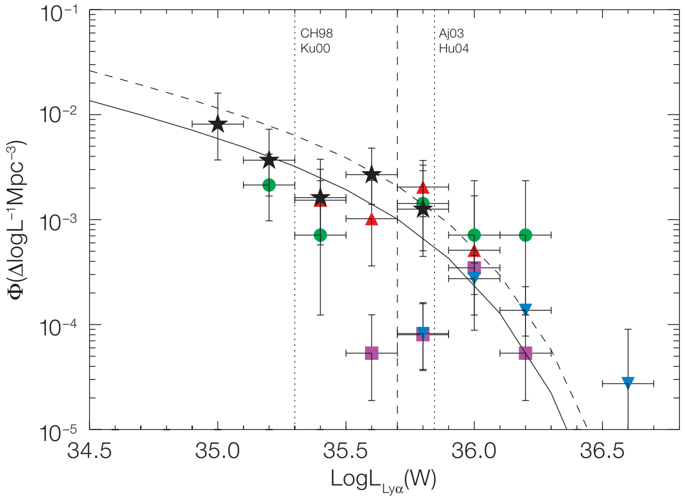
J094531-242831 (hereafter J0945-242) exhibits these bright narrow-emission lines, in the C IV doublet ($\lambda\lambda = 154.8$ nm, 155.1 nm), He II ($\lambda = 164.0$ nm) and C III] ($\lambda = 190.9$ nm), all characteristic of a type-II AGN. The radio map shows that there is no radio emission down to a radio flux limit of 0.15 mJy at 5 GHz. At a redshift of $z = 1.65$ this is significantly below the typical luminosity of a radio galaxy, thus we confirm that this is a genuine radio-quiet type-II quasar. The line luminosity ratios of the C IV, He II and C III] lines are also consistent with the ratios for radio galaxies, and not the generally lower-luminosity Seyfert-I galaxies and the unobscured quasars. Using these line luminosities it is possible to estimate the lower mass limit of the accreting black hole in the centre of this galaxy. We assume the typical line ratios of radio galaxies to convert the He II luminosity to a line luminosity in [O II], which is correlated with the total bolometric luminosity of the AGN. Under the assumption that the quasar is accreting at its maximum rate, i.e. the Eddington limit, then this bolometric luminosity equates to a black-hole mass of $3 \times 10^8\ M_\odot$.

In the local Universe there is now a well-known correlation between the mass of black holes and the luminosity of their host galaxy (see e.g. Magorrian et al. 1998). The near-infrared *K*-band (2.2 μm) magnitude of J0945-242 is very faint, with K = 20.5. Radio galaxies at $z = 1.65$ typically have host galaxy luminosities of K ~ 18. Thus the host galaxy of J0945-242 appears to be 2.5 mag (or a factor of 10) fainter than that for a typical radio-loud type-II AGN. If this faintness of the host galaxy is caused by extinction from dust then we would expect the blue end of the galaxy spectrum to be fainter, as dust attenuates the blue light more readily than at red wavelengths. However, the host galaxy of J0945-242 is extremely blue, indicative of ongoing star formation. Therefore, the faintness in the *K*-band light indicates that the host galaxy has a dearth of old, massive stars, which in turn implies that the galaxy is not yet fully formed at $z = 1.65$. Whereas the black hole has already grown, presumably by accretion of matter, close to its final mass due to the fact that the low-redshift black-hole mass function shows that supermassive black holes appear to have a maximum mass of around $10^{10}\ M_\odot$.

This relatively large black-hole mass associated with a host galaxy approximately a factor of 10 fainter than what would be expected from the local relation implies that supermassive black holes at high redshift may essentially be fully grown before the host galaxy has fully formed. This is in qualitative agreement with what we already see in high-redshift radio galaxies, where the small, young, radio sources appear to have extremely bright sub-millimetre luminosities. This extremely luminous sub-millimetre emission is due to reprocessed UV light from young stars which has been absorbed by the

Figure 2: The number density of Lyα emitters plotted against luminosity. The filled symbols mark surveys with an average redshift similar to ours (triangles and circles) and the open symbols stand for surveys at redshift $z = 5.7$ (squares and inverted triangles). Overplotted are two Schechter luminosity functions: the solid line is the fit to all our data points and the dashed line is the fit to our two highest luminosity data points and those of the surveys at similar redshift with L > 5 × 1035 W (dashed horizontal line) to ensure completeness. The dotted horizontal lines mark the detection limits of the surveys.

▲ Cowie and Hu 1998
● Kudritzki et al. 2000
■ Ajiki et al. 2003
▼ Hu et al. 2004
★ This project



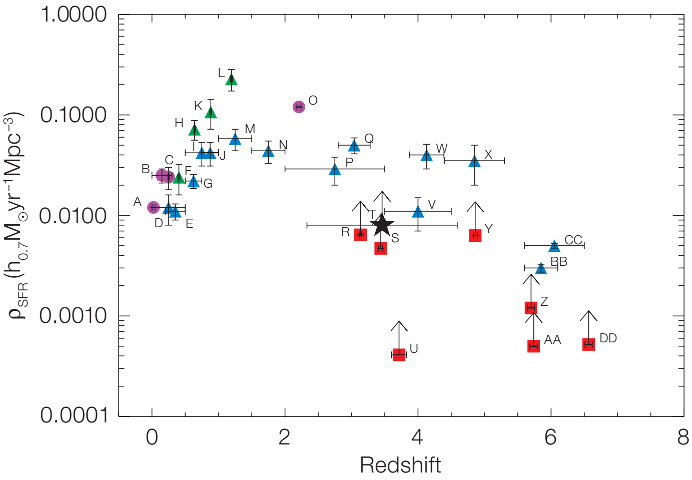


Figure 3 (above): Star-formation-rate densities as derived by various types of surveys. The result from this work is denoted by the filled star derived from integrating over the luminosity function fit to our data alone. The different types of surveys are marked with different symbols: the open circles are Hα searches, the open triangles are surveys aimed at oxygen emission lines, the filled triangles are multicolour surveys, and the open squares are Lyα searches.

● Hα emitters
▲ O-lines
▲ Multi-colour
■ Lyα emitters
★ This paper

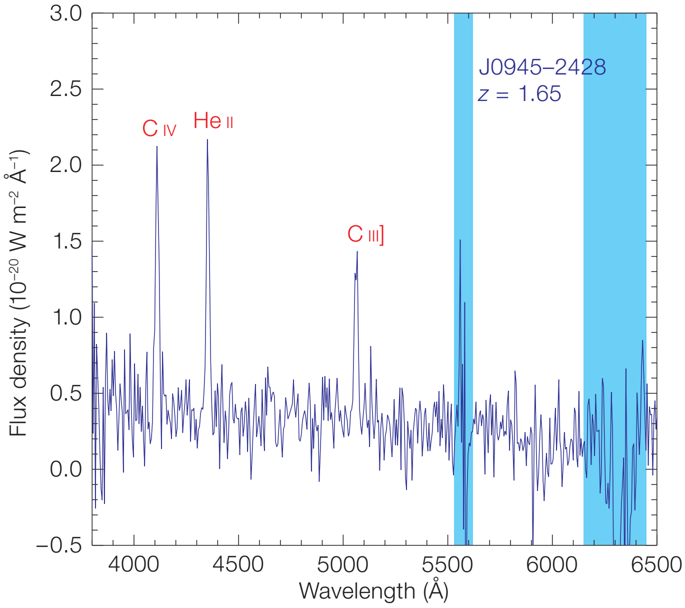


Figure 4 (left): The 1-D spectrum of the type-II quasar, J0945-2428 at $z = 1.65$. The spectrum was extracted over the whole galaxy (seven IFU fibres). The shaded regions show the wavelengths affected by sky-line emission.

large amounts of dust associated with star-forming regions, and re-radiated in the far-infrared. In order to produce these sub-millimetre luminosities, star-formation rates of up to 1000 $M_\odot yr^{-1}$ are needed, typical of a galaxy undergoing its first major bout of star-formation activity.

Conclusions

The new method of detecting emission-line galaxies at high redshift along with the serendipitous discovery of an obscured quasar at $z = 1.65$, highlights the way in which relatively wide-area integral-field units on large telescopes can open up a unique window on the Universe. VIMOS is currently the only instrument which has the capability of large spectral coverage coupled with a ~ 1 square arcminute field-of-view. However, future instruments, such as the Multi-Unit Spectroscopic Explorer (MUSE; *http://muse.univ-lyon1.fr*), will expand the initial work taking place in this field with VIMOS. Furthermore, volumetric surveys with IFUs may begin to find types of objects we have yet to discover in traditional surveys, and thus offer a whole new view of the Universe.

Full details of the work presented in this article can be found in van Breukelen, Jarvis & Venemans (2005) and Jarvis, van Breukelen & Wilman (2005).

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The zCOSMOS Redshift Survey

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

The last ten years have seen the opening up of dramatic new vistas of the furthest reaches of space and time – an exploration in which the VLT has played a major role. However, the work so far has been exploratory, and sampled only small and possibly unrepresentative volumes of the distant Universe. The next step is to bring to bear on a single large area of sky the full range of techniques that have been developed, using almost all of the most powerful observing facilities in the world. This next step is called COSMOS and the ESO VLT will make a major enabling contribution to this programme through the zCOSMOS survey being carried out with the VIMOS spectrograph.

It is well known that the finite speed of light enables us to observe very distant objects as they were when the Universe as a whole was much younger, and thereby to directly observe the evolving properties of the galaxy population over cosmic epoch. The most distant objects presently known lie at redshifts between six and seven ($6 < z < 7$) corresponding to a "look-back" time of about 95 % of the age of the Universe. Indeed, at the time that these objects emitted the light that we now detect, the Universe was less than one billion years old.

These observations have revealed a rich phenomenology in the early Universe. As we look back in time, we see that the global star-formation rate was about a factor of ten or more higher in the first third of the history of the Universe (at $z > 1$) than it is now. It is clear that the most violent star-bursting objects are enshrouded in dust and will make productive targets of study in the future with ALMA. Alongside these very active galaxies, there are also examples of more passive galaxies which must have completed their star formation quite early on. Consistent with our knowledge of the stellar content of galaxies today, we see in the high redshift Universe that high levels of star formation, and other signatures of youthfulness, appear in progressively more massive galaxies as we look back further in time, a phenomenon given the rather confusing name of "down-sizing".

In parallel, developments in cosmology and in particular the emergence of the "concordance cosmology" (from observations of the microwave background, large-scale structure in the present-day Universe and the Hubble diagram of distant Type 1a supernovae) have given us for the first time a theoretical paradigm for the formation of galaxies and other, larger scale, structures in the Universe – the Λ-CDM model: Structures in the Universe are the product of the gravitational growth of initially tiny density fluctuations in the distribution of dark matter in the Universe – fluctuations which likely arise from quantum processes in the earliest moments of the Big Bang, $\tau \sim 10^{-35}$ s. These density fluctuations eventually collapse to make gravitationally-bound dark matter structures within which the baryonic material cools, concentrating at the bottom of the gravitational potential wells where it forms the visible components of galaxies.

In many respects, the Λ-CDM paradigm is strikingly successful, especially in describing large-scale structure. On galactic scales, current implementations of it face some difficulties: for example, real galaxies appear to have more angular momentum than predicted in numerical Λ-CDM simulations and the down-sizing trend is in a sense opposite to that expected. There is also no clear understanding of the links between galaxies and their nuclear supermassive black holes. These various shortcomings almost certainly reflect our poor understanding of how dark matter and baryons interact, of the feed-back loops operating within the baryonic material due to energy injection from star formation and active galactic nuclei and of the relative importance in galaxies of internal dynamical evolution and externally driven events such as mergers, in redistributing material within them. Many of these current uncertainties are likely related to the environments that a forming and evolving galaxy finds itself in. Except for the very richest environments (i.e. the rich clusters of galaxies), knowledge of the environments of distant galaxies is rather poor. One of the aims of zCOSMOS is to characterise these environments over a wide range of redshifts and thus to lead to a much better physical understanding of the forces controlling the formation and evolution of galaxies through cosmic time.

Much of the progress in this field has been driven by "Legacy" style programmes, such as the Hubble Deep Fields (HDF), and the GOODS project, in which the data have been archived and released to the research community in a scientifically usable form. This allows a much larger community of astronomers, extending well beyond the original team who acquire and first analyse the data, to use

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[22] Tohoku University, Tokyo, Japan

the data to carry out their own research programmes. COSMOS and zCOSMOS are both undertaken in this spirit, and the purpose of this Messenger article is to bring to the attention of potential users across the ESO community the features of the zCOSMOS programme, which has just started on the VLT in P75.

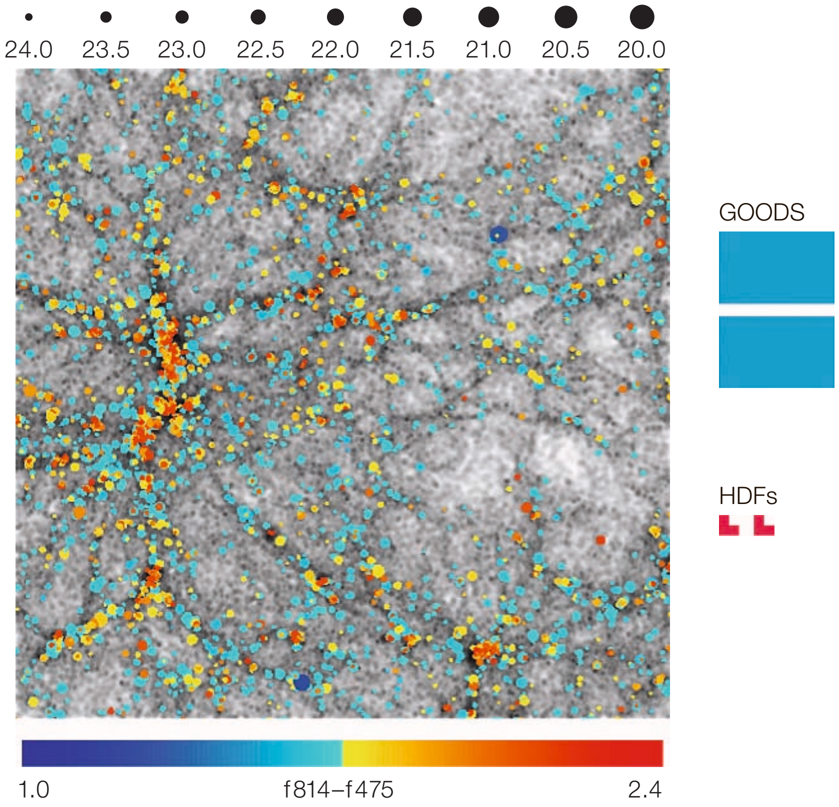

Figure 1: The 1.7 deg^2 COSMOS field compared with large-scale structure in a $\Delta z = 0.02$ slice of the Universe at $z \sim 1$ (courtesy Andrew Benson). Dots represent galaxies, colour-coded according to their observed colour (lower scale) and by size according to apparent magnitude (upper scale). The distribution of galaxies in the cosmic web of filaments and voids is clearly seen. By comparison the much smaller fields of view of the HDFs and the GOODS surveys (on the right) do not well sample the range of structures and environments that are present in the Universe at any epoch.

The global COSMOS project

The Cosmic Evolution Survey (COSMOS) was designed to bring to bear on a single very large field all of the tools and observational techniques that have been developed for the study of the distant Universe. The COSMOS field (centred on $10^{h}\,00^{m}\,29^{s}$ +02° 12′ 21″) was chosen to be near the Celestial Equator so that it can be accessed from observatories in both hemispheres, e.g. the ESO VLT and ALMA as well as the large optical/infrared telescopes in Hawaii and Chile and the VLA radio telescope in New Mexico, USA.

The COSMOS project is built around a mosaic of 600 images taken with the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (HST). The mosaic covers a contiguous area of 1.7 deg^2 and represents the largest single programme undertaken with the HST to date. The field spans a transverse dimension of 80 comoving Mpc at $z \sim 1$ and 160 comoving Mpc at $z \sim 3$ and covers a volume to $z \sim 3$ (about 50 million Mpc^3) that is approaching that of the entire local Sloan Digital Sky Survey at redshifts $z < 0.1$. The HST observations were completed in June 2005. Despite being only single-orbit exposures, the broad F814W filter reaches to within 0.3 magnitudes of the well-known GOODS images even though the survey covers an area twenty times larger than the combined GOODS-N and GOODS-S fields (see Figure 1).

Impressive as the HST images are, the real power of COSMOS stems from the addition of a wealth of other observations that are being amassed on this field by the truly global COSMOS consortium. Most notably, the SuprimeCam on the Subaru 8-m has been used to obtain very deep BGVRIZ images of the whole field with a limiting magnitude (5σ) of about AB ~ 26–27. These have been supplemented by *U*-band and *K*-band images from the CFHT and NOAO 4-m telescopes. The combined photometric catalogue contains well over 1 million galaxies with photometrically estimated redshifts and approximate spectral types. The field has also been observed with the GALEX ultraviolet satellite to a depth of AB ~ 26 at 150 and 225 nm. Observing time on the Spitzer observatory has been awarded to extend this photometric coverage into the mid-infrared 3–8 μm which will substantially improve the photometric redshifts and the estimates of the stellar masses of the galaxies. Ultimately, we hope to have photometry and images from a suite of almost 30 intermediate- and broad-band filters spanning the full range of starlight in the ultraviolet, optical and near-infrared (150 nm – 8 μm) wavebands.

Deep imaging observations at other wavelengths, e.g. the X-ray and radio, reveal the signatures of accretion onto black holes in active galactic nuclei (AGN) and of energetic bursts of star formation that are obscured by dust. A mosaic of deep X-ray images obtained with the ESA XMM-Newton satellite have already yielded more than 1000 active galactic nuclei and about 100 X-ray selected groups and clusters of galaxies, while deep VLA images at 1.4 GHz reaching to about 50 μJy (5σ) will detect 4000 radio sources. Future observations planned at far-infrared and sub-millimetre wavelengths will complete the observational picture.

What distinguishes COSMOS from previous programmes such as the Hubble Deep Fields, GOODS and COMBO-17/GEMS, is its enormous area. This gives us:

- unprecedentedly large samples of objects in the distant Universe, thereby ensuring statistical weight even for rare classes of objects (see Table 1);
- confidence that we are sampling truly representative volumes of the Universe at high redshift (mitigating the so-called cosmic variance problem associated with smaller surveys that effectively probe a one-dimensional beam through the Universe);
- the ability to place all objects in their environment, from small scale groups of galaxies up to the largest structures in the Universe.

Table1: Numbers of representative objects in the COSMOS survey.

COSMOS Inventory Category	Selection	Number
Faint galaxies	$I_{AB} < 27$	1 million
X-ray selected AGN	$I_{AB} < 27$	3 400
X-ray selected clusters	$S_X > 5 \times 10^{-16}$ c.g.s.	100
Radio sources	$S_{1.4} > 50$ µJy	4 000
Bright quasars	$B < 21$	100
High z quarsars ($z > 4$)	$I_{AB} < 25$	50
ULIRGS	…	3 000
Lyman break galaxies	$I_{AB} < 25.5$	10 000
Passive galaxies ($z \sim 3$)	$K_{AB} < 24$	10 000
zCOSMOS $0.3 < z < 1.2$ galaxies with redshift	$I_{AB} < 22.5$	25 000
zCOSMOS $1.3 < z < 2.5$ galaxies with redshift	$B_{AB} < 25$	12 500

Such a unique data set of course opens other equally unique possibilities. For instance, the HST images will allow the distribution of dark matter to be mapped down to structures of order 3×10^{13} $M_{\odot}$, which may be compared with the distribution of luminous galaxies. In addition, the large number of quasars bright enough for absorption line spectroscopy (Table 1) will enable us to map the distribution of neutral gas in the intergalactic medium and again, compare that with the large-scale structure defined by the galaxies.

The zCOSMOS redshift survey

The COSMOS data sets mentioned above consist of exquisite two-dimensional images of the sky at almost every imaginable wavelength. The crucial third dimension is added by knowledge of the redshifts of the sources. Some information on the redshifts may be derived from the broad-band colours of the objects, so-called "photometric redshifts", but the more secure and precise "spectroscopic redshifts" are required for many purposes: The increased precision relative to the best attainable photometric redshifts enables the delineation of the cosmic web of large-scale structure in the Universe, from small groups of galaxies up to the largest filaments and voids. The measurement of individual velocities of galaxies enables dynamical studies of these structures, yielding masses, dynamical states and cosmological information. The spectra themselves yield important diagnostics of the evolutionary state of individual galaxies, including measures of the star-formation rate, dust extinction, the gas and stellar metallicities, and stellar population parameters such as ages. The spectra can confirm the identifications of radio and X-ray sources through the characteristic signatures of AGN or starburst activity. Precise spectroscopic redshifts can of course also be used to improve and characterise the photometric redshift schemes which can then be applied to every galaxy in the field.

The VIMOS instrument on the VLT provides ESO with a unique capability for undertaking such a survey and in P75 a Large Programme was awarded 540 hours of observation time to carry out the zCOSMOS redshift survey. This programme is complementary to the other large VIMOS programme, the VVDS Survey carried out by the VIMOS Instrument Team.

The design of the zCOSMOS programme has been driven primarily by the desire to quantify the environments of galaxies and AGN over a broad range of epochs. This requires: A high sampling completeness (~ 70 % of objects observed from a given target sample); uniform sampling coverage across the whole field; a broadly contiguous redshift coverage from very low redshifts to redshifts $z > 2.5$ spanning 80 % of cosmic time; relatively high velocity accuracy (100 $\text{km}\,\text{s}^{-1}$). To achieve these requirements efficiently, the zCOSMOS programme is split into two components, each requiring different VIMOS configurations and exposure times.

The "bright" sample of 25 000 COSMOS galaxies is selected to have $I_{AB} < 22.5$. The straight *I*-band selection yields a sample of galaxies at $0.2 < z < 1.2$, reaching 1.5 mag below L* at $z \sim 0.7$ where it corresponds to selection in the rest-frame *V*-band. With a sampling rate of at least 70 % and a velocity accuracy of at least 100 $\text{km}\,\text{s}^{-1}$, enabling the isolation of groups down to $3 \times 10^{12.5}$ $M_{\odot}$, the "bright" sample is designed to be directly comparable to the very large zero-redshift samples (SDSS and 2dfGRS) but at a look-back time of half the age of the Universe. The input target list is generated from the HST/ACS images. The observations are made with the VIMOS MR grism in 1 hr exposures between $550 < \lambda < 960$ nm at resolution $R \sim 600$. About 160 galaxies can be observed simultaneously. Successive VIMOS pointings are stepped in Right Ascension and Declination so that every galaxy in the target sample has eight opportunities to be selected into a spectroscopic mask, ensuring a uniform statistical sampling across the field without significant biases against near neighbours, etc.

The extension to higher redshifts requires a different strategy. We know from the VVDS survey that simply selecting fainter galaxies results in a sample that is still dominated by relatively low redshift galaxies, with only a small “tail” at higher redshifts $1.5 < z < 4$ emerging faintwards of AB ~ 23.5. In order to isolate this tail, the zCOSMOS “faint” sample of 12 500 galaxies is selected using a combination of proven colour-colour selection criteria, specifically the (B-Z)/(Z-K) selection proven by the VLT K20 survey and a development of the (U-G)/(G-R) selection used by Charles Steidel and collaborators to isolate star-forming galaxies. These two selection criteria yield a sample of galaxies at $1.2 < z < 2.4$ and $B_{AB} < 25.0$. In order to keep the total programme size manageable, the higher redshift part of zCOSMOS is limited to the central 1 deg^2 area, which nevertheless still yields a comparable comoving transverse dimension to that of the lower redshift component. A four-pass strategy with VIMOS and the LR-Blue grism ($370 < \lambda < 670$ nm at R ~ 200) should yield redshifts in 4.5 hr exposures for 12 500 such galaxies, with a similar sampling rate as for the bright sample, and a velocity accuracy of 300 kms^{-1}.

In both parts of the survey, radio source and X-ray source candidate identifications are added to the masks either as random targets (which will be observed with a roughly 70 % sampling rate) or, for high priority and urgently needed sources, as compulsory targets which are observed with close to 100 % efficiency early in the programme.

zCOSMOS schedule and data release plans

Execution of a programme of the size of zCOSMOS on a single field places unique demands on ESO in the scheduling of the VLT: to be completed in a timely manner, the UT3 must be used for this programme for essentially all the time that the field is observable. Periodic data releases will be made with a final comprehensive data set placed in the ESO Archive shortly following completion of the programme, thereby providing the general research community with a detailed census and sample of the distant Universe.

URL references

http://www.astro.caltech.edu/~cosmos
http://www.exp-astro.phys.ethz.ch/zCOSMOS

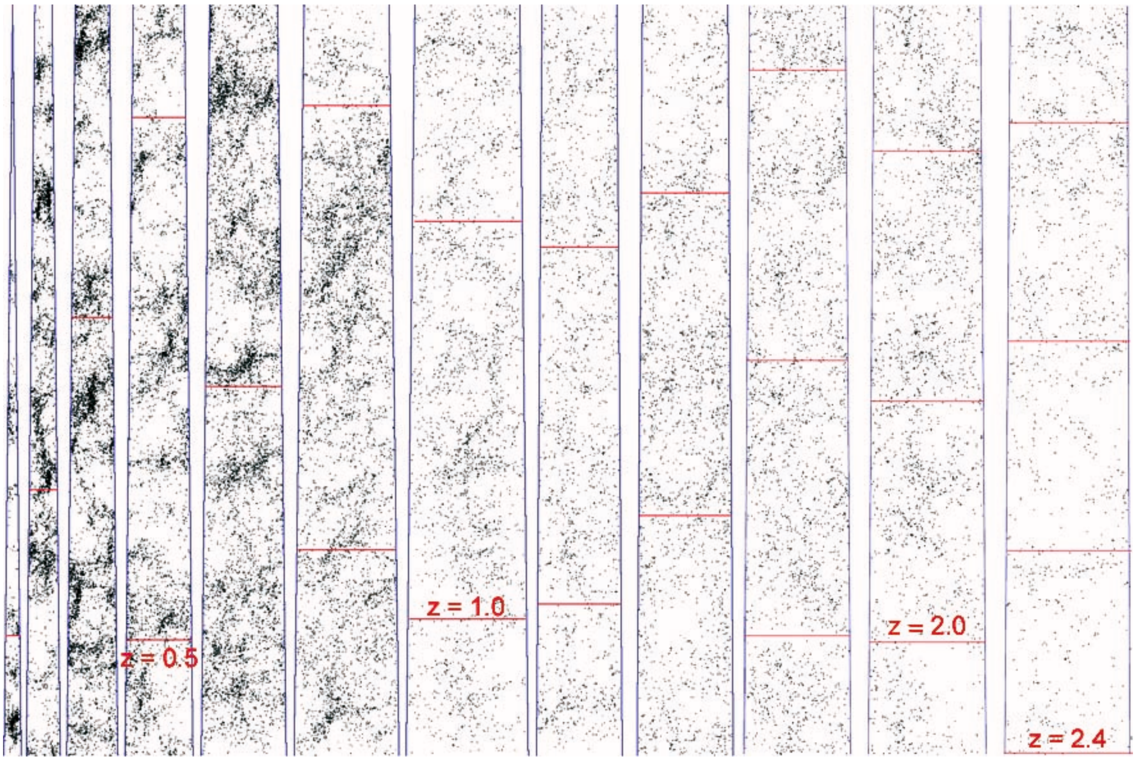

Figure 2: Simulation of the final zCOSMOS redshift survey showing the spatial distribution (in comoving space) of objects in the survey over the redshift interval $0 < z < 2.4$, in which every dot represents a zCOSMOS galaxy with spectroscopically determined redshift. The red bars mark increments of 0.1 in redshift z. The figure has been generated from the COSMOS mock catalogues produced from the Millennium Run cosmological simulation (courtesy of Manfred Kitzbichler).

Observing with the New High-Speed Camera ULTRACAM on Melipal

British astronomers[1] have opened a new window on the Universe with the recent commissioning of the Visitor Instrument ULTRACAM on the VLT).

ULTRACAM is an ultrafast camera capable of capturing some of the most rapid astronomical events. It can take up to 500 pictures a second in three different colours simultaneously. It has been designed and built by scientists from the Universities of Sheffield and Warwick (United Kingdom), in collaboration with the UK Astronomy Technology Centre in Edinburgh.

ULTRACAM employs the latest in charged coupled device (CCD) detector technology in order to take, store and analyse data at the required sensitivities and speeds. CCD detectors can be found in digital cameras and camcorders, but the devices used in ULTRACAM are special because they are larger, faster and most importantly, much more sensitive to light than the detectors used in today's consumer electronics products.

Figure 1: The ULTRACAM instrument mounted on the visitor focus of Melipal (UT3).

In May 2002, the instrument saw "first light" on the 4.2-m William Herschel Telescope (WHT) on La Palma. Since then the instrument has been awarded a total of 75 nights of time on the WHT to study any object in the Universe which eclipses, transits, occults, flickers, flares, pulsates, oscillates, outbursts or explodes. These observations have produced a bonanza of new and exciting results, leading to eleven scientific publications already published or in press.

To study the very faintest stars at the very highest speeds, however, it is necessary to use the largest telescopes. Thus, work began two years ago preparing ULTRACAM for use on the VLT.

"Astronomers using the VLT now have an instrument specifically designed for the study of high-speed phenomena", said Vik Dhillon, from the University of Sheffield (UK) and the ULTRACAM project scientist. "Using ULTRACAM in conjunction with the current generation of large telescopes makes it now possible to study high-speed celestial phenomena such as eclipses, oscillations and occultations in stars which are millions of times too faint to see with the unaided eye."

The instrument saw first light on the VLT on May 4, 2005, and was then used for 17 consecutive nights on the telescope to study extrasolar planets, black-hole binary systems, pulsars, white dwarfs, asteroseismology, cataclysmic variables, brown dwarfs, gamma-ray bursts, active galactic nuclei and Kuiper-belt objects.

One of the faint objects studied with ULTRACAM on the VLT is GU Muscae. This object consists of a black hole in a 10-hour orbit with a normal, solar-like star. The black hole is surrounded by a disc of material transferred from the normal star. As this material falls onto the black hole, energy is released, producing large-amplitude flares visible in the light curve. This object has magnitude 21.4, that is, it is one million times fainter than what can be seen with the unaided eye. Yet, to study it in detail and detect the shortest possible pulses, it is necessary to use exposure times as short as 5 seconds. This is possible with the large aperture and great efficiency of the VLT.

These unique observations have revealed a series of sharp spikes, separated by approximately seven minutes. Such a stable signal must be tied to a relatively stable structure in the disc of matter surrounding the black hole. The astronomers are now in the process of analysing these results in great details in order to understand the origin of this structure.

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[1] The ULTRACAM team is composed of Vik Dhillon, Stuart Littlefair, and Paul Kerry (Sheffield, UK), Tom Marsh (Warwick, UK), Andy Vick and Dave Atkinson (UKATC, Edinburgh, UK). For the installation on the VLT, they received support from Kieran O'Brien and Pascal Robert (ESO, Chile). The ULTRACAM project page can be found at *http://www.shef.ac.uk/~phys/people/vdhillon/ultracam*

Another series of observations were dedicated to the study of extrasolar planets, more particularly those that transit in front of their host star. ULTRACAM observations have allowed the astronomers to obtain simultaneous light curves, in several colour-bands, of four known transiting exoplanets discovered by the OGLE survey, and this with a precision of a tenth of a per cent and with a one-second time resolution. This is a factor ten better than previous measurements and will provide very accurate masses and radii for these so-called "hot-Jupiters". Because ULTRACAM makes observations in three different wavebands, such observations will also allow astronomers to establish whether the radius of the exoplanet is different at different wavelengths. This could provide crucial information on the possible exoplanets' atmosphere.

The camera is the first instrument to make use of the Visitor Focus on Melipal (UT3), and the first UK-built instrument to be mounted at the VLT. The Visitor Focus allows innovative technologies and instrumentation to be added to the telescope for short periods of time, permitting studies to take place that are not available with the current suite of instruments.

"These few nights with ULTRACAM on the VLT have demonstrated the unique discoveries that can be made by combining an innovative technology with one of the best astronomical facilities in the world", said Tom Marsh of the University of Warwick and member of the team. "We hope that ULTRACAM will now become a regular visitor at the VLT, giving European astronomers access to a unique new tool with which to study the Universe."

The next run with ULTRACAM on the VLT is currently scheduled for November 2005, and plans are under way for a third run sometime during 2006. Anyone interested in applying for time on the instrument should contact one of the authors in the first instance. (Any such observations also require the approval of the OPC.)

(Based on ESO Press Release 17/05)

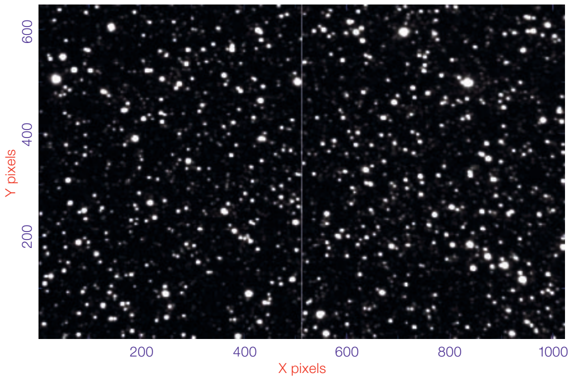


Figure 2: First light with ULTRACAM on the VLT: The field of the transiting extrasolar planet OGLE-TR-56b. The image shows only a portion of one of the three ULTRACAM CCD chips. Thousands of such one-second images were obtained in order to derive an accurate light curve of the transit at three different wavelengths, thereby enabling an accurate determination of the radius of the planet.

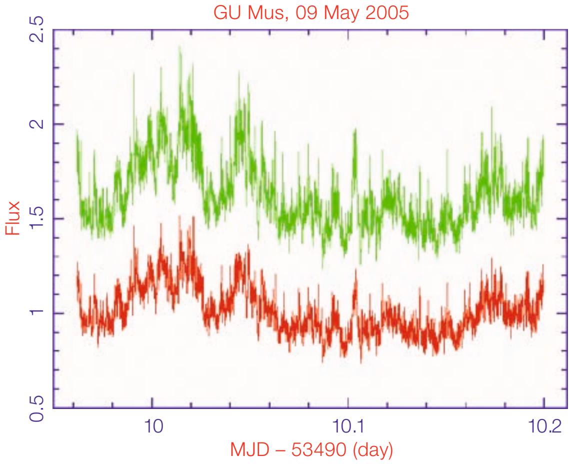


Figure 3: Light curves of the black hole GU Muscae. This figure shows an early scientific highlight from the first few nights of the ULTRACAM observing campaign on the VLT: light curves in the *I*- (red) and *G*-band (green) of the quiescent black hole X-ray transient GU Muscae. This object consists of a black hole in a 10-hour orbit with a normal solar-like star. The black hole is surrounded by an accretion disc of material transferred from the solar-like star. As this material accretes onto the black hole, energy is released, and this is evident from the large-amplitude flares visible in the light curves. What was not expected, however, is the series of sharp spikes that can be seen, and which are separated by approximately seven minutes. Such a stable signal must be tied to a relatively stable structure in the accretion disc.

Figure 4: The ULTRACAM commissioning team in the VLT control room at first light. From left to right: Pascal Robert (ESO), Ariel Lopez (ESO), Kieran O'Brien (ESO), Andy Vick (UKATC), David Atkinson (UKATC), Paul Kerry (Sheffield), Vik Dhillon (Sheffield), Stuart Littlefair (Sheffield), Andreas Kaufer (ESO), Tom Marsh (Warwick).

ALMA News

Tom Wilson (ESO)

Antenna procurement

The antennas are the largest single item in the ALMA budget. Thus the status of antenna procurement is of the highest importance for the project. Associated Universities Inc/NRAO have been given ALMA Board approval and permission by the US National Science Foundation to procure their antennas. On July 11, they signed a contract with VertexRSI for up to 32 antennas for ALMA. ESO is moving ahead with its antenna procurement as quickly as possible. The Joint ALMA Office is leading the rebaselining (a reassessment of project costs). This is proceeding at full speed. There will be discussions of both the rebaselining and antenna procurement issues at the next meetings of the ESO Council to be held in September.

New European Project Manager

Hans Rykaczewski is the new European ALMA Project Manager and Head of the ESO ALMA Division. He studied physics in Aachen. He completed a doctoral thesis on searches for new quark flavours at the Deutsches Elektronen Synchrotron DESY in Hamburg. In 1984, he moved to M.I.T. and was delegated to CERN for working on the design and construction of the L3 detector which was installed and taking data at CERN's Large Electron Positron Collider, LEP. There he was responsible for the timely fabrication of several subdetector elements, like magnet, calorimeter systems and the precision muon spectrometer. Since 1989 he has held a position as Scientific Associate at the Laboratory for High Energy Physics of the Eidgenössische Technische Hochschule (ETH) in Zürich. He was intensively involved in many scientific and managerial issues concerning the L* Experiment at the Superconducting Super Collider, SSC, and the proposed Lepton-Photon-Precision-Physics (L3P) Experiment for the Large Hadron Collider, LHC, at CERN. Since the beginning of 1994, he took over important scientific, organisational and financial responsibilities for the Compact Muon Solenoid (CMS) experiment. He was engaged in many areas of the construction of the lead tungstate crystal detector and was deeply involved in the organisation of the construction of the CMS Magnet.

Hans Rykaczewski joined ESO in July 2005 and is very much looking forward to helping in making ALMA a success, in fruitful collaboration with the international partners in this project.

Progress for the ALMA Front Ends

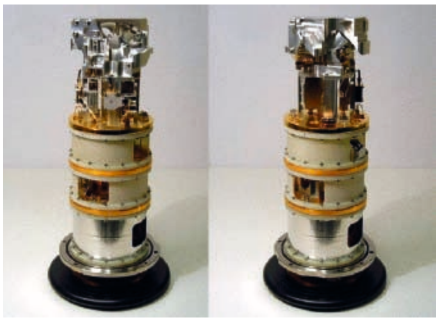
The most important factors that determine ALMA sensitivity are the transmission of the astronomical signals through the earth's atmosphere, the effective collecting area, and the quality of the first stage of the receivers, that is, the Front Ends. The quality of Front Ends depends on their stability and noise temperature. That is, they should not introduce any systematic errors, and should add the smallest possible amount of noise. The ALMA Front Ends show noise temperatures that are 3 to 5 times the limit determined by quantum mechanics. In recent months the ALMA Front End Integrated Project Team (IPT) has shown several important signs of concrete progress towards the construction of receivers for the ALMA project.

On July 6 and 7, 2005 the FE IPT successfully completed its delta Preliminary Design Review (PDR). The review meeting was held at ESO Headquarters in Garching, Germany. The review panel, chaired by the European ALMA System Engineering & Integration IPT Lead, Christoph Haupt, consisted of experts both internal to the project as well as noted receiver experts from Australia and the USA. Based on documentation made available in preparation of the meeting and the presentations at the meeting the review panel came to a unanimous decision that the Front End design was well beyond the PDR status. The reviewers also provided valuable constructive criticism that will be taken into account in finalising the ALMA receiver design. The success of this design review was very much due to the joint efforts made by the FE IPT sub-system engineers, Hans Rudolf (ESO) and Kamaljeet Saini (NRAO), and the support they received from others within the FE IPT.

That the ALMA FE IPT makes progress is also shown in a more tangible manner in that important assemblies are nearing the completion of their construction. At IRAM in Grenoble, France, the first pre-production unit of the Band 7 Cartridge, covering the frequency range from 275 GHz to 373 GHz, is currently undergoing extensive testing to both verify the design and this first unit itself. Noise measurements on the completed unit, using the first local oscillator delivered by NRAO, show exceptionally good performance. The results are much better than the requirements (see graph).

The first Band 9 pre-production cartridge, covering the frequency range from 610 GHz to 720 GHz, has also been copleted (see picture) and is undergoing extensive testing at NOVA/SRON in Groningen, The Netherlands. Following the Front Ends, one must have Intermediate Frequency amplifiers to increase the power to the desired value. These IF amplifiers must also have low noise and high stability. The present tests are being done with IF amplifiers having a bandwidth of 4 to 8 GHz. The final IF amplifiers will cover the required band from 4 to 12 GHz. These were recently delivered by Yebes Observatory in Spain and will be mounted in the Band 9 cartridge shortly.

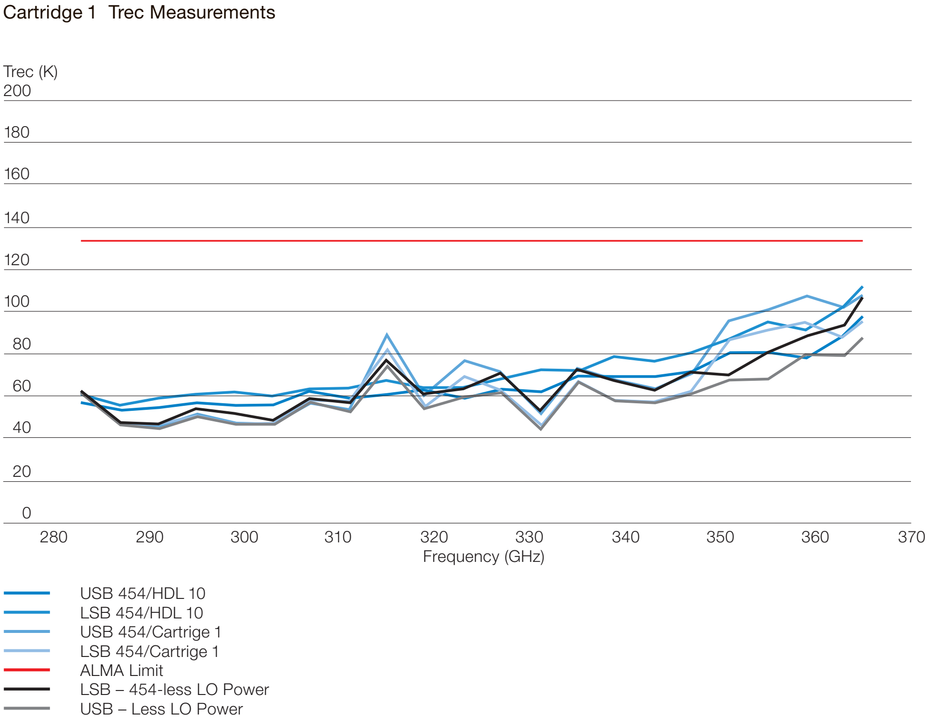
ALMA receiver cartridges.



In summary it can be stated that the receiver noise temperatures achieved on the Band 7 and 9 cartridges are likely the best in the world over these wide frequency bands in the sub-millimetre range. Until recently the standard practice was to use mechanical tuners in the receivers to obtain the optimum noise performance. The quality of the ALMA Band 7 and 9 receivers become even more remarkable when one takes into account that both Band 7 and 9 receivers use no mechanical tuning. The combination of modern, state-of-the-art design technology, well-equipped laboratories and last, but definitely not least, very skilled and dedicated staff at both IRAM and NOVA/SRON have been crucial for this success. (Contributed by Gie Han Tan, see also Tan et al. 2004, The Messenger 118, 18.)

Construction progress

The excavations for the Operations Support Facility (OSF) buildings are now progressing very well. The two levels of the future building are now clearly discernible. In addition, construction of the road between the OSF and the Array Operations Site at 5 000 m has moved up to the higher and more difficult part of the road at an altitude of 4 000 m. (Photo credits: Jörg Eschwey, see also his article next page.)



ALMA Site Development

Jörg Eschwey (ESO)

In the remote Atacama Desert, some 30 km South of the budding tourist hub of San Pedro de Atacama, the next giant leap for the world's astronomical community is under way. Nestled at approximately 2 900 metres above sea level amid the rolling foothills of the Andean Plateau the facility for the OSF (Operation Support Facility) base camp is complete, and we are overseeing the initial earthwork for the Technical Area Buildings.

Overlooking the vast expanse of the Salar de Atacama salt flats, the ALMA offices, dormitories and dining hall are an appropriate reflection of the efficiency and resilience of the surrounding desert life. Fully equipped with all the amenities such as modern communication systems, high-speed internet and e-mail, satellite TV, ecological waste water treatment, heating and air conditioning systems and excellent catering services, the camp is a self-contained kernel of the 21st century amid the harsh desert terrain.

A cheerful and fastidious staff maintain the more than comfortable dormitories, prepare three meals daily with surprising variety, and enjoy an occasional barbecue at the camp's very own outdoor barbecue hut.

Throughout the day, there are the sounds of crews hard at work excavating, crushing and filling and leveling the desert's soil to create the foundation base of the OSF Technical buildings. As the sun sets, impenetrable silence shrouds the camp under a blanket of the most magnificent starry display only the Atacama can offer. In the middle of this splendid scenery, the development of the site for the ALMA project has been carried out since its beginnings in respectful concordance with the Chilean environmental law and with the firm priority of maintaining friendly relations with the local communities of San Pedro and Toconao, our neighbours.

This true commitment to environmental and cultural preservation is clear as one explores the access road branching from the Chilean Highway 23 that climbs toward the camp. The road meanders its way past fields of cacti, some over 300 years old and reaching over 5 metres in height, historical sites of primitive hunter-gatherers, vicuñas, llamas and other wild life. The surrounding mountains (reaching as high as 6 000 metres) include active, dormant and extinct volcanoes.

Equipped with supplemental oxygen and two-way radio contact staff and visitors negotiate their way along some 28 km of gravel road below rounded peaks peppered with abandoned sulfur mines to the foot of Cerro Chajnantor. Here we find the site of the APEX and the Japan ASTE radio telescopes and within the location of the ALMA project, a marked field where 64 radio telescopes will come together to form the world's largest radio telescope array.

Back at the OSF, there are no overhead lines disturbing the views to earth and sky as all technical installations are kept underground. Waste water and effluents are treated biologically and with the use of state-of-the-art treatment facilities. Each day the cleaning staff removes the dust of the ever-encroaching desert from inside and outside the habitat of the staff. Visitors are impressed by the community spirit as passers by greet them with warmth and friendliness. When all come together in the dining room at meal times, there is the true sense of everyone working as an enthusiastic team.

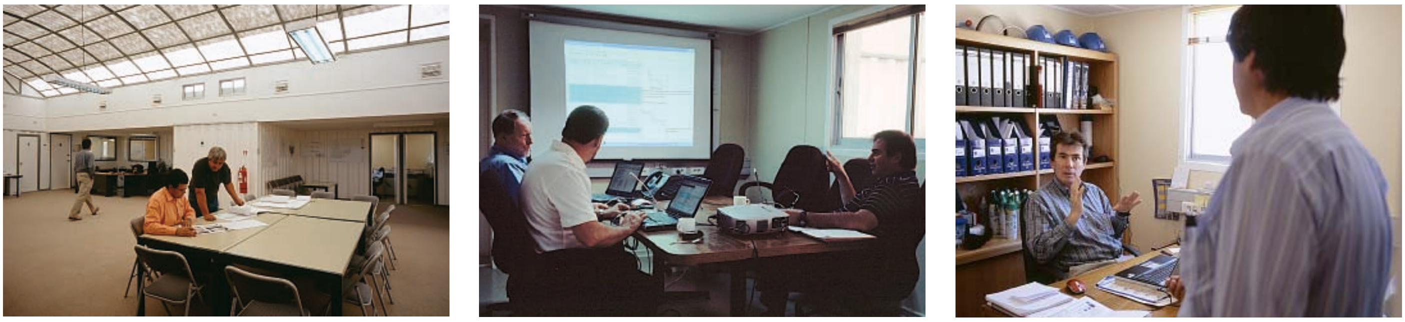
To find an international group of European, North American, Japanese and Chilean professionals and workers collaborating on the project, is truly inspiring.

Although much of the ALMA Camp construction is finished, 15 new dormitories will soon be added. The office building will be fitted with a number of cubicle-style office spaces, a recreational facility will be constructed, and the dining room will be extended to welcome and accommodate incoming European, North American, Japanese and Chilean staff.

The construction of the permanent Technical Facilities and the completion of the Contractors Camp at the OSF are currently being tendered. Construction start is scheduled for January 2006 and September 2005 respectively.

Construction of the foundation and superstructure of the Technical Building at the Chajnantor site at an elevation of approximately 5 000 metres above sea level is scheduled to start in September–October 2005 and the rough finish of the access road will be completed by the end of this year.

Photos: H. H. Heyer, ESO (4)



Above: Work at the Operational Support Facility (OSF).

Right: The APEX telescope at Chajnantor.

Technology Transfer at ESO

Martin Cullum (ESO)

Technology Transfer has become an important theme for the European Commission as a means of promoting innovation and competitiveness within European industry. It is also an area where organisations like ESO, that are engaged in developing highly advanced research facilities, can and do make significant contributions. This article discussed some of the processes involved in Technology Transfer and provides several examples of technological innovations developed by ESO in-house and through its procurement activities.

Broadly defined, Technology Transfer concerns the transfer of knowledge and innovations from laboratories and research institutes to industry, or the use of ideas and developments from one field in others that were not originally intended.

At its meeting in Lisbon in 2000, the European Council set the objective of transforming the EU into the “most competitive and dynamic knowledge-based economy in the world” by 2010. To achieve this very challenging goal, a number of measures were planned, including revision of the framework for state aid for R&D, stimulating mobility of researchers between academia and industry, encouraging Public-Private Partnerships (PPPs), support for R&D innovations with Small and Medium-sized Enterprises (SMEs) as well as optimising the mechanisms for Technology Transfer within Europe.

Technology Transfer is also being actively promoted by the European Competitiveness Council that comprises ministers of research, education and industry or economy, as an essential element of improving European competitiveness.

Although Europe has traditionally been rather good at technological innovation, it has often lagged behind its main industrial competitors in exploiting innovations commercially. There are many reasons for this, but one important aspect is the relatively large contribution made to the overall economy in Europe by SMEs. Even before the recent enlargement of the European Union, 65 % of the EU GDP was generated by SMEs, and this figure is even larger now. This compares to only 45 % in the USA, for example. In general, larger enterprises have their own research departments and development laboratories, and the research carried out is largely, although by no means entirely, oriented towards specific products and fields that the company exploits commercially. This is often referred to as the “closed” model for technological innovation.

But even in the USA, SMEs invest three to six times more in R&D than their European counterparts who have traditionally relied more on “open” collaborations with external academic and research organisations. This can have certain advantages in that the accessible areas of research are very broad but experience has shown that the transfer of innovations from academia to industry is not a very efficient process. Not infrequently, promising open collaborations fail due to problems relating to the protection of Intellectual Property Rights that do not exist with in-house developments.

Apart from targeted research collaborations, there are other processes that can lead to Technology Transfer and ones in which scientific research organisations like ESO make significant contributions. Many European organisations, including ESA, EMBL, CERN, ESRF as well as national organisations such as the Max-Planck-Gesellschaft have adopted Technology Transfer as a core activity, and proactively search for market applications for their technological developments. In some cases this even extends to promoting start-up companies through venture capital funds.

Why is Technology Transfer important for ESO?

More than ever before, the governments of ESO’s Member States are looking not only at the scientific return but also at the industrial return they get from their contributions to ESO and the indirect benefits to their economies and to society as a whole. In these days of strained national budgets, the pursuit of scientific knowledge alone is not always sufficient to justify the investment into ever more ambitious and expensive projects.

Although ESO has no official mandate or funds to invest in Technology Transfer activities, it is a clear goal in the charter of EIROforum[1] of which ESO is a member. Through the very nature of its activities, ESO makes a significant contribution to Technology Transfer within the Member States. To help quantify this contribution and to highlight the process at ESO, a survey of ESO Technology was carried out in 2004 and the results presented to the ESO Council in December 2004. The results are accessible from the main ESO web page under *Projects & Developments* and provide a compendium of technologies that have been developed or promoted by ESO over the last 15 years or so. Most of the examples are associated with the VLT development period.

Processes of transferring technology at ESO

The transfer of ESO developed or promoted technologies to industry can take several forms.

1. Novel technologies that have been developed by ESO or pushed beyond customary limits, or novel combinations of technologies that have been developed by ESO and made available for industrial exploitation.
2. Technologies that have been developed or extended in collaboration with industry through ESO development contracts.
3. Technologies that have been developed or extended by industry through the execution of an ESO procurement contract.
4. ESO developments that have been used for other similar projects elsewhere.
5. ESO patents.

Examples of Technology Transfer at ESO

The following paragraphs give a few examples of such technologies to illustrate the processes just described.

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[1] EIROforum is a collaboration between seven European intergovernmental scientific research organisations that are responsible for infrastructures and laboratories (CERN, EFDA, EMBL, ESA, ESO, ESRF and ILL).

In-house developed technologies

Active Optics

The ESO New Technology Telescope (NTT) was the first optical telescope with actively controlled optics. The main driver behind this development was to break the classical cost-diameter law for large telescopes but, even at first light, the NTT demonstrated image quality almost never seen previously on ground-based telescopes. Since the NTT, essentially all large optical telescopes worldwide use active optical control.

A crucial step towards realising a practical active optics telescope was the development of the so-called Shack-Hartmann wavefront sensor at ESO. It combines a compact optical device following an idea originally proposed by Roland Shack at the University of Arizona in 1970 with CCD detectors that started to be used for astronomy in the early 1980's. This device allows the optical alignment and shape of the main optics of the telescope to be measured and corrected in real-time. A key component of the wavefront sensor is the lenslet array which contains 400 lenslets, each 0.5 or 1.0 mm across depending on the application. ESO worked together with the Paul-Scherrer-Institut in Switzerland to develop the master and Jobin-Yvon France to manufacture the final copies of these arrays.

A number of commercial products based on Shack-Hartmann wavefront sensors have since been commercialised, for example devices for optical testing by Imagine Optic in France, for eye surgery by Zeiss in Germany and for optical alignment and testing by Spot Optics in Italy. Shack-Hartmann wavefront sensors are widely used in adaptive optics systems which correct aberrations caused by atmospheric turbulence – a technology that was also pioneered by ESO.

ESO technology development contracts

Volume Phase Holographic Gratings

Since Volume Phase Holographic Gratings (VPHGs) were first proposed for astronomy in 1998, they have had major impact on astronomical spectroscopy.

Figure 1: Diagram showing the principle of Active Optics. The Wavefront Sensor detects telescope aberrations and misalignments and corrects the shape of the main mirror and position of the secondary mirror to provide real-time correction.

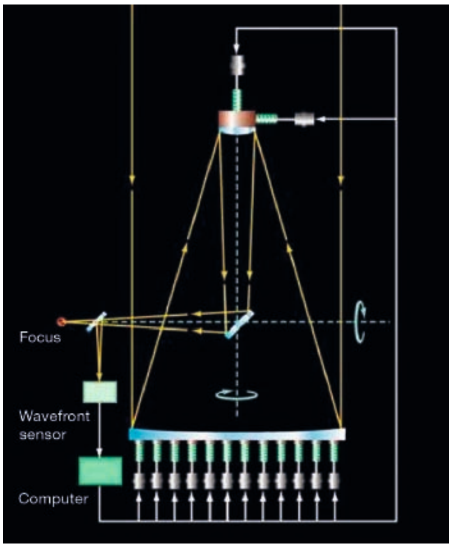
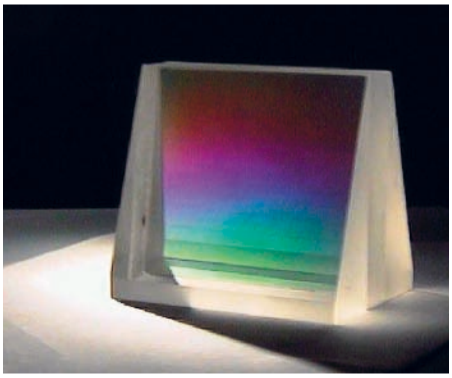


Figure 2: Example of a Volume Phase Holographic Grating sandwiched between two prisms to allow linear transmission.



The light passing through a VPHG, instead of being diffracted by a surface relief pattern as in a classical diffraction grating, undergoes Bragg refraction as it passes through a thin transparent layer in which the refractive index is modulated. This provides a very high optical efficiency together with low sensitivity to polarisation and reduced scattering.

The original VPHGs were produced for Raman Spectroscopy and these were small and not ideally suited for astronomy. A facility to manufacture large Volume Phase Holographic Gratings was set up at the Centre Spatial de Liège. ESO led a consortium of 5 astronomical institutions that allowed 10 prototype gratings to be manufactured up to 30 cm in size. The Centre Spatial de Liège has since created a spin-off company that is the leading European supplier of VPH gratings and currently the world's largest facility for the manufacture of these products.

Strip tape encoders

Important components of any large telescope are the high accuracy angular position encoders needed for axis control. When ESO originally approached the world's leading manufacturer of high-precision strip tape encoders, Heidenhain in Germany, they could not guarantee that the stringent technical requirements for the VLT encoders could be met. Moreover, the tape mounting technique used at the time required a complex mechanical system to ensure that the tension in the tape was always constant and uniform. ESO placed a development contract with Heidenhain to produce an internally mounted tape encoder and provided them with a full-sized bearing for tests. The results of this development were so conclusive – in terms of both improved accuracy and simplified mechanics – that this subsequently became the standard way of mounting high-precision strip encoders.

Technology developed through procurement contracts

8-m mirrors – blanks and polishing

One of the main technological hurdles to be overcome for the VLT project was the manufacture of the 8-m blanks for the primary mirrors. Mirrors of this size had never been manufactured before and several approaches were investigated by ESO. A contract was eventually placed with Schott in Germany for the supply of the blanks. This necessitated the creation of new manufacturing facilities and the development of the production processes for glass-ceramics to completely new dimensions. The successful completion of the VLT contract put Schott in a leading position to bid for future projects requiring large optics.

The size of the VLT primary mirrors also required a major jump in the state of the art in optical polishing. Indeed, the French firm REOSC (now part of the SAGEM group), who received the ESO contract to polish the four 8-m mirrors, had to build a completely new factory outside Paris for their manufacture.

Not only was the size of these mirrors unprecedented, but also the required image quality set new benchmarks. Indeed, testing the mirrors proved almost as challenging as polishing them. ESO engineers worked closely with the manufacturer to produce a method of specification that not only fulfilled the high technical demands of the VLT project and could be verified at the factory, but also made optimum use of the VLT's Active Optics system for correcting large spatial frequency errors.

The manufacturing and testing facilities developed by REOSC for the VLT were subsequently used to polish the two 8-m mirrors for the US/UK Gemini telescope, as well as for smaller optics for other advanced projects.

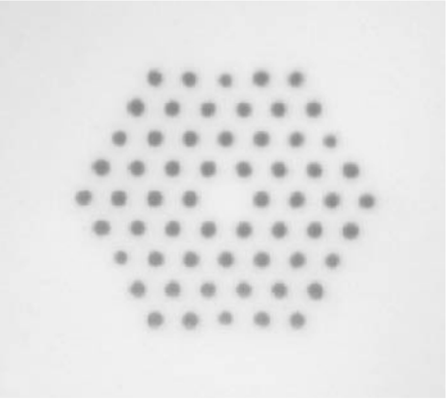
Photonic crystal fibres

Another technology promoted by ESO is the use of mono-mode optical fibres to transmit high power (≈ 10 Watt) visible laser beams. These are a key element of ESO's Laser Guide Star Facility and are used to transmit the light from the laser laboratory to the launch telescope located at the very top of the VLT. Compared to previous mirror transmission systems, fibre-optic transmission allows a significant reduction in the cost, complexity and maintenance.

However, a fundamental limitation in using classical mono-mode fibres is due to Stimulated Brillouin Scattering (SBS), a non-linearity which severely limits the laser power that can be transmitted through the fibre. Photonic Crystal fibres – "holey fibres" – were first demonstrated in the laboratory by researchers at Bath University in 1996. These offer an ingenious way of overcoming the problem of SBS by allowing an increase in the effective core diameter of the fibre but without losing the single mode transmission characteristics. This significantly reduces the power density inside the fibre and hence the effects of SBS.

Working initially with Crystal Fibre A/S in Denmark, ESO promoted the development of fibres with characteristics suitable for the LGSF wavelength of 598 nm and with good optical transmission to demonstrate the feasibility of this technology with high laser powers. Since then, production fibres have been manufactured by Crystal Fibres and also Mitsubishi which meet ESO's requirements.

Figure 2: Section through a photonic crystal optical fibre showing the hexagonal pattern of holes that run axially through the fibre.



ESO's developments have been followed with great interest by other laser guide star projects as well as industry because of the wider commercial implications, for example in the telecommunications industry and the medical field. As a next step, ESO is currently working on the application of hollow-core photonic crystal fibres to the LGSF, which are now becoming available.

Direct drive systems for telescopes

Brushless torque motors offer a number of advantages over conventional telescope drive systems, including the elimination of the classical gear train (and hence mechanical simplicity) together with exceptionally good performance. Nevertheless, they had never before been used in large telescopes and nothing of the sizes required for the VLT existed in standard catalogues.

ESO commissioned a study to be carried out by the Swiss firm ETEL, and the results of this confirmed the suitability of the concept. In the VLT, direct drives from ETEL were used in the twelve Adapter/Rotators, and another specialist firm, PHASE in Italy, was contracted to design and manufacture the drives for the four Unit Telescopes, including the 10-m-diameter azimuth drives. Since the VLT, both these firms have expanded into this market and are now among the world market leaders in this field. PHASE, for example, has recently manufactured the drives for the 10-m Gran Telescopio Canarias on La Palma.

ESO technologies used in other projects

Optical design

ESO has a unique experience in the field of optical design, covering the wavelength range from UV to far infrared. Although an optical design made for one instrument is not readily useable for another, some ESO designs have been copied manyfold for use at other observatories.

The ESO Faint Object Spectrograph and Camera – EFOSC – was originally developed at ESO for the 3.6-m telescope on La Silla. It pioneered the use of new optical glasses for astronomical instrumentation to produce a very efficient transmissive optical train. Since that time, some 15 copies of this design have been manufactured and put into service at other observatories around the world. Similarly, the design of UVES – the UV and Visual Echelle Spectrograph developed by ESO for the VLT has been reproduced at least 10 times for application elsewhere.

Apart from these specific examples, ESO has had a significant impact, through optical design proposals and design reviews, on the optical design of a very large number of instrumental developments in the ESO Member States and beyond over the last 25 years.

Computer systems and software

Ever since the first "mini-computers" were introduced at La Silla in the early 1970's, ESO has been pioneering the use of computers for real-time control of telescopes and interactive data-reduction methods. This led initially to the development of the IHAP data-reduction package for spectroscopic observations and, in the 1980's, the more versatile MIDAS system which has been used by several hundred institutions worldwide.

More recently, ESO has developed a software bundle known as SCISOFT which is a unified collection of the major software packages for astronomical data analysis currently in use today (including IRAF/STSDAS, MIDAS and IDL) as well as many other utilities. The SCISOFT CD-ROM is distributed to over 400 institutions worldwide per year.

A fundamental part of the VLT concept are the Telescope Control Software and Data Flow Systems that allowed, for the first time in a ground-based observatory, the complete end-to-end observing cycle to be condensed into a single homogeneous automated process. This process starts with the preparation of the observing programme, and continues through programme selection, observation simulation, automatic or semi-automatic execution of the observations at the telescope (with or without the presence of the astronomer at the telescope), quality control, data archiving and finally the return of the calibrated data to the observer. Although at the outset it was not easy for many traditional astronomers to accept this revolutionary concept, it has become a standard that has since been emulated by most of the world's major observatories. In recognition of this work, ESO was recently presented with the prestigious 21st Century Achievement Award from the Computerworld Honours Program for the Data Flow System as reported in the June 2005 issue of the ESO Messenger.

ESO patents

In the past ESO has generally preferred to openly publish ideas rather than to seek patent protection, but in areas where there could exist worldwide commercial application, for example in the communications industry, patent protection has been obtained to allow better regulation of eventual usage through licensing and partnership agreements with industry or other institutes. For example, an ESO patent has been granted for developments related to narrow-band high-power fibre lasers, and a second patent has recently been filed for a high-power fibre laser and amplifier.

Knock-on benefits due to ESO's industrial procurements

There are also secondary industrial benefits to firms that receive ESO procurement contracts. A study carried out by CERN in 2003[2] amongst firms receiving CERN contracts for technology intensive projects (accounting for about half of all CERN procurement contracts) concluded that: 38 % of all respondents developed new products as a direct result of the original contract; 13 % started new R&D teams; 14 % started a new business unit; 17 % opened a new market; 42 % increased their international exposure; 44 % indicated technological learning; and 36 % indicated market learning.

Without the CERN contract, 52 % of all respondents would have had poorer sales; 21 % would have had lower employment growth; 41 % would have had poorer technological performance; and 26 % would have had poorer performance in valuation growth.

These data collected by CERN are impressive and present additional arguments for maintaining government support for the Organisation. Although no similar study has been carried out at ESO, the similarities between the two Organisations would lead one to expect that comparable benefits would also accrue to ESO suppliers as well.

Socio-economic benefits of ESO Technology Programmes

The fact that ESO actively pursues projects at the cutting edge of technology and maintains a pool of engineering expertise that is probably unique in the world in the field of ground-based astronomy, also brings socio-economic benefits to the ESO Member States which can also help enhance the economic competitiveness of European industry as a whole.

Through its Student, Fellowship and Associate Programmes, ESO has contributed to the training of a considerable number of young scientists and engineers over the years. After spending some time at ESO engaged in forefront research or developing highly advanced astronomical facilities, these people leave the Organisation, taking with them their accumulated professional experience. This benefits not only their future careers, but also stimulates the research in their home institutions and helps to improve the competitiveness of Europe's industries. In 2004, for example, ESO employed over 100 Students, Fellows and Associates under these programmes.

Similarly, many ESO engineering staff members eventually leave the Organisation to return to industry to work on other high-tech projects, taking with them their professional expertise acquired in the course of their work at ESO.

Additionally, ESO has organised, either alone or with other institutions, many seminars, workshops and summer schools on diverse scientific topics as well as on technical aspects such as adaptive optics and optics. These events also help to develop the scientific and technical competencies within industry and scientific institutions in the Member States.

Less easy to quantify but also valuable are the personal links established during a period of employment at ESO. Even many years later, these personal links can provide a useful channel for information on ESO technologies and programmes and professional advice. The European Commission has long since recognised the importance of mobility amongst young researchers and engineers for enhancing European competitiveness, and has established several programmes to facilitate this.

As can be appreciated from this article, the process of Technology Transfer is many-faceted. It is a process in which, over the years, ESO has made significant contributions, both in encouraging innovation in industries within the Member States as well as improving commercial competitiveness.

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[2] "Technology Transfer and Technological Learning through CERN's procurement activity", CERN2003-005, 11 Sept 2003, Education and Technology Transfer Division

The ESA-ESO Topical Science Working Groups

Robert A. E. Fosbury (ST-ECF)

Starting in September 2003, ESO and ESA have now held two science planning coordination meetings in order to ensure that there remains a joint awareness of potential future synergies or missed opportunities on the ground or in space. The meetings were attended by the chairs (or representatives) of the scientific advisory committees and by the executives of both organisations. The initiative was taken with the realisation that the two organisations are serving essentially the same scientific communities and share common scientific goals.

At the first meeting, it was decided to set up a small number of working groups that would examine scientific topics or specific instrumental synergies that would be important over the next decade or so. The first of these was on the topic of the search for and the subsequent characterisation of extra-solar planets – the report of this group, chaired by Michael Perryman (ESA/ESTEC) and co-chaired by Olivier Hainaut (ESO, Chile) is summarised in the accompanying article by Kerber and Hainaut. The second was to look at the joint opportunities offered by Herschel and ALMA in the infrared and sub-mm wavebands. Chaired by Tom Wilson (ESO Garching) and co-chaired by David Elbaz (CEA/Saclay), it is nearing completion and will become available towards the end of 2005.

During the second meeting in February 2005, a new working group was proposed with the intention of reviewing cosmology with particular emphasis on the investigations of the nature of dark energy and dark matter from an astrophysical perspective. This new working group on Fundamental Cosmology was established in June 2005, with John Peacock (Edinburgh) as Chairman and Peter Schneider (Bonn) as Co-Chairman. It will consider projects in the areas of dark matter, dark energy, and other aspects of the early universe, with the aim of reporting in February 2006.

The full membership of these groups and access to their reports as they become available can be obtained from: *http://stecf.org/eso-esa/*

ESA-ESO Working Group on Extra-Solar Planets

Florian Kerber (ST-ECF),
Olivier Hainaut (ESO)

The ESA-ESO working group on extra-solar planets was the first of a number of such groups to make a careful analysis of scientific fields that are of interest to both ESA and ESO. The groups also make recommendations for the development of the fields facilitating coordinated planning between the two leading European organisations advancing astronomy from the ground and from space.

The extra-solar planet working group, chaired by Michael Perryman (ESA), consisted of: Olivier Hainaut (Co-chair ESO), Dainis Dravins (Lund), Alain Léger (IAS), Andreas Quirrenbach (Leiden) and Heike Rauer (DLR). Florian Kerber and Robert Fosbury from the ECF were the support scientists. A group of experts contributed on specific subjects[1]: François Bouchy (COROT), Fabio Favata (Eddington), Malcom Fridlund (Darwin), Anne-Marie Lagrange (Planetfinder), Tsevi Mazeh (Transits), Daniel Rouan (Genie), Stéphane Udry (Radial velocity), and Joachim Wambsganss (Microlensing). The group operated between June and December 2004 and documented their findings and recommendations to both agencies in a report which is available in printed form from the ST-ECF and on both ESO and ESA websites (*http://www.eso.org/gen-fac/pubs/esaesowg/* and *http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=36935*). This article gives a very brief summary of the report and encourages feedback from the community.

The terms of reference provided by ESA and ESO called on the working group to the following:

1. Survey of the Field: this will comprise: (a) review of the methods used or envisaged for extra-solar planet detection and study; (b) survey of the associated instrumentation worldwide (operational, planned, or proposed, on ground and in space); (c) for each, a summary of the potential targets, accuracy and sensitivity limits, and scientific capabilities and limitations.
2. Role of ESO and ESA Facilities: this will: (a) identify areas in which current and planned ESA and ESO facilities will contribute; (b) analyse the expected scientific returns and risks of each; (c) identify areas of potential scientific overlap, and thus assess the extent to which the facilities complement or compete; (d) identify open areas which merit attention by one or both organisations (for example, follow-up observations by ESO to maximise the return from other major facilities); (e) con-

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[1] The working group membership was established by the chair and co-chair: the report is not a result of consultation with the community as a whole. The experts contributed considerable information to the report, but the conclusions and recommendations are the responsibility of the members.

clude on the scientific case for the very large facilities planned or proposed.

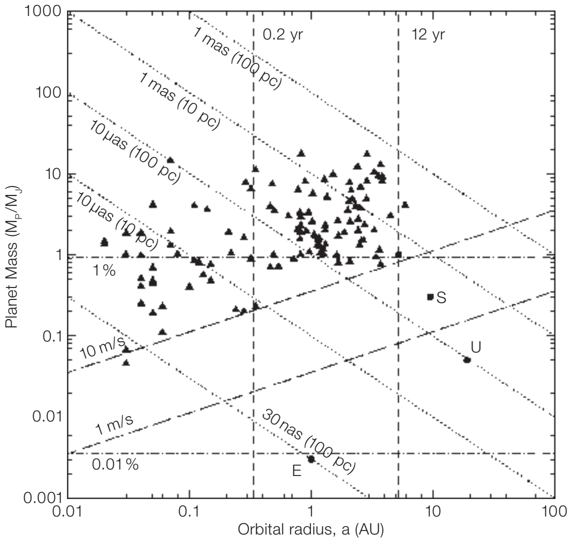


Figure 1: Detection domains for methods exploiting planet orbital motion, as a function of planet mass and orbital radius, assuming $M_* = M_\odot$. Lines from top left to bottom right show the locus of astrometric signatures of 1 milli-arcsec and 10 micro-arcsec at distances of 10 and 100 pc; Vertical lines show limits corresponding to orbital periods of 0.2 and 12 years. Lines from top right to bottom left show radial velocities corresponding to K = 10 and K = 1 m s^{-1}. Horizontal lines indicate photometric detection thresholds for planetary transits, of 1 % and 0.01 %, corresponding roughly to Jupiter and Earth radius planets respectively (neglecting the effects of orbital inclination). The positions of Earth (E), Jupiter (J), Saturn (S) and Uranus (U) are shown, as are the lower limits on the masses of known planetary systems as of December 2004 (triangles).

As a final step the members of the working group came up with a number of recommendations that will help the further development of the field. These are directed at both agencies separately but a subset specifically calls for joint or coordinated efforts of the two agencies. Note that the recommendations of a similar ESO working group in 1997 (appendix C in the present report) directly led to the development of HARPS, the leading spectrograph for radial-velocity work today.

Survey of the field

A mere 10 years after the first detection of exoplanets around normal stars, this field has become one of the most active and exciting branches of astrophysics. Detection methods for extra-solar planets can be broadly classified into those based on:

(i) dynamical effects (radial velocity, astrometry, or timing in the case of the pulsar planets);
(ii) microlensing (astrometric or photometric);
(iii) photometric signals (transits and reflected light);
(iv) direct imaging from ground or space in the optical or infrared; and
(v) miscellaneous effects (such as magnetic superflares, or radio emission).

Each method has its strengths, and advances in each field will bring specific and often complementary discovery and diagnostic capabilities. Detections are a prerequisite for the subsequent steps of detailed physical-chemical characterisation demanded by the emerging discipline of exoplanetology.

As of December 2004, 135 extra-solar planets had been discovered from their radial velocity signature, comprising 119 systems of which 12 are double and 2 are triple. One of these planets has also been observed to transit the parent star. Four additional confirmed planets have been discovered through transit detections using data from OGLE (and confirmed through radial-velocity measurements), and one, TrES-1, using a small 10-cm ground-based telescope. One further, seemingly reliable, planet candidate has been detected through its microlensing signature. A much more detailed assessment of the current status, which is illustrated in Figure 1, can be found in the working group's report.

The working group surveyed the experiments that are planned or in prospect, and estimated their output qualitatively and quantitatively. Table 1 (see next page), expanded from a similar table in the report, summarises the situation for the next 15 years.

The projects can roughly be classified in "pathfinders", which find new populations, projects characterising populations as a whole, and finally projects aiming at detailed physical studies. It is crucial to have a good balance between these three categories of projects in order to ensure at the same time a consolidation of the current knowledge and a long-term development of the field.

The pathfinders typically expand the explored region of parameter space, and will lead to the discovery of a small number of objects, but these define new classes of planets. NACO on the VLT is a typical example: the instrument was originally not designed for planet search, but by opening a new window to high-resolution and high-contrast imaging, it led to the discovery of 2M1207b, the first planet detected by direct imaging, and the first planet around a brown dwarf. (The Messenger 120, 2005, page 25). HARPS has demonstrated its capability to explore the very-low mass end of the exoplanet mass distribution (Pepe et al. 2005, The Messenger 120, 22). The VLT Planet Finder is expected to make an important contribution to the study of bright, well separated planets for which it is built (therefore belonging to the "population study" projects), but its new capabilities will also put it in the pathfinder category, and one can expect new discoveries in regions that cannot be explored today.

Large, dedicated projects or missions are ideal to characterise a whole population: for instance, Kepler is expected to find tens of thousands of planets of a given type (transiting giants), therefore permitting a detailed study of the global properties of this population. A major programme using FLAMES for follow-up studies of transit candidates from OGLE has provided physical properties for seven planets and has demonstrated that small stellar companions are about as frequent as hot Jupiters, emphasising the need for spectroscopic confirmation and study of candidates (Pont et al. 2005, The Messenger 120, 19).

Finally, some experiments are best at performing detailed analysis of specific objects. For instance, while the number of planets that it will be able to reach is modest, the VLTI is expected to produce spectra of planets, which will be of extraordinary value for exoplanetology.

Method	Ground/Space	Time	Project	Pathfinder	Population $> 0.1\ M_{Jup}$ / $< 0.1\ M_{Jup}$	Spectroscopic studies
Radial Velocity	Ground	< 2004		First detection		
Radial Velocity	Ground	2004	Harps and others		120/0	
Adaptive Optics	Ground	2005	NACO	First direct detection	Few	Few
Interferometry	Ground	2005	VLTI	All nearby stars	Few	Some
Adaptive Optics	Ground	2010	VLT Planet finder	New parameter space	20/0	Some
Radial Velocity	Ground	2010	many		450/20	
Transit	Space	2008	COROT		200/50	
Transit	Ground	2010	many		1 000/0	
Transit	Space	2010	Kepler		30 000/1 500	
Astrometry	Space	2015	SIM		250/25	
Astrometry	Space	2016	GAIA		20 000/0	
Transit	Space	2016	GAIA		4 000/0	
Photometry	Space	2016	GAIA	Protoplanetary collisions	3 000/0	
Interferometry	Ground	2015	OWL partially filled		125 000/60	
Photo-/Spectrometry	Ground	2018	OWL complete			60 “Jupiter” 5 “Earths”

Table 1: Prospects for the coming years. The first column lists the method used, the second identifies whether it is a ground-based or space-borne method. The third column gives an approximate time scale. Project identifies the name or class of the project. The next three columns summarise the main emphasis of the project, either as pathfinder (few, but significant discoveries), or in terms of the number of planets discovered for the projects aiming at defining the populations (detailed for planets more massive and less massive than 0.1 $M_{Jupiter}$), or finally in terms of detailed physical studies of the objects. This table is an expanded version of Table 5 in the report.

Beyond 2015 the current plans call for a detailed characterisation of individual planets and systems. In that framework, OWL could play an important role by searching for targets during its assembly phase (while the mirror is still partially filled), and then studying them in detail once the mirror is completed. Other projects, possibly by interferometry from Antarctica and by interferometers and coronographs in space, are also starting to be conceived.

ESA-ESO facilities

The working group then carefully analysed the future needs of research and what role current and planned facilities of ESA and ESO can be expected to play. Specifically they tried to give some answers to the following questions: What follow-up observations and facilities are required to characterise these systems more completely? What does the resulting (statistical) knowledge of exoplanet distributions imply for the targeted observations of Darwin and OWL? What information will be available, or should be anticipated, for a deeper astrophysical characterisation of the host stars of planetary systems? The working group also looked into the potential overlap amongst the major facilities currently planned or studied by ESO and ESA. They tried to identify specific long-lead time space or ground facilities which should be considered to fill observational gaps anticipated over the next 10–20 years? And, finally, they looked at other considerations that ESO/ESA should investigate for proper interpretation of the data which will be generated by these two European organisations, or others, and which might limit the development of the field unless suitably coordinated. From the above facts and considerations the working group then came up with recommendations to the agencies. The first goal is to establish an offensive policy to optimise the scientific return of instruments already built or foreseen in the near future. The second goal is to prepare new initiatives. Suggested directions are detailed in the report.

First steps towards implementation

ESO has established a high-level working group supervising the implementation of the report’s recommendations. A number of steps have already been initiated. For example ESO will study the feasibility of a high-resolution spectrograph on the VLT for radial-velocity work and for high-cadence transit spectroscopy. Coordinators have been appointed by both ESA and ESO to develop a plan for supporting observations from the ground for the COROT satellite mission. We are also carefully looking into the options for an amateur involvement in extra-planet research. Finally, ESO is undertaking a number of concept studies for OWL instrumentation at this point that will also address issues related to e.g. the search for earth-mass planets and the study of exoplanet atmospheres. ESO and ESA are committed to making sure that the findings and recommendations of the ESA-ESO working group are fully appreciated, and are studying how to best implement them.

Report on

The ESO-ESA-IAU Conference Communicating Astronomy with the Public 2005

Ian Robson[1]
Lars Lindberg Christensen[2]

[1] UK Astronomy Technology Centre, UK
[2] Hubble European Space Agency Information Centre, Germany

Over one hundred astronomers, public information officers, planetarium specialists and image-processing gurus descended on ESO Garching in June for CAP 2005 – Communicating Astronomy with the Public 2005. This was the third international conference addressing astronomy outreach; the previous venues being La Palma and Washington DC. The main aim was to bring together the specialists from the various strands of astronomy undertaking outreach in the broadest sense. The four-day conference was a resounding success, much was achieved and the work of ESO was better appreciated (especially from the non-European perspective) through a tour of the facility. Some of the highlights of the local environs were much enjoyed through the conference dinner at the Deutsche Museum's aviation museum "Flugwerft Schleißheim" – (including cockpit tours of an F4 Phantom) and a splendid (and well liquid refreshed) evening at the Augustinerkeller, one of the largest Munich Biergartens.

The previous meeting in Washington was run along a workshop format focussed on specific outcomes out of which arose: the setting up of a Commission-wide Working Group of the IAU; the production of the Washington Charter (see *http://www.communicatingastronomy.org/washington_charter*); and the formulation of the first principles of an image repository (in the widest sense). The format of that meeting included breakout session to debate these issues. CAP 2005 sought to build on these foundations and move all issues forward, and as such had a number of plenary sessions followed each day by three workshops devoted to four specific topics.

There were a number of key themes for the meeting covered in the plenary sessions. Each session was led-off by invited speakers and one of the main highlights of the meeting was the extremely high level of both content and presentational style by all the speakers. The sessions were: 1. Setting the Scene, 2. The TV Broadcast Media, 3. What Makes a Good News Story?, 4. The Role of the Observatories, 5. Innovations, 6. The Role of Planetaria, 7. Challenges and New Ideas, 8. Keeping our Credibility – Release of News, 9. The Education Arena, 10. Astronomical Images – Beauty Is in the Eye of the Beholder, 11. Cutting-edge Audiovisuals, 12. Virtual Repositories

Photo: L. H. Nielsen, ESA/Hubble

The "Credibility discussion" at the conference.

A most successful discussion on credibility and the general theme of communication ethics took place in the session "Keeping our Credibility", where we were delighted to field a star-studded panel, including the ESO Director General, Catherine Cesarsky.

Technology and the power of the web was much to the fore throughout the conference. The PowerPoint presentations were all posted online on the conference website on the same day as the talk took place.

The live Web casts that were transmitted from the conference were clearly a success as a number of speakers received e-mails while at the conference commenting on aspects of their talk or responding to invitations for information. Web casts on the other hand promote a somewhat less intimate form of talk, as the audience in principle goes far beyond those in the auditorium. When some of the speakers occasionally clearly forgot this, it promoted some hasty interjections of the words "Web cast, Web cast" from the front row to much amusement from the audience. The Web casts were also posted online daily during the conference and have helped participants afterwards with the preparation of their proceedings papers.

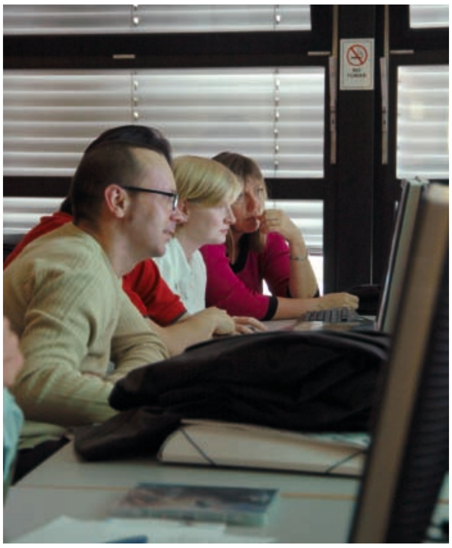
The "Hands-on" workshop sessions running in parallel in the afternoons were a huge success and a number were oversubscribed. This had been anticipated in the planning and so the more popular ones were repeated on subsequent days. The workshops were woven around the themes of: image processing; interactions with the media; a communicating toolkit.

Zolt Levay (STScI) and Lars Lindberg Christensen (ESA/Hubble) presented two workshops on basic image processing, from image acquisition through import with the FITS Liberator to the task of handling multiple layers within Photoshop. Hubble images were used as the testbed, so that the participants could experiment and see the changes to the final image product through different techniques within Photoshop.

Lisa Frattare and Robert Hurt extended this theme with two workshops on more advanced image processing ‘tips & tricks’ for how to clean and correct the colour images as well as make a better composition. Greg Bacon (NASA/STScI) presented a session on how to undertake simple animation studies. Finally in this theme, Martin Kornmesser and Lars Lindberg Christensen hosted a session devoted to producing your own DVD. Govert Schilling gave two sessions devoted to how to write for the media and an interactive discussion on the rights and wrongs of producing a good press release. Terry Mahoney gave an overview of the basic contents of a toolkit for astronomers involved in outreach and the do’s and don’ts of a successful programme. There is no doubt that this focused skills-based workshop-style was extremely beneficial and well appreciated by the attendees.

The conference summing-up was undertaken by Professor Paul Murdin (Cambridge) who brought together the various themes, tensions and links and additionally suggested a possible theme for the next conference, which will be in 2007.

One of the “Hands-on Workshops” at the conference.



The meeting was organised by Ian Robson and Lars Lindberg Christensen supported by Scientific and Local Organising Committees. The work of the ‘FITS Liberator’ team was enormous in making the conference both successful and right up to the minute in terms of technology.

So all those interested in outreach should go to the IAU Working Group web-page: *http://www.communicatingastronomy.org* and enrol on the “Supporters” sign-up sheet so that we can keep you informed of progress and future events. The proceedings of this conference are currently being edited and are planned for publication in September.

The organisers wish to acknowledge financial and infrastructure support from ESO, as well as support from ESA and the IAU.

Photos: L. H. Nielsen, ESA/Hubble (2)

Social event: Visit to one of Munich’s many Biergartens.

Report on the ESO Workshop on

Virtual Observatory Standards and Systems for Data Centres and Large Projects

Paolo Padovani, Markus Dolensky (ESO)

The Virtual Observatory (VO) is an innovative, evolving system, which will allow users to interrogate multiple data centres in a seamless and transparent way, to best utilise astronomical data. New science will be enabled, moving astronomy beyond “classical” identification by allowing the characterisation of the properties of very faint sources by using all the available information. The VO requires good communication, that is the adoption of common standards between data providers, tool users, and developers. These are being defined using new international standards for data access and mining protocols under the auspices of the International Virtual Observatory Alliance (IVOA: *http://ivoa.net*), a global collaboration of the world’s astronomical communities. At the European level, in addition to seven national VO projects, the European Community funded collaborative EURO-VO is the successor of the Astrophysical Virtual Observatory (AVO: e.g., Padovani et al. 2004, The Messenger 117, 58) and the logical next step from AVO as a deployment of an operational VO in Europe (more on EURO-VO in a future issue of The Messenger).

Data centres lie at the foundation of the VO, as obviously access to astronomical data at all wavelengths is a key requirement. The VO cannot (and does not) dictate how a data centre handles its own archive. All that is needed is a VO-layer to “translate” any locally defined parameter to the standard (i.e., IVOA compliant) ones. For example, right ascension can be identified in different ways but the VO user needs to know which of the many parameters accessible through an archive interface is the right ascension. The longer-term vision of the VO is also to hide away any observatory/telescope/instrument specific detail and work in astronomical units, for example, “wavelength range” and not grism or filter name. Data providers are then advised to systematically collect metadata (“data about data”) about the curation process, assign unique identifiers, describe the general content (e.g., physical coverage) of a collection, and provide interface and capability parameters of public services. Finally, the VO will work at its best with high-level or “science-ready” data, and data centres should make an effort to provide such data.

To get data providers started in most of the above, the EURO-VO held a workshop at ESO Headquarters in Garching from June 27 to July 1, 2005. The workshop was explicitly designed for data centres and large projects to acquire the knowledge and experience necessary to allow them to become “publishers” in the VO. In tutorials and lectures, participants were instructed in the use of VO analysis tools, libraries, and the existing web service infrastructure to build VO compliant services. The workshop was aimed at software engineers and designers building archive interfaces, writing applications accessing remote data, or designing archive facilities and data flows for future instruments and missions.

More than 120 participants, coming from 47 different institutions and 16 countries, attended the workshop, with representatives from 11 out of 15 IVOA members.

The workshop started with an overview of the EURO-VO project structure. An introduction on the current status of standardisation efforts and international IVOA working groups was then followed by a conceptual approach to the software architectures available to publish data to the VO.

Group photo of the ESO workshop on Virtual Observatory Standards and Systems for Data Centres and Large Projects held from June 27 to July 1 at ESO Headquarters.

Photo: H. H. Heyer, ESO

More specific lectures prepared the participants for two full days of hands-on tutorials. Several software demonstrations by various VO projects illustrated the current capabilities.

The seven tutorials took place in parallel sessions and exercises were conducted on the participant’s own laptops. Up to 100 laptops were on-line through the wireless Local Area Network (LAN), challenging ESO’s excellent internal network infrastructure without actually reaching its limits. The tutorials dealt with the following topics: Data access layer, that is tools and protocols for sharing images and spectroscopic data; Astronomical Data Query Language (ADQL)/Skynode, which is about accessing databases and publishing catalogues; VOTable, the Extensible Markup Language (XML) VO standard format for the interchange of data, and the rich variety of tools and libraries to support it; Metadata, that is how to tag concepts in Astronomy in a machine readable form using a defined vocabulary called Unified Content Descriptors (UCD); Grid and web services, namely Information Technology basics and how to set up a service in order to share it on the local network; Registries, which are places where available resources such as astronomical data collections and software services are described. Participants learned how to set up such a registry as well as how to populate and search it.

Finally, the data centre infrastructure tutorial brought all of the above together and demonstrated a prototype framework supporting the various formats, protocols and concepts.

Judging from the participants’ feedback, which was collected through a questionnaire, the workshop was considered “useful” or “extremely useful” by 95 % of the respondents. The tutorial material (see below) is a collection of software which, although still not in a final state, represents a unique and up-to-date snapshot of “state-of-the-art” VO technology.

The workshop agenda and contributions are available on *http://www.euro-vo.org/workshop2005*. The tutorial software was packaged and can also be accessed through FTP from the workshop page. It is mostly in Java and works on the most common platforms such as Linux, XP, and Mac OS.

Report on

The EPS-ESA-ESO-CERN Conference on Relativity, Matter and Cosmology

Peter Shaver, Bruno Leibundgut, Jochen Liske (ESO)

This year the joint ESA-ESO-CERN symposium was held in conjunction with the European Physical Society, on the occasion of the Centennial of Einstein's *annus mirabilis* and the World Year of Physics. It took place on July 11–14 in Bern, where Einstein wrote his famous papers in 1905, and was part of a wide range of events to celebrate the centennial.

A highlight of these events was the 13th triennial General Conference of the European Physical Society (EPS13), with the title "Beyond Einstein – Physics for the 21st Century". It consisted of three parallel conferences, one of which was the EPS-ESA-ESO-CERN conference on "Relativity, Matter and Cosmology".

As is usual in these joint conferences, the objective was to provide a broad overview of current and future developments in the fields of fundamental physics, particle physics and cosmology. The fact that altogether some 600 participants attended the three conferences attests to the interest generated by the wide range of topics, as well as the wonderful setting in Einstein's Bern.

Some 80 talks were given at the conference on *Relativity, Matter and Cosmology*, and a substantial number of posters were presented. In a conference of this size and scope it is difficult to give a comprehensive summary, but an idea of the range of the science covered can be gleaned from this brief overview based largely on the invited plenary reviews.

A stimulating introductory talk entitled "100 Years of Relativity" was given by T. Damour. He summarised the remarkable success of the theory in a variety of stringent tests, provocatively going on to ask whether we should now just conclude that Einstein was 100 % right and stop testing! Of course he then went on to describe ever more sophisticated planned tests, and concluded that new and exciting frontiers lay before us, including the great mysteries of dark matter and dark energy.

Gravity, including both theory and observations, was obviously a major topic at this conference. As H. Nicolai commented, reconciling general relativity and quantum theory into a consistent and predictive theory of quantum gravity is probably the greatest challenge facing theoretical physics in the 21st century. He described the successes and challenges of the two main approaches, superstring theory and canonical quantum gravity. C. Everitt described the dedicated space mission Gravity Probe B, designed to accurately test two aspects of Einstein's General Relativity: the effect of space curvature on a free gyroscope and the effect of relativistic frame dragging. It is currently collecting data and the first release will be in mid-2006. The direct detection of gravitational waves has been a dream for decades that may be realised in the near future. B. Schutz summarised the physics and possible astrophysical and cosmological sources of gravitational waves and the fundamental physics that we may learn from their detection, and K. Danzmann described current and future experiments and their prospects, in particular the planned LISA mission. Pulsars provide excellent natural astrophysical laboratories for tests of General Relativity, and D. Lorimer described results over the last years and the wonderful prospects with these remarkable systems, like the recently discovered double pulsar, that are increasingly being found.

Three speakers discussed the current state of observational and theoretical cosmology, and looked to the future challenges and horizons. J. Silk discussed the challenges of the cosmic microwave background, and stressed the potentially great importance of any hints of non-gaussianities, unexpected topologies or global anisotropies that may be found (either in the microwave background or the large-scale distribution of galaxies). G. Efstathiou gave a talk with the provocative title "Is There Cosmological Concordance?". He expressed confidence in the concordance of an impressive array of cosmological observations, including the microwave background, galaxy surveys and supernovae. He made the case for the existence of dark energy, suggesting that it may argue for anthropic reasons that we can observe it right now. Finally, D. Spergel gave an overview of early universe physics and the achievements of WMAP so far. While he also highlighted the remarkable concordance of present observational results, he went on to emphasise the challenges: "Beyond Einstein: the physics we don't know and the physics we don't know how to calculate". He described the potential for rapid development in this field, with a whole host of new observational facilities becoming available over the next years.

Recent breakthroughs in neutrino physics, using neutrinos both from the sun and the laboratory, were summarised by G. Drexlin, including the now conclusive evidence for neutrino oscillations and hence for nonzero neutrino masses. He mentioned several open questions, and the new round of experiments proposed to answer them. E. Fiorini summarised ongoing work on neutrinoless double beta decay, and prospects for the detection of weakly interacting massive particles, a possible candidate for dark matter, based on seasonal variations due to the earth's motion around the sun. J. Bluemer gave a review of the study of cosmic rays since their discovery over 90 years ago, and the current and planned experiments to understand the astrophysical sources and the extraordinary energies involved.

The fundamental problem of the origin of mass was addressed by G. Ross. He described how explorations of this problem have led to extensions of the Standard Model which unify all the fundamental interactions including gravity; a new energy frontier may exist which can affect early universe physics and will be probed by CERN's Large Hadron Collider (LHC). A new state of matter, the Quark-Gluon Plasma, was the subject of J. Stachel's presentation. She summarised the recent experimental support for the existence of this state, which may have existed in the early universe until 10 microseconds after the Big Bang, and the potential of the LHC in studying it. F. Iachello gave an overview of symmetries and supersymmetries in nuclei, and placed them in the broader context of complex systems in general. They, too, will be major targets for the LHC. The huge scientific potential of the LHC was described by J. Engelen, in particular the possibility of detecting the Higgs boson; he summarised the status

of the project, which should become available for experiments in 2007.
W. Gelletley spoke on the broad perspectives, challenges and opportunities in nuclear physics, including the upcoming new experimental facilities. A different kind of huge project, the first experimental fusion reactor (ITER), was described as part of F. Wagner's comprehensive overview of the current state of plasma physics.

Possible variations in the fundamental "constants" of physics also generated a lot of interest. Recent VLT data have contradicted earlier claims of the fine structure constant having been smaller in the early universe than today. M. Murphy summarised this controversy and described ongoing efforts to resolve it.
E. Reinhold reported on recent progress in trying to detect a change in the proton-to-electron mass ratio, also using VLT data.

The importance of dark energy to modern physics was emphasised by several speakers. Its existence was first established through observations of distant type Ia supernovae and the talks by R. Pain and J. Sollerman demonstrated that searching for these transient events remains a vigorous industry. They outlined the two main projects in this field: SNLS and ESSENCE. Understanding the nature of dark energy was the subject of several theoretical talks, involving D-branes (P. Gusin), Casimir Energy (R. Garattini), quantum gravity (A. Ernest and C. Bryja) and Modified Chaplygin Gas (U. Debnath).

Finally, J. Liske outlined plans to use OWL, the VLT's successor, for the Cosmic Dynamics Experiment (CODEX). The aim is to supplement our knowledge of the universe's *geometry* (derived from the microwave background and supernovae) with an unprecedented measurement of its *dynamics* and hence to provide us with a fundamental consistency check of General Relativity.

The sampling above gives some idea of the wide range of physics and cosmology that was covered at the conference. The full proceedings of the conference will become available; they will be published by the ESA Publications Division as ESA Special Publication SP-605.

ESO Public Activities in July 2005

Ed Janssen (ESO)

The month of July is, in many parts of Europe, considered to be a relatively "quiet time" of the year with many millions of people away on summer vacation. Not so for ESO's Public Affairs Department. The month began with a series of press activities around the Deep Impact event and included several press conferences at the ESO Headquarters (mostly at odd hours!), video press conferences with Paranal, La Silla and ESTEC in the Netherlands, live TV transmissions from ESO Garching as well as from Paranal, etc.

In parallel, from July 4–8 the Joint European and National Astronomy Meeting (JENAM) took place at the Amphithéâtres de l'Europe in Liège, Belgium. The meeting, organised this year by the Astronomy Department of the Liège University, had the theme "Distant Worlds". It was attended by over 200 astronomers. The meeting also enjoyed a good media attendance, probably also due to the Deep Impact Mission. As at previous JENAM meetings, ESO maintained an information stand in the lobby area and participated in the press conference.

Several ESO staff members gave talks, including the ESO DG, Françoise Delplancke, Henri Boffin, Maximilian Kraus and Marc Sarazin. Furthermore, a Round Table was held to discuss financing, organisation and industrial aspects of large European astronomical projects. It was chaired by Lodewijk Woltjer, former ESO director general. From ESO Roberto Gilmozzi participated as a speaker.

On July 7, ESO participated in a major Press Event on the Future of Astronomy Research Infrastructures, organised by the European Commission and hosted by JIVE, in Dwingeloo, the Netherlands. The event was attended by EC Research Commissioner Janez Potocnik and Maria van der Hoeven, Dutch Minister for

Prof. Jean Surdej, one of the local organisers, being interviewed by RTL television at the JENAM conference.

Photo: E. Janssen, ESO

Photo: JIVE

EU Commissioner Dr. Janez Potocnik and Mrs. Maria van der Hoeven, Dutch Minister for Education, Culture and Science answer questions from the media representatives at the press meeting in Dwingeloo.

Education, Culture and Science. About 60 science journalists from across the EU attended, together with coordinators of the various astronomical projects supported by the EC, including RadioNet, OPTICON, EUROPLANET, ILIAS, the ELT Design Study, the SKA Design Study, the ALMA Enhancement Programme and VO-TECH. ESO displayed an information stand, which was well visited and appreciated by both the participants and the media.

A few days later, from July 11–14 ESO had an exhibition at the University of Berne, in connection with "EPS 13". (see page 60). At the end of the conference, on July 15, an Open Day on Physics and Society was co-organised with the Swiss Academy of Sciences and the Swiss Physical Society. In the context of a joint EIROforum presentation, ESO participated by means of a live video conference with ESO Paranal, moderated by Barbara Vonarburg, well-known Swiss science journalist and Rolf Landua from CERN.

ESO staff astronomer Thomas Szeifert answers questions at the EPS 13 Open House videoconference at the University of Berne.

Photos: E. Janssen, ESO (2)

Prof. Jean-Philippe Ansernet, President of the Swiss Physical Society, Prof. Martin Huber, outgoing President of the European Physical Society, Dr. C. Rossel, Conference coordinator, and Dr. Ingrid Kissling-Näf, Director of the Swiss Academy of Sciences at the EPS 13 Conference venue.

Public Information and Education in Chile

Gonzalo Argandoña, Felix Mirabel (ESO)

One of the initiatives of ESO in Chile is the strengthening of the links with Chilean and Latin American media, to provide the information needed to educate the public in Latin America on the latest advancements in astronomy and astrophysics.

This initiative has produced a considerable increase in the media coverage of ESO science activities, as described in Figure 1, which shows the evolution in the number of media publications in Chile on recent achievements at ESO.

Certainly, the active involvement of the La Silla Paranal Observatory in the global observation campaign of Comet 9P/Tempel 1 was an excellent opportunity to further promote this strategy in a multi-approach way. A dedicated website in Spanish language (*http://www.impactoprofundo.cl*) was released in advance to emphasise the contribution of the La Silla Paranal Observatory to the long-term monitoring campaign of Comet 9P/Tempel 1. This website, that included general information about comets, became an important reference in the Spanish language for the public and journalists who covered the event.

ESO also joined the Chilean Ministry of Education to organise a national educational videoconference (see Figure 2) that linked Paranal with young students in 18 different cities along the country, from Arica (in the Northern extreme of the country) to Punta Arenas (in the Chilean Patagonia, at the very end of the South American continent). Thanks to this joint initiative with Chilean authorities, enthusiastic secondary students could learn about VLT capabilities.

In parallel to this educational activity, a series of press events at ESO Vitacura were offered, with the valuable support of Comet 9P/Tempel 1 observers. The outcome was a large number of reports and news stories, where observers at Paranal and La Silla played an important role as primary sources of information for editors and journalists. Not all the reports were of extreme quality, and precisely one of the challenges for the future is to promote in the region best practices in science journalism and communication of astronomy for the general public.

A week after the most intensive part of the observing programme of Comet 9P/Tempel 1 had ended, the main national TV network in the country, in conjunction with ESO, presented a 50-minute documentary. This special chapter showed the excitement behind Comet 9P/Tempel 1 observations, along with some basic principles of modern observation of the sky. In its first projection by TV, about half a million people watched the documentary (Source: Time-Ibope).

A complementary approach to this media strategy has been the presence of ESO in public events and exhibitions, as the Public Affairs Department of ESO in Garching has done for many years in Europe.

Last June, ESO was present at EXPONOR, the most relevant industrial convention in northern Chile, held every two years (see Figure 3). Based in Antofagasta, it is attended by thousands of visitors, who are the natural neighbours of Paranal and ALMA.

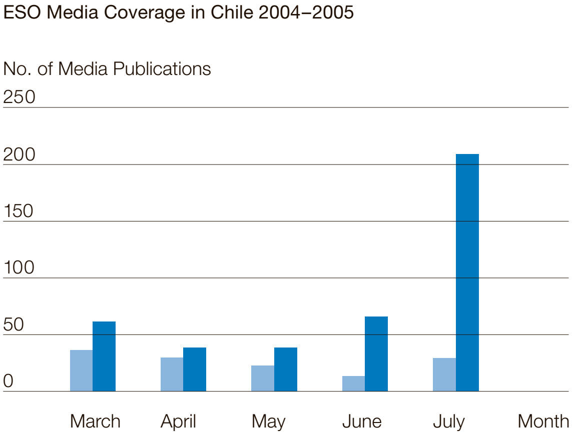


Figure 1: This graph shows the evolution of media coverage in Chile of ESO activities, including TV, radio, written and electronic media, based on independent reports provided by the external company Litoral Press. The peak on July 2005 is due to the media coverage of ESO observations of Comet 9P/Tempel 1 and Deep Impact.

Figure 2: National videoconference on Comets and Deep Impact, jointly organised by ESO and the Chilean Ministry of Education. After a motivating introduction given by astronomers located in Santiago and Paranal, students in 18 different Chilean cities had the opportunity to ask their questions about Comets and the Solar System, a few days before impact.

Figure 3: Representing ESO/ALMA, Jörg Eschwey, Manager of Site Development at Chajnantor, and Roberto Tamai, Head of Engineering of the La Silla Paranal Observatory, receive the award to the best exhibition during Exponor 2005 (the main industrial convention in Antofagasta, capital of Region II, where Paranal and Chajnantor are located). Scale models of the VLT and ALMA, documentaries in Spanish version and informative panels were part of the ESO-ALMA exhibition.

For the future, more exhibitions in public events are expected, most of them in collaboration with the Chilean Ministry of Education. In the long run, this will mean an increase on the public awareness of ESO's commitment with Chile and its people, sharing a cultural identity with the community and contributing to the promotion of a science culture and a better understanding of the Universe.

Universe Awareness for Young Children

George Miley[1]
Claus Madsen[2]
Cecilia Scorza de Appl[3]

[1] Leiden University
[2] ESO
[3] University of Heidelberg

Universe Awareness (UNA) is an international programme that will expose economically-disadvantaged young children, between ages 4 and 10 years, in developed and developing countries to the inspirational aspects of modern astronomy.

Introduction

From the dawn of history, the beauty of the sky and its intimate connection with the development of human civilisation have inspired countless generations with a sense of wonder. Modern astronomy continues to play a unique role in conveying the excitement of science to the general public. In recent years considerable resources have been devoted to astronomical outreach in developed countries, aided by the spectacular images produced by modern astronomical facilities and the continuing list of major astronomical discoveries that have changed our views of the Universe. Universe Awareness is a new programme intended to reach a target group that has so far been neglected by such outreach programmes, namely children between four and ten years of age.

The programme is motivated by the premise that access to simple knowledge about the Universe is a basic birthright of everybody. The formative ages of four to ten years are crucial in the development of a human value system. This is also the age range in which children can readily appreciate and enjoy the beauty of astronomical objects and can learn to develop a "feeling" for the vastness of the Universe. Exposing young children to such material is likely to broaden their minds and stimulate their world-view.

The programme concentrates on *disadvantaged* young children for two reasons. Firstly, most other children will be exposed to some knowledge about the Universe in later years. Secondly, the educational disparities between advantaged and disadvantaged children are smallest for the youngest children.

ESO workshop

Following the setting up of an ad-hoc UNA steering committee in 2004, a workshop was held at ESO Headquarters on May 27 and 28, 2005 to discuss the feasibility of the Universe Awareness idea. The 16 participants from 14 countries in 5 continents included professional astronomers, educators, scientific outreach professionals and a social anthropologist. The participants were unanimously enthusiastic about Universe Awareness as an idea and about the feasibility of developing it into a useful programme. At the workshop two sub-committees were formed to follow up on detailed aspects of the project. The first is studying educational aspects of Universe Awareness, including the content of the programme and the optimum didactic methods for delivering it. The second sub-committee is focusing on questions of organisation and funding.

The project

UNA is intended to be a programme that is *inspirational* and entertaining rather than to impart facts or develop specific cognitive skills. The minimum goal will be to make young children aware of the *beauty and scale of the Universe*. It also carries the implicit message that Nature can be interrogated by rational means. The tools and methods of UNA will be developed with the aim of eventually reaching as large a number of children as possible. The development and implementation of UNA will be driven by the needs and wishes of active educators in the target countries, combining the innovative use of professionally developed tools, including songs, games, toys and animation films in a coordinated modular programme.

The UNA programme will begin with "Earth Awareness", emphasising that the child is a member of a diverse human family of children living on a particular planet. Universe Awareness will then introduce the concept of the Sun, the Solar System, stars and galaxies. Through excitement, adventure and wonder, children will be stimulated to appreciate the beauty and enormity of the Universe.

Young disadvantaged children live in diverse environments. For example, the educational infrastructure for disadvantaged children in the inner cities of European countries is qualitatively different from the situation for disadvantaged children in an agricultural African village. UNA will therefore initially develop, implement and evaluate a pilot project in a small number of countries representative of the following three different educational environments:
(i) Environment 1:
- School starting at age 7–8 or non-existent;
- Television scarce.

(ii) Environment 2:
- School starting at age 6–7;
- Sporadic access to Internet;
- Television at home and at school;
- Poorly trained teachers.

(iii) Environment 3:
- School starting at age 4–5;
- Access to Internet at school and often at home;
- Well-trained teachers;
- UNA accepted as in-school curriculum.

For each environment a phased, coordinated modular programme will be prepared and training courses will be developed, all specifically tailored to fit the culture and language of the target group.

Tools and methods

Where very young children do not attend school (Environment 1), creative appealing materials will be developed for distribution by any available delivery method (e.g. national television or travelling UNA buses). For Environments 2 and 3, the programme will provide teachers with materials that involve children more actively.

Several *short films* will be developed to illustrate the two aspects of Universe Awareness, beauty and scale and gradually make children aware of the Earth, the Solar System and the Universe. The films will be designed to appeal to young children by entertaining them. They will


Photo: H. H. Heyer, ESO

From the UNA workshop at ESO Headquarters.

make use of *cartoon characters, animation and exciting adventure stories*. These films will be made by experienced makers of children's entertainment films and creative educators, with advice provided by astronomers. The adventures, featuring some of the most beautiful images made by modern telescopes, will be set in a variety of exotic environments known to exist in the Universe. They will attempt to cultivate the sense of imagination that is widespread in young children.

Additional coordinated material tailored for each country will be developed with the aid of talented educators, scientists and artists from these countries. These will include *games and songs*. They will often focus on the cartoon characters, feature UNA images and emphasise relevant aspects of Universe Awareness. Where appropriate, involvement of ancient local cultures with astronomy will be woven into the material. A goal will be to stimulate active group participation by the children, where possible, but will also include simple board games that children can play on a one-to-one basis. By including a uniform set of characters, images and environments over a range of material, the UNA message will be reinforced.

Internet will be used to creatively enhance the programme for disadvantaged children in advanced educational environments (Environment 3). Special material will be developed to enable UNA *"twinning"* activities, for class collaborations between young children in deprived regions of advanced countries and young children in developing countries. For example, children would learn from each other that developing countries are often "richer" in sources of UNA wonderment than developed ones. For example, skies in agricultural regions are generally darker and less polluted by light, so that children can count much larger numbers of stars.

Special attention will be devoted to optimum methods for *delivering the programme* in less developed environments. Tailoring films to local needs so that they can be transmitted on national or local television is one option. Another option is to equip travelling UNA buses with interactive games and exciting exhibits. Such buses are already frequently used for educational purposes in Tunisia, travelling between widely dispersed villages, stopping as appropriate.

To coordinate the programme and maintain links with the schools, teachers, parents and children in the target countries, several Universe Awareness Coordinators will be trained for each target country.

Pilot project

We propose to commence Universe Awareness with a pilot project that will target a limited number of developing countries and disadvantaged groups in up to four European countries. There are two reasons for combining these two target groups. First, the concept of "earth awareness" provides a good reason for linking these two geographically separated target groups. Secondly, a well-defined European involvement in such a one-world educational programme fits

Present Organisation of Universe Awareness

Universe Awareness International Steering Committee

Co-Chairpersons:
Mr. Claus Madsen, Head of the Public Affairs Department, ESO, Garching, Germany
Prof. George K. Miley, Royal Netherlands Academy Professor, Leiden University, the Netherlands

Dr. Cecilia Scorza de Appl, Landessternwarte Heidelberg, Germany
Prof. Alec Boksenberg, Chairman, UK National Commission for UNESCO, Institute of Astronomy, Cambridge, United Kingdom
Ms. Alexa Joyce, International Programme Coordinator, European Schoolnet, Brussels Belgium

UNA Project Manager Coordinator
(from September 15, 2005):
Dr. Carolina Ödman, Leiden University, the Netherlands

Universe Awareness Education Sub-Committee

Chairperson:
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Mr. Gonzalo Argandona, *Astronomical Outreach*, ESO, Santiago, Chile
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Dr. R. West, *Outreach Astronomer (rtd.)*, ESO, Garching, Germany

Universe Awareness Organisation Sub-Committee

Chairperson:
Prof. Alec Boksenberg, *Astronomer*, Chairman, UK National Commission for UNESCO, Institute of Astronomy, Cambridge, United Kingdom

Ms. Marina Joubert, *Scientific Outreach*, South African Agency for Science and Technology Advancement, Pretoria, South Africa
Mr. Claus Madsen, *Head of the Public Affairs Department*, ESO, Garching, Germany
Prof. George K. Miley, *Astronomer*, Royal Netherlands Academy Professor, Leiden University, the Netherlands

well with the aspirations of the European Union and several individual European countries.

An “announcement of opportunity” will be disseminated at the end of 2005, requesting expressions of interest by national groups that are interested in participating in UNA. Although the pilot project will concentrate on the selected target countries, UNA material will be made available generally.

Organisations

At present the following organisations support the Universe Awareness Programme: ESO, the European Schoolnet (ESN), the European Association for Astronomy Education, (EAAE), the International Astronomical Union, Leiden University and the Royal Netherlands Academy of Arts and Sciences (KNAW). During the next year we will seek further endorsements.

The development of the UNA project is presently being overseen by a 5-member Universe Awareness International Steering Committee (UNAISC) and two sub-committees devoted to education and organisation/funding respectively. Dr. Carolina Ödman has been appointed as UNA international project manager/coordinator at Leiden from September 15, 2005.

It is planned to hold a second larger interdisciplinary workshop to discuss progress in the project in the late summer of 2006. All those who are interested in UNA and wish to be kept informed of developments should contact Carolina Ödman (*odman@strw.leidenuniv.nl*).

Preliminary Timeline

Three stages in the pilot project are envisaged:

September 2005–December 2006
Preparation
- Contacting suitable funding organisations
- Refinement of educational goals and needed material
- Preparation of funding proposals

2007–2008
Development
- Production of actual animation films, games, toys, and internet tools
- Development and organisation of coordinator training courses

2009
Implementation
- Start of pilot project with evaluation

Note that the expected implementation date for the pilot project coincides with the International Year of Astronomy planned for 2009.

Catherine Cesarsky Elected Member of Academies of Sciences

On April 20, 2004, the US National Academy of Sciences selected 72 new members and 18 foreign associates from 13 countries, including Dr. Catherine Cesarsky, ESO’s Director General. This brought the total number of active members to 1949, including 351 foreign associates.

Among its distinguished members, the National Academy includes 83 astronomers. Catherine Cesarsky was elected in recognition of her role as a pioneer of space infrared astronomy and a leader of European physics and astronomy, and more particularly, for her seminal contributions to the study of star formation in near and distant galaxies, the cosmic infrared background, and the confinement and acceleration of cosmic rays.

The US National Academy of Sciences is a private, non-profit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters.

On April 30, 2005, at the Annual Meeting of the US National Academy of Sciences, Catherine Cesarsky, was officially inducted into this highly prestigious society.

At about the same time, Catherine Cesarsky became a Foreign Member of the Royal Swedish Academy of Sciences. Founded in 1739, this Academy was modelled on the pattern of the Royal Society of London and of l’Académie Royale des Sciences in Paris. It is an independent organisation whose overall objective is to foster the sciences, particularly mathematics and the natural sciences. And, of course, every year the Academy awards the Nobel Prizes in Physics and Chemistry, the Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel, the Crafoord Prize and a number of other large prizes. It might be worth mentioning that this year’s laureates of the Crafoord Prize are three astronomers: James Gunn and James Peebles from Princeton University, USA, and Sir Martin Rees from the University of Cambridge, UK.

Photo: L. Bulatis/The Royal Society

Catherine Cesarsky is inducted into the British Royal Society.

On May 27, 2005, Dr. Cesarsky was also elected Foreign Member of the British Royal Society, thereby joining the 1292 Fellows and 132 Foreign Members of the world’s oldest scientific academy in continuous existence. The Royal Society was founded in 1660 and has, throughout its history, promoted excellence in science through its Fellowship and Foreign Membership, which has included Newton, Montesquieu, Darwin, Rutherford, Einstein, Hodgkin, Crick, Watson and Hawking.

Fellows at ESO

Cédric Foellmi

After my studies in Geneva and my PhD in Montréal, I moved to ESO and La Silla. Like many others, I was fulfilling a dream. I was not only visiting La Silla, but actually working in it! Long *turnos* provide this very peculiar feeling of a little community of specialised workers whose goal is to observe the sky every night. And the people in La Silla are really great. As much as the sky.

I have been right away attached to the NTT. These were hard and great times. I was still finishing my PhD, and having duties at the NTT in the “old” control room: cold, very dry, moving all night. Tough. However, I was not only learning how ESO operates, but also how to become an efficient observer on large telescopes. “Efficient” here means having a strong vision of the variety of astronomical objects and phenomena, and a detailed knowledge of instruments and techniques. This proves to be of the greatest importance for my research.

Research is the other part of the fellowship, and actually the most important for me. Greatly enhanced by a unique experience of the “backstage” of telescope operations, I can conduct my research freely at Vitacura. Even in the context where none of my colleagues is directly working in my field. Of course, not everybody is aware of the great interest Wolf-Rayet stars might represent ... But I am slowly making more and more people aware of it! And I realise after these years the advantages of being an ESO fellow: in Vitacura there are simply all the “instruments scientists” of all ESO instruments! And the fellowship is three years in Chile. It gives precious time to start serious collaborations, and develop a coherent research. Friends, coherence and sense. Isn’t it what we all are looking for? Some lucky ones looking at the beautiful southern sky.

Margrethe Wold

I arrived at ESO in the winter of 2003. I had been working as a post doc at the Spitzer Science Center at Caltech in Pasadena, so arriving in cold Garching was quite a dramatic change from warm and sunny California. From early on, I had a deep interest in science, not just astronomy, but several different topics like archaeology, ornithology and particle physics. In the end, I decided to study astronomy, even though I first started an engineering education at a technical university.

My astronomy career started at the University of Oslo where I did my master degree. During this period, I went on frequent observing trips to the 2.5-m Nordic Optical Telescope on La Palma, and hence got observing experience fairly early. To pursue my PhD, I moved to the University of Stockholm. My PhD concentrated on clustering of galaxies around quasars, but I also worked with weak gravitational lensing by clusters of galaxies. I still find weak gravitational lensing a very fascinating technique to measure the masses of the largest bound structures in the Universe.

During my post doc at the Spitzer Science Center I started a programme to study the centres of nearby radio galaxies, in particular to measure their black hole masses. For this, I used the historic 5-m Hale telescope on Mt. Palomar. During my time here at ESO, I have continued this project using both the NTT and the 3.6-m telescope. Being interested in what is going on in the centres of galaxies, I am now using the new mid-infrared VLT instrument, VISIR, to study gas in the centres of active galaxies.

Never did I dream that my interest for astronomy as a kid would take me to so many different places in this world, and would allow me to meet so many interesting people. This is still an adventure for me!

International Conference on

Relativistic Astrophysics and Cosmology – Einstein's Legacy

November 7–11, 2005, Munich, Germany

100 years ago Albert Einstein published three seminal papers on the theories of special relativity, of the photoelectric effect and of Brownian motion, which made the world call the year 1905 the miraculous year. Together with Einstein's theory of general relativity fundamental building blocks were provided for modern astrophysics and cosmology and can thus be considered as a true legacy to mankind.

The conference "Relativistic Astrophysics and Cosmology – Einstein's Legacy" will give an overview on recent progress in relativistic astrophysics and cosmology. It will be one of the final highlights of the "International Year of Physics" and the German "Einstein Year".

Scientific themes are:
- Gamma-Ray Bursts – the Creation of Black Holes?
- Neutron Stars, Black Holes, Microquasars
- The Galactic Centre and Supermassive Black Holes in Galaxies
- Active Galactic Nuclei, Feeding and Feedback
- Gravitational Wave Astrophysics
- Clusters of Galaxies and Large-Scale Structure
- Dark Matter and Dark Energy – Einstein's greatest triumph?

Invited speakers:
Roger Blandford, Jürgen Ehlers, Neil Gehrels, Reinhard Genzel, Riccardo Giacconi, Piero Madau, Felix Mirabel, Lyman Page, Sterl Phinney, Edward L. Wright.

Scientific Advisory Committee:
Roger Blandford, Jürgen Ehlers, Reinhard Genzel, Günther Hasinger (Chair), Bruno Leibundgut, Gernot Neugebauer, Martin Rees, Hans-Walter Rix, Peter Schneider, Bernard F. Schutz, Rashid A. Sunyaev, Joachim Trümper.

Further information and registration:
www.mpe.mpg.de/~e05/

Latin American Astronomy Summer School

December 8–10, 2005, Santiago, Chile

ESO – the European Organisation for Astronomical Research in the Southern Hemisphere – and the Sociedad Chilena de Astronomía (SOCHIAS) are organising a Latin American Astronomy Summer School. It will take place from December 8–10, 2005, the week before the Regional Meeting of the International Astronomical Union to be held on December 12–16, 2005 in Pucon, Chile (~ 800 km South of Santiago).

The aim of this multi-thematic Latin American School is to provide students and young researchers exposure to different front-line areas of research presented by major players in promoting and/or executing those areas. The lectures will have a pedagogical character.

The lecturers are:
Malcolm Longair (Cambridge University, UK), Bob Williams (STScI, USA), Gloria Dubner (IAFE/CONICET, Argentina), Pat Osmer (Ohio State University, USA), Luis Felipe Rodriguez (UNAM, Mexico), Dante Minniti (Pontificia Universidad Católica, Chile), Felix Mirabel (ESO, Chile).

The lectures will cover the following themes:
- Extrasolar planets
- Star Formation and the Interstellar Medium
- Supernovae
- Black Holes
- Evolution of Galaxies.
- Distant Quasars
- The Deep Universe

This School is sponsored by:
ESO, SOCHIAS, and the I. Municipalidad de Vitacura.

Local and Scientific Organising Committee members are:
Felix Mirabel (ESO – Chair), Monica Rubio (Universidad de Chile), Dante Minniti (Pontificia Universidad Católica, Chile), Maria Eugenia Gomez (ESO), and Andrea Lagarini (ContactChile Comunicaciones).

The School e-mail is *school2005@eso.org*. Interested participants should fill in the preregistration form at the webpage link: *www.sc.eso.org/santiago/science/LASS2005/*

There is no registration fee, and limited funds may be available to cover local expenses in Santiago. The School announcements will be posted; check for updates at: *www.sc.eso.org/santiago/science/LASS2005/*

Personnel Movements

July 1, 2005–September 30, 2005

Arrivals

Europe

Alves de Oliveira, Catarina (P)	Student
Fedele, Davide (I)	Student
Feng, Yan (CN)	Paid Associate
Hötzl, Stefan (D)	Electronics Technician
Igl, Georg (D)	Quality Engineer
Kolb, Johann (F)	Paid Associate
Kornmesser, Martin (D)	Graphics Designer
Landsmann, Michael (D)	Student
Lapeyre, Pascal (F)	Engineering Work
Lopez, Gil Ignacio (E)	Accountant
Lyubenova, Mariya (BG)	Student
Manescau, Hernandez Antonio Ramon (E)	Instrumentation Engineer
Mieske, Steffen (D)	Fellow
Rivas, Rodrigo (RCH)	Student
Rykaczewski, Hans (D)	Head of the ALMA Division
Vernet, Elise (F)	Paid Associate
Wesse, Yves (F)	Contract Officer

Chile

Aguilera, Hugo Freddy (RCH)	Accounting Officer
Amico, Paola (I)	Operations Astronomer
Badel, Arnaud (F)	Student
Dierksmeier, Claus (D)	Civil Engineer
Groothuis, Charlotte (NL)	Opto-Mechanical Engineer
Guniat, Serge (CH)	Mechanical Engineer
Lassalle, Jacques (F)	Safety Engineer
Luhrs, Javier (RCH)	Software Engineer
Mella, Juan Alberto (RCH)	Safety Engineer
Schmidtobreick, Linda (D)	Operations Astronomer

Departures

Europe

Blondin, Stephane (F)	Student
Credland, John D. (GB)	Head of the ALMA Division
Da Costa, Luiz Alberto (I)	Astronomer
Döllinger, Michaela (D)	Student
Fechner, Matthias (D)	Student
Gerken, Bettina (D)	Student
Guzman, Ronald (BOL)	Student
Hastie, Morag Ann (GB)	Student
Järvinen, Arto (FIN)	Student
Kalaglarsky, Damyan (BG)	Student
Karl, Simon (D)	Student
Kniazev, Alexei (RU)	Paid Associate
Koenig, Emilie (F)	Student
Landsmann, Michael (D)	Student
Renzini, Alvio (I)	VLT Programme Scientist
Rivas, Rodrigo (RCH)	Student
Rolland, Lucie (F)	Student
Sartoretti, Paola (I)	Operations Scientist
Valat, Bruno (F)	Student
Verdoes Kleijn, Gijsbert (NL)	Fellow
Zhuang, Tao (CN)	Student

Chile

Aguilar, Raul (RCH)	Safety Engineer
Baes, Maarten (B)	Fellow
Billeres, Malvina (F)	Fellow
Couronne, Cristophe (F)	Student
de Brito Leal, Luis Filipe (P)	Student
Ederoclite, Alessandro (I)	Student
Fossati, Luca (I)	Student
Haubois, Xavier (F)	Student
Hurtado, Norma (RCH)	Telescope Instruments Operator
Jaunsen, Andreas (N)	Operations Astronomer
Leproux, Anais (F)	Student
Martinez, Mauricio (RCH)	Telescope Instruments Operator
Roa, Mauricio (RCH)	Software Engineer
Scatarzi, Alberto (I)	Student

ESO – European Organisation for Astronomical Research in the Southern Hemisphere

invites applications for the position of a

European Affairs Officer

Assignment: The successful candidate will
- Identify relevant funding possibilities within the EC Framework Programme and other activities, advise applicants and monitor the progress of applications and contracts;
- Follow developments in European Science Policy and provide advice to the ESO management;
- Assist with ESO's interaction in the EIROforum partnership;
- Organise policy-related debates and events in member states as well as in the institutions of the EU, attracting key decision-makers and media;
- Organise special visits and events for opinion formers and target groups in member states.

Qualification and Experience: Advanced university degree in Science, preferably astronomy/astrophysics. Knowledge of contemporary science policy isues as well as of the EC Framework Programme and other European funding schemes is required. Experience in interaction with science administrators and policy makers at all levels is necessary. Experience in public science communication and interest in societal aspects of science are an advantage. Fluency in English is essential as well as a good knowledge in French.

Duty station: Garching near Munich, Germany
Starting date: As soon as possible
Further information under: *http://www.eso.org/gen-fac/adm/pers/vacant/europeanaffairs.html*

ESO. Astronomy made in Europe

ESO is the European Organisation for Astronomical Research in the Southern Hemisphere. Whilst the Headquarters (comprising the scientific, technical and administrative centre of the organisation) are located in Garching near Munich, Germany, ESO operates three observational sites in the Chilean Atacama desert. The Very Large Telescope (VLT), is located on Paranal, a 2 600 m high mountain south of Antofagasta. At La Silla, 600 km north of Santiago de Chile at 2 400 m altitude, ESO operates several medium-sized optical telescopes. The third site is the 5 000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a new submillimetre telescope (APEX) is in operation, and a giant array of 12-m submillimetre antennas (ALMA) is under development. Over 1 600 proposals are made each year for the use of the ESO telescopes.

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

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Front Cover Picture: The Radio Galaxy Centaurus A
This image (NGC 5128) was obtained by João Alves and colleagues using the WFI instrument mounted on the 2.2-m ESO telescope of La Silla. This composite colour image is a combination of five filters (U, B, V, R and Hα). The observations were reduced and combined by Benoît Vandame (ESO).