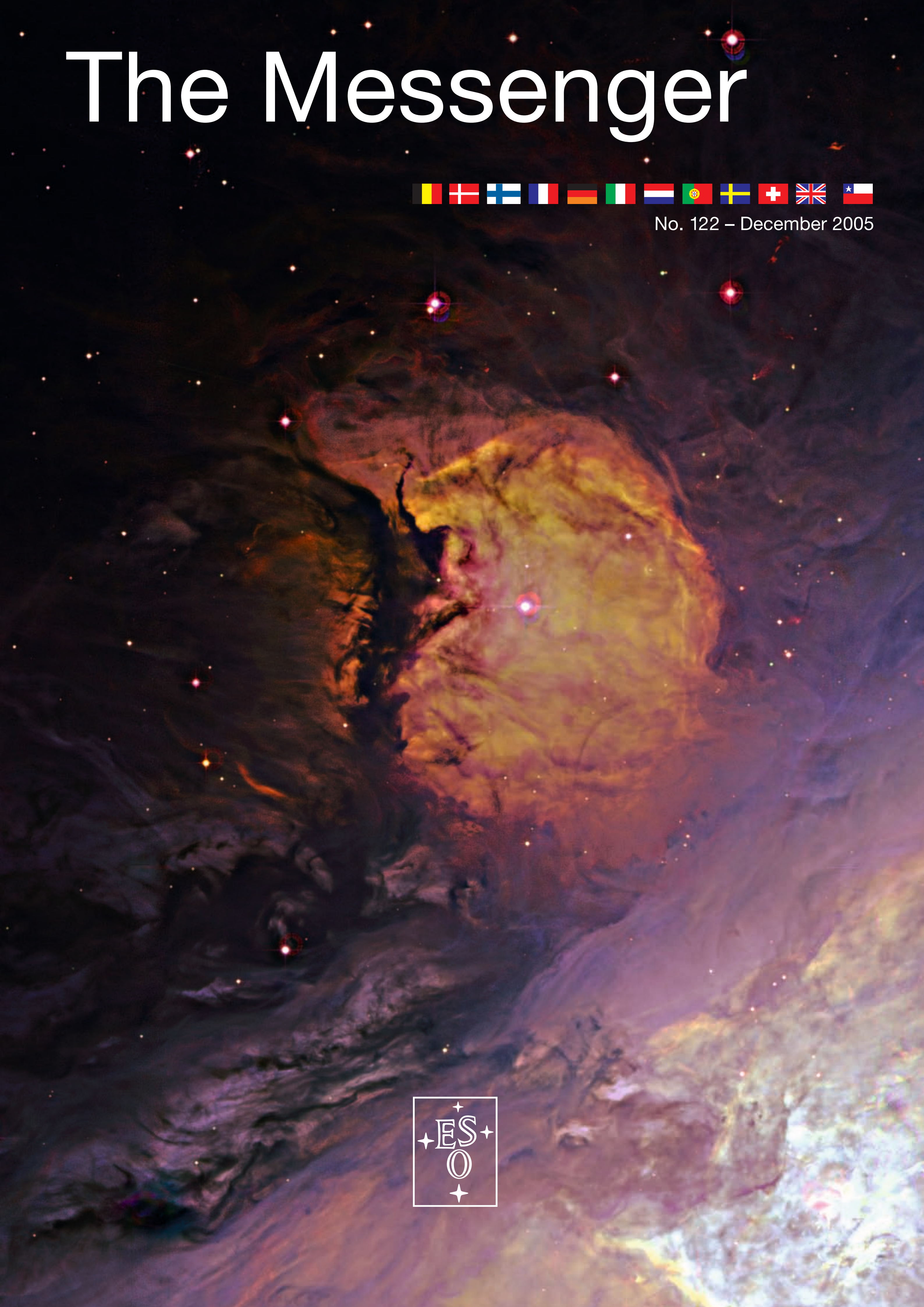
The Messenger

No. 122 – December 2005



Surveying the High-Redshift Universe with KMOS

Ray Sharples[1]
Ralf Bender[2,4]
Richard Bennett[3]
Keith Burch[3]
Paul Carter[3]
Mark Casali[6]
Paul Clark[1]
Robert Content[1]
Richard Davies[4]
Roger Davies[5]
Marc Dubbeldam[1]
Gert Finger[6]
Reinhard Genzel[4]
Reinhold Häfner[2]
Achim Hess[2]
Markus Kissler-Patig[6]
Ken Laidlaw[3]
Matt Lehnert[4]
Ian Lewis[5]
Alan Moorwood[6]
Bernard Muschielok[2]
Natascha Förster Schreiber[4]
Jeff Pirard[6]
Suzie Ramsay Howat[3]
Phil Rees[3]
Josef Richter[2]
David Robertson[1]
Ian Robson[3]
Roberto Saglia[2]
Matthias Tecza[5]
Naranjan Thatte[5]
Stephen Todd[3]
Michael Wegner[2]

[1] Department of Physics, University of Durham, United Kingdom
[2] Universitätssternwarte München, Germany
[3] UK Astronomy Technology Centre, Royal Observatory, Edinburgh, United Kingdom
[4] Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany
[5] Sub-Department of Astrophysics, University of Oxford, United Kingdom
[6] ESO

KMOS is a near-infrared multi-object integral-field spectrometer which has been selected by ESO as one of a suite of second-generation instruments to be constructed for the VLT. The instrument will be built by a consortium of UK and German institutes working in partnership with ESO and is currently in the preliminary design phase. KMOS will be capable of obtaining simultaneous spatially resolved spectroscopy at a sampling of 0.2 arcseconds for up to 24 targets distributed over a field of view of 7.2 arcminutes diameter.

The past decade has seen remarkable progress in cosmology, with the combination of measurements from microwave background experiments and large-scale redshift surveys placing precise constraints on many of the fundamental parameters of the cosmological world model. Photometric selection techniques and gravitational lensing have opened up the universe beyond $z = 1$ and allowed the detection of massive star-forming galaxies which must have formed within a few billion years of the Big Bang. The precise details of the physical processes which drive galaxy formation and evolution in these models remain elusive however. To study these processes in detail requires a capability to map the variations in star-formation histories, merger rates and dynamical masses for well-defined samples of galaxies across a wide range of redshifts and environments. Single-integral-field-unit (IFU) spectrographs like SINFONI/SPIFFI are beginning to provide exquisite views of some of the most spectacular examples (e.g. Figure 1) but statistical surveys of these galaxy properties, and follow-up of future surveys of high-redshift galaxies obtained, for example, with HAWK-I and SCUBA-2, will require a spectrograph that can observe many objects simultaneously. This is the capability which will be delivered by a new instrument now under development known as KMOS (*K*-band Multi-Object Spectrograph) which, when commissioned on the VLT in 2010, will be unique on any 8-metre-class telescope.

For any instrument to address these fundamental questions about how galaxies evolve it should: (1) have a substantial multiplex capability and field of view, commensurate with the surface density of accessible targets; (2) have the ability to obtain more than just integrated or one-dimensional information since forming galaxies are often observed to have complex morphologies; (3) be able to resolve the relatively small velocity differences observed in rotation curves, velocity dispersions, and merging galaxy pairs; (4) have the ability to observe several targets in proto groups and clusters concentrated in small areas of the field; (5) enable observations of high-redshift galaxies using the well-studied rest-frame optical diagnostic features used at low redshift. These general characteristics imply a near-infrared multi-object spectrograph using deployable integral field-units (d-IFUs). Deployable IFUs also have a significant advantage over multi-slit spectrographs because of the reduced slit contention in crowded fields and their insensitivity to galaxy morphology and orientation. The specific choices made to deliver these capabilities involve a complex trade of cost and scope which is reflected in the baseline capabilities of KMOS listed in Table 1.

Requirement	Baseline Design
Instrument throughput	J = 20 %, H = 30 %, K = 30 %
Sensitivity (5 σ, 8 hrs)	J = 21.2, H = 21.0, K = 19.2
Wavelength coverage	1.0 to 2.5 μm
Spectral resolution	R = 3400, 3800, 3800 (J, H, K)
Number of IFUs	24
Extent of each IFU	2.8 × 2.8 arcseconds
Spatial sampling	0.2 × 0.2 arcseconds
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	> 3 within 1 arcmin^2
Closest approach of IFUs	edge-to-edge separation of 6 arcsec

Table 1: Baseline design specification for the KMOS spectrograph.

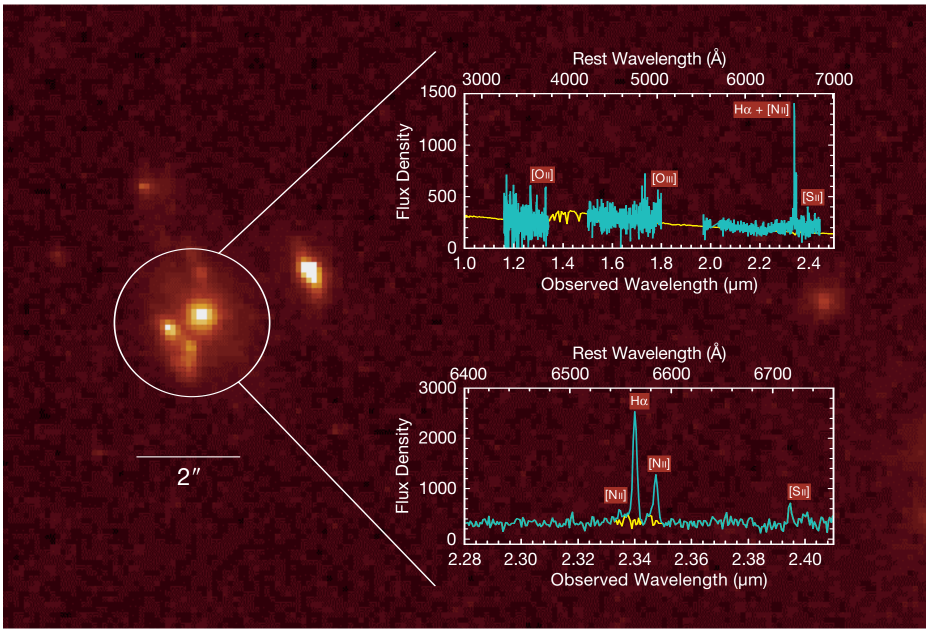


Figure 1: SPIFFI spectra of the central 2.5″ of the submillimetre galaxy SMM J14011+0252 showing the often complex morphology of these targets (from Eisenhauer et al. 2003).

KMOS will be mounted on the VLT Nasmyth rotator and will use the Nasmyth A&G facilities. The top-level requirements are: (i) to support spatially-resolved (3-D) spectroscopy; (ii) to allow multiplexed spectroscopic observations; (iii) to allow observations across the *J*, *H*, and *K* infrared atmospheric windows (extension to shorter wavelengths may be incorporated). The baseline design employs 24 configurable arms that position fold mirrors at user-specified locations in the Nasmyth focal plane, each of which selects a sub-field of 2.8 × 2.8 arcseconds. The size of the sub-fields is tailored specifically to the compact sizes of high redshift galaxies. The sub-fields are then anamorphically magnified onto 24 advanced image slicer IFUs that partition each sub-field into 14 identical slices, with 14 spatial pixels along each slice. Light from the IFUs is dispersed by three identical cryogenic grating spectrometers which generate 14 × 14 spectra, each with ~ 1000 Nyquist-sampled spectral resolution elements, for all of the 24 independent sub-fields. The spectrometers will each employ a single 2k × 2k Hawaii-2RG HgCdTe detector. The optical layout for the whole system has a threefold symmetry about the Nasmyth optical axis allowing a staged modular approach to assembly, integration and test. End-to-end raytraces through four of the pickoff arms in one of the three spectrometers are shown in Figure 2. Our goal is to employ careful design choices and advances in technology to ensure that KMOS achieves a comparable sensitivity to the current generation of single-IFU infrared spectrometers and gains at least an order of magnitude in survey speed for typical target fields.

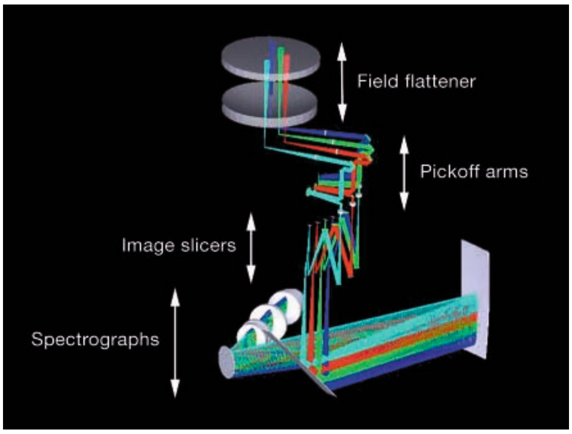


Figure 2: Optical raytrace through four pickoff arms, their associated IFUs and one of the spectrometers. Light exiting the pickoff arms is brought to an intermediate focus using a 3-element *K*-mirror, which aligns the edges of all 24 IFU fields on the sky so that they can be put into a compact sparse array configuration for blind surveys of contiguous areas on the sky.

Pickoff module

One of the more unusual KMOS elements is the pickoff module which relays the light from 24 selected regions distributed within the patrol field to an intermediate focus position at the entrance to the integral-field-unit module. The method adopted for selecting these subfields uses robotic pick-off arms whose pivot points are distributed in a circle around the periphery of the patrol field and which can be driven in radial and angular motions by two stepper motors which position the pickoff mirrors with a repeatable accuracy of < 0.2 arcsec. The arms patrol in one of two layers positioned either side of the Nasmyth focal plane to improve the access to target objects in crowded fields. This focal plane is flattened and made telecentric by a pair of all-silica field lenses, one of which forms the entrance window to the cryostat. The arm design has been refined to allow maximum versatility in allocation of targets whilst achieving stringent goals on accuracy and reliability. Independent monitoring of arm positions to avoid collisions will be available using both step counting and position encoders; a collision-detection sensor will also be implemented as a third level of protection. The efficiency of allocation has been benchmarked against several real target fields selected from deep imaging surveys; Figure 3 shows one such configuration with the arms overlaid on a sample of high-redshift targets selected from the FORS Deep Field (Noll et al. 2004).

The changing path length within the arm is compensated via an optical trombone which uses the same lead screw, but with a different pitch, as for the main radial motion. The pickoff module also contains the instrument calibration unit and a filter wheel which acts as a focus compensation device between the different bands. The cold stop for the instrument is at the base of the arm, after which an intermediate image is formed by a *K*-mirror assembly which also acts to orientate the pick-off fields so that their edges are parallel on the sky. A prototype pickoff arm is currently being manufactured, which will be subject to an extensive series of tests in a cryogenic environment before manufacturing the full batch of 24 arms. A solid model of one of the pickoff arms, together with its patrol space envelope, is shown in Figure 4.

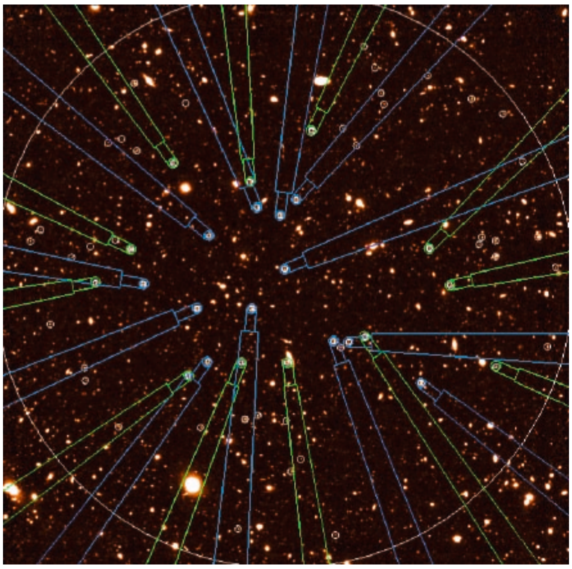


Figure 3: *I*-band image of the FORS Deep Field (Noll et al. 2004) with KMOS pickoff arms assigned to 24 Extremely Red Objects (EROs). The blue arms belong to the lower plane (and can therefore be vignetted by arms in the upper plane) whilst the green arms patrol the upper plane. The positioning efficiency of the arms has been checked against a number of important science cases which demonstrate a high multiplexing factor on interesting targets.

Integral Field Unit module

The IFU subsystem contains optics that collect the output beams from each of the 24 pickoffs and reimages them with appropriate anamorphic magnification onto the image slicers. The anamorphic magnification is required in order that the spatial sampling pixels (“spaxels”) on the sky are square whilst maintaining Nyquist sampling on the detector in the spectral dimension. The slices from groups of 8 sub-fields are aligned and reformatted into a single slit for each of the three spectrometers. The optical design of the IFU sub-systems is based on the Advanced Image Slicer concept (Content 1997) and draws heavily on experience developed in building the GNIRS integral-field unit for Gemini South (Dubbeldam et al. 2000). Three off-axis aspheres are used in the fore-optics to facilitate a production method based on diamond-turning, rather than raster fly-cutting, in order to improve the surface roughness. Important considerations in developing the design for 24 optical trains, have been the need to incorporate manufacturability into the optimisation process, and a desire to use monolithic optical components wherever possible. In the current design the slicer mirrors are all spherical with the same radius of curvature, and so are the pupil mirrors. The slit mirrors are toroidal with the same radius of curvature in the spectral direction, but different radii of

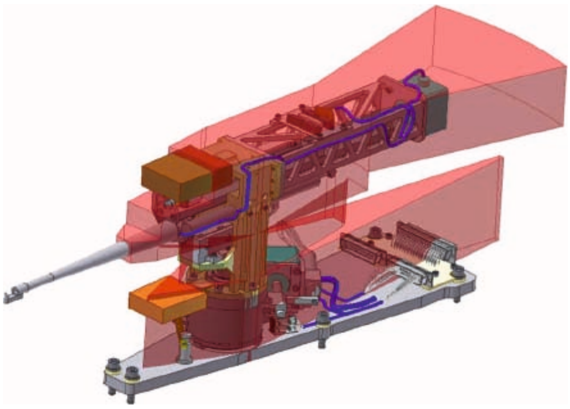


Figure 4: Solid model of a KMOS arm in the upper plane. The lower arms contain identical components but are compressed vertically. The transparent red region shows the space envelope occupied by the arm over its full range of motion. Each arm patrols approximately 30 % of the pickoff field.

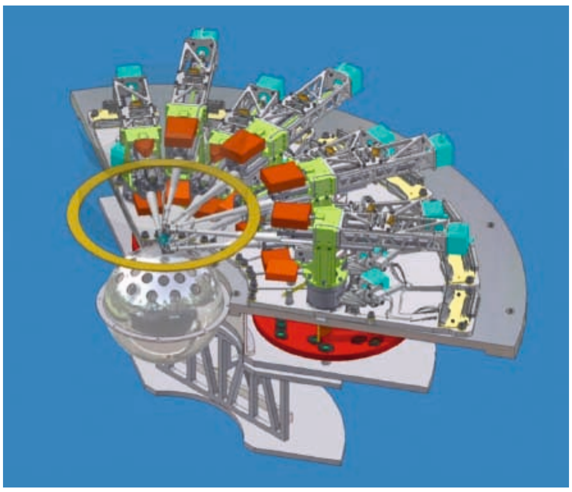


Figure 5: One of the three integrated pickoff and IFU sub-modules showing the three mounting plates for the pickoff arms, the filter wheels and the IFU optics. Each sub-module is attached to the main cryogenic optical bench within the cryostat. At the centre of the unit is shown the integrating sphere of the calibration unit and the ring mirror which reflects light from the calibration sources in to the pickoff arms.

curvature in the spatial direction. This configuration was chosen because it is well adapted to the available methods of machining. Each IFU sub-module produces a 254 mm long slit containing 112 separate slices from 8 subfields. The mechanical design of a single pickoff and IFU sub-module containing eight pickoff arms and eight integral field channels is shown in Figure 5 and emphasises the three-fold symmetry of the KMOS system and the advantages from a mechanical perspective of positioning common components in a single plane.

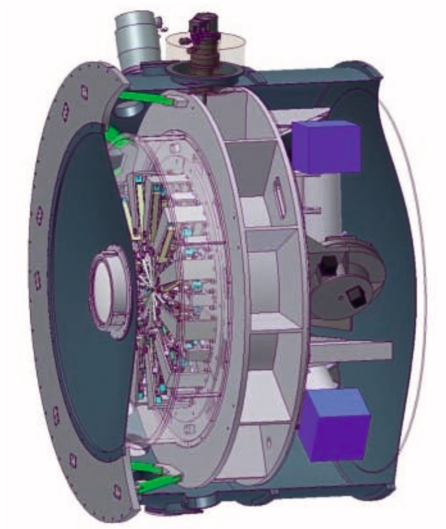


Figure 6: Cutaway view of the main KMOS cryostat showing the entrance window and the pickoff arm module at the front, and the spectrograph module at the rear. The cryostat will be an aluminium/stainless steel hybrid to reduce weight. Not shown here are the electronic racks which will mount on a supporting frame around the cryostat.

Spectrograph module

The three identical spectrographs use a single off-axis toroidal mirror to collimate the incoming light, which is then dispersed via a reflection grating and refocused using a 6-element transmissive achromatic camera. The gratings are mounted on a 6-position wheel which allows optimised gratings to be used for the individual *J*-, *H*-, *K*-bands together with two lower-resolution gratings and the option of a *z*-band grating to enhance versatility (Tecza et al. 2004). Each spectrograph contains a 2048 × 2048 Hawaii-2RG HgCdTe array which is mounted on a three-axis translation stage in order that focus can be adjusted and, if required, some components of flexure can be compensated. All three spectrographs are mounted in a plane perpendicular to the Nasmyth rotation axis for maximum stability (Figure 6).

Software and electronics

KMOS will be one of the most complex astronomical instruments ever built for a ground-based telescope with over 60 degrees of freedom in the cryogenic mechanisms alone. Robust efficient software and reliable control electronics will be key to successful long-term operations. In addition to instrument control software and housekeeping diagnostics, KMOS will have an optimised target allocation tool, currently known as KARMA, in the ESO observation preparation software (P2PP). KARMA will assign arms to targets in a prioritised way, whilst ensuring that no invalid arm positions are selected and allowing the user to manually reconfigure the list of allocated targets. A customised data reduction pipeline will be provided which will allow the observer to precisely reacquire the targets during multiple visits to the same field and to evaluate the data quality after each readout. With over 4000 spectra per integration, automatic data processing and reduction methods will be essential to fully exploit the scientific potential of KMOS.

Project status

KMOS is being built by a balanced consortium of UK (University of Durham, University of Oxford and the UK Astronomy Technology Centre) and German (Universitätssternwarte München and the Max-Planck-Institut für Extraterrestrische Physik) institutes working in collaboration with ESO, who will provide the science detectors and associated readout electronics and software. The project is currently in the preliminary design phase and is expected to be shipped to Paranal in mid-2010. The list of key milestones is given in Table 2.

Table 2: Key KMOS milestones.

Milestone	Date
Preliminary Design Review (PDR)	March 2006
Final Design Review (FDR)	March 2007
Preliminary Acceptance Europe (PAE)	March 2010
Preliminary Acceptance Chile (PAC)	September 2010

References

Content, R. 1997, Proc. SPIE, 2871, 1295
Dubbeldam, M. et al. 2000, Proc. SPIE, 4008, 1181
Eisenhauer, F. et al. 2003, The Messenger 113, 17
Noll, S. et al. 2004, A&A, 418, 885
Tecza, M. et al. 2004, Proc. SPIE, 5492, 1395

Instrument Concepts for the OWL Telescope

Sandro D'Odorico (ESO)

During the past year ESO has coordinated a number of instrument concept studies as a complement to the OWL Observatory Design Study. Eight teams of scientists and engineers from different institutes in Europe and ESO have identified a variety of science programmes at the frontier of astrophysics and developed concepts of instruments at OWL which would be able to carry them out. This exercise has provided a first view of the unique astronomical observations at Blue to IR wavelengths which will become possible with a future European Extremely Large Telescope.

Table 1: Instrument Capability and Primary Science Goals.

Instrument	Wavelength range	Main capability	Primary science goals
CODEX	0.4–0.7 µm	High-velocity-accuracy, visual spectrograph	To measure the dynamics of the Universe
QuantEYE	0.4–0.8 µm	Photometry at 10^{-3}–10^{-9} second resolution	Astrophysical phenomena varying at sub-millisecond time scale
HyTNIC	1.1–1.6 µm	High-contrast diffraction-limited imaging	Imaging of massive planets, bright galactic and extragalactic sources
EPICS	0.6–1.9 µm	Camera-Spectrograph at diffraction limit	Imaging and spectroscopy of Earth-like planets
MOMFIS	0.8–2.5 µm	Near IR spectroscopy using many deployable IFUs	First galaxies in the Universe
ONIRICA	0.8–2.5 µm	NIR Camera at diffraction limit	Faint stellar and galaxy population
T-OWL	3–24 µm	Thermal, Mid-Infrared Imager and Spectrograph	Search, study of planets, high-redshift Hα galaxies
SCOWL	350–450–850 µm	Imaging at sub-millimetre wavelengths	Surveys of dusty regions, of extra-galactic fields for star-forming galaxies

Table 2: Instrument Teams.

Instrument	PI	ESO scientist	Institutes
CODEX	Luca Pasquini	–	ESO, INAF – Trieste, Observatoire de Genève, IoA Cambridge
QuantEYE	Cesare Barbieri Dainis Dravins	Robert A. E. Fosbury	University of Padova and Lund University
HyTNIC	Olivier Lardière Virginie Borkowski Antoine Labeyrie	Guy Monnet	LISE – Collège de France
EPICS	Norbert Hubin Markus Kasper, Christophe Verinaud	–	ESO and external experts from 10 institutes
MOMFIS	Jean-Gabriel Cuby	Mark Casali	LAM, GEPI, CRAL, LESIA, ONERA
ONIRICA	Roberto Ragazzoni	Enrico Marchetti	INAF – Arcetri, Bologna, Padova, Roma and MPIfA Heidelberg
T-OWL	Rainer Lenzen Bernhard Brandl	Hans-Ulrich Käufl	MPIfA Heidelberg, Leiden University, ASTRON, ESO
SCOWL	William Dent	Ralf Siebenmorgen	UK ATC

Establishment and overview of the studies

It is generally recognised in the astronomical community that it is essential to develop instrument concepts very early in the design of a new telescope. Instruments represent the vital link between the photon-collector, however sophisticated and powerful, and the scientific goals of the project. Instrument studies effectively probe the telescope interface and operation scheme and they verify whether the required scientific observations can be obtained with feasible and affordable instruments. This path was followed by the VLT project, in which an instrumentation plan was developed almost a decade before first light (Reference 1). For OWL, ESO launched eight instrument concept studies in 2004 (see Tables 1 and 2) in collaboration with several European institutes.

In the selection of the initial instrument concepts, we have been guided by the Science Case for the European ELT (a generic 50–100-m telescope) prepared within the OPTICON Network (Editor Isobel Hook) and by preliminary studies on the OWL scientific goals. The selected instruments offer various imaging and spectroscopic modes of observing and operate in different bands from the blue to submillimetre wavelengths. They are well representative of the different possible modes of operation of OWL and probe well the telescope's ultimate capability. The sample is however by no means exhaustive of all potentially unique observations to be done with an ELT of the OWL class. High resolution spectroscopy in the near infrared and astrometry at the diffraction limit are two scientifically very interesting modes not explored in this phase.

Six of the studies were led by PIs from different European Institutes, and two were coordinated by ESO. The instrument study teams were asked to identify the specific science drivers and use them to define the requirements, to develop an instrument concept and to evaluate its performance at OWL. They had to compare them with the expected capability of major planned ground-based and space-borne facilities like ALMA and the JWST. They had also to address the dependence on telescope diameter in the range 50–100-m and to underline any critical aspects in the interface to the telescope. Critical aspects in cost or the required technical developments also had to be identified.

This first effort on possible OWL instruments saw the active involvement of more than 150 astronomers and engineers from over 20 institutes in seven European countries. Through this exercise they become familiar with ELT concepts and produced a first batch of attractive opto-mechanical solutions for the instruments. For most of those who were involved it was a first impact with the "overwhelming" capabilities of a 100-m aperture telescope but also with the differences with respect to the 10-m-class telescopes we are used to work with. All responded in an enthusiastic way to the new challenge. The eight studies were completed in a time frame of 12 months.

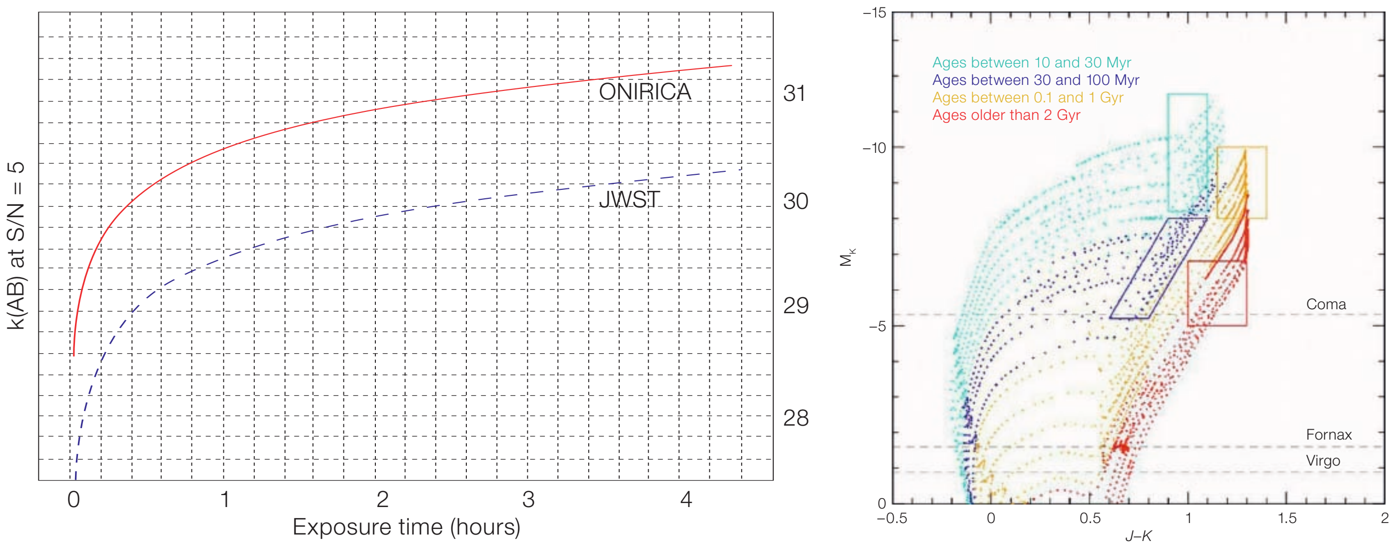


Figure 1a and b: The potential capability of a diffraction-limited NIR camera at OWL for the study of stellar populations in distant galaxies is illustrated in these figures. On Figure 1a the K limiting magnitudes for ONIRICA for stellar sources are compared to JWST. The advantage of ONIRICA would be even larger in the *J*-band. With a 60-m or a 30-m telescope the curves would have to be lowered by ~ 1 and ~ 2.5 mag respectively. Figure 1b shows a theoretical Colour-Magnitude diagram of an evolved galaxy population in which stars of different ages are identified. The dashed lines correspond to an m_K = 30 star at the distance of different clusters of galaxies (see Reference 7 for details).

Science cases and instrument concepts

Two of the instruments are foreseen for the *Blue-Visual and Red* wavelength bands with natural seeing image quality: CODEX and QuantEYE. They both use the outstanding collecting power of OWL to do unique science. CODEX makes use of the photon plethora to achieve high S/N ratio, high-resolution spectroscopy of faint stars and quasars with unmatched (~ 1 cm/s) velocity accuracy. The main science goal is the direct measurement of the dynamics of the Universe, but several other fields of astrophysics will be boosted by CODEX observations, as discussed in Reference 2 and summarised in a separate article on CODEX in this issue of The Messenger (page 10). QuantEYE (Reference 4) explores the temporal dimension of the photon flux. By covering the time resolution range 10^{-3}–10^{-9} s, it will permit for the first time the exploration of the quantum properties of the light from a variety of astrophysical sources.

There are two "wide"-field instruments for *NIR wavelengths (0.8–2.5 μm)*: ONIRICA (Reference 7), the imaging camera, and MOMFIS (Reference 6), the multi-field spectrograph. Both address many of the "classical" ELT science cases and as such reveal the power but also the peculiarities of observing with OWL. The ONIRICA team has identified diffraction limited imaging over a field of ~ 30″ as the primary observing mode. Using a MCAO system one can expect up to 30 % of the light to be concentrated in the diffraction peak of the PSF over the entire field in periods of very good natural seeing. With this performance the imaging capability of ONIRICA clearly surpasses that of the future James Webb Space Telescope (JWST) in terms of limiting magnitudes of stellar sources. Detailed studies of stellar population in Virgo and up to Coma become possible (see Figure 1). In particular we will be able to investigate for the first time the old populations of giant elliptical galaxies, a key to understanding the star formation history in the early Universe.

The baseline concept of MOMFIS foresees 30 IFU units which can be positioned over the 3′ × 3′ scientific field of OWL. Its main scientific goal is spectroscopy of high-redshift galaxies ($z >> 3$) to trace the first sources which reionised the Universe. Their expected half-light sizes are typically ~ 0.1″ and this value drives the IFU size to sub-arcsec and the sampling to 20–30 mas. At a spectral resolution of 4 000, MOMFIS would be more powerful than JWST in spectroscopy of faint high-redshift candidates identified by multi-colour JWST imaging. While working far from the diffraction limit, MOMFIS requires a distributed AO system (MOAO) to deliver a moderate concentration of light at the sampling resolution. A first run of simulations with natural guide stars has shown that this might be possible but with limitations on the sky coverage. The use of laser guide stars at a 100-m telescope has its own problems and will require further studies.

One of the key science cases for OWL is the search for Earth-like planets close to nearby stars. Starting from the results of the Planet Finder studies for the VLT, the EPICS study (Reference 8) addresses various observational approaches to detect and characterise Earth- and Jupiter-like planets. Using differential imaging and a coronograph, the EPICS study investigated the possibility to detect the planets in polarimetry and at the wavelength of biomarkers such as water and Oxygen. A NIR IFU and FTS spectroscopy for planet light characterisation are also briefly discussed. The spectral range in which these modes should operate spans from the *Visual to the J-band*. EPICS will require a third-generation AO system (XAO) to achieve the diffraction limit with high Strehl and the required contrast with respect to the star light at the wavelengths of operation. A set of first-order simulations carried out during the study suggest that an Earth-like planet could indeed be detected with EPICS at a 100-m OWL telescope (see Figure 2). The selection of the final instrument configuration, of its primary observing modes and the prediction on its ultimate performance will have to wait for more extensive modelling and prototyping in the next phase of the project.

T-OWL is an imager-spectrograph to operate in the thermal infrared between *3 and 24 µm*. In this spectral region the requirements on the AO system are relatively modest. A wide range of targets from dusty planetary systems (see Figure 3) to black holes in the nuclei of active galaxies will be the primary science goals of T-OWL. In the bands where the atmosphere is transparent, T-OWL will outperform the Mid-Infrared Imager MIRI at the JWST in the observations of point-like sources and offer unique angular resolution. In spectroscopy, T-OWL can be especially competitive in the observations of narrow emission and absorption features at high resolving power (Reference 3).

SCOWL is a large field (~ 2.5′ × 2.5′) submillimetre camera to observe in the three submillimetre bands at *350, 450 and 850 µm*. It capitalises on the expertise acquired with the SCUBA1 and SCUBA 2 instruments and uses it to draw the concept of a powerful survey instrument. SCOWL would supply the ALMA interferometer with a wide range of newly-discovered sources for detailed investigation. It benefits from the diffraction limit given from the OWL size (~ 1–2″) at submillimetre wavelengths without the need of an AO system. The advantage with respect to ALMA in the mapping mode is outstanding as shown in Figure 4. SCOWL requires the telescope to be installed at a very high and dry site and most likely a tip-tilt mirror correction linked to a water-vapour monitor to achieve its full potential (see Reference 5).

HyTNIC explores the application of the concept of a hyper telescope (Reference 9) as a multi-element imaging interferometer array with a densified pupil to the OWL construction phase. It allows direct imaging with enhanced resolution during the segment-filling phase of the M1 with a *NIR* camera and without adaptive optics, providing observations of unique scientific value before OWL's completion.

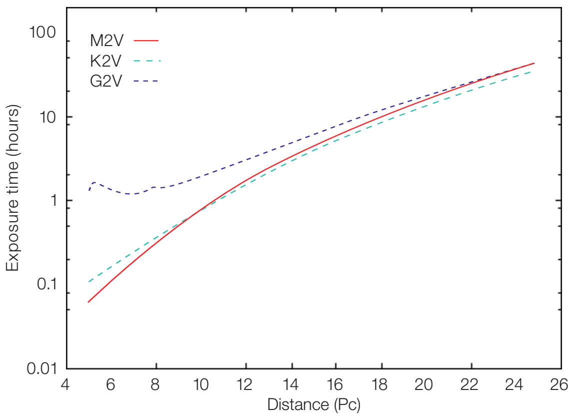
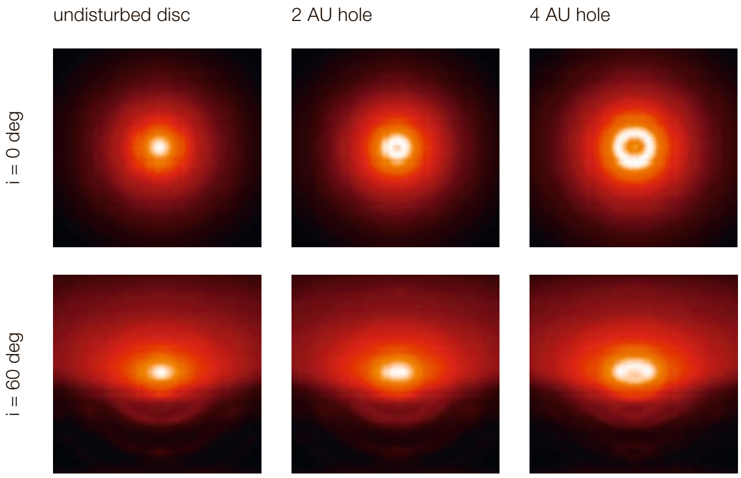


Figure 2 (left): Time to detect an Earth-like planet orbiting a Main-Sequence star at 5 σ with differential imaging in water bands in the *J* region. Assumptions: 80 nm bandwidth, 0.44 atmospheric transmission, 0.32 contrast, $t_0 = 4$ ms, $r_0 = 20$ cm. See Reference 8 for additional details.

Figure 3 (below): Simulations of the reemitted light at 10 microns, for an undisturbed circumstellar disc and a disc with a hole of radius 2 AU and 4 AU, respectively, as seen at two different inclinations and convolved with the OWL PSF (see Reference 3 for more details). The Herbig Ae star is assumed to be at 140 parsec.



Feedback to the telescope design and future prospects

The studies have identified some critical aspects of the instrument–telescope interface and pinpointed a number of critical components which will require special developments. This feedback will be taken into account in the next phase of the project.

The present OWL Concept Design underwent an external review at the beginning of November 2005 and the outcome together with financial and science policy considerations by the ESO management will be a subject of discussion at the ESO Council in December. If, as we hope, a consensus on the construction of a European ELT will mature in the next months, the work done on the Instrument Concept Studies will have to be further expanded and tuned to the science goals and the revised telescope design.

In the meantime, probing of instrument concepts is also going on within the ELT Design Study (a network funded under the EC FP6 initiative). At the kick-off meeting of the ELT instrument "Small Studies" in September 2005, eight instruments were identified which will extend or complement the work carried out for OWL. Many of the OWL Instrument Concept Study teams are involved in this effort and will put to best use their newly-acquired expertise there.

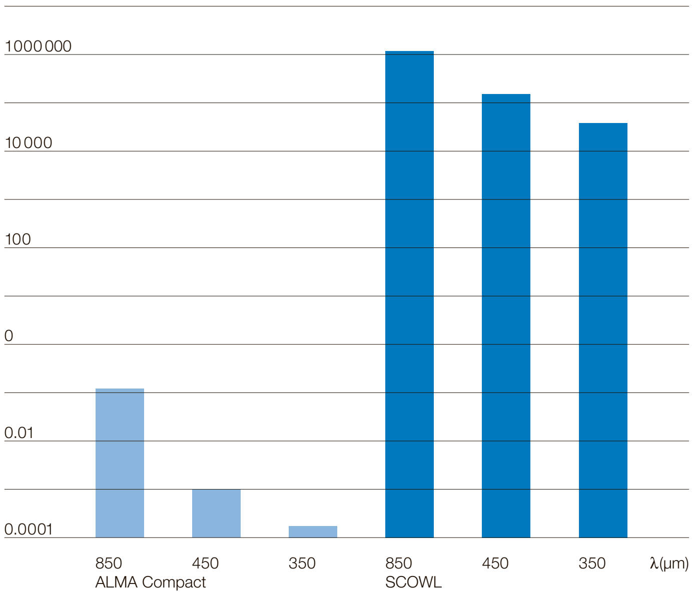


Figure 4: Relative mapping speed of SCOWL versus the ALMA Compact Configuration.

References

The OWL Instrument Concept Studies have been published as ESO internal reports. They can be obtained from the PI's or ESO.

(1) D'Odorico S., Moorwood A. F .M., Beckers, J. 1991, Journal of Optics 22, 85
(2) CODEX, Cosmic Dynamics Experiment, OWL–CSR-ESO-00000-0160, October 2005
(3) T-OWL, Thermal Infrared Imager and Spectrograph for OWL, OWL–CSR-ESO-00000-0161, October 2005
(4) QuantEYE, OWL–CSR-ESO-00000-0162, October 2005
(5) SCOWL, Submillimeter Camera for OWL; OWL–CSR-ESO-00000-0163, September 2005
(6) MOMFIS, Multi Object Multi Field IR Spectrograph, OWL–CSR-ESO-00000-0164, September 2005
(7) ONIRICA, OWL NIR Imaging Camera, OWL–CSR-ESO-00000-0165, October 2005
(8) EPICS, Earth-like Planet Imaging Camera and Spectrograph, OWL–CSR-ESO-00000-0166, October 2005
(9) HyTNIC, Hyper-Telescope Near Infrared Camera, OWL–CSR-ESO-00000-0167, October 2005

The Centre of the Active Galaxy NGC 1097

Near-infrared images of the active galaxy NGC 1097 have been obtained by a team of astronomers[1] using NACO on the VLT. Located at a distance of about 45 million light years in the southern constellation Fornax, NGC 1097 is a relatively bright, barred spiral galaxy seen face-on. It is a very moderate example of an Active Galactic Nucleus (AGN), whose emission is thought to arise from matter (gas and stars) falling into a central black hole. NGC 1097 possesses a comparatively faint nucleus only, indicating that the infall rate is small.

The new images probe with unprecedented detail the very proximity of the nucleus. The resolution achieved with the images is about 0.15 arcsecond, corresponding to about 30 light years across. The newly released NACO near-infrared images show in addition more than 300 star-forming regions, a factor four larger than previously known from Hubble Space Telescope images. These "H II regions" can be seen as white spots in the image shown here.

See ESO Press Photo 33/05 for more details.

[1] M. Almudena Prieto (Max-Planck Institute für Astronomie, Heidelberg, Germany), Witold Maciejewski (University of Oxford, UK), Juha Reunanen (ESO).

A colour-composite image of the central 5 500 light-years wide region of the spiral galaxy NGC 1097, obtained with NACO on the VLT. More than 300 star-forming regions – white spots in the image – are distributed along a ring of dust and gas in the image. At the centre of the ring there is a bright central source where the active galactic nucleus and its supermassive black hole are located. The image was constructed by stacking *J*- (blue), *H*- (green), and *Ks*-band (red) images. North is up and East is to the left. The field of view is 24 × 29 arcsec^2.

CODEX: Measuring the Expansion of the Universe (and beyond)

Luca Pasquini[1]
Stefano Cristiani[2]
Hans Dekker[1]
Martin Haehnelt[3]
Paolo Molaro[2]
Francesco Pepe[4]
Gerardo Avila[1]
Bernard Delabre[1]
Sandro D'Odorico[1]
Jochen Liske[1]
Peter Shaver[1]
Piercarlo Bonifacio[2]
Stefano Borgani[2]
Valentina D'Odorico[2]
Eros Vanzella[2]
François Bouchy[4]
Miroslava Dessauges-Lavadsky[4]
Cristoph Lovis[4]
Michel Mayor[4]
Didier Queloz[4]
Stéphane Udry[4]
Michael Murphy[3]
Matteo Viel[3]
Andrea Grazian[5]
Sergei Levshakov[6]
Lauro Moscardini[7]
Tommy Wiklind[8]
Shay Zucker[9]

[1] ESO
[2] INAF – Osservatorio Astronomico di Trieste, Italy
[3] Institute of Astronomy, Cambridge University, United Kingdom
[4] Observatoire de Genève, Switzerland
[5] INAF – Osservatorio Astronomico di Roma, Italy
[6] Ioffe Physical-Technical Institute, St. Petersburg, Russian Federation
[7] University of Bologna, Italy
[8] ESA-STScI
[9] Weizmann Institute of Science, Tel Aviv, Israel

CODEX, a high-resolution, super-stable spectrograph to be fed by OWL, the most powerful telescope ever conceived, will for the first time provide the possibility of directly measuring the change of the expansion rate of the Universe with time … and much more. The concept of this instrument has been studied in a collaboration launched by ESO in July 2004 together with INAF – Osservatorio Astronomico di Trieste, the Institute of Astronomy, Cambridge University, and the Observatoire de Genève.*

The expansion of the Universe

The discovery of the expansion of the Universe in the late 1920s by Edwin Hubble was a major milestone in cosmology. It brought to an end the belief held by most physicists of the time including Albert Einstein that the Universe is static and not evolving. Hubble's discovery of the expansion of the Universe has been confirmed by a vast range of astronomical observations. It eventually led to the widely accepted Hot Big Bang Theory, which predicts that the Universe was very dense and hot at early times, and is an essential aspect of the cosmological standard model.

Einstein's theory of General Relativity (GR) led to the description of the Universe as a homogeneous and isotropic four-dimensional space time, the so-called Friedman-Robertson-Walker (FRW) Universe. In 1922 Friedman (and independently Lemaître in 1927) found that Einstein's original equations did not allow static solutions. Ironically this prompted Einstein to "spoil" his new theory of gravity by introducing a cosmological constant to allow static solutions in his field equations. This same cosmological constant, which Einstein in his later years considered as "the biggest blunder" of his life, has now become another pillar of the modern cosmological standard model.

In the Early Universe a large vacuum energy density acting like a cosmological constant is believed to have been responsible for the rapid expansion of the Universe in a phase called Inflation. Furthermore, recent observations of the luminosity distance of Type Ia supernovae have established the presence of a form of Dark Energy which appears to have an effect similar to that of Einstein's cosmological constant within the framework of a FRW Universe.

It is possible in principle to *directly* measure the change of the expansion rate of the Universe with time. If we consider in an expanding FRW Universe the light of a source which is emitted at time t_e and received at time t_0, the change of redshift z of the source with time can be expressed as: $\dot{z} = (1+z)H_0 - H(t_e)$. The time derivative of the redshift of light emitted by a source at fixed coordinate distance is thus related in a simple manner to the evolution of the Hubble parameter $H(t_e)$ between the epoch of emission and reception. The Hubble parameter is related to the energy content of the Universe as

$$H = H_0\left[\Omega_{mat}\left(\frac{a_0}{a}\right)^3 + \Omega_R\left(\frac{a_0}{a}\right)^4 + \Omega_{de}\left(\frac{a_0}{a}\right)^{3(1+w)} + (1-\Omega_{tot})\left(\frac{a_0}{a}\right)^2\right]^{1/2}$$

where $\Omega_{tot} = \Omega_{mat} + \Omega_R + \Omega_{de}$ and Ω_{mat}, Ω_R, Ω_{de} are the energy density of matter, radiation, and dark energy expressed in terms of the critical density, respectively, and a and a_0 are the scale factor at the time t_e and t_0. The dark energy density is characterised by an equation of state of the form $p_{de} = w\rho_{de}c^2$, and $w = -1$ corresponds to the case of a cosmological constant. Note that we do not know much about the dark energy term, and its redshift dependence could well be more complicated than parameterised here by a simple equation of state. At the redshifts here considered ($z \sim 2$–5) the radiation energy density is small $\Omega_R << \Omega_{tot}$ and can be neglected. The majority of astronomical observations, most prominently those of the CMB, supernovae, Lyα forest and the clustering of galaxies are consistent with a FRW Universe with no curvature and a cosmological constant which corresponds to an energy density about twice that of the matter at present.

It is important to characterise the physical effects of "dark energy" as completely as possible and in particular it is essential to establish whether the dark energy actually has the dynamical effects expected in GR. We recall that all observational constraints are basically geometric in nature as they mainly constrain the angular diameter distance to the last scattering surface (CMB) and the luminosity distance at moderate redshifts (supernovae). The constraints on actual dynamical effects of the cosmological constant as probed by the clustering of the matter distribution are coupled in a complicated way to geometrical constraints and are actually rather weak.

* See also the article by Sandro D'Odorico on page 6 in this issue of The Messenger.

The CODEX experiment is conceptually very simple: by making observations of high redshift objects with a time interval of several years, we want to detect and use the wavelength shifts of spectral features of light emitted at high redshift to probe the evolution of the expansion of the Universe *directly*.

It is convenient to express the expected wavelength shift over a period Δt in terms of the velocity of the equivalent Doppler shift, $v = (\Delta\lambda/\lambda)c$. Figure 1 shows the expected change of Doppler shift for a range of FRW models with no curvature as a function of redshift. There are a few things to note. The wavelength shift has a very characteristic redshift dependence. At some redshifts the wavelengths are "stretched" while in others they are "compressed". The wavelength shift corresponds to a Doppler shift of about 1–10 cm/s over a period of 10 years.

This amount is extremely small, and brought Sandage (1962) to conclude that such a measurement was beyond our capabilities. Why do we think that this experiment is possible now? For three reasons: (1) Extremely Large Telescopes such as OWL should be capable of providing the huge number of photons required. (2) In the last two decades our capability of accurately measuring wavelength shifts of astronomical sources has dramatically improved (Mayor et al. 2002). (3) A suitable class of astronomical objects for this measurement has been identified: the Lyα forest lines, which are extremely numerous and beautifully trace the cosmic expansion with negligible peculiar motions (at least ten times smaller than the Hubble flow).

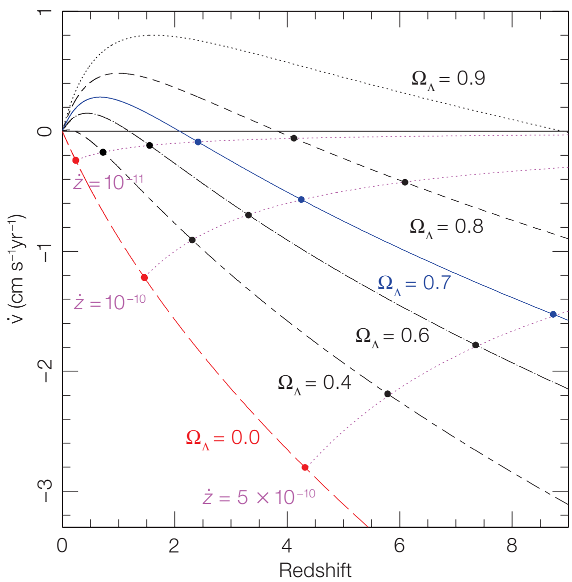
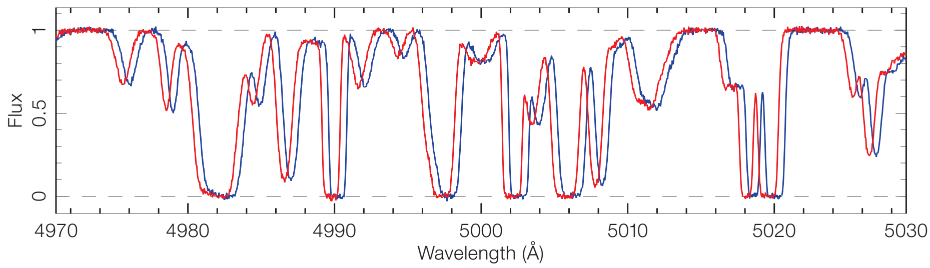


Figure 1 (left): Evolution of $\dot{v}$ as a function of redshift. The cosmological parameters have been fixed to $\Omega_{tot} = 1$, $H_0 = 70$ and different values of Ω_Λ have been considered. The $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$ cosmology is shown with a blue solid line, and the Einstein-de Sitter model is plotted with a red long-dashed line. The filled circles connected by dotted lines show loci of constant $\dot{z}$, in units of yr^{-1}.

Figure 2 (below): This figure shows the displacement of intergalactic absorption features caused by the evolution of the Universe's expansion rate. We show a small portion of the simulated Lyα forest in the spectrum of a $z \sim 3$ QSO as we would observe it today (blue line) and 10^7 years from now (red line). The time interval between the two observations is huge (10^7 years) for the sake of visualisation. In the real experiment it will be about six orders of magnitude smaller, as will be the displacement of the spectral features.



Measuring the wavelength shift in high redshift objects

A priori it is not obvious which objects and which spectral features are best suited for a precise measurement of $\dot{z}$. For a given energy flux the precision of the final measurements will increase with the sharpness of spectral features (less noise) and increasing wavelength (more photons). Another important consideration is the expected peculiar acceleration associated with peculiar motions relative to the Hubble flow, which will act as additional noise. The numerous absorption lines in the spectra of high-redshift QSOs, which make up the so-called Lyα forest, appear to be the most promising targets for a measurement of $\dot{z}$. The most striking feature of the Lyα absorption is the large number of lines in a single spectrum.

There are about one hundred suitable features in a single spectrum which have a typical width $\Delta\lambda_{line}$ of 30 km/s. With QSO absorption spectra we can probe a wide redshift range from $z \sim 1.5$ up to 4 and beyond. There is a generally accepted paradigm for the origin of the Lyα forest absorption and the associated metal absorption which has been established by extensive comparison of cosmological hydrodynamical simulations and analytical calculations with the exquisite data which have become available from 10-m-class telescopes (see Rauch (1998) for a review). The peculiar acceleration distribution as derived from state-of-the-art hydrodynamical simulations shows that for the vast majority of these systems the expected acceleration is indeed negligible. The Lyman series absorption lines are thus ideally suited to measure the global evolution of the Hubble parameter. Figure 2 illustrates the Lyα absorbers and the cosmic shift with time.

The simulations

In order to quantitatively assess the feasibility of the measurement, Monte-Carlo simulations have been carried out independently by several groups. The high-resolution spectra of QSO were simulated, noise added and the process repeated for the second epoch. The pairs of spectra so produced were compared and the 'measurement' performed. Figure 3 shows the difference expected among pairs of spectra, where the second epoch spectrum has been redshifted according to different cosmological models. The results of the simulations agree with the fact that, if the lines are resolved, the final accuracy of the experiment can be expressed as a function of signal-to-noise (S/N) ratio and redshift as:

$$\sigma_v = 1.4 \left(\frac{S/N}{2350}\right)^{-1} \left(\frac{N_{QSO}}{30}\right)^{-1/2} \left(\frac{1+Z_{QSO}}{5}\right)^{-1.8} \text{cm/s}$$

(where S/N refers to a pixel of 0.0125 Å). This implies that observing each epoch for (e.g.) 40 QSOs with a S/N ratio of 2000 each, an accuracy of 1.5 cm/sec can be obtained. Figure 4 shows that for a QSO of magnitude 16.5 and 2000 hours of observations, such a S/N ratio is within reach for some of the larger next-generation telescopes currently under consideration, provided that the whole system has an efficiency comparable to that of UVES at the VLT.

A sufficient number of bright QSOs is already available. Selecting objects from published catalogues, we find 91 QSOs brighter than m = 16.5, out of which 25 have redshifts between 2 and 4, and the number of suitable objects should increase with the large, all-sky photometric surveys planned in the coming years.

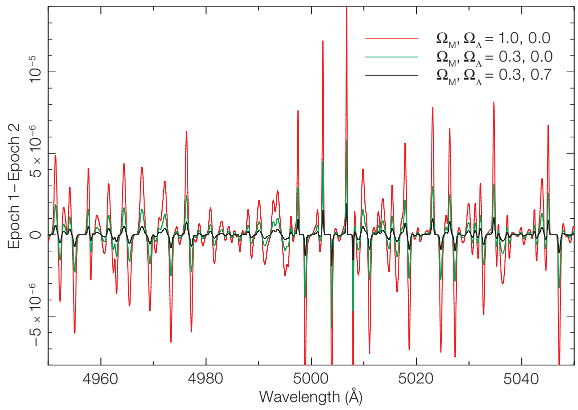


Figure 3: Flux difference of two simulated, noiseless Lyα forest spectra at z = 3.1 taken Δt = 10 years apart for different cosmological parameters as indicated and H_0 = 70 km/s/Mpc.

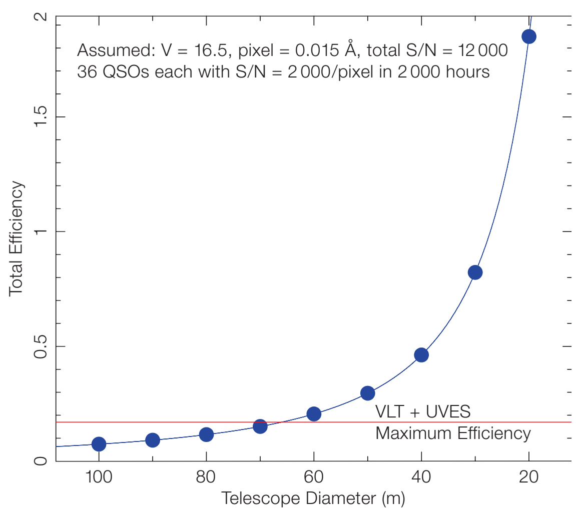


Figure 4: Telescope + CODEX efficiency versus telescope diameter, for a S/N ratio of 12000, integration time of 2000 hours and a QSO magnitude of V = 16.5. The plot shows the total efficiency that the system should have to reach the goal with the above assumptions. The red line is the UVES + VLT efficiency.

The instrument concept

We have therefore developed an instrument design concept with the characteristics given in Table 1. In order to obtain a resolving power of 150000 on a seeing-limited ELT (1 arcsecond aperture on a 60-m telescope or 0.65 arcsecond on a 100-m), five identical spectrographs are foreseen. To obtain the highest stability, each spectrograph will be contained in a vacuum tank, hosted in a temperature-stabilised room nested in an environmentally quiet laboratory. In order to keep to a limited size for each spectrograph, several new concepts (pupil anamorphysm and slicing, special crossdisperser) have been adopted, and each spectrograph will have an echelle grating only twice the size of those of UVES, with an 8 k × 8 k detector.

While it is possible to predict the behaviour of the individual elements of CODEX, it will be extremely difficult to model the whole system, including, for instance, the complex interactions with the telescope. We therefore anticipate that a full CODEX unit, exactly similar to one of the five installed at OWL, has to be developed and operated for several years at the VLT, in order to gain the experience and to (im)-prove the CODEX concept.

Chasing the systematics

When aiming at precise measurements which go almost a factor 100 beyond presently achievable performance, special care must be taken to account for subtle systematic effects. "Local" forms of noise are relevant; an evaluation of the barycentric correction terms is given in Table 2, which shows that the corrective terms are under control and within reach at present. One important number missing from Table 2 is the value of the acceleration of the Sun in the Galaxy, which is comparable to the amount of the cosmic signal. This important term can in principle be measured by CODEX observing QSOs well distributed in the sky, but it will be determined with superior accuracy by the ESA GAIA satellite at a level of 0.5 mm/sec/year – an accuracy ten times smaller than the cosmic signal.

The accuracy of the wavelength calibration is another concern (we shall recall that a shift of 1 cm/sec corresponds to

Table 1: Main characteristics of CODEX.

Acceptance aperture on the sky	1 arcsec for 60 m, 0.65 arcsec for 100 m
Location	Underground in nested thermally stabilised environment
Feed	Coudé feed
Peak DQE including injection losses (with GLAO)	14 % (Coudé feed)
Number of unit spectrographs	5 (11 for 100-m OWL and 1 arcsec aperture)
Unit Spectrograph dimensions	Diameter 2.4 × 4 m (vacuum vessel)
Spectral resolution	150 000
Wavelength coverage	446–671 nm in 35 orders
Spectrograph layout	White pupil
Echelle	41.6 l/mm, R4, 170 × 20 cm, 4 × 1 mosaic
Crossdisperser	VPHG 1 500 l/mm operated off-Littrow
Camera	Dioptric F/2.3, image quality 30 μm
Detector	CCD mosaic 8 k × 8 k, 15 μm pixels Stabilised to a few mK
Noise performance	Photon shot noise limited for m_v = 16.5 in 10 minutes
Sampling	4 pixels per FWHM

Table 2: Sensitivity matrix of the accuracy of the barycentric correction with regard to their input parameters.

Parameter	Induced error on the correction [cm s^{-1}]	Comment
Earth orbital velocity		
– Solar-system ephemerides	< 0.1	JPL DE405
Earth rotation		
– Geoid shape	~ 0.5	
– Observatory coordinates	< 0.1	Any location in atm.
– Observatory altitude	< 0.1	along photon path may
– Precession/nutation corrections	< 0.1	be chosen
Target coordinates		
– RA and DEC	?	70 mas → 1 cm s^{-1}
– Proper motion	~ 0	negligible
– Parallax	~ 0	negligible
Relativistic corrections		
– Local gravitational potential	< 0.1	
Timing		
– Flux-weighted date of observation	?	0.6 s → 1 cm s^{-1}

about 3 Å shift on the detector). Tests made with HARPS indicate that the Th-Ar lamps used in most spectrographs are not adequate for such accuracy, and that a new calibration system should be devised. In addition, such a novel calibration system must be perfectly reproducible and stable over the long term (20 years or more) of the duration of the experiment. We have been investigating with the Max-Planck-Institut für Quantenoptik (MPQ) the possibility of using new superb standards based on newly-developed laser frequency combs. The group at MPQ is led by Prof. Hänsch, one of the Nobel Prize Winners in Physics this year.

CODEX beyond the measurement of the cosmic signal

The scientific applications of CODEX, as a high-resolution spectrograph with extremely high performance fed by OWL, will go well beyond the main experiment proposed above. In the following we give a glimpse of three outstanding applications:

Search for variability of fundamental constants

Fundamental constants are supposedly universal and unvarying quantities. Any measured variations would have far-reaching consequences for the unified theories of fundamental interactions, for the existence of extra dimensions of space and/or time and for the existence of scalar fields acting in the late universe. Only astronomical observations hold the potential to probe the values of fundamental constants in the past, and in remote regions of space. In 2001, observations of QSO absorption lines brought the first hints that the value of the fine-structure constant α – the central parameter in electromagnetism – might change over time (Murphy et al. 2001), but more recent observations are consistent with a null result. An effective two to three order of magnitude precision gain is foreseen with a spectrograph with R ≈ 150 000 at OWL. The accuracy of the $\Delta\alpha/\alpha$ variation measurements will be a few times 10^{-9} – more precise than any other astronomical and geological measurement.

Search for other earths

Exo-planets and, in particular, terrestrial planets in habitable zones, will be one of the main scientific topics of the next decades, and one of the main OWL science drivers. CODEX with OWL will lead the discoveries in at least three main cases in exo-planetary science, providing with unique capabilities and observations: (i) discovery and confirmation of rocky planets, (ii) search for long-period planets, (iii) Jupiter-mass planets around faint stars.

The need for a ground-based follow-up facility capable of high radial velocity accuracy has been stressed in the recent ESO-ESA working group report on solar planets: a high-precision radial-velocity instrumentation for the follow-up of astrometric and transit detections, to ensure the detection of a planet by a second independent method, and to determine its true mass. For Jupiter-mass planets, existing instrumentation may be technically adequate; for Earth-mass candidates, special-purpose instrumentation (like CODEX) on a large telescope would be required. CODEX will also allow us to search for hot Jupiters around solar-mass stars in different environments and star-forming histories, such as globular clusters and nearby companions to the Galaxy.

Primordial nucleosynthesis

Standard Big bang nucleosynthesis presents a pressing cosmological conundrum. There is some evidence suggesting a cosmological origin for ^{6}Li, and the stellar value for primordial ^{7}Li does not agree with primordial Deuterium from QSOs and with Ω_b from WMAP. Although Li observations in low metallicity Galactic halo stars are plagued by possible systematic uncertainties due to modelling of stellar atmospheres and the treatment of convection, it is possible that both discrepancies can be reconciled with physics beyond the standard model during the Quark-Hadron phase. CODEX will provide the first observations of ^{7}Li and ^{6}Li in dwarf stars in galaxies of the Local Group and will make it possible for the first time to measure the interstellar ^{7}Li/^{6}Li ratio in unprocessed material of High-Velocity Clouds. The latter is a direct and robust probe of the yields of the Big Bang Nucleosynthesis yields, providing important insights on whether new physics is playing a role in the early Universe.

In addition to these selected applications, many other science cases have emerged over recent years. Stellar oscillations, the study of the most metal-poor stars in our Galaxy and in its local group companions, the use of cosmochronometers to determine the age of the Universe, the history of the metal enrichment of the Universe … all these cases (and surely many more) will receive a major boost from CODEX on OWL, far beyond what can be now conceived.

References

Mayor, M. et al. 2002, The Messenger 110, 9
Murphy, M. T. et al. 2001, MNRAS 327, 1244
Rauch, M. 1998, ARA&A, 36, 267
Sandage, A. 1962, ApJ 136, 319

Afterglows of Elusive Short Gamma-Ray Bursts

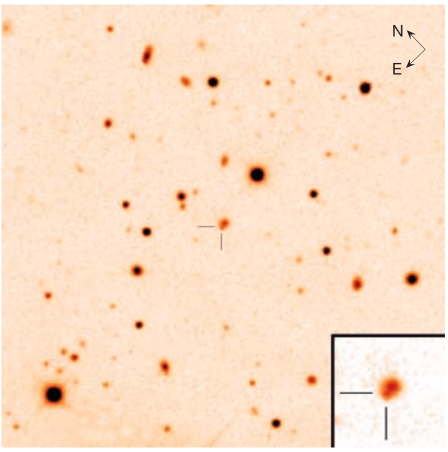
An international team of astronomers[1] has for the first time observed the visible light from a short gamma-ray burst (GRB). Using the 1.5-m Danish telescope at La Silla (Chile), they showed that these short, intense bursts of gamma-ray emission most likely originate from the violent collision of two merging neutron stars. The same team has also used the VLT to constrain the birthplace of the first ever short burst whose position could be pinpointed with high precision. The results were published in the October 6 issue of the journal *Nature*.

Gamma-ray bursts, the most powerful type of explosion known in the Universe, have been a mystery for three decades. They come in two different types, long and short. Over the past few years, international efforts have convincingly shown that long gamma-ray bursts (longer than about 2 sec) are linked with the explosion of massive stars. It is thought that short-duration GRBs may be due to the merging of two neutron stars; they have evaded optical detection for more than 30 years.

In the night of July 9 to 10, 2005, the NASA HETE-2 satellite detected a burst of only 70-millisecond duration and, based on the detection of X-rays, was able to determine its position in the sky. Thirty-three hours after, Jens Hjorth and his team obtained images of this region of the sky using the Danish 1.5-m telescope at ESO La Silla. The images showed the presence of a fading source, sitting on the edge of a galaxy.

The burst resides 11 000 light years from the centre of a star-forming dwarf galaxy that is about 2 400 million light years away and is quite young – about 400 million years old. From observations conducted until 20 days after the burst, the astronomers ruled out the occurrence of an energetic hypernova as found in most long GRBs. This supports the hypothesis that short GRBs are the consequence of the merging of two very compact stars.

(Based on ESO Press Release 26/05)



First image in the visible (more precisely, in the so-called *R*-band) of a short gamma-ray burst. The image was taken with the Danish 1.5-m telescope and the DFOSC camera at La Silla on July 11, 2005. It shows the gamma-ray burst to be situated on the edge of a low-redshift galaxy.

[1] Jens Hjorth (Dark Cosmology Centre – DARK, Niels Bohr Institute, University of Copenhagen), Darach Watson (DARK), Johan P. U. Fynbo (DARK), Paul A. Price (Institute for Astronomy, University of Hawaii), Brian L. Jensen (DARK), Uffe G. Joergensen (DARK), Daniel Kubas (ESO), Javier Gorosabel (Instituto de Astrofísica de Andalucía), Pàll Jakobsson (DARK), Jesper Sollerman (DARK and Department of Astronomy, Stockholm University), Kristian Pedersen (DARK), and Chryssa Kouveliotou (NASA/Marshall Space Flight Center). The team is part of the Gamma-Ray Burst Afterglow Collaboration at ESO (GRACE) carrying out gamma-ray burst afterglow studies.

ALMA News

Tom Wilson (ESO)

A view of a presentation on the first day of the independent ALMA Cost Review held at Garmisch-Partenkirchen. The total number of attendees was about 80. The chair was Steven Beckwith (STScI) and the vice chair was Thijs de Graauw (SRON).

ALMA Cost Review

An independent international Cost Review of the ALMA project was held in Garmisch-Partenkirchen on October 13–16. The general response of the Cost Review Committee was positive. The three ALMA Project Managers (Tony Beasley, Joint ALMA Office; Adrian Russell, North America; Hans Rykaczewski, Europe) wrote that "The response from the committee is pretty much as good as it could be ..." Massimo Tarenghi, the ALMA Director, added "This excellent outcome reflects the very hard work of many people in the ALMA project, and the conscientious way in which the review was carried out." More details of the review will follow when the final report becomes available.

Milestones

There are a number of milestones for the completion of ALMA. The largest is the contract for antennas, since this contract is more than 30 % of the total cost of the bilateral (North America and Europe) ALMA. Here, we report the news on antenna procurement.

The ESO Council resolution from the meeting of September 30 states that "the ALMA project is affordable and compatible with ESO's strategic priorities". It further states that the ESO Council "requests the Finance Committee to proceed to decide on the proposal to award a contract for the production of the ESO ALMA antennas". The ESO Finance Committee met on October 5, and has approved the negotiation and conclusion of a contract with the selected vendor. At the ALMA Board meeting in Santiago, Chile, on November 1, it was announced that the ALMA Board concurs with the ALMA Director's recommendation that the European Executive proceed with the issuance of a contract to procure its share of the ALMA antennas.

Another important milestone is the Front End Integration Center. The Band 3 (3 millimetres, or 84–116 GHz) and Band 6 (1.3 mm, or 211–275 GHz) Front Ends are built in North America, while Band 7 (0.9 mm, or 275–373 GHz) is built at IRAM Grenoble and Band 9 is built at SRON, Groningen, Netherlands (0.5 mm, or 602–720 GHz). The decision has been made to have two Integration Centres, one in Europe at the Rutherford-Appleton Laboratory in Oxfordshire, UK, the other in North America, at the NRAO in Charlottesville.

With this level of progress, we are now much closer to the beginning of the assembly of individual components to produce a working system.

ALMA software development

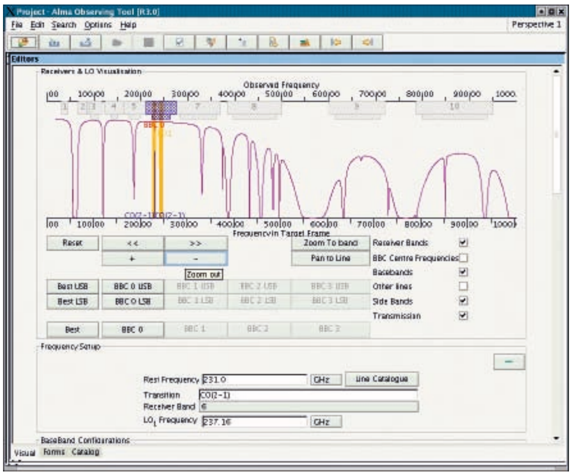
It is expected that the ALMA array will be used by a relatively large community of astronomers that are less experienced in using radio interferometers and/or doing science at millimetre and sub-millimetre wavelengths. Therefore, it is of utmost importance to take this into account in development of software products that will eventually be used by the community.

Observing preparation

The ALMA Observing Tool (OT) will be the software tool that supports astronomers in constructing a full Observing Project for the ALMA Observatory. Basically, such Observing Programmes will be submitted to the Observatory in two parts. The first is a Phase I Observing Proposal that will have its emphasis on the scientific justification of the proposed observations. The second part of the project is the Phase II Observing Programme that can be submitted to the ALMA Observatory if observing time has been granted by the Time Allocation Committee (TAC) on the basis of the accepted proposal.

Central in the OT is the creating of a set of Scheduling Blocks (SBs) which are required to drive observing with ALMA. The SB is the smallest (indivisible) unit in ALMA observing that can be scheduled independently. It is self contained and usually provides scientifically meaningful data. The SB contains a full description of how the science target and the calibration targets are to be observed, and sets of SBs can be combined with a description for the post processing of the data, ultimately resulting in an image.

In order to serve both less experienced and experienced astronomers, the OT will be equipped with two so-called "Views" to make Observing Programme preparations. It is intended that the main view on the ALMA system will be the "Science View". As the name indicates, in this view the users can concentrate on inputting the science requirements of their observing programme: the area to be observed for each target, required sensitivity and frequencies. For most observing even experienced users should only need to use this view. The required SBs will be constructed by the system and the user will only be bothered with system parameters when this is absolutely necessary, in general detailed parameters will be determined from the science input.



A typical display produced by the Observing Tool (OT) using the Visual Spectral Editor. The graphics shows the ALMA receiver bands and the user-selected positions for the basebands and sidebands. Also, the atmospheric transmission curve is displayed.

However, it is recognised that for some programmes, and indeed for developing new observing modes, an ALMA-experienced observer will need more. The “System View” (or expert mode) will provide such a user with a complete set of parameter fields that enable a detailed specification of each scheduling block: the observing process of science and calibration targets, including data acquisition and reduction recipes. These parameters include the setting of the local oscillator, the upper and lower side bands, the correlator parameters and the selection of the basebands and subband sets within each baseband. Whichever “View” is used, SBs must be created.

An interesting functionality in the System View that has been added recently is the Visual Spectral Editor. This will help somewhat experienced users to carefully position LO frequency, and the frequency characteristics of the basebands configuration within the ALMA receiver band. In the figure a part of this editor is visible. It shows the upper part of the Visual Editor display with the all ALMA Frequency bands (note that these will not all be available; see also *http://www.eso.org/alma/specifications/FreqBands.html*), the transmission curve of the atmosphere over the full ALMA observable spectrum (note Band 6 has been selected), the setting to the LO frequency and upper and lower side bands, and one baseband selection. A later version of this tool will aid less experienced observers, without subjecting them to the detailed setup.

The development of the Observing Tool is a shared effort between the UK Astronomy Technology Centre in Edinburgh, ESO and the NAOJ, with science advice provided by Osservatorio Astrofisico di Arcetri and the NAOJ. Development is currently focused on the Science and System View of the Phase II Observing Programme definition. Work has been ongoing for two years with a major and a minor release each year. User test cycles immediately follow releases of the software. Currently, it is planned to have four major user test sessions and three minor ones. The major user tests provide important and timely input feedback to the team for possible upgrades in the following releases and are performed by typically eight people. Minor test sessions are follow-ups of the major releases but possibly include further tests and input for the development team toward the next major release. The next major user test will take place this November. It is planned to hold wider “beta testing” in advance of the first release of the tool to the community.

Data reduction

All ALMA data will be reduced using the ALMA offline reduction and imaging package. This package is based on the C^{++} code base in $AIPS^{++}$ but the code itself is undergoing some fairly major changes to optimise it for ALMA and the user interface is being redesigned. For many observations the automated calibration and imaging pipelines will produce reference images suitable for analysis.

During the past 1.5 years, ALMA has conducted external user tests every six months to ensure that the reduction software development is adequate for ALMA needs. This is an ongoing process designed to incrementally test functionality as it is developed. To date, three test cycles have been completed. The testing has focused on verifying that the underlying C^{++} code has adequate functionality and is robust enough for ALMA needs (e.g. make sure that users can process datasets from end-to-end using specific ALMA cases). The user interface (both the GUIs and the script language) will change significantly over the next several years and thus, current testing could not yet evaluate the robustness or user-friendliness of the interface. Essentially, if testers could do what was necessary to get a scientifically accurate image and evaluate the image quality (even if the syntax or process was a bit complicated) then the test was considered a success. User interface elements will begin to be tested in early 2006. External testers have been volunteers from the world-wide astronomical community. So far, only expert interferometrists have been asked to test the software. Later, when the new user interface is developed, novice users may be asked to help with the testing. The tests have been successful to date – all testers have been able to fill, edit, calibrate, image, and analyse the test data sets. Based on these tests, it appears that the offline reduction and imaging package is on schedule for meeting ALMA data processing needs at the beginning of early science operations. For more details, see the $AIPS^{++}$ homepage (*http://aips2.nrao.edu/docs/aips++.html*) or the latest test report (*http://aips2.nrao.edu/projectoffice/almatst2.0/Offline.Test3.Report.7july05-final.pdf*). (Based on a contribution by Rein Warmels (ESO) and Debra Shepherd (NRAO).)

ALMA Antenna Contract Signed

On December 6, ESO signed a contract with the consortium led by Alcatel Alenia Space and composed also of European Industrial Engineering (Italy) and MT Aerospace (Germany), to supply 25 antennas for the Atacama Large Millimeter Array (ALMA) project, along with an option for another seven antennas. The contract, worth 147 million euros, covers the design, manufacture, transport and on-site integration of the antennas. It is the largest contract ever signed in ground-based astronomy in Europe.

The ALMA antennas present difficult technical challenges, since the antenna surface accuracy must be within 25 microns, the pointing accuracy within 0.6 arc seconds, and the antennas must be able to be moved between various stations on the ALMA site. This is especially remarkable since the antennas will be located outdoor in all weather conditions, without any protection. Moreover, the ALMA antennas can be pointed directly at the Sun. ALMA will have a collecting area of more than 5 600 square metres, allowing for unprecedented measurements of extremely faint objects.

The signing ceremony took place on December 6, 2005 at ESO Headquarters in Garching, Germany. “This contract represents a major milestone. It allows us to move forward, together with our American and Japanese colleagues, in this very ambitious and unique project”, said ESO’s Director General, Dr. Catherine Cesarsky. “By building ALMA, we are giving European astronomers access to the world’s leading submillimetre facility at the beginning of the next decade, thereby fulfilling Europe’s desire to play a major role in this field of fundamental research.”

Pascale Sourisse, Chairman and CEO of Alcatel Alenia Space, said: “We would like to thank ESO for trusting us to take on this new challenge. We are bringing to the table not only our recognised expertise in antenna development, but also our long-standing experience in coordinating consortiums in charge of complex, high-performance ground systems.”

ALMA is an international astronomy facility. It is a partnership between Europe, North America and Japan, in cooperation with the Republic of Chile. The European contribution is funded by ESO and Spain, with the construction and operations being managed by ESO. A matching contribution is being made by the USA and Canada, which will also provide 25 antennas. Japan will provide additional antennas, thus making this a truly worldwide endeavour.

Photos: H. Zodet, ESO (2)

Above: Signing event, from left to right: Mr. Thomas Zimmerer (Head Antennas and Mechatronic, MT Aerospace AG), Mr. Hans Steininger (Chief Financial Officer, MT Aerospace AG), Mr. Patrick Mauté (General Manager, BU Observatorion and Science of Alcatel Alenia Space France), Dr. Catherine Cesarsky (ESO Director General), Mr. Giampietro Marchiori (Managing Director, European Industrial Engineering s.r.l.), Mr. Vincenzo Giorgio (Director of Scientific Italian Programmes, Alcatel Alenia Space Italy), and Dr. Ian Corbett (ESO Deputy Director General).

Left: The Alcatel Alenia Space/European Industrial Engineering Prototype Antenna.

ALMA will be located on the 5 000 m high Llano de Chajnantor site in the Atacama Desert of Northern Chile. ALMA will consist of a giant array of 12-m antennas separated by baselines of up to 18 km and is expected to start partial operation by 2010–2011.

The excellent site, the most sensitive receivers developed so far, and the large number of antennas will allow ALMA to have a sensitivity that is many times better than any other comparable instrument. “ALMA will bring to sub-millimetre astronomy the aperture synthesis techniques of radio astronomy, enabling precision imaging to be done on sub-arcsecond angular scales, and will nicely complement the ESO VLT/VLTI observatory”, said Dr. Hans Rykaczewski, the ALMA European Project Manager.

A prototype antenna has already been built by Alcatel Alenia Space and European Industrial Engineering and thoroughly tested along with prototype antennas from Vertex/LSI and Mitsubishi at the ALMA Antenna Test Facility located at the Very Large Array site in Socorro, New Mexico.

For more information on the ALMA project, see *http://www.eso.org/projects/alma/*

(Based on ESO Press Release 31/05)

Inauguration of the APEX Telescope

Gonzalo Argandoña, Felix Mirabel (ESO)

The serene Andean village of San Pedro de Atacama, in northern Chile, was the epicentre of the two-day official inauguration of APEX, the 12-metre telescope working at the Llano of Chajnantor.

On September 25 and 26, representatives of the three organisations running this antenna hosted a lively scientific celebration. Dr. Catherine Cesarsky (ESO's Director General), Prof. Karl Menten (Director of the Max-Planck-Institute for Radio Astronomy and Chairman of the APEX Board) and Prof. Roy Booth (Director of the Onsala Space Observatory) presented the key features of this new astronomical facility that will provide privileged access to the "cold universe".

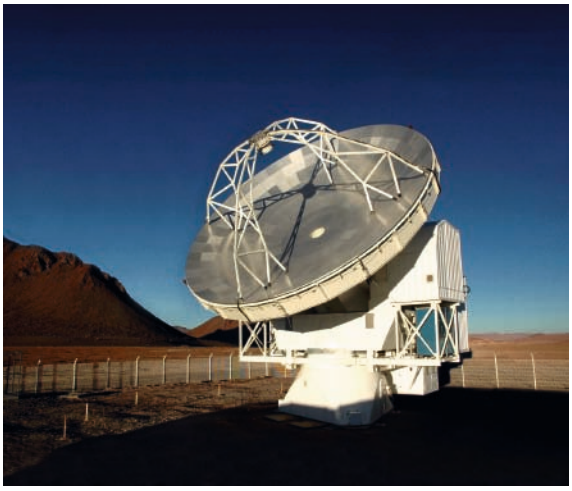
The intendente Jorge Molina, representative in Region II of the President of Chile Ricardo Lagos, remarked that Paranal Observatory, APEX and in the near future ALMA have turned this part of Chile into an active astronomical centre, with significant benefits to the local economy and the education of the people living there.

On behalf of local communities, the Mayor of San Pedro de Atacama, Sandra Berna, celebrated the active cultural exchange and dialogue between members of European astronomical organisations and the inhabitants of San Pedro, most of them belonging to the ancient Lican Antai culture.

Ambassadors in Chile of some of ESO's member states, the Executive Director of the Chilean Science Agency (CONICYT), the Presidents of the Communities of Sequitor and Toconao, as well as representatives of the Ministry of Foreign Affairs and Universities in Chile also attended the ceremony.

Photos: G. Argandoña, ESO (top); A. A. Lundgren, ESO (bottom)

Above: After months of hard work setting up the telescope, the members of the three organisations behind APEX celebrated at San Pedro de Atacama the beginning of regular science observations. They were joined by representatives of the Chilean government, universities and local communities during the two-day event.



Left: APEX is the largest sub-millimetre facility in the southern hemisphere. The surface of the antenna has been adjusted to an accuracy of 17 microns, less than one fifth of the thickness of a human hair, all across the surface and at all times and positions.

On the second day of the programme, the group visited the APEX base camp in Sequitor, near San Pedro, from where the antenna is operated through a microwave link to Chajnantor. Visitors had a guided tour of Sequitor facilities, including the main control room. Here, they could have a glimpse of some of the scientific results already obtained with APEX.

The telescope, designed to work at submillimetre wavelengths, in the 0.2- to 1.5-mm range, successfully passed its Science Verification phase in July, and since then has been performing regular science observations.

Among other astronomical targets, APEX will be used for comprehensive surveys of the Galactic Plane, which will locate the sources that ALMA will study in minute detail. In that sense, it is considered as a real pathfinder that will prepare the way for ALMA in the years to come.

Towards an Automatic Reduction of FORS2-MXU Spectroscopy

Harald Kuntschner, Martin Kümmel, Søren Larsen, Jeremy Walsh (ST-ECF)

A brief report is presented of a feasibility study for an automatic, science quality spectral extraction of FORS2-MXU spectra using the aXe package developed for slitless spectroscopy. We briefly describe the aXe data reduction concept, which is usually applied to HST-ACS data, and demonstrate the applicability of this concept by reducing a subset of the Great Observatories Origins Survey (GOODS) FORS2 spectroscopic survey.

The large numbers of objects which can be observed simultaneously with modern multi-object spectrographs demand the availability of automatic reduction software. Such pipeline-supported data-reduction is often used in space astronomy. One example is the purpose-built software aXe (*http://www.stecf.org/software/aXe*), which provides science-quality spectra for the slitless modes of the ACS instrument aboard HST. ACS shows a high degree of stability, which allows the production of a generic calibration (e.g., reference files for the trace, the wavelength solution, flat-field and sensitivity curves) for each of the dispersive elements, removing the need to calibrate each individual set of observations. The data-reduction software is then only driven by the object coordinates within the Field of View (FoV). For long exposures, the spectra of thousands of objects can be extracted, which is clearly beyond manual effort. The software has been successfully used on ACS data in various projects such as the Hubble Ultra Deep Field HRC Parallels (Walsh, Kümmel & Larsen, 2004), high redhift supernovae search (Riess et al. 2004) and the Grism ACS Program for Extragalactic Science (GRAPES, Pirzkal et al. 2004). It was designed such that the instrument specific parameters are stored in external configuration files. The configuration files are defined in a very general and thus flexible way. Therefore the software can be easily adapted to new instruments, even multi-slit spectrographs such as FORS2 at the VLT. Currently there is no software reduction package available for the FORS2-MXU mode, which prompted us to conduct a feasibility study of automatic spectral extraction with the aXe software.

The aXe concept

In slitless spectroscopy there are no apertures such as slitlets, which allow only a small region of the sky to enter the spectrograph. An unambiguous conversion between pixel coordinates and wavelength is therefore impossible. All spectral object extractions must be based on local solutions to the trace description and dispersion solution, which are globally described in the configuration file. To evaluate the local solutions, an object coordinate (stored in the Input Object List) must be provided for every object whose spectrum will be extracted with aXe. Taking into account the optical distortions of the instrument, the object coordinates are transformed to the so-called reference position in CCD coordinates, which drives the local solution. In addition to the object coordinates, the Input Object List also contains other parameters such as the object extension. With this information it is possible to adjust the spectral extraction width for each object individually.

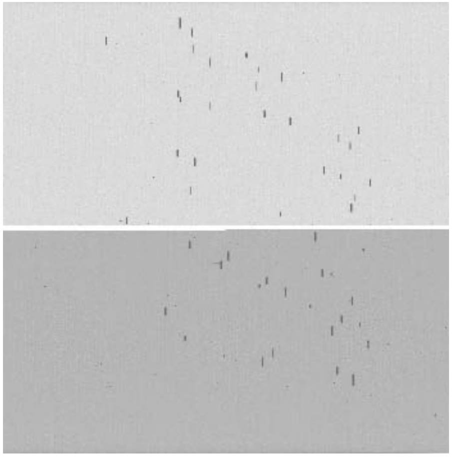
Given a stable instrument configuration and operation, the aXe approach of a global calibration makes it possible to extract multi-object spectroscopy data in an extremely efficient and largely unsupervised way. The main task of the data-reduction is reduced to the creation of the Input Object List. Especially for the production of large science-ready data-products, to be stored in Virtual Observatory compliant archives, a software package like aXe is of paramount importance. In the traditional data reduction, the accuracy of the instrumental calibration is limited to the accuracy of the set of calibrations taken with the science data. In the aXe approach of a global calibration, however, the accuracy is limited by the stability of the instrument and the accuracy of the calibration data to calibrate the telescope/instrument setup.

Observing with FORS2-MXU

FORS is the visual and near-UV FOcal-Reducer and low-dispersion Spectrograph for the Very Large Telescope (VLT). FORS2 offers the possibility to insert in the focal plane a mask in which slits of different length, width and shape can be cut with a dedicated laser-cutting machine (MXU mode). The FORS Instrumental Mask Simulator (FIMS) tool is used to design and define the masks. Within the FIMS tool the slit positions and a number of reference stars are selected. These reference stars will be automatically identified on the acquisition image taken within the target acquisition sequence. From these positions the translation and rotation offsets are calculated and transferred automatically to the telescope. Thus one ensures that the objects are accurately located within the slits of the mask. The FIMS tool is very versatile and thus allows designing masks in different ways. The masks are normally based on pre-imaging with the FORS instrument and slits are placed on objects visible on these images. This can be done by hand or in a semi-automatic fashion. One can also create masks on the basis of catalogues only. Common to all of these methods is that the object position is generally not in the centre (along the spatial direction) of the slit. Although the slit positions and dimensions of each mask are carried through to the final science images, the object positions within these slits are not generally stored. Therefore, only the person who has created the mask may have this information. From the viewpoint of automatic data-reduction or the use of this data by other astronomers than the original science team, the absence of the object positions is a major drawback.

Calibrating FORS2-MXU

As a test bed for our feasibility study we have selected the GOODS/FORS2 spectroscopic survey. This data set was chosen since it provides a rich and challenging use of the FORS2-MXU mode. Additionally, we can compare with an existing ”by-hand” data reduction (Vanzella et al. 2005) and thus are able to evaluate the quality of our data products. In Figure 1 a typical mask design and the associated spectral exposure are shown. In our feasibility study we derive a calibration for FORS2 only for the spectral mode of the GOODS data set.



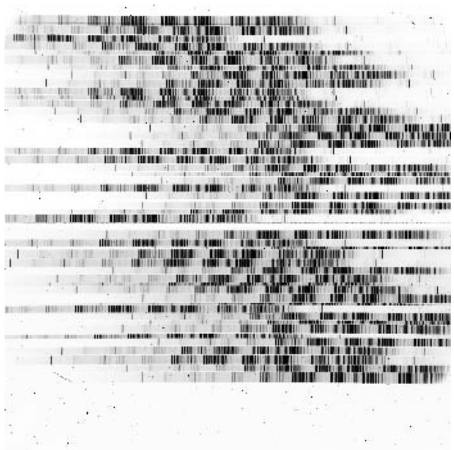


Figure 1: Left: A "through-slit" image of a typical mask from the GOODS/FORS2 survey. The slits appear as short black lines in this image. Right: One 20-min spectroscopic exposure showing the spectra obtained with the mask at left and the 300I grism inserted. The typical wavelength range is 600 to 1000 nm at a resolution of R = 660 and thus the signal is dominated by the sky background, which is clearly visible.

In order to apply the aXe software concept to FORS2-MXU data, two major items need to be addressed: (a) the production of the Input Object List which drives the data-reduction tasks; and (b) the construction of the aXe configuration files which describe the imprint of the spectrograph on the incoming beam and other instrument characteristics such as the detector flat field.

In the case of FORS2 one can establish the overall sky-coordinate to CCD-coordinate transformation via the mandatory through-slit images and the known optical distortions of the instrument. In the absence of individual object coordinates one can instead use the slit centres (and lengths) in the Input Object list and thus extract two-dimensional spectra from the raw images. An external source-finding algorithm could then be used to extract one-dimensional spectra of all the objects within the individual slits. Of course, the aXe software can also be used in the normal configuration if, as in the case of the GOODS survey, the object positions are accurately known.

In order to derive a global calibration for FORS2 and the 300I grism used for the GOODS survey, we have obtained through-slit, flat-field and wavelength exposures with a special calibration mask in daytime. This mask features 47 slits uniformly covering the typical area of science slits. The main calibrations needed for aXe are the trace and wavelength solution as a function of the reference position. To derive the trace calibration, all object traces were determined on the flat-field exposures. The traces over the FoV can be reasonably well approximated by a field-dependent second-order polynomial yielding residuals of less than 0.15 pixel rms (1 pixel corresponds to 0.25 arcsec on the sky). See Figure 2 for an example.

Using the trace solution we have examined arc-lamp exposures obtained with our special calibration mask to derive a global wavelength solution. Here a field-dependent 4th-order polynomial fit is needed to describe individual wavelength solutions with a typical rms of 0.13 Å.

As a check of our global wavelength calibration we compared the predicted wavelengths with arc-lamp observations taken through a science mask during daytime. Furthermore, we compared our wavelength predictions with the observations of relatively isolated and strong night skylines with known wavelength. The systematic errors in the mean, absolute wavelength scale appear to be generally less than 0.1 nm, and may be reduced even further by adopting global shifts based on measurements of skylines. More importantly, wavelength-dependent errors also appear to be small (< 0.1 nm), except perhaps at wavelengths shorter than 600 nm where the error may reach 0.2 nm. Note that the average dispersion is 0.32 nm/pixel.

The quality of our trace and wavelength predictions can be best demonstrated when running the aXe software in a mode in which two-dimensional spectra are extracted. In this mode, fully-calibrated and rectified spectra are produced for each slit on the science mask. An example of this is shown in Figure 3 in which we addition ally apply a simple background removal procedure.

Since aXe was initially designed for slitless spectroscopy data, the assumption is made that any pixel can receive a spectral element from any wavelength over the sensitive range of the detector and spectral elements. Thus in order to apply a pixel-flat-field correction (a P-flat in HST terminology), the wavelength dependence of the flat field for each pixel must be determined. For the ACS this was performed by fitting the wavelength dependence, pixel-by-pixel, of flat fields taken with the available filters (for details see Walsh & Pirzkal 2005). The flat field used by aXe is a polynomial fit to the wavelength dependence of these flat fields; the flat field is then stored as a flat field cube with each plane holding the coefficient of the polynomial fit per pixel. An identical procedure was implemented for FORS2.

Required modifications to aXe

Some additions to aXe had to be implemented in order to reduce FORS2-MXU data. The additions mostly deal with the "special" needs of slit spectroscopy

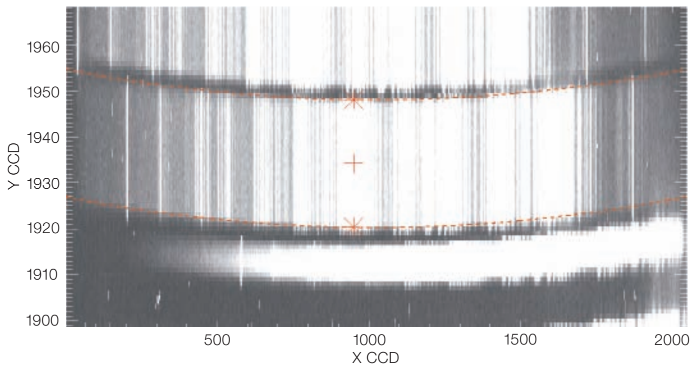


Figure 2: An example of our trace predictions (orange dashed lines) for an individual slit in CCD coordinates. The plus sign marks the projected slit centre and the star symbols indicate the projected slit edges.

Figure 3: Top: The fully calibrated and rectified two-dimensional spectrum for one 20-min exposure of one slit from the GOODS/FORS2 test data set as produced by aXe is shown. Night skylines largely dominate the signal. Bottom: The same spectral region after the application of a simple background removal procedure. A clear signature of a continuum source is visible. Note that for demonstration purposes the y-axis is heavily stretched.

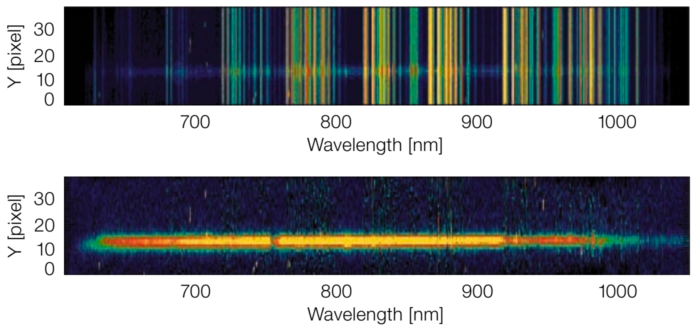
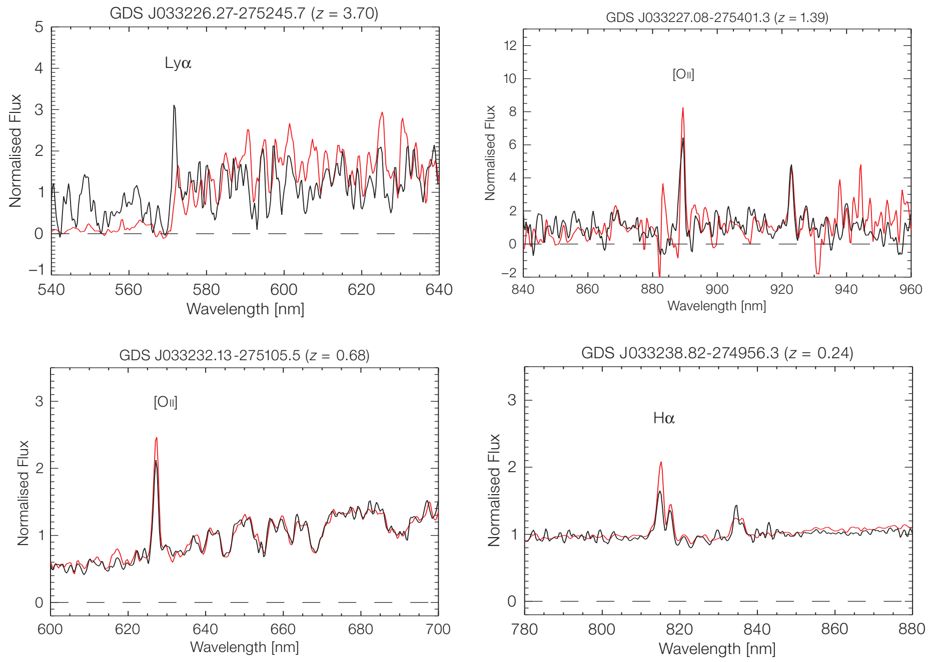


Figure 4 (below): A comparison with the GOODS team "by hand" reduction for four galaxies spanning a range in red-shift from 0.24 to 3.70. The black solid line represents the GOODS team spectrum, the red line the aXe reduction.



and ground-based astronomy, but do not touch aXe core parts. (a) In contrast to ACS slitless spectroscopy the finite length of slits limits the useful area for background determination. Furthermore, the background estimator in aXe had to include cosmic-ray detection and rejection, which is done prior to running aXe on ACS data. (b) The production of a science-ready two-dimensional spectrum for each slit was introduced. This allows the user to check results and fine-tune parameters. These intermediate products can even be used as starting points for data reduction with other software packages such as IRAF (see also Figure 3). (c) The possibility to extract spectra from significantly bent traces such as in FORS2-MXU also had to be added.

Comparison with GOODS "by hand" extraction

In order to verify the quality of our aXe data reduction, we compared our one-dimensional spectra with the GOODS team "by-hand" extraction[1]. The test data set consisted of 12 individual exposures (total = 14 400 s) taken with one mask. Each of the science exposures was treated separately, and by driving the aXe software with accurate object coordinates, one-dimensional spectra for all objects on the mask were produced. Finally the one-dimensional spectra of the individual objects were combined using a sigma-clipping algorithm.

Figure 4 compares a subset of our spectra with the ones extracted by the GOODS team. The overall agreement between the aXe and GOODS team data reduction is good. We recover all important emission and absorption lines, which are used to determine the redshift of the objects. However, there are sometimes significant differences in the line strength of emission lines. We note that in the aXe reduction the individual one-dimensional spectra were median scaled before combination, while the GOODS team combines the spectra with a weighting according to spectral quality and seeing. The different scaling methods and cosmic-ray-rejection algorithms may account for some of the differences.

[1] We are grateful to the GOODS team for early access to the spectra.

Concluding remarks

In this feasibility study we demonstrate that the current implementation of aXe can successfully extract one-dimensional spectra from FORS2-MXU data of the GOODS survey. Although the reduction process is largely unsupervised we can produce spectra of similar quality to the "by hand" reduction of the GOODS team. There are significant tasks to be carried out before the software reaches the maturity of a common-user reduction package, for example, trending of the trace and stability of the wavelength solution for various grisms. Furthermore there are a number of reduction steps which require improvements such as catalogue generation and determination of reference position for each FORS2-MXU spectrum. We encourage astronomers who are interested in the application of this software to FORS2 to contact us (email: *stdesk@eso.org*) and let us know what demands their data would require of our software.

References

Pirzkal, N., Xu, C., Malhotra, S. et al. 2004, ApJS 154, 501
Riess, A., Strolger, L. G., Tonry J. et al. 2004, ApJ 607, 665
Vanzella et al. 2005, A&A 434, 53
Walsh, J., Kümmel, M., Larsen, S. 2004, ST-ECF Newsletter 36, 8
Walsh, J., Pirzkal, N. 2005, ACS instrument science report 05-02

The Virtual Observatory in Europe and at ESO

Paolo Padovani, Peter Quinn (ESO)

Virtual Observatories are moving from a "research and development" to an "operational" phase. We report on the EURO-VO, a project to build an operational Virtual Observatory in Europe, and on the new Virtual Observatory Systems department at ESO.

The Virtual Observatory (VO) is an innovative, evolving system, which will allow users to interrogate multiple data centres and services in a seamless and transparent way, to best utilise astronomical data. The main goal of the VO is to enable new science by making the huge amount of data currently available easily accessible to astronomers. The VO initiative is a global collaboration of the world's astronomical communities under the auspices of the recently formed International Virtual Observatory Alliance (IVOA; *http://ivoa.net*; see Figure 1).

The Astrophysical Virtual Observatory

The status of the VO in Europe is very good. In addition to seven current national VO projects, the European funded collaborative Astrophysical Virtual Observatory (AVO) project had the task of creating the foundations of a regional-scale infrastructure by conducting a research and demonstration programme on the VO scientific requirements and necessary technologies. The AVO had been jointly funded by the European Commission (under the Fifth Framework Programme [FP5]) with six European organisations (ESO, the European Space Agency [ESA], AstroGrid, the Centre de Données astronomique de Strasbourg [CDS], TERAPIX, and Jodrell Bank) participating in a three-year, Phase-A work programme.

The AVO project was driven by a strategy of regular scientific demonstrations of VO technology and is now formally concluded. AVO's main achievements can be thus summarised:

Three science demonstrations

These were held on an annual basis, in coordination with the IVOA, for the AVO Science Working Group (SWG), established to provide scientific advice to the project. Three very successful demonstrations were held in January 2003 (Jodrell Bank), 2004 (ESO, Garching), and 2005 (ESAC, Madrid).

First VO paper

We reported last year (Padovani et al. 2004 b) on AVO's second demonstration, held on January 27–28, 2004 at ESO, which led to the discovery of 31 new optically faint, obscured quasar candidates (the so-called QSO 2) in the two Great Observatories Origins Deep Survey (GOODS) fields. These results, in turn, led to the publication of the first refereed astronomical paper enabled via end-to-end use of VO tools and systems (Padovani et al. 2004 a). The paper was also publicised by an ESA/ESO press release (see *http://www.euro-vo.org/pub/articles/AVO1stSciencePressRelease.html*).

VO tools

For the purpose of the demonstrations progressively more complex AVO demonstrators have been constructed. The current one is an evolution of Aladin, developed at CDS, and has become a set of various software components, provided by AVO and international partners, which allows relatively easy access to remote data sets (images and spectra), manipulation of image and catalogue data, and remote calculations in a fashion similar to remote computing. The AVO prototype is a VO tool which can be used now for the day-to-day work of astronomers and can be downloaded from the AVO Web site as a Java application. We note that this is by definition a prototype and will not be maintained on the long term. Most of the functionalities developed for the AVO demonstrations are now available in the public version of Aladin, and the inclusion of the remaining ones is being assessed.

Science Reference Mission

The Science Reference Mission is a definition of the key scientific results that the full-fledged VO in Europe should achieve when fully implemented. It consists of a number of science cases, with related requirements, against which the success of the operational VO in Europe will be measured. It was put together by the AVO SWG.

The AVO was also a founding member of the IVOA, and has provided fundamental input for the development of VO standards and their usage.

The AVO project is now formally concluded. Links to various documents and to the software download page can be found at *http://www.euro-vo.org/twiki/bin/view/Avo/*.

Figure 1: The International Virtual Observatory Alliance, the Member Organisations.

The EURO-VO

The EURO-VO work programme is the logical next step from AVO as a Phase-B deployment of an operational VO in Europe. Building on the development experience gained within the AVO Project, in coordination with the European astronomical infrastructural networks OPTICON and RADIONET, and through membership and support of the IVOA, EURO-VO will seek to obtain the following objectives: (1) technology take-up and full VO compliant data and resource provision by astronomical data centres in Europe; (2) support to the scientific community to utilise the new VO infrastructure through dissemination, workshops, project support, and VO facility-wide resources and services; (3) building of an operational VO infrastructure in response to new scientific challenges via development and refinement of VO components, assessment of new technologies, design of new components and their implementation. EURO-VO is open to all European astronomical data centres. Initial partners include ESO, the European Space Agency, and six national funding agencies, with their respective VO nodes: Istituto Nazionale di Astrofisica (INAF, Italy), Institut National des Sciences de l'Univers (INSU, France), Instituto Nacional de Técnica Aeroespacial (INTA, Spain), Nederlandse Onderzoekschool voor Astronomie (NOVA, the Netherlands), Particle Physics and Astronomy Research Council (PPARC, United Kingdom), and Rat Deutscher Sternwarten (RDS, Germany). The total planned EURO-VO resources sum up to approximately 60 persons per year over three years, i.e., about three times those of the AVO.

EURO-VO will seek to obtain its objectives by establishing three new interlinked structures: 1. the EURO-VO Data Centre Alliance (DCA), an alliance of European data centres who will populate the EURO-VO with data, provide the physical storage and computational fabric and who will publish data, metadata and services to the EURO-VO using VO technologies; 2. the EURO-VO Facility Centre (VOFC), an organisation that provides the EURO-VO with a centralised registry for resources, standards and certification mechanisms as well as community support for VO technology take-up and dissemination and scientific programme support using VO technologies and resources; 3. the EURO-VO Technology Centre (VOTC), a distributed organisation that coordinates a set of research and development projects on the advancement of VO technology, systems and tools in response to scientific and community requirements.

The DCA will be a persistent alliance of data centre communities represented at a national level. Through membership in the DCA, a nation's community of data curators and data service providers will be represented in a forum that will facilitate the take-up of VO standards, share best practice for data providers, consolidate operational requirements for VO-enabled tools and systems and enable the identification and promotion of scientific requirements from programmes of strategic national interest that require VO technologies and services. Funds for the DCA have been requested in an FP6 proposal submitted in September 2005.

The VOFC will provide a "public face" to the EURO-VO. Through outreach, support of VO-enabled science projects in the community, workshops and schools, the VOFC will represent a central support structure to facilitate the broad take-up of VO tools by the community. The VOFC will also support the EURO-VO Science Advisory Committee (SAC) to ensure appropriate and effective scientific guidance from the community of leading researchers outside the mainstream VO projects. The SAC will provide an up-to-date stream of high-level science requirements to the EURO-VO. The VOFC will further provide central services to the DCA for resource registry, metadata standards and EURO-VO access. Funding for the VOFC has yet to be fully defined but will come initially from ESO and ESA with activities ramping up in 2006. The first VOFC activity was the organisation of the EURO-VO workshop at ESO Headquarters in Garching from June 27 to July 1, 2005 (Padovani & Dolensky 2005).

The VOTC will consist of a series of coordinated technology research and development projects conducted in a distributed manner across the member organisations. The first project under the VOTC is the VO-TECH project, funded through the EC FP6 Proposal and contributions from the Universities of Edinburgh, Leicester, and Cambridge in the United Kingdom, ESO, CNRS and Université Louis Pasteur (France), and INAF (Italy). Additional projects can be brought to the VOTC via other member organisations; one such example is ESA-VO. The VOTC provides a mechanism to coordinate and share technological developments, a channel for DCA and VOFC requirements to be addressed and for technological developments to be distributed to the community of data centres and individual scientists in a coordinated and effective manner.

The EURO-VO project will be proactive in reaching out to European astronomers. As a first step, the EURO-VO has started making regular appearances at Joint European and National Astronomy Meetings (JENAM), as of the one in Liège in July 2005.

VO and ESO

Data centres have a major role in the VO, as they are the primary source of astronomical data. The VO cannot (and does not) dictate how a data centre handles its own archive. However, a "VO-layer" is needed to "translate" any locally defined parameter to the standard (i.e., IVOA compliant) ones. For example, right ascension can be defined in different ways by different data centres 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-grade" data, so that the VO user is spared as much as possible any complex and time-consuming data reduction. Data centres should then make an effort to provide such data.

All these issues obviously affect ESO as well. To address them, the Data Management and Operations Division created the Virtual Observatory Systems (VOS) Department on November 1, 2004. VOS' role is to manage ESOs involvement in VO activities and to make the Science Archive Facility (SAF) into a powerful scientific resource for the ESO community. The new department, headed by Paolo Padovani, includes, at present, the Virtual Observatory Technology (VOT) and the Advanced Data Products (ADP) groups, led respectively by Markus Dolensky and Piero Rosati, and is made up of thirteen people.

The specific tasks of VOS are the following:

1. Creation of ADP, i.e., science-ready ("level-3" in ESO terms) data products from the ESO archive; this will be done by using a redesigned imaging pipeline built on top of the EIS/MVM software and also via a coordinated activity between the ADP and the Data Flow System (DFS) groups to single out possible upgrades of specific DFS pipelines from level-2 to level-3. A recent ADP effort has been the processing via the EIS/MVM software and release of the ISAAC/GOODS data, which include 11600 science frames and 10600 calibration frames, photometrically calibrated using pre-determined zero points from SOFI data. These data are available at *http://www.eso.org/science/goods/releases/20050930/* (see Figure 2);

2. Ingestion of ADP into a VO-compliant SAF; these will include not only products generated by the ADP group but also by the community. For example, science-ready data products from a number of ESO projects, which are currently available in a heterogeneous fashion from customised web pages. In particular, as of Period 75 PIs of Large Programmes are requested to provide ESO with their reduced data products at the time of publication of their results. Moreover, Public Survey data products will also be ingested and published in a VO-compliant way, as they will be extremely useful to VO users, being highly homogeneous and well calibrated. These will include data from OmegaCAM on the VLT Survey Telescope (VST; Cappellaro 2005; Capaccioli et al. 2005) and from VISTA (Emerson et al. 2004);

3. Publication of ADP within the VO infrastructure; this will require a complete redesign of the SAF and of its interface. As a first step in that direction, on the occasion of the opening of the ESO archive to the world on April 4, 2005, VOS has deployed a redesigned archive interface. Its aim is to facilitate data queries to archival users who might not be familiar with ESO instruments. The new interface is accessible at *http://archive.eso.org/eso/eso_archive_main.html*;

4. Development of VO technology, standards, and tools for the ESO SAF, also via participation to European VO activities, in particular through the VOTech project.

References

Capaccioli, M., Mancini, D., Sedmak, G. 2005, The Messenger 120, 10
Cappellaro, E. 2005, The Messenger 120, 13
Emerson, J. P. et al. 2005, The Messenger 117, 26
Padovani, P. et al. 2004a, A&A 424, 545
Padovani, P. et al. 2004b, The Messenger 117, 58
Padovani, P., Dolensky, M. 2005, The Messenger 121, 60

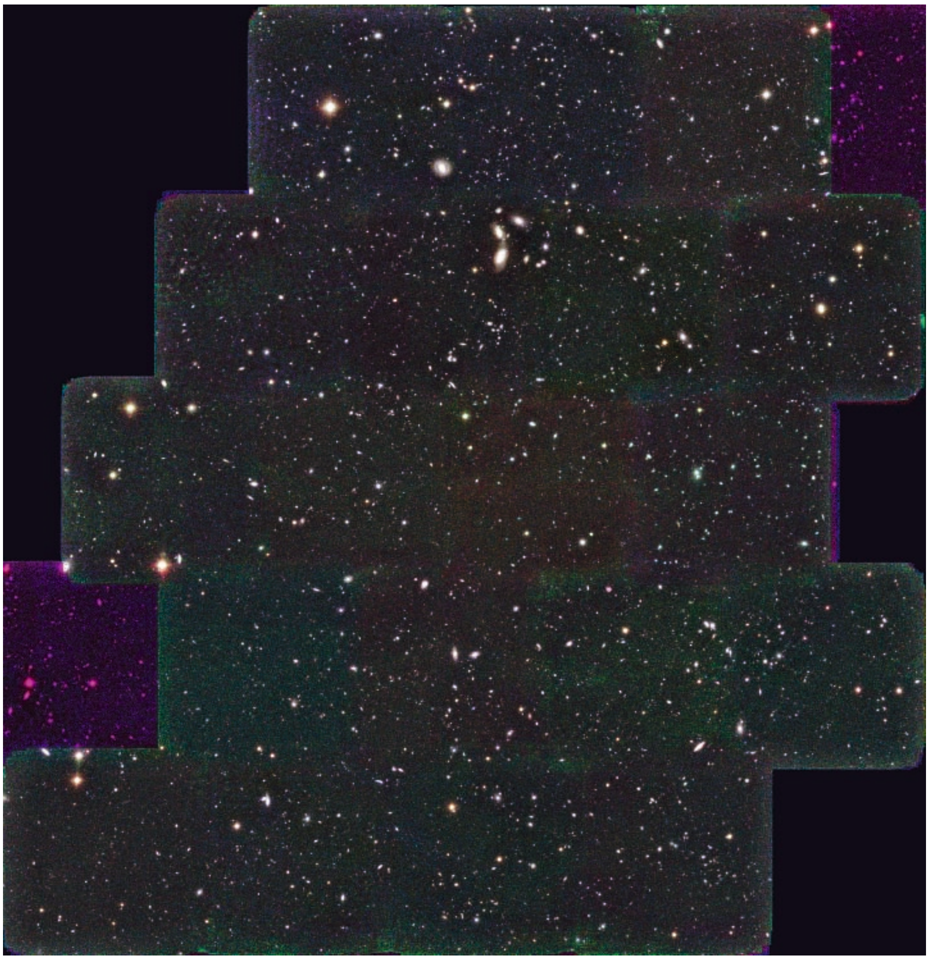


Figure 2: *JHK* colour composite of the ISAAC/GOODS mosaic part of the latest Advanced Data Products group of the Virtual Observatory Systems (VOS) Department release, which includes 21 tiles in the *J*-, *H*- and *Ks*-bands, and five additional tiles in the *J*- and *Ks*-bands (not visible in this image). Each ISAAC field is 2.5 arcmin across. See *http://www.eso.org/science/goods/releases/20050930/*

GOODS' Look at Galaxies in the Young Universe

Eros Vanzella[1]
Stefano Cristiani[1]
Mark Dickinson[2]
Harald Kuntschner[7,3]
Alessandro Rettura[3,4]
Leonidas A. Moustakas[6]
Mario Nonino[1]
Paola Popesso[3]
Piero Rosati[3]
Daniel Stern[6]
Catherine Cesarsky[3]
Henry C. Ferguson[5]
Robert A. E. Fosbury[7]
Mauro Giavalisco[5]
Jonas Haase[7]
Alvio Renzini[8]
and the GOODS Team

[1] INAF – Osservatorio Astronomico di Trieste, Italy
[2] National Optical Astronomy Observatory, Tucson, Arizona, USA
[3] ESO
[4] Université Paris-Sud XI, France
[5] Space Telescope Science Institute, Baltimore, Maryland, USA
[6] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA
[7] ST-ECF
[8] INAF – Osservatorio Astronomico di Padova, Italy

The Great Observatories Origin Deep Survey is using the most advanced observing facilities, ESO/VLT, HST, Spitzer, Chandra, XMM/Newton, etc. to discover infant galaxies at epochs when the Universe was only 900 million years old. The FORS2 spectroscopic survey has confirmed 33 galaxies in the redshift interval $5 < z < 6.2$, producing one of the largest spectroscopic samples in that redshift range to date.

The quest for primordial galactic structure

One of the major goals of contemporary cosmology is to understand the processes leading to the formation of galaxies. According to the present standard model the growth of structure, from the first tiny fluctuations of matter (about one part over 10^5 at the time of recombination, as recorded by CMB experiments) to galaxies and clusters of galaxies, advanced through hierarchical mergers of dark matter concentrations. Eventually the gravity of the largest aggregates grew enough to pull in and concentrate the gas needed to build infant galaxies. The first generations of stars are thought to have produced the ultraviolet photons needed to reionise the Universe ending the Dark Ages that had followed the recombination.

Astronomers are closing the gap between the CMB experiments, i.e. the epoch recombination 380 000 years after the Big-Bang, and the observations of primordial galaxies, thanks to the development of more and more powerful instruments. Taking advantage of the imaging capabilities of the Advanced Camera for Surveys (ACS) onboard the Hubble Space Telescope and the spectroscopic power of the FORS2 instrument at the ESO/VLT our team has been able to identify a substantial population of galaxies at redshifts up to 6.2, when the Universe was only 900 million years old. The programme has been carried out in the framework of the Great Observatories Origins Deep Survey (GOODS), which unites extremely deep observations from NASA's Great Observatories, the Spitzer Space Telescope, Hubble, and Chandra, ESA's XMM-Newton, and from the most powerful ground-based facilities, ESO/VLT, Keck, etc. (the GOODS project has already been described in a previous article (The Messenger 118, 45)).

The GOODS HST Treasury Program uses the ACS to image the HDF-N and CDF-S fields through four broad, non overlapping filters: F435W (*B*), F606W (*V*), F775W (*i*) and F850LP (*z*). The exposure time is 3, 2.5, 2.5, and 5 orbits per filter, respectively, reaching extended-source sensitivities within 0.5–0.8 mags of the WFPC2 HDF observations. GOODS is a deep survey, not a wide one, but it is much larger than most previous, deep HST/WFPC2 surveys, covering 320 square arcmin, 32 times the combined solid angles of the HDF-N and S, and four times larger than their combined flanking fields. The *z*-band observations image the optical restframe light from galaxies out to $z = 1.2$, with angular resolution superior to that from WFPC2. The ACS *BViz* imaging makes possible a systematic survey of Lyman break galaxies at $4 < z < 6.5$, reaching back close to the epoch of reionisation.

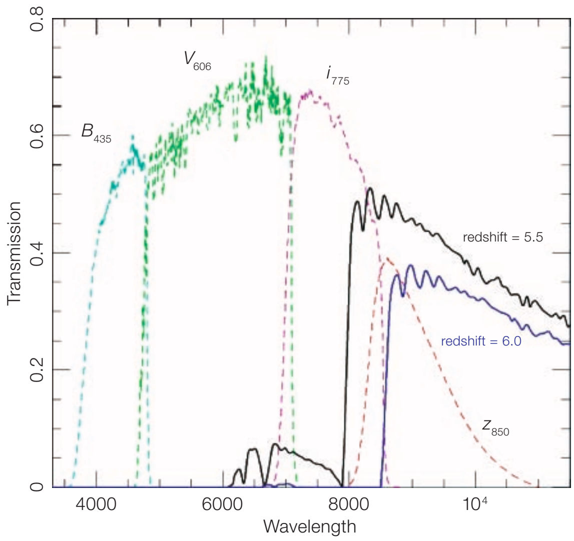
How are the primordial galaxy candidates selected?

High-redshift objects can be identified by sharp breaks in their spectra due to strong absorption of the UV photons by intervening hydrogen gas. Multi-colour imaging identifies these sources as they "disappear" in images taken through filters sensitive to light with wavelengths shorter than that of the break (also known as "dropout" or "Lyman break" technique). An example is shown in Figure 1, where in the upper panel two model spectra of starburst galaxies are superimposed on the four ACS filter transmissions. In this illustrative example the fluxes of the galaxies drop in the *B*-, and *V*- (and also in the *i*-band for the redshift 6 galaxy) due to the high-redshift nature of the sources. In the bottom panel, the direct images of Lyman break galaxies at redshifts 5.5 and 6.0 are shown: the source at redshift 6 "disappears" in the *B*-, *V*- and *i*-filters. This Lyman break technique for identifying distant star-forming galaxies has been in use for over a decade and was championed by Steidel and collaborators to find $z = 3$ and 4 galaxies (Steidel et al. 1999).

At redshift $z < 5.5$ the technique involves three filters: one below the Lyman limit ($\lambda_{rest} = 912$ Å), one in the Lyman forest region and a third longward of the Lyman-α line ($\lambda_{rest} = 1216$ Å). For example, in this way Giavalisco et al. 2004a selected samples of star-forming galaxies at redshifts between 3.5 and ~ 5.5 in the GOODS fields. At redshift > 5.5, only two filters can be (effectively) used, since the integrated optical depth of the Lyman-α forest is >> 1 and the break in the Spectral Energy Distribution (SED) is located between the *i*- and *z*-filters. The key issue is to work at a sufficiently high signal-to-noise ratio that the *i*-band dropouts can be safely identified through detection in a single redder band (i.e. the *z*-band). This is guaranteed by the exquisite images obtained with the ACS onboard HST.

The expected colour $(i–z)$ of a star-forming galaxy at redshift > 5.5 increases with increasing redshift because the break at the Lyα wavelength (1216 Å) shifts out of the *i*-band (see Figure 1). In this way adopting a simple colour cut of $(i–z) > 1.3$

it is possible to select $z > 5.5$ galaxies. The old stellar populations of elliptical galaxies at redshift around 1–2 have also very red colours (Extremely Red Objects, or EROs) and may contaminate the samples of colour-selected high-redshift galaxies. This is due to the fact that the 4 000 Å break of an evolved stellar population at redshift around 1–2 moves beyond the *i*-filter producing redder colours. Also Galactic cool dwarf stars can contaminate the sample, in particular at the bright end of the magnitude distribution. Recent results from the FORS2 spectroscopic campaign in the same field at lower redshift show that the mean $(i–z)$ colour for ~ 50 early-type galaxies at redshift 1–1.3 is 0.9 ± 0.2, with a maximum of 1.25, consistent with the colour predicted for a typical (L*) non-evolving elliptical galaxy in that redshift interval (Vanzella et al. 2005). The availability of a wide multi-band coverage in the GOODS field, in particular the near- and mid-infrared observations performed with the VLT/ISAAC and the Spitzer/IRAC facilities (from 1 to 8 microns) helps to disentangle between high-redshift star-forming galaxies and lower-redshift sources on the basis of their spectral energy distribution.



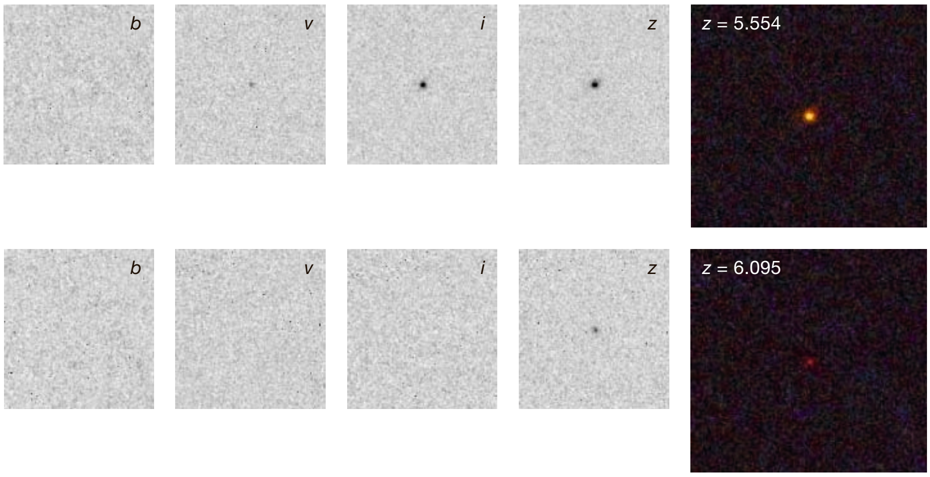


Figure 1: An example of the Lyman break technique. In the upper panel two model spectra of starburst galaxies calculated at redshift 5.5 and 6.0 are superimposed on the four ACS filter transmissions. The bottom panel shows the direct images of two observed Lyman break galaxies at redshift 5.554 and 6.095, respectively. Note how the source at redshift 6 "disappears" in the filters *B*, *V* and *i*.

Spectroscopic confirmation and redshift measurement

Although the colour selection is very accurate with the exquisite data described above, it is still important to get a spectrum of the candidates to measure their redshift beyond any reasonable doubt and obtain information about their physical and chemical properties. Reliable redshifts provide the time coordinate needed to delineate the evolution of galaxy masses, morphologies, clustering, and star formation. This is precisely the goal of the spectroscopic follow-up carried out by our team with FORS2 at the ESO/VLT. *I*-band dropouts (and also *B*- and *V*- band dropouts) have been observed in multiple spectroscopic masks and co-added in order to improve the S/N ratio. The total exposure time ranges from 10 000 to ~ 80 000 seconds.

Figure 2 shows the two-dimensional FORS2 spectra (from 6 600 Å to 10 000 Å) of 33 galaxies at redshift $z > 5$ (25 of them are *i*-band dropout sources at $z > 5.3$).

The redshift determinations, shown at the left-hand side of each sub-panel in the figure, have different quality (7 are certain, 13 are possible and 13 tentative) and the sources will be described in detail in a forthcoming paper (Vanzella et al., in preparation).

At present, the success rate of the colour selection of these very high-redshift galaxies is 96 %. As expected and shown in Figure 3, the majority of the galaxies at redshift > 5.4 are redder than $(i–z) = 1.3$. There are five sources with a $(i–z)$ colour bluer than 1.3. These are galaxies with redshift between 5.4 and 5.6 (the two star symbols in Figure 3 represent two sources in the redshift interval 5.4–5.5) at the limit of redshift selection using a simple colour cut. Part of them have been selected as *V*-dropout sources. The application of the photometric redshifts technique, exploiting all the photometric information available in the GOODS field, will improve the selection of high-*z* galaxies.

Properties of the Lyman-break galaxies

The spectra are in general very blue, indicating the presence of young stellar populations with ages of the order of 10^7–10^8 years, consistently with the UV colour selection adopted. Figure 4 shows the composite rest-frame UV spectrum constructed stacking 25 emission-line spectra in the redshift range $5.1 < z < 6.2$ ($<z> = 5.72 \pm 0.26$). The Lyα emission line, the break and the flatness of the continuum redward of the Lyα are clearly visible. The rest frame equivalent width of the

Lyα line turns out to be ~ 30 Å, comparable with the value measured for emission-line LBGs at redshift 3 (Shapley et al. 2003). The shape of the UV continuum is suppressed shortward of the Lyα by a decrement due to intergalactic H I absorption. In one galaxy the N IV]-1485 Å emission line is also detected, suggesting that we are seeing H II regions characterised by very hot ionising stars (Fosbury et al. 2003). It will be interesting to compare the properties of our sample based on the Lyman-break selection with the survey by Hu et al. 2004, which selects Lyman-α emitters on the basis of narrow-band imaging. Thanks to the large number of spectroscopically confirmed galaxies and from the ultraviolet continuum, it is possible to estimate (after correction for dust extinction) the global star-formation rate of the Universe at $z \sim 6$ (e.g. Giavalisco et al. 2004, Dickinson et al. 2004) and their contribution to the reionisation of the Universe (e.g. Panagia et al. 2005). But GOODS is much more. From the VLT/ISAAC and Spitzer/IRAC observations covering the electromagnetic spectrum from 1.2 to 8 microns, in combination with the current high-redshift sample, it will be possible for the first time to conduct a systematic study of the stellar-mass content of galaxies at $z \sim 6$ and explore even earlier formation times (e.g. Eyles et al. 2005 for two *i*-dropout galaxies).

The present sample will also allow us to study the presence of large-scale structure and the clustering properties of galaxies at such primordial epochs (e.g. Lee et al. 2005) giving an indication on the typical masses of the dark matter halos in which they reside. In these ways GOODS is providing stringent tests of scenarios of galaxy formation.

References

M. Dickinson et al. 2004, ApJ 600, 99
L. Eyles et al. 2005, (astro-ph/0502385)
R. Fosbury et al. 2003, ApJ 596, 797
M. Giavalisco et al. 2004b, ApJ 600, L 103
E. Hu et al. 2004, AJ 127, 563
K. Lee et al. 2005, Submitted to ApJ (astro-ph/0508090)
N. Panagia et al. 2005, ApJ 663, L 1
A. E. Shapley et al. 2003, AJ 588, 65
C. C. Steidel et al. 1999, ApJ 519, 1
E. Vanzella et al. 2005, A&A 434, 53

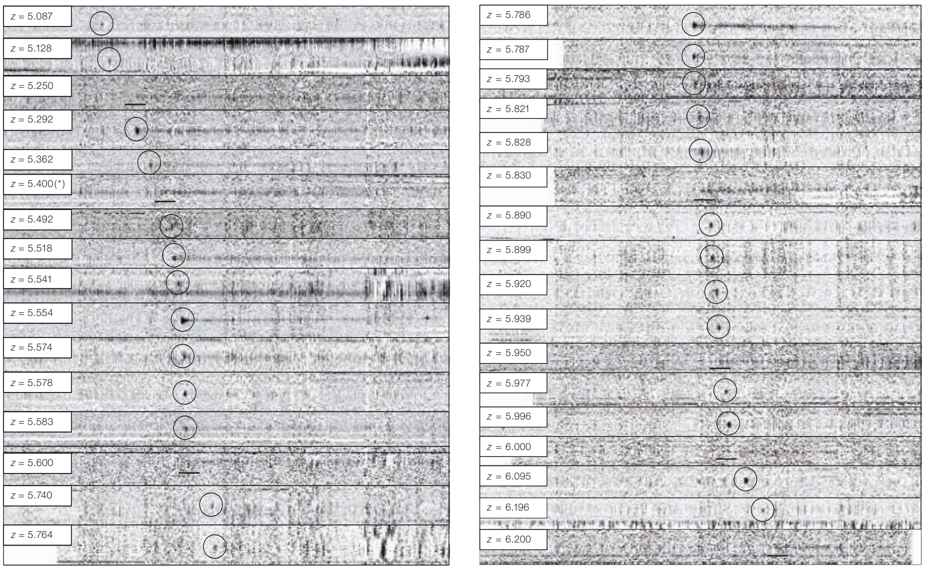


Figure 2: A sample of two-dimensional spectra of galaxies at $z > 5$ discovered during the ESO/FORS2 spectroscopic survey in the GOODS-S field. The position of the Lyα line is marked with a circle and where Lyα is not present the continuum break is underlined with a segment. The quality of the redshift determination depends on the reliability of the spectral features detected (i.e. on the S/N ratio). The source at $z = 5.400$(*) shows a blue continuum blueward of the Lyα line, because this spectrum is a combination of two close sources in the slit, an *i*-band dropout candidate and a lower-redshift object.

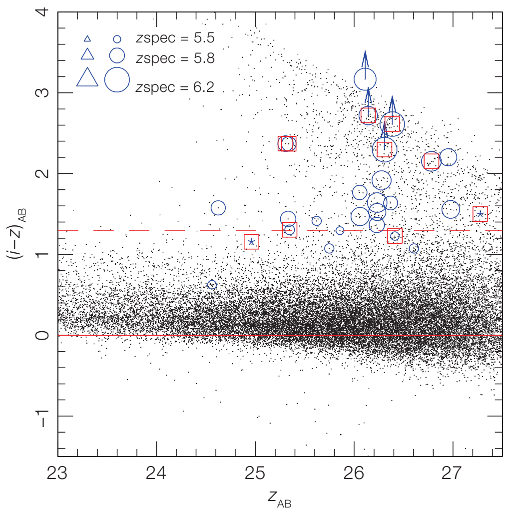


Figure 3: Colour-magnitude diagram for the selection of *i*-band dropout galaxies. The colour cut $(i–z) = 1.3$ (dashed line) outlines the region of the selection. The black dots are all sources down to $z = 27.5$. The open circles represent objects with redshift > 5.4 and the arrows indicate the 1σ lower limit in the $(i–z)$ colour. The size of the symbols scales with the spectroscopic redshift value. Star symbols are sources with $5.4 < z < 5.5$. Sources with an uncertain spectroscopic redshift are identified with a square.

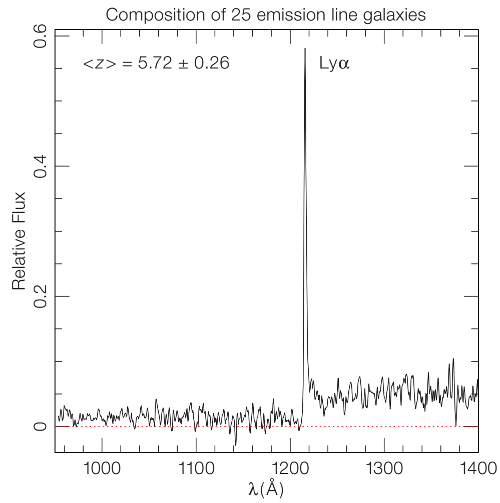


Figure 4: A composite spectrum of 25 emission-line Lyman break galaxies in the redshift interval $5.2 < z < 6.2$ (the mean of the redshift distribution is $<z> = 5.72 \pm 0.26$). The Lyα line and the break in the continuum blueward of the emission are apparent.

The Dynamics and Evolution of Luminous Galaxy Mergers: ISAAC Spectroscopy of ULIRGs

Linda J. Tacconi[1]
Kalliopi Dasyra[1]
Richard Davies[1]
Reinhard Genzel[1]
Dieter Lutz[1]
Andreas Burkert[4]
Thorsten Naab[4]
Eckhard Sturm[1]
Sylvain Veilleux[2]
Andrew J. Baker[2,3]
David B. Sanders[5]

[1] Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany
[2] University of Maryland, USA
[3] NRAO, Charlottesville, USA
[4] Ludwig-Maximillians-Universität, Department für Physik, Munich, Germany
[5] Institute for Astronomy, University of Hawaii, USA

Local ultraluminous galaxy mergers provide us with a quantitative observational means to track an important process for galaxy formation and evolution at high redshift. This article presents first results from a near-infrared spectroscopic study of a moderately large sample of local universe mergers that we have undertaken at the VLT with ISAAC. This study is providing compelling observational evidence that mergers of near-equal-mass, gas-rich galaxies can evolve into intermediate-mass elliptical galaxies after passing through an ultraluminous infrared phase.

The role of mergers in galaxy evolution

Galaxy merging is one of the main driving forces of galaxy evolution. In hierarchical CDM models of galaxy formation and evolution, merging leads to the formation of elliptical galaxies, triggers major starbursts, and accounts for the formation of supermassive black holes and quasars. Many studies have shown that the importance of mergers increases with redshift. Luminous, merger-induced starbursts and AGN at high redshift provide readily observable signposts for tracing out the main epoch of elliptical galaxy and quasar formation.

Before we can begin to assess quantitatively the physics of the merger process at high redshift and its link to the epoch of elliptical and QSO formation we need to first understand the details of galaxy merging and its relationship to starbursts and AGN in the nearby universe. The most violent local mergers and the probable analogus to luminous high-redshift mergers are the ultraluminous infrared galaxies (ULIRGs). Discovered 20 years ago with the IRAS satellite ULIRGs are now known to be mergers of gas-rich disc galaxies. They span the full range of merger states beyond the first encounter to complete coalescence (see Figure 1). They are amongst the most luminous objects in the local Universe, with both their luminosities ($L > 10^{12}$ $L_{\odot}$ emerging mainly in the far-infrared) and their space densities similar to those of quasars. The near-infrared light distributions in many ULIRGs resemble those of elliptical galaxies. They also have large molecular gas concentrations in their central kpc regions (e.g. Downes and Solomon 1998) with densities comparable to stellar densities in ellipticals. These observational results have led several groups (e.g. Sanders et al. 1988) to posit that ULIRGs evolve into ellipticals through dissipative collapse triggered by a merger. In this scenario, the mergers first go through a luminous starburst phase, followed by a dust-enshrouded AGN phase, and finally evolve into optically bright, "naked" QSOs once they either consume or shed their shells of gas and dust.

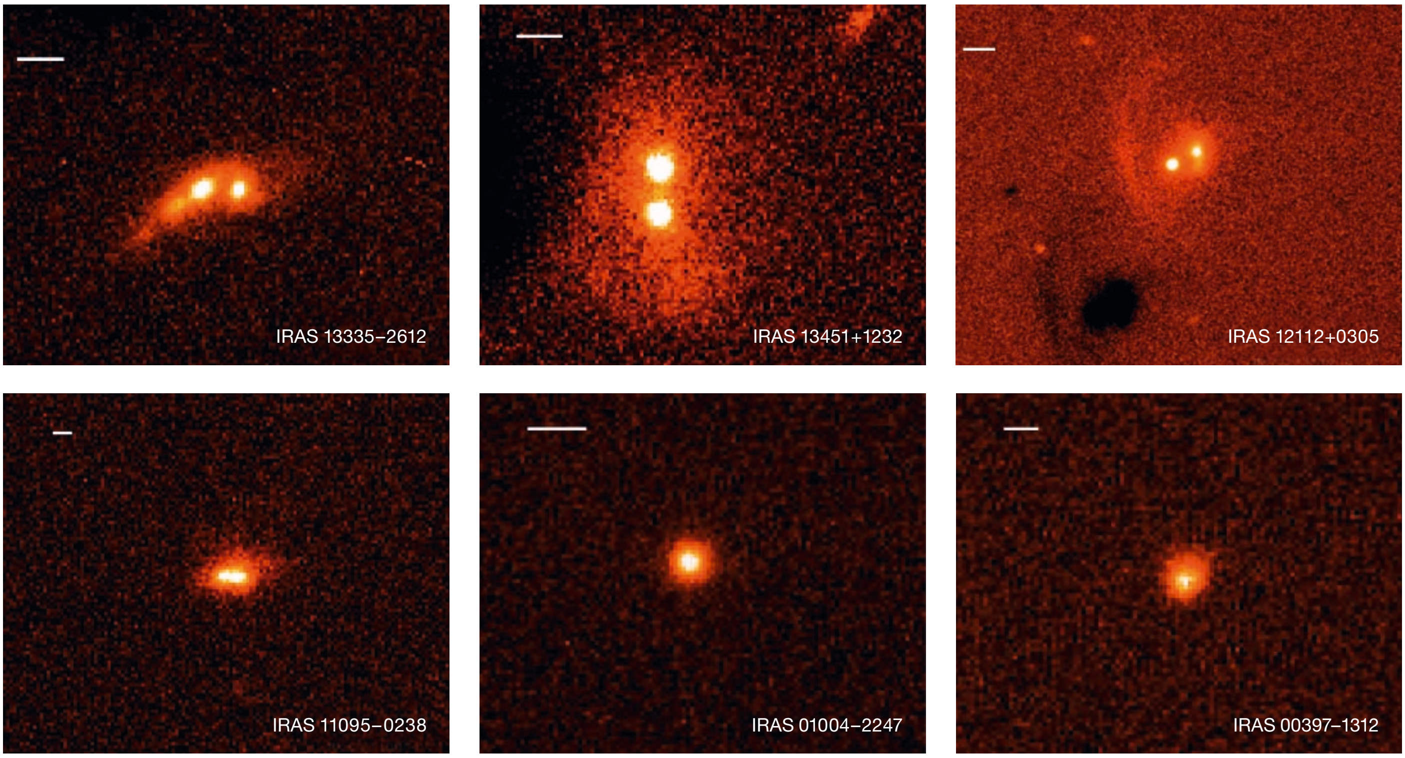
Numerical simulations undertaken by a number of groups also show that the violent merging of massive disc galaxies produces ULIRGs that evolve into spheroidal remnants with properties similar to those of elliptical galaxies (e.g. Barnes and Hernquist; Naab and Burkert 2003). The simulations trace the merging process from the initial encounter to final coalescence, when the merger remnant has settled into dynamical equilibrium. They predict that soon after the first encounter, the interstellar medium of the two galaxies is efficiently concentrated in the central few kiloparsecs on a dynamical timescale (a few tens of millions of years) due to large gravitational torques removing angular momentum from the gas. Equal-mass mergers of massive galaxies produce the highest central gas concentrations. Even in these most violent mergers, the kinematics of the system already reach their equilibrium values of rotation and dispersion by the time the two merger nuclei approach to within about one kiloparsec of each other, on a timescale of a few rotation periods (~ 10^8 yrs) (e.g. Bendo and Barnes 2000).

Therefore, the kinematic and structural properties of ULIRG mergers provide an excellent observational means to track the merging process, and to test how and on what timescales star formation and AGN activity are triggered. In order to trace the full potential evolutionary sequence of ULIRGs we have undertaken a spectroscopic programme with ISAAC of a flux-limited, moderately large sample of ULIRGs and a smaller sample of Palomar-Green QSOs. We were awarded 21 nights as a Large Programme, and during this time allocation we have been able to observe a total of 38 ULIRGs and 12 QSOs in a mixture of visitor and service mode. The three main goals of the programme are: (1) to investigate which merger progenitor configurations are likely to result in an ultraluminous infrared phase; (2) to establish an evolutionary connection between ultraluminous infrared galaxies and elliptical galaxies by comparing the dynamical properties of late-stage ULIRGs with those of elliptical galaxies; and (3) to investigate whether there is a fundamental link between ULIRGs and optically bright quasars by comparing the host and central massive black hole properties of late-merger-stage ULIRGs with those of a sample of optically selected QSOs and IR-excess QSOs in the same redshift and luminosity range. The rest of this article presents results that address the first two scientific goals. Our analysis of the QSOs is now in progress.

ISAAC – the ideal instrument to study merger evolution

To derive accurate kinematic properties from stellar absorption features, we needed high-quality, S/N of 30–50 on the continuum, near-IR spectroscopy of the sample sources. For the ULIRGs we selected sources for the study largely from the 1 Jy catalogue (Kim and Sanders 1998). The 1 Jy catalogue comprises a complete flux-limited (at 60 μm) sample of 118 ULIRGs compiled from a redshift survey of IRAS Faint Source Catalog objects.

Figure 1: The ISAAC *H*-band acquisition images for a selection of the programme sources, which show the variety of merging stages of the ULIRGs and also the excellent conditions at the VLT while the data were obtained. The horizontal bar in the upper left corner of each panel corresponds to 5 kpc at the redshift of the source.



We have observed those sources with declinations < 25°, and with redshifts where the strong rest frame *H*-band stellar absorption lines lie in parts of the *H*- and *K*-band with high atmospheric transmission ($z < 0.13$ and $z > 0.20$). For these very dusty systems, observations in the near-infrared are superior to those in the optical for this purpose, since optical spectroscopy cannot penetrate to the centres of most ULIRGs. We chose to observe in the rest-frame *H*-band, where there are a host of stellar absorption features (e.g. CO $\Delta v = 3$ bands) and gas emission lines (e.g. [Fe II]) readily available. Such observations are only possible on 8-metre-class telescopes with sensitive IR spectrometers, since the strength of the absorption features is only a few per cent of the continuum. The VLT with ISAAC in its medium-resolution mode was a winning combination with which to carry out the programme.

We typically integrated for one hour on source per slit, and observed along at least two position angles per source. Our group had previously completed a smaller pilot study of about 15 ULIRGs (Genzel et al. 2001, and Tacconi et al. 2002), also largely with ISAAC on the VLT, and we have augmented the current programme sample with those sources as well. The total sample thus comprises 54 ULIRGs and 12 PG QSOs, and is the most complete and unbiased dynamical study of these systems to date. The sample covers the full range of the local ULIRG luminosity function, merger state and AGN activity. Our observations of these ULIRGs have yielded unprecedented, high-quality spectra, from which we have been able to derive stellar dynamical quantities (Figure 2). From the spectra we extract the stellar velocity dispersion, σ, and the rotational velocity, V_{rot}, for each source. We analyse the kinematic parameters together with structural quantities taken mostly from the 1 Jy sample photometric study of Veilleux et al (2002). Our group is also conducting an HST NICMOS imaging programme (PI Sylvain Veilleux) of many of the sample galaxies.

Dynamical evidence for major mergers

The present ULIRG sample contains 21 binary (early-stage merger) systems that we have observed to track the pre-coalescence merger phases, and to measure the mass ratios of these systems. For the binary ULIRGs we have measured the kinematic properties separately for each progenitor nucleus in the system. From the stellar dispersions and rotational velocities we compute the dynamical masses of the merging galaxies. We find that ultraluminous luminosities are mainly generated by almost equal-mass mergers; the average mass ratio of the binary ULIRGs is 1.5 : 1 and 68 % of these sources are 1 : 1 encounters. Less frequently, we also find 3 : 1 mergers in our sample, but do not have a firm case where the dynamical mass ratio would indicate ULIRG activity being triggered in a minor merger. Mergers of mass ratio > 4 : 1 typically do not drive enough gas to the centre of the merger to generate ultraluminous luminosities. These results are in agreement with many merger models in the literature (e.g. Naab & Burkert 2003) that all predict that ultraluminous activity is efficiently triggered in a major merger of two massive, gas-rich galaxies.

ULIRGs evolve into intermediate-mass elliptical galaxies

We are investigating the relationship between ULIRGs and elliptical galaxies by

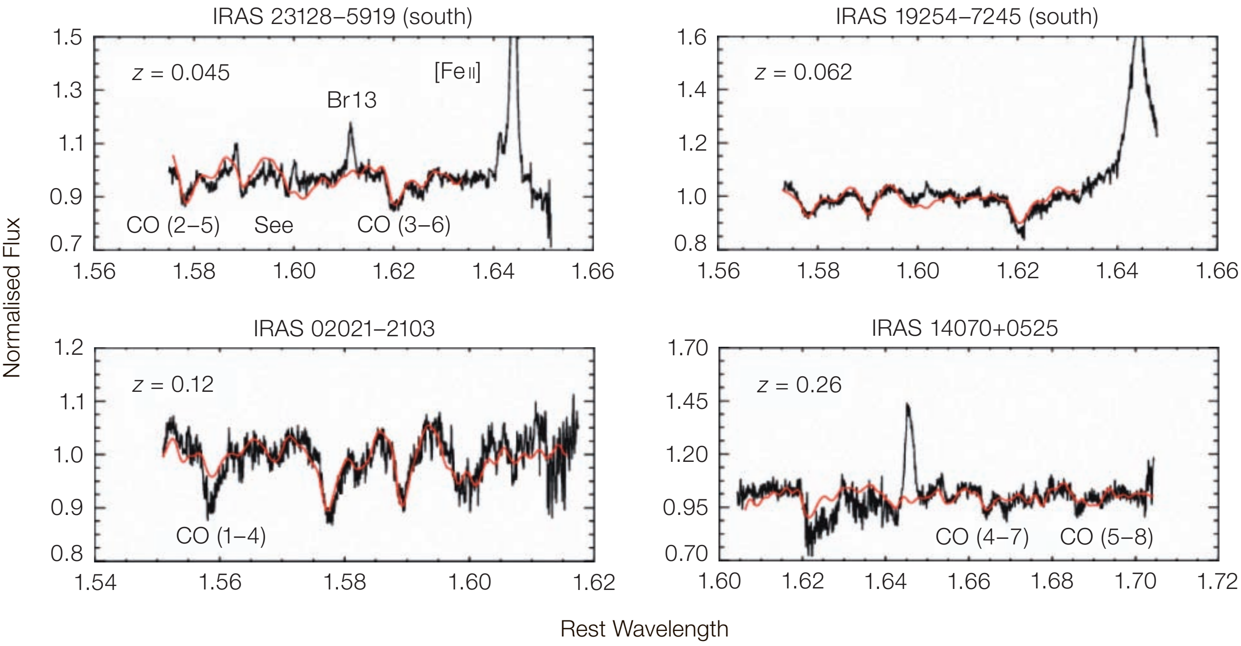


Figure 2: The normalised *H*-band spectra for a selection of the programme sources as a function of rest-wavelength. For comparison, the stellar templates, convolved with the Gaussian that best represents the broadening function (velocity dispersion) of the galaxy are over-plotted in red.

comparing the dynamical properties of the late merging stage ULIRGs (i.e. those coalesced into a single system) with those of representative samples of local elliptical galaxies. The mean stellar velocity dispersion of the fully coalesced, single nucleus ULIRGs is 157 (± 40) km s^{-1}. This mean dispersion is comparable or slightly lower than that of an L* elliptical galaxy (defined as M_B ~ – 20.4 mag). The velocity dispersion distribution of the ULIRG sample, in fact, closely matches that of compact-core, discy-isophote elliptical galaxies with intermediate masses, and is very different from the (more massive) slowly-rotating/large-core/boxy-isophote ellipticals.

As a result of the virial theorem and common formation and evolution processes, dynamically hot systems (elliptical galaxies, lenticular galaxies, and spiral galaxy bulges) are all found in a well-defined plane of a space comprised of velocity dispersion (σ), effective radius (r_{eff}), and surface brightness with that radius (μ_{eff}). One particularly instructive way of investigating a possible evolutionary track of ULIRGs into elliptical galaxies, therefore, is to place both the ULIRG and elliptical samples on the same fundamental plane. Placing the young, infrared luminous merger systems in this space and comparing them to much older ellipticals is tricky, however, because of the influences of stellar evolution, extinction, and perhaps incomplete dynamical relaxation, all of which will strongly affect the central surface brightness and effective radii even if they are determined in the less extinguished near-infrared bands. To minimise these effects, we consider only the less evolution-sensitive, effective radius – host velocity dispersion (r_{eff}–σ) projection of the fundamental plane. We present this projection of the fundamental plane in Figure 3 for our ULIRG sample together with samples of giant (boxy-isophotal profile) ellipticals, moderate-mass (discy-isophotal profile) ellipticals (both from the work of Bender et al. 1992 and Faber et al. 1997), local cluster ellipticals (from Pahre 1999), and a small sample of luminous infrared galaxies (LIRGs; 10^{11} $L_\odot$ < L < 10^{12} $L_\odot$; from James et al. 1999 and Shier and Fisher 1998). The location of an elliptical galaxy along the fundamental plane is correlated with its luminosity (mass) and its dynamical and structural properties. The most massive ellipticals with boxy isophotes and large cores are found in the upper right of the diagram, while somewhat lower-luminosity, less massive ellipticals and lenticulars with discy isophotes are found in the central part of the plane. Figure 3 shows that most ULIRGs are remarkably close to or on the fundamental plane of early-type galaxies, strongly supporting the hypothesis that they will ultimately evolve into elliptical galaxies. As indicated by their moderate velocity dispersions and compact effective radii, the majority of the ULIRGs populate the region of the plane occupied by the intermediate-mass, discy-isophote elliptical galaxies. Although the late-merger-stage ULIRGs are dynamically hot systems (i.e. the velocity dispersion dominates the kinematics) the ULIRGs still show a significant rotational component in their stellar dynamics. We find a mean rotational to dispersion velocity ratio (v_{rot}/σ) of 0.6 for these late-stage ULIRGs. We again compare the ULIRGs to elliptical galaxies (see Figure 4), and find that ULIRGs have a v_{rot}/σ ratio comparable to what is found for intermediate-mass elliptical and lenticular galaxies. We conclude that there is strong dynamical evidence connecting late-stage local ULIRGs over the full range of the ULIRG luminosity function and intermediate-mass elliptical galaxies. Our previous pilot study (Genzel et al. 2001; Tacconi et al. 2002) showed a similar trend, although there we sampled only a small range of parameter space.

Ongoing work

The detailed results from the early-merging stage ULIRGs are presented in Dasyra et al. 2005, which has just been accepted by the Astrophysical Journal. A paper investigating the dynamical and black-hole properties of the late-merging-stage, single-nucleus systems in the sample is now in the final stage of completion. In the third part of the programme, we are investigating the possible evolutionary connection between ULIRGs and local QSOs, and we are currently analysing the ISAAC *H*-band spectroscopy of our sample of 12 Palomar-Green QSOs spanning the same redshift and luminosity range as the ULIRG sample.

Acknowledgements

We are extremely grateful to the ESO staff for the excellent support we have received during both the visitor- and service-mode phases of this programme.

References

Barnes, J. E., Hernquist, L. 1996, ApJ 471, 115
Bender, R. et al. 1992, ApJ 399, 462
Bendo, G. J., Barnes, J. E. 2000, MNRAS 316, 315
Dasyra, K. M. et al. 2005, ApJ, in press, astro-ph/0510670
Downes, D., Solomon, P. M. 1998, ApJ 507, 615
Genzel, R. et al. 2001, ApJ 563, 527
James, P. et al. 1999, MNRAS 309, 585
Kim, D.-C, Sanders, D. B. 1998, ApJS 119, 41
Naab, T., Burkert, A. 2003, ApJ 597, 893
Pahre, M. A. 1999, ApJS 124, 127
Sanders, D. et al. 1988, ApJ 328, L 35
Shier, L. M., Fischer, J. 1998, ApJ 497, 163
Tacconi, L. J. et al. 2002, ApJ 580, 73
Veilleux, S. et al. 2002, ApJS 143, 315

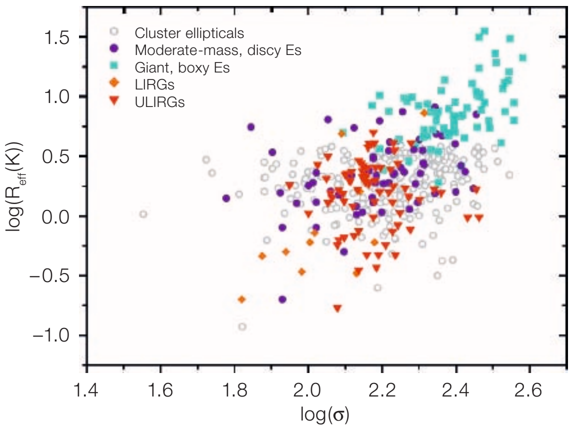


Figure 3: The dynamical projection (effective radius – velocity dispersion, r_{eff}–σ) of the fundamental plane for our sample of ULIRGs, compared with samples of elliptical galaxies and lower-luminosity infrared galaxies (LIRGs). See text for references.

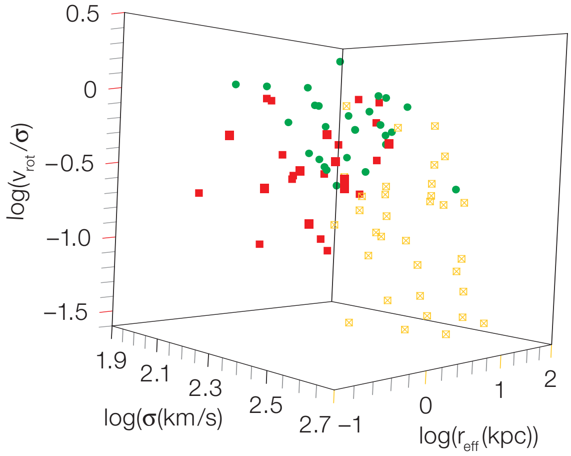


Figure 4: Here we show a three-dimensional plot ($\sigma - r_{eff} - v_{rot}/\sigma$), which indicates the distribution of the ratio of rotation-to-dispersion velocity for the fully coalesced ULIRGs and local elliptical galaxies. The ULIRGs are shown in red, intermediate-mass (discy) ellipticals in green and giant (boxy) ellipticals in gold. The elliptical galaxy properties are taken from Bender et al. (1992) and Faber et al. (1997).

Supernova in NGC 1559

Colour-composite image of the spiral galaxy NGC 1559 in the Reticulum constellation, obtained with FORS1 on the VLT. NGC 1559 is located about 50 million light years away and is about seven times smaller than our Milky Way. The supernova SN 2005df, discovered on the night of August 4, 2005, is visible as the bright star just above the galaxy. SN 2005df has been further classified as a somewhat unusual type Ia supernova, caught probably 10 days before it reached its maximum brightness. Dietrich Baade, Ferdinando Patat (ESO), Lifan Wang (Lawrence Berkeley National Laboratory, USA), and their colleagues studied its polarisation properties and found that SN 2005df resembles closely SN 2001el, whose explosion was significantly asymmetric.

See ESO Press Photo 26/05 for more details.

Lithium Isotopic Abundances in Metal-Poor Stars: A Problem for Standard Big Bang Nucleosynthesis?

Poul E. Nissen[1]
Martin Asplund[2]
David L. Lambert[3]
Francesca Primas[4]
Verne V. Smith[5]

[1] Department of Physics and Astronomy, Aarhus University, Denmark
[2] Research School of Astronomy and Astrophysics, Mt. Stromlo Observatory, Australia
[3] The W. J. McDonald Observatory, The University of Texas at Austin, USA
[4] ESO
[5] National Optical Astronomy Observatory, Tucson, USA

Spectra obtained with VLT/UVES suggest the existence of the ^{6}Li isotope in several metal-poor stars at a level that challenges ideas about its synthesis. The ^{7}Li abundance is, on the other hand, a factor of three lower than predicted by standard Big Bang nucleosynthesis theory. Both problems may be explained if decaying supersymmetric particles affect the synthesis of light elements in the Big Bang.

Ever since the discovery of a plateau for lithium abundances in warm, metal-poor halo stars by Spite & Spite (1982), the Big Bang has been identified as the initial and major origin of the ^{7}Li isotope, with the plateau abundance being used to test theories of Big Bang nucleosynthesis. According to the standard Big Bang model, the relative abundances of the light elements (hydrogen, deuterium, helium and lithium) depend on only one parameter: the baryon-to-photon ratio η. Using the recent precise determination of η from cosmic microwave background fluctuations, the lithium-to-hydrogen ratio is predicted to be $N_{^7\mathrm{Li}}/N_\mathrm{H} = (4.15 \pm 0.5) \times 10^{-10}$ (Coc et al. 2004). This corresponds to a logarithmic abundance $\log\varepsilon(^7\mathrm{Li}) \equiv \log(N_{^7\mathrm{Li}}/N_\mathrm{H}) + 12.0 = 2.62 \pm 0.05$ on the traditional astronomical scale, where the logarithmic hydrogen abundance is normalised to 12. The predicted ^{7}Li abundance is about a factor three higher than Li abundances found in very metal-poor stars on the Spite plateau. Thus, a key question has become – How does one bridge the gap between ^{7}Li observation and prediction?

A second question has arisen from the detection of ^{6}Li in the metal-poor star HD 84937 (Smith et al. 1993; Hobbs & Thorburn 1994; Cayrel et al. 1999) with an abundance that is orders of magnitudes higher than predicted from standard Big Bang nucleosynthesis. How does one explain this unexpected high ^{6}Li abundance?

In order to study these two lithium problems in more detail, we have conducted a survey of isotopic lithium abundances in a sample of 24 dwarf stars ranging in metal abundance, $[\mathrm{Fe/H}] \equiv \log(N_\mathrm{Fe}/N_\mathrm{H})_\mathrm{Star} - \log(N_\mathrm{Fe}/N_\mathrm{H})_\mathrm{Sun}$, from –1 to –3, i.e. with metal-to-hydrogen ratios that are a factor of 10 to 1000 smaller than the ratio in the Sun. Hence, the stars are likely to have been formed from interstellar gas relatively little affected by element production in stars.

VLT/UVES high-resolution spectra

The isotopic shift of the 670.8 nm resonance line of ^{6}Li relative to the corresponding ^{7}Li line is only 0.016 nm. This is comparable to the width of the lithium line due to fine structure splitting and line broadening caused by turbulence in the stellar atmosphere. In addition, it turns out that the ^{6}Li/^{7}Li ratio does not exceed 10 %. Hence, the presence of ^{6}Li is revealed by a slight additional asymmetry of the 670.8 nm line. Consequently, both very high spectral resolution and signal-to-noise are needed to detect ^{6}Li. With 4-m-class telescopes, only a few fairly bright ($V < 9$ mag) stars, such as HD 84937, could be studied, but beginning in 1999 the VLT and its high-resolution spectrograph UVES opened up the possibility to conduct a systematic search for ^{6}Li in fainter and more metal-poor stars.

The spectra used in the present study were obtained in July 2000, February 2002 and August 2004. In order to obtain the highest possible spectral resolution ($\lambda/\Delta\lambda = 120\,000$) we used an image slicer, which transforms the seeing disc of the star to a rectangular image matching the narrow (0.3 arcsec) entrance slit of the UVES spectrograph. In addition to improving the efficiency of the observations, the image slicer also serves to broaden the spectrum, and hence to minimise problems of flatfielding the spectra to a smooth continuum.

A detailed description of the observations and data reduction is given in Asplund et al. (2005). The spectra cover the spectral region 600–820 nm, except for the August 2004 observations, when the very metal-poor star LP815-43 was re-observed with a different UVES setting corresponding to the 500–700 nm region in order to test a tentative detection of ^{6}Li based on the July 2000 spectrum.

Figure 1 shows the spectra of three stars in the wavelength region around the Li 670.8 nm line. The signal-to-noise (S/N) per spectral bin (0.0027 nm) is 600, which is typical for the sample. Note the differences in metallicity between the three stars as reflected in the strength of the calcium line at 671.8 nm.

Stellar parameters

In order to derive isotopic lithium abundances we must know the basic physical parameters that characterise the atmosphere of a given star. These parameters

Figure 1: Sample spectra around the Li I 670.8 nm line with CD –48°2445 and CD –33°3337 shifted 0.10 and 0.20, respectively. Note, that the region between the Li I and the Ca I lines in the spectrum of CD –33°3337 is affected by several faint lines not identified on the figure.

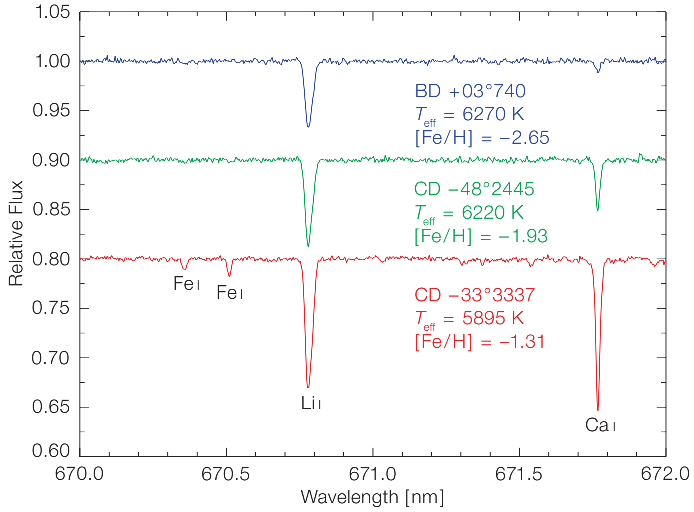
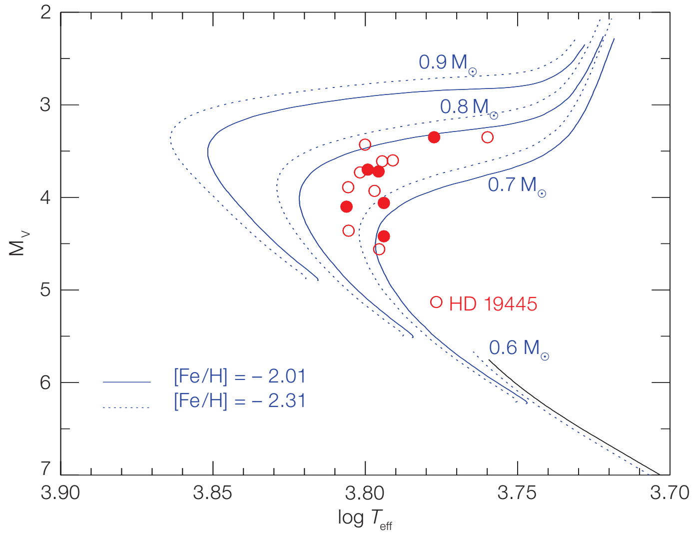


Figure 2: HR-diagram for stars with [Fe/H] < –1.7. Filled circles are stars with a ≥ 2σ detection of ^{6}Li, and open circles refer to stars with no clear detection of ^{6}Li. Evolutionary tracks corresponding to a range of masses are from VandenBerg et al. (2000).



are: the effective temperature T_{eff}, the surface gravity g, and the metallicity [Fe/H].

Precise values of T_{eff} are particularly important. Often this characteristic surface temperature is derived from the stellar colour, but as the observed colour may be affected by interstellar reddening the value obtained can be wrong. Instead, we have obtained T_{eff} by comparing the observed Hα line in the UVES spectra with synthetic profiles calculated for model atmospheres having a range of effective temperatures. As discussed in Asplund et al. (2005), relative values of T_{eff} are determined to a precision of about ± 30 K; the absolute T_{eff} scale is, however, more uncertain.

The surface gravity of a star was estimated via its absolute magnitude M_V as determined from Strömgren photometry and Hipparcos parallaxes. The metallicity is based on Fe II lines. The values of these parameters are not critical for the derived isotopic Li abundances, but they are important when discussing the interpretation of our results. Thus, the M_V-logT_{eff} diagram in Figure 2 shows that our most metal-poor stars (except HD 19445) lie close to the turnoff region of halo stars. From a comparison with evolutionary tracks from VandenBerg et al. (2000) we derive ages of about 12–14 Gyr confirming that the sample is indeed representative of the oldest stellar population in our galaxy.

Deriving ^{6}Li/^{7}Li

The lithium isotopic ratio was derived by comparing synthetic profiles of the Li I 670.8 nm line with the observed profile. Traditional plane-parallel model atmospheres were applied, but it has been checked that 3D hydrodynamical models give similar or even higher ^{6}Li/^{7}Li ratios than 1D models.

The method is illustrated in Figure 3. First, the width of spectral lines due to macroturbulence in the stellar atmosphere and instrumental broadening is determined as shown in the upper panel for the Ca I 612.2 nm line. Several such lines were applied to determine the macroturbulence velocity and a minor variation of the instrumental broadening with wavelength as determined from the width of thorium comparison lines was taken into account.

In the next step (middle panel) the average macroturbulence velocity plus instrumental broadening are applied in a synthesis of the observed Li I 670.8 nm line. The comparison between the theoretical and observed profiles is quantified by calculating the chi-square function $\chi^2 \equiv \Sigma(O_i - S_i)^2/\sigma^2$, where O_i and S_i denote the observed and synthetic flux at wavelength point i, respectively, and σ = (S/N)$^{-1}$ is estimated in three nearby continuum windows. For each ^{6}Li/^{7}Li, the total Li abundance, the wavelength zeropoint of the observed spectrum and the continuum level are allowed to vary in order to optimise the fit and thus minimise χ^2.

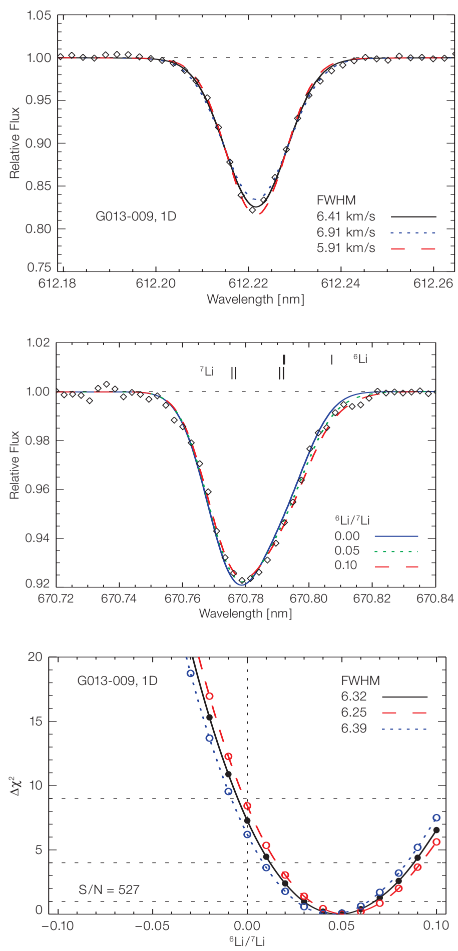


Figure 3: Illustration of the method applied to determine ^{6}Li/^{7}Li in G 013-009. See text for a description of the three panels.

The most probable value for ^{6}Li/^{7}Li corresponds to the minimum of χ^2.

In the case of G 013-009 the derived value of ^{6}Li/^{7}Li is close to 0.05 as seen from the lower panel of Figure 3. This value is quite insensitive to the estimated error in the macroturbulence velocity. The 1σ, 2σ and 3σ confidence limits of the determination correspond to $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ = 1, 4 and 9, respectively. As seen, ^{6}Li is detected in G 013-009 with a confidence limit of about 2.5σ, i.e. with a probability of 99 %.

The derived ^{6}Li/^{7}Li ratios are plotted as a function of [Fe/H] in Figure 4. As seen, there are nine stars with a $\geq 2\sigma$ detection of ^{6}Li. Many of the other stars may also have a small amount of ^{6}Li; the average of ^{6}Li/^{7}Li for the whole sample is close to 2 %. In this connection, it is natural to ask if there could be a systematic error in the ^{6}Li/^{7}Li determinations of this small amount. If so, there would be very few significant detections of ^{6}Li. The fact that the main-sequence star HD 19445 has a ^{6}Li/^{7}Li ratio close to zero (see Figure 4) is, however, an argument against this possibility. As shown in Figure 2, HD 19445 is an unevolved main-sequence star. With its mass of about 0.65 solar masses, it has a rather deep upper convection zone, and according to models of stellar structure, ^{6}Li cannot survive proton destruction in such a star. Hence the star can be considered as a reliable check of the zero point of the ^{6}Li determinations.

Except for HD 19445, the stars in Figure 4 are all turnoff stars or slightly evolved beyond the turnoff. Particularly interesting is the very metal-poor star LP 815-43 (T_{eff} = 6 400 K, $\log g$ = 4.2 and [Fe/H] = −2.7). From the July 2000 spectrum, we obtained ^{6}Li/^{7}Li = 0.078 ± 0.033. Given the rather large error bar, it was decided to re-observe the star in August 2004 with a different setting of UVES to get an independent determination of ^{6}Li/^{7}Li. The new result is ^{6}Li/^{7}Li = 0.046 ± 0.022. Within the error bars the two results agree fairly well, and the weighted average value is ^{6}Li/^{7}Li = 0.056 ± 0.018, i.e. formally a 3σ detection of ^{6}Li.

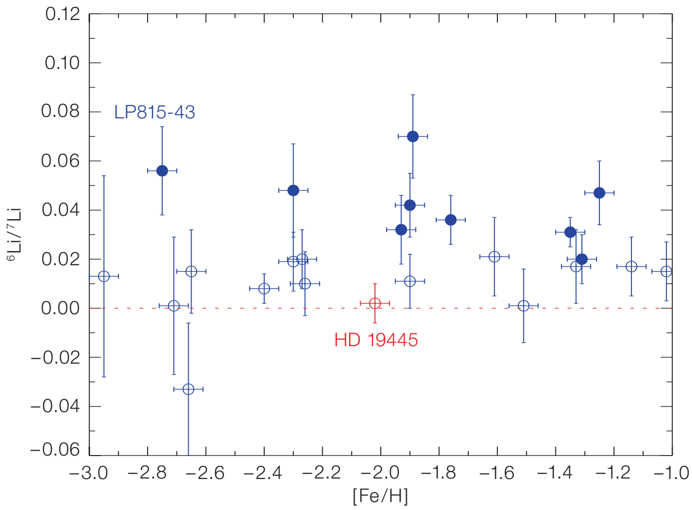


Figure 4: The derived ^{6}Li/^{7}Li ratio as a function of [Fe/H]. Stars considered to have a significant detection ($\geq 2\sigma$) of ^{6}Li are shown with filled circles.

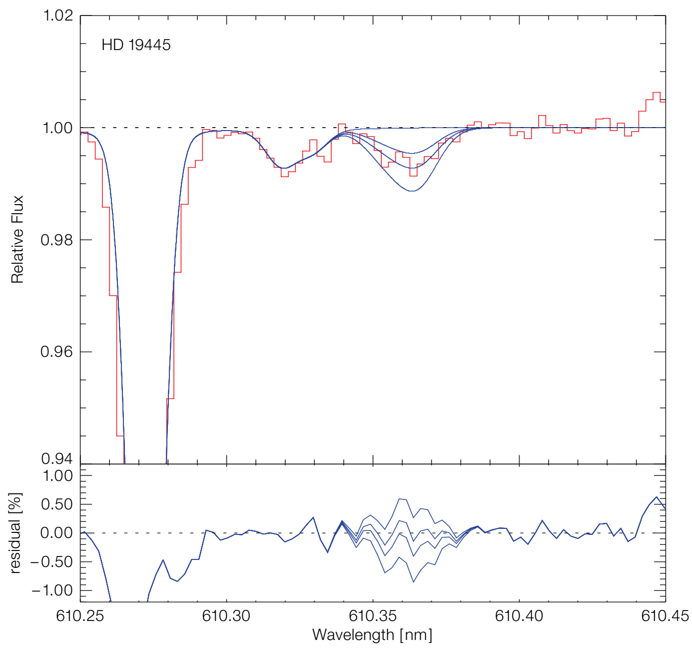


Figure 5: Observed (red) and theoretical (blue) Li I 610.4 nm profiles for HD 19445. The four synthetic profiles are computed with no Li and $\log\varepsilon$(Li) = 2.0, 2.2 and 2.4, respectively.

The two lithium problems

In addition to ^{6}Li/^{7}Li, we derive precise values for the total lithium abundance from the fits to the 670.8 nm line. Furthermore, the exceptionally high quality of our UVES spectra allows Li abundances to be derived from the subordinate Li I line at 610.36 nm. Figure 5 shows this line in HD 19445 together with synthetic spectra calculated for various Li abundances. The best fit is obtained for $\log\varepsilon$(Li) = 2.19 ± 0.05, close to the value obtained from the 670.8 nm line. The subordinate line is detected in 22 of the 24 stars, and the mean difference of Li abundances derived from the subordinate line and the resonance line is + 0.05 ± 0.05 dex. This is an encouraging confirmation of the reliability of our Li abundance scale.

In Figure 6, ^{6}Li and ^{7}Li abundances are plotted as a function of [Fe/H]. Except for one star, HD 106038 (known to have peculiar high *s*-process abundances), the scatter in ^{7}Li is remarkably small, i.e.

~ 0.03 dex at a given metallicity. The ^{7}Li abundance appears to increase slightly with increasing metallicity, which may be due to Galactic cosmic-ray production of ^{7}Li. The trend implies an apparent "primordial" ^{7}Li abundance of about 2.1 dex, i.e. a factor of three below the value of 2.6 dex predicted from standard Big Bang nucleosynthesis and the WMAP-based value of the baryon-to-photon ratio. People studying stellar structure and evolution have tried to explain this difference as due to depletion of ^{7}Li by processes that mix the gas in the stellar atmosphere with hotter layers, where Li is destroyed by reactions with fast protons. Turbulent diffusion seems to be the most promising mechanism; for the right choice of free parameters it can provide both a factor of three depletion and retain a very small dispersion of ^{7}Li among the plateau stars (Richard et al. 2005).

The turbulent diffusion models, which deplete ^{7}Li with a factor of three, predict, however, a depletion of ^{6}Li by more than a factor of 30. This would mean that the observed ^{6}Li values in Figure 6 should be corrected upwards by at least 1.5 dex to correspond to the original ^{6}Li abundance at the time of star formation. Such high ^{6}Li abundances seem impossible to be explained by production of ^{6}Li through Galactic cosmic-ray processes involving $\alpha + \alpha$ fusion and spallation of CNO nuclei. The production in a realistic model by Ramaty et al. (2000), involving cosmic rays accelerated out of supernova ejecta-enriched superbubbles, is shown as a dashed line in Figure 6; as seen the model has already difficulties in explaining the uncorrected ^{6}Li abundances in the most metal-poor stars. More speculative models of pregalactic synthesis of ^{6}Li have been suggested. Thus, Suzuki and Inoue (2002) suggest that α-particles are accelerated by gravitational shocks induced by infalling matter during hierarchical structure formation, and Rollinde et al. (2005) suggest an early burst of cosmological cosmic rays perhaps caused by population III stars. The energetics of such a scenario were, however, not considered.

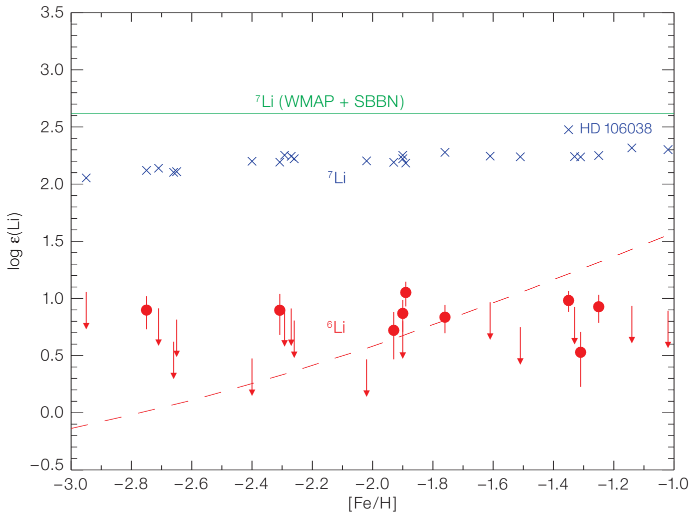


Figure 6: Observed logarithmic abundances of ^{6}Li (red circles) and ^{7}Li (blue crosses) as a function of metal abundance. Stars with a $\geq 2\sigma$ detection of ^{6}Li are shown with filled circles; 2σ upper limits are shown for the other stars. The predicted evolution of ^{6}Li due to Galactic cosmic-ray processes (dashed line) is taken from Ramaty et al. (2000), and the predicted ^{7}Li abundance due to standard Big Bang nucleosynthesis is shown as a green horizontal line.

Big Bang nucleosynthesis of lithium

The most interesting feature of Figure 6 is perhaps that the observed ^{6}Li abundances appear to form a plateau in contrast to the rise of ^{6}Li predicted by Galactic cosmic-ray processes. A plateau in ^{6}Li could be an indication that ^{6}Li has a primordial Big Bang origin like ^{7}Li. Standard Big Bang nucleosynthesis predicts, however, ^{6}Li/^{7}Li ~ 10^{-5}, i.e. orders of magnitudes below the ^{6}Li observations.

Extensions of standard particle physics to supersymmetry predict the existence of various exotic particles, including the gravitino. The decay of such relic particles during the era of Big Bang nucleosynthesis can alter the resulting light element abundances, provided the masses and lifetimes of these putative particles are right. As shown by Jedamzik (2004), the injection of energetic nucleons through hadronic decay about 10^3 s after Big Bang can lead to substantial ^{6}Li production without spoiling the agreement with observed values of the primordial abundance of D and He. Furthermore, simultaneous destruction of ^{7}Li with a factor 2 to 3 is possible. This would explain both the observed ^{6}Li plateau and the low ^{7}Li abundances in metal-poor stars. Thus, both of the Li problems can conceivably be solved at the same time.

While this idea is attractive, it rests on as yet unproven physics. Furthermore, it should be noted that the ^{6}Li results we have obtained are at the borderline of being clear detections. Hence, more work is needed in order to obtain additional data especially for the most metal-poor stars and also to verify the zero-point of the ^{6}Li/^{7}Li determinations.

References

Asplund, M. et al. 2005, astro-ph/0510636
Cayrel, R. et al. 1999, A&A, 343, 923
Coc, A. et al. 2004, ApJ 600, 544
Hobbs, L. M. and Thorburn, J. A. 1994, ApJ 428, L 25
Jedamzik, K. 2004, Phys. Rev. D 70, 063524
Ramaty, R., et al. 2000, ApJ 534, 747
Richard, O., Michaud, G., and Richer, J. 2005, ApJ 619, 538
Rollinde, E., Vangioni, E., and Olive, K. 2005, ApJ 627, 666
Smith, V. V., Lambert, D. L., and Nissen, P. E. 1993, ApJ 408, 262
Spite, F. and Spite, M. 1982, A&A 115, 357
Suzuki, T. K. and Inoue, S. 2002, ApJ 573, 168
VandenBerg, D. A. et al. 2000, ApJ 532, 430

The VLT-FLAMES Survey of Massive Stars

Christopher Evans[1,2]
Stephen Smartt[3]
Daniel Lennon[2]
Philip Dufton[3]
Ian Hunter[3]
Rohied Mokiem[4]
Alex de Koter[4]
Mike Irwin[5]

[1] UK Astronomy Technology Centre, Edinburgh, United Kingdom
[2] Isaac Newton Group of Telescopes, La Palma, Spain
[3] Queen's University of Belfast, Northern Ireland
[4] University of Amsterdam, the Netherlands
[5] Institute of Astronomy, Cambridge, United Kingdom

We have observed an unprecedented sample of 800 massive stars in open cluster fields in the Magellanic Clouds and Milky Way, primarily with the multi-fibre FLAMES instrument. The survey addresses the role of environment, via stellar rotation and mass-loss, on the evolution of the most massive stars, which are the dominating influence on the evolution of young, star-forming galaxies.

The Large and Small Magellanic Clouds (LMC and SMC) are our nearest cosmic neighbours to the Milky Way. Detailed studies of stars and gas regions in the Clouds over the past 50 years have revealed that conditions in them are very different to those seen in our galaxy. Compared to the Sun, the Clouds are found to be metal-poor ("metals" meaning elements heavier than helium). The metal content, or metallicity, in the LMC is 40 % of that found in the Sun, and drops to 20 % in the SMC. These different abundances mean that the Clouds are an excellent laboratory to test our understanding of the role of metals in star formation and stellar evolution.

Interest in massive stars in the Magellanic Clouds has been particularly strong in recent years. The evolution of O and early B-type stars is dominated by the effects of mass-loss from their strong stellar winds, with the most massive O stars already losing a significant amount of their initial mass over their core hydrogen-burning lifetimes. Stellar winds are accelerated by momentum transfer from photons in the radiation field to metal ions (such as carbon, nitrogen, and iron) in the outer atmosphere of the star. It follows that the intensity of these winds, and therefore the mass lost by a star over its lifetime, are expected to be dependent on the metallicity of the region in which the star formed (Kudritzki et al., 1987). Observational evidence of this has been relatively scarce, limited to small samples of O stars (Puls et al. 1996) and luminous B-type supergiants (Evans et al. 2004; Crowther et al. 2006).

Another factor that strongly affects the evolution of a star is its rate of rotation. Stellar evolutionary models that include the effects of rotation predict enhanced amounts of helium and nitrogen at the surface of the atmosphere. The importance of this process is thought to depend on the initial metal abundance (Maeder and Meynet, 2001). There are also suggestions that the distribution of stellar rotation rates may depend on the metal abundance (Maeder et al. 1999).

Understanding the physical processes in massive stars has far-reaching implications, from the feedback of kinetic energy into the interstellar medium and metal enrichment of their host galaxies, to issues such as the progenitors of supernova explosions and gamma-ray bursts. The unique combination of high-resolution, multi-object spectroscopy from FLAMES provides us with an excellent opportunity to expand on previous studies, which were limited to a few tens of stars by the available instrumentation. The FLAMES Survey of Massive Stars has observed a large sample of O and B-type stars, in a range of environments (i.e. the Milky Way, the LMC and the SMC) to fully investigate the role of metallicity on stellar evolution.

Target fields

Our FLAMES fields were centred on seven stellar clusters, selected to sample a range of age and metallicity as summarised in Table 1. Our targets were selected from images taken with the Wide-Field Imager (WFI) on the 2.2-m telescope at La Silla, most of which were from the ESO Imaging Survey pre-FLAMES programme. We have observed 750 stars with FLAMES, using six of the standard wavelength settings of the Giraffe spectrograph at high resolution (R ~ 20 000). This gives continuous wavelength coverage from 385–475 nm in the blue, with additional coverage from 638–662 nm. The red region includes the Hα Balmer line, an important diagnostic of mass-loss from stellar winds and invaluable for identification of Be-type stars. The brightest 50 stars in the three Milky Way clusters were observed separately with FEROS on the 2.2-m. The survey is introduced at length

Table 1: Summary of fields observed with VLT-FLAMES.

	Metallicity	"Young clusters" (< 5 Myrs)	"Old clusters" (10–20 Myrs)
Milky Way	Solar	NGC 6611	NGC 3293 and NGC 4755
LMC	0.4 * Solar	N11	NGC 2004
SMC	0.2 * Solar	NGC 346	NGC 330

Figure 1: *V*-band WFI image of FLAMES targets in N11 in the LMC. O-type stars are marked as open blue circles, B-type stars by yellow circles. Star #26 is an early O-type star in the north of the field, with its spectrum shown in Figure 2. The solid black lines are simply the gaps between CCDs in the WFI mosaic array.

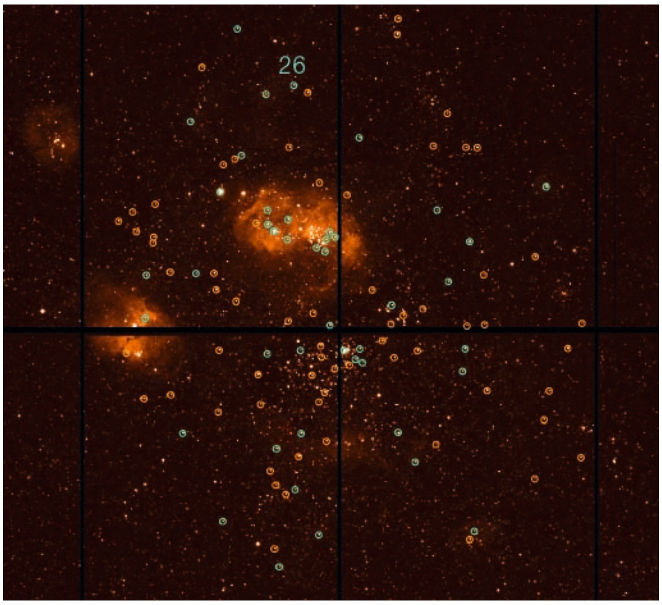
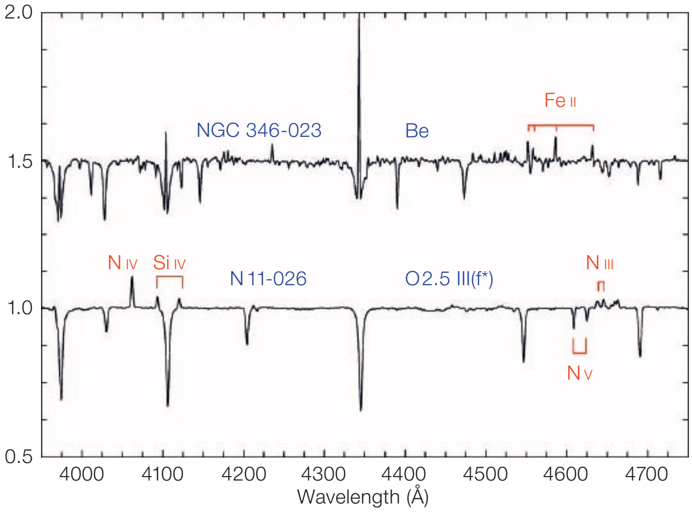


Figure 2: Two FLAMES spectra of note. The lines identified in N11-026, from left to right, are N IV λ4058; Si IV λλ4089-4116; N V λλ4604-4620; N III λλ4634-4640-4642. The lines identified in NGC 346-023 are Fe II λλ4549-4556-4584-4629. For clarity both spectra have been smoothed by a 1.5 Å FWHM filter.



by Evans et al. (2005), together with a discussion of the Milky Way data. A similar paper giving a thorough overview of the LMC and SMC data will also be published in due course. The distribution of spectral types in the whole survey is summarised in Table 2.

A *V*-band WFI image of the N11 region in the LMC is shown in Figure 1. Most of the FLAMES targets are highlighted, distinguishing between O and B-type stars. There is significant structure in the N11 region, with many subtle gaseous arcs and filaments seen only in the near-IR. The dense nebula to the north of centre is Lucke-Hodge 10 in which, as one might expect, a number of O-type stars are found.

The hottest normal stars are those classified as types O2 and O3, with three of these discovered in Lucke-Hodge 10 by Parker et al. (1992). There are still only ~ ten O2-type stars known anywhere, so the statistical sample for attempting studies of these objects remains small. Star #26 in our N11 field (marked in Figure 1, with the FLAMES spectrum shown in Figure 2) is particularly interesting and is classified as O2.5 III (f*). Aside from providing a further example of one of these extreme objects, its location away from the centre is also of note. The general consensus is that this region is a two-stage starburst. Star #26 and the other O stars beyond the central region of the field are likely members of this "second generation" of star formation.

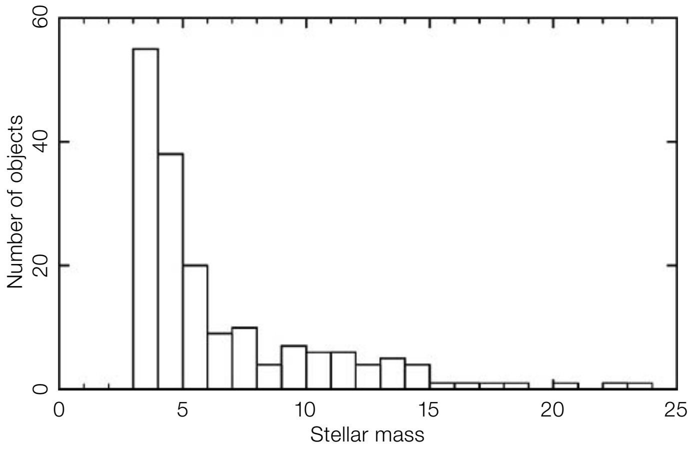
Naturally we have found a number of Be-type stars in the survey, with some displaying permitted Fe II emission lines. The morphology of both the Hα and Fe II profiles suggest that we are observing the stars from a range of perspectives. Single-peaked emission is seen in some, compared to others which show twin-peaked profiles, usually interpreted as observing the star 'edge-on' through a circumstellar disc. One of these Be-type stars in our NGC 346 field is shown in Figure 2. These high-resolution data will provide new insights into the physical properties and nature of Be-type stars.

The FLAMES data are uniquely powerful in another regard. With repeat observations at each of the different wavelength settings, the survey took over 100 h of VLT time to complete. The survey was therefore undertaken in service mode, entailing observations at many different epochs in Periods 71 and 72. This means that we are very sensitive to the detection of binaries, enabling firm lower limits to be put on the binary fraction in our fields, of interest in the context of star formation and the initial mass function – such spectroscopic monitoring has rarely been done before, and certainly not with such high-quality data as that from FLAMES. In some cases the spectroscopic data are sufficiently well-sampled enough to yield periods, and to constrain the properties of the individual components. The FLAMES data provide us

Table 2: Overview of the distribution of spectral types in the FLAMES survey.

Field	O	Early-B (B0-3)	Late-B (B5-9)	AFG	Total
NGC 3293	–	48	51	27	**126**
NGC 4755	–	54	44	10	**108**
NGC 6611	13	28	12	32	**85**
NGC 330	6	98	11	10	**125**
NGC 346	19	84	2	11	**116**
NGC 2004	4 (+ 1 WR)	101	6	7	**119**
N11	43	77	–	4	**124**
Total	**86**	**490**	**126**	**101**	**803**

Figure 3: Distribution of stellar masses in NGC 3293 and NGC 4755, showing all stars with spectral types earlier than B9. The most massive objects are early B-type supergiants and giants, which have evolved from hotter main-sequence stars.



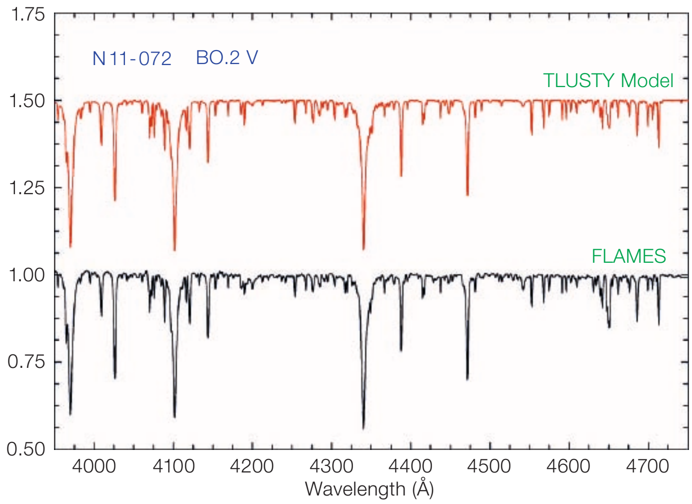


Figure 4: FLAMES spectrum (black line) of the narrow-lined star N11-072, classified as B0.2 V. A model spectrum from the model atmosphere code TLUSTY is shown above in red, for which T_{eff} = 28 800 K and log$g$ = 3.75. Both spectra have been smoothed by a 1.5 Å FWHM to aid clarity, and the model has been convolved by a rotational broadening function of 15 km/s.

with an excellent resource to contribute to studies considering the evolutionary effects of binarity, particularly with regard to mass-transfer of processed elements.

Atmospheric analysis

The use of self-consistent methods and a uniform dataset are the key asset of the FLAMES survey. However, by their very nature O and B-type stars warrant different approaches in terms of analysis. In O stars the stellar winds are a significant factor to be considered when attempting to synthesise their observed spectra, requiring more sophisticated atmospheric models than the majority of B stars.

A total of 86 O-type stars were observed in the survey, nearly half of which were previously unknown. Those in the LMC and SMC fields are now being analysed with one of the state-of-the-art model atmosphere codes, employing a new automated approach with genetic algorithms (Mokiem et al. 2005). With multi-object instrumentation yielding ever larger samples in all fields of astronomy, such automation is becoming increasingly relevant.

Table 2 reveals that the dominant component of the survey is a large number of early B-type stars. These span a range of luminosity classes and rotational velocities. The analysis of the B stars in the three Milky Way clusters will be presented by Dufton et al. (in preparation), in which basic physical parameters such as effective temperatures and gravities are derived, enabling precise determination of the projected rotational velocities. The next step is to determine the velocity distributions for the LMC and SMC stars using similar methods, to investigate whether any evidence for a metallicity dependence is seen. One by-product of the atmospheric analyses by Dufton et al. are estimates of the stellar masses of the sample. Figure 3 shows the mass distribution for NGC 3293 and NGC 4755, which includes all stars in the spectral range B0–B8.

Narrow-lined stars (i.e. those with low projected rotational velocities) are simpler to analyse than those rotating more quickly. In addition to basic properties such as temperature and gravity, chemical abundances of metals can be found because of the well-resolved, narrow lines. Our initial study of the B stars in the Magellanic Clouds has analysed 35 of those with narrow-lined spectra in the N11 and NGC 346 fields (Hunter et al., in preparation). In Figure 4 we show a sample FLAMES spectrum and the model that best matches the observations. Such comparisons provide a wealth of information regarding the evolutionary effects on stellar abundances. Furthermore, analysis of the least evolved stars also provides diagnostics of the baseline, primordial abundances in the Clouds, complementing contemporary studies of A-type stars and H II regions.

References

Crowther P. A. et al. 2006, A&A in press, astro-ph/0509436
Evans C. J. et al. 2004, PASP 116, 909
Evans C. J. et al. 2005, A&A 437, 467
Kudritzki R.-P. et al. 1987, A&A 173, 293
Maeder A. et al. 1999, A&A 346, 459
Maeder, A. and Meynet, G. 2001, A&A 373, 555
Mokiem M. R. et al. 2005, A&A 441, 711
Parker J. W. et al. 1992, AJ 103, 1205
Puls J. et al. 1996, A&A 305, 171

Why are G and K Giants Radial Velocity Variables?

Michaela Petronilla Döllinger [1]
Luca Pasquini [1]
Artie Peter Hatzes [2]
Johny Setiawan [3]
Licio da Silva [4]
Jose Renan de Medeiros [5]
Oskar von der Lühe [6]
Leo Girardi [7]
Maria Pia Di Mauro [8]
Achim Weiss [9]
Markus Roth [6]

[1] ESO
[2] Thüringer Landessternwarte Tautenburg, Germany
[3] Max-Planck-Institut für Astronomie, Heidelberg, Germany
[4] Observatorio Nacional, Rio de Janeiro, Brazil
[5] Departamento de Fisica, Universidade Federal do Rio Grande do Norte, Natal, Brazil
[6] Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
[7] INAF – Osservatorio Astronomico di Trieste, Italy
[8] INAF – Istituto di Astrofisica Spaziale e Fisica Cosmica, Roma, Italy
[9] Max-Planck-Institut für Astrophysik, Garching bei München, Germany

G and K giants are low- and intermediate mass stars that have evolved off the main sequence. Almost 20 years ago they were shown to be Radial Velocity (RV) variables with amplitudes of up to 300 ms^{-1}. After several years of observations with ESO's Fibre-fed, Extended Range, Echelle Spectrograph (FEROS) at La Silla and with the Tautenburg 2-m telescope, we have found that three mechanisms (pulsations, planetary companions, rotational modulations) contribute to the RV variability of these stars.

In the last two decades, the dramatic increase in RV precision from several hundreds to a few ms^{-1} has led to the discovery of RV variability in stars previously thought to be constant. G-K giants are excellent examples of this transformation. These stars occupy a wide region of the cool portion of the Hertzsprung-Russel (H-R) diagram. Low- and intermediate-mass (1–5 $M_{\odot}$) stars that have migrated off the main sequence will spend some hundred million years in this region, either evolving along the Red Giant Branch (RGB), burning helium in the core (clump stars), or climbing the Asymptotic Giant Branch (AGB). In the past, many G-K giants were used as RV standard stars, but over 15 years ago it was discovered that several of them were RV variable. Subsequent investigations of a few objects have established that they show multiperiodic variability on large time scales, from one day to over 600 days.

Are all G-K giants RV variable? Why do these objects vary with such diverse periods?

The short-period (1–10 days) variations are certainly due to oscillations where pressure is the restoring force (p-mode oscillations). The long-period variations can be explained by the presence of stellar/substellar companions orbiting around the giant star. However, this is not the only possible explanation since the variations may also result from so-called rotational modulation. If a large surface inhomogeneity (for instance a starspot) passes the line-of-sight of the observer as the star rotates, distortions of the spectral line profile may result which will be detected as an RV variation with the rotation period of the star. The fact that RV variability in giants has higher amplitudes (50–500 ms^{-1}) than that commonly seen in main-sequence stars suggests that this may be related to some specific characteristics of these stars. For instance, giants have lower surface gravities and more extended atmospheres than main-sequence stars, and this may result in pulsations with higher amplitudes.

Although K giant RV variability can be complicated, it is possible to distinguish between these three mechanisms (pulsations, rotational modulation, or companions) by analysing other stellar parameters. For instance, the characteristics of stellar oscillations are expected to vary with stellar gravity. The presence of large inhomogeneities is expected to produce additional spectral features, such as the variation of chromospheric activity indicators in phase with the RV period and asymmetries in the line spectral shape (bisector). RV variations due to companions, on the other hand, should not produce changes in the line shape or spectral features measuring the level of chromospheric activity.

In October 1999 we started a spectroscopic survey of a sample of 83 G and K giants with the high-resolution (R = 48 000) spectrograph FEROS at the ESO 1.5-m telescope (1999–2002). Observations have continued on a less regular basis under Max-Planck-Gesellschaft (MPG) time on the 2.2-m MPG/ESO telescope at La Silla. The long-term FEROS RV accuracy at the 1.5-m telescope over these years is of 23 ms^{-1}, well within the instrument specifications of 50 ms^{-1}. The large spectral coverage of the spectrograph also allowed us to record chromospheric indicators such as the *H*- and *K*-lines of Ca II.

This survey covers a large part of the cool section of the H-R diagram, including a broad region of the red giant branch (RGB) from the stars of luminosity class IV to II, including RGB stars, and clump giants. This programme found 13 new spectroscopic binaries. The majority of the other stars in the sample (63 %) showed RV variability above the measurement error that seemed to increase with stellar luminosity. About 20 % of the sample was constant within the measurement accuracy.

Accurate distances to stars as measured by the HIPPARCOS satellite allowed us to derive absolute magnitudes, and in Figure 1 we plot the degree of variability observed (as measured from the scatter of the RV variations) versus absolute visual magnitude (from Setiawan et al. 2004). In this picture the stars with low-mass companions (planets or brown dwarfs) are indicated with filled symbols. Confirmed binaries have been excluded. The trends of increasing RV variations with absolute magnitude are clearly seen.

Rotational modulation of stellar surface inhomogeneities

In order to unveil the nature of the RV variations we measured the changes in the photospheric line shapes by measuring the line bisector. In addition, we measured chromospheric activity using the asymmetry of the Ca II K line core, which is an excellent chromospheric indicator (see e.g. Pasquini et al. 1988).

We found eight G and K giants whose RV variations correlate with changes in the asymmetry in the spectral line profiles (line bisectors) and with changes in the chromospheric Ca II K line emission core. The bisector velocity span versus radial velocity is shown in Figure 2 for one of these objects: HD 81797.

Several of these stars have large diameters, up to 20 milliarcseconds, which could be easily resolved by the ESO Very Large Telescope Interferometer (VLTI). They are therefore excellent candidates for VLTI observations, in which the effect of the surface inhomogeneities can be detected from detailed investigations of the fringe contrast as a function of wavelength.

AMBER, the near-infrared/red focal instrument of the VLTI, can use three telescopes (thereby yielding information on spot geometry in addition), with baselines providing up to 1 mas angular resolution, and a spectral resolution up to 10 000.

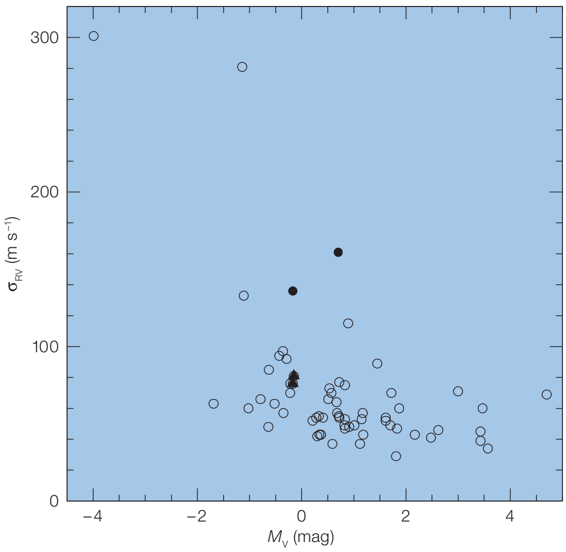


Figure 1: RV variability versus M_V for FEROS giants. The sample has been cleared of binaries. Stars which are candidates to host exoplanets are shown as filled triangles. Two stars hosting brown dwarfs are shown as filled circles. They stand out of the main "low level variation" group. A fraction of the stars shows no variability at the accuracy of 23 ms^{-1}. Spread and amplitude of the variations seem to increase for more luminous stars.

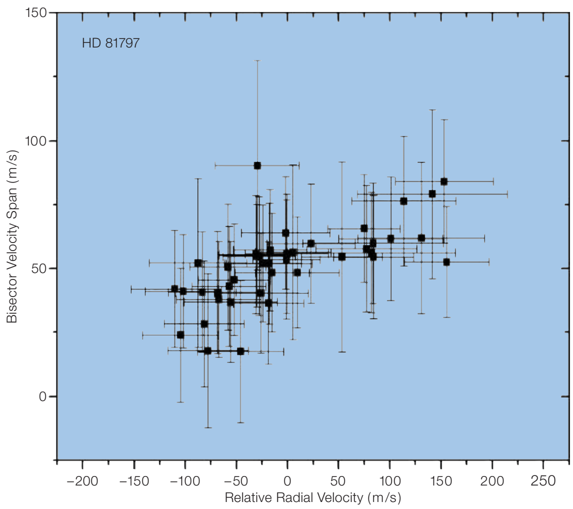


Figure 2: Bisector velocity span versus radial velocity for a K giant from our target sample. A clear correlation is present, indicating the presence of large surface inhomogeneities.

Low-mass companions

Doppler shifts of spectral lines caused by low-mass companions are neither expected to induce any variations in the spectral line shape nor to be accompanied by variations in stellar activity indicators. By measuring the projected rotational velocity of the stars and estimating their radius we can also derive the rotational period and check whether it differs substantially from the orbital period of the companion. This will further enable us to exclude rotational modulation as a possible cause of RV variations. We have so far identified three stars which possess companions (Setiawan et al. 2005).

These cool evolved stars lie in the clump region, where stars undergo core helium burning after having ascended the RGB. Clump giants spend 10–20 % of their main-sequence lifetime in this evolutionary stage. The comparison with theoretical evolutionary tracks allows a precise determination of the stellar mass, which we determined to be about 1.9 $M_\odot$.

This result is very interesting, because it shows that by analysing evolved stars we are able to explore planet formation in a different range of stellar masses than what is sampled in radial velocity surveys around main-sequence stars, which is limited to stars less massive than ~ 1.3 $M_\odot$.

Our high-quality FEROS data allow us to derive quite accurate metallicities for our sample stars. In addition to the metallicity [Fe/H], the effective temperature and surface gravity (log *g*) have been determined. Surprisingly, we found that the three stars proposed to host planets are not metal-rich. Studies of host stars of exoplanets around main-sequence stars show that these tend to have higher metallicites than stars that do not possess exoplanets (e.g. Santos et al. 2004). G-K giants seem to go against this trend. However, a much larger sample of planets harbouring K giant stars is needed to establish any trend with metallicity.

Pulsations

Asteroseismology is a powerful tool that uses stellar oscillations to probe the internal structure (e.g. sizes of convective cores) of stars and thus provides tests of stellar structure and evolution theory. Asteroseismology is expected to provide further information about stellar ages and masses in the near future. Although great advances have been made in helioseismology, asteroseismology is still in its infancy and it has been applied with success to some solar-type stars, white dwarfs, and rapidly oscillating Ap stars. More recently, precise stellar radial-velocity measurements with a precision of better than 1 ms^{-1} have discovered solar-like pulsations in η Bootis (Kjeldsen et al. 2003), a G0 subgiant. Current investigations have detected quite short periods in K giants. There exists evidence that oscillations as short as a few hours are possible. Frandsen et al. (2002) detected oscillation periods as short as 2–5 hours in the giant ξ Hya.

We also do not know the lowest amplitude for oscillations in K giants. The RV precision of FEROS may have just been insufficient to probe the lowest RV amplitudes, because about 20 % of our investigated sample showed no variations above the measurement error (23 ms^{-1}). Since the K giant α Ari (Kim et al., submitted) has recently been shown to be a pulsating star with a period of 0.84 day and an amplitude of only 20 ms^{-1}, our "constant" K giants may just be low-amplitude variable stars. We have indeed indications that some of our stars may have short-period variability.

In order to be effective for asteroseismology we must detect as many pulsation modes (periods) as possible (the so-called oscillation spectrum). This requires a higher radial-velocity accuracy than has been obtained with FEROS as well as better time sampling of the observations. Oscillation modes reach down to different depths in the stellar atmosphere depending on the period. If we detect many frequencies we can sound the interior of the star and determine stellar fundamental parameters such as its mass and evolutionary status. These can be used to directly test theoretical models.

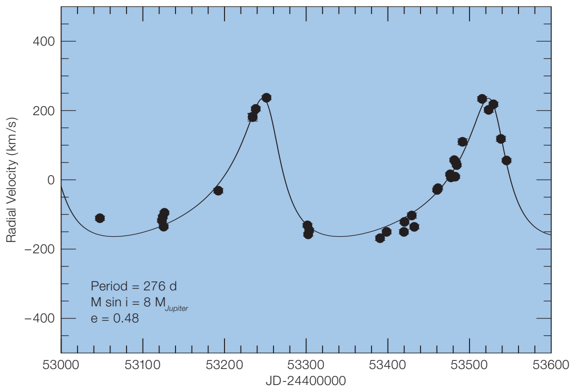


Figure 3: Example of long-term variability for one giant observed at the TLS observatory. The fit represents an orbital solution for an exoplanet companion with P = 276 d, e = 0.48 and M sin i = 8 $M_{Jupiter}$.

Beyond FEROS

We have shown that by determining the long-term and short-period RV variations in a sample of evolved stars we can learn about planet formation, surface structure, and pulsations in intermediate-mass stars. Our southern sample of G-K giants is sufficiently large to establish what fraction of G-K giants are short-period variable stars. Those showing significant night-to-night variations will form a group suitable for more detailed investigations by multi-site campaigns with increased time resolution and coverage. For some of our purposes a substantial increase in accuracy with respect to what has been obtained with FEROS at the 1.5-m telescope is needed; the high-resolution spectrograph HARPS, the High Accuracy Radial velocity Planet Searcher, at the 3.6-m at La Silla is the ideal instrument for this follow-up.

Work is also being undertaken in the northern hemisphere. In February 2004 we started a programme to observe a sample of 62 K giants from Tautenburg Observatory (TLS), in Germany. Precise stellar radial-velocity measurements were made using the echelle spectrograph of the 2-m telescope and an iodine absorption cell. We have continued our programme for these stars with observations typically made every other month. After 19 months of observations we have some preliminary results.

These show a typical RV precision of 3–5 ms^{-1} which is considerably better than our FEROS survey. So far 60 % of the sample shows short-period (night-to-night) variations. About 15 % of the sample exhibit long-term low-amplitude variations and several of these may be due to planetary companions. As an example, Figure 3 shows the long-term variability for one giant observed at the TLS observatory. The fit represents a solution with an exoplanet companion having P = 276 d, e = 0.48 and M sin i = 8 $M_{Jupiter}$.

In the TLS sample only 9 % of the stars seem to be constant. We interpret this as an evidence that most G-K giants indeed are RV variable and that the higher accuracy of the Tautenburg survey is the reason for the difference with the FEROS statistics. 11 stars (16 %) belong to binary systems.

In spite of our progress, we would still like to answer the important question: What makes a G-K giant pulsate and Radial Velocity variable?

References

Frandsen, S., Carrier, F., Aerts, C. et al. 2002, A&A 394, L5
Kim, K. M., Mkrtichian, D. E., Lee, B. C., Han, I., and Hatzes, A. P., A&A, submitted
Kjeldsen, H., Bedding, T. R., Baldry, I. K. et al. 2003, AJ 126, 1483
Pasquini, L., Pallavicini, R., Pakull, M. 1988, A&A 191, 253
Santos, N. C., Israelian, G., Mayor, M. 2004, A&A 415, 1153
Setiawan, J., Pasquini, L., da Silva, L., 2004, A&A, 421, 241
Setiawan, J., Rodmann, J., da Silva, L. et al. 2005, A&A 437, L 31

ASTRONET: Towards a Strategic Plan for European Astronomy

Anne-Marie Lagrange
ASTRONET Coordinator
(CNRS/INSU, France)

Establishing a comprehensive long-term plan for the development of European astronomy – optical and radio, ground and space – has been discussed for many years, but still waits to be done. Also, European astronomy would benefit much from better-coordinated actions among countries. A consortium of European funding agencies is now launching ASTRONET, a four-year ERA-NET initiative to achieve these goals.

European astronomy has achieved many successes in the second half of the twentieth century, especially by pooling its previously scattered efforts into multilateral partnerships. The most important of these are ESO for ground-based optical astronomy and ESA for space astronomy.

If we wish to be at least as successful in the future, we need to reinforce these joint efforts and expand them to all domains of astronomy. This requires a shared *Science Vision* throughout Europe and an agreed roadmap for infrastructures in astronomy. We also need to identify the barriers which impede collaborative projects among countries and make proposals to overcome them.

Why invent ASTRONET?

First, the "European astronomy" referred to above is essentially confined to the member states of ESO and ESA. Astronomers in the new member states of the European Union have largely been left out of this development. And they represent an intellectual capital no less valuable than that of their more fortunate colleagues.

Second, while long-term plans are being prepared by ESO and ESA, they do not cover the whole field by any means. Apart from ALMA, planning for radio astronomy is not integrated with these plans, and little if any coordination exists between the plans for ground- and space-based astronomy. Surely, if European astronomy is to overcome the funding limitations restricting our future development, we must prove able to transcend our own mental barriers and present a unified front to the outside world.

Motivated by the clear and urgent need to bring European forces together for the development of astronomy at the European level, funding agencies and ministries from France, Germany, Italy, the Netherlands, Spain, the United Kingdom, plus ESA, ESO and NOTSA, decided early January 2005 to propose a programme to coordinate a strategic planning exercise for European Astronomy.

This so-called ASTRONET initiative was submitted to the European Commission (EC) early March 2005 under the ERA-NET Instrument of Framework Programme Six (FP6). The proposal was accepted by the EC, and ASTRONET started September 1, 2005. It involves a human effort of 299 person-months, and the total budget is 3.9 M€, including an EC contribution of 2.5 M€. The duration of the programme is four years.

ASTRONET objectives

ASTRONET *covers all astrophysical objects* from the Sun and Solar system to the global structure of the Universe, as well as every observing approach, in *space and from the ground* and from the detection of photons at *any wavelength to astroparticles and gravitational waves*. It addresses the whole scientific "food chain" from infrastructure and technology development to observation, including the virtual observatory, modelling, and theory.

The ASTRONET project is divided into four main activities (work packages):

1. Networking

This work package deals with exchange of information between ASTRONET and other relevant partners in European astronomical research. As a prime goal of ASTRONET is to establish regular coordination between programme managers throughout all of European astronomy, two important tasks are to integrate new participants early in the life of the project, and to define mechanisms to maintain the Europe-wide, cross-disciplinary coordination initiated by ASTRONET on a permanent basis.

2. A Science Vision for European astronomy

This work package aims at developing a global census of European astronomical resources and national strategies, followed by a science-oriented Strategic Review for the next 15–20 years. The Review is to be conducted by a Science Vision Working Group with input from, and endorsed by, a wide European astronomical community by March 2007.

3. A roadmap for the development of infrastructure for European astronomy

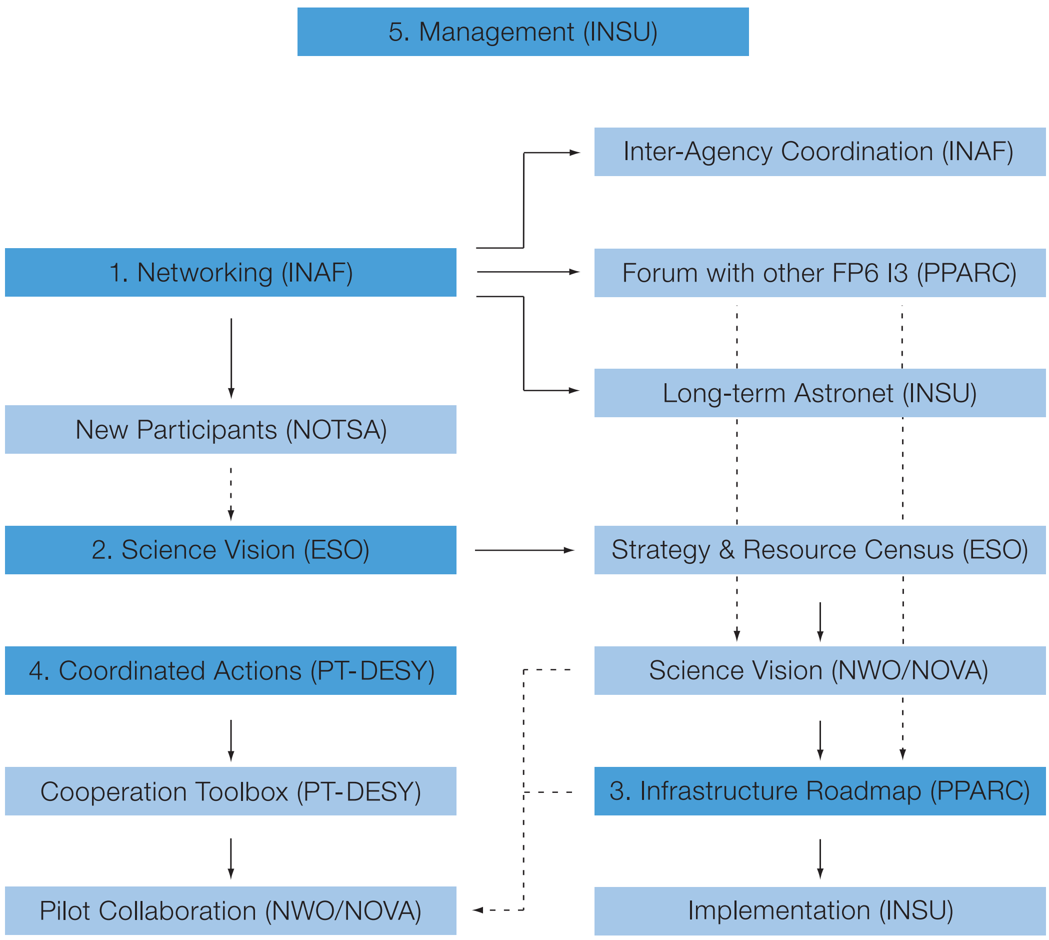
Based on the recommendations of the "Science Vision", this third work package will produce a strategic plan for the coordinated development of space- and ground-based astronomy in Europe, including the identification of key enabling technologies, by December 2008. It will also identify and initiate concrete mechanisms to implement this roadmap.

4. Targeted coordinated actions to strengthen astronomy and astrophysics in Europe

This work package will identify formal barriers to the further development of Europe-wide cooperation and initiate coordinated actions to strengthen astronomy in Europe, through the development of common evaluation procedures and the launch of a specific multi-agency research programme.

Who is ASTRONET?

ASTRONET has, so far, two levels of involvement, participants and associates. Participants are responsible for fulfilling the ASTRONET programme. Associates participate fully in the work programme, but, contrary to participants, do not lead any task and do not manage EC funding.



The five work packages (deep blue) and their sub-tasks (light blue), with the corresponding work package and task leaders in parentheses. The interaction between the various tasks is shown schematically.

As of the start of the programme, participants are: (1) Institut National des Sciences de l'Univers du CNRS (CNRS/INSU, France); (2) Bundesministerium für Bildung und Forschung (BMBF, Germany); (3) ESO; (4) Istituto Nazionale di Astrofisica (INAF, Italy); (5) Particle Physics and Astronomy Research Council (PPARC, United Kingdom); (6) Nordic Optical Telescope Scientific Association (NOTSA); (7) Ministerio de Educación y Ciencia (MEC, Spain); 8) Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO, the Netherlands) and (9) Projektträger DESY (PT-DESY, Germany). Associates are currently: (1) European Space Agency (ESA) and (2) Max-Planck-Gesellschaft (MPG, Germany).

Present ASTRONET membership represents about 80 % of the total astronomical resources in Europe. One of the goals of ASTRONET is to involve other countries who may wish to join, at the most appropriate level. If necessary, a third level of involvement will be introduced.

How will astronomers contribute?

Full participation from the European astronomical community at large is essential to ensure the quality and validity of the output, in particular of the Science Vision and the Infrastructure Roadmap. A number of panels are being established, in the first case organised by (broad) scientific themes, in the second case by observational technique.

The panels will develop draft reports, to be amended and validated through dedicated symposia addressing the whole community. These will be held around December 2006 for the Science Vision, and March 2008 for the Infrastructure Roadmap. Careful attention will be given to avoid unnecessary duplication, e.g. through close contacts to other relevant FP6 activities like the ELT and SKA Design Studies. With ESA participating fully in the exercise, an important objective is to achieve better coordination between the plans for ground- and space-based astronomy. For further information on ASTRONET status, goals and objectives, see our web site at *http://www.astronet-eu.org*

ASTRONET will be a true success if it helps to join the forces of all funding agencies towards the development of the future, large and expensive research infrastructures that European astronomy will need to keep abreast, and to develop true collaborations between all European astronomical communities. The enthusiastic contribution of the community in this effort will be essential for reaching this goal.

The Current and Future ST-ECF

Robert A. E. Fosbury (ST-ECF)

After 15 years in orbit, the Hubble Space Telescope is facing an uncertain future although there is a real possibility of a fifth servicing mission within the next two to three years. ESA and ESO have jointly been pondering the future of the ST-ECF at the ESO headquarters in Garching and this article outlines their conclusions.

The Space Telescope – European Coordinating Facility (ST-ECF) was established by ESA and ESO in 1984 for the purpose of supporting European astronomers in their use of the Hubble Space Telescope (HST). The subsequent history of the group and its evolving role up to 2002 is described in an article in the STScI Newsletter (Fosbury and Albrecht 2002; *http://sco.stsci.edu/newsletter/PDF/2002/summer_02.pdf*) and will not be repeated in detail here.

With the HST already in orbit beyond its design lifetime of fifteen years, both ESA and ESO have been giving thought to the functions that the ST-ECF should perform during the remaining active phase of the Hubble project – however long that is – and also to their own requirements for maintaining such a joint group into the post-Hubble era. The purpose of this article is to outline the results of these deliberations and to sketch the anticipated future activities of the group.

Current tasks

Following a mid-term review in 1996, carried out by Len Culhane, Rolf-Peter Kudritzki and George Miley, the ST-ECF shifted emphasis from user support to direct contributions to the HST project in collaboration and coordination with STScI. It also took on additional tasks and some additional staff at the request of ESA as part of a renewed ESA/NASA Hubble Memorandum of Understanding (MoU). These tasks were to pre-process the plate scans used for the second Guide Star Catalog (GSC II), to improve the calibration of selected post-operational Hubble instruments using instrument modelling techniques, and to provide a European channel for Hubble-related public outreach. The first of these has been completed, the second is being absorbed within the now primary ST-ECF task of providing high-level science data products for selected current – as well as post-operational – Hubble instruments. The available manpower has, however, been reduced as a result of the current evolution of the ESA/NASA MoU which takes account of ESA's considerable contributions to JWST. The third: European Outreach for Hubble, JWST and some other ESA activities, is continuing as a mainstream ST-ECF activity.

By early 2006 and at the request of ESA, the ST-ECF will have reduced its staff from a maximum of twenty-one back to the original complement of seven ESA-funded and seven ESO-funded personnel with the expectation that this level will be maintained until the decommissioning of the HST spacecraft. When this event will happen is currently very uncertain. If NASA decides to carry out the next servicing mission (SM4) before any catastrophic failure, this could be many years ahead: at least five years after the servicing mission takes place. However, for planning purposes, ESA is using the date of 2010 as the anticipated Hubble End of Life (EoL).

While the HST remains operational – and probably somewhat beyond EoL, the ST-ECF will continue its focus on Hubble-related tasks, principally in the areas of high-quality science-data products and public outreach. Projects currently underway in the instrument science area are predominantly in the area of spectroscopy, notably the provision of high quality, physical-model-based wavelength, charge transfer efficiency calibrations and correction procedures for STIS and the calibrations and procedures for reducing the slitless spectroscopy data from the ACS. The STIS project is a natural follow-on from similar work done for FOS and the ACS work has its heritage in NICMOS and STIS. Descriptions of this work can be found in recent issues of the ST-ECF Newsletter which can be found on-line at the ST-ECF website (*http://www.stecf.org/newsletter/*). The wavelength calibration work has involved extensive laboratory work to characterise the on-board lamps and has resulted in a new set of wavelengths for the Pt/Cr-Ne lamp (Sansonetti, C. J. et al. 2004).

If SM4 is carried out successfully within the next two to three years, Hubble will be equipped with two new instruments: a NUV-NIR imager (WFC3) and a high-efficiency UV spectrometer (COS). There is also the realistic possibility that the STIS will be repaired. Such a dramatic increase in HST capabilities would carry serious implications for the ground support at both the STScI and at the ST-ECF.

It has been clearly apparent that there are a number of resonances between these Hubble-based instrument projects and the interests of ESO for several VLT instruments. The physical similarities between STIS and UVES have already been exploited in the current UVES pipeline and the similar problems facing CRIRES are currently yielding to similarly effective procedures for the high-quality calibration of this new infrared spectrometer. There has been a recent feasibility study for the application of the slitless spectroscopy procedures developed for ACS to the MXU-mode of the FORS2 spectrometer; work that is described in the article by Kuntschner et al. on page 19 of this issue of The Messenger.

The fruits of these HST instrument science labours are ultimately destined for the so-called Hubble Legacy Archive (HLA) which has been conceived to be the repository of the highest-quality, science-ready data products that can be constructed by the combined efforts of the STScI, the Canadian Astronomical Data Centre (CADC) and the ST-ECF. Destined to be fully VO-compliant, the HLA will – together with the published scientific papers based on the data (currently somewhat in excess of 5000) – be the lasting legacy of this extraordinarily successful scientific endeavour.

The public are overwhelmingly supportive of the HST observatory and, at least in the USA, the word "Hubble" has become synonymous with astronomical telescope. The efforts to make the European public more aware of the project and ESA's role in it are led by the small (2.5 FTE) ST-ECF outreach group who has set up a very efficient and productive infrastructure to increase public awareness – especially amongst young people. The recent celebration of Hubble's 15th year in orbit has had a very high worldwide visibility with more than half a million copies of the DVD "HUBBLE – 15 years of discovery" being distributed. The web site (*http://www.spacetelescope.org/*) has become one of the most visited science sites in the world.

Future role

In the post-Hubble era, both ESA and ESO will continue to share common interests and goals. Given their common obligations to astronomy and the very large overlap between the communities they serve, both organisations have expressed a desire to maintain a joint ESA/ESO activity based at the ESO Headquarters in Garching. This group will carry out a range of technical, outreach and coordination tasks of interest and benefit to both parties.

The current plans for such a group, which would evolve from the ST-ECF, have been developed with ESA and ESO over the last year or two. They include a continuation of the high-quality science-data product intitiative which necessarily forms the foundation of the VO endeavour. Target projects would come from both ESA and ESO instrument developments. In addition, there are a number of coordination activities between the two organisations that would benefit from a joint group in Garching. The first steps have already been taken with the publication of the ESA/ESO Working Group report on extrasolar planets described in the previous issue of The Messenger. This will shortly be followed by a report on the synergies between Herschel and ALMA and then by one on Fundamental Cosmology. These are anticipated to be the beginning of a continuing series of initiatives that map out the joint interests and capabilities of both ESA and ESO to address major scientific problems.

Finally, the continuation of a vigorous public outreach programme is considered to be vital to ensure a continuing interest in the progress of science into the next generation and the future ST-ECF will carry out part of this programme for ESA in close collaboration with ESO.

As a footnote to this description, it should be pointed out that the ST-ECF has been in the past and is currently a substantial contributor to the ESO Astronomy Faculty and the scientific environment. With seven of its staff being Faculty members, it is well represented on Faculty committees and currently holds the (elected) Faculty chairmanship.

Reference

Sansonetti, C. J., Kerber, F., Reader, J., and Rosa, M. R., "Characterization of the Far-ultraviolet Spectrum of Pt/Cr-Ne Hollow Cathode Lamps as Used on the Space Telescope Imaging Spectrograph on Board the Hubble Space Telescope", 2004, Astrophysical Journal Supplement Series 153, 555–579

PPARC Council at ESO

On October 27, members of the PPARC Council paid a full-day visit to the ESO Headquarters. The Council members were welcomed by ESO's Director General, Dr. Catherine Cesarsky, and in the course of the day received an extensive briefing on key ESO activities including the current science activities at ESO's La Silla Paranal Observatory in Chile, the status of the ALMA project and the OWL project for an extremely large optical/near-IR telescope. Furthermore, ESO's instrumentation programme – arguably the world's most comprehensive and ambitious instrumentation development programme in astronomy – was described as well as industrial relations and technology transfer, and ESO's substantial education and public outreach activities. The Council members also had an opportunity to see the ESO Science Data Archive and the Integration Hall where new instruments are tested prior to being shipped to the observing sites in Chile. During lunch, the participants had a chance to meet UK and Commonwealth staff working at the Headquarters.

Photo: H. H. Heyer, ESO

Open House at ESO Garching

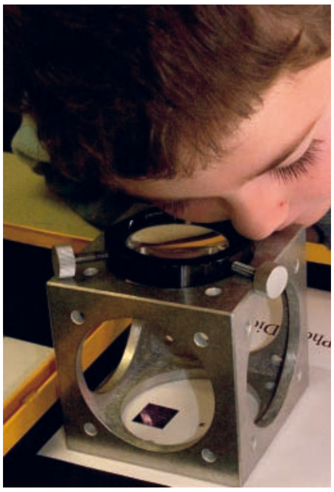
Henri Boffin (ESO)

Photos: H. H. Heyer, ESO (3)

The videoconferences with Paranal generated a lot of interest and enthusiasm.

On October 22, ESO in Garching opened its doors to the public, as part of the traditional all-campus Open House. The event was successful again this year, clearly generating a lot of public interest, with 2000–2500 visitors passing through our building within a seven-hour period. For ESO, the Open House is an important element of our continued dialogue with the local community, playing a key role in maintaining awareness about astronomy in general and about our organisation in particular.

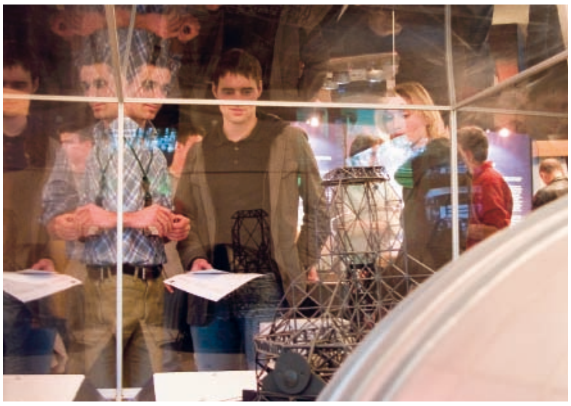
About forty ESO staff, from many different divisions, participated in the event to provide, in an attractive and varied programme, information about ESO and the ongoing work at this organisation. The visitors could, for example, watch a specially edited 15-min movie about ESO, listen to different talks on topics such as "exoplanets", "the life of an astronomer" or "spectroscopy", view demonstrations of image processing, the Virtual Observatory, the principle of interferometry, CCD cameras and infrared detectors, as well as examine the VLT, ALMA and OWL models. Regular videoconferences were also done with Paranal and they all generated a lot of interest and enthusiasm in the public. In addition, there was an indoor planetarium – always very successful among children, an exhibition of astronomical paintings and ceramics as well as exhibitions of the Volkssternwarte München and the Observatory of Königsleiten. The Personnel Department provided visitors with information about employment opportunities at ESO, and the ST-ECF also had a stand. The ESO amateur group, AGAPE, had kindly prepared several activities, viz. the observation of the Sun and a demonstration of radio astronomy.



The Open House was also very successful among children.

The visitors were also given a chance to participate in the famous ESO Quiz, and many entered the competition. Among the numerous correct answers to the twelve questions, 46 winners were selected and were offered books, CD-Roms or posters.

Visitors came from all over Bavaria, but also from Austria, and even from Italy and France. Many expressed their satisfaction with the activities being offered. There was clearly a lot to do and see as some even spent the whole day at ESO!



The OWL model attracted much interest.

Danish Minister visits ESO Chile

Gonzalo Argandoña, Felix Mirabel (ESO)

On October 21, the Danish Minister for Education, Mr. Bertel Haarder, paid a visit to ESO in Santiago, accompanied by a small entourage including the Danish Ambassador to Chile, Anita Hugau.

Mr. Haarder, who had visited La Silla 15 years ago, was received by the ESO Representative in Chile, Felix Mirabel, and Claus Madsen, Head of the ESO Public Affairs Department. The guests were also introduced to two Danish fellows who currently work at ESO in Chile, Lise Christensen and Thomas Dall.

During the meeting, the minister was briefed on the current science operations in Chile, the relationship between ESO and Chile, the status of the ALMA project as well as on the progress regarding ESO's ELT plans.

The discussion also covered ESO's many-sided educational outreach activities, both in Chile and in Europe and how these initiatives can play a role in a larger effort to stimulate interest in the natural sciences amongst young people.

Photo: I. Lemus, ESO

At the ESO office in Santiago, Bertel Haarder (Danish Minister of Education) talks to Lise Christensen. At the back, Claus Madsen, Felix Mirabel and Mrs. Haarder.

Photo: G. Argondoña, ESO

The Danish Minister was particularly interested in science educational projects promoted by ESO in Chile and Europe. The picture shows children at the 2005 Fair of Physics that took place in October in Santiago, as part of the celebrations of the Chilean National Science and Technology Week.

Science on Stage 2005

Douglas Pierce-Price, Henri Boffin, Claus Madsen (ESO)

"Science on Stage", the European Science Teaching Festival, is a major educational outreach programme for science teachers. It aims to identify and foster innovation within formal science education by means of exchange of best practice, workshops and seminars involving educators from all over Europe.

Almost five hundred science educators from twenty-seven countries met in November at CERN, Geneva, for "Science on Stage" (SOS). The delegates had been selected through elaborate national procedures involving contests and national "festivals" in which participants were invited to present their ideas and projects.

The SOS programme and indeed the European Science Teaching Festival is arranged by the EIROforum, of which ESO is a member, and was developed from the successful "Physics on Stage" events.

An inspiring programme of presentations and workshops, and a lively fair where delegates could demonstrate exciting experiments and teaching projects, allowed educators to share techniques and take new ideas back to their schools across Europe.

This dedicated initiative for teachers, which is co-funded by the European Commission, aims to promote innovative science teaching in the formal education system. The event has gathered increasing support from education authorities, learned societies, and industry in many of the participating countries, which are clearly keen to ensure that their educational systems maximise the benefits from taking part in the programme.

Henri Boffin and Douglas Pierce-Price from ESO presented workshops for teachers on the ALMA Interdisciplinary Teaching Project and an introduction to Gamma-Ray Bursts, respectively.

In another workshop, delegates learnt about and discussed the new European journal for science teachers, "Science in School". This journal is based at the EMBL and published by the EIROforum. It will be launched in spring 2006 and published quarterly. It is part of the NUCLEUS project funded by the European Commission.

An international jury presented "European Science Teaching Awards" to the best projects at the fair, in a ceremony attended by Jean-Michel Baer, the Director of Science and Society in the EC Directorate General for Research. The four general awards, together with individual awards from each of the seven EIROforum organisations, had a total value of 17 000 € .

ESO's prize was awarded to the "Einstein Year Library Project", by Mandy Curtis, from the United Kingdom. The general prizes were won by Catherine Garcia-Maisonnier of France for "Building a Weather Balloon at School" (1st prize), Wim Peeters of Belgium for "Physics is Cool! – the Box of Experiments" (2nd prize), Jerzy Jarosz and Aneta Szczgielska of Poland for "The Cardiovascular System" (3rd prize), and Tobias Kirschbaum of Germany for "Tracing Earthquakes (Chinese Seismograph)" (4th prize). The other EIROforum prizes went to Maria Joao Carvalho of Portugal for "Lichen and Water Quality" (CERN), Eilish McLoughlin *et al.* of Ireland for "Teaching Science as a Process" (EFDA/JET), Evanthia Papanikolau of Greece for "DNA Helix" (EMBL), Agota Lang of Hungary for "Neurode, or Garfield the Lazy Cat" (ESA), Gianluca Farisi of Italy for "Humanism and Science" (ESRF), and Nanna Kristensen of Denmark for "Jewellery is chemistry" (ILL).

The next Science on Stage event will take place in Grenoble in April 2007.

Festival participants enjoy the magic of chemistry on stage.

Photo: H. Boffin, ESO

ESO at CER 2005

Claus Madsen (ESO)

On November 14–15, the Brussels Exhibition Centre (Heysel) was the home of a major international conference on science communication with the title "Communicating European Research" (CER 2005).

The conference was officially opened with speeches by Commissioner Dr. Janez Potočnik (Commissioner for Science and Research) and Commissioner Viviane Reding (Commissioner for Information Society and Media), with former Commissioner Philippe Busquin, now a prominent member of the European Parliament, chairing the session.

Over the two days, about 2 100 participants from 56 countries, including more than 200 journalists, discussed all aspects of public science communication, including science education, informal science learning, science festivals and media work. The conference also saw the launch of the "Communiqué Initiative", a first step towards creating a European Media Centre for science.

ESO participated through the EIROforum partnership, that acted as organisers of two sessions – one on formal science education and one on media work. ESA and ESO were also represented in a lively panel discussion on communication of astronomy and space science. Finally, EIROforum had a major information stand in the exhibition area.

The conference offered ample opportunity for stimulating exchanges, not just between European scientists and media experts but also with participants from overseas, including the US and China. It

EU Research Commissioner Dr. Janez Potočnik (right) visiting the EIROforum stand in the CER exhibition hall.

Photo: M. Pedoussaut, ESA

seems clear that public awareness and understanding of science is not a "side-issue" *vis-à-vis* scientific progress. Rather, it is increasingly seen as central to the future of science in a democratic society. Thus it is a burning issue across the entire world and one that must be addressed through a large number of initiatives and on an appropriate scale.

Report on the Conference on

Science Perspectives for 3D Spectroscopy

Jeremy Walsh (ST-ECF)
Markus Kissler-Patig (ESO)

About four years ago when discussions were taking place to plan the proposal to the European Commission for a Research Training Network (RTN) on 3D spectroscopy, we decided to make an international conference one of the closing highpoints of the network. At that time there were only a few 3D instruments routinely taking data on large telescopes (such as Integral on the WHT and Oasis on the CFHT) and some of us thought that a full-scale international conference on science with 3D spectroscopy might be rather difficult to fill. However, as it transpired, we had problems containing the conference in four and a half days. The RTN, called Euro3D, shared the hosting of the conference with ESO and it was held at ESO Headquarters in Garching from October 10–14, 2005.

At the inception of the Euro3D RTN, in July 2002, it was perceived that Europe had a strong instrument advantage in optical and NIR 3D spectroscopy. By 3D spectroscopy is generally meant the technique of obtaining multiple spectra over a 2D field of view; there are various implementations from scanning slits, to imaging Fabry-Perots, to integral field units (IFU) with fibres, lenslet arrays or slicers. A number of instruments were in the planning stage, not least three planned for the VLT – the IFU mode of VIMOS, the FLAMES/Giraffe Argus mode and SINFONI. However, the expertise in handling of the data was mostly confined to the instrument groups themselves and there was a perceived "difficulty" in reduction and analysis of optical/NIR 3D data. This is partly a result of the large quantities of data delivered by IFU instruments but also a reflection that significant development beyond the tools for longslit spectroscopy is required to analyse the resulting data cubes (2 spatial + 1 spectral dimension). One of the aims of the Euro3D RTN was to narrow the bridge of difficulty by training young researchers in 3D spectroscopy observation and analysis, so that they could spread the word that 3D data need not be intimidating. The RTN also planned software development, science projects, a conference and an IAC winter school.

Figure 1: The Euro3D Research Training Network (*www.aip.de/Euro3D*) initiated and sponsored this conference, together with ESO.

The RTN funding will be completed as planned at the end of this year and has proved a great success. There were ten young post-doc researcher positions spread across ten European institutes all with connections to 3D spectroscopy (AIP (Potsdam), Cambridge, Durham, IAC (Teneriffe), IAP (Paris), Leiden, Lyon, Marseille, Milan, MPE (Garching)); there was also a team from ESO but without a post-doc. Despite worries that it would be difficult to find enough keen post-docs with interest and/or experience in 3D astronomy, all the positions were occupied and two early departures were also filled. Most of the young researchers have moved (or are about to move) on to further positions in astronomy. Six of the Euro3D post-docs presented their work at the meeting, so the aim of showcasing their work as a culmination to the RTN was satisfied.

The conference was aimed at 3D science, as there had been a previous technical workshop at Durham University in July (Integral Field Spectroscopy – Techniques and Data Reduction), which was incidentally also partly sponsored by Euro3D. At the Garching conference there were a total of 92 participants; with eight invited talks, 41 contributed talks and 30 posters (previewed by two poster oral sessions); it was a full schedule. However, there was time for a visit to the Aying brewery late one afternoon, where much beer was tasted, followed by the conference dinner, Bavarian style.

The first afternoon was devoted to an overview of current and future instrumentation to set the scene for the following science presentations. Guy Monnet (ESO) brought his many years of involvement in 3D spectroscopy to the fore in the opening review on the past and up to the present. This was followed by a review by Jeremy Allington-Smith (Durham) on current instrumentation. Then there were a number of talks on instrument projects in various states of planning and funding. Martin Roth (AIP, Potsdam) described the MUSE project with its 1′ square field and 24 spectrographs, funded for the VLT. This instrument was out-multiplexed by HETDEX, the Hobby-Eberly Telescope Dark Energy EXperiment, with its proposed 145 identically replicated IFU spectrographs described by Karl Gebhardt (University of Texas). While the science case for MUSE is centred on deep searches for high-*z* galaxies, HETDEX, with some initial funding for a prototype, aims to measure redshifts of one million galaxies to constrain the equation of state of dark energy. SINFONI, the most recent 3D instrument to go into regular operations, had an exciting entry with Frank Eisenhauer's overview of the large palette of impressive first scientific results.

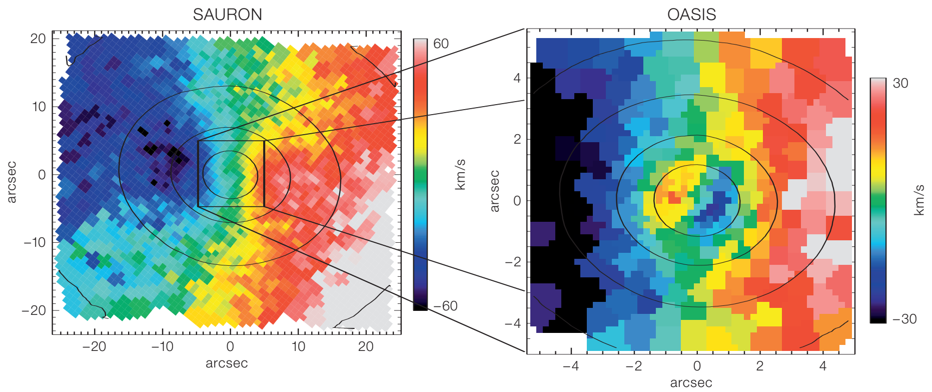


Figure 2: Kinematically Decoupled Cores (KDCs) are best viewed with IFUs. Some, however, require adaptive optics systems for their resolution as shown here in kinematic maps from OASIS, as compared with SAURON (taken from Richard McDermid's presentation).

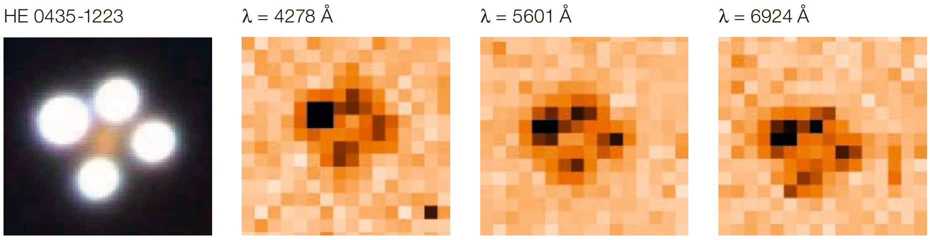
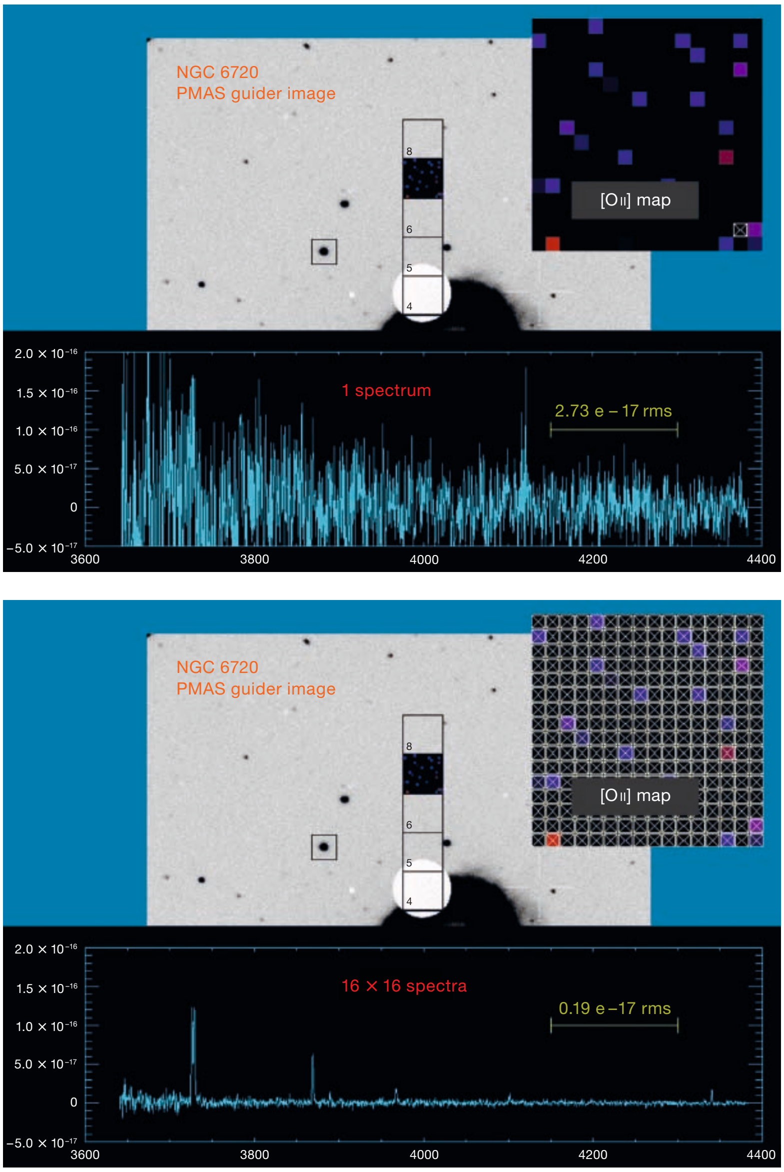


Figure 3: Gravitational lenses recently became targets of IFU observations. Atmospheric dispersion, which shifts the position of the targets as a function of wavelength, can be used to advantage to provide spatial "super-sampling" of the IFU images (PMAS data, taken from Lutz Wisotzki's presentation, see also Wisotzki et al. 2003).

The science covered at the conference was intendend to be wide and in fact covered Solar System objects, extra-solar planets, Galactic stars and nebulae, the structure of nearby galaxies, and distant galaxies out to the highest known redshifts. Santiago Arribas (IAC) described IFU observations of the planetary transit of HD 209458b which came close to the spectrophotometric accuracy of HST observations and Jean-Pierre Maillard (IAP) described applications of imaging Fourier transform spectrometry, a technique which has been eclipsed in popularity by IFU's in recent years. Most of the second day of the conference was devoted to the most mature field in which 3D spectroscopy has been applied – that of the morphology, kinematics and study of stellar populations in nearby galaxies. The Sauron survey (conducted with a dedicated instrument on the WHT) featured very prominently and Eric Emsellem (Lyon) reviewed the field and extensively used an acronym new to at least some of us: KDCs – Kinematically Decoupled Cores. It was clear that such features could not be guessed at from the surface brightness distribution and could be lost if a slit was placed along the major or minor axis of a galaxy only. The Sauron survey which has taken as a sample 72 galaxies with a representative range of properties (Hubble type, luminosity, location) is able to give statistical trends in 2D galaxy kinematic and chemical properties.

IFU observations are not only useful for well-resolved nearby galaxies, but, as described by Lutz Wisotzki (AIP, Potsdam), they are also well suited to smaller more irregular objects such as gravitational lenses. Both the lenses and the lensing galaxy can be imaged at once and spectral variations among the lenses, which can be caused by microlensing, can be simultaneously determined. In particular the strong lensing by galaxy clusters creates curved sources which are not well matched to long-slit spectra. IFU observations in galaxy clusters are uniquely powerful both for studying the cluster galaxies and the lenses. If the lensing model of the cluster is well determined, then the elongated lenses can be de-distorted to derive the true velocity field

Figure 4: The faint halos of planetary nebulae profit from the power of IFUs to integrate over a large aperture (without degrading the spectral resolution). The spectrum of a single spaxel (spatial element – top) is compared to the spectrum obtained with the same area 16 × 16 spaxel binned (bottom) (taken from Martin Roth's presentation).



for background galaxies. A number of talks emphasised this approach (Mark Swinbank, Durham, and Marie Lemoine-Busserolle, Cambridge/Oxford); initial results in the cluster RCS0224-002 were reported by Swinbank et al. in the last issue of The Messenger (121, 33).

IFUs do not always have to have a large field: if they are targeted at a number of small objects within one field then multiple IFUs are a more efficient use of precious detector pixels. This mode is already available in FLAMES and observations of the velocity fields of $z \sim 0.5$ galaxies was described by François Hammer (Observatoire de Paris). The ability to build up samples of galaxies with resolved velocity fields at substantial redshift allows the evolution of the Tully-Fisher relation (rather the lack of evolution over the last ~ 4 Gyr) as also illustrated by near-IR IFU observations with CIRPASS by Andrew Bunker (Exeter). Future multiple IFU instruments for the VLT, such as KMOS, will explore this area in the infrared.

The nuclei of galaxies with a rich array of kinematic processes and strong gradients in surface spectra present ideal targets for IFUs. Reinhard Genzel (MPE) updated the participants on the continuing saga of the Milky Way Galactic Centre, where integral-field observations have played a fundamental role in discovery, of course in the IR on account of the high extinction. As well as providing the kinematics and stellar classifications of the luminous young stars orbiting the central black hole, IFU observations, most lately taken with SINFONI on the VLT, have

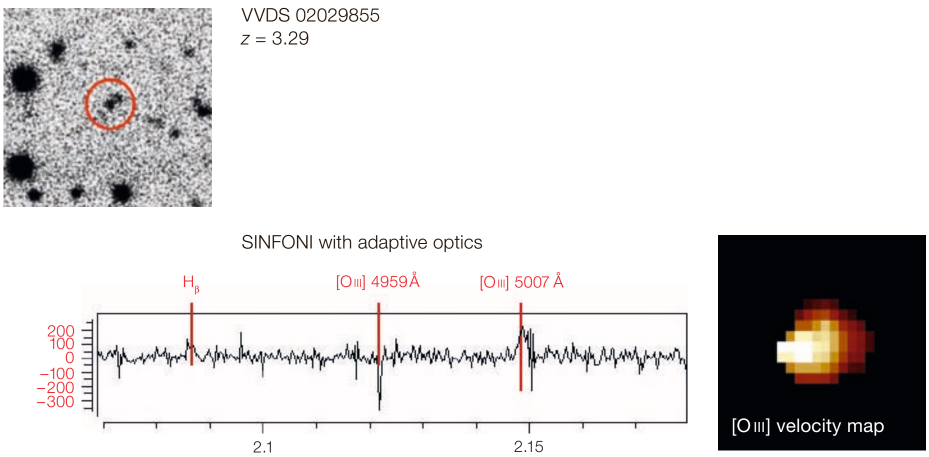


Figure 5: SINFONI study of the galaxy VVDS 02029855 at a redshift $z = 3.29$. The CFHT I-band image shows the faint object, for which SINFONI (assisted by adaptive optics in this case) obtained a spectrum. A velocity field was obtained from the detected [O III] 5007 Å line (taken from Marie Lemoine-Busserolle's presentation).

enabled the spectra of the central object Sag A* to be followed as it undergoes outbursts on a time scale of hours. It was salutory to see spectra of tens of stars in an area the size of a ground-based seeing disc! The "weather" around the nearby Seyfert nucleus of NGC 1068 was described by Gerald Cecil (University of North Carolina) with some fine animations. This environment has been systematically studied by IFUs and probes how shocks play an important role proximate to the active nucleus.

Emission-line nebulae were often considered the staple targets for 3D instruments providing well-resolved, kinematically complex targets. A number of talks described imaging spectroscopy studies of planetary nebulae (Martin Roth, AIP, using the PMAS instrument; Katrina Exter, IAC, using Integral) and H II regions such as the proplyds in Orion (Henri Plana, LATO, Brasil, using the Gemini GMOS IFU) and Herbig Haro objects (Rosário Lopez, Universidad de Barcelona). The ability to post-bin the IFU data enables the detection of very low surface brightness features, such as the faint emission-line haloes around planetary nebulae. Several talks described work done with the MPFS on the Russian 6-m telescope which has been collecting data for almost 15 years. Sergei Fabrika (Special Astrophysical Observatory, Russia) and Pavel Abolmasov (Moscow State University) discussed IFU observations of the shock nebulae associated with Ultra-luminous X-ray binaries (high luminosity cousins of SS433); here He II emission is an important diagnostic. The SNR around SN1987A is now large enough for AO corrected imaging spectroscopy and Karina Kjær (ESO) described VLT SINFONI observations.

Far from being restricted to large extended objects, IFUs are beginning to make an impact in high-redshift observations to which the entire last day was dedicated. The often complex, knotty appearance of high-redshift galaxies, which are probably interacting or merging, can be sampled in an unbiased way with an IFU. This can be important since the obvious nucleus may not be apparent and rotation curves can be derived for apparently rather chaotic objects and emission-line haloes, as shown for example by Montse Villar-Martin (Andalucia) and Richard Wilman (Durham). Deep surveys of blank sky, or regions around QSOs for indications of local overdensity of galaxies, are being conducted with Sauron and the VIMOS IFU, as shown in several talks (see Jarvis et al. in the last issue of The Messenger (121, 38)). Serendipitous discovery of emission-line objects which can be missed by photometric surveys was highlighted, although the number of such objects is small.

The conference summary was presented by Andreas Quirrenbach (Leiden). He said that October 14 was a historic day: it was the last day of the last conference devoted to the subject of 3D spectroscopy. The technique has come of age and can now enter the repertoire of standard observational tools employed by an astronomer. (Imagine a conference on long-slit spectroscopy!). The very wide range of topics covered at the conference to which imaging spectroscopy had been applied was indeed striking. There seemed to be little area of the parameter space of spatial coverage, spatial scale, spectral coverage and spectral resolution which had not been described at the meeting. The discussion following the summary concentrated on instrumental issues and possible developments, such as the ideal detector able to determine the position, wavelength and polarisation state of each incoming photon, currently imperfectly realised but the ultimate goal of 3D spectroscopy.

Report on the

Science Day in Honour of Alvio Renzini

Catherine Cesarsky, Bruno Leibundgut
(ESO)

The scientific legacy of Alvio Renzini was celebrated with a one-day workshop in Garching on October 19. Alvio retired as the VLT Programme Scientist in June this year and this conference was a way to look back at his many scientific achievements and his influence on ESO and the VLT project.

The programme of the day was only a partial reflection of Alvio's scientific work. There were no presentations of his early work, e.g. on stellar evolution. Instead the topics concentrated on research he is currently interested in and actively working. The programme was as varied as Alvio's work. The diversity was clear right from the start: Pascale Jablonka (Lausanne) described work on the bulge of M31, followed by a status report on white dwarfs in globular clusters given by Sabine Moehler (ESO). Gianpaolo Piotto (Padova) introduced globular cluster oddities and Markus Kissler-Patig (ESO) used globular clusters as template stellar populations. A topic that was hot when Alvio joined ESO were flares at the centre of elliptical galaxies, and Francesco Bertola (Padova) gave an update of this research. Moving into more cosmological topics Adriano Fontana (Rome) talked about the galaxy mass function at high redshifts and Claudia Maraston (Oxford) presented work inspired by Alvio on the importance of AGB stars in the interpretation of spectral energy distributions at high redshifts. The large surveys, for which Alvio played a pivotal role in having ESO making significant contributions were presented by Piero Rosati (ESO), who gave a status report on GOODS, and Simon Lilly (Zurich) provided a glimpse at what is to come for zCOSMOS. The latest update on the continuation of the K20 survey and the GMASS project was presented by Andrea Cimatti (Arcetri). Massimo Tarenghi (ESO) looked back at the time when the VLT was being built and elaborated on the important scientific input and guidance Alvio provided. The day was rounded of by Alvio himself giving his view on current research (adding the latest result on a search for eclipsing planets in the direction of the Galactic bulge) and some more speculative ideas. A recurring theme in all presentations was that Alvio must not retire from his scientific career and several pleas were made for him to continue to contribute his physical insights into the many diverse projects he has been involved in.

Coming to ESO was a gamble for Alvio (maybe also for ESO). Entering the world of hard observational realities as a theorist has not always been easy. Even before coming to ESO, Alvio was deeply involved in observational research. However, he was collaborating with observers and helping them interpret their data. At ESO he formulated important parts of the ESO programme, introduced ESO to survey work and gave scientific direction for the use of the telescopes and future instrumentation. He sensed interesting scientific developments very early on and prepared ESO for them. He led a working group to discuss the best ways to observe extra-solar planets, which led to the construction of HARPS, and organised the best way to observe GRBs with the VLT. The latter has provided an observational mode, the rapid response mode, which is not offered at any other ground-based observatory. The VLT has always been at the heart of his concerns and he has been an unwavering champion in its support.

Unknown to many astronomers Alvio had a defining influence on the way the VLT has developed and is used by astronomers. He wrote the Level 1 Requirements for the VLT kind of as a "warm-up." The VLT Science Policy document was also part of his work. Alvio led a group of ESO scientists to discuss conceptual tests of the VLT system (and define reference programmes) to see whether the system was able to cope with them. He effectively assessed design and construction decisions for their implications for the (then future) science applications and found ways to involve the ESO science community with the VLT project. Once the first telescope became reality Alvio led the science verification of the first UT and later the instruments as they came online.

Alvio was deeply involved in the instrumentation programme for the VLT. He constantly tried to improve the performance of the instruments and made many proposals for upgrades. The improvement of the red sensitivity of FORS 2 was his proposal, as was the fibre connection from FLAMES to UVES. He was told several times that this was not possible and should not be considered. But he persisted and today this is one of the most successful instrument combinations.

Alvio made sure that the second HDF happened and was located in the Southern Hemisphere so that the VLT would have access. He followed through with the large cosmological surveys and involved ESO in them. The ESO contribution to GOODS was initiated by Alvio. The ISAAC IR imaging and the FORS 2 (see the article by Vanzella et al. on page 25 in this issue of The Messenger) and VIMOS spectroscopy are due to his initiative and his constant support. zCOSMOS is the logical continuation of these activities.

Alvio in general was a great ambassador for the VLT project in the astronomical community in Europe. He advocated VLT science wherever he went.

As Alvio's last months and weeks at ESO were approaching many young people were wondering "How will research at ESO continue without Alvio?". This question was asked many times at coffee and in the corridor. Who will replace Alvio and his scientific input, his scientific insights and his experience? This was (and is) a real concern among many younger scientists who enjoyed the quiet scientific leadership Alvio provided on the fourth and fifth floor of the ESO building in Garching. His contributions to the journal clubs, seminars and colloquia were very much appreciated and they always showed a new and different aspect of the scientific topic at hand. His vast research experience was a guiding light for many at ESO. It was not by chance that he organised five ESO workshops and provided new ideas every year.


Photo: H. H. Heyer, ESO

Alvio has been amongst the most highly regarded and respected ESO astronomers in the community. In a sense he represented the scientific conscience of ESO.

The science day was a great success and enjoyed by all. We wish Alvio many more successful and fruitful years to come.

Conference on

Globular Clusters – Guides to Galaxies

March 6–10, 2006, Universidad de Concepción, Chile

The Universidad de Concepción, the Centro de Astrofísica FONDAP (Chile), the Cerro Tololo Interamerican Observatory and ESO are organising a conference on "Globular Clusters – Guides to Galaxies", which will take place on March 6–10, 2006.

The principal question of whether and how globular clusters can lead to a better understanding of galaxy formation and evolution is perhaps the main driving force behind the overall endeavour of studying globular-cluster systems. Naturally, this disperses into many individual problems.

The objective of our conference is to bring together researchers, both observational and theoretical, to present and discuss the most recent results. Topics to be covered are: internal dynamics of globular clusters and interaction with host galaxies (tidal tails, evolution of cluster masses), accretion of globular clusters, detailed descriptions of nearby cluster systems, ultracompact dwarfs, formations of massive clusters in mergers and elsewhere, the ACS Virgo survey, galaxy formation and globular clusters, dynamics and kinematics of globular-cluster systems, and dark-matter-related problems.

Invited speakers: Holger Baumgardt, Michael Beasley, Kenji Bekki, Jean Brodie, Andreas Burkert, Rupali Chandar, Patrick Côté, William Harris, Michael Hilker, Andres Jordan, Oleg Gnedin, Dean McLaughlin, Bryan Miller, Kathy Perrett, Aaron Romanowsky, François Schweizer, Stephen Zepf.

Scientific Organising Committee: Bruce Elmegreen, Duncan Forbes, Doug Geisler, Eva Grebel, Leopoldo Infante, Markus Kissler-Patig, Søren S. Larsen (co-chair), Tom Richtler (chair).

Visit our webpage: *www.astro-udec.cl*
Contact: *gcgg@www.astro-udec.cl*

NEON Observing Schools

The Fifth NEON Observing School
July 23–August 6, 2006
Observatoire de Haute-Provence, France

The Second NEON Archive Observing School
August 30–September 9, 2006
ESO, Germany

The purpose of these summer schools is to provide the opportunity for young researchers to gain practical experience in observational techniques, data reduction and analysis and the use of virtual observatory tools. Students will carry out small research projects, centred on selected astrophysical topics, in small groups under the supervision of experienced astronomers. These practical exercises will be complemented by lectures on general observational techniques and archival research for both ground and space based astronomy.

The observing school at the telescopes in Haute-Provence will largely concentrate on the skills required to execute an observing programme (imaging and spectroscopy), giving emphasis to spectroscopy and instrumental developments. The Archive Observing School at ESO will concentrate more on the quality appraisal of existing data and the research possible with large databases combining ground and space data, with emphasis on data-reduction techniques and the new tools now available within the Virtual Observatory.

The schools are sponsored by the European Community, Marie Curie Actions.

The organising consortium is composed of Asiago Observatory (Italy), Calar Alto Observatory (Germany, Spain), ESO (Germany; including participation from the Space Telescope European Coordinating Facility), Observatoire de Haute-Provence (France), Institut d'Astrophysique de Paris (France) and La Palma Observatories (ING and NOT, the United Kingdom, the Netherlands, Spain and Nordic Countries).

The schools are principally open to Astronomy PhD students and postdocs who are nationals of a Member State or an Associate State of the European Union. Applications from non-European students will also be considered, depending on the resources available.

The application deadline is April 30, 2006 for both schools.

For further details, see:
http://www.eso.org/neon-2006 and
http://www.iap.fr/eas/neonNew.html

Personnel Movements

October 1, 2005–December 31, 2005

Arrivals

Europe

Arnaboldi, Magda (I)	User Support Astronomer
Aspinall, Gareth (GB)	Project Planner
Boneva, Kristina (BG)	Student
Caproni, Alessandro (I)	Software Engineer
Di Lieto, Nicola (I)	Control Engineer
Doherty, Michelle (AUS)	Fellow
Esteves, Raul (P)	Electronics Engineer
Jost, Andreas (D)	Electronics Engineer
Kainulainen, Jouni (FIN)	Student
Kotak, Rubina (EAK)	Fellow
Kurlandczyk, Hervé (F)	Engineer
Martinez, Patrice (F)	Student
Möhler, Sabine (D)	Operations Scientist
Neeser, Mark (D)	Operations Scientist
Parker, Laura Catherine (CDN)	Fellow
Pierce-Price, Douglas (GB)	Education Officer
Sivertsen, Beatrice (D)	Secretary
Swat, Arkadiusz (PL)	Optical Engineer
Valenti, Stefano (I)	Student
Vandame, Benoît (F)	Software Engineer
Villegas Mansilla, Daniela (RCH)	Student

Chile

Christensen, Lise Bech (DK)	Fellow
De Figueiredo Melo, Claudio (BR)	Operations Astronomer
Durand, Yves (F)	Head of the Engineering Department Paranal
Geissler, Kerstin (D)	Student
Gilmour, Rachel Emily (GB)	User Support Astronomer
James, Gaël (F)	Fellow
Jullo, Eric (F)	Student
Noterdaeme, Pasquier (B)	Student
Risacher, Christophe (F)	Instrument Scientist
Schütz, Oliver (D)	Operations Astronomer
Vehoff, Stefan (D)	Student

Departures

Europe

Ahmadia, Aron (USA)	Student
Almagro Garcia, Susana (E)	Secretary
Blondin, Stéphane (F)	Student
Carmona Gonzalez, Andres (CO)	Student
Kniazev, Alexei (RUS)	User Support Astronomer
Mignani, Roberto (I)	Operations Scientist
Mottini, Marta (I)	Student
Nylund, Matti (S)	Software Engineer
Silva, David Richard (USA)	Head Data Flow Operations

Chile

Amado Gonzalez, Pedro Jose (E)	Operations Astronomer
Baumont, Sylvain (F)	Student
Delle Luche, Céline (F)	Student
Gil, Carla (P)	Student
Housen, Nico (B)	Software Engineer
Lombardi, Gianluca (I)	Student
Nesvacil, Nicole (A)	Student

List of Proceedings from the ESO Astrophysics Symposia

Volume	Title	Editors
2005	Growing Black Holes: Accretion in a Cosmological Context	Andrea Merloni, Sergei Nayakshin, Rashid A. Sunyaev
2005	High Resolution Infrared Spectroscopy in Astronomy	Hans-Ulrich Käufl, Ralf Siebenmorgen, Alan F. M. Moorwood
2005	Multiwavelength Mapping of Galaxy Formation and Evolution	Alvio Renzini, Ralf Bender
2005	Science with Adaptive Optics	Wolfgang Brandner, Markus Kasper
16/2003	Astronomy, Cosmology and Fundamental Physics	Peter A. Shaver, Luigi DiLella, Alvaro Giménez
15/2004	Toward an International Virtual Observatory	Peter J. Quinn, Krzysztof M. Górski
14/2003	Extragalactic Globular Cluster Systems	Markus Kissler-Patig
13/2003	From Twilight to Highlight: The Physics of Supernovae	Wolfgang Hillebrandt, Bruno Leibundgut
12/2003	The Mass of Galaxies at Low and High Redshift	Ralf Bender, Alvio Renzini
11/2003	Lighthouses of the Universe: The Most Luminous Celestial Objects and Their Use for Cosmology	Marat Gilfanov, Rashid A. Sunyaev, Eugene Churazov
10/2003	Scientific Drivers for ESO Future VLT/VLTI Instrumentation	Jacqueline Bergeron, Guy Monnet
9/2003	The Origin of Stars and Planets: The VLT View	João F. Alves, Mark J. McCaughrean
8/2003	Gamma-Ray Bursts in the Afterglow Era	Enrico Costa, Filippo Frontera, Jens Hjorth
7/2003	Deep Fields	Stefano Cristiani, Alvio Renzini, Robert E. Williams
6/2003	Mining the Sky	Anthony J. Banday, Saleem Zaroubi, Matthias Bartelmann

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:

ESO Headquarters
Karl-Schwarzschild-Straße 2
85748 Garching bei München
Germany
Phone +49 89 320 06-0
Fax +49 89 320 23 62
information@eso.org
www.eso.org

The ESO Messenger:
Editor: Peter Shaver
Technical editor: Jutta Boxheimer
www.eso.org/messenger/

Printed by
Peschke Druck
Schatzbogen 35
81805 München
Germany

ISSN 0722-6691

Contents

Front Cover Picture: H II region NGC 1982 in the Orion Nebula Complex
This image of the H II region NGC 1982 (M43) was obtained from observations made with the WFI instrument on the 2.2-m telescope at La Silla in December 2001 by Massimo Robberto and colleagues. The dramatic rendering of this image is due to a combination of three narrow band filters (O III, $H\alpha$ and S II, with a total of 1.5 hours of integration). The observations were reduced and combined by Benoît Vandame (ESO).