# The Messenger

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# ESO Welcomes Finland as Eleventh Member State

Catherine Cesarsky, ESO Director General

In early July, Finland joined ESO as the eleventh member state, following the completion of the formal accession procedure. Before this event, however, Finland and ESO had been in contact for a long time. Under an agreement with Sweden, Finnish astronomers had for quite a while enjoyed access to the SEST at La Silla. Finland had also been a very active participant in ESO's educational activities since they began in 1993. It became clear, that science and technology, as well as education, were priority areas for the Finnish government.

Meanwhile, the optical astronomers in Finland had been engaged in the Nordic Optical Telescope at La Palma and a consensus evolved that full access to ESO would be important for the further development of Finnish astronomy as a whole.

Consequently, in September 1999, we were approached informally by a Finnish delegation, headed by Mirja Arajärvi, special government advisor to the Minister of Education and Science, and exchanged preliminary information. I was then invited to Helsinki and, with Massimo Tarenghi, we presented ESO and its scientific and technological programmes and had a meeting with Finnish authorities, setting up the process towards formal membership. In March 2000, an international evaluation panel, established by the Academy of Finland, recommended Finland to join ESO "anticipating further increase in the world-standing of Astronomy in Finland". In February 2002, we were invited to hold an information seminar on ESO in Helsinki as a prelude towards membership. This we did in May 2002 and this time six of us went to Helsinki: in addition to Massimo, I was accompanied by Ian Corbett, Richard Kurz, Claus Madsen and Richard West. The event attracted a great deal of attention and was very successful.

The Finnish Government decided in March 2002 to ask for formal negotiations which started in June 2002, and were conducted satisfactorily through 2003, making possible a visit to Garching on 9 February 2004 by the Finnish Minister of Education and Science, Ms. Tuula Haatainen, to sign the membership agreement together with myself.

Before that, in early November 2003, ESO participated in the Helsinki Space Exhibition at the Kaapelitehdas Cultural Centre with approx. 24,000 visitors.

ESO warmly welcomes the new member country and its scientific community that is renowned for its expertise in many frontline areas. The related opportunities will contribute to strengthening of pioneering research with the powerful facilities at ESO's observatories, to the benefit of Astronomy and Astrophysics as well as European science in general. ESO also looks forward to collaboration with the Finnish high-tech industry and further interaction in the areas of outreach and education.

ESO's stand at the Helsinki Space Exhibition at the Kaapelitehdas Cultural Centre.


*H. Heyer (ESO)*

# Astronomy in Finland

*An overview is given of astronomical research in Finland. There are three institutes devoted to Astronomy in general, at the Universities of Helsinki, Oulu, and Turku, and a Radio Astronomy Observatory at the Helsinki University of Technology. In addition, Solar system research with space-borne instrumentation is being carried out by the Physics Departments at the Universities of Helsinki and Turku, and by the Finnish Meteorological Institute.*

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Finland has a long tradition in Astronomy. The first University in Finland, the Academy of Turku (Åbo), was founded in 1640, and Astronomy was taught there from the very beginning. The first Finnish scientist to rise to world fame was the astronomer and mathematician Anders Lexell who was appointed Docent of the Academy in 1763. Lexell showed that a comet, discovered in 1770, would, after a passage close to Jupiter in 1779 be slung out of the solar system. This happened as predicted, was a great victory of celestial mechanics and Newton's theory, and made Lexell's name and the comet famous all over Europe.

In 1748 the first dedicated position in Astronomy, Observator, was established, and in 1817-19 an observatory was built, equipped with the best instruments of its time. The observator Henrik Johan Walbeck became known for his study on the size and shape of the Earth. In 1823, the Academy invited, following the advice of Wilhelm Bessel, his pupil Friedrich W. A. Argelander to the Observator position. Argelander's grandfather, a smith and a descendant of the family of Kauhanen-Argillander from Savo county in eastern Finland, had moved to Prussia where his son became a wealthy merchant. Argelander's activity at the new observatory was soon to be interrupted by the great fire of Turku. In his observing logbook of the evening of September 4th, 1827, one can read the following classical statement by a scientist living in his "ivory tower": "*These observations were interrupted by a terrible fire which put into ashes almost the whole city, but thank the Lord, left the observatory intact*."

As a consequence of the fire, the capital of Finland and the University were relocated to Helsinki. There, a new observatory, designed in close collaboration between Argelander and the state architect C. L. Engel, was established in 1834 (Fig. 1). The Observator position was upgraded to Professor's chair in 1828, and Argelander was appointed its first holder. Based on accurate proper motions from his own meridian circle observations in Turku and earlier data from others, Argelander published in 1837 a famous study on the determination of the Solar Apex. However, within the same year he moved to Bonn where he founded a new observatory and rose to become one of the leading figures of 19th century Astronomy.

After Argelander, the Observatory participated under the leadership of Adalbert Krüger, in the big international catalog work AGK1 of the Astronomische Gesellschaft. At the turn of the century the most extensive international enterprise in Astronomy so far, the photographic "*Carte du Ciel*" survey, started with the participation of Helsinki (Anders Donner) and seventeen other leading observatories around the world. The celestial mechanics tradition was continued at the beginning of the 20th century by Karl F. Sundman whose works on the three-body problem brought him international fame. Later on, research in celestial mechanics and relativity theory was carried out by Gustaf Järnefelt and Paul Kustaanheimo. Astrophysical and Radio Astronomy research were introduced at the University of Helsinki by Jaakko Tuominen after World War II.

After a hiatus of a hundred years, astron-

**Figure 1:** Helsinki Observatory, established in 1834, belongs to the group of neoclassical, historical buildings of the centre of the city.

**Figure 2:** The 13.7-metre radio telescope of the Metsähovi Radio Observatory, Helsinki University of Technology, is enclosed within a 20-metre radome that protects the telescope from rain, snow and wind. The surface accuracy of the telescope is 0.1 mm (rms). The observing frequencies available at Metsähovi range from 2 to 150 GHz, the lower end being used for geodetic VLBI and the higher end for millimetre VLBI. The primary observing frequencies, however, are in the mid-range, 22 and 37 GHz.

| Institute | Senior staff | Post-docs | PhD students | Technical/ admin. staff |
|---|---|---|---|---|
| Observatory University of Helsinki | 11 | 5.5 | 10 | 7 |
| Tuorla Observatory University of Turku | 16 | 11 | 13 | 4 |
| Division of Astronomy University of Oulu | 4 | 7 | 6 | – |
| Metsähovi Radio Observatory Helsinki University of Technology | 4.2 | – | 1.7 | 8.4 |
| Dpt of Physical Sciences University of Helsinki and Helsinki Institute of Physics | 2.6 | 1.8 | 8.6 | 3.3 |
| Dpt of Physical Sciences University of Turku | 4 | 3 | 4 | 1 |
| Finnish Meteorological Institute Geophysical Research | 5 | – | 3 | 8 |

**Table 1.** Personnel resources of Astronomy in Finland, year 2003. Included in Astronomy is all space research beyond the Earth's magnetosphere. (unit: person-years of work).

omy returned to Turku in 1924 when Yrjö Väisälä, the professor of physics at the newly founded University of Turku, also started giving lectures in Astronomy. The main interests of Väisälä were classical astronomy, celestial mechanics, and precision optics. These traditions were continued by Liisi Oterma and are still active fields in Tuorla Observatory, a separate research institute of the University of Turku, which Väisälä founded in 1951.

Astronomy teaching at the University of Oulu started in the early 1960's and a professor's chair was established in 1964 with Antero Hämeen-Anttila as its first holder. His research traditions in celestial mechanics and planetary science are being continued by his pupils both in Oulu and Helsinki.

The Metsähovi Radio Observatory, founded in 1975 by Martti Tiuri, then professor of Radio Technology, is a separate research institute of the Helsinki University of Technology (HUT). It operates a 14m diameter radome-enclosed radio telescope (Fig. 2) in Kylmälä, about 35 km west from the HUT campus in Espoo.

## Present resources

The present personnel resources of Astronomy in Finland are summarized in Table 1. Besides the four astronomical institutes mentioned above, solar system research is also being carried out by Space Physics groups at the Universities of Helsinki and Turku as well as at the Finnish Meteorological Institute (FMI). Particle cosmology groups are active at the Universities of Helsinki and Turku. In total the Astronomy community in 2003 counted 47 senior researchers (including 6 professors in Astronomy and 3 in related fields of Physics), 28 Post-docs, 46 PhD students, and 32 technical/administrative staff. The number of PhD degrees awarded was 10. The personnel costs, including salaries and student grants, were 5.9 M€, half of which was covered by soft money from the Research Council for Natural Sciences and Engineering, private foundations and similar sources. The running costs were 1.2 M€, the participation fees in the Nordic Optical Telescope (NOT)(29.7% share) and Swedish-ESO Submillimetre Telescope (SEST) (5% share until 30.6.2003) were 380 K€. Finland's membership fee in ESA's space science programme was ca. 5 M€, more than half of which can be accounted for by Astronomy. Two major space instrumentation projects (Planck 70 GHz receiver; X-ray detector development) received government funding, partly via astronomy institutes, in a total of 3.4 M€ in 2003.

Thanks to Finland's membership of ESA since 1995 there has been active participation in several of its space missions, including e.g. SOHO, Cluster, ISO, INTEGRAL, Mars Express. The hardware participation

**Table 2.** Finnish space science instrumentation and industrial participation in ESA and bilateral Astronomy missions since 1995.

| Program | Main partners | Finnish participation | Launch |
|---|---|---|---|
| SOHO | ESA | ERNE and SWAN instruments | 1995 |
| Huygens | ESA | HASI instrument, lander radar altimeter | 1997 |
| XMM-Newton | ESA | Telescope structure and satellite electronics | 1999 |
| INTEGRAL | ESA | JEM-X instrument | 2002 |
| Mars Express | ESA | ASPERA-3 instrument, participation in Beagle-2 lander, satellite power electronics | 2003 |
| SMART-1 | ESA | XSM and SPEDE instruments | 2003 |
| Rosetta | ESA | In Main S/C: OSIMA, ICA, LAP and MIP instruments, satellite power electronics, satellite structure<br>In Philae lander: PP instrument CDMS mass memory | 2004 |
| Venus Express | ESA | ASPERA-4 instrument; S/C power distribution units | 2005 |
| Herschel | ESA | Main mirror | 2007 |
| Planck | ESA | 70 GHz receiver for LFI | 2007 |
| Mars-96 | RUS | Central electronics units, sensors and S/W for landers | 1996 failed |
| Cassini | USA | Hardware for IBS, CAPS and LEMS instruments | 1997 |
| Stardust | USA | CIDA instrument | 1999 |
| Odin | SE,CAN,F | 119 GHz receiver and antenna measurements | 2001 |
| Radioastron | RUS | 22 GHz VLBI receiver | TBD? |

by institutes and industry in Space Astronomy projects since 1995 is listed in Table 2. One ongoing project with particularly wide Finnish hardware participation is the Rosetta Cornerstone Mission (Fig. 3).

In the following chapters we describe in more detail the current research fields and highlight some results of the four astronomical institutes in Finland.

## Observatory, University of Helsinki

Most of the research work at the Helsinki Observatory is done in three research groups: Interstellar medium and star formation; High energy astrophysics; and Planetary-system research.

*Interstellar medium and star formation*

Physical and chemical conditions in star forming clouds and the star formation process itself are being studied using observations from radio to optical wavelengths, and by applying advanced radiative transfer modelling to their interpretation.

Pre-protostellar and young stellar objects, still deeply embedded in their parental molecular clouds, are being detected and physically characterized by using far-IR mappings with the Infrared Space

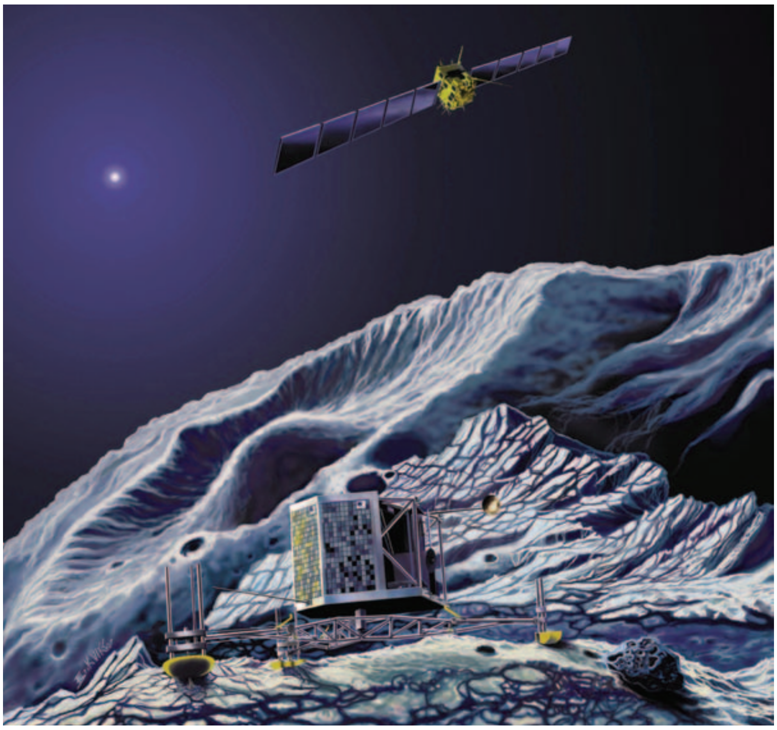


**Figure 3:** Rosetta Mission to comet Churyumov-Gerasimenko. The Finnish Meteorological Institute has provided subsystems to four scientific units aboard the main Rosetta spacecraft and is responsible for the permittivity probe and the solid state mass memory of the lander Philae. Finnish industry has built the mechanical structure of Rosetta and the power distribution system. (Picture ESA)

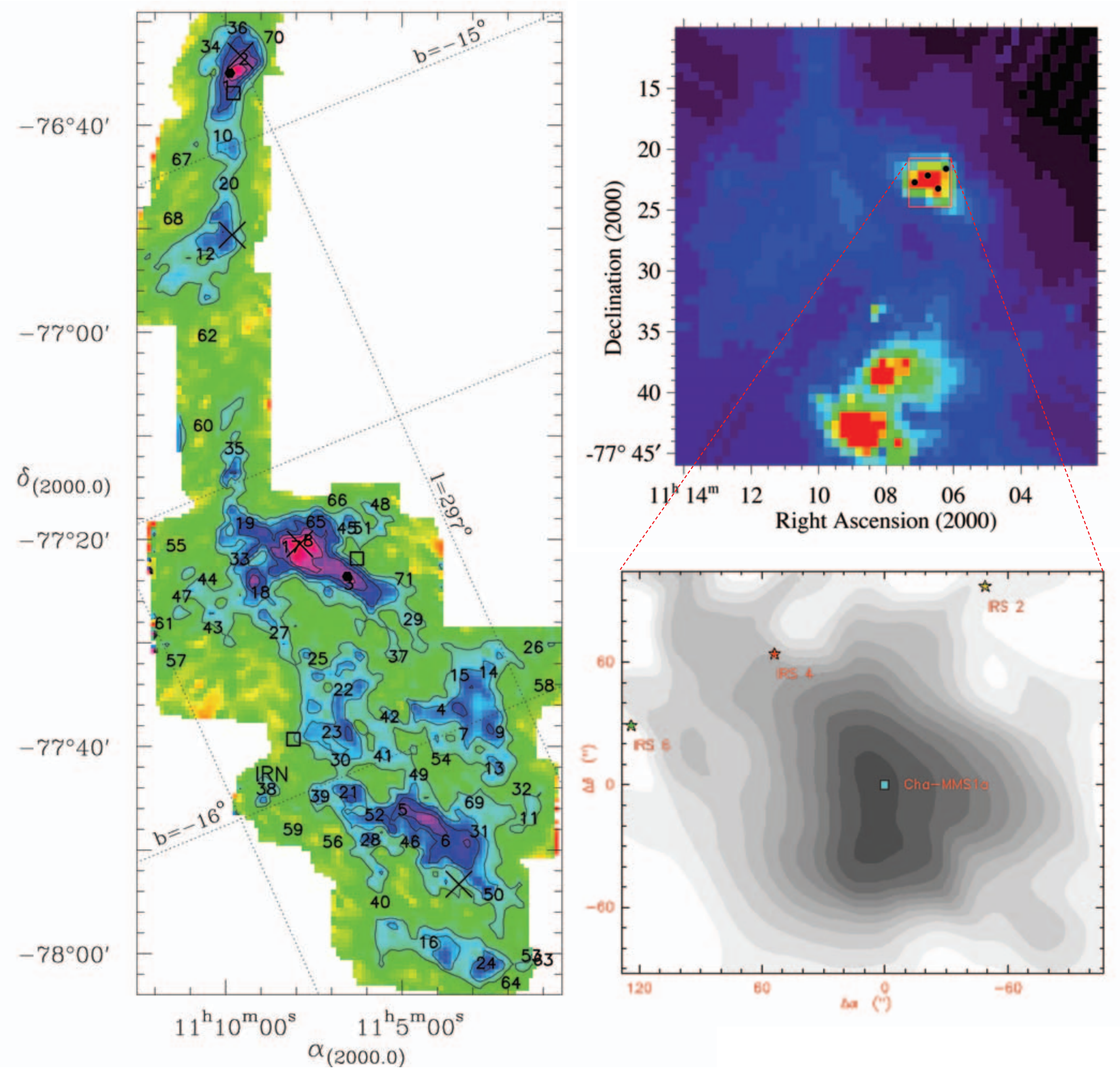



**Figure 4:** **a)** Clumpy filaments in the Chamaeleon I molecular cloud: the integrated $C^{18}O$ (J=1–0) intensity map measured with SEST. The locations of clumps, identified in the $C^{18}O$ spectral data cube with an automatic routine, are indicated with numbers (Haikala, Harju et al. 2004); **b)** ISOPHOT 100 μm mapping of the Ced 110 area in Chamaeleon I with four embedded infrared sources indicated as dots (Lehtinen et al. 2001); **c)** $HC_3N$(J = 10–9) map from SEST of the Ced 110 area with the four embedded sources. The $HC_3N$ emission peaks at the position of the Class 0 protostar candidate Cha-MMS1 (Kontinen et al. 2000). Recent high resolution ATCA $NH_3$(1,1) mapping by Harju et al. reveals velocity structure, suggesting a proto-binary with precessing jets at this position.

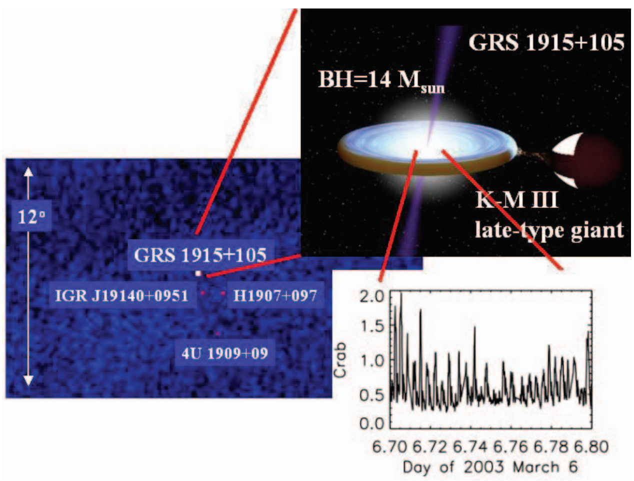



**Figure 5:** The left-hand side shows the INTEGRAL image of the field around the micro-quasar GRS 1915+105 (also visible is the new source discovered during the observation, IGR J19140+0951). The top-right diagram shows an artist's conception of GRS 1915+105, which consists of a 14 solar-mass black hole accreting matter from its companion. In the lower right-hand corner is the X-ray lightcurve showing the newly discovered 5-minute oscillations. (Hannikainen et al. 2003)

Observatory (ISO) and by molecular line spectroscopy with SEST of nearby molecular clouds (Fig. 4). Interaction between protostellar systems and their immediate surrounding ISM have been studied with the aid of high-resolution interferometric radio continuum observations at the Australian Compact Array ATCA.

The structure, energy balance, and dense core formation in interstellar clouds have been studied by applying three-dimensional radiative transfer codes, which have been developed for both the mm-wave molecular spectral lines and optical-infrared continuum radiation from dust.

Using ISO, the group has also studied the properties of the different populations of interstellar dust. The distribution and properties of the so-called *Unidentified Interstellar Bands*, probably due to large aromatic molecules like PAHs, have been studied over the whole inner Galaxy, and in different individual clouds.

The group is studying the *Extragalactic Background Light* (EBL) both at optical and far infrared wavelengths. Early photometric studies at La Silla with the "dark cloud method" have been described by Mattila and Schnur (1990). Spectroscopic observations are now going on at the VLT.

The group has been involved as Co-Investigator in the ISO Photometer instrument consortium. Several VLT observing programs have already been carried out. Two previous group members have recently served at ESO positions, one at SEST and another at the VLT. The group is participating in the relevant Galactic foreground science projects of ESA's Planck Mission.

*High energy astrophysics*

Specific fields of interest are stellar and solar coronas and flares, and the mass accretion processes in compact binary stars containing a white dwarf, a neutron star or a black hole.

Recent highlights of the group include:

- The micro-quasar GRS 1915+105, consisting of a 14 solar-mass black hole accreting matter from a red giant, is being observed with ESA's INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL). One of the more remarkable features of GRS 1915+105 is the episodic ejection of matter at relativistic velocities in bipolar jets. The extreme X-ray variability of GRS 1915+105 has been categorized into 12 distinct classes and INTEGRAL has revealed a hitherto undiscovered class characterized by 5-minute oscillations seen in the X-ray lightcurve (Hannikainen et al. 2003). Using INTEGRAL, a new source, designated IGR J19140+0951, was discovered near GRS 1915+105. Its nature is still unclear, i.e. whether it is a binary system containing a black hole or a neutron star (see also Figure 5).
- The puzzling compact binary Cygnus X-3 is being constantly monitored using INTEGRAL and ground based infrared and radio telescopes. Observed properties of Cyg X-3 indicate that the source is closely similar to known Galactic black holes Cyg X-1 and GRS 1915+105.
- Using NOT, the group has optically monitored several X-ray emitting binaries. Recently, the candidate for the shortest period binary (RXJ0806+15) has been identified, with an orbital period of only 5 minutes (Ramsay, Hakala, Cropper, 2002). The system is spinning up, consistent with the predictions of general relativity. Double degenerate sources like this are expected to be the strongest constant sources of gravitational radiation, and are important targets for future missions like LISA.
- First results with the XSM X-ray solar monitor aboard ESA's SMART-1 mission have indicated that the XSM 1–20 keV high time resolution spectra of the full Sun provide a very powerful method for the analysis of individual flare events. Combined with simultaneous imaging data from other satellites, they will also enable semi-empirical modelling of X-ray coronas of other stars.

The group also conducts development of space science instruments. These include SMART-1/XSM, SMART-1/D-CIXS, and INTEGRAL/JEM-X. Future plans include X-ray detectors for ESA's BepiColombo and XEUS missions, and also new technology sub-mm and infrared detectors. The wide range of technical expertise needed is provided by VTT (Technical Research Centre) and industrial companies (e.g. Metorex, Patria, SSF), which work in close collaboration with the Observatory.

*Planetary-system research*

The group carries out both physical and dynamical studies of mainly solar-system objects. One central area of interest are the asteroids, both their physical properties such as surface structure, form and rotation, as well as their orbit determination. Other atmosphere-less bodies, like the Moon and the transneptunian objects (TNOs) are also included.

Theoretical research is focused on scattering and absorption of light by single small particles and by particulate media. Novel numerical techniques have been developed, for example, for computation of light scattering by non-spherical particles, for modelling the stochastic Gaussian shapes and cluster geometries of small particles, as well as for coherent backscattering of light by complex media of small particles. Laboratory experiments are carried out using a scatterometer device, and the group has significant responsibilities in the future ICAPS (Interactions in Cosmic and Atmospheric Particle Systems) experiment aboard the International Space Station. Significant industrial applications have been found for the scattering techniques developed.

The research on inverse problems divides into the development of mathematical methods and the interpretation of astronomical observations. The group has pioneered in the fields of statistical orbit computation for asteroids and asteroid lightcurve inversion for their spin vectors and shapes. The group is currently developing statistical techniques for exoplanet orbit computation from radial velocity data as well as for the asteroid identification problem. The dynamical stability of extra-solar planetary systems is studied numerically using a supercomputing environment.

At NOT, in an effort to accrue in-depth knowledge of near-Earth objects, the group leads an astrometric and photometric observing program. At ESO, the group has started an astrometric program at the 2.2m/WFI and is participating in polarimetric observing programs on TNOs at the VLT. It also makes use of space-borne instruments in studies of the Moon (SMART-1) and Mars (Mars Express) and is involved in the preparations of the ESA Cornerstone missions Gaia and BepiColombo.

## Tuorla Observatory, University of Turku

Four themes dominate the research: the dynamics of the Universe, from the three-body problem to cosmology; active galaxies, with particular emphasis on high energies and multi-frequency connections; stars, especially interacting binaries; and finally, ground- and space-based research of our Sun. Väisälä's tradition of precision optical engineering is carried on by Opteon Company at Tuorla. The optical workshop of Tuorla Observatory remains the only place in the world with the capability of polishing large silicon carbide mirrors. Work on the Herschel Space Observatory 3.5-metre mirror has just begun.

*The dynamical universe*

Cosmology is currently in a golden age of discovery. Tuorla researchers are addressing such questions as the size and shape of the Universe, its age, its matter, dark matter and dark energy content, its past and present expansion rate and the growth of structures within it. Careful mapping of the (cosmologically speaking) local environment, up to a few hundred megaparsecs, can provide strong constraints on cosmology by testing structure formation via hierarchical collapse in the cold dark matter scenario.

Both dark matter and dark energy can manifest themselves in various ways on scales of a few Mpc. For example, Tuorla researchers are studying the possibility that the enigmatic smoothness of the local Hubble flow, first recognized by Allan

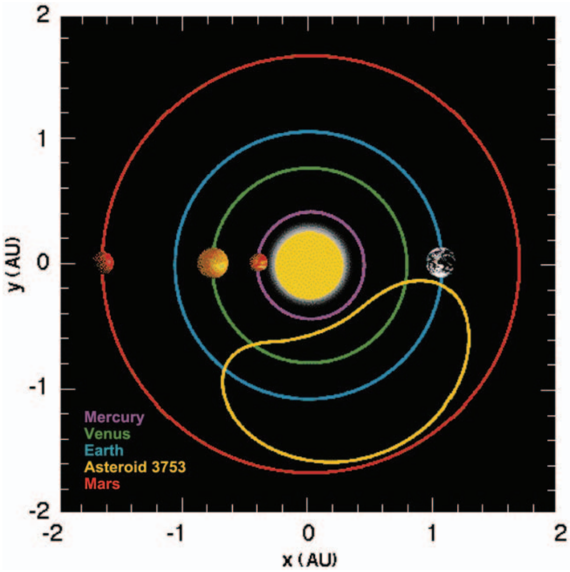
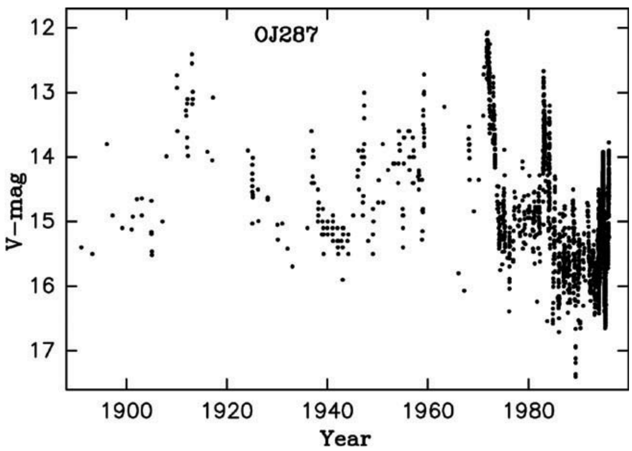



**Figure 6:** Earth's second "Moon": Asteroid (3753) Cruithne has been found by University of York and Tuorla researchers to be in a unique heliocentric orbit which appears geocentric when viewed from the Earth (Wiegert, Innanen and Mikkola 1997, picture: York University)



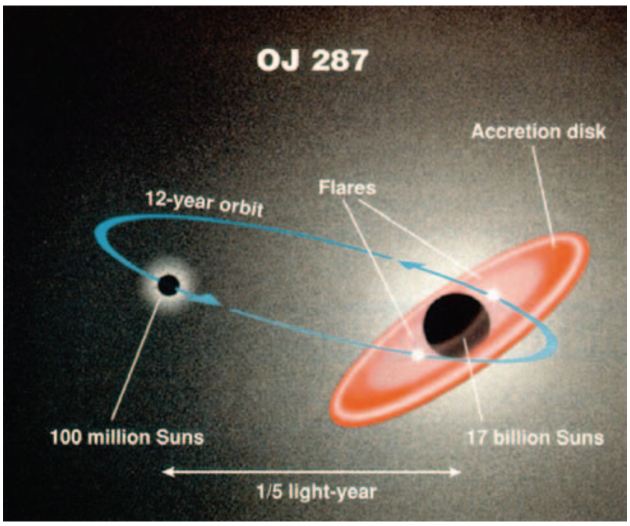




**Figure 7: a)** The historical light curve of the blazar OJ 287 for 1891-1998. Credit : A. Sillanpää/Takalo and the OJ Collaboration; **b)** Model for the binary black hole system in OJ 287, the first AGN with periodic behavior, discovered by Tuorla researchers. (Lehto and Valtonen 1996)

Sandage over thirty years ago, results from the dominance of a perfectly smooth vacuum density. On still smaller scales, studies of the dynamics of our Galaxy have already eliminated black holes and white dwarfs as significant contributions to the putative dark matter halo or galactic shroud.

Tuorla researchers are measuring accurate distances to our "local sheet" of galaxies using the tip of the red giant branch, surface brightness fluctuations, and planetary nebulae. Beyond these distances, Tuorla researchers are building the *KLUN+* galaxy sample in collaboration with the Paris and Lyon groups. On still larger scales, the distribution of clusters and super-clusters is studied with *N*-body simulations in a collaboration with Tartu Observatory. The results are compared with the Las Campanas and Sloan surveys. Light cone simulations will be developed for detailed comparisons with future observational data. This work is also a part of Tuorla's involvement in the Planck satellite project.

On the most fundamental, mathematical level, Tuorla researchers have for a long time been studying the three- to *N*-body problem and its applications from spacecraft orbits to the dynamics of our Solar System, extra-solar planets, multiple stars and galaxies. One notable achievement has been the identification, by York University and Tuorla researchers, of the asteroid (3753) Cruithne as a second "moon" of the Earth (Fig. 6).

*Active galaxies*

Radio and optical monitoring programs of blazar-type AGN were already started in 1980, and continue to provide a unique insight into the long-term behavior of the shocked relativistic jets present in these sources. During the last decade, the focus has shifted to the highest energies, to gamma-rays detected first by the Compton and now by the INTEGRAL satellite, and to TeV radiation observed with ground-based Cerenkov detectors. Tuorla has joined the international MAGIC TeV telescope collaboration, providing multi-frequency support in addition to the normal operations. The other important AGN collaboration is the EU-funded ENIGMA, which organizes large multi-frequency campaigns. The single dish studies are supported with extensive VLBA campaigns.

Most of the work has focused on testing and developing the shocked jet paradigm. Earlier, Tuorla astronomers have found that all radio variations can be explained by growing and decaying shocks in the AGN jets; now the connections to IR and optical variations, as well as to the inverse Compton flux are being investigated using INTEGRAL and MAGIC data. Evidence has been found that the gamma-rays come from the shocks, much farther away from the core than is usually assumed.

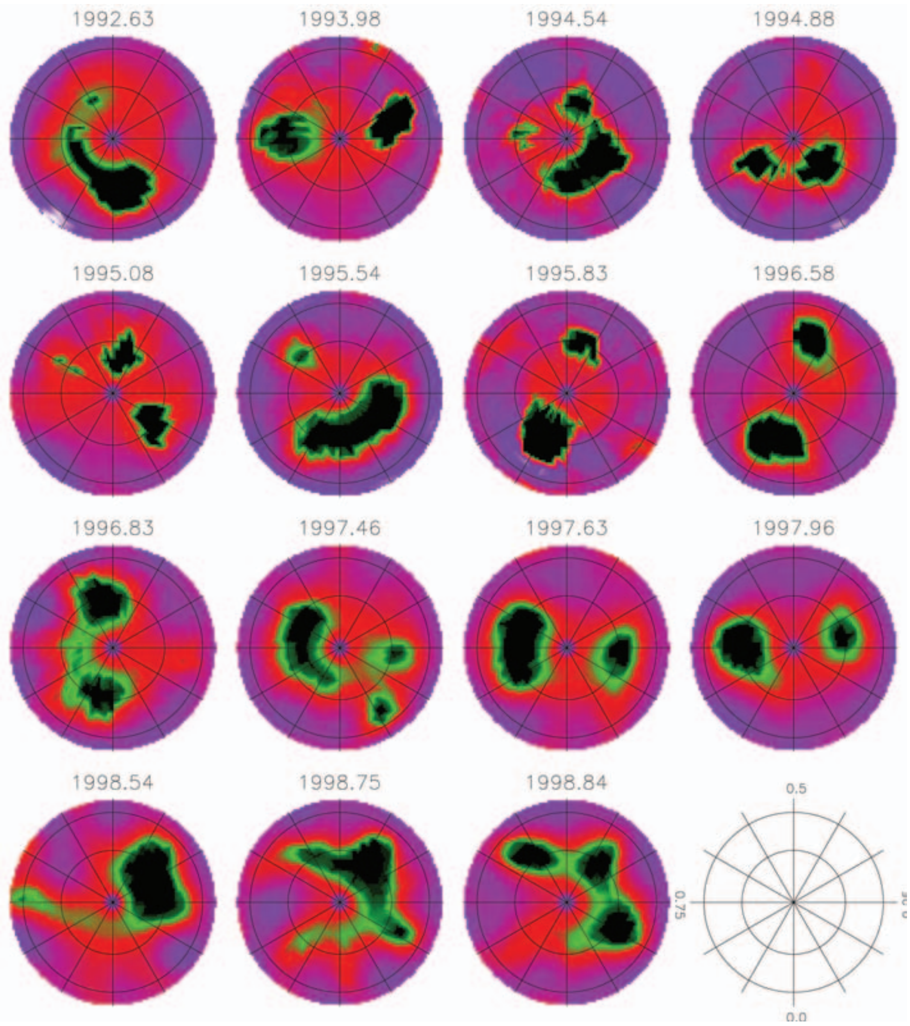



**Figure 8:** Pole-on views of the primary star of the RS CVn binary II Peg for different years. The spots preferably appear near two active longitudes which migrate over the stellar surface. While the total spotted area does not vary significantly, the relative activity level of the two regions changes abruptly in 1994 and 1998, indicating "flip-flop" events.

High resolution imaging with ESO telescopes, especially in the near-IR, is being used to study the cosmological evolution of AGN, their host galaxies and environments, the relationship between the different classes of AGN, as well as the star formation history of the hosts. Recent highlights include the imaging of high redshift host galaxies, the first determination of black hole masses of BL Lac objects, and near-IR spectroscopy of the nuclear regions of Seyfert galaxies. Preparations are also underway for the predicted 2006 outburst of the only known periodic AGN, OJ 287, which was identified as a binary black hole by Tuorla researchers in 1988 (Fig. 7).

*Stars*

The stellar research at Tuorla observatory focuses on stars with unusual properties: interacting binaries, magnetic cataclysmic variables (mCvs), intermediate polars, X-ray binaries, white dwarfs, and K dwarfs. In addition to seeking answers to many open questions about the evolution of these stars, these studies also reveal how plasma behaves in extreme circumstances, such as environments with very strong magnetic fields. The dwarf stars are essentially stellar fossils, which can be used to study the production of helium and heavy metals in our Galaxy.

The group has a unique blend of instrumental expertise, international collaboration and use of the NOT, multi-wavelength monitoring and space observations (ROSAT, XMM). Recent developments include spectropolarimetric facilities, and an extensive observational program on circular spectropolarimetry of mCVs. An ongoing monitoring campaign of 28 X-ray binaries with the Nançay radio telescope is the largest ever conducted. In the future, the VLT, as well as the 3.5m class ESO telescopes will enable phase-resolved spectroscopy and spectropolarimetry, including detailed studies of weaker features, such as polarization in intermediate polars. Ultra-high time resolution can also be achieved to map the details of accretion discs in eclipsing binaries.

*The Sun*

The Tuorla solar group specializes in multi-wavelength analyses of eruptive solar events. Scientific interests range from particle acceleration to shock waves and plasma emission, but solar atmospheric models have also been tested. The long-term use of solar radio data from the Metsähovi radio telescope has given the Tuorla group special expertise in data acquisition and analysis. In particular, Metsähovi observations have been used to study the activity in the polar regions of the Sun. Multi-wavelength analysis of halo-type coronal mass ejections is being carried out in collaboration with the Paris Observatory and the Space Research Laboratory of the University of Turku, the SOHO ERNE PI institute.

## Astronomy Division, University of Oulu

There are four main research fields in Oulu: stellar and Solar astrophysics; high energy astrophysics; dynamics of planetary rings and disc galaxies; and planetology of terrestrial planets.

As a highlight of the research carried out in the *Astrophysics Group*, the project concentrating on solar-stellar activity is presented. It combines powerful observational techniques and computational tools. An extensive time series has been collected using the SOFIN spectrograph at the Nordic Optical Telescope. It contains more than ten years of high-resolution spectroscopic observations of active late-type stars of FK Com- and RS CVn-types, and rapidly rotating solar type stars. The major finding of these investigations has been the persistent two-spot structure in visible hemispheres, two large high latitude cool areas, spots, situated in opposite longitudes (see Fig. 8 and Tuominen, Berdyugina & Korpi 2002). Moreover, their strength varies in cyclic manner with a few years' period, the so-called *flip-flop* effect. In addition to these spectroscopic investigations which use Doppler imaging inversion methods developed by the group members, the "flip-flop" behavior is also confirmed by long-term photometric time series.

The recent dynamo models developed in the group for rapidly rotating stars predict stable non-axisymmetric magnetic fields in the form of active longitudes. The active longitudes in the same stellar hemisphere are predicted to be of opposite polarities. There are, however, no definite measurements of the magnetic field strength yet and only a preliminary proof of the polarity of the two active longitudes for such stars. Also, there is no information on polarity changes during stellar cycles. The development of the dynamo models is accompanied by detailed investigations on stellar magneto-convection using high-resolution, three-dimensional turbulence models. Such models have yielded important revisions of the turbulent transport quantities needed in the dynamo theory, especially in the rapid rotation limit relevant for the understanding of the active rapid rotators.

The main research interests of the *High Energy Astrophysics Group* are the processes in the vicinities of black holes, both stellar-mass holes found in X-ray binaries and the super-massive ones found in the nuclei of Seyfert galaxies, as well as the accreting neutron stars, and the gamma-ray bursts. X-ray and gamma-ray observations are being carried out using the Rossi X-ray Timing Explorer (RXTE), INTEGRAL, and other satellites, and theoretical models are being developed.

Large efforts are devoted to the analysis of the broad-band X-and gamma-ray spectra of black holes in our Galaxy, such as Cygnus X-1 and the micro-quasar GRS 1915+105. A hybrid thermal/non-thermal Comptonization spectral model proposed by the group members was found to describe the observed properties exceptionally well. In the field of accretion-powered X-ray sources, the group's activity is now shifting to the recently discovered accreting X-ray millisecond pulsars which constitute a link between low-mass X-ray binaries and radio millisecond pulsars. Detailed analysis of the energy-dependent pulse profiles of SAX J1808.4-3658 have provided very strong constraints on the equation of state of the extremely dense matter of neutron stars (Poutanen & Gierlinski 2003).

Spectra of the prompt soft gamma-ray emission of gamma-ray bursts are still not explained and seem mysterious despite strong theoretical efforts devoted to this problem. The Oulu group in collaboration with the Lebedev Physical Institute in Moscow is now actively involved in a project to develop the necessary tools to model the emission mechanisms. Synchrotron self-Compton emission of nearly mono-energetic electron-positron pairs seems to explain most of the observed properties.

The *Dynamics Group* studies planetary rings and disc galaxies, combining analytical and *N*-body modelling with observations. An important result has been the prediction of local trailing wake structures in Saturn's rings (Salo 1992), forming spontaneously due to mutual gravity between colliding ring particles. The existence of such non-resolved wakes with radial scale of ~100 metres is indirectly supported by photometric modelling of global azimuthal brightness asymmetries seen in Voyager, HST and Arecibo radar data. An intriguing new prospect is the direct detection of wakes in high resolution Cassini data: like density waves driven by external satellite resonances, intrinsic wakes provide constraints for ring velocity dispersion and viscosity.

The group's galactic research concentrates on numerical modelling of prototypical interacting and barred galaxies, and on the role of bars on the nuclear activity and secular evolution of disc galaxies. In particular, methods for estimating the bar gravitational field from near-IR images are developed and applied to recent galaxy surveys (2MASS, Ohio State University Bright Galaxy Survey). A new observational survey is also in progress, addressing the bar strength distribution in S0 galaxies as a clue of their origin. Planetary ring studies are performed in collaboration with U. Potsdam, Wellesley C. and U. Cornell, and galaxy studies mainly with U. Alabama.

The *Planetology Group* of the University of Oulu studies the surface structures of terrestrial planets. The strategy of the group is to combine data from planetary missions and tools from space science, geosciences and remote sensing with the group's own expertise in planetology. The goal is to gain a detailed view of the evolutionary processes which are forming the surface structures of terrestrial planets.

The group is currently involved in a long-term study of Mars. Based on its previous research experience the group is participating as a Co-Investigator in the HRSC-camera team of ESA's Mars Express mission. The HRSC data analyses have already begun and will enable, as the data accumulates, very detailed investigations of Martian surface structures.

The group also contributes to the new mission initiatives and participates in other European space activities within ESA's planetary science program, such as the Venus Express mission in 2005.

## Metsähovi Radio Observatory, Helsinki University of Technology

The main research topics are the multi-frequency behavior of active galactic nuclei (AGNs) and the solar microwave radiation. The Metsähovi group is also active in developing radio astronomical instrumentation and measurement methods. Both solar and AGN research is being done in very close collaboration with the Tuorla Observatory (see also the section on Tuorla Observatory for information on the Metsähovi Solar research).

*Active galactic nuclei*

The main research project at Metsähovi is the study of active galactic nuclei. Data across the whole electromagnetic spectrum are being used. However, the backbone of the research has always been the long-term monitoring of the AGN radio variability that has been going on in Metsähovi since the late 1970's. The group has also been very active in using the SEST for studying AGNs between 1988 and 2003.

The details of the flux density evolution at various radio frequencies help in modelling the radio shock formation and development, and determination of the physical parameters related to the shock-in-jet structure. Studying the relationships between outbursts observed in the radio domain and other frequency domains helps to constrain the models for the high-energy emission in AGNs.

*Quick Detection System for the Planck satellite.* The knowledge of the nature, number and behavior of foreground sources is essential for the success of the Planck satellite's primary mission, the measurement of the CMB. The group is involved in the study of the extragalactic foreground sources and is also developing a special software that will be used for detecting strong, possibly flaring, radio sources in the time ordered data stream of the Planck satellite within 1–2 weeks of the time of the observation. The supporting theoretical studies in connection to the software include radio variability modelling of various source types, needed for defining the triggering criteria for follow-up observations.

*Inverted-spectrum radio sources.* Gigahertzpeaked spectrum (GPS) radio sources are extragalactic radio sources characterized by convex spectra peaking in the GHz range and steep at high radio frequencies. Only very few sources with extremely high (> 10 GHz) peak frequencies have been reported earlier. Recently, the group has identified several new extreme-peaking sources. Identifying high-peaked sources is related to the work on the Planck satellite's extragalactic foreground.

Work is currently going on with new data sets from the Metsähovi and RATAN-600 telescopes to search for new high-peaked sources, to study the variability behavior of *bona fide* GPS sources, to work on the models for inverted-spectrum sources and to study the contribution of the high frequency tail of the radio spectrum to the extragalactic foreground. Also, VLBI observations have been made of the extreme-peaking sources newly identified by the group.

*Radio properties of BL Lacertae Objects.* The two main BL Lacertae Object (BLO) subclasses, radio-selected BLOs and X-ray-selected BLOs are a product of different discovery techniques. It is not currently known whether these two classes of objects are two extremes of one class, or whether they have intrinsically different properties. A complete set of BLOs has been observed in Metsähovi, and additional observations using other facilities have also been made.

The study of the BLOs is also related to the Planck foreground science: if some of the X-ray selected BLOs turn out to be brighter than previously assumed, or if the number of Intermediate BLOs turns out to be large, then this information is also essential for the Planck mission.

*Correlations between the radio and high-energy behavior in AGNs.* The Metsähovi radio monitoring data are also used for studying the correlation between radio and high-energy domains: activity states and flares, differences in various source populations, etc. Multifrequency radio-to-submm data and VLBI images are used to study the radio-to-gamma connections. According to the studies of the group, the strong gamma-ray emission in AGNs clearly occurs after the formation of the radio shock in the relativistic jet, i.e. the site of the gamma-ray emission must be at a distance well outside the accretion disc or even the broad line region usually considered to be responsible for the gamma-ray emission.

*Instrumentation*

As part of its VLBI instrumentation project the group has recently designed and manufactured next generation VLBI recording systems that enable world record data acquisition rates: on March 12, 2003, the first European 1 Gbit/s VLBI experiment and on June 17, 2003, the first international 2 Gbit/s experiment.

Along with developing high-speed data recording systems for VLBI the Metsähovi team is also developing e-VLBI technologies. The team has been evaluating high-speed Internet protocols for e-VLBI and in the preliminary data transfer tests, the team has achieved an order of magnitude improvement to the normal TCP/IP transfer speed.

The Metsähovi group is also involved in the Alpha Magnetic Spectrometer (AMS) project. This instrument will be placed aboard the International Space Station. The project is a very large international collaboration project, in which Metsähovi's responsibility is the hardware and software for the ground-based high-rate data link, receiving science data from the instrument.

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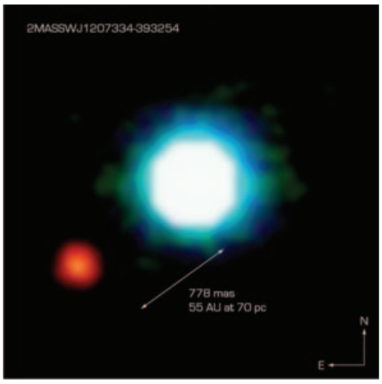
# Is this Speck of Light an Exoplanet?




**Is this newly discovered feeble point of light the long-sought bona-fide image of an exoplanet?**

A research paper [1] by an international team of astronomers [2] provides sound arguments in favour, but the definitive answer is now awaiting further observations.

On several occasions during the past years, astronomical images revealed faint objects, seen near much brighter stars. Some of these have been thought to be those of orbiting exoplanets, but after further study, none of them could stand up to the real test. Some turned out to be faint stellar companions, others were entirely unrelated background stars. This one may well be different.

In April of this year, the team of European and American astronomers detected a faint and very red point of light very near (at 0.8 arcsec angular distance) a brown-dwarf object, designated 2MASSWJ1207334-393254. Also known as "2M1207", it is a member of the TW Hydrae stellar association located at a distance of about 230 light-years. The discovery was made with the adaptive-optics supported NACO facility at the 8.2-m VLT Yepun telescope at the ESO Paranal Observatory (Chile).

The feeble object is more than 100 times fainter than 2M1207 and its near-infrared spectrum was obtained with great efforts in June 2004 by NACO, at the technical limit of the powerful facility. The spectrum shows the signatures of water molecules and confirms that the object must be comparatively small and light.

None of the available observations contradict that it may be an exoplanet in orbit around 2M1207. Taking into account the infrared colours and the spectral data, evolutionary model calculations point to a 5 jupiter-mass planet in orbit around 2M1207. Still, they do not yet allow a clear-cut decision about the real nature of this intriguing object. Thus, the astronomers refer to it as a "Giant Planet Candidate Companion (GPCC)".

Observations will now be made to ascertain whether the motion in the sky of GPCC is compatible with that of a planet orbiting 2M1207. This should become evident within 1-2 years at the most.

**ESO Press Release 23/04**

[1] The research paper (A Giant Planet Candidate near a Young Brown Dwarf by G. Chauvin et al.) will appear in Astronomy and Astrophysics on September 23, 2004 (Vol. 425, Issue 2, page L29). A preprint is available as astro-ph/0409323.

[2] The team consists of Gael Chauvin and Christophe Dumas (ESO-Chile), Anne-Marie Lagrange and Jean-Luc Beuzit (LAOG, Grenoble, France), Benjamin Zuckerman and Inseok Song (UCLA, Los Angeles, USA), David Mouillet (LAOMP, Tarbes, France) and Patrick Lowrance (IPAC, Pasadena, USA).

# Successful Commissioning of VISIR: the mid-infrared VLT Instrument

VISIR is the ESO-VLT instrument dedicated to observations through the two mid-infrared atmospheric windows (the so-called N and Q bands). VISIR was installed in April 2004 at the Cassegrain focus of Melipal, the third of the four 8.2 meter VLT unit telescopes; first light was obtained on May 1st. This cryogenic instrument combines imaging capabilities at the diffraction limit of the telescope (0.3 arcsec at 10 microns) over a field up to 51 arcsec, and long-slit (32 arcsec) grating spectroscopy capabilities with various spectral resolutions up to 25,000 at 10 microns and 12,500 at 20 microns. The instrument will be offered to the community for ESO period 75 (proposal due date: October 1st 2004 ).

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[4]European Southern Observatory

VISIR stands for VLT Imager and Spectrometer for the mid-InfraRed (mid-IR). This cryogenic instrument, optimised for diffraction-limited performance in both mid-IR atmospheric windows, the *N* and *Q* bands (Fig. 1), combines imaging capabilities with various magnifications, with slit grating spectroscopy with various spectral resolutions, up to R = 25,000 at 10 µm and 12,500 at 20 µm.

The contract to design and build VISIR was signed in November 1996 between ESO and a French-Dutch consortium of institutes led by Service d'Astrophysique of CEA/ DSM/DAPNIA; the Dutch partner is ASTRON, Dwingeloo. One year after the signature of the contract, VISIR passed the *Preliminary Design Review*, which concluded that VISIR was feasible (Rio et al. 1998). The project passed the *Final Design Review* in 1999 (Lagage et al. 2000). The instrument was then manufactured, integrated and suffered from unexpected events, such as fire and then flooding in the Saclay building housing the VISIR laboratory! After extensive tests in the laboratory (Lagage et al. 2003), VISIR was shipped to Paranal in March 2004; after that everything went very smoothly. The instrument was transported fully integrated, so that in April it could be mounted almost right away onto Melipal, the third of the four 8.2-m VLT Unit Telescopes (Fig. 2). First images were obtained on May 1st, a few hours after feeding VISIR with sky light. The second commissioning (from June 30 to July 7) was jeopardized by bad weather conditions (4 nights fully lost and 3 nights rather poor). During the two commissioning runs, several observing modes were sufficiently tested to consider to offer them to the community at the next call for observing proposals (deadline October 1, 2004). To finish commissioning, a third commissioning run took place from August 27 to September 5. All the VISIR modes have now been successfully tested. The results from this last run will be reported later.

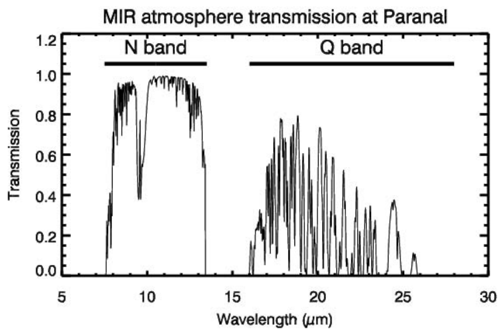


**Figure 1:** Mid-IR transmission of the atmosphere at Paranal, computed using the HITRAN model. The *N* window (8-13 microns) is a good window, especially in the 11 micron range; the only bad part is around 9.5 microns (ozone band). The *Q* window (17-25 microns) is a poorer window and the transmission depends crucially on the water vapour content of the atmosphere. For the transmission given in the figure, good atmospheric conditions of 1.5 mm of precipitable water vapour were assumed.

## Scientific capabilities and observing modes

The mid-IR region is the domain of excellence to study both warm dust and gas (molecular or atomic) in various objects in the Universe, from nearby objects such as comets to quasars. Warm dust at an equilibrium temperature ranging between 80 and 400 K is best detected in the mid-IR through its thermal emission; grains small enough to be transiently heated to high temperature, the so-called VSGs (Very Small Grains), can emit in the mid-IR, even if their "mean" temperature is very low. Broad solid-state dust features (for amorphous or crystalline silicate dust around 10 and 20 microns) are observable from the ground, as well as the so-called PolyAromatic Hydrocarbonates (PAHs) bands at 12.7, 11.3 and 8.6 microns. Concerning gas transitions, two of the three lowest energy (i.e. pure rotational) quadrupole transitions of molecular hydrogen in the vibrational ground state ($H_2$(0,0)S(2) at 12.28 microns and $H_2$(0,0)S(1) at 17.03 microns) are observable from the ground, at least using high spectral resolution (>10,000) to find them between atmospheric lines. A variety of atomic lines are accessible from ground-based observations in the mid-IR, such as the forbidden lines of [Ne II] at 12.8 microns, the [S IV] line at 10.5 microns, and [Ar III] at 8.99 microns.

The main advantage when observing from the ground in the mid-IR is the high angular resolution achievable with large telescopes. Indeed, in this wavelength range, the angular resolution is mainly limited by the diffraction of the telescope. Until the launch of the James Webb Space Telescope (JWST), scheduled for 2011, the angular resolution achievable using ground-based facilities will be 10 times higher than from space facilities. With VISIR the diffraction Airy pattern of the Spitzer Space Telescope (formerly known as SIRTF, the Space Infrared Telescope Facility) can be resolved into 100 elements (full width half maximum of 2.6 arcsec at 10 μm for a 80 cm telescope, to be compared to 0.26 arcsec for a 8-meter class telescope). Thus, the top priority in the VISIR specifications has been the image quality.

Of course, the huge atmospheric and telescope background dramatically limits the sensitivity achievable with ground-based mid-IR instruments. Thus the "niche" for ground-based mid-IR astronomy is the observation of relatively bright sources (a few mJy) for which high angular resolution is needed. Examples of such programs are the study of circumstellar environments, the study of multiplicity in early stages of star formation, …

To conduct the various observing programs with VISIR, several observing modes were implemented :

- imaging with a choice of 3 magnifica-

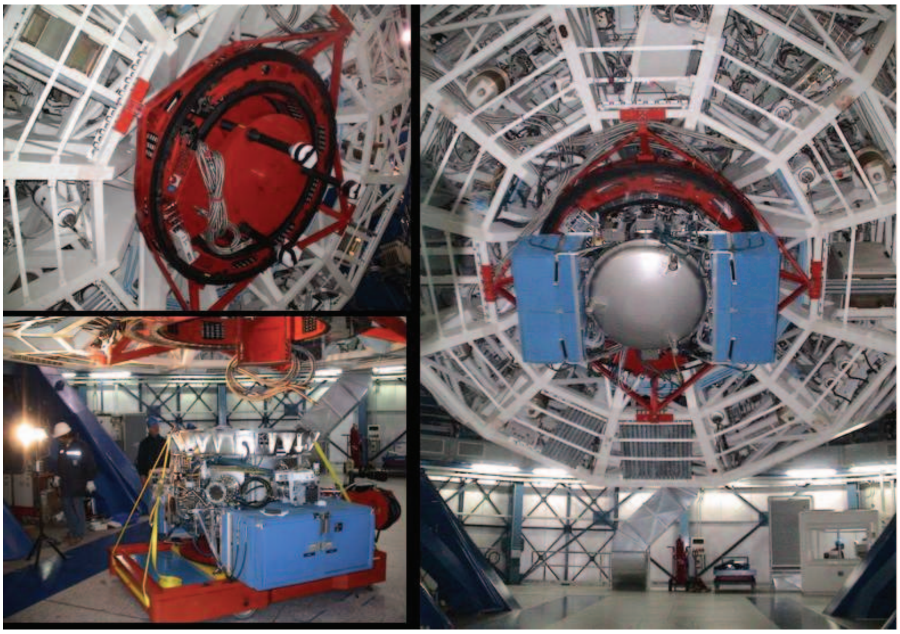

**Figure 2:** Top left: VISIR cable wrap mounted at the Cassegrain focus of MELIPAL. The cable wrap carries the electrical cables and closed-cycle cooler hoses to the instrument and rotates with it as the telescope tracks objects on the sky. At that time, a mass dummy was mounted on the cable wrap instead of VISIR. Bottom left: the mass dummy has been removed and VISIR, on its carriage, is going to be mounted onto the cable wrap. We can recognize the vacuum vessel (cylindrical shape with a diameter of 1.2 m and a height of 0.7 m) and the blue cabinets containing electronics for controlling and monitoring the instrument functions. Just above the middle of the blue boxes, we can see one of the three cryocoolers, used to cool the instrument to about 20K and the detector arrays to 7K. Right: VISIR fully mounted behind the primary mirror of MELIPAL. The total weight of VISIR is 2.3 tons.

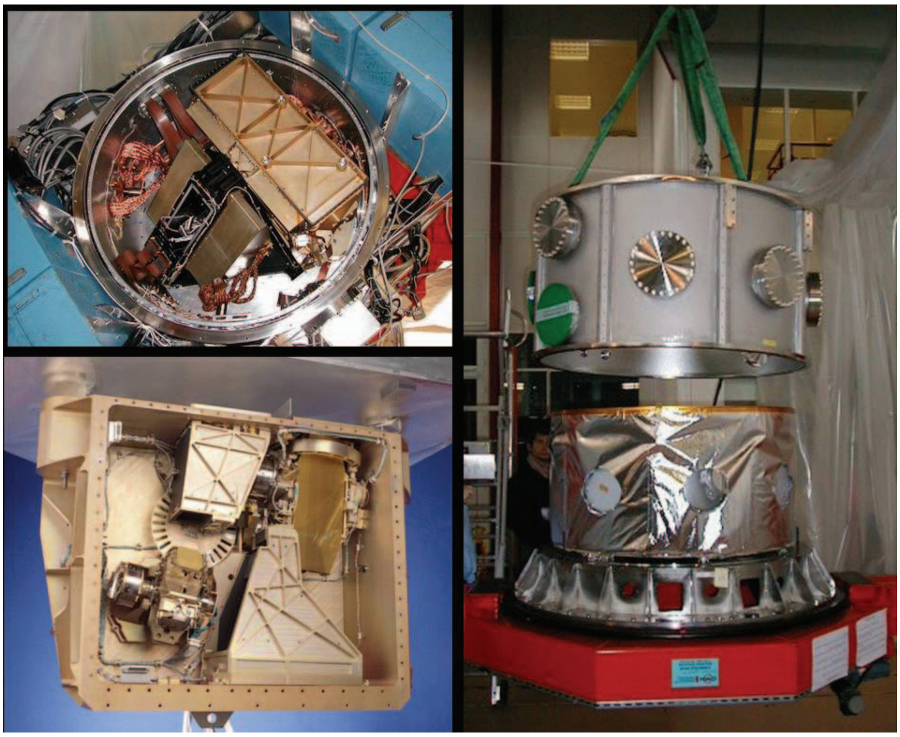

**Figure 3:** Top left: inside the cryostat; after removing the dome at the back of the cryostat, as shown in Figure 2 (right), one can see two sub-units: the imager (bottom left) and the spectrometer (top right). Bottom left: inside the spectrometer, partly integrated; one can see the slit wheel, the high-resolution duo-echelle grating (top right) and the grating carrousel carrying the 4 gratings including one scanner each for the low- and medium- spectral resolution arm (bottom left). Right: VISIR cryostat being assembled; the cryostat consists of a vacuum vessel and radiation screens; the vessel is composed of a flange to interface VISIR with the telescope adapter rotator (bottom of the image), a cylinder and a dome. The vessel is equipped with a radiation screen with superinsulation to lower the temperature of the surface radiating towards the cold optical bench.

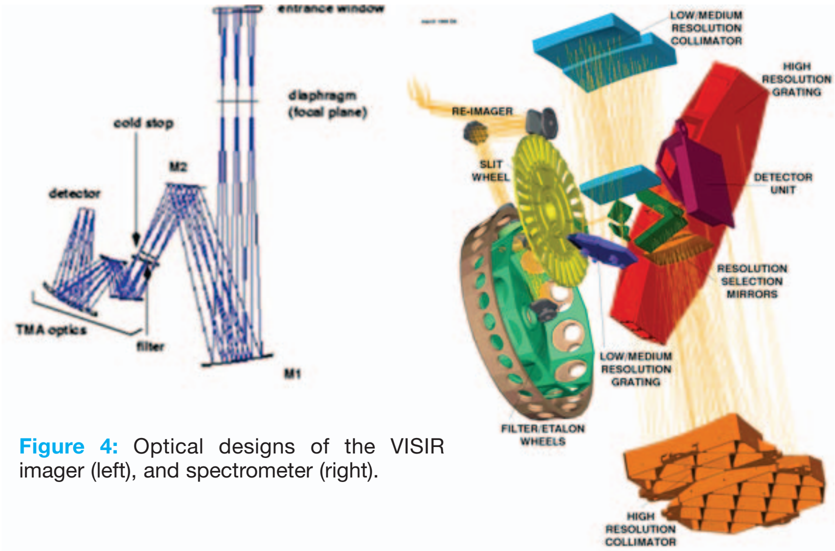


**Figure 4:** Optical designs of the VISIR imager (left), and spectrometer (right).

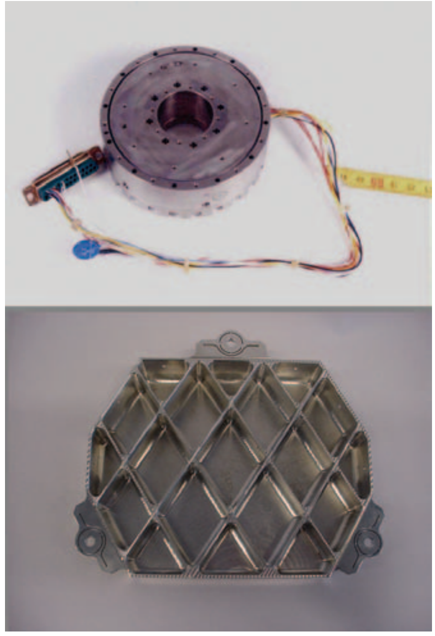

**Figure 5:** Top: Novel compact, precise and cryogenic motor/clutch unit actuator of VISIR. Such compactness was a key requirement to achieve a very compact mechanical design, imperative for a cryogenic instrument. Bottom: light-weighted structure on the back of one of the mirrors of the spectrometer. Also shown are the special mounting 'ears' for stress-free isostatic mounting.

tions and 24 narrow- and broad-band filters. The three Pixel Fields Of View (PFOV) are 0.075 arcsec, 0.127 arcsec and 0.2 arcsec. The corresponding fields of view are 19.2×19.2 arcsec$^2$, 32.5×32.5 arcsec$^2$ and 51.2×51.2 arcsec$^2$.

- slit grating spectroscopy with various spectral resolutions (R=$\lambda/\delta\lambda$), given for an entrance slit width set to 2$\lambda$/D, (where, as usual, $\lambda$ is the wavelength and D the telescope diameter). Three spectral resolutions are available in the *N* band: low (R = 350 at 10 µm), medium (R = 3200 at 10 µm) and high (R = 25,000 at 10 µm). Two spectral resolutions are available in the *Q* band: medium (R = 1600 at 20 µm) and high (R = 12,500 at 20 µm). There is also the possibility to have a low resolution mode in *Q* band (R = 175 at 10 µm) but the usefulness of such a mode in the poor *Q* band atmospheric window has to be proven. The PFOV along the slit is 0.127 arcsec. There are 28 slits with selectable width between 0.3″ and 4″. In low and medium resolution the slit length is 32 arcsec. The nominal high-resolution echelle spectroscopy mode is performed with cross-dispersion grisms for order separation. With these low-dispersion grisms four to five echelle orders are imaged simultaneously on the detector. To avoid order overlap the slit length is reduced to 4.5 arcsec for the cross-dispersed mode. Alternatively, for astrophysically important isolated lines, long slit Echelle spectroscopy observations are possible. At the moment four order-selection filters are available to perform long-slit high-resolution echelle spectroscopy: $H_2$ at 8.02 microns, [Ne II] at 12.81 microns, $H_2$ at 17.03 microns and [S III] at 18.68 microns.

## Design and development

The choice was made in the early stage of the ESO VLT instrumentation plan to have only one VLT instrument in the mid-IR, able to combine imaging and spectroscopy. This decision resulted in VISIR being a rather complex multi-mode instrument. On top of that, in order to limit the contribution of the optical bench to the photon background to less than 1%, the optical bench has to be cooled to a temperature lower than 60 K for the imager and lower than 32 K for the spectrometer. Thus VISIR is a cryogenic instrument (Fig. 3).

VISIR is made of two subsystems: an imager and a spectrometer. Each subsystem has its own detector array. The detectors are both 256×256 Si:As BIB arrays developed by DRS Technologies (Galdemard et al. 2003). The acquisition system is the common-user IRACE system developed by ESO. The software is based on the general VLT software. The detectors have to be cooled down to ~8K to avoid prohibitive dark current.

The optical design of the imager is an all-reflective system made of five mirrors (Fig. 4). The first mirror images the telescope pupil onto a cold stop (18 mm in diameter) to block extra background. The second mirror is a folding flat to ease the mechanical implementation. The last three mirrors form a Three Mirror Anastigmat (TMA) configuration. They ensure the re-imaging of the field onto the detector. The three magnifications of the imager are implemented by a set of three TMA systems mounted on a wheel, named TMA wheel. Near the focal plane another wheel (the diaphragm wheel) is used to adapt the entrance field aperture to the selected magnification, in order to limit possible extra-background. Three positions of the wheel are occupied by aperture masks and folding flats to deflect the telescope beam into the spectrometer. The third wheel of the imager is a filter wheel, which is located just after the cold stop and which can hold up to 40 filters.

In the spectroscopic mode the telescope beam enters the spectrometer via the 're-imager' unit with a cold stop, two filter wheels (with order-selection filters and fixed Fabry-Perot etalons for wavelength calibration) and an entrance slit wheel (Fig. 4). The actual spectrometer has two arms, one for Low- and Medium- Resolutions (LMR) and one for the High-Resolution (HR) mode. Like the imager, the spectrometer makes use of Three Mirror Anastigmat systems, but now in double pass: in the first pass the TMA acts as a collimator, in the second pass as a camera. Each arm has its own TMA, with a collimated beam diameter of 125 mm in the HR arm and 53 mm in the LMR arm. Via switchable folding flats the spectra from both arms are imaged onto the spectrometer detector. The LMR arm gives a choice between four small reflective gratings. All are used in 1$^{st}$ order in the *Q*-band and in 2$^{nd}$ order in the *N*-band. The HR arm is built around the 'duo-echelle': two large echelle gratings mounted back-to-back on an aluminium blank of 350×130 mm. Both echelles have slightly different rulings (80.0 and 77.3 grooves/mm), resulting in two sets of "interlaced" grating orders. By choosing either the 'A' or the 'B' side of the duo-echelle, one can select for each wavelength the grating order with optimum blaze efficiency.

Given that VISIR is a cryogenic instrument and given the number of modes, the leading mechanical design criteria were high

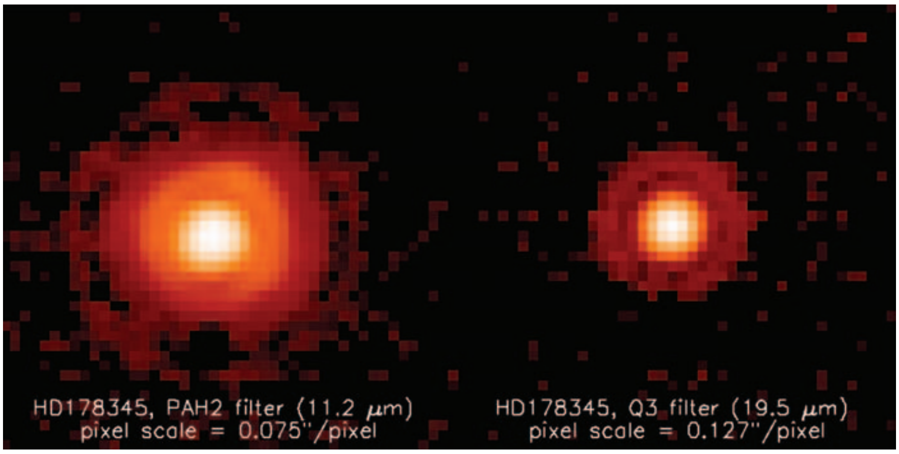


**Figure 6:** Point source with diffraction rings at 11.2 microns and 19.5 microns.

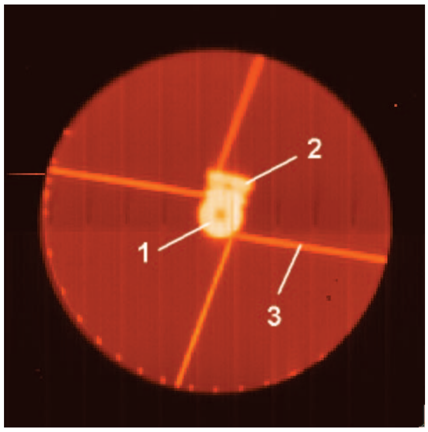


**Figure 7:** *N*-band pupil image for the spectrometer. In the thermal infrared, the pupil-image is an inverse of an 'optical' pupil image. What would show up dark in an optical image is radiating strongly at 10 microns. We can see thermal emission of 1) the (circular) M3-tower, 2) the rectangular attachment of the M3-tower in the stow-position and 3) the spiders of the VLT-M2 with their V-shaped geometry.

stiffness to weight ratio, low mass and high thermal stability. Such criteria have led to the development of a novel type of cryomechanism by the CEA/DAPNIA (Fig. 5). These devices have to actuate, at cryogenic temperature, optical devices with a very high accuracy and positioning repeatability (5 arcsec). By design, the cryomechanisms are very rigid and can be used in a cantilever position. The concept allows open loop control by use of a stepper motor with high torque and direct drive and includes a zero position switch as well. The power dissipation is zero when the cryomechanism is locked in position. Eleven such cryomechanisms are used in VISIR: three for the imager and eight for the spectrometer. The low mass criterion has also led to light-weighting of the opto-mechanic parts of VISIR, such as the mirrors (Fig. 5).

## Performance

The image quality of the imager was checked to be diffraction limited both in *N* and *Q* band (Fig. 6), at least under good seeing conditions. In the mid-IR at 10 microns the influence of atmospheric turbulence on image quality is obviously much less than at optical wavelengths. However, it is important to note that, when the optical seeing is worse than about 0.6 arcsec, a departure from diffraction limited performance at 10 microns is also observed.

The pupil alignment was also checked and found to be correct within a few percent (Fig. 7).

The sensitivity depends considerably on the weather conditions, especially in the *Q* band. While we achieved reasonable sensitivities in the *N* band (for example, down to 3.6 mJy 10σ 1 hour for the 11.3 μm PAH filter in good weather conditions), we were far off (an order of magnitude) in the *Q* band. The origin of such bad sensitivity is probably bad weather conditions.

To achieve the required sensitivity, the huge photon background has to be removed. This is done following the classical chop-

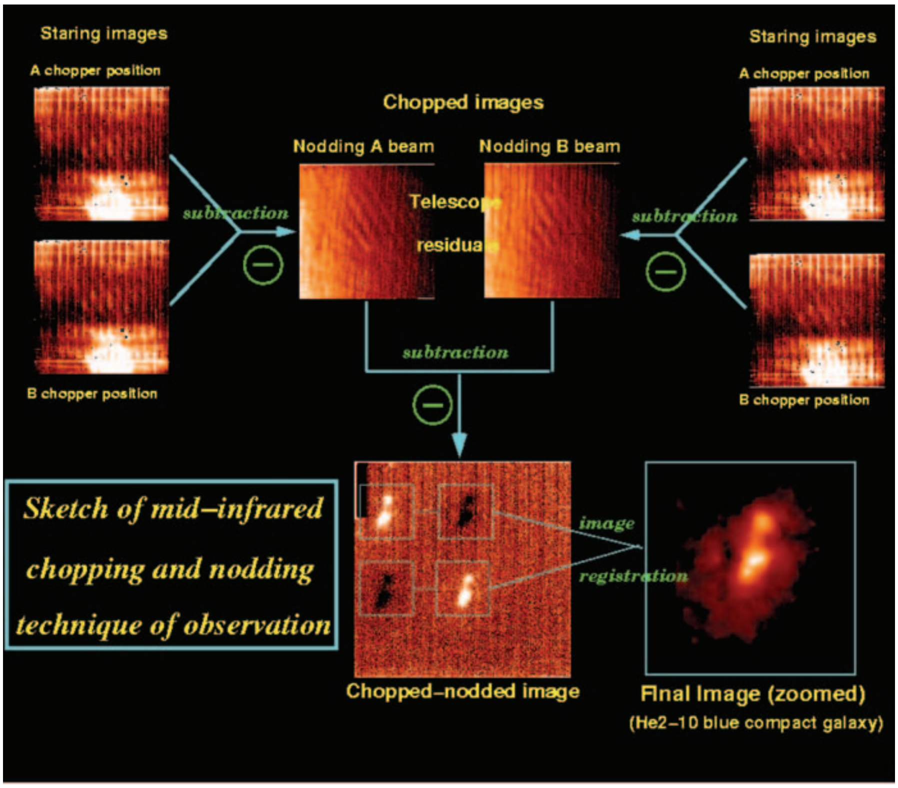


**Figure 8:** Illustration of the chopping-nodding technique when observing the He2-10 blue compact galaxy (see ESO press release about VISIR for more information about the object). The basic idea to remove the huge photon background generated by the atmosphere and the telescope is to make the difference between two observations: one on-source (background plus source) and the other off-source (background alone). Given the background fluctuation time scale, the on- and off-source measurements have to be done at a rate typically in the Hz range. Such a high rate cannot be achieved by moving the telescope. That is why it is done by moving the secondary mirror of the telescope (positions A and B on the left of the illustration); this is called *chopping*. The chopping technique allows us to remove the sky background and most of the telescope background. However the optical path on the primary mirror is not exactly the same according to the chopper position. That is why a residual background remains after chopping and one cannot detect the galaxy (see image labeled *nodding A beam* in the illustration). The time scale for the fluctuations of the residual background is long and can be monitored by moving the telescope off source and doing the same chopping observation sequence as in the preceding telescope position (resulting in the image labeled *nodding B beam*). After subtracting beams A and B, the galaxy is detected. If the chopping throw and nodding throw are small enough, the source is always present in the field of view of the instrument, so that we end up with four sources on the final image (two positive and two negative).

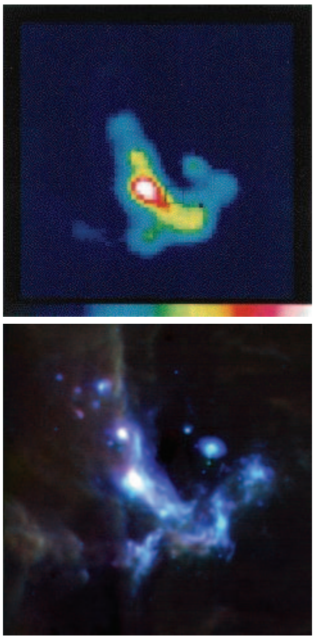

**Figure 9:** Top : image of the galactic centre obtained with the TIMMI instrument mounted on the 3.6-meter telescope on La Silla (H. Zinnecker et al. 1996). Bottom: image of the galactic centre obtained with VISIR. This illustrates the huge improvement when going from a 3-meter class to a 8-meter class telescope.

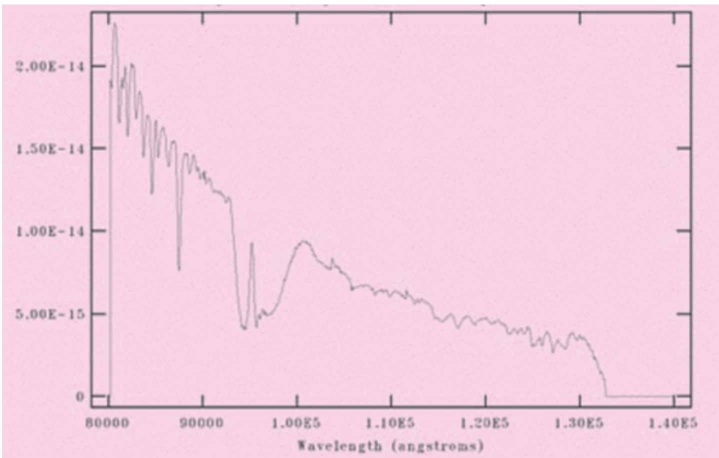


**Figure 10:** Full low-resolution *N*-band spectrum of standard star HD175775 (20.2 Jy at 12 μm). Note that the spectra have not been corrected for atmospheric effects.

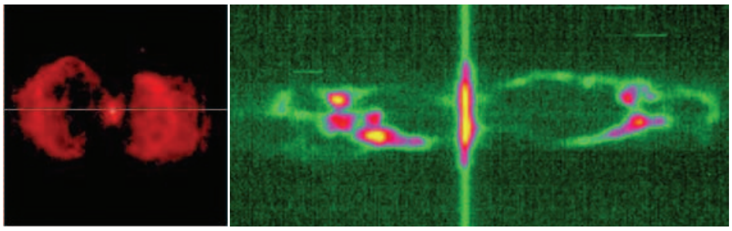

**Figure 11:** Left: image in the [NeII] line at 12.8 microns of the "Ant" Planetary Nebula (Mz3). Right: long-slit high-resolution spectrum around the [NeII] line; spatial direction is horizontal and spectral direction vertical. The slit was located as indicated by the line on the left image. The velocity resolution is about 17km/s.

ping-nodding technique illustrated in Fig. 8. While the VLT secondary mirror assembly allows chopping up to typically 5 Hz, substantially lower frequencies are being used, so that active field-stabilisation with the VLT-secondary mirror (M2) while chopping becomes possible. This is necessary for ultimate image quality under typical wind conditions. For the commissioning runs chopping frequencies as low as 0.25Hz were used to detect sources at a level of a few tens of mJy in imaging. Further tests are pending, to see whether these low frequencies compromise the sensitivity.

With VISIR a huge hurdle in improving ground-based mid-IR observation has been passed. We knew that with observations on a 3-meter class telescope we were only seeing the "tip of the iceberg" and that improvements should be achieved with VISIR. But, we were surprised by what we saw (Fig. 9)! With VISIR, we can obtain from the ground, mid-IR images with a quality rivalling that of shorter wavelength observations.

The spectrometer is also performing very well. Complete low-resolution *N*-band spectra were taken on July 4 and 6 in four settings (two with the LSW grating and two with the LLW grating) for various standard stars. The result for HD 175775 is shown in Fig. 10. In general the different parts of the spectrum join up quite well. The ratio of the spectra of two standard stars is reasonably close to the ideally flat distribution, except at wavelengths with strong atmospheric features like in the ozone band around 9.5 microns, where the atmospheric contributions do not cancel sufficiently due to difference in air mass and atmospheric variations.

Of special interest is the high spectral resolution mode, which has, so far, no equivalent in the Southern hemisphere (Fig. 11).

## Observing with VISIR

VISIR is one of the instruments which will generally be used during bright time. Given the international competition (for example the T-ReCS instrument on Gemini South), VISIR will be offered to the community as soon as possible. The VISIR modes that have been sufficiently tested during the first two commissionings will be offered to the community in the call for proposals for Period 75 (proposal due date: October 1st).

## Acknowledgments


VISIR would have not been possible without the contributions of numerous people in the consortium and at ESO. We would like to thank all those who have contributed to this superb instrument:

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ESO press release 13/04, May 2004

# First Light of SINFONI at the VLT

*SINFONI is an Adaptive Optics assisted cryogenic Near Infrared Spectrograph developed by ESO and MPE in collaboration with NOVA. It was successfully commissioned between June and August at the Cassegrain focus of VLT UT4 (Yepun). The instrument will be offered to the community from April 2005 onwards (Period 75) and will provide a unique facility in the field of high spatial and spectral resolution studies of compact objects (star-forming regions, nuclei of galaxies, cosmologically distant galaxies, galactic centre etc.).*

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The ESO STC recommended the construction of SINFONI ("Spectrograph for INtegral Field Observation in the Near-Infrared") in October 1997. The instrument was conceived as the combination of an Adaptive Optics facility (the AO-Module), developed by ESO, and SPIFFI (SPectrometer for Infrared Faint Field Imaging), a Near Infrared Integral Field Spectrograph developed by the MPE. It merges in one instrument the experience gained by ESO in Adaptive Optics (AO) with the development of the MACAO product line and the experience of MPE in integral field spectrometry with 3D, the world's first infrared integral field spectrometer.

A two year detailed design phase was initiated in 2000. At the final design review (2001), the board recommended the upgrade of the instrument to a higher spectral resolution (nearly 4000) with a 2048 by 2048 pixel infrared detector. NOVA joined the consortium at that time to undertake the development of the so-called '2K Camera' scaling the spectral images to the size of the new detector.

## Functionalities

The AO correction is based on the analysis of the wavefront of a reference star picked up close to the science Field of View (FOV). The sharing of the Cassegrain FOV between the two sub-systems is realized by an infrared dichroic mounted at the entrance of the SPIFFI cryostat. The visible flux (450 to 1000 nm) is reflected towards the wavefront sensor and the infrared (1.05 to 2.45 µm) is transmitted to the science focal plane.

The AO reference star can be acquired up to one arcmin off-axis. The optimum performance is achieved with stars brighter than $R = 12$ mag picked up within ~20 arcsec but fair correction can be obtained in good atmospheric conditions over the full 1×2 arcmin$^2$ FOV with stars up to $R = 17$ mag. The AO-Module also supports seeing-limited operations when no guide star is available.

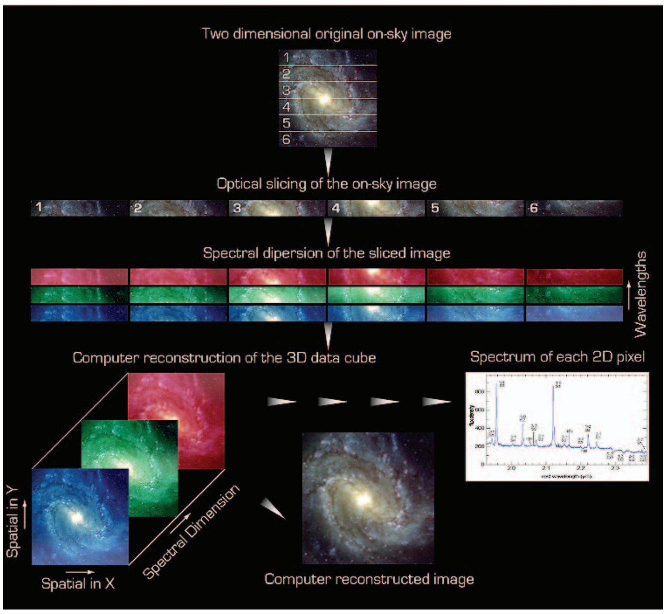


**Figure 1:** Principle of SPIFFI.

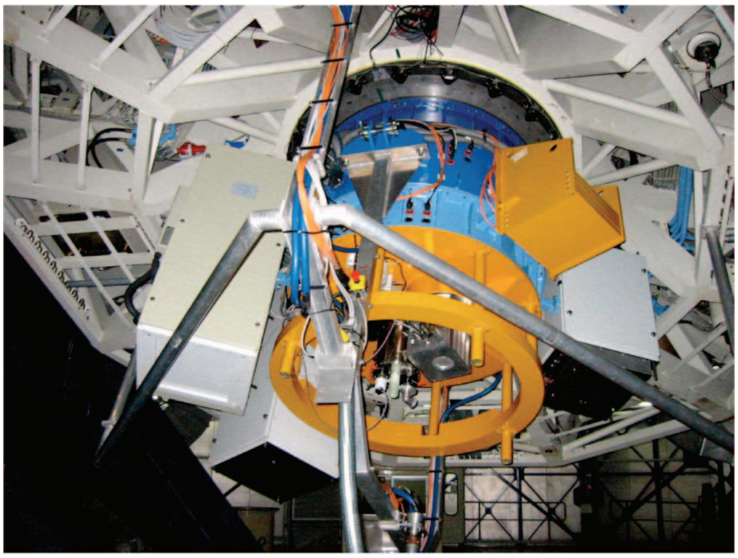

**Figure 2:** The AO-Module at the VLT UT4 Cassegrain focus for its stand-alone commissioning. The AO optical bench is the light-blue ring. It interfaces to the VLT Cassegrain flange through the AO-Housing (intermediate ring) and the interface flange (top dark ring). The yellow test structure simulates the mass of SPIFFI and provides the mechanical interface to the Infrared Test Camera (aluminum box in the yellow ring).

SPIFFI obtains spectra for each spatial element of its two-dimensional FOV. Its functional principle is shown in Fig. 1. After some processing of the raw data the outcome is a data cube, with 2 spatial (64 by 32 pixels) and one spectral (2048 pixels) dimensions. Spatially, three magnifications are offered. The high-resolution mode, with 25 mas× 12.5 (milli-arcsec) per pixel, provides a Nyquist sampling of the diffraction-limited Point Spread Function (PSF) at 2 µm with a narrow FOV (0.8×0.8 $arcsec^2$). This mode will offer spatially resolved spectral data on cosmologically distant galaxies, but will be limited by readout noise in many applications even in the case of long integrations (30 minutes). The intermediate pixel scale (100 × 50 mas/pixel) offers the best compromise between FOV, sensitivity and spatial resolution for most applications. The coarse mode (250 × 125 mas/pixel) is suitable for seeing-limited operations and also, thanks to its "wide" 8×8 $arcsec^2$ FOV, is very useful to help identifying the target during the acquisition.

Four spectroscopic modes are supported: the *J*-, *H*- and *K*-band gratings provide a spectral resolution of approx. 2000–4000. A lower resolution (~2000) is achieved with the combined *H* and *K* grating.

## Installation and Commissioning Sequence

The integration of SPIFFI with the "1K Camera" was completed at the beginning of 2002 in a configuration enabling a direct interface to the VLT for seeing-limited observations. SPIFFI was then operated as a guest instrument without AO for a period of three months, producing outstanding scientific data (see *The Messenger* 113, 17) as well as valuable experience in preparation for the AO-assisted operations. The instrument was then shipped back to Europe and conditioned to interface to the AO-Module. The integration of the latter and its performance demonstration in the laboratory were completed in December 2003. The two subsystems were coupled for the first time in the ESO Garching integration facility in January 2004 and the Preliminary Acceptance in Europe was awarded in March. The 2K Camera and Detector assembly was then integrated in SPIFFI while the AO-Module was shipped to Chile for re-integration and stand-alone commissioning on the sky.

The first "AO" light was obtained on May 31st. On this occasion, an Infrared Test Camera was mounted at the AO-Module corrected focus to provide direct imaging capabilities (Fig. 2). The adaptive optics loop was immediately closed on a bright star ($m_V$ ~ 11) and provided a corrected image concentrating into a diffraction-limited core 56% of the energy in the *K*-band (λ = 2.2µm, Figure 3). This performance conformed to expectations based on laboratory experiments and the experience obtained with the two MACAO systems that had already been tested at the Coudé foci of the VLTs.

The re-integration of SPIFFI with the AO-Module took place in the assembly hall of Paranal in June and SINFONI first light was obtained on July 9 (Fig. 4). The first commissioning was devoted to the testing of all the observing modes and the tuning of the many automatic control loops which will ultimately make this complex instrument user-friendly. The success of the July run allowed for dividing the August commissioning run among commissioning activities for fine-tuning operations, Science Verification and Guaranteed Time Observations.

## Opening to the Community

The instrument is currently equipped with an engineering-grade detector that is suitable for technical qualification but affected by flaws which would limit the science capabilities of SINFONI. The final science-grade detector is currently undergoing characterization tests in Garching and will be integrated in the instrument in November.

Meanwhile, the first call for proposals to the astronomical community will be issued in September and the start of regular observations is scheduled for Period 75 (starting April 1st 2005).

Adaptive Optics correction requires the presence of a reasonably bright reference star in the vicinity of the science target. This constraint limits AO operations to a small fraction of the sky. This limitation will be overcome as soon as Yepun (UT4) is equipped in 2005 with a Laser Guide Star Facility (LGSF). The LGSF will launch a 10W Sodium laser beam along the telescope line of sight to create an artificial beacon in the high atmospheric sodium layer (~100km), providing a reference for wavefront sensing. The upgrade of SINFONI to laser guide star operations is foreseen for the second quarter of 2005.

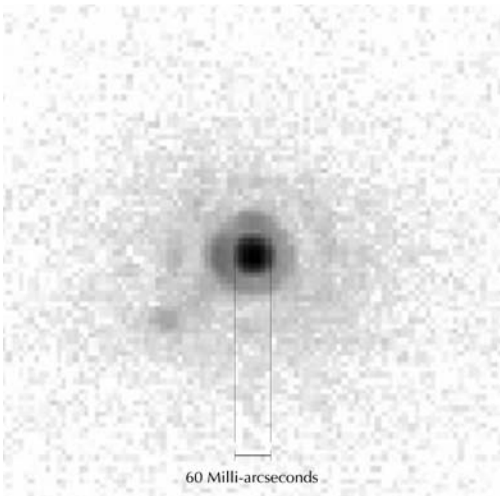


**Figure 3:** AO-Module first light. The magnitude of the star is ~11 in *V*, the seeing 0.65 arcsec. The measured Strehl is 56% (λ = 2.16 µm). The displayed FOV is 0.5 arcsec, with a sampling of 15 mas/pixel.

**Figure 4:** SINFONI during installation at UT4. The SPIFFI cryostat vessel is the grey aluminum part below the AO-Module (blue). To the left, the M1 cell of the VLT.

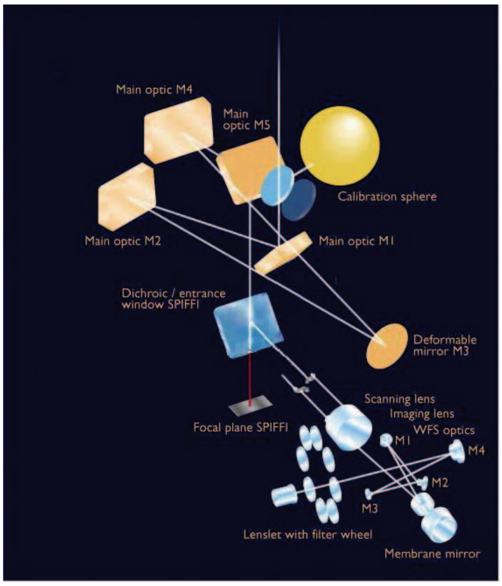


**Figure 5:** Optical layout of the AO-Module.

## Instrument Overview

### The Adaptive Optics Module

**Optical layout**

The AO-Module was developed in the ESO headquarter laboratory in Garching (Bonnet et al. 2003). It consists in an optical relay from the VLT Cassegrain focus to the SPIFFI entrance focal plane, which includes a deformable mirror conjugated to the telescope pupil. The curvatures of the 60 actuators are updated at 420 Hz to compensate for the aberrations produced by the turbulent atmosphere. The optical layout is shown in Fig. 5.

At the reflected focus, a pick-up lens mounted to a tri-axial linear stage collects the visible flux of the AO guide star, which is then imaged on the membrane mirror. The wavefront sensor box (mirrors M1 to M4) collimates the beam and re-images the pupil (conjugated to the deformable mirror) on the lenslet array. There, the flux is split among 60 sub-apertures and forwarded to a second array of lenslets, which image the sub-apertures on the cores of 60 optical fibers. The photons are then guided to 60 Avalanche Photo Diodes (APDs) located in a cabinet mounted to the instrument housing.

In closed loop, a speaker located at the exit of an acoustic cavity forces the membrane mirror to oscillate at 2.1kHz. As a result, the pupil plane moves back and forth along the optical axis allowing the lenslet array to intercept alternatively the intra- and extra-focal regions. An aberration in the wavefront would de-collimate the beam locally, causing the flux density to vary along the optical axis. As APDs are read out synchronously with the oscillations, the relative intensity difference between the intra- and extra-focal phases is proportional to the local wavefront curvature. This signal is used to generate the corrective command to the deformable mirror. The correction is updated at 420Hz, with a closed-loop bandwidth of 30 to 60Hz. The control gains are optimized for the actual atmospheric conditions and the guide-star brightness.

Additional opto-mechanical elements are already integrated in the AO-Module in view of the Laser Guide Star mode operations. They are not shown in the optical layout of Fig. 5.

**Performance demonstration on the sky**

The Infrared Test Camera (ITC) mounted to the AO-Module during the stand-alone commissioning run of June was used to demonstrate the performance of the AO-Module. The ITC provides direct imaging over a fairly large FOV (15×15 arcsec$^2$) with a sampling adapted to the diffraction-limited PSF in the near infrared (15 mas/pixel).

The typical AO-corrected PSF of a star features a diffraction-limited core superimposed on a larger halo generated by uncorrected high-order aberrations. The quality of the correction is evaluated with the Strehl ratio, computed as the fraction of the incoming energy which falls into the diffraction-limited core. In addition to the star brightness, the Strehl ratio is driven by the amplitude and the coherence time ($\tau_0$) of the seeing: in poor seeing conditions, the PSF is blurred by the larger amplitude of the high-order aberrations, while the AO-Module reactivity becomes insufficient for fast seeing conditions.

The measured performance of the AO-

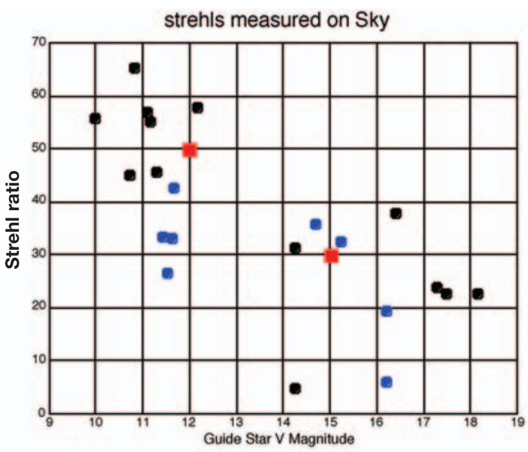


**Figure 6:** Strehl measurements obtained during AO-Module commissioning. Red squares show the specified Strehl performance. Black (resp. blue) dots are values obtained with $\tau_0$ > 3 ms (resp. $\tau_0$ < 3 ms )

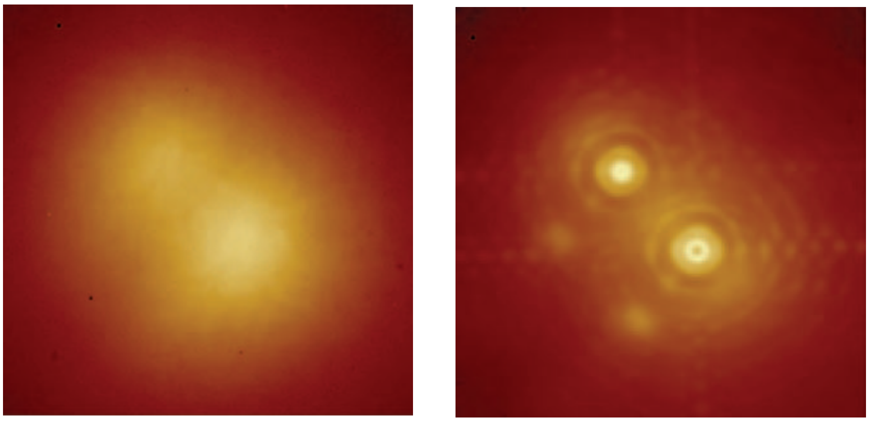

**Figure 7:** Observation of a binary system with a separation of 0.75″. To the left, open loop image acquired with a seeing of 0.6 arcsec. To the right, closed loop image obtained in the same conditions. The brighter component (lower right) served as a reference for the wavefront sensing. The additional "companions" at the lower left of the PSF cores are ghost images produced by a multiple reflection at the entrance window of the Infrared Test Camera.

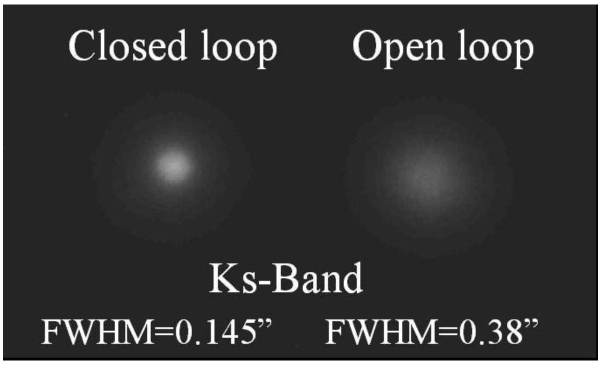


**Figure 8:** Performance of AO-Module on faint guide star (visual magnitude 17.5). To the right, the seeing-limited K-band image (FWHM 0.38 arcsec). To the left, the AO-corrected image (FWHM 0.145 arcsec). The ability to perform AO corrections on very faint guide objects is essential for SINFONI observations of faint extragalactic objects.

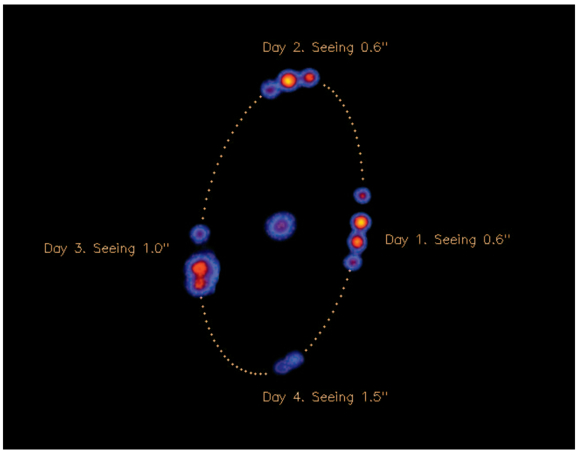


**Figure 9:** Image of asteroid Kalliope and its satellite Linus. The frames were acquired over four consecutive nights, surveying a complete orbital revolution of the system. The brightness of the central body (Kalliope) has been scaled down by a factor 15 to reduce the contrast with Linus. Changes in the size of the unresolved Linus image are due to variable seeing conditions from night to night.

Module is plotted vs. the guide-star magnitude in Fig. 6. Black dots are Strehl ratios obtained in conditions better than the median Paranal atmosphere, i.e. with a seeing < 0.65″ in the visible and a $\tau_0$ > 3 ms, for which the AO-Module was specified (specifications are shown by the red squares). Strehl ratios obtained in degraded conditions are plotted in blue, for which the reduction in performance is larger than expected from the experience of the other MACAO systems. We believe that they were caused by a loss of bandwidth of the instrument induced by a variation of the membrane mirror gain between the laboratory and the telescope environmental conditions.

An illustration of the image quality achieved in good conditions with a bright reference star is given in Figure 7, which displays a pair of stars with similar magnitudes (~7.5) and a separation of 0.75″. The brightest component was used as the reference star, with an absorbing filter dimming the flux by 2.5 magnitudes to avoid saturating the detectors of the wavefront analyzer. The Strehl ratio cannot be estimated due to the saturated peak of the bright component, but the image quality can be qualitatively appreciated from the number of visible Airy rings.

The ability to perform AO corrections on faint guide objects is essential for SINFONI in order to enable observations of faint extragalactic objects without nearby bright reference stars. This capability was demonstrated for good seeing conditions with a star of magnitude 17.5 (see Figure 8). The measured Full Width at Half Maximum (FWHM) of the corrected PSF in *K*-band was 0.145″ while the uncorrected FWHM was 0.38″.

Figure 9 shows the reconstructed 3.6-day orbit of Linus, a satellite of Kalliope. Kalliope is a 180km-diameter asteroid orbiting the sun from within the asteroid main belt, between the orbits of Mars and Jupiter, at nearly three times the Earth-Sun distance (three astronomical units). The binary system was observed in early June 2004 over four consecutive nights using the SINFONI AO module. Due to the geometry of the binary system at the time of the observations, the orbital plane of the satellite was seen at an angle of 60 degrees with respect to our line of sight. In fact, the satellite (~50km diameter) revolves around Kalliope on a 2000km-diameter circular orbit, with a direction of motion similar to the rotation spin of Kalliope (prograde rotation). The discovery of this asteroid satellite, named Linus after the son of Kalliope, the Greek muse of heroic poetry, was reported in September 2001 by a group of astronomers using the Canadian-France-Hawaii telescope in Hawaii (IAUC 7703). Additional observations of Kalliope have been obtained since 2001, which led to the determination of the main orbital characteristics of this binary system. Although Kalliope was previously thought to consist of metal-rich material, the discovery of Linus allowed scientists to derive a low ~2 g/cm$^3$ mean density for Kalliope. This number is inconsistent with a metal-rich object and Kalliope is now believed to be a rubble-pile stony asteroid. Its porous interior is due to a catastrophic collision with another smaller asteroid which occurred early in its history and gave birth to Linus. The VLT data obtained with the AO-Module of SINFONI will help refine our knowledge of the orbital characteristics and structural properties of this binary system.

Finally, the most impressive image so far was obtained during the August commissioning with SPIFFI: the Einstein Cross (Figure 10), a quadruple image of a single QSO amplified by the gravitational lensing induced by the foreground galaxy visible at the centre of the cross. This *H*-band reconstructed image was obtained with 20 minutes of integration time in the intermediate plate scale. The AO-Module was guiding on the brighter southern component, with a visual magnitude of 16. The total extension

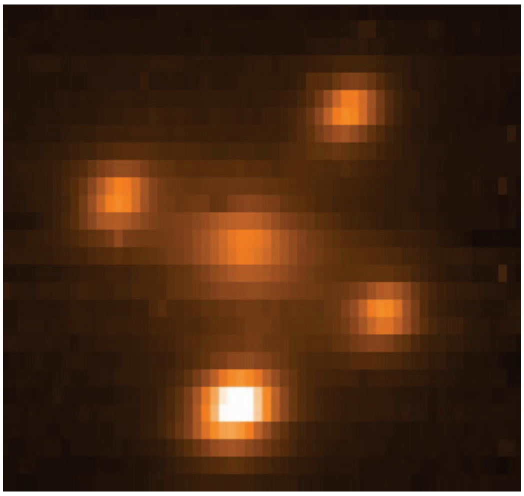

**Figure 10:** Reconstructed H-band image of the Einstein cross obtained with SINFONI using the 100mas/pix mode (image size 3″x3″) under very good seeing conditions (0.45″). This image demonstrates the capability of the MACAO AO system to sharpen the images of faint astronomical objects (here the guide star is the brighter component and has V=16 mag). The Einstein cross was discovered in 1985 and is one of the best-known examples of gravitational lensing. A massive black hole at the centre of a nearby galaxy, located along the line of sight to a distant quasar, deforms the geometry of space in its immediate surroundings. As a result, the light from the quasar reaches us through different paths as if the quasar was observed through a kaleidoscope, creating multiple images of the same object. This special optics distorts and magnifies the light of background quasars, providing a means of probing the distribution of intervening matter in the cosmos.

of the system is 1.8 arcsec, making it a very challenging target for the wavefront sensor due to its complex structure and low brightness. The seeing conditions were excellent during this integration (~0.5 arcsec with $\tau_0$ ~ 4ms).

## The near-infrared integral field spectrometer SPIFFI

SPIFFI was developed at the MPE (Eisenhauer et al. 2003) in collaboration with NOVA and ESO. It provides imaging spectroscopy of a contiguous, two-dimensional field of 64 × 32 spatial pixels in the wavelength range from 1.1 – 2.45 µm at a resolving power of 2000 to 4000. As a result, the instrument delivers a simultaneous, three-dimensional data-cube with two spatial dimensions and one spectral dimension. Originally equipped with a $1024^2$ pixel detector, SPIFFI was upgraded with a new camera unit built by NOVA and a HAWAII $2048^2$ RG detector array from Rockwell in the two months between the SINFONI system tests in Garching and the commissioning in Paranal. The integral field unit of SPIFFI is a so-called mirror slicer (Tecza et al. 2002). This image slicer consists of two stacks of 32 plane mirrors, cutting the field of view into 32 narrow stripes and rearranging these slitlets to form a single long slit. Depending on the selected image scale, the FOV of the integral field unit ranges from 8″ × 8″ for seeing-limited observations to 0.8″ × 0.8″ for imaging spectroscopy at the diffraction limit of the VLT. The intermediate magnification with a 3.2″ × 3.2″ field of view provides a compromise between reduced spatial resolution and improved sensitivity, and is best-suited for AO-assisted observations of objects with low surface brightness. The slit width in the three image scales is 250, 100, and 25 mas, with equivalent pixel sizes of 125, 50, and 12.5 mas. SPIFFI is equipped with four directly ruled gratings optimized for covering the atmospheric *J, H, K,* and combined *H+K* bands in a single exposure. The spectral resolving power for the 250 mas slit width is about 2000 in *J,* 3000 in *H*, 4000 in *K*, and 2000 in *H+K*. When using the adaptive optics image scale, the spectral resolving power increases up to about 2400 in *J*, 5500 in *H*, 5900 in *K*, and 2700 in *H+K*, but spectral dithering is necessary to recover the full resolution from the undersampled spectra. The entire instrument is cooled with liquid nitrogen to a temperature of –195° C. Figure 11 shows an inside view of SPIFFI.

A quick-look image reconstruction allows the instantaneous display of the reconstructed image during acquisition and observing. SPIFFI is equipped with its own data-reduction software, which is presently implemented in the VLT data-reduction

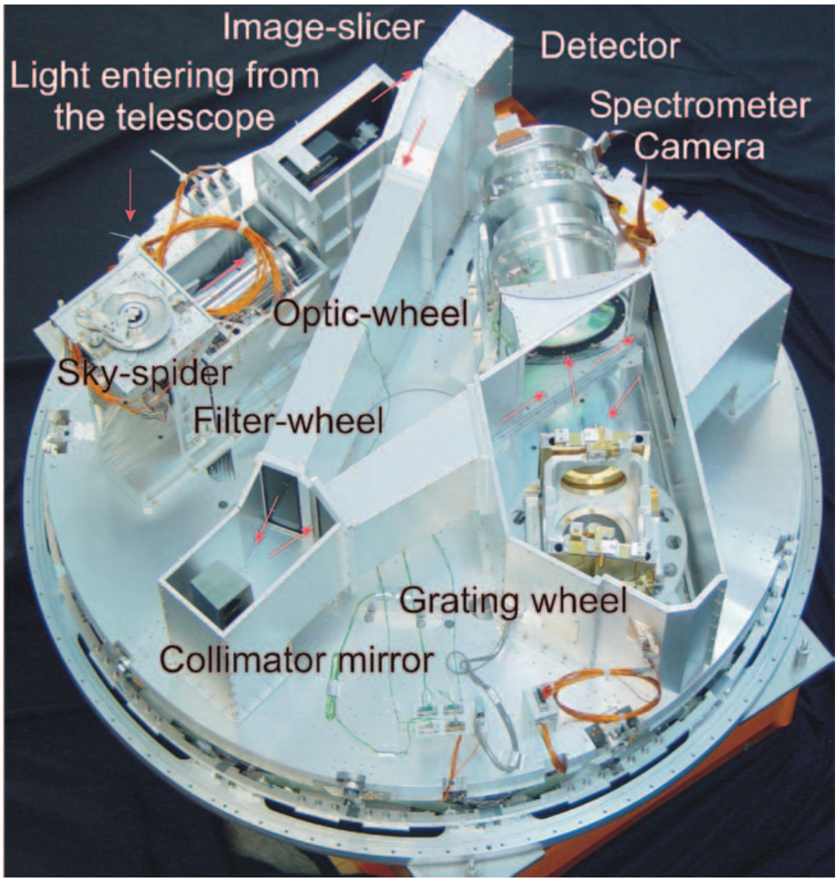


**Figure 11:** An inside view of SPIFFI: the cryostat cover and the reinforcing structure have been removed to provide a view of the opto-mechanical components of SPIFFI. The light enters from the top. The pre-optics with a filter-wheel and interchangeable lenses provides three different image scales. The image slicer rearranges the two-dimensional field into a pseudo-long slit, which is perpendicular to the base plate. Three diamond-turned mirrors collimate the light on the gratings. In total, four gratings are installed on the grating drive. A multiple-lens system then focuses the spectra on a Rockwell HAWAII array. In the meantime the spectrometer has been upgraded with an $2048^2$ pixel detector and a new spectrometer camera. The diameter of the instrument vessel is 1.3 m.

| Slit width | 250 mas | 100 mas | 25 mas |
|---|---|---|---|
| J Band | 18.0 | 18.5 | 17.0 |
| H Band | 17.5 | 18.5 | 17.3 |
| K Band | 16.9 | 18.0 | 17.2 |
| H+K Band | 17.7 | 18.9 | 18.2 |

**Table 1:** Limiting magnitudes for the observations of a point source. The sensitivities are calculated for a signal/noise of 10 per spectral channel and one hour integration on source (6 x 10 minutes, plus additional sky observations). We assume that 50%, 50%, and 25% of the flux is encircled within a diameter of 0.65″, 0.2″, and 0.1″ for seeing-limited observations with the 250 mas slitlets, and AO assisted observations with the 100 mas and 25 mas slitlets, respectively.

pipeline. This software package provides all tools for the calibration and reduction of SPIFFI data, including wavelength calibration and image reconstruction. The final data format is a three-dimensional data cube with 64 × 60 spatial pixels, and up to ~4500 spectral elements.

Table 1 lists the limiting magnitudes for the observation of a point source in the various instrument configurations.

## First science from commissioning

In addition to performance characterization and optimization, the commissioning runs were used to explore the capabilities of the instrument via test observations on a selection of exciting astronomical targets.

### Diffraction-limited integral-field spectroscopy of the Galactic Centre

Because of its proximity of only 8 kpc, the centre of the Milky Way is a unique laboratory for studying physical processes that are thought to occur generally in galactic nuclei. The central parsec of our Galaxy contains a dense star cluster with a remarkable number of luminous and young, massive stars, as well as several components of neutral, ionized and extremely hot gas. For two decades, evidence has been mounting that the Galactic Centre harbors a concentration of dark mass associated with the compact radio source SgrA* (diameter about 10 light minutes), located at the centre of that cluster. Measurements of stellar velocities and (partial) orbits with the ESO NTT (SHARP) and VLT (NACO) have established a compelling case that this dark mass concentration is a massive black hole of about $3.5{\cdot}10^6$ $M_\odot$ (Schödel et al. 2002). The Galactic Centre thus presently constitutes the best proof we have for the existence of massive black holes in galactic nuclei. High-resolution observations offer the unique opportunities to stringently test the black-hole paradigm and study stars and gas in the immediate vicinity of a black hole, at a level of detail that will never be accessible in any other galactic nucleus. AO-assisted integral-field spectroscopy will play a unique role in studying this important region.

The Galactic Centre was observed during SINFONI commissioning on July 15, 2004, for about 2 hours in ~0.6″ seeing conditions. The AO-Module was locked on a 14.6 mag star located about 20″ to the north-east of SgrA* and the centre of the star cluster. We observed with the finest plate scale (0.0125″ × 0.025″ per pixel) and the H+K grating (resolving power ~2000). Figure 12 (left insets) shows the *K* cube collapsed into a quasi-continuum image whose FWHM resolution is 75 mas, i.e. very close to the diffraction limit of the VLT in the *K* band. The Strehl ratio was about 10% in *K* band but is wavelength dependent.

The SINFONI data provide for the first time a complete census of the near-IR spectra of most K ≤ 16 stars within about 20 light-days of the black hole. The right upper insets of Figure1 show that a number of these “S-stars” exhibit HI Brγ (and HeI) absorption, characteristic of early type, O–B main sequence stars. In fact we find that at least 2/3 of all stars with K ≤ 16 in the central arcsecond have Brγ in absorption. This finding increases dramatically the ‘paradox of youth’ (Ghez et al. 2003), as to how these massive and presumably young stars have managed to reside in the central few tens of light days around the black hole. A number of ideas have been put forward, including *in situ* formation in an extremely dense circum-nuclear gas disc, in-spiraling of a massive young star cluster, perhaps aided by intermediate-mass black holes, scattering by stellar black holes, and collisional build-up of massive stars from lower-mass stars, but none is so far fully convincing. The orbital properties of the S-stars, now better constrained with the radial velocities obtained by SINFONI, promise to give important additional clues to the origin of the massive central star cluster.

Additional SINFONI observations on July 16 also provide new information on the spectral properties of massive blue supergiants further away from SgrA*. An AO-assisted observation of IRS13 E (lower right inset in Fig. 12), for the first time permitted spatially resolved spectroscopy of all three major components of this compact concentration of stars, which has been proposed to be the remnant core of an in-spiraling young star cluster. We find that all these three components have the characteristics of different types of Wolf-Rayet stars.

During the observations of July15 we had the good luck to catch a small flare of infrared radiation from SgrA* itself (lower left inset in Fig. 12). These infrared flares, seen for the first time in NACO observations last year (Genzel et al. 2003 b), probably sample in-falling hot gas in the immediate vicinity of the event horizon. By revealing the spectral properties of this flare the SINFONI data offer key new insights into the emission processes that cause infrared flares.

These few hours of data taken on the Galactic Centre during commissioning pro-

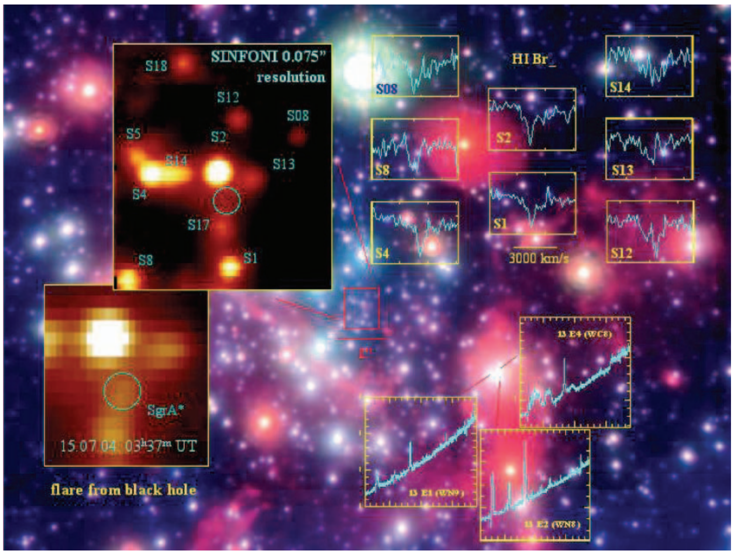


**Figure 12:** Diffraction-limited integral-field spectroscopy of the Galactic Centre with SINFONI. The background image shows a composite H,Ks,L’-band, three-colour image taken with the AO imager NACO, delineating the distribution of the different types of stars and the hot interstellar dust in the central parsec.

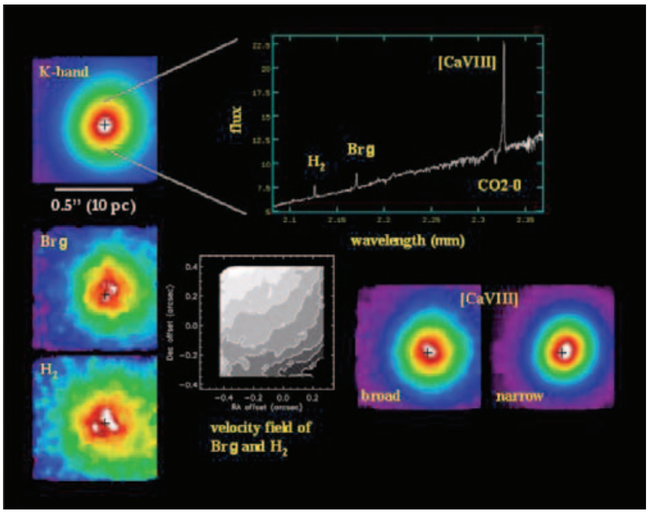


**Figure 13:** The Circinus galaxy - the nearest galaxy with an active centre (AGN) - was observed in the *K* band (2 μm) using the nucleus to guide the SINFONI AO-Module. The seeing was 0.5 arcsec and the width of each slitlet 0.025 arcsec; the total integration time on the galaxy was 40 min. At the top is a *K*-band image of the central arcsec of the galaxy (left insert) and a *K*-band spectrum of the nucleus (right). In the lower half are images (left) in the light of ionised hydrogen (Brγ) and molecular hydrogen ($H_2$) lines, together with their combined rotation curve (middle), as well as a CO 2-0 bandhead map, which traces cool stars in the nucleus, and images of broad and narrow components of the high-excitation [Ca VIII] spectral line (right). The false colours in the images represent regions of different surface brightness.

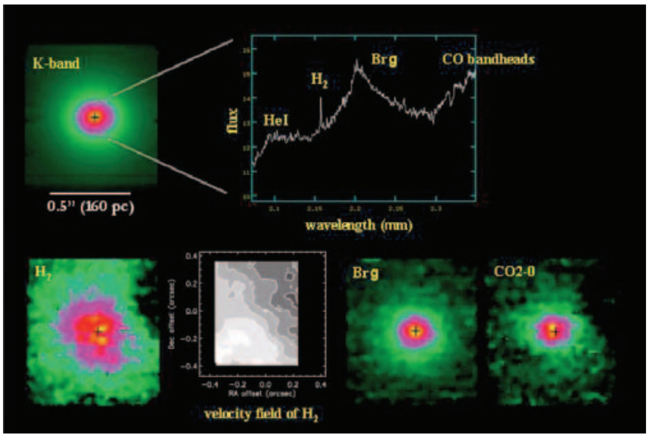


**Figure 14:** NGC 7469 was observed in *K* band (2 μm) using the nucleus as the wavefront reference for the adaptive optics and with slitlet widths of 0.025″. At the time of the observations the seeing was 1.1″. The total integration time on the galaxy is 1 hour 10 min. Upper left: image of the *K*-band continuum in the central arcsec of NGC 7469. Upper right: a spectrum extracted from the nucleus. Lower left: image of the molecular hydrogen line together with its rotation curve. Lower centre: image of the Brγ line. Lower right: image of the CO 2-0 absorption bandhead which traces cool stars.

vide a small glimpse of the fantastic information that diffraction-limited spectroscopy will bring for Galactic Centre (and star cluster) research in the next few years. More will undoubtedly follow next year when the instrument becomes available for science exploitation.

## A SHARP LOOK AT ACTIVE GALACTIC NUCLEI

The role of star formation in active galactic nuclei (AGN) has long been a contentious issue. Increasing evidence that starbursts do occur in the vicinity of at least some AGN has led to a change in thinking from the "starburst or black hole" debate of the last 10–20 years to a new framework in which the fundamental questions concern the physics linking the two phenomena. This is more than just an issue of driving gas in to small scales because AGN and star formation activity impact each other via feedback mechanisms. But the extent of this interaction can only be ascertained by addressing how common, how extended, how recent, and how energetically significant starbursts around AGN are. Commissioning observations of the Circinus galaxy and NGC 7469 demonstrate the potential of SINFONI to probe the environment around AGN on small scales, and to reveal in detail the distribution and dynamics of both the stellar and gaseous components.

The Circinus galaxy harbours a Seyfert 2 nucleus and, at a distance of only 4 Mpc, is one of the nearest such objects. Although the AGN itself is highly obscured, the compact K-band core also reveals the AGN indirectly, since it has a non-stellar origin: the distribution of the stellar continuum is revealed by the CO 2–0 absorption bandhead at 2.29 μm to have a much broader distribution. This more extended morphology is also reflected in the $H_2$ 1–0 S(1) 2.12μm line, as reported by Davies et al. (1998), and the Brγ 2.17 μm line. Because these lines are narrow and show ordered rotation, it is likely that they arise in a disc around the AGN. The position angle and speed of the rotation are consistent with those at larger radii, indicating that down to scales of a few parsecs there is no warp in the galactic plane. Circinus is known to exhibit a number of high-excitation coronal lines. Of these, the [CaVIII] line at 2.32 μm (the ionisation potential of which is 127 eV) is particularly strong. An initial analysis of the line properties reveals an increase in the velocity and decrease in its dispersion from the nucleus to a region offset to the northwest. Our interpretation is that there are two components to this line: a broad component centred on the nucleus at the systemic velocity and probably associated with the Broad Line Region; and a narrow component, which is redshifted by an additional 140 km/s, offset in the direction of the prominent ionisation cone, and likely associated with it.

NGC 7469 is a prototypical Seyfert 1 galaxy at a distance 66 Mpc that is well known for its circumnuclear ring, as well as a significant contribution from star formation to the nuclear luminosity (e.g. Genzel et al. 1995). Recent adaptive optics long-slit spectra combined with a millimeter interferometric map of the cold gas (Davies et al. 2004) led to a dynamical model in which the gas forms two rings, at 2.5″ (800 pc) and 0.2″ (65 pc). In this interpretation, the nuclear star forming region, which contributes at least half of the mass within 30 pc of the nucleus, was confined within the inner ring. These results are confirmed by new data from SINFONI which reveal the full 2-

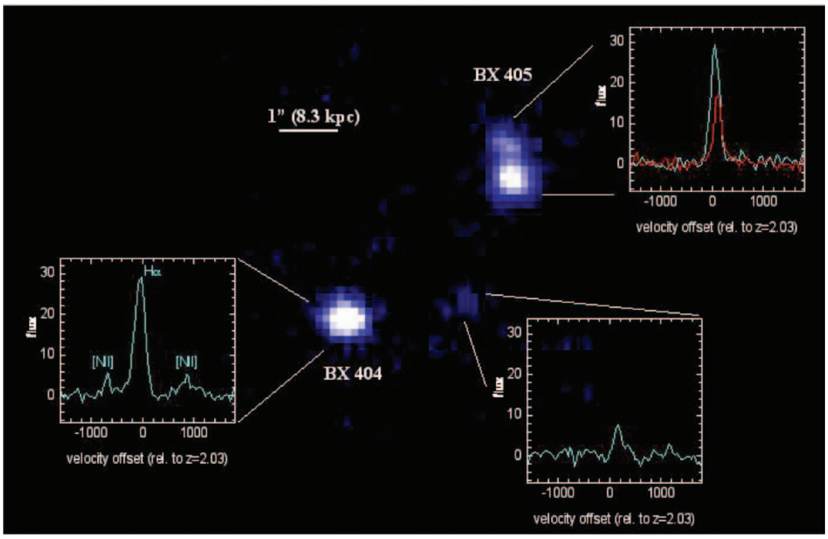


**Figure 15:** Image of the Galaxy pair BX 404/405 (redshift 2.03) in the light of the Hα recombination line (rest-frame wavelength 656 nm). One of the spectra (upper right) clearly reveals signs of a velocity shear while the other does not. Such shear may be a sign of rotation, a possible signature of a disc galaxy – or of a merger. The relatively small velocity offsets of the galaxies suggest that they are interacting and may perhaps merge to form a massive galaxy.

dimensional distributions of the $H_2$ 1–0 S(1) line and the nuclear star forming region, through the CO 2–0 bandhead.

## A Pair of Star-Forming Galaxies at z=2

It is becoming increasingly clear that most of the baryonic mass in galaxies was put in place between about 8 and 11 billion years ago (redshifts between 1 and 3). However, the real test of our understanding of galaxy formation and evolution is not just when the mass accumulated, but rather: How did it accumulate? Did mass assembly occur in the same way in different types of galaxies (i.e., spiral galaxies like the Milky Way and elliptical galaxies)? Was the mass accumulation rate mass-dependent so that more massive galaxies formed earlier in the history of the Universe? Why do some galaxies have large amounts of angular momentum, while others do not?

To address these questions, astrophysicists in Europe and the US have defined samples of galaxies that are at redshifts where most of the mass was likely put in place, namely around 2. For example, Steidel and collaborators have defined selection criteria based on three optical colours which efficiently select actively star-forming galaxies at redshifts between 1.5 and 2.5 (the so-called "BM and BX galaxies"; Steidel et al. 2004). Galaxies selected this way are forming stars at approximately 20–60 $M_{\odot}$/yr, appear to be substantially evolved with stellar masses of about $10^{11}$ $M_{\odot}$ and have approximately solar metallicity. All these properties suggest that they are highly evolved systems, even though their star-formation rates are substantial. In contrast, they tend to have complex UV morphologies and their dynamical properties are confusing – typical for galaxies that are rather unevolved. Interestingly, BM/BX galaxies with elongated, sometimes flattened morphologies like those usually associated with discs, appear to have smaller line widths than galaxies of more irregular shape. Erb et al. (2004) hypothesized that these galaxies are in the course of a merger, and not showing signs of systematic rotation which would be associated with a disc.

It is this last argument that led us to carry out observations with SINFONI of a pair of BX galaxies – BX 404/405 – during commissioning. Since the morphologies of BM/BX galaxies are complex and the most extended structures are not necessarily due to coherent rotation but to companion merging galaxies, it is difficult or even impossible to define the "kinematic major axis" (the angle along which the velocity change or gradient reaches its maximum). Exploiting SINFONI's integral field capability, one does not *a priori* have to choose a position angle, but simply puts the target in the field of view and then measures the source kinematics. If for example a system consists of a pair of merging galaxies, then there might even be two or more velocity components: Each galaxy could show a rotation curve of its own inclined by a different angle, and superimposed on the relative velocity along the line connecting the two galaxies. With such complicated objects, SINFONI is particularly powerful in determining the nature of the sources by obtaining the complete picture of the dynamics at once.

The galaxies BX 404 and 405 are especially interesting because this is an association of two star-forming galaxies at almost exactly the same redshift only about 3–4 arc seconds apart (about 30 kpc at this redshift). Thus we could cover both objects in a single pointing. What we found is fascinating: the relative velocity of BX 404 and 405 is only about 150 km/s. They are separated by about 30 kpc, while the emission-line object to the south and west of BX 404 and 405 has a velocity of 150 km/s relative to BX405 and about 300 km/s relative to BX404. The two components of BX405 have velocities that differ by about 70 km/s, with a spatial separation of about 6 kpc. The velocity and size allow us to roughly estimate that BX405 has a dynamical mass of about $10^{10}$ $M_{\odot}$.

The overall similar velocities in this system suggest that this may be an interacting set of galaxies, which could merge to form a single more massive object. If BX 404 and 405 are part of a larger gravitationally bound structure, their relative velocities and projected distances suggest a total mass of about $10^{11}$ solar masses. In addition, the ratio of [NII]/Hα can be used to give a crude estimate of the gas-phase metal abundances. In BX 404, the [NII]/Hα line indicates a total metallicity similar to the Sun. We only have an upper limit for BX405, suggesting that its metallicity is less than that of BX 404 and the Sun.

Obviously, these results are only a first step: before any robust statement can be made, a statistically significant sample of such high-redshift galaxies will have to be observed. Nonetheless, these observations illustrate the great promise of SINFONI for obtaining a detailed picture of the properties of star-forming galaxies in the high-redshift Universe.

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# Third MACAO-VLTI Curvature Adaptive Optics System now installed

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In July of this year the MACAO team returned to Paranal for the third time to install another MACAO-VLTI system. These are 4 identical 60 element curvature adaptive optics systems, located in the Coudé room of each UT whose aim is to feed a turbulence corrected wavefront to the VLTI Recombination Laboratory. This time the activities took place on Yepun (UT4). The naming convention has been to associate the MACAO-VLTI number to the UT number where it is installed. Therefore, although we speak here of MACAO#4, it is the third system installed in Paranal.

This short note will summarize the status of the MACAO-VLTI project, put forward a few results obtained recently and point out that with 3 operational MACAO-VLTI AO systems in Paranal, phase closure can now be attempted using AMBER fed with 3 AO corrected beams.

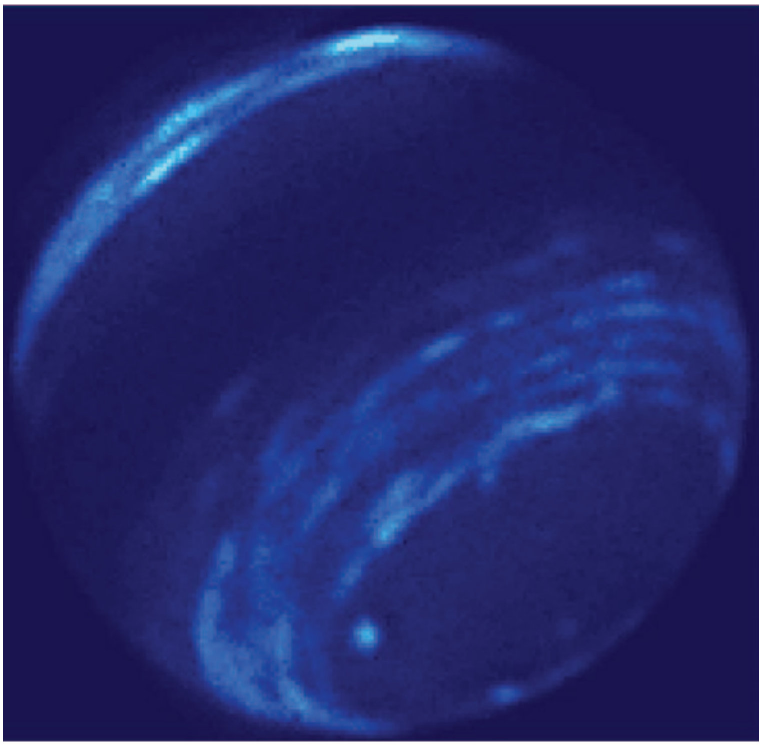

**Figure 1:** An impressive result of the August'03 commissioning; an image of Neptune in *H*-band (Van Cittert deconvolved). Besides the spectacular resolution of the atmospheric bands, this picture illustrates the capability of MACAO-VLTI to correct the wavefront on extended objects. The angular diameter of Neptune is 3 arcsec and the width (FWHM) of the narrowest bands is 67 mas.

## The Advantages of Serial Production

The opportunity of producing a series of instruments is not given to all, and this is unfortunate. We could not emphasize enough the advantages of such strategy. MACAO benefited from this situation from the start of the project all the way to the end at the commissioning activities.

For the ESO Adaptive Optics Department the standardization of several instruments presented numerous advantages: four (4) MACAO-VLTIs plus one spare, SINFONI and CRIRES. To name a few of these advantages:

- Similar concepts for the design documents,
- Optimization of staff efforts,
- Single procurement and acceptance for all units (in general 7 units),
- Great flexibility and margin during acceptance and integration of first systems; if some of the 7 units are not acceptable, others are and allow to pursue the assembly/integration activities,
- Compatibility among MACAO, SINFONI, CRIRES allowing exchange of components (during the whole life of the project),
- Large flexibility for improving the system performance. Basic specifications/functionalities were fulfilled for the first systems and became better as the team acquired a deeper understanding of its functioning.
- Repeated and improved assembly/integration procedures, test procedures (PAE) and commissioning activities

Similar benefits, of course, came from the serial production of the VLT Unit Telescopes.

## MACAO#4 (UT4) Commissioning

In 2003 the first and second MACAOs (UT2 and UT3) were commissioned in April and August respectively. A press release (ESO PR/11 03; 13 May 2003) was published to present the first light results. In November a joint effort between the AO dept. and VLTI used 3 nights on sky to characterize the gain

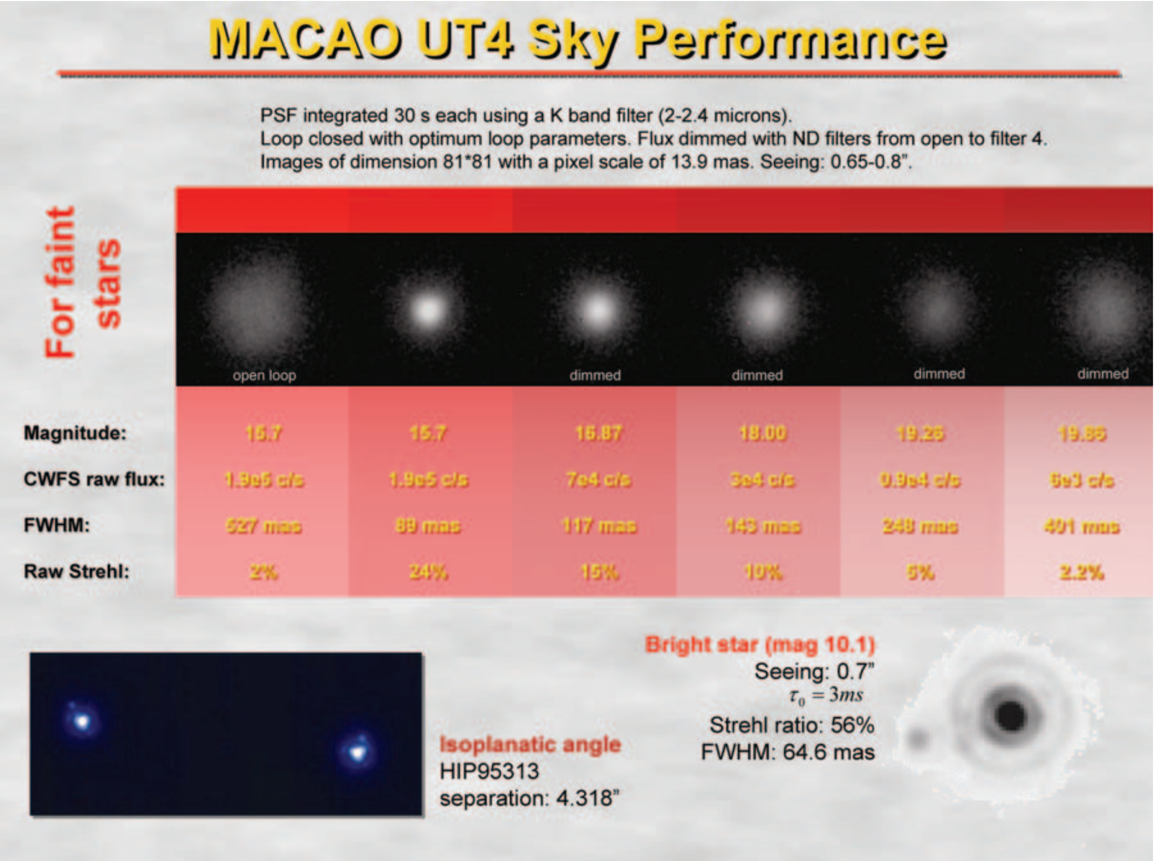


**Figure 2:** MACAO#4 (UT4) commissioning results (self-explanatory).

of using VINCI with the MACAO-VLTIs. Results of these various activities can be found in Arsenault et al. (2002, 2004a, 2004b), and Wittkowski et al. (2004). A general description is also provided in the Adaptive Department web pages at: http://www.eso.org/projects/aot/

The commissioning activities of this MACAO system were reduced to a minimum given the small number of nights on the sky (3) due to the busy UT schedules. Given the success of the previous commissioning on UT2 and UT3, this appeared to be a low risk strategy.

In July (2004) the Tip-Tilt Box on UT1 was decommissioned and some components re-used to integrate the UT4 MACAO-VLTI system. The commissioning went smoothly, especially the re-assembly/integration phase. It was completed early and the calibrations could start several days before the on-time sky.

The loop was closed on July 29th, approximately one half hour after the object was acquired. Usual verifications were performed: star acquisition, off-axis acquisition with XY table, atmospheric refraction compensation (for different guiding and scientific wavelength), chopping algorithm test, throughput of the system, performance on bright star etc.

Only after these tests were completed was the faint star performance of MACAO characterized. The results are summarized in Figure 2. A $V$~15.7 magnitude star was acquired, adaptive optics correction optimized and a K-narrow band image was taken. Strehl and FWHM were measured. The star was then dimmed artificially by inserting a neutral density filter in the beam. The faintest equivalent magnitude reached was $V$~19.8 (K-type star) but this value can vary depending on whether the star is red or blue. For a G-type star one should expect a similar performance for $V$~18 magnitude. The inconvenience of this method is that the sky background is also dimmed by the neutral density filter, but we believe that the fact that this test was carried out by full moon compensates for this effect.

During this particular run UT2 and UT3 systems went through a software upgrade in order to have similar configurations on all three MACAOs.

## MACAO-VLTI Summary of Performance

The critical specifications for MACAO-VLTI are few: strehl ratio versus guide star magnitude, artificial piston over the pupil introduced by the deformable mirror.

The K-band strehl ratio specifications for MACAO-VLTI are 50% for stars $V$<11 and 25% for $V$=15.5 in seeing conditions of 0.65″. In 0.8″ seeing MACAO has obtained strehl ratios >50% for bright sources ($V$<11.5) even 60% if one corrects for the imperfect strehl of the test camera (typically ~90%). On fainter stars the strehl ratio remains larger than 25% until $V$~16; however performance can deteriorate for a blue object of $V$~16 (Avanlanche Photodiodes have a peak of sensitivity at ~0.7 µm).

The piston specification of 25 nm RMS in a 48 msec time window has always been very critical; progress has been made recently allowing us to fulfill this very challenging requirement. The improvements leading to this are:

- Control frequency of 420 Hz rather than 350 Hz; important decrease in the excitation of the deformable mirror main resonances
- Improvement in the control matrix and higher accuracy of the interaction matrix measurement
- Taking into account the non-linearity of the deformable mirror at large stroke.

In conclusion the MACAO VLTI installations and commissioning activities are proceeding according to schedule and the results are extremely encouraging showing performance better than expected and a high system robustness. The fourth and last MACAO will be installed in the course of 2005.

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# The Visible & Infrared Survey Telescope for Astronomy

*VISTA's 4-metre primary mirror and 1.65-degree diameter infrared field of view feeds a 64 megapixel (0.34" pixel) camera. Rapid deep IR (0.85–2.3μm) imaging surveys will both select objects for follow-up with the VLT, and directly study a wide variety of astronomical topics.*

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VISTA (Visible and Infrared Survey Telescope for Astronomy) is the result of a 1998 application, to the UK's Joint Infrastructure Fund, by the VISTA Consortium of 18 UK Universities (see acknowledgments) for funding for a 4-m wide field survey telescope, which was approved in summer 1999. The purpose of the wide field (1.65° diameter in the IR) survey telescope and camera facility is to perform extensive surveys of the southern skies whose sensitivity is matched to the needs of today's 8-m class telescopes. Imaging surveys not only generate much science directly but also are needed to efficiently choose objects for further study by the VLT. IR surveys particularly target the cold universe, the obscured universe, and the high redshift universe.

The VISTA Consortium used competitive tendering to choose the UK Astronomy Technology Centre (UKATC) in Edinburgh to take on the technical responsibility for design and construction and a VISTA Project Office was accordingly set up. Their preliminary conceptual design studies resulted in Technical Specifications and Statements of Work for various work packages, which were awarded through a process of open competitive tenders. After investigating various potential telescope sites in Chile, and discussions with the site sponsors, the VISTA Consortium decided that the Cerro Paranal Observatory was the best site for maximizing the survey speed of VISTA. Interestingly this decision by the VISTA Consortium helped considerably in bringing about the subsequent decision by the UK to join ESO. As an ESO telescope, VISTA and its large surveys will now be fully exploited by the whole ESO community. This article provides an overview of some aspects of the system.

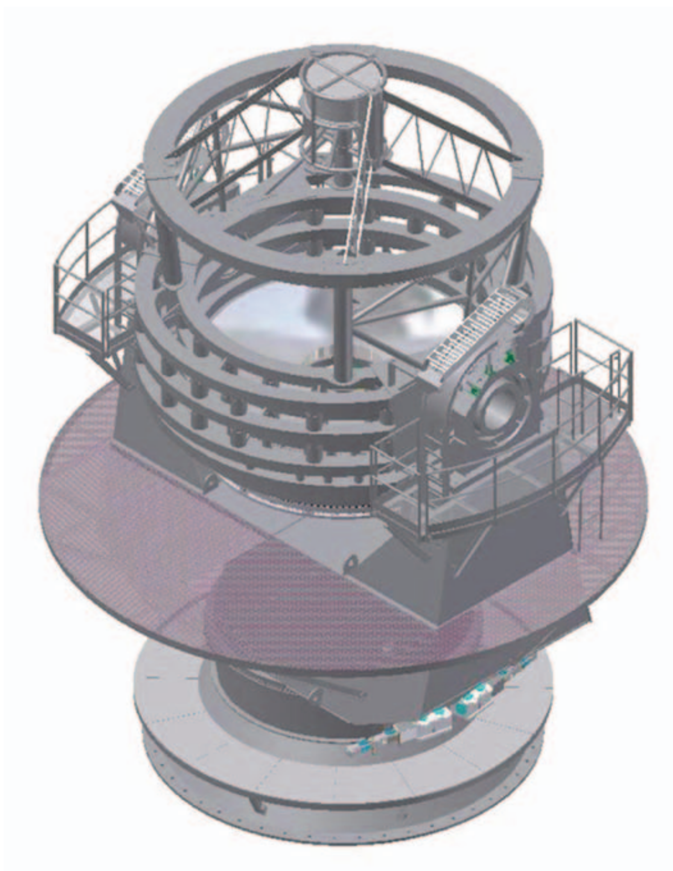


**Figure 1:** Drawing of VISTA telescope (camera not mounted).

## Design drivers

The purpose of VISTA is to survey both spatially and over time, through monitoring. Good image quality is required both to

**Table 1:** Design Reference Program for IR System Design.

| Survey name | Area Sq. deg | Limiting magnitude | | |
|---|---|---|---|---|
| Band | | *J* | *H* | $K_s$ |
| Wide high galactic latitude | 3000 | 21.2 | 20.0 | 19.5 |
| Wide low galactic latitude | 1500 | 20.5 | 19.5 | 19.0 |
| Deep | 100 | 22.8 | 21.5 | 21.0 |
| Very Deep | 15 | 23.8 | 22.5 | 22.0 |

enhance sensitivity and resolution, and to minimize confusion, leading to the requirements for an excellent site and a pixel scale matched to sample at least the median seeing at the site. Good sensitivity is required (e.g. to go deep in a reasonable integration time, and to enable monitoring of faint objects) leading to a requirement for a 4-m diameter primary mirror. To get statistical samples of sky area/objects (for example to study intrinsic scale sizes of clustering, to find rare objects, and to generate the large samples needed to get accurate properties) large areas must be surveyed, leading to a requirement for a large field of view. Both near-IR and visible surveys were required.

The design of VISTA was thus driven by the requirements of good image quality in both the near-IR (0.5″ fwhm) and visible and over a large (1.5–2.0°) diameter field of view with a 4-m class telescope, together with the ability to change between use of a visible or an IR camera. Finally, design trade-offs were to be resolved whenever possible in favour of maximizing the survey speed (in square degrees/hour for a specified set of surveys taking into account the overheads of changing filters, slewing, reading out etc) within the available financial budget. As the funding needed to build the visible camera is not yet available we focus here on the IR, without forgetting that VISTA is potentially an extremely powerful visible 2.1° diameter survey telescope with 50 red-optimized 4096×2048 CCDs with 0.25″pixels to complement the blue-optimized VST.

To turn the concept of survey speed into a quantitative tool, the surveys that VISTA might be expected to undertake were defined to assist the VISTA Project Office in optimizing VISTA for survey work. By examining the science drivers the VISTA Consortium defined a Design Reference Programme (Table 1) to match the science aims. Each survey is primarily defined by a solid angle of sky, a set of pass bands, and a detection limit to be reached in each pass band. In addition monitoring programmes involve a number of repeat observations of each field, and there is a goal of a southern sky atlas using the worst-quartile seeing time over 4 years, this would cover the hemisphere in two bands to over 3 mag deeper than the 2MASS survey. [N.B. There is also a *Y* (1.02 micron) filter available, narrow band filters could be purchased, and the detector system would allow use of a $z_{IR}$ filter.]

The surveys that VISTA will actually undertake remain to be decided, and will depend on the properties of the final commissioned system, progress in survey science by 2006, and the deliberations of the ESO bodies that will determine the actual time usage.

VISTA's strength, in addition to its specifications, is that it is a survey machine with time dedicated to ambitious, communally planned legacy programmes. The key, apart from the performance of VISTA itself, is to design survey strategies that maximize the utility of the data to many different science programmes. Thus, for example, many surveys will likely be constructed in multiple passes to enable completion of monitoring programmes and some key fields will be monitored over many years. VISTA is conceived as a blend of 75% of 'public' time (e.g. Schmidt-like sky surveys) used for preplanned large survey and monitoring programs together with 25% of competitively (traditional) based time.

## Design concept

To cover large areas of sky rapidly enough to produce timely results requires as large a field of view as possible. At the same time off-axis (and chromatic) aberrations over the large field must be kept down to a level that does not much degrade the size of the stellar images incident at the telescope. VISTA adopts an unusual design solution where the primary and secondary mirror conic constants are optimised jointly with the IR camera lenses to optimise image quality over the entire field of view. This leads to a quasi-Ritchey-Chretien solution but with significant aberrations for the 2 mirrors alone. The two mirrors provide most of the power of the system, whereas three lenses in the Cassegrain camera act as a reasonably conventional field corrector mainly serving to correct the off axis aberrations, without introducing much chromatic aberration, out to a field diameter of 1.65° (or 2.1° in the case of the visible camera design). As the telescope alone produces significant spherical aberration and off-axis coma, it must be used with the camera to produce good images. (This leads to challenges in testing the telescope and camera separately). The 4-m diameter primary is f/1 and with a 1.24-m diameter secondary, the resulting beam at the focal plane is f/3.26 producing 0.34″ pixels with the 20-micron pixel size of the IR detectors. For pixels at either extreme of the large focal plane not to look off the primary, any individual pixel cannot use the entire primary physical diameter. In fact any indi-

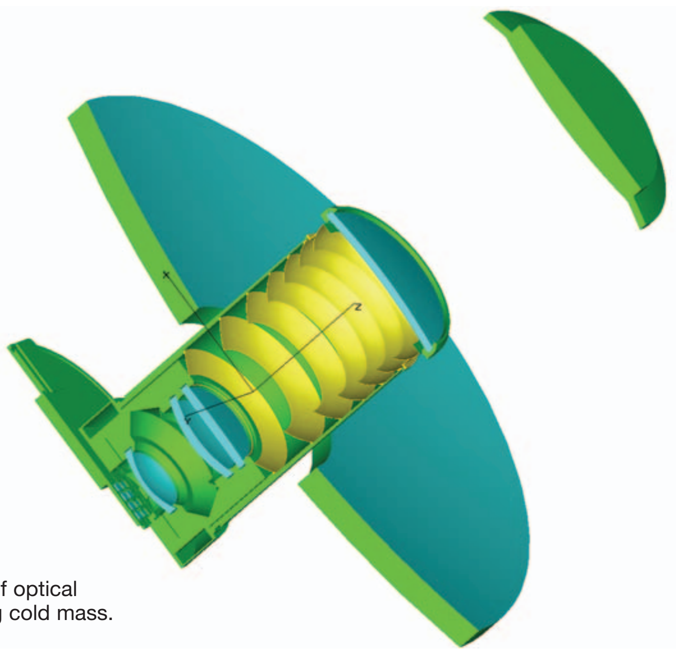


**Figure 2:** Cutaway of optical assemblies including cold mass.

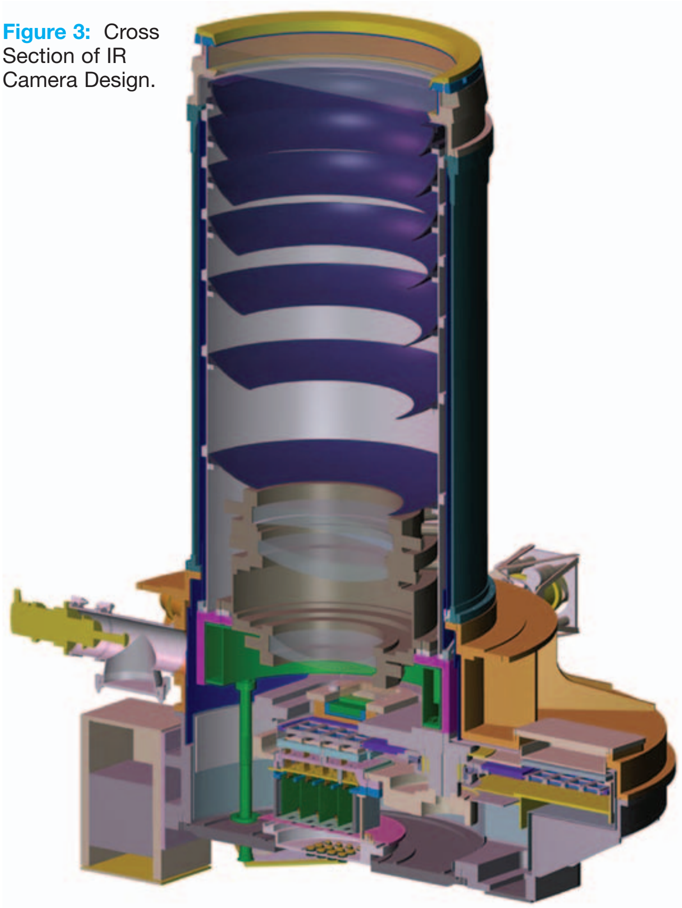


**Figure 3:** Cross Section of IR Camera Design.

**Table 2:** VISTA's 1st VIRGO science detector properties.

| Parameter | First Science detector VM301-SCA-22 (72K) |
|---|---|
| Quantum efficiency | 71% (*J*)<br>74% (*H*)<br>75% (*Ks*) |
| Well depth | 156 ke$^-$ (0.7 V bias) |
| Dark generation | 1.7 e$^-$/pix/sec |
| Read noise | 17 e$^-$ (rms) |
| No. of outputs | 16 outputs (1.001s) |
| Non-linearity | 3.3% (100 ke$^-$ FW) |
| Pixel defects | <1% |
| Flatness | ~6 µm (p-v) |
| Conversion gain | 3.58 µV/e$^-$ |
| Output DC level | 3.23 V |
| Operability (%) | 99.18% |

vidual pixel in the focal plane uses 3.7-m diameter of the primary. The f/1 primary allows a relatively squat telescope that helps contain construction costs, and delivers a fast Cassegrain focus with an acceptable secondary diameter. The curvature of the primary is unusually high for such a large mirror.

The standard method of rejecting the unwanted IR background from telescope structure, dome etc. in most IR instruments is to form an image of the pupil and to place a cold stop at that image to baffle out the unwanted background radiation. This ensures that the detector "sees" only cold surfaces inside the cryostat, the highly reflective low emissivity telescope optics, and the sky being imaged. VISTA's large diameter and large field of view, together with the need to maintain image quality, led to severe difficulties with cold stop designs, either using lenses (e.g. no IR glasses available in ~600mm size and with the achromatic properties needed) or using mirrors (e.g. packaging and obscuration problems). VISTA's solution (see Fig. 2) is to dispense with the traditional cold stop, and incorporate a long cold baffle at the front of the camera to reduce the background on the detectors. If the cryostat/baffle system is long enough, ensuring that the detectors see the smallest possible solid angle out of the cryostat, and the secondary slightly undersized to form the system stop, the field of view of all pixels is limited and does not overlap the edge of the primary mirror, or see other parts of the telescope structure. The cold baffle tube forward of the corrector contributes negligibly to the background in the focal plane.

There could however be an extra thermal component due to emission from the sky (mainly OH) that enters around the secondary mirror. This extra sky emission is blocked with a warm reflective annular (1.65-m) baffle around the (1.24-m) secondary mirror, so all that the detectors see from this annulus is the reflection of the cold interior of the camera. The result is that the total

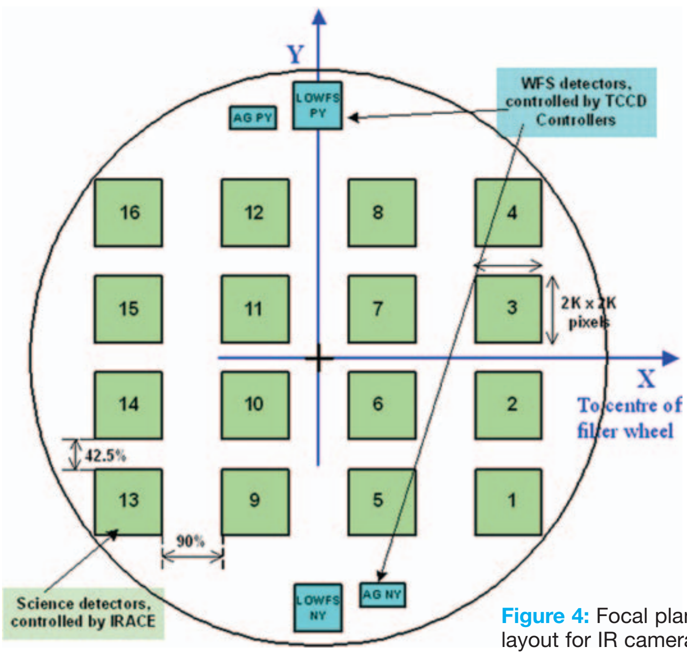



**Figure 4:** Focal plane layout for IR camera.

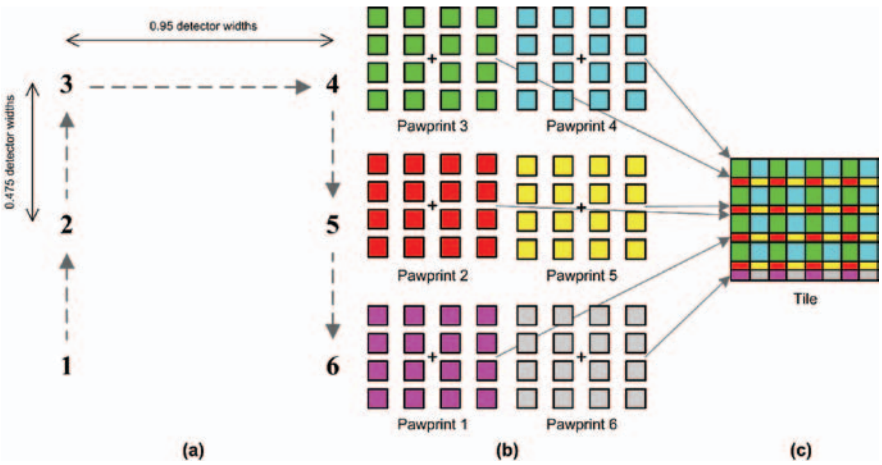



**Figure 5:** Making a filled tile (c) from 6 pawprints (b) at various offsets (a). Each sky position is observed at least twice.

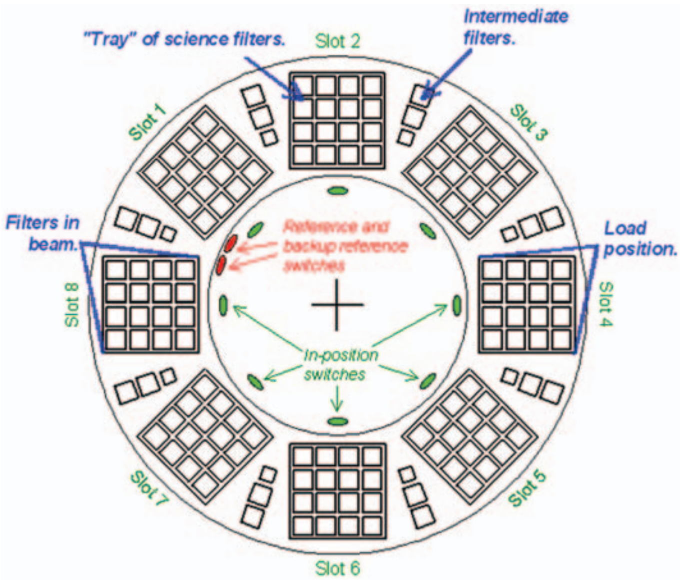
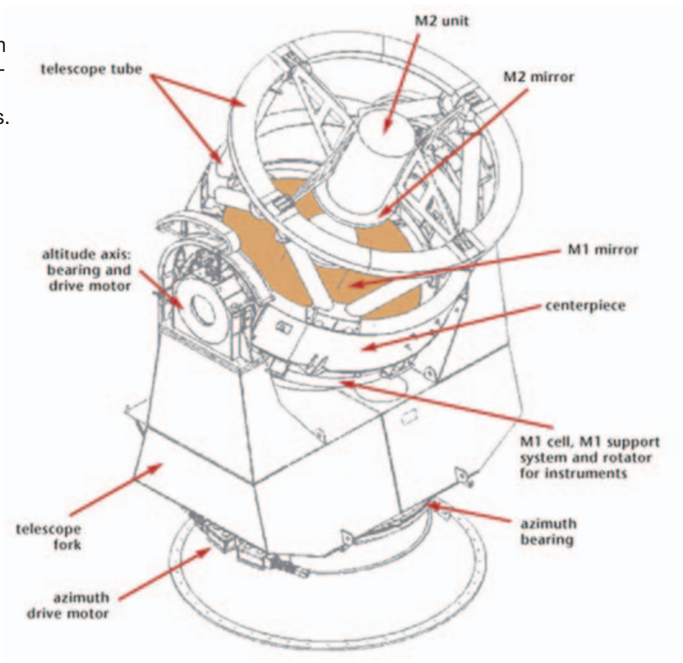



**Figure 6:** Filter wheel schematic.

**Figure 7:** Diagram of telescope structure showing the major components.




background is limited to unavoidable thermal emission from the primary, secondary, spider, and cryostat window, plus a modest contribution from the reflective baffle. Thermal contributions from the optics are of course present whether or not a cold stop is used. Analysis shows the system delivers performance certainly no worse than an (impractical) cold stop system would have done.

## IR Camera

The camera includes the entrance window, cold baffle tube, lenses, filter wheel and detectors and is being constructed by a consortium of Rutherford Appleton Laboratory, UKATC and Univ. of Durham (Dalton et al 2004). A cross section is shown in Fig. 3. The cold baffle approach inevitably results in a large (950mm IR grade fused silica) entrance window which potentially delivers a large heat load to the cryostat, potentially requiring a large number of closed cycle coolers to maintain the required temperatures. The solution adopted is to coat the reflecting baffle surfaces in the cryostat with a selectively reflective coating with high reflectivity around 10 µm, where the thermal emission peaks, and good absorption below 3 µm, where the detectors are sensitive, so that much of the heat load is returned to the window. Normally the window should not be subject to dewing or frosting, and measures to prevent this during ambient conditions when it is a danger are designed in. The baffles and lenses are mounted in a tube so that when mounted on the telescope the camera protrudes through the primary. The all-up camera system has a mass of 2900 kg.

The focal plane contains a sparse 4×4 array of Raytheon VIRGO 2048×2048 HgCdTe IR detectors (Love et al 2004) and will be the largest IR focal plane ever built. The parameters of the first delivered science detector are given in Table 2 as measured at the UKATC. A specially developed version of ESO's IRACE controller will be used to synchronously control the 16 VIRGO detectors (Bezawada et al 2004) .

As the detectors are not 4-edge buttable, some gaps are inevitable. Analysis has shown that the most effective way to maximize the survey speed, given the available field of view and detectors, was to space the detectors by 90% of a detector width in one (X) direction and 42.5% of their width in the other (Y) direction (Fig. 4).

A single exposure with this focal plane produces a 0.6 square degree 'pawprint' on the sky, and other exposures must be used to fill in the gaps between the 16 detectors to produce a contiguous image or 'tile' of sky of minimum size 1.5 degree × 1.0 degree. The simplest way to achieve this is with a series of 6 suitably offset exposures (Fig. 5): first expose at position 1, then move up 0.475 of a detector in Y to position 2 and expose, then up another 0.475 in Y to position 3 and expose, then move across 0.95 of a detector in X to position 4 and expose, then down 0.475 in Y to position 5 and expose, and finally down 0.475 in Y to position 6 for the final exposure which completes the tile. This ensures each piece of sky is covered at least twice, except for single exposures at the upper and lower extremes in Y, which will find matching single exposures when the next tile is made.

Inspection of Fig. 4 also shows two fixed autoguider visible (red) CCDs (AG +Y and –Y). Only one chip will be used to autoguide at any time, but a suitably bright guide star may be chosen from either. A patrolling mechanism for acquiring a guide star was rejected to minimize moving cryogenic mechanisms. There is also a curvature sensing device near each autoguider chip. These are used to feedback signals to the secondary and mirror support to allow adjustments to maintain the image quality.

Filters can be changed via a 1.37-m diameter filter wheel (Fig. 6) which has space for 7 sets of 16 filters (each filters covers one detector) and an (opaque) position for taking dark frames. The filter wheel also contains slots between the science filters for sets of auxiliary optics. These are occasionally used with the IR detectors in a wavefront sensing mode to monitor the figure of the primary, perhaps once just before observing and once again during the night.

With 16 detectors, each 2048×2048, and 4-byte output, each pawprint will be 268.4 Mbytes. Exposures are frequent in the IR so a typical night's observing should produce several hundred Gbytes of raw data. As VISTA will be a dedicated survey facility, this leads to around 100 Tbytes per year. Processing this data rate requires very careful attention to standardizing data taking procedures and calibrations.

## Telescope & Mirrors

The telescope is an altitude azimuth design with the azimuth axis above the primary mirror (Fig. 7). It will be produced by Vertex-RSI, who have recently completed the 4-m SOAR telescope on Cerro Pachon.

The f/1 primary zerodur blank was figured to a meniscus shape of 17cm thickness by Schott Glas (Fig. 8), and is being polished by LZOS near Moscow, who also polished the mirrors for the VST. The primary is supported on 84 active pneumatic axial and 24 lateral pneumatic supports, the forces on which are controlled to ensure the mirror keeps its shape and position at various elevations. The f/1 design keeps the telescope relatively short but a consequence of the fast primary is that the image quality is very sensitive to the exact position of the secondary mirror. Therefore the results from the wavefront sensors near the focal plane are used to slowly adjust the position, tip and tilt of the


**Figure 8:** Preparing the f/1 meniscus primary to leave Schott.

**Figure 9:** Telescope support base. The central column takes the azimuth encoder, the inner ring is the pier on which the telescope itself will be supported, and the enclosure will sit on the outer wall. The VLT on Cerro Paranal can be seen in the background.

**Table 3:** Anticipated performance with IR camera.

| IR camera Band | *Y* | *J* | *H* | *Ks* |
|---|---|---|---|---|
| Assumed Sky Brightness mag /arcsec | 17.2 | 16.0 | 14.1 | 13.0 |
| Assumed Extinction coefficient mag /airmass | 0.05 | 0.1 | 0.08 | 0.08 |
| Sensitivity 5σ 15 min limiting (Vega=0) mag | 22.5 | 22.2 | 21.0 | 20.0 |

secondary by sending signals to a hexapod secondary mirror support system provided by NTE SA of Barcelona.

## Site & Enclosure

As there was not enough space to fit VISTA on the Cerro Paranal summit as originally envisaged, the "NTT peak", which is ~1,500m north-east of the VLT, was assigned to VISTA. By February 2003 the summit was lowered by 5-m to a height of 2518m to produce a ~4,000m$^2$ platform on which to construct VISTA, and by June an asphalted road was constructed to the summit. This was accompanied by conduits to hold the necessary electrical, communications and other services needed at the summit. In July 2004 the foundations for all the buildings were in place and the circular base on which the enclosure will sit was completed (see Fig. 9).

The design of the enclosure is along similar principles to those of the VST to minimise seeing effects due to the enclosure. An auxiliary building will sit next to the enclosure to contain all the necessary equipment and materials for maintenance. There is space to store a second camera (if the visible camera is eventually funded) and some office space. The auxiliary building will also contain mirror washing and stripping facilities, and a coating plant. This has been contracted to Stainless Metalcraft, and will be capable of coating with protected silver because of its lower IR emissivity than traditional aluminium. Both the enclosure and auxiliary buildings are contracted to EIE (Mestre, Italy) who are also responsible for the enclosure for the VLT Survey Telescope.

## Expected Performance

Table 3 gives the anticipated 5σ 15 minute magnitudes on the Vega scale for photometry at 1.2 airmass in a 1.6 arcsec diameter software aperture, for a median site seeing of 0.66″ at 0.5µm, using the predicted system performance with protected silver coated mirrors, and assuming the given sky brightness and atmospheric extinction.

The survey speed actually achieved for large-area surveys depends on the limiting magnitudes sought, the detailed observing strategy used and the overheads for the various dithers, steps and readouts, and control activities needed. For large-area surveys the combination of VISTA's collecting area and field of view will make it the world's leading facility for large-area near-IR surveys from 2007.

## Acknowledgments

We thank: the Office of Science and Technology and the Higher Education Funding Council for England for funding through the Joint Infrastructure Fund; the Particle Physics and Astronomy Research Council for additional funds; the Particle Physics and Astronomy Research Council and their UK Astronomy Technology Centre for organizing the realization of VISTA through the VISTA Project Office, and ESO for providing the site and advice. None of this could have been achieved without the help of more than 50 people from the 18 Consortium Universities, ESO, and PPARC establishments who continue, with others, to work for the realization of VISTA, and who are too numerous to acknowledge individually.

VISTA is supported by a grant from the UK Joint Infrastructure Fund to Queen Mary University of London on behalf of the 18 University members of the VISTA Consortium of: Queen Mary University of London; Queen's University of Belfast; Universities of Birmingham; Cambridge; Cardiff University; Universities of Central Lancashire; Durham; Edinburgh; Hertfordshire; Keele University; Leicester University; Liverpool John Moores University; Universities of: Nottingham; Oxford; St Andrews; Southampton; Sussex; and University College London.

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# ALMA News

T. Wilson

The first edition of the European ALMA newsletter is now available at: http://www.eso.org/projects/alma/newsletter/

This contains information about progress in the planning and construction of the Atacama Large Millimeter Array. A staff consisting of Carlos De Breuck, Martin Zwaan, and Tom Wilson assembles and edits project information. The newsletter will appear quarterly, so the next edition will appear in October 2004.

In the the first edition are short descriptions of: the ALMA Construction site near San Pedro de Atacama; the ALMA Regional Centers (ARCs); new personnel; the current state of the antenna selection process; the plans for ALMA community day (Sept 24, 2004, in Garching); and upcoming events.

The newsletter can be viewed as a web page or can be downloaded as a PDF file. You can also add yourself to the mailing list by sending an email to: majordomo@eso.org with "*subscribe alma-newsletter*" in the first line of the body. You will then receive email announcements when new editions become available.

# La Silla News

L. Germany

It is with a very heavy heart that I have had to bid farewell to La Silla after my four years there as an ESO fellow. I have really enjoyed the work, my colleagues, and meeting a substantial fraction of the European observational community during that time.

Arriving to fill the service queues at the 2p2m is a new OPA, Mauro Stefanon. Mauro is not a stranger to La Silla Observatory – he was involved in setting up the REM project. We welcome him back and wish him well for his year as part of *SciOps*.

# Gasgano & ESO VIMOS Pipeline Released

Carlo Izzo[1], Nick Kornweibel[1], Derek Mc Kay[1,2], Ralf Palsa[1], Michele Peron[1], Mark Taylor[3]

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[2]Rutherford Appleton Laboratory, Didcot, UK
[3]Starlink, Bristol University, UK

In collaboration with instrument consortia, the Data Flow Systems Department (DFS) of the Data Management and Operation Division is implementing data reduction pipelines for the most commonly used VLT/VLTI instrument modes. These data reduction pipelines have the following three main purposes:

- Data quality control - pipelines are used to produce the quantitative information necessary to monitor instrument performance.
- Master calibration product creation - pipelines are used to produce master calibration products (e.g. combined bias frames, super-flats, wavelength dispersion solutions).
- Science product creation - using pipeline-generated master calibration products, science products are produced for supported instrument modes (e.g. combined ISAAC jitter stacks; bias-corrected, flat-fielded FORS images, wavelength-calibrated UVES spectra). The accuracy of the science products is limited by the quality of the available master calibration products and by the algorithmic implementation of the pipelines themselves. In particular, adopted automatic reduction strategies may not be suitable or optimal for all scientific goals.

Even though the main focus of the pipeline recipe development has been, and remains, VLT science operation support, ESO is endeavoring to release all operational instrument pipelines to the community as rapidly as possible. Instrument pipelines consist of a set of data processing modules that can be called from the command line, from the automatic data management tools available on Paranal or from *Gasgano*.

Gasgano is a data management tool that has been available on Paranal and as a desktop application for several years. It simplifies the data organization process and allows file classification tasks such as: "What kind of data am I?", e.g. BIAS, "to which group do I belong?", e.g. to a particular Observation Block or template. Gasgano also makes the association of appropriate calibration files with science frames easier. The next logical step in the development of Gasgano was to extend its functionality to allow pipeline recipes to be executed directly on a set of user selected files. This upgrade has been completed by the DFS in the past year.

In addition to extending Gasgano, DFS has also started the development of a set of pipeline recipes for the IFU mode of VIMOS. The main requirements were to develop recipes which could be executed in a robust and automatic way, to support all existing grisms, to provide the operational teams with the information required to assess the quality of the observations and the health of the instrument and, last but not least, to be Gasgano compliant enabling astronomers to reduce their own data at their home institute. The first release of the IFU recipes has been operational on Paranal since May 2004.

In the middle of July 2004, the VIMOS pipeline recipes, including IFU support as well as imaging and MOS components based on the code delivered by the VIRMOS consortium, were released to the public together with Gasgano and are available for the community from the ESO web site as a bundled package.

The following sections summarise the technical capabilities of the Gasgano interface and provide an overview of the reduction strategy adopted by the pipeline recipes for the processing of VIMOS IFU data.

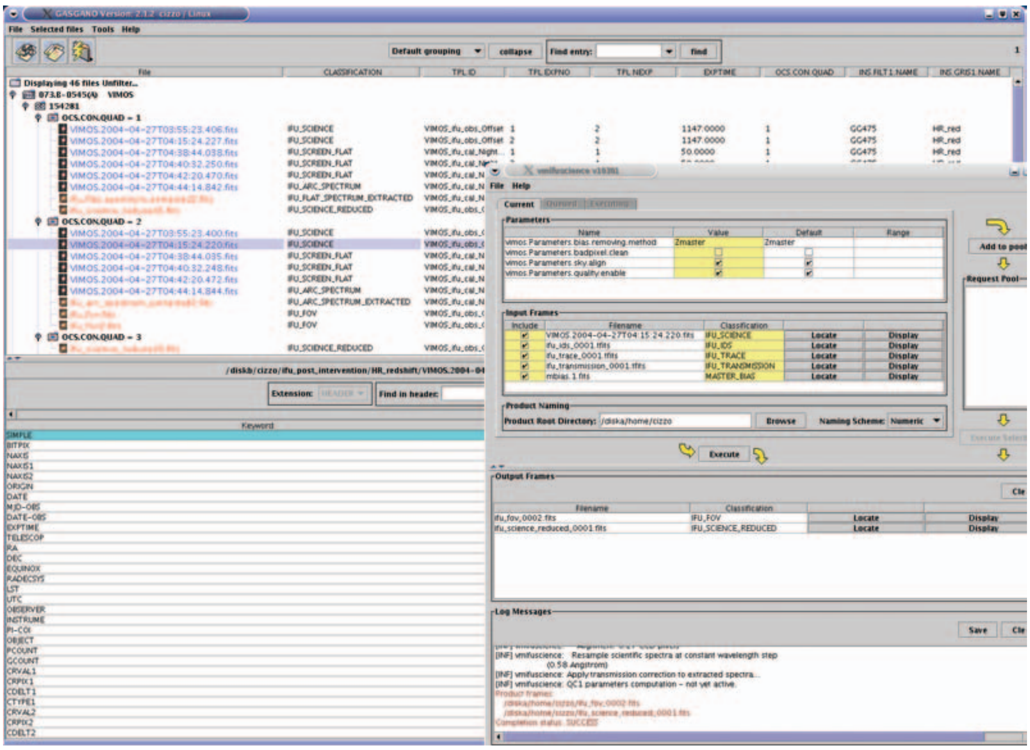


**Figure 1:** Gasgano main window and recipe panel. A set of IFU frames are loaded into the main panel. The recipe panel is opened with the recipe *vmifuscience* loaded. A science exposure is being processed using a number of calibration frames. The resulting log file is displayed at the bottom of the panel.

## Gasgano

Gasgano provides a means to automatically identify and classify FITS files (e.g. BIAS, FLAT, SCIENCE). Classification rules for the VLT instruments are part of the distribution package. Gasgano also automatically groups files located on a specified set of directories in a tree structure based on the Run ID and Observation ID of the files as well as additional instrument specific keywords. Gasgano allows the user to view and search all the relevant information in a file and displays FITS files and keyword values from the headers, and it provides the user with an interface to pipeline recipes. The user selects the file(s) to be reduced and the appropriate recipe, launches the recipe panel and configures the execution of the data reduction procedure by entering parameters. The recipe can be executed directly from the panel, the log files reviewed and the generated products visualized. Figure 1 shows the main Gasgano window as well as the recipe panel after loading a VIMOS data set and selecting the *vmifuscience* recipe.

## VIMOS IFU pipeline recipes

The VIMOS IFU pipeline consists of two main recipes, *vmifucalib* and *vmifuscience*, to process calibration and science data respectively. The recipe *vmifucalib* determines the spectral extraction mask, the dispersion solution and the fibre relative transmission correction. The results of this recipe are used by the recipe *vmifuscience* which in turn produces the extracted, wavelength calibrated and transmission corrected science spectra, plus an image of the field of view of a single VIMOS quadrant reconstructed from the extracted spectra by integrating over a predefined wavelength range.

For a complete processing of a scientific IFU exposure, three types of data are required by the pipeline: one or more flat field lamp exposures, an arc lamp exposure, and a science exposure.

In addition the software assumes that flat-fields and arc-lamp exposures are obtained almost simultaneously, without moving the instrument between exposures. This is to ensure that the spectral extraction parameters obtained by processing the flat-field exposures are still valid for the arc-lamp exposure and can be applied directly.

The spectral extraction mask is created from the flat-field exposure by identifying the spectra, i.e. the association of a spectrum on the CCD with a particular fibre and the subsequent tracing of the spectra along the dispersion direction on the CCD. The fibres are identified using a cross-correlation technique which requires a preexisting and certified fibre identification as reference. Tracing the spectra is also used to determine dead fibres (a fibre which cannot be traced is considered dead). The spectral trace is modeled by a low order polynomial. The accuracy of the tracing is typically 0.01 pixel.

The spectral extraction is based on an empirical spectral profile which has been constructed by examining the half-profiles of the first and last spectrum of each 80 fibres block of each pseudo-slit. The larger gap between the last fibre of a block and the first fibre of the next one allows the determination of the profile down to the background level. Because of the spectral curvature, a different sampling of the fibre profile is available at different positions along the dispersion direction. An example of such a empirical spectral profile is shown in Fig. 2. The obtained profile shows a negligible colour dependency (less than 2%); however,

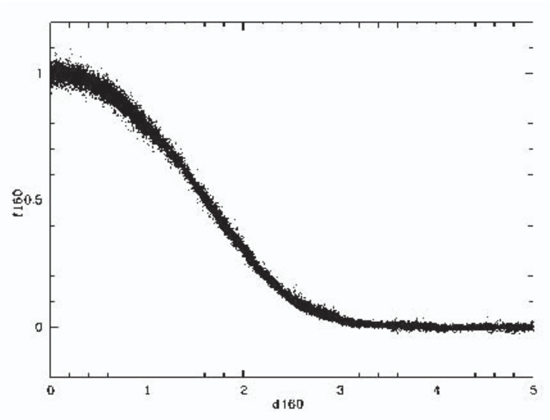
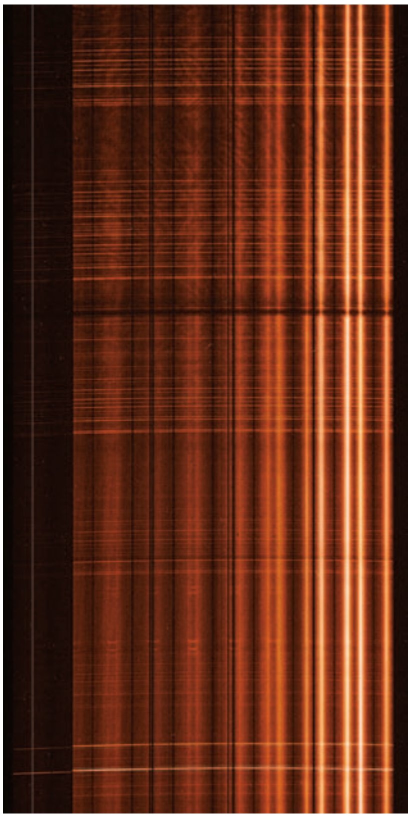
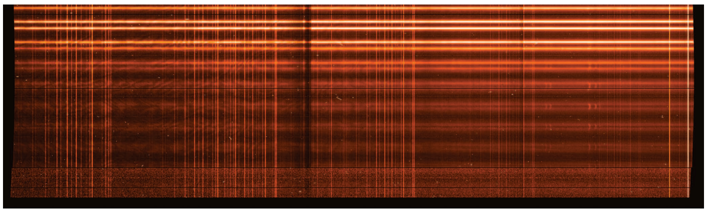



**Figure 2:** Data (about 24000 pixel values) from which the empirical fibre profile has been constructed for one fibre spectrum obtained with the HR_orange grism





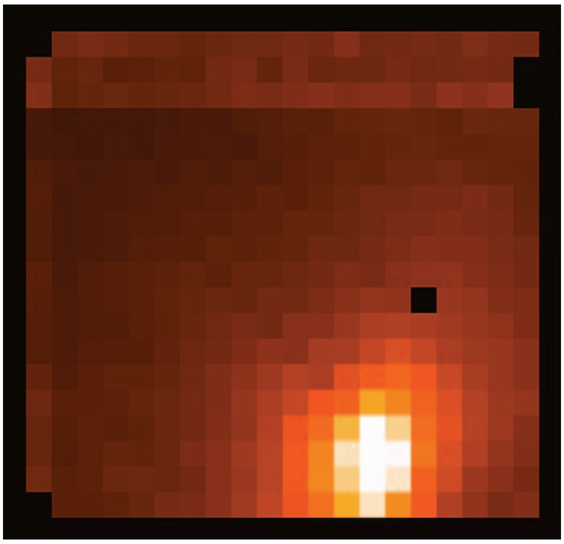


**Figure 3:** Raw spectra (left) of an IFU observation (quadrant two) obtained using the high resolution grism HR_red. The dark area on the left is due to the lower transmission of those fibres. The extracted spectra (top right) has been wavelength calibrated and corrected for the relative fibre transmission effects. The noisy area at the bottom of the image corresponds to the dark area on the left of the corresponding raw image. The reconstructed image (bottom right) is also a product of the pipeline

profiles obtained from different fibres show differences, which may, in the future, be taken into account by a parameterised model of the profile. The currently implemented spectrum extraction algorithm uses only the values of the 3 pixels closest to the fibre centroid position, corrected for the profile shape and averaged, since up to 1.5 pixels from the centroid position, the cross-talk contamination by nearby fibres can be neglected.

The wavelength calibration is carried out on the extracted arc-lamp spectra. For high and medium resolution spectra an accuracy of 0.2 pixels is achieved, while for low resolution spectra the accuracy is approximately 0.5 pixels because of the multiplexing of spectra which leads to systematic errors due to the contamination of adjacent spectra along the dispersion direction.

When science observations are processed the spectral extraction mask is aligned to the science exposure using the brightest spectra in the science exposure as a reference. This compensates for changes in the positions of the science spectra on the CCD with respect to the positions of the flat-field spectra. Offsets along the dispersion direction are corrected by adjusting the dispersion solution computed by *vmifucalib* to the position of the selected sky lines. Using a single spectrum of the science exposure is sufficient to achieve a mask alignment accuracy of 0.1 pixel for all fibres. With a fibre-to-fibre distance of about 5 pixels in the direction perpendicular to the dispersion, there is a maximum displacement of about 2 pixels in that direction that can be corrected for. Should these displacements be larger (e.g. because of flexures due to a large rotation of the instrument or changes in the mechanical configuration), the fibres may not be correctly identified and the spectral extraction mask will not be correctly aligned.

Finally the extracted science spectra are corrected for the differences in the fibre transmission where the correction factor is computed from the flat-field spectra by integration over a fixed wavelength range (avoiding the 0th order contamination in the case of multiplexed spectra), normalised to the median of these integrated fluxes. The recipe *vmifuscience* does not currently apply a flat-field correction to the extracted science spectra. Instead, the extracted flat-field spectra are provided as an additional product, which can be used for an approximate flat-field correction, if desired. Figure 3 shows one quadrant of an IFU raw observation, the extracted spectra as well as the reconstructed image produced by the pipeline.

A description of how the IFU recipes are used by the Quality Control group in Garching can be found at http://www.eso.org/qc under the VIMOS section.

## Getting the software

Gasgano & the VIMOS recipes can be downloaded together with user manuals from (www.eso.org/observing/gasgano/vimos-pipe-recipes.html). We look forward to the extensive use of these new data reduction tools among the community of investigators who have obtained VIMOS data. Your feedback is welcome at *usg-help@eso.org* and will help us to improve our tools.

## Acknowledgments

The software package on which the VIMOS pipeline is based was developed by the VIRMOS consortium and is still the foundation of the current ESO VIMOS imaging and MOS pipelines. A version of the IFU data reduction routines was also delivered by the consortium but not adopted by ESO because it was not suitable for automatic pipeline processing of all supported configurations. In particular we would like to thank Paola Sartoretti (DMD) who has been extensively testing the pipeline recipes and was a continuous source of good ideas for improving the algorithms. We are grateful to Sandro D'Odorico (INS) for useful advice and to Gianni Marconi, Stephane Brillant and Stefano Bagnulo (ESO-Paranal) for their patience, the very good collaboration and constant support. The feedback we received in numerous discussions with our "beta testers", Martino Romaniello (DMD), Markus Kissler-Patig (INS) and Harald Kuntschner was very much appreciated. Valuable suggestions on IFU data reduction strategies were provided by Eric Emsellem and Arlette Rousset-Pecontal (Centre de Recherche Astronomique de Lyon) and by Martin Roth (Astrophysikalisches Institut Potsdam).

Nico Housen/ESO

**The Milky Way above La Silla.** To the left is the decommisioned 15-metre dish of the Swedish-ESO Submillimetre Telescope (SEST), and on the right in the background is the dome of the ESO 3.6-metre telescope, at the highest point of the mountain. The southern Milky Way is seen along the right border of the SEST and above the 3.6 metre telescope. In the highly polished antenna dish of the SEST there is a upside-down reflection of the sky and the horizon behind the photographer. The yellow area of light to the right is the reflection of the city lights of La Serena, about 100 km away and too faint to disturb observations of celestial objects high above La Silla. Photo: *Nico Housen (ESO) – ESO PR Photo 27/04.*

# The Birth of a Massive Star

*New results from ESO and IRAM suggest that massive stars form in the same way as their low-mass counterparts. In the Omega nebula, a young stellar object of more than ten solar masses is surrounded by a huge rotating disc with at least 100 solar masses of gas and dust. Part of the gas that falls onto the growing star is ejected perpendicularly to the disc, producing a bipolar jet and an hourglass shaped nebula.*

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[3]European Southern Observatory

There is general consensus that stars condense from clouds of gas and dust within a mass range from about a tenth to a hundred solar masses. The formation of stars up to ten solar masses (1 solar mass [$M_\odot$] = 1.989 × $10^{33}$g) can be explained by the gravitational collapse of a cloud fragment and the subsequent accretion from the surrounding interstellar medium onto a so-called protostar (Shu et al. 1987). The associated density enhancement of the order of $10^8$ implies that the protostar becomes optically thick at some point and starts to increase its temperature: the object is on its way to becoming a low-mass hydrogen burning star. Closely connected with the accretion phase is the formation of a circumstellar disc which provides the necessary material and, eventually, the conditions for the creation of planets and life. Another associated phenomenon is a bipolar outflow of mass that expands perpendicularly to the plane of the disc and is believed to be a direct consequence of the accretion process. Most of the above theoretically expected stages could be verified observationally, and as such the formation of low-mass stars is a fairly well-understood process.

Theoretical considerations, however, show that the accretion scenario may work only for stars of up to about 10 $M_\odot$ (Wolfire & Cassinelli 1987). Beyond that, a massive protostar evolves so rapidly into a hydrogen burning core that its radiation pressure onto the in-falling dust and gas can halt or even reverse the accretion process, and thus can prevent the formation of stars of higher mass. Details depend on the geometry of the parent cloud and on the physical properties of the dust grains. Given this theoretical limit of 10 $M_\odot$ and the observational fact that most massive stars are born in dense clusters where they occur as multiple systems, it was suggested that high-mass stars might be the result of the merging of lower mass stars (Bonnell et al. 1998). This merging process requires extremely high stellar densities which have never been observed in today's star clusters, but which could have existed during their early history. Recently, theoretical calculations have shown that – depending on the original cloud mass and the opacity of the grains – stars between 20 and 40 $M_\odot$ can in principle be formed via accretion through a disc (Yorke & Sonnhalter 2002).

Discriminating between both formation scenarios observationally is rather difficult due to several reasons: first, high-mass stars are extremely rare objects. Second, massive stars are generally far away and deeply embedded within dust clouds which diminishes their light substantially. Third, they usually occur in the centres of stellar clusters where source confusion is a major problem. Finally, their lifetimes are only a few million years and their early evolution is accordingly short. In particular, massive stars start the hydrogen burning process at a point where they still have not yet reached their final mass. Thus, depending on the formation scenario, one either has to observe the merging process between two or more young stars or one has to witness the accretion through a disc; both observations require high spatial resolution and kinematic information that is almost impossible to achieve with present day instrumentation.

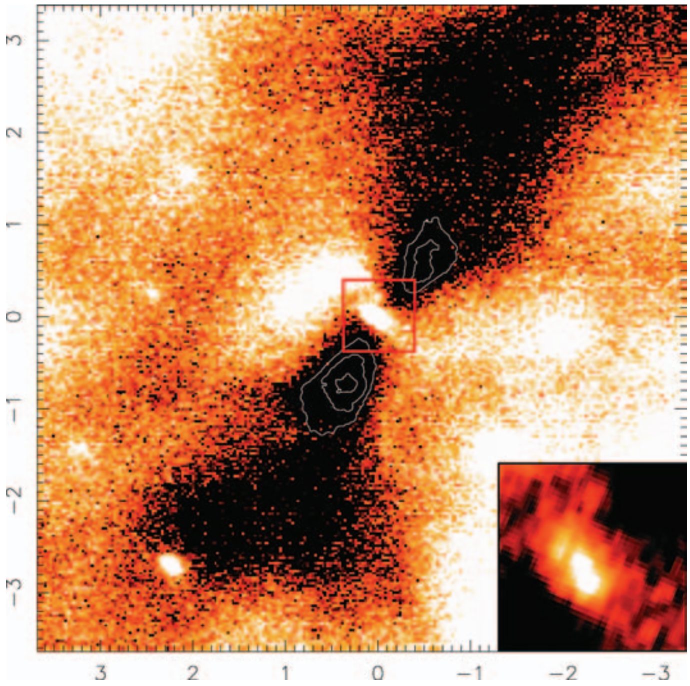


**Figure 2:** High-resolution adaptive optics 2.2 µm image of the accretion disc. The field size is about 7 × 7 arc seconds; the effective spatial resolution is about 0.057 arc seconds. The disc silhouette is seen in absorption against the bright background of the HII region; the white contours delineate the densest parts of the inner disc. A bipolar outflow emerges from the central object. The insert shows the inner region in more detail suggesting that there is an elongated – possibly binary – source of about 450 × 250 AU whose major axis is tilted by about 15 degrees with respect to the disc axis.

## Looking into the cradle

The Omega nebula (M 17) is a well-known region of star formation in our Galaxy (Chini & Wargau 1998) at a distance of 2200 parsec (1 parsec = 3.086 × $10^{18}$ cm). Figure 1 is part of a three-colour infrared mosaic of the area which was the initial observation leading to our investigation. It consists of 9 individual, partly overlapping fields at 1.25, 1.65 and 2.2 µm and was obtained with the infrared camera ISAAC at the ESO Very Large Telescope (VLT) in September 2002. The composite image shows a dense cluster of young stars embedded in clouds of gas and dust with unprecedented detail and depth; several high-mass stars, whose total energy output exceeds that of our sun by almost a factor of $10^7$ ionise the surrounding hydrogen gas. Adjacent to its south-western edge, there is a cloud of molecular gas which is a site of ongoing star formation. Due to the sensitivity of our measurements the molecular cloud was largely transparent and the nebular emission of the HII region could shine through the dust. Against this nebular background, we discovered a tremendous opaque silhouette, associated with an hourglass shaped nebula and surrounded by a larger disrupting dust envelope. As we will show in the following, this object resembles theoretical predictions of a newly forming high-mass star surrounded by a huge accretion disc and accompanied by an energetic bipolar mass outflow.

◀ **Figure 1:** Three-colour ISAAC mosaic of the star forming region M 17. The field size is about 7 × 7 arc minutes, the effective spatial resolution is about 0.6 arc seconds; wavelength coding: blue 1.25 µm, green 1.65 µm, red 2.2 µm. A similar image from SOFI was released some years ago as ESO-Press-Photo 24/00.

## The accretion disc

After the discovery of the object, we applied for discretionary time in order to study the morphology of the system in more detail. In June 2003 we obtained three extremely rewarding hours with NAOS-CONICA at the VLT; Figure 2 shows the corresponding high-resolution 2.2 µm image of the new object. Due to the adaptive optics technique – which eliminates atmospheric turbulence – the morphology of the silhouette was nicely resolved into two triangular shaped dust lanes that resemble a flared disc, seen nearly edge-on. The disc has a diameter of about 20,000 AU (1 astronomical unit [AU] = 1.496 × $10^{13}$ cm) which is about 200 times the size of our solar system and by far the largest circumstellar disc ever detected. When going from the centre towards its outer edges the disc widens substantially. Using the background nebular light as a homogenous source of illumination, the extinction and thus the column density of interstellar matter within the disc can be

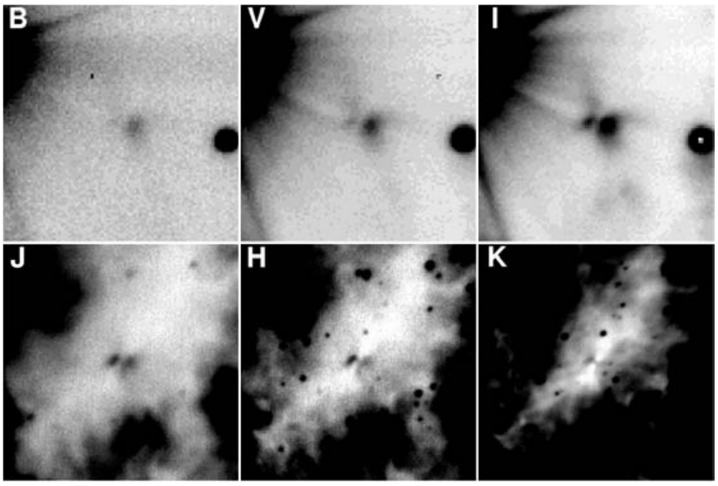


**Figure 3:** Multi-colour sequence of the hourglass-shaped nebula. The change in morphology is displayed as a function of wavelength; the upper row was taken at optical (0.44, 0.55, 0.78 µm), the lower row at infrared (1.25, 1.65, 2.2 µm) wavebands. In the upper row, the nebula is dominated by reflected light from a bipolar cavity; the south-western (right) lobe is much stronger while the north-eastern (left) lobe is obscured by the disc. The lower row is dominated by more compact emission from a bipolar jet (see also Fig. 2). Each frame has a size of 30 × 30 arc seconds.

determined at each point along the line of sight. The maximum column density of hydrogen inferred from the optical depth at 2.2 µm is ~ $6 \times 10^{22}$ atoms $cm^{-2}$; the associated dust produces a visual obscuration of a factor of $10^{23}$ towards the central object.

Further physical properties concerning the mass and the kinematics of the disc and its surroundings can be obtained from millimetre observations. We have observed the region in molecular line transitions of several CO isotopomeres like $^{12}CO$, $^{13}CO$ and $C^{18}O$ and in the adjacent continuum at 1.3 and 3 mm with the IRAM Plateau de Bure Interferometer. The molecular spectroscopy indicates that the system rotates with a velocity of about 0.85 km/s at a radius of 15,400 AU; its north-western part is approaching the observer. From $^{13}CO$ we derive a gas mass of at least 100 $M_{\odot}$.

## The bipolar nebula

Perpendicular to the plane of the disc there is an hourglass shaped nebula visible throughout the entire spectral range from 0.4 to 2.2 µm; Figure 3 shows a corresponding sequence of images, where the optical data have been obtained with EMMI at the ESO NTT. Obviously, the two nebular lobes show different wavelength dependent intensities. The fact that optical light is detectable throughout the huge amount of foreground extinction can only be explained if the emission is – at least partly – due to reflected light scattered by dust grains. The nebular light consists of two separate components, a diffuse extended shimmer and a more compact emission in the central region.

Firstly, the diffuse emission – particularly prominent at optical wavelengths – is symmetric and seems to mark the walls of an hourglass shaped cavity. It extends at least up to $5 \times 10^{17}$ cm above the plane of the disc towards both sides with a maximum width of about the same size (see Fig. 3.); the image of the NE lobe is fainter and somewhat distorted by stray light from a nearby bright star. The emission of this hourglass feature is due to scattered light from the walls of a bipolar cavity that has probably been cleared by an energetic mass outflow. From the fact that the NE lobe becomes brighter with increasing wavelength while the intensity of the SW lobe remains almost constant we conclude that the former suffers from more extinction. This suggests an inclination of the disc of about 15 degrees with respect to the line of sight which hides the NE lobe partly behind the disc. Vice versa we are facing the disc slightly from below and thus are looking into the SW cavity. The hourglass morphology of the SW cavity is supported by two curved dusty ejecta that end in typical bow-shocks as a result of their interaction with the ambient medium. This picture is further corroborated by our CO data which, in part, also seem to trace the walls of both cavities.

Secondly, there is a more compact emission at both sides of the innermost disc. Both blobs show strong wavelength dependence with the western one being bright in the optical and almost vanishing in the infrared; at about 1 µm the clumps are of equal intensity and attain simultaneously their maximum brightness. Beyond 1 µm the eastern blob is stronger by 10% at *J* and *K* and by 40% at *H*. This is in contrast to what one would expect from the extinction which is higher along the eastern line of sight due to the inclination of the disc. We therefore conclude that there must be intrinsic intensity differences between the two features which are most probably caused by an asymmetric outflow. Likewise, we speculate that additional line emission contributes to the different morphological shapes.

The eastern outflow shows a pronounced morphology which is nicely resolved by our adaptive optics image (Fig. 2); it seems to originate close to the central object and resembles a precessing flow that turns over shortly after leaving the innermost region; farther out the orientation of the flow axis is almost parallel to the disc plane. The much fainter western flow is more diffuse and has an angle of about 45° with respect to the disc plane.

In order to explore the origin of the optical nebula, we have taken spectra between 0.4 and 0.9 µm that cover both cavities and the flows (Fig. 4); the spectra were obtained

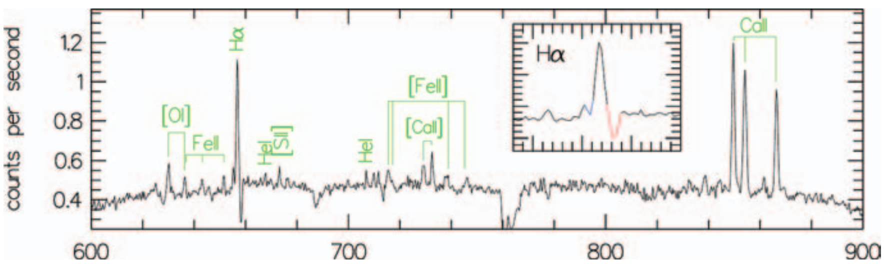


**Figure 4:** Optical spectrum of the bipolar nebula. The slit was oriented perpendicular to the disc plane. The emission from the HII region has been subtracted by averaging several offset positions. The various emission lines in the reflected light indicate evidence for ongoing accretion.

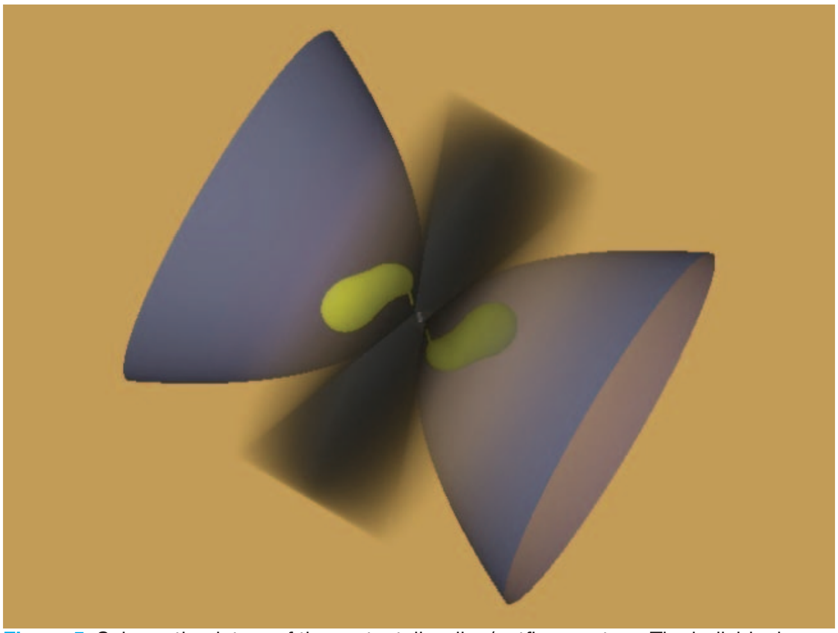

**Figure 5:** Schematic picture of the protostellar disc/outflow system. The individual components are drawn to scale with the suggested orientation to the observer; accretion disc (black), hourglass shaped cavity (blue), bipolar precessing jet (yellow), elongated central object (white).

in April/June 2003 with EFOSC2 at the ESO 3.6 m and with EMMI at the ESO NTT. The accuracy of the wavelength calibration allows sampling velocities down to 40 km/s. The spectrum is dominated by the emission lines of Hα, the Ca II triplet 8498, 8542 and 8662 Å, and He I 6678 Å which provide unquestionable evidence for an ongoing accretion process (Hartmann et al. 1994, Muzerolle et al. 1998). Particularly the Hα line is extremely broad and shows a deep blue-shifted absorption as well as an inverse P Cygni profile; blue-shifted absorption components in permitted lines are typically associated with accretion disc-driven outflows (e.g. Calvet 1997). The same is true for forbidden emission lines such as [O I] 6300 Å and [S II] 6731 Å which are also present in our spectrum. Numerous permitted and forbidden Fe II lines which are velocity-shifted by ±120 km/s are clear signposts for high velocity dissociative shocks with velocities of more than 50 km/s. Recent spectroscopy with UVES in July 2004 shows evidence for a variation in the Hα line; the line profile varies with time and as a function of the location across the lobes. Obviously, the infall and outflow of matter is not a continuous process but the protostar takes a morsel of fuel every now and then.

## The nature of the protostar

As mentioned above, the disc is deeply embedded in the molecular cloud probably behind a visual extinction of about 50 magnitudes if we take the results from our infrared photometry for stars in the immediate neighbourhood of the system as a guideline. The dust within the disc produces another contribution of about 50 magnitudes toward its centre which makes it impossible to obtain any optical information about the accreting protostellar object. Nevertheless, Fig. 2 shows an elongated 2.2 µm emission feature at the expected position of the forming star whose inclination is different from the orientation of the channel produced by the outflow, i.e. from the inner gap of the disc. One may speculate whether this elongated feature marks the starting point of the precessing massive outflow or whether it originates from a binary system that is currently born from a common accretion disc. NACO *JHKLM* measurements are scheduled for the current period to clarify the nature of this object in more detail. Assuming that the central emission is due to direct stellar light we derive an absolute infrared brightness of $K \sim -2.5$ magnitudes which would correspond to a main sequence star of about 20 solar masses and a temperature of 35,000 K. An independent mass estimate from dynamical considerations, concerning the rotation of the molecular disc, yields a mass of about 15 solar masses for the central gravitational object. Given the fact that the accretion process is still active, and that the gas reservoir of the disc still allows for a substantial mass gain, we argue that in the present case a massive protostar is on its way to becoming an O-type star. Theoretical calculations (Yorke & Sonnhalter, 2002) show that an initial gas cloud of 60 to 120 $M_\odot$ evolves into a star between 33 and 43 $M_\odot$ while the remaining mass is ejected into the interstellar medium.

From all this evidence we conclude that a massive star is currently forming via accretion through a disc while the associated energetic mass outflow disrupts the surrounding environment and ejects part of the accreted material into the ambient medium. Our observations show – for the very first time – all theoretically predicted ingredients of the star formation process directly and simultaneously with a single object and therefore improve our current understanding of such an event tremendously (Chini et al. 2004). The schematic picture of Fig. 4 summarises the individual components as revealed by our different observing techniques. A central protostar (maybe even a binary system), is surrounded by a flared, slowly rotating disc from which it accretes mass along a reconnected magnetospheric field. A considerable fraction of the transferred mass is accelerated from the polar regions of the protostar/disc interface into opposite directions along the open stellar magnetic field. This reconnection-driven jet is further accelerated magneto-centrifugally due to stellar rotation and excavates the ambient medium. Eventually, a bipolar high-velocity neutral wind forms an hourglass-like cavity which reflects light from the very inner regions of the system. Further out this neutral wind drives the observed molecular bipolar flow.

In more general terms, our data show for the first time that massive star formation via accretion is a realistic scenario. Large accretion discs can obviously withstand the harsh environment of a dense stellar cluster and are not disrupted by tidal forces. Likewise, the ionising radiation and the stellar winds of nearby massive stars do not disturb the accretion process. As a by-product of our results it follows that the star formation process which started some million years ago in M17 is still continuing and is currently producing a second generation of massive stars. Thus, it is likely that once star formation has been started in a molecular cloud, the parent generation of stars triggers the creation of a new generation.


## Acknowledgements

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# The Stellar Content of the Hamburg/ESO Survey

We report on the exploitation of the stellar content of the Hamburg/ESO objective-prism survey (HES), which covers the total southern extragalactic sky down to $B \approx 17.5$. Quantitative criteria have been developed for selecting interesting stars in the digital HES database, containing almost 5 million spectra. We give an overview of ongoing projects directed at finding extremely metal-poor stars, field-horizontal branch A-type stars, carbon stars, and white dwarfs. Highlights of these efforts are the discovery of more than 200 new extremely metal-poor ([Fe/H] < –3.0) stars, including the most metal-poor star known so far, HE0107-5240 ([Fe/H] = –5.3), and the discovery of many new magnetic DA and DB white dwarfs and other peculiar white dwarfs.

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The Hamburg/ESO objective-prism survey (HES) was carried out with the ESO-Schmidt telescope from 1990 to 1998 in the course of a Key Programme (No. 145.B-0009; P.I.: Reimers). The final survey area consists of 380 fields covering a nominal area of 9500 square degrees, i.e., the total southern extragalactic sky. The plates have been digitized at Hamburger Sternwarte, yielding a data base of almost 5 million spectra of objects in the magnitude range $10 \lesssim B \lesssim 17.5$. The driving aim of the HES during its constitution was the pursuit of a wide angle survey for the brightest quasars in the southern hemisphere (see Reimers 1990; Reimers & Wisotzki 1997). The digital database enabled us to efficiently select quasar candidates using various colour criteria supplemented by spectral feature detection (Wisotzki et al. 2000). Quasar candidates were followed up mostly by ESO telescopes, which resulted in the measurement of over 2000 quasar redshifts, providing by far the largest existing homogeneous set of bright quasars in the south. Besides constraining the bright end of the QSO luminosity function, the survey yielded highlights such as the discovery of several gravitationally lensed quasars, and the first detection of the epoch of He II reionization.

It was realized right from the start that the spectral resolution of the objective-prism spectra would be sufficient for stellar survey work as well. The spectral resolution is typically 1 nm at Ca II K, depending on the seeing conditions during the observations of the plates. The resolution of the spectra proved quite useful, at first, mainly to *eliminate* the stellar contamination of quasar candidate samples. Notice that already a pure UV excess selected sample in the magnitude range of the HES has more than 90% stars and less than 10% quasars. This ratio increases further if the selection includes also non-UV-excess objects. Yet, the strong Balmer lines of DA white dwarfs and Field Horizontal-Branch A-type (FHB/A) stars are easily detected already in the digital prism spectra, but also e.g. the much weaker He I lines of DB white dwarfs and hot subdwarfs, or the Ca II H and K lines of cool stars (see Figs. 1 and 3). Recognizing these features helped enormously to achieve a hitherto

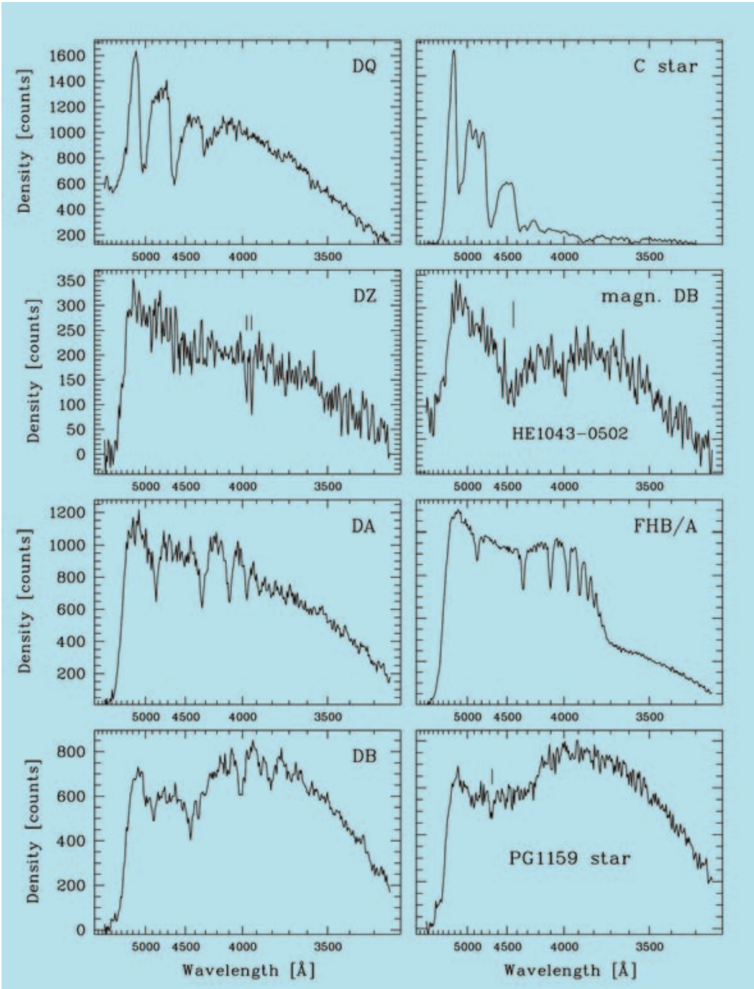


**Figure 1:** Sample spectra of various stellar objects detected in the Hamburg/ESO survey. Note that wavelength is decreasing from left to right. The sharp drop at about 5400 Å is due to the sensitivity cutoff of the photographic emulsion (IIIa-J) of the HES objective-prism plates.

unparalleled (for an optical quasar survey) follow-up efficiency of ~70%, without any compromises in completeness (Wisotzki et al. 2000). However, one person's leftovers may become another person's wealth, in this case a wealth of interesting stars. It was decided that there was so much potential information in this survey for studies of the stellar populations of the Milky Way that a dedicated effort was certainly desirable, and we developed quantitative methods for the selection of interesting stellar objects in the HES. We started by exploring techniques of automatic spectral classification applied to the entire digital HES data base (Christlieb et al. 2002). Our work subsequently focused on searching for specific types of rare stars with efficient selection techniques.

Here we describe some of the most successful projects that emerged: selection of metal-poor stars, carbon stars, FHB/A stars, and white dwarfs. Other projects which we do not discuss here are searches for T Tauri stars, subdwarf B and O stars, and cataclysmic variable stars.

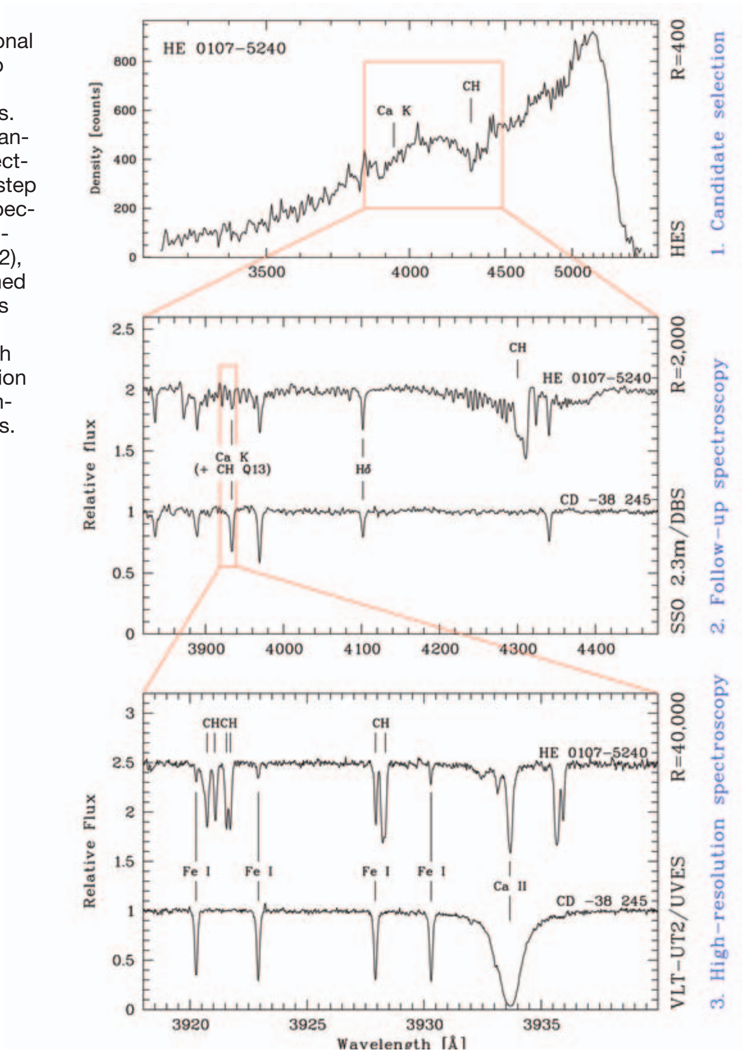


**Figure 2:** The three observational steps leading to abundances of metal-poor stars. About 10,000 candidates are selected in the HES (step 1). These are spectroscopically followed up (step 2), yielding confirmed metal-poor stars which are then observed at high spectral resolution (step 3) with 8m-class telescopes.

## Stellar Archaeology and Near-Field Cosmology with Metal-Poor Stars

Metal-poor stars preserve in their atmospheres, to a large extent, the chemical composition of the gas clouds from which they formed. They can hence be used for "stellar archaeology": their abundance patterns provide information on the first, now extinct generation of massive stars which ended their lives in supernova type-II (SN II) explosions. In particular, the most metal-poor stars constrain the yields of these SN II of Population III stars (i.e., stars with the chemical composition of Big Bang material), and the mass-distribution of the first generation of stars. They also allow one to determine the nature and constrain the sites of nucleosynthesis processes such as the slow (s) and rapid (r) neutron-capture processes in the early Universe. There are also cosmological applications of metal-poor stars. Their ages provide an independent lower limit for the age of the Universe. Metal-poor stars with strong enrichment of elements produced in the r-process provide the opportunity to determine individual stellar ages using long-lived radioactive isotopes, such as $^{232}$Th (half-life 14.05Gyr) or $^{238}$U (4.468Gyr). By comparing the abundance ratio of one of these elements relative to a stable r-process element (e.g., Th/Eu or U/Eu) to the production ratio expected from theoretical r-process yields, the time elapsed since the nucleosynthesis event that produced these elements took place can be derived. Alternatively, U/Th can also be used as a "cosmo-chronometer" (Cayrel et al. 2001).

The convection zones of unevolved stars near the main-sequence turnoff are shallow enough to prevent lithium from being destroyed in deeper, hotter layers of the star. Therefore, it is thought that the Li abundances in the atmospheres of old, metal-poor turnoff stars reflect the Li abundance produced in Big Bang nucleosynthesis (BBN). Using BBN models, the baryon density of the Universe can be derived from the "Spite plateau" value of the Li abundance. However, a recent investigation based on 23 metal-poor stars in the range[1] $-3.6 <$ [Fe/H] $< -2.3$ has shown that the Spite plateau is actually not a plateau but exhibits a trend with [Fe/H]. The scatter around this trend is very small (i.e., $\sigma < 0.031$ dex) and fully accountable by measurement errors, not an intrinsic scatter (Ryan et al. 1999). The Li trend can be explained by galactic chemical evolution (i.e., Li might have been produced e.g. by Galactic cosmic-ray spallation). A larger sample of metal-poor turnoff stars extending to lower [Fe/H] would help to pin down the steepness of the Li trend more accurately and reduce the extrapolation to the primordial Li abundance.

The above reasons justify the investment of considerable amounts of telescope time (in addition to the survey itself) in finding more metal-poor stars and studying large samples of them in detail. In the HES, only *candidates* for metal-poor stars can be selected. These have to be confirmed by moderate-resolution follow-up spectroscopy before they can enter target lists for high-resolution spectroscopy (see Fig. 2 for sample spectra from these observational steps).

### Selection of Metal-Poor Candidates

A total of ~10,000 metal-poor candidates has been selected in the HES. Stars with a Ca II K line which is weaker than expected for a star with [Fe/H] = –2.5 at a given *B–V* colour are selected as candidates. *B–V* can be measured with an accuracy of 0.1mag from the HES objective-prism spectra (Christlieb et al. 2001a) and is therefore available for all HES stars. Figure 3 illustrates the selection procedure with three bright stars of similar temperature from the HK survey of Beers and collaborators (Beers et al. 1992) which have been rediscovered in the HES. One can clearly see the decreasing strength of Ca II K with decreasing [Fe/H].

[1] $[X/H] = \log_{10} [N(X)/N(H)]_* - \log_{10} [N(X)/N(H)]_\odot$ , and analogously for [X/Fe].

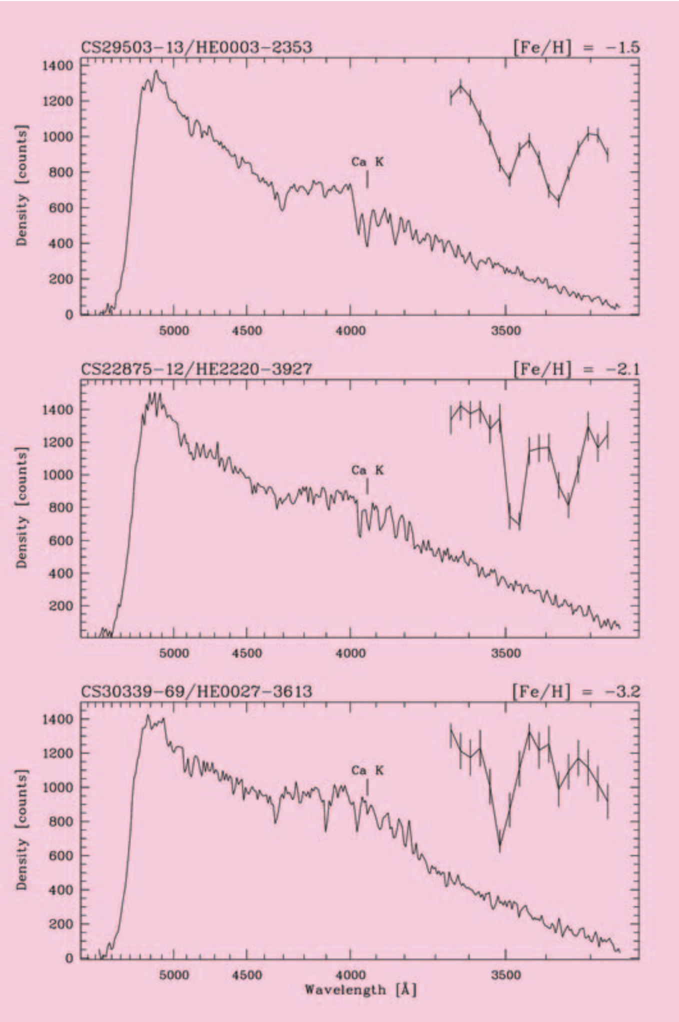


**Figure 3:** HES sample spectra of metal-poor stars. An enlargement of the spectral region covering Ca II H + Hε and Ca II K is shown in the upper right corner of each panel. The 1-σ noise level of each pixel of the digital objective-prism spectra is overplotted. In the spectrum of the bright (*B* = 14.9) star CS30339-69 = HE0027-3613, the Ca K line is barely detected even though the star has a metallicity as low as [Fe/H] = –3.2.

It is impossible to follow-up thousands of metal-poor candidates in single-slit mode at a single observatory, because typically only 20–40 stars can be observed in a clear night. Therefore we employ a variety of facilities in both hemispheres for this task.[2]

About half of the metal-poor candidates have been observed so far, and more than 200 stars have been confirmed to have [Fe/H] < –3.0. This trebles the total number of known stars in this metallicity regime from previously ~100 to now more than 300. In Fig. 4 we compare the metallicity distribution function (MDF) of a representative subset of the observed HES candidates with the MDF of the HK survey candidates. It can be seen that the fraction of stars at [Fe/H] > –2.0 is considerably lower in the HES, i.e., the candidate selection efficiency is much higher. While in the HK survey only 11% and 1% of the candidates are genuinely below [Fe/H] = –2.0 and [Fe/H] = –3.0, respectively, the efficiency for stars having unsaturated spectra in the HES is about a factor of five higher (Christlieb 2003). For the 1767 (partly) saturated HES stars in the magnitude range 10 ≲ B ≲ 14, the efficiency is still a factor of two higher than in the HK survey (Frebel et al., in preparation). The reasons are the higher quality of the HES spectra and the employment of an automated and quantitative selection as opposed to visual inspection of objective-prism plates using a binocular microscope.

High-resolution spectra of the confirmed metal-poor stars are being obtained with VLT/UVES, Keck/HIRES, Subaru/HDS and Magellan/MIKE. In the next two sections we present selected highlights from these efforts.

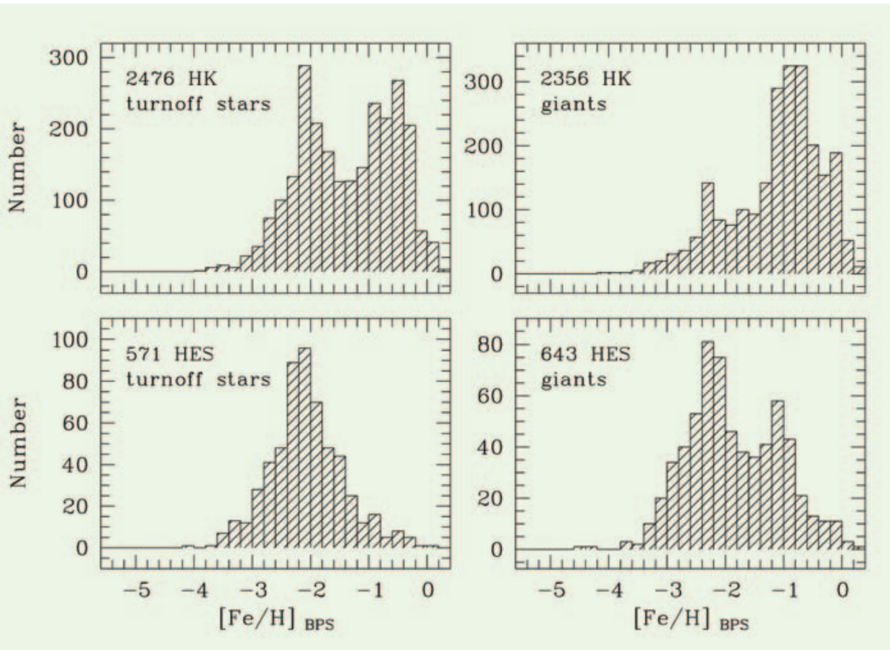


**Figure 4:** Metallicity distribution function of metal-poor candidates selected in the HK (upper panels) and HE (lower panels) surveys. Note the much smaller fraction of stars with [Fe/H] > –2.0 in the HES.

## HE0107-5240

For more than 20 years, it has been assumed that there is a low-metallicity "cutoff" in the metallicity distribution function of the galactic halo, at [Fe/H] ~ –4.0, i.e., 1/10,000 of the metallicity of the Sun (see Fig. 4). Two of the physical reasons that have been suggested to explain the absence of stars with [Fe/H] < –4.0 are pre-enrichment of the interstellar medium by supernovae of type II to [Fe/H] > –4.0, or suppression of low-mass star formation due to the absence of cooling mechanisms in ultra metal-poor gas clouds (see e.g. Bond 1981).

Hence it was rather surprising to discover HE0107-5240, a giant with [Fe/H] = –5.3 (Christlieb et al. 2002; see also ESO Press Release 19/02). This star was found during spectroscopic follow-up observations at the Siding Spring Observatory 2.3m. High-resolution spectra were obtained with VLT/UVES in 2001 and 2002. The elements

[2]This includes the ESO 3.6m/EFOSC2, SSO 2.3m/DBS, UK 1m-Schmidt/6dF, Magellan 6.5m/B&C, Palomar 200″/DS, CTIO and KPNO 4m/RCSPEC, and the 4m Anglo-Australian Telescope/RGO.

heavier than Na are depleted by amounts similar to that seen for Fe, while carbon and nitrogen are strongly enhanced with respect to iron and the Sun, by 3.7–4.0 and 2.3–2.6 dex, respectively. Na is also strongly enhanced ([Na/Fe] = +0.8 dex).

A lot of the discussion in the recent literature has focused on explaining the origin of the abundance pattern of HE0107-5240. Particularly interesting is the supernova model of Umeda & Nomoto (2003) of a Population III star of about 25 solar masses that explodes with low explosion energy ($E_{exp} = 3 \cdot 10^{50}$ erg) followed by mixing and fallback. It produces elemental yields that fit the overall abundance pattern of HE0107-5240 rather well, in particular the high C to N and light to heavy element ratios. However, the oxygen abundance predicted for HE0107-5240 is [O/Fe] = 3.0 dex, while Bessell et al. (2004) measure [O/Fe] = $2.3^{+0.2}_{-0.4}$ dex. It remains to be studied whether this disagreement can be reduced by modifying one of the free parameters of the Umeda & Nomoto model, e.g., the progenitor mass, and/or the mass coordinate range in which mixing occurs. One advantage of the Umeda & Nomoto pre-enrichment scenario is that it might solve the "star formation problem". While it is difficult to form a 0.8 solar mass star from a gas cloud with [Fe/H] = –5.3, the presence of a lot of carbon and oxygen would provide efficient cooling channels (Umeda & Nomoto 2003; Bromm & Loeb 2003).

It has also been argued that HE0107-5240 might even be a Population III star, i.e., a star originally consisting only of material produced in the Big Bang. The abundances of most heavy elements observed in HE0107-5240 are so low, and the age of the star presumably so large (on the order of the age of the Universe), that its abundances might have been severely changed by accretion from the interstellar medium (Christlieb et al. 2002; Shigeyama et al. 2003). The large amount of carbon, nitrogen and oxygen might have been accreted from a formerly more massive companion which is now a white dwarf (Christlieb et al. 2002; Suda et al. 2004). However, if it is assumed that there was no pre-enrichment of the gas cloud from which HE0107-5240 formed, it is unclear how the star could have formed.

Based on new calculations of the evolution of and nucleosynthesis in ultra metal-poor low-mass stars, two groups argued independently that self-enrichment of HE0107-5240 with CNO can be excluded (see Weiss et al. 2004, and references therein), because the predicted abundances of C and N are too large by several orders of magnitude; the predicted C/N ratio is close to 1, while 50 is observed; and the predicted $^{12}C/^{13}C$ isotopic ratios are about a factor of ten lower than the lower limit of 50 observed in HE0107-5240.

In summary, HE0107-5240 gives us the opportunity to learn about star formation processes in the early Universe, the first generation of stars exploding as supernovae, and stellar evolution at extremely-low metallicities. Therefore, its discovery has sparked a lot of new research. Some of the elements that we see in HE0107-5240 might be associated with the very first nucleosynthesis events in the Universe, occurring in the stars that formed only about 200 Myr after the Big Bang, according to recent results obtained with the Wilkinson Microwave Anisotropy Probe.

### R-process enhanced stars

We have started a dedicated effort to find more stars with strong enhancements (i.e., by more than a factor of 10) of neutron-capture elements associated with the r-process. In the course of a Large Programme (No. 170.D-0010; P.I.: Christlieb), "snapshot" spectra of 373 confirmed metal-poor giants brighter than $B \sim 16.5$ mag, including 4 comparison stars, are scheduled to be obtained with VLT/UVES. Most of the targets are from the HES. The snapshot spectra typically have R = 20,000 and S/N = 30, which is sufficient for measuring the abundances of some 20 elements and recognizing r-process enhanced and other interesting stars. The snapshot spectra are being secured when the seeing at Paranal is > 1.2″, and the constraints on the other observing conditions are very low. This "filler program" philosophy has already been employed successfully in the SPY project (Napiwotzki et al. 2003) aiming at finding supernova type Ia (SN Ia) progenitors (see also below).

So far we have received and analyzed snapshot spectra of 350 stars. We have found 10 new stars with enhancements of r-process elements by more than a factor of 10, as traced by Eu (i.e., [Eu/Fe] > 1 dex). That is, we have increased the number of known stars of this kind by more than a factor of 4, from previously 3 (CS22892-052, CS31082-001, and CS22183-031) to now 13. High-quality spectra of at least 5 of the new stars will be obtained in the course of the Large Programme.

The first new strongly r-process enhanced star that we discovered, CS29497-004, shows an enhancement of Ba to Dy by on average 1.5 dex with respect to iron and the Sun (Christlieb et al. 2004). The abundances of the elements with Z ≥ 56 match a scaled solar r-process pattern well, while Th is underabundant relative to that pattern by 0.3 dex, which we attribute to radioactive decay. The CH features in the spectrum of this star are much weaker than in CS22892-052 and about as weak as in CS31082-001, making it a good candidate for an attempt to detect uranium. VLT/UVES spectra of sufficient quality for this enterprise have already been obtained and are currently being analyzed. As a by-product of the Christlieb et al. Large Programme, we have almost doubled the number of stars confirmed by high-resolution spectroscopy to have [Fe/H] < –3.5, from 8 to 15. Furthermore, we have assembled by far the largest homogeneously analyzed sample of extremely metal-poor stars to date. This allows us to examine the abundance trends and scatter around these trends for this large sample, which is of unprecedented value for investigations of galactic chemical evolution.

The homogeneous analysis of 350 stars was feasible because an automated abundance analysis technique (Barklem et al. 2004) has been used. It has been specifically developed for our Large Programme, but it is general in the sense that it can be applied to high-resolution spectra of other stars as well (e.g., more metal-rich stars) if appropriate line lists are compiled.

## Carbon Stars

Christlieb et al. (2001b) identified 403 faint high latitude carbon (FHLC) stars in the HES by means of their strong $C_2$ and CN features (see upper right panel of Figure 1 for an HES example spectrum). Spectroscopic follow-up observations have revealed that this sample consists of a mixture of intermediate-mass asymptotic giant branch (AGB) stars and earlier type, metal-poor, but carbon-rich stars. Already from the HK survey it was apparent that about 20% of the metal-poor stars at [Fe/H] < –2.5 have strong overabundances of carbon, i.e., [C/Fe] > 1.0. This is confirmed by the HES, with the most extreme case found so far being HE0107-5240. A selection of stars with strong carbon features therefore provides an independent means for selecting the most metal-poor stars.

The carbon-enhanced metal-poor stars that show enrichment with s-process elements give us observational access to an extinct generation of extremely metal-poor AGB stars that via mass transfer left their "fingerprints" on their less massive companions, which we observe today. They provide strong observational constraints for simulations of the structure, evolution and nucleosynthesis of AGB stars, and allow us to investigate the s-process at very low metallicities. One extreme case which was found in the HES is HE0024-2523. Lucatello et al. (2003) analyzed high-resolution spectra obtained with Keck/HIRES as well as VLT/UVES, and find that it is a short-period (P = 3.4126 days) binary with a very large overabundance of the s-process elements; e.g., [Ba/Fe] = 1.5, and [Pb/Fe] = +3.3. The high overabundances of Pb in this and other "lead stars" are in concert with theoretical calculations, which predict that an efficient production of s-process elements takes place even in very low metallicity AGB stars despite the shortage of iron seeds, provided that protons are mixed into carbon-rich layers. Proton mixing results in formation of $^{13}C$, which is a strong neutron source due to the reaction $^{13}C(\alpha, n)^{16}O$.

It is likely that there are more "lead stars" among the 403 HES FHLC stars of Christlieb et al. (2001b). High-resolution spectra of many good candidates and additional stars from the metal-poor star sample have already been obtained with VLT/UVES.

Among the original motivations for selecting FHLC stars in the HES was also to compile a large, homogeneously selected sample of dwarf carbon stars (dCs), i.e., main-sequence stars with strong overabundances of carbon – not to be confused with DQs, i.e., white dwarfs with strong carbon features in their spectra (see upper left panel of Figure 1 for an example). However, these efforts have now been superseded by the (much deeper) Sloan Digital Sky Survey (SDSS), in which so far more than 100 dCs have been found, and a total of 200-300 are expected to be detected in the full survey.

## Field-Horizontal Branch A-type Stars

Field horizontal branch A-Type (FHB/A) stars are valuable tracers for the structure and kinematics of the halo of the Galaxy. In the HES, FHB/A stars with distances of up to ~ 30 kpc can be found. Another application of FHB/A stars is distance estimation of High Velocity Clouds (HVCs). HVCs are clouds of neutral hydrogen having radial velocities incompatible with Galactic differential rotation. There is an ongoing discussion as to whether HVCs are Galactic objects, or if they are extragalactic. Distances to HVCs can be determined by using stars of known distance in the line of sight of the clouds. Provided that the HVC under consideration has a detectable metal content, we see absorption lines of these metals at the velocity of the cloud in the spectra of stars located behind the cloud, but do not see these lines in spectra of stars located in front of the cloud. By using several stars at different distances in the line of sight of the cloud we can constrain its distance. FHB stars are particularly well-suited for this purpose, because they are numerous, distant, and their spectra are almost free of intrinsic absorption lines of metals.

Using the techniques of automatic spectral classification of Christlieb et al. (2002), we have identified 8321 FHB/A candidates in the HES. Representative follow-up observations of ~200 stars with the 3.6m/EFOSC2 as well as the CTIO and KPNO 4m telescopes have shown that the contamination of the sample with the less distant "blue metal-poor stars" of Preston et al. (the majority of which are likely halo blue stragglers) is less than 10%, while it would be as high as 1/3 in purely flux-limited sample of field A-type stars at high galactic latitudes. The contamination could be kept low by using the Strömgren $c_1$ index, which can be directly measured in the HES spectra with an accuracy of 0.15 mag (Christlieb et al. 2001a), as a gravity indicator. The stars are being used as HVC distance probes in ongoing observational programs at ESO and elsewhere.

**Table 1:** Remarkable "faint blue stars" from the HES

| Name | Type |
|---|---|
| HE0015+0024 | magn. DB with Zeeman triplets; B = 6MG (Figure 5) |
| HE1043-0502 | magnetic DB, B ~ 800MG |
| HE1211-1707 | variable magn. DB, B = 50MG, P = 110 minutes |
| HE0330-0002 | non-DA magn. WD, unidentified lines |
| HE0236-2656 | non-DA magn. WD, unidentified lines |
| HE0241-0155 | magn. DA, B = 150-400 MG, Grw +70° 8247 type |
| HE1045-0908 | magn. DA, P = 2-4 hours, B = 30 MG [20 MG?; Schmidt et al.] |
| HE0504-2408 | DO with ultrahighly excited lines |
| HE1314+0018 | DO with unexplained strong He II lines |
| HE1414-0848 | double degenerate, $M_1 + M_2 = 1.26\ M_\odot$ |
| HE2209-1444 | double degenerate, $M_1 + M_2 = 1.15\ M_\odot$ |
| HE0301-3039 | first sdB + sdB binary |
| HE1146-0109 | DQ with exceptionally strong $C_2$ and CI lines |
| HE0127-3110 | variable He I spectrum, transient $C_2$ bands, variable high velocity components, AM CVn type? |

## White dwarfs and other "faint blue stars"

White dwarfs (WDs) are a common by-product of any QSO survey since blue colour selection will detect WDs with T ≳ 10,000 K. At the HE survey limit of $B \lesssim 17.5$ for the stellar work, typically two DA WDs per Schmidt plate can be selected unambiguously. The advantage of the HE compared to the PG survey, a UV excess QSO survey, is that blue subdwarfs, which dominate the population at 16 mag, can be reliably separated from QSOs and WDs spectroscopically at the spectral resolution of the HES. The DA search yielded 830 DA candidates, 737 of them are not listed in the catalogue of McCook & Sion (1999). Christlieb et al. (2001a) estimate that the contamination of this sample with non-WDs is less than 10%.

The high and uniform density of bright WDs over the whole southern sky provided by the HES was a pre-requisite of the SPY project, a search for SNIa progenitors among double degenerates (DDs) conducted as a Large Programme with UT2/UVES (Napiwotzki et al. 2003). In addition to the DA search, an automated DB search has been conducted for SPY as well (Christlieb et al., in preparation). Besides the dedicated search for WDs, the follow-up spectroscopy of QSO candidates yielded a number of more peculiar WDs not recognizable directly on the Schmidt plates, e.g., WDs with extremely high magnetic field strengths and extremely hot new types of WDs. In the following we highlight the most important new HE faint blue stars. Table 1 lists these highlights.

### Magnetic WDs

The discovery of HE1211-1707 and HE1043-0502 (Reimers et al. 1996, 1998) together with dedicated calculation of the He I spectrum in fields up to 1000 MG (e.g. Becken 2001) which were motivated also by these discoveries, led to an improved (first) understanding of He I in strong magnetic fields. HE1211-1707 is an ideal test object since it is a highly spectrum variable DB white dwarf with a mean field of 50 MG (Wickramasinghe et al. 2002) and a period of 110 min (Jordan 2001). An even more exotic case is HE1043-0502: it shows an extremely strong feature near 445.0nm (Reimers & Wisotzki 1997; see also Fig. 1). According to Wickramasinghe et al. (2002) these features can be explained on the basis of Beckens and Schmelchers (2001) quantum mechanical calculation of He I in strong magnetic fields as $2^1S_0$–$3^1P_0$ transition at 800 MG. Since the 445.0nm feature is a "stationary component" one would expect more objects of the HE1043-0502 type. However, our dedicated search in the HES data base, using the spectrum of HE1043-0502 as a template, and follow-up spec-

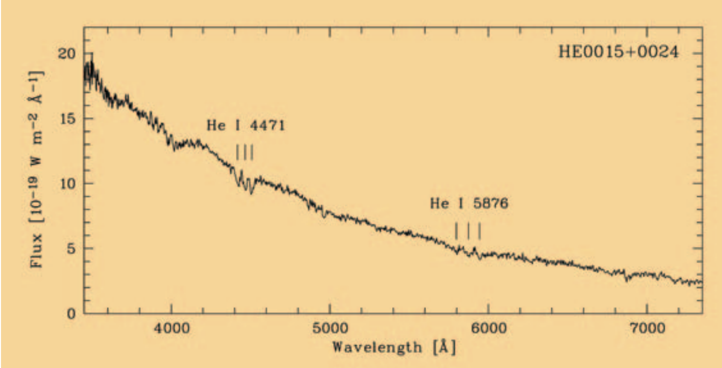


**Figure 5:** 3.6m/EFOSC2 spectrum of the magnetic DB white dwarf HE0015+0024, clearly showing Zeeman triplets of He I 4471 and He I 5876.

troscopy of candidates at the 3.6m telescope was not successful. Instead, a number of highly peculiar broad-absortpion line quasars with a feature at 445.0nm and many new DBs were discovered. In conclusion, DB white dwarfs with field strengths as high as 800 MG appear to be extremely rare.

Among the newly-discovered magnetic DAs, two are especially noteworthy: HE1045-0908 and HE0241-0155. The former shows a distinctive, rich Zeeman spectrum. Schmidt et al. (2001) discovered spectrum and circular polarization variability over one hour. The period is not yet precisely known, but should be in the range 2–4 hours. Observing and modeling this star might yield new information on departures from simple dipole configuration (see Schmidt et al. 2001).

HE0241-0155, with a magnetic field of 150–400 MG, is similar to the prototype of strong field DAs, Grw +70° 8247. On the other hand it shows features in the spectrum between 500 and 550nm which cannot be explained by the normal stationary components that require a large homogeneous field with 200 MG field strength, possibly due to a large spot. One might expect variability due to the spot. However, a new spectrum taken 5 years later (2003) does not reveal any variations.

## New DO types

Werner et al. (1995, 2004) have discovered two new types of extremely hot WDs among the HE follow-up spectra. HE0504-2408 is one of the prototypes of DO white dwarfs with lines from ultra-high ionization states like Ne IX or O VIII. HE1314+0018 is a DO with exceptionally strong He II absorption lines. Both phenomena are not explainable within the concept of static non-local thermodynamic equilibrium stellar atmospheres. They possibly originate in expanding coronae/winds of hot WDs. The strong He II lines could also be due to an unusual composition of the atmospheres not detectable in the optical spectral range.

## SPY – The search for SNIa progenitors

This ESO Large Program has been described in detail by Napiwotzki in the *Messenger* (Napiwotzki et al. 2003). In recent years SNIa have played an increasing role as distance indicators in cosmology up to redshifts of more than 1 and they have provided evidence for a non-vanishing cosmological constant, independent of other measurements like microwave background fluctuations. However, since the progenitors of SNIa are not known there remains room for speculations on intrinsic variations of SNIa peak luminosities with cosmic epoch. One of the progenitor scenarios is the double degenerate (DD) scenario where two WDs with total mass above the Chandrasekhar limit (1.4 solar masses) merge within a Hubble time due to angular momentum loss via gravitational radiation. SPY aimed at detecting DD systems by repeated spectroscopy of about 1000 WDs, including DAs as well as non-DAs. More than 100 DDs have been discovered, 16 with double lines. Two systems (HE1414-0848, HE2209-3039) qualify nearly for SNIa progenitors, a third one appears to make it (Napiwotzki et al., in preparation). SPY has demonstrated that the DD scenario is one of the possible evolutionary paths leading to a SNIa. The large population of newly discovered DDs will allow us to study more quantitatively the pre-SNIa stages, e.g. the common envelope phase which is difficult to model from first principles.

## HE0127-3110
### A never ending story?

Three spectra of HE0127-3110 taken in September and December 1994 show broad absorption features at 465.0nm and 505.0nm and a relatively narrow line at 587.0nm. These spectra have been reproduced successfully by a magnetic DA model with field strengths between 85 MG and 235 MG, in particular the 587.0nm feature appeared to be the well-known stationary $^2S_0 \rightarrow {}^3P_0$ Hα component (Reimers et al., 1996). It was also discussed in the discovery paper that the broad features might be the $C_2$ Swan bands, and that the 587.0nm is He I 587.6nm, while He I 447.1nm was missing. However, this possibility was dismissed because no single WD model can explain the simultaneous occurrence of strong $C_2$ and He I.

Later, we discovered that we had taken a spectrum of HE0127-3110 already in September 1992, which looked like a pure DB spectrum with both He I 447.1 and 587.6nm but without the “$C_2$ features” (Friedrich et al. 2000). The magnetic DA hypothesis was wrong. This conclusion was independently also reached by Schmidt et al. (2001), who found that HE0127-3110 does not show any circular polarization.

Was the $C_2$ band due to a cool spot on the DB which would re-appear one day by rotation? We have taken more than a dozen spectra between 1998 and 2003 with the hope to see again the $C_2$ bands, but without success (see Fig. 6). However, the He I 587.6nm and 447.1nm lines appear to vary on the timescale of days, in particular He I 447.1nm is weak or absent in several spec-

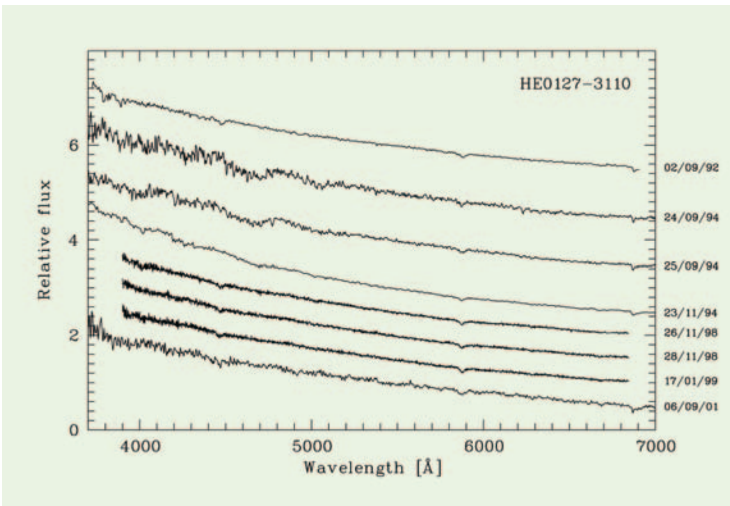


**Figure 6:** Slit spectra of the spectrum variable object HE0127-3110.

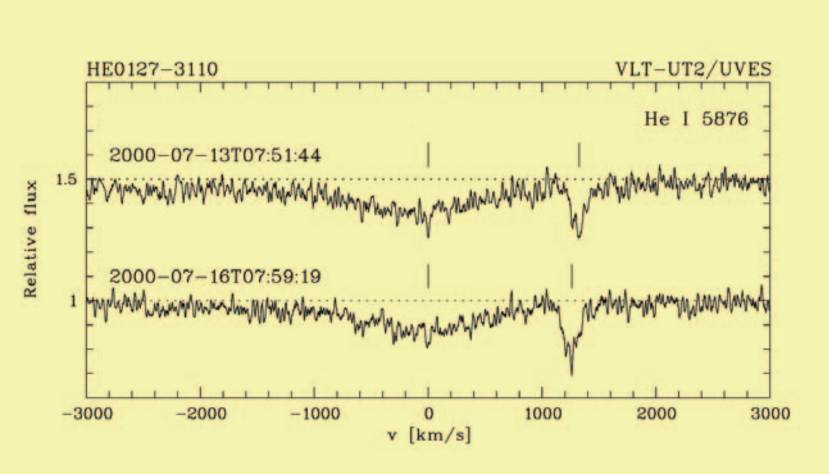


**Figure 7:** VLT/UVES spectra of He I 5876 in HE0127-3110. Note the sharp, moving component at a radial velocity of ~1300 km/s relative to He I 5876.

tra. Two UVES spectra of HE0127-3110 taken in the course of the SPY project within 3 days give a hint to a possible solution of the problem. The He I 587.6 nm line is very broad and shallow (line depth 20 %) and has a narrow, deeper satellite component at +1330 km/s relative to the broad He I 587.6 nm line (see Fig. 7). The narrow component moved to +1260 km/s within 3 days. Velocities that high and variable on short timescales in the context of an otherwise mostly "normal" DB spectrum hint to a close double degenerate (DD), possibly of the AM CVn type, i.e., binaries in contact, with periods as short as 15 minutes. And what about the $C_2$ features? Could they have been produced as transient features in an outburst which ejected carbon? We invite the interested CV community to take the next obvious steps: photometry and spectroscopy with high time resolution (minutes) and polarimetry – not easy for a $B$ = 16 mag star.

## Outlook

Due to technical reasons, so far only 329 of the 380 HES plates have been used for the exploitation of the stellar content of the survey. Given the tremendous success of this effort, we are now in the process of extending it to the remaining 51 plates.

We also plan to continue with collecting medium-resolution follow-up spectroscopy for at least the most interesting of the remaining ~5000 HES candidates for metal-poor stars. The ESO 3.6m with its very efficient instrument EFOSC2 is the ideal telescope/instrument combination at ESO for such an effort, which emphasizes the continued need for "small" telescopes even in the era of 8-10m class telescopes.

In addition to the more than 200 new stars with [Fe/H] < –3.0, we have also found a few more stars which appear from the moderate-resolution spectra to have [Fe/H] < –4.0. Some of them might turn out to have metallicities even much lower, because the Ca II K line, which is used for estimating [Fe/H] from the follow-up spectra, might be contaminated by CH lines (which is the case in HE0107-5240), interstellar absorption, or the Fe abundance might be overestimated due to the presence of a strong over-abundance of the α-element Ca. This can only be clarified by high-resolution spectroscopy. HE0107-5240 was found in a set of ~2000 of the best metal-poor candidates (which in turn have been selected from about 1 million objects). Since the total number of HES candidates is about 10,000, it is not excluded that a few more stars with [Fe/H] < –5.0 might be found in the HES. For the determination of the primordial Li abundance it is most desirable to find a turnoff star at this metallicity.

For all stars estimated to have [Fe/H] < –3.5 from the follow-up spectra, high-resolution spectroscopy is being obtained in ongoing observing programs at 8-10m-class telescopes. We plan to use the VLT for this in the future as well. Very high S/N is needed because the lines of elements other than hydrogen are exceedingly weak at the lowest metallicities.

Finding more metal-poor stars with [Fe/H] < –5.0 and significant numbers of other interesting stellar objects would require us to extend the survey volume significantly with respect to the HES; that is, it has to be much deeper. Such a survey is only feasible if either the candidate selection efficiency is further improved, to reduce the number of candidates to be followed up in single-slit mode, or if a large amount of time at a suitable telescope with a multi-fiber spectrograph is available. Only in this way can one cope with the large number of metal-poor candidates which would result e.g. from a deeper colorimetric survey.


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# FLAMES Spectroscopy of RGB stars in the Globular Cluster NGC 2808: Mass Loss and Na-O Abundances

*A spectroscopic survey with FLAMES of 137 red giant stars in the globular cluster NGC 2808 has revealed the likely presence of mass loss in a large number of stars among the brightest sample. Chemical inhomogeneities all along the 3-mag monitored interval suggest primordial pollution from a previous generation of intermediate mass stars.*

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The multi-object spectrograph FLAMES is one of the most recent and valuable additions to the instrument family of the ESO Very Large Telescopes. Its technical characteristics (see Pasquini et al. 2002 for details) make it the ideal instrument for medium-high resolution spectroscopic studies of large numbers of stars in relatively wide fields, reaching much fainter magnitude limits than previously possible with good accuracy. Galactic globular clusters (GC) are typical places where these conditions are met, and therefore are excellent targets for FLAMES.

The scope of this article is to highlight the results we obtained with the first FLAMES observations, taken during Science Verification (SV) in January-February 2003, on the GC NGC 2808. This is a very interesting and puzzling cluster (e.g. second-parameter bimodal horizontal branch [HB] morphology, possible connection with the recently discovered CMa dwarf galaxy), yet no detailed spectroscopic study of its RGB stars was available so far. The primary aim of these observations was to fill in this gap, with two scientific purposes in mind: i) investigate the mass loss phenomenon by detecting evidence of mass motions in the atmosphere of these stars; and ii) derive the abundance of some key elements (e.g. sodium and oxygen) to study the chemical (in)-homogeneity along the RGB.

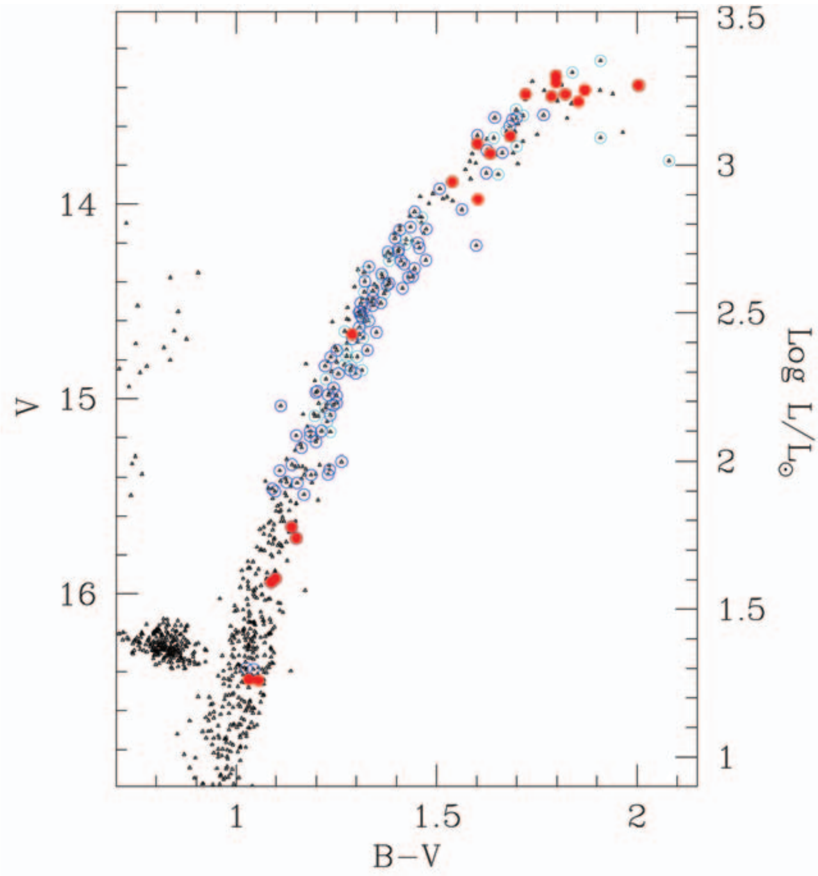


**Figure 1:** Colour-Magnitude diagram of NGC 2808 (Bedin et al. 2000) showing the 137 RGB stars observed with FLAMES. Filled red circles indicate the stars observed with UVES, circled blue dots indicate the stars observed with GIRAFFE/MEDUSA.

One of the basic requirements of stellar evolution theory is that some amount of mass (~ 0.1-0.2 $M_{\odot}$) must be lost by GC stars during the RGB evolutionary phase, in order to explain the morphology of the subsequent HB evolutionary phase (cf. Renzini & Fusi Pecci 1988). However, very little observational evidence has been found so far either of the mass already lost, or of the mass loss phenomenon while it is happening. Several spectroscopic surveys have been carried out for this purpose during the past three decades, but no firm conclusion could be reached mainly because of lack of adequate data. The mass loss is likely a stochastic phenomenon, and accurate high resolution spectra of a large number of faint stars are needed in order to gather the statistical significance that is required for a correct understanding.

The indicators traditionally used to trace mass motions in the atmospheres (hence possibly mass loss) are the Ca II K, Na I D and Hα lines, through the analysis of profile asymmetries (e.g. Ha and Ca II K emission wings) and core (blue) shifts. Other, perhaps better, indicators exist in the UV and IR ranges (e.g. Mg II at 280nm, Lyα, He I at 1083nm, cf. Dupree 1986), but are inaccessible for such faint stars with available equipment. Therefore, we have observed these three visual lines in 137 RGB stars with GIRAFFE in MEDUSA mode (R=19,000–29,000), monitoring ~3 mag down from the RGB tip. Of these stars, 20 were observed in UVES mode to get the Na I D and Hα lines at higher resolution

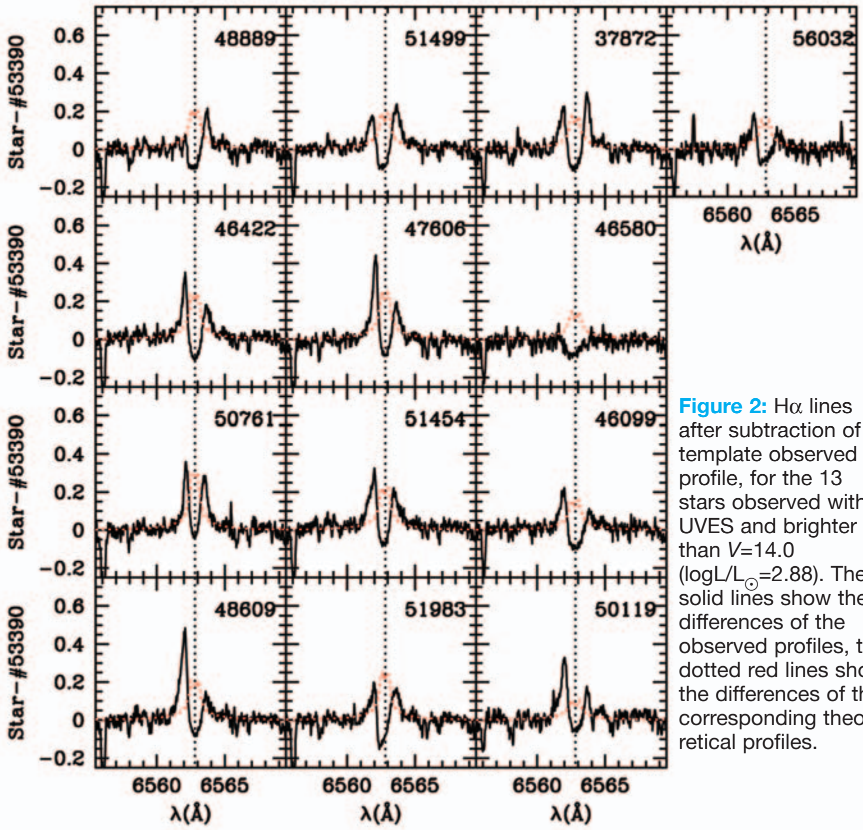


Figure 2: Hα lines after subtraction of a template observed profile, for the 13 stars observed with UVES and brighter than $V$=14.0 (logL/L$_\odot$=2.88). The solid lines show the differences of the observed profiles, the dotted red lines show the differences of the corresponding theoretical profiles.

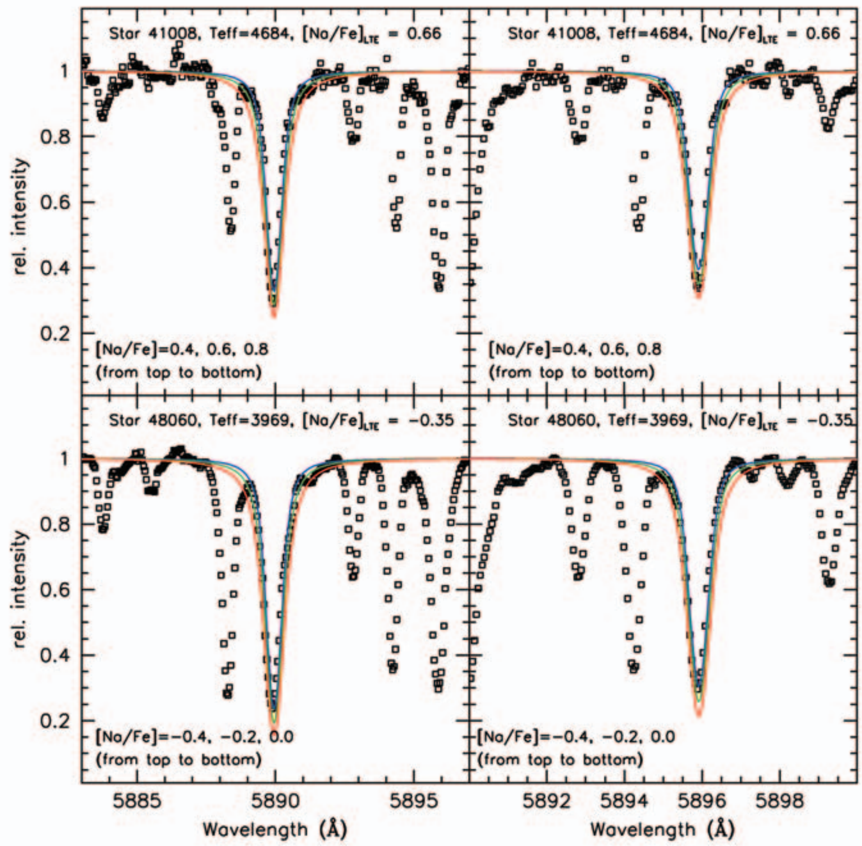


Figure 3: Spectrum synthesis of the Na $D_1$ and $D_2$ lines in two RGB stars. Open squares are the observed spectrum, while lines represent the synthetic spectra computed for appropriate values of temperature and 3 different sodium abundances: [Na/Fe]=0.4 (blue), 0.6 (green) and 0.8 (red) dex. All abundances are given in the LTE assumption.

(R=47,000). The location in the Colour-Magnitude diagram of these 137 RGB stars in shown in Figure 1. The results of this study, as well as a detailed discussion and references to previous studies, have been presented by Cacciari et al. (2003) and are here summarized.

We show in Fig. 2 the Hα lines after subtraction of a template observed profile and of a theoretical profile, for the 13 stars observed with UVES and brighter than $V$=14.0 (logL/L$_\odot$=2.88). They all show clear evidence of emission wings. Considering also the GIRAFFE spectra, we found that ~95% of the stars brighter than this value do show Hα emission wings. This is a much larger fraction than detected by any previous analysis. The nature of this emission is not assessed definitely, as it may be present in either stationary or moving chromospheres. However, blue-shifted Hα absorption cores were detected in 7 out of the 20 UVES stars, and these are indicative of outward motion in the layer of the atmosphere where the Hα line is formed. Similarly, we found negative coreshifts of the Na I $D_2$ line in about 73% of the stars brighter than logL/L$_\odot$~2.9. The Ca II K line was observed in 83 stars, 22 of which show the central emission $K_2$ and reversal absorption $K_3$ features, with a detection threshold for these features at logL/L$_\odot$~2.6. Asymmetry B/R (i.e. the intensity ratio of the blue [$K_{2b}$] and red [$K_{2r}$] emission components) could be detected in about 75% of stars brighter than logL/L$_\odot$~2.9, and is mostly red (B/R<1) indicating outward motion. Velocity shifts of the $K_3$ reversal relative to the photospheric lines have been measured, and are mostly negative indicating that there is an outflow of material in the region of formation of the $K_3$ core reversal. The onset of negative $K_3$ coreshifts occurs at logL/L$_\odot$~2.8, i.e. at a slightly lower luminosity level than the onset of red asymmetry, and applies to nearly 90% of the stars brighter than this value. This set of observational evidence confirms that mass loss may indeed be present along the RGB, especially in the brightest ~0.8 mag interval from the RGB tip, and in a larger number of stars than previously estimated within any given GC.

These same data were used to derive sodium abundances (for 81 of the stars observed with GIRAFFE), and sodium plus oxygen abundances (for the 20 stars observed with UVES). The results have been published by Carretta et al. (2003, 2004), and are briefly summarized here.

The astrophysical scenario that considered GCs as the best approximation of *Simple Stellar Populations*, i.e. groups of coeval stars with the same chemical abundance, has been questioned in recent years. Apart from the blatant, peculiar case of ω Cen, stars in any given GC share the same metallicity only as far as heavy elements

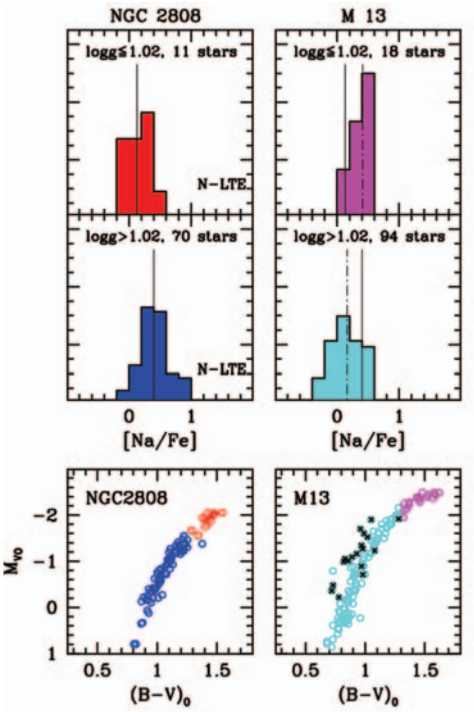


**Figure 4:** [Na/Fe] abundance histograms for the NGC2808 RGB stars, shown separately for the brightest stars (log $g$ ≤1.02) and the fainter ones (log $g$>1.02). Similar data for M13 (Kraft et al. 1997) are shown for comparison.

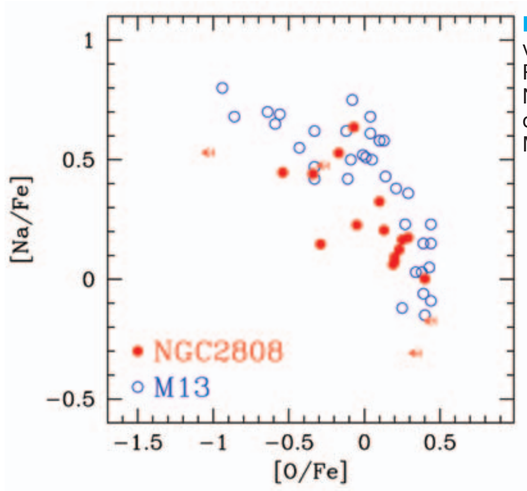


**Figure 5:** [Na/Fe] vs [O/Fe] for the RGB stars in NGC2808 (red dots) compared to M13 (blue dots).

(i.e. those belonging to the Fe group) are concerned. On the contrary, lighter elements (*in primis* carbon and nitrogen) show significant abundance variations along the RGB, and even among unevolved main sequence and turn-off stars. Sodium and oxygen abundances are anti-correlated among the first ascent RGB stars in almost all the GCs surveyed, for at least one magnitude below the RGB tip. This Na-O anticorrelation has been detected also among turn-off stars in three GCs so far, i.e. NGC 6397, NGC 6752 and 47 Tuc, where both Na-rich/O-poor and Na-poor/O-rich stars are present. These anomalies are found only in cluster stars, whereas the abundance pattern of field stars is well explained by the classical scenario of a first dredge-up and a second mixing episode taking place above the magnitude level of the RGB bump. We refer the reader to Gratton et al. (2004) for a recent and comprehensive review of this intricate subject.

The presence of these abundance variations and anticorrelation in RGB stars indicates that both the CN-cycle and the ON-cycle (of the complete CNO H-burning cycle) are at work in GC stars. In particular, the proton-capture fusion mechanism, taking place in the same (inner) regions where high temperatures are reached and O is transformed in N, is able to produce Na from $^{22}$Ne, as indicated by the Na-O anticorrelation. The products of these nucleo-synthesis mechanisms are then brought to the surface by the convective motions in the red giant extended atmospheres. However, the presence of these abundance variations in unevolved stars cannot be explained this way. These stars do not have the physical characteristics needed to produce the observed abundance pattern, namely central high temperatures (to produce these elements in the observed proportions) and extended convective envelopes (to bring them to the surface by internal mixing). Therefore, this pattern must be due to pre-existing abundance variations. Among the possible sources of primordial contamination, a previous generation of intermediate-mass AGB stars has been proposed, that might have polluted with Na-rich, O-poor ejecta the material from which the subsequent generation of stars was formed. Most likely, the overall chemical pattern observed in GC stars requires a contribution of both primordial contamination and evolutionary mixing. The debate seems presently focussed on how to disentangle primordial variations and subsequent evolutionary effects, and to properly ascertain their relative proportions in a given cluster and in clusters of different physical properties (HB morphology, density, age, metallicity, etc.). This, of course, requires the accurate knowledge of chemical abundances for a large number of GCs and for many stars within each cluster. For this reason the use of FLAMES is especially important, and has led to very interesting results in NGC 2808. We show in Fig. 3 an example of Na I D lines that were analysed with spectral synthesis techniques to derive the Na abundances. Similarly, O abundances were derived.

The [Na/Fe] abundances thus derived are shown in Fig. 4. The histograms of the abundances, plotted separately for the 11 brightest stars (log $g$ ≤ 1.02) and the 70 fainter ones (log $g$ > 1.02), reveal a similar spread in the distributions, and slightly lower average values for the brighter group. The spread in the distribution is therefore independent of luminosity and most likely of primordial origin, whereas the average abundance value, that depends on luminosity, is likely due to internal mixing phenomena. So it seems that the [Na/Fe] abundance variations found in NGC 2808 are mostly primordial, with some noise added by evolutionary effects. We show for comparison the results obtained in M13, where the situation is similar except that the brighter stars have *higher* values of [Na/Fe] than the fainter stars. Incidentally, a comparison with other clusters, i.e. M5, M15 and M92, not shown here, where the average [Na/Fe] abundance values do not vary significantly with luminosity, indicates that in these latter clusters the [Na/Fe] abundance variations detected along the RGB are likely of primordial origin. In Fig. 5 we show the anticorrelated [Na/Fe] and [O/Fe] abundances for the 20 stars analysed in NGC 2808 (red dots), and for comparison the analogous data for M13 (blue dots). In both clusters the anticorrelation is clear and well defined, and very O-poor stars are present.

To conclude, we note that this is the first time that such a large sample of RGB stars have been observed in any given GC with high resolution spectroscopy. This survey has allowed us to assess that mass loss may indeed be present along the RGB, and to trace the occurrence and onset of this phenomenon down to fainter luminosity thresholds than previously estimated. These results are important for a better understanding of the subsequent stellar evolutionary phases, in particular of the peculiar HB morphology of NGC 2808. The chemical inhomogeneities detected in these stars seem to be mostly due to a previous generation of intermediate mass stars, as has been found also in other clusters. This has important consequences for a better understanding and modelling of GC formation processes.

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# VLT Observations of Beryllium in a Globular Cluster:

## a clock for the early Galaxy and new insights into Globular Cluster formation

*The first-ever measurement of the beryllium content in two stars of a globular cluster obtained with UVES at the VLT shows that beryllium can be used as a powerful cosmochronometer to date the oldest stars. In this way we estimate that the globular cluster NGC 6397 formed 0.2–0.3 Gyrs after the onset of star formation in the Milky Way. Assuming that this started shortly after the Big Bang (13.7 Gyrs ago according to WMAP), and the subsequent "dark ages" which are thought to last about 0.2 Gyr, the NGC 6397 stars were therefore born ~13.2–13.3 Gyrs ago, a result which is consistent with the age of the cluster as independently derived from main sequence fitting. This consistency would indicate a remarkable agreement between stellar evolution, cosmic-ray nucleosynthesis and cosmology. The UVES spectra prove as well that the gas which formed the stars must have gone through CNO processing in the protocluster cloud before their formation.*

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Dating stars, in particular the oldest ones, is one of the challenges for stellar astronomers. By dating them, we can, for instance, test evolutionary theories and set lower limits to the age of the Galaxy and of the Universe. The most common approach to dating involves the determination of a star's age, that is, the time elapsed from its birth to the present.

We present here an orthogonal perspective, investigating if it is possible for the oldest stars to provide a reliable measurement of the time elapsed between the beginning of star formation in the Galaxy and the birth of these objects.

In order to achieve this goal we need a tracer which, at least in the early Galaxy, was growing steadily (possibly slowly) and homogeneously, not suffering from inhomogeneities which may have been present, given the limited time available for an efficient mixing to occur.

Such a tracer is $^{9}$Be. Unlike most elements, which are produced either in stars or by big bang nucleosynthesis, in fact, $^{9}$Be (together with B and the $^{6}$Li isotope) can only be produced in the interstellar medium by Galactic Cosmic Rays (GCRs) through the spallation of heavier nuclei, such as carbon, oxygen and nitrogen (Reeves et al. 1970). In the early Galaxy, Be was produced by energetic particles generated in SN explosions and transported globally on a Galactic scale; its abundance is predicted to increase uniformly with time, showing less scatter than the products of stellar nucleosynthesis such as Fe or O. The dominant spallation process is expected to be the so called "primary" process, where Be is produced by the collisions of accelerated C,N,O nuclei in Galactic Cosmic Rays with interstellar medium (ISM) protons and α-particles. This process is called primary because it is expected to lead to a linear dependence of Be on metallicity. A tight trend between Be and metallicity has been confirmed observationally down to [Fe/H] ≅ –3.3 in metal-poor field halo stars (Gilmore et al. 1992, Molaro et al. 1997, Boesgaard et al. 1999). This makes Be a potentially powerful "cosmic clock" for dating the first stages of Galactic halo evolution (Suzuki et al. 2001).

To test Be as a cosmic clock it is necessary to measure Be in stars which can be dated independently. In this respect stars in old globular clusters, such as NGC 6397, are ideal candidates, because their ages can be determined in a reliable way through, for instance, main sequence fitting and stellar evolutionary theory, and they have been shown to be formed within ~1 Gyr after the Big Bang (Gratton et al. 2003).

However, the search for Be poses several challenges, because the only available Be lines are the Be II resonance doublet at 313.1 nm. This wavelength is very close to the atmospheric cut-off at 300 nm and the terrestrial atmosphere heavily absorbs the incoming radiation, making observations very challenging. In addition, the Be lines are very weak and the spectral region around them very crowded, so that high spectral resolution is necessary.

The high UV efficiency of UVES at the VLT telescope Kueyen has opened a new possibility, allowing for the first time the detection of Be in two turn-off (TO) stars in NGC 6397. It is essential to reach the cluster TO because these stars are the most suitable for Be analysis; in fact it must be borne in mind that Be may be destroyed in the stellar interiors at temperatures above ~3.5 million K, that is at temperatures about 1 million K higher than the more fragile Li. Previous studies of this cluster (Bonifacio et al. 2002)

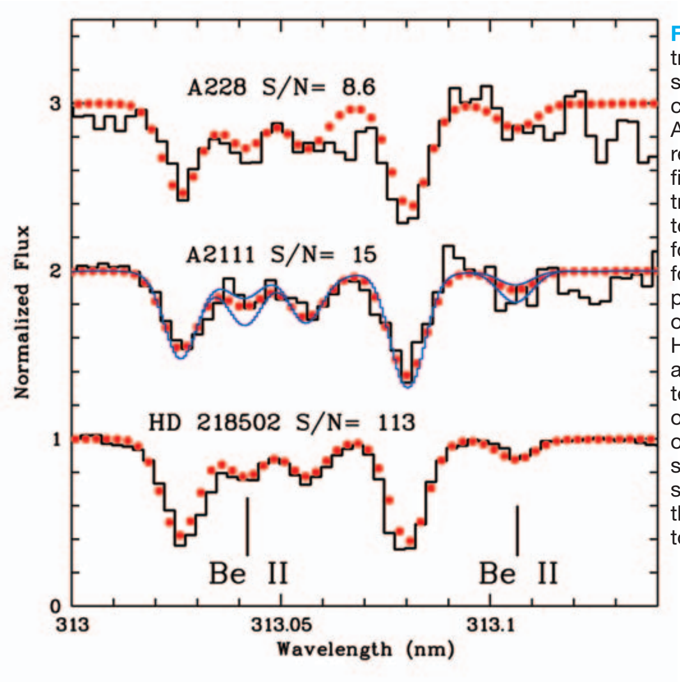


**Figure 1:** UVES spectra of the two turn-off stars of the Globular cluster NGC 6397: A2111 and A228. The red dots are the best-fitting synthetic spectra which correspond to Log(Be/H)= –12.27 for A228 and –12.43 for A2111. For comparison, the spectrum of the bright halo star HD 218502, whose atmospheric parameters are close to those of the NGC 6397 turn-off stars, is also shown. The best fit synthetic spectrum for this star corresponds to Log(Be/H)=–12.36.

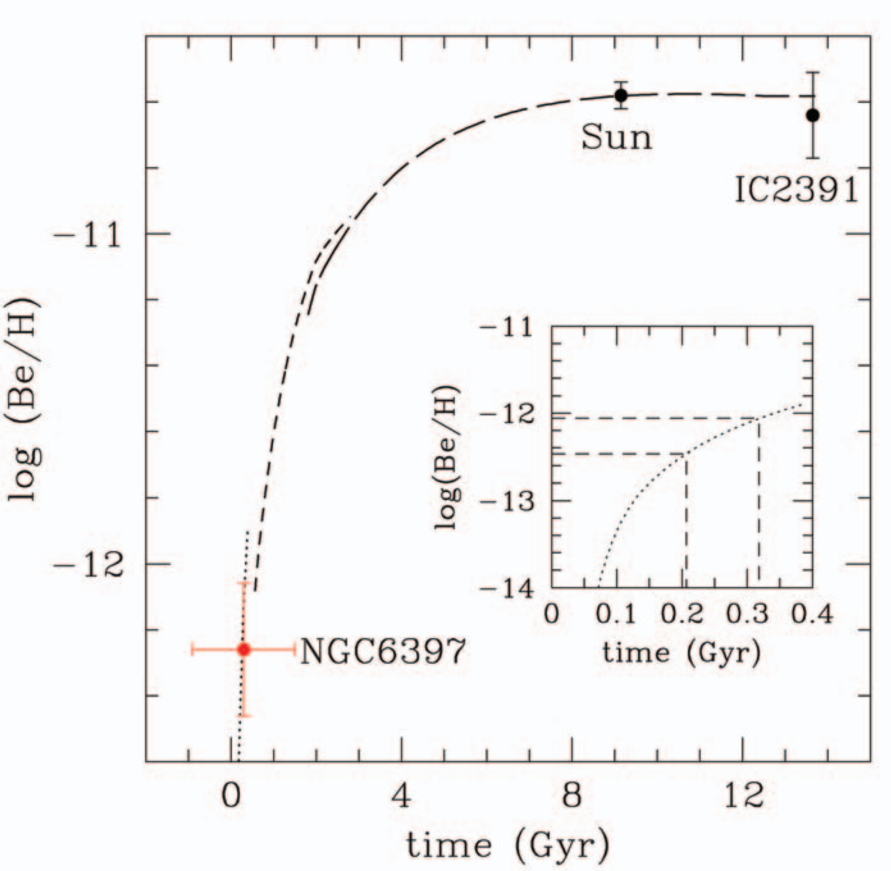


**Figure 2:** Evolution of Be with time in the Galaxy according to a three-zone Galactic chemical evolution model (Valle et al. 2002). The three curves refer to the halo, thick disc, and thin disc. The data points show the Be abundance in the young open cluster IC 2391 (age 50 Myr), the Sun (age 4.55 Gyr), and the globular cluster NGC 6397 (age 13.4±0.8 Gyr). The model result is normalized to the solar meteoritic abundance. The inset illustrates the use of Be as a "cosmic clock" to constrain the formation of NGC 6397. The horizontal lines corresponds to the 1σ contours around the measured Be abundance. The cluster birth is constrained to the first 0.2–0.3 Gyr after the onset of star formation in the Galactic halo.

have shown that these TO stars have an abundance of Li as high as the primordial value. Since this more fragile element is at its original level, then, *a fortiori*, Be has not been depleted in their atmospheres. Conversely, brighter subgiants in the same cluster show clear evidence of Li dilution. Even if NGC 6397 is the second closest cluster, its TO is still relatively faint, placed at an apparent magnitude of V~16. This means that a jump of almost 3 magnitudes with respect to the faintest star previously observed for Be abundance determination was necessary. Even with UVES and the VLT it has been necessary to expose each star for 10.5 hours.

The observed spectra in the region around the BeII lines are shown in Figure 1, together with the best-fit synthetic spectra. Thanks to the high resolution (R=45,000) and signal-to-noise ratio (8.5 and 15) of the spectra, the two Be II lines are clearly detected and measurable in both stars. The resulting abundance is very similar for both stars, and we obtain log (Be/H) =–12.35±0.2 (where errors include uncertainties in the adopted gravity). The log (Be/H) retrieved is in excellent agreement with that of field stars with similar [Fe/H] abundances. In the same figure the spectrum of a brighter field star is also shown, which has parameters similar to the targets and is used as a control star.

The measured Be abundance of the two targets is plotted in figure 2, together with the time evolution of Be resulting from a model of chemical evolution following the enrichment of three different regions in the Galaxy, coupled by mass flows: the halo, the thick disk and the thin disk (Valle et al. 2002). The other data point in the Figure shows the Be abundance in the Sun and in the young open cluster IC 2391, an indicator of the present-day value. In this Figure, star formation in the Galaxy is assumed to start 13.7 Gyr ago. This value represents the age of the Universe (time elapsed from the Big Bang) according to WMAP (Bennet et al. 2003). A more realistic age of the galaxy should take into account the time interval between the Big Bang and the epoch of re-ionization. The best estimate for this interval is 0.18 Gyr (WMAP data), well within the errors on the age estimate of NGC 6397.

The inset in Fig. 2 shows the halo evolution of Be on a finer time scale, with the two horizontal lines limiting the 1σ range of Be abundance in NGC 6397. This plot emphasizes the possible use of Be as a "cosmic clock": the measured value of Be indicates that the formation of NGC 6397 occurred about 0.2–0.3 Gyr after the onset of star formation in the Galactic halo. Given the uncertainty in the model assumptions, it is safe to conclude that the birth of the stars composing NGC 6397 took place within the first ~0.5 Gyr of halo evolution, in agreement with the main-sequence dating of the cluster. In fact under the previous assumptions, the "Beryllium age" retrieved for the cluster is 13.45 Gyr, which is in very good agreement with the absolute age of 13.4 ± 0.8 ± 0.6 Gyr, recently derived on the basis of the main sequence fitting method with standard isochrones (Gratton et al. 2003). Although the almost exact coincidence between the two "ages" is fortuitous, the combination of

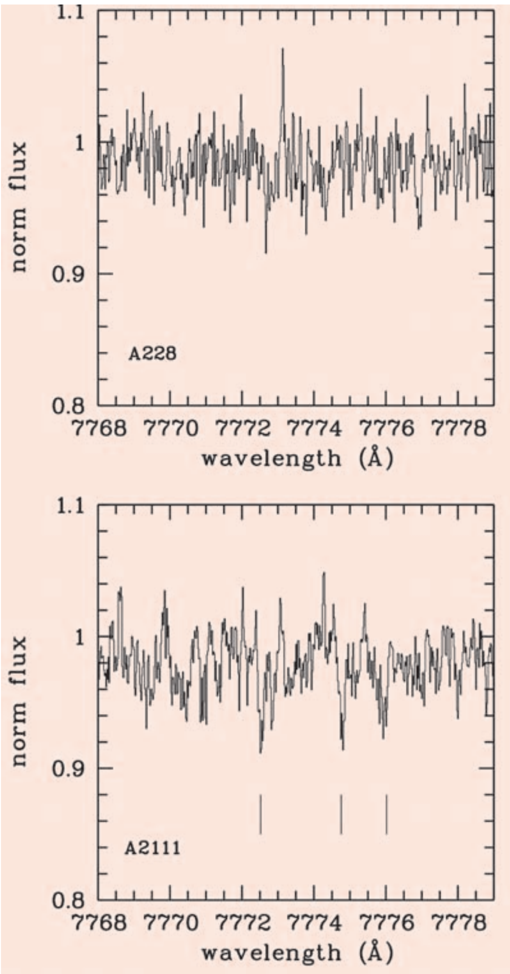


**Figure 3:** UVES spectra of the two NGC 6397 stars in the region of the Oxygen triplet. The two stars have identical stellar parameters but clearly different line strengths; their O abundances differ by almost 0.6 dex.

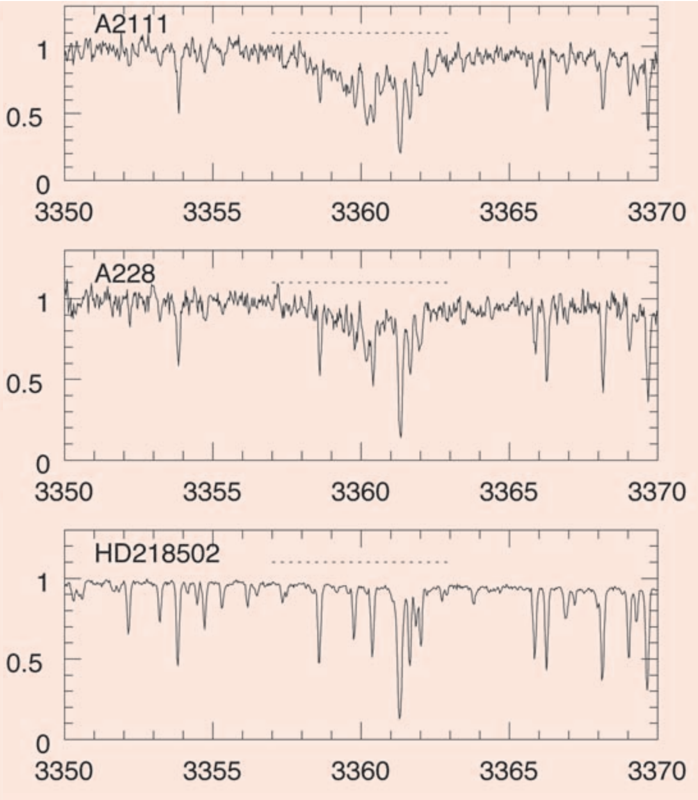


**Figure 4:** UVES spectra of the two NGC 6397 stars and of the comparison field star HD218502 in the region around the NH band at 336 nm. The band is very well pronounced in the two globular cluster stars, while it is virtually absent in the reference star, indicating the strong N overabundance in the NGC 6397 stars.

the evolutionary and of the Be age clearly show that the halo of the Galaxy must have formed shortly after the Big bang.

## More exciting results about the Cluster

Many Globular Clusters show peculiar patterns in their chemical composition, which are not observed among field stars and are therefore clearly related to the peculiar Globular Cluster environment. Although this anomaly was first discovered more than 30 years ago, no clear answer yet exists for its origin. The superb UVES spectra, thanks to the combination of resolving power, signal to noise and spectral coverage, add some significant new results on this topic. In addition to the Beryllium lines, we also observed important bands of Nitrogen in the UV and the Oxygen triplet in the near infrared.

While the rest of the elements show an impressively constant value in NGC 6397 stars, our spectra show that the two observed stars have a difference of up to 0.6 dex in their O abundance, and a rather high N content ([N/Fe]~1.3) with respect to field stars of similar metallicity. We also confirm that the average oxygen level is low with respect to that of field stars of similar metallicity, as found by Gratton et al. 2003.

Figures 3 and 4 shows the spectra around the Oxygen triplet and the NH regions respectively. In figure 3 the difference in the Oxygen line strength among the two stars is evident, while in figure 4 the comparison between the two cluster stars and the similar field star HD218502 shows clearly how much stronger the NH band in the cluster stars is with respect to the field object.

This abundance pattern suggests that the stars of NGC 6397 were either formed from, or partially polluted by, material bearing the signature of the products of stellar nucleosynthesis, such as that occurring in massive asymptotic giant-branch (AGB) stars (Ventura et al. 2002). In this phase, stellar material is processed at very high temperatures (~$10^8$ K) where O is effectively burnt to N in the CNO cycle and then returned to the ISM by mass loss. This process could explain both the low O and the high N values observed, while most other elements would conserve their previous abundances. However, at the high temperatures characterizing AGB nucleosynthesis, Li and Be are completely destroyed. The normal Pop II stars level of Li observed in NGC 6397 (Bonifacio et al. 2002) could have been restored during this AGB phase because Li is predicted to be produced by AGB stars and could be brought to the surface from the interior through the so called Cameron-Fowler mechanism: convective cells bring up to the surface freshly synthesized Li before it is destroyed. Of course this hypothesis requires a remarkable fine-tuning between Li production and destruction. However the special nature of $^9$Be means that this element cannot be synthesized in stars, but that it is only destroyed during the AGB phase, and our observations therefore seem to be at variance with this picture. Thus, our detection of Be rules out the possibility that a considerable fraction of the gas of the protocluster was processed by a previous generation of AGB stars, unless the gas was processed extremely early in these stars and immediately released back to the ISM, where it was exposed to the Galactic Cosmic Rays.

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# Cepheid Pulsations Resolved by the VLTI

*The very high spatial resolution provided by the VLTI makes it possible to measure directly the change in angular diameter of several southern Cepheids over their pulsation cycle. When combined with radial velocity measurements, this allowed us to measure precisely their distances in a quasi-geometrical way. This is essential information to calibrate the Cepheid's Period-Luminosity law, as well as the Period-Radius and Surface Brightness-Colour relations.*

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For almost a century, Cepheids have occupied a central role in distance determinations. This is thanks to the existence of the Period-Luminosity relation $M = a \log P + b$ which relates the logarithm of the variability period of a Cepheid to its absolute mean magnitude. These stars became even more important since the HST Key Project on the extragalactic distance scale has totally relied on Cepheids for the calibration of distance indicators to reach cosmologically significant distances. In other words, if the calibration of the Cepheid P-L relation is wrong, the whole extragalactic distance scale is wrong.

There are various ways to calibrate the P-L relation. The avenue chosen by the HST Key Project was to assume a distance to the Large Magellanic Cloud (LMC), thereby adopting a zero point for the distance scale, but the LMC distance is currently the weak link in the extragalactic distance scale ladder. Another avenue is to determine the zero point of the Period-Luminosity relation with Galactic Cepheids, using for instance parallax measurements, Cepheids in clusters, or through the Baade-Wesselink (BW) method (see e.g. Bersier et al. 1997). We proposed in the present work to improve the calibration of the Cepheid Period-Radius (P-R), Period-Luminosity (P-L) and surface brightness-color (SB) relations through the combination of spectroscopic and interferometric observations of bright Galactic Cepheids.

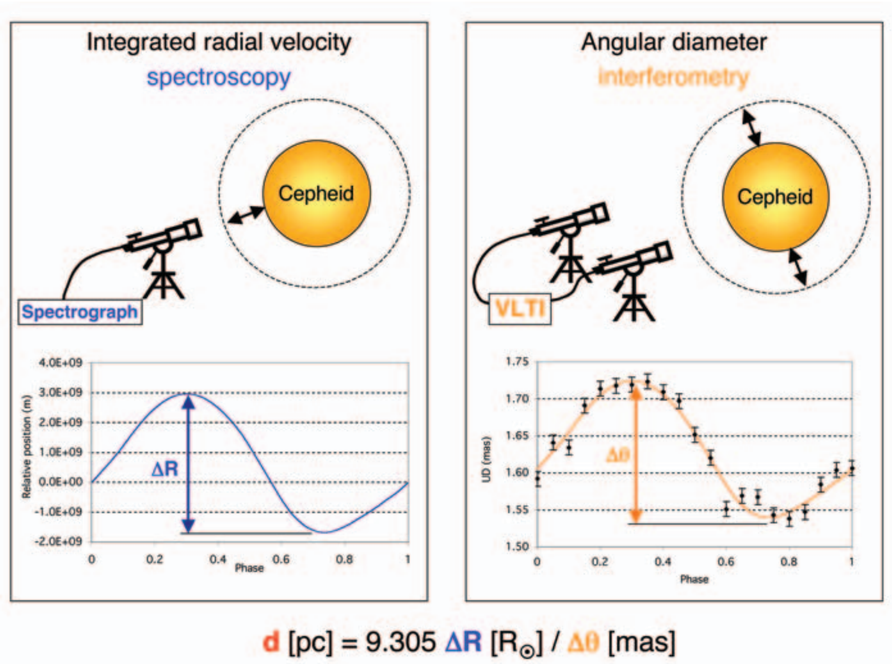


**Figure 1:** The two observational techniques used for the interferometric version of the BW method are high resolution spectroscopy (left) and interferometry (right). The former provides the radial velocity curve over the pulsation cycle of the star. Once integrated, this provides the linear radius variation of the star (in metres). The interferometric observations give access to the angular radius variation of the star. The ratio of these two quantities gives the distance of the Cepheid.

## The Interferometric Baade-Wesselink Method

The basic principle of the BW method is to compare the linear and angular size variation of a pulsating star, in order to derive its distance through a simple division. This method is a well-established way to determine the luminosity and radius of a pulsating star. Figure 1 illustrates the two quantities measured for this technique: the radius variation curve (left part), that is integrated from the radial velocity curve, and the angular diameter variation, measured by interferometry.

On one hand, the linear size variation can be obtained by high resolution spectroscopy, through the integration of the radial velocity curve obtained by monitoring the Doppler shift of the spectral lines present in the spectrum. A difficulty in this process is that the measured wavelength shifts are inte-

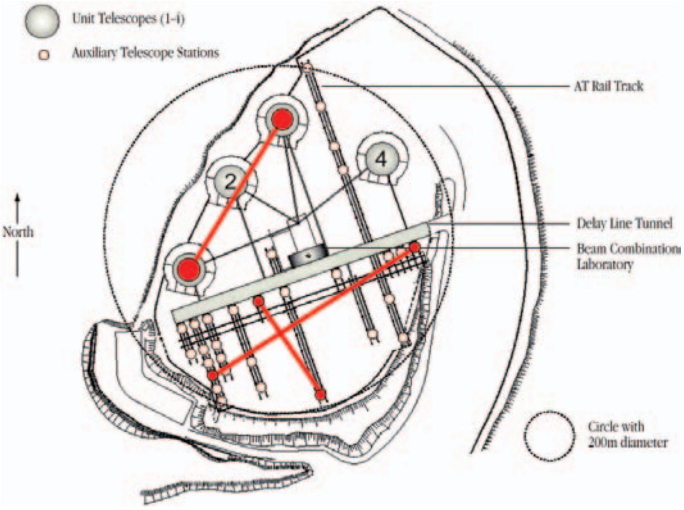


**Figure 2:** View of the Paranal platform with the three baselines used for the VLTI observations of Cepheids (in red).

grated values over the full stellar disc. To convert them into a pulsation velocity, i.e. a physical displacement of the photosphere at the center of the disc, we have to multiply it by a projection factor $p$ that encompasses the sphericity of the star and the structure of its atmosphere (limb darkening,…). Unfortunately, the $p$-factor is still uncertain at a level of a few percent but classical high resolution spectroscopy coupled with the dispersed fringes mode of AMBER are expected to bring strong constraints on this important factor. We have also started a theoretical approach in order to strongly constraint this parameter and to improve our distance determinations (Nardetto et al. 2004).

On the other hand, the angular size is difficult to estimate directly. Until recently, the only method to estimate the angular size was through the surface brightness of the star. With the advent of powerful infrared long baseline interferometers, it is now possible to resolve spatially the star itself, and thus measure directly its photospheric angular diameter. An uncertainty at a level of about 1% remains on the limb darkening of these stars, that is currently taken from static atmosphere models. In the near future, the gain in spatial resolution brought by the short wavelength modes of AMBER ($J$ and $H$ bands) will allow us to measure directly the intensity profile of several Cepheids.

## Observations with VINCI and the VLTI Test Siderostats

For our observations, the beams from the two VLTI Test Siderostats (0.35m aperture) or the two Unit Telescopes UT1 and UT3 were recombined coherently in VINCI, the VLTI Commissioning Instrument. We used a regular $K$ band filter ($\lambda$ = 2.0–2.4 µm) that gives an effective observation wavelength of 2.18 µm for the effective temperature of typical Cepheids. Three VLTI baselines were used for this program: E0-G1, B3-M0 and UT1-UT3 respectively 66, 140 and 102.5m in ground length. Figure 2 shows their positions on the VLTI platform.

In total, we obtained 69 individual angular diameter measurements, for a total of more than 100 hours of telescope time (2 hours with the UTs), spread over 68 nights (Kervella et al. 2004a). One of the key advantages of VINCI is to use single-mode fibres to filter out the perturbations induced by the turbulent atmosphere. The resulting interferograms are practically free of atmospheric corruption, except the piston mode (differential longitudinal delay of the wavefront between the two apertures) that tends to smear the fringes and affect their visibility. But this residual can be brought down to a very low level by using a fast acquisition rate. As a result, the visibility measurements from VINCI are currently the most precise ever obtained, with a relative statistical dispersion that can be as low as 0.05% on bright stars.

## Selected sample of Cepheids

Despite their apparent brightness, Cepheids are located at large distances, and ESA's Hipparcos satellite could only obtain a limited number of Cepheid distances with a relatively poor precision. If we exclude the peculiar first overtone pulsator Polaris, the closest Cepheid is $\delta$ Cep, located at approximately 250 pc. Using the interferometric BW technique, it is possible to derive directly the distance to the Cepheids for which we can measure the amplitude of the angular diameter variation. Even for the nearby Cepheids, this requires an extremely high resolving power, as the largest Cepheid in the sky, L Car, is only 0.003″ in average angular diameter. Long baseline interferometry is therefore the only technique that allows us to resolve these objects.

The capabilities of the VLTI for the observation of nearby Cepheids are outstanding, as it provides long baselines (up to 202m) and thus a high resolving power. Though they are supergiant stars, the Cepheids are generally very small objects in terms of angular size. A consequence is that

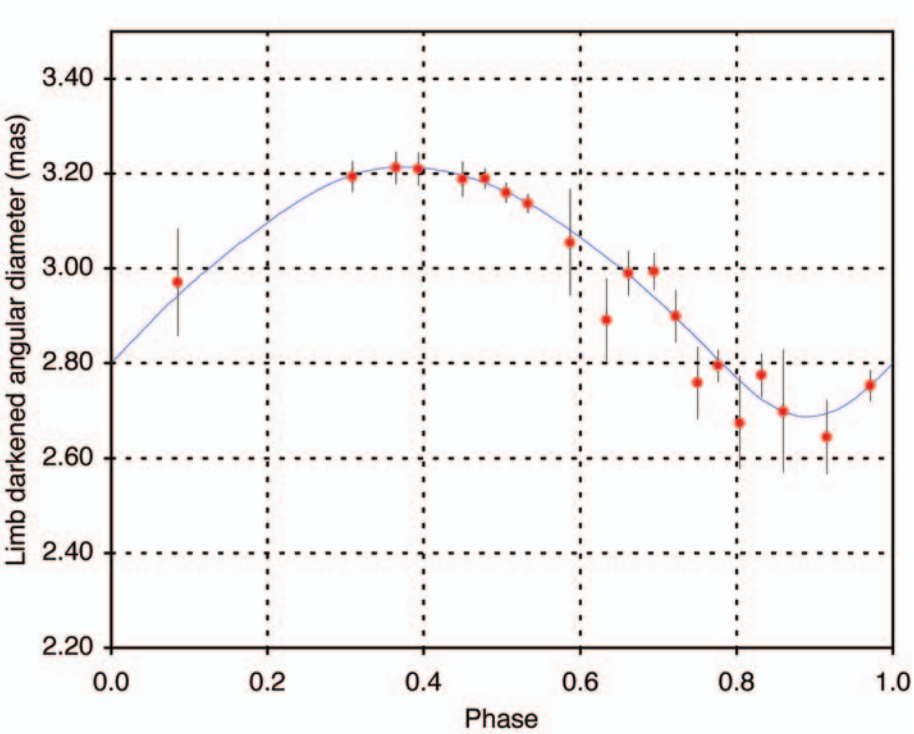


**Figure 3:** VINCI observations of the pulsation of L Car ($P$ = 35.5 days, red dots) and the adjusted radius curve (green line), as deduced from the integration of the radial velocity measured on this star over its pulsation.

the limit on the number of interferometrically resolvable Cepheids is not set by the size of the light collectors, but by the baseline length. From photometry only, several hundred Cepheids can produce interferometric fringes using the VLTI Auxiliary Telescopes (1.8m aperture). However, in order to measure accurately their size, one needs to resolve their disc to a sufficient level, and this reduces the total number of accessible Cepheids to about 30.

Considering the usual constraints in terms of sky coverage, limiting magnitude and accessible resolution, we selected seven bright Cepheids observable from Paranal Observatory (latitude –24 degrees): X Sgr, η Aql, W Sgr, β Dor, ζ Gem, Y Oph and L Car. The periods of these stars cover a wide range, from 7 to 35.5 days, an important advantage to properly constrain the P-R and P-L relations. Using the interferometric BW method, we derived the distances to η Aql, W Sgr, β Dor and L Car. For the remaining three objects of our sample, X Sgr, ζ Gem and Y Oph, we obtained average values of their angular diameters, and we applied a hybrid method to derive their distances, based on published values of their linear diameters. Figure 3 shows the angular diameter curve and the fitted radius curve of L Car ($P$ = 35.5 days), that constrains its distance to a relative precision better than 5%. A discussion of these data can be found in Kervella et al. (2004d).

## Period-Radius relation

The Period-Radius relation (P-R) is an important constraint to the Cepheid models (see e.g. Bono et al. 1998). It takes the form of the linear expression $\log R = a \log P + b$. In order to calibrate this relation, we need to estimate directly the linear radii of a set of Cepheids. To complement the VINCI sample of seven Cepheids, we added the measurements of δ Cep, ζ Gem and η Aql obtained previously by other interferometers. We have applied two methods to determine the radii of the Cepheids of our sample: the interferometric BW method, and a combination of the average angular diameter and trigonometric parallax. While the first provides directly the average linear radius and distance, we need to use trigonometric parallaxes to derive the radii of the Cepheids for which the pulsation is not detected. For these stars, we applied the Hipparcos distance, except for δ Cep, for which we considered the recent parallax measurement by Benedict et al. (2002).

Figure 4 shows the distribution of the measured diameters on the P-R diagram. When we choose to consider a constant slope of $a$=0.750±0.024, as found by Gieren, Fouqué & Gómez (1998, hereafter GFG98), we derive a zero point of $b$=1.105±0.029 (Kervella et al. 2004b). As a comparison, GFG98 obtained a value of $b$=1.075±0.007,

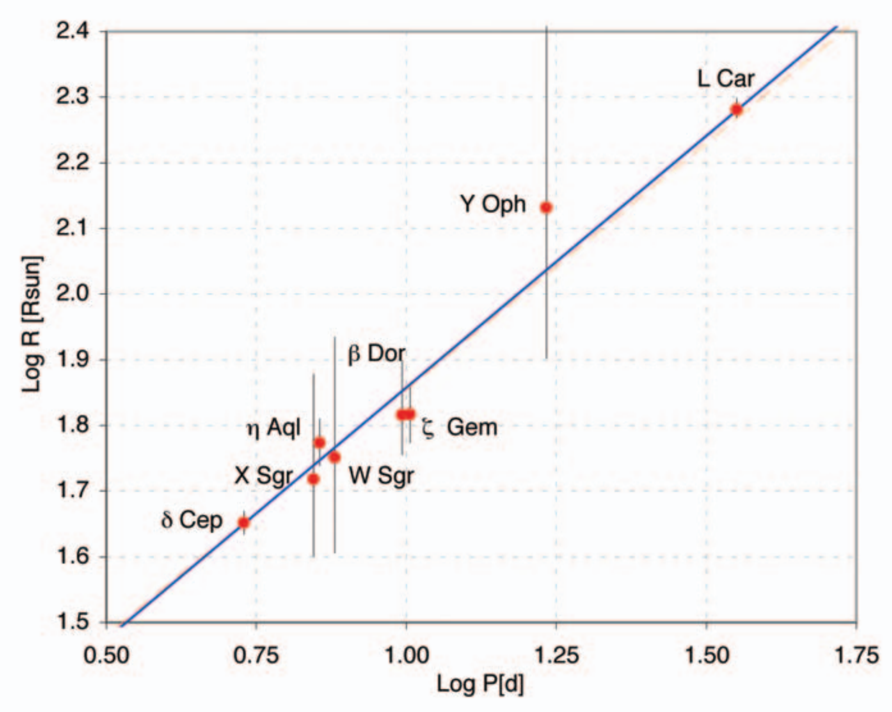


**Figure 4:** Period-Radius relation deduced from the interferometric measurements of Cepheids. The blue line corresponds to the simultaneous fit of both the zero point and slope of the line. The orange dashed line assumes the slope from GFG98, fitting only the zero point.

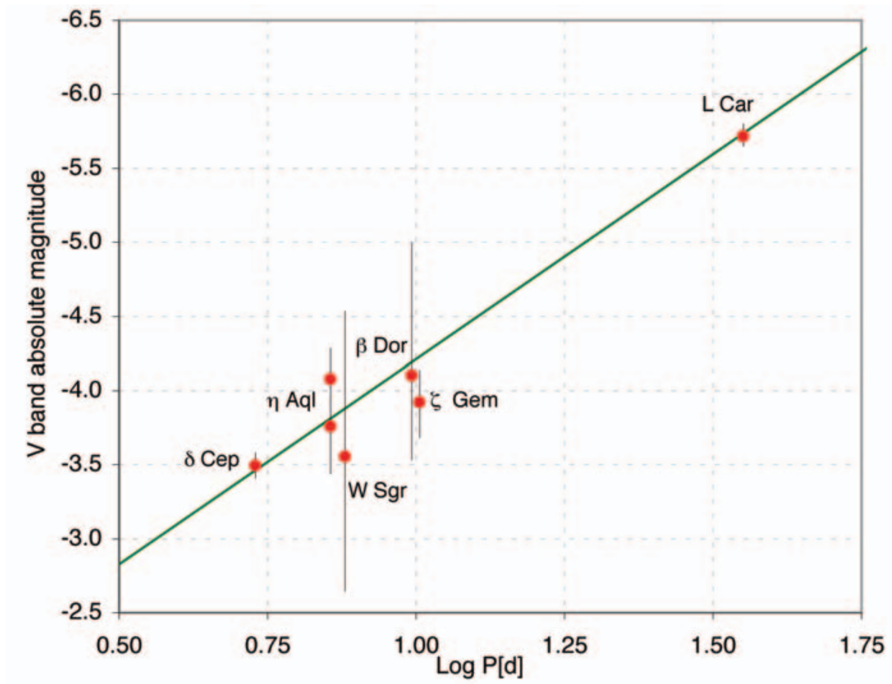


**Figure 5:** Period-Luminosity relation in the *V* band, as deduced from the interferometric observations of Cepheids and the HST parallax measurement of δ Cep. The green line is the fitted *P-L* relation, assuming the slope from GFG98. The agreement between the model and the measurements is excellent, in particular for the high precision measurements of δ Cep and L Car.

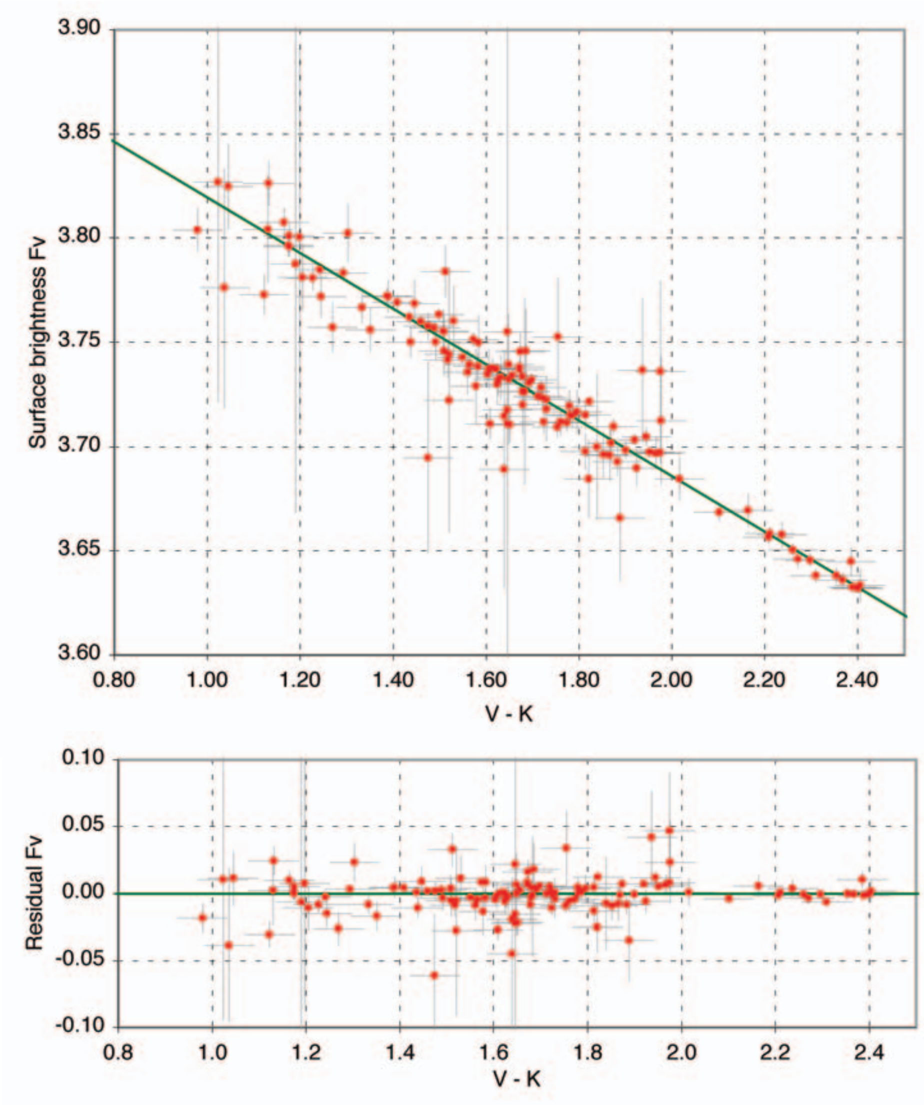


**Figure 6:** Surface brightness-colour relation $F_V(V\text{-}K)$ of Cepheids (upper part) and the residuals of the fit (lower part). The 145 individual interferometric measurements are displayed as red dots, and the fitted linear model as a green line.

only $-1.6\sigma$ away from our result. These relations are compatible with our calibration within their error bars. Fitting simultaneously both the slope and the zero point to our data set, we obtain $a$=0.767±0.009 and $b$=1.091±0.011. These values are only $\Delta a$ = +0.7σ and $\Delta b$= +1.2σ away from the GFG98 calibration. Considering the limited size of our sample, the agreement is very satisfactory. On the other hand, the slopes derived from numerical models of Cepheids are significantly different, such as the slope $a$=0.661±0.006 found by Bono et al. (1998).

## Period-Luminosity relation

The Cepheid P-L relation is the basis of the extragalactic distance scale, but its calibration is still uncertain at a ΔM = ±0.10 mag level. Moreover, it is not excluded that a significant bias of the same order of magnitude affects our current calibration of this relation. Until now, the classical BW method (where one combines photometry and radial velocity data) was used to obtain the distance and radius of a Cepheid. A recent application of this method to individual stars can be found for instance in Taylor & Booth (1998). A requirement of this method is a very accurate measurement of the Cepheid's effective temperature at all observed phases, in order to determine the angular diameter. Interferometry allows us to bypass this step and its associated uncertainties by measuring directly the variation of angular diameter during the pulsation cycle. The latest generation of long baseline visible and infrared interferometers has the potential to provide precise distances to Cepheids up to about 1 kpc, using the interferometric BW method.

Our sample is currently too limited to allow a robust determination of the P-L relation, defined as $M_\lambda = \alpha_\lambda\,(\log P - 1) + \beta_\lambda$ that would include both the slope and the log $P$ = 1 reference point $\beta_\lambda$. However, if we suppose that the slope is known *a priori* from the literature, we can still derive a precise calibration. We have considered for our fit the P-L slope measured on LMC Cepheids. This is a reasonable assumption, as it was checked successfully on the Magellanic Clouds Cepheids, and in addition our sample is currently too limited to derive both the slope and the reference point simultaneously.

For the $V$ band, we obtain $\beta_V$= –4.209±0.075 (Kervella et al. 2004b). The positions of the Cepheids on the P-L diagram are shown on Fig. 5. Our calibrations differ from GFG98 by $\Delta\beta_V$ = +0.14 mag, corresponding to +1.8σ. The sample is dominated by the high precision L Car and δ Cep measurements. When these two stars are removed from the fit, the difference with GFG98 is slightly increased, up to +0.30 mag, though the distance in σ units is reduced (+1.5). From this agreement, L Car and δ Cep do not appear to be systematically different from the other Cepheids of our sample. It is difficult to conclude firmly that there is a significant discrepancy between GFG98 and our results, as our sample is currently too limited to exclude a small-statistics bias. However, if we assume an intrinsic dispersion of the P-L relation $\sigma_{PL}$~ 0.1 mag, as suggested by GFG98, then our results point toward a slight underestimation of the absolute magnitudes of Cepheids by these authors. On the other hand, we obtain precisely the same log $P$ = 1 reference point value in $V$ as Lanoix et al. (1999) did, using parallaxes from Hipparcos. The excellent agreement between these two fully independent, geometrical calibrations of the P-L relation is remarkable.

Averaging our $K$ and $V$ band zero point values, we obtain a final LMC distance modulus of $\mu_0$ = 18.55 ± 0.10. This value is statistically identical to the LMC distance used for the HST Key Project, $\mu_0$ = 18.50 ± 0.10. We would like to emphasize that this result is based on six stars only, and our sample needs to be extended in order to exclude a small-number statistics bias. In this sense, the P-L calibration presented here should be considered as an intermediate step toward a final and robust determination of this important relation by interferometry.

## Surface brightness relations

The surface brightness (hereafter SB) relations link the emerging flux per solid angle unit of a light-emitting body to its colour, or effective temperature. Intuitively, the conservation of the SB can easily be understood as both the solid angle subtended by a star and its apparent brightness are decreasing with the square of its distance. In theory, for a perfect blackbody emission, their ratio is therefore a constant for a given effective temperature. In practice, the stars are not perfect blackbodies, and we have to rely on

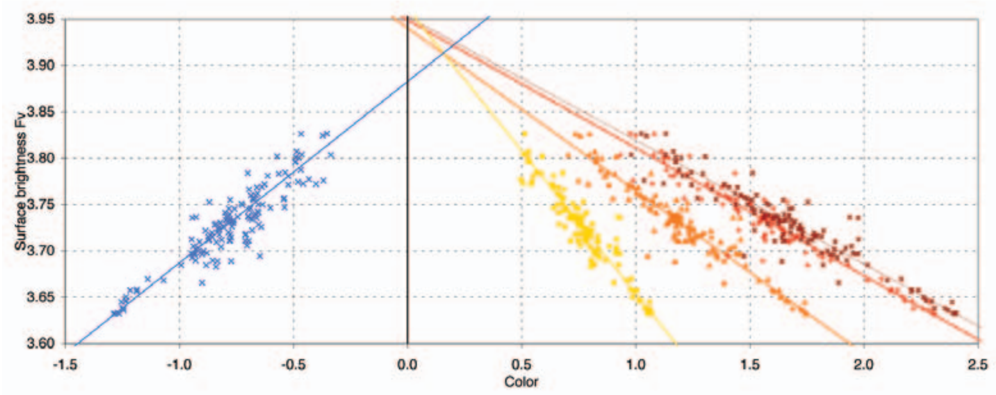


**Figure 7:** Overview of the surface brightness-colour relations in the *V* band, based on the *V-B* (blue), *V-I* (yellow), *V-J* (orange), *V-H* (red) and *V-K* (dark red) colors.

a colour index (i.e. the difference between magnitudes in two photometric bands) as a tracer of the effective temperature.

The SB relations are of considerable astrophysical interest for Cepheids, as a well-defined relation between a particular colour index and the surface brightness can provide accurate predictions of their angular diameters. When combined with the radius curve, integrated from spectroscopic radial velocity measurements, they give access to the distance of the Cepheid through the classical (non interferometric) BW method. This method has been applied recently to Cepheids in the SMC (Storm et al. 2004), i.e. at a far greater distance than what can be achieved by the interferometric BW method. But the accuracy that can be achieved on the distance estimate is conditioned for a large part by our knowledge of the SB relations.

When considering a perfect blackbody curve, any colour can in principle be used to obtain the SB, but in practice, the linearity of the correspondance between log Teff and color depends on the chosen wavelength bands. The surface brightness $F_\lambda$ is given by the following expression (Fouqué & Gieren 1997) : $F_\lambda = 4.2207 - 0.1\ m_\lambda - 0.5 \log q_{LD}$ where $q_{LD}$ is the limb darkened angular diameter, i.e. the angular size of the stellar photosphere. To fit the individual measurements, we used a linear function of the stellar color indices, expressed in magnitudes (logarithmic scale), and SB relations can be fitted using for example the following expression: $F_V(V\text{-}K) = a\ (V\text{-}K)_0 + b$. The $a$ and $b$ coefficients represent respectively the slope and zero point of the SB relation.

We assembled a list of 145 individual interferometric measurements of Cepheids, related to nine stars. For each measurement epoch, we estimated the *BVRIJHK* magnitudes based on Fourier interpolations of the available photometric data from the literature and corrected them for interstellar extinction.

The resulting $F_V(V\text{-}K)$ relation fit is presented in Fig. 6. The other relations based on the *V* band surface brightness $F_V$ and *BIJHK* colours are plotted on Fig. 7. The smallest residual dispersions are obtained for the infrared based colors, for instance: $F_V = -0.1336{\pm}0.0008(V{-}K){+}3.9530{\pm}0.0006$ (Kervella et al. 2004c). The intrinsic dispersion is undetectable at the current level of precision of our measurements, and could be as low as 1%.

## Prospects with AMBER

While our present results are very encouraging, the calibration of the P-R and P-L relations as described here may still be affected by small systematic errors. In particular the method relies on the fact that the displacements measured through interferometry and through spectroscopy (integration of the radial velocity curve) are in different units (milli-arcseconds and kilometers respectively) but are the same physical quantity. This may not be exactly the case, as the regions of a Cepheid's atmosphere where the lines are formed do not necessarily move homologously with the region where the *K*-band continuum is formed. The limb darkening could also play a role at a level of ~1%. An exploration of these refined physical effects will soon be possible with the high spectral resolution mode of the AMBER instrument.

The upcoming availability of 1.8m Auxiliary Telescopes on the VLTI platform in 2004, to replace the 0.35m Test Siderostats, will allow us to observe many Cepheids with a precision at least as good as our observations of L Car (Fig. 3). In addition, the AMBER instrument will extend the VLTI capabilities toward shorter wavelengths (*J* and *H* bands), thus providing higher spatial resolution than VINCI (*K* band). The combination of these two improvements will extend significantly the accessible sample of Cepheids, and we expect that the distances to more than 30 Cepheids will be measurable with a precision better than 5%. This will provide a high precision calibration of both the reference point (down to ±0.01 mag) and the slope of the Galactic Cepheid P-L. As the galaxies hosting the Cepheids used in the HST Key Project are close to solar metallicity on average, this Galactic calibration will allow us to bypass the LMC step in the extragalactic distance scale. Its associated uncertainty of ±0.06 due to the metallicity correction of the LMC Cepheids will therefore become irrelevant for the measurement of the Hubble constant $H_0$.

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# First Science for the Virtual Observatory

*The Virtual Observatory will revolutionise the way we do Astronomy, by allowing easy access to all astronomical data and by making handling and analysing datasets at various locations across the globe much simpler and faster. We report here on the status of the Virtual Observatory in Europe and on the first science result coming out of it, the discovery of ~30 supermassive black holes that had previously escaped detection behind masking dust clouds.*

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Astronomy in the 21st century is facing the need for radical changes. When dealing with surveys of up to ~1,000 sources, one could apply for telescope time and obtain an optical spectrum for each one of them to identify the whole sample. Nowadays, we have to deal with huge surveys (e.g., the Sloan Digital Sky Survey [SDSS], the Two Micron All Sky Survey [2MASS], the Massive Compact Halo Object [MACHO] survey), reaching (and surpassing) 100 million objects. Even at, say, 3,000 spectra at night, which is only feasible with the most efficient multi-object spectrographs and for relatively bright sources, such surveys would require more than 100 years to be completely identified, a time which is clearly much longer than the life span of the average astronomer! But even taking a spectrum might not be enough to classify an object. We are in fact reaching fainter and fainter sources, routinely beyond the typical identification limits of the largest telescopes available (approximately 25 mag for 2–4 hour exposures), which makes "classical" identification problematic. These very large surveys are producing a huge amount of data: it would take about two months to download at 1 Mbytes/s (a very good rate for most astronomical institutions) the Data Release 2 SDSS images, about two weeks for the catalogues. The images would fill up about 1,000 DVDs. And the final SDSS will be about three times as large. These data, once downloaded, need also to be analysed, which requires tools which may not be available locally and, given the complexity of astronomical data, are different for different energy ranges. Moreover, the breathtaking capabilities and ultra-high efficiency of new ground- and space-based observatories have led to a "data explosion", with astronomers world-wide accumulating of the order of a Terabyte of data per night. Finally, one would like to be able to use all of these data, including multi-million-object catalogues, by putting this huge amount of information together in a coherent and relatively simple way, something which is impossible at present.

All these hard, unescapable facts call for innovative solutions. For example, the observing efficiency can be increased by a clever pre-selection of the targets, which will require some "data-mining" to characterise the sources' properties before hand, so that less time is "wasted" on sources which are not of the type under investigation. One can expand this concept even further and provide a "statistical" identification of astronomical sources by using all the available, multi-wavelength information without the need for a spectrum. The data-download problem can be solved by doing the analysis where the data reside. And finally, easy and clever access to *all* astronomical data worldwide would certainly help in dealing with the data explosion and would allow astronomers to take advantage of it in the best of ways.

## The Virtual Observatory

The name of the solution is the *Virtual Observatory* (VO). The VO is an innovative, evolving system, which will allow users to interrogate multiple data centres in a seamless and transparent way, to best utilise astronomical data. Within the VO, data analysis tools and models, appropriate to deal also with large data volumes, will be made more accessible. New science will be enabled, by moving Astronomy beyond "classical" identification with the characterisation of the properties of very faint sources by using all the available information. All this will require good communication, that is the adoption of a common language between data providers, tool users and developers. This is being defined now using new international standards for data access and mining protocols under the auspices of the recently formed *International Virtual Observatory Alliance* (IVOA: http://ivoa.net), a global collaboration of the world's astronomical communities.

One could think that the VO will only be useful to astronomers who deal with colossal surveys and huge amounts of data. That is not the case. The World Wide Web is equivalent to having all the documents of the world inside one's computer, as they are all reachable with a click of a mouse. Similarly, the VO will be like having all the astronomical data of the world inside one's desktop. That will clearly benefit not only professional astronomers but also anybody interested in having a closer look at astronomical data. Consider the following example: imagine one wants to find *all* the observations of a given source available in *all* astronomical archives in a given wavelength range. One also needs to know which ones are in raw or processed format, one wants to retrieve them and, if raw, one wants also to have access to the tools to reduce them on-the-fly. At present, this is extremely time consuming, if at all possible, and would require, even to simply find out what is available, the use a variety of search interfaces, all different from one another and located at different sites. The VO will make all this possible very easily.

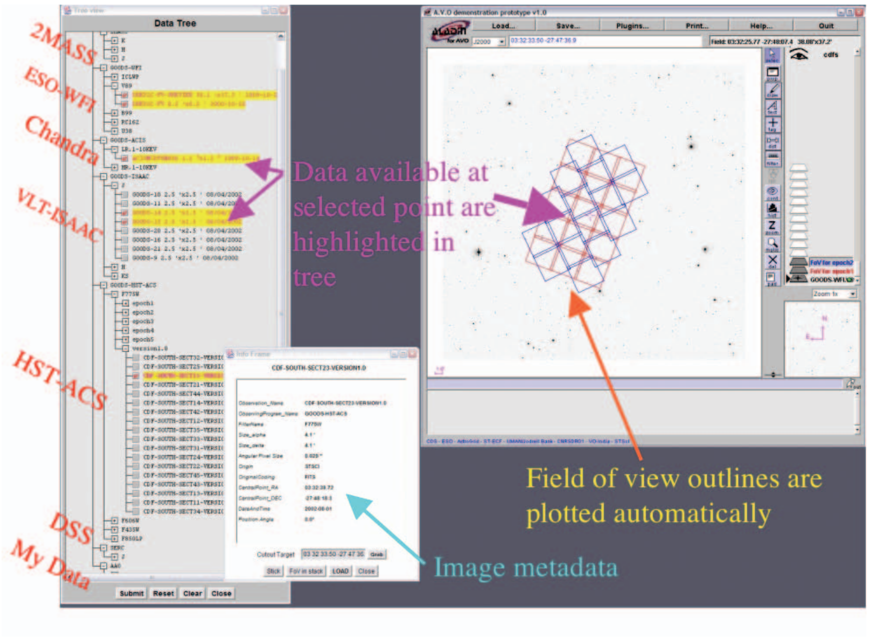


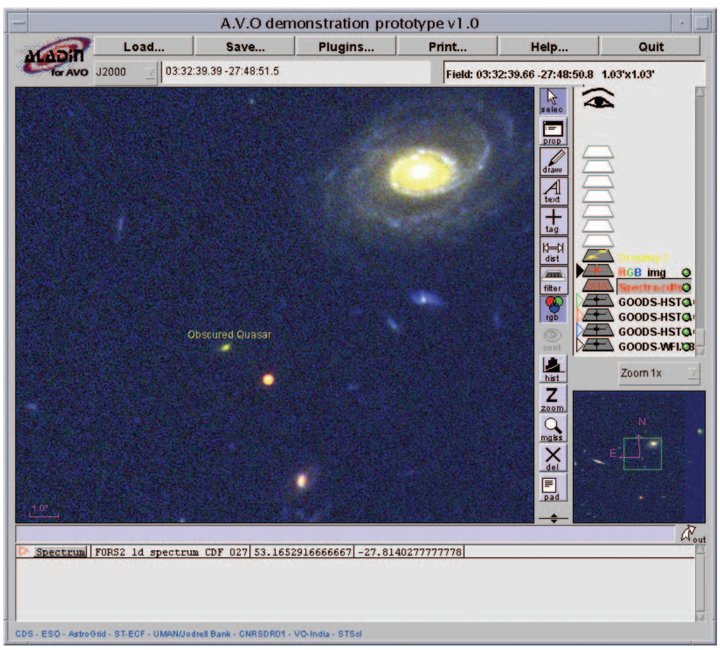

**Figure 1:** The AVO prototype in action. An ESO/WFI image of the GOODS southern field, overlaid with the HST/ACS data field of view outlines. The "data-tree" on the left shows the images available in the *Aladin* image server. Data available at selected coordinates get highlighted in the tree. Metadata information is also accessible. The user's own data can also be loaded into the prototype. This is based on the use of IVOA agreed standards, namely the Data Model, descriptive Metadata, and data interchange standards.

## The VO in Europe: the Astrophysical Virtual Observatory

The status of the VO in Europe is very good. In addition to seven current national VO projects, the European funded collaborative *Astrophysical Virtual Observatory* initiative (AVO: http://www.euro-vo.org) is creating the foundations of a regional scale infrastructure by conducting a research and demonstration programme on the VO scientific requirements and necessary technologies. The AVO has been jointly funded by the European Commission (under the Fifth Framework Programme [FP5]) with six European organisations participating in a three year Phase-A work programme. The partner organisations are ESO in Munich, the European Space Agency, AstroGrid (funded by PPARC as part of the United Kingdom's E-Science programme), the CNRS-supported Centre de Données Astronomiques de Strasbourg (CDS) and TERAPIX astronomical data centre at the Institut d'Astrophysique in Paris, the University Louis Pasteur in Strasbourg, and the Jodrell Bank Observatory of the Victoria University of Manchester. The AVO is the definition and study phase leading towards the Euro-VO – the development and deployment of a fully fledged operational VO for the European astronomical research community.

The AVO project is driven by its strategy of regular scientific demonstrations of VO technology, held on an annual basis in coordination with the IVOA. For this purpose progressively more complex AVO demonstrators are being constructed. The current one is an evolution of *Aladin*, developed at CDS, and has become a set of various software components, provided by AVO and international partners, which allows relatively easy access to remote data sets, manipulation of image and catalogue data, and remote calculations in a fashion similar to remote computing.

The AVO held its second demonstration, "AVO 1st Science", on January 27–28, 2004 at ESO. The demonstration was truly multiwavelength, using heterogeneous and complex data covering the whole electromagnetic spectrum. These included: MERLIN, VLA (radio), ISO [spectra and images] and 2MASS (infrared), USNO, ESO 2.2m/WFI



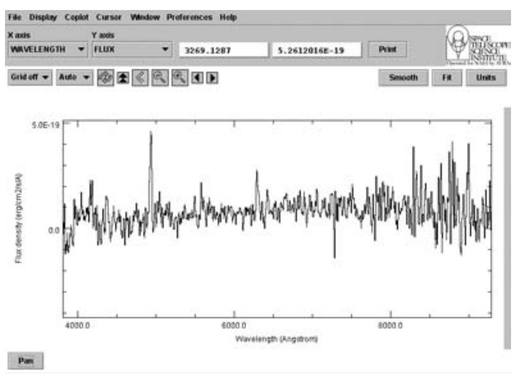




**Figure 2:** An example of the direct links between imaging and spectral data: an obscured source selected via its X-ray (Chandra) properties, imaged by the HST/ACS, and identified through an ESO/VLT FORS2 spectrum (below) as a type 2 quasar at redshift 3.06 (Szokoly et al. 2004). The great majority of our new QSO 2 candidates are too faint to be classified even by the VLT or Keck. The colour-composite image has been generated on-the-fly from HST images in three different bands and the spectrum is displayed using SpecView, an application plugged-in into the AVO prototype.

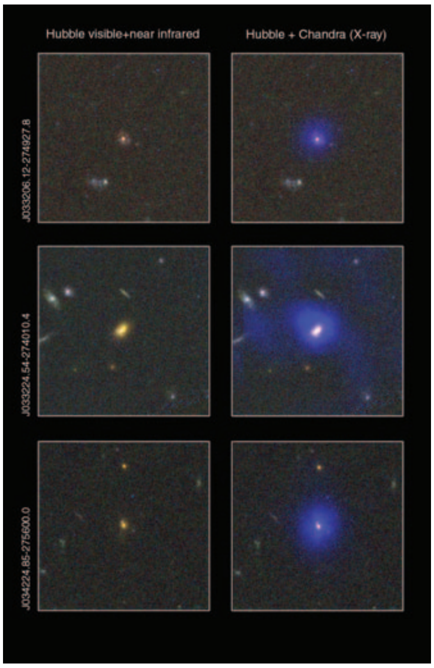



**Figure 3:** Colour-composite images of the host galaxies of three of the newly found dust-enshrouded supermassive black holes. To the left, images taken with the Advanced Camera for Surveys on-board the NASA/ESA Hubble Space Telescope. To the right these images are overlaid with images (in blue) from NASA's Chandra X-ray Observatory.

and VLT/FORS [spectra], and HST/ACS (optical), XMM and Chandra (X-ray) data and catalogues. Two cases were dealt with: an extragalactic case on obscured quasars, centred around the Great Observatories Origin Deep Survey (GOODS) public data, and a Galactic scenario on the classification of young stellar objects.

The extragalactic case was so successful that it turned into the first published science result fully enabled via end-to-end use of VO tools and systems.

## Discovering optically faint, obscured quasars with VO tools

How did we get a scientific paper out of a science demonstration? The extragalactic science case revolved around the two GOODS fields (Giavalisco et al. 2004), namely the Hubble Deep Field-North (HDF-N) and the Chandra Deep Field-South (CDF-S), the most data-rich, deep survey areas on the sky. Our idea was to use the AVO prototype to look for high-power, supermassive black holes in the centres of apparently normal looking galaxies.

Black holes lurk at the centres of active galaxies (AGN) surrounded by dust which is thought to be, on theoretical and observational grounds (see, e.g., Urry & Padovani 1995; Jaffe et al. 2004), distributed in a flattened configuration, torus-like. When we can look down the axis of the dust torus and have a clear view of the black hole and its surroundings these objects are called "type 1" AGN, and display the broad lines and strong UV emission typical of quasars. "Type 2" AGN, on the other hand, lie with the dust torus edge-on as viewed from Earth so our view of the black hole is totally blocked by the dust over a range of wavelengths from the near-infrared to soft X-rays.

While many dust-obscured low-power black holes, the Seyfert 2s, have been identified, until recently few of their high-power counterparts were known. This was due to a simple selection effect: when the source is a low-power one and therefore, on average, closer to the observer, one can very often detect some features related to narrow emission lines on top of the emission from the host galaxy, which qualify it as a type 2 AGN. But when the source is a high-power one, a so-called QSO 2, and therefore, on average, further away from us, the source looks like a normal galaxy.

Our approach was to look for sources where nuclear emission was coming out in the hard X-ray band, with evidence of absorption in the soft band, a signature of an obscured AGN, and the optical flux was very faint, a sign of absorption. One key feature was the use of a correlation discovered by Fiore et al. (2003) between the X-ray-to-optical ratio and the X-ray power, which allowed us to select QSO 2s even when the objects were so faint that no spectrum, and therefore no redshift, was available.

We used a large amount of data: deep X-ray (Chandra) and optical (HST/ACS) catalogues, and identifications, redshifts, and spectra for previously identified sources in the CDF-S and HDF-N based on VLT and Keck data. Using the AVO prototype made it much easier to classify the sources we were interested in and to identify the previously known ones, as we could easily integrate all available information from images, spectra, and catalogues at once (see Fig. 1 and 2). One interesting feature is the prototype catalogue cross-matching service, which can access all entries in Vizier, at CDS, and allowed us to cross-correlate a variety of catalogues very efficiently.

Out of the 546 X-ray sources in the GOODS fields we selected 68 type 2 AGN candidates, 31 of which qualify as QSO 2 (estimated X-ray power > $10^{44}$ erg/s; see Fig. 3). Our work brings to 40 the number of QSO 2 in the GOODS fields, an improvement of a factor ~4 when compared to the only nine such sources previously known. These sources are very faint (⟨R ~ 27⟩) and therefore spectroscopic identification is not possible for the large majority of objects, even with the largest telescopes currently available. By using VO methods we are sampling a region of redshift - power space so far unreachable with classical methods. For the first time, we can also assess how many QSO 2 there are down to relatively faint X-ray fluxes. We find a surface density greater than 330 deg$^{-2}$ for $f$(0.5–8 keV) ≥ $10^{-15}$ erg cm$^{-2}$ s$^{-1}$, higher than previously estimated.

The identification of a population of high-power obscured black holes and the active galaxies in which they live has been a key goal for astronomers and will lead to greater understanding and a refinement of the cosmological models describing our Universe. The paper reporting these results has just been published (Padovani et al. 2004).

## Using the AVO Prototype

The AVO prototype can be downloaded from the AVO Web site at http://www.-euro-vo.-org/twiki/bin/view/Avo/SwgDownload. We encourage astronomers to download the prototype, test it, and also use it for their own research. For any problems with the installation and any requests, questions, feedback, and comments you might have please contact the AVO team at twiki@euro-vo.org. (Please note that this is still a prototype: although some components are pretty robust, some others are not.)

## Future Developments

The next AVO demonstration event is to be held in January 2005 and this will see the rollout of the first version of the Euro-VO portal, through which the European astronomer will gain secure access to a wide range of data access and manipulation capabilities. The science drivers for this next demonstration release are being developed by the AVO science team with input from the AVO Science Working Group. The AVO Phase-A study is now being completed. The Science Reference Mission, on which the AVO team is also working, will form the scientific basis for the wider scale development of the Euro-VO.

## Acknowledgements

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# Students at ESO/Santiago: the period 1999-2004

Danielle Alloin, ESO/Chile Office for Science

In parallel with the start of VLT operations in the last quarter of 1998, the development of ESO's research facilities in Santiago has provided increased opportunities for students, from ESO member states in particular, to be trained in Chile under different ESO programmes.

In this short review, I will essentially discuss students undergoing short-term training and students preparing a PhD (ESO studentship programme) at ESO/Santiago. I will show how the number of students trained at ESO/Santiago has more than doubled since 1999 and discuss the impact of the student training programs on the visibility and attractiveness of ESO/Chile.

This analysis is restricted to students in physics/astrophysics, as the training of student-engineers and student-technicians, mostly performed at (and for) the observatories (LaSilla, Paranal, APEX, ALMA) has not been taken into account. Finally, one should also mention that student training at ESO/Santiago is organized in a way similar to student training at ESO/Garching and all under the responsibility of the Office for Science.

## Students on short-term training

This term corresponds in fact to a variety of training, with the common characteristic of a stay at ESO/Santiago which is less than 6 months. Included under this term is research training at the level of Licenciatura or Magistere (2 years before the start of a PhD), of the MSc, DEA/DESS or Laurea graduation (1 year before the start of a PhD), but also some training performed in the course of PhD preparation, for example if the student's PhD supervisor is collaborating with an ESO/Chile staff member. Therefore, the funding for the training may come from different sources within or outside ESO, such as the visitors' programme or the students' home institute (or a mixture). As such, training is in relation with university schedules, mostly taking place during the period January-August.

Since 1999, the number of students at ESO/Santiago has evolved dramatically, demonstrating increasing interest. We hosted in 1999: 5 students; in 2000: 7 students; in 2001: 18 students; in 2002: 12 students; in 2003: 10 students, and in 2004: 13 students. Over 6 years, 65 students have been trained at ESO/Santiago, which gives a mean of around 11 per year.

Analyzing the university affiliations of these 65 students, we observe that 84% of the students are registered at a university in an ESO-member state. Breaking down this figure per country, we get: 37% in France, 18.5% in Italy, 9.5% in Germany, 9.5% in the Nordic countries and 6.5% in the UK. This distribution is obviously related to the university's requirements: whenever research training is mandatory during the university course, the students apply in greater number: this is the case for France, while it does not seem to be as stringent for Germany, Italy or the UK.

Regarding their academic level, about half of the trainees were advanced students (one year before PhD or during PhD).

Regarding the topics of the training, they reflect the scientific interests of the ESO/Chile staff at a given time, and therefore have been changing with time. Over the 6 year period, 26% of the short-term training was in planetary science (including the Solar System), 11% about stellar and ISM studies, 34% in the field of galaxies and active galactic nuclei, 14% in cosmology and 9% in relation with instrumentation and data reduction techniques.

The training output is frequently a report which the student has to write and defend at her/his university and which is taken into account for the evaluation and award of the degree. We observe that a good proportion of the students have taken their degree at a ranking within the top quartile, demonstrating that ESO/Santiago attracts excellent students. Moreover, the scientific results obtained during the training are often included in a poster presentation or a refereed paper published with the ESO/Chile supervisor and collaborators.

A large fraction of the short-term students seem to have appreciated their training. As much as possible, they were given the opportunity to visit one of ESO's observatories in Chile. For all of them, it has been the occasion of testing their motivation for research and of discovering the reality of astronomical observations and analysis. Many have confirmed their original choices, and a few changed their mind and decided to move to other types of activities. This is exactly the goal of training: in all cases, whether research interests have been consolidated or not, the training has been useful and has contributed to reducing the gap which exists sometimes between dreams and reality. Some of the students on short-term training later prepared their PhD at ESO/Santiago (see below).

In practice, the conditions for a successful training are: a strong motivation, curiosity, adaptability to a new environment, ability to work with some independence and to be pro-active in the interaction (since the ESO/Chile staff spend part of their time at the observatories and cannot provide a close, day-to-day supervision). Therefore, advanced students are better suited for short-term training at ESO/Santiago. It is also recommended to start contacts with potential ESO/Chile supervisors very early (in November/ December) so that a good training-project can be prepared and its funding put in place.

Information about short-term student training at ESO/Santiago can be found in the webpage: www.sc.eso.org/santiago/science (check the ESO/Chile Scientific Visitors Programme).

## Students preparing a PhD in co-supervision

This is the ESO studentship programme, of which a detailed description can be found on the ESO webpage (www.eso.org/gen-fac/adm/pers/vacant/). In brief, ESO provides a two year studentship for students preparing their PhD in co-supervision. The student has to be registered in the university where the PhD will be defended, and has two co-supervisors: one at ESO/Santiago (or ESO/Garching if the student is hosted at ESO/Garching) and one in her/his home university (preferably located in one of the ESO member states, although this is not mandatory). The third year of PhD preparation should normally be funded by the university or laboratory of the co-supervisor. Applications for this programme can be submitted once a year, by mid-June. Currently, about 20 PhD students are under this ESO programme, half at ESO/Garching and half at ESO/Santiago. There must be an excellent coordination between the two co-supervisors, for a good definition of the PhD project and a smooth development of the PhD.

Regarding the PhDs prepared at ESO/Santiago, again, there has been an increase in the number of studentship offered since 1999, by almost a factor two. In 1999, there were 6 PhD students at various stages of their PhD, while as of September 2004 we have 10 and another one arriving within a few months. Of course this number fluctuates slightly as the students' works advance, but a figure of 10 is the base.

From 1999 to 2004, there were a total of 26 PhD students at ESO/Santiago: 10 have successfully defended their PhD, and all but one are now postdocs in various observatories or laboratories; 6 are planning to defend their PhD at the end of 2004 or early 2005; 2 will present their PhD around the end of 2005; and 6 others are just finishing their first year and therefore will present their PhD at the end of 2006, while 2 are just starting.

For this sample of 26 PhD students, 90% of the PhD affiliations are at universities in ESO member-states (13 in France, 3 in Italy, 3 in Germany, 2 in Belgium, 1 in Sweden and 1 in the UK). The distribution per subject is as follows: 7 PhDs are in the field of planetary science, 7 in the field of galaxies and active galactic nuclei, 7 in cosmology, 3 in stellar physics and 2 in relation with instrumentation or data reduction techniques.

Contrary to a classical university environment, PhD students at ESO/Santiago do not have many opportunities to attending dedicated courses on a given subject. We tried to compensate for this lack of formal course work in several ways: most of the international astronomical workshops organized in Chile start with a tutorial by a prominent speaker specifically targeted for students, several schools and topical meetings have been organized and senior visitors who can bring in their academic experience have been invited. As well, Chilean universities offer a variety of excellent astronomy courses which PhD students can attend if deemed necessary. The student's non-ESO co-supervisor is also encouraged to come and spend some time at ESO/Santiago to appreciate the scientific environment of the student and make the necessary adjustments. In general, this works quite well.

As a specific feature, PhD students at ESO/Santiago have the possibility to take part in an observatory project (La Silla or Paranal) which puts them in close contact with telescopes, instrumentation and observing procedures. Most students enjoy the observatory projects during which they gain observational expertise.

## Concluding remarks

Over the past 6 years, students' short-term training and PhD preparations at ESO/Santiago have become an important activity and played a significant role in advertising ESO facilities. ESO/Chile has increased its attractiveness, in particular at the postdoctoral level (as shown by a steady growth in the number and quality of fellowship applications for ESO/Chile). The short-term training helps students to test their motivation for research. Short-term training and PhD preparations contribute to strengthening links between ESO/Chile staff and astronomers in the ESO member states. They also stimulate in an excellent manner the research activities of ESO/Chile staff and give ESO/Santiago its multi-cultural flavour and its youth, our future!

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Report on the joint MPA/MPE/ESO/USM workshop on

# Growing Black Holes: Accretion in a Cosmological Context

Andrea Merloni and Sergei Nayakshin (MPA-Garching)

The goal of the meeting was to draw some of the best astronomy researchers from every part of the world to showcase the most recent scientific successes of the Garching/Munich astronomy community, and to also allow the local researchers to learn from the rest of the world. The Conference was held at the Institute for Plasma Physics in Garching, Germany on June 21–25, 2004.

Supermassive black holes (SMBHs) are among the most spectacular objects in the Universe, that shed light on fundamental physical phenomena occurring in their immediate vicinity, such as accretion of gas and strong gravity effects. Historically, theories of accretion have been developed and refined based on observational studies of individual SMBHs that are believed to be powering quasars, first discovered more than 40 years ago. This research stood somewhat separate from cosmology that deals primarily with the formation and evolution of galaxies. However, in recent years, it has been established that black holes lie in the centres of practically all galaxies, and significant links between cosmic structure formation and evolution and supermassive black holes have been demonstrated. Nowadays, SMBH are not just interesting laboratories of exotic physics, but have direct impact on the evolution of the Universe as we see it: they are an important ingredient of cosmological models.

The meeting brought together about 170 scientists from the extra-galactic astronomy, cosmology and accretion physics communities to discuss the implications of the connection between supermassive black hole growth and galaxy formation. For the first time in a meeting of this series, a video-conference connection was established between the Conference hall and both MPA and ESO, to allow the local students to listen to some of the most interesting talks.

We started on Monday with a welcome address from Rashid Sunyaev (MPA), and continued with a session dedicated to the observations of supermassive black holes in the local Universe. Topical reviews were given by Ralf Bender (MPE/USM), who discussed the fundamental correlations observed between SMBHs and their host galactic bulges, and Guineviere Kauffmann (MPA), who presented the analysis of the impressive amount of data on local AGN gathered by the Sloan Digital Sky Survey (SDSS). They both pointed out the important fact that only relatively small mass black holes are actively accreting (and growing) today, while many hints suggest that the biggest black holes in the Universe were formed at very high redshift.

The second session was devoted to the observations of SMBH in the distant universe. Xiaohui Fan (Arizona) and Niel Brand (Penn State) presented the optical and X-ray views, respectively, of the most distant QSOs known. They have vividly illustrated the great progress being made in this area thanks to the SDSS and the Chandra and XMM-Newton X-ray satellites. The first day ended with a few talks, including a review by Bernhard Brandl (Leiden), on the first scientific results in the field from the Spitzer Space Telescope, launched into space in August 2003.

One of the most important open questions in the field is whether black holes were seeds or by-products of galaxy formation. The second day of the meeting was entirely devoted to the theory of black hole formation and growth in the early Universe. The morning session started with a review by Martin Rees (Cambridge) on the physical process through which the first black holes might have formed, while Piero Madau (U of California Observatories) and Abraham Loeb (Harvard) discussed in more detail what predictions can be made by incorporating the physics and dynamics of growing black holes into standard Cold Dark Matter Cosmological models. Also, state-of-the-art cosmological numerical simulations were presented at the meeting: Volker Bromm (Harvard) concentrated on simulating the process of formation of the first stars and black holes, while Volker Springel and Tiziana Di Matteo (MPA) showed spectacular simulations of evolving and interacting galaxies with supermassive black holes in their centres. Finally, Zoltan Haiman (Columbia University) discussed the role of accreting black holes in the re-ionization of the Universe.

The day, started under a chilly rain, ended with a sunny 'Beer and Brez'n' party in the MPE/MPA garden. Faithful to the Bavarian spirit, the organizers provided the guests with more than 250 liters of locally brewed beer!

The following morning the centre of attention was the centre of our own galaxy: the SMBH also known as Sgr A*. Reinhard Genzel (MPA), Mark Morris (UCLA) and Fred Baganoff (MIT) presented the amazing new data gathered in the last few years with the biggest telescopes on earth (VLT, Keck) as well as in space (Chandra). Thanks to these efforts, the case for a black hole in the Galactic Centre appears now to be iron-clad. Moreover, future theoretical interpretation of the data will likely significantly improve our understanding of the black hole growth mechanisms and the associated star formation very close to the black hole.

Another important question was discussed on Wednesday afternoon: the role of galaxy mergers, accretion and stellar captures for the overall black hole growth. David Merritt (Rochester) reviewed the various mechanisms by which SMBHs induce observable changes in the distribution of luminous and dark matter at the centres of galaxies. Later in the afternoon, Marek Abramowicz (Chalmers University) suggested that there are no theoretical limits on the rate at which the gas can be swallowed by a black hole.

On Thursday morning a new window of the gravito-electro-magnetic spectrum was opened to the study of SMBHs: gravitational waves. Sterl Phinney (Caltech) gave a comprehensive overview of the exciting prospects and challenges that lie ahead for gravitational wave astronomy. Bernard Schutz (MPI-Potsdam) illustrated the breathtakingly complex numerical simulations of BH-BH merger events, a possible target of the upcoming Laser Interferometer Space Antenna (LISA). And an overview of the technical aspects of the LISA mission was given by Karsten Danzmann (AEI Hannover).

How important is the feedback from supermassive black holes in structure formation? This fundamental question was deeply investigated by many of the speakers of Thursday afternoon's session. Andrew King (Leicester) advocated the importance of powerful outflows from rapidly accreting black holes in establishing the observed links between SMBHs and host galaxies. Mitchell Begelman (Colorado) showed how AGN feedback can solve the mystery of the lack of strong cooling flows in the centres of many clusters of galaxies, and William Forman (Harvard) presented many new Chandra observations of hot gas in galaxy clusters.

A chance to relax during this intense conference was the conference dinner at the Augustiner Grossgaststaetten in central Munich. The local organizing committee, Jorge Cuadra, Andrea Merloni, Emmi Meyer, Sergei Nayakshin and Rashid Sunyaev, all MPA, Thibaut Paumard (MPE) and Gijs Verdoes Kleijn (ESO), presented some gifts to the MPA secretaries (Maria Depner, Gabi Kratschmann, Kate O'Shea and Cornelia Rickl), whose help throughout the organization of the conference and during it was a real blessing to the LOC.

On the last day of the meeting, the classical problem of what the X-ray Background tells us about AGN activity and obscuration, both at low and at high redshifts, was revisited in the light of the most recent results from deep X-ray surveys by Andy Fabian (Cambridge) and Guenther Hasinger (MPE), and from the multi-waveband GOODS survey by Meg Urry (Yale University). The meeting was closed in an optimistic and somewhat humorous way by the 'Black Hole Manifesto' of Roger Blandford (Caltech), in which some of the most interesting developments from the meeting were summarized.

Those interested in more details of the meeting are invited to visit http://www.MPA-Garching.MPG.DE/~bh-grow/. Conference proceedings are to be published by Springer Verlag as a part of the "ESO Astrophysics Symposia" series.

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Report on a brainstorming meeting about the

# ALMA Interdisciplinary Teaching Project

Henri Boffin and Richard West (ESO)

Recent large-scale surveys have documented a widespread lack of interest in science and technology among Europe's young people. This development is highly worrying as it may lead to a lack of qualified scientists and teachers and may ultimately have dramatic demographic consequences on this continent. Various reasons for this situation have been identified and it is generally acknowledged that teaching quality at the primary and secondary levels plays a crucial role in this context. Means and methods to remedy this undesirable situation are being looked into in many countries and the European Commission has issued a strong plea for the creation of new educational initiatives, in particular broad and general ones that are easily adaptable to national curricula.

Having conducted educational programmes at the European level since 1993, the Education and Public Relations Department (EPR) of the European Southern Observatory has recently embarked upon another ambitious teaching project, this time in connection with the ongoing, intercontinental ALMA programme that aims at the installation of a unique astrophysical research facility consisting of 64 12-m radio antennas at 5000m altitude in the Chilean Atacama desert by 2011. The related frontline science and technology, as well the unusual site, clearly have a great potential for interdisciplinary education.

A first presentation of ideas for an ALMA educational project took place during the large-scale "Physics on Stage 3" educational meeting/fair at ESA/ESTEC in Noordwijk (The Netherlands) in November 2003. For this, Bernhard Mackowiak (ESO EPR) had produced a first draft text on some subjects that may be included in a future "ALMA Teachers' Cookbook". A direct outcome was the creation of a small group of expert teachers from secondary schools in several European countries, who expressed interest in contributing to the development of ALMA-related educational material for interdisciplinary teaching.

A first exchange of views with the members of this group took place in December 2003. Following the extensive and time-consuming preparations for the Venus Transit event in June 2004, the ESO EPR Department is now promoting a new international pilot educational project referred as the ALMA-Interdisciplinary Teaching Project (ALMA-ITP). The main goal is to develop and produce ALMA-related educational material at the secondary level, in particular a comprehensive ALMA Guide for Interdisciplinary Teaching. This project is fully in line with the current trend of lowering the walls between the various subjects and moving towards more interdisciplinary teaching in Europe's secondary schools. It constitutes a contribution towards alleviation of the current educational crisis, by attempting to provide attractive opportunities for more real-life, project-oriented education to teachers and their students. At the same time, it is obvious that the material may also form a very useful basis for similar efforts in other countries involved in the


H. Heyer (ESO)

Expert teachers and scientists from all over Europe attended the first ALMA-ITP meeting at ESO HQ in Garching (Sept. 4, 2004).

ALMA programme, following suitable adaptation to the national and regional curricula. For this, the ALMA Integrated Project Team (IPT) on Outreach and Education will act as a clearing house.

As a next step in this process, we invited a small number of expert teachers, many of whom participated in last year's ALMA-presentation during Physics on Stage 3 and also a number of scientists to come together during a one-day brainstorming meeting at the ESO-HQ in Garching. It started with an overview of the ALMA programme presented by H. Boffin (ESO), co-leader of the ALMA IPT. As well as illustrating the importance of millimetric and sub-millimetric astronomy for the study of some of the most relevant astrophysical fields of the 21st century, the talk also tried to answer the question "why is ALMA what it is and why is it located at Chajnantor?" It was followed by an overview by R. West (ESO) on future ESO projects and their potential role for education. A series of more specialised talks were then delivered: on the geography of the region (B. Mackowiak, ESO), on geology and the effect of Plate Tectonics on the formation of the Andes (E. Scheuber, Institute of Geological Sciences, Free University Berlin, Germany), on the fauna and flora of the Atacama desert (M. Grenon, Geneva Observatory, Switzerland), and on the medical aspects of living and working at high altitude (H. Welsch, German Air Force Institute of Aviation Medicine, Königsbrück, Germany).

These talks clearly illustrated the unique and highly exciting potential of the ALMA programme for education in various domains. This should come as no surprise, however: ALMA will be located on one of the highest plateaus in the world at a altitude of more than 5000m. As Ekkehard Scheuber pointed out, Chajnantor is surrounded by volcanoes, one of which still active (Lascar), and also by ignimbrite outcrops with large calderas, some of which are potentially explosive as they overlay large quantities of gas. The Atacama Desert is by all means the most arid place on Earth with an annual precipitation of less than 10 mm. By comparison, the Sahara desert receives 20 mm of water per year and Death Valley in California no less than 120 mm a year! But as Michel Grenon also showed with a unique and beautiful set of pictures obtained during numerous trips to this region during the past three decades, the Atacama Desert is far from being a place without life. Nature has – as always – shown wonderful creativity to explore many ways to circumvent the extreme UV-exposure, the dramatic lack of water as well as the enormous temperature variations, e.g., by having plants growing into the ground instead of out of it. And he had found plants at an altitude of 5150m, that is, even higher than the ALMA site!

The important medical aspects of living and working at high altitude were well exposed by German Air Force medical specialist Heiko Welsch who discussed the physiological mechanisms behind mountain sickness and how the lack of oxygen at high altitude can lead to hypoxia and sometimes incur life-threatening situations where quick action is paramount. Nobody should think that this added circumstance of the ALMA programme may be taken easily and the medical service must be well planned and always ready.

After this first series of talks, H. Wilson (ESA Education Office) presented the ESA Educational Kit on the International Space Station (ISS) and the lessons learned from preparing an interdisciplinary teaching kit at a European level. She stressed the great importance of involving experienced teachers from the start and to have a thorough review of a prototype teaching kit before the final release. Christiane Henkel and Denis van de Wetering (University of Bielefeld, Germany) presented a research project on interdisciplinary teaching and the importance of stating right from the beginning the objectives of the project as well as the target audience. They also reminded the participants of one of the goals of interdisciplinary teaching: to teach students core skills which are needed in our modern, accelerated and communicative society. These are, they assert, flexibility, creativity, cooperation and communication ability, teamwork ability, and tolerance, all keys for learning and working with others.

Two additional talks, both very much appreciated by all the participants, were given via a videoconference link from the ESO Santiago office, by Daniel Hofstadt (ESO) and Jörg Eschwey (ESO). Daniel Hofstadt shared his deep knowledge of the Atacama culture with its centuries-old traditions and the uniqueness of the scenery around San Pedro de Atacama. He also presented the various environment impact studies which were done prior the start of the ALMA project. These covered cultural, anthropological, archaeological and biological aspects. Jörg Eschwey embarked the audience on a trip from Antofagasta to the Chajnantor ALMA site to illustrate the complex logistics necessary to build major infrastructures in such extreme conditions. He explained the numerous challenges to be solved to construct a 12m wide road that allows the transport of 100 ton antennas, on a variety of soils between 2700m to 5000m altitude and the need to take into account and protect the different biotopes along the route. One example concerned the safety of a local species of rats, named tuco-tuco, by constructing tunnels under the road to allow the animals to transit it without trouble. All this has to be done while chasing large numbers of very curious donkeys watching the progress of the roadwork.

With all this information in hand to realise the enormous potential of ALMA-related education, the meeting participants embarked upon a wide-ranging discussion. It was clear from the beginning that the experience of interdisciplinary teaching is very different from country to country. It was therefore quickly realised that any material to be produced must be in modular form and be easily adaptable to the curricula of individual countries. The need to translate the material into as many different languages as possible was obvious, adding another complex element to this project.

The participants expressed a lot of enthusiasm and are eager to start the development and realisation of the project. During the discussion, a list of about 30 specific topics that could be addressed in a modular way was drawn up, serving as a useful starting point. Many of the teachers volunteered to work on them, with the goal to circulate drafts of the individual modules in some months' time. Specific conclusions were drawn about the desirable format of the future ALMA educational toolkit and on its foci. It will be concerned with the extraordinary and unique science to be made using the ALMA observatory and the variety of challenges to build an observatory like ALMA at Chajnantor. As one participant stated, this is really about "*how to make frontier science in extreme conditions*". The primary target audience is students in secondary schools, i.e. 11–18 years old.

A first draft of the ALMA Interdisciplinary Teaching Project should become available early 2005. It will then be evaluated and tested by teachers after which improvements will be made in a next iteration. It is planned to have a useful version ready for distribution via existing networks by the end of the summer of next year.

**Obituary**

# Jürgen Stock
## 1923 – 2004

On April 19, 2004 Jürgen Stock passed away at the age of 80. Jürgen Stock was never on the payroll of ESO, but he had tremendous impact on the early years of the organisation. In 1951 Stock did his PhD in Hamburg - his supervisor was Otto Heckmann, who later became the first Director General of ESO. After some years in Cleveland - and with a one year interval at Boyden Observatory, South Africa - Stock was asked by Gerard Kuiper to do a site test in Chile. The University of Chicago looked for a mountain in the Santiago area to put up a 1.5-m-telescope in the southern hemisphere. Stock accepted and took off for Chile within days. The trip, that was supposed to last a few weeks, lasted more than three years. "As a result, the world's largest collection of astronomical instruments is now in Chile", recalled Jürgen Stock four decades later.

After his arrival in Chile, Stock realised immediately, that the three pre-selected mountains close to Santiago were not really suited for an observatory. He decided to do site tests much further north, in the area of La Serena with its unique climate conditions between the cold Pacific Ocean and the high mountains. Stock travelled to Vicuña and climbed a nearby mountain on foot. At some distance he spotted a mountain with a perfect topography - quite isolated with an almost flat top. As the mountain was 40 km off the next accessible road, he organised mules and horses and made a trip to the top a few months later. He remembered it vividly: "The first night was so impressive: a perfectly clear night, absolutely calm, with a comfortable temperature: It couldn't be better. On top of that, it was perfectly dark in all directions." In those times an unknown mountain somewhere in Chile, this mountain has now a magnificent name: Cerro Tololo.

Due to Stock's euphoric reports from Chile, the project was handed over from University of Chicago to AURA. Now, the astronomers thought of something much bigger than just a site for a 1.5-m-telescope. With sufficient funds, Stock set up several teams for extensive site testing activities in that area. He checked almost a dozen mountains - Stock spent nearly three years on horse back to climb many mountains. While he was on expedition, he made notes every day - including not only the atmospheric conditions and astronomical observations but also the everyday life: Stock mentioned problems with the mules, the progress in the construction of some shelter on the mountains, the need for a support team bringing food and water, the conduct of the local people and so on. Each time he was back in Vicuña, he sent a letter with those notes to his boss Donald Shane at Lick Observatory. In a stroke of genius, Shane decided to type the reports, copy and distribute them among the astronomers in the US. Due to that, the "Stock reports" survived until today. The reports should be read by everyone who wishes to get an idea of what it meant to conquer the Andes for astronomy - there is a copy in the ESO historic archives.

In 1962, Tololo was finally chosen and Stock became the founding director of that observatory. In fact, he did almost everything: He was involved in the road construction, the blasting, the construction of the domes and support buildings etc. Due to his personal contact with Otto Heckmann and Jan Oort, Stock kept the Europeans informed about the progress in Chile. ESO - at that time about to sign the contracts with South Africa - decided to establish their observatory in Chile. Without this personal contact between Heckmann and Stock, ESO's first observatory might well have been erected in South Africa.

At first, there was a plan to build the American and the European observatories on the same mountain. But ESO soon decided to keep its independence and to build an observatory on La Silla. A wise decision, but Jan Oort realised the problems connected with that. He wrote in a letter to Heckmann in late 1963: "The worst thing is that we need some extra time to check the quality of the mountain and to construct a road to the top - and we should always keep in mind that we don't have a Dr. Stock."

In the 1960s, both Stock and Heckmann were directors of major observatories. In 1970 Stock was forced to leave Chile. He went to Venezuela and founded the CIDA observatory in the Andes near Mérida. His achievements for astronomy in Chile have almost been forgotten. Those of us who had the privilege to know him will remember his fine sense of humour, his brilliant mind and his great heart. Jürgen Stock was a man of great vision - modern astronomy has lost one of its last pioneers.

Dirk H. Lorenzen
Hamburg, Germany

Report on the

# EuroScience Open Forum 2004

Claus Madsen, ESO

Science reigned supreme in Stockholm for a period of four days in late August this year, as some 1800 scientists, administrators, policy-makers and media representatives from 68 countries convened at the EUROSCIENCE Open Forum, the first pan-European inter- and transdisciplinary science meeting on our Continent.

The purpose of the meeting was to '*provide an interdisciplinary forum for open dialogue, debate and discussion on science and technology in society*'. With such an ambitious goal, a new meeting format to enforce the interdisciplinarity, and a fairly heterogeneous target audience, the participants clearly realized the experimental nature of this undertaking.

Nonetheless, with 270 speakers from 33 countries and more than 80 scientific workshops, symposia, plenary lectures and debates, it was clearly anything but a modest beginning. Further to this, exhibition stands at the Conference Centre, an impressive public outreach programme, including numerous events and happenings, e.g. in the nearby King's Gardens, completed the programme.

As reported in the last issue of the *Messenger*, ESO took an active part in the meeting, together with its EIROforum partners. The activities included a 3-hour session on some of the scientific activities within the EIROforum organizations, a very successful outreach event with videoconferences between some of our facilities and Swedish schoolchildren and a major exhibition stand.

Given the experimental character of the event, how did it fare?

Firstly, with a wide offer of parallel sessions, participants may have had a hard time choosing what to attend. Secondly, some scientists may have found the interdisciplinary aspect unusual. Nonetheless, as the meeting got underway, the overwhelming impression was that the idea had caught on and the format became accepted.

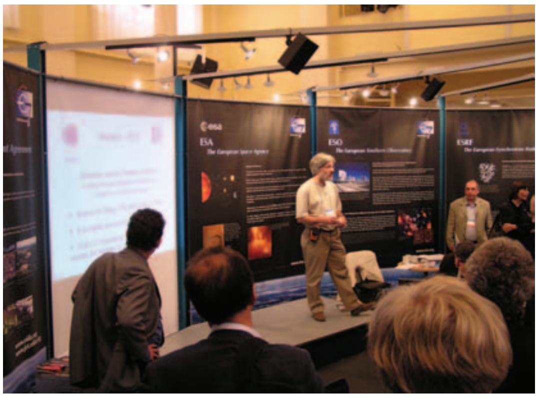
Many science policy makers and administrators used the opportunity to deepen their understanding of individual fields of science while at the same time discussing a wide variety of policy-related issues. These sessions were very well attended.

But the idea of the 'Open Forum' was clearly to further the dialogue between science and society. For this reason, it was particularly pleasing to note the strong media interest. Some 350 journalists (60 from Sweden) attended the meeting, which featured a series of dedicated press briefings. One of the first press briefings dealt with the possible discovery of a rocky exoplanet, as announced by ESO on 25 August (cf ESO Press Release 22/04 'Fourteen Times the Earth - ESO HARPS Instrument Discovers Smallest Ever Extra-Solar Planet'). The media coverage, both of this particular announcement and of the many other topics discussed during the meeting was highly gratifying, conquering the front pages of renowned broadsheet newspapers such as the *Financial Times* and, on occasions, rivalling the coverage of the ongoing 2004 Olympic Games in Athens.

The next EUROSCIENCE Open Forum will take place in Munich, between 15-19 July 2006. It is hoped that many more scientists will wish to attend this meeting supporting a much increased and needed interaction between scientists, the media and the public.

All photos: Jennifer Hay (EFDA-JET/EIROforum)

The ESOF 2004 venue: The Stocholm City Conference Centre, Folkets Hus, and 'Norra Latin'.



The launch of the EIROforum Science Teachers Initiative, now embedded in the NUCLEUS programme, was announced at the EIROforum stand. Speaking to the media is Russ Hodge from the EMBL.

Moderated by Richard West from ESO, the Outreach session gave schoolchildren from Stockholm an opportunity to talk directly with scientists at the EIROforum organisations. From Paranal, Nancy Ageorges presented the VLT and took numerous questions. Seen here is Wojciech Fundamenski from the JET fusion reactor in Culham.

# Fellows at ESO

## Carlos De Breuck

My interest in Astronomy started very early by browsing books in the local library. After finishing high school in Belgium, I decided to study Astronomy at the University of Leiden. Moving to a country with different culinary standards/traditions wasn't always easy, but I have found it a very rewarding experience to get to know other places, and to work in an international environment such as ESO. After my undergraduate studies, I continued as a PhD-student in Leiden to search for the most distant radio galaxies using new all-sky radio surveys. After a few months, I moved for 3 years to Livermore, California, which gave me access to the new Keck telescopes. Just before returning to Leiden we found what we were looking for: the most distant known radio galaxy at $z$=5.2.

After obtaining my PhD in 2000, I became a Marie Curie Fellow at the IAP in Paris. Spoiled by using large telescopes, I started several observing programs on the VLT. I also expanded my horizons into mm-astronomy to observe the CO gas and dust in the high redshift radio galaxies found during my thesis. With the development of ALMA, the ESO Fellowship was a logical next step in my career. Since I arrived in Garching in September 2003, I have spent most of my time on research, but I have also used the opportunities to get to know ESO better. In particular, I have helped organizing the Journal Club, which is only one of the many weekly talks happening on the ESO-MPA-MPE campus. I am also involved in the scientific preparation of ALMA, which will soon become an important tool in my research. Recently, we have set up the European ALMA newsletter to inform the European millimetric community about the construction of ALMA.

## Pierre Kervella

During the five years that I spent at ESO, in Garching and then in Chile, it seems to me that I lived several lives altogether. The first one was that of an international student, as I left Paris to start my thesis at ESO Headquarters in Garching. I still remember the first time I arrived in Munich, with just a single suitcase, checking carefully that I was taking the right U-Bahn and bus to reach ESO. Of course, all the German language that I learnt in school had vanished completely from my mind... The VLTI team at this time was quite small, with only five members, while it is now a solid group of more than 20 staff. Overall, my installation went well, and I soon began my work on what was to become VINCI, the test instrument for the VLTI. Over the course of my Ph.D., I took an active part in the construction of this instrument, from the blank page up to its installation and operation at Paranal. In between, I had the great privilege to see the first fringes of the VLTI with the test siderostats (March 2001) and then with the Unit Telescopes (October 2001) in the control seat of the interferometer.

After the defence of my thesis, a second life started in early 2002, when I moved to Chile to take up duties at Paranal in the VLTI team. Living in Chile is a very pleasing experience, thanks in particular to the kindness of the Chilean people and the beauty of the landscapes. Until the MIDI instrument started operations in 2004, VINCI got more time than initially foreseen to observe the wonderful Paranal sky. It was eventually operated for almost three years. The large quantity of public commissioning data and their good quality allowed me to conduct a number of interesting research projects, among which several made their way to ESO Press Releases ($\alpha$ Centauri, Achernar,…). Today, I feel that my 300 nights at Paranal were very well spent time! I left Chile and ESO in February 2004, to take up a permanent position at Paris Observatory in France. Working for ESO was a rich and fulfilling experience that I warmly recommend to any astronomer, both from the professional and personal point of views!

## Celine Peroux

A few years back, I crossed the British Channel one way in order to spend my nights gazing at a starry sky as part of undergraduate projects. After completing my PhD at the University of Cambridge in 2001, I worked in Italy before joining ESO in late 2003.

I am curious to understand the global properties of galaxies over large time scales. Rather than studying the light they emit, which fades at large distances, my approach consists of decoding the imprints that gaseous structures leave in the spectrum of a background quasar. These "quasar absorbers" provide a measure of both the neutral gas and metallicity content of the Universe back to early cosmic times. My work, in particular, suggests that a sub-class of the quasar absorbers, named sub-Damped Lyman-alpha systems, are major contributors to the observable baryonic content at high-redshift. I have used ESO archive data to build a sample of these systems in order to measure the global metallicity in the neutral gas phase. I am now able to extend this work to higher redshifts thanks to a new set of VLT data. Quasar absorbers are indeed extremely powerful observational tools but, paradoxically, they are also mysterious and their relation to emitting galaxies still remains to be clearly established.

As part of my contribution to the organisation, I am involved in making the pipeline-reduced UVES science frames available to the community. In parallel, I am supporting the *X-shooter* project, the first of the second generation of VLT instruments. The way new ideas and global astrophysical issues are debated with both locals and visitors makes ESO a very unique place to me. The only problem is that the way the building is laid out means I still have troubles finding my office coming back from the bathroom...

# A New Start for Public Surveys

Alvio Renzini (ESO)

With VST and OmegaCam nearing completion it became urgent to define new procedures for the most efficient exploitation of these survey facilities, also in view of the VISTA infrared survey telescope expected to join the Paranal Observatory in 2007. Moreover, even before VISTA, the UKIDSS project (Warren 2002) will provide the ESO community with major infrared surveys that may be in need of an extensive optical counterpart.

The issue was extensively discussed at the dedicated ESO Workshop on "Large Programmes and Public Surveys" that was held in Garching in May, 2003 (see Wagner & Leibundgut 2004, for a summary of the Workshop). A set of guidelines emerged from the discussion which are worth summarizing here again.

Public Imaging Surveys ought to be conducted with the widest direct involvement of the community and should comply with the following guidelines:

- Ensure scientific excellence, enabling competitive research by ESO community on frontier scientific areas;
- Provide a continuous supply of scientific targets for the instrument complement of the VLT/VLTI;
- Ensure that the set of implemented surveys covers the main scientific areas being actively investigated by the ESO community;
- Ensure the optimization of each survey for both primary and other possible scientific exploitations of the same data set;
- Ensure a balanced distribution of survey targets over right ascension, so as to avoid scheduling congestion at the survey telescopes and at the VLT/VLTI;
- Ensure optical/near-IR coverage of sky areas covered by complementary ground and/or space facilities at other wavelengths and which data are publicly accessible to the ESO community;
- Ensure coordination between optical and near-infrared surveys. To properly match UKIDSS and VISTA surveys it is anticipated that VST will have to dedicate to large surveys a fraction of its total time comparable to that dedicated by VISTA (75%, according to the ESO/UK Agreement).

On the basis of previous experience, it was expected that several surveys will have to be implemented in parallel, so as to explore a variety of depth, area, multi-band, and galactic latitude combinations, while avoiding excessive concentrations at specific right ascensions.

It was soon recognized that the normal procedure for ESO proposals (with teams in the community directly submitting proposals for OPC evaluation) could not ensure the scientific and scheduling coordination that is indispensable for a most efficient utilization of the telescopes. An intermediate step was then envisaged in order to ensure that any given survey could serve the broadest possible range of scientific applications, that a proper balance is maintained among the various scientific areas, and that the resulting set of surveys is distributed as uniformly as possible in right ascension.

Following these guidelines ESO submitted to the STC a document describing the new "Procedures for Public Surveys". The document was then discussed in depth by a Working Group jointly appointed by STC and OPC. The final document was approved by the STC in April 2004, and is reproduced fully below.

It was also recognized that the completion of a survey and the timely delivery of its science grade products (co-added, mosaiced and photometrically and astrometrically calibrated images, catalogs, etc.) is a major undertaking, especially in terms of human resources. It appeared that a team would be more likely to embark in such an effort for the benefit of the community, if there was a clear perspective of scientific follow up at the VLT/VLTI. As a result, the new procedures foresee that a team proposing itself for carrying out a survey can also submit to OPC a proposal for the scientific follow-up at the VLT/VLTI, which will be evaluated jointly with the survey proposal. Such a procedure will both help motivating the team, and ensuring that the survey products comply with their scientific specifications.

Before proceeding to appoint the Public Survey Panel (PSP), ESO issued on September 15 a call for "Letters of Intent" for public survey proposals. Teams intending to submit such proposals will be asked to provide a succinct description of the survey, including its scientific objectives and a brief description of the observations. With this information in hand ESO will then proceed to appoint the PSP members, making sure that the PSP scientific expertise will match the whole range of astronomical applications of the surveys to be proposed.

## References

Wagner, S., & Leibundgut, B. 2004, ESO Messenger, 115, 41
Warren, S. 2002, ESO Messenger, 108, 31

## Procedures for ESO Public Surveys

A Public Survey is understood to be an observing programme in which the investigators commit to produce and make publicly available, within a defined time, a fully reduced and scientifically usable data set that is likely to be of general use to a broader community of astronomers. The practical implementation of Public Imaging Surveys will proceed as follows.

1. ESO will periodically issue a "Call for Public Imaging Survey Proposals", for groups in the community to propose Public Imaging Surveys. Proposals shall include a scientific rationale, observing strategy, estimated observing time, and its distribution over observing Periods, as well as a detailed description of the responsibilities the team would be ready to take in case of approval of the proposed survey.

2. ESO will ask INAF (for the VST Consortium) and the *OmegaCam* Consortium to provide detailed descriptions for the observing programmes they intend to conduct in their guaranteed time (GTO) at the VST over the first 4 semesters. A similar procedure will be repeated every two years until the completion of the GTO time.

3. ESO will establish a *Public Survey Panel* (PSP) including scientists expert in a broad range of current astronomical research, with particular emphasis on those areas that can profit from Public Surveys. The PSP prime mandate will be to review the Public Survey Proposals and, taking into account the GTO programmes, elaborate a scientifically and observationally well coordinated set of Public Surveys. This process may well imply merging different proposals, or expanding their aims beyond the original ones e.g., in the filter set, depth, area, coordinates, etc. In order to achieve these goals the PSP will involve representatives from both the GTO teams and selected teams having submitted Survey Proposals. On the basis of the achieved coordination the selected survey teams will modify the survey proposals, describing the scientific rationale, observational strategy, and data product specifications (e.g. photometric and astrometric accuracy, images, catalogs, delivery time, etc.) as agreed in the course of these activities.

4. The PSP will review these modified proposals and forward them to the OPC along with a document illustrating the criteria adopted for the optimization and coordination of the recommended

set of surveys, and the motivations for having rejected others.

5. These resulting proposals for Public Survey may include proposals for subsequent proprietary observations with other ESO facilities which are designed to exploit the results of the survey in question. The OPC will then provide simultaneous recommendations on the time to allocate both to the survey and to its followup. A Management Plan for each survey will also be attached to the proposal for ESO review.

6. For each approved Public Survey ESO will negotiate with the PI the extent of ESO support that could be given, and the timeline of product delivery. The allocation of observing time for the scientific follow up of the survey will be subject to the timely delivery of the survey products and their compliance to the specifications.

7. The PSP Document, the final proposals for Public Surveys and the description of the GTO programmes will be made available on the web prior to the regular *Call for Proposals* for the VST.

8. Proposals for *Proprietary Surveys* can be submitted as usual following the regular *Calls for Proposals*, thus ensuring that the OPC evaluates all survey proposals (public and proprietary).

9. The ESO/ST-ECF *Science Archive Facility* (SAF) will be the collection point for the survey products and the primary point of publication/availability of these products to the ESO community. ESO will assist the survey teams to define and package their data products in a manner consistent with *SAF* and *Virtual Observatory* standards and will integrate the products into the SAF.

10. Survey programs that directly complement other public surveys should themselves be carried out as Public Surveys. In case of GTO programs in this category, ESO will encourage the GTO Teams making their survey products public and to submit proposals for the scientific follow up at other ESO telescopes, following the same procedures outlined in item 5 above. In all cases the allocation of the OPC recommended observing time for the scientific follow up will be subject to the timely delivery of the survey products and their compliance to the specifications.

11. The PSP will periodically review the progress of the surveys and will assess the compliance to the specification of the survey products. The PSP will then forward to ESO Directorate its recommendations concerning the continuation of each survey and the allocation of the associated follow-up time at other facilities.

# PERSONNEL MOVEMENTS

**(1 June 2004 - 31 August 2004)**

## ARRIVALS

### EUROPE

| | |
|---|---|
| BIANCHINI, Andrea (I) | Student |
| KHRISTOFOROVA, Maria (RU) | Student |
| KORNWEIBEL, Nicholas (UK) | Software Engineer |
| MARTEAU, Stephane (F) | Oper.support Scient. |
| MARTINEZ, Pascal (F) | Paid Associate |
| MÜLLER, Michael (D) | Mechanical Engineer |
| PATT, Ferdinand (D) | Engineer |
| POPESSO, Paola (I) | Paid Associate |
| RETZLAFF, Jörg (D) | Paid Associate |
| SOENKE, Christian (D) | Software Engineer |
| TAIT, Donald (UK) | Project Planner |
| VERNET, Joel (F) | Fellow |

### CHILE

| | |
|---|---|
| DUMKE, Michael (D) | Paid Associate |
| HUNTER, Ian (UK) | Student |
| MASON, Elena (I) | Op.staff Astronomer |
| PANTIN, Eric (F) | Paid Associate |
| RAGAINI, Silvia (I) | Student |
| STEFANON, Mauro (I) | Paid Associate |

## DEPARTURES

### EUROPE

| | |
|---|---|
| AHMADIA, Aron (US) | Student |
| ANTONIUCCI, Simone (I) | Student |
| BERTA, Stefano (I) | Student |
| DIETL, Ottomar (D) | Maint. Technician |
| DI FOLCO, Emmanuel (F) | Student |
| GRILLO, Claudio (D) | Student |
| HAU, George (UK) | Fellow |
| KURZ, Richard (US) | Chief Engineer |
| SNEL, Ralph (NL) | Paid Associate |
| SURDEJ, Isabelle (B) | Student |
| VUCHOT, Luc (F) | Student |
| WEGERER, Stefan (D) | Mechanics Technician |
| WEIDINGER, Michael (DK) | Student |

### CHILE

| | |
|---|---|
| CARVAJAL, Alfredo (CL) | Procurement Officer |
| CLARKE, Fraser (UK) | Fellow |
| DELVA, Pacome (F) | Student |
| DISSEAU, Ludovic (F) | Student |
| GERMANY, Lisa (AUS) | Fellow |
| GIUFFRIDA, Giuliano (I) | Student |
| HAUBOIS, Xavier (F) | Student |
| ILLANES, Esteban (CL) | Public Relations Officer |
| MEDVES, Giuseppe (I) | Paid Associate |
| MILLOT, Nadia (F) | Student |
| NOTERDAEME, Pasquier (B) | Student |
| PEREZ, Juan Pablo (CL) | Electronic Engineer |
| VAISANEN, Petri (FI) | Fellow |

**Applications are invited for the position of a**

# Desktop Publishing/Graphics Specialist

Career Path: III

**Assignment**: Within the ESO Education and Public Relations Department team, her/his main tasks will comprise:

- Layout and complete pre-press preparation of ESO publications (Quarterly journal, Annual Report, brochures, posters, etc.)
- Interaction with printers
- Preparing multimedia/web presentations
- Assisting in keeping the ESO EPR website up to date
- Assisting in the preparation of scientific illustrations

**Qualification and experience:** Diploma in Graphic Arts (or equivalent), at least 3 years of experience in a relevant professional environment. She/he must be proficient in standard software packages for:

- DTP (print and electronic media) (Quark Xpress/In-Design)
- Photoshop, Illustrator
- Macromedia Director/Flash or equivalent
- GoLive/Dreamweaver (or equivalent)/knowledge of HTML

Experience in scientific animations (e.g. morphing, etc.) would be an advantage. She/he must be fluent in English. German at working level would be an advantage.

**Duty Station:** Garching near Munich, Germany.

**Starting date:** As soon as possible.

**Remuneration and Contract:** We offer an attractive remuneration package including a competitive salary (tax free), comprehensive pension scheme and medical, educational and other social benefits as well as financial help in relocating your family. The initial contract is for a period of three years with the possibility of a fixed-term extension or permanence. The title or grade may be subject to change according to qualification and the number of years of experience.

**Applications:** If you are interested in working in a stimulating international research environment and in areas of frontline science and technology, please send us your CV (in English) and the ESO Application Form by

**25 October 2004**

All applications should include the names of four individuals willing to give professional references and preferably samples of work.

For further information please contact Mrs. Barbara Ounnas. You are also strongly encouraged to consult the ESO Home Page (http://www.eso.org) for additional information about ESO.

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# ESO Workshop Proceedings Still Available

Many ESO Conference and Workshop Proceedings are still available and may be ordered at the European Southern Observatory. Some of the more recent ones are listed below.

| No. | Title | Price |
|---|---|---|
| 54 | Topical Meeting on “Adaptive Optics”, October 2–6, 1995, Garching, Germany. M. Cullum (ed.) | € 40.– |
| 55 | NICMOS and the VLT. A New Era of High Resolution Near Infrared Imaging and Spectroscopy. Pula, Sardinia, Italy, May 26–27, 1998 | € 10.– |
| 56 | ESO/OSA Topical Meeting on “Astronomy with Adaptive Optics – Present Results and Future Programs”. Sonthofen, Germany, September 7–11, 1999. D. Bonaccini (ed.) | € 50.– |
| 57 | Bäckaskog Workshop on “Extremely Large Telescopes”. Bäckaskog, Sweden, June 1–2, 1999. T. Andersen, A. Ardeberg, R. Gilmozzi (eds.) | € 30.– |
| 58 | Beyond Conventional Adaptive Optics, Venice, Italy, May 7–10, 2001. E. Vernet, R. Ragazzoni, S. Esposito, N. Hubin (eds.) | € 50.– |

# ESO Fellowship Programme 2004/2005

The European Southern Observatory awards several postdoctoral fellowships to provide young scientists opportunities and facilities to enhance their research programmes. Its goal is to bring them into close contact with the instruments, activities, and people at one of the world's foremost observatories. For more information about ESO's astronomical research activities please consult http://www.eso.org/science/.

Fellows have ample opportunities for scientific collaborations: a list of the ESO staff and fellows, and their research interest can be found at http://www.eso.org/science/sci-pers.html and http://www.sc.eso.org/santiago/science/person.html. The ESO Headquarters in Munich, Germany host the *Space Telescope European Coordinating Facility* and are situated in the immediate neighbourhood of the Max-Planck-Institutes for Astrophysics and for Extraterrestrial Physics and are only a few kilometers 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 between ESO and the host country's academic community.

**In Garching**, fellows spend beside their personal research up to 25% of their time on support or development activities of their choice in the area of e.g. instrumentation, user support, archive, VLTI, ALMA, public relations or science operations at the Paranal Observatory. Fellowships in Garching start with an initial contract of one year followed by a two-year extension.

**In Chile**, the fellowships are granted for one year initially with an extension of three additional years. During the first three years, the fellows are assigned to either the Paranal or La Silla operations groups. Together with the astronomer in charge, they contribute to the operations at a level of 80 nights per year up on the mountain 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 be eligible to apply for Chilean observing time on all telescopes in Chile. The other options are to spend the fourth year either at ESO's Astronomy Center in Santiago, Chile, or the ESO Headquarters in Garching, or any institute of astronomy/astrophysics in an ESO member state.

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

Candidates will be notified of the results of the selection process in December 2004/January 2005. 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 **October 15, 2004**.

Please apply by:

- filling the form available at http://www.eso.org/gen-fac/adm/pers/forms/fellow04-form.pdf attaching to your application: a Curriculum Vitae including a publication list (the latter split into refereed and non-refereed articles, please) an outline of your current and past research, as well as of your research plans if you came to ESO (max. 2 pages) a brief outline of your technical/observational experience (max. 1 page)
- arranging for three letters of reference from persons familiar with your scientific work to be sent to ESO before the application deadline.

All documents should be typed and in English. The application material has to be addressed to:

European Southern Observatory
Fellowship Programme
Karl-Schwarzschild-Str. 2
85748 Garching bei Muenchen
Germany
vacancy@eso.org

**Contact persons:**

Nathalie Kastelyn, Tel. +49 89 320 06-217, Fax +49 89 320 06-497, e-mail: nkastely@eso.org for applications for Chile
Katjuscha Haase, Tel. +49 89 320 06-219, Fax +49 89 320 06-497, e-mail: khaase@eso.org for applications for Garching

All material must reach ESO by the deadline (**October 15**); the same applies to recommendation letters which should be sent directly by the reference person; applications arriving after the deadline or incomplete applications will not be considered!

ESO, the European Southern Observatory, was created in 1962 to "... establish and operate an astronomical observatory in the southern hemisphere, equipped with powerful instruments, with the aim of furthering and organising collaboration in astronomy..." It is supported by eleven countries: Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Sweden, Switzerland and the United Kingdom. ESO operates at three sites in the Atacama desert region of Chile. The Very Large Telescope (VLT), is located on Paranal, a 2,600 m high mountain approximately 130 km south of Antofagasta. The VLT consists of four 8.2 metre diameter telescopes. These telescopes can be used separately, or in combination as a giant interferometer (VLTI). At La Silla, 600 km north of Santiago de Chile at 2,400 m altitude, ESO operates several optical telescopes with diameters up to 3.6 m. The third site is the 5,000 m high Llano de Chajnantor, near San Pedro de Atacama. Here a new submillimetre telescope (APEX) is being completed, and a large submillimetre-wave array of 64 antennas (ALMA) is under development. Over 1300 proposals are made each year for the use of the ESO telescopes. The ESO headquarters are located in Garching, near Munich, Germany. This is the scientific, technical and administrative centre of ESO where technical development programmes are carried out to provide the Paranal and La Silla observatories with the most advanced instruments. ESO employs about 320 international staff members, Fellows and Associates in Europe and Chile, and about 160 local staff members in Chile.

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

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Technical editor: Henri Boffin
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## Reports from Observers



## Other Astronomical News



## Announcements



**Front Cover Picture: *The Birth of a Massive Star***

Three-colour ISAAC mosaic of the star forming region M 17. The field size is about 7 × 7 arc minutes, the effective spatial resolution is about 0.6 arc seconds; wavelength coding: blue 1.25 µm, green 1.65 µm, red 2.2 µm. See the article by R. Chini et al. on page 36.