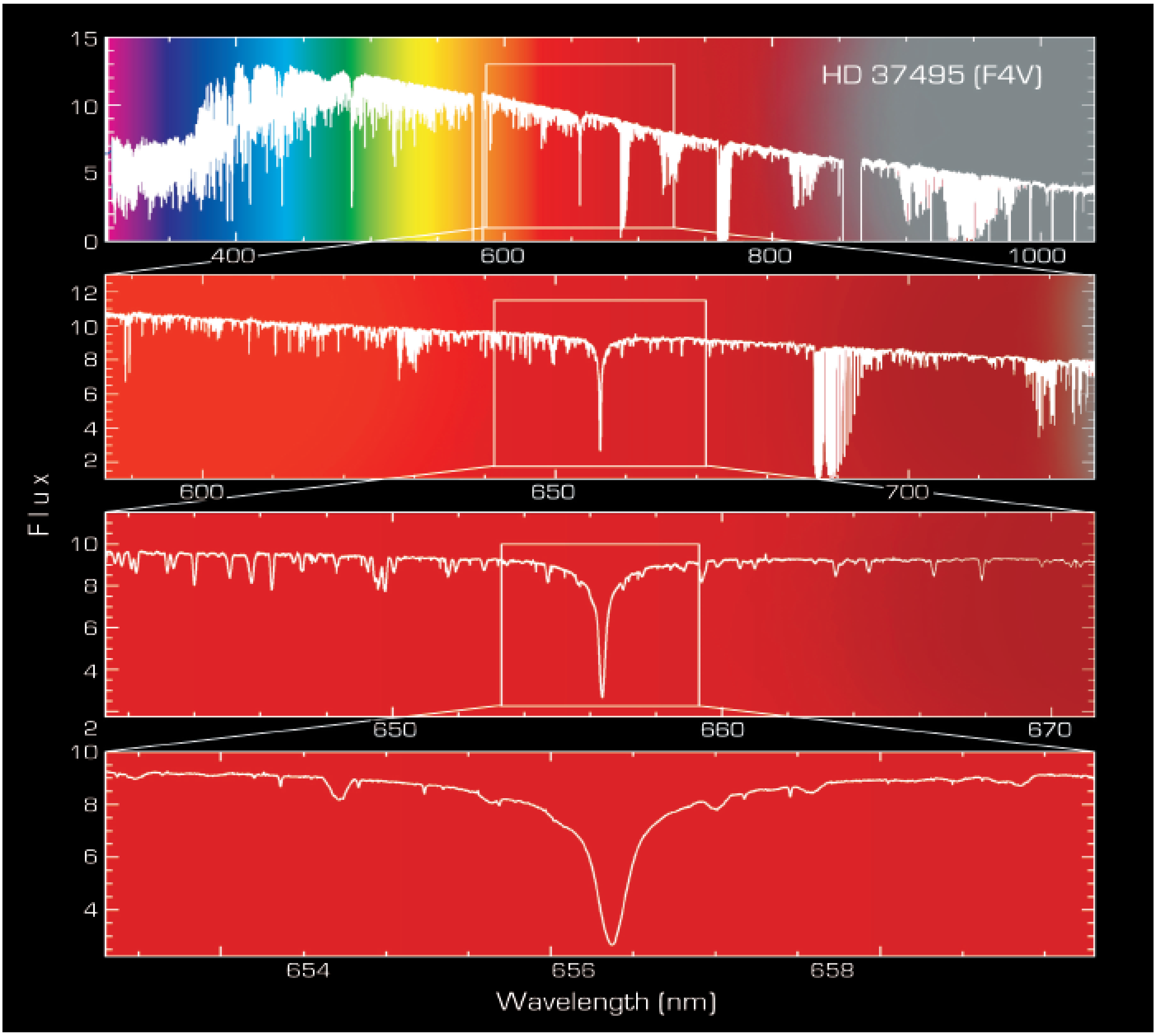
THE MESSENGER

EL MENSAJERO

No. 114 – December 2003



Spectrum of the star HD 37495 observed in the framework of the UVES Paranal Observatory Project (see S. Bagnulo et al., page 10)

ALMA Groundbreaking Ceremony

A momentous event took place on 6 November, at the site of the ALMA "Operations Support Facility" (OSF), near Chajnantor where the array will be built. About 170 scientists and dignitaries from Europe, North America, Japan and Chile attended the groundbreaking ceremony for this global project. The pictures shown here and two of the speeches that were given (those by the ESO Director General and President of Council) tell the story.

ALMA will be the highest-altitude, full-time ground-based observatory in the world, at 5,000 metres altitude. Work at this altitude is difficult.

To help ensure the safety of the scientists and engineers at ALMA, operations will be conducted from the OSF, a compound located at a more comfortable altitude of 2,900 metres, between the cities of Toconao and San Pedro de Atacama, and within relatively easy reach of the array itself. The OSF will also be the base for the construction teams, and the 64 antennas will be assembled here.

A number of containers and other facilities are already located at the OSF, and it is very reminiscent of the early days of the construction of the VLT. Work on the OSF and on the ALMA site itself will now take place at an accelerated pace, paving the way for the arrival of the first elements of the array.

Also, at the Ground breaking ceremony, the new ALMA logo (see facing page) was unveiled.

The President of Council, Professor P. van der Kruit, energetically breaks the ground for ALMA along with Dr. W. Van Citters (NSF, Director of the Division of Astronomical Sciences) and Prof. M. Tarenghi (ALMA, Director).

Directions to everywhere from the site of the OSF, where the groundbreaking took place.

Address by Prof. P. van der Kruit, President of ESO's Council

Mrs. Paulina Saball, Undersecretary of the Bienes Nacionales,
Mr. Jorge Molina, Intendente of the Second Region,
Distinguished Ambassadors,
Esteemed Authorities,
Dear colleagues,
Ladies and Gentlemen,

We are children of the Universe. Actually, we are children of the universe in a very strict sense. Look at our bodies. By weight we are made up for about a quarter or so of hydrogen. The rest is in other chemical elements, of which carbon, nitrogen and oxygen are the major contributors. In contrast, the Universe, when it was about three minutes old and sufficiently cool that atomic nuclei could exist, consisted for three-quarters of hydrogen and one quarter of helium. There was no carbon, no nitrogen, no oxygen or any other chemical element except traces of lithium and boron. We now know that the chemical elements that make up most of our bodies were formed by nuclear reactions in heavy stars that live for a very short while and blow themselves up as supernovae and release the heavy elements into the interstellar gas so that new planets and possibly life can be formed. We are stardust.

Astronomy, astrophysics and nuclear physics have made it possible for us to understand how the chemical elements were formed. I regard this as one of the greatest accomplishments of science in the twentieth century. It is amazing that physical science is so powerful to make it possible for us to appreciate our origin.

Astronomers study our roots and our relation as human beings to the cosmos. But astronomy is an observational science. We will not understand the universe simply by pure thought, but rather we start by looking at it. We presently observe in the optical with giant telescopes, such as the VLT, Gemini, Keck, Magellan, etc., some of which are here in Chile. We use telescopes in space to observe at wavelengths that cannot be observed from the ground, such as in the X-ray region and the far infrared. We have built very large radiotelescopes and we have linked these or have constructed arrays, using the same principle as ALMA will use.

In the last few decades, astronomers have realized the richness of the millimetre and submillimetre spectrum and the potential for observations there to solve the current questions in astrophysics. Therefore millimetre telescopes have been built, again including one on Chilean soil at La Silla, and arrays have been constructed in particular in North-America, Europe and Japan. These already use the spectral lines that can be observed at millimetre wavelengths to study the chemical composition in regions of star formation, especially in the gas and dust in cool regions.

In spite of progress in the twentieth century, such as understanding nucleosynthesis mentioned above, there are still fundamental questions left. Some important ones among these are the following. When and how did galaxies form and in what way did early star formation and chemical enrichment take place? How do planets form around young stars? To completely solve all aspects of these and other problems we absolutely need to be able to observe at millimetre and sub-millimetre wavelengths.

I myself had the privilege as a graduate student in Leiden, the Netherlands, to have professor Jan Oort as my thesis supervisor. This was in the days of completion of the construction of the Westerbork radiotelescope and he always stressed that it was the unexpected to look forward to. So will it also be for ALMA.

In order to build an instrument like ALMA we need a site in a very dry climate, at a high altitude and with a relatively flat area with dimensions of order ten kilometres. We have been fortunate that such a unique site is in existence here in Chile at Chajnantor.

After a number of initiatives in various continents to start a project to construct a millimetre array, eventually collaboration grew out of this between North America (that is, the U.S.A. and Canada) and Europe (the member states of the European Southern Observatory and Spain; ESO states are Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Sweden, Switzerland and the United Kingdom). Unfortunately Japan, which was involved in the definition of the project, is not taking part now and the original plan had to be scaled down to what we call the "baseline ALMA". But we are very hopeful, and actually heard very encouraging news the last few days at the ALMA Board, that Japan will join us soon to build an even more powerful ALMA than we are constructing now.

I would like to express, also on behalf of the ALMA Board, my gratefulness to:

– the visionaries who believed ALMA was the biggest step astronomy could make at the present time and never gave up to try to convince others;

– the scientists and engineers that believed in it and showed that ALMA is possible technically and financially;

– administrators and politicians that also believed in it and convinced ministers and high officials that ALMA should be funded;

– authorities that solved political and legal problems;

– and last but not least everyone at whatever level, in whatever capacity and from whatever country that contributed in whatever way to the fact that today we can formally start the construction of ALMA.

A los Chilenos y particularmente a la gente de la comuna de San Pedro: Muchas gracias por su cooperación en este lugar tan único y para permitir el desarrollo de la astronomía en su territorio hermoso. Estamos agradecidos y les deseamos todo lo mejor.

Address by Catherine Cesarsky, Director General of ESO

THIS IS A GREAT DAY FOR ASTRONOMY. This is indeed a great day for Chile, for the II Region and for San Pedro de Atacama. And this is indeed a great day for all of us, a moment to which we have all been looking forward with great anticipations. This is the real beginning of a joint adventure. We will be reaching towards the stars, searching for the earliest, remotest objects in the Universe, peering beyond current horizons into the deep unknown.

Here, on Chilean soil, in the great emptiness of the Atacama desert and closer to the sky than ground-based astronomers have ever been, we are now embarking upon an ambitious exploration of new and unknown celestial territories. We do so in the service of science and society, ultimately for the benefit of humanity.

There have been astronomers in Chile since long, but it was only in the early 1960s that the true potential for our science of this wonderful country with its pure atmosphere and clear skies was understood by scientists from North America and Europe. Already in those early days, people from ESO and AURA discussed opportunities to collaborate closer in their efforts to establish new and powerful observatories in the IV Region. However, time was not yet ready for such joint ventures and our predecessors in the end decided to set up separate facilities at La Silla and Cerro Tololo.

ESO signed the first agreement with Chile, exactly forty years ago today. Meanwhile, more observatories have been created in Chile, and in parallel Chilean science and technology has developed enormously. We have all benefited from increasingly closer collaboration and many young Chilean astronomers and engineers are now working at these observatories, also at La Silla and Paranal.

ALMA is the pinnacle of this long and steady development in which so many partners have come together to realize what is the first truly global astronomical project. Joining their considerable forces, the power and experience of dedicated specialists on three continents are now striving to open a new, unique window towards the Universe which will allow us to explore vistas which have been completely hidden from view until now. We are convinced that Chajnantor is the best possible site for this new instrument, a unique site which provides the ALMA telescopes with optimal conditions for sensitive, prolonged series of complex observations.

We are together today to celebrate the beginnings of a great project. We are gathering here in a beautiful and, for many of us, very remote region in which unspoiled nature will soon meet the highest technology available on this planet. We have come here to construct a unique instrument in these pristine surroundings, well aware that this vast country has a long historical and cultural tradition of ancient peoples. Peoples who have asked the same fundamental questions about the Universe and man's place in it, as we now do. While the incentives and the search remain the same, we may come closer to the answers with ALMA.

The Chajnantor plateau is a serene site where man can be alone with his thoughts. It is in many ways one of the most extreme places on this planet and nobody who has been up there remains unmoved. Once I thought of the distant past, imagining a small group of ancient, daring travelers crossing that plain in front of me, melting into the stark landscape. They would watch the night fall, the stars appearing in a darkening sky, marveling at the incredible beauty of the majestic panorama above. Would it ever have occurred to them that on this very site, hundreds of years later, a forest of giant structures would be built to collect those cryptic signals from above – messages from the depths of space with information about the beginnings of that mysterious Universe in which they - and we – live? Or would they ever imagine that people from many other societies and from other continents would sometime assemble here, working together in their quest to unravel our distant origins?

ALMA is indeed a unique project, both in terms of science, technology, operation, management. In addition this project possesses a great number of aspects that fascinate young people and it provides a fantastic opportunity to create an inviting path towards modern science, with excitement and learning going hand in hand.

Why is this so? Why has ALMA this great appeal? There is first of all the Chajnantor site itself, its remoteness, the high altitude, the desert, the volcanoes, the population in this area, the ancient peoples with their unique culture, their history. There is the challenge of high technology, the joining of so many antennas and the almost magical possibility to combine the signals so that at the end a radio image of unequalled penetration and sharpness is obtained. And then there is of course the marvelous science which ALMA will do, all the way from nearby stars with exoplanets in the making to complex interstellar molecules and onwards to the earliest and most remote galaxies.

I sense that soon the word ALMA may also become equivalent to excitement, exploration of the unknown and, not least, exemplary international collaboration. People will proudly declare that they are part of this project. Let us rejoice that we have come this far! And let us now together tackle the next crucial phase with determination. Now we begin the construction of this great facility in this exceptional place.

I would like to read to you the message received today from Norio Kaifu, Director of the National Astronomical Observatory of Japan: "Congratulations for the wonderful start of the ALMA construction. Breaking the ground, flying over the Andes, the ALMA will visit a number of marvelous new worlds in the Universe where the humankind could never reach before it. We sincerely wish safe and successful construction on the Atacama site. And, the third condor is ready to fly join you!"

I express my gratitude to all those people, in Europe, in North America and in Chile, who have helped us to reach this crucial milestone. We know that the way ahead is still long and that there will be problems. Together we shall solve them and in not too many years we will then begin to reap the fruits of this hard labour. Muchas gracias.

With the Director General in this photograph, are (left to right) Robert Dickman (NSF), Eduardo Hardy (NRAO), Fred Lo (NRAO), Massimo Tarenghi (ALMA) and Daniel Hofstadt (ESO).

CRIRES TAKES SHAPE

THE CRYOGENIC INFRARED ECHELLE SPECTROGRAPH BEING DEVELOPED BY ESO WILL PROVIDE A TOTALLY NEW CAPABILITY FOR HIGH RESOLUTION ($R \sim 10^5$) INFRARED SPECTROSCOPY BETWEEN 1 AND 5 μm AND OPEN UP ENTIRELY NEW FIELDS OF RESEARCH WITH THE VLT STARTING IN 2005.

ALAN MOORWOOD* (ESO)

THE CRYOGENIC INFRARED ECHELLE Spectrograph (CRIRES) has had a relatively long gestation. It was included in the Call for First Generation VLT Instruments in 1989 as one of several options which were then discussed at the Workshop on High Resolution Spectroscopy with the VLT held at ESO in 1992 (High Resolution Spectroscopy with the VLT, ESO Conference and Workshop Proceedings No. 40, ed. M.-H. Ulrich). At that time there was still a lively ongoing debate about the relative merits of Fourier and dispersive spectrographs for high resolution infrared spectroscopy. Pierre Connes had pioneered the use of the former for very high resolution planetary spectroscopy already in the 1960s, when infrared arrays had only 1 pixel and dispersive instruments could not compete with the multiplex advantage of Fourier spectrometers. By 1992, however, low noise infrared array detectors were already available to infrared astronomers although still with rather small formats for echelle spectroscopy. Nevertheless there was clearly a consensus at the Workshop to include such a cryogenic echelle spectrograph in the instrument complement of the VLT. For various reasons (like finishing the VLT and its 1st complement of instruments), the real start of CRIRES was delayed for several years but since its real start in 1999 the progress has been rather rapid with PDR in April 2000, FDR in Oct. 2001 and start of the integration phase in Garching in 2002.

The characteristics of CRIRES are summarized in Table 1. Of particular interest are the fact that the detector mosaic actually being used now has over 4000 pixels in the dispersion direction (compared with around 64 proposed in 1992) and the use of adaptive optics to both minimize slit losses and improve the spatial resolution along the slit.

Table 1. CRIRES Main Characteristics

- Resolving power of ~10^5 from 1 to 5 µm
- Adaptive optics feed to maximize SNR and spatial resolution
- Echelle grating and prism pre-disperser
- Polarimetry with Fresnel rhomb retarder and Wollaston Prism
- Pixel size ~ 0.1″
- 0.2″ × 50″ slit
- 4096 × 1024 InSb array mosaic
- Slit viewing camera with 1024 × 1024 InSb array (0.05″ pixels)
- Calibration unit including absorption cells for accurate radial velocity measurements (< 50 m/s)
- Limiting magnitudes ~17 (*J*) to 11(*M*) in 1 hr

SCIENCE OBJECTIVES

The 1–5 µm region is rich in both atomic and molecular spectral features which offer unique probes of the chemical and physical conditions in a wide range of astrophysical environments. Table 2 summarizes some of the areas expected to be of high interest for observations with CRIRES. Most of these objectives require not only the wavelength coverage but also the high spectral resolution corresponding to a few km/s (e.g. for studying the kinematics of the cold ISM and for stellar abundance determinations) and with radial velocity precision better than 50 m/s (e.g. for radial velocity searches for exoplanets around cool low mass stars). Stellar magnetic field measurements are also of particular interest due to the existence of some particularly favourable infrared lines whose magnetic Zeeman splitting will be easier to measure than the visible lines currently used.

Testimony to the growing interest in high resolution infrared spectroscopy is the 4 day Workshop devoted to High Resolution Infrared Spectroscopy which took place in Garching from 18–21 Nov. 2003. There were about 130 attendees and a packed programme covering all of these topics as described in the summary which also appears in this issue (see page 52).

Table 2: Science Areas

- Planetary Atmospheres
- Exoplanets
  - Radial velocity reflex motion searches (cool and dust embedded stars)
  - Direct detection of planetary atmosphere spectral features
- Stars (atomic and molecular transitions, SiO, CO, CN, OH)
  - Abundances, COmospheres, winds, pulsations
  - Magnetic fields (Zeeman Doppler imaging)
  - Discs and their velocity fields
  - YSO inflows/outflows
- Interstellar Medium (ISM) - Milky Way and nearby galaxies
  - Chemistry and kinematics - $CO, CH_4, H_2O, OH, H_3^+$
  - Line of sight to YSOs
- Extragalactic
  - Nuclear kinematics
  - Intergalactic absorption studies

*on behalf of the CRIRES Team:

Peter Biereichel, Bernard Delabre, Rob Donaldson, Reinhold Dorn, Enrico Fedrigo, Gert Finger, Gerhard Fischer, Francis Franza, Domingo Gojak, Gotthard Huster, Yves Jung, Hans-Ulrich Käufl, Jean-Louis Lizon, Hamid Mehrgan, Manfred Meyer, Jean-François Pirard, Jérome Paufique, Estzer Pozna, Ralf Siebenmorgen, Armin Silber, Barbara Sokar, Jörg Stegmeier, Stefan Wegerer

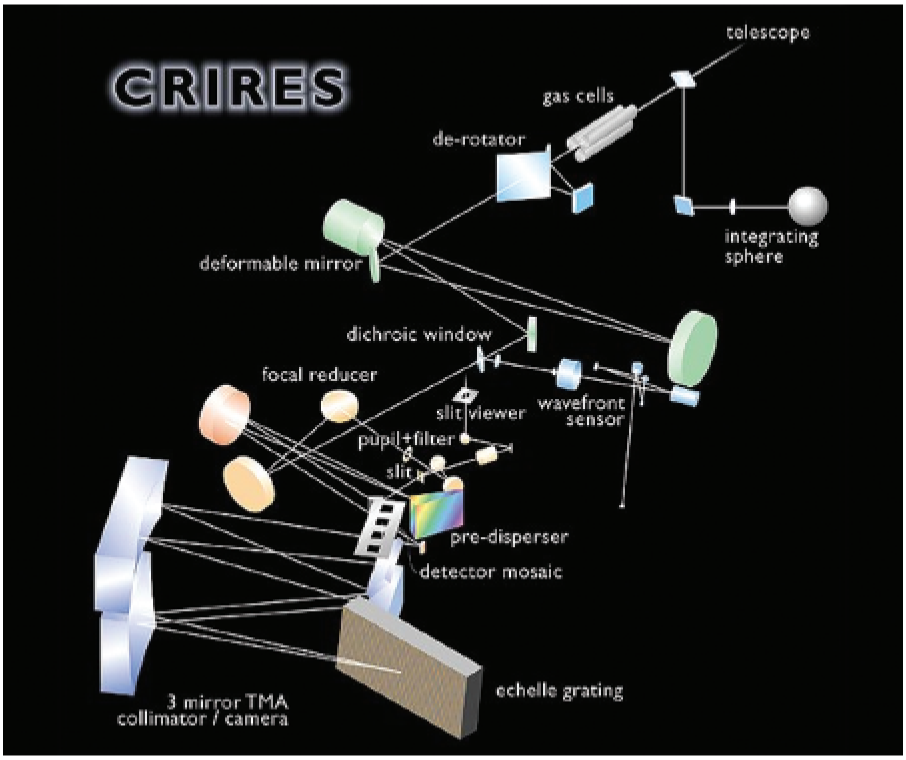


Figure 1: Optical layout of CRIRES. Light entering from the Nasmyth focus or the calibration unit passes through the de-rotator and adaptive optics system before entering the cryogenically cooled spectrograph via a dichroic window. Visible light reflected from this window is directed to the AO wavefront sensor. The cryogenically cooled optics comprises a pupil re-imaging system and Wollaston prism; the pre-disperser prism and the high resolution echelle spectrometer. The final spectrum is imaged on a 4096 × 1024 pixel mosaic of InSb detectors.

Instrument Design

Optical Layout

Figure 1 shows the optical layout of CRIRES. Light enters from the direction of the Nasmyth focus, either from the telescope or a calibration unit consisting of an integrating sphere illuminated by continuum or line lamps for flat-fielding and wavelength calibration. Higher accuracy wavelength calibration is achieved using sky lines or narrow absorption lines in gas cells which can be inserted in the beam as shown. The gas cell slide will also contain a specially designed ZnSe Fresnel rhomb whose insertion can be combined with that of a MgF_2 Wollaston prism in the first pupil image plane for measuring circular polarization. Following the calibration unit is a 3 mirror de-rotator which is used to counteract the telescope field rotation when making long slit observations. Then comes the adaptive optics system used to concentrate the light at the 0.2 arcsec wide spectrograph slit. It features a 64 element deformable mirror mounted on a tip-tilt stage and on which is formed a pupil image by the two mirror relay optics. The dichroic window then transmits infrared light to the cryogenically cooled spectrograph while reflecting visible light to the wavefront sensor (WFS) which uses an optical CCD detector and can be translated in x,y at ~0.5 Hz to maintain object centring as determined by the slit viewer. As far as possible, the design of the AO system and its individual components have been copied from the MACAO system developed by ESO for VLTI (Arsenault et al., *The Messenger*, 112, 7). The spectrograph is housed in a vacuum vessel and with its optics cooled to ~ 65 K and the detectors to ~ 25 K. Following the input window, a pupil image is formed at the position of a cold stop which limits parasitic background and where the Wollaston prism can be inserted. Light then either passes through the slit or is reflected to the slit viewing camera. Light passing through the slit enters the prism spectrometer where it is dispersed and then exits through an output slit sized to limit the wavelength range passing into the high resolution section to a single order. The high resolution spectrograph consists of a 40×20 cm, 31.6 lines/mm, 63.5 deg. blaze echelle grating plus a TMA (three mirror anastigmat) which acts first as the collimator and then as the camera to image the spectrum on the 4096×1024 pixel array detector.

Cryomechanical System

Figure 2 shows how CRIRES is expected to look when mounted at one of the VLT Nasmyth focii. The main elements are the cryogenically cooled spectrograph in its grey vacuum vessel; the table mounted pre-optics (calibration unit, field de-rotator, adaptive optics system coloured green) and the electronics racks (detector electronics in red and control electronics in yellow). The instrument is mounted stationary on the platform primarily to

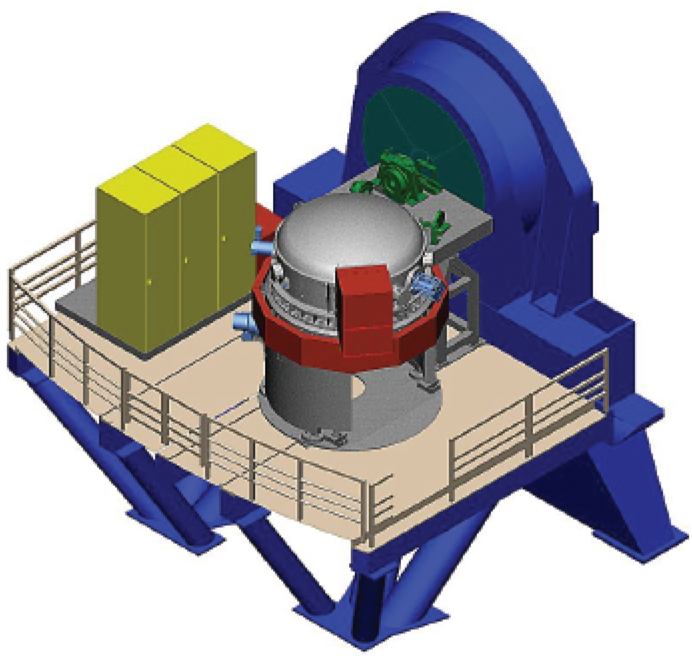


Figure 2: CRIRES installed at a Nasmyth focus. Shown in green are the de-rotator and part of the adaptive optics sytem installed on an optical table between the Nasmyth focus and the spectrograph. The spectrograph is cryogenically cooled and housed in the grey vacuum vessel. One of the closed cycle coolers plus the turbomolecular and backing pumps are coloured blue. The red boxes contain the front-end IRACE detector electronics and the yellow cabinets the control electronics for the complete instrument.

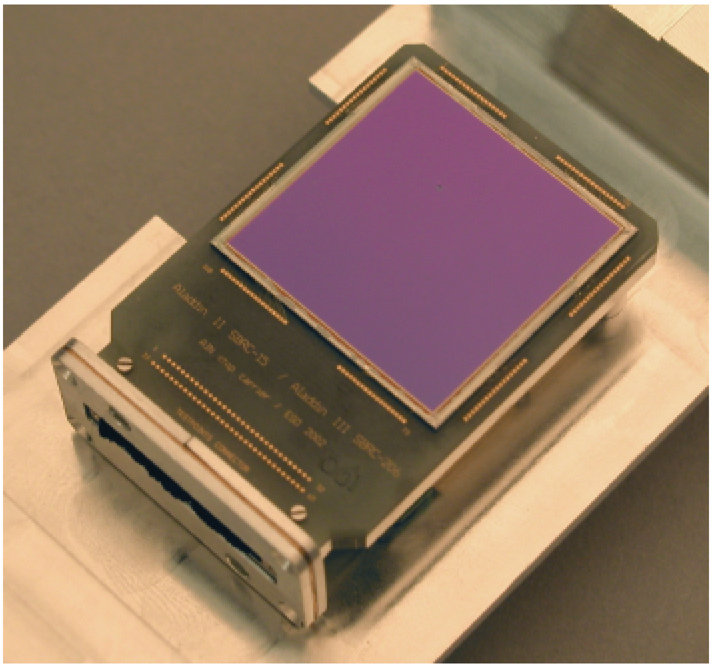


Figure 3: One of the Aladdin III 1024 × 1024 InSb arrays mounted on an ESO designed ceramic board.

ensure achievement of the high wavelength stability requirements by minimizing flexure and temperature variations. The vacuum vessel is made of austenitic stainless steel with a high internal reflectivity achieved by manual polishing followed by electro-polishing and inclusion of a warm shield. Attached to the vessel can be seen the cold head of one of the two Leybold closed cycle coolers, the instrument mounted turbomolecular pump, connector flanges, pressure gauges and the overpressure safety valve. Underneath is the support and alignment structure which also provides access to a port in the lower lid of the vacuum vessel through which the grating unit can be accessed and removed. To the left can also be seen the pre-vacuum pump.

Inside, the mirror optics and most of the mechanical structure is made of aluminium alloy. The TMA mirrors have a thin (~30 μm) nickel coating on the reflective surface which has been diamond turned then conventionally polished and finally ion beam polished before gold coating. Although nickel coating is usually applied on both sides we have found by modelling that, although reducing bending, this increases the total wavefront aberration compared with plating a single surface. The remaining mirrors are being nickel plated, diamond turned and hand post polished. The only non-reflecting optics in the system apart from the window is the ZnSe prism used for order sorting.

Cryogenic mechanisms are required for scanning the prism (2 deg.) and echelle grating (12 deg.), the two slits plus the slit viewer filter and Wollaston wheels. The scanning functions will be driven by Phytron cryogenic stepper motors and high precision screws and equipped with high precision encoders.

The total mass cooled to cryogenic temperatures is around 550 kg. Based on our experience with ISAAC we are confident that this can be cooled down to ~65 K in 30 hours using the in-built liquid nitrogen flow pre-cooling system. The two closed cycle coolers are then used to maintain the instrument at this temperature and the detectors at around 25 K.

The goal on thermal stability is to maintain the temperature stable within 0.1 K and limit any variations of temperature gradients to < 50 mK/m/hr. As CRIRES is stationary, has a high thermal inertia due to its large cryogenic mass and is rather uniformly cooled by the attachment of heat exchangers at several points on the cooling circuit, the short term stability may be better than this. To counter drifts due e.g. to the external diurnal temperature variations, however, active temperature control is also foreseen using heaters mounted on a ring whose temperature will be controlled to ~0.1 K and is connected to various points in the instrument by conducting braids. The pre-disperser collimator mirror is also equipped with piezos to allow fine active control of the spectrum position using atmospheric

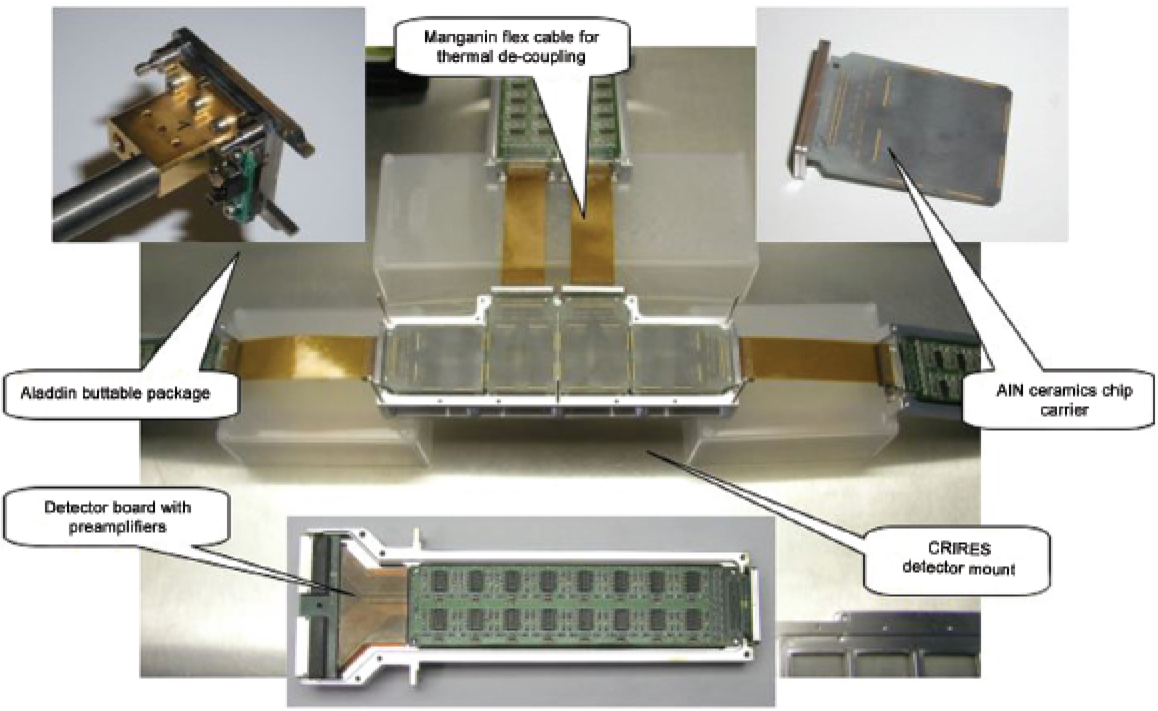


Figure 4: Detector mosaic. Each of the four array detectors is glued to a ceramic carrier of the type shown on the upper right and then mounted on the unit shown at the upper left which comprises a kinematic mount, a copper block for cooling and a temperature sensor. They are each connected to the acquisition electronics via 64 cryogenic preamplifiers and manganin flat band cables and mosaiced together as shown in the centre.

spectral lines for programmes requiring the highest spectral stability.

In order to meet the stringent thermal and straylight requirements the entire optical system is enclosed within a light shield plus an aluminium alloy radiation shield with mirror finish quality. Care is also being taken (e.g. by using an intermediate connector) to avoid light leaks at the penetrations of cables. Essentially the only light path into the high resolution section of the instrument is through the narrow order isolation slit at the exit of the prism pre-disperser.

Detector Mosaic

CRIRES uses 5 Raytheon 1024 × 1024 pixel InSb Aladdin arrays, one for the slit viewer and 4 in the spectrograph focal plane which provides a useful optical field of 135 × 21mm. Three of the arrays are Aladdin IIIs procured specifically for CRIRES while the fourth is a rather old Aladdin II, from the first best effort batch made for ESO which yielded the ISAAC and CONICA arrays, and which had a number of cracks but exceptionally low dark current (< 0.001 e^-/s). These arrays have now been re-packaged to be 3 side buttable so that they can be packed in a 4×1 format with a spacing between arrays of only 264 pixels. To do this, each array was removed from its original LCC package by Raytheon and glued onto the specially designed ESO mount consisting of a multilayer, co-fired, AIN (aluminium nitride) ceramic carrier, as shown in Fig. 3, and then glued to an adjustable invar base plate. These are then mounted to form the mosaic as shown in Fig. 4. The upper left hand view shows the rear side of the mount on which are a copper block for the cooling braid connections, a 3-point kinematic mount and a temperature sensor. Also to be seen is the connector to the two layer flexible manganin boards which interface each detector to a preamplifier board equipped with 64 cryogenic operational amplifiers. As the slit is only 512 pixels long we do not require 4 useable quadrants per array and have thus saved money by buying 'reject' arrays with one or more defect quadrants. The re-packaging has recently been completed and the first array is now under test at ESO. Unfortunately, the old Aladdin II, which has a thinner substrate than the Aladdin IIIs, was broken during the re-packaging process and it remains to be seen if the required two quadrants are still operational.

The arrays will be read-out using a standard ESO IRACE controller having 128 channels (4×32) for the science arrays and 1×32 channels for the slit viewing camera.

Optomechanics Manufacture and Integration

Most of the CRIRES hardware has now been manufactured and integration has already started in Garching. Fig. 5 shows the vacuum vessel and its support structure on the right and the light shield on the left in the now very crowded assembly hall in Garching where also SINFONI, OmegaCam and various other systems are being integrated. The vacuum vessel partially visible on the far left is the old IRSPEC one which has been converted since retirement into a a cryogenic test

Figure 5: CRIRES vacuum vessel on the right and light shield to the left in the Garching assembly hall.

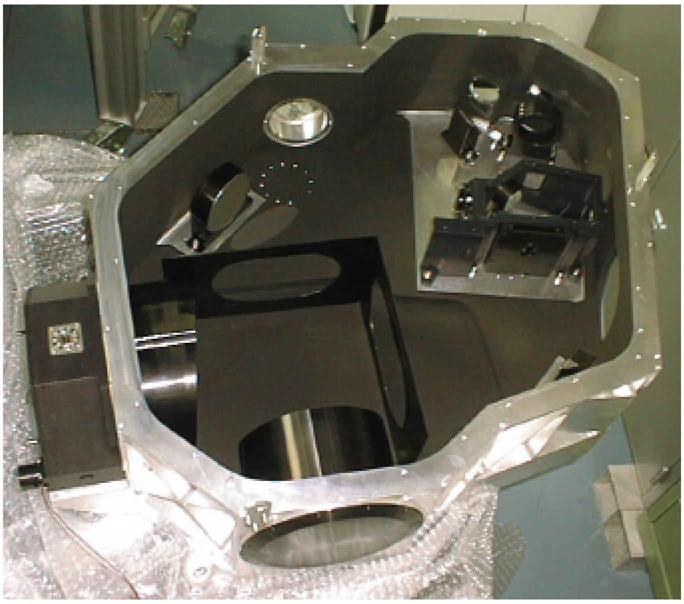


Figure 6: Partially assembled cryogenic pre-slit assembly.

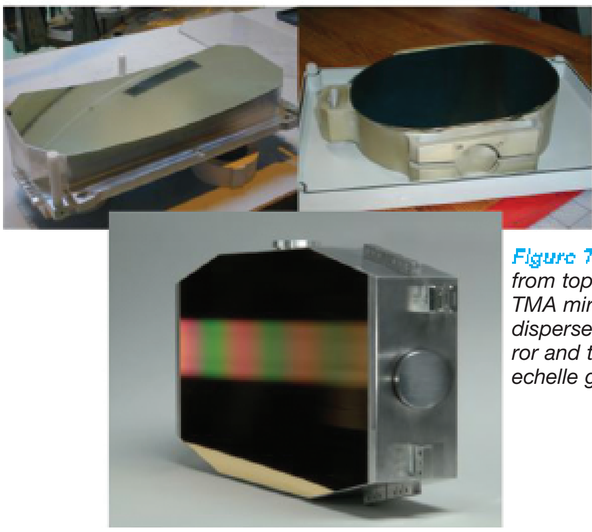


Figure 7: Clockwise from top left - one of the TMA mirrors, the pre-disperser collimator mirror and the 40×20cm echelle grating.

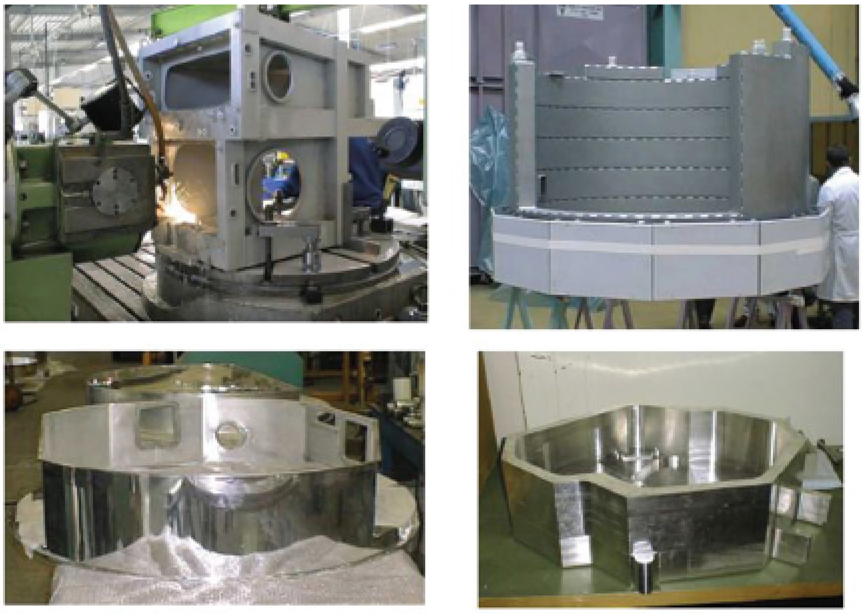


Figure 8: Clockwise from top left - the TMA support structure, instrument support structure, radiation shield and pre-slit optics housing during manufacturing.

facility used to qualify many of the ISAAC, SOFI and now CRIRES functions before integration. Figures 6 – 8 show various other optical and mechanical parts as described in the captions. In principle, everything could now go ahead full steam – were it not for those other instruments just mentioned plus a few other activities which are currently overloading our integration laboratory. To be fair however, some of items shown were also delivered late and we are still awaiting delivery from Sagem of the TMA mirrors which have just been accepted at their premises in France.

Electronics and Software

The electronics and software for controlling both the CRIRES spectrometer and the AO system are proceeding well. Motors are being driven and their control parameters fine tuned. The Observing Software and Real Time Displays are being finalized. The IRACE detector acquisition electronics and software are being used for the detector tests. On the Science Operations side, the instrument observing modes have also been defined, the corresponding observing templates are being coded and first thoughts are being given to the pipeline.

CRIRES on sky?

Unless anything goes seriously wrong with CRIRES or one of those other projects competing for the same manpower we expect to see 1st light on the VLT in the first quarter of 2005. Watch this space.

Addendum to "The History and Development of the ESO Active Optics System" (The ESO Messenger No.113)

R.N. Wilson

Following my article, I received a most interesting e-mail from my ex-colleague of ESO and good friend, Daniel Enard. He was concerned about the precise chronology of the development of the ESO Shack-Hartmann image analyser – see the second section of my article. Enard pointed out that *he* and I first visited Roland Shack together in February 1976, *before* the 3.6 m telescope was set up some months later. Already before then I knew of the Shack proposal as I had been receiving the “Optical Sciences Center Newsletter”, in which it was first published in 1971 (see Ref. W99 in my article). This was why we visited Shack to learn more about it. Shack complained bitterly of lack of interest in the American community and was encouraged by our deep and practical interest.

In further discussions with Francis Franza, we have now concluded that he and I visited Shack again in 1977 (not in 1979 as I wrote in my article) and it was then that Shack gave me the lenslet raster. This was the difficult element: otherwise the construction of the S-H image analyser was quite straightforward. It was with this original raster, made on a lathe by Shack, that ANTARES I was built in 1978 (see W99, Fig. 2.24) for testing *off-line* ESO telescopes on La Silla. The S-H plates were measured on the PDS measuring machine at ESO Garching. We believe that this was the first Shack-Hartmann image analyser actually built and used for testing telescopes. In view of its importance today in so many active and adaptive optics applications, we see this now as an important step forward in the necessary technology.

Franza and I investigated a number of possibilities of producing S-H rasters mechanically with a German firm, but the firm went bankrupt before any results came out. The breakthrough in this procurement problem came when I gave a talk in Graz about Active Optics in 1981 and Franza saw a poster presentation of a *laser etching* technique presented by the RCA Laboratories in Zurich, later renamed the Paul Scherrer Institute (see W99). Two successful negative masters were afterwards made to an ESO contract and replicas were made for the final raster screens by Jobin-Yvon in Paris. This was the source of all successful screens used for the further experiments in ESO and for the NTT. The masters for the VLT were also made by the Paul Scherrer Institute, which also supplied the replicas.

Shack's original mechanical method of raster manufacture is now probably only of historical interest, but it nevertheless showed his genius. He produced rows of cylindrical lenses by stepping on the lathe and fine grinding and polishing with a concave cylindrical rod. Then he turned the raster through 90° and produced cross-cylindrical lenses. He had proved theoretically that the difference between these cross-cylindrical lenses and true axially symmetrical lenses was well below the diffraction limit for such extremely weak lenses with 1 mm square aperture and 80 mm focal length.

My thanks are due to Daniel Enard and Francis Franza for further clarifying this historical development, which was of fundamental importance for both the NTT and the VLT.

The UVES Paranal Observatory Project
a Library of High-Resolution Spectra of Stars across the Hertzsprung-Russell Diagram

We present the UVES Paranal Observatory Project, consisting of acquisition, reduction, and public release of high-resolution, large wavelength coverage, and high signal-to-noise ratio stellar spectra obtained with the UVES instrument of the ESO Very Large Telescope. Data for about 400 stars across the Hertzsprung-Russell diagram have been taken and reduced by members of the Paranal Science Operations Team and made publicly available through a web interface at www.eso.org/uvespop.

S. Bagnulo, E. Jehin, C. Ledoux, R. Cabanac, C. Melo, R. Gilmozzi (ESO)
and the ESO Paranal Science Operations Team

Most of the observational constraints to stellar astronomy come from low to medium resolution spectra obtained in spectral bands a few hundred nm wide or, in other cases, from high-resolution spectra in bands a few tens of nm wide. In spite of the capabilities of the existing instruments, there is a lack of a library composed of high-resolution spectra with complete optical coverage for stars representative of the entire Hertzsprung-Russell (HR) diagram. This is due to the fact that the best instruments are attached to largely over-subscribed telescopes, and are dedicated to very specific projects. At the same time, using large telescopes to observe bright targets is very inefficient, as overheads are comparable to, or even much longer than, open shutter times.

On Cerro Paranal, twilight time is normally used for calibration of the instruments in operation. At the beginning of each evening twilight, and at the end of several morning twilights, telescopes point to empty fields, in order to provide the calibrations of the various instruments with fresh sky flats. At the VLT Unit 2 Kueyen, the Nasmyth foci host two instruments dedicated to high-resolution UV and optical spectroscopy: UVES and FLAMES. The UVES calibration plan is restricted to spectro-photometric standard stars that are observed during the darker part of the twilights. With Kueyen and UVES, overheads are short enough that even the early evening twilight time (or late morning twilight) is sufficiently long to take a full spectrum of a bright star. Hence, the use of UVES during twilights appears well suited to build up a library of stellar spectra with no impact on normal operations.

Members of the Paranal Science Operations Team have thus been authorized to make use of the brighter part of twilight times for a task of public interest, and have started the UVES Paranal Observatory Project (UVES POP): an on-going project of acquisition, reduction, and public release of high-resolution, large wavelength coverage, and high signal-to-noise ratio (SNR) stellar spectra. Telescope time was granted under DDT Prog. ID 266. D-5655(A).

The targets were selected in order to sample the various spectral types of the HR diagram, but the limited amount of time available during twilight (about 20 minutes) and the desire to obtain high SNR data, set the limiting magnitude of the targets, as a general rule, to V=7.5.

All the observed spectra cover almost completely the wavelength interval from 304 to 1040 nm (except for a few narrow gaps). With a slit width of 0.5″, the achieved spectral resolution $R = \lambda/\Delta\lambda$ is about 80000. For most of the spectra, the typical final SNR obtained in the V band is between 300 and 500.

The UVES POP library is the richest available database of observed stellar optical spectral lines. Many transitions and oscillator strengths are often only theoretically studied and a comparison with stellar spectra may permit one to refine or correct the theoretical predictions. The UVES POP library is thus an observational counterpart of atomic databases such, as, e.g., the Vienna Atomic Line Database (see Kupka et al. 1999 and reference therein; see also [1]).

POP stellar spectra can be used for many different studies. For instance, one can check thoroughly our capability of reproducing stellar spectra with model atmospheres and spectral synthesis codes, from very normal main sequence stars, to peculiar stars or less common objects; element abundances can be calculated with unprecedented accuracy for many different kinds of star; population studies may take special advantage of the large wavelength coverage of the POP star spectra (although it should be pointed out that UVES spectra are not absolute flux-calibrated due to slit losses); features of the nearby interstellar medium also appear in great detail in the intrinsically featureless spectra of the hottest observed stars. Note also that, although many of the observed targets appear to be well-known objects, it is probably not unreasonable to surmise that serendipitous discoveries may follow a close inspection of such a large and high-quality observational database – unknown and interesting signatures in bright stars might well have escaped detection so far. This is particularly true for the observed spectral region before the Balmer jump (λ= 304 – 364.6 nm), that represents an almost unexplored realm even for bright stars. Note also that in most of the cases *several* exposures of the same target are taken within a very short period of time, with identical settings. This might permit one to discover short-term spectral variability. Finally, it should be pointed out that the UVES POP library may help to improve stellar spectral classification: thanks to the large spectral coverage and the high resolution, one may discover spectral indicators that have escaped detection in previous studies.

The UVES POP library is also a user-friendly database for teaching purposes: several examples of stellar spectral features may be promptly found and compared among each other, in particular thanks to a specially designed tool, the *Spectrum Preview Interface* (SPI) that is available at the UVES POP web site.

Target selection

Program stars fall into two groups, i.e., field stars, and stars belonging to two open clusters.

For field stars, the only selection criterion applied was to cover the largest possible variety of spectral types in the HR diagram, including peculiar objects, e.g., Ap and Bp stars, Wolf-Rayet stars, Be stars, and carbon stars. Most of the observed objects are brighter than 7.5 in the *V* band, and in the solar neighbourhood. Hence, most of the POP stars have solar metallicity. However, a few metal poor stars (with [Fe/H] ranging from –2.5 to –0.5) were also included in the target list. Spectral types were taken from SIMBAD and other more specialised catalogues, such as, e.g., the 14th General Catalogue of MK Spectral Classification (Buscombe 1999), and the General Catalogue of Ap and Am stars (Renson et al. 1991). It should be noted that the spectral classification of the observed targets came from a quick search in the literature, and that in general the spectral type assigned to our targets *cannot be considered accurate or definitive*. Spectral reclassification might eventually be performed on the basis of UVES POP data. So far, more than 300 field stars have been observed. About 20 of them are extremely bright (V<2.5) and very famous stars (Aldebaran, Betelgeuse, Rigel, etc.). These latter stars were specifically observed in order to allow easy comparison with the observations obtained with other spectrographs on smaller telescopes. The stars observed up to the moment of writing represent about 80% of the different spectral types and luminosity classes of the HR diagram. In Fig. 1 we show the colour-magnitude diagram of the observed field stars for which parallaxes and photometry could be found in the HIPPARCOS catalogue (ESA 1997).

Table 1: Wavelength intervals of the UVES POP observations in DIC1 and DIC2 mode

Mode	Setting name	Wavelength coverage	Optical path/arm
DIC1	346B	304 – 388 nm	blue
	580L	476 – 577 nm	red (lower chip)
	580U	584 – 684 nm	red (upper chip)
DIC2	437B	373 – 499 nm	blue
	860L	660 – 854 nm	red (lower chip)
	860U	866 – 1040 nm	red (upper chip)

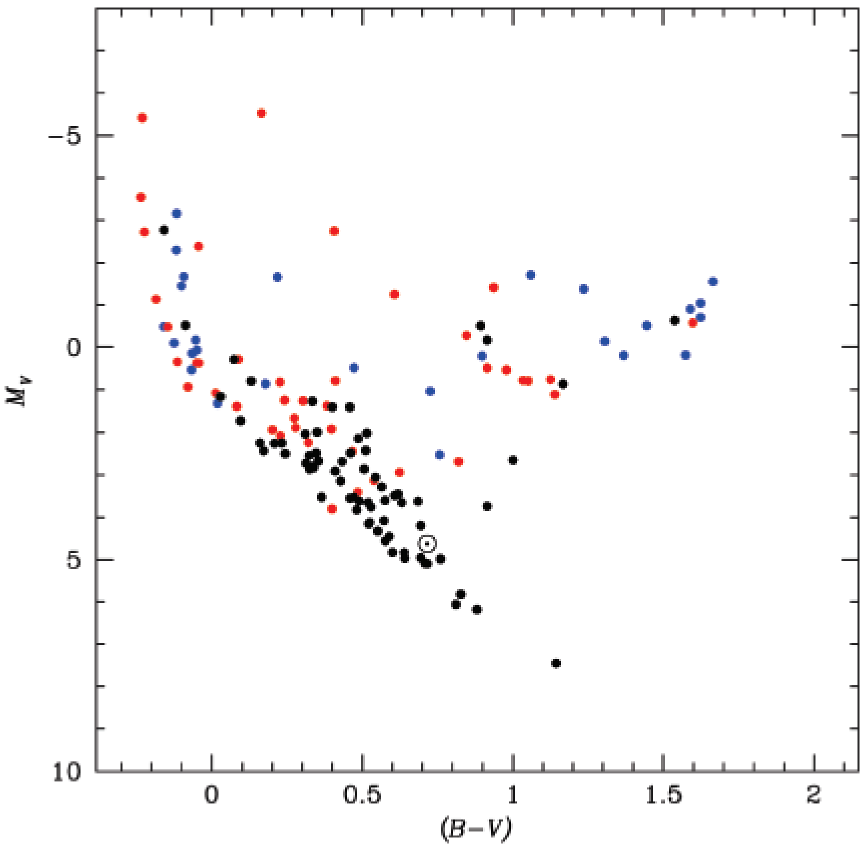


Figure 1: The colour-magnitude diagram of the field stars observed within the framework of the UVES POP. (B-V) and absolute magnitudes have been computed using parallaxes and photometry from the Hipparcos catalogue, and were not corrected for interstellar extinction. The colours blue, red and black indicate an accuracy on the parallax better than 20 %, 10 % and 5 %, respectively. Stars with parallax errors larger than 20 % are not plotted. The position of the Sun is also indicated.

Spectra have also been obtained for a number of (presumed) members of two selected open clusters, IC 2391 and NGC 6475 (M7). Due to the unforeseen move of FORS2 from Kueyen to Yepun in P66, the UVES service mode queues were sometimes undersubscribed. Hence, about 30 hours of telescope time were used for night-time observations of some faint objects in the two selected open clusters (IC 2391 in P66, from 7 to 12 February 2001, and NGC 6475 in P67, in the second half of August 2001). For target selection, extensive use has been made of *WEBDA*, a WEB database for open clusters [2]. In total about 50 stars of IC 2391 and about 30 stars of NGC 6475 have been observed. With the open cluster data, more specific scientific projects can be carried out, for example to accurately determine cluster membership, metallicity, and angular momentum distribution.

Instrument setup

The Ultraviolet-Visual Echelle Spectrograph (UVES) instrument is described in detail by Dekker et al. (2000), in the instrument manual by Kaufer, D'Odorico, & Kaper (2003), and, more generally, in [3]. UVES is a very efficient high resolution spectrograph designed to operate from about 300 nm to 1100 nm. This wavelength range can be almost fully observed using two instrument modes (hence with two different sets of exposures), each of them characterised by the use of a special dichroic (DIC1 and DIC2). Dichroics are used to split the light beam coming from the telescope to feed the two arms of the spectrograph, the blue arm, and the red arm. The blue arm hosts an EEV 2K×4K CCD, and the red arm hosts a mosaic of two (EEV and MIT) 2K × 4K CCDs. Table 1 gives the wavelength ranges covered by the UVES POP observations.

The use of a 0.5″ slit width provides a spectral resolution of about 80000. Almost the full wavelength interval from 304 to 1040 nm is observed, but with a few gaps. Two main gaps, corresponding approximately to 577–584 nm and 854–866 nm, are due to the physical gap between the two chips of the red CCD mosaic. Because of this gap, the component at 854.2 nm of the famous CaII triplet around 860 nm is normally not covered in the UVES POP observations. However, for stars with blueshifted velocities ≥ 70 km/s (prior to the conversion of the wavelength scale to the heliocentric rest-frame) this component may become visible, and the one at 866.2 nm may enter into the gap. In addition, there are several small gaps, about 1 nm-wide each, due to the lack of overlap between the reddest echelle orders in the 860U setting.

The vast majority of stars were observed with the slits oriented along the parallactic angle, in order to minimize losses due to the atmospheric dispersion.

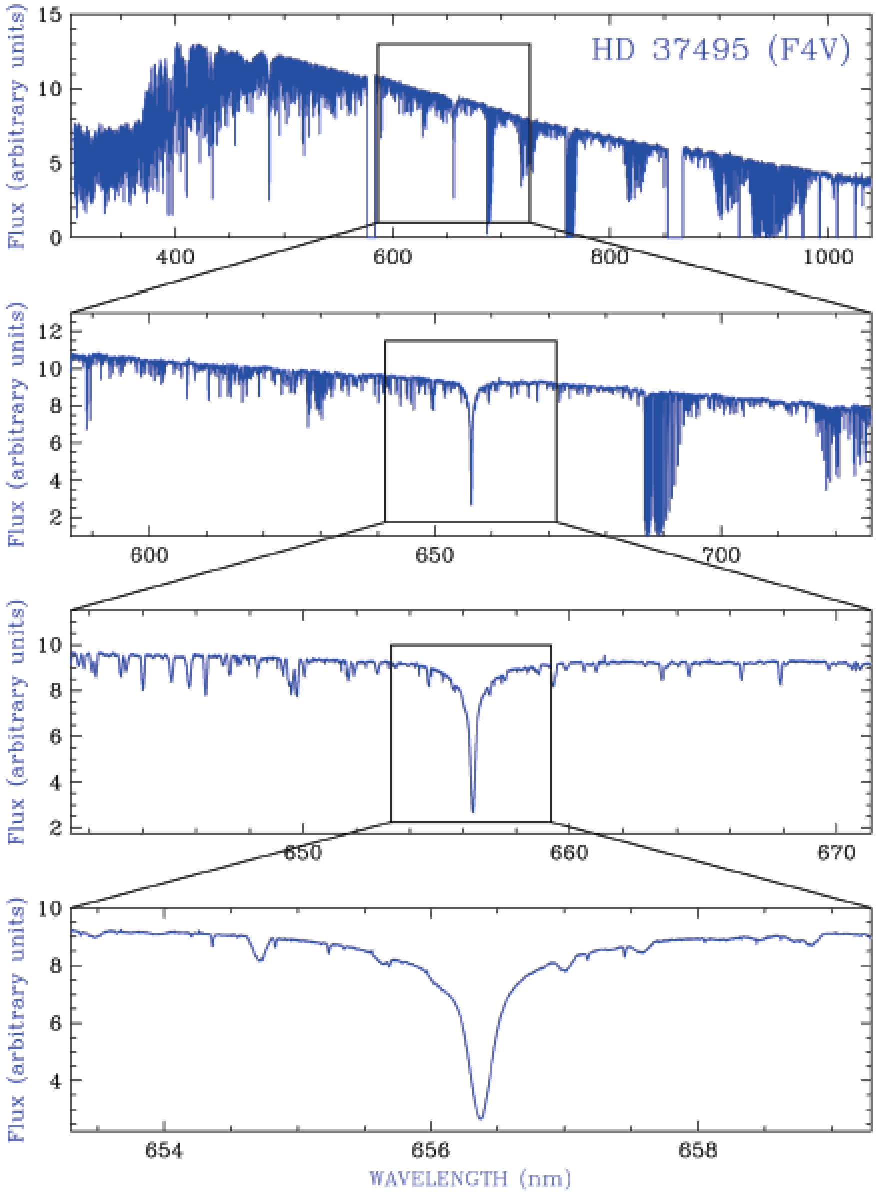


Figure 2: *The overall spectral energy distribution of an F4V star (HD 37495) observed with UVES, together with several enlargements around the Hα absorption line. The quality of this spectrum is representative of the entire library: high SNR, high spectral resolution, large spectral coverage; on the other hand, some ripples around 800 nm (discussed in [5]) are visible. In the top panel, note also the gaps around 580 nm and 860 nm due to the physical gap in the CCD mosaic of the red arm.*

Data Reduction

For this project, data reduction has been a particularly demanding task. The obvious problem is related to the *huge* amount of data that are involved, both in terms of science data and calibrations. A science exposure in dichroic mode (i.e., when both arms are used) takes about 46 Mbytes (12 Mbytes for the blue arm CCD, and 34 Mbytes for the two red arm CCDs). In fact, each star is observed with two instrument settings, and multiple exposures are taken for each setting. For each observing night, and for each instrument setting, five flat fields, five biases, one wavelength calibration, plus two special calibrations (one 'order definition' and one 'format check' frames) are taken. This corresponds to 1.25 Gbytes of calibration frames. The data delivered up to the end of P71 (namely science and calibration data for about 400 stars) occupy almost 100 DVDs!

UVES data obtained in service mode are routinely reduced by the ESO Garching *Data Flow Operations* (DFO) group using an automatic pipeline that is described in Ballester et al. (2000) (see also [4]). Together with raw data, service mode UVES users receive pipeline products that are generally ready to be used for science. Unfortunately, POP data cannot be processed through the standard DFO pipeline in Garching, mainly because the software used by the DFO group is optimised for lower SNR spectra (≤ 100). An *optimum* extraction algorithm is used, that assumes a Gaussian profile for the cross-dispersion flux distribution. However, the use of this method leads to poor results when applied to SNR ≥ 100 data (for details see [5]). For this project, it has been found more appropriate to use an *average extraction* algorithm.

Therefore, it was decided to take care of the data reduction with the help of a dedicated Linux machine at ESO Vitacura facilities in Chile. A number of MIDAS routines and display tools have been designed for the specific format of UVES POP data, and for the specific requirements of the project, although the core of data reduction procedures is still the UVES context v1.2 of MIDAS. An automatic procedure has been developed to convert the wavelength scale of the spec-

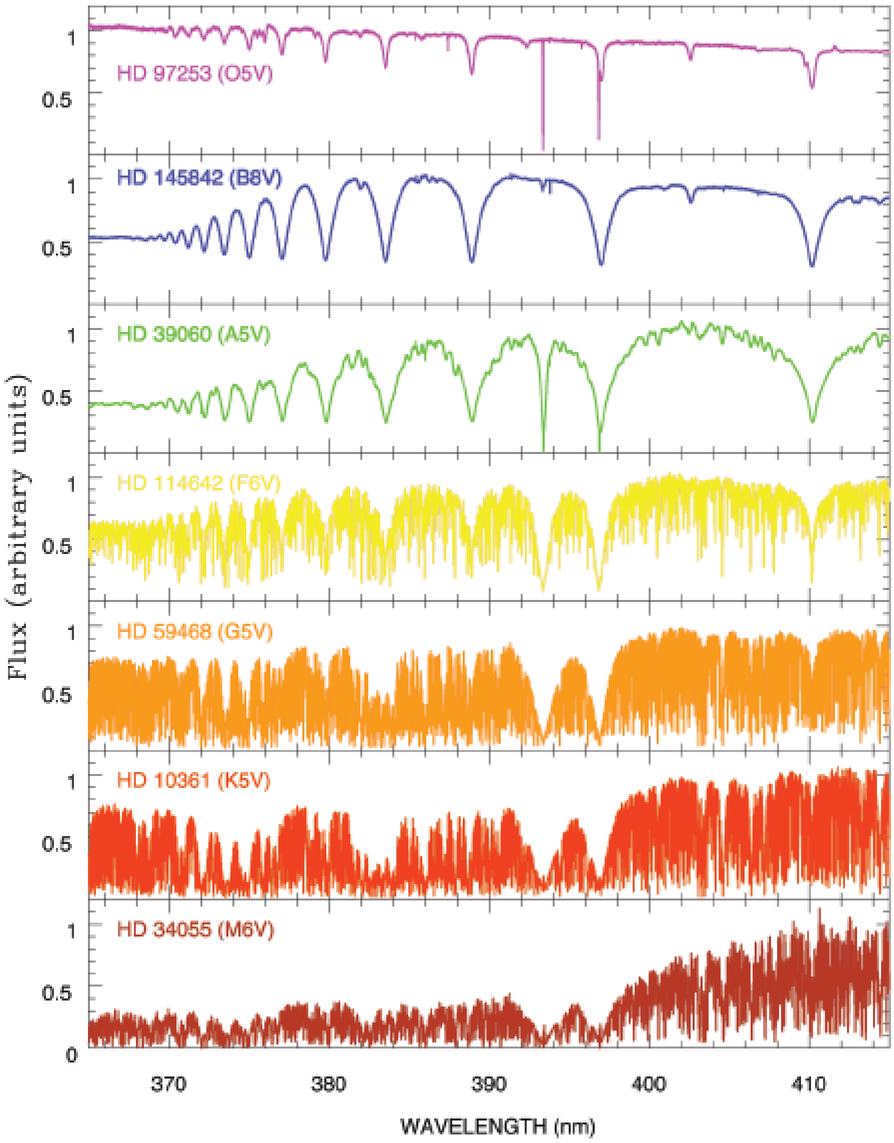


Figure 3: The spectral region from 360 to 420 nm for a sample of stars of the OBAFGKM spectral types. All Balmer lines from Hδ down to the Balmer jump are clearly visible in the hotter stars. In the O star spectrum (top panel), the two sharp absorption features at about λ393.4 nm and 396.8 nm are due to interstellar CaII.

tra to heliocentric rest-frame, average multiple individual exposures (with cosmic ray rejection), and merge the spectra from different settings all together. During this process, all individual reduced spectra were extinction-corrected and flux-calibrated as explained in [6] (see also Hanuschik 2003) using the master response curves determined by ESO Garching Quality Control [7]. Note that because of slit losses occurring when a 0.5″ slit width is used under variable seeing conditions, the final flux spectrum is not suitable for absolute flux measurement, hence one can recover only the shape of the star's spectral energy distribution.

The final result is one individual spectrum per star (plus its associated variance) covering the whole optical range from about 304 to 1040 nm. Some examples of reduced and globally merged files are shown in Figs. 2 and 3. Figure 2 shows the large spectral coverage of UVES POP observations, that are at the same time characterised by a high SNR and a high spectral resolution. Figure 3 is an example of the variety of stellar spectra observed across the main sequence of the HR diagram.

Quality Control (QC)

A number of checks were performed on the reduced spectra, and results are reported in a dedicated *logfile* that is released together with the data. First, target coordinates written in the fits-headers are cross-checked using the SIMBAD database, or with specific literature, to make sure that the target is correctly identified. The epoch of the various observations is also noted down, in particular it is checked that all observations of a given star have been taken during the same night. If not, a warning is issued in the logfile, bearing in mind the possibility that some stars in the sample are actually variable.

Finally, a close inspection of the reduced spectra is performed independently by two members of the team. In some cases, science frames do not pass the quality check and are rejected (for instance, spectra with too low SNR, or saturated, or for which extraction has failed, or those that for any reason have a quality substantially lower than expected). Note that even if the worst cases are rejected, the released spectra may still be affected by some problems like ripple effects (due to inaccurate blaze function correction) and lower-quality extracted order merging. These well-known problems are documented in [5].

Data Release and Spectrum Preview Interface (SPI)

The data are released through an ESO WEB page: *http://www.eso.org/uvespop*. The home page gives some general information about the project, and points to three main tables: *i*) stars belonging to the open cluster IC 2391, *ii*) stars belonging to the open cluster NGC 6475 (M7), and *iii*) field stars ordered by spectral types. A fourth table is devoted to some of the brightest (V<2.5) stars in the Southern Hemisphere.

All tables are organized in a similar way. Each table entry corresponds to an individual star, and includes links to the SIMBAD database, to the UVES reduced spectra, and to a QC logfile.

For each star, the reduced spectra are made available – through a direct link – in the form of seven gzipped tar files, plus one fits table. Each tar file includes a number of fits files that are the straight output of the MIDAS UVES pipeline modified for this project. Six tar files are relevant, respectively, to the six observed spectral ranges, i.e., 346B, 437B, 580L, 580U, 860L, and 860U. Each of these tar files includes all individual reduced spectra and the associated variance spectra.

Since the merging of the various echelle orders is a delicate step of the data reduction process, data release comes along with a seventh tar file, containing the pipeline products *prior to merging the orders*, plus the sky spectra. Unmerged spectra may be used to check if some features are due to an artifact produced by the merging, and in some cases, may be preferred to merged spectra for science use.

The naming convention is self-explanatory. All file names explicitly refer to the star's name (generally the entry in the Henry Draper Catalogue), the instrument setting, and the time-stamp, whenever applicable. For instance, a file called hd123456_437B_2001_03_21:01:15:00.fits corresponds to the spectrum of star HD 123456 obtained using the 437B setting and observed on the 21st of March 2001, at 01:15:00 UT (date-stamp in fact corresponds to the time of shutter opening).

Ideally, the very final product is the fits table that is obtained by averaging/merging all final pipeline products as explained before. This table includes the star's spectrum and its variance. It is available through a direct link from the WEB tables, and its name only refers to the target name (e.g., hd123456.tfits). This file should be used with some caution. For instance, it may come from spectra taken at distant epochs, and, in the case of variable stars, different spectral regions may have been produced under different physical conditions. Moreover, the globally merged file may come from original spectra of uneven quality in terms of, for instance, blaze function correction. Users should check the QC logfile and the fits headers of individual spectra. Note also that, since the globally merged spectra have their wavelength scale converted to the heliocentric rest-frame, telluric lines, that in the observed frame are fixed in wavelength, appear *mis-aligned*. Telluric lines appear at the correct wavelengths only in the spectra included in the gzipped tar files. However, in many cases, and for many applications, the fits table is close to the best product that can be obtained out of the original raw data.

It should be finally stated that the UVES POP reduced data are the result of a *mass production* process, that cannot be tuned to individual cases. Hence, some problems will remain in the final products. For individual stars, better results may possibly be obtained by retrieving the raw data and corresponding calibrations at the ESO UVES archive [8] using program ID 266. D-5655(A).

A collection of basic cgi plotting routines using PGPERL and CFITSIO perl allows the user to overview the merged spectrum of a given star in the desired spectral range. These routines form the *Spectrum Preview Interface* (SPI), a display tool that has been specifically created for the public release of UVES POP spectra. Users can choose to have the spectrum displayed in GIF format, or to save it as a postscript file. A third possibility allows the user to download the spectrum as an ASCII file in a given wavelength interval.

The SPI can be activated in two different ways: *i*) through a special link from the table with the target list, and *ii*) through the main SPI web page. The former is the most basic and probably the most convenient method to select and display *individual* spectra. The latter method permits one to perform elementary searches through the POP database (e.g., for a given name string and/or spectral type and/or spectral peculiarity) and to display up to five spectra altogether. Overplotting has two options: spectra can be stacked together, or shifted along the *y* direction.

Acknowledgements

We are grateful to A. Modigliani for useful discussions about the UVES pipeline, D. Silva and S. Hubrig for their comments to the manuscript, V. Andretta, J.D. Landstreet, P. Prugniel for their comments to the UVES POP web pages. This project has made use of the SIMBAD database, operated at CDS, Strasbourg, France. Among SciOps team members we acknowledge a special support from: S. Brillant, D. Hutsemekers, A.O. Jaunsen, A. Kaufer, R. Scarpa, J.V. Smoker, T. Szeifert. We are also very much indebted to the Paranal TIOs who have been participating to the observations: M.T. Aceveido, H. Alarcon, S. Cerda, L. Faundez, C. Herrera, N. Hurtado, A. Lopez, C. McKinstry, J. Navarrete, H. Nuñez, A. Pino, A. Ramirez, and A. Zarate.

References

Ballester, P., Modigliani, A., Boitquin, O., Cristiani, S., Hanuschik, R., Kaufer, A., & Wolf, S., 2000, *The UVES Data Reduction Pipeline*, The ESO Messenger, 101, 31

Buscombe, W., 1999, *14th General Catalogue of MK Spectral Classification,* VizieR On-line Data Catalog: III/222. Originally published in: Northwestern Univ., Evanston, Illinois ISBN 0-939160-12-9 (1999)

Dekker, H., D'Odorico, S., Kaufer, A., Delabre, B., Kotzlowski, H., 2000, *Design, construction and performance of UVES, the echelle spectrograph for the UT2 Kueyen telescope at the ESO Paranal Observatory,* SPIE Munich [4008-534]

ESA, 1997, *The Hipparcos Catalogue*, ESA SP-1200

Hanuschik, R. W., 2003, A&A, 407, 1157

Kaufer, A., D'Odorico, S., & Kaper, L., 2003, *UVES User manual,* Doc. No. VLT-MAN-ESO-13200-1825

Kupka, F., Piskunov, N. E., Ryabchikova, T. A., Stempels, H. C., & Weiss, W. W., 1999, A&AS, 138, 119

Renson, P., Gerbaldi. M., & Catalano, F. A., 1991, A&AS, 89, 429

Web links cited in this paper

[1] The VALD database:
http://www.astro.univie.ac.at/~vald/

[2] The WEBDA database:
http://obswww.unige.ch/webda/

[3] The UVES web pages:
http://www.eso.org/instruments/uves/

[4] The UVES pipeline:
http://www.eso.org/observing/dfo/quality/UVES/pipeline/

[5] Problems with the pipeline reduced spectra:
http://www.eso.org/observing/dfo/quality/UVES/pipeline/pipe_reduc.html#problems

[6] How to flux calibrate UVES data:
http://www.eso.org/observing/dfo/quality/UVES/qc/response.html

[7] The UVES master response Curves:
http://www.eso.org/observing/dfo/quality/UVES/qc/std_qc1.html#response

[8] The ESO UVES archive:
http://archive.eso.org/wdb/wdb/eso/uves/form

Pushing Technologies: ESO Fibre Laser Development for Laser Guide-Star Adaptive Optics

In the context of developments toward mature Adaptive Optics systems for large telescopes, we describe the present activities at ESO in the area of fibre lasers.

D. Bonaccini[1], W. Hackenberg[1], L. Taylor[1,2]

[1]European Southern Observatory, Garching, Germany
[2]University of California, Lawrence Livermore National Laboratory, USA

The new technologies for astronomical Adaptive Optics are progressively becoming mature. Adaptive Optics in Astronomy allows the telescopes to deliver diffraction limited images, correcting the atmospheric turbulence effects: image motion and image blur. ESO already has three facility Adaptive Optics systems deployed on the VLT, with four more to be installed in the coming years.

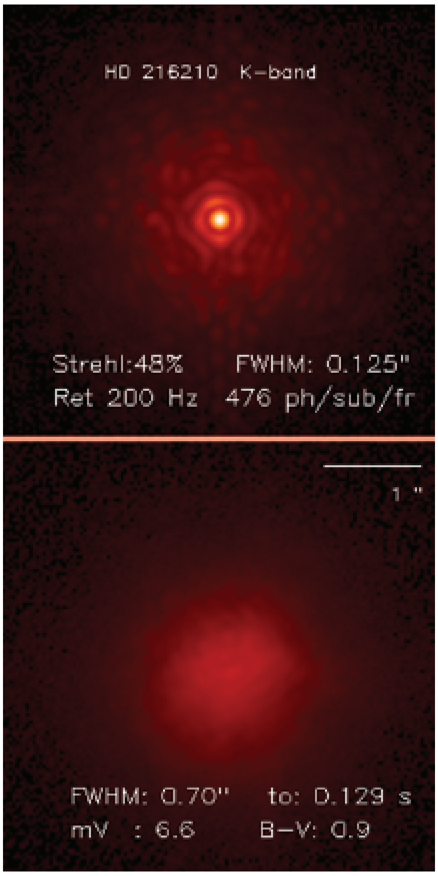


Figure 1: K band images obtained at the ESO La Silla 3.6m telescope with the Adonis system, in May 1997. The Adaptive Optics closed loop (top) and open loop (bottom) images show the difference between diffraction limits and seeing. The 5 second exposure image is in log scale to show the Point Spread Function details.

The Adaptive Optics servo control needs a bright reference source in order to perform the real-time correction at frequencies up to 1 kHz refresh rates. Besides, the optical wavefront correction is valid only within isoplanatic patch areas around the reference source, which at K-band (2.2 µm wavelength) at VLT sites have about 30″ radius in median seeing conditions.

Therefore the current two *limitations* of Adaptive Optics are the need of a bright reference point source, and the limited field of view. One would wish to extend the corrected field of view to one arcmin radius. Adaptive Optics has in recent years successfully demonstrated on the field its capabilities with single natural or laser reference sources (Takami et al., 2003; Wizinowich et al., 2003). ESO with its community has been one of the first players (Beuzit et al. 1997) with facility systems [Fig.1].

Adaptive Optics (AO) is still a young and rapidly evolving technology which in its maturity promises to overcome the current limitations. Toward this goal, useful for 8–10 m class telescopes, and vital for Extremely Large Telescopes of the future, strategic R&D work is being done at ESO as well as in other observatories around the world.

The stars are the natural reference sources for Adaptive Optics; however the brightness required limits to less than 1% the area of the sky which can effectively be used with Natural Guide Stars Adaptive Optics (NGS-AO) on 8–10 m class telescopes. Laser Guide Stars (LGS), i.e. artificial reference sources created by the backscattering of laser beams, allow the user to point almost anywhere in the sky, obtaining extremely large sky coverage. This opens the door to AO for extragalactic astrophysics, and allows overcoming the first of the two limitations.

Lick Observatory (USA), with a prototype system, has reported (Gavel et al., 2003) on the 3 m Shane telescope Strehl Ratios as high as 0.6 when imaging at wavelengths around 2.2 µm [Fig.2]. It is clear from their experience and from the European experience obtained with ALFA at the German Calar Alto observatory (Eckart et al., 2000), that an LGS-AO system requires multidisciplinary technologies, very well engineered systems and an overall tuning together with the science instrument, in order to perform as expected at a good astronomical site.

To extend the field of view, the Multi-conjugate AO technique has been proposed (Beckers, 1988) and is being actively pursued worldwide. Multiple guide stars of sufficient brightness and correct separation are necessary for this technique. Again this may be obtained with groups of bright Natural Guide Stars

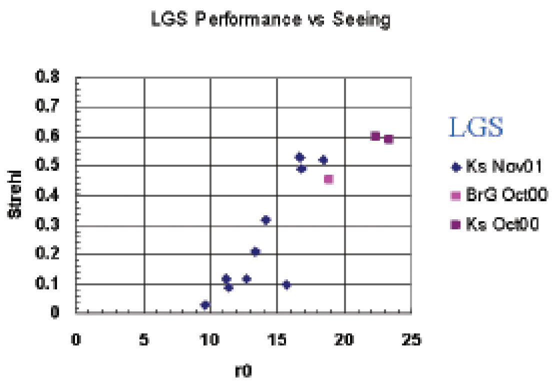


Figure 2: Lick Observatory 3 m telescope results with their experimental LGS-AO. The K-band Strehl ratio vs Fried parameter size, r_o, is shown. A Fried parameter of 15 cm at 0.5 µm wavelength corresponds to a seeing of 0.7 arcsec (Courtesy of Don Gavel, Lick Obs.).

which happen to be of the right magnitude and angular separation, the so-called "asterisms", or with multiple Laser Guide Stars (Ellerbroek et al., 2003). The latter give a preciously uniform Point Spread Function across the field of view in closed loop.

Around the world there are at the moment more than 13 telescopes being equipped with single or multiple LGS-AO systems.

ESO is integrating a Laser Guide Star Facility (LGSF) on the VLT [see *Messenger* No. 100], which will serve the NACO and SINFONI instruments equipped with AO. We are building the LGSF with provision for up to 5 LGS to be projected and diagnosed by the system [Fig 3], in order to be ready for an upgrade toward Multi-conjugate Laser Guide Star Adaptive Optics.

Although much research is still in progress, looking at the past trend it is likely that in the timeframe of 10 years LGS-MCAO will become a mature, advanced, deployable technology enabling AO to overcome or make negligible, the current limitations of guide star brightness and field of view. By the use of single or multiple *laser guide stars* current and future adaptive optics (AO) systems will provide imaging at the diffraction limit of resolution over a wider field of view and at shorter wavelengths than currently possible. This is because laser guide stars (LGSs) can be virtually projected anywhere in the sky and made bright enough to fulfil the utmost flux requirements for real-time compensation of the atmospheric turbulence.

The ESO group working on the Laser Guide Star Facility project, aimed at LGS Adaptive Optics, is following this strategic view. For this reason it is pushing R&D for two different technologies crucial to LGS-AO systems for astronomy: the fibre lasers and the high power laser beam relays based on Photonic Crystal Fibres.

We report briefly in this article on the fibre laser program at ESO, which has provided so far two Patents for our organisation. We will report on the fibre relays in a coming article.

ESO has carried out internally, and then double checked with consulting companies, the fibre laser design and its numerical simulations. We are now in the breadboarding phase of a prototype fibre laser to be transferred later to European industry for commercialization.

Which Lasers

Laser guide stars created in the mesospheric sodium layer at an altitude of about 90 km (and a wavelength of 589 nm) play a major role, since they are generated at the greatest possible distance in the earth's atmosphere, making them most star-like and minimizing focus anisoplanatism effects.

The requirements for a sodium-guide star laser for multiple-guide-star AO systems are stringent: it needs to be an efficient, highly reliable and turn-key system. The output wavelength needs to be precisely centred on the mesospheric, 3 GHz wide sodium D_2 line at 589 nm. The format may be Continuous Wave (CW) or pulsed (800 Hz repetition rate, 200 microsec duration pulses) to exploit techniques which reduce or eliminate the perspective elongation effects. The equivalent power to be emitted is 10 W (15 W goal) per LGS. A polarised output is desirable for optical pumping of the mesospheric sodium atoms in order to enhance the resonant backscatter signal. For multiple sodium guide-star adaptive optics at least four laser guide stars will be required on an 8 m class telescope.

The laser beam quality when emitted at the launch telescope has to have a wavefront variance equal or comparable with the variance introduced by the atmospheric turbulence in the uplink beam (from telescope to Mesosphere). Therefore the high power laser beam quality has to be also quite good (better than 1.3 times the diffraction limit beam Full Width Half Maximum, $M^2 = 1.3$).

On the other end, the different LGS beams do not have to be coherent and may be generated separately or the lasers distributed at different locations. Other requirements apply specifically to the telescope environments. The laser should be efficient in term of power conversion (i.e., less energy to dissipate per watt emitted). It should be rugged, turn-key and ideally require little or no maintenance.

Off the shelf solid state lasers at 589 nm with these characteristics do not yet exist.

The suitable 589 nm lasers available today are only of the dye type. One model has been built by Lawrence Livermore National Laboratory for Lick Observatory and Keck, a different model is built by the Max Planck Institut für Extraterrestrische Physik in Garching as part of the ESO-LGSF collaborative project.

Very recently the US Air Force has demonstrated a sum frequency laser able to produce 20 W, which will be scaled up to 50 W CW. Development programs for discrete solid-state lasers are in place at GEMINI Observatory and the University of Chicago.

For the next-generation laser guide star and multiple guide-star adaptive optics systems ESO's strategy is to develop 10 W fibre lasers at 589 nm, together with industry. This strategy has created a collaboration agreement with the Lawrence Livermore National Laboratory (LLNL) in the U.S to develop a sum-frequency fibre laser and an internal effort on a less complex fibre Raman laser. The decision for fibre lasers was based on a number of advantages which are hard to overestimate. Moreover they have been very recently demonstrated with powers up to 500 W at visible wavelengths, both in CW and pulsed formats.

• Due to their waveguide structure, there are no bulk optical cavities to be kept precisely aligned and thermostatized.

• There are no hot temperature spots, astigmatisms of optical components, vibration-induced instabilities.

• Beam splitters, reflectors and dichroics are today all integrated in the fibre itself giving very high efficiencies.

• Fibre lasers are very compact and efficient, and rugged

• They are alignment-free (simplifying turn-key operation)

• They are power scalable up to the power of interest

• They provide in-built fibre delivery with diffraction-limited output.

• They have also a potential for low

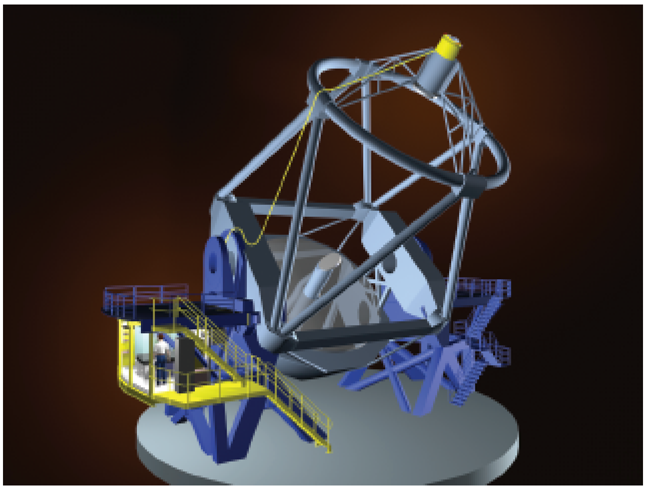


Figure 3: The ESO LGSF projects the laser beam from behind the M2 hub, where a 500 mm Launch Telescope is installed. The 589 nm laser is mounted on the laser clean room installed under the Nasmyth A platform. A single mode Photonic Crystal Fibre relays the laser power for 30 meters, from the laser location to the focal plane of Launch Telescope System behind M2. The LGSF has provision for 5 such fibres to be installed, producing up to five Laser Guide Stars.

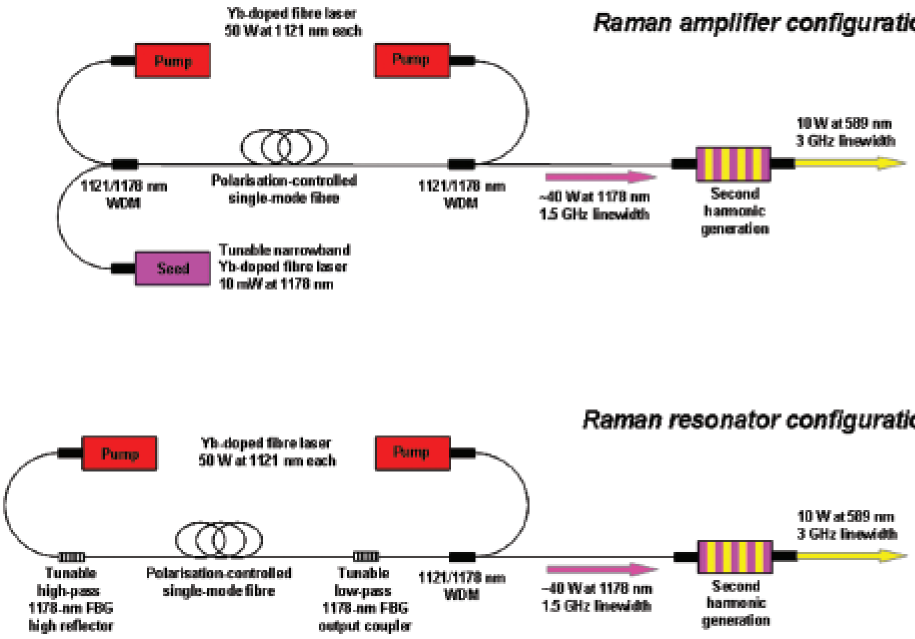


Figure 4: The fibre Raman laser at 589 nm is obtained by frequency doubling a laser at 1178 nm via a second harmonic generation crystal. The 1178 nm wavelength is obtained as the first Stokes of a Stimulated Raman Scattering process. The two configurations of amplifier (upper drawing) and resonator (lower drawing) are being breadboarded.

cost, whereby current 10 W CW Raman lasers cost ~40 kEUR.

Moreover, the fibre laser single mode output ensures diffraction limited beam qualities, with M^2 values ≅ 1.1 (confirmed at high power in our laboratory). The fibre output allows the laser beam to be relayed around the telescope with diffraction limited beam quality deployed directly in the Launch Telescope Systems area. This is in most LGSF systems a major engineering effort, coping with laser beam degradation and fast jitter. With fibre lasers this effort is removed from the LGS telescope facility cost and complexity.

Which Fibre Lasers

Since there are no optical materials known that are directly lasing at 589 nm, nonlinear optical frequency conversion processes have to be exploited in the fibre laser design.

Our approach (Hackenberg et al, 2003) is optical frequency-shifting of infrared light by stimulated Raman scattering (SRS) to exactly twice the sodium wavelength (or 1178 nm) in combination with subsequent frequency doubling. This is a Raman fibre laser which we have designed and is being breadboarded at the ESO laser laboratory.

We are also collaborating with LLNL, which has proposed a sum-frequency mixing (SFM) from two suitable fibre lasers at infrared wavelengths, 1583 nm and 938 nm. Common to both approaches is the use of periodically poled crystals for the nonlinear optical frequency conversion of infrared light to the wavelength of 589 nm. Both fibre laser concepts will be described in more detail in the following.

Fibre Raman Laser

The Raman laser approach is the simplest, more robust fibre laser configuration and it is directly scalable up to 20 W CW. It uses the inelastic scattering of photons by the molecules of the fibre. The input or pump laser photons excite the molecules to a higher vibration state and are thus downshifted in frequency by an amount equal to the energy difference between the final and initial state of the molecule. This so-called Stokes shift of course depends on the material composition and is, e.g., 17 THz in silica.

In our fibre Raman laser a germanosilicate single-mode fibre is used as the Raman scattering medium (see Figure 4). The fibre is pumped by a 40 W CW commercial ytterbium-doped fibre laser (YDFL) operating at 1121 nm. By this the incident pump photons experience a frequency shift to exactly 1178 nm or twice the sodium D_2 wavelength. The efficiency of this process, on the first Raman Stokes, is known to reach 80–90% levels in single mode fibres. YDFLs are commercially available at very high output powers (up to 100 W CW), which make them the ideal pump source for our application. In a final frequency conversion step (see Figure 4) the 1178 nm output of the Raman fibre is frequency-doubled in a nonlinear crystal to produce light at 589 nm (the second harmonic). Ideally the frequency doubling happens in a single-pass through a periodically poled crystal (see below). Alternatively, second harmonic generation by a bulk crystal in a small resonant cavity can be used, a concept that is used in commercial frequen-

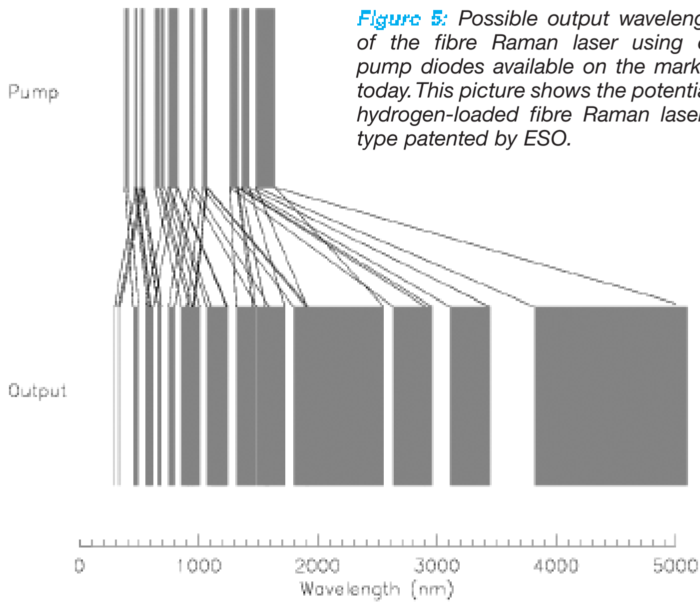


Figure 5: Possible output wavelengths out of the fibre Raman laser using different pump diodes available on the market as of today. This picture shows the potentiality of a hydrogen-loaded fibre Raman laser of the type patented by ESO.

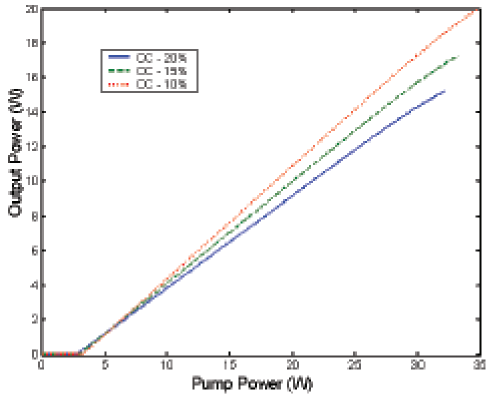


Figure 6: Numerical Simulations results for the fibre Raman laser. The 1178 nm output power obtained vs. pump power is shown, for different output couplers. A 10% output coupler will give the best performance of the fibre laser. 1121 nm pump powers up to 100W are now commercially available.

cy-doubled laser.

The fine tuning of the output wavelength and bandwidth to exactly the sodium D_2 line wavelength can be obtained in two ways (see Figure 4), in an amplifier or a resonator configuration.

Raman amplifier configuration

The Raman fibre is seeded with light from a tunable narrowband laser operating at exactly twice the sodium D_2-line wavelength. The output is the seed light amplified by the SRS process in a single pass. This possibility has now become very attractive due to the recent commercial introduction of low-power tunable and narrowband 1178 nm laser. Parasitic nonlinear optical effects like stimulated Brillouin scattering (SBS) are suppressed by the use of a sufficiently short Raman fibre.

Raman resonator configuration

A narrow-band resonator is created within a single mode fibre, using a pair of dedicated fibre Bragg gratings tuned to 1178 nm wavelength. The Bragg gratings for the Raman-shifted light are designed such that they only reflect 1178 nm and not wavelengths that might be created by parasitic nonlinear processes such as Stimulated Brillouin Scattering. Thus, only the 1178 nm (Raman Stokes I) light will be enhanced in the laser cavity by multiple pass reflections from the Bragg gratings, whereas any parasitic nonlinear light will leave the resonator in a single pass without additional reflections, thus preventing the stimulated SBS emission. Again, having the fibre made sufficiently short, SBS will not build up in a single pass.

This configuration allows building narrow band Fibre Raman Lasers at many other wavelengths than 589 nm, and also multiple wavelength lasers. It has therefore the potential for many applications besides astronomical LGS-AO. This is shown in Fig. 5, for hydrogen loaded fibres. It is likely the most attractive configuration for industry, as high power *narrow-band* Raman fibre laser do not exist on the market yet. ESO is patenting the invention and is applying for technology transfer funds together with interested industries. Our goal is to have compact and turn-key commercially available fibre lasers for LGS-AO within three years.

In Figure 6 the predicted narrowband (0.5 GHz) output power at 1178 nm is shown as a function of pump power. At each pump power the optimal fibre length maximising the output power has been assumed. This length is less than 100 m at the highest pump powers shown here. With commercially available YDFL as pump sources output powers in excess of 40 W at 1178 nm are feasible. This sets an upper limit to the conversion efficiency needed in the subsequent second harmonic generation.

Sum-Frequency Fibre Laser

The sum-frequency fibre laser is developed at LLNL, with collaboration from ESO. It is based on two rare-earth doped fibre amplifiers (Fig.7).

An erbium-doped fibre amplifier (EDFA) operates at 1583 nm, and a neodymium-doped fibre amplifier (NDFA) works at 938 nm. Both fibre amplifier outputs are mixed in a nonlinear crystal to generate light at the sum frequency corresponding to 589 nm. The fibre amplifiers are double-clad pumped by high-power diode laser. The seed lasers needed for output frequency control are low-power tunable and narrowband diode laser.

The EDFA is constructed entirely of commercially available components. The NDFA requires development to bring it to realisation. This will be discussed in the next Section.

ESO contributions are for design issues on the 938 nm arm, some basic components and joint work on the non-linear crystals.

Fibre Laser Development Status

Raman Laser

We have done at ESO, and in parallel contracted out to Directed Energy Solutions, full numerical simulations for the Amplifier and Resonator Raman laser configurations. Both indicate feasibility of the laser system and sufficient suppression of the SBS.

We have procured all discrete components, and assembled the amplifier configuration with discrete components. Thanks to the work of Daniela Werner, a student who has done her master thesis with us, we have obtained practical experience with the fibre amplifier and Raman emissions up to 4 W CW.

We are now procuring and assembling the all-fibre configurations from industry, which will give a better Raman conversion efficiency. We have prepared the test set-up and the doubling crystal to first get ~1 W CW of yellow light, and will then scale it up. We have sufficient pump power and all components are specified to perform 10 W CW tests in our labs.

The breadboard tests are mandatory for the technology transfer to have the fibre laser engineered by industry.

Sum Frequency

The sum frequency laser has produced the first yellow light (50 mW) from fibre laser obtained in November 2002, and it is close to the 1 W level today.

The 938 nm laser (Dawson et al., 2003) is the technological challenge. It is getting close to specifications. Problems to be resolved are the amplified mode selection with the large core NDFA fibre, and polarization control. Currently we have achieved 4.5 W CW useful output at 938 nm. We have achieved 5 W CW at 938 nm and 6 W CW at 1583 nm, polarized, which at the time of this writing are being combined into the sum-frequency crystal.

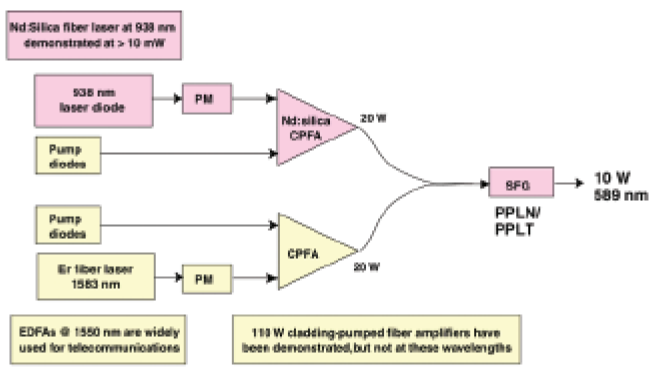


Figure 7: Scheme of the sum-frequency fibre laser pursued at LLNL. The sum of 1583 nm and 938 nm photons energies creates photons at 589 nm in a Periodically Poled SFG crystal.

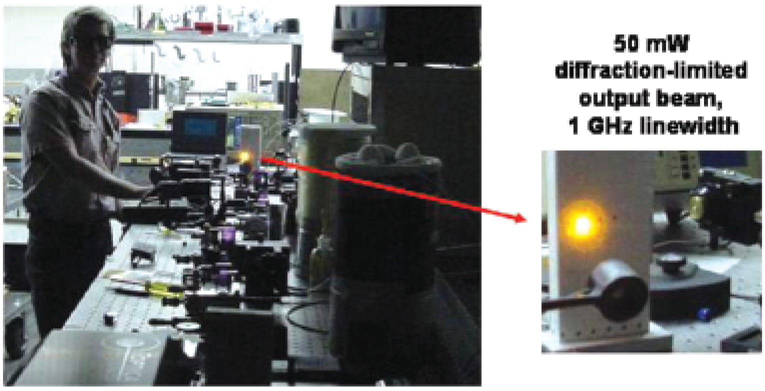


Figure 8: Alex at LLNL tuning up the laser to get the maximum output at the time (Nov 6, 2002). This is the first yellow light from a fibre laser, produced at 589 nm with 1 GHz bandwidth, 50 mW.

Technologies related

In pursuing the fibre laser we are pushing some technologies which are related to it, together with industry. These are described in the following.

Narrow band high power Raman lasers

Although high power Raman lasers are commercially available at 1178 nm with powers up to 15 W CW, their linewidth is of the order of 1 nm. We are pushing the linewidth to 1 pm, the main challenge in doing this is to suppress the Stimulated Brillouin Scattering. For this we have a viable path supported by design, numerical simulations and soon by experiments.

High power fibre couplers

Beam splitters and dichroics are fully integrated in the fibre laser, in the form of TAP couplers and WDM. Recently high power (20 W CW) couplers have been developed and are commercially available. Couplers and dichroics for polarisation preserving fibres are still under development by the industry. Although not mandatory, they will be an asset for the fibre Raman laser.

Periodically-poled nonlinear crystal

Periodically-poled crystals have the advantage of a very high nonlinear coefficient. They can be inserted directly in the laser beam and give efficient conversions. Such a crystal consists of a sequence of permanent ferroelectric domains of alternating polarity perpendicular to the optical axis (see Figure 9). By this the sign of the nonlinear coefficient is reversed every period, and quasi-phase matching is achieved for the three interacting waves in the crystal. Without poling the fundamental and second harmonic waves would quickly run out of phase due to chromatic dispersion.

The periodically poled crystals commercially available are sensitive to the so-called photorefractive damage. Together with LLNL we are investigating several methods to avoid this type of damage. This include elliptical beam formatting to keep the power density low and improved (i.e., stochiometric) crystal growth and poling techniques. For this purpose a crystal test facility has been set up at LLNL to investigate conversion efficiency and long-term reliability. European laser industries have expressed strong interest in this technology. We are investigating PPSLN and PPSLT materials.

Fibre Bragg Gratings

Fibre Bragg Gratings (FBG) are reflective optical elements or filters created by periodic modulation of the refractive index in the fibre core. They are written permanently into the glass of the fibre by exposing it once to a suitable ultraviolet light interference pattern.

Apodized Fibre Bragg gratings of the required extinction and shape for the Raman fibre laser are feasible, although our specifications have been considered by industry as high-end, low-yield FBGs.

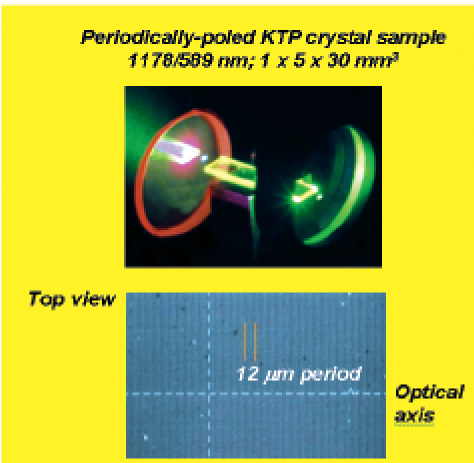


Figure 9: Periodically poled cristals allow to obtain sum frequency or frequency doubling effects, without the need of a resonant cavity. They are an emerging laser technology.

938 nm Neodimyum Doped Fibre Amplifier

In the NDFA design the main technical challenge is the suppression of amplified spontaneous emission (ASE). To force the amplifier to operate at 938 nm and to suppress the ASE at longer wavelengths we are using in parallel several methods: seeding at high power, introducing bend losses to the longer wavelengths which is especially effective in fibres of low numerical apertures and finally long-period Bragg gratings for frequency-selective feedback in the amplifier fibre. These methods have different efficiencies, but more or less independent from each other. We have designed and developed a special fibre to use for the 938 nm laser, together with the Institut für Physikalische Hoch Technologie in Jena (Germany)

What are we going to do next on the fibre Raman laser

For the ESO Raman fibre laser we will receive the all-fibre lasers breadboard around mid 2004, and perform the tests in the summer in our laboratory. The periodically poled crystals activities shared at LLNL will help us to choose the appropriate crystal for the Second Harmonic Generation required by the Raman laser.

We will in the meantime apply for European funds for technology transfer of these new laser types to industry. We are forming a consortium of companies with member state countries and preparing the funding application for the beginning of 2004. The deliverable will be fibre lasers at 589 nm, to be field tested at our LGSF facility. An option for pulsed formats fibre lasers will be opened.

The first part of the program will last two years leading to a tested, well engineered preproduction unit. The second part will call for a field test final unit, to be delivered in the subsequent year.

References

Beuzit, J-L., Demailly, L., Gendron, E. et al., 1997, in *Experimental Astronomy*, 7, 285

Beckers, J.M., 1998, in Proc. "*ESO Conference on Very Large Telescopes and Their Instrumentation*", ed M-H Ulrich, p. 693

Dawson J.W., Drobshoff A., Liao Z.M. et al., 2003, in "*Advances in Fibre Lasers*" ed. L.N. Durvasula, SPIE Proc. 4974, p. 75

Ellerbroek B., Rigaut F., Bauman B. Et al., 2003, in "*Adaptive Optical System Technologies*", eds P. Wizinowich and D. Bonaccini, SPIE Proc. vol 4839, p. 55

Gavel D., Gates E., Max C. et al., 2003, in "*Adaptive Optical System Technologies*", *op. cit.*, p. 354

Hackenberg W., Bonaccini D. and Werner D., 2003, in "*Adaptive Optical System Technologies*", *op. cit.*, p. 421

Takami H., Takato N., Hayano Y. et al., 2003, in "*Adaptive Optical System Technologies*", *op. cit.* p. 21

Wizinowich P.L., Le Mignant D., Stomski P.J.Jr. et al., 2003, in "*Adaptive Optical System Technologies*", *op. cit.*, p. 9

Setting New Standards with HARPS

By October 1st, 2003, ESO's new and unique planet-hunting machine HARPS (High-Accuracy Radial velocity Planetary Searcher) has become operational. The measurements made during the commissioning phase and the first weeks of operation are of outstanding quality. In this article we report among other examples on the first extra-solar planet discovered with HARPS and on the detection of tiny stellar oscillations. The results presented demonstrate that HARPS is currently the most precise Doppler-measurements machine in the world. With this acquisition ESO places itself at the head of a scientific domain, whose interest has continued to grow during the past years.

M. Mayor[1], F. Pepe[1], D. Queloz[1], F. Bouchy[2], G. Rupprecht[3], G. Lo Curto[4], G. Avila[3], W. Benz[5], J.-L. Bertaux[6], X. Bonfils[1], Th. Dall[4], H. Dekker[3], B. Delabre[3], W. Eckert[4], M. Fleury[1], A. Gilliotte[4], D. Gojak[3], J.C. Guzman[4], D. Kohler[7], J.-L. Lizon[3], A. Longinotti[3], C. Lovis[1], D. Mégevand[1], L. Pasquini[3], J. Reyes[3], J.-P. Sivan[7], D. Sosnowska[1], R. Soto[4], S. Udry[1], A. Van Kesteren[3], L. Weber[1], U. Weilenmann[4]

[1]Observatoire de Genève, Switzerland;
[2]Laboratoire d'Astrophysique de Marseille, France;
[3]ESO Garching;
[4]ESO La Silla;
[5]Physikalisches Institut der Universität Bern, Switzerland;
[6]Service d'Aéronomie, Verrières le Buisson, France;
[7]Observatoire de Haute-Provence, France

The HARPS Project was born in May 1998 when ESO issued an Announcement of Opportunity asking for the design, construction, and procurement of an instrument dedicated to the search for extrasolar planets and aiming at an unequalled precision of 1 m/s. In response to ESO's call the Observatoire de Genève together with the Physikalisches Institut der Universität Bern, the Observatoire de Haute-Provence, and the Service d'Aéronomie du CNRS have formed a Consortium which realized, in collaboration with ESO, this ambitious project in only three and a half years. The instrument was installed by the Consortium on ESO's 3.6-m Telescope at La Silla in January 2003 and first light took place on February 11th. HARPS was commissioned during the periods 70 and 71. During period 71 a first GTO run of seven nights had been allocated for the Consortium as well. These observations have already produced many exciting results.

The instrument was handed over to ESO La Silla by the end of September 2003 and made available to the Community for period 72. Together with the 3.6-m telescope HARPS is now delivering fantastic scientific frames to the observers. But this is not the only data product of HARPS. The powerful HARPS pipeline provides any observer with extracted and wavelength calibrated high-resolution spectra, as well as the precise radial velocity of the observed star. The observer will thus leave the Observatory with fully reduced spectra. Additional information on how to observe with HARPS can be found at *http://www.ls.eso.org/lasilla/sciops/harps/*.

An unequalled facility for radial-velocity measurements

HARPS is a fibre-fed, cross-dispersed echelle spectrograph. Two fibres, an object and a reference fibre, feed the spectrograph with the light from the telescope and the calibration lamps. The fibres are re-imaged by the spectrograph optics onto a mosaic of two 2k4 CCDs, where two echelle spectra of 72 orders are formed for each fibre. The covered spectral domain ranges from 380 nm to 690 nm. The resolution of the spectrograph is given by the fibre diameter and attains a value of about R=115,000. At this resolution each spectral element is still sampled by 3.2 CCD pixels. A summary of the main HARPS features is given in Table 1. For a detailed description of the instrument we refer to the article published in Pepe et al. (2002) and to the HARPS Users Manual.

HARPS is an ordinary spectrograph with outstanding efficiency and spectral resolution. The main characteristics of HARPS is however its extraordinary stability. The ThAr-reference technique is able to measure and correct the tiniest instrumental drifts; nevertheless a lot of effort was put into making the spectrograph intrinsically stable, in order to avoid

Table 1: HARPS spectrograph characteristics

Optical design	fibre-fed, cross-dispersed echelle spectrograph
Technique	simultaneous ThAr Reference
Number of fibres	2
Fibre aperture on sky	1 arcsec
Collimated beam diameter	208 mm
Covered spectral range	380 nm to 690 nm
Spectral resolution	R=115,000
Spectral format	72 echelle orders 61.44 x 62.74 mm
CCD chip	mosaic, 2xEEV2k4 pixel size=15µm
Sampling	3.2 pixels/SE
Min. inter-order	33 pixels

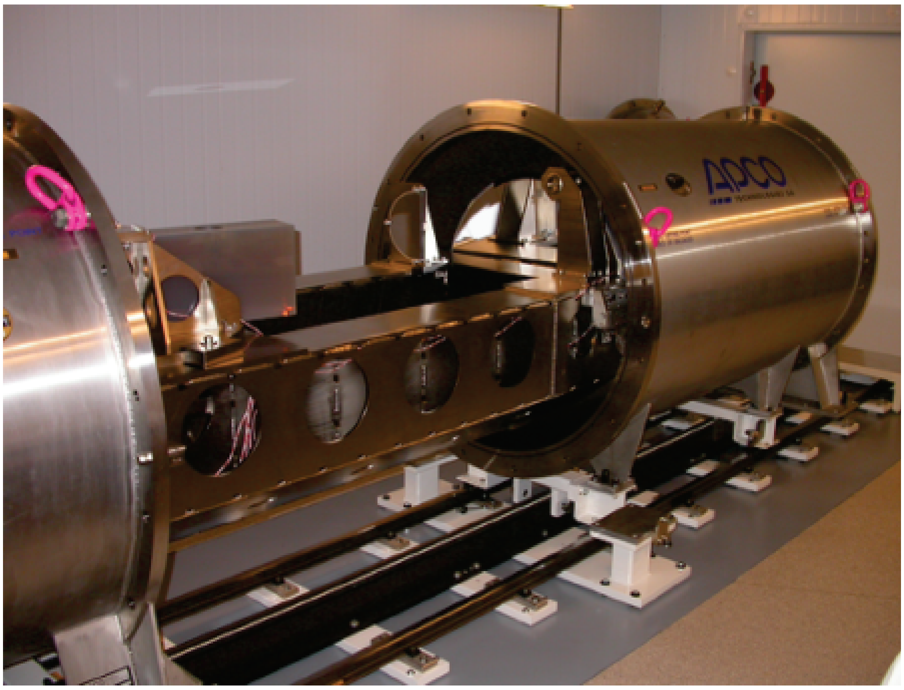


Figure 1: The HARPS spectrograph inside the air-conditioned room at La Silla just before being closed and evacuated.

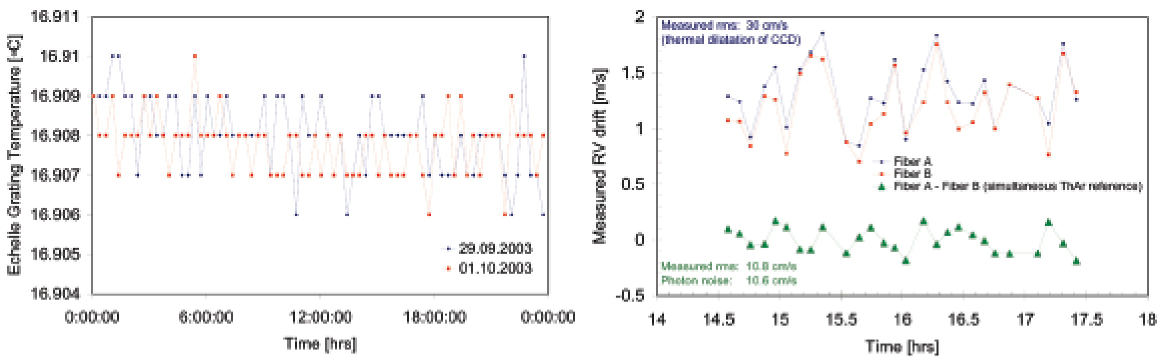
as far as possible any kind of second-order instrumental errors. As a consequence, we have decided to operate the spectrograph in vacuum (see Figure 1), since ambient pressure variations would have produced huge drifts (typically 100 m/s per mbar). The operating pressure is always kept below 0.01 mbar such that the drifts never will exceed the equivalent of 1 m/s per day.

Not only the pressure but also the temperature is strictly controlled. In fact, a two-stage air-conditioning around the vacuum vessel controls the air temperature to 17°C with a long-term stability of the order of 0.01°C. Because of the huge thermal inertia of the vacuum vessel and the excellent thermal insulation between spectrograph and vessel provided by the vacuum, the short-term temperature stability obtained is even better. Over one day we have measured variations of the order of 0.001 K rms. An example of the excellent control is given by the behaviour of the echelle grating temperature plotted in Figure 2a.

The extraordinary stability translates directly into the stability of the radial velocity measurements. This is most impressively shown by the measurement series presented in Figure 2b. Both fibres have been exposed repetitively with the ThAr calibration light and the drift – expressed in m/s – was computed as a function of time. During several hours the total drift remains well below 1 m/s and the measurement is dominated by "noise". This noise is introduced by the CCD whose temperature varies by ±0.02 K and produces microscopic dilatation of the chip. In fact, both fibres show the same behaviour and when subtracting one fibre from the other this "noise" disappears and we obtain the dispersion values expected from the photon-noise level of the simultaneous ThAr reference. These measurements prove that the simultaneous ThAr reference technique is perfectly able to track instrumental drift at a level of 0.1 m/s rms.

HARPS has been optimised for radial-velocity efficiency, i.e. to obtain in the shortest possible exposure time the most precise radial-velocity measurement. However, this requirement is not necessarily synonymous with optical efficiency. For example, spectral resolution is an important factor in reducing the photon noise of the radial-velocity measurement but is often in competition with the optical efficiency of the spectrograph or with the size of the instrument and the telescope. On the other hand the instrumental errors must also be low, at least as low as the goal for the photon-noise equivalent. The

Figure 2: a) Temperature of the echelle grating over 24 hours recorded at two different days. b) Drift of the spectrograph during a ThAr series of several hours proving that the spectrograph is extremely stable and that the simultaneous ThAr reference is able to track and correct tiniest instrumental drifts.



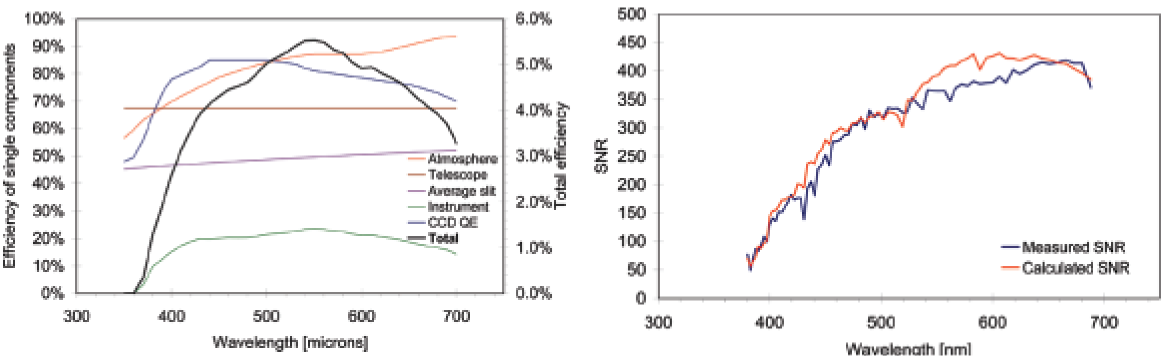


Figure 3: a) Total efficiency of HARPS (right-hand ordinate) and efficiency of single components (left-hand ordinate). b) Comparison of the measured SNR with the values calculated by means of the Exposure Time Calculator. For comparison we performed a 71s exposure on HD10700 (m_V=3.5) at an airmass of 1.1. The DIMM monitor was indicating a seeing of 0.9 arcsec.

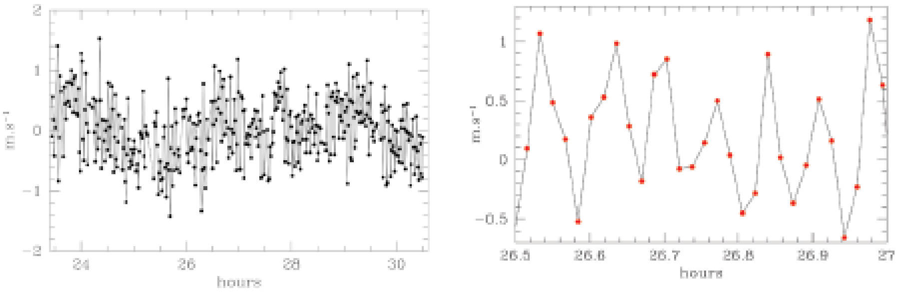


Figure 4: a) Series of 7 hours and 420 exposures on α Centauri B proving the extraordinary short-term precision of HARPS. b) Zoom of figure a) to illustrate the presence of a periodic signal produced by the stellar pulsation.

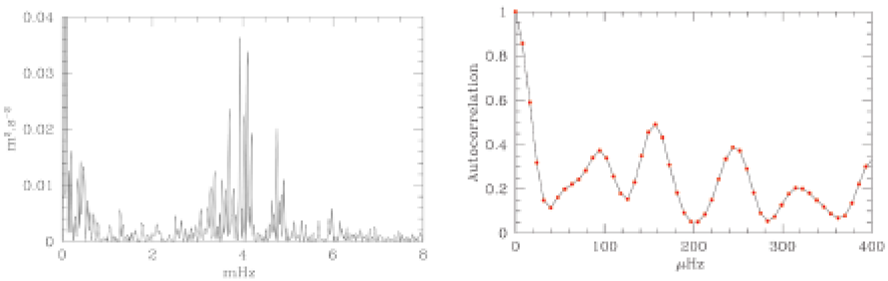


Figure 5: a) Power spectrum of α Cen B. The acoustic modes corresponding to the 4-minutes oscillation are clearly identified and emerge well above the noise. b) Autocorrelation of the power spectrum of α Centauri B.

design of HARPS is consequently the result of an accurate trade-off between all the relevant factors. Despite various compromises regarding for example the fibre diameter (1 arcsec on the sky) and the fibre-feed itself, the optical efficiency obtained is remarkable. Figure 3a shows the calculated total optical efficiency of the instrument and some of its subsystems. These values have been adopted in the current version of the HARPS-Exposure Time Calculator (ETC) which serves to estimate the SNR obtained during an exposure. In Figure 3b we compare the results obtained using the ETC with real measurements on the star HD 10700.

HARPS delivering precision never reached before

During the HARPS commissioning we monitored the star α Centauri B, which is a K-type star substantially smaller than our Sun. During 7 hours we collected a total of 420 spectra with typical SNR of 500 each at λ=550 nm. The radial-velocity measurement sequence plotted in Figure 4a indicates a dispersion of 51 cm/s but the zoom shown in Figure 4b shows that this dispersion is completely dominated by 4-minutes stellar oscillations. In fact, the power spectrum of this sequence shown in Figure 5 clearly exhibits a series of peaks around 4 mHz, corresponding to individual acoustic modes of the star, with amplitude in the range 10-20 cm/s. The positive interference of several oscillation modes may lead to amplitudes much larger than the amplitude of single modes. From the power spectrum we estimate that the average contribution of modes to the total dispersion reaches 0.44 m/s. By quadratic subtraction of this value from the measured dispersion we obtain a noise level of 0.26 m/s, which is in good agreement with the value extrapolated from the mean white noise level measured in the high frequency range between 6 and 8 mHz in the power spectrum. The photon noise on a single measurement is of 0.17 m/s, which leaves less than 0.2 m/s for all other possible error sources (ThAr noise, guiding errors, influence of the atmosphere, instrumental errors).

The long-term precision of the instrument cannot be checked easily because it requires a long time base on one hand, and the knowledge of stable stellar sources on the other hand. Especially the latter point represents a new challenge since the intrinsic stability of the stars has never been studied at this level of precision before. Nevertheless we have been able to gain some indication of the long-term precision of HARPS by observing the star HD 83443 which has a planetary companion with well known orbital parameters. Figure 6 shows a total of nine radial-velocity data points, some of them collected during the first commissioning period in February 2003, and some others about 4 months later during the second commissioning held in June 2003. All the data fit well the calculated orbit whose parameters are fully consistent with the previously known solution. The obtained dispersion *(o–c)* is only 1.7 m/s and partly due to photon noise. The residual noise is a combination of calibration errors (< 0.5 m/s) and effects due to the star itself, which can be due to pulsations, activity and jitter. It is also worth noting that the HARPS vaccum has been broken between the two commissioning runs.

We conclude that the short-term precision (1 night) of HARPS is well below 1 m/s. Even on the time scale of a commissioning period (2 weeks) we have been able to measure standard stars which showed radial-velocity dispersions of 1 m/s including photon noise. The same level of precision is obtained on HD 83443 over a time scale of 4 months. Apart from photon noise a major contribution to the residuals probably comes from the star itself (pulsations, activity, jitter). Only an in-depth, long-term study will allow us to identify the relative importance of the various error sources.

Catching the tiny melody of a solar-like star

Stars, which are spheres of hot gas, propagate very well in their interiors acoustic waves which are generated by turbulent convection near their surfaces. Frequencies and amplitudes of these acoustic waves, also called oscillation modes or *p*-modes, depend on the physical conditions prevailing in the layers crossed by the waves and provide a powerful seismological tool. Helioseismology, which monitors the oscillation modes of our Sun, has been used since the 1970's and led to major revisions in the "standard model" of the Sun and provided, for instance, measures of the Sun's inner rotation, the size of the convective zone and the structure and composition of the external layers. Solar-like oscillation modes generate periodic motions of the stellar surface with periods in the range 3 – 30 min., but with extremely small amplitudes. The corresponding amplitudes of the stellar surface velocity modulations are in the range 10 – 100 cm/s.

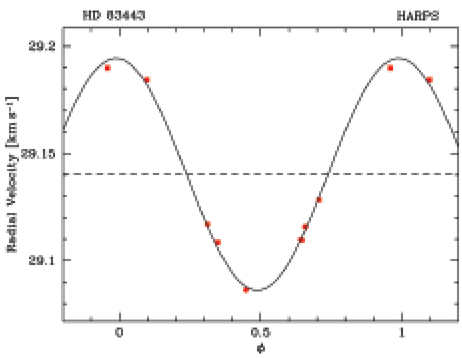


Figure 6: Radial-velocity data of HD 83443, which harbours a known extra-solar planet. The data fit well the calculated orbit with a weighted dispersion of 1.7 m/s.

Two years ago, we were able to detect with the CORALIE spectrograph an unambiguous oscillation signal of 31 cm/s amplitude of the star α Centauri A, a nearby solar twin (Bouchy & Carrier, 2001 & 2002). With these measurements several oscillation modes were separated and clearly identified.

The measurements made on α Centauri B with HARPS have lower frequency resolution because of the limited duration of the tests. To obtain the same resolution we would have had to observe the star for 13 consecutive nights. On the other hand the measurement obtained with HARPS are impressive mostly because of efficiency, cycle time and precision. Figure 4 illustrates clearly the detectivity obtained with HARPS: despite the small amplitude the 4-minutes stellar oscillation can be detected "by eye" directly in the time series, and they become even more evident in the Fourier Transform space shown in Figure 5a. Figure 5b shows the autocorrelation of the power spectrum. The plot clearly indicates that the peaks have a comb-like structure, with a main peak separation of about 160 μHz. This is the typical signature of oscillation modes of identical angular degree expected for solar-like stars. The intermediate peaks appearing in the figure correspond to the correlation between modes with angular degree l=1 and l=0 or 2.

Such a level of accuracy in the detection of solar-like oscillation modes has never been reached before. This result obtained with HARPS on a very short sequence (7 hours), clearly shows the unique potential of this instrument in the domain of asteroseismology. Long sequences (several nights are needed to reach a sufficient frequency resolution to characterize individual p-modes) of high sampling radial-velocity measurements will permit to measure acoustic waves with amplitudes as tiny as a few cm/s.

Table 2: Stellar parameters and oscillation modes properties

Star	Spectral type	Period	Peak to Peak modulation	RMS Dispersion
α Cen B	K1V	4 min.	1.5 m/s	0.5 m/s
HD20794	G8V	5 min.	2.5 m/s	0.8 m/s
HD160691	G5IV-V	9 min.	5 m/s	1.7 m/s
β Hydri	G2IV	16 min.	5 m/s	1.7 m/s

Down to the Stellar Limit

After the amazing results obtained on α Centauri B we have decided to monitor a small set of solar type stars. Figure 7 shows short sequences of radial velocity measurements obtained on these objects. On *each* of these sequences the stellar oscillations are clearly visible. Stellar parameters and observed oscillation modes are listed in the Table 2. As expected, these measurements clearly show that period and amplitude of the oscillation modes are directly related to the stellar properties. They demonstrate the full capability of HARPS for asteroseismology, not only on very bright stars.

These results show however also that the main limitation for HARPS will come from the stellar "noise" itself. The individual mode amplitudes of these stars are in the range 10–50 cm/s but their additive interference leads to modulation of the Doppler time series of up to 10 times their value. This is clearly a limitation for high precision exoplanet surveys at the level of 1 m/s and requires us to define a precise strategy of target selection and observation. Short-period oscillations (4–8 min.) of small amplitudes, which occur in G and K dwarfs, can be easily averaged out with typical exposures times of 15 minutes. Sub-giants and giants, which can show larger amplitudes and longer periods, should however be carefully removed from the sample. This kind of precaution should permit us to detect exoplanets at the level of 1 m/s.

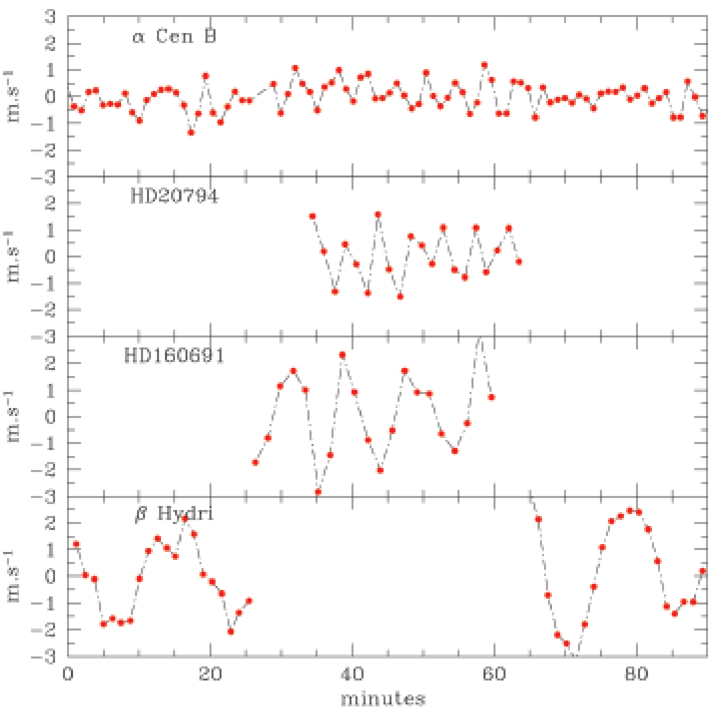


Figure 7: Summary plot of the radial-velocity of stars for which we have made long observations series. All of them show clear indications of star pulsation.

Observing Faint Objects

The OGLE-III programme, involved in an extensive ground-based photometric survey for planetary and low luminosity object transits, has recently announced the detection of transiting candidates around stars located in the direction of the Galactic centre. The radii of these objects were estimated to be in the range between 0.5 and 5 Jupiter radii, meaning that some of these objects are probably in the planetary domain. In order to measure the mass of these objects, and then determine their real nature, a radial velocity follow-up is necessary.

In order to test the limiting magnitude of HARPS, we observed the faint candidate OGLE-TR-56 (m_v=16.6). One hour exposure allowed us to reach a signal-to-noise ratio between 3 and 4 corresponding to a photon noise uncertainty on the radial velocity of about 30 m/s. The five RV measurements presented in Figure 8 demonstrate the full capability of HARPS to find and characterize hot Jupiters around stars as faint as OGLE-TR-56. We have fitted to these data points a sinusoidal curve with fixed period as given by the photometric study. The measured amplitude is however much different and in contrast to the results published by Konacki et al. (2003). A complete analysis of these measurements will be required in order to determine whether this RV modulation is due to a planetary companion or to a binary system blended and

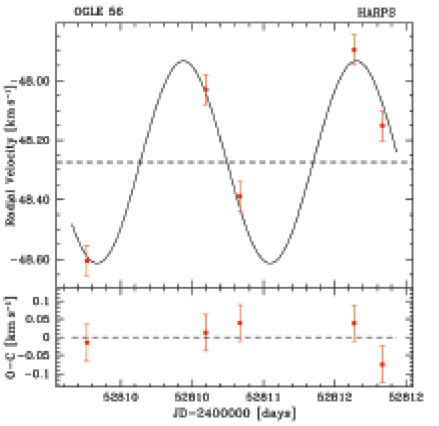


Figure 8: Radial-velocity of OGLE-TR-56 measured with HARPS. Despite the faint magnitude of the object, the dispersion of the data points around the fitted curve is only 30 m/s.

masked by the main star. This kind of study has a huge interest for the future radial-velocity follow-up of exoplanets detected by the satellite COROT.

The HARPS Exoplanet Programme

The HARPS Consortium GTO programme will be devoted exclusively to the study and characterization of exoplanets, in continuation of a planet-search programme initiated 10 years ago (Queloz & Mayor, 2001). For a large, volume-limited sample we will do a first screening in order to identify new "Hot Jupiters" and other Jovian-type planets. Increasing the list of "Hot Jupiters" will offer a chance to find a second star with a planetary transit among relatively bright stars. Better statistics are needed to search for new properties of the distribution of exoplanet parameters.

This part of the programme already started in July 2003 within the first GTO period assigned to the Consortium. In this short run of only 9 nights HARPS unveiled all its characteristics, its optical efficiency, the unique precision and, in particular, the outstanding efficiency of the reduction pipeline. In fact, we have collected about 500 spectra and radial velocity measurements of several hundred stars. Many of them show a varying radial velocity, sometimes with a clear periodicity. In the case of HD 330075 the signal is most probably due to an exoplanet orbiting this star in 3.37 days. The radial-velocity curve of HD 330075 is shown in Figure 9. Precise photometric measurements carried out on the SAT Danish Telescope and by the Swiss-Euler Telescope have shown the absence of a photometric transit, which would have allowed us to determine the radius and the orbital inclination of the planet. Nevertheless, these measurements have also demonstrated that the photometric variability is low, and that we can exclude therefore the radial-velocity variation to be produced by stellar activity. This makes HD 330075 the first HARPS extra-solar planet candidate.

Only a few of the hundred detected planets have masses less than the mass of Saturn, and due to the present precision of radial velocity surveys the distribution of planetary masses is heavily biased (or completely unknown) for masses less than half the mass of Jupiter. We will take advantage of the very high precision of HARPS to search for very low mass planets. For a sample of pre-selected non-active solar-type stars we will be able to explore the domain of the mass-function for planetary masses less than the mass of Saturn down to a few Earth masses for short periods.

A systematic search for planets will be made for a volume-limited sample of M-dwarfs closer than 11 parsecs. Such a survey of very low mass stars will give us a chance to derive the frequency of planets as a function of the stellar mass. These objects are of prime importance for future astrometric studies to be carried out with the VLTI or space-mission like SIM.

Stars with detected giant planets exhibit an impressive excess of metallicity in contrast to stellar samples without giant planets (Santos et al., 2001). The excess of metallicity does not seem related to the mass of the convective zone and probably finds its origin in the chemical composition of the primordial molecular cloud. To add new constraints to the link between star chemical composition and frequency (or properties) of exoplanets, we will carry out two additional programmes: The first programme is a search for exoplanets orbiting solar-type stars with notable deficiency (for most of them [Fe/H] between −0.5 and −1.0). Among the existing detections of exoplanets only two or three have been found with metallicity in that range. We aim at being able of estimating the frequency of exoplanets in that domain of metallicity and, if possible, to compare their characteristics (masses, orbits) to planets orbiting metal rich stars. The second programme aims at exploring the link between stellar metallicity and properties of exoplanets. Visual binaries with solar-type stars of almost identical magnitudes have been selected. We will search for exoplanets orbiting one of the components of these systems. For those including giant planets a detailed chemical analysis will be done for both stellar components to search for possible differences in their chemical compositions.

Follow-up radial velocity measurements for stars with planetary transits detected by the COROT space mission will be made with HARPS. Photometric transits provide an estimate of the radius of the transiting planet as well as the orbital period and phase. Complementary ground-based spectroscopic measurements with HARPS will constrain the planetary mass and then the planet mean density. The main scientific return for the planetary programme of the COROT mission will come from the combination of the photometric and radial velocity data.

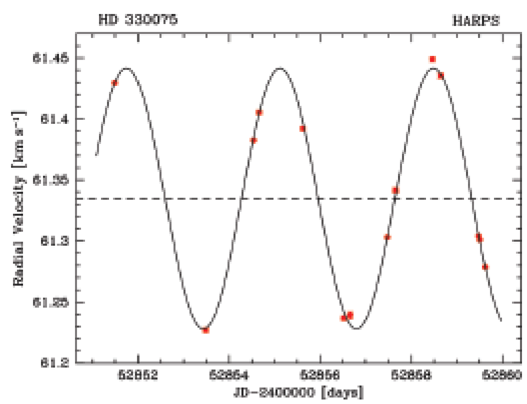


Figure 9: First HARPS extra-solar planet candidate HD 330075. The planet has a minimum mass of 0.8 M_J and orbits the star in 3.37 days at a distance of 0.044 AU from its parent star, and belongs therefore to the category of Hot Jupiters. The induced radial-velocity variation has a semi-amplitude of 107 m/s. The total dispersion with regard to the orbital solution is (o-c)=2.5 m/s, and includes photon noise, stellar pulsation and possible jitter.

Acknowledgements

We would like to acknowledge the many people whose names do not appear among the authors but have contributed to the great success of the HARPS project through their valuable and dedicated work. This project has been financed by the Swiss National Science Foundation, the French region "Provence, Alpes et Côte d'Azur", the Institut National des Sciences de l'Univers INSU (F), the Université de Genève (CH), the Observatoire de Haute-Provence (F), the Physikalisches Institut der Universität Bern (CH), and the Service d'Aéronomie du CNRS (F). The HARPS Project is a collaboration between the HARPS Consortium and the European Southern Observatory (ESO).

References

Bouchy F. & Carrier F., 2001, ESO *Messenger*, 106, 32
Bouchy F. & Carrier F., 2002, *A&A*, 390, 205
Konacki M. et al., 2003, *Nature*, 421, 507
Pepe F. et al., 2002, ESO *Messenger*, 110, 9
Queloz D. & Mayor M., 2001, ESO *Messenger*, 105, 1
Santos N. et al., 2001, *A&A*, 373, 1019

NEWS FROM THE LA SILLA SITE

LISA GERMANY
SciOps

DOCUMENTATION

Those of you who applied for WFI time in P73 will (hopefully!) have noticed the new-look WFI web pages (you do read them don't you?). These pages should be easier to navigate, and you should be able to find the information you are after much quicker than in the past.

A similar thing has just happened for SUSI2 on the NTT. The SUSI2 webpages have just had a complete revamp to make important information much easier to find.

As a result of two successful upgrades, TIMMI2 has a new user's manual available online. A postscript version will soon be released.

In addition, the postscript version of the EFOSC2 user manual has had a major overhaul for the first time since 1999. The new manual can be found under the "Documentation" link on the EFOSC2 webpage.

One way to improve our documentation and make it more useful to the user community is for you to provide us with feedback. If you have any comments you would like to make on any of the La Silla documentation, please email us at *lasilla@eso.org*

SOFI

The InfraRed spectro-imager at the NTT has not been at all well over the past few months, suffering several mishaps one after the other. Several wheels have either lost their initialization switches or become stuck, making the operation of SofI quite challenging. The final days of October will see SofI undergo a thorough maintenance mission, during which time the instrument will be almost completely dismanteled and three of the wheels replaced. We expect that this intervention will restore SofI's reliability.

FEROS (John Pritchard)

FEROS is once again undergoing a major upgrade. After last year's successful move from the ESO-1.52m to the MPG/ESO-2.20m, FEROS, the last non-VLT compliant instrument, is now being given a "VLT makeover". The major result of this, as far as the community is concerned, is that observers will now use the ESO standard P2PP to observe with FEROS. This will also allow FEROS to be operated in Service Mode, opening the door for new types of projects (e.g. long term monitoring). This will result in a significant increase in productivity of the 2.20m telescope since the constraints for WFI and FEROS programmes are largely complimentary.

The first stage of this upgrade, the Fibre Service mission, was carried out in October. This involved a complete replacement of the Science fibres, and has successfully restored FEROS to its intrinsic high efficiency (approximately 18% for Telescope+Instrument+Detector). We now finally realise the factor 2 increase in throughput (compared to the ESO-1.52m) due to the increased light collecting area of the 2.20m.

The November commissioning period should see the complete implementation of the VLT standard Instrument and Detector Control Systems, and the replacement of the current Copenhagen University Astronomical Observatory CCD Controller with an ESO standard FIERA CCD Controller.

The new FEROS (FEROS-II) will be back online in mid-November and will immediately be put to work on several Service Mode programmes. The first visiting astronomer to use FEROS-II will arrive in late December.

SEST

In the June Messenger we brought you highlights from the last dishwalk at the SEST. Since the end of August however, the SEST has been stowed and we have had to bid the staff of SEST farewell from La Silla. Some of them can now be found moving further up in the world (in both latitude and altitude) and we wish them every success with APEX.

MARS

27th August 2003 found Mars at the closest it has been to Earth in a very long time, and the staff of La Silla as well as the kids from the village of Cachiyuyo at the ESO 1m telescope to witness the event. A brief presentation explaining the astronomy behind the close approach preceded the viewing session through a mounted eyepiece (not often you actually get to look through a 1m telescope these days!). The seeing conditions were really quite good and you could clearly see lighter and darker regions on the surface of Mars, as well as the bright, white polar cap. La Silla University really put on a wonderful evening for all who could attend, and it was amazing to see such a lot of detail on the surface of Mars with my own eyes. Thanks to our resident photographer, Peter Sinclaire, photographs of the event can be found at:
http://www.pbase.com/psinclai/marte&page=all

The kids from Cachiyuyo and the line of La Silla staff all waiting to glimpse a peek at Mars

Harvesting Scientific Results with the VLTI

The ESO Very Large Telescope Interferometer (VLTI) has been included for the first time in the official call for proposals requesting ESO telescopes for the period starting in April 2004. This marks the official start of public interferometric observations open to the community. It is the start of a new approach to interferometry as a standard astronomical technique, and a point of pride and satisfaction for all the people who have been working with this challenging goal for many years. But it should not be forgotten that the VLTI has already logged over two years of intensive commissioning, as well as some initial science demonstration runs. Over 16,000 observations of hundreds of objects have been collected and are available publicly over the ESO archive on the web. In 2003, the first scientific results of this remarkable effort have appeared. Already more than a dozen papers based on VLTI data have been submitted or accepted by refereed journals, with a similar volume of contributions to workshops and conferences of a scientific nature. We provide here an overview of this early scientific production of the VLTI, ranging from the determination of fundamental parameters of many classes of stars to the first interferometric measurement of the inner regions of the nucleus of the Seyfert galaxy NGC 1068.

Andrea Richichi and Francesco Paresce (ESO)

What does a botanical garden share with astronomy? Not much at first glance, granted. But in Munich you find a wonderful example of the former, and many professionals of the latter. Strolling through the century-old trees and the colourful flowerbeds of the Botanischer Garten, one wonders how different plants display different growth patterns. The bamboo grows 30 centimeters per day in the tropical jungle, and at the other extreme the canadian white cedar (*Thuja occidentalis*) takes one and half century to reach a height of 10 centimeters. Then the thought strikes us: is it not the same with astronomical research? Some ideas produce wonderful results almost immediately, while some others have to wait patiently for decades before becoming accepted. And of course, some ideas never succeed at all.

If the ESO Very Large Telescope Interferometer (VLTI) were a plant, it would be indeed a strange mix. Its first seed was planted about twenty years ago when European astronomers started to be fascinated by the idea of creating a quadruplet of four identical giant telescopes and combining them interferometrically. A visionary concept that took decades of engineering feats to become reality. One by one the four VLT telescopes were erected, changing forever the skyline of Cerro Paranal. As the giant mirrors swept the skies, the first incredible images began to open new opportunities for astronomers around the world.

But underground, in tunnels and isolated rooms, other activities continued as ESO astronomers and engineers assembled hundreds of mirrors, fine mechanical mounts, and scores of computers: the skeleton of the most powerful interferometer was growing rapidly. Finally, in March 2001, the VLTI saw its first fringes. From that moment, the growth has been definitely bamboo-like. Every few months, or even every few weeks, a new bud has been added, a new branch has been spawned. Even the astronomers and engineers in the VLTI group have trouble sometimes keeping up with the news from one side or the other of the ocean, be it the addition of a new delay line or the inauguration of a new baseline.

As 2003 comes to an end, more than two years of patient commissioning with the test instrument VINCI have been completed, accumulating over 16,000 observations of hundreds of stars and making them available publicly to the whole community (see Table 1). The small siderostat test telescopes have been the workhorses of this enormous effort, but the Unit Telescopes (UTs) have been used as well and are ready to be offered publicly. The first VLTI scientific instrument, MIDI, has been opened to the community starting from Period 73, while the second one, AMBER, is completed and awaiting shipment from Europe. Schools and workshops have been organized around

Table 1. *Statistics of the VINCI commissioning observations (up to August 2003). A total of 321 independent objects have been observed.*

Year	Number of OBs	Total number of files	Number of nights	Volume (Gb)
2001	4827	19308	206	25.2
2002	4966	19864	235	35.9
2003	6125	24500	180	56
Total	15918	63672	621	117.2

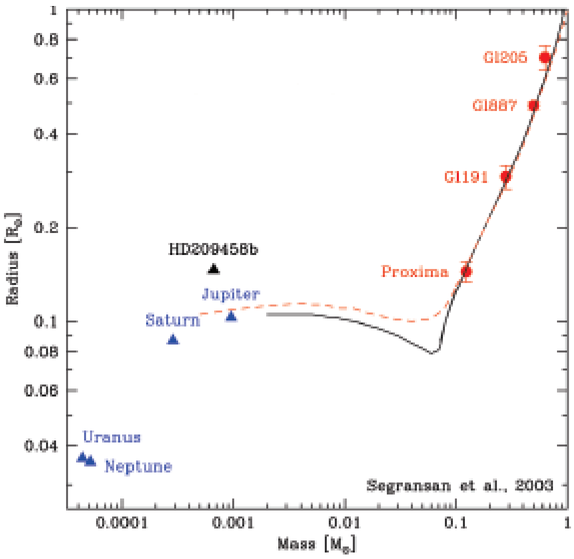


Figure 1: Radii and masses of the four very-low-mass stars now observed with the VLTI, GJ 205, GJ 887, GJ 191 (also known as "Kapteyn's star") and Proxima Centauri (red filled circles; with error bars). For comparison, the masses and radii of the Solar System planets (blue triangles) and of HD 209458 B (black triangle) are also shown. The two curves represent theoretical models for stars of two different ages (400 million years - red dashed curve; 5 billion years - black fully drawn curve). The VLTI results are from Sègransan et al. (2003), the models from Baraffe et al. (1998).

the VLTI, with several students choosing it as the basis of their scientific career in their thesis and dissertations.

Amidst all this enthusiastic flowering, more than a few remained skeptical. Was interferometry really worth the effort? Where was the long-awaited scientific production? When would we see the first papers? Solid questions, which have now received a solid answer. This year, the first publications have appeared, and not just one or two as one might expect from a facility which after all is just emerging from commissioning of its basic systems. In 2003, more than a dozen papers based on VLTI data have been submitted or accepted by refereed journals with a similar volume of contributions to workshops and conferences of a scientific nature.

The key to this early successful exploitation has been the public release of all on-sky commissioning data of scientific interest. Every few months, a new release appears on the VLTI web page, listed by object observed as well as by night of observation. The data can be requested from the ESO archive and are usually delivered very quickly. With much of the commissioning tasks completed, the VLTI is beginning to be accessible to the community for open time observations. Already for period 73, 30 proposals for the MIDI instrument have been submitted on the basis of the standard ESOFORM package, and they will be reviewed by the OPC as any other proposal for ESO telescopes. As for all ESO instruments, a complex and extensive system of user support, data quality, and archiving has been developed also for the VLTI. Interferometry for all astronomers might have been a vision until now, but it has definitely become a reality on Paranal.

Fundamental stellar properties

If astronomy has a peculiarity among modern scientific disciplines, it must be that it allows us to obtain insight and understanding of objects that we cannot ever subject to our direct scrutiny. From stars to nebulae, from black holes to active galaxies, we predict birth, evolution and death of a universe where distances are so immense that they defeat imagination. Come to think of it, the wonderful monument of our scientific knowledge rests on a system of pillars which is, after all, relatively simple: we have to build on fundamental blocks such as stellar masses, sizes, luminosities and chemical composition in order to derive almost everything else, from the properties of the newly found extrasolar planets to the energy liberated at the heart of the most distant quasars.

Interferometry is the key technique to measure some of these fundamental blocks. A recent review of its technical and scientific aspects provided by Monnier (2003) could be a helpful introduction for many interested readers. Typical angular size scales of the closest stars and their immediate circumstellar environment are on the order of a few milliarcseconds (mas), inaccessible at the diffraction limit of current single telescopes but easily resolvable with long-baseline interferometry. Stellar angular diameters, combined with measurements of bolometric fluxes, give model-independent effective temperatures. An accuracy of 50 K or less in T_{eff} is required, for example, to put significant constraints on the current theoretical models of late-type stars. This corresponds to an accuracy of 2% or better in the angular diameter.

The VLTI routinely achieves a precision well below the 1% level, and is ideally suited to expand our knowledge in this area, especially for main sequence stars where the data are very scarce. When combined with accurate parallaxes such as those from HIPPARCOS, angular diameters can be converted into linear diameters. Finally, when applied to binary stars, interferometry can measure the orbital motions in close pairs: together with spectroscopic radial velocities, this information leads to the determination of the masses and distances.

Angular diameters have traditionally constituted the primary targets of all interferometers, and at least in this respect the VLTI is no exception. Already from the first observations on both siderostats and UTs, several tens of stars have been observed with diameters susceptible to being resolved on the available baselines. Faithful to the commissioning mission, these stars encompassed a wide variety of types: from calibrator objects with a well-estimated diameter, to late-type giant stars, to solar analogues like α Centauri, to pulsating variables such as Miras and AGB stars. For many of these objects, the VLTI measurements

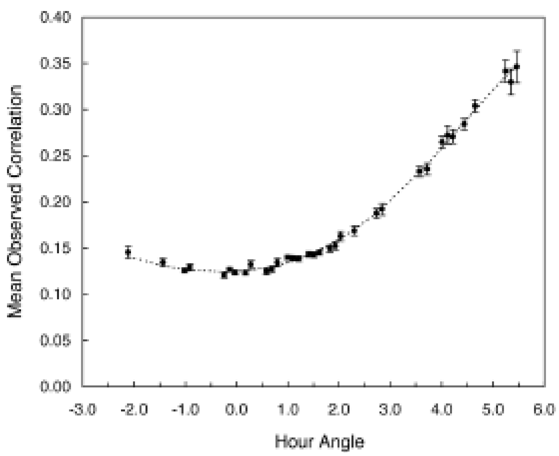


Figure 2: The correlation measurements obtained on Fomalhaut on the night of October 20, 2002, as a function of hour angle, i.e. of baseline projected length. The solid line is the best fit for a uniform-disc angular diameter of 2.086 mas (Davis et al. 2003).

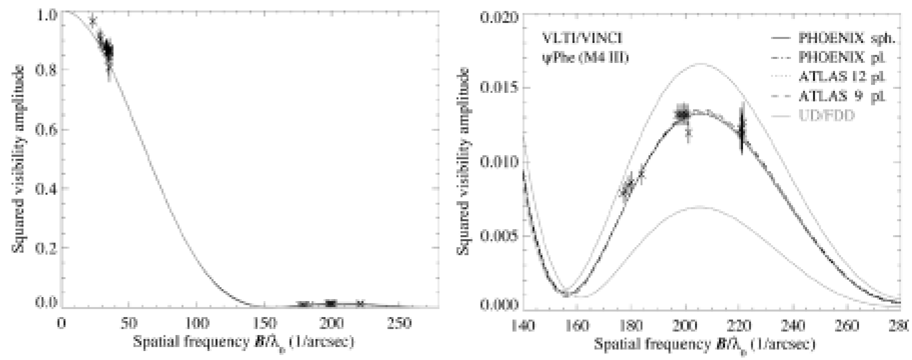


Figure 3: Measured squared visibility amplitudes of Psi Phe together with predictions by a (solid black line) spherical PHOENIX model atmosphere, (dashed-dotted line) plane-parallel PHOENIX model atmosphere, (dotted line) plane-parallel ATLAS 12 model atmosphere, (dashed line) plane-parallel ATLAS 9 model atmosphere. The models were constructed by comparison to spectrophotometry. The gray lines denote uniform disc and fully darkened disc models. The left panel shows the full range of the visibility function while the right panel is an enlargement of the low squared visibility amplitudes in the second lobe. From Wittkowski et al. (2003).

were the first ever obtained, given that the southern sky has remained so far largely untapped by interferometers as sensitive as the VLTI.

A notable achievement of the VLTI in this field has been the measurement of the angular diameter of several main sequence late-type stars, with spectral types between M0.5 and M5.5 (Sègransan et al. 2003). Other main sequence stars of earlier spectral types have also been measured by the VLTI: these include α Centauri A and B, Sirius, α Eridani, Procyon and τ Ceti. As opposed to giant stars, for which hundreds of direct angular diameter determinations exist by several techniques (Richichi & Percheron 2002), only a handful of angular diameters are available for main sequence stars, which are two orders of magnitude smaller. In particular for the coolest types, the VLTI result by Sègransan and his collaborators has already almost doubled the available statistics and the prospects look very promising with the forthcoming introduction of the AMBER instrument.

The conversion from angular diameters to linear sizes is straightforward thanks to the HIPPARCOS parallaxes for these nearby stars. However, the conversion to masses is more problematic, since these stars are single and no direct determination is possible. Some empirical calibration of the mass-radius relation exists for the lower main sequence (Delfosse et al. 2000), and can be used to convert the VLTI measurements into masses. A plot of this result as a function of the luminosity is shown in Fig. 1, together with the Solar System planets and the eclipsing planet HD 209458 B. The two curves represent theoretical models for stars of two different ages – calculated before the interferometric data became available (Baraffe et al. 2003).

These VLTI results show that the models are at present satisfactory but also that new challenges lie ahead. One might notice in Fig. 1, for example, the apparent discrepancy of HD 209458 B from the model. Furthermore, it can be appreciated that, for masses around 0.1 $M_\odot$, the relation between mass and luminosity is predicted to be quite flat and improved accuracies will be required. If this challenge can be met, the reward will consist in strong observational constraints on both atmosphere and interior physics. The mass range between 0.001 and 0.1 $M_\odot$ is particularly interesting since this is the realm of brown dwarfs and eventually of large planets. Objects in this range are too faint at the moment for the VLTI but will become accessible with off-axis phase-referencing provided by PRIMA.

The VLTI equipped with the VINCI test instrument has demonstrated an intrinsic accuracy well below the 1% level, and even higher standards are expected with the AMBER instrument. However, the accuracy in the fringe contrast is not the only factor in the quest for improved stellar diameters. On one hand, it is necessary to compare the fringe contrast of the science target with that of a calibrator star. In this case, the aim is to make sure that the calibrator diameter is so precisely known that no additional error is introduced but, unfortunately, this is often not the case at the level of precision attained by the VLTI. On the other hand, the angular diameter, be it of a tenuous giant or of a compact main sequence star, can only be as precise as our understanding of the stellar surface. Generally, we imagine the star as a disc of uniform brightness, but when the accuracy increases, then we must take into account phenomena such as limb-darkening.

On both counts, significant help comes from the VLTI commissioning efforts. An intense program of observations of calibrator stars coordinated by A. Richichi, I. Percheron and M. Wittkowski has been given high priority. An initial list of bright candidate calibrators for the VINCI instrument has been established based on both estimated diameters and existing previous measurements. A similar effort has been undertaken in parallel by the MIDI consortium for the specific needs of their instrument. A dedicated mini-workshop was held in Garching in January 2003 with about 30 attendees from ESO, the instrument consortia, and the community in general.

As a result, a list of potential VLTI calibrators has been made public, including almost 600 objects for both the VINCI and the MIDI instruments. Up to August 2003, 133 sources from this list have been observed successfully with VINCI. Fifty-two of these objects have more than 100 observations each on more than 3 baselines. The data are being analyzed by the pipeline and by specially developed global fitting programs aimed at computing the best solution to all calibrator observations on a nightly basis as well as over several nights (Percheron et al. 2003).

While this approach has, by necessity, the style of an automated large-scale processing, individual calibrator stars are also being measured accurately on a case by case basis. An example of this is given by the observations of Fomalhaut (α PsA), a bright star which, with its small angular diameter, lends itself well to being a calibrator for the hectometric VLTI baselines. During continued observations of this star over one night, J. Davis et al. followed the relative change of the fringe contrast as a function of time, i.e. of the change in the projected baseline due to Earth's rotation (see Fig. 2).

This particular kind of measurement does not require an external calibration, provided that the baseline is accurately known. An uncertainty term is introduced by the changing characteristics of the atmosphere which affects the interferometric contrast (particularly since a variety of zenith angles are sampled). Davis and collaborators, even after allowing a large increase in the error bars to take into account such adverse factors, obtained a precise limb-darkened angular diameter for Fomalhaut of 2.109 ±

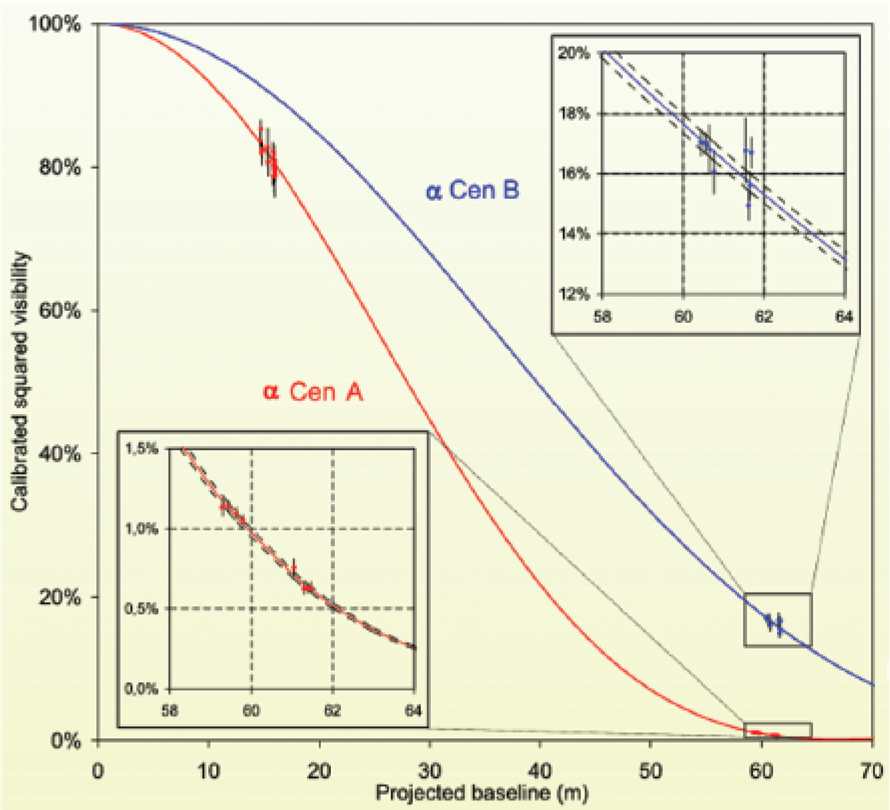


Figure 4: Overview of the α Cen A (red) and B (blue) squared visibilities and the corresponding best fit uniform disc (UD) models. Details of the lower visibility points are shown in the upper right (α Cen B) and lower left panels (α Cen A). The dashed lines represent the limits of the ± 1σ error. From Kervella et al. (2003).

0.013 mas, which confirms and improves the original measurement of this star by the intensity interferometer (2.10 ± 0.14 mas, Hanbury-Brown et al. 1974). Considering the recognized accuracy of that special interferometer, this is no small prize for the VLTI. In parallel, also an improved value of the effective temperature Teff=8819 ± 67 K was obtained.

Regarding limb-darkening, this important aspect of the stellar surface is quite difficult to measure directly. The main reason for this is that the change in the visibility curve introduced by limb-darkening, as opposed to a uniform or fully darkened disc, is noticeable mostly at the baseline frequencies after the first minimum, and then only marginally (see Fig. 3). As a consequence, very few measurements are available, but the VLTI is moving quickly to fill this gap. Already only one month after the first UT fringes, commissioning observations of the M4 giant star Psi Phe were obtained. Using the large sensitivity of these telescopes, as well as their long baseline, the visibility was accurately measured in the critical range beyond the first minimum. By combining these measurements with others at lower frequencies (for which the siderostats were sufficient), an accurate confirmation of the model-predicted strength of the limb-darkening effect for this star has been obtained by Wittkowski et al. (2003). The models were independently constructed by comparison to available spectrophotometry. They used a grid of stellar atmospheric models, and computed the corresponding visibilities, selecting the ones which best fit the VLTI data (see Fig. 3).

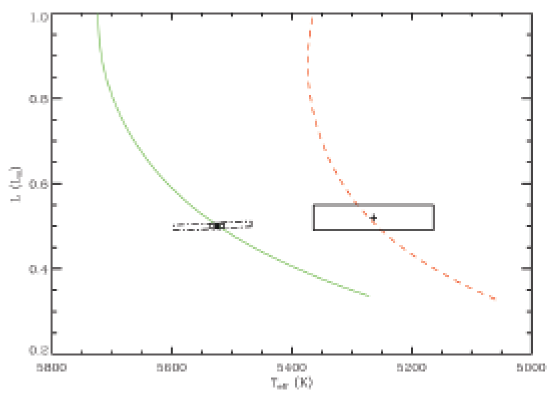
This is a delicate process, which must take into account issues of calibration and particularly the effect of the broad-band filter employed in VINCI, since visibility functions are strongly chromatic and the effect of limb-darkening varies across the band. Even several definitions of the angular diameter exist, and one must take care to be consistent between models and data. At the end of their analysis, the authors were able to determine a thickness of 6% of the atmospheric layer for this star, and derive a brand new set of its fundamental properties: T_{eff} = 3472 ± 125 K, radius = 86 ± 3 $R_\odot$, mass = 1.3 ± 0.2 $M_\odot$, log g = 0.68. These data constitute a valuable observational check for theoretical model predictions.

Clearly new similar measurements are needed to constrain the models but this should be no difficult task for the VLTI, with a large number of potential candidates available. These measurements constitute also an important precursor for studying stellar surface structure in more detail, including features such as surface spots. Studies of stellar surface structure require high-precision measurements of low-contrast fringes in the second and following lobes. Wittkowski et al. (2002) showed that a realistically modeled spot on a magnetically active star can likely be directly detected and its parameters constrained using squared visibility amplitudes and triple products obtained with the VLTI and the AMBER instrument.

An important new trend in the exploitation of accurate stellar diameters is represented by asteroseismology, and also in this area the VLTI has started off with important contributions. The outer layers of most stars, including our Sun, are constituted by ionised gas which is held in balance between the pull of gravity and the pressure of the enormous radiation emitted from the interior. These layers have their own characteristic frequency of oscillation under the influence of these forces and this frequency can be excited by mechanisms such as convection. As in a giant musical bell agitated by an invisible hand, the outer layers of these stars resonate in harmony, resulting in slow but regular shifts of their spectra.

These effects have been very well identified in our Sun, and are now beginning to be measured in some of the stars closest to us. In fact, theory predicts a whole system of characteristic frequen-

Figure 5: Location of τ Cet in the Hertzsprung-Russell diagram, according to the determination inferred from interferometry (left) and spectroscopy (right), with the associated uncertainty boxes. The solid and dashed lines correspond to two models of the star, with significantly different values of the scale of the mixing-length in the star. From Pijpers et al. (2003).



cies for each star, depending on mass, radius, temperature of the gas. Most importantly, they depend on details of their interior composition and energy production mechanisms. Like a fingerprint, the oscillation frequencies of each star are different from any other. Unfortunately, the number of parameters involved is so large that observations are often well consistent with several, significantly different models.

Now, long-baseline interferometry is coming to the rescue, and once again with its most basic and simplest type of measurement: the accurate determination of a stellar angular diameter. At least for nearby stars where accurate parallaxes are available, we can, thus, obtain the linear size and this is a precious piece of information for asteroseismologic modeling. In its debut year, the VLTI has already produced four papers with this important keyword. In some cases, the stars measured are very well known like α Cen, Sirius, and Procyon, and the corresponding results are certainly exciting for experts and casual readers alike.

We take here as illustrations of the VLTI contribution to this field, the well known stars α Cen A and B (Kervella et al., 2003) our closest stellar neighbour and the lesser known star τ Cet (Pijpers et al. 2003). The angular diameters of the two main components of the system, α Cen A and B, were measured using VINCI with a relative precision of 0.2% and 0.6% respectively. The measured uniform disc angular diameters for α CenA and B were 8.314 ± 0.016 and 5.856 ± 0.027 mas, respectively and limb darkened angular diameters of 8.511 ± 0.020 and 6.001 ± 0.034 mas, respectively (see Figure 4).

Particular care was taken in the calibration of these measurements considering that VINCI estimates the fringe visibility using a broadband K filter. Combining these values with the known parallax, the linear diameters of 1.224± 0.003 $D_\odot$ and 0.863 ± 0.005 $D_\odot$ were derived for the two components A and B, respectively. The measurement of α Cen A is the most precise photospheric angular size ever obtained by interferometry.

The measurements were compared to recent model diameters constrained by asteroseismic observations. The reported values are compatible with the most recently published masses for both stars.

If α Cen, the closest solar analogue, is slightly hotter and larger than our Sun, τ Cet provides an interesting bracketing comparison because it is slightly smaller and cooler than our Sun (spectral type G8, temperature approximately 5300 K). More interestingly, while the direct measurement by the VLTI resulted in a diameter largely in agreement with theory in the case of α Cen, in the case of τ Cet there appears to be a significant difference (see Fig. 5). The radius and effective temperature of this star estimated on the basis of its spectral and photometric characteristics are 0.87 ± 0.04 $R_\odot$ and 5264 ± 100 K respectively, while using VLTI data, Pijpers et al. (2003) obtained 0.773± 0.004 $R_\odot$ and 5525±12 K.

However, they also recognize that their estimate suffers from having only one single calibrator available, and that the actual uncertainty could be five times larger than the formal one. The difference between these results is shown in Fig. 5, which makes clear that the two sets of values correspond to models with significantly different assumptions on the initial hydrogen content and the scale of the mixing-length. Further observations by the VLTI, along with a more refined data analysis, are certainly desirable.

Asteroseismology predicts oscillation frequencies quite different for the two situations above: a peak at 3570 μHz and a frequency spacing of 173 μHz in the case favoured by the interferometric measurement, and 2950 μHz and 1148 μHz, respectively for the other case. High-accuracy spectroscopic measurements with an instrument like HARPS will be able soon to shed light on this discrepancy. In the future, high-accuracy interferometric and spectroscopic measurements will go hand in hand, and allow us to understand better the internal composition and energy transfer mechanisms of many more stars.

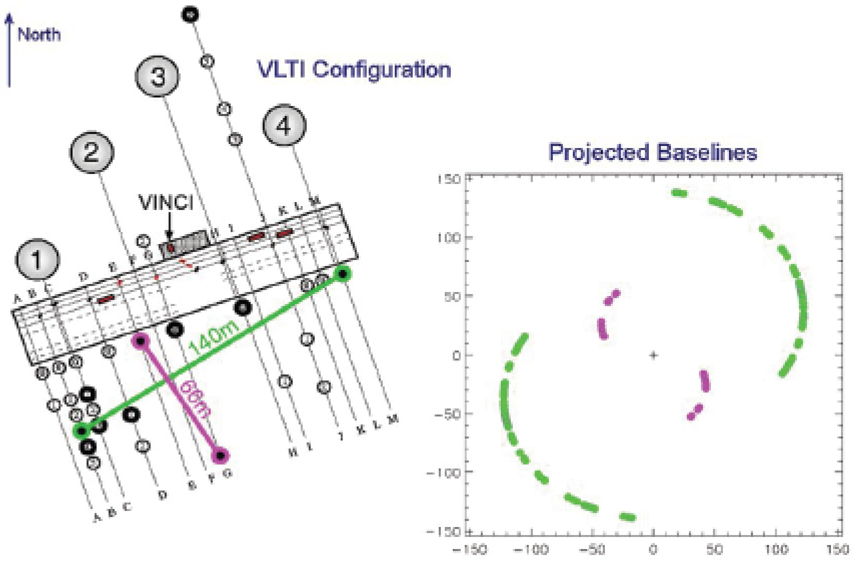


Figure 6: VLTI ground baselines for Achernar observations and their corresponding projections onto the sky at different observing times. Left, scheme of VLTI baselines for the two pairs of siderostats used for Achernar observations. Colour magenta represents the 66 m (E0-G1; azimuth 147°, counted from North to East) and green the 140 m (B3-M0; 58°). Right, Corresponding baseline projections onto the sky (B_{proj}) as seen from the star. Note the very efficient Earth-rotation synthesis resulting in a nearly complete coverage in azimuth angles.

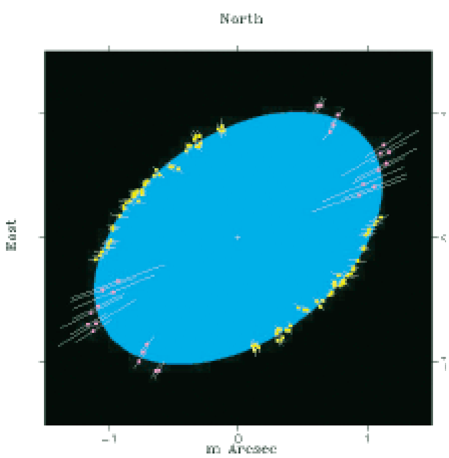


Figure 7: Fit of an ellipse over the observed V^2 points of Achernar, translated to equivalent uniform disc angular diameters. Magenta points are for the 66 m baseline and yellow points are for the 140 m baseline. The fitted ellipse results in major axis 2a= 2.53 ± 0.06 milliarcsec, minor axis 2b= 1.62 ± 0.01 milliarcsec, and minor-axis orientation α_0=39°±1° (from North to East). The points distribution reveals an extremely oblate shape with a ratio 2a/2b = 1.56 ± 0.05. From Domiciano de Souza et al. (2003).

New aspects of stellar research: Achernar and Eta Carinae

Stellar angular diameters may be considered the staple food of interferometry, but as sensitivity and accuracy increase new exciting results are produced even with this basic kind of measurement. We have seen that already in the case of more or less regular stars such as late-type giants and solar analogues, we are beginning to tackle interesting subjects such as limb-darkening and asteroseismology. However, when we move to less ordinary objects, interferometry is the key to open completely new doors. The VLTI is bringing facts, after many promises, also in this area, and as an example we take the recent results obtained on the fast rotating star Achernar, and the ultra-luminous star η Carinae.

Rotation is an intrinsic property of all stars, but for some classes of stars it can be a rather extreme phenomenon, with important consequences on the stellar structure. The most obvious is the geometrical deformation that results in a radius larger at the equator than at the poles. Another well established effect, known as gravity darkening or the von Zeipel effect, is that both the surface gravity and emitted flux decrease from the poles to the equator. Although well studied in the literature, such effects of rotation have rarely been directly tested against observations. The best candidates for such observational tests are represented by Be stars. A Be star is defined as a B type star that has presented episodic Balmer lines in emission, whose origin is attributed to a circumstellar envelope (CSE) ejected by the star itself. Physical mechanisms like non-radial pulsations, magnetic activity, or binarity have been invoked to explain CSE formation in Be stars in combination with their fundamental property of rapid rotation.

Struve's original vision of a critically rotating Roche star ejecting material from its equator has been discarded in the past by observing that Be stars rotate at most at 70% to 80% of their critical velocity (typically 500 km/s for a B0V star) a value not sufficient to explain the presence of discs. However, this statistically observed limit may be biased by the fact that close to or beyond such velocities the diagnosis of Doppler-broadened spectral lines fails to determine the rotation value due to gravity darkening. Only direct measures of Be star photospheres by interferometry can overcome the challenge of proving whether these objects rotate close to a few percent of their critical velocity or not. This will have a profound impact on the dynamical models for Be star disc formation due to rapid rotation combined with mechanisms like pulsation, radiation pressure of photospheric hot spots or expelled plasma by magnetic flares.

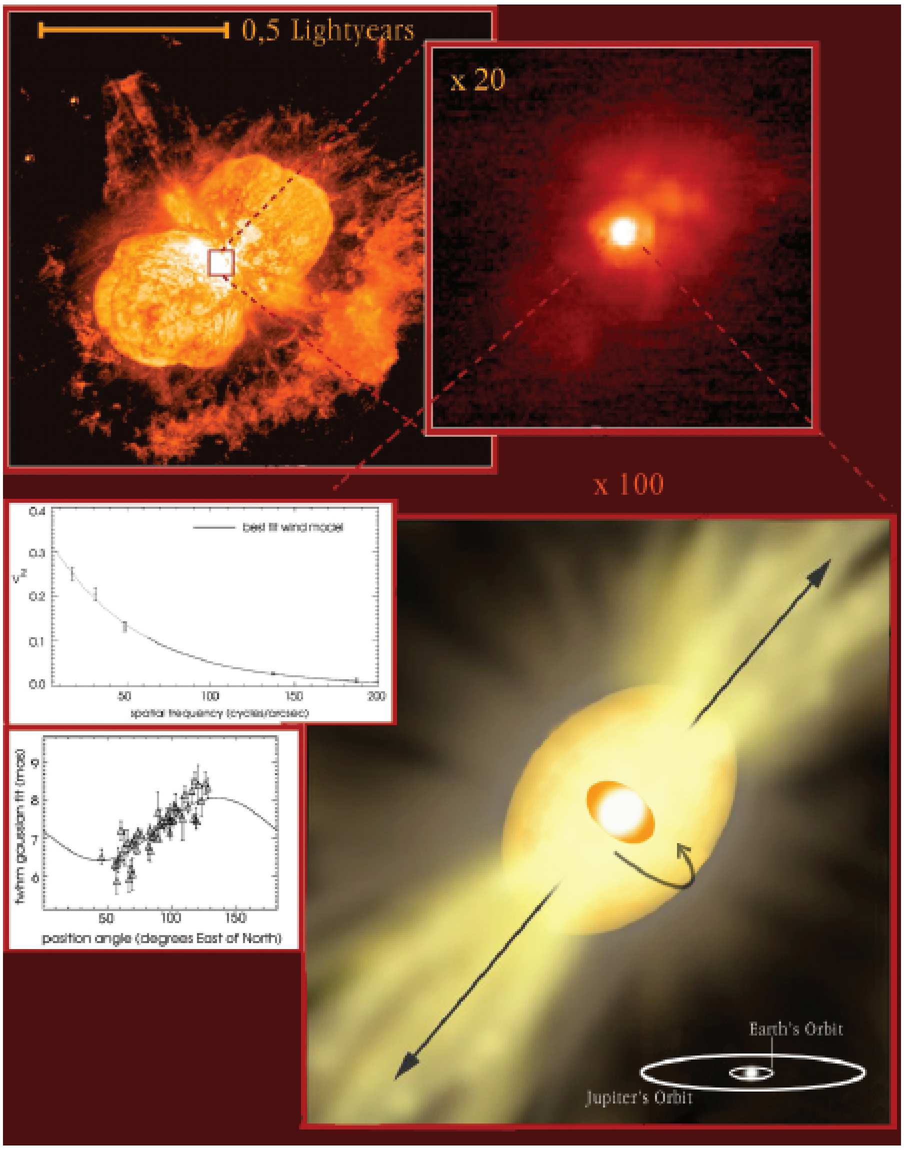


Figure 8: Zoom into the η Carinae nebula. Top left: WFPC2 image (Morse et al. 1998). Top right: NACO observations at 2 µm. Centre left : VINCI data reveal an object with size 5 mas. This is not the photosphere of the star, but the radius at which the stellar wind becomes opaque. Bottom left: VINCI data, converted to an effective diameter, plotted against the position angle of the baseline. Bottom right: the diameter change with position angle implies that the object is elongated; the orientation is the same as that of the large-scale nebula shown in the top left panel. Courtesy R. Van Boekel.

The southern star Achernar (α Eridani, spectral type B3Vpe) is the brightest Be star in the sky and, therefore, a perfect target for the VLTI and the siderostats. It also represents a convenient object to test the validity of the concepts briefly described above. A recent paper by Domiciano de Souza et al. (2003) describes VLTI observations of this star and exciting new results. Dedicated observations of Achernar were carried out from 11 September to 21 December 2002, with quasi-uniform time coverage using the siderostats. Two interferometric baselines (66 m and 140 m) were used (Fig. 6 left). Their orientations are almost perpendicular to each other giving an excellent configuration for the detection of stellar asymmetries. Moreover, Earth rotation produced an efficient synthesis effect (Fig. 6 right).

Analysis of the processed data gives the results summarized in Fig.7 which reveal an extremely oblate shape from the distribution of equivalent UD diameter values on an ellipse. The results of this fit are: major axis 2a=2.53±0.06 mas, minor axis 2b=1.62±0.01 mas and minor-axis orientation α_0=39°±1°. Note that the

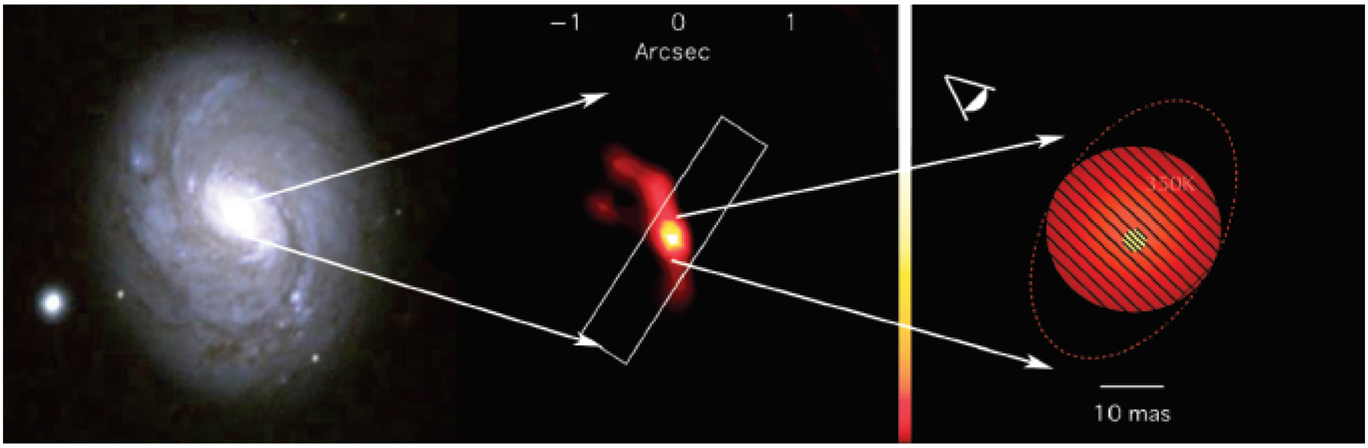


Figure 9: Left: 3.4 × 3.4 arcmin optical image of NGC 1068, (NOAO/AURA/NSF). Centre: non-interferometric acquisition image of NGC 1068 taken by MIDI with a 8.7 micron filter, showing the structures on arcsec scales. Also shown are the position of the spectroscopic slit used in the interferometric observations and the directions of North (toward top left) and East (toward bottom left) on the sky. The projected baseline was essentially North/South and the fringe spacing in this direction was 26.3 mas at 10 micron wavelength. Right: sketch of the dust structure in the nucleus of NGC 1068, as derived from modeling the MIDI observations. It contains a central hot component (T > 800 K, yellow) which is significantly smaller than the interferometric beam, and a much-larger well-resolved warm component (T=330 K, red) of diameter 33±5 mas, corresponding to 2.8 pc at the distance of NGC 1068. From Jaffe et al (2003).

corresponding ratio 2a/2b=1.56±0.05 determines the equivalent star oblateness only in a first-order UD approximation. It can be shown that, in the particular case of Achernar, the observed asymmetry of Achernar reflects its true photospheric distortion with a negligible CSE contribution. Under this assumption, and using the Hipparcos distance (*d*=143.8±3.6 light-years), an equatorial radius Req = 12.0 ± 0.4 $R_\odot$ and a maximum polar radius equal to 7.7 ± 0.2 $R_\odot$ can be derived from the equivalent UD measurements. From simple geometrical considerations, the actual polar radius R_{pol} will be smaller than for polar inclinations $i < 90°$, while R_{eq} is independent of *i*.

Using an interferometry oriented code which includes radiation transfer and the von Zeipel law applied to Achernar in the Roche approximation, it was found that the commonly adopted Roche approximation (uniform rotation and centrally condensed mass) fails to explain Achernar's extreme oblateness. This result opens new perspectives in basic problems in stellar physics such as rotationally enhanced mass loss of Early-type stars. In addition to its intimate relation with magnetism and pulsation, rapid rotation thus provides a key to understanding the Be phenomenon, which is one of the outstanding non-resolved problems in theoretical astrophysics.

If energetic rotation is the key for a star such as Achernar, pure energy is the main keyword for the next object in the new flavour of angular diameters that the VLTI is biting into. With $5 \cdot 10^6\ L_\odot$, η Carinae is the most luminous star known in the Galaxy; its initial mass must have been between 150 and 200 $M_\odot$. It loses mass at a prodigious rate (of order 10^{-3} $M_\odot$/year) in a 500 km/s wind. In an enormous eruption in the middle of the 19th century, several solar masses were ejected; the nature of this eruption is still not understood. The resultant debris now forms a large prolate nebulosity surrounding the star, with an elongation along a position angle of 135°. Clumps are found at all spatial scales; the strong inhomogeneities make it impossible to determine the mass loss rate from spectroscopy alone.

The highest-resolution observations of η Car from a single telescope are the VLT / NACO data, shown in the top right panel of Figure 8. They resolve much of the sub-arc second structure, but about 60% of the flux within the inner 1.5″ remains unresolved in a central object whose size must be smaller than 70 mas.

VLTI / VINCI observations clearly resolve this central object; its size can now be measured to be 5 mas at 2 µm corresponding to 10 AU at η Car's distance. This is clearly much larger than the stellar photosphere so that we must be observing the radius at which the stellar wind becomes opaque. The radiation is dominated by free-free emission and electron scattering; the radius of the surface is determined by the mass-loss rate and the wind clumping factor. The diameter measurement with the VLTI breaks the degeneracy between these two parameters in previous modeling efforts; mass loss rate and clumping factor can be derived separately from the combination of HST / STIS spectroscopy with the interferometric data.

A second important conclusion from the VLTI data is that the central object is not spherically symmetric (Figure 8, centre left panel). In fact, its major axis is aligned with that of the large-scale structure (Figure 8, bottom right panel). This alignment on all scales means that the 1840 outburst looks like a scaled-up version of the present-day wind, and that this wind is stronger along the poles than in the equatorial plane. This can be understood in the framework of radiation-driven winds from rapidly rotating stars: centrifugal forces favour mass-loss in the equatorial plane, but the radiation pressure in these massive stars is stronger in the polar regions because of the von Zeipel effect (the stronger gravity near the poles leads to a higher temperature).

For η Car, the von Zeipel effect is more important than the centrifugal levitation leading to a polar wind. The VLTI observations, thus, favour a model that interprets the morphology of η Car on all scales with a radiation-driven wind from a rapidly rotating star, and they have allowed us to more precisely determine the very high mass-loss rate from this object.

A New Window is Open: Interferometry of Extragalactic Objects

The few selected results presented so far are just highlights of the massive amount of observations accumulated by VINCI, the test instrument which was originally designed to test the VLTI at system level, and has instead operated almost continuously for over two years. Soon, the two facility instruments MIDI and AMBER will enable observations with an increased range of wavelengths, spectral dispersions and number of beam combinations. In fact, MIDI arrived on Paranal almost exactly one year ago, and having successfully achieved first fringes as well as having undergone a few commissioning runs, it is now offered for open observations in period 73 starting from April 2004. In the meantime, under a shared-risk basis, already some GTO and science demonstration observations have taken place.

The results are certainly impressive: from young stars, to evolved late-type objects, from the luminous star η Car previously described, to early-type emission line stars, dozens of targets have been observed. One should note that MIDI represents the first Michelson-type beam combiner operating at 10 microns ever to scan the skies in a routine fashion (ISI, another innovative and successful interferometer operating at these wavelengths is based on a different principle of beam combination using heterodyne technology). Add to that the fact that it is fed by the giant 8.2 m mirrors of the VLT, and it comes as little surprise that even these initial observations are rich in new results. Indeed, every object that MIDI is pointed towards represents a first timer for this kind of observation. It is certainly not too optimistic to expect that several new exciting discoveries will be made possible soon by MIDI.

Already now, new ground has been broken: the first 10 micron interferometric observation of an extragalactic source, NGC 1068. This result was one, but not the only, outcome of the first observations in the framework of the science demonstration program. This is a form of guaranteed time awarded to those partners who have made practical contributions to the VLTI, an open club where new members are always welcome. This represented an historical landmark for the whole field of interferometry, often regarded as a tool useful only for stellar research. Even more so, when one considers that almost simultaneously the Keck Interferometer, making use of their two 10 m telescopes equipped with adaptive optics, also obtained for the first time an interferometric observation of NGC 4151, an extragalactic source, in the near-infrared.

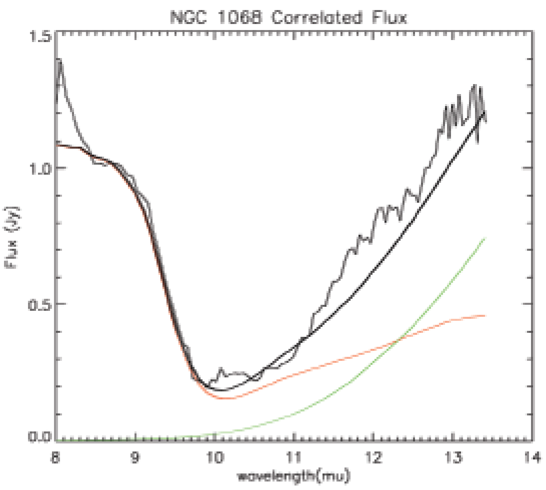
Both galaxies belong to the well-known category of active galactic nuclei (AGN), some of the most spectacular objects in the sky. AGNs display a plethora of very energetic phenomena: relativistic jets, broad and narrow emission lines, X-ray continuum and line emission, radio lobes all of which probably ultimately originate from the accretion of matter onto a central supermassive black hole. The varying relative importance of these phenomena results in a complex classification scheme which includes quasars, radio galaxies, BL Lac objects, Seyfert 1 and 2 galaxies etc. It is generally agreed that at least part of the observed diversity is caused by orientation effects: from certain viewpoints, circum-nuclear dust blocks the direct view of the central accretion disc and central jets. However, this model still remains to be demonstrated by direct observations, since the angular resolution provided by even the largest telescopes fails to resolve the dust geometry in even the nearest AGNs.

The first interferometric observation of NGC 1068, a Seyfert 2 AGN, by MIDI at the VLTI has probed the inner regions of this object with the unprecedented resolution of 30 mas. The combined spatial and spectral information reveals that the central dust distribution has a size of a few parsecs and contains an unresolved hot core, which might be the outer part of the accretion disc (see Fig. 9).

A significant amount of the warm component is located in front of the hot component. The narrow versus wide hatching in Fig. 9 indicates that the silicate absorption towards the hot component is significantly larger than the (averaged) silicate absorption towards the warm dust. Although the observations clearly resolve the warm component along PA 58°, there is no spatial information available in the orthogonal direction: this uncertainty is indicated by the dashed ellipse. The displacement of the warm component by several mas relative to the hot core indicates that the current interferometric data allow for both components being not concentric.

These MIDI observations represent the first interferometric spectrum of an extragalactic source at IR wavelengths, and they reveal a deep absorption feature which appears significantly different from that seen in our galaxy. The 10 micron feature revealed in the interferometric spectrum provides, at a first interpretation, evidence for an alumino-silicate composition of the central dust (see Fig. 10). This is different from the olivine-type dust (commonly seen around stars in our Galaxy) feature that is revealed in non-interferometric, single telescope spectra. However, other more exotic interpretations such as the existence of PAHs compounds, cannot be yet completely excluded. Besides, the observations need to be complemented by more baselines to extend the coverage of position angles and resolutions. Such observations are being carried out as this article is being written, and hopefully we will soon hear more exciting news on this.

Figure 10: The interferometric spectrum of NGC 1068 showing the flux on scales of 30 milli-arcsec and smaller. The jagged line shows the data and the smooth line the best fitting two-component gaussian model described in Fig. 9. The red and green lines indicate the individual contributions of the "hot" and "warm" components, respectively. The dip near 10 micron is probably caused by alumino-silicate dust, as opposed to the olivine-type, silicate dust absorption noted in the same spectrum obtained without the interferometric combination. From Jaffe et al. (2003).



THE FUTURE, NOT SO FAR

The scientific results described above are only a selection of what has been achieved so far. Other data already available are currently being analyzed or waiting for additional complementary observations by the VLTI as well as by other instruments. Preliminary results have already been presented at a number of meetings and conferences, from national and international meetings to the XXV IAU General Assembly, from topical symposia to the recent MIDI workshop held last September. Astronomers will soon be able to make additional important steps in several areas, including stellar diameters, pulsation, circumstellar environments and binary stars.

Noteworthy are the results expected in the fields of pulsation, both among Cepheid stars and very evolved objects. The former are expected to permit a decisive improvement in the accuracy of the empirical period-luminosity relation for these important distance indicators, with important implications also at an extragalactic level. Regarding the latter, pulsation and mass loss of evolved stars are a key to understanding important phenomena such as the late-stages of the evolution of stars like our Sun, and are also responsible for the chemical enrichment of the interstellar medium. Already a large number of observations have been collected by the VLTI for these kinds of objects.

This wealth of initial results attests to the fact that the VLTI is working well. This might come as no surprise for the many engineers and astronomers that dedicated so much effort through the years to its design and construction, but it certainly is comforting news to the large community that is longing for long baseline interferometry as a wide-ranging, user-friendly and reliable technique to be used by many new enthusiasts and not just a few black belts of applied opto-mechanics. Still, one should not forget that all this wealth comes from what has been until now a rather limited configuration of the VLTI. The majority of the first observations have been limited in sensitivity by the size of the small test siderostats, the lack of adaptive optics and of a fringe tracker. Flexibility has been severely limited by the lengthy relocation of the siderostats and by the number of delay lines (three) currently installed. Last but not least, the test instrument VINCI is equipped with a wide band *K* filter only.

All these limitations are being lifted as we write. The first two of four MACAO adaptive optics systems specific for the VLTI have been put into operation on the UTs, and the rest will follow in the course of next year. In parallel, the first 1.8 m Auxiliary Telescope (AT) has been accepted in Europe and is about to start its test period in Paranal. It will be soon be joined by the second AT in the course of 2004, while two more will follow later: together, the ATs will constitute an independent observatory on Paranal, fully dedicated to interferometry and quickly relocatable on a system of 30 stations. The FINITO fringe tracker is about to complete its commissioning on the mountain, and three more delay lines are ready to be added in the underground tunnel: the former will extend the sensitivity by permitting long integrations on faint objects, the latter will enable a much larger set of baseline combinations than has been possible until now. Finally, the two facility instruments AMBER and MIDI will offer a wavelength coverage which spans the *J, H, K* and *N* bands respectively, with various sets of spectral resolution up to 10,000.

With these additions, the VLTI will soon be a more complete facility, but its development will be by no means terminated. Second-generation instruments are being proposed, including the ESA-funded GENIE nulling interferometry demonstrator for DARWIN. The PRIMA facility, crucial for the observation of faint sources and for accurate narrow band astrometry through the use of off-axis reference sources, is planned to be integrated in about two years. It will extend the sensitivity limit of the VLTI well into the realm of extragalactic sources and permit the detection of the tiny gravitational pulls induced on stars by their orbiting planets. In the course of 2003, what was once a tiny seed timidly buried in hard ground, has finally grown and started producing its fruits. The harvesting has begun, and the prediction is that it will last many seasons.

Acknowledgements

If we can speak about VLTI results today, it is only thanks to the efforts of a large group of people in Europe and Chile. It is impossible to mention here all their names, and we hope we can be forgiven for this negligence. However, we take special pleasure in mentioning the former head of the Telescope Division, Massimo Tarenghi, who has defended the VLTI seed from the very first moment. Although he is now devoting himself to other projects, he still pays the occasional, unannounced surprise visit at the VLTI and still shows the same enthusiasm as ever. We would also like to mention by name the current members of the VLTI Science Group, on both sides of the Atlantic: Pascal Ballester, Emmanuel Di Folco, Emmanuel Galliano, Andreas Glindemann, Christian Hummel, Pierre Kervella, Sebastien Morel, Francesco Paresce, Isabelle Percheron, Fredrik Rantakyrö, Andrea Richichi, Markus Schöller, Martin Vannier, and Markus Wittkowski.

First publications related to the VLTI:

First radius measurements of very low mass stars with the VLTI, Sègransan et al., 2003, A&A, 397, L5

The diameters of α Centauri A and B: a comparison of the asteroseismic and VLTI views, Kervella et al., 2003, A&A, 404, 1087

Interferometry and asteroseismology: The radius of τ Cet, Pijpers et al., 2003, A&A, 406, L15

The spinning-top Be star Achernar from VLTI-VINCI, Domiciano de Souza et al., 2003, A&A, 407, L47

The interferometric diameter and internal structure of Sirius A, Kervella et al., 2003, A&A, 408, 681

First VLTI observations of Mira stars, Richichi and Wittkowski, 2003, Ap&SS, 286, 219

The VLTI Calibrators Program: Getting ready for high accuracy measurements, Percheron, Richichi, and Wittkowski, 2003, Ap&SS, 286, 105

Direct measurement of the size of the star η Carinae, Van Boekel et al., 2003, A&A, in press (astro-ph/0310399)

Tests of stellar model atmospheres by optical interferometry: VLTI/VINCI limb-darkening measurements of the M4 giant ψ Phe, Wittkowski et al., 2003, A&A, in press

The diameter and evolutionary state of Procyon A, Kervella et al., 2003, A&A, in press (astro-ph/0309148)

J-K DENIS photometry of a VLTI-selected sample of bright southern stars, Kimeswenger et al., 2003, A&A, in press

Introduction to VINCI/VLTI interferometric data analysis, Kervella et al., 2003, A&A, submitted

Calibration observations of Fomalhaut with the VLTI, Davis et al., 2003, A&A, submitted

Dust in the nucleus of the active galaxy NGC1068: structure and composition on parsec scales, Jaffe et al., 2003, Nature, submitted

Other references

Baraffe, Chabrier, Allard, Hauschildt, 1998, A&A 337, 403

Baraffe, Chabrier, Barman, Allard, Hauschildt, 2003, A&A 402, 701

Dwarkadas, Owocki, 2002, ApJ 581, 1337

Monnier, J.D. 2003, Reports on Progress in Physics, Volume 66, Issue 5, p. 789

Richichi A., Percheron I. 2002, A&A, 386, 492

Wittkowski, Schoeller, Hubrig, Posselt, von der Luehe, 2002, AN 323, 241

Our Own Starburst

In this article we present the first results from a near-infrared campaign to characterize our Galaxy's own starburst event, W49A, a prodigious factory of massive stars at a distance of about 12 kpc and concealed from observations at visible wavelengths by more than 25 magnitudes of intervening dust extinction. Our results so far reveal the presence of previously unknown massive stellar clusters containing more than 100 OB stars, some as massive as 120 $M_\odot$, most still embedded in their parental molecular cloud and with ages as young as 10^{4-5} yr. We argue that this ongoing starburst appears to have been multi-seeded instead of resulting from a coherent trigger.

João Alves[1] and Nicole Homeier[1,2]

[1]European Southern Observatory, Garching, Germany
[2]John Hopkins University, Baltimore, USA

Stars with mass above 8 $M_\odot$ are the main suppliers of heavy elements in the Universe, the same elements that make up your body and the Messenger article you are reading. Massive stars also inject energy into a galaxy's interstellar medium (ISM) playing a critical role in regulating star formation and driving galaxy evolution. It is not clear today if massive stars are destroyers of embryonic planetary systems or if they act, under some conditions, as triggers to planet formation. Finally, because they die in spectacularly bright fashion as supernovae/ gamma-ray bursts, their death can be seen across the Universe providing unique information to observational cosmology.

Despite their fundamental role in shaping our Universe, our knowledge of how Nature forms massive stars is rather primitive, in part because objects for study are rare due to the combination of small number statistics and the rapidity with which they pass through their early stages. With this in mind, the abundance of embedded massive stars in the Galactic star-forming region W49A marks it as a scientific gem.

Well known to radio astronomers, W49A (Mezger et al. 1967, Shaver et al. 1970) is one of the brightest Galactic giant radio H II regions (~10^7 $L_\odot$), powered by the equivalent of about 100 O7 V stars. It is embedded in the densest region of a ~10^6 $M_\odot$ Giant Molecular Cloud (GMC) extending more than ~100 pc in size (Simon 2001) and is the best Galactic analogue to the starburst phenomenon seen in other galaxies. W49A lies essentially on the Galactic plane (l = 43.17°, b = +0.00°) at a distance of 11.4±1.2 kpc (Gwinn 1992), has ~40 well studied ultra-compact (UC) HII regions (e.g., De Pree et al. 1997), each associated with at least one stars earlier than approximately B3. About 12 of these radio sources are arranged in the well known Welch "ring" (Welch et al. 1987). A few other young Galactic clusters have a large number of massive stars, e.g., η Carinae, NGC 3603, the Arches cluster, but no other known region has a high number of massive stars in such a highly embedded and early evolutionary state. For this reason W49A is unique in our Galaxy.

In an attempt to uncover and characterize the embedded stellar population in W49A we performed an unbiased 5′×5′ (16 pc × 16 pc), deep *J, H,* and K_s-band imaging survey with the SOFI camera on ESO's New Technology Telescope (NTT), centred on the densest region of the W49 Giant Molecular Cloud (Simon 2001) (see Figure 1).

The first results

The observations were taken in June 2001, with the SOFI near-infrared camera on the ESO 3.5 m New Technology Telescope (NTT) on La Silla, Chile, during a spell of good weather and exceptional seeing (FWHM ~ 0.5″) (see Alves & Homeier 2003). Follow-up Adaptive Optics observations of an embedded compact HII region powered by a new-born 80 $M_\odot$ candidate star were taken with NACO on the Very Large Telescope (VLT) during September 2003.

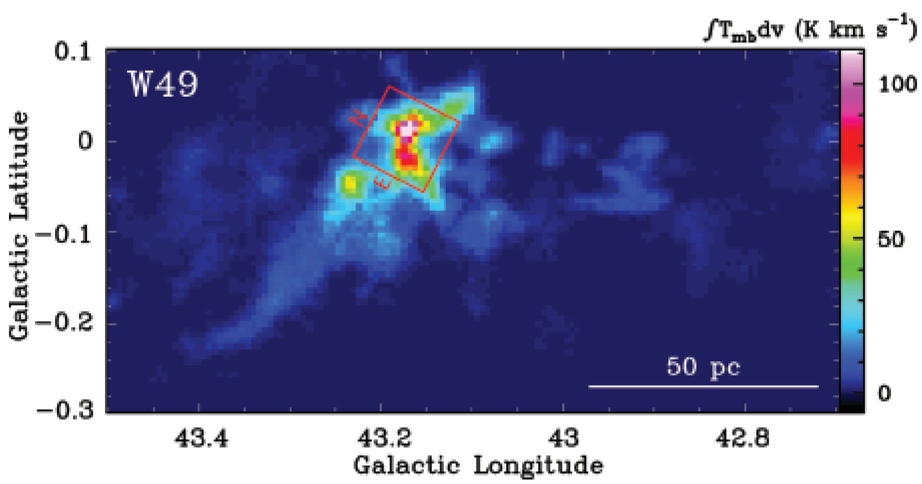


Figure 1: ^{13}CO Map of W49 giant molecular cloud. Our NTT-SOFI survey, marked as a red box, targeted the densest regions of this 10^6 $M_\odot$ giant molecular cloud. The survey covers an area of 16 × 16 pc at the distance to the complex (11.4 ± 1.2 kpc). ^{13}CO data taken from Simon et al. (2001).

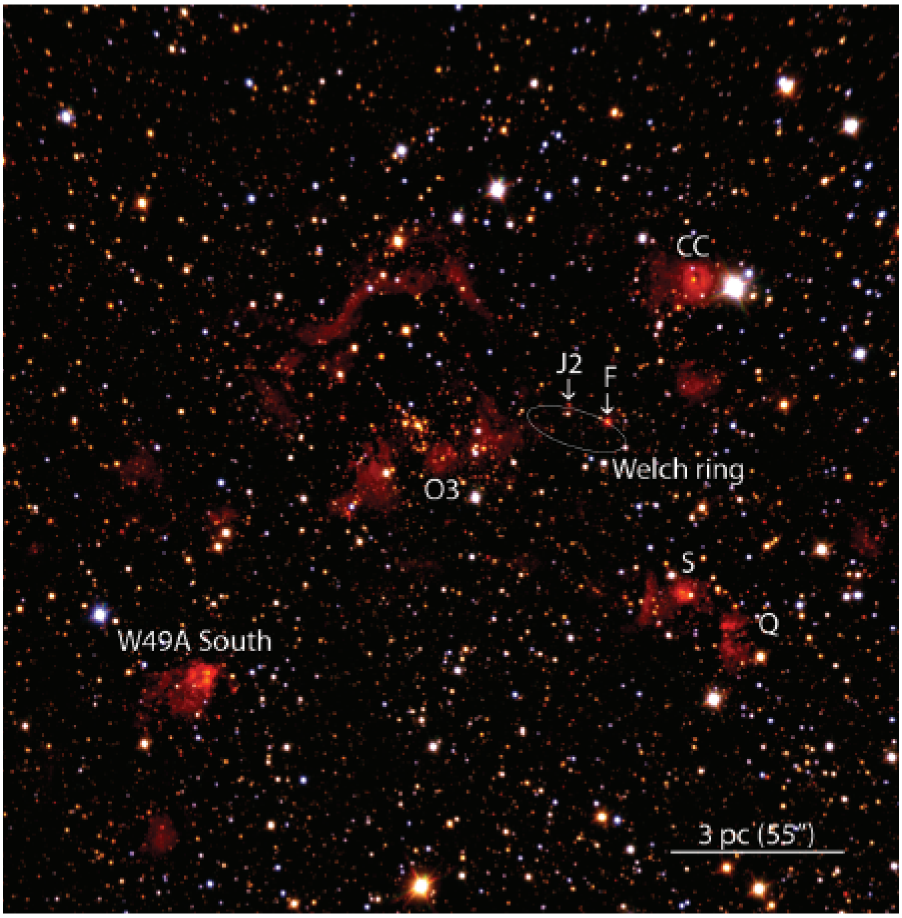


Figure 2: $5' \times 5'$ JHK_s colour composite of our survey. North is up and East is to the left. The red, green, and blue channels are mapped logarithmically to the K_s, H, and J-band respectively. The labels identify known radio continuum sources (De Pree et al., 1997). Sources F and J2 are UC HII regions in the Welch ring. The main cluster (Cluster 1) is seen NE of O3. Several candidate exciting sources of compact HII regions are visible (e.g., the sources at the centre of the CC, O3, W49A South HII regions). Dark pillars of molecular material are seen associated with radio sources Q and W49A South. None of W49A sources are optically visible. The coordinates of the image centre are: 19:10:16.724; +09:06:11.16 (J2000).

In Figure 2 we present the composite JHK_s colour image for our NTT-SOFI survey. The image covers an area of $5' \times 5'$ on the sky and the red, green, and blue channels are mapped logarithmically to the K_s, H, and J-band respectively. Because most field stars are essentially colourless in the near-infrared one expects the colour of a star in this image to be, to first order, a qualitative measure of the amount of extinction towards this star. For this reason, all blue stars in this Figure are foreground sources to the star forming region.

In Figure 3 we present a 3.6 cm radio continuum (red), K_s (green), and J (blue) colour composite of the central regions of the survey. The radio continuum data is taken from De Pree et al. (1997) and has a spatial resolution of 0.8″, close to the spatial resolution of the NTT images. The red-only features in this image represent regions of ionised hydrogen so deeply embedded in the W49A molecular cloud that they cannot be detected in our K_s-band image, e.g., the Welch ring of UC HII regions with the exception of sources F and J2 (that appear in yellow in the image). Several HII regions and UC HII regions detected at radio continuum wavelengths are clearly detected on the K_s-band, suggesting that the K_s extended emission is dominated by hydrogen lines. The most prominent are identified in Figure 2 following De Pree (1997) nomenclature. Several point sources lie prominently in the centre of some of these regions (e.g., CC, O3, W49A south), are extincted by $A_V > 24$ mags of visual extinction (see below), and are excellent candidates to be the exciting sources powering these regions (Homeier & Alves, 2004).

The main feature in Figures 2 and 3 is the central 6 pc diameter region E of the ring of radio sources, with a stellar cluster at its projected centre. From here on we will refer to this cluster as Cluster 1. Note that only the North part of this 6 pc region is visible in the JHK_s colour composite, suggesting that there is a larger optical depth towards the South of Cluster 1, perhaps due to chance alignment of the embedded compact regions (e.g., JJ, O3) in front of it.

We present in Figure 4 the spatial distribution of the detected sources as a function of (H-K_s) colour. In Figure 5 we present the H-K_s vs. K_s Colour–Magnitude diagram for our survey. The solid line represents a 1 Myr old population taken from the Geneva tracks (Lejeune & Schaerer, 2001) and the slanted dotted lines represent a reddening in this diagram of A_V = 48 mag. The filled circles represent sources likely associated with the new clusters (see Figure 4).

Uncovering the Beast

Since the W49A star forming region is at a distance of 11.4 kpc, virtually on the Galactic plane, one expects a large amount of unrelated line-of-sight dust extinction to W49A, as well as dust associated with the star forming region. We will take advantage of the large amounts of dust extinction to isolate a reliable stellar population associated with the W49A giant molecular cloud. We present in Figure 4 the spatial distribution of the detected sources as a function of (H-K_s)

Figure 3: J (blue), K_s (green), and 3.6 cm radio continuum (red) colour composite of W49A star forming region. Red only features represent radio HII regions too embedded to be detected in our deep K_s image (e.g., most of the Welch ring of UC HII regions). Yellow represents features seen in both the radio continuum and K_s-band, green-only sources are K_s sources too reddened to be detected at the J-band (essentially all of W49A young stellar population), while blue sources are foreground stars unrelated to the star forming region.

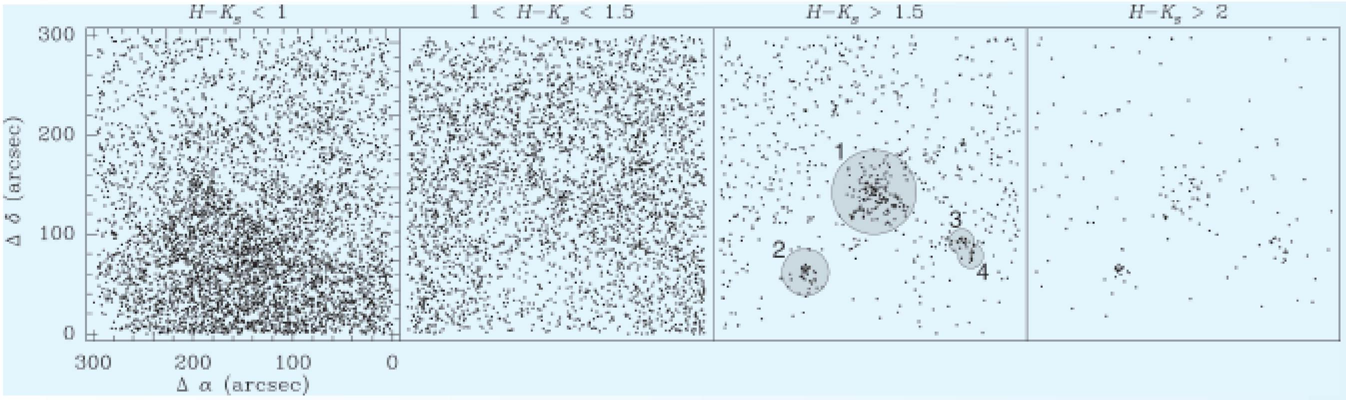


Figure 4: Spatial distribution of detected sources as a function of (H-K_s) colour. The clusters (labeled 1, 2, 3, and 4) become apparent in the third panel (where $A_V \sim 20$ mag). The non-uniform distribution of sources in panel 1 and 2 could be due to the intervening cloud GRSMC 43.30-0.33 located at a distance of ~3 kpc. The field shown is the same as in Figure 1.

colour. Starting with the bluer sources, (H-K_s < 1 mag) we find a non-uniform distribution in which about two third of the sources are found on the southern half of the field. Sources in this first bin are mainly foreground sources to the W49A star forming region, extincted by less than about 14 magnitudes of visual extinction, and the non-uniform distribution is likely caused by an intervening cloud at a distance of about 3 kpc (cloud GRSMC 43.30–0.33, Simon et al. 2001). The second panel (1 < H-K_s < 1.5 mag; 14 < A_V < 24 mag) further suggests this interpretation. We see the opposite spatial distribution with an increase in extinction and the region that in the first bin seemed under-populated is now over-populated. The majority of these stars are likely to be highly reddeneded stars in the background of GRSMC 43.30-0.33 but further work would have to be done to confirm this. In the third panel we clearly detect 4 clusterings of reddened sources. These make up the stellar population of W49A and some are still visible in the fourth panel where we find sources extincted by over 32 magnitudes of visual extinction, more than half associated with the newly found clusters. The positions of these 4 clusters are given in Table 1.

The Product of the W49A Starburst

Based on H-K_s colour and K_s magnitude, we preliminarily identify more than 100 O-stars candidates associated with the W49A region. We should bear in mind that due to the very high values of foreground and local (inhomogeneous) extinction *we are not complete even for the most luminous stars in W49A*. Nevertheless, this number compares already surprisingly well with the luminosity of the entire region (about 10^{51} Lyman continuum photons emitted per second). We can now say that the census of massive stars in W49A agrees with the number of Lyman continuum photons derived from radio observations. In fact, photon leakage or absorption by dust could be operating in the W49A region, as our count of candidate O-stars (incomplete due to severe inhomogeneous extinction), added to the number of known UC HII regions, gives ~140 stars with masses greater than 15–20 $M_\odot$, suggestive perhaps of a slight overabundance of ionizing stars. An estimate of the Initial Mass Function (IMF) in the main cluster suggests a Salpeter IMF down to ~ 2–3 $M_\odot$.

It is remarkable that the Welch ring of UC HII regions is seen in projection against the edge of the giant region powered by Cluster 1 (Figure 3). It necessarily invokes the classical triggering scenario of Elmegreen & Lada (1977) as one can easily imagine that, chronologically, the densest part of the W49A GMC collapsed to form Cluster 1, and the combined action of stellar winds and UV radiation compressed the abundant nearby gas to the West, triggering its collapse into the Welch ring. Recent theoretical calculations suggest timescales for massive star formation of the order of ~10^5 yr which for a typical sound speed of ~10 km/s agrees well with the crossing time in the Welch ring. However, we argue that the formation of the three smaller clusters to the South, undoubtedly associated with the burst of star formation in W49A, is unlikely to have been triggered by Cluster 1. The minimum distance (because of projection) between these less massive clusters and Cluster 1 is ~6 pc, which is larger than the bubble of ionised gas surround-

Table 1: W49 Stellar Clusters

Cluster	R.A. (J2000)	Decl.	Associated Radio Source
1	$19^h\,10^m\,17.5^s$	+9° 06′ 21″	Extended
2	$19^h\,10^m\,21.9^s$	+9° 05′ 04″	W49 A south
3	$19^h\,10^m\,11.9^s$	+9° 05′ 28″	S
4	$19^h\,10^m\,10.8^s$	+9° 05′ 14″	Q

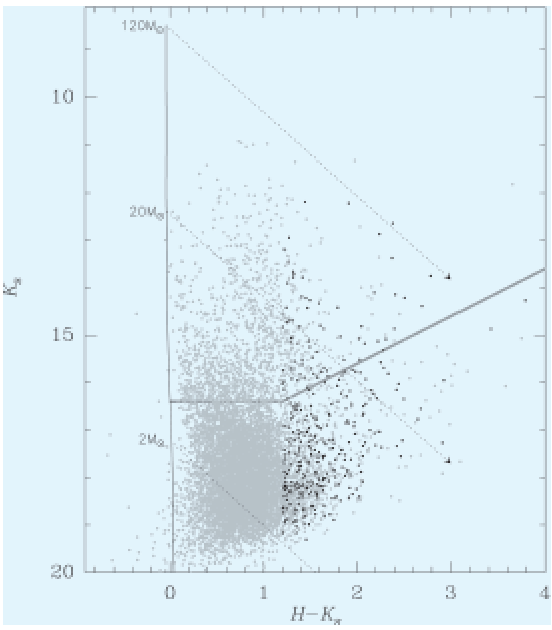


Figure 5: (H-K_s) vs. K_s Colour-Magnitude diagram for our survey. The solid line represents a 1 Myr old population taken from the Geneva tracks (Lejeune & Schaerer, 2001) and the slanted lines represent a reddening of A_V = 48 mag. The black circles identify stars likely associated with the W49A clusters. The 90% completeness limit for a star with errors less than 15% is marked as a bold grey line.

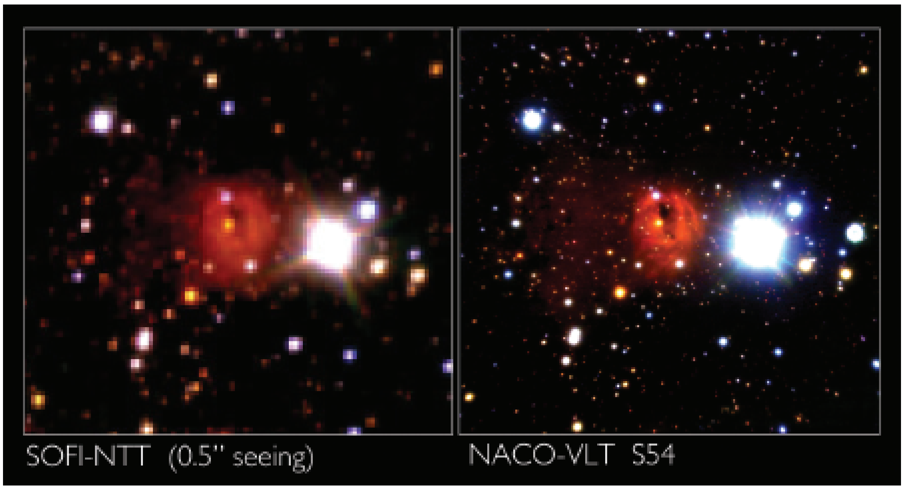


Figure 6: SOFI and NACO JHK_s colour composites of the only compact HII region that is accessible to NACO using natural guide stars. The object in the centre of the compact HII region is a newborn ~80 $M_\odot$ star candidate. Through comparison with models (Freyer et al. 2003) we estimate the age of the HII region to be remarkably young: 4 • 10^4 yr. This is a very young massive star caught in the rare act of passing from the ultracompact to compact HII region stage.

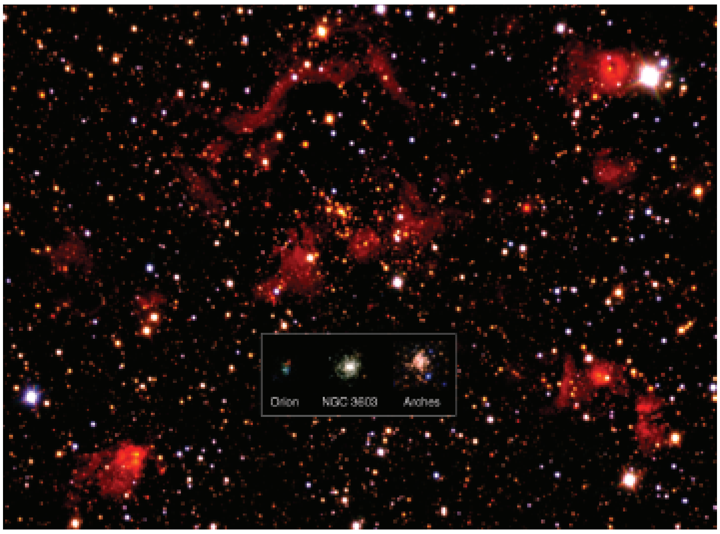


Figure 7: Size comparison between W49A and 1) Orion, 2) NGC 3603, and 3) the Arches cluster seen in the near-infrared as if they were located at the same distance and observed with the same instrument (SOFI on the NTT).

ing it, the giant central H II region in Figure 3. Also, given the short lifetimes of compact regions and the fact that they can be found almost over the entire surveyed region (e.g., the projected distance between source CC and W49A South is ~11 pc) suggests a multi-seeded, largely coeval, star formation episode in the W49A.

In Figure 6 we present preliminary results of a diffraction limited imaging follow-up on the only compact region that is accessible to NACO using natural guide stars. The object in the centre of the compact region is a newborn ~80 $M_\odot$ star candidate. We find that the source is unresolved down to the resolution of the image (600 AU at the distance of W49A) and through comparison with models (Freyer et al. 2003) we estimate the age of the region to be 4 • 10^4 yr.

Our first results suggests that W49A is indeed the most massive and youngest known star forming region in the Galaxy and that it extends over a larger area than previously thought (see Figure 7 for a visual comparison with well known young Galactic clusters). Moreover, star formation in W49A is still ongoing (the GMC is not exhausted yet) as 6 hot cores (the precursors of UC HII regions) were recently found in the vicinity of the Welch ring (Wilner et al., 2001). Although W49A is clearly of the class of 30 Dor in the Large Magellanic Cloud (LMC), a size comparison with the most luminous cluster in the Antennae galaxy (Figure 8), makes clear that the star forming conditions in the LMC and our Galaxy have to be radically different. Most important, our results show that a considerable part of the stellar population of W49A is accessible in the 2 µm window. Further characterization of the embedded population (via *H* and *K*-band spectra and adaptive optics techniques) is called for and will surely provide much needed information on the starburst phenomenon seen across the Universe.

Acknowledgements

We are pleased to acknowledge Miguel Moreira for discussions and assistance with the observations, Robert Simon for providing molecular line data from the BU-FCRAO Galactic Ring Survey on W49 giant molecular cloud and Chris De Pree for providing radio continuum data of the HII regions associated with W49A.

References

Alves, J., & Homeier, N. 2003, *ApJ*, 589, 45
De Pree, C.G., Mehringer, D.M., Goss, W. M. 1997, *ApJ*, 482, 307
Elmegreen, B. G., & Lada, C. J. 1977, *ApJ*, 214, 725
Gwinn, C. R., Moran, J. M., & Reid, M. J. 1992, *ApJ*, 393, 149
Homeier, N., & Alves, J. 2004, *A&A* in prep.
Lejeune, T., & Schaerer, D. 2001, *A&A*, 366, 538
Mezger, P. G., Schraml, J., & Terzian, Y. 1967, *ApJ*, 150, 807
Shaver, P.A., & Goss, W.M. 1970, *AuJPA*, 14, 133
Simon, R., Jackson, J.M., Clemens, D.P., Bania, T. M., & Heyer, M. H. 2001, *ApJ*, 551, 747
Welch, W. J., Dreher, J. W., Jackson, J. M., Terebey, S., & Vogel, S. N. 1987, *Science*, 238, 1550
Wilner, D. J., De Pree, C. G., Welch, W. J., & Goss, W. M. 2001, *ApJLet*, 550, L81

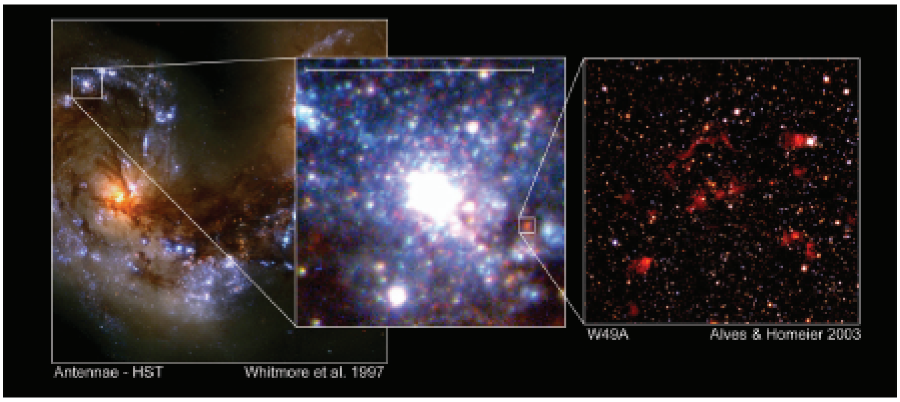


Figure 8: Size comparison between W49A and the most luminous cluster in the Antennae (starburst) galaxy. W49A is approximately an order of magnitude smaller. The luminosity comparison is not fair as the wavelengths of the two images are different (visible and near-infrared). Also, while the Antennae cluster is essentially extinction free, W49A is seen behind a wall of more than 30 mags of dust extinction.

Extraplanar Star Formation in NGC 55

We present the first VLT spectra of two compact Hα-emitting objects, located in the halo of the edge-on spiral galaxy NGC 55. The detection of stellar continuum and the observed emission-line characteristics indicate that these objects are extraplanar HII-regions. CLOUDY model simulations establish photoionisation by single OB-type stars as ionisation mechanism and finally confirm the HII-region character. Hydrodynamical considerations unambiguously restrict the origin of these regions to the halo. Their creation was most likely triggered by star formation activity in the disc below. In this picture the gas clouds, out of which the OB stars formed, could cool and collapse only between two successive bursts of star formation.

R. Tüllmann[1],
M. R. Rosa[2],
T. Elwert[1],
D. J. Bomans[1],
A. M. N. Ferguson[3],
R.-J. Dettmar[1]

[1]Astronomisches Institut, Ruhr-Universität Bochum, Germany;
[2]Space Telescope-European Coordinating Facility, Garching, Germany;
[3]Max-Planck-Institut für Astrophysik, Garching, Germany

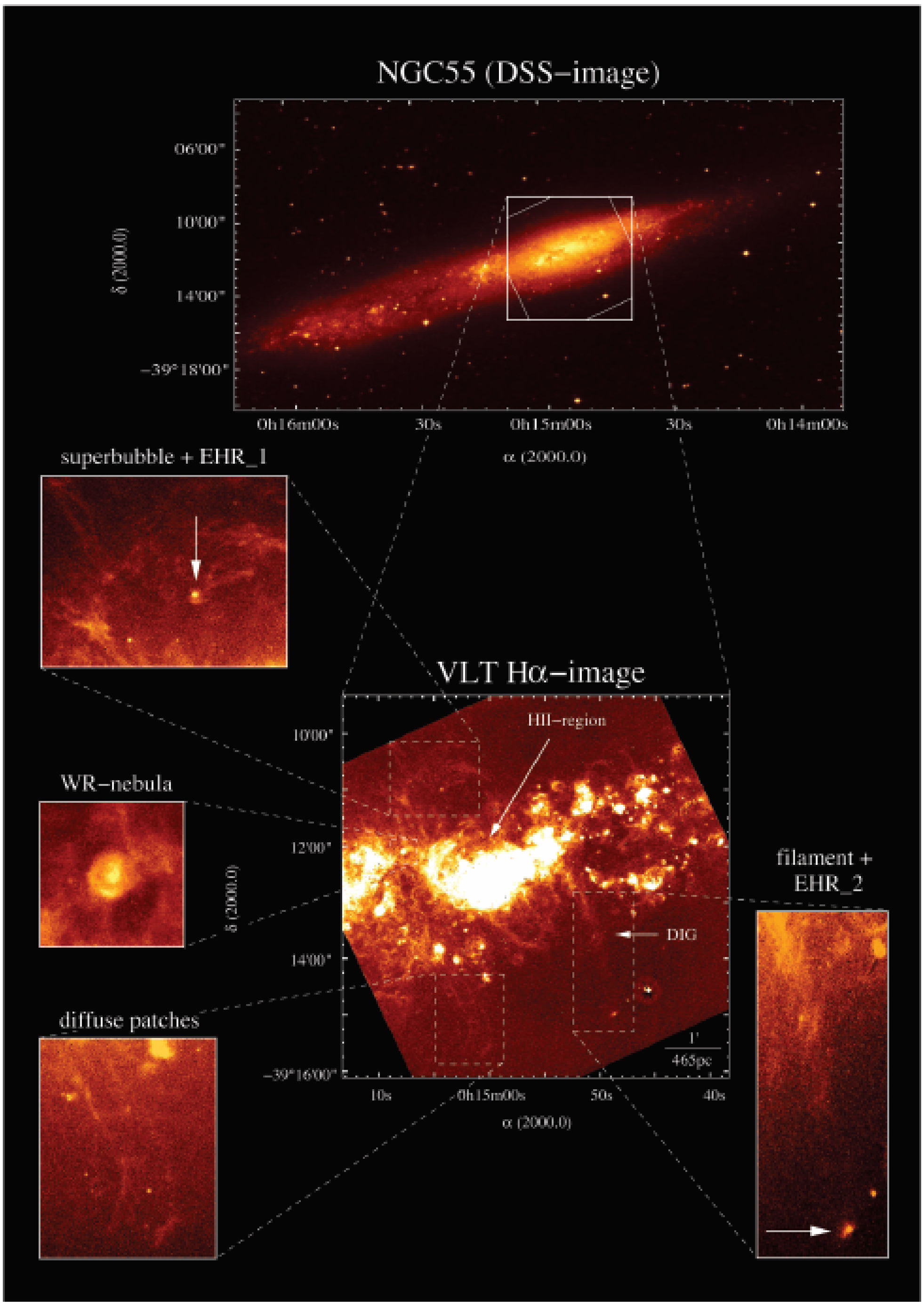


Figure 1: Zooming into the centre of NGC 55. This Hα-image has been obtained with UT1+FORS1 at the VLT. It reveals various spectacular features, such as filaments, colliding shells, superbubbles, and a newly detected Wolf-Rayet nebula of surprisingly high temperature. Note the extraplanar HII-region (EHR_1) located within the extended northern SN shell and EHR_2 which sits on top of a huge elongated (1kpc) filamentary structure.

During the last decades the formation of massive stars in galaxies of different Hubble-Types has been studied in great detail. For spirals this process is considered to be almost exclusively concentrated to the disc as the efficiency with which gas is converted into stars is highest there. On the other hand, the existence of a young and massive OB-star population in the halo of the Milky Way galaxy and other spiral galaxies, such as NGC253, is widely accepted.

However, as these stars are detected at large distances (~15 kpc) above the star forming disc, their creation and origin are rather poorly constrained. In order to clarify the origin of this young stellar component in the halo different scenarios have been proposed, such as ejection from the disc as a consequence of supernova (SN) explosions, ejection from stellar clusters as a result of gravitational encounters, and star formation in the halo itself (Keenan 1992, Ferguson 2002).

Estimates of the distance a star could travel at a given speed through the halo during its lifetime reveals that 'in situ' star formation in the halo is the most likely scenario for a large fraction of the studied sample of halo stars. If proper motions of these stars are reasonably low, it should be possible with future investigations to detect their stellar birthplaces, faint gaseous envelopes in the vicinity of these stars, and thus to further strengthen extraplanar star formation (ESF). Although the mechanism that triggers ESF still remains unclear, especially in view of low gas densities, we have increasing evidence that star formation occurs at rather unusual sites, such as in a galaxy halo.

In the following, we investigate the possibility of ESF and its triggering mechanism by analysing first VLT data of compact extraplanar gas clouds with embedded stellar sources located in the disc-halo interface of the edge-on galaxy NGC 55.

Extraplanar HII-regions

There are fairly compact and isolated objects visible in Hα-imaging data for NGC 55 (Ferguson et al. 1996) which are located at distances of up to 1.5kpc above the disc of this galaxy. From a morphological point of view, these objects appear very much like a small scale disc HII-region with embedded clusters of massive stars formed recently. Interestingly, similar regions are also discernable in other well known edge-on galaxies, such as NGC891, NGC3628, or NGC5775. In order to detect these objects, the target galaxy should be nearby to ensure sufficiently high spatial resolution and seen close to edge-on (large inclination angles of $i > 70°$), as in this case the halo separates well from the disc.

What makes the barred spiral galaxy NGC 55, a member of the Sculptor Group, an ideal target to study ESF is its proximity of only ~1.6Mpc and its high inclination of $i = 80°$. Moreover, this galaxy reveals violent ongoing star formation in the centre and at least two prominent extraplanar HII-region (EHR) candidates. All these features can be seen very nicely from Figure 1 where the VLT Hα-image obtained with UT1+FORS1 is presented.

A huge curved filament of gas and dust, anchored to the disc, is protruding off the image plane, apparently pointing towards R.A.(2000): $00^h15^m07^s$ and Dec.(2000): -39°12′00″. Of particular interest are the two objects marked by arrows, whose magnifications are shown in Figure 2.

EHR_1 has a diameter of 17pc and is located 0.8 kpc above the disc, whereas EHR_2 reveals a projected distance of 1.5 kpc and spans 22 pc in diameter.

If effects along the line-of-sight are negligible, EHR_1 is located within an expanding oxygen-bright SN shell that was detected over 20 years ago by Graham & Lawrie (1982). It would be interesting to learn from similar observations in other galaxies if these extraplanar regions predominantly occur at points where such shells, created by OB stars and SNe, intersect and the gas is piled up. At least the compressed gas at R. A.(2000): $00^h15^m07^s$ and Dec.(2000): -39°11′00″ is in favour of this idea.

However, the most important immediate result is provided by optical multi-object-spectroscopy (MOS) and concerns the detection of spatially concentrated continuum emission, which originates

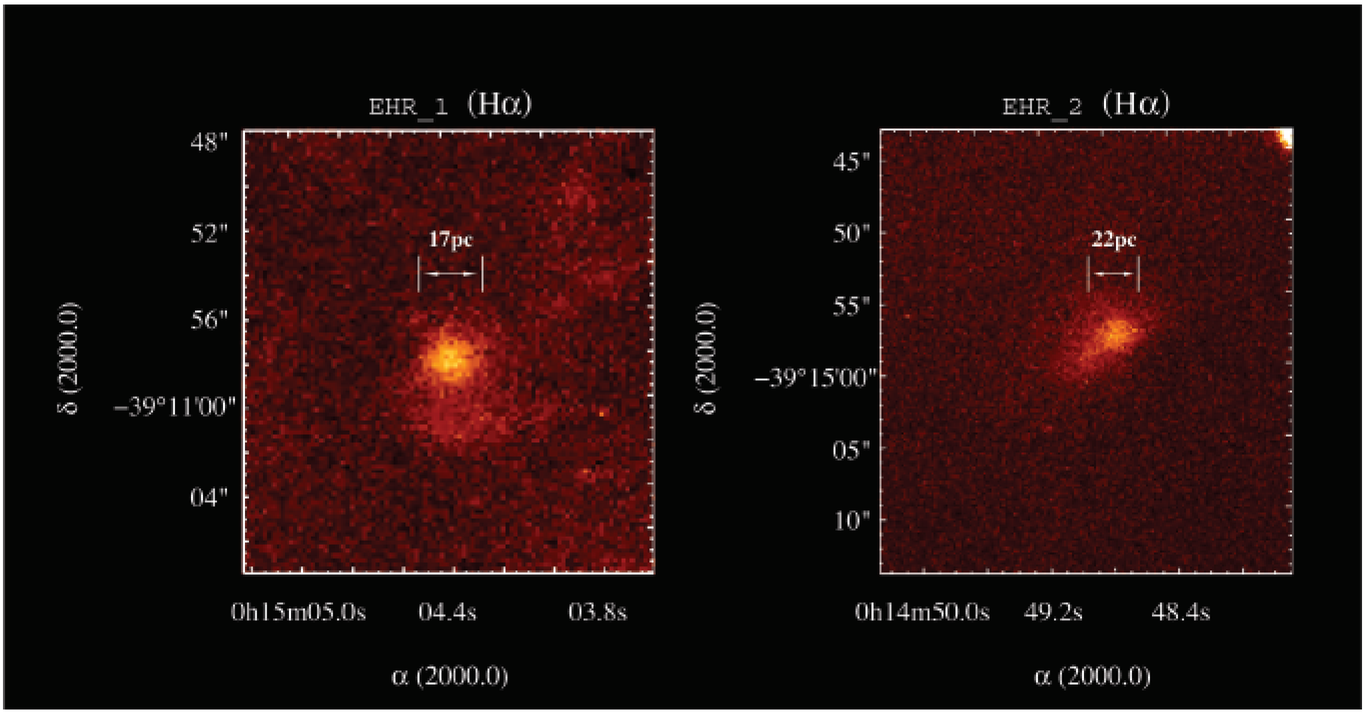


Figure 2: Blow-up views of EHR_1 In the northern (left) and EHR_2 in the southern halo (right). Both objects show a dense central core with diffuse Hα-emission in their outskirts which is sharply bounded towards the halo.

Table 1: Element abundances for the HII-region and the EHRs as calculated by NAT for gas temperatures of 11500K. Values in brackets were derived with the empirical R23-calibration. Solar abundances are compiled from the most recent data including Christensen-Dalsgaard (1998) and Grevesse & Sauval (1998). The average metallicity <Z/Z$_\odot$> has been calculated from oxygen abundances as this element is the most abundant and efficient coolant.

Parameter	HII-region	EHR_1	EHR_2	Solar
R_{23}	0.88	0.68	0.72	–
12 + log(He/H)	10.94 ± 0.02 (10.94)	(10.93)	10.84 (10.93)	10.98
12 + log(O/H)	8.05 ± 0.10 (8.08)	7.77 (7.61)	7.81 (7.68)	8.71
log(N/O)	–1.26 ± 0.05 (-1.30)	–1.50 (-1.54)	–1.31 (–1.50)	–0.78
log(Ne/O)	–0.85 ± 0.10	–	–	–0.71
log(S/O)	–1.41 ± 0.15	–1.94	–1.69	–1.51
log(O^+/O)	–0.731	–0.133	–0.127	–
log(S^+/S^{++})	–0.722	–	–	–
<Z/Z$_\odot$>	0.45	0.10	0.10	1.0

within the more diffuse body of the extraplanar objects (Figure 3).

The morphology of the continuum and the nebular emission-line distribution is direct evidence for stellar sources responsible for the excitation of these regions. Correspondingly, the flux-calibrated and background-subtracted spectra, integrated along their total spatial extent (Figure 4), are very similar to low excitation HII-regions.

For EHR_1, continuum emission is very weak and can hardly be seen in the spectrum presented in Figure 4. However, it is clearly visible in Figure 3. Figure 4 also shows the spectrum of EHR_2 which reveals a continuum much more prominent than that found in EHR_1.

A comparison with CLOUDY model simulations reveals that the ionisation mechanism of these compact objects is most likely photoionisation by single OB stars (O9.5 to B0). Further analysis of diagnostic diagrams unambiguously confirms the HII-region character.

Constraining the Origin of the EHRs

The existence of HII-regions in the halo immediately raises the question whether these objects originated from the prominent extraplanar gas of this galaxy or have just been expelled from the disc into the halo.

Ejection from the disc can be ruled out by hydrodynamical considerations due to the enormous drag, the gas phase of these regions encountered on its way out of the disc into the halo. Even a small amount of interstellar matter located along the path would lead to a separation of cloud and embedded stars due to the enormous difference in impact parameters cloud vs. cloud as compared to stars vs. cloud. Therefore, we conclude that these objects must have formed within the halo.

In addition, knowledge of the gas phase abundances also helps to distinguish between different creation mechanisms of the extraplanar ionised regions. Rather low metallicities compared to the disc abundances would indicate that these regions have formed from almost pristine local halo material. Relatively high abundances would restrict the origin of the clouds to material processed in star-forming regions of the disc.

We therefore determined the element abundances of both EHRs and compared them to those measured in the disc using two independent methods (R23 and the nebular abundance tool (NAT), see Tüllmann et al. 2003 for details). The results are shown in Table 1.

A comparison between the average metal abundance of the central disc HII-region of NGC 55 (45% Z$_\odot$) and both EHRs reveals substantially lower [O/H] abundances of about 10% Z$_\odot$ and thus independently also supports the ESF scenario.

With metal abundances derived this way, we can visualise for the first time the strong differences in the metal content along the minor axis of this galaxy. From Figure 5 it is obvious that the gas phase of oxygen is less abundant in the halo by about a factor of 4.

In order to reach a better coverage of the oxygen abundance along the minor axis, Figure 5 also plots the metal abundance of the Diffuse Ionised Gas (DIG). This gas phase is pushed into the halo of a galaxy by multiple SNe where it is visible as a diffuse extended Hα-emitting gaseous layer surrounding the disc. The ionisation of the DIG is maintained most likely by photoionisation from stars

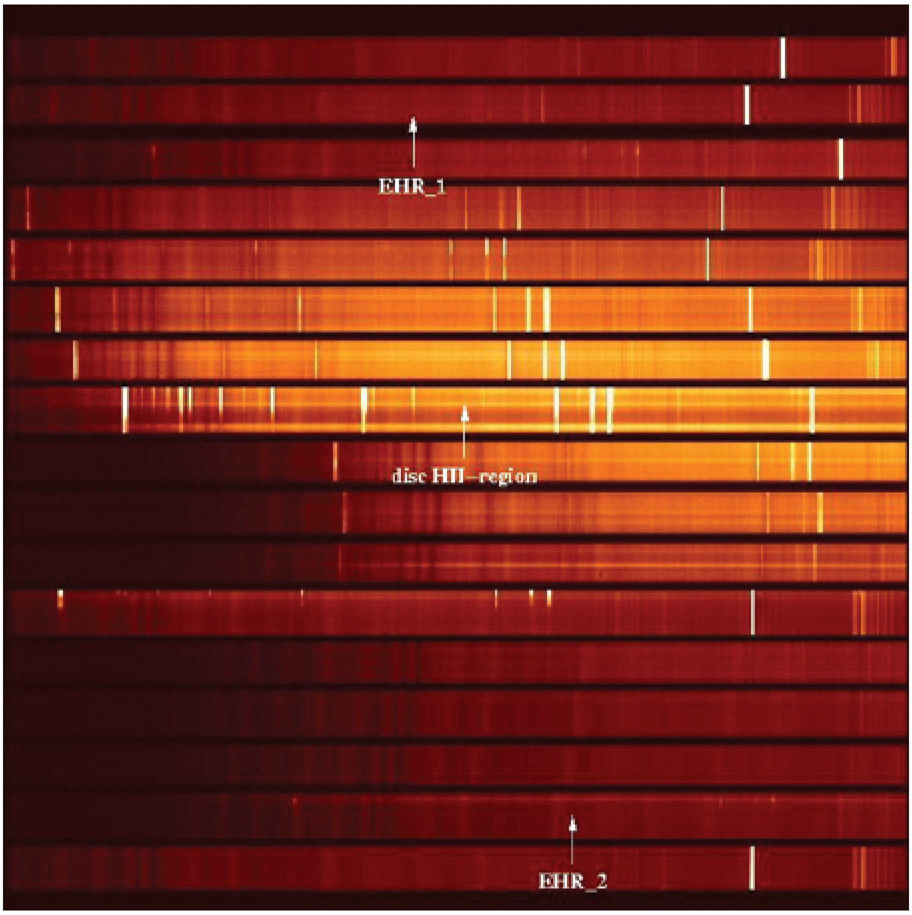


Figure 3: MOS-frame covering the "blue" wavelength region from about 3500Å to 5600Å. Both EHR-spectra, reveal only faint stellar continuum and line emission contrary to the central HII-region in the disc.

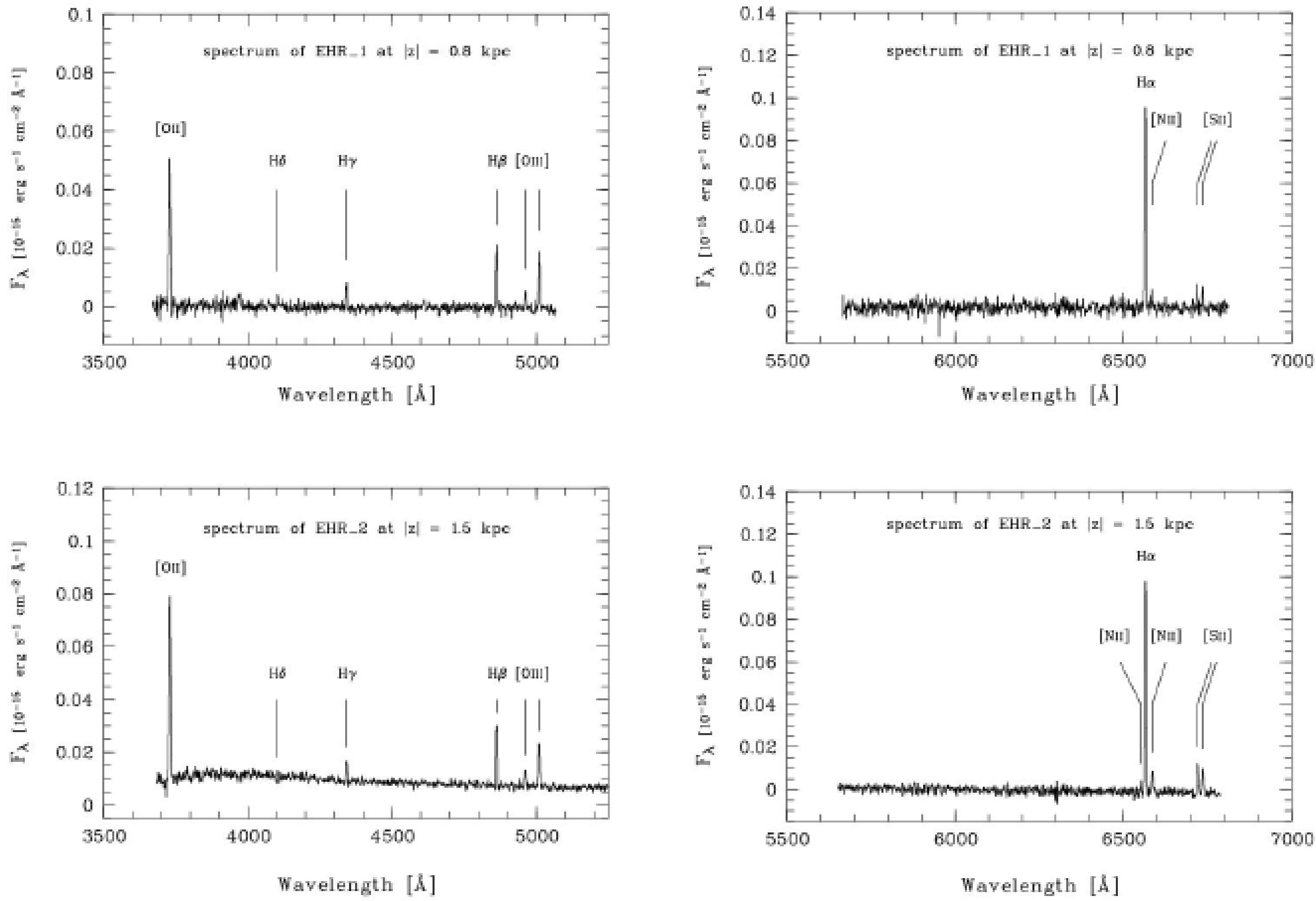


Figure 4: Integrated spectra for both EHRs. Although their emission-line characteristics is similar to ordinary disc HII-regions, it appears that EHRs are ionised by a slightly softer radiation field, as implied by a significantly lower flux in the [OIII]λ5007 emission-line.

located in the star forming disk below. As the DIG is no longer involved in star formation processes, it is expected to be also a good tracer of the metal content of the halo gas. The interested reader is referred to Dettmar (1992) for a comprehensive review.

The Global Picture

Two important questions directly emanate from the ESF hypothesis: (a) how did gas reach the halo in a quantity to cool, collapse, and form neutral, dense clouds from which new stars were born, and (b) what triggered the collapse to actually form those stars?

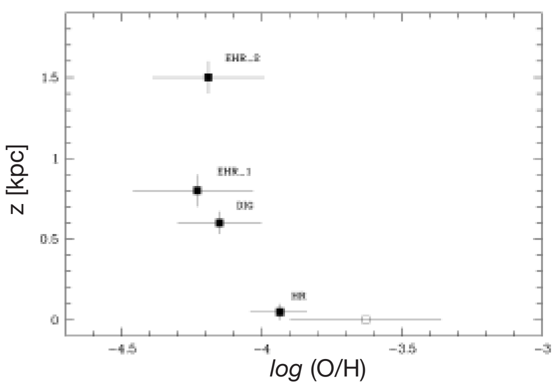
The most simple and natural explanation is to assume that clustered SNe during an early burst of star formation ejected a significant amount of ionised material into the halo.

After star formation stopped the extraplanar gas had time to cool, collapse, and form dense molecular clouds. These molecular gas clouds, out of which EHRs have formed, can survive and collapse only in the period between two successive bursts of star formation.

Since both EHRs are located above the central part of NGC 55, it appears likely, that their formation was triggered by star formation activity in the disk below. In this global picture star formation in the disk could stimulate as well as terminate the creation of EHRs.

Future work will test the ESF scenario for a larger sample of galaxies, investigate initial formation conditions for EHRs, and check if the central stars can separate within their lifetime far enough from their birthplaces and contribute to the observed stellar halo population.

Figure 5: Oxygen abundance as a function of |z|, the distance along the minor axis of NGC 55. The open symbol represents the averaged oxygen abundance for the disc, whereas the error bar represents data published by other authors. The data-point labelled "HR" has been slightly shifted along |z| to separate error bars. The one named "DIG" represents a special component of the ISM at intermediate |z|-distance (see text for details).



References

Christensen-Dalsgaard, J., 1998, Space Sci. Rev. 85, 19
Dettmar, R.-J., 1992, Fundamentals of Cosmic Physics, 15, 143
Ferguson, A. M. N., Wyse, R. F. G., & Gallagher, J. S., 1996, AJ 112, 2567
Ferguson, A. M. N., 2002, BAAS 200, 3306
Graham, J. A., & Lawrie, D. G., 1982, ApJ 253, L73
Grevesse, N., & Sauval, A. J., 1998, Space Sci. Rev. 85, 161
Keenan, F. P., 1992, QJRAS 33, 325
Tüllmann, R., Rosa, M. R., Elwert, T., Bomans, D. J., Ferguson, A. M. N., & Dettmar, R.-J., 2003, A&A, 412, 69

Flares from the direction of the Black Hole in the Galactic Centre

In recent dramatic observations using NAOS-CONICA on the VLT, near-infrared flares from the direction of the the black hole at the Galactic centre have been detected. The signals, rapidly flickering on a scale of minutes, must come from hot gas falling into the black hole, just before it disappears below the "event horizon" of the monster. The new observations strongly suggest that the Galactic Centre black hole rotates rapidly. Never before have scientists been able to study phenomena in the immediate neighbourhood of a black hole in such a detail. These results were published recently by Reinhard Genzel and colleagues* in the journal *Nature***, and were presented in ESO Press release PR 26/03.

This flare, and several others like it, were coming from exactly the direction of the supermassive black hole at the heart of the Milky Way. The team members were certain that the black hole must be accreting matter from time to time. As this matter falls towards the surface of the black hole, it gets hotter and hotter and starts emitting infrared radiation. But no such infrared radiation had been seen until that night at the VLT.

A careful analysis of the new observational data, reported in the Nature article, has revealed that the infrared emission originates from within a few thousandths of an arcsecond from the position of the black hole (corresponding to a distance of a few light-hours) and that it varies on time scales of minutes. This proves that the infrared signals must come from just outside the so-called "event horizon" of the black hole, that is the "surface of no return" from which even light cannot escape. The most likely emission process of the infrared emission is synchrotron emission from relativistic electrons. The observed intensity of the infrared emission and its spectral energy distribution suggest that a significant fraction of the electrons near the event horizon are accelerated to energies much above the virial equilibrium, in a non-thermal distribution, perhaps through magnetic reconnection events as in solar flares. The rapid variability seen in all data obtained by the VLT clearly indicates that the region around the event horizon must have chaotic properties.

The team members have commented that the data give unprecedented information about what happens just outside the event horizon and let us test the predictions of General Relativity. The most striking result is an apparent 17-minute periodicity in the light curves of two of the detected flares. If this periodicity is caused by the motion of gas orbiting the black hole, the inevitable conclusion is that the black hole must be rotating rapidly.

It is known from theory that a black hole can only have mass, spin and electrical charge. Last year the team was able to unambiguously prove the existence and determine the mass of the Galactic Centre black hole (ESO Press Release 17/02). If their assumption is correct that the periodicity is the fundamental orbital time of the accreting gas, they now have also measured its spin for the first time. And that turns out to be about half of the maximum spin that General Relativity allows. As Reinhard Genzel comments, "the era of observational black hole physics has truly begun".

Variability on time scales of one hour to several days was also observed in late May/June 2003 at 3.8 microns at the Keck telescope by a team of observers lead by Andrea Ghez (UCLA, paper in press ApJ Letters). As in the case of the VLT data, the Keck observers find the variable *L*-band source to be coincident with the black hole position to within less than 10 mas.

(based on ESO Press Release 26/03)

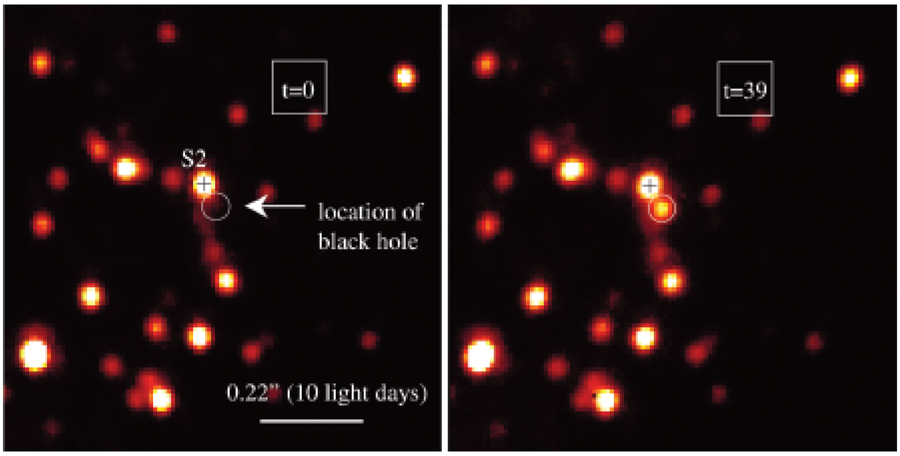


Figure 1 shows the detection of one of these flares, obtained with a resolution of 0.040 arcsec in the near-infrared H-band (λ=1.65 μm). The observations were made with the NACO imager on the 8.2-m VLT YEPUN telescope at Paranal on May 9, 2003. The image covers a sky area of about 1 x 1 arcsec, corresponding to about 45 light-days at the distance of the Galactic Centre. The time (in minutes from the beginning of the data set) is shown at the upper right of each image. North is up and East to the left. The position of the 15-year orbiting star S2 is marked by a cross and the astrometric location of the black hole is indicated by a circle.

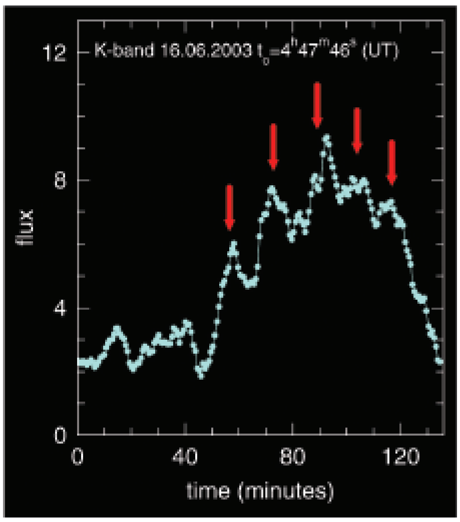


Figure 2 displays the "light curve" of a light flare from the Galactic Centre, as observed in the K-band (λ=2.2 μm) on June 16, 2003. This and a second flare discovered about 24 hours earlier show variability on a time scale of a few minutes and appear to show larger variations (arrows) with a 17-minute periodicity. The rapid variability implies that the infrared emission comes from just outside (the event horizon of) the black hole. If the periodicity is a fundamental property of the motion of gas orbiting the black hole, the Galactic Centre black hole must rotate with about half the maximum spin rate allowed by General Relativity. The present observations thus probe the space-time structure in the immediate vicinity of that event horizon.

* The team consists of Reinhard Genzel, Rainer Schödel, Thomas Ott and Bernd Aschenbach (Max-Planck-Institut für extraterrestrische Physik, Garching, Germany), Andreas Eckart (Physikalisches Institut, Universität zu Köln, Germany), Tal Alexander (The Weizmann Institute of Science, Rehovot, Israel), François Lacombe and Daniel Rouan (LESIA -Observatoire de Paris-Meudon, France).

**R. Genzel et al. (2003) Nature 425, pp. 934-937: "Near-IR Flares from Accreting Gas around the Supermassive Black Hole in the Galactic Centre"

Roses in the Southern Sky

The Wide-Field-Imager at La Silla Unveils Intricate Structures Illuminated by Hot Stars

(ESO PR Photos 31a-e/03)

N44 in the Large Magellanic Cloud is a spectacular example of a giant HII region. Having observed it in 1999 (see ESO PR Photos 26a-d/99), a team composed of Fernando Comerón and Nausicaa Delmotte from ESO, and Annie Laval from the Observatoire de Marseille (France), again used the Wide-Field-Imager (WFI) at the MPG/ESO 2.2-m telescope of the La Silla Observatory, pointing this 67-million pixel digital camera to the same sky region in order to provide another striking - and scientifically extremely rich - image of this complex of nebulae. With a size of roughly 1,000 light-years, the peculiar shape of N44 clearly outlines a ring that includes a bright stellar association of about 40 very luminous and bluish stars.

These stars are the origin of powerful “stellar winds” that blow away the surrounding gas, piling it up and creating gigantic interstellar bubbles. Such massive stars end their lives as exploding supernovae that expel their outer layers at high speeds, typically about 10,000 km/sec.

It is quite likely that some supernovae have already exploded in N44 during the past few million years, thereby “sweeping away” the surrounding gas. Smaller bubbles, filaments, bright knots, and other structures in the gas together testify to the extremely complex structures in this region, kept in continuous motion by the fast outflows from the most massive stars in the area.

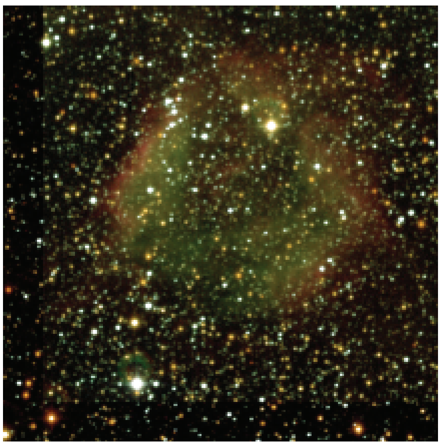
The new WFI image of N44

The colours reproduced in the new image of N44, shown in Fig. 1 (with smaller fields in more detail in Fig. 2–4) sample three strong spectral emission lines. The blue colour is mainly contributed by emission from singly-ionised oxygen atoms (shining at the ultraviolet wavelength 372.7 nm), while the green colour comes from doubly-ionised oxygen atoms (wavelength 500.7 nm). The red colour is due to the Hα line of hydrogen (wavelength 656.2 nm), emitted when protons and electrons combine to form hydrogen atoms. The red colour therefore traces the extremely complex distribution of ionised hydrogen within the nebulae while the difference between the blue and the green colour indicates regions of different temperatures: the hotter the gas, the more doubly-ionised oxygen it contains and, hence, the greener the colour is.

The composite photo produced in this way approximates the real colours of the nebula. Most of the region appears with a pinkish colour (a mixture of blue and red) since, under the normal temperature conditions that characterize most of this HII region, the red light emitted in the Hα line and the blue light emitted in the line of singly-ionised oxygen are more intense than that emitted in the line of the doubly-ionised oxygen (green).

However, some regions stand out because of their distinctly greener shade and their high brightness. Each of these regions contains at least one extremely hot star with a temperature somewhere between 30,000 and 70,000 degrees. Its intense ultraviolet radiation heats the surrounding gas to a higher temperature, whereby more oxygen atoms are doubly ionised and the emission of green light is correspondingly stronger, cf. Fig. 2.

More information, including technical information on the images, can be found at *http://www.eso.org/outreach/press-rel/pr-2003/phot-31-03.html.*



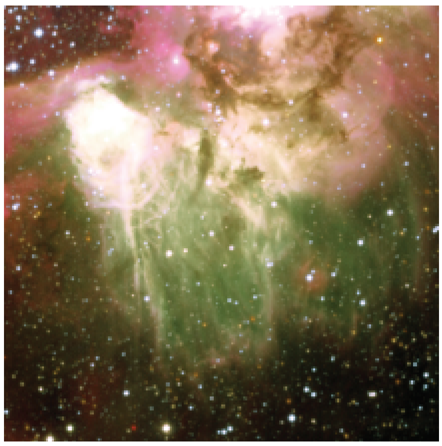
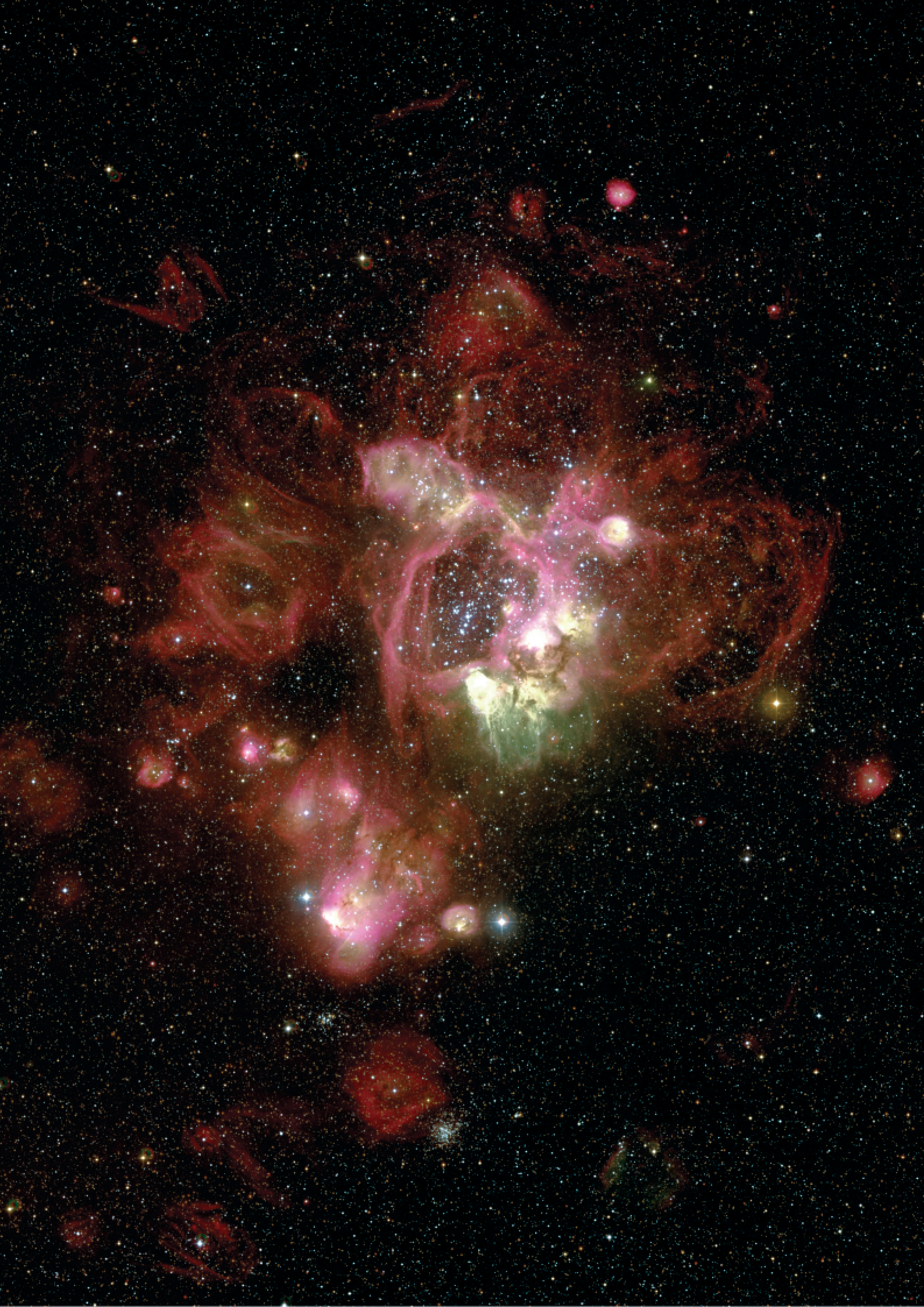


Figure 1 (right) shows the southern part of the spectacular N44 region in the Large Magellanic Cloud. The green colour indicates areas that are particularly hot. The field measures 27.5 × 26.5 arcmin^2. North is up and East is left. Figure 2 (above, middle) shows the ionised region DEM L 159 and two clusters with hot stars named KMHK 840 (top left) and KMHK 831 (bottom right). Figure 3 (above, left) shows a region with pink-green shades that has been designated DEM L 144 and is located at the bottom centre of figure 1. It is a region of ionised hydrogen. Note that in figures 2 and 3, the colours have been enhanced compared to figure 1 to clearly show the different shades. Figure 4 (above, right) shows a part of the central nebula, known as N44C. The green colour indicates areas that are particularly hot. The nature of the exciting source that delivers the necessary energy has been the subject of studies during two decades but is still not known with certainty.



Metrics to Measure ESO's Scientific Success

Based on publication statistics, we provide a first assessment of ESO's scientific impact after four years of VLT operation. A brief discussion of the complexity of measuring scientific success and its inherent problems is given. We present publication and citation statistics drawn from the ESO publication database and provide some preliminary interpretation.

B. Leibundgut, U. Grothkopf, A. Treumann (ESO)

ESO's ultimate goal is to advance astronomical knowledge and provide tools for progress in our understanding of the world we live in. There is a long chain of actions, interactions and activities which lead to such results, and it is important for organisations to evaluate the impact they have on their specific research field and on society as a whole.

The scientific procedure is to produce a hypothesis (often based on previous data and well-known and -loved paradigms), design a test for this hypothesis, carry out the test, analyse the outcome and finally publish the results. It is this last bit, the publication and dissemination that closes the loop and enables others to continue the line of thought.

As an organisation providing resources to the European astronomical community, ESO has to evaluate how successful and competitive it is compared to other observatories and astronomical institutions. This can be done in many ways, ranging from assessing user satisfaction, efficiency of observations and quality of delivered data to the achieved scientific breakthroughs. While the first three metrics lie within ESO's purview, the last one is a joint effort of the research community and ESO. The recent questionnaire on user satisfaction with the service mode offered by ESO (Comerón et al. 2003, Messenger, no. 113, 32) and the evaluations given to the Users Committee in the end of run reports for visitor mode observations measure how well ESO is doing compared to the expectations of its users. The statistics on telescope downtime indicate how well the observatories function. However, the final aim of the combined work of astronomers and ESO is scientific progress.

Measuring scientific success

The definition of scientific success is not easy. This becomes obvious when one does a small literature survey of previous studies on scientific success. Comparisons among observatories (e.g. Trimble, 1995, PASP, 107, 977; Bergeron and Grothkopf, 1999, Messenger, no. 96, 28; Benn and Sanchez, 2001, PASP, 113, 385), astronomical institutions (Abt, 1994, PASP, 106, 107) and individual astronomers (Burstein, 2000, BAAS, 32, 917) are all available. Observatories in particular attempt to quantify their impact (Meylan, Madrid and Macchetto, 2003, STScI Newsletter, 20, no.2, 1). Another recent example is the statistical study on the productivity of ESO's La Silla observatory (see Annex I of the La Silla 2006+ report; available at *www.eso.org/gen-fac/commit/ls2006/*). Investigations on publication behaviour and patterns have also been published (Abt and Zhou, 1996, PASP, 108, 375; Abt, 1998, PASP, 110, 210).

Most of the studies apply bibliometrics, i.e., the quantitative analysis of average or total numbers of publications and citations. However, they all use specific methods which are often not reproducible by other organisations, and so far no general scheme has been developed. One reason was that up to a few years ago, no uniform non-commercial database was available to the astronomical community. This has changed with the availability of the ADS system that collects publications and citations of basically all astronomical literature. Astronomy is privileged in that this nearly complete (and free of charge) database exists, as it represents a situation completely different from almost all other sciences.

In the following, we present publication and citation statistics drawn from the ESO publication database with some preliminary interpretations. After describing how the information is assembled (section 2), we will discuss different criteria that could serve for interpretation (section 3). In section 4 we present the ESO statistics.

Assembling the information

Publications resulting from ESO data should be clearly identified as such. The Call for Proposals specifies that papers must list the observing programme(s) within which the data were obtained in a footnote. This serves several purposes; most importantly, it helps to measure the observatory's scientific success. Astronomers are increasingly following this requirement, although not yet as consistently as necessary.

At ESO, the librarians search all major astronomy journals for publications deriving from ESO data. When ESO-related information is not obvious from the publication, a cross-match with the observing schedule is made. Should the records still be incomplete we contact the first author or PI in order to obtain missing details. For completeness, the ADS database is queried at regular intervals.

This procedure leads to the most comprehensive possible record of refereed publications based on observations with ESO facilities. A recent comparison with automated searches in ADS showed that a considerable fraction of papers is not identified as based on ESO data in the ADS database, while others are wrongly attributed to ESO (Grothkopf and Treumann, 2003, LISA IV proc., *www.eso.org/libraries/lisa4/Grothkopf1.pdf*). The main reason is that automated retrieval tools are not capable of interpreting the context in which search terms appear and thus cannot discriminate between relevant and irrelevant papers.

The ESO publication database is publicly available through the libraries webpage at *www.eso.org/libraries/*. Entries contain authors and title of papers, publication year, journal, volume and pages as well as ESO-specific information, such as programme IDs, telescopes and instruments used and the observing mode (service or visitor) in which the observations were carried out. The records are linked to ADS for download of citation information or access to the online version of papers. This database was used to assess how ESO's new and existing observing facilities impact the progress in our science.

Criteria for the interpretation

There are many ways to look at the impact facilities and scientific collaborations have. The two extremes are counting papers and counting Nobel prizes. The latter is not meant as a joke, although of course it is reaching high. It does, however, illustrate that the interpretation strongly depends on the weights assigned to different criteria. Reaching too high will decrease statistics to small numbers and diminish their meaningfulness. On the other hand, simple quantitative statistics, ignoring any quality issues, are just as dangerous. It is essential to find the right balance and to refrain from over-interpreting results.

Papers

Once the data have left the observatory, it is up to the astronomers to convert the bits into knowledge. The most tangible results are scientific publications. The observatory influences the process by providing data products that raise the researchers' interest in writing papers. This requires adherence to strict quality standards, in particular when the user base is growing. Still, some projects may not result in any publication for a variety of reasons and the goal must be to keep this number as low as possible. The publication rate of course depends on the efficiency and size of the observatory. An observatory that serves a large user community will generate more papers.

An increasing number of publications are based on data from more than one telescope, and even more than one observatory. These papers will be regarded by several organizations as originating from 'their' data and hence will appear in several statistics.

Citations

The number of citations indicates how well a publication is accepted and how important it is considered within the community. Similar to observatories that do not produce data suitable for publication, scientific papers that are not cited are useless. But simply counting citations is problematic, and one must be aware of the pitfalls. Some papers create strong reactions because they are wrong or misinterpret data. Catalogues can generate many citations as they are the basis for derivative results. Papers in a popular field will generally attract more attention than those which address very specific topics within a small community. Hence, citation statistics are not necessarily a measurement of quality, but certainly of attention, and they have to be put into context.

Citations critically depend on how much time has elapsed since a paper was published. Publications have a mean life time after which they are either forgotten or superseded by more recent findings. Only very few papers become 'classics' or even enter textbooks; many will be outdated within a rather short time. The mean attention span for papers has shortened from six years in the 1990s (Abt, 1996, PASP, 108, 1059) to about two years today (Crabtree and Bryson, 2001, JRASC, 95, 259). Electronic publishing and a general acceleration in information exchange have contributed substantially to this decrease. Accordingly, there can be strong fluctuations in citation statistics within a relatively short time for recent papers, while older publications that have passed their peak will not be cited much longer.

A frequently discussed issue are self-citations. While self-cites can influence statistics for individual papers, their number typically is too low to cause much concern for whole observatories. Scientists simply can not publish fast enough to increase the number of citations of their own papers considerably.

High impact

Some publications become highly visible and important for the progress of astronomy. They may introduce a paradigm change, produce the fundamental data set for a given subfield or are seminal reviews. Everybody will be able to identify the five most important papers in their field of research; they enter the syllabus of discussions and are the pillars upon which research fields stand. By definition these publications are rare as the selection is so severe.

For an observatory it cannot be the goal to produce high-impact papers itself, but it must aspire to provide the facilities which allow astronomers to explore new territory and make fundamental discoveries.

In bibliometrics, typically citation counts determine which publications are regarded as 'high impact papers'. Such statistics have been used to compare various observatories against each other as well as to argue that certain telescopes are not 'competitive' any longer. One should be careful in using such number statistics blindly as important information may be easily overlooked. An example is the ongoing discussion between 4m- and 8m-telescope science. The extra-solar planets were discovered at small telescopes (1m to 2m diameter) with the important factors of time baseline and progress in analysis software.

The evaluation of papers has to take into account other phenomena as well. If a publication 'finishes off' a field and the trend moves to other problems, it will not be cited very often. Many people will have personal lists of 'most important contributions' that are not necessarily borne out in the statistics. Such contributions are of fundamental importance, yet they do not produce the reaction one would expect.

ESO statistics

The ESO statistics presented in this section were compiled and analysed with the above remarks in mind. They provide a snapshot of the current status (beginning of October 2003) and give a first assessment of the impact of the VLT on astron-

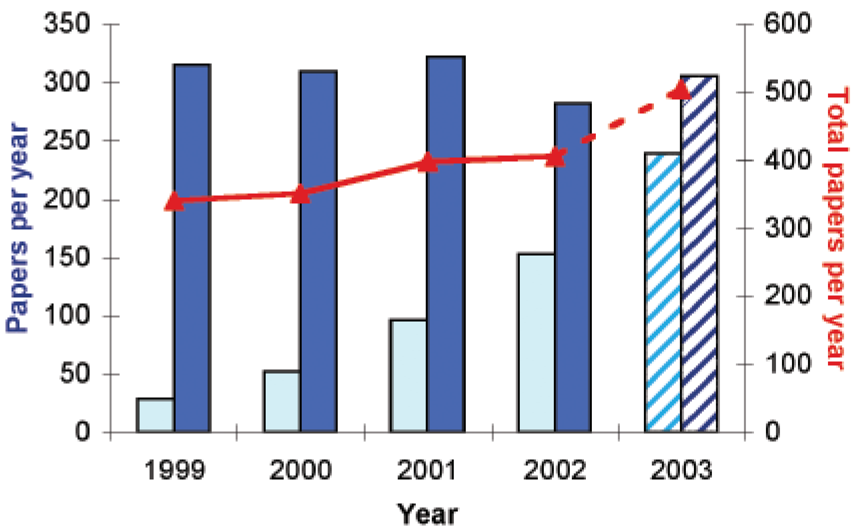


Figure 1: Number of papers based on ESO data published per year. The data for La Silla (dark blue) and Paranal (light blue) are shown individually (left scale). In addition, the total number is shown as the red line (right scale). The 2003 values were extrapolated from the first nine months. Note that papers can be based on data from both observatories, hence the total number is smaller than the sum of papers from individual sites.

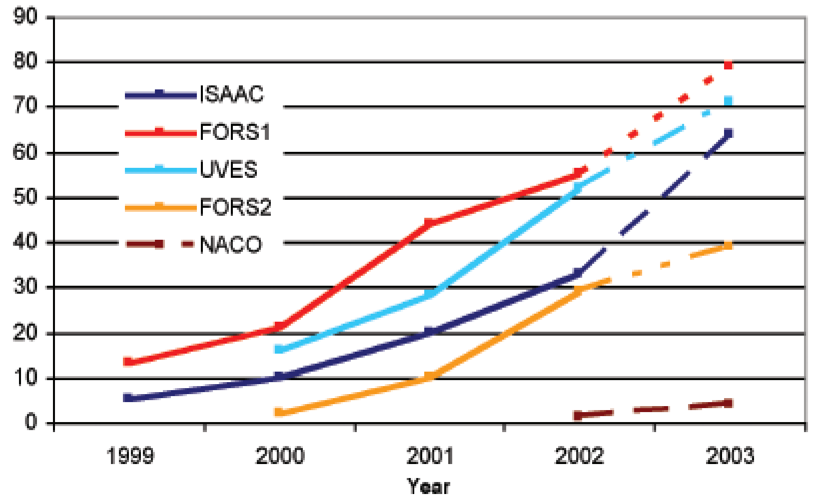


Figure 2: A steady increase in the numbers of papers per year is observed for all VLT instruments. The 2003 values were extrapolated from the first nine months.

omy. Some earlier statistics, in particular those on La Silla, have been presented in the La Silla 2006+ report. We will concentrate here on the early years of the VLT.

Papers

The La Silla 2006+ report showed that around 400 publications based on ESO telescopes were published each year. Since 1999, the share of papers coming from La Silla telescopes has been fairly stable; the VLT has generated a steady increase. The number of publications depends of course on how many facilities are offered. While La Silla has reduced the number of telescopes by closing the smaller ones, Paranal has seen all four VLT unit telescopes come into operation between 1999 and 2002. The number of instruments increased, and so did the observing opportunities and the fraction of the astronomical community that could be attracted. Figure 1 shows the publications in refereed journals per year separately for the two observatories as well as the total number for all ESO-based papers. During the first nine months of 2003 already more VLT papers have been published than in the entire year 2002. Extrapolating from the first three quarters to the end of the year yields a total number near 500 publications for this year with about 240 – or nearly half – of the papers coming from the VLT. This is a higher number of papers based on ESO data than ever before. Overall, it represents an increase in publications of about 20%.

The increase of VLT papers is a good sign. We expect this trend to continue in the near future as more instruments are added to the observatory.

Figure 2 shows the statistics for the individual instruments. The increase of publications per year is comparable for most instruments. NACO is somewhat special as most publications for this instrument currently come from commissioning data. The next years will show whether more complicated instruments produce similar (or higher) publication rates. Other important issues could be the average run length and the larger observing time overheads for IR instruments.

It is interesting to compare these statistics to trends observed at other facilities. Numbers are available for some ground-based observatories as well as space missions, like ISO and HST. The rate of papers continuously increases during the first few years (see Meylan, Madrid and Macchetto 2003). The comparisons are not straightforward, however, as the space missions typically have a smaller instrument suite and different observing patterns. Ground-based telescopes are mostly confined to night-time observing, while this is not necessarily the case for space missions, where other constraints play a role.

We investigated whether VLT service and visitor mode observations lead to different publication behaviour as the way astronomers deal with data may depend on how they were obtained. Also, the two modes offer different astronomical opportunities, for instance monitoring projects in service mode. In Figure 3 a first comparison of the numbers of papers derived from service and visitor mode observations is made. The distribution is fairly even between the two modes. The fluctuations are at this point probably statistical. One has to take into account the delay between observations and their corresponding publications so that the original distribution of modes for the observing programmes per observing semester is blurred by the time of publication. Hence, it is too early to draw firm conclusions. However, both modes appear rather successful in producing results suitable for publication. Among other things this means that the quality of service observations matches that from visitor mode runs, and service mode is accepted as a viable option by the observer community.

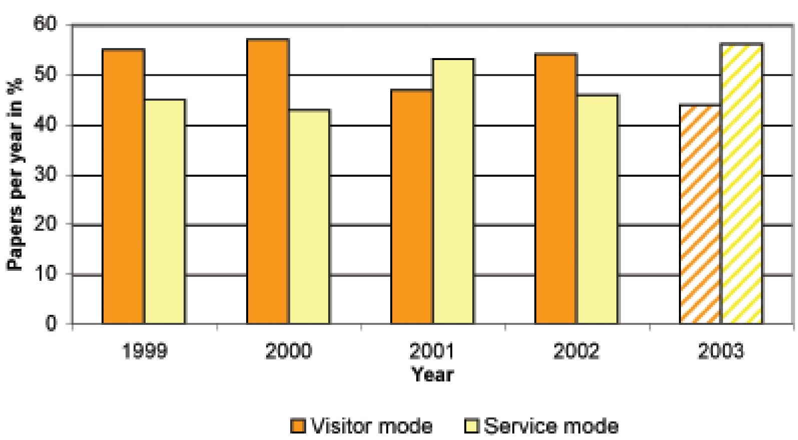


Figure 3: Comparison of publication rates from VLT service and visitor mode programmes. The 2003 values were extrapolated from the first nine months.

Citations

The citation statistics of ESO papers were gathered with information provided by ADS. Although there may be inaccuracies at the individual level, we believe that these are mostly negligible for comparisons at the scale of observatories. There appear to be no known systematics in the ADS system.

It is obvious that citation statistics depend on the time when they are assembled. The dynamics of citation rates are beyond this investigation, but one needs to keep in mind that statistics of recently published papers can change quickly. This is illustrated in Figure 4. The citations for papers published in 2001 nearly doubled during the first nine months of 2003! This trend may continue for papers published in 2002. After a few years, citation rates reach a peak; afterwards they drop. The VLT publications have not yet reached this level, but the early papers are not cited as much as the more recent ones.

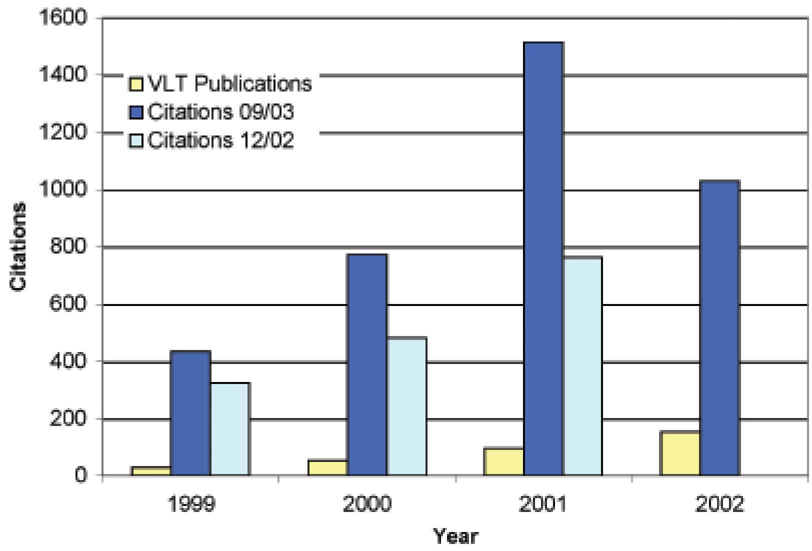


Figure 4: Changes of citations from December 2002 to October 2003.

The number of citations per paper is rather high; on average, VLT papers receive more than 10 cites after a few years. As of October 2003, citation rates for papers published in 2001 and 2002 are significantly higher than those for the very first papers.

Potentially, there are various mechanisms at work. The VLT has received greater attention with time. Also, more extensive projects, e.g. Large Programmes that lead to a larger body of data take longer to complete. Possibly, papers appearing in 2001 and 2002 presented more comprehensive studies, while the early papers may have mostly been letters and short communications which were superseded by the more substantial papers following a bit later. Other possibilities are that with more users and more papers, the rate of self-citations is going up with time. This is, however, unlikely to cause such high citation numbers.

In general, the VLT seems to produce a healthy reaction from the astronomical community and its contributions are recognised.

High impact

As there is no clear definition of what high-impact publications are, we restrict this section to a discussion of some ideas. We are able to identify the most frequently cited papers coming from ESO telescopes. This is the first step in such an analysis. Where to draw the line between average publications and those that change the way we look at the universe is probably somewhat arbitrary. In addition, the perception of the community changes over time and the impact of publications becomes obvious only in retrospect.

We observe that citations for ESO publications typically result in a bifurcated distribution. Some papers receive only few citations even after several years, others increase their total citations over a long time. About 5 to 10% of papers based on VLT data achieve rather high citation rates (more than 10 citations per year). More specifically, over 20% of the papers published in 2001 show citation rates above 10 per year, and 8% received more than 20 citations per year two years after publication. While the first two years of VLT operations have not yielded publications attracting more than 50 citations in total, there are six papers from 2001 that exceeded 50 citations within less than two years of publication. One paper from 2002 has reached this number within one year of publication.

Comparison with other observatories

At present, the different observatories and organisations assemble publication statistics according to their respective policies. As the selection criteria can vary vastly, comparisons have to be done with great care. Meaningful results can only be achieved when statistics are compiled based on the same rules and methodology. This of course requires a close collaboration among observatories and emphasizes their inter-dependence rather than their competition.

Bearing these comments in mind, we note that the first four years of VLT publication statistics are similar to those of HST (see the recently published statistics in Meylan, Madrid and Macchetto, 2003, STScI Newsletter, 20, no. 2, 1). Both VLT and HST experienced comparable start-up phases with an annual increase in published papers of approx. 75%. Meylan et al. also presented the mean number of citations per year for all refereed astrophysics papers and found that publications based on HST data on average are cited twice as often. With a mean citation rate of approx. 15 for papers published in 1999, 2000 and 2001, we recognize a similar trend for VLT papers. A more detailed analysis is only feasible though with a larger baseline.

Conclusion

After four years of VLT operation, we start to see clear signs of the impact the observatory has on the astronomical community. The overall publication rate of papers based on ESO data – approximately one refereed paper published per calendar day – remained constant for the past few years. In 2003, the total number of publications is now increasing, mostly in line with the growing number of facilities offered at Paranal. La Silla still maintains a high publication rate despite a reduction in available telescopes. With regard to observing modes, no clear preference can be stated. Up to now, service and visitor mode programmes result in roughly the same number of publications, which generally corresponds to the time allocation. The large percentage of highly cited papers and the overall citation statistics prove that the scientific results produced by the VLT are highly visible and well recognised within the astronomical community.

Once the number of years over which we look back is sufficiently large to average out misleading short-term effects, we will be able to re-investigate the scientific impact of the VLT in a more comprehensive study. The results will be published in a future *Messenger* article.

Report on the Topical Meeting

Resolved Stellar Populations

George Hau & Danielle Alloin (ESO)

Advances in ground- and space-based observational capabilities, as well as modelling tools, have enabled the study of resolved stellar populations with unprecedented details. This topical meeting, held at ESO Vitacura on June 27, 2003, was aimed at bringing astronomers together to examine the progress that has been made in this field.

D. Minniti kicked off the Topical Meeting with an introduction to the Local Group and outlined some of the outstanding questions.

Concerning MACHOS, A. Rest described how the shape of the LMC luminosity function affects the number of microlensing events expected.

Tidal streams and mergers were the subjects of several talks. Deep wide field searches conducted around M31 and M33 show contrasting results. A. Ferguson found a giant stellar stream in the outer parts of M31, while M33 shows no evidence of substructure. D. Geisler found that the halo of M33 may host an intermediate-age population.

Closer to home, G. Marconi finds that the Sagittarius Dwarf has a metal rich young population with zero alpha-element overabundance, possibly resulting from some recent starburst triggered by a passage through the Galactic disc.

Complex star formation histories can also be seen in other Local Group dwarfs. A. Walker showed that Carina has a well defined blue-plume of young Main Sequence stars and a narrow RGB. The star count exhibits a "shoulder" in the northeast direction which may be evidence of extra-tidal stars. Like Carina, E. Hardy showed that Fornax also has a complex star formation history. The Ca II triplet equivalent widths show substantial metallicity enrichment, which suggests that metal ejection effects must be small. D. Faria described the study of metallicity distribution using Strömgren photometry, and I. Saviane described the Relative-Ages project.

Are there more Local Group galaxies to be discovered? Probably very few, said A. Whiting, who is conducting an all-sky survey.

Going further afield, an exciting development is the possibility to resolve the stellar populations in nearby groups. D. Minniti described the work on Centaurus A, which has substantial intermediate age stars amongst a metal-rich halo population. More than 1000 Mira long-period variables have been detected, which are used to derive a distance of 4.2 Mpc for this galaxy.

Altogether this Topical Meeting has been very fruitful. Many of the results discussed at the meeting demonstrate the capabilities of large telescopes such as the VLT, and of wide-field imagers. It is evident that there is a large community of astronomers in Chile working on different aspects of the same topic. Exchanging information about their programs and results has been an enlightening experience.

Warm thanks go to A. Lagarini for taking care of the logistics of the meeting.

ESO-ESA Meeting on a Coordinated Approach to Astronomy

Cosmology and Fundamental Physics

Peter Shaver (ESO)

Astronomers of ESA and ESO share their views on future cooperation between space and ground-based astronomy.

A meeting between representatives of the ESA and ESO science advisory structures took place in Garching (Germany) on 15–16 September 2003, to explore possibilities for future coordination between ground and space astronomy. Members of the executives of both ESO and the ESA Science Programme also participated.

The meeting took place in the context of the long range planning activities currently underway at both ESO and ESA. The objective was to exchange ideas for further coordination of activities, given the European nature of the two organizations and their service to essentially the same scientific community, and to serve as input for the long range studies being carried out by both organizations.

The meeting started with brief overviews of the current programmes of both organizations, followed by discussions of scientific areas of common interest. Areas of overlap and complementarity were identified, and possibilities for future coordination were discussed.

A number of actions are being undertaken as a result of the meeting.

1. A document is being jointly prepared on the relevant activities carried out by both organizations and the synergies identified for future planning. This information will be widely distributed to the scientific community in Europe.

2. A framework is being outlined on how to deal jointly with large programmes requiring space and ground-based support. Further discussion will then lead to a proposal to ESA and ESO for possible implementation.

3. A proposal is being prepared for exchanging time on existing facilities. A practical case discussed at the meeting was the joint use of Newton-XMM and VLT.

4. Initially three working groups are being established, to consider coordination in the areas of extrasolar planets, the scientific exploitation of the Herschel and ALMA projects, and the monitoring and study of NEOs.

At the meeting, ESO and ESA reconfirmed their support to the further development of the AVO activities in integrating access to data archives from ground and space-based facilities. The documents and reports from the above activities will be released as they become available.

The agenda and the contributions are available on *http://www.eso.org/gen-fac/meetings/esaeso-2003/agenda.html*

ESO Workshop on "Science with Adaptive Optics"

Wolfgang Brandner (MPIA Heidelberg) and Markus Kasper (ESO Garching)

From September 16 to 19, 2003, the ESO Workshop on "Science with Adaptive Optics" took place at ESO Headquarters in Garching. Its scope was to bring together users of adaptive optics (AO) from all fields of astronomy in order to discuss the latest scientific results obtained with AO systems, and to exchange ideas on how to reduce and analyse such observations.

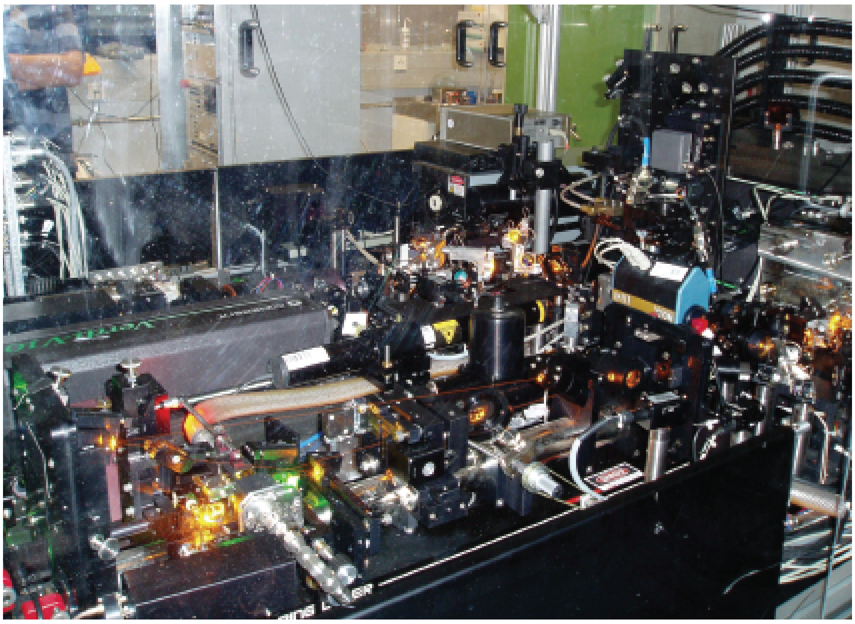
More than 100 researchers working in many different areas of astronomy came together, providing a comprehensive picture of the utilization of AO, and highlighting the unique science potential of AO for all branches of astronomy. September 2003 also marked the completion of the first year of science operations of NACO and the first VLT AO System (Brandner et al. 2002, *ESO Messenger* 107, 1).

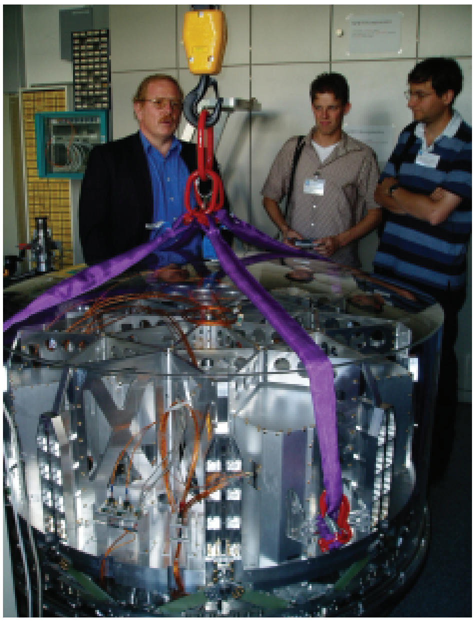
Both the "Lessons Learned" by the ESO staff and community, and a significant number of science results obtained with NACO were presented at the workshop.

The meeting opened with a brief, yet concise introduction to the history of AO presented by François Rigaut (Gemini Obs.), and continued with overviews of various AO systems, as well as talks on observing and data analysis strategies. Christoph Keller (NSO) started off the science sessions with a review talk on the results of high spatial resolution observations of the Sun. The session on solar astronomy was followed by talks on Solar System objects, circumstellar discs (review by François Menard, LAOG), substellar companions, HII regions with a focus on Orion, as presented by Daniel Rouan (Obs. de Paris) and colleagues, and starburst environments. Hideki Takami (SUBARU telescope) presented differential spectroscopy of the extended molecular layers of late-type stars. The highlight of the session on "The Galactic Center and beyond" was the review talk by Reinhard Genzel (MPE), summarizing the latest results on the supermassive black hole in the centre of our Galaxy.

In recent years, the field of AO has matured considerably, as shown by the large number of contributions dealing with extragalactic objects. Tim Davidge's (Herzberg Institute, NRC) review on "Resolved Stellar Populations in Star Clusters and Nearby Galaxies" drew the link between Galactic and extragalactic studies, followed by several talks on NGC 1068 and other nearby AGNs, and quasar host galaxies. One of the highlights here was the measurement of the inner rotation curve around the central black hole in Centarus A as presented by Nadine Häring (MPIA). The workshop closed with an outlook on "Science with future AO systems", and with a review by Roberto Gilmozzi (ESO) on "Science with OWL".

In summary, the 54 talks and more than 25 poster contributions gave a lively picture of the multitude of science topics to be addressed by AO, and proved that AO has become an essential tool in observational astronomy.





Technical and ethnological excursions during the workshop: Visit to the Laser lab at MPE, the VLT Laser Guide Star PARSEC (above), Reinhard Genzel explaining SPIFFI to workshop participants (above right), happy workshop participants visiting the opening of Oktoberfest after the end of the meeting (right). All images are courtesy of Dimitrios Gouliermis.

ESO-Workshop on

High Resolution Infrared Spectroscopy in Astronomy

Hans Ulrich Käufl and Alan Moorwood (ESO)

Infrared spectroscopy at a resolution of a few km/s allows to study rotational-vibrational transitions of many abundant molecules as well as important atomic lines in a multitude of interesting astrophysical environments. The ESO VLT will shortly be equipped with two unique infrared spectrometers which combine spectral resolution with spatial resolutions of ≈ 0.2 arcsec:

- CRIRES, an adaptive optics fed 1–5 µm spectrograph with $\lambda/\Delta\lambda \approx 10^5$
- VISIR, including a mode with $\lambda/\Delta\lambda \approx 3{\bullet}10^4$ between 8–13 µm.

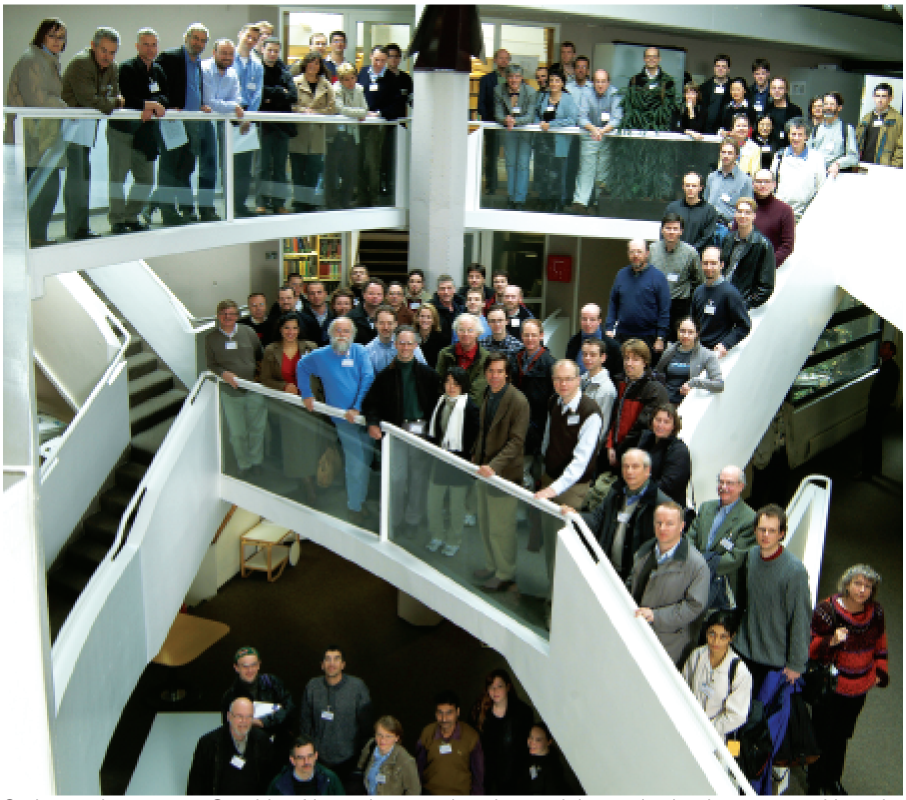
The Workshop held in Garching on November 18–21, 2003 was organized mainly to create awareness of these new observational capabilities and to stimulate their use by the community. The first positive result was that more than 100 astronomers braved the November weather and made it to Garching, twice as many as attended a similar workshop in 1992 devoted to both optical and infrared high resolution spectroscopy. Many late applicants also, unfortunately, could not be accommodated. The second clear difference compared to 1992 was the breadth and maturity of the scientific interest despite the still limited high resolution instrumentation available.

There were 26 invited, 29 contributed and 39 poster papers covering the observable universe between 0.2 AU and several Mpc. State-of-the-art instrumentation, observational highlights, exciting new observational projects, sophisticated models and laboratory studies were presented covering as diverse fields as our solar system, star-formation and young stars, "normal" stars, late-type stars, AGB stars and post-AGB-Objects, the possible direct detection of exoplanets, measurements of the abundances and magnetic fields of stars, studies of ISM chemistry and the kinematics of stars and gas in galactic centres.

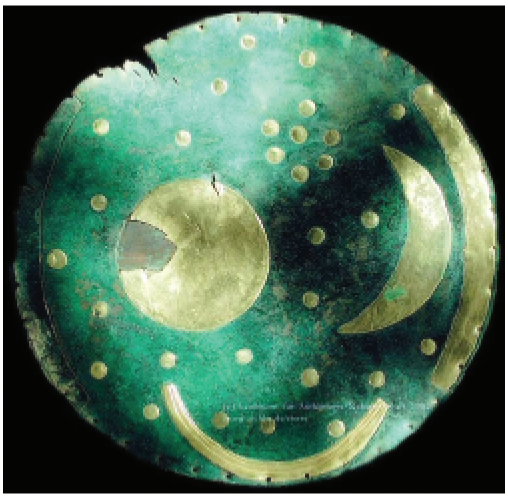
As the "cement" for this conference was infrared spectroscopy many people came together from different fields who would normally not meet at conferences focused on a specific astronomical topic. There is thus a good chance that the workshop has fostered new contacts and collaborations. Certainly the participants went away very happy and we at ESO learned a lot which is relevant to the fine tuning and putting into operation of the CRIRES and VISIR instruments.

In the next issue of The Messenger there will be an in-depth article summarizing the highlights and Lessons Learned of this particular workshop.

Those interested in the programme or any other details please consult the webpage: *http://www.eso.org/gen-fac/meetings/ekstasy2003.*



Owing to the average Garching November weather the participants had to be squeezed into the ESO central staircase for a group photo.



Intrigued by the aesthetic beauty of this creation of our colleagues in earlier epochs, the photo of the Nebra Disc (courtesy of the Landesmuseum für Vorgeschichte of Saxony-Anhalt, Germany) was selected as the basis of the workshop poster.
This 32 cm diameter bronze disc, which is by itself already very fascinating, appears even more thrilling given the fact that this artifact is being interpreted by archeo-astronomers as a pocket-version of the Stonehenge site. For more information, please look at the conference web site.

ESO-USM-MPE WORKSHOP ON

MULTIWAVELENGTH MAPPING OF GALAXY FORMATION AND EVOLUTION

A. RENZINI (ESO Garching)

CO-ORGANIZED with the Universitäts-Sternwarte-München and the Max-Planck-Institut für Extraterrestrische Physik, this workshop was held in Venice, Italy, from October 13 through 16, 2003. The venue, on the premises of the *Venice International University* on the island of S. Servolo, proved ideal for hosting the 173 participants for the four full days of the meeting.

The workshop was meant to expand over a broader range of issues compared to the ESO-USM workshop on *The Mass of Galaxies at Low and High Redshift* that was held in 2001 in the same place. Much indeed has occurred in the meantime, worth reporting and discussing. An impressive set of facilities, in space and on the ground, are now used to map galaxy populations in all relevant windows, from X-rays to radio wavelengths, from the local universe to the highest possible redshifts, from pencil-beam probes to wide scale surveys. The primary goal of the meeting was to document these observational efforts while trying to answer the current main questions on galaxy formation and evolution:

- When did star and galaxy formation begin?
- What kind of sources have been responsible for the re-ionization of the universe?
- How has the overall star formation evolved with time?
- What is the interplay between galaxy and AGN formation and evolution?
- What has been the relative role of thermonuclear vs. accretion power in the global energetics of the universe?
- How did the mass assembly of galaxies proceed with cosmic time?
- When did the morphological differentiation of galaxies take place?
- At what pace have these processes proceeded as a function of the LSS environment?

Following cosmic time, presentations and discussions proceeded from high to low redshift, starting on the first day with an exciting review of the WMAP major results by Licia Verde. The most intriguing result was, of course, the very high redshift of re-ionization advocated by the WMAP team. As then emphasized by Piero Madau and Andrea Ferrara, the observed luminosity density of the ionizing radiation (from either galaxies or AGN) does not seem to increase fast enough with redshift, leaving open the first two questions above, and highly speculative our description of the universe between $z \sim 6.6$ and ~ 1000.

The search and characterization of the highest redshift galaxies was the next major topic. Quite successful has been the narrow-band filter technique to find Ly-α emitters, especially with the Suprime Camera on Subaru (Yoshiaki Taniguchi, Len Cowie), with several objects at $z \sim 5.7$ and $z \sim 6.6$ having been identified thanks to Ly-α passing through OH-free spectral windows. Promising results from the dropout technique were also reported, using ACS multicolour data from public GOODS (Matt Lehnert) and ACS/GTO data (Garth Illingworth). While we still know very little about the galaxy population beyond redshift ~ 5, these studies demonstrate that observing strategies exist to make rapid progress.

Mostly focused on AGNs, a full session was dedicated to X-ray observations, also in combination with optical and sub-mm observations. The space density of both obscured and unobscured AGNs appears to peak at the fairly low redshift $z \sim 0.7$, and then declines steadily at higher redshifts (Günther Hasinger), thus exhibiting a quite different behaviour compared to the cosmic star formation history, which reaches a maximum at $z \sim 2$ and then stays nearly constant, as several speakers reported (e.g., David Elbaz, Mauro Giavalisco, Chuck Steidel).

With much of the star formation being

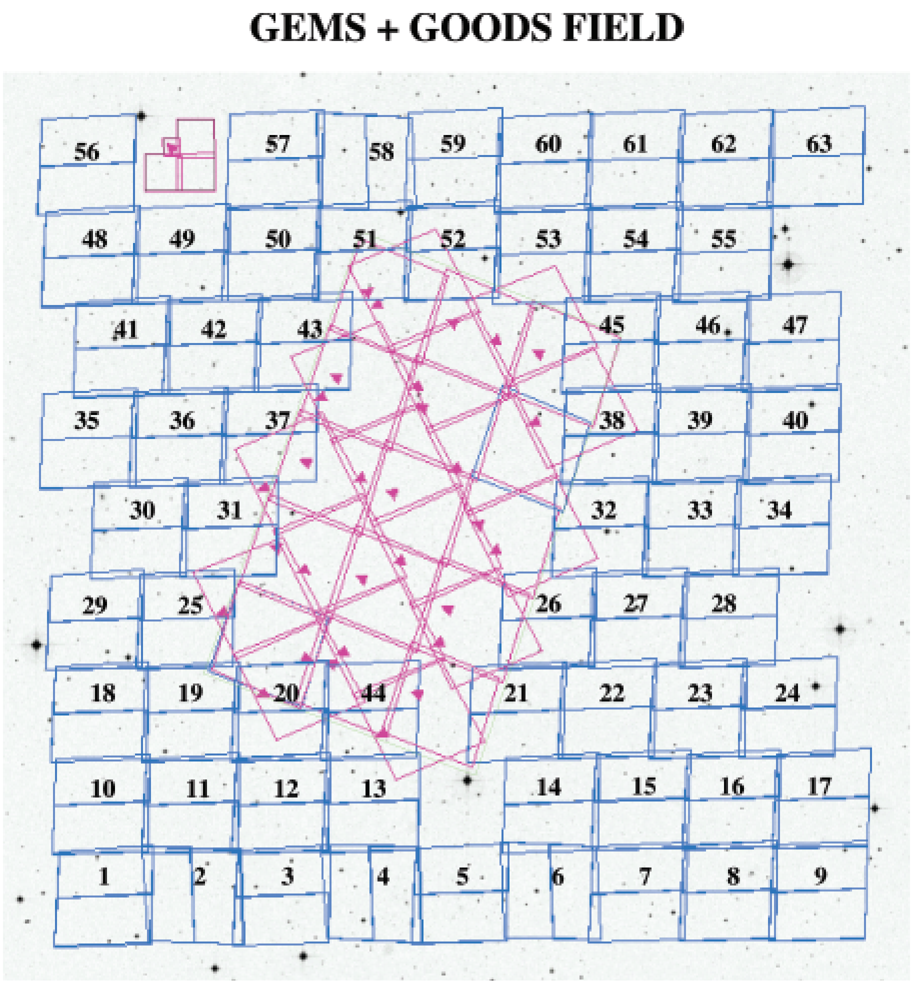


Figure 1: The mosaics of the GEMS (blue) and GOODS (magenta) individual ACS exposures in the CDF-S field (courtesy of Hans-Walter Rix). ACS data are publicly available.

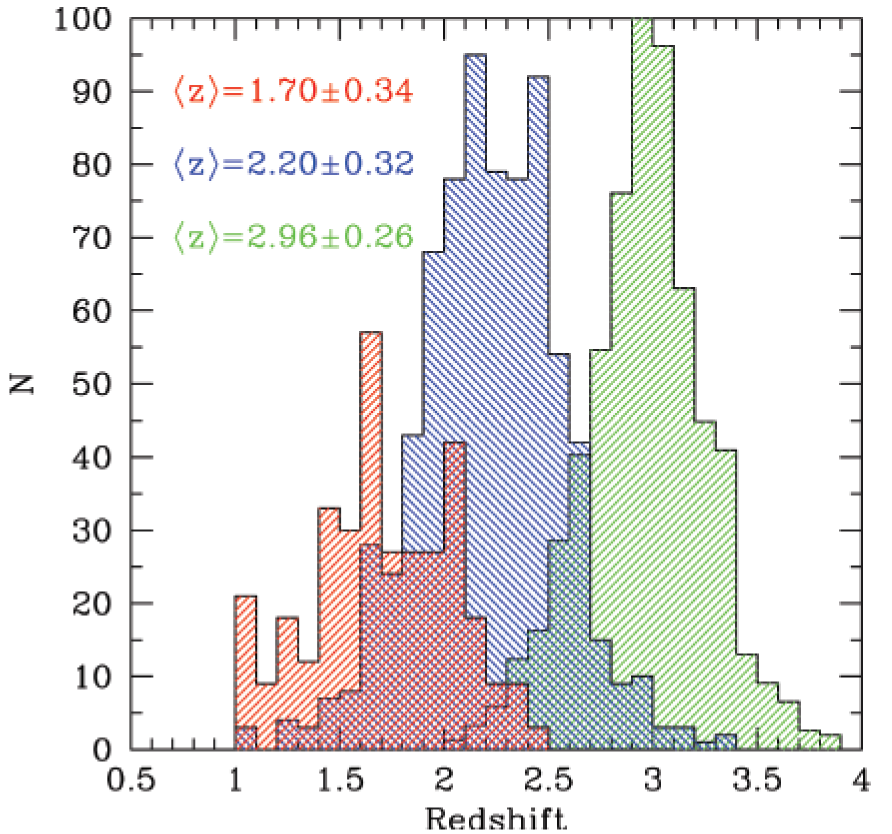


Figure 2: The redshift distribution of 2-colour selected high redshift galaxies observed at Keck with LRIS-Blue and LRIS-Red (courtesy of Chuck Steidel).

hidden by dust in the optical and near-IR, we can learn a lot from mm and sub-mm observations of high redshift galaxies. So, while waiting for ALMA, reports of SCUBA, MAMBO, SIMBA and IRAM observations (respectively by Ian Smail, Frank Bertoldi, Tommy Wiklind, and Reinhard Genzel) were followed with much interest. In particular, Reinhard reported the IRAM measurement of the very high mass of a z=2.8 galaxy via the CO linewidth, showing that the sub-mm can do much more besides offering a better measure of the star formation rate. As SCUBA angular resolution is too coarse, in a fully multifrequency approach Scott Chapman used high-resolution observations in the radio to identify the likely optical counterparts of a sizable sample of SCUBA sources, then obtained their redshifts using optical emission lines. The objects lie at a median redshift 2.4, and with a space density over 1000 times higher than in the local universe they contribute significantly to the global star formation rate at their epoch.

The central part of the workshop was occupied by multifrequency surveys. The status, first results, and perspectives of GOODS were reported by Mark Dickinson, Mauro Giavalisco, Stefano Cristiani, and others. With the ACS data fully acquired, reduced, and publicly released along with the VLT/ISAAC near-IR coverage of about 1/3 of the GOODS-South field, astronomers are eagerly waiting for all the promised complementary data to become available. Besides completing the near-IR coverage, this includes especially the SIRTF mid-IR coverage now to be completed in 2004, along with the FORS2 and VIMOS spectroscopy. While the GOODS database is still largely incomplete, important scientific results are nevertheless being produced with what is already in hand. In particular, a robust estimate of the UV luminosity density and of the space density of Lyman-break galaxies (LBG) all the way to $z \sim 6$ was presented (Giavalisco), along with the evolution of their size (Ferguson), while combining *Chandra* X-ray and ACS observations it has been possible to estimate the space density of high-z QSOs in the GOODS fields (Cristiani).

The Combo17 project, along with its HST/ACS "GEMS" extension (see Fig. 1) was presented by Hans-Walter Rix and Eric Bell. Some 30,000 photometric redshifts from 17 intermediate and broad bands led to an estimate of the evolution of the red-sequence (or early type) galaxies all the way to $z \sim 1$, with their colour change being consistent with passive evolution.

However, their luminosity density at $z \sim 1$ falls short by a factor 2–3 with respect to a pure luminosity evolution (PLE) model, with the missing galaxies being the faint ones, rather than the bright ones, as one may have expected. ACS images confirm that the vast majority of red-sequence galaxies are morphologically early type (i.e., Sersic index $n \geq 2$).

Chuck Steidel reported how he was able to "*colonize*" the so-called "redshift desert" ($1.5 \leq z \leq 2.5$) using LRIS-Blue at the Keck telescope, hence sampling the rest-frame UV of star-forming galaxies selected by a two-colour criterion, similar to the one first used for LBGs at $z \sim 3$. Fig. 2 shows the wealth of galaxies that can be seen in the desert once a UV-blue sensitive spectrograph is used, as indeed required to detect the interstellar absorption lines over the UV continuum of star-forming galaxies (see an example in Fig. 3).

Compared to surveys of UV/optically selected galaxies, the observation of galaxies selected in the near-IR (such as in the FIRES, MUNICS, GDDS and the K20 projects) offers a somewhat different, complementary view of the distant universe. Ultradeep near-IR observations over the HDF-S have revealed a population of galaxies with photo-$z \sim 3$ which only marginally overlaps with LBGs, nearly doubling the estimated stellar mass at this redshift (Ivo Labbé). The growth with cosmic time of the stellar mass density was one of the central themes of the conference, along with the number density evolution of very massive stars. Both the K20 and the GDDS spectroscopic surveys (Andrea Cimatti, Emanuele Daddi, Adriano Fontana, Hsiao-wen Chen) appears to indicate that much more many massive galaxies were already in place at $z \gtrsim 1.5$ than so far predicted by semi-analytical models. Yet, while their number density appears to be in better agreement with a PLE model, they are in fact starburst galaxies much different from the galaxy population in the model itself. On the other hand, the discrepancy with respect to semi-analytical models seems less severe in the MUNICS photo-z survey (Niv Drory), which is ~ 0.5 magnitude shallower in K but extends over 20 times larger area. In the end, everybody agreed that cosmic variance may go some way towards accounting for apparent discrepancies between different surveys, along with different selection effects.

The formation and evolution of early-type galaxies remains a key issue that was widely discussed at the meeting, using both the low-redshift and high-redshift evidence (e.g., Emanuele Daddi, Daniel Thomas, Nobuo Arimoto, Mariangela Bernardi, Guinevere Kauffmann, Roberto de Propris, Scott Trager) with the prevailing opinion favouring a very early formation epoch ($z \geq 2$–3) for the bulk of stars in these galaxies, with rather small dependence on the environment.

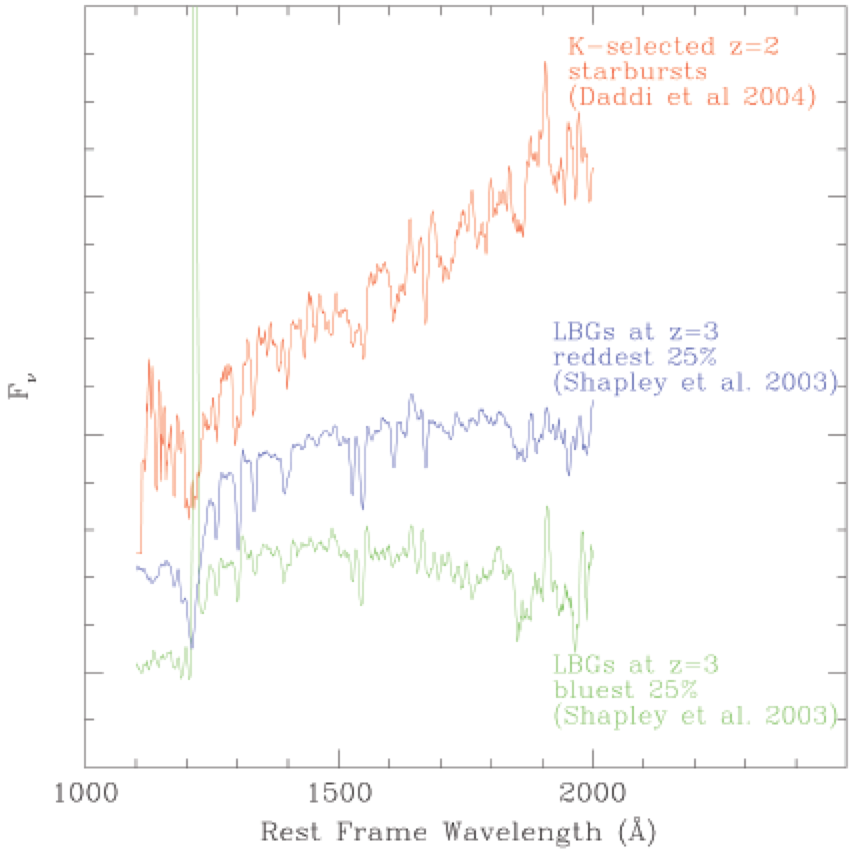


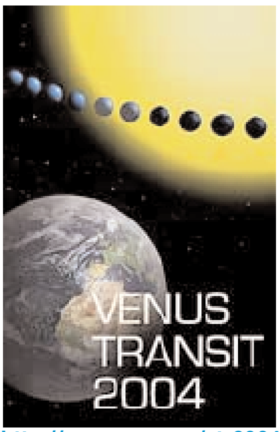
Figure 3: VLT/FORS2 coadded spectra of starburst galaxies with $1.7 \leq z \leq 2.3$ from the K20 sample (courtesy of Emanuele Daddi), are compared to the coadded spectra of the 25 bluest and 25 reddest classical z= 3 Lyman-break galaxies.

While the meeting was mostly dedicated to observations, hence dominated by observers, a few theorists also attended and made lively contributions to it (Avishai Dekel, Cedric Lacey, Rachel Somerville, Simon White). Rachel, in particular, presented efforts in tuning model parameters trying to push the assembly of massive galaxies towards earlier epochs.

Imaging/spectroscopic surveys that have just started were also illustrated, showing early results from the VLT VIMOS Deep Survey (VVDS, Olivier Le Fèvre), the Keck DEEP/DEEP2 survey (David Koo, Jeffrey Newman), and GALEX (Chris Martin, Mike Rich). For other major surveys that are about to start, motivations, plans, and expectations were also illustrated, including SWIRE on SIRTF (Alberto Franceschini, Seb Oliver), the near-IR Ultra Deep Survey which is part of UKIDSS (Omar Almaini) and the COSMOS 2-square degree ACS survey (Nick Scoville). Given its convenient equatorial/10^h location, COSMOS is attracting virtually every major facility on the ground and in space with the goal of providing a full multiwavelength, public dataset, thus promising astronomers the means they need to cope with cosmic variance while mapping galaxy and LSS evolution all the way to at least $z \sim 3$.

All in all, during the four days of the meeting 66 oral and over 100 poster contributions were presented, and I apologize for the many I could not mention in this cursory summary. Much of the success of the meeting was also due to the 30-minute long discussions at the end of each session, and to the colloquial atmosphere favoured by the city and by the daily vaporetto trips to and from the island.

The VT-2004 Educational Programme - A Unique Opportunity



http://www.eso.org/vt-2004

On June 8, 2004, Venus passes in front of the Sun as seen from the Earth. This very rare event (the last one was in 1882 and no living person has ever seen one!) lasts about 6 hours and will be visible from most of Europe, Africa and Asia. It will most certainly generate unprecedented attention from the media and the public, not just in these areas, but all over the world.

The VT-2004 project is launched in this connection and aims at transforming public curiosity into knowledge and interest in science through a broad set of actions. It is managed by the European Southern Observatory (ESO) and the European Association for Astronomy Education (EAAE), together with the Institut de Mécanique Céleste et de Calcul des éphémérides (IMCCE) and the Observatoire de Paris in France, as well as the Astronomical Institute of the Academy of Sciences of the Czech Republic. The programme is supported by the European Commission in the frame of the European Science Week 2004. It starts officially on January 1, 2004, but provisional information is already available at the dedicated website (www.eso.org/vt-2004/). When ready, it will provide access to a wealth of related information in many (European) languages about many different aspects (scientific, technical, historical etc.) of this event.

The VT-2004 project invites active participation of all interested individuals (including teachers, students, amateur astronomers, etc.) and educational institutions (planetariums, public observatories, science centres, etc.). It will provide comprehensive information about the related - scientific, technical, social and historical - aspects. It encourages and will coordinate real-time measurements of the transit, thus publically re-enacting the determination of one of the most fundamental astronomical parameters, the distance from the Earth to the Sun. It also explains the relation of this event to the search for extra-solar planets by the transit method, the only one which, in the near future, might be able to discover Earth-size planets.

The VT-2004 project promotes international collaboration throughout a large part of the world, by observing the same rare celestial event, debating it via the web and adding local observational contributions to a large, common database. Real-time feed-back via the web and the media will ensure that this will become a very special public event. A large, international network of educational institutions that will be actively involved in the Venus Transit event is being established (see the website).

Physics on Stage 3: Life and New Frontiers

B. Mackowiak and R. West (ESO)

THE TEACHING OF PHYSICS in Europe's schools is changing. In a growing number of places, thanks to well-informed and dedicated teachers, it is becoming an increasingly fascinating subject, appreciated by the students. More and more educators are beginning to realize that physics lessons may be a stage for demonstrations of how our daily life is influenced by numerous physical phenomena and processes. Moreover, as new frontiers of research open, new opportunities arise for interesting and effective teaching means and methods.

The new trends in the teaching of physics and basic facts about this and related subjects were high on the agenda when more than 400 delegates from 22 European countries met during this year's "Physics on Stage 3" festival (POS 3), organized at ESTEC/ESA (Noordwijk, The Netherlands) on November 8–15, 2003 by the EIROforum Working Group on Outreach and Education, and held with support from the European Commission under the auspices of the European Science and Technology Week. Following the preceding, vastly successful events in 2000 and 2002, the main theme this year was "Physics and life", reflecting the decision to broaden the Physics on Stage activities to encompass more of the natural sciences, in particular biology, within an interdisciplinary approach.

On the first day, the seven EIROforum organizations (CERN, EFDA, EMBL, ESA, ESO, ESRF, ILL) presented selected aspects of their current work during individual 3-hour sessions. An eighth session was organized by the European Physical Society and the European Association for Astronomy Education (EAAE). ESO had chosen to run an

ALMA presentation session.

"experimental" session to demonstrate new and exciting possibilities of the wide and fascinating field of interdisciplinary teaching, with the ALMA project at the centre and the title "The Atacama Large Millimeter Array Project and Related Educational Opportunities". Emphasis was placed on the opportunity to illustrate the workings of a major international science and technology project, not just through research goals and techniques, but to introduce other fields, for example geography, chemistry, biology and history. The subject of ALMA can thus be made more "interesting" and useful in an educational context because of the many entry points, be it geological aspects (volcanoes, earthquakes), historical (the native people in the Atacama region), biological (the sparse life in the desert or the high-altitude effects on human beings) or political/international ones (the making of the ALMA project; management; operation). About thirty teachers from more than a dozen countries listened to talks given by Peter Shaver, Tom Wilson, Bernhard Mackowiak and Richard West; each of them received a comprehensive booklet and a souvenir. During the ensuing discussion, the participants explained about their experience with interdisciplinary teaching and made various proposals on how to fuse ALMA and education. They were told to send in their ideas to ESO's Educational Office, thereby contributing to the start-up of this new educational project.

As before, ESO had set up a stand at the fair, informing the POS 3 participants about this organisation's main goals, as well as its present and future projects, and leading to interesting and useful discussions with the teachers. Also at POS 3, ESO and EAAE announced the winners of this year's European student contest "Catch a Star!".

Spectacular and original performances by students and professional actors, intensive encounters at the central fair, seminars and workshops were the components of the rich, one-week POS 3 programme. Among the highlights were the Opening Ceremony with the attendance of Prince Johan Friso of the Netherlands and the Dutch Minister for Education as well as the Farewell Dinner with the presentation of the Project Development Awards. Four teachers were awarded cash sums for the further development and dissemination of their excellent projects. A documentary film was shown about the solar race across Australia and the presentation of the Netherlands winner crew proved that physics is life.

The next event in this series will be "Science on Stage 4", to take place in Grenoble (France) in the first half of 2005.

Look at the website of the ESO Educational Office (*www.eso.org/outreach/eduoff/*) for more information and links to related programmes.

Prince Johan Friso (right) of the Netherlands inaugurated the one-week event.

A display during the POS 3 festival.

Visualising acoustic waves.

Fellows at ESO

George Hau

I joined ESO in July 2001. Until June 2003 I was Instrument Scientist for EFOSC2 on the 3.6m, whose manual I have rewritten recently (see News From La Silla). What I like most about my work is the quality of training received. It is very refreshing to arrive at La Silla every time to know that I would learn something different but invariably interesting. The human factor is also important. I really enjoyed the interactions with the visiting astronomers and to learn about the science they are doing, and to share the excitement when the data arrives!

Apart from duties on La Silla, I was a member of the Visiting Scientist Committee in Santiago. In June 2003 I co-organised a Workshop on Resolved Stellar Populations in Vitacura.

Since July 2003 I am based in Garching with reduced duty. My research is concerned with elliptical galaxy formation at different mass scales from a low-redsift perspective. Although the trend is to go to higher and higher redshifts, I think that a lot can still be learned from nearby galaxies. At the low mass scale I am involved in a ESO Large Program on the nature of dwarf ellipticals. In the intermediate mass scale I am comparing galaxy properties in different environments, such as Kinematically Decoupled Cores and shells which often provide clues on the past merger history. At the high mass scale I am leading a collaboration to study the properties of cD galaxy halos. In several cases we found an outwardly rising velocity dispersion profile which shows that the stars in the outer parts of cD halos are responding to the gravity of the cluster as a whole. On an unrelated topic, I am also participating in an all-sky hunt for Local Group dwarf galaxies. So far we have found two dwarfs, but it seems that there isn't a big population of dwarfs in the Local Group which have been predicted in some CDM simulations.

I think that the fellowship program is excellent and I would not hesitate to recommend it to anyone who considers applying. It has been fun living in Chile and the experience has been fantastic!

Nuria Huelamo

I joined ESO in November 2002. I was supposed to start my Fellowship in Garching, but decided to move to Chile for a short period of time. I knew the country because I had visited La Silla very often as a PhD student, and I always had the feeling that it was a nice place to live. Professionally speaking I feel I am in the right place: Vitacura is a lively institute full of special people.

As do many fellows I have my duties in Paranal. From the scientific point of view my experience could not be better: I am in touch with sophisticated instruments and it is always fruitful to discuss with visiting astronomers. Although the work can be stressful, I find the atmosphere amongst the fellows and the rest of Paranal divisions very good and collaborative, which helps to solve the problems in an efficient way. There is also time to relax and I usually visit the music room with some colleagues.

Before joining ESO I spent three years in Garching where I obtained my PhD. I was working in the neighbouring Max-Planck-Institute (MPE) and the main topic of my thesis was the study of magnetic activity and rotation in a group of young late-type stars in binary systems. Most of my thesis was based on X-ray and optical data. However, I also had the opportunity to work on adaptive optics (AO) data which I found really exciting. I started to get interested in AO techniques and that was one of the reasons why I asked to be an ESO fellow: I wanted to work with NAOS-CONICA (NACO). I made the right decision: I am learning something new every day and it is a pleasure to support top scientific research involving this instrument. As a scientist, I am leading different scientific projects with NACO which include imaging and polarimetry of young stars. Moreover, I am collaborating with the star-formation people in Vitacura. This is a very active group with astronomers working in different research fields, providing me a wider knowledge of different aspects of star formation.

Elena Mason

I arrived at ESO and Chile in September 2001, as a fellow with duty in Paranal. I have just started my third year of fellowship which I decided to spend within ESO too, for the simple reason that I am really enjoying both the Paranal and the Vitacura environments. I believe that the time spent at the observatory, despite subtracting working weeks from your own research time, provides you with a competitive knowledge on top instruments, while the contact with colleagues and other scientist gives new ideas and perspectives. Indeed, I am very happy about this experience.

My research focuses on the world of cataclysmic variables (CVs) where I gained expertise both on short orbital period dwarf novae (DNe), and classical novae (CNe). In dwarf novae I study accretion discs and spectral energy distributions, continuing the research project started during my PhD. While in classical novae I am mainly studying their spectroscopic evolution. Working on CNe, I have realised the limit of current analyses, which lack systematic quantitative studies and/or modelling for a correct measurement of the ejected mass and the shell shape. I thus started new projects which either make use of new (to me) techniques (e.g. polarimetry) to investigate the asymmetries in the ejected shell, or intend to recover archive data of CN nebular spectra for a consistent determination of ejecta abundances. The expertise gained on Paranal also gave me the chance to get involved in new projects, while the lively ESO-Vitacura department offered to me chances for new collaborations. Both will help me broadening my knowledge and working field.

Living in Chile/Santiago one can profit from the Andes mountain range to do high altitude mountaineering, my major hobby during university years. Unfortunately my constantly cracking knee did not help me in a healthy active use of my free time.

Markus Nielbock

My first contact with ESO was a visit at the SEST on La Silla in 2000 in order to help with the installation and testing of the computer facilities for the planned bolometer array SIMBA. This matched my scientific background of early stages of star formation for which I mostly investigate in the millimetre and sub-millimetre, but also in the infrared regime of the electromagnetic spectrum. It was the team leader Lars-Ake Nyman who encouraged me to apply for the ESO Fellowship programme. At that time, I was in the middle of working on my PhD in Bochum (Germany) under the supervision of Rolf Chini, and I really had not thought about post-doc positions yet, but the prospect sounded very tempting. So, I applied and got the job. But this also meant, I had to speed up and finish the PhD within 2,5 years, since the installation of SIMBA required me to assume this new position on June 1st, 2001.

I began to study physics in Düsseldorf, but then moved to Bochum in order to be able to concentrate on astronomy. I still remember a professor in Düsseldorf claiming that those not having specialised on physics in grammar school might not be suitable for this college career. Well, this was obviously not true. I found physics in school very boring, and the topics I was interested in were not taught there. So, I helped myself by reading books like Steven Weinberg's "The First Three Minutes".

Leaving Europe and going to Santiago for a couple of years was a big step and a personal challenge for me, but definitely a rewarding one. What I liked most was the large variety of scientific disciplines besides astronomy (cryogenics, microwave engineering, software programming, computer system maintenance) I got in contact with, especially at the SEST, where everyone did almost everything. During the more than 2 years (until its closure in August 2003), I was also in charge of the operations and data quality management of the newly installed bolometer array SIMBA attached to this 15-m millimetre telescope. Also the contact with colleagues, guests and visiting observers was very inspiring.

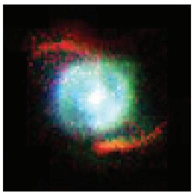
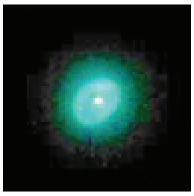
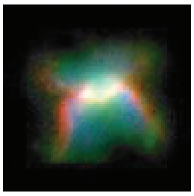
Despite the amounts of functional work at the observatory, there was ample time to pursue my own scientific interests in ESO-Vitacura. I am mostly interested in the formation of stars, both in the low-mass and the high-mass range. In order to probe the earliest stages of the protostellar collapse and thereby look for protostars, I mainly use millimetre and submillimetre telescopes which made me a bit exotic among the scientists in Santiago. Already in my PhD thesis I reported on the detection of numerous low-mass protostars and determined their physical properties. Recently, I started to concentrate on the higher end of the mass scale with two projects. The first one deals with the investigation of masers in star forming regions. They are of potential value for locating young massive protostars. The other programme is about the recent first detection of a massive accreting protostar. This is the work of a group of German and Austrian astronomers in which I participate. As a next step, we need to constrain the properties of our find more precisely.

After more than two years living in Santiago, I returned to Bochum in September 2003. But I am looking forward to visiting Chile for observations next year.

ESO Workshop on

Planetary Nebulae beyond the Milky Way

ESO Headquarters, Garching, May 19-21, 2004

Planetary nebulae (PN) can be detected out to quite large distances from their strong emission lines, principally of [O III]. Photometry of the [O III]5007Å emission line allows distance determination through the Planetary Nebula Luminosity Function. Spectrophotometry of the emission lines can provide nebular abundances, enabling the use of PN as chemical probes of galaxies. The emission lines are also narrow, making PN ideal kinematic probes of a galaxy's gravitational potential. Thus the properties of dark-matter haloes can be studied by modelling the PN kinematics. Recently PN have been detected in intra-cluster regions of nearby galaxy clusters. These PN can bring a unique handle on the stars in regions that may harbour a substantial amount of mass.

Extra-galactic PN serve as versatile probes of nearby galaxies. Planetary nebulae have traditionally been regarded as bright objects; however in the Local Group, and beyond, they can be faint. Large telescopes thus open up the field of extra-galactic PN study. HST and Adaptive Optics can provide images of PN in the LMC and SMC, at resolutions previously expected for Milky Way PN. New instrumentation is also being exploited to measure PN spectra in bulk. The field of extra-galactic PN research is developing rapidly and a conference to review the progress so far and to chart new developments is now timely.

This will be the first full workshop dedicated to the subject of extra-galactic planetary nebulae.

The format of the meeting will consist of invited reviews, in the key areas of extra-galactic PN research, contributed talks and posters, and two discussion sessions.

Central topics will include:

- Surveys for extra-galactic PN
- The PN luminosity function
- PN in the Magellanic Clouds
- Observational dynamics and modelling of PN in galaxies
- Nebular abundance determinations in PN
- PN as probes of galactic chemical evolution and star formation history
- PN in galaxy clusters

Scientific Organising Committee:
M. Arnaboldi, R. Ciardullo, N. Douglas, K. Freeman, G. Jacoby, R. Mendez, R. Shaw, L. Stanghellini (co-Chair), G. Stasinska, J. Walsh (co-Chair)

Full details, list of invited speakers and registration information can be retrieved from *http://www.eso.org/extgalpn04/* or by by email to *pnconf04@eso.org*

Deadline for first registration: 31 January 2004
Final deadline: 15 April 2004

Applications are invited for a position in the Instrumentation Division at the ESO Headquarters in Garching near Munich, Germany. This post is open to suitably qualified men and women.

Infrared Astronomer
Head of the Infrared Instrumentation Department

CAREER PATH: V-VI

Assignment: The Instrumentation Division consists of about 30 astronomers, physicists and engineers, who work closely with other Divisions at ESO plus many national and international Institutes to define, design, build, commission and use cutting-edge optical and infrared instrumentation on ESO's telescopes at its Paranal (VLT) and La Silla observatories in Chile.

You will be responsible and report to the Head of the Instrumentation Division for essentially all aspects of ESO's infrared instrumentation and detector programme. This includes follow-up maintenance and upgrading of instruments operating in Chile (SOFI, TIMMI2, ISAAC, CONICA, VLTI IR detector systems); completion of instruments under development in Europe (VISIR, SINFONI, CRIRES, VLTI and IR detector systems for Adaptive Optics instruments); design studies of future VLT instruments (HAWK-I, KMOS, ...); maintenance of an active IR detector and controller development programme and definition of future instrumentation for the existing and possible future extremely large telescopes. In addition to the scientific and technical aspects this will make strong demands on your personal and project management as well as reporting and presentation skills.

As a senior astronomer you will be a member of the ESO Astronomy Faculty and will be expected to conduct an active research programme.

Education: Ph.D in Astronomy or Physics.

Experience and Knowledge: An outstanding record of both astronomical research and instrument development is required. Excellent communication skills and command of the English language plus proven team leadership skills are essential. Ideally, you will have experience of managing medium sized projects and teams.

Duty station: Garching near Munich, Germany (with stays at the ESO Observatories in Chile as required e.g. to participate in the commissioning of instruments.)

Starting date: As soon as possible.

Contract and Remuneration: 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 support 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, grade and level of responsibility may be subject to change according to qualification and experience.

Application: If you are interested in working in a stimulating international research environment and in areas of frontline technology, please complete the application form to be found at *http://www.eso.org/gen-fac/adm/pers/forms/* and send it to Mr R. Block, Head of the Personnel Department at ESO together with the names of four individuals willing to provide professional reference letters by **31st January 2004.**

For further information, please contact Mr Roland Block, Head of Personnel Department, Tel. +49 89 320 06 589; e-mail: *rblock@eso.org*. You are also strongly encouraged to consult the ESO Home Page (*http://www.eso.org*) for additional information about ESO.

PERSONNEL MOVEMENTS

International Staff

(1 September 2003 - 31 December 2003)

ARRIVALS

EUROPE

ARNDT, Angela (D), Paid Associate
BERRINGTON, Sylvia (PL), Paid Associate
BIALETSKI, Yury (UA), Student
CAPRONI, Alessandro (I), Associate
CARMONA GONZALEZ, Andrés (CO), Student
CHUZEL, Olivier (F), Application Software Designer/Developer
CLENET, Yann (F), Associate
DE BREUCK, Carlos (B), Fellow
DÖLLINGER, Michaela (D), Student
EGHOLM, Mathias (DK), Student
ESTEVES, Raul (P), Associate
FIORENTINO, Mauro (I), Science Data Analyst/Programmer
FRANCK, Christoph (D), Opto-Mechanical Engineer
KÜMMEL, Martin (D), Science Data Analyst/Programmer
LAING, Robert (GB), European ALMA Instrument Scientist
LARSEN, Soeren (DK), Instrument Scientist
LISKE, Jochen (D), Fellow
PEROUX, Céline (F), Fellow
POTT, Jörg-Uwe (D), Student
RAIMONDO, Gabriella (I), Student
RETTURA, Alessandro (I), Student
RIELLO, Marco (I), Student
SADIBEKOVA, Tatyana (UZ), Student
SANTOS, Joana (P), Associate
VAN HEST, Franck (NL), Student
WILSON, Thomas (GB), European Project Scientist ALMA
WOLD, Margrethe (N), Fellow
ZINS, Gérard (F), Associate
ZWAAN, Martin (NL), Fellow

CHILE

BAUMONT, Sylvain (F), Student
CHAUVIN, Gael (F), Fellow
DELLE LUCHE, Céline (F), Student
EDEROCLITE, Alessandro (I), Student
FISCHER, Michael (CND), Associate
GIL, Carla (P), Student
NESVACIL, Nicole (A), Student

DEPARTURES

EUROPE

ENARD, Daniel (F), Senior Optical Engineer
FRANZA, Francis (F), Opto-Mechanical Technical Engineer
GEORGIEVA, Radostina (BG), Associate
GUIMARAES, Rodney (BR), Associate EIS
KOKE, Thomas (D), Administrative Software Systems Specialist
LIMA, Jorge (P), Associate
NORMAN, Colin (AUS), Associate
OLIVIER, Nathalie (F), Associate
PASQUALI, Anna (I), Astronomer
WERNER, Daniela (D), Associate

CHILE

CUBY, Jean-Gabriel (F), Infrared Instrumentation Specialist
FOUQUE, Pascal (F), Associate Eros II
RASSIA, Effrosyni (GR), Student
RÖHRLE, Claudia (D), Student
SKOLE, Steen (DK), Software Engineer

Local Staff

(1 September 2003 – 30 November 2003)

ARRIVALS

ARRIAS GALANO, Andres, Finance Officer
EDMUNDS CONCHA, Ann, Executive Bilingual Secretary
MORNHINWEG, Manfred, Execution Engineer, Electronics
RITZ SOLARI, André, Procurement Officer ALMA
SALAZAR BARRERA, Daniel, Software Engineer
SCHEN, Tzu-Chiang, Software Engineer
SEPULVEDA ORTEGA, Jorge, Software Engineer

DEPARTURES

GUTIERREZ CHEETHAM, Pablo, Electronic Engineer
LOBOS LOBOS, Claudio, Optical Technician

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 ten countries: Belgium, Denmark, 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:

EUROPEAN
SOUTHERN OBSERVATORY
Karl-Schwarzschild-Str. 2
D-85748 Garching bei München
Germany
Tel. (089) 320 06-0
Telefax (089) 3202362
Email: *ips@eso.org*
URL: *http://www.eso.org*

The ESO Messenger:
Editor: Peter Shaver
Technical editor: Henri Boffin
http://www.eso.org/messenger/

Printed by
Universitätsdruckerei
WOLF & SOHN
Heidemannstr. 166
D-80939 München
Germany

ISSN 0722-6691

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.–

Contents