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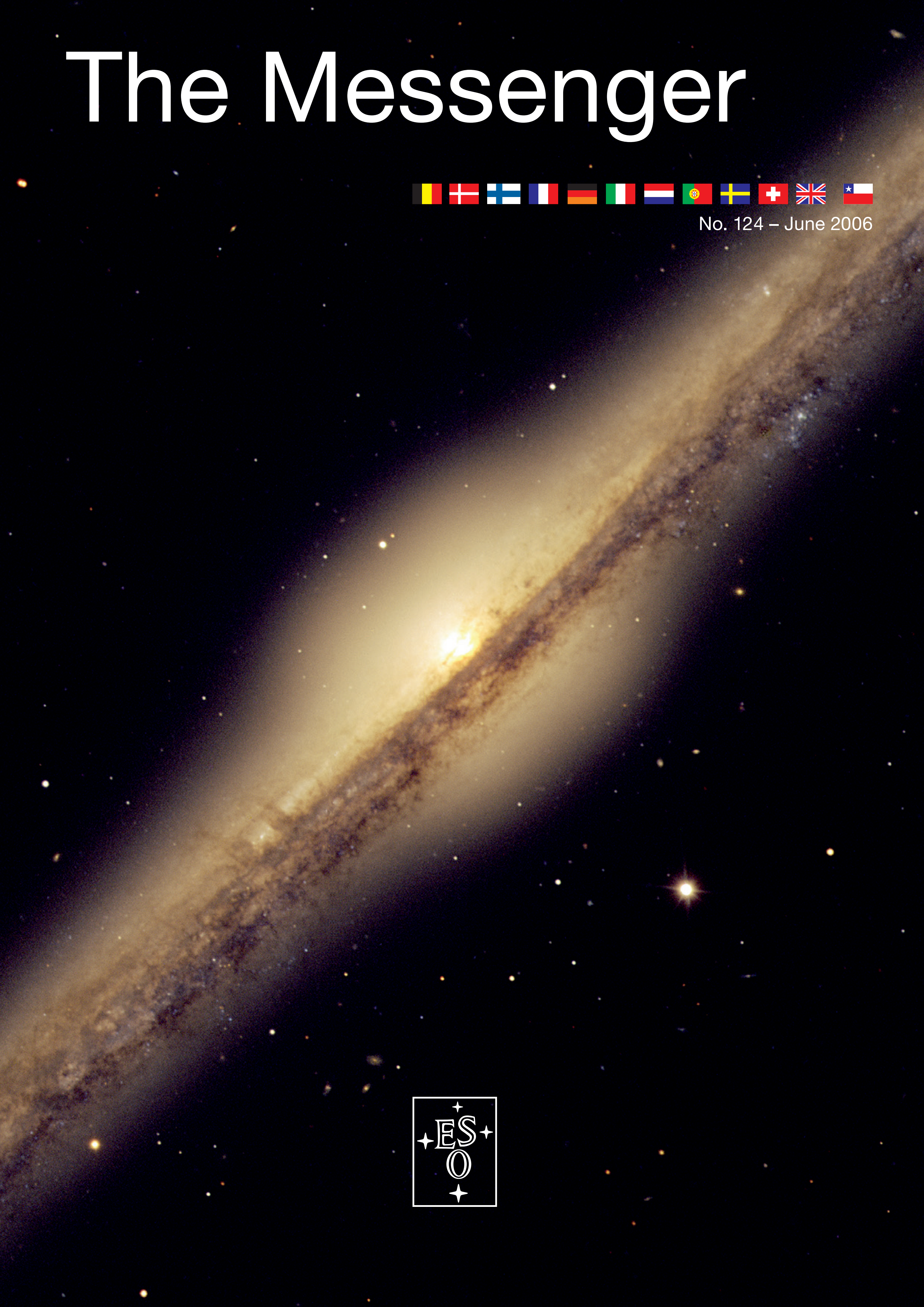

CRIRES: Commissioning of the MACAO Adaptive Optics Module and General Status Report

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The installation and commissioning of CRIRES, the Cryogenic Infrared Echelle Spectrograph, marks the completion of the original plan for the first generation of VLT instrumentation. Here we report on the commissioning of the curvature sensing adaptive optics part (MACAO) of CRIRES in April 2006. This activity also brings the quasi-series production of the MACAO systems to an end. All four UTs are now equipped with one MACAO system each to feed interferometry while UT1 and UT4 have one additional dedicated system each integrated into instruments. A summary of the overall status of CRIRES is given as well.

CRIRES is a cryogenic, pre-dispersed, infrared echelle spectrograph designed to provide a resolving power $\lambda/\Delta\lambda$ of 10^5 between 1 and 5 µm at the Nasmyth focus A of the 8-m VLT Unit Telescope 1 (Antu). A curvature sensing adaptive optics system feed is used to minimise slit losses and to provide diffraction-limited spatial resolution along the slit. The nominal slit width of CRIRES is 0.2 arcsec.

A mosaic of four Aladdin III InSb-arrays packaged on custom-fabricated ceramics boards has been developed. This provides for an effective 4096 × 512 pixel focal plane array, to maximise the free spectral range covered in each exposure. Insertion of gas cells to measure high-precision radial velocities is foreseen. Spectro-polarimetry (circular and linear polarisation) will be added in the course of the project. To that end a cryogenic Wollaston prism in combination with retarders for magnetic Doppler imaging is foreseen. CRIRES is part of the initial first-generation instrumentation complement and is an in-house project done by ESO (for an in-depth description of CRIRES see e.g. Moorwood 2003 or Käufl et al. 2004). The CRIRES MACAO system carries series number 6 of the highly successful ESO curvature sensor AO systems which were originally developed for the interferometry feed of the VLT UTs, but were later also used for the VLT instruments SINFONI and CRIRES (see Arsenault et al. 2004, Bonnet et al. 2004 or Paufique et al. 2004; alternatively one can consult the ESO AO webpage *http://www.eso.org/projects/aot/* which contains detailed information).

In mid-2005 the assembly and integration activities of CRIRES had progressed such that the in-depth verification of the performance could be started. As the requirements on stability and reproducibility are relatively demanding this test phase resulted in requests for a variety of modifications which did not allow keeping the original schedule.

However, in February 2006 CRIRES ultimately passed the last fundamental milestone on its way to the VLT: the successful completion of an 'end-to-end' test of the system. Using a simulated cool star (black-body source and a gas cell with CO mimicking a COmosphere[1]) and a turbulence generator to generate 'seeing', the overall stability of the system, that is the Adaptive Optics System and the cryogenic spectrograph, was checked by recording spectra over many hours. The result of this test was that vibrations and other instabilities are generally at a level of the equivalent of 1/20th of a pixel (75 m/s Doppler shift equivalent) or less and thus in line with the specifications reflecting the astrophysical requirements.

How to move CRIRES from Garching to the VLT

Like any other VLT instrument, CRIRES had to pass the scrutiny of a review before shipment, termed PAE (Preliminary Acceptance Europe) in 'ESO-speak'. CRIRES consists of two relatively independent subunits: the adaptive optics part with the derotator, also carrying the calibration facilities and the cryostat with the cryogenic optical bench. Hence it was decided to split the PAE process in two, and to have the 'warm optics' part reviewed ahead of the rest of the instrument. This approach is also very much in line with the reintegration process at the VLT. The integration, alignment and testing of the AO part require special tools and a special test camera which in turn require a sequential integration at the telescope. The CRIRES warm-optics acceptance review took place at ESO on 24 February 2006, and thereafter packing and shipment of the units could start, subject to few additional checks. Packing of the 'warm optics' finally started on 28 February 2006 and the crates left ESO Headquarters on 8 March 2006. All boxes of this first batch arrived in good order on Paranal on 17 March and were met by a joint team of the ESO Instrumentation and Telescope Systems Divisions. Reintegration and installation of the components progressed rapidly with hardly any problem.

In the meantime, the CRIRES cold part underwent further improvements and testing in Garching. By the time of writing of this article the PAE for the complete instrument had been granted and the spectrograph arrived in good order on Paranal on 5 May. The commissioning of the complete instrument will be reported in the next issue of *The Messenger*.

Testing the adaptive optics at the telescope

The commissioning of the warm-optics part ran in parallel with the final preparation for the second part of the PAE. Thanks to the joint efforts of the team and of Paranal staff, the integration and realignment of the warm part in Paranal were successful: the MACAO system is now functional at full performance level.

Figure 1a shows the adaptive-optics part of CRIRES after reintegration. For test purposes an infrared test camera with a spatial sampling of 17 mas/pix (milli-arcseconds per pixel) was additionally installed to characterise the AO performance (to be compared with the diffraction limit: e.g. 1.2 λ/D = 45 mas at 1.45 µm). In fact, once CRIRES is installed with its infrared slit viewer, the sampling –

[1] COmosphere is a term coined by Tom Ayres to account for the very special chromospheres of cool stars dominated by the CO-molecule.

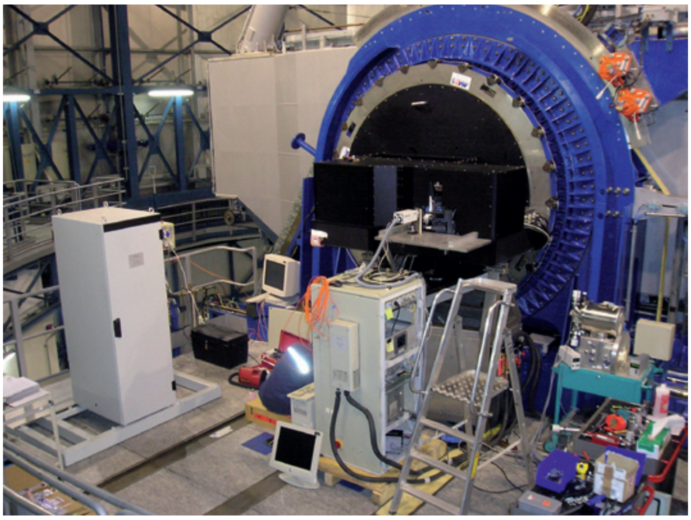

Figure 1a: A view of the CRIRES 'warm optics' nearly completely installed on the Nasmyth A platform of Antu (aka VLT UT1). The left electronics rack houses most of the entire AO related electronics, that is the real-time computer, the local control unit (LCU), the adaptive mirror control and the power supplies for all motors. Moreover the warm optics part comprises the calibration unit with continuum sources, spectral lamps and the gas-cell slide, which allows to port the 'Iodine-cell-method' for high-precision radial-velocity measurements into the infrared. The electronics rack in the centre is an auxiliary rack for the infrared test camera (which can be seen on the right side in preparation: the shiny cryostat cylinder on a blue table). At this point a normal CCD camera is still used for alignment. For the reflection in the centre, see Figure 1b.

Figure 1b: A team member, trying to sort out and reconnect the fibre bundle connecting the wave-front sensor lenslet array with the 60 avalanche photo diodes (APDs) contained in a special cabinet. The APDs are solid-state photon-counting detectors. As curvature wavefront sensing systems basically need only one fast photometric channel per sub-pupil, APDs were given preference over CCD-detectors, due to their extremely low noise level (typically 0.4 counts per loop cycle). APDs, however, are very sensitive and fragile devices, and the prevention of accidental (and catastrophic) overexposures is a key issue.

45 mas/pix – is no longer well suited to explore the AO-image quality (this camera scale was chosen to be able to explore a larger field for offset-guiding). Figure 1b shows part of the integration.

Figure 2 (next page) shows details inside the MACAO box. The commissioning culminated within a few minutes of twilight on 3 April to check the derotator algorithm. Official first light for the adaptive optics part with the infrared test camera was on 6 April when the AO control loop was closed at 23h24 UT on the 5th-magnitude B-star η Muscae. The following commissioning tasks could be finished so smoothly that the team gave back one night of commissioning time. The AO system characteristics are summarised in Table 1 and Figure 3 (next page) shows – as an example – an image of Io, the innermost Galilean moon of Jupiter with one of its active volcanoes showing up as a 'hot spot'[2]. The system has proven its stability by observing in all typical seeing conditions from 0.5 up to 1.5 arcsec. For bright stars with $m_R < 11$, Strehl ratios in *K*-band above 55 % are obtained for median seeing conditions (0.8″, τ_0 between 3 and 4 ms at 0.5 µm), at the level of performance of the other MACAO units.

Outlook

The commissioning of the complete system is ongoing and everything is prepared for first light on 4 June. A second commissioning run and potentially some science verification are planned for 4–13 August 2006. In mid-June there will be a first call for proposals for science verification programmes and at this point CRIRES will most likely be included in the next call for proposals (P79). More science verification is planned for P78 (1 October 2006 to 31 March 2007) and potentially also an early start of operations of CRIRES for normal programmes selected by ESO's OPC through the normal selection process.

[2] The first author remembers that during the time of his thesis project 20 years ago, 1 arcsec image quality on a 2–4-m-class telescope was considered 'excellent' and 2 arcsec was certainly average quality. Against this background, the images shown here constitute an amazing achievement of technology.

References

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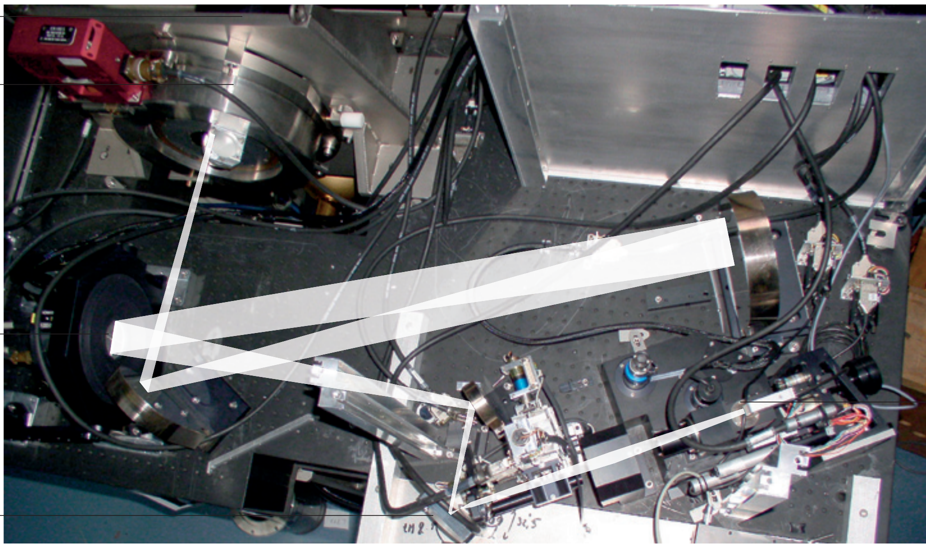

Figure 2: A close view of the optical path with the protective cover removed. The mirror labelled 'Dichroic' will be replaced at some point in late June by the CRIRES Cryostat Entrance Window. The dichroic shown here on a provisional mount will then become part of the CRIRES vacuum vessel. This mirror separates the light path at a transition wavelength of ~ 950 nm. This limits a bit the overlap with the corresponding optical spectrograph (UVES). 'DM + TTM' stands for deformable mirror in fast tip-tilt mount. It should be noted that the complete AO wavefront correction comes at the expense of only four extra reflections. The optical derotator is based on the one used in the VLT UV and Visible Echelle Spectrograph (UVES).

Table 1: Performance of the system; 'good seeing' was when the seeing was below 0.78″, while the 'bad seeing' was above 0.73″ (DIMM measurements). The Strehl values and ensquared energy indicated are for *K*-band, taking into account the aberrations introduced by the infrared test camera (82 %), and are therefore pessimistic. For a guidestar magnitude of R = 17.4 the value given for the Strehl ratio is only indicative: it is so low, that the concept of Strehl ratio starts loosing its meaning.

	R = 10	R = 13.5	R = 15	R = 17.4
Ensquared energy, good seeing	63 %	58 %	–	–
Ensquared energy, bad seeing	56 %	50 %	43 %	30 %
Best Strehl achieved	61 %	47 %	25 %	(6 %)

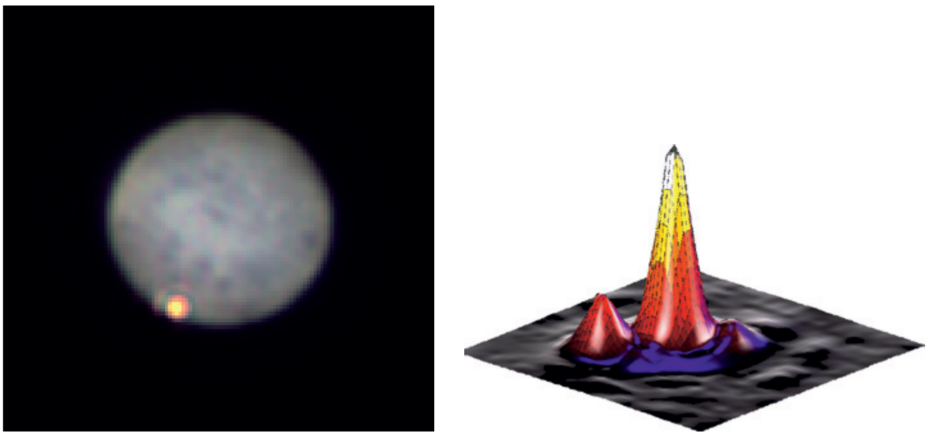

Figure 3: Left: A composite *JHK* false colour image of the Jovian Satellite Io. Io measures 3600 km and was at a distance of 4.45 AU. A volcanic eruption is visible, so bright that its airy pattern appears above the planet's background. The apparent diameter of the disc is 1.1 arcsec. On the right a 3D-image in *K*-band of the binary star HD 105196 ($m_V = 8.3/\Delta m_K = 1.3$) having a separation of 85 milliarcsec.

Probing Unexplored Territories with MUSE: a Second-Generation Instrument for the VLT

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The Multi Unit Spectroscopic Explorer (MUSE) is a second-generation VLT panoramic integral-field spectrograph presently under preliminary design study. MUSE has a field of 1 × 1 arcmin^2 sampled at 0.2 × 0.2 arcsec^2 and is assisted by the VLT ground layer adaptive optics ESO facility using four laser guide stars. The simultaneous spectral range is 0.465–0.93 µm, at a resolution of R ~ 3000. MUSE couples the discovery potential of a large imaging device to the measuring capabilities of a high-quality spectrograph, while taking advantage of the increased spatial resolution provided by adaptive optics. MUSE has also a high spatial resolution mode with 7.5 × 7.5 arcsec^2 field of view sampled at 25 milli-arcsec. In this mode MUSE should be able to obtain diffraction-limited data cubes in the 0.6–0.93 µm wavelength range.

Imager or spectrograph?

Imagers and spectrographs are the most common tools of optical astronomers. In most cases, astronomical observations start with imaging surveys in order to find the interesting targets and then switch to spectrographic observations in order to study the physical and/or dynamical properties of the selected object. Thanks to the excellent throughput and large format of today's detectors, large fractions of the sky can be surveyed in depth with imagers. As far as spectroscopic follow-up is concerned, this is still a very time-consuming task, given the relatively small multiplex capabilities available. Recent development of large multi-object spectrographs such as VIMOS at VLT (Le Fèvre et al. 2003) or DEIMOS at Keck (Fabers et al. 2003) has somewhat improved the situation. However, the total number of sources in a typical imaging survey is much larger than what is possible to observe with spectroscopy. The selection of sources is then mandatory. Usually the selection criterion is based on a series of multi-colour images and is intended to select the appropriate spectral characteristics of the population of the searched objects. This incurs a direct cost in telescope time since more than one exposure must be made at each sky location. As another disadvantage, the selection process is never 100 % efficient, and thus a fraction of time of the follow-up spectroscopy is lost due to misidentifications.

The major weakness of this approach, however, is probably not the relatively low efficiency of the method, but the *a priori* selection of targets. This pre-selection severely biases the spectrographic observations and limits considerably the discovery space.

Imager and spectrograph

The ideal instrument is one which simultaneously performs both imaging and spectroscopy. The idea is to merge into one instrument the best of the two capabilities: for imaging it is field of view and high spatial resolution; and for spectrography it is high resolving power and large spectral range.

Such an instrument will overcome the difficulty inherent to the classical method. Because there is no longer the need to pre-select the sources, one can even detect objects that would not have been found or pre-selected in the pre-imaging observations. In the most extreme case, such as objects with very faint continuum but relatively bright emission lines, the objects can only be detected with this instrument, not with direct imaging techniques.

A simple computation shows that such an ideal instrument will necessarily need a lot of detector pixels. For example consider a spatial field of view corresponding to a standard 2048 × 4096 pixel detector and a wavelength range of 0.4–0.8 μm with a spectral resolution of 3000, which translate to 4000 spectral pixels. The total number of pixels is then 16×10^9. Given that some optics are needed in front of these pixels, one can immediately see the feasibility problem.

The Multi Unit Spectroscopic Explorer

The Multi Unit Spectroscopic Explorer (MUSE) for the ESO/VLT telescope is a major step towards this ideal instrument. MUSE is being studied and built by a consortium consisting of six major European institutes, at Lyon (PI institute, CRAL, France), Göttingen (IAG, Germany), Potsdam (AIP, Germany), Leiden (NOVA, Netherlands), Toulouse (LATT, France), Zurich (ETH, Switzerland) and ESO. It is an integral-field spectrograph (or IFU) which combines large field of view, high spatial resolution, medium resolving power and large simultaneous spectral range.

Nowadays, integral-field spectroscopy is part of the panoply of modern telescopes. However, most of the currently operating integral-field spectrographs have only a small field of view and are thus devoted to the detailed physical study of single objects. Some multi-IFUs, like Giraffe at the VLT (Pasquini et al. 2002), have multiplex capabilities of a dozen objects, which increase their efficiency. This however does not break the operational three steps (imaging, selection and spectrography) paradigm.

MUSE has three operating modes: a wide-field mode which can work with and without adaptive optics correction and a narrow-field mode with high spatial resolution. The observational parameters are given in Table 1.

The total number of information elements is given by the product of the number of spaxels[1] (90000) with the number of spectral pixels (4000), resulting in 360 million elements in the final data cubes. Such a large number of pixels is not feasible with a single piece of optics and a single detector. MUSE is thus composed of 24 identical modules, each one consisting of an advanced slicer, a spectrograph and a $(4k)^2$ detector. A series of fore-optics and splitting and relay optics derotates and splits the square field of view into 24 subfields. These are placed on the Nasmyth platform between the VLT Nasmyth focal plane and the 24 IFU modules. AO correction will be performed by the VLT deformable secondary mirror. Four sodium laser guide stars are used, plus a natural star for tip/tilt correction. All guide stars are taken outside the scientific field of view in order to minimise the amount of scattered light, while the only additional optic located within the scientific field of view is a revolutionary Na notch filter, reducing transmission losses with respect to traditional AO systems. This complex AO system is part of the general VLT AO facility (Arsenault et al. 2006). The part specific to MUSE is called GALACSI.

Table 1: MUSE Observational Parameters

Simultaneous spectral range	0.465–0.93 μm
Resolving power	2000 at 0.46 μm 4000 at 0.93 μm
Wide-Field Mode	
Field of view	1 × 1 $arcmin^2$
Spatial sampling	0.2 × 0.2 $arcsec^2$
Spatial resolution at 0.75 μm (median seeing)	0.46 arcsec (AO) 0.65 arcsec (non AO)
AO condition of operation	70th percentile
Sky coverage with AO	70 % at galactic pole 99 % at galactic equator
Limiting magnitude in 80 h	I_{AB} = 25.0 (full Res) I_{AB} = 26.7 (R = 180)
Limiting flux in 80 h	$3.9\ 10^{-19}$ erg s^{-1} cm^{-2}
Narrow-Field Mode	
Field of view	7.5 × 7.5 $arcsec^2$
Spatial sampling	0.025 × 0.025 $arcsec^2$
Spatial resolution at 0.75 μm (median seeing)	0.042 arcsec
Strehl ratio at 0.75 μm	5 % (10 % goal)
Limiting magnitude in 1 h	R_{AB} = 22.3
Limiting flux in 1 h	$2.3\ 10^{-18}$ erg s^{-1} cm^{-2}
Limiting surface brightness (mag)	R_{AB} = 17.3 $arcsec^{-2}$

The MUSE narrow-field mode uses an additional optical system inserted into the fore-optics to change the spatial sampling from 0.2 arcsec to 0.025 arcsec. The field of view is proportionally reduced to 7.5 × 7.5 $arcsec^2$. The most significant change is in the AO optimisation and configuration (laser guide stars are moved closer) and the tip/tilt, which is performed at IR wavelengths on either a natural guide star within the field of view or the object itself. With such a configuration, the AO facility is expected to deliver a diffraction-limited image with a Strehl ratio of 5 % (goal 10 %) at 0.75 μm.

Science with the Wide-Field Mode

MUSE has a broad range of astrophysical applications, ranging from the spectroscopic monitoring of the Solar System's outer planets to very high-redshift galaxies. We give in the following sections a few examples of scientific applications that are considered to be important instrument drivers.

The most challenging scientific and technical application, and the most important driver for the instrument design, is the study of the progenitors of normal nearby galaxies out to redshifts $z > 6$. These systems are extremely faint and can only be found by their Lyα emission. MUSE will be able to detect these in large numbers (~ 15000) through a set of nested surveys of different area and depth (Figure 1). The deepest survey will require very long integration (80 hrs per field) to reach a limiting flux of 3.9×10^{-19} erg s^{-1} cm^{-2}, a factor of 100 times better than what is currently achieved with narrowband imaging. These surveys will simultaneously address the following science goals:
– Study of intrinsically faint galaxies at high redshift, including determination of their luminosity function and clustering properties,
– Detection of Lyα emission out to the epoch of reionisation, study of the cosmic web, and determination of the nature of reionisation,
– Study of the physics of Lyman break galaxies, including their winds and feedback to the intergalactic medium,
– Spatially resolved spectroscopy of luminous distant galaxies, including lensed objects (Figure 2)
– Search of late-forming population III objects,

[1] Spatial elements (to be distinguished from detector pixels).

Figure 1: Simulated MUSE deep field. Galaxies are coloured according to their apparent redshift. Galaxies detected by their continuum (I_{AB} < 26.7 mag) and/or by their Lyα emission (Flux > 3.9 × 10^{-19} erg s^{-1} cm^{-2}) are shown.

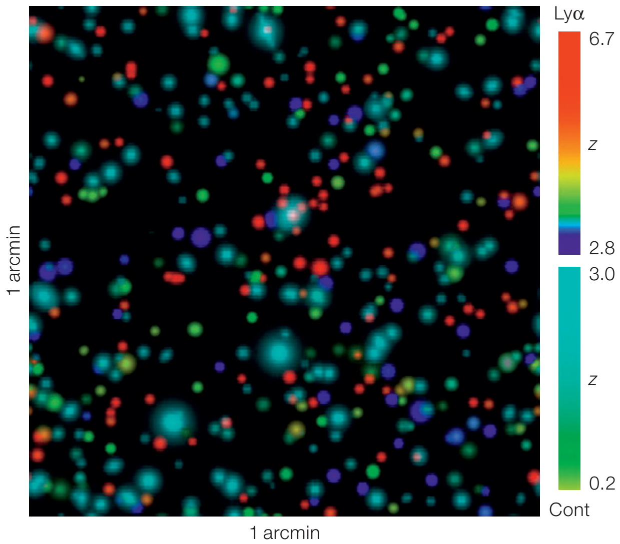
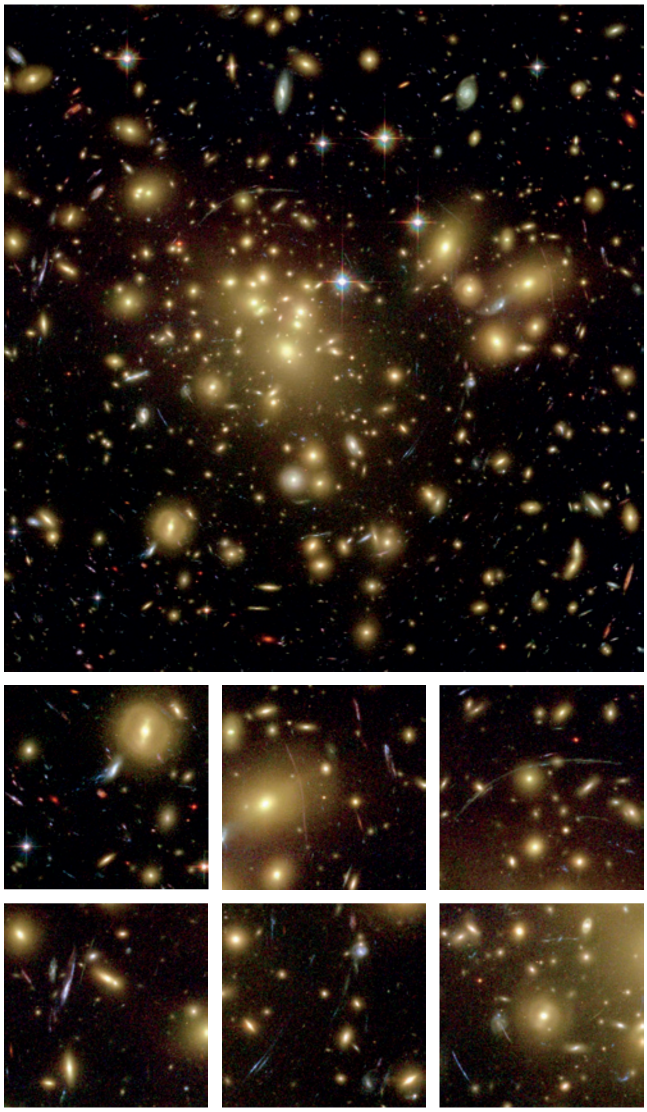


Figure 2: An HST-ACS image of the lensing cluster Abell 1689 (Broadhurst et al. 2005). This cluster is a prime candidate for strong lensing studies with MUSE, given its very large Einstein radius, and the large number of arcs identified. Broadhurst et al. identified at least seven systems which were multiply imaged. The upper panel shows the full image, the lower panels show some of the strongly lensed galaxies.



– Study of active nuclei at intermediate and high redshifts,
– Mapping of the growth of dark matter haloes,
– Identification of very faint sources detected in other bands, and
– Serendipitous discovery of new classes of objects.

Multi-wavelength coverage of the same fields by MUSE, ALMA, and JWST will provide nearly all the measurements needed to answer the key questions of galaxy formation.

At lower redshifts, MUSE will provide exquisite two-dimensional maps of the kinematics and stellar populations of normal, starburst, interacting and active galaxies in all environments, probing sub-kiloparsec scales out to well beyond the Coma cluster. These will reveal the internal substructure, uncovering the fossil record of their formation, and probe the relationship between super massive black holes and their host galaxies (Figure 3).

MUSE will enable massive spectroscopy of the resolved stellar populations in the nearest galaxies, outperforming current capabilities by factors of over 100. This will revolutionise our understanding of stellar populations, provide a key complement to GAIA studies of the Galaxy, and a preview of what will be possible with an ELT (Figure 4).

Science with the Narrow-Field Mode

In contrast to the Wide-Field Mode, the Narrow-Field mode science is dedicated to detailed studies of single objects at very high spatial resolution. We give in the following a few examples.

The study of supermassive black holes: During galaxy mergers, supermassive black holes sink to the bottom of the potential well, forming binary systems which 'scour out' lower-density cores in the central regions of the remnant. Such processes should leave detectable signatures in the environment of the SMBH. Likewise, accretion of mass onto supermassive black holes should trigger activity and feedback to the local regions and beyond. However, observationally very little is known about this environment, either in terms of stellar orbital structure or chemical enrichment history.

Young stellar objects: The key contribution from MUSE will be both in spectral grasp (covering key diagnostics of density, temperature and ionisation) and the ability to provide very high spatial resolution over a relatively large field of view. This will allow the physical processes involved in the formation and structure of the jets to be investigated in detail.

Solar System: MUSE NFM would allow observations of various bodies within our Solar System at a spatial resolution approaching that of more costly space

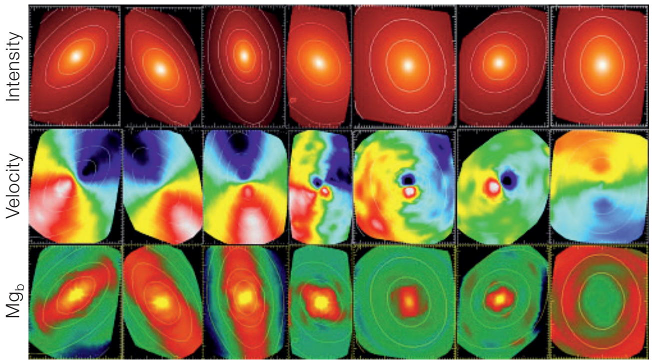


Figure 3: Selection of nearby early-type galaxies observed with SAURON (de Zeeuw et al. 2002). Top row shows the reconstructed images, which are regular and smooth. The middle row shows the velocity field, and the bottom row shows the distribution of Mg_b absorption strength. MUSE will be able to expand this pilot study at larger distance and in different cluster environments.

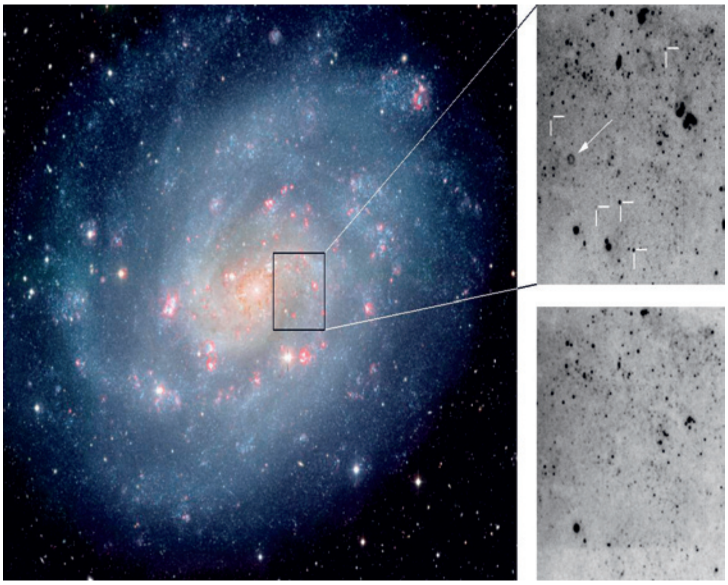


Figure 4: Left: Composite image of the southern spiral galaxy NGC 300, illustrating the power of massive spectroscopy with MUSE. The frames to the right are a narrowband [O III] 5007 exposure (top), and a corresponding nearby continuum exposure (bottom), obtained with the NTT over a FOV of 2.2 × 2.2 arcmin^2 (Soffner et al. 1996). MUSE will cover the same field in a total of four exposures. Unlike the narrowband imaging example, the MUSE data cube will provide full spectral information for each spatial element, with a huge discovery potential for massive stars, super bubbles, H II regions, PNe, SNRs, novae – virtually the full inventory of the stellar and gaseous constituents of the galaxy.

missions. Applications are: monitoring volcanic activity on the Galilean satellites, spectral monitoring of Titan's atmosphere, global monitoring of the atmospheres of Uranus and Neptune, internal structure and composition of comets and mineralogical surface heterogeneities of asteroids.

Opto-mechanical concept

The opto-mechanical concept has to fulfil the following challenging requirements:
- Replication of modules at low cost in order to achieve the required number of spatial and spectral elements.
- High throughput despite the required number of optical surfaces
- High image quality in order to optimally use the image quality delivered by the AO facility
- High stability and reliability over long exposures
- Maintain cost, mass and volume

The 24 IFUs are central to MUSE. They have been designed to achieve an excellent image quality (85 % enclosed energy within 15 × 30 µm^2 in the detector plane), and make use of innovative slicer and spectrograph concepts. The slicer is based on a two-mirror compact design, suitable for diamond machining (Figure 5 and 6). Recent progress of the manufacturing process has enabled high-precision metal surfacing with good surface roughness (3 nm rms). Such mirrors are now compatible with optical wavelength requirements and are much more cost effective than other approaches for the large-scale production foreseen for MUSE. The compact spectrograph design achieves an excellent image quality over the large spectral bandwidth of MUSE. In this design, the tilt of the detector compensates for the axial chromatism, which then does not need to be corrected optically. This is a cost-effective solution, avoiding the use of expensive optical materials, e.g. CaF2.

To maintain a high throughput (40 % for the whole instrument) despite the relatively large number of required surfaces, attention is paid to use state-of-the-art transmission and reflection coatings. Detectors are 4k × 4k 15 µm deep depletion devices with improved quantum efficiency in the red. Furthermore we will use new volume phase holographic gratings with a high efficiency over the large (one octave) spectral range.

To simplify the interfaces between GALACSI and MUSE, all AO components, including the tip/tilt sensor, are mounted in the Nasmyth derotator. There is therefore a risk of misalignment of the AO

Figure 5: Each MUSE slicer consists of four stacks of 12 slit-mirror arrays (right side of the figure) and four stacks of 12 pupil-mirror arrays (left side). This gives a total of 2304 spherical mirrors for the full instrument.

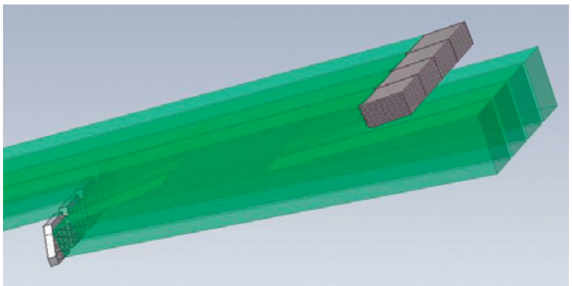
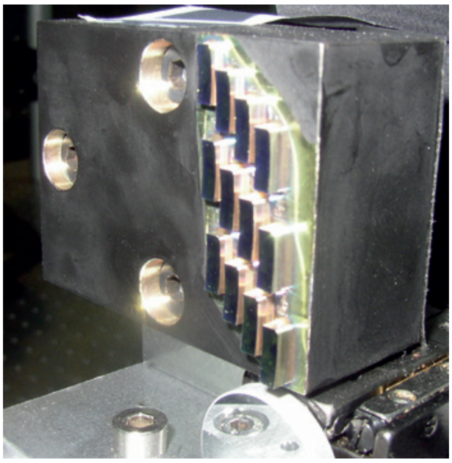
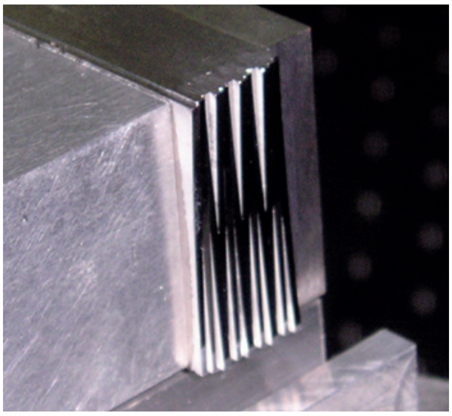


Figure 6: Breadboard slit (bottom) and pupil mirror array (top) in test at CRAL.





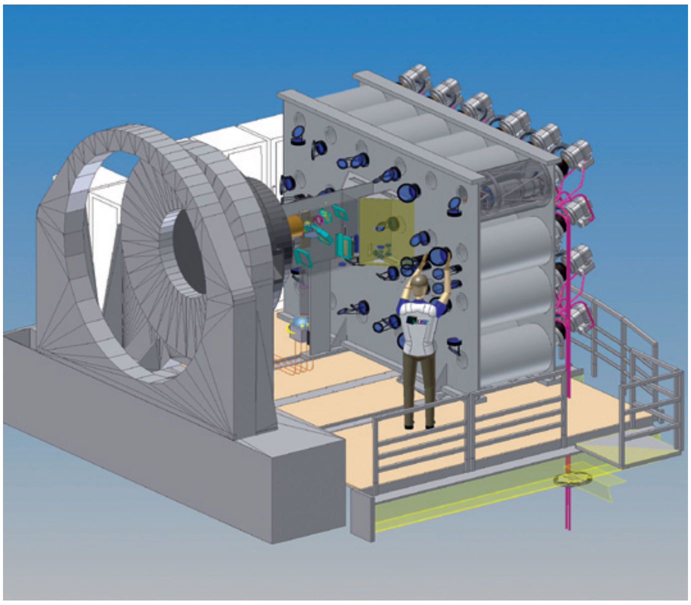


Figure 7: General view of MUSE at the VLT Nasmyth platform.

reference system with respect to MUSE, which is located on the platform. To mitigate this risk and to maintain the optical axis within the tight tolerances required by the spatial performances and stability, a metrology system has been designed. It is a closed-loop system based on four reference light sources located in the fore-optics and imaged into the AO system.

The cryogenic system is based on pulse tubes, which are compact and which avoid refilling 24 dewars with liquid nitrogen. The accompanying compressors are located outside the Nasmyth platform on the telescope floor to avoid any possible transmittance of vibrations onto the instrument.

The instrument weight is approaching eight metric tons in total and its size will fill basically the entire volume of the Nasmyth platform of roughly 50 m^3. This is bigger than every instrument that has been built so far for the VLT and will make MUSE an impressive instrument (Figure 7 and 8). With these dimensions, assembling and providing the necessary access to all the components is a challenge. The main instrument structure is designed as a single unit to fulfil the highly demanded stability of all optical components with respect to each other in order to maintain the superb image quality given by GALACSI on long exposures.

The latter is done with a complex optical system that has to derotate and to split the observing field and to distribute and feed the spectrographic units with these sub-fields. Despite its 24 spectrographs mounted into a monolithic structure, MUSE will act as a single instrument with respect to the telescope and the AO system. Nevertheless, the instrument is set up with a highly modular character for the assembly, maintenance and any operational exchange.

Operations and data reduction

Despite its impressive number of opto-mechanical elements, MUSE will be easy to operate. There are no moving parts in the 24 modules and the switch between wide to narrow-field mode implies only the addition of some optics within the fore-optics train. MUSE has only three operating modes: non-AO and AO wide field mode, and AO narrow-field mode. The three modes differ only by the presence of AO and the spatial sampling. In the wide-field non-AO mode, operations will be limited to the simple point-and-shoot scheme. In the other modes, the complexity is related to the operations of AO including the lasers. All modes share the same spectroscopic configurations (wavelength range and resolution).

On the other hand, with 1.6 Gb per single exposure, the data reduction is a challenge, not only because of this data volume, but also because of its 3D characteristics. The handling of such large data cubes is not straightforward. As an example, one can mention the optimal summation of a series of data cubes obtained with AO and different atmospheric conditions. This is intrinsically a 4-dimensional problem because the AO-delivered PSF changes with time, location within the field of view, and wavelength.

Project status

The project is currently in its preliminary design phase. In July 2006, the optical preliminary design review will be the starting point for the manufacturing of a complete breadboard consisting of a slicer, a spectrograph and a detector, while the full preliminary design review is scheduled for early 2007. Results of the breadboard will be analysed for the final design review in July 2008. Manufacturing, assembly and integration will then take place up to mid 2011. First light is scheduled on Paranal in early 2012.

Conclusions

Astronomy is to a significant degree still driven by unexpected discovery (e.g. dark matter and dark energy). These discoveries are often made by pushing the limit of observations with the most powerful telescopes and/or opening a new area of instrumental parameter space. MUSE is designed to push the VLT to its limit and to open a new parameter space area in sensitivity, spatial resolution, field of view and simultaneous spectral coverage. We are convinced that it fulfils all the required conditions to have a large potential of discoveries:

– It will be the first spectrograph that can blindly observe a large volume of space, without any imaging pre-selection.
– It will be the first optical AO-assisted IFU working at improved spatial resolution in most atmospheric conditions with large sky coverage.
– It will be the first spectrograph optimised to work with very long integration times and to reach extremely faint emission-line detection.

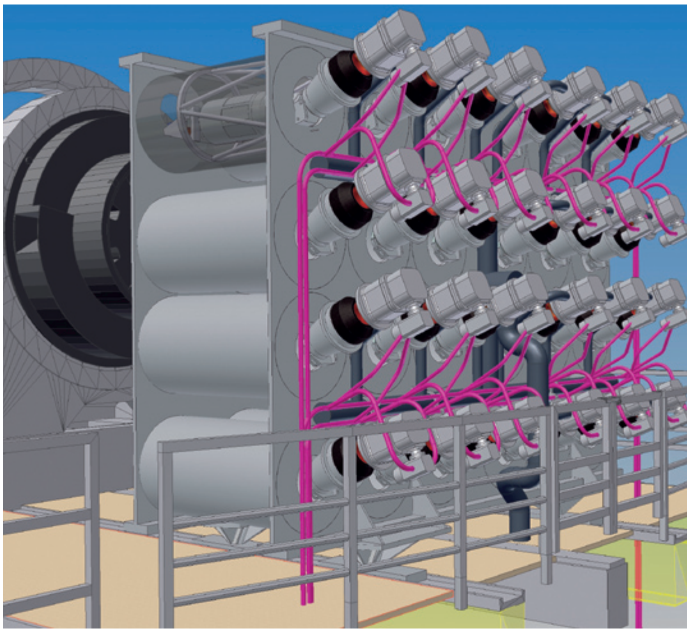


Figure 8: MUSE view from the back of the Nasmyth platform. One can see the 24 spectrograph cameras and the cryogenic systems.

MUSE will thus be able to discover objects that have measurable emission lines, but with a continuum that is too faint to be detected in broad-band imaging. For example, the deepest broad-band imaging available today is the HST Ultra Deep Field (UDF) with $I_{AB} < 29$. According to CDM simulations, however, only 15 % of MUSE high-z Lyα emitters ($z > 5.5$) will have a continuum bright enough to be detected in the UDF. MUSE is also the only instrument capable of detecting faint diffuse ionised gas, like extended halos or filaments. Finally, objects with unusual spectral features should also be detected by MUSE, whatever their broad-band magnitude and colours are. The unprecedented capabilities of MUSE should also lead to discoveries far away from our present expectations.

In many aspects, MUSE is a precursor of future ELT instrumentation. For example, manufacturing, integration and maintenance of a large number of identical, high-performance optical systems at low cost and on reasonable time scale will be a critical aspect for most of the ELT instruments.

Acknowledgements

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– The *Verbundforschung* of the Federal Ministery for Education and Research (BMBF), managed by PT-DESY, by the Astrophysical Institut Potsdam and by the University of Göttingen for the German participation
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A dedicated integration hall for MUSE will be build at CRAL. This building is funded by the *Région Rhône-Alpes*, the CNRS, the city of Lyon, the *Ministère de la Recherche et de la Technologie*, the University Claude-Bernard Lyon I, the Grand Lyon, the town of Saint-Genis-Laval and the Rhône department.

MUSE public web site: *http://muse.univ-lyon1.fr*

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New, Efficient High-Resolution Red VPH Grisms in VIMOS

Gianni Marconi, Stefano Bagnulo, Jean-Louis Lizon, Bernard Buzzoni, Hans Dekker, Sandro D'Odorico, Carlo Izzo, Burkhard Wolff (ESO)

VIMOS is the visible (360 to 1000 nm) wide-field imager and multi-object spectrograph mounted on the Nasmyth focus B of Melipal (UT3) (Le Fèvre et al. 2003). The instrument is comprised of four identical arms each with a field of view of 7′ × 8′ with a 0.205″ pixel size and a gap between each quadrant of ~ 2′. Each arm is equipped with six grisms providing a spectral resolution range from ~ 200–2500 and with an EEV 44-82, thinned, anti-reflection coated, 4k × 2k pixel CCD. VIMOS operates in three different modes: Imaging (IMG), Multi-Object Spectroscopy (MOS), and with Integral Field Unit (IFU). For a summary of the instrument capability and performance, see *http://www.eso.org/instruments/vimos/*

One of the High-Resolution Red grisms (600 grooves/mm) was damaged during the instrument testing phase. From the beginning of operation in 2003, observations in this mode had to be executed using a HR_{orange} grism in one of the channels. Coupled with the relatively low efficiency intrinsic to the old grisms, this mismatch was a strong limitation to the performance of the instrument in this particular setup. In September 2005 the HR_{red} grisms were replaced by a new set of Volume Phase Holographic (VPH) grisms offering a superior efficiency while maintaining the same spectral resolution. The VPH grisms were manufactured by CSL and their operating characteristics are given in Table 1.

The definition of requirements, the VPH specifications, the procurement and the gluing of the prisms and the VPHGs were done by the Optical Instrumentation Department. The mounting design, integration and testing by the Integration Department. Commissioning and characterisation were carried out by the Operation Staff in Paranal and VIMOS-assigned staff in the Data Management Division.

Figure 1: Prisms and grating optical elements glued together.

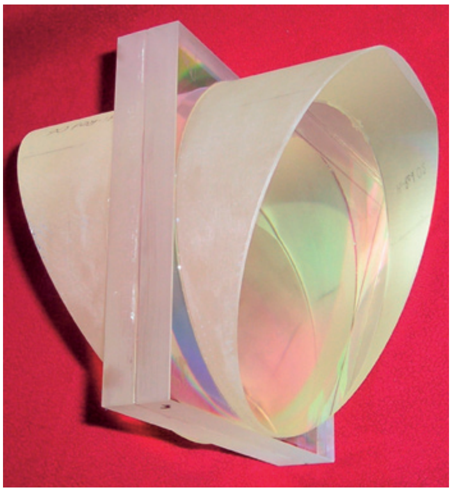


Figure 2: The VPH grism as hosted inside the new mounting.

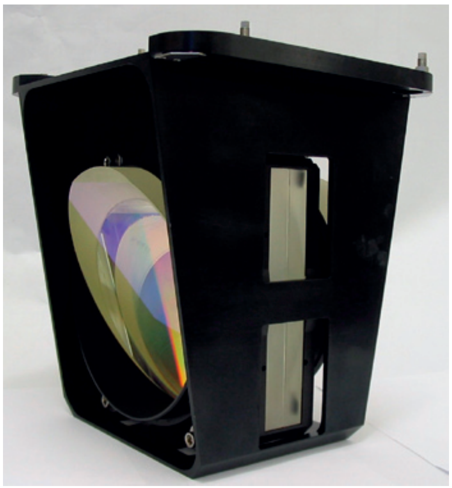


Table 1: VPHG HR_{red} grism characteristics.

Wavelength range	0.50–1.05 micron
Spectral resolution	R ~ 2500
Dispersion	~ 0.6 Ångstrom/pixel

One of the final prisms and grism optical assemblies is shown in Figure 1; the same element as hosted into the new mechanical mount is shown in Figure 2. This new mounting includes an on-board alignment system which reduces the time needed to realign the grisms in case of dismounting or earthquake events to a few minutes.

The comparison of the old versus new grism efficiency curves as measured in the ESO optical lab is shown in Figure 3; the wavelength range 0.6–0.9 micron corresponds to a slit at the centre of the field. The response of the new VPH grisms with VIMOS was measured by observing spectrophotometric standard stars on different photometric nights. The global efficiencies of the UT3+VIMOS+grism with both the old and the new VPHG HR_{red}, as provided by the ESO-VIMOS pipeline, are shown in Figure 4. A notable improvement (~ 40–70 %, depending on wavelength) has been obtained in the full spectral range covered by the grisms.

Reference

Le Fèvre O. et al. 2003, SPIE 4841, 1670

Figure 3: The efficiency curve of the old grism (black line) and the new one (red line) as measured in the laboratory.

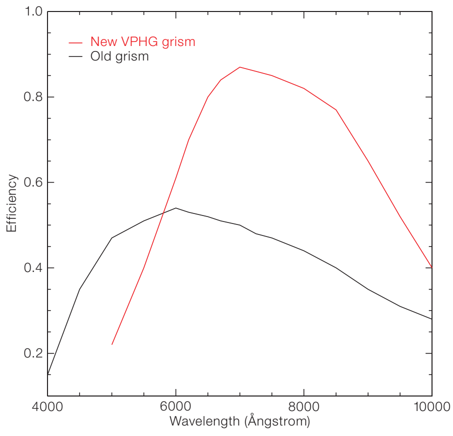
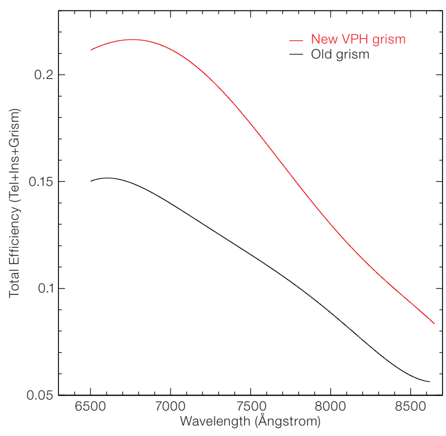


Figure 4: The comparison between the global efficiency (telescope+instrument+grism) as measured on sky by using the same spectrophotometric standard star; old grism (black line) new grism (red line).



The Atacama Pathfinder EXperiment

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APEX, the Atacama Pathfinder Experiment, is operational on Llano de Chajnantor, on what is considered one of the world's best sites for submillimetre astronomy. With its large primary reflector of 12 m diameter, carefully adjusted to a surface smoothness of only 17–18 µm r.m.s, APEX will allow observations up to 200 µm, through all atmospheric submm windows accessible from the ground. Scientific opportunities to explore the 'cold universe' are discussed, and first scientific results are presented.

Go Atacama!

Because submillimetre radiation from space is heavily absorbed by water vapour in the Earth's atmosphere, APEX is located at an altitude of 5 100 metres in the high Atacama desert on the Chajnantor plains, 50 km east of San Pedro de Atacama in northern Chile. The ALMA site characterisation, covering the years 1995 to 2004, has shown that the location is one of the driest places on Earth: the 50 (25) % quartile of the precipitable water column is 1.0 (0.6) mm, respectively. During the Chilean winter months (June through September), for an appreciable fraction of the time conditions are better than 0.3 mm pwv – exceptional conditions for which the supra-THz atmospheric windows become transparent for dedicated experiments (see Figure 2).

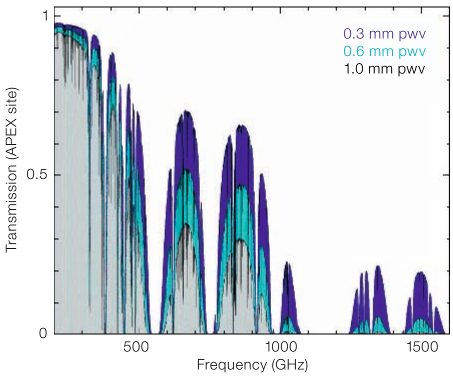


Figure 2: Zenith transmission of the atmosphere above Llano de Chajnantor at submillimeter wavelengths. Using data from the ALMA site characterisation, we calculate the 50 and 25 % quartile columns of precipitable water to 1.0 and 0.6 mm, respectively – excluding data taken during the Bolivian winter months (day numbers 15–90). The dark blue figure corresponds to 0.3 mm pwv, a rare, but not uncommon event that opens up the supra-THz windows.

A brief project history

By the mid 1990s, the astronomical richness of the submillimetre wavelength range had been demonstrated by the early successes of the 15-m James Clerk Maxwell telescope and the Caltech Submillimeter Observatory 10.4-m telescope, both operating on the 4 000-m high Mauna Kea on Hawaii. At that time, in North America, Europe, and Japan plans for a large millimetre interferometer array were made and extensive site testing campaigns were undertaken. In the course of these, the 5 100-m high Llano de Chajnantor was identified as possibly the best accessible site on Earth for submillimetre astronomy, outside of Antarctica. In fact, the weather statistics for that site looked so good that the initial interferometer concept was extended and, despite its name, the Atacama Large Millimeter Array (ALMA) was planned to cover all the millimetre *and* submillimetre windows with good transmission to the ground.

Photo: A. Lundgren, ESO

Convinced of the quality of the Chajnantor site, Karl Menten persuaded the Max-Planck-Society to provide funding to acquire a copy of one of the ALMA prototype antennas (at that time three prototypes were planned) with as early as possible deployment to Chajnantor – as a pathfinder for ALMA. ESO and the Onsala Space Observatory (OSO) appeared as natural partners, since they had been operating the highly successful 15-m Swedish-ESO Submillimetre Telescope (SEST, Booth et al. 1987) since 1987 on the lower altitude La Silla. The new ESO Director General, Catherine Cesarsky, and Onsala Space Observatory Director Roy Booth welcomed the idea enthusiastically – the Atacama Pathfinder EXPeriment was born.

Immediately after the Memorandum-of-Understanding between the partners was signed on 02 July 2001, MPIfR contracted the design and construction of the telescope to VERTEX Antennentechnik GmbH, Germany. Construction at the high site started in spring 2003; commissioning began in spring 2004. After successful verification of the performance of the telescope to specifications, the facility was inaugurated on 25 September 2005. With operational readiness the responsibility for operation of the facility was entrusted to ESO, and responsibility was transferred from Rolf Güsten (Project Manager since spring 2004, during the commissioning phase) to the Station Manager Lars-Åke Nyman.

Operation of the Facility

The unique observing opportunities come with the costs of demanding logistics required to operate a frontier science observatory at a place as remote as Llano de Chajnantor. The telescope is operated from the APEX base in Sequitor in San Pedro de Atacama at an altitude of 2 440 m. However, it was essential that infrastructure to support operations and maintenance of the telescope was built on Chajnantor as well as in Sequitor. Duty staff sleep in the Sequitor base. The telescope can be controlled remotely from Sequitor through a 36 Mbit/s microwave link and the Sequitor base has a 2 Mbit/s connection to the outside world. Chajnantor is accessed either by the international highway to Argentina, the Paso Jama road (paved), for the first 60 km, followed by a 15-km dirt road, or through the ALMA road, which is now being constructed.

Figure 1: Panoramic view of the ALMA site, Llano de Chajnantor, taken from Cerro Chico. The APEX telescope is seen to the left, and our next neighbour, the CBI experiment, to the right. The ALMA AOS technical building (now under construction) and the compact array configuration will be located in the centre of the picture.

The telescope is situated on Chajnantor about 2 km north of the newly constructed ALMA AOS building and array centre. The area includes the telescope and a set of containers consisting of a control room, emergency dormitory, laboratory, kitchen, storage and sanitary facilities. The control room and dormitory are oxygenated to a level of 29 %, which makes it reasonably comfortable to work inside. For outside work the staff use portable oxygen systems. Electrical power is provided through two generators, each producing 450 kVA at sea level (downgraded to about half of that at 5100 m). Telephone connections and network are provided through the microwave link, and there is radio communications equipment for contact between the pick-up trucks, Chajnantor and Sequitor. Work at the high altitude is governed by strict safety rules; access to the site requires authorisation by the Station Manager.

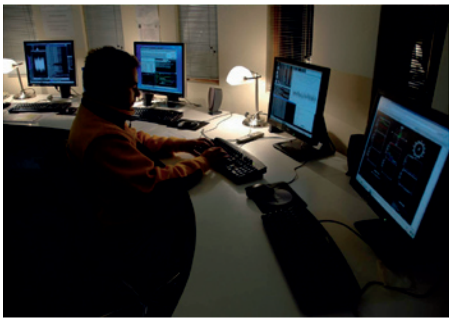
The Sequitor base is situated about 6 km south of the centre of San Pedro de Atacama on 2.2 ha of land. It is located in the oasis of San Pedro with trees and vegetation, and access to irrigation water every three weeks. The buildings are made of adobe and follow the local style of construction. There is a building containing offices, laboratories and a control room, as well as 17 dormitories, a cafeteria, a meeting/recreation building and storage. Power is provided through two generators, water is provided from San Pedro, hot water is produced through a combined solar/electrical heating system and there is a sewage treatment plant as well as a gasoline station.

The staff of 25, including astronomers, operators, engineers, technicians and maintenance personnel, is contracted to ESO. The APEX staff must deal with the many kinds of logistics activities of a remote site, including trips and transfers for staff and visitors, transport of materials to and from Santiago and abroad, deliveries of diesel fuel for the generators, catering and cleaning services, infrastructure maintenance and truck maintenance (APEX operates five pick-up trucks).

APEX is part of the local community of Sequitor and San Pedro de Atacama, and participates in local activities and contributes funds for educational, cultural and community projects.

Figure 3: The APEX control room in the Sequitor base, from which Claudio Agurto operates the telescope (lower left). The radio link transmitters are visible on top of the building. To the left, the laboratory wing is seen, with our open air meeting room.

Photos: A. Lundgren, ESO



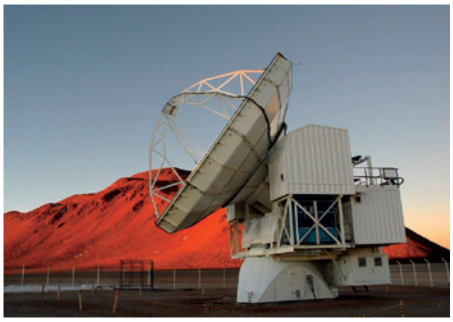


Figure 4: APEX at sunset with Cerro Chajnantor in the background.

The Telescope

The APEX telescope is a modified copy of the VERTEX ALMA prototype, customised for stand-alone (single-dish) operation. Two additional Nasmyth cabins for heterodyne receivers and two large instrument containers for supplementary equipment (such as spectrometers, synthesizers, compressors and chillers) add to a total mass of the modified antenna of ~ 125 t.

The telescope is a Cassegrain system with a parabolic main reflector, on an alt-az mount. The 12-m-diameter reflector, consisting of 264 aluminium panels in 8 rings, is mounted on a carbon fibre reinforced plastic (CFRP) back-up structure of 24 sandwich shell segments. The back-up structure is supported by an INVAR cone, which is attached to the top of the Cassegrain cabin. The adjustable panels, manufactured to a surface accuracy of 8 μm rms, have been chemically etched to scatter solar radiation, allowing daytime observations.

The aluminium secondary reflector, supported by CFRP quadripod legs, provides a field-of-view suitable for wide-field bolometer arrays in the Cassegrain cabin. For operation (of basically the heterodyne receivers) in the Nasmyth cabins, the telescope waist from the secondary is transformed (through the elevation tube) by refocusing optics into the Nasmyth waists. The tertiary mirror package is on a rotary support to select between the two Nasmyth foci and to clear the optical path for the bolometer pick-up mirror (on the floor of the Cassegrain cabin).

Figure 5: Adjustment of the surface. 1320 positioners on in total 264 aluminium panels were adjusted with a few μm accuracy. The small images show APEX engineer Juan Fluxa riding the cherry picker, and Leo Vanzi with Jorge Corante in the cage.

Photos: R.Güsten, MPIfR

Striving toward the perfect telescope

The coupling efficiency of a radio telescope to an astronomical source is basically controlled by the surface smoothness ε of its parabolic reflector: the classical *Ruze* formula describes the loss of efficiency with wavelength λ as an exponential decrease $\propto \exp(-(4\pi\,\varepsilon/\lambda)^2)$, i.e. for $\varepsilon = \lambda/15$ the antenna coupling efficiency has decreased to half its maximum already. In order to operate with high efficiency in the last of the classical atmospheric windows (around 300 μm wavelength, see Figure 2), the specifications for the APEX require for a surface smoothness of better than 20 μm rms. This requires that, over the 12-m diameter of the main dish, the deviation from the perfect parabola has to be less than one fifth of the average thickness of a human hair – a rather challenging requirement on the manufacturing, assembly and adjustment of the antenna.

After assembly, the main reflector was pre-aligned by VERTEX by means of optical photogrammetry to 35–40 μm rms surface accuracy. From there on the APEX holography team performed near-field holography with a 92.4 GHz transmitter located near the summit of Cerro Chajnantor, at an elevation angle of 13 deg. During three holography sessions (May and June 2004, April 2005), in an iterative process, phase residuals were measured and converted to surface error maps which were then used to correct for panel-to-panel misalignments and panel flexures. The manual adjustment of the (maximally) 1320 vertical adjuster elements typically took a full workday, depending on the environmental conditions, with teams working in shifts (Figure 5). In April 2005, the surface was finally set and verified to an excellent 15 μm rms smoothness towards the transmitter (Figure 6). Because of gravitational deformations the performance of the antenna would rapidly degrade towards higher elevations. Therefore the finite-element model of the APEX dish was used to pre-load and thus optimise the surface settings for elevations that will actually be used for astronomical observations. The effective surface smoothness for the elevation range 30–80 deg, calculated to 17–18 μm, is confirmed by carefully calibrated measurements of the telescope's coupling efficiencies to astronomical sources (planets). This makes APEX a superb telescope with performance well within specifications that allows observations into the supra-THz windows.

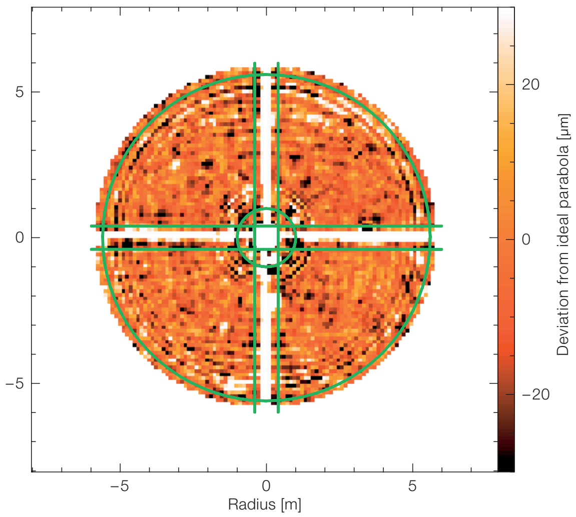


Figure 6: The surface error pattern of the APEX main reflector after the final (April 2005) holography session. The surface smoothness is 14.7 µm rms (Güsten et al. 2006).

Science with APEX

As its name implies, APEX is a pathfinder for other (sub)millimetre wavelength missions, most directly for ALMA. This giant array of 50 12-m antennas separated by baselines up to 14 km, will also be located on Llano de Chajnantor (Figure 1) and is expected to start operation in 2012 (*www.eso.org/projects/alma*). There are great complementarities to the Herschel Satellite and the Stratospheric Observatory for Infrared Astronomy (SOFIA), whose instruments will reach to higher frequencies into the far-infrared wavelength range not accessible from the ground. Towards longer wavelengths, APEX picks up where the wavelength coverage of, e.g., the IRAM 30-m telescope on Pico Veleta (Spain) ends. Together, the latter two instruments cover all atmospheric windows observable from the ground between 0.2 and 4 mm with comparable angular resolution (the half-power beamwidth of the 30-m antenna at the frequency of the CO(2–1) transition, ~ 11″, compares nicely with the 9″ resolving power of APEX observations of warm CO(6–5) at 690 GHz).

What does APEX observe? Mostly the cold and cool universe, through radiation from molecules and dust. Molecular lines in the submillimetre range sample warmer and denser gas than millimetre lines, so the formation of stars and galaxies and the astrochemistry associated with these events are central work areas for APEX. Molecular cores show very line-rich spectra in the submillimetre range, the analysis of which gives insight into the ignition phase of, particularly massive, stars. Studying the submillimetre region is also crucial for understanding the feedback of newly born stars, through outflows and the creation of photon dominated regions. APEX will make particularly valuable contributions to the study of galaxies, where we are faced with the somewhat paradoxical situation that the high-J (submillimetre) CO lines are well observed in highly redshifted objects, since the frequencies are shifted to the millimetre range, but we know very little about the very same transitions in nearby starburst and merger galaxies. Particularly the CHAMP$^+$ heterodyne array will remedy this imbalance.

Early results from the first months of science observations since operation readiness will be published soon in a special issue of Astronomy & Astrophysics Letters. Here we highlight a few examples to demonstrate APEX's immediate impact on different fields of astronomy.

APEX detects a new molecular ion

More than 120 different molecules are known in the interstellar medium, about 10 % of them positively charged ions. Most of these molecules contain hydrogen, oxygen, carbon, and nitrogen, the four most abundant elements. A few molecules containing silicon, sulfur, phosphorus and one even containing iron have been found as well. However, only two halogen-bearing molecules had been known to exist in the interstellar medium: HCl and HF. HF, the main reservoir of interstellar fluorine, unfortunately is impossible to observe from the ground but was detected with the Infrared Space Observatory by a team led by David Neufeld (Johns Hopkins University) that included APEX project scientist Peter Schilke. Neufeld and colleagues recently put fluorine chemistry to closer scrutiny and predicted CF^+ to be the second most abundant F-containing species.

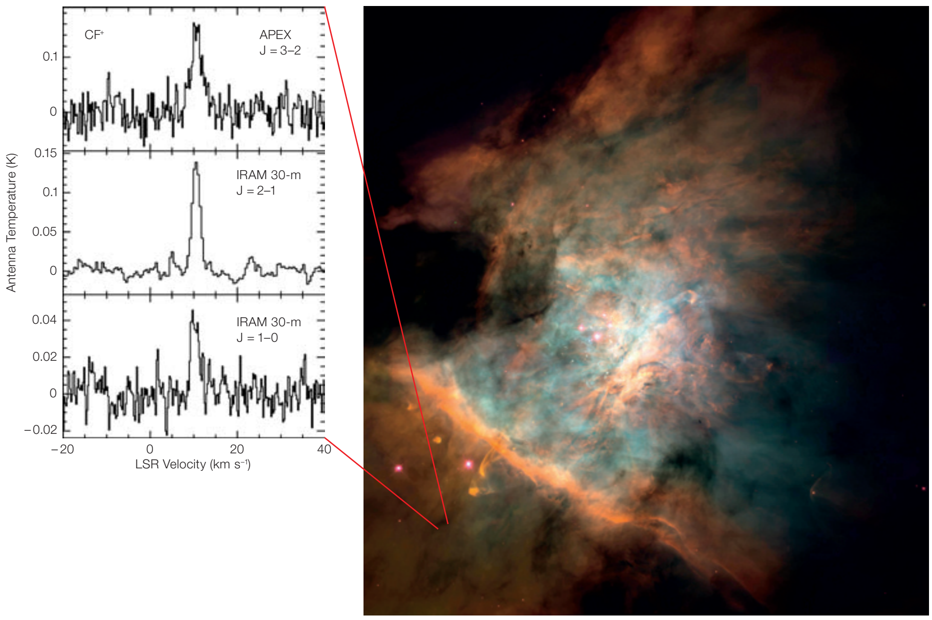
In a concerted effort with the IRAM 30-m telescope, APEX has identified for the first time CF^+ (fluoromethylidynium) in space. While its two lowest energy (and lowest frequency) spectral lines were discovered with the former, APEX clinched the identification with a third line. This interesting molecule exists in an UV exposed molecular interface region where the hot stars that excite the famous Orion Nebula also provide the ionising radiation. Our observations indicate that models of the chemistry of fluorine-bearing molecules are realistic and that these molecules can be used to probe interstellar clouds. They thus open a new chapter in interstellar chemistry.

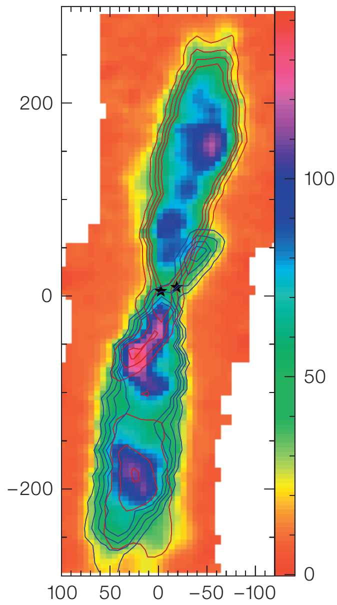
APEX reveals the nature of the BHR71 outflow

It is commonly believed that highly-collimated outflows are the first stage in outflow evolution, and their study is thus central to understand the interaction of the jet with the surrounding cloud. BHR71, a small Bok globule at 200 pc distance, harbours a beautiful example of such a highly collimated outflow. This outflow is powered by a young low-mass protostar, IRS1, belonging to a binary system. Submm observations with APEX of the CO(3–2) emission have confirmed the existence of a second fainter and more compact bipolar outflow, associated with the other protostar of the binary system (Parise et al. 2006). Temperature enhancements in the lobes of the extended outflow are constrained by

Figure 7: HST image of the Orion nebula. Towards the so-called Orion 'bar' interface region APEX, together with the IRAM 30-m telescope, have detected a new ion molecule: CF^+ (Neufeld et al. 2006). Credit: NASA, C. R. O'Dell and S. K. Wong (Rice University).

Figure 8: CO(3-2) map of the BHR71 outflow. The colour scale represents the integrated intensity over the whole velocity range of the IRS1 outflow. Red and blue contours mark the integrated intensities of the two lobes of the outflow powered by IRS2 (Parise et al. 2006).





observations of high-energy lines of methanol. The authors derive temperatures between 30 and 50 K, with densities ~ 10^5 cm^{-3}. The small outflows appear to be even warmer (up to 300 K).

APEX goes extragalactic from the beginning

The first extragalactic object at which APEX was pointed during its commissioning was NGC 253, which is considered – with M82 – the archetypical nuclear starburst galaxy. Because of its proximity, less than 10 million light years away in the southern constellation of Sculptor, APEX can spatially resolve its central circumnuclear gas layer. In Figure 9 we display the emission of the CO J = 4–3 rotational transition (at a wavelength of 650 μm), superimposed on an optical image of the galaxy. Mapping different CO and atomic carbon lines allows studies of the density and temperature of the gas in this interesting environment. By modelling the excitation of CO(4–3) and CO(7–6), we derive a kinetic temperature of 60 K and H_2 density of ~ 10^4 cm^{-3} for the central gas layer. The submm rotational transitions of CO are shown to be the main cooling lines of the warm dense interstellar gas, peaking at J = 6–5 for the central 250 pc of NGC 253.

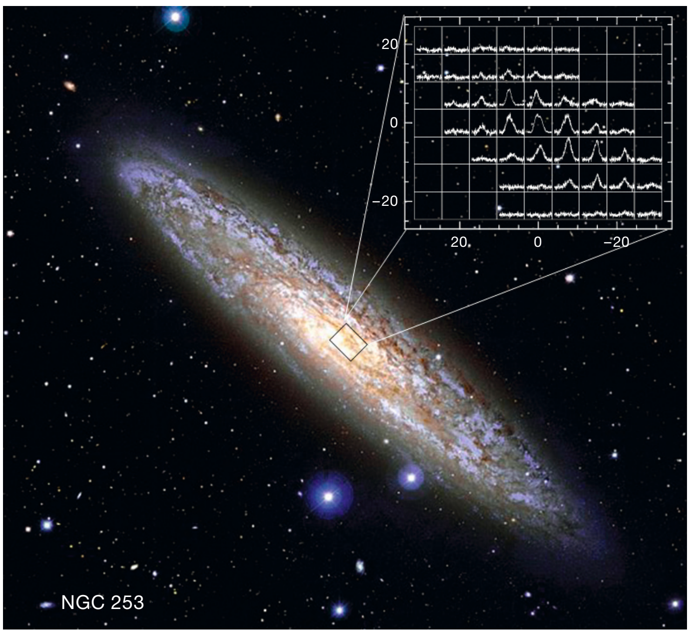


Figure 9: Distribution of warm carbon monoxide, as measured with APEX in its J = 4–3 rotational transition at 461 GHz (Güsten et al. 2006), superimposed on an optical image of NGC 253. Spectra have been sampled at half beam spacing (the beam of APEX at this frequency is 13.3″).

These very first observations of a nearby starburst nucleus reveal the potential of APEX in constraining the gas excitation in these nuclei. With broader band spectrometers and the chopping secondary coming soon, and given the exceptional observing conditions at the site, the impact of this facility on extragalactic astronomy will be significant.

Instruments for APEX

In parallel to the construction and commissioning of the APEX, a demanding cutting-edge technology programme has been launched to provide the best possible detectors for this outstanding facility. For its first observations, APEX was equipped with state-of-the-art submm receivers developed by MPIfR's Division for Submm Technology (FLASH I and II, Heyminck et al. 2006, with new technology Fast-Fourier-Transform spectrometers, Klein et al. 2006) and with a first facility receiver (working in the 345 GHz atmospheric window) build at Chalmers University (Risacher et al. 2006).

Soon the first array receivers will be commissioned: LABOCA, the 870 μm 295 pixel facility bolometer camera, is scheduled for June this year, and later in August the Champ$^+$ 2 × 7 pixel heterodyne array of the MPIfR will be commissioned. In December OSO will deliver a suite of single pixel facility receivers covering the 210–500 GHz frequency range.

Observing with APEX

The observing time will be shared in proportion to the partner's investments (45 % MPIfR, 24 % ESO, and 21 % OSO), with 10 % allocated to Chile as host nation. On the ESO side, APEX proposals are reviewed by the ESO OPC and deadlines follow the normal ESO deadlines for proposal submission. The APEX web pages (*www.apex-telescope.org*) include technical descriptions of the system and observing time calculators. The observations are done in service mode, mainly during night-time. The Principal Investigators are asked to fill in a project submission form found in the web pages, which includes all information necessary for the APEX staff to perform the observations. The APEX raw data are stored in MBFits, the calibrated data in CLASS format. ESO and Swedish data are transferred to the ESO archive, and the release of data follow the ESO archive rules.

Acknowledgements

We thank the APEX staff and our teams at the home institutes, whose outstanding support during the build-up and commissioning phase has made this project become reality on a compressed schedule. We acknowledge with pleasure the support from Dave Morris and Albert Greve (both retired from IRAM), and Nimesh Patel and T. K. Sridharan (CfA) for the holography of the telescope.

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ALMA News

Tom Wilson (ESO)

ESO has selected Dr. Paola Andreani as the ARC Manager for ESO. Dr. Andreani will begin work at ESO Garching on 1 June 2006. Dr. Andreani is presently an Associate Astronomer at the Astronomical Observatory of Trieste, a part of INAF. Dr. Andreani is also a Co-I of Herschel/PACS and the local Project Manager of Herschel/SPIRE. She has been a working group manager of the Italian Herschel community, participating in the Herschel GTO process. Dr. Andreani is a well-known researcher in the field of extragalactic astronomy, and has carried out significant work on the Sunyaev-Zeldovich effect using the SEST.

Dr. Paola Andreani

The 2006 SPIE Symposium on Astronomical Telescopes and Instrumentation – Observing the Universe from Ground and Space

Alan Moorwood (ESO)

The most recent of these biennial SPIE (The International Society for Optical Engineering) Symposia was held from 24–31 May in the Orlando World Center Marriott Resort & Convention Center in Florida, USA. Over the last decade, these meetings have grown to become the main forum for presenting and discussing all aspects of ground-based, airborne and space telescopes and their instrumentation, including associated advances in technology, software, operations and even astronomical results. As a consequence the meetings are large and well attended by people at all levels in the process of initiating, approving, implementing and operating astronomical projects and facilities. This year there were ~ 1700 registered participants who presented ~ 1600 papers and posters in the following 12 parallel conferences which formed the heart of the meeting.

– Space Telescopes and Instrumentation I: Optical, Infrared and Millimetre
– Space Telescopes and Instrumentation II: Ultraviolet to Gamma Ray
– Ground-based and Airborne Telescopes
– Advances in Stellar Interferometry
– Ground-based and Airborne Instrumentation for Astronomy
– Observatory Operations: Strategies, Processes and Systems
– Modelling, Systems Engineering and Project Management for Astronomy II
– Advances in Adaptive Optics
– Opto-Mechanical Technologies for Astronomy
– Advanced Software and Control for Astronomy
– Millimetre and Submillimetre Detectors and Instrumentation for Astronomy III
– High Energy, Optical and Infrared Detectors for Astronomy II

In addition were
– four invited keynote plenary talks
– a plenary conference of invited talks on the search for extrasolar planets
– six specialist workshops/technical meetings/panel discussions
– nine courses teaching special aspects of optics, detectors and software
– two major interactive poster sessions
– two networking receptions
– a special invited session featuring the best student papers
– tours of the University of Central Florida
– an exhibit featuring a full-scale model of the James Webb Space Telescope
– 68 industrial and other exhibits – including the ESO stand shown in Figure 1

The main conferences listed above covered space telescopes and instruments sensitive over the full gamma ray to radio wave range, including overview talks on the NASA and ESA programmes; ground-based and airborne telescopes again covering all wavelengths and including ALMA and future extremely large telescopes (ELTs); ground-based and airborne instrumentation with invited overview talks on the instrumentation at all the major observatories; interferometry; observatory operations; adaptive optics; opto-mechanical technologies; software and control and detectors.

ESO staff and their achievements were very much in evidence in essentially all the conferences dealing with ground-based topics. Everybody also seemed to benefit from learning what the others are doing from the highest level overviews down to the most detailed exchanges of technical details. I don't know of any other such possibility for hearing so many top-level talks covering such a range of topics in so short a time. Unfortunately, with so many parallel activities, considerable time is spent in navigating the programme and, again, the organisers have vowed next time to try and make a chronological as well as conference based programme to facilitate this more efficiently.

In the first keynote plenary talk titled "Challenges for Astronomy and Astrophysics in a Changing Budget Environment", Garth Illingworth illustrated the variety and strength of the current US Space Science programme but then drew attention to its anticipated reduction in the future due to the decline of the NASA budget expected following completion of the JWST. Of particular interest to many people was his list of estimated full-cycle costs, including operations, for several flagship missions which ranged from 9 billion dollars for HST down to ~ 2 billion for the airborne observatory SOFIA, recently slated for possible cancellation by NASA. Nevertheless, Garth made a strong case for retaining the concept of flagship missions rather than just trying to increase the number of smaller ones. Maybe he also put the current $ 4.5 billion cost of JWST in perspective for some people?

The second plenary talk was devoted to a less political but currently hot scientific topic "The Central Black Hole and Nuclear Star Cluster of the Galaxy" which was delivered by Reinhard Genzel from the MPE in Garching who presented a dazzling collection of recent VLT and other data made possible by developments in ground-based adaptive optics and integral-field infrared spectroscopy. These have now established the presence and mass of the black hole at the centre of the Milky Way beyond reasonable doubt

Photo: E. Janssen, ESO

Figure 1: Visitors to the ESO stand – another first at the Orlando 2006 meeting.

and have revealed and partially characterised its associated infrared flares – which can provide further insight into its properties (e.g rotation) – but appear to have increased the mystery of the origin of its surprisingly young surrounding star cluster.

The next plenary talk, on "Astronomy in Europe: Status and Prospects", was delivered by Catherine Cesarsky, Director General of ESO, whose main theme was the growth of European astronomy over the last few decades and the breadth and depth which have already been achieved by the combination of the ESO, ESA and national programmes. She also stressed Europe's commitment to the future, including the building of an Extremely Large Telescope on the ground. The final plenary talk was on "Novel Technology for Optical and Infrared Astronomy" in which Colin Cunningham of the UKATC in Edinburgh took us on a tour of the latest ideas which may transform future ground-based instrumentation including robotic and other smart focal-plane systems, developments in integrated optics, exotic filters, etc.

The mental stress was relieved by a free Sunday in the middle when attendees could enjoy a wide range of leisure options including swimming and playing golf at the conference hotel, touring the varied attractions at the bewildering array of nearby Disney and other theme parks or visiting the Kennedy Space Center with the Memorial Day holiday crowds.

Particularly pleasing to me was the apparent success of the plenary conference on "The Search for Extrasolar Planets". This was an innovation at these meetings, introduced to provide an opportunity for all participants to come together for half a day to hear about developments in one of the currently most exciting astronomical topics engaging and motivating both the ground and space community. More than 1000 attendees were present for the introductory keynote review by Michel Mayor (ESO Council member) of exoplanet discoveries to date which included the discovery, announced just prior to the Symposium, of an extrasolar system containing three Neptune-mass planets in which his group played a leading role using the HARPS instrument at the ESO

Photo: E. Janssen, ESO

Figure 2: Catherine Cesarsky, Director General of ESO, delivering her plenary talk on "Astronomy in Europe: Status and Prospects" to a packed audience.

3.6-m telescope on La Silla (see ESO Press Release 18/06).

Other papers of particular European interest included those on the contributions to be expected in the future from astrometry with the VLTI (Didier Queloz); imaging with future ELTs (Roberto Gilmozzi); results and plans for transit/eclipse observations with MOST, COROT and Kepler (Jaymie Matthews) plus the capabilities for exoplanet research of other future major space missions including Gaia (Dimitri Porbaix) and JWST (George Rieke). Other talks covered various proposed US space missions including SIM (Michael Shao) and TPF (Wesley Traub), whose timescales may have unfortunately lengthened recently as a result of NASA's budget forecasts, and a thought-provoking closing review by Sara Seager of the latest ideas for searching for life on extrasolar planets and a reminder that it may be vastly different from what we are used to.

Topics covered in more detail in the specialist meetings included adaptive optics and the future and relative merits of ground, space and Antarctic interferometry – which have all blossomed into large areas of interest within the last few years – plus the production of glass blanks for large lenses and filters which sounds less exciting but has become a major issue for the development of instruments for ELTs and wide-field telescopes. The special courses also featured optical interferometry; adaptive optics; opto-mechanics in space; astronomical optics; principles of Fourier optics and diffraction; telescope systems: materials choices for performance and stability; use of visible and infrared sensors, CCD and CMOS imaging sensors and applications and scalable frameworks for observatory software infrastructure. As far as I can judge, all seemed well attended whenever I passed by on the way to somewhere else.

The large number of attendees and papers plus its seven-day duration reflects the feeling of most present that we are still enjoying a golden age of astronomical exploration from ground and space as echoed in the subtitle of the Symposium. The realities now include many ground-based observatories operating 8–10-m-class telescopes equipped with suites of powerful instruments plus (great) space observatories sensitive from gamma to radio wavelengths and with more to come in the near future (e.g. COROT, Herschel and Planck in Europe). Much of what was presented and discussed however still falls in the category of dreams for the future. This applies to many space projects; to the development of a new generation of extremely large ground-based telescopes; new interferometers; observatories in Antarctica, etc. In most of these cases, however, the funding has not yet been secured or is even already in doubt. Increased efforts by the astronomical community may thus be necessary to prolong the life of this golden age. It will be interesting to meet again and review how things have progressed in two years time when this Symposium series will be continued in Europe, at a location which has not yet been decided but will most probably be in a sunny, French-speaking city south of Munich. Hope to see you there.

The Compact Discs of Post-AGB stars

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Many post-AGB stars are predicted to show compact discs less than ~ 100 AU in size. The VLT is uniquely able to trace these size scales, using adaptive optics (NACO) and optical interferometry (VLTI). We here report on observations of four such objects, showing direct detections of these structures.

Stars like the Sun, with masses in the range 0.8–8 $M_\odot$, end their active lives with a catastrophic mass-loss event: the so-called *superwind*. Within a period of less than 10^5 yr, between 20 % and 80 % of the total mass of the star is ejected. The superwind occurs on the Asymptotic Giant Branch (AGB). The AGB star consists of a degenerate carbon-oxygen core, surrounded by the nuclear burning shell, in turn surrounded by the convective hydrogen envelope. The superwind removes almost the entire envelope. When the envelope mass has been reduced to ~ 10^{-2} $M_\odot$, the photosphere collapses, the superwind ceases and the star moves rapidly to the blue in the HR diagram. The star now begins to ionise the expanding ejecta, forming a planetary nebula. Roughly 10^4 yr later hydrogen burning ceases and the remaining core of the star enters the white-dwarf cooling track. The nebula fades and eventually merges with the interstellar medium. The superwind is responsible for such diverse aspects as the white dwarf mass distribution (and therefore the SN Ia rate), interstellar hydrogen recycling (accounting half the hydrogen in the local ISM), and interstellar nitrogen, carbon and dust.

Planetary nebulae (PNe) show intricate structures, evidence that the superwind is not a constant, spherical flow. The HST planetary nebula gallery shows a staggering range of morphologies, including ellipticals, bipolars, and core-halo objects – a few are even round. The interacting stellar wind model (ISW) explains these structures by a spherical, fast post-AGB wind blowing into the earlier, slow AGB ejecta. A snowplough develops, amplifying any asymmetries already present. The model works well but requires that the original AGB wind is already strongly asymmetric. The origin of this initial asymmetry is still not fully clear, but the most accepted model involves a binary system. Three cases can be distinguished

1. Common envelope systems, where the companion triggers a fast mass loss. These system will rarely reach the AGB, as the common envelope is likely to develop already on the preceding Red Giant Branch. Orbital separations are of the order of 1 AU. Perhaps 10 % of 'protoplanetary nebulae' may derive from such systems, although fewer would evolve into PNe.

2. Wider systems, where the geometry of the mass loss is affected, but not the mass-loss rate itself. Orbital separations are a few to tens of AU. The system may form a circumbinary disc. They may account for ~ 25 % of the PN birth rate.

3. Systems with minor effects on the mass-loss geometry. Typical separations are ~ 100 AU. The geometry may show the movement of the mass-losing star, as in the spiral nebula around AFGL 3068 (Mauron and Huggins 2006). The prototypical AGB star, o Ceti (Mira) has such a white dwarf companion ~ 100 AU away.

Circumstellar discs

Many post-AGB stars show evidence for dense, dusty discs. They are unresolved but show up because of the high opacity in the disc which may obscure the star. The cold dust in the disc also adds a strong far-infrared excess with a typical spectral index (de Ruyter et al. 2006). The small sizes suggest that these discs are Keplerian and do not take part in the overall expansion of the (much larger) nebulae. In the ISW model, the small disc provides an initial asymmetry into which the subsequent fast wind causes the bipolar lobes to form. But detecting and resolving such discs requires extreme angular resolution which only now is becoming feasible from ground-based observatories.

The prototype of the bipolar post-AGB stars is OH231.8+4.2. It shows two (ionised) bipolar lobes on either side of a central obscuring lane. The obscured central star (QX Pup) shows Mira-like variability, indicative of an evolved AGB star. We obtained a range of observations, including AO-assisted infrared imaging (NACO), OH maser observations using the MERLIN array, and VLTI/MIDI. The resulting data are arranged in Figure 1. The left panel shows the 2.12 micron image, with the base of the two lobes clearly identifiable (the lobes themselves are much larger). The dark lane is seen to consist of several substructures with brighter regions embedded. The right panel, (b), shows an *L*-band image. Here the central region shows a bright core, and the main dark lane is shown to be located about an arcsecond south. A thin dark lane is seen towards the north. Panel (c) shows a focus on the compact core seen on panel (b). We obtained several VLTI/MIDI baselines across this source. Fringes were detected: we estimate the core to have a diameter of approximately 30–40 mas (Matsuura et al. 2006).

The distance to OH231.8+4.2 is derived from its association with the open cluster M13, as 1.3 kpc. The VLTI/MIDI source has a radius of 40–50 AU, which is within range of expectations for a circumbinary disc. The dark lane is very much larger, at 1000 AU, and may either be a thick torus or an ionisation shadow caused by the inner disc. Panel (d) shows OH maser data obained with MERLIN: the OH traces the dark lane very well. The colour indicates the velocity, in m/s. Almost all emission is blueshifted with respect to the systemic velocity, indicating that only OH emission in front of the source is seen. This can be explained if the OH maser amplifies the radio continuum from the inner ionised nebula. The velocities increase with distance from the centre, as expected from an ISW-driven bipolar outflow (Zijlstra et al. 2001).

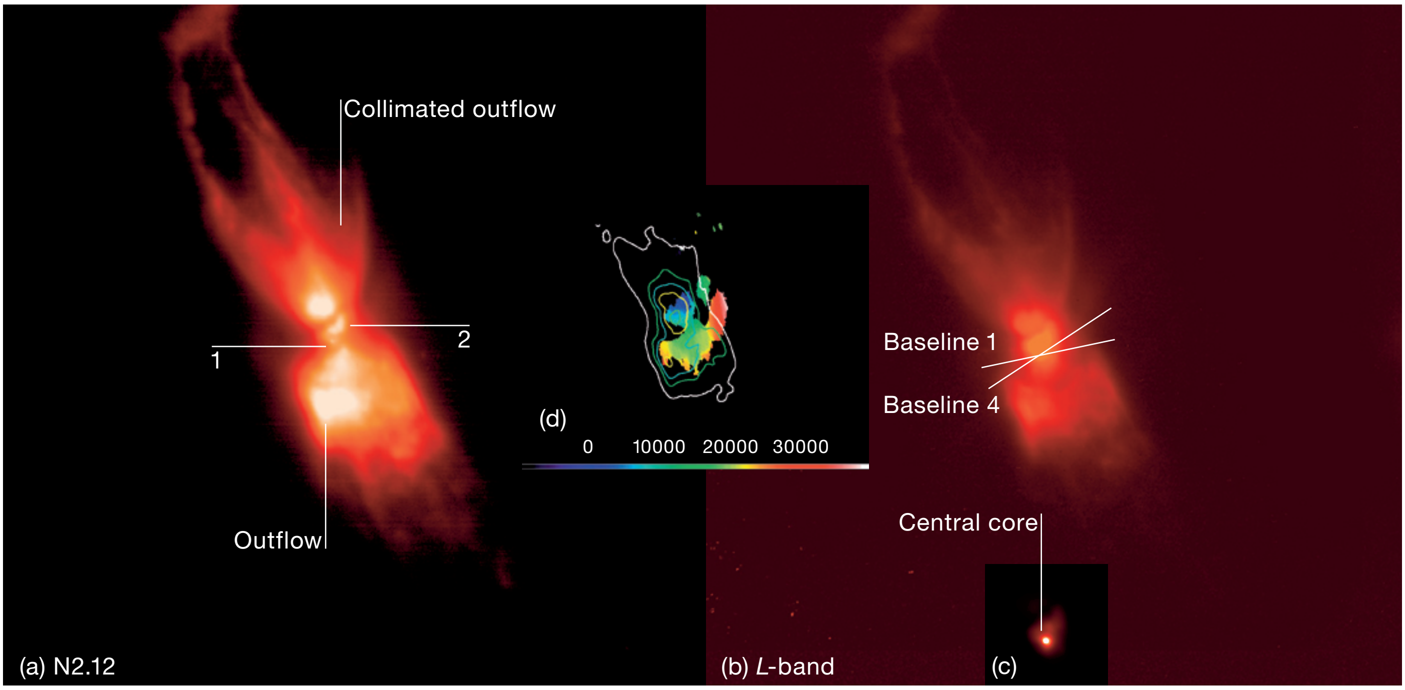

Figure 1: Composite of OH231.8+4.2. (a) 2.12 micron image. For scale, the banana-like structure (2) is 0.7 arcsec across. (b) *L*-band image: The position angles of the VLTI baselines are indicated. (c) A zoom on the bright core seen in the NACO *L*-band image. (d) OH maser velocities measured with MERLIN; the colour scale is in m/s.

OH231.8+4.2 is the first source to show all components expected from the ISW model: an inner disc with size consistent with a circumbinary disc, a bipolar outflow, and a velocity field as predicted by a fast wind–slow wind interaction. The only missing ingredient is the putative binary companion. The very high opacity of the inner region may make this hard to find.

A tale of two chemistries

The disc forms relatively early on the AGB. If, during the AGB, the continuing dredge-up forms a carbon star, the disc will show the earlier, oxygen-rich chemistry while the current wind is carbon-rich. The oxygen-rich chemistry leads to silicate dust, whilst the carbon-rich wind is dominated by silicate carbide dust, and once the star becomes hotter, PAH features are seen. A number of post-AGB stars display both PAH at shorter wavelengths, and features attributed to crystalline silicates at longer wavelengths. This combination of incompatible chemistries requires distinct regions, where the PAH are located in the UV-irradiated (warm) outflow and the silicates in the opaque, cold disc. The original example of this structure is the Red Rectangle, where ISO spectra revealed the presence of the crystaline silicates. Direct imaging

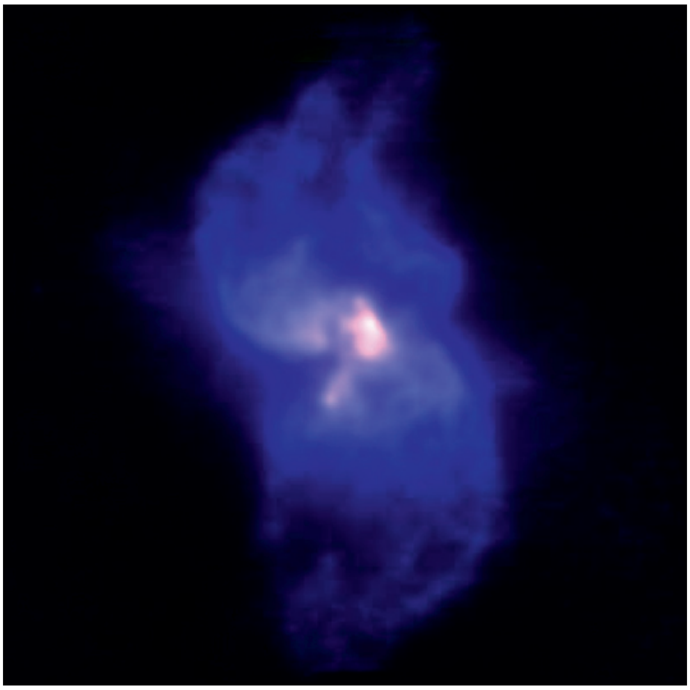

Figure 2: NACO three-colours image of Roberts 22, combining H_2, Brγ and 2.24 μm continuum images. The field of view is 7″ × 7″.

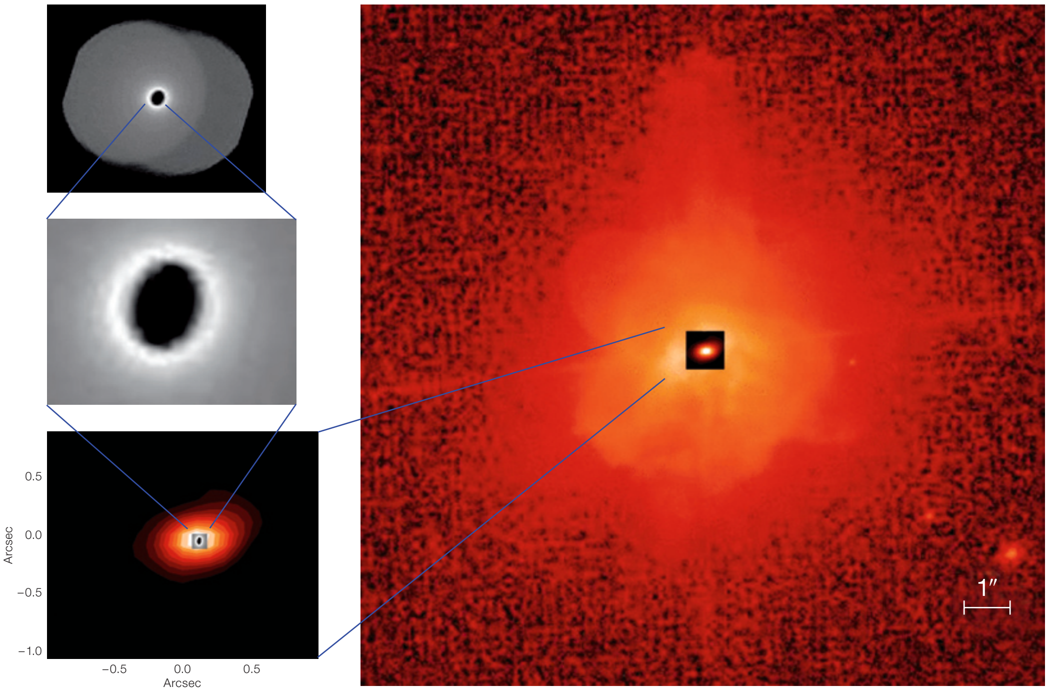

Figure 3: Mosaic of images of CPD-56°8032. **Right:** HST (F435). **Bottom left:** MIDI 8.7 μm image (deconvolved); **middle:** model of the observed inner rim of the disc based on VLTI data; **top:** 10 μm model image of the disc observed by MIDI.

of the silicate disc would require 20-micron observations.

Roberts 22 is one such post-AGB star which shows evidence for both oxygen and carbon-rich chemistry. It is a reflection nebula, with an obscured central star: a spectral type of A2 I was inferred from the scattered light from the two lobes. HST images of this bipolar nebula show a dark lane across the centre of the object, with additional dark regions to the north, close to where the dark lane is least clear. The oxygen-rich nature is proven by the presence of OH maser emission. Figure 2 shows our VLT/CONICA image. Compared to the HST image, the dark lane is less clear (although still evident from the wedge on the left) but a bright central, resolved source is seen at the centre. The OH maser coincides with the wedge: it lacks the redshifted emission at the central position, and this indicates a compact ionised source in the centre which is optically thick at 18 cm. The outer emission shows pronounced bending, and in fact structures are visible at many position angles. Little of this was visible in the optical HST image: it is possible that the scattered optical light is too much influenced by the limited available escape routes from the central source, to show the intrinsic structure. The multiple flows and directions can be interpreted in terms of the 'warped disc' scenario of Icke (2003). The OH emission shows that the 'wedge' is oxygen rich. The location of the PAH emission is at the edge of the equatorial disc.

The IR-[WC] stars

[WC] stars are PNe central stars which show emission lines very similar to those of the massive WR stars. Their origin is not well understood, but the absence of hydrogen in the stellar spectra suggests they have been fully stripped of their hydrogen envelope. A few of these objects are extremely strong infrared emitters, with infrared excess (the ratio of dust luminosity over Lyα flux) higher than in any other PN. Most or all of these IR-[WC] stars show the chemical dichotomy, with both very strong PAH emission and pronounced crystalline silicates.

CPD-56°8032 and He 2-113 are two members of this group. Figures 3 and 4 show images of these two objects. Figure 3 shows, on the right, an HST image (F435) of CPD-56°8032. The nebula has an irregular appearance surrounding the bright central star. The VLTI/MIDI single dish image shows a bright core at 8 micron: after deconvolution, the core is found to be resolved with an elliptical diameter of 0.4 × 0.3 arcsec. The VLTI/MIDI shows very weak fringes, with visibilities depending on position angle. We model these fringes using an ellipsoidal ring, with an aspect ratio of 0.5 (equivalent to a ring viewed on angle of 30°) and a radius of 75 mas. For an assumed distance of 1.35 kpc, the inner radius of this inner ring is 97 AU. There is no indication for any preferred axis in the system from our HST images and VLTI/MIDI observations.

The expectation that the inner disc is the location of the silicates is not fully confirmed. Our VLTI/MIDI spectra show that a part of the strong PAH emission arises from the central source. About a third of the integrated flux from the 7.8 and 8.6 micron PAH features are recovered from the VLTI/MIDI spectrum, but only about 1/4 of the 11–14-micron plateau, and the 11.2 feature is almost absent from the VLTI/MIDI spectrum. Part of the difference may arise if the PAHs in the central object are ionised. The observed features are mostly C-H modes, and therefore the central PAHs are hydrogenated even though the star is hydrogen poor. The oxygen-rich material is not seen, but we note that this dust is too cold to emit at 10 microns. Our model of the infrared spectrum indicates that the disc extends outwards to perhaps 1000 AU: the observed core corresponds to the inner edge of this disc. This suggests a model where the PAHs are located at the inner rim of an otherwise oxygen-rich disc that could be flared. The PAHs may form at the turbulent, shocked interface between the carbon-rich, H-poor wind from the star, and the disc.

He2-113 shows a more regular morphology (Lagadec et al. 2006). Figure 4 shows a three-colour image with indication of a large torus (~ 1500 AU) and a bipolar outflow. But there is again an infrared source located at the centre, with a diameter of ~ 150 mas, surrounded by a void. VLTI data did not show any more compact structure. The inner rim seen in CPD-56°8032 appears to lack a counterpart in He2-113, and neither does the PAH emission show an obvious central source. The large disc does appear to be present.

Binarity

All four objects show evidence for the compact disc required by the ISW model. These discs indicate likely binary companions, evolving through either scenario 1 or 2 above. But in none of these cases do we find direct evidence for a stellar companion. This may be understandable, in view of the large luminosity difference between an AGB star and a main-sequence or white-dwarf companion, but it leaves a weak link in the argument. (One could argue that we don't find direct evidence for the primary star either.)

The IR-[WC] stars also show the disc morphology, and binarity is likely for these objects. However, the strong relation between emission-line central stars and the IR-bright, dual-chemistry nebulae remains unexplained. The late thermal pulse scenario for the [WC] stars (Hajduk et al. 2005) does not predict any link between the unusual star and the unusual nebula. Binary coalescence may be considered, removing the hydrogen envelope in the process. Otherwise, accretion from the circumstellar disc on the post-AGB star or a white-dwarf companion may be involved.

The results show the power of the new, high-angular-resolution observing modes available at the VLT. The origin of the structures seen in these objects are found within 100 AU of the star. Adaptive optics and optical interferometry are uniquely able to trace these size scales.

Now, if only we could detect the binary companions!

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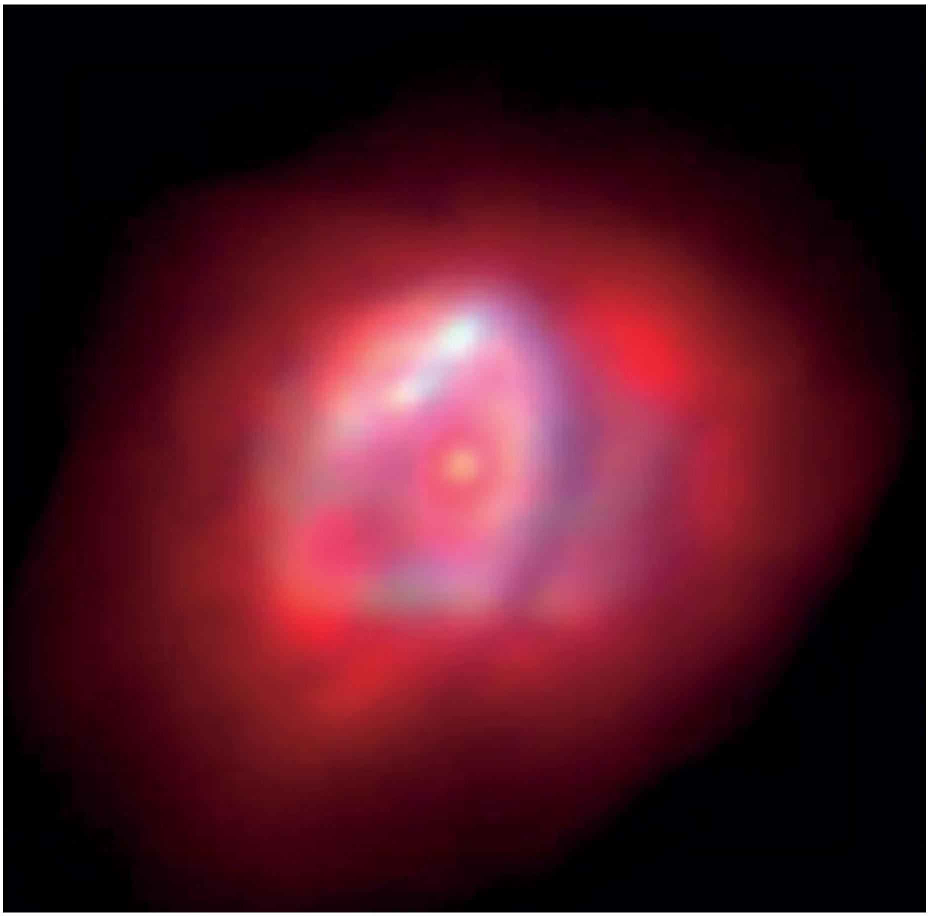

Figure 4: Three-colour image of He2-113, combining HST Hα (coded as red), NACO L′ (green) and M′ (blue). The bright ring is approximately 1.5 arcsec across.

Probing the Dark Matter Content of Local Group Dwarf Spheroidal Galaxies with FLAMES

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We present preliminary kinematic results from our VLT programme of spectroscopic observations in the Carina dwarf spheroidal galaxy using the FLAMES multi-object spectrograph. These new data suggest that the dark matter halo of this galaxy has a uniform density core. The implications for our understanding of the nature of the dark matter are discussed.

Dark matter in dSphs

According to the current cosmological paradigm, non-luminous, non-baryonic matter contributes approximately 20 % of the overall mass-energy budget of the Universe. Locally, on the scale of galaxies like the Milky Way, it constitutes about 90 % of the gravitating mass. Determining the nature of this dark matter is a key goal of contemporary astronomy. The dwarf spheroidal galaxies (dSphs) of the Local Group provide a particularly valuable window on the properties of dark matter on small (~ 1 kpc) scales. Several of these low-luminosity galaxies have been found to have extremely large mass-to-light (M/L) ratios (up to 1000 in solar units) which suggests that these are the most dark-matter-dominated stellar systems known in the Universe (e.g. Kleyna et al. 2001, Wilkinson et al. 2004, Mateo et al. 1998). Given the apparent absence of dark matter in globular star clusters, they are also the smallest stellar systems (in terms of stellar mass and radial length scale) which are inferred to contain dynamically significant quantities of dark matter.

The proximity of the Milky Way dSph satellites makes it feasible to obtain spectra for large numbers of individual stars in them, facilitating more detailed studies of their properties than are possible for galaxies beyond the Local Group. These spectra provide radial velocities and chemical abundance determinations which, respectively, enable us to to probe the stellar velocity distribution function and halo potential within a dSph and provide detailed information about the star-formation history of these systems. Two recent Messenger articles have discussed in detail the insights into the chemical evolution of the stellar populations in dSphs which have been gained by recent observations with the FLAMES spectrograph on the VLT (Koch et al. 2006a; Tolstoy et al. 2006). In this article we will focus on the implications of the kinematic data in the Carina dSph for our understanding of the dark matter.

The dSphs are the lowest-luminosity satellites of the Milky Way and M31, characterised both by their low stellar luminosities (up to 2×10^7 solar luminosities, with the majority in the range 10^5–10^6 solar luminosities) and the apparent absence of gas and on-going star formation. The recent discovery of the Ursa Major dSph (Willman et al. 2005) and the Canes Venatici (Zucker et al. 2006) and Bootes (Belokurov et al. 2006) dSph candidates brings to twelve the number of dSphs around the Milky Way. A similar number have been identified orbiting M31. At least one dSph is clearly being disrupted by the tidal field of the Milky Way – the Sagittarius dSph has extensive debris trails which have been observed over much of the sky. The stellar distributions of most dSphs exhibit some level of disturbance in their outer regions, although whether this is due to their proximity to their parent galaxies remains controversial. Although the dSphs were once thought to be the primordial building blocks whose disruption contributed to the hierarchical build-up of the stellar halo of the Milky Way, recent studies have found that the chemical composition of the stars in the present-day dSphs differs substantially from that of field stars (Shetrone et al. 2001; Tolstoy et al. 2006). Thus, the Galactic halo was not predominantly formed by disrupting galaxies like the present-day dSphs. Nevertheless, the chemical properties of dSphs provide valuable insights into the processes of galaxy formation and evolution on the smallest scales.

It is the large apparent mass-to-light ratios of dSph galaxies, and the conclusion that they contain significant amounts of dark matter, that has caused them to attract much attention in recent years. The first evidence of this emerged in 1983, when Aaronson published velocity measurements of three carbon stars in the Draco dSph. These data implied a velocity dispersion for Draco of 6.5 km/s, from which Aaronson cautiously inferred a mass-to-slight ratio of 30 solar units. As this was significantly higher than the values typical of globular star clusters, this provided the first hint that the dSphs were a class of stellar system distinct from the globular clusters, despite the fact that in many cases their stellar mass was similar. Subsequent observations have borne out these early estimates and all dSphs observed to date have velocity dispersions in excess of 6.5 km/s.

By 1998, due to the dedicated efforts of several teams, velocity dispersions had been measured for eight dSphs (Mateo 1998). However, dSph velocity distributions were still represented solely by the central velocity dispersion, which contains only limited information about the nature of the system. The situation changed in 1997, with the publication of the first velocity dispersion *profile* for a dSph (Mateo 1997). Using 215 individual stellar velocities in Fornax, Mateo showed that the velocity dispersion remains approximately flat almost to the edge of the light distribution. This profile is inconsistent with the simplest model of Fornax in which the mass is distributed in the same way as the light and the stars have an isotropic velocity distribution.

The past decade has seen a rapid increase in the size of dSph kinematic data sets, driven by the availability of multi-object spectrographs on 4-m to 10-m-class telescopes which allow the simultaneous acquisition of spectra for large numbers of stars. The first dSph dispersion profile based on multi-fibre observations was that of Draco, based on velocities for 159 stars obtained using the WYFFOS spectrograph on the William Herschel Telescope (Kleyna et al. 2001). Since that time, dispersion profiles have been measured for all the Milky Way dSphs. For most Milky Way dSphs, the large (25 arcmin diameter) field of view of the FLAMES spectrograph on the VLT is ideally matched to their angular size facilitating the efficient coverage of the full area of each object.

The properties of dSph haloes are largely determined by the physical properties of the dark matter. For example, the number of low-mass dark-matter haloes in the vicinity of a Milky Way-type galaxy is a strong function of the nature of the dark matter – cold dark matter (CDM) simulations typically predict hundreds of low-mass haloes around the Milky Way while warm dark-matter models contain significantly fewer. However, it is currently not clear which objects in the simulations correspond to the observed dSphs. A number of authors have claimed that the properties of dSphs are consistent with their residing in haloes of mass > 10^9 solar masses. In this case, the numbers of dSphs might be consistent with CDM simulations. One of the key goals of our observations in Carina is to test in detail whether its properties are consistent with those of an object with a massive, extended dark halo.

The shapes of the dark-matter density profiles of dSphs are also sensitive to the type of dark matter. Galaxy haloes composed of cold dark matter are predicted to be cusped, with the density in the inner regions rising as $1/r^n$, where n lies in the range 1–1.5. Alternatively, if the dark matter were warm, i.e. composed of particles which had a non-negligible intrinsic velocity dispersion, then this would lead to a shallow or uniform density core, whose size depends on the actual velocity dispersion of the particles. The presence or absence of a cusp, as well as its precise steepness is one of the most direct measurements of the nature of dark matter. There is already evidence of cored haloes in some dSphs (e.g. Kleyna et al. 2003; Goerdt et al. 2006) but the identification of a property of the dark matter requires a universal result. The global stellar kinematics of all the dSphs have not yet been defined sufficiently well to yield definitive results on the inner slope of their dark matter distributions. Our Carina data set will be sufficiently large to place robust constraints on the profile of a dSph dark-matter halo, while our modelling will further the analyses of the data from all the dSphs.

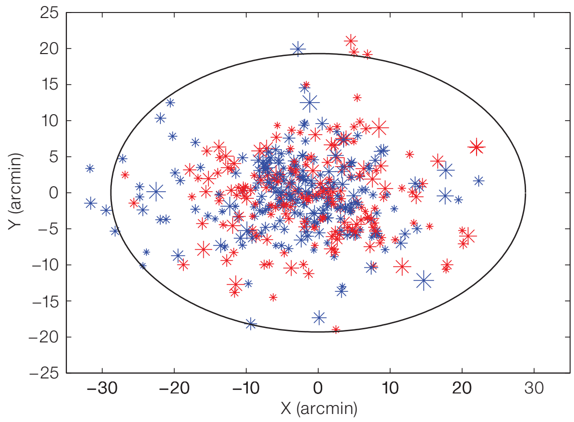

Figure 1: Spatial distribution of Carina members observed in our survey. Stars approaching and receding (relative to Carina) are shown as blue and red symbols, respectively. The size of the symbol is proportional to the magnitude of the radial velocity. The ellipse indicates the nominal tidal limit of Carina with semi-major axis of 28.8 arcmin.

Observations of the Carina dSph

The Carina dSph has previously attracted attention due to its unusual, bursty star-formation history, with the most recent peak occurring around 3 Gyr ago (e.g. Monelli et al. 2003). Its central velocity dispersion is 6.8 km/s (Mateo et al. 1993), implying a mass-to-light ratio of about 30–40 (solar units). Majewski et al. (2005) provide evidence of irregularity in the outer regions of the light profile, perhaps associated with tidal disturbance. Our Carina data were obtained as part of VLT Large Programme 171.B-0520 (PI: Gilmore). The targets were selected to lie on the red giant branch of the colour-magnitude diagram of Carina and span the magnitude range V = 17.5 to 20 (see Figure 2 of Koch et al. 2006a). The photometric and astrometric data for the input catalogue were obtained by the ESO Imaging Survey (EIS) as part of the Wide-Field Imager Pre-FLAMES survey. The spectroscopic data were taken in visitor mode and reduced using the standard GIRAFFE reduction software, with sky subtraction performed using our own in-house software (see Wilkinson et al. 2006 [in prep.] for more details on the data processing). Median velocity errors are 1.2 km/s for the entire data set and 1.5 km/s for the faintest stars (V = 20–20.5).

A total of 1257 targets in Carina were observed. Of these, 535 are probable members of Carina (based on their radial velocities). The remainder are foreground Milky Way stars which can be used to investigate the properties of the velocity distribution of our own Galaxy (see below). Of the probable members, some 437 stars have spectra with sufficient signal-to-noise to enable chemical abundances to be determined using the Calcium triplet estimator (Koch et al. 2006b). The spatial distribution of Carina members from our survey is shown in Figure 1. As our primary goal in this survey is to map out the velocity structure of Carina, it is particularly important to observe stars at large projected radii as these place the strongest constraints on the mass and extent of the galaxy. As can be seen in the figure, our targets probe to the nominal tidal radius of Carina (around 28.8 arcmin). Our sample increases the number of measured stellar velocities for Carina members by almost an order of magnitude and extends to radii at which both the effects of an extended halo as well as the tidal effects of the Milky Way may be observable.

The histogram in Figure 2 shows the distribution of velocities for our full sample of stars along the line of sight to Carina. The members of Carina are clearly visible as the narrow peak centred at about 223.8 km/s. The systemic velocity of Carina is not well separated from the velocities of Milky Way stars along the line

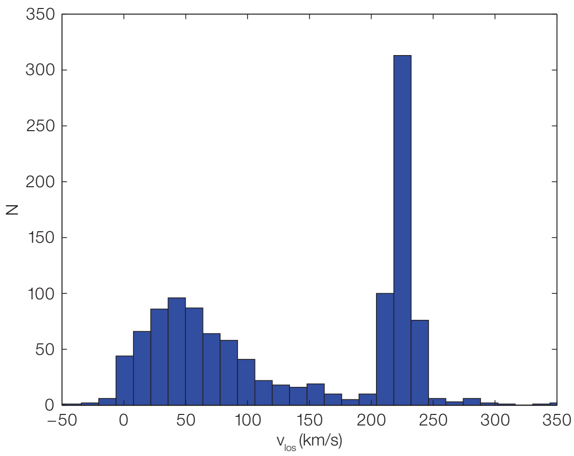

Figure 2: Velocity distribution of all stars observed along the line of sight to Carina. The peak due to Carina members at around 223.8 km/s is clearly visible.

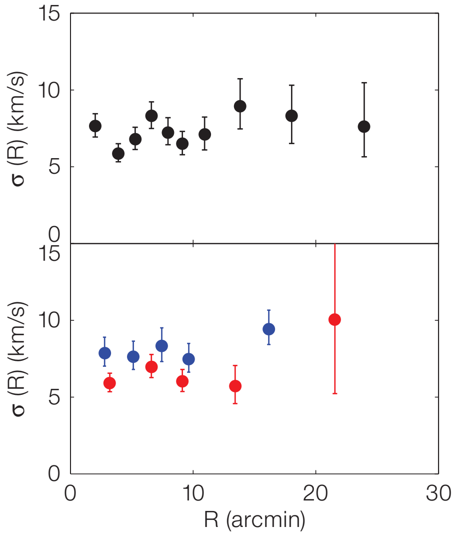

Figure 3: Top: Velocity dispersion profile for all stars in Carina. Bottom: Velocity dispersion profiles for stars with [Fe/H] < −1.68 (blue) and [Fe/H] > −1.68 (red).

of sight. This makes it more difficult to establish membership, as simple criteria (e.g. the standard velocity cut of three times the internal velocity dispersion) may include a non-negligible level of foreground contamination.

Dark matter in Carina

The large central velocity dispersions in dSphs are usually interpreted as evidence of significant amounts of dark matter. Much stronger constraints on the amount of dark matter in a dSph, as well as its spatial distribution, can be obtained from knowledge of the variation of the velocity dispersion with position in the dSph. In Figure 3 we present the dispersion profile for Carina, plotted as a function of projected radius. To calculate the dispersion in each radial bin of this profile, we assume that the projected velocity distribution in each bin is a Gaussian convolved with the stellar velocity errors (which are also assumed to be Gaussian). We also introduce a power-law interloper velocity distribution to take account of the presence of foreground Milky Way stars in our velocity samples.

The dispersion profile of Carina based on the complete data is remarkably flat, with an amplitude of about 7–8 km/s out to the edge of the data at a radius of approximately 45 arcmin. Koch et al. (2006b) showed that if the stellar population is divided at a metallicity of [Fe/H] = −1.68, the 'metal-rich' sample is slightly more centrally concentrated than the 'metal-poor' population. The lower panel of Figure 3 shows the dispersion profiles for the metal-rich and metal-poor stars in Carina based on the above definition. The amplitude of the dispersion profile of the metal-rich stars appears to be systematically lower than that of the metal-poor stars. This is consistent with their relative spatial distributions, since the more extended metal-poor population would be expected to exhibit a larger velocity dispersion. The observation by Harbeck et al. (2001) that the younger stellar populations in Carina are more centrally concentrated than the older stars, combined with the age-metallicity relation for Carina stars identified by Koch et al. (2006b), would then suggest an interpretation of the kinematic data in terms of a secondary, more recent burst of star formation concentrated towards the centre of Carina.

The flatness of the velocity dispersion profile has important implications for the dark-matter density profile of Carina. For a stellar system in virial equilibrium, the Jeans equations provide a simple estimator of the halo mass distribution once the spatial distribution of the stars and their velocity-dispersion profile are known. Figure 4 shows the density profile inferred from our Carina data set. We have used the surface-density profile determined by Majewski et al. (2005) to determine the stellar-density distribution and have assumed that the gravitational potential is everywhere dominated by the dark matter. Spherical symmetry is assumed and we have simplified the form of the Jeans equations by assuming that the velocity distribution is everywhere isotropic. The black line in the density plot shows the form of the density

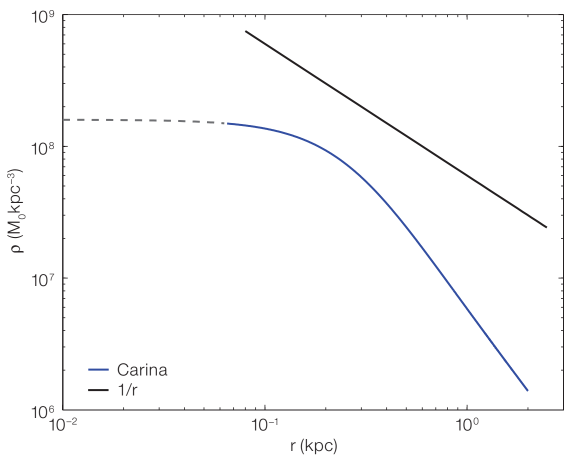

Figure 4: Mass density profile of Carina as inferred from the velocity dispersion profile using Jeans equations and assuming velocity isotropy. The black curve shows the expected relation for a standard cusped halo.

profile expected from cosmological simulations of galaxy formation in the cold dark-matter paradigm. In contrast to the profiles of the haloes seen in simulations, in the central regions of Carina it appears that the dark-matter density is close to uniform.

We emphasise, however, that the dark-matter density profile presented here is based on strong assumptions about the stellar spatial and velocity distributions which may not be justified, particularly at very large radii. By assuming velocity isotropy, we are prey to the strongest degeneracy of this problem, namely that a flat dispersion profile in an isolated dSph can be produced either by the presence of large amounts of mass at large radii, or by radially varying anisotropy in the velocity distribution. In our modelling of the Draco dSph (Wilkinson et al. 2002), we constructed a family of dynamical models which included dark matter haloes of varying extent, as well as radially varying velocity anisotropy. We are currently extending this methodology to new dynamical models appropriate for the (multi-population) case of Carina (Wilkinson et al. 2006, in prep.). These models will enable us to quantify the properties of the dark-matter density profile of Carina. Our models incorporate multiple tracer populations, to enable us to use the metal-rich and metal-poor sub-populations of Carina (and other dSphs) as independent tracers of the underlying dark-matter potential.

In addition to their value in constraining models of the dark matter, it has become apparent that our kinematic data can also be used to investigate the properties of the Milky Way velocity distribution along the line of sight to Carina. Two recent papers have investigated this novel possibility. Wyse et al. (2006) compared the velocity distributions along the line of sight to three dSphs (Carina, Draco and Ursa Minor) and found an excess of stars with an azimuthal velocity of about 100 km/s relative to the predictions of smooth Galaxy models. They conclude that this kinematic structure, which is seen along widely separated lines of sight, may be the remains of an object which fell into the Milky Way at early times, and may even have contributed to the formation of the Thick Disc. In their investigation of our Carina data, and a velocity sample towards M31, Martin et al. (2006) provided an alternative interpretation, namely that they detect the velocity signature of the Monoceros ring, another large stellar structure which is suggested to surround the Milky Way disc at low latitude.

In order to gain a better understanding of what the internal kinematics of dSphs can tell us about the nature of the dark matter, it is important to consider the properties of these objects as a class. In Figure 5, we plot the mass-to-light ratios of the local group dSphs against their absolute V-band magnitudes. The figure is based on that given in Mateo et al. (1998) but includes more recent mass determinations where these are available – the mass for Carina is based on the simple dynamical modelling presented above. The solid curve shows the expected relation for a population of objects with a stellar mass-to-light ratio of unity (solar units) and a total halo mass of 4×10^7 solar masses. In this case, the total mass-to-light ratio, $(M/L)_{Tot}$ is simply given by $(M/L)_{Tot} = (M/L)_{Stars} + M_{DM}/L_V$, where M_{DM} is the mass in dark matter and L_V is the total V-band luminosity. Notwithstanding the significant scatter about this relation, it appears that most observations to date are consistent with dSphs having a common halo mass scale of around 4×10^7 solar masses, generally cored mass distributions, and a low central dark-matter density. It is important to note that this mass scale refers to the mass *interior* to the edge of the stellar distribution, since this is the region which is probed by kinematic observations. Further, several of the dSph mass estimates presented in this plot are based only on the central velocity dispersion – the mass scale may therefore be somewhat different once detailed dynamical models are completed for all dSphs. However, this plot demonstrates that it is possible to interpret the velocity dispersions of dSphs in terms of the intrinsic properties of the dark matter.

Future work

Now that velocities have been measured as far out as the nominal tidal radii in most dSphs, the next major advance will be to obtain usefully large samples of stars at much larger radii. Although Wilkinson et al. (2004), and Munoz et al. (2005) have taken the first steps in this direction, the results are still controversial and larger data sets are needed. The key difficulties are the large areas of sky which must be surveyed, and the preselection of targets in regions where the expected surface density of dSph members is extremely low. However, stars in these regions will provide extremely useful information about dSph haloes. We expect that at some level all dSphs must be affected by the tidal field of the Milky Way. However, thus far there is no definitive *kinematic* evidence of this process in any dSph. Constraining the radii at which the Milky Way begins to disturb dSphs will make it possible to derive the current total mass and extent of their dark haloes. Of course, identifying fundamental properties of the dark matter re-

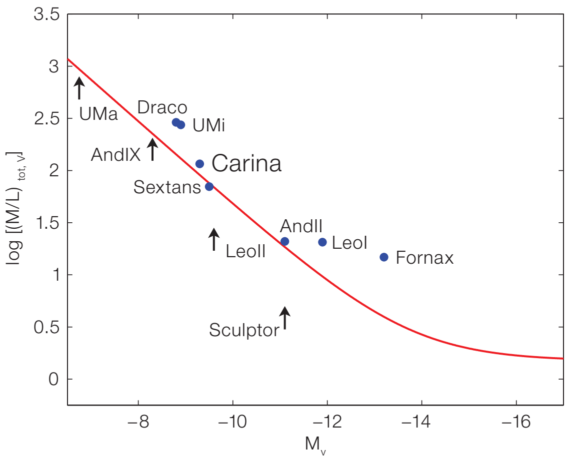

Figure 5: Mass-to-light ratios versus absolute V magnitude for Local Group dSphs. The solid curve shows the relation expected if all dSph haloes contain about 4×10^7 solar masses of dark matter interior to their stellar distributions. Arrows indicate mass estimates which are lower limits based on central velocity dispersions only.

quires that common properties in all the dSphs be identified – we must therefore carry out similar studies of all dSphs.

Finally, in the area of dynamical modelling, identifying correlations between the kinematics and abundances of the stellar populations in dSphs (e.g. Tolstoy et al. 2006) is likely to provide important new information about the formation and evolution of these objects, which in turn will further constrain models of any astrophysical feedback on their dark matter.

Acknowledgements

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A Three-Planet Extrasolar System

Using the ultra-precise HARPS spectrograph on ESO's 3.6-m telescope at La Silla, a team of astronomers[1] has discovered that a nearby star is host to three Neptune-mass planets. The innermost planet is most probably rocky, while the outermost is the first known Neptune-mass planet to reside in the habitable zone. This unique system is likely further enriched by an asteroid belt.

Over more than two years, the team carefully studied HD 69830, a rather inconspicuous nearby star slightly less massive than the Sun. Located 41 light years away towards the constellation of Puppis, it is, with a visual magnitude of 5.95, just visible with the unaided eye. The team's precise radial-velocity measurements allowed them to discover the presence of three tiny companions orbiting their parent star with periods of 8.67, 31.6 and 197 days.

Planetary System around HD 69830 (Artist's Impression).

"Only ESO's HARPS instrument installed at the La Silla Observatory, Chile, made it possible to uncover these planets", said Michel Mayor, from Geneva Observatory, and HARPS Principal Investigator. "Without any doubt, it is presently the world's most precise planet-hunting machine."

The detected velocity variations are between two and three metres per second. Such small signals could not have been distinguished from noise by most of today's available spectrographs.

The newly found planets have minimum masses between 10 and 18 times the mass of the Earth. Extensive theoretical simulations favour an essentially rocky composition for the inner planet, and a rocky/gas structure for the middle one.

The outer planet has probably accreted some ice during its formation, and is likely to be made of a rocky/icy core surrounded by a quite massive envelope. Further calculations have also shown that the system is in a dynamically stable configuration.

The outer planet also appears to be located near the inner edge of the habitable zone, where liquid water can exist at the surface of rocky/icy bodies. Although this planet is probably not Earth-like due to its heavy mass, its discovery opens the way to exciting perspectives.

With three roughly equal-mass planets, one being in the habitable zone, and a possible asteroid belt, this planetary system shares many properties with our own Solar System.

(Based on ESO Press Release 18/06)

[1] Lovis et al. 2006, Nature 441, 305. The team is composed of Christophe Lovis, Michel Mayor, Francesco Pepe, Didier Queloz, and Stéphane Udry (Observatoire de l'Université de Genève, Switzerland), Nuno C. Santos (Observatoire de l'Université de Genève, Switzerland, Centro de Astronomia e Astrofisica da Universidade de Lisboa and Centro de Geofisica de Evora, Portugal), Yann Alibert, Willy Benz, Christoph Mordasini (Physikalisches Institut der Universität Bern, Switzerland), François Bouchy (Observatoire de Haute-Provence and IAP, France), Alexandre C. M. Correia (Universidade de Aveiro, Portugal), Jacques Laskar (IMCCE-CNRS, Paris, France), Jean-Loup Bertaux (Service d'Aéronomie du CNRS, France), and Jean-Pierre Sivan (Laboratoire d'Astrophysique de Marseille, France).

The Shapley Supercluster: the Largest Matter Concentration in the Local Universe

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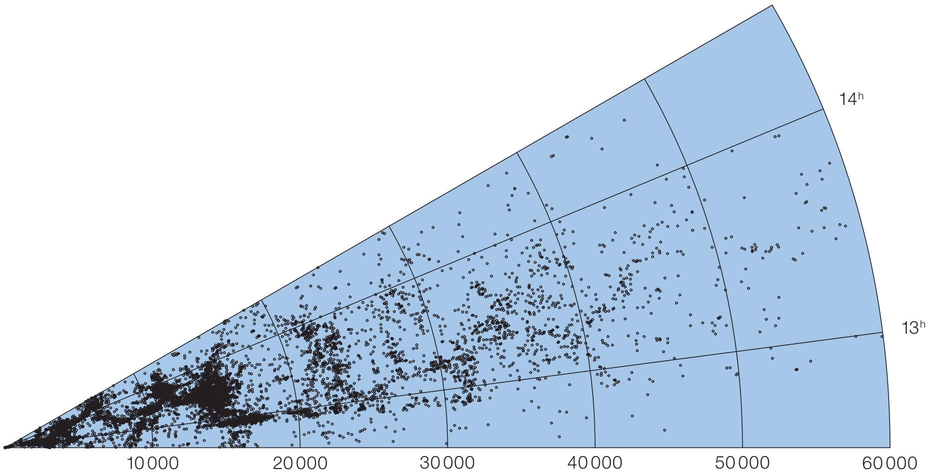

Figure 1: Cone diagram (right ascension) of the galaxies observed in the area of the Shapley supercluster (SSC) up to a recession velocity of 60 000 km/s.

Since the 1980s, we have known that the *Local Group* of galaxies is moving at a velocity of 366 ± 125 km/s in the direction of Centaurus. In this region, the well-known Shapley supercluster of galaxies (SSC) consists of many clusters and groups of galaxies in the redshift range 0.04 < z < 0.055. An international collaboration has highlighted this greatest matter concentration in the local Universe, less than 500 million light years from us. The SSC may be able to account for half of the sought for 'Great Attractor'.

The supercluster of galaxies Shapley 8 (SSC), located in the north of the constellation of Centaurus (α 13^{h}25^m, δ −30°), was observed in 1930 by Harlow Shapley; he then noticed an oval cloud of galaxies in Centaurus which appears to be one of the richest currently detected, having dimensions of approximately 2.8° by 0.8°. In the 1980s, this structure interested astronomers particularly because they discovered that the Local Group, formed by about thirty galaxies surrounding us, moved with respect to the cosmic microwave background frame of reference at the velocity of 366 ± 125 km/s in the direction of Centaurus (Dressler et al. 1987). This meant that an enormous amount of matter attracted our Galaxy and the surrounding galaxies; it took the generic name of *Great Attractor*. In this direction, there is already the Hydra-Centaurus supercluster, whose galaxies have on average a recession velocity of 4 000 km/s. However, in spite of its wealth of galaxies, this huge complex has only a negligible gravitational effect on the Local Group. This is why we undertook a dynamical analysis of the SSC by studying galaxies as faint as magnitude m_b = 18.0, beyond the Hydra-Centaurus complex, in an area of the sky extending over 30° × 12°.

The galaxies were selected from photographic plates of ESO, then digitised on the MAMA at Paris Observatory. The observations were carried out with the 2.5-m Du Pont telescope at Las Campanas with the spectrograph 2D-frutti, the ESO 3.60-m telescope with the OPTOPUS and MEFOS spectrographs, and the 1.8-m UKST telescope at the Anglo-Australian Observatory with the spectrographs FLAIR and 6dF. By supplementing the observations with velocities from the NASA extragalactic database (NED), 10 529 velocity measurements were gathered, corresponding to 8 632 galaxies. In the central part of the supercluster, 92 % of the galaxies could be measured, and on the whole 61 % of the objects were observed.

Figure 1 shows the 'cone diagram' of these galaxies. Velocity is plotted versus right ascension, ranging between 12^{h}30^m and 14^{h}30^m. Each cluster of galaxies is characterised by an apparent elongated structure along the line of sight, due to the velocity dispersion inside the cluster. Note the presence of the foreground Hydra-Centaurus supercluster. It is connected by a bridge of galaxies to the Shapley supercluster itself, whose 5 701 galaxies have a mean recession velocity of 15 400 km/s. Many structures connect the SSC to other superclusters, underlining the filamentary distribution of the matter in the Local Universe. The longest one appears to extend out to 48 000 km/s, joining structures evidenced by Einasto et al. (2001). The analysis of the SSC made by Ragone et al. (2006) based on simulations, shows that it is composed of 122 galaxy systems; 60 are new and 44 belong to the supercluster (Figure 2). The galaxies contained in the SSC represent an average matter overdensity of 5.4 ± 0.2, definitely larger than nearby superclusters such as Horologium-Reticulum whose density excess is only 2.4. The SSC extends more than 120 million light years, its volume being equivalent to that of a sphere of 80 million light years in radius: it is the largest matter concentration in the Local Universe, less than 500 million light years from us.

Clusters of galaxies related with X-ray sources are located at the centre of the SSC, indicating the presence of gas at very high temperature, more than ten million degrees. They were analysed by Bardelli et al. (1996), deriving a mass $M = 3.1 \times 10^{14}\, h^{-1}\, M_{sun}$ within a radius of $2h^{-1}$ Mpc ($h = H_o/100$ km/s/Mpc). Using our catalogue, we determined the luminosity and the mass of the supercluster using various models such as the determination of the mass by X-ray properties, the analysis of the velocity fields of each galaxy cluster and the spherical collapse model. We obtained a total luminosity of about $1.4 \times 10^{14}\, h^{-2}$ times that of the Sun for a total mass of the supercluster $M_t = 5 \times 10^{16}\, h^{-1}\, M_{sun}$. Although very high, this mass would represent only half of that required to attract the Local Group (Hoffman et al. 2001) in the direction of the supercluster. In addition to this, at least an identical amount of matter in the same direction must be present in order to account for the particular motion of our Galaxy.

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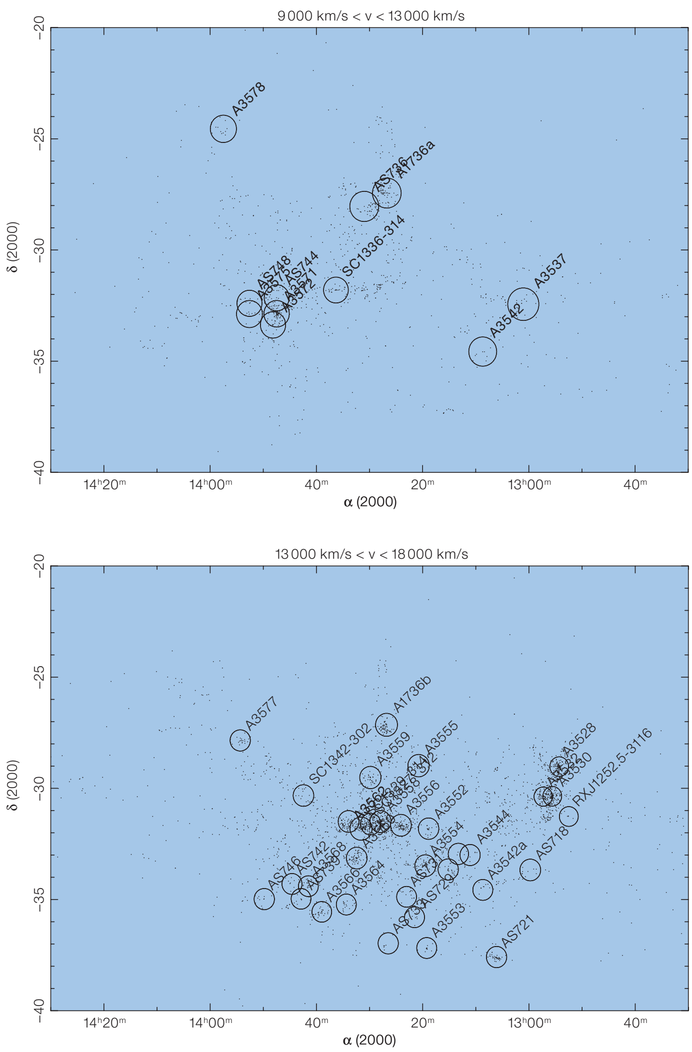
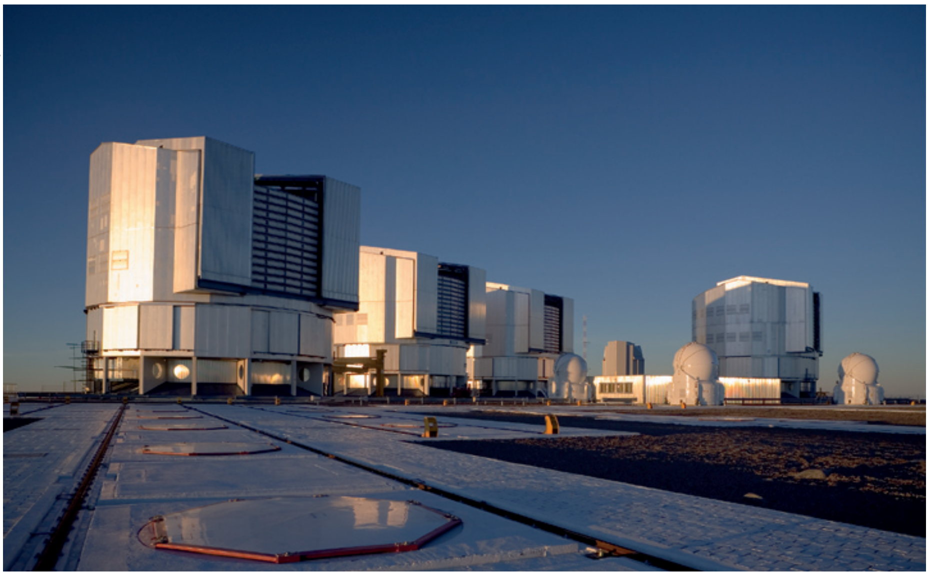


Figure 2: Distribution on the sky of the 44 clusters and galaxies in the velocity range of the SSC. **Upper panel:** clusters with velocities between 9 000 and 13 000 km/s. **Lower panel:** clusters between 13 000 and 18 000 km/s.

Photo: H. H. Heyer, ESO



The VLT and its Auxiliary Telescopes at Sunset.

The Host Galaxies of the Brightest Quasars: Gas-Rich Galaxies, Mergers, and Young Stars

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Because they are faint and hidden in the glare of a much brighter unresolved source, quasar host galaxies still challenge the most powerful telescopes, instrumentation and processing techniques. Determining their basic morphological parameters and their integrated colours is feasible, but difficult, from imaging alone. However, detailed information on their stellar and gas contents and on their dynamics is achievable with deep spectroscopy. We have completed such a deep spectroscopic study, with the VLT and FORS1 in MOS, for the host galaxies of 20 bright quasars ($M_V < -23.5$). A new observational approach is implemented, based on spatial deconvolution and decomposition of the spectra. Our clean, deep, spectra of quasar host galaxies show that the brightest quasars reside in all types of galaxies, that their stellar populations are compatible with those of young discs, even when the host galaxy is an elliptical one. Most of the host galaxies show prominent gas emission lines, whose metallicity suggests a rather inefficient star formation. The source of ionisation of the gas is the quasar in 50 % of the objects. All these objects are undergoing interactions, suggesting that interactions play a major role in the ignition and fuelling of the brightest quasars.

Quasars are among the most luminous objects in the Universe. Powered by the accretion of matter falling onto a 10^7–10^{10} $M_\odot$ supermassive black hole, they radiate at almost every wavelength of the electromagnetic spectrum, from γ-rays and X-rays to the radio domain. Although, at the time of their discovery, quasars were found to be point sources, it was soon realised that they were in fact located in the centre of much larger, but also much fainter, envelopes. The envelopes of the most nearby quasars extend over a few arcseconds, making it possible to obtain spectra of their external parts, even in moderate seeing conditions. Boroson et al. (1984) obtained the very first spectra of a small sample of 'quasar envelopes', and demonstrated that they were made of gas and stars, and that they were at the same redshift as the quasars. These pioneering observations unambiguously established the connection between quasars and galaxies.

The huge quantities of luminous energy escaping from quasars immediately leads to questions about the properties of their host galaxies. Are quasar host galaxies normal galaxies? Are they more massive? Where does the matter fuelling the central black hole come from? What are the physical processes responsible for the ignition of a quasar and what is its life-time, if any typical value exists at all? The answers to these questions rely not only on accurate observations of quasars themselves, but also on the characterisation of their host galaxies. Most quasar host studies carried out over the last two decades concentrate on imaging and have led to the global picture that the most luminous quasars reside in large elliptical galaxies. The VLT spectroscopic observations described in this article support a different picture, where galaxies of all types can harbour bright quasars and where gravitational interactions between galaxies or even mergers, play a major role in the ignition and fuelling of quasars. This was suggested already by the discovery of binary quasars (e.g., Djorgovski et al. 1987, Meylan et al. 1990) but has never been investigated in detail for single quasars.

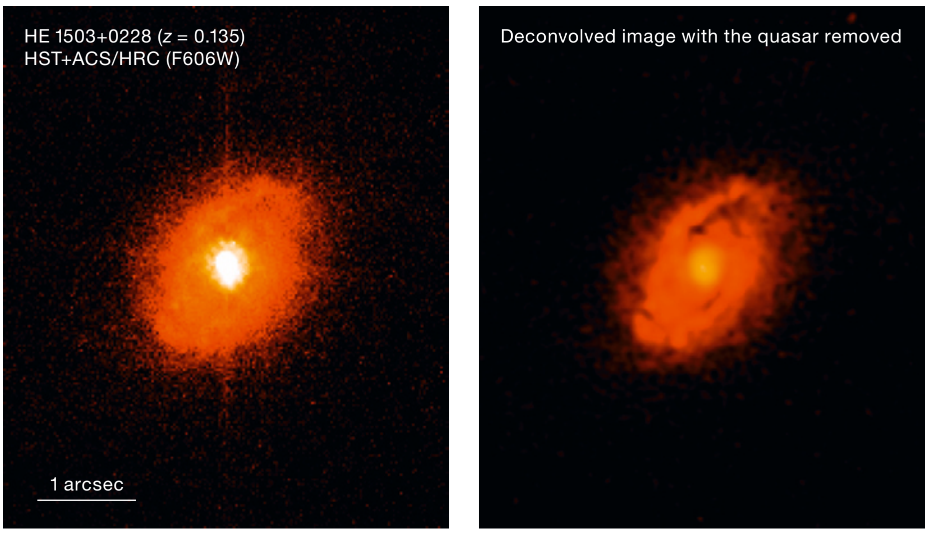


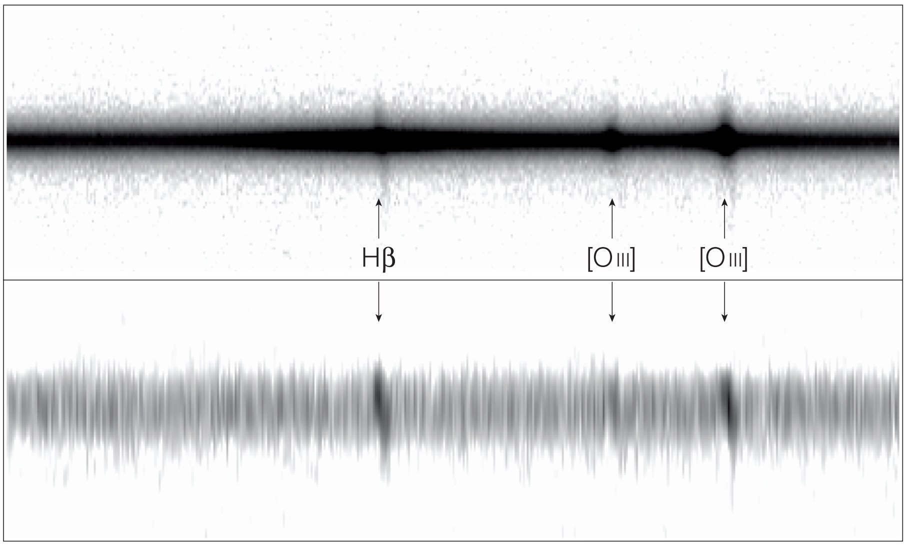
Figure 1: Example of an HST/ACS observation of a low-redshift quasar with its spiral host galaxy, HE 1503+0228, at $z = 0.135$. Even with the excellent resolution of the High-Resolution Channel of the ACS, the bright central quasar makes it difficult to see the internal parts of the galaxy. The image on the right has been spatially deconvolved and the quasar has been subtracted using the MCS deconvolution algorithm. The spiral arms are now obvious even in the centre of the galaxy, as well as the bulge of the galaxy (Letawe et al. 2006b).

A VLT/FORS1 MOS study of quasar host galaxies

The high contrast between the central quasar and its host, and the small angular size of the host are the main limitations to a spectroscopic study. Quasar host galaxies are typically 2–3 magnitudes fainter than their central quasar. Their angular size is only a few arcseconds at low redshift ($z \sim 0.1$–0.3). Figure 1 gives an example of a spiral galaxy hosting a quasar. Even with excellent seeing or HST data, the observations remain challenging, because the wings of the observed PSF, even a few arcseconds away from the quasar, still strongly contaminate the data. Two observational strategies are then possible to minimise the mutual contamination of the quasar and host spectra: (1) to carry out 'off-axis spectroscopy', by placing the slit of the spectrograph a few arcseconds away from the quasar in the hope that less quasar light will contaminate the host galaxy, (2) to develop reliable decomposition techniques in order to separate the individual spectrum of the quasar from that of its host galaxy. We make the latter choice for our study, which considers 'on-axis spectra' of 20 bright quasars with the VLT and FORS1.

We adopt the Multi-Object-Spectroscopy mode (MOS) of FORS1 and devise a new observational strategy in which one of the 19-arcsecond-long slitlets is used to observe the quasar while the other slitlets are used to simultaneously observe field stars used as PSFs. The simultaneous observation of the object of scientific interest and of several PSF stars allows us to use the spectroscopic version of the 'MCS deconvolution algorithm' (Magain et al. 1998, Courbin et al. 2000), which takes advantage of the *spatial information* contained in the spectrum of PSF stars in order to carry out a *spatial deconvolution and decomposition of the spectra*. This strategy was already proposed by Courbin et al. (1999, 2002). It has now been used to decompose numerous VLT spectra of quasar hosts and of galaxies lensing distant quasars (e.g., Eigenbrod et al. 2006). Figures 2–3 give an example of our spectra decomposition, applied to a FORS1 spectrum of the $z = 0.23$ quasar HE 2345-2906. Both figures indicate no residual contamination of the host spectrum by that of the quasar. With a mean signal-to-noise of 10–20 per spectral resolution element, this spectrum allows us to measure several of the important Lick indices describing the stellar content of the galaxy. The prominent emission lines are used to infer the ISM gas metallicity as well as the ionisation source (stars versus central AGN) responsible for the measured emission line ratios. Curved emission lines are seen in the 2-D spectra of the host galaxy (Figure 2), making it possible to measure its velocity field.

Figure 2: Example of spectra decomposition for the $z = 0.23$ quasar HE 2345-2906, using the MCS deconvolution algorithm (Magain et al. 1998, Courbin et al. 2000). The top panel shows a portion of the original VLT/FORS1 spectrum, after reduction and sky subtraction. The bottom panel shows the spectrum of the host galaxy alone, after removal of the quasar spectrum. The continuum and emission lines of the host can be followed even 'underneath' the quasar PSF. The height of the spectrum is 19 arcseconds. The seeing during the observations was 0.7 arcsecond and the spatial resolution after deconvolution is 0.2 arcsecond (Letawe et al. 2006a).



The variety in quasar and quasar-host properties is such that many objects in our sample require slight modifications of the general techniques used to analyse the sample as a whole. While a few quasar hosts are in isolated spiral galaxies (e.g. HE 1503+0228; Courbin et al. 2002), about 50 % are undergoing interactions to the point that it is hard to even infer a morphological type. While the fraction of quasar hosts with gravitational interactions is about the same as for normal galaxies, we show with our data (see below) that the most powerful quasars are systematically in hosts with signs of interactions. In one extreme case, the host galaxy may have been even completely disrupted in a strong collision with a galaxy (HE 0450-2958; Magain et al. 2005; see also ESO Press release 23/05).

Aside from the extreme cases, our spectroscopic sample allows us to infer general characteristics of quasar hosts, as compared with their quiescent, non-AGN, counterpart. While the full analysis and interpretation are described in Letawe et al. (2006a), we summarise here the main conclusions.

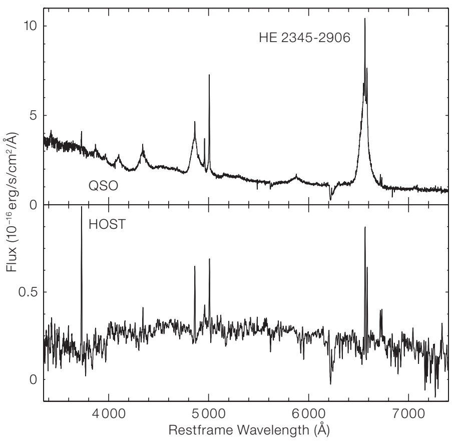


Figure 3: Integrated spectrum of HE 2345-2906. The top and bottom panels display respectively the spatially deconvolved quasar and host spectra, integrated in the spatial direction. Each spectrum is obtained by using the three FORS1 grisms G600B,R,I, ($R \sim 400$) in order to cover the full optical range. The spectra are displayed in the rest frame. Note the quasar broad emission lines, that are seen narrow in the host galaxy. The Hα + N II (6565 Å) emission line is even resolved in the spectrum of the host, because of the lower circular velocity than in the quasar (Letawe et al. 2006a).

Stellar populations

Studies based on imaging only conclude that almost all of the most luminous quasars reside in massive elliptical galaxies (e.g., Floyd et al. 2004, based on HST imaging). We measure in our spectra the Mg2, Hβ and G4300 Lick indices, indicative of the stellar content of the galaxies. The results are plotted in Figure 4 along with the same measurements for two control samples of non-AGN galaxies. Most objects have stellar populations that compare well with late-type rather than early-type galaxies. Only two objects have stellar populations consistent with their early-type morphology. Quasar host galaxies show on average bluer colours than those of non-AGN galaxies, indicative of an additional underlying young stellar population (e.g., Jahnke et al. 2004) that might be explained by recent gravitational interactions. The majority of the objects we study here shows stellar populations inconsistent with normal inactive isolated early-type galaxies or massive bulges, but rather shows spectral features more typical for young discs.

Gas ionisation and metallicity

Emission-line ratios are well-known indicators of the source of ionisation of the Interstellar Medium (ISM). We measure in Figure 5 the [O III]/Hβ ratio as a function of the [N II]/Hα ratio for 14 quasar host galaxies that have significant narrow emission lines. These two ratios compare high and low ionisation lines, hence allowing us to discriminate between high-energy ionisation sources and sources of lower energy. Galaxies where the ISM is ionised by star formation are therefore located, in such a diagram, at a different place than the galaxies where the ISM is ionised by the central quasar. The result is striking: half of the galaxies show the signature of an ISM ionised by the quasar itself. All these are undergoing interactions. In addition, the line ratios in these objects indicate that even the gas located several kpc away from the centre of the quasar is ionised by the hard radiation field of the quasar. The objects are also the brightest of the sample, making it clear that interactions play a major role in the ignition and fuelling of

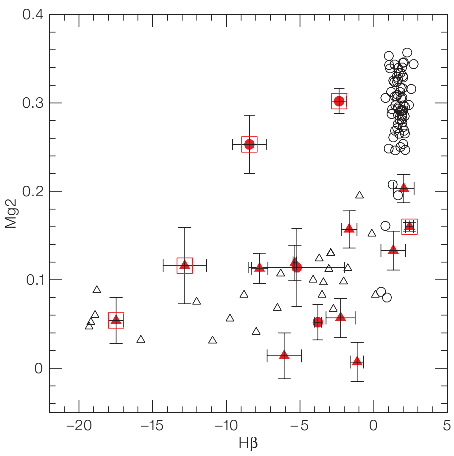


Figure 4: Lick Mg2 and Hβ indices for 14 of the quasar host galaxies (red symbols), compared with the non-active galaxies of Trager et al. (1998) and Kennicutt (1992). Circles stand for elliptical galaxies, while triangles indicate later-type galaxies. Red open squares indicate the objects that contain gas ionised by the central AGN itself. Our values of the Lick indices match well those measured for late-type galaxies. The only two objects that have metallicities compatible with elliptical galaxies are undergoing interactions (Letawe et al. 2006a).

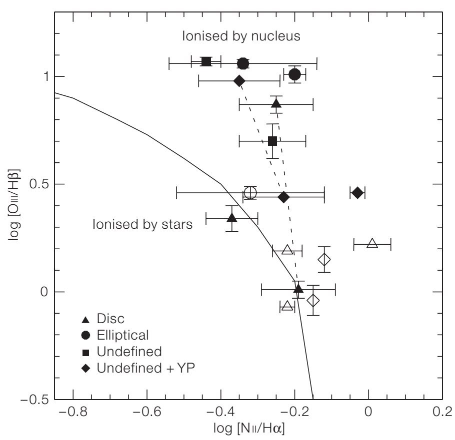


Figure 5: Emission-line ratios for 14 of the quasar host galaxies. The solid line indicates the limit between objects with an ISM ionised by star formation and the objects with an ISM ionised by the central quasar. Filled symbols represent objects with obvious signs of interactions, while open symbols are isolated objects. All objects with ionisation by the quasar are undergoing interactions. They also correspond to the brightest quasars. Measurements connected by a dashed line are for the same object but correspond to measurements in the central or external parts of the galaxy, where the ionisation is found to be respectively by stars or by the AGN (Letawe et al. 2006a).

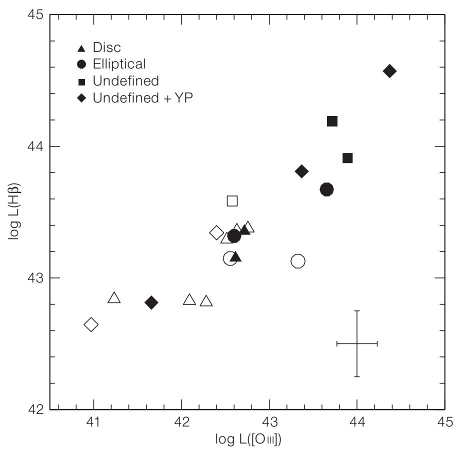


Figure 6: Luminosity of the *quasar* in the Hβ emission line (erg s^{-1}) as a function of its [O III] (5007 Å) luminosity. The typical 1-σ error bar is given in the lower right corner. The characteristics of the host galaxies are as stated in the legend, where open symbols represent isolated galaxies, and filled symbols are for galaxies that display signs of interactions. It is immediately seen that the quasars with the brightest emission lines tend to reside in interacting systems (Letawe et al. 2006a).

the brightest quasars. Figure 6 adds more support to this picture, by establishing a clear correlation between the luminosity of the central quasar in the emission lines, and the fact that the quasar resides in an interacting system. In Figure 6, all the bright quasars are undergoing interactions, while the faintest ones rather reside in disc-dominated galaxies. Isolated elliptical galaxies host only moderate-luminosity quasars.

When the source of ionisation of the ISM is stellar, it is possible to estimate the Star-Formation Rate (SFR) using the [O II] equivalent width. Although more objects would be needed to draw a definite conclusion, we note that three hosts out of four with confirmed elliptical morphology have significant [O II] emission, in contrast with non-AGN elliptical galaxies. In all the cases where it can be measured, the SFR is comparable to what is generally found in young discs.

The metallicity of the gas traces how galaxies have evolved. The hosts of our sample have a mean log (O/H)+12 of about 8.4, i.e., in the low part of the metallicity distribution of spiral galaxies (see Figure 7). Only two galaxies have a gas metallicity well compatible with the mean value of 8.8, typical for spirals. This suggests that star formation has been rather inefficient, and that the ignition of the quasar activity might therefore be related to an early stage of evolution of their host. Note, however, that a statistically more significant sample is necessary to confirm this trend, as we have selected the objects where we are sure that the gas is ionised by star formation, i.e., a subsample dominated by a young stellar population.

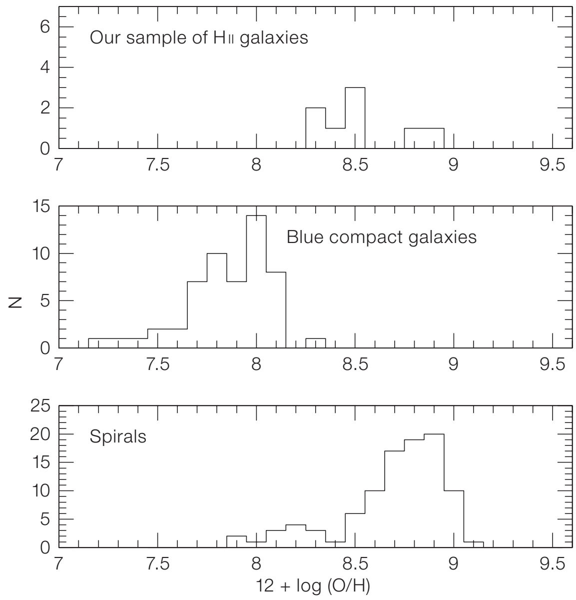


Figure 7: Gas metallicities of the quasar host galaxies (top), and of two samples of metal-poor blue compact galaxies (middle panel), and metal-rich galaxies (bottom). Although our sample is dominated by discs/spirals, their metallicity remains low compared with normal spirals, suggestive of a low efficiency of star formation (Letawe et al. 2006a).

Dynamics

The spectral resolution of the data is sufficient to derive rough velocity information on the host galaxies, as can be noticed already from Figure 2. This information is valuable, not only in estimating the total mass of the galaxies when unperturbed rotation is seen, but also to unveil signs of interactions. Indeed, all objects that show irregular or even distorted shapes on the VLT acquisition images, also have disturbed velocity curves, hence confirming the presence of interactions. When the host is a spiral galaxy, we fit a three-component velocity model including a central point mass, a rotating disc, and a dark matter halo. The masses we compute in that way are in the range 10^{11}–3 10^{12} $M_{\odot}$, integrated over a 10-kpc aperture, i.e., in good agreement with the masses of normal, non-AGN galaxies.

Not all symmetrical velocity curves can be adequately fitted by three-component models, and other structures in the quasar host galaxies are found to mimic rotating discs when observed at such small angular sizes. The case of HE 1434-1600 is a good example, where highly ionised gas displaying a velocity field that can be mistakenly interpreted as circular motion, is in fact distributed in shell-like structures along the slit. However, accurate fit of the velocity curve allows us to rule out circular rotation (Letawe et al. 2004), as confirmed by HST imaging that unveils the details of the gas distribution in the host. Figure 8 shows an HST/ACS image that we have obtained for HE 1434-1600. The host galaxy of this quasar is classified as an elliptical galaxy using ground-based imaging. The HST image immediately confirms shell structures. By combining these data with 3D spectra, as can be obtained with ARGUS (Figure 9), it will be possible to decide whether the shells are expanding away from the central quasar or whether they are residual material left in the host's ISM after an encounter with a neighbour. Indeed, the companion galaxy seen in the HST image is at the same redshift as the quasar. It is however already apparent from the FORS1 spectra and from the HST images that interactions are or have been present during the history of this elliptical galaxy.

On the role of interactions in quasar formation

Accurate image-processing techniques combined with deep slit spectroscopy yields a wealth of information that makes it possible to unveil connections between the physical properties of quasars and of their host galaxies.

We find that bright quasars do not exclusively reside in large elliptical galaxies. Half of the galaxies in our sample show stellar populations typical of young discs.

A second striking result is that most of the host galaxies, including the ellipticals, contain large amounts of gas. This gas has probably been brought into the ISM through gravitational interactions. Indeed, the brightest quasars are *systematically* in interacting systems, independent of their morphological type, when a morphological type can be determined at all.

In all galaxies with interactions, the gas is ionised by the central AGN rather than by star formation, even several kpc away from the quasar. This remains true for quasars that have large reddening values, hence ruling out the possibility that bright quasars are seen brighter because the dust in their host has been destroyed during mergers or encounters.

Finally, we find that quasars that reside in non-interacting galaxies appear to be in metal-poor but gas-rich spiral galaxies. These galaxies harbour the less luminous quasars.

The general picture drawn from our study is that the brightest quasars are clearly related to gravitational interactions or even mergers between several galaxies. Aside from the clear case of the brightest quasars, the fainter quasars might form in the early stage of formation of their host galaxy, which are all metal-poor, i.e., galaxies where star formation has been rather inefficient so far. While we find very large amounts of gas in the latter galaxies, it is not clear what mechanism brings the gas to their central AGN. The mechanisms involved are probably more 'local' than global mergers or interacting systems, e.g., the explosion of supernovae, gravitational instabilities or bar-driven fuelling. It will be interesting in the future to investigate the correlation between quasar luminosity and the presence of bars in the host galaxy.

On the technical side, our study shows that clean, deep, multi-slit spectroscopy is a powerful way to characterise high-contrast objects such as quasar host galaxies. While integral-field spectroscopy is useful in order to map the ionisation state of the gas across the galaxy and to measure the velocity field of the gas, obtaining deep continuum spectra remains only accessible to slit spectra in MOS. In addition to be much more sensitive, slit spectrographs and their MOS capability provide easy access to the PSF information mandatory to the removal of the central quasar. There is therefore a strong complementarity between 3D and slit spectroscopy as far as quasar host galaxies are concerned. The general trends unveiled by the present 20-object sample call for a more systematic study including, e.g., all known bright low-redshift quasars and Seyfert galaxies.

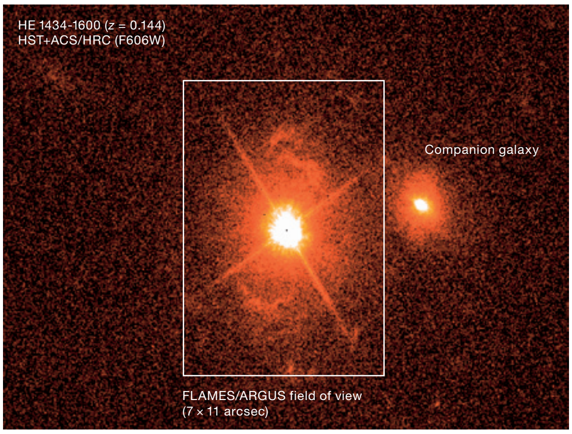


Figure 8: HST image of the $z = 0.144$ quasar HE 1434-1600. The image has been taken through the F606W filter, using the High-Resolution Channel of the Advanced Camera for Surveys onboard the HST. The slit of our FORS1 spectrum is about vertical in this image. The FLAMES/ARGUS field of view is also indicated. Note the obvious shell-like structures that may expand away from the quasar. The companion galaxy to HE 1434-1600 is at the same redshift and is in gravitational interaction with the quasar and its host galaxy (Letawe et al. 2004).

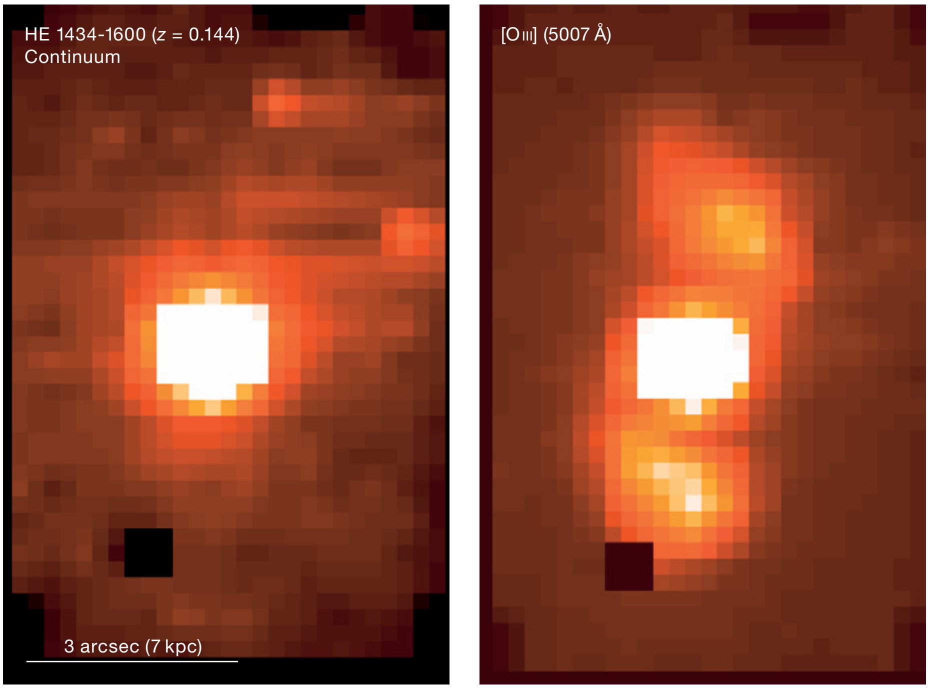


Figure 9: ARGUS quasi-monochromatic images of the $z = 0.144$ quasar HE 1434-1600. The fibre size in this image is 0.25 arcsecond, after subsampling of the original data (which have 0.5 arcsecond fibres). The seeing was 0.6 arcsecond during the observations. The images display the two spectral regions centred on the [O III] (5007 Å) emission line (right) and on a continuum region (left) with the same wavelength coverage. These data allow us to trace the gas across the galaxy and to determine its ionisation state from the central kpc to the outer parts. However, the stellar continuum remains only accessible to slit spectra, hence pointing to the complementarity between the two techniques.

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André B. Muller (25.9.1918–1.4.2006)

Richard M. West (Munich, Germany)

With great sadness, we have learned about the death of André Muller on 1 April, at the age of 87. Living in retirement in his native Holland since 1983, he was one of ESOs true pioneers, an outstanding representative of the select group of European astronomers who succeeded in steering ESO through the difficult initial phases. André was closely associated with the entire process, from the first site monitoring programmes in South Africa to the subsequent search in Chile, the decision in favour of the La Silla site, as well as the management of ESOs early activities in Chile, including the construction of the headquarters and observatory and the installation of the first generation of ESO telescopes. Few persons, if any, have been so intimately connected to the setting-up of ESOs facilities and it would be impossible to list in detail all of the services André performed for the organisation with such great expertise and zeal during his long career.

André Muller obtained his PhD in Leiden in 1953, with a study of the variable star XZ Cygni. His thesis advisor was Pieter Oosterhoff, one of the twelve leading European astronomers who authored the historical statement in January 1954 that ultimately led to the creation of ESO.

Based at the University of Groningen as an associate of Adriaan Blaauw, ESO Director General (1970–74), André worked for some time at the Leiden Observatory station on the premises of the Union Observatory in Johannesburg, South Africa. Thus he was well prepared to participate in the early site studies in that country. He led the 'Quick Look Expedition' at the Table Mountain in the Klavervlei Farm area in 1959–60, reporting to the ESO Committee (the precursor of the Council) in July 1960. He went on to supervise several stages of the following 'Comprehensive Programme' that included testing at four different observing sites in 1961–63. Site monitoring in those days was very hard work indeed, as illustrated by the following instructions: "… Observers and assistants have to work during 25 consecutive nights and after this period have to take leave during five consecutive nights. ... With the exception of these five nights, there will be no opportunity for outings, whatsoever …" It was during this period that André concluded that the astronomical quality of a site is critically dependant on the amount of temperature change during the night: the less, the better.

As ESO began to orient itself towards Chile, André Muller was sent to that country in late 1962 and joined Jürgen Stock's travelling team. Following the decision by the ESO Council in November 1963 to place the future ESO observatory in Chile, André became an ESO staff member on 1 January 1964, as superintendent in Chile. Together with his wife Louise and their six children, he moved from South Africa to La Serena in March of that year and soon thereafter, he made the first and decisive visit to the La Silla mountain, together with ESO Director General Otto Heckmann. He was closely involved in the acquirement of this exceptional location and was responsible for the smooth establishment of the extensive infrastructure needed to run an observatory in the middle of the desert. He set up the Pelícano base camp and traced the path along which the road to the summit was later constructed. He had an incredible workload over the next years, as the buildings were constructed and the telescopes began to arrive. In March 1966, Council held its first meeting in Chile and the La Silla road was dedicated. On this occasion, great admiration was expressed for André Muller and his able team of Chileans and Europeans. Work also proceeded on the ESO Headquarters in Chile at the Vitacura site in the capital, Santiago de Chile. At the end of this exceedingly busy period, the official dedication of the La Silla Observatory took place on 25 March 1969, with the associated visits and a major international symposium in Vitacura on the Magellanic Clouds, the proceedings of which were edited by André Muller.

Photo: EHPA, made available by J. Rösch

Searching for a site in March 1964: Jean Rösch (left) and André B. Muller (right) in front of the mountain Cinchado.

Having done far more than any call of duty, André Muller then transferred in October 1969 to the Office of the Director General in Bergedorf near Hamburg, Germany. Here he assumed the crucial task of leading the ESO Visiting Astronomers Programme, being responsible for the scheduling of the rapidly growing number of observing programmes with the expanding telescope park at La Silla. He continued to supervise the important, preparatory seeing studies for the 3.6-m telescope dome. From now on, André would also remain closely connected to the 1-m Schmidt telescope project. This instrument was under construction in Hamburg but had become somewhat delayed and now needed a firm hand to get ready as soon as possible for its main task, the Southern Sky Surveys. Working in close contact with the ESO Telescope Project Division at CERN, he contributed to the development of the first computer-based telescope control system. Together with Hans-Emil Schuster, who had worked with André in Chile since 1964 and who was responsible for the operation of the Schmidt telescope, he spent much time at La Silla over the next years in order to tune this very delicate instrument to optimal performance. By the end of September 1983, André Muller left ESO for a well-deserved retirement in his native country. Unfortunately, André and Louise would only be together a few years, before she died in March 1987.

All of us who had the privilege to work with André Muller will remember him not only as an extremely competent astronomer/instrumentalist/manager in his many functions, but also as a delightful and friendly person. He was always ready to help and to provide guidance from his rich experience. Few possessed his intimate knowledge of the organisation and its colourful history.

Thank you André, for your kindness and your great services to ESO and all those young European astronomers who gained access to some of the best observational facilities in the world. We will never forget what you have done for astronomy!

Finnish Parliamentary Committee at ESO Headquarters

Claus Madsen (ESO)

On 15 March, members of the Education and Culture Committee of the Finnish Parliament paid a visit to the ESO Headquarters. The guests were welcomed by the Director General in her office. Following this were extensive briefings on the main activities of ESO by various ESO staff members. After the session, the deputies had a chance to visit the Science Archive and the Optics Laboratory, followed by a late lunch. Finland is the most recent member of ESO and there was a strong interest by the delegation members to learn more about the work and the projects carried out by our organisation. Amongst the many topics discussed were also the role of astronomy in science education and the SAMPO project, which is part of the initial Finnish contribution to ESO.

Dr. Ilkka Taipale, MP, asking a question to the ESO team. At the centre, Committee Chairperson Ms. Kaarina Dromberg, MP and Mr. Tuomo Hänninen, MP (right in the picture).

Photos: H. H. Heyer, ESO

Several Committee members showed considerable interest in Adaptive Optics.

Report on the ESO-FONDAP Conference on

Globular Clusters – Guides to Galaxies

held in Concepción, Chile, 6–10 March 2006

Tom Richtler[1]
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[2] University of Utrecht, the Netherlands

Background and venue

The role of ESO in the development of astronomy in Chile is difficult to overstate. However, the Chilean government is also well aware of the significance of science for the development of the country and has created large programmes for Chilean science to grow and maintain a scientific productivity competitive with that of countries with a longer scientific tradition. One of these programmes is called FONDAP (Fondo de Investigación Avanzado en Areas Prioritarias) and there is no question that astronomy is a priority field in Chile. The astronomy FONDAP programme (*www.cenastro.cl*) unites groups from Santiago (Universidad de Chile, Universidad Católica) and Concepción (Universidad de Concepción). One of the FONDAP goals is to support schools and conferences. Since globular clusters play an important role in the research of the Concepción group, we had the feeling that a small workshop of two or three days on globular cluster research would be due. But the reaction from the community was overwhelming and within a short time we had to drop the idea of an intimate workshop and instead had to face the challenge of a full-scale international conference, which would stretch our organisational and infrastructural capabilities to the limit. As so often, ESO was very generous and so a joint ESO-FONDAP conference on Globular Clusters in Concepción became reality.

The conference marked the five-year anniversary of the first-ever IAU symposium on Extragalactic Star Clusters (also the first IAU Symposium on Chilean soil) which was held 2001 in Pucón and was also co-organised by the Concepción group (Doug Geisler). In the intervening five years, an ESO workshop on the subject was organised in 2002 in Garching (Markus Kissler-Patig) and another meeting (primarily devoted to young star clusters) was held in Cancún, Mexico, in November 2003. Several other smaller workshops on star clusters have been organised since the Pucón meeting, and star clusters are often included in many other contexts (e.g. star formation, galaxy evolution), but it seemed very timely to meet once again in 2006 and discuss the vast amount of progress made.

The venue of the conference was the Lecture Hall of the Universidad de Concepción in the Facultad de Humanidades y Arte on the university campus. Many of the participants stayed at the Hotel Araucano in central Concepción, where also the welcome reception and conference dinner were held. With about 150 participants and many more requests for contributed talks than available slots, putting together the schedule was not an easy task. The final programme was busy with 23 review talks and 43 contributed talks, distributed over the five days (with Wednesday afternoon free). In addition, 58 posters were presented at the meeting. While the tight schedule unfortunately did not allow for a dedicated poster session, the posters were permanently mounted in the lobby adjacent to the lecture hall so that poster viewing was possible during every coffee break.

In the following, we describe in a general manner a few of the topics discussed, omitting all author names. The forthcoming proceedings will give the full credit to individual researchers.

Scientific topics

The selection of scientific topics discussed at the meeting already reflects much of the progress made over the past five years. The trend from previous meetings to view globular clusters (GCs) as members of an increasingly diverse 'zoo' of star clusters continued. At the high-mass end of the mass spectrum, several contributions discussed the objects now commonly referred to as 'Ultra Compact Dwarfs' (UCDs). It does not yet seem quite clear whether UCDs are a distinct class of objects, or if there is a gradual transition from high-mass GCs to UCDs and dwarf galaxy nuclei. Populations of relatively faint, extended star clusters which do not fit the classical description of globular clusters are now also being discovered in several galaxies, both in the halo of M31 and in the discs of lenticular galaxies. Young, massive star clusters (YMCs) in actively star-forming galaxies were discussed in several talks and the identification of these objects as young versions of globular clusters is becoming less controversial. Populations of intermediate-age (few gigayears) star clusters have now been identified in some merger remnants and may provide a crucial 'missing link' between the rich populations of YMCs observed in starbursts and mergers and the 'classical' old GCs. However, explaining the differences in the mass functions of young and old star clusters continues to be a field of active investigation. Increasing amounts of data are being collected for very young, still embedded star clusters, which may provide important clues to the star-formation process leading to GC/YMC formation. Such studies are likely to receive a tremendous boost once ALMA comes on-line.

Observational studies of extragalactic globular clusters are becoming more quantitative and detailed. Five years ago, little information was available about the age distributions of globular clusters beyond the Local Group. In the meantime, several spectroscopic and photometric studies have been published and tighter constraints are becoming available, although the measurements are demanding and the presence of intermediate-age GC populations in early-type galaxies is still debated. Even so, the distinction between 'old' and 'young' is still one between formation redshifts greater or less than 1.5–2, and it would clearly be desirable to push the limits further than that. Doing so for large samples of clusters may have to await future generations of extremely large telescopes. Constraints on alpha-to-Fe abundance ratios are becoming available from spectroscopy. An entirely new avenue of research is abundance analysis of extragalactic star clusters from high-dispersion spectroscopy, with some first results being presented at this meeting. In principle, this would already have been observationally possible five years ago with HIRES or UVES, but only now has the modelling of integrated GC spectra at high resolution reached a sufficiently mature level to allow a meaningful analysis. Other new results on old GCs included the discovery of a colour-luminosity relation among the metal-poor globular clusters (the 'blue tilt'), and the possible presence of intergalactic globular clusters in some rich galaxy clusters. There was also a lively discussion of the colour bimodality in globular-cluster systems and its interpretation as a metallicity bimodality, a subject that has recently become quite controversial.

As in many other fields, large data sets are playing an increasingly important role for research in extragalactic globular clusters. One example is the ACS Virgo and Fornax surveys, which provide high-quality imaging of more than 100 early-type galaxies and their globular-cluster systems and were covered in several talks. This has allowed many results to be established with much greater significance than before. For example, correlations between the mean colours (metallicities) of globular cluster sub-populations and luminosities of their host galaxies are better revealed in these new data, and more accurate measurements of globular cluster sizes are possible with the better spatial resolution of ACS compared to earlier WFPC2 studies. Interesting links are also appearing between galaxy nuclei and supermassive black holes, whose masses follow very similar scaling relaions with respect to the host-galaxy mass.

Dynamics of globular-cluster systems is another case where large data sets are playing an important role. Several hundreds to ideally 1000 or more radial velocities are needed in order to carry out a satisfactory modelling of the kinematic properties of GC systems. With such data sets, it becomes possible to put constraints on the detailed dark-matter distributions in galaxies, test alternative theories to dark matter (e.g. MOND), and determine the radial anisotropy of the velocity distributions, which has important implications for the dynamical evolution of GC systems. Such data sets are now becoming available, thanks to effective multi-object spectrographs on larger telescopes (GEMINI/GMOS, VLT/FORS2, FLAMES, VIMOS, Magellan/IMACS, Keck/DEIMOS, etc.).

Our own Galaxy and other galaxies in the Local Group will always be those that can be studied at the greatest level of detail and serve as comparison cases for more distant systems. Although the emphasis was on extragalactic GCs, a few talks covered classical topics in Galactic GCs (abundances, stellar-mass functions, CMDs) with less classical results. In particular, complementary information about the stellar populations in many Local Group galaxies is available by other means (e.g. from studies of field stars). Catalogues of globular clusters in M31 are still being improved and a large amount of photometric and kinematic information is now available for GCs there, which can be compared with other constraints on the accretion/merger history of M31 from studies of tidal streams. One controversial issue is the presence of intermediate-age globular clusters in M31, where adaptive optics imaging suggests that at least some objects previously identified as such may instead be loose groupings of stars ('asterisms') and not real GCs. Detailed studies of star clusters in M33 are more scarce, although it is now catching up with its larger cousins. In particular, M33 is interesting because of its relatively rich population of young populous star clusters.

While research in extragalactic star clusters remains dominated by a flurry of observational results, an increased interplay with theory is now forthcoming. Several talks covered aspects of galaxy formation and evolution in the cosmological context, and it is encouraging to see that cosmological simulations are starting to reach a resolution and sophistication including dissipational processes, where the formation of globular cluster-sized objects can be addressed. Different views about galaxy formation and the role of accretions, mergers and early collapse are now starting to converge, although the details are not yet clear. The spatial distributions of GC systems may even provide constraints on truly cosmological questions such as the epoch of reionisation. N-body simulations are now able to model star clusters with GC-like masses over cosmological timescales, resulting in a better theoretical understanding of the dynamical evolution of star clusters. However, the simulations are still having difficulties producing the observed, virtually universal mass function of old globular clusters as a result of evolution from an initial power-law distribution, except under special circumstances. The fractal structure of the interstellar medium might play an important role.

Final remarks

The lively response of the community attested to the fact that research in globular clusters is as active a field as ever. As noted by William Harris, a good indicator of the health of any field is its ability to attract new bright students, and there were many examples of this in Concepción. When will there be nothing left to work out for the next generation? Perhaps this will be when the actual cluster-formation processes and their dependences on physical parameters and environment are understood, when nucleation of galaxies is understood, when star formation is understood, when chemical enrichment is understood, in other words: not too soon. Globular clusters are involved in so many aspects of galaxy formation and evolution that they are really "Guides to Galaxies".

Our field seems well prepared to take advantage of the many new facilities that will become available in the next decade and beyond (ALMA, ELTs, JWST). We are therefore confident that there will be ample supply of new results for the next many more meetings to come.

Acknowledgements

Many thanks to all who helped making the conference possible: FONDAP Centre of Astrophysics, ESO, Las Campanas Observatory, Cerro Tololo Observatory, Universidad de Concepción. The tireless work of the Local Organising Committee was absolutely essential. Maria Eugenia Geisler, with her engagement and her skills, deserves most of the credit. Finally, we want to thank all participants for their enthusiasm which made the conference such a scientifically (and non-scientifically) enjoyable event.

Fellows at ESO

Andreas Lundgren

Andreas Lundgren

I arrived in Chile as an ESO fellow in September 2004 and I was immediately thrown into the buzzing APEX project, which back then still had one year left to inauguration.

Even if I have worked with data in most wavelength regimes, my scientific work is mostly based on millimetre and submillimetre data. More specifically, I am interested in the distribution, kinematics and physical properties of the molecular gas in spiral galaxies. In my thesis I concentrated on the nearby barred spiral galaxy M83, and this galaxy is still the core of my science.

I was born in Sweden, and I did my undergraduate studies in Gothenburg, and graduate studies at the Observatory of Stockholm. During my PhD years I did several observing trips to the SEST, and I really enjoyed visiting La Silla. Therefore it was an easy decision to make when I was offered the opportunity to take a sabbatical year from my PhD studies 2002–2003 in order to work at SEST.

SEST and APEX are in many aspects similar, but some things are very different. When we operate APEX from the base station in Sequitor, some 70 km from the site, the work is very much like sitting in the SEST control room with the dark curtains down. But when we go to Chajnantor in order to carry out morning or daytime observations (Since APEX is a radio telescope, it can be used 24 hours per day) the differences becomes vividly clear: Sitting in a container at 5 100 m altitude, and while observing, sniffing oxygen. Outside there is nothing but rock and sand, and one of the driest atmospheres on earth.

Vincent Reveret

Since I started to study physics, I have always been interested in optics and all the incredibly different ways to detect light. After graduating in applied physics in England, I did my PhD in Saclay near Paris. I specialised in the development of a new kind of detector for submillimetre astronomy, the so-called large bolometer arrays (the equivalent of CCD cameras for submillimetric range). That was a pleasant time: a very good team spirit associated with the successful development of a totally new kind of detectors. I thought I could never find such a nice lab again. I was wrong.

After the defence of my thesis, I decided to see the other side of submillimetre astronomy, going from the development of detectors in the lab, to their use in an astronomical observatory. I arrived in Chile in May 2004 to work at the APEX telescope near San Pedro de Atacama. APEX is one of these new-generation telescopes, like ALMA or the HERSCHEL satellite, that lead the 'revolution' in submillimetre astronomy. Even if working conditions at APEX can be difficult (oxygen molecules are very rare up on the telescope site!), I love going there because of San Pedro's beauty and the excellent working atmosphere in the team.

With the next arrival of a large bolometer camera (called LABOCA), APEX will be one of the most powerful submillimetre telescope in the world. We know that many astrophysical hot topics can benefit from APEX capabilities, like star formation for example. This is one part of my research: I study the relationship between intense UV fields coming from OB associations and the conditions of star formation inside long columns of gas (sometimes called elephant trunks). I still work in instrumentation, even if now I focus more on simulations to prepare for the next generation of bolometer cameras that maybe we will see on APEX one day ...

Vincent Reveret

Walloon Space Days

Claus Madsen (ESO)

On 28–29 March, the Cluster Wallonie Espace, mainly a partnership of companies in the Walloon 'Space Valley', organised the first so-called 'W Space Days' at the Colonster Castle, located on the premises of the University of Liège. The primary aim of these days is to encourage meetings between professionals in the sector and to identify new scientific and technological opportunities. They should also help to raise awareness of the activities of the space sector amongst the general public and young people in particular. Indeed the event successfully brought together scientists, industrialists, funding agencies and policymakers. On the first day, some 210 representatives of research centres, industries and organisations from 13 countries in Europe participated in the professional event, while the next day was a 'public day'. The first morning's programme comprised a series of talks, including ELT presentations by Roberto Gilmozzi and Philippe Dierickx.

The event coincided with the completion of the fourth VLTI Auxiliary Telescope and the programme thus included a celebration and a press conference at the AMOS factory, located in the nearby Liège Science Park. The afternoon offered opportunities for company consultations and the day finished with a well-attended public lecture by Philippe Dierickx. On the following day, university students had a chance to see the Auxiliary Telescope at AMOS. As an extension to the programme, AMOS opened its doors again to the public on 1 April, with more than 450 visitors learning about the VLTI ATs.

W Space Days will be organised again in 2008, providing an interesting forum for discussion of current and future programmes in astronomy, astrophysics, and astronautics, for the members of the Cluster Wallonie Espace, but – with broad European participation – also extending far beyond this region.

Photos: H. H. Heyer, ESO

Jean-Pierre Swings (University of Liège), Roberto Gilmozzi and Philippe Dierickx (ESO) taking questions from the floor.

Marie-Dominique Simonet, Minister for Science, New Technologies and External Relations for the Walloon regional government was the guest of honour at the demonstration of the fourth VLT Auxiliary Telescope in the AMOS assembly hall.

From the AT4 Ceremony at AMOS.

Schoolchildren Worldwide Compete to “Catch a Star!”

Douglas Pierce-Price (ESO)

“Catch a Star!”, an international competition for school students organised by ESO’s Educational Office and the European Association for Astronomy Education, has had its fourth successful year.

The competition encourages students to work together in teams, learning about astronomy and discovering things for themselves by researching information. The most important goal is to develop an interest in science and astronomy through investigation and teamwork. This is why many of the prizes are awarded by lottery, to make the competition inclusive and avoid a sense of elitism. There are, however, also four major travel prizes which are awarded by jury. “Catch a Star!” was originally open to European countries and Chile, but from this year the competition was made truly international.

More than 130 teams from 24 countries worldwide took part. They chose an astronomical object, such as a nebula, star, planet, or moon, or a more general theme such as ‘black holes’ or ‘star formation’. They then wrote about this topic, researching and discussing how large telescopes such as those of ESO could be used to study it. Younger students were invited to take part in a separate picture competition, for which they created a large number of very impressive drawings and paintings.

Other prizes, of astronomy posters and CD-ROMs, were also given. Some were awarded by lottery, and some as ‘highly commended’ prizes by the jury. For the picture competition, all the children won “Catch a Star!” T-shirts, with other prizes awarded with the help of a public web-based vote.

Given the importance of gender issues in science, and especially physics, it is encouraging to note that girls did particularly well in the competition. For example, 10 out of the 11 students who won travel prizes are girls. There was also, as we have consistently seen in ESO’s educational projects, a strong showing from central and eastern European nations. It would be interesting to analyse these results further, to investigate whether there are specific reasons for the girls’ success, and why certain countries are particularly well represented. Such an analysis could provide useful information for future educational projects.

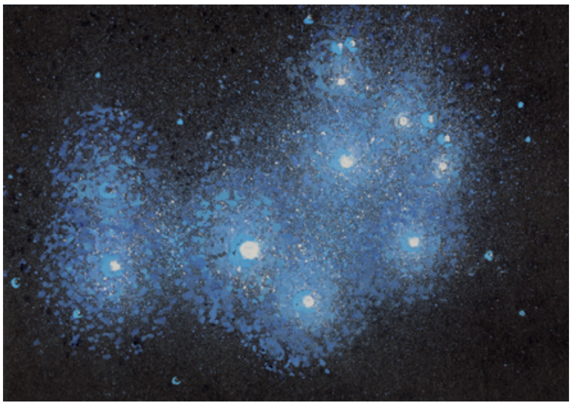
About the same number of countries took part as last year, with more than half of the entries coming from just three countries. Our aims for the future are to make the competition easier to enter, and to widen participation. We hope that even more students, from even more countries, will “Catch a Star!” next time.

Find out more about the competition at *http://www.eso.org/catchastar/*

Prize	Project	Students	Teacher/Group leader	Country
Trip to ESO at Paranal and Santiago (Chile)	Star clusters and the structure of the Milky Way	Edina Budai Andrea Szabo Judit Szulagyi	Akos Kereszturi	Hungary
Trip to Königsleiten Observatory (Austria) and ESO Headquarters	The Fireworks Galaxy – NGC 6946	Alexandra Georgieva Rumen Stamatov	Petar Todorov	Bulgaria
Trip to Wendelstein Observatory (Germany) and ESO Headquarters	The Annular Solar Eclipse versus the Venus Transit	Aida Pallàs Ramos Violeta Porta Alonso Alícia Tiffon Calvet	Anicet Cosialls Manonelles	Spain
Trip to Hispano-German Astronomical Observatory at Calar Alto (Spain)[1]	Sunspots	Denitsa Georgieva Tanya Nikolova Rositsa Zhekova	Dimitar Kokotanekov	Bulgaria

Table of winners of the “Catch a Star!” travel prizes.

[1] This prize was kindly provided by Spain’s Consejo Superior de Investigaciones Científicas.



Two of the winners of the drawing competition section of “Catch a Star!”, by Karolis from Lithuania (left) and Yuriy from Belarus (right).

A Solar Eclipse Expedition to Turkey

Stefan Uttenthaler (ESO)
on behalf of all the participants listed in the caption to Figure 3

On 29 March 2006, a total solar eclipse occurred over South America, Africa, Turkey, Russia and Kazakhstan. It was the first one close to central Europe after the eclipse of 11 August 1999, and was calculated to have a maximum duration of totality of 4 min 7 sec. A group of eleven persons from ESO, accompanied by three from MPE and several amateur astronomers from the Augsburg area (altogether 20 participants) travelled to the Antalya region of Turkey to observe the eclipse. The Turkish Riviera could be rated as a good, but not excellent observing site, with a probability of seeing the eclipse of 48 % for Antalya.

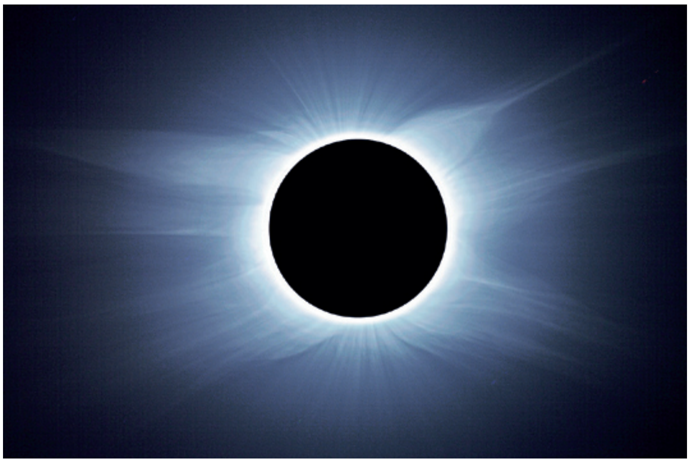


Figure 1: Image of the corona obtained by combining digital photos taken by Karl Thurner and by Thomas and Claudia Winterer.

The weather on the eclipse day was very good with wind coming from the South, dissolving the clouds along the coast and building them up in the mountains inland. Our observing site was a remote hill located between Side and Antalya close to the coast. The exact GPS coordinates were determined by Christian Clemens to be 36° 52′ 18″.8 N 31° 13′ 52″.8 E. The duration of totality at this place was calculated using an on-line JavaScript[1] to be 3 min 42 sec. The eclipse took place in the early afternoon.

Figure 2: The diamond ring effect, captured by Christian Clemens.

Our photographic and observing equipment was very diverse and aimed at capturing the prominences, the corona, the mysterious shadow bands as well as the surroundings. The event itself was very hectic for the photographers among us, and a simply breathtaking view for those who were just enjoying the spectacle. We celebrated the event with champagne. The fully successful photo campaigns certainly were another reason to celebrate (Figures 1 and 2). Figure 3 shows a group picture of the expedition crew. The happy faces show what an exciting event it was for all of us, and plans are already being made for trips to upcoming solar eclipses!

Figure 3: The ESO expedition crew. Back row (from left to right): Alexander Stefanescu, Christian Clemens, Arjan Bik, Stefan Uttenthaler, Christiane Leitner, Jürgen Keberle, Bruno Rino, Karl Thurner, Françoise Delplancke, Stefan Ströbele, Yuri Bialetski, Thomas Winterer. Front row: Thomas Eimüller, Jochen Sokar, Burkhard Wolff, Margrethe Wold, Barbara Sokar, Nataliya Prymak, Anna Beletskaya, Claudia Winterer. Sebastian Deiries observed the eclipse from a different site in Kemer, south-west of Antalya.

[1] Eclipse calculator: *http://www.chris.obyrne.com/Eclipses/new-calculator.html*

2007 ESO Instrument Calibration Workshop

23–26 January 2007, ESO Headquarters, Garching, Germany

The ESO La Silla Paranal Observatory (LPO) is currently operating 19 optical, NIR, and MIR instruments (9 VLT, 2 VLTI, 8 La Silla). To monitor and calibrate both the performance of each of these instruments and the quality of the data they deliver, ESO executes dedicated calibration plans. These systematic and regular measurements further aid in the calibration of data from science programmes, at least to specified levels of accuracy.

The first ESO/ST-ECF workshop on calibrating and understanding HST and ESO instruments was held in 1995 to review the calibration strategies of HST and ESO La Silla instruments and to prepare for the start of operation of the VLT.

Now in 2006, after seven years of science operation with the innovative, complex, and still growing instrumentation suite at the VLT, it is timely to review the achievements and limitations of the established instrument calibration plans together with the ESO user community.

Therefore, we invite you to join us at the first ESO Instrument Calibration Workshop to be held from 23–26 January 2007 at the ESO headquarters in Garching, Germany.

The goals of this workshop are to foster the sharing of information, experience and techniques between observers, instrument developers, and instrument operation teams, to review the actual precisions and limitations of the applied instrument calibration plans, and to collect the actual and future requirements by the ESO users.

Workshop topics are the calibration and data reduction of
– Optical Spectro-Imagers
– Optical Multi-object Spectrographs
– NIR and MIR Spectro-Imagers
– High-Resolution Spectrographs
– Integral Field Spectrographs
– Adaptive Optics Instruments
– Polarimetric Instruments
– Wide-field Imagers
– Interferometric Instruments
– Pipelines, Quality Control, Science Archive, AVO, Data-Reduction Systems, Software and Techniques.

The workshop will be focused on ESO instrumentation. A limited period of the workshop will be dedicated to new instruments on the horizon of the LPO, i.e. the VST, VISTA, and the VLT second generation instruments. Future challenges as arising with ELT instrumentation are of interest for the workshop but their presentation will be limited to invited talks. We expect that this workshop will lead to improved calibration plans to the benefit of the entire ESO user community as well as the ESO Science Archive.

ESO Organising Committee: Reinhard Hanuschik, Andreas Kaufer (chair), Florian Kerber (co-chair), Nando Patat, Michele Peron, Martino Romaniello, Michael Sterzik, Christina Stoffer, Lowell Tacconi-Garman.

Workshop webpage:
http://www.eso.org/cal07
Contact: *cal07@eso.org*

Towards the European Extremely Large Telescope

27 November–1 December 2006, Marseille, France

European astronomical research is at a critical juncture with the European Extremely Large Telescope (E-ELT) project currently being defined by the ESO ELT Project Office with a large involvement of the community through, in particular, topical working groups, OPTICON and the ELT Design Study, and with a decision to proceed designing the facility to be taken end 2006/early 2007. This meeting will offer the European astronomical community at large the opportunity to provide precious feedback to the goals and means of that ambitious long-term programme. It will successively address the E-ELT Science case, its basic reference design and instrumentation concepts.

The meeting is organised in three main sessions: Science (1.5 days), Presentation by ESO of the E-ELT status and discussion (1.5 days), Instrumentation (1 day). Contributed talks (approximately 15 minutes each) and posters are invited for the Science and Instrumentation sessions. Invited speakers will introduce the sub-sessions of the Science and Instrumentation sessions. Some important deadlines are as follows:
– Paper and poster submission: 31 July 2006
– Author notification: 30 September 2006
– Final programme: 31 October 2006

For further information, see *http://www.popsud.org/elt2006/index.php*

ESO Fellowship Programme 2006/2007

ESO awards several postdoctoral fellowships each year. The goal of these fellowships is to offer young scientists opportunities and facilities to enhance their research programmes at one of the world's foremost observatories.

With ALMA becoming operational in a few years, ESO offers ALMA Fellowships to complement its regular fellowship programme. Applications by young astronomers with expertise in mm/sub-mm astronomy are encouraged.

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

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

All fellows have ample opportunities for scientific collaboration within ESO, both in Garching and Santiago. For more information about ESO's astronomical research activities please consult *http://www.eso.org*. A list of current ESO staff and fellows and their research interests can be found at *http://www.eso.org/science*. Additionally, the ESO Headquarters in Munich, Germany, hosts the Space Telescope European Coordinating Facility and is situated in the immediate neighbourhood of the Max-Planck-Institutes for Astrophysics and for Extraterrestrial Physics and is only a few kilometres away from the Observatory of the Ludwig-Maximilian University. In Chile, fellows have the opportunity to collaborate with the rapidly expanding Chilean astronomical community in a growing partnership.

We offer an attractive remuneration package including a competitive salary (tax-free), comprehensive social benefits, and provide financial support for relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added. The outline of the terms of service for Fellows provides some more details on employment conditions/benefits (see *http://www.eso.org/gen-fac/adm/pers/fellows.html*).

Candidates will be notified of the results of the selection process between December 2006 and February 2007. Fellowships begin between April and October of the year in which they are awarded. Selected fellows can join ESO only after having completed their doctorate.

The closing date for applications is 15 October 2006.

Please apply by filling the form available at *http://www.eso.org/genfac/adm/pers/forms/fellow06form.pdf* attaching to your application:
- your Curriculum Vitae including a (refereed) publication list
- your proposed research plan (max. two pages)
- a brief outline of your technical/observational experience (max. one page)

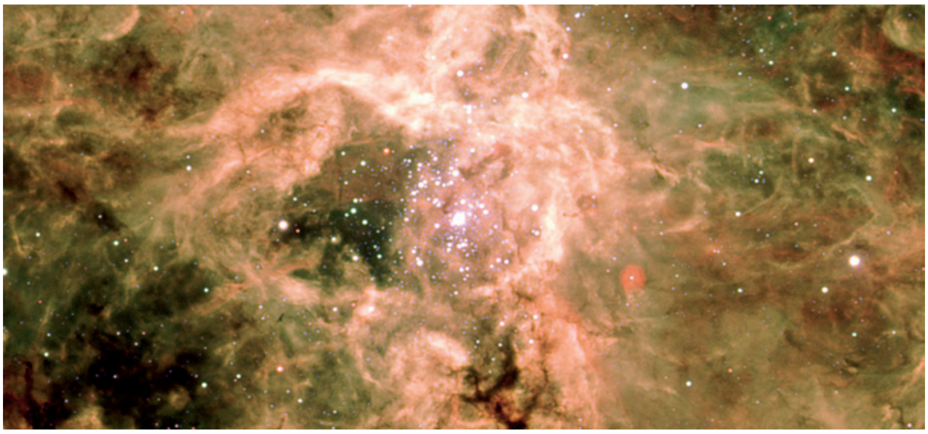
In addition three letters of reference from persons familiar with your scientific work should be sent directly to ESO before the application deadline.

Applications and letters of reference shall be submitted electronically to *vacancy@eso.org* by the deadline.

Please read our list of FAQs regarding fellowship applications (*http://www.eso.org/~mkissler/fellows_FAQ.html*).

Questions about the fellowships not answered by the above FAQ pages can be sent to: Markus Kissler-Patig,
Tel +49 89 320 06-2 44,
e-mail: *mkissler@eso.org*

Questions about the application proces can be sent to: *vacancy@eso.org*



Three-colour image of the Tarantula Nebula in the Large Magellanic Cloud. The image is based on observations made on 10 February 2002 and 22 March 2003 with the FORS1 multi-mode instrument on ESO's Very Large Telescope in three different narrow-band filters (centred on 485 nm, 503 nm, and 657 nm), for a total exposure time only slightly above three minutes. (ESO PR Photo 13a/06)

Personnel Movements

1 April–30 June 2006

Arrivals

Europe

Andreani, Paola (I)	European ARC Manager
Comendador Frutos, Laura (E)	Administrative Assistant
Cristiani, Silvia (I)	Secretary/Administrative Employee
De Breuck, Carlos (B)	APEX Support Astronomer
Duhr, Linda (NL)	Secretary/Assistant
Erm, Toomas (S)	Electronics Engineer
Gobat, Raphael (CH)	Student
Heissenhuber, Florian (D)	Network Specialist
Kiekebusch, Mario (RCH)	Software Engineer
Lorch, Henning (D)	Software Engineer
Lowery, Simon (GB)	Communications Specialist
Malapert, Jean-Christophe (F)	Software Engineer
Naets, Thomas (B)	Internal Auditor
Pedicelli, Silvia (I)	Student
Randall, Suzanna (GB)	Fellow
Saitta, Francesco (I)	Student
Shida, Raquel Yumi (BR)	Student
Toft, Sune (DK)	Fellow

Chile

Andersson Lundgren, Andreas (S)	Operations Astronomer
Gil, Carla (P)	Fellow
Herrera, Leonardo (RCH)	Electronic Engineer
Jimenez, Nestor (RCH)	Telescope Instruments Operator
Le Bouquin, Jean Baptiste (F)	Fellow
Monaco, Lorenzo (I)	Fellow
Morell, Merilio (RCH)	Telescope Instruments Operator
Nuernberger, Dieter (D)	Operations Astronomer
Reveret, Vincent (F)	Operations Astronomer
Sana, Hugues (B)	Fellow
Valdes, Guillermo (RCH)	Software Engineer
Wright, Andrew (GB)	Network/Communications Specialist

Departures

Europe

Pierfederici, Francesco (I)	Software Engineer
Quinn, Peter (AUS)	Head of Data Management and Operations
Quiros-Pacheco, Fernando (MEX)	Student
Vossen, Gisela (D)	Administrative Assistant Purchasing

Chile

Borissova, Jordanka (BG)	Astronomer
Dall, Thomas (DK)	Fellow
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Saldias, Christian (RCH)	System Administrator

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Front Cover Picture: Spiral Galaxy NGC 4565
This image is based on data obtained by FORS1 and FORS2 at the VLT. The data were extracted from the ESO Science Archive and further processed by Henri Boffin (ESO). They are based on exposures made through four optical filters – *B*, *V*, *R* and *I*. More information can be found in ESO PR Photo 24a/05.