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EL MENSAJERO

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Dear Readers,

With this issue, I am leaving the Editorship of THE MESSENGER, a task which I valued and enjoyed. The Editorship now passes to my ESO colleague Peter Shaver. MARIE-HÉLÈNE DEMOULIN

NAOS+CONICA at YEPUN: First VLT Adaptive Optics System Sees First Light

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1. Introduction

NAOS+CONICA (hereafter NACO) saw first light on November 25, 2001, at VLT UT4 (YEPUN). NACO partially compensates the effects of atmospheric turbulence (seeing) and provides diffraction-limited resolution for observing wavelengths from 1 to 5 μm, resulting in a gain in spatial resolution by a factor of 5 to 15 (diffraction limit of an 8-m-class telescope in K-band corresponds to 60 mas). This article gives an overview of the main characteristics and science drivers of NACO and briefly summarises the first results obtained during commissioning. Prospective users of NACO are kindly asked to cite [7] and [13] as a general reference to NACO in their scientific papers.

2. History

Adaptive Optics (AO) has a long history at ESO, stretching back to the early operations of COME-ON, COME-ON+,

Figure 1: NAOS (light blue) and CONICA (red) attached to the Nasmyth B adapter of Yepun/UT4.

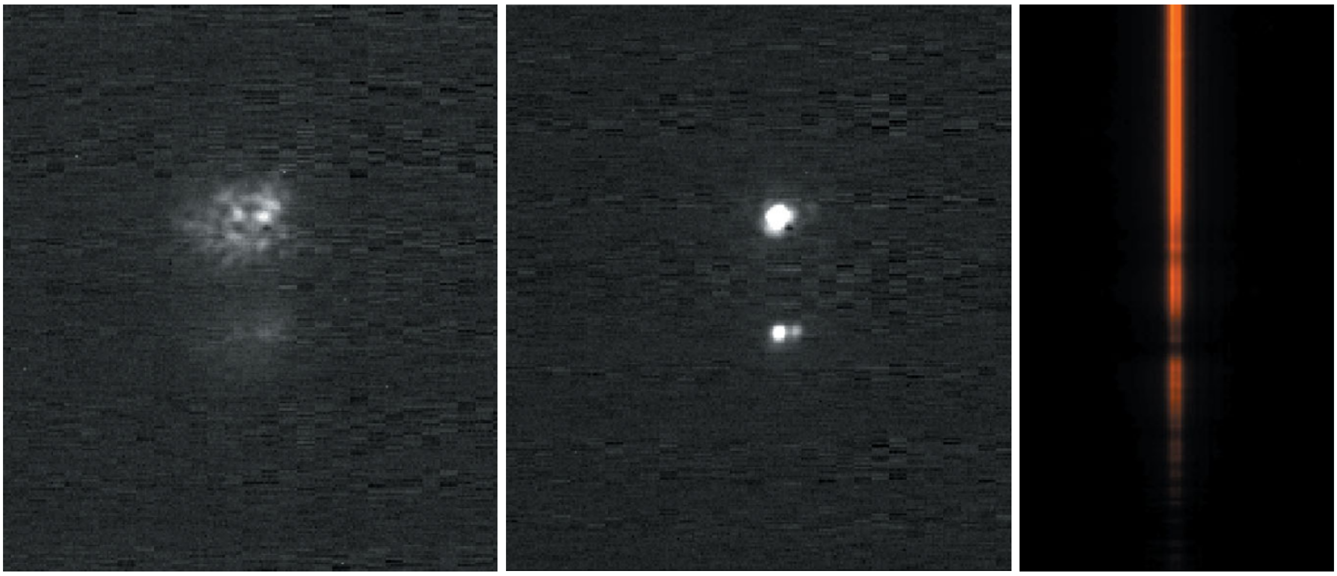

Figure 2: The triple system T Tauri. Shown on the left is an open-loop image (obtained through a narrow-band filter at 2.16 μm with an exposure time of 0.4 sec). Only the 0.7″ binary T Tauri North and South is resolved, while the close binary T Tauri South itself remains unresolved. The image in the middle was obtained with the same instrumental set-up, but with the AO loop closed. The 0.1″ binary T Tauri South is now nicely resolved. The image to the right finally shows a 2D long-slit K-band spectrum of both components of T Tauri South.

and finally ADONIS at the ESO 3.6-m telescope on La Silla (see [1], [6]). Based on this experience, an early decision was made to equip the VLT coudé foci with AO systems ([9]).

CONICA (the COudé Near-Infrared CAmera), a 1 to 5 μm infrared camera for diffraction-limited imaging and spectroscopy, was proposed by a consortium of the Max-Planck-Institut für Astronomie, Max-Planck-Institut für Extraterrestrische Physik, and the Osservatorio Astronomico di Torino in response to an ESO Call for Proposals. It was selected in 1991 as one of the first-generation VLT instruments. Subsequent re-organisations in the VLT schedule led to the (temporary) cancellation of the AO equipped coudé foci and the loss of the Osservatorio Astronomico di Torino to the CONICA project. In 1994 studies for implementing AO at the VLT Nasmyth foci were initiated ([5]) and, in parallel, an effort started to re-design CONICA and transform it into an instrument for a Nasmyth focus. In 1997, a consortium consisting of Office National d'Etudes et Recherches Aérospatiales (ONERA), Observatoire de Paris and Laboratoire d'Astrophysique de l'Observatoire de Grenoble was awarded a contract to develop and build the Nasmyth AO System (NAOS) for the VLT.

After a period of integrated testing at the CNRS facilities in Bellevue, near Paris, NACO was shipped to Paranal in October 2001 and achieved its first light at UT4 at the end of November 2001.

Figure 1 shows NACO mounted at Nasmyth B of UT4. More detailed information can be found at
http://www.eso.org/instruments/naco

3. Instrumental Characteristics and Science Drivers

3.1 NAOS

NAOS ([13]) is a state-of-the-art AO system optimised for operation at the VLT telescopes, and designed to provide a Strehl ratio (SR) of ≥ 70% in the K band when wavefront sensing on a bright natural reference source under average atmospheric conditions on Paranal (yet not compromising its compensation capabilities on very faint sources – V ≥ 16 mag and K ≥ 12 mag). Active optical elements of NAOS include a tip-tilt plane mirror and a deformable mirror (DM) with 185 actuators. NAOS is equipped with two Shack-Hartmann type wavefront sensors (WFS) for wavefront sensing in the optical (450 to 950 nm) and in the near-infrared (0.8 to 2.5 μm).

Both the visual and infrared wavefront sensor can be operated either in 14 × 14 array configuration with 144 active subapertures (in the pupil) or in 7 × 7 array configuration with 36 active subapertures. A range in fields of view per subaperture, temporal sampling frequencies, and pixel scales (binning) of the WFS are available in order to provide optimal performance over a very wide range of observing conditions and reference source characteristics. Dichroics split the light between the wavefront sensing channel (NAOS IR or vis WFS) and the science channel (CONICA). Reference sources for wavefront sensing can be selected at angular separations of up to 60″ from the on-axis science target. Guiding on reference sources with a relative motion is of course possible, and the differential atmospheric refraction between NAOS and CONICA is also taken into account. Last but not least, NAOS can handle VLT M2 beam chopping in order to provide CONICA with the best observing conditions in the thermal infrared.

The NAOS Real Time Computer (RTC) constitutes a highly optimised symbiosis of hardware and software elements ([12]), and is capable of controlling the Adaptive Optics at frequencies up to 444 Hz. It continuously monitors the turbulence and the optimisation of the correction, taking into account the detected brightness of the reference source. It has been designed to easily facilitate the upgrade for a Laser Guide Star (see [2] for more details on the VLT Laser Guide Star facility).

Initial testing indicates that NAOS is delivering full correction (on-axis Strehl ratio of up to 50% in K-band for average atmospheric conditions on Paranal) for a reference source with V = 12 mag. Still higher Strehl ratios might be achievable after various instrument parameters have been fine tuned. The adaptive optics loop has been closed on point sources as faint as V = 17.5 mag (vis. WFS) and K = 12 mag (IR WFS).

3.2 CONICA

CONICA ([7]) operates with the f/15 beam, which is passed through NAOS from the Nasmyth B focus of UT4. CONICA is equipped with a 1024 × 1024 pixel ALADDIN2 InSb detector (pixel size 27 × 27 μm). The ALADDIN2 detector is sensitive to radiation between 0.9 and 5 μm, and is operated at a temperature of 27K. Instrumental background is below 1 e^-/s. CONICA uses

Table 1: List of available Cameras with f-ratios, scales, magnification, field of view, wavelength range.

Camera	f-ratio	Scale [mas/pixel]	Magnification	FOV [arcsec]	Spectral range
C50S	52.7	13.25	3.50	13 × 13	1–2.5 μm
C25S	25.8	27.03	1.72	27 × 27	1–2.5 μm
C12S	12.8	54.3	0.85	54 × 54	1–2.5 μm
C06S	6.36	109.3	0.425	73 Ø	1–2.5 μm
C25L	25.7	27.12	1.71	27 × 27	2.5–5.0 μm
C12L	12.7	54.7	0.85	54 × 54	2.5–5.0 μm
C06L	6.33	109.9	0.42	73 Ø	2.5–5.0 μm

the ESO-developed IRACE readout electronics and acquisition software ([10]). The read-out noise is 40e⁻ for double correlated read-out (ReadReset Read), and can be reduced to ≤ 10e⁻ for longer exposures by using Fowler sampling (FowlerNSamp). Sustainable data rates can be as high as 2 MByte/s (i.e., one full frame saved to disk every two seconds), and exposure times can be as short as 0.2 sec for full frame read-out (or even shorter for windowed read-out) and for short sequences of up to 8 exposures or by using the NDIT > 1 option (frames averaged by IRACE).

CONICA houses seven cameras, which provide Nyquist sampling for the corresponding bands between 1 and 5 μm (see Table 1). Four of the cameras are optimised for observations between 1 and 2.5 μm with pixel scales of 13.25 mas/pixel (C50S camera), 27.03 mas/ pixel (C25S camera), 54.1 mas/ pixel (C12S camera) and 107 mas/ pixel (C06S), and three of the cameras are optimised for observations between 2 and 5 μm (C25L, C12L, C06L with corresponding pixel scales). The field of view for individual cameras ranges from 13″ × 13″ (C50S) to a circular aperture of 73″ diameter (C06S and C06L).

A large variety of optical analysing elements can be rotated into the CONICA beam. For broad- and narrow-band imaging one can select among 34 different filters. Polarimetric observations are supported both by two Wollaston prisms (split approx. 3.4″ in K-band for dual imaging observations) and four wiregrids (“wide field”). For spectroscopy one can choose between four grisms (R = 500 to 2000, with various orders covering the range from 1 to 5 μm) and a cryogenic Fabry-Perot with a resolution of around 1000. Coronography is supported by a Lyot-type coronograph with mask diameters ranging from 0.7″ to 1.4″.

3.3 Science Drivers

The science drivers for NACO were early on defined by the CONICA Instrument Science Team chaired by Marie-Hélène Ulrich. The working group identified both Galactic and extragalactic science drivers:

Galactic astronomy

- Outflows and disks of young stellar objects
- Search for low-mass/substellar companions of nearby stars
- Structure of young embedded objects
- Ionisation fronts in HII regions
- Galactic centre
- Close companions and circumstellar material around T Tauri stars
- Structure of Red Giant envelopes

Extragalactic astronomy

- Quasars and host galaxies
- Emission line imaging of super-luminous IRAS galaxies
- Search for Black Holes in centres of galaxies
- Resolved images of radio jets and hot spots
- Obscured quasars
- The cosmic distance scale

In addition, NACO will facilitate high spatial resolution studies of Solar system objects and astronomical targets in the solar neighbourhood.

4. Observing with NACO

4.1 Preparation of Observations

All AO observations depend on the availability of a reference source suitable for wavefront sensing. Thus a crucial part in the preparation of observations with NACO is to check for such a reference source in the proximity to the science target. The minimal requirement for partial correction by NACO will be a point source with V < 17.5 mag or K < 12 mag within 60″ of the science target. Due to the presence of angular anisoplanatism (see [14]), the best AO correction is achieved in the on-axis case (science target identical with reference source). Online versions of the Guide Star Catalog 2 and the 2MASS point source catalog aid the prospective user of NACO in the search for suitable reference sources (follow links on the main NACO web page http://www.eso.org/instruments/naco)

The operation of NAOS and its internal configuration will be largely transparent to the user. This is achieved by the NAOS Preparation Software (PS, [8]). The PS determines the optimal NAOS configuration given external constraints such as brightness of the reference source used for wavefront sensing, angular separation between reference source and science target, or atmospheric conditions. The result of this optimisation is saved in an AO-configuration file (*.aocfg), which in turn is read by the Phase 2 Preparation Software (P2PP). In addition, it provides the user with information on the expected performance taking into account observing conditions. Finally, it delivers to the CONICA ETC the parameters characterising the image peak intensity and the width after AO correction.

Estimates for required exposure times can be obtained from the CONICA exposure time calculator (ETC). The CONICA ETC is closely related to other ETCs for VLT instruments and should thus feel familiar to most users. As a rule of thumb, the overall throughput of NACO is about half that of ISAAC, and required exposure times can be scaled accordingly. Because of the smaller “footprint” of the diffraction-limited Point Spread Function (PSF) of NACO compared to the seeing limited PSF of ISAAC, point source sensitivity in the sky-background limited case tends to be higher for NACO than for ISAAC.

Similar to other VLT instruments, NACO observations are supported by a dedicated set of acquisition, observing and calibration templates. Using P2PP, these templates can be grouped in observing blocks in order to define observing sequences. For each observing block, the AO-configuration file created by the PS has to be specified only once in the corresponding acquisition template.

4.2 Observing with NACO at the VLT

At the time of writing, NACO is still in its commissioning phase, and not all instrument modes have been validated, yet. Initially it is expected to offer imaging and polarimetry from 1 to 4 μm as well as long-slit spectroscopy (R = 500 to 2000) and coronography, though the latter two only with a restricted set of slits and grims, and coronographic masks, respectively. The cryogenic Fabry-Perot and observations in the M-band (still requiring more testing of the chopping mode) will very likely only be offered at a later stage.

A typical observing sequence consists of presetting the telescope to the science target, acquisition of a guide star by the telescope’s active optics,

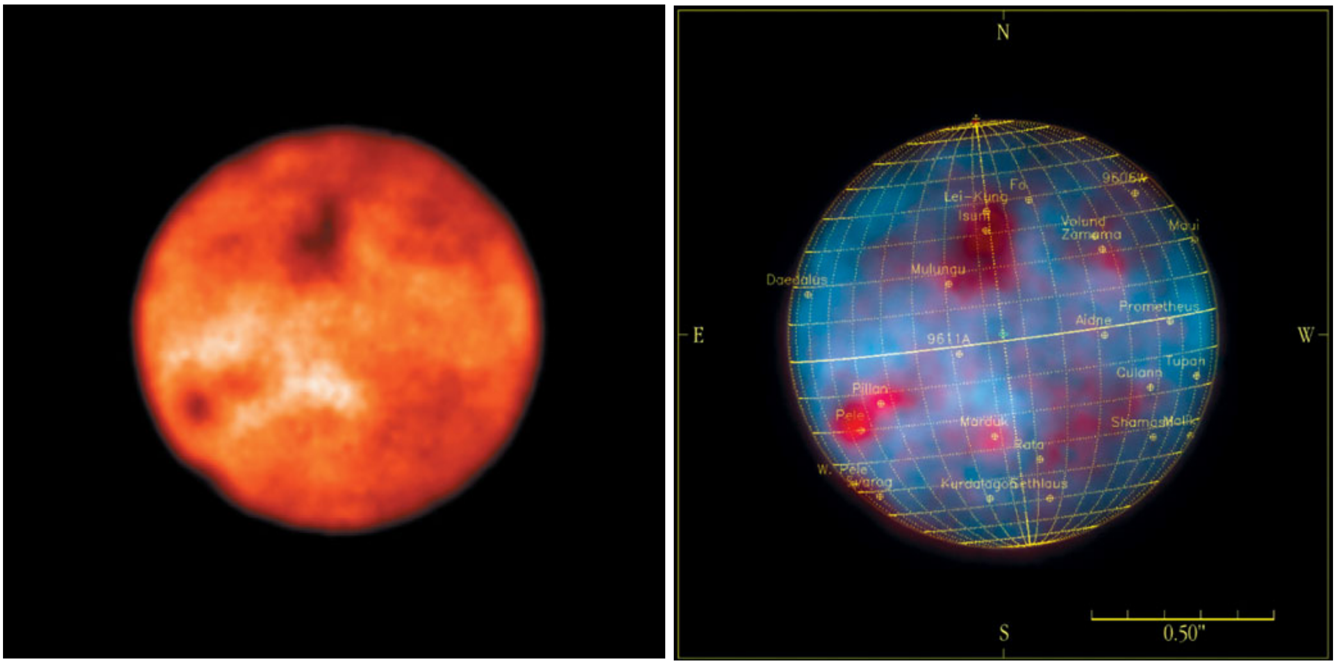

Figure 3: left: Io, the volcanic moon of Jupiter, as imaged with NACO on December 5, 2001, through a near-infrared, narrow-band filter at 2.166 µm. Despite the small angular diameter of Io of only about 1.2″, many features are visible at this excellent angular resolution of 60 mas as provided by NACO. Shown on the right is a composite of the same exposure with another obtained at a longer wavelength (L'-filter at 3.8 µm), with a latitude-longitude grid superposed. Many of the volcanic peaks clearly stand out in the longer-wavelength image.

then the acquisition of the reference source with NAOS, check of exposure times, and finally the start and execution of the observing sequence. Because of the need to acquire a reference source (and to frequently open and close the loop – for instance in the course of dithering or autojitter sequences) instrumental time overheads for NACO tend to be higher than, e.g., for observations with ISAAC. All these steps are, however, handled by the templates and the software controlling NACO, and are hence transparent to the user ([15]).

Calibration data for the most commonly used modes will be obtained on a regular basis by ESO. For more specialised observing modes the individual users are requested to include the calibration needs in the time request.

4.3 Archiving and pipeline

As soon as a NACO data file is saved on the instrument workstation, it is automatically transferred to the archive computer on Paranal. All NACO data will be incorporated in the VLT archive, and be searchable through the database. After the end of the proprietary period, data will become available to astronomers from ESO member countries by access to the VLT archive.

A data pipeline is being developed in order to facilitate quick-look analysis of the data and assessment of the data quality. Pipeline-reduced data will also be distributed together with the raw data files through the VLT archive ([11]). Dedicated software tools will be made available through the eclipse library ([4]).

5. Initial Results and Science Prospects

While commissioning of NACO is still ongoing, it has been delivering impressive astronomical results virtually from its first hour of operation. Initial results have been publicised in two press releases aimed at providing the ESO community and the general public with a first impression on the unique capabilities of NACO at ESO VLT:

http://www.eso.org/outreach/press-rel/pr-2001/pr-25-01.html

http: //www. eso.org/outreach/press-rel/pr-2002/phot-04-02.html

Science demonstration targets observed include solar-system objects such as Io and Saturn, a nearby free-floating binary brown dwarf, nearby star-forming regions such as the Becklin-Neugebauer object with the associated Kleinmann-Low nebula, T Tauri stars, evolved stars such as Frosty Leo or Eta Car, crowded stellar fields in starburst clusters, and extragalactic objects.

A series of 2.16 μm narrow-band images of the prototypical pre-main sequence triple star T Tauri nicely demonstrates the effect of adaptive optics. Shown on the left-hand side of Figure 2 is an open-loop image. The 0.4-sec exposure freezes the speckle pattern, which in a longer exposure will average out to a seeing-limited image with a resolution of 0.5″. The middle image has been obtained with the AO correction turned on. The right-hand side shows a K-band spectrum of the two components of T Tauri South.

Io, the innermost of the four Galilean moons of Jupiter and the most volcanically active place in the Solar System was imaged with NACO on December 5, 2001. At the time of observations, Io's diameter of 3660 km corresponded to an angular diameter of 1.2″. Despite this relatively small diameter, NACO was able to resolve a wealth of details. Many of the volcanic peaks clearly stand out (Fig. 3). With VLT instruments like NACO it will be possible to continue the "volcano watch" on Io from the ground now that the Galileo spaceprobe has expired.

Observations of the Solar System's "Lord of the Rings" were even more challenging than the observations of Io. While CONICA's and hence Yepun's field of view had to be steadied on Saturn, NAOS had to track the small Saturn moon Tethys, which was used as a reference source for wavefront sensing, while the active optics of Yepun had to track a star used for determining active optics corrections and autoguiding. The initial experiment worked very well, and validated the ability of NACO to do off-axis wavefront sensing on "moving targets", while steadying the science beam on a target with different sidereal motion. Observations like these can be used to monitor weather patterns on Saturn, study the fine structure of the rings, and track the movement of smaller moons.

In the morning of February 4, 2002, in the final hour of the 2nd commissioning run, Yepun was pointed to-

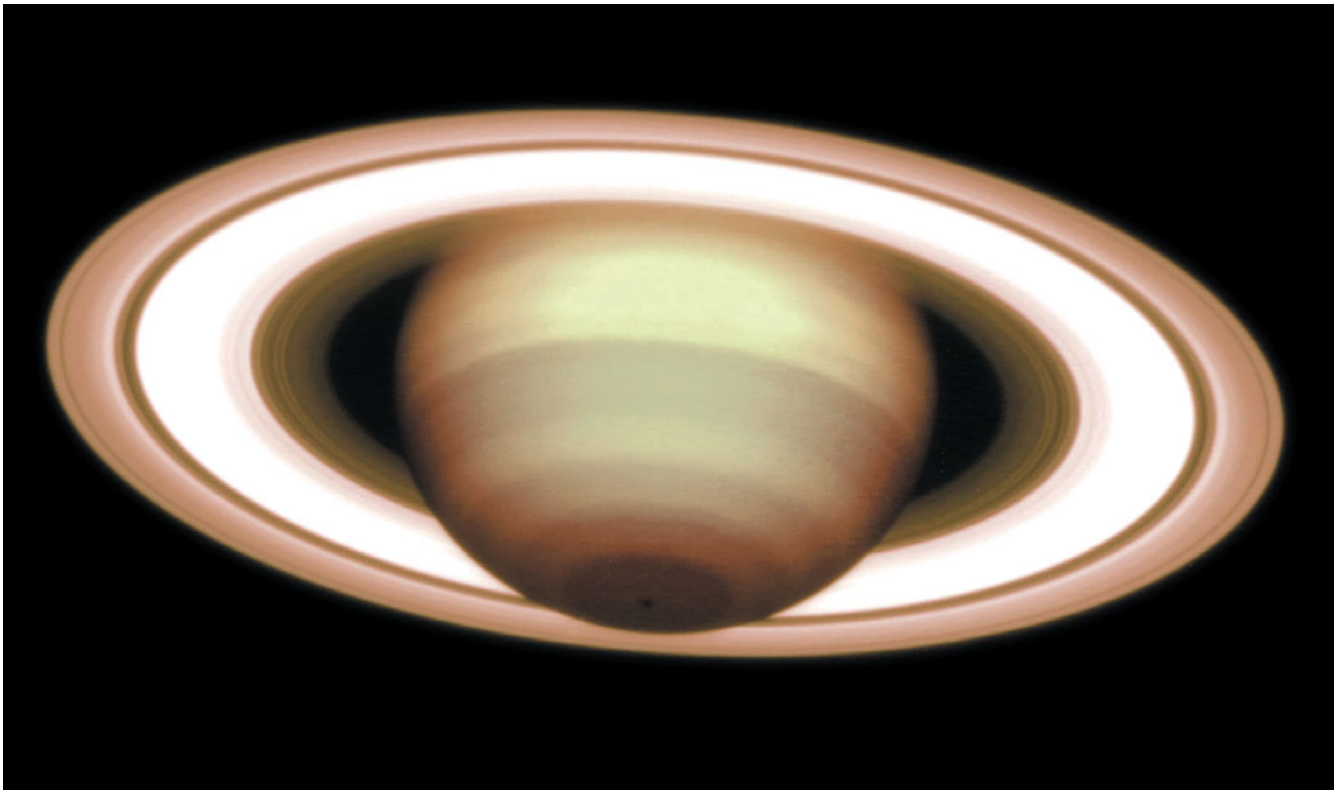

Figure 4: This image shows the giant planet Saturn, as observed with the VLT NAOS-CONICA Adaptive Optics instrument on December 8, 2001. The distance between Earth and Saturn was 1209 million km. It is a composite of exposures in two near-infrared wavebands (H and K) and displays well the intricate, banded structure of the planetary atmosphere and the rings. Note also the dark spot at the south pole at the bottom of the image.

wards the free-floating binary brown dwarf 2MASS1426316+155701 ([3]). Despite atmospheric seeing as determined by the Astronomical Site Monitor at a wavelength of 500 nm varying between 0.8″ and 1.2″, and an average airmass of 1.4, NAOS was able to close the loop on the R = 15.6 mag (B–R = 1.0 mag) binary brown dwarf. Figure 5 shows the closed-loop K-band image (60 sec exposure time), and a 5-min K-band spectrum nicely separating both components of the 0.15″ binary. For a distance of 18 pc to 2MASS1426316+155701, 0.15″ correspond to a projected separation of 3 AU. Observations like these can be used to monitor the orbital motion of nearby binary brown dwarfs.

Already in the second night of the first commissioning run, NACO closed

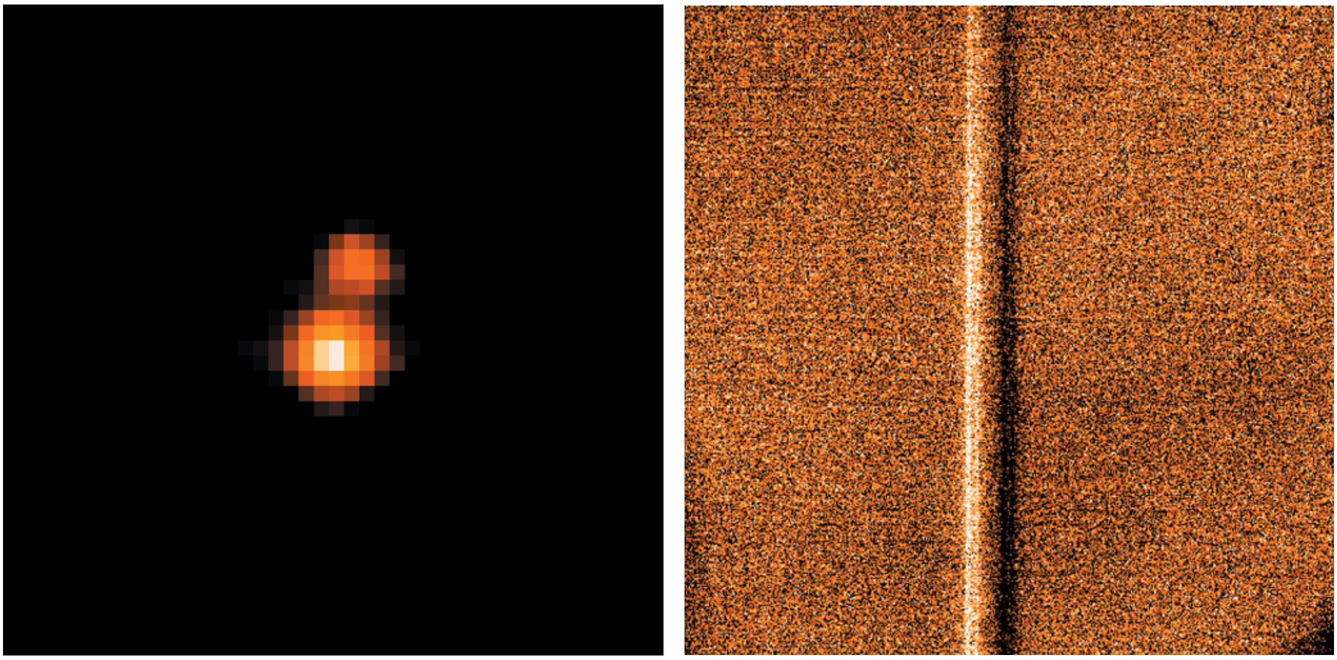

Figure 5: The faint (R = 15.6 mag) free floating binary (0.15″) brown dwarf 2MASS1426316+155701 nicely resolved by NACO under non-optimal observing conditions. Left: 60-sec K-band image. Right: difference of two 300-sec K-band spectra of the brown dwarf binary. The two binary components with K = 12.2 mag and K = 12.8 mag are clearly detected.

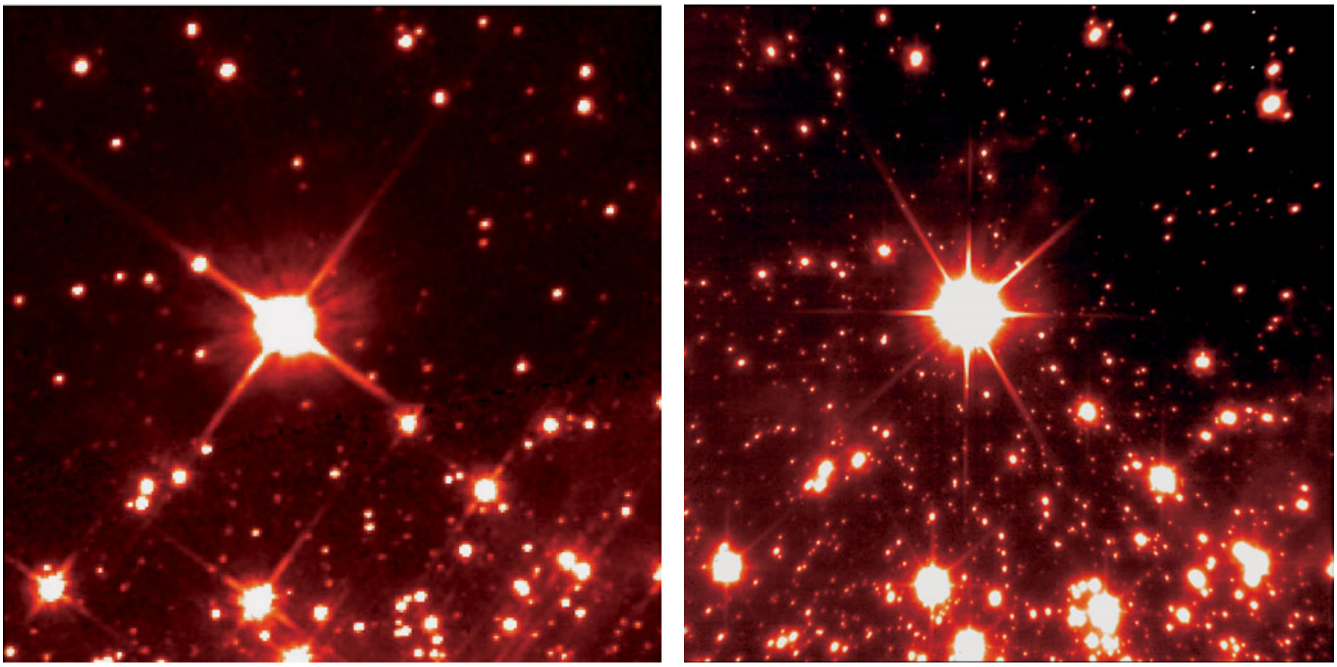

Figure 6: Left: this image of NGC 3603 was obtained with the WFPC2 camera on the Hubble Space Telescope (HST) in the I-band (800 nm). It is a 400-sec exposure and shows the same sky region as in the 300-sec NACO image shown to the right. The image nicely demonstrates that Yepun with NACO is capable of achieving in the K-band the same spatial resolution as HST/WFPC2 at three times shorter observing wavelength of 800 nm (I-band). The HST image was extracted from archival data. HST is operated by NASA and ESA.

the loop on the blue supergiant Sher 25, which is located at a distance of 7 kpc in the NGC 3603 starburst region. A comparison to an HST/WFPC2 image of the same region highlights that – provided a reference source suitable for wavefront sensing is available – NACO at Yepun can achieve in the K-band the same spatial resolution as HST/WFPC2 in the I-band (Figure 6).

6. Outlook: NACO and Beyond

A 3rd (and final) commissioning run of NACO is planned for the period March 22 to April 4, 2002. After this, two runs for instrument “Paranalisation”, and subsequently dry runs (including science verification) are planned before the new VLT instrument is deemed ready for science operations. At the time of writing, it is planned to offer NACO, the 5th VLT instrument to become operational, from Period 70 on to the general ESO community. More details on the proposal process can be found in the Call for Proposals.

In the meantime, work on a panoply of other advanced AO systems for the VLT and VLTI is in progress. The LGS facility at UT4 is expected to come online in 2003. Both NACO and SINFONI (an integral field NIR spectrograph fed by a curvature sensing AO system) will greatly benefit from the increased sky coverage facilitated by a laser guide star. With the implementation of MACAO-VLTI the coudé foci of all the four VLT Unit Telescopes at last will also be equipped with AO as was initially envisioned when the original CONICA proposal was selected more than a decade ago. Adaptive Optics will enable the VLTI to reach still fainter magnitudes, opening a wide range of astronomical objects for research. More details on VLT AO systems and development will be presented in future articles in *The Messenger*.

These projects ensure that the VLT will stay competitive throughout this decade, and give European astronomy a leading edge in studies of the universe.

Acknowledgements: Contributors to the CONICA and NAOS Projects

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The Atacama Large Millimetre Array

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This article is based on the Executive Summary of the European proposal for ALMA, which was prepared with input from many persons, including J. Baars, R. Bachiller, A. Benz, A. Blain, D. Bockelée-Morvan, R. Booth, C. Carilli, F. Combes, J. Conway, P. Cox, J. Crovisier, A. Dutrey, E. Falgarone, T. Forveille, M. Guélin, S. Guilloteau, C. Henkel, R. Kurz, E. Lellouch, J. Lequeux, J-F. Lestrade, R. Lucas, K. Menten, R. Pallavicini, J. Richer, P. Shaver, L. Tacconi, E. van Dishoeck, M. Walmsley, T. Wiklind.

1. Introduction

The Atacama Large Millimetre Array (ALMA) is one of the highest priority projects in astronomy today, combining the aspirations of scientists in Europe, the U.S. and elsewhere around the globe. The project has now reached a critical milestone: this is the year when the project officially enters the construction phase. It has already been approved for construction funding by the U.S., and the European decision to approve the construction phase is expected later this year.

ALMA will image the Universe at millimetre and submillimetre wavelengths with unprecedented sensitivity and angular resolution. This frequency range is unique in providing access to the lowest transitions from most simple molecules, and in its sensitivity to the thermal emission from cold gas and dust in the clouds where stars are forming. The expansion of the universe also brings the mid-infrared peak of emission from active star-forming galaxies into this frequency domain for redshifts larger than 3.

Progress in mm receiver performance, which now approaches quantum limits, in fast digital electronics, including photonics techniques, and in antenna design coincide to make possible an order of magnitude jump in project scale for millimetre arrays. The time is ripe for ALMA to be a major step for astronomy, making it possible to study the origins of galaxies, stars, and planets. With a capability of seeing star-forming galaxies across the Universe and star-forming regions across the Galaxy, it will open new horizons in science.

ALMA will be a millimetre/submillimetre counterpart of the VLT and HST, with similar angular resolution and sensitivity but unhindered by dust opacity. It will be the largest ground-based astronomy project after the VLT/VLTI, and, together with the Next Generation Space Telescope (NGST), one of the two major new facilities for world astronomy coming into operation at the end of this decade.

ALMA will be comprised of 64 12-metre diameter antennas of very high precision, with baselines extending up to 12 km. Figure 1 shows an artist's impression of a portion of the array in a compact configuration. The array of antennas will be reconfigurable, giving ALMA a zoom-lens capability. The highest resolution images will come from the most extended configuration, and lower resolution images of high surface brightness sensitivity will be provided by a compact configuration in which all antennas are placed close to each other. The instrument thus combines the imaging clarity of detail provided by a large interferometric array together with the brightness sensitivity of a large single dish. The large number of antennas provides over 2000 independent interferometer baselines, making possible excellent imaging quality with "snapshot" observations of very high fidelity. The receivers will cover the atmospheric windows at wavelengths from 0.3 to 10 millimetres. ALMA will be located on the high-altitude (5000 metre) Llano de

Figure 1. An artist's impression of several of ALMA' s antennas in a compact configuration.

Chajnantor, east of the village of San Pedro de Atacama in northern Chile. This is an exceptional site for millimetre astronomy, possibly unique in the world.

2. Project Development

To make such an ambitious project possible, ALMA has become a joint endeavour involving many nations and scientific institutions, and it is likely that it will become the first global project in ground-based astronomy – an essential development in view of the ever-increasing complexity and cost of front-line astronomical facilities.

For years Europe has had a major involvement in millimetre astronomy, with several of the leading facilities in the world. Many institutions throughout Europe have active research programmes in this field, and several of them have developed technical expertise in this area together with European industry, so it is natural that Europe should be a primary participant in ALMA.

The idea of a large European southern millimetre array (“Large Southern Array”, LSA) has been discussed since 1991, and in 1995 an LSA project collaboration was formally established to explore the possibility in a two-year study which included site surveys in Chile and critical technical studies. A report published in April 1997 concluded this first phase.

An important step was taken in June 1997. A similar project had also been under study in the U.S. since 1984, the “Millimetre Array” (MMA), and an agreement was made to explore the possibility of merging the two projects into one. The basic principle was that of a 50-50 partnership between Europe and the U.S., with joint overall direction. Three aspects were studied in detail – scientific, technical and management – and a feasibility study was published in April 1998.

The framework for the formal European collaboration in Phase 1 of this project (the 3-year design and development phase) was established in December 1998. A European Co-ordination Committee (ECC) was created to direct the European effort, with participation and funding from the European Southern Observatory (ESO), the Centre National de la Recherche Scientifique (CNRS), the Max-Planck-Gesellschaft (MPG), the Netherlands Foundation for Research in Astronomy (NFRA) and Nederlandse Onderzoekschool Voor Astronomie (NOVA), and the United Kingdom Particle Physics and Astronomy Research Council (PPARC). In early 2000 the Swedish Research Council (VR), and the Instituto Geográfico Nacional (IGN) and Ministerio de Ciencia y Tecnología (MCYT) of Spain were added to the European collaboration.

In June 1999 a formal agreement between Europe and the U.S. regarding collaboration on Phase 1 of a bilateral project, now called the Atacama Large Millimetre Array (ALMA), was signed. The U.S. side of the partnership is led by the National Radio Astronomy Observatory (NRAO), operated by Associated Universities, Inc. (AUI) under a co-operative agreement with the National Science Foundation (NSF). Recently, Canada has formally joined the U.S. in the North American collaboration. The overall direction for the project is provided by an ALMA Co-ordination Committee (ACC), which oversees the activities of an ALMA Executive Committee (AEC) and several technical project teams, with advice from international Scientific and Management Advisory Committees.

The design and development Phase 1 of the project is being completed at present, and the construction phase (Phase 2) is scheduled to begin, pending final decisions, with completion foreseen in 2011. The total estimated cost for Phase 2 of the bilateral project is 552 million (year 2000 US$), to be shared equally between Europe and North America.

Japan has also been working towards a project of this kind, the Large Millimetre and Submillimetre Array (LMSA). The Japanese astronomical community has decided that it would be best to fully merge this project with the bilateral project. A Japanese design and development phase, which is closely co-ordinated with the European and North American efforts, will be completed in 2003. Japanese participation will provide significant scientific enhancements to the bilateral project, and this possibility has been extensively studied. If it is realised, ALMA will become a truly global project, the first ever in ground-based astronomy.

3. Science with ALMA

3.1 Introduction

The scientific case for ALMA is overwhelming. The main science drivers are the origins of galaxies, stars and planets: the epoch of first galaxy formation and the evolution of galaxies at later stages including the dust-obscured star-forming galaxies that the VLT and HST cannot see, and all

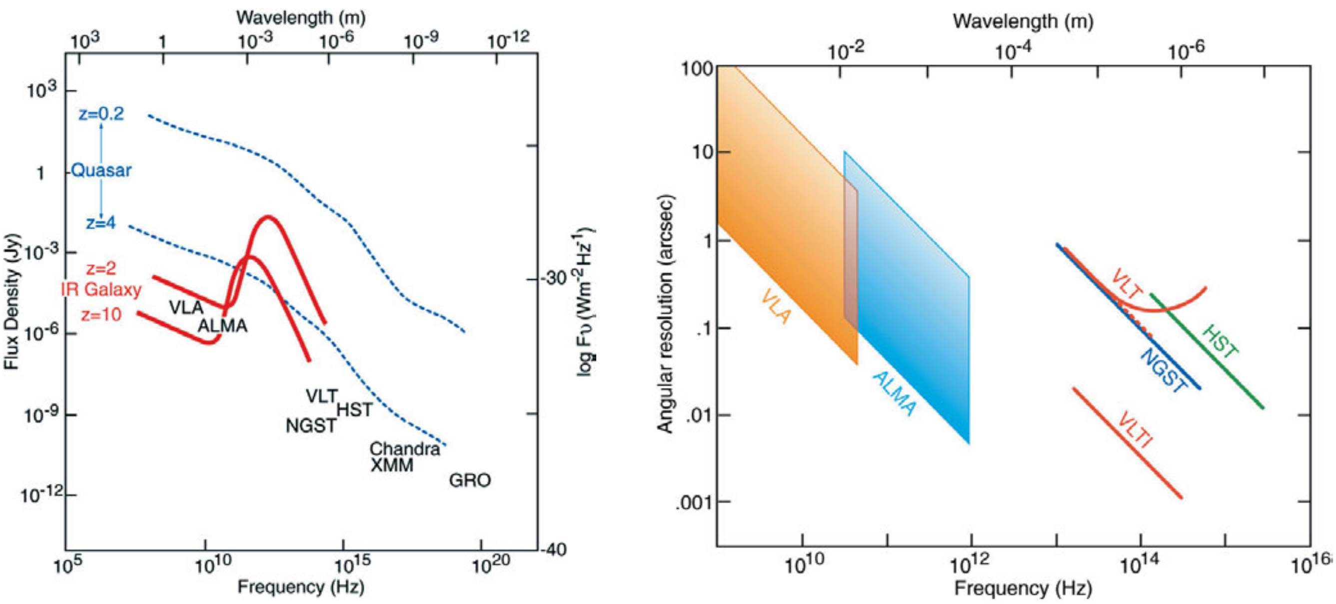

Figure 2: Left: Sensitivity of ALMA, compared with some of the world’s other major astronomical facilities, for typical integration times of several hours. Right: Angular resolution of ALMA, compared with other major telescopes. The top of the band shown for ALMA corresponds to the compact 150-m configuration, and the bottom corresponds to the large array with 12 km baselines. For the VLT, the solid line corresponds to the seeing-limited case, and the dashed line to the diffraction-limited case with adaptive optics.

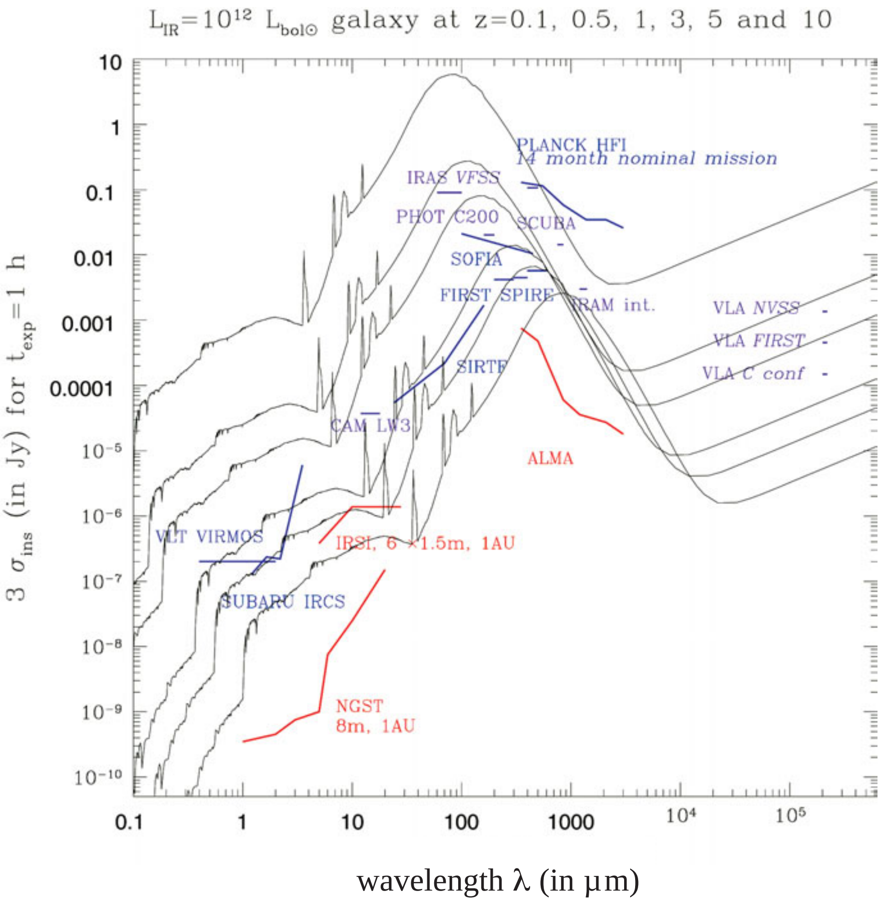

Figure 3: A detailed view of the typical spectral energy distribution of a star-forming galaxy at redshifts of 0.1 to 10. In the millimetre and submillimetre bands the observed flux is almost independent of redshift, and ALMA will be sensitive to such objects out to redshifts well beyond 10 (Guiderdoni et al., 2001, in "The Birth of Galaxies", eds. B. Guiderdoni et al., The Gioi Publ., p. 95).

tant Universe: the discovery of CO emission in a z = 2.3 ultraluminous infrared galaxy, the discovery of the far-infrared background radiation, and the discovery of a large population of star-forming galaxies that probably dominate the luminosity of the Universe at high redshift. The most remarkable discovery is that large amounts of dust and molecules were present already at z = 4.7. This redshift corresponds to a look-back time of 92% of the age of the Universe and shows that enrichment of the interstellar medium occurred at very early epochs.

It is now clear that the mm/submm wavebands are exceptionally well suited for the study of the distant Universe. Whereas the broadband flux from distant galaxies is diminished in the UV and optical due both to the redshift and obscuration by internal dust, the same dust produces a large peak in the rest-frame far-infrared, which, when redshifted, greatly enhances the millimetre and submillimetre emission from these objects. Thus, ALMA may provide one of the best ways to find the first galaxies that formed after the "dark ages".

Current studies are limited to the very brightest objects. ALMA will make it possible to detect objects one hundred times fainter, and will make a decisive contribution to one of the key questions in current astronomy: the origin of the infrared background and the star-formation history of the Universe. The "ladder" of molecular transitions essen-

phases of star and planet formation hidden away in dusty cocoons and protoplanetary disks. But ALMA will go far beyond these main science drivers – it will have a major impact on virtually all areas of astronomy. It will be a true mm/submm counterpart of the other major facilities for world astronomy, as illustrated by its relative performance in Figure 2.

3.2 Galaxies and Cosmology

Three dramatic events over the last decade have spectacularly opened up the mm/submm wavebands to the dis-

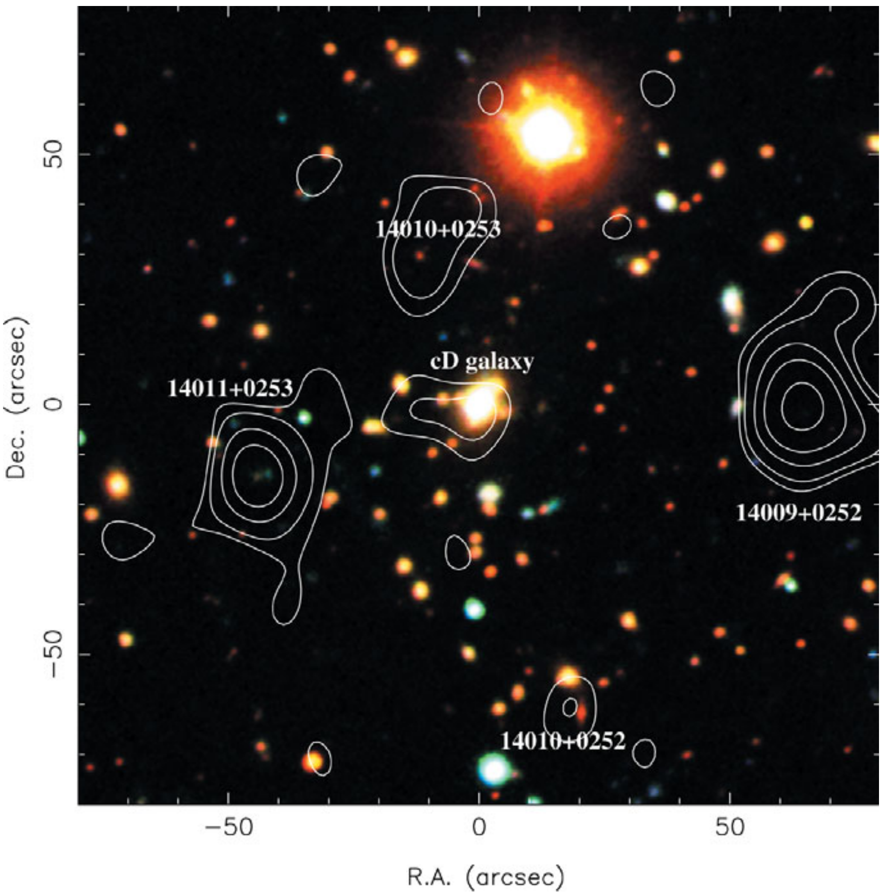

Figure 4. The submillimetre and optical wavebands provide complementary views of the Universe. This figure shows submillimetre contours superimposed on an optical image of the galaxy cluster A1835 (Ivison et al., 2000, MNRAS 315, 209). It is clear that the submillimetre sources are very faint optical objects, while the red cluster galaxies are not prominent submillimetre sources. The mm/submm wavebands are particularly sensitive to the most distant galaxies; the source 14011+ 0253 is at a redshift of 2.55, as determined directly from CO line observations. ALMA will provide submillimetre images with much finer resolution than the optical image

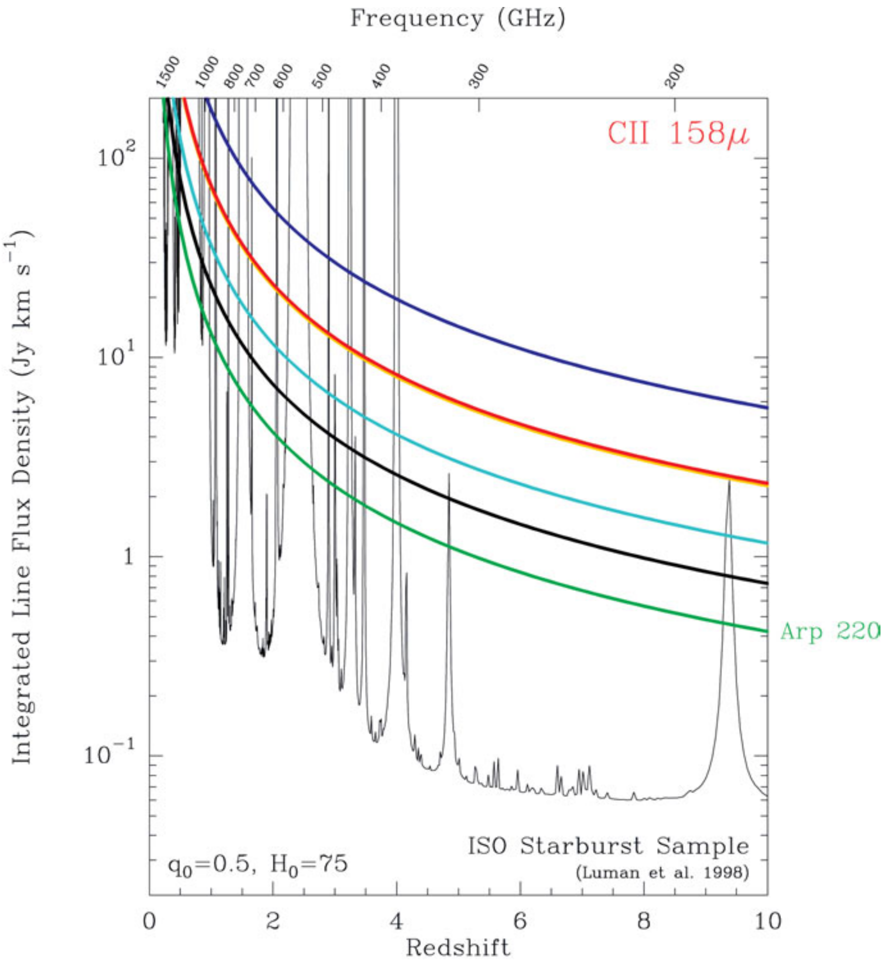

Figure 5. The detectability of the powerful [C II] line by ALMA. The coloured lines represent the integrated line flux densities one would observe for the 158 mm C II fine structure line from the sample of ultraluminous infrared galaxies observed by Luhman et al. (1998, ApJ 504, L11) using the ISO satellite if those galaxies were at the redshifts indicated by the abscissa. The thin line indicates the typical 5-sigma noise level of ALMA in two hours of integration, for a velocity resolution of 300 km s^{-1}, and assuming the precipitable water vapour content of the atmosphere is 0.8 mm.

tially guarantees that a redshifted spectral line will appear in one of the observing bands. ALMA will be thus able to obtain the redshifts of distant galaxies, and study their detailed morphology and kinematics. It will be able to detect not only molecular lines from these objects, but potentially also the atomic fine-structure lines of carbon, oxygen, and nitrogen, which, at high-z, are redshifted into the submm bands.

At present, even the strongest submillimetre sources are very difficult to identify. Most of them are not associated with previously known bright objects, yet this population probably dominates the luminosity of the distant Universe. With ALMA's high angular resolution, precision and sensitivity, it will be possible to accurately locate such sources in minutes, and measure their redshifts through the detection of CO lines in less than an hour. ALMA may also detect a population of more distant, optically obscured, objects that would escape detection at other wavelengths.

The study of the early epochs of galaxy formation is one of the main goals of ALMA, and one of the main reasons for a very large collecting area.

Many gravitational lenses will be found by ALMA, possibly more numerous and at higher redshifts than in the optical or radio wavebands because of the very steep source count. Gravitational arcs will be mapped in molecular lines.

Molecular absorption lines will be observed in the spectra of many quasars. This is a new field with great potential. Already, in the few sources bright enough, over 30 transitions from 18 different molecules have been observed in absorption systems up to z = 0.9. This opens up the study of detailed chemistry at cosmological distances, and makes possible direct measurement of the cosmic background temperature at high redshifts. Thousands of sources will be accessible to ALMA.

Active galactic nuclei can be studied in depth at millimetre wavelengths because of the low synchrotron and dust opacity and the unprecedented angular resolution of millimetre VLBI. The optically-obscured molecular tori and the circumnuclear starbursts of nearby galaxies can be resolved with linear resolutions of a few parsec. ALMA will be able to map both the gas and the dust that obscure the nuclei. The presence of central black holes can be studied kinematically in a large number of galaxies. The centre of our own Galaxy can be observed free of obscuration, in particular the gas dynamics of the 1-pc circumnuclear disk around the galactic centre source Sgr A*.

ALMA will make observations of normal galaxies at z = 1–2 with the same detail as is presently possible in nearby galaxies. The main dynamical features of nearby spirals will be observed with enough resolution and sensitivity to constrain theoretical scenarios of galaxy evolution. The mass spectrum of molecular clouds in galaxies of different types will be determined. Detailed studies of nearby mergers and IR luminous galaxies will be important to serve as templates for objects found at high redshifts. In the Magellanic Clouds, star-formation processes can be compared with those in our Galaxy. This would be highly interesting, because star formation is closely related to the ambient radiation field, dust content, and metallicity.

3.3 The Formation of Stars and Planets

A major astronomical goal of the 21st century is an understanding of how stars and planets form. Studying star- and planetary-system formation requires very high angular resolution, because protoplanetary disks are small (100–500 AU) and the nearest star formation regions are ~ 100 pc away. ALMA will provide a linear resolution as fine as 1 AU at these distances.

Because it can observe at wavelengths free of extinction, ALMA will be the premier instrument for studying how gas and dust evolve from a collapsing cloud core into a circumstellar disk that can form planets. The array will be able to directly observe astrophysical phenomena that have until now only been conjectured in theoretical models of the early stages of star formation. ALMA will yield new unique information on the gravitational contraction of protostellar cloud cores, with accurate kinematics and mass distributions inside the cores and their envelopes. It will give new clues on the role of the magnetic field in the cloud cores, the circumstellar envelopes, and the accretion disk. Observations of high-excitation submm lines of various molecules will allow us to study the physics and chemistry of the shocks in the ubiquitous outflow jets that carry away the original angular momentum.

For the later stages, when the newly-formed stars are surrounded by protoplanetary disks, imaging the gas and dust on scales of several AU will be the only way to study the earliest stages of planet formation. Current mm arrays have revealed large (hundreds of AU) rotating disks around single T Tauri stars, but the angular resolution necessary to resolve the inner regions, where planets are expected to form, will only be provided by ALMA. ALMA will be able to reveal, within protoplanetary disks, the gaps that are tidally cleared by Jovian sized planets at distances of a few AU from their young, central stars. Multi-wavelength studies of such objects will be powerful tools for analysing the dust and gas properties on the scale of the Solar System. Maps of dust and optically thin molecular lines with 0.1″ to 0.05″ beams will provide crucial data on the chemistry, the reservoirs of the biogenic elements, and the timescales on which planets form. ALMA will provide the masses of the pre-main-sequence stars through the measurement of the Keplerian motion in the protoplanetary disks.

The high sensitivity of the array will allow us to make unbiased surveys of pre-main-sequence stars to obtain the statistics of disk properties and frequency of protoplanetary systems in different star-forming regions. Comparison between isolated star formation and dense clusters will become possible. ALMA will also address the high-mass star-formation problem. Dense, hot cores are known to exist around massive (proto)-stars, but the existence of circumstellar disks analogous to those found around low mass star remains uncertain.

The study of star and planet formation is another major goal of ALMA, and one of the drivers for the highest angular resolution.

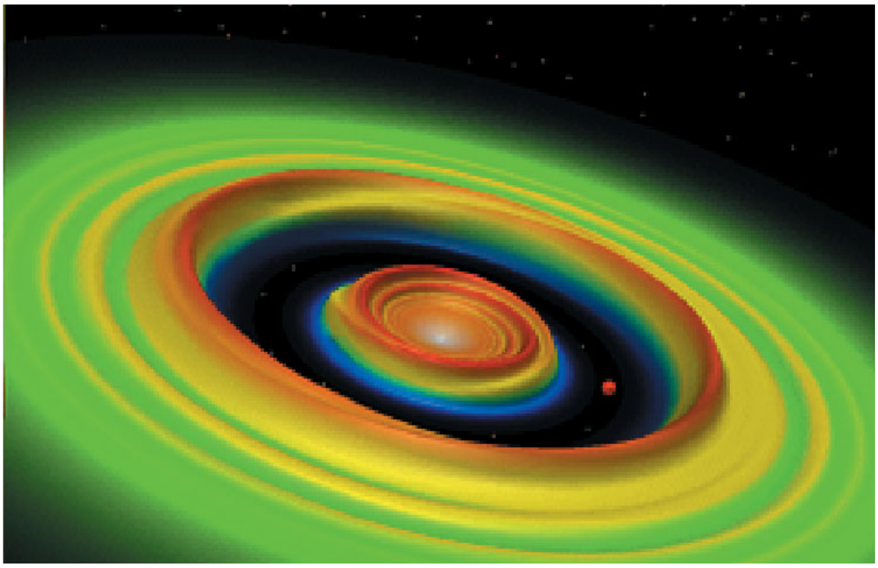

Figure 6. ALMA will reveal the details of planet formation. The figure shows a hydrodynamic model of a protostellar accretion disk in which a giant protoplanet is forming (Bryden et al., 1999, ApJ 514, 344). The newly-formed protostar resides (invisibly) at the centre of the accretion disk and a Jupiter-mass protoplanet orbits around it at the Jupiter–sun distance. A gap in the disk is cleared out by the protoplanet. Using ALMA it will be easy to image such gaps in protostellar disks in nearby star-forming regions. In this plot surface density is coded as "height".

3.4 Stars and their Evolution

With its coverage of the millimetre and submillimetre ranges, ALMA will greatly expand the field of stellar astronomy. It will detect tens of thousands of stars over the entire H-R diagram. It will cover the full life cycle of stars. ALMA may provide the *only* way to observe some massive stars that spend their entire brief lives hidden by dust in their parent molecular clouds. It will provide unique information on the winds of hot stars, novae, the photospheres of giants and supergiants, and non-thermal processes in flare stars, Be stars, and dust formation in supernovae and in the outflows of planetary nebulae. It will resolve the photospheres and chromospheres of giant and supergiant stars within a few hundred parsec.

ALMA is designed to be able to observe the nearest star, our sun. This is a challenging problem because of the thermal constraints on the antenna and receiver design. If successful, ALMA could address two of the most interesting solar physics problems: the acceleration of the highest energy electrons in flares, and the thermal response of the low chromosphere to waves and shocks from the interior.

ALMA will yield fundamental knowledge for our understanding of the dynamics and chemistry of the envelopes of evolved, oxygen-rich and carbon-rich stars, where important scientific goals are the understanding of dust formation and the enrichment of the interstellar medium with heavy elements. The winds of these red giant stars rapidly remove the outer layers, terminating further evolution. The winds have low outflow speeds and high densities, so that matter easily condenses into dust grains. ALMA will image the distribution of matter in the outflows at distances of a few stellar radii, to solve the long-standing problem of dust formation and study the interaction between stellar pulsations and wind acceleration. It will be possible to study such objects across the Galaxy, and even in the Magellanic Clouds

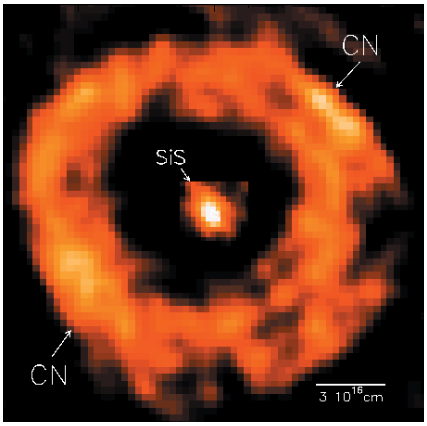

Figure 7. Distributions of the SiS and CN 3-mm emission in the CSE IRC+10216. The colours represent the line intensities integrated in a narrow velocity interval centred on the systemic velocity of the star (Guélin et al., 1996, in "Science with Large Millimeter Arrays", ed. P. Shaver; Springer Publ., p. 276).

Supernovae and gamma-ray bursts will both be important targets for ALMA. In both cases mm and submm observations provide unique and important information. Radio supernovae first appear at these wavelengths, where the flux is relatively unaffected by free-free and synchrotron self absorption. SN 1987A in the LMC will be a prime target for ALMA. In the case of gamma-ray bursts, mm/submm observations provide unique information on the peak of the burst and important constraints on the physical parameters. ALMA will allow detection of all GRBs detectable in the optical.

3.5 The Solar System

Because of its high angular resolution, its fast imaging capabilities, and its wide instantaneous bandwidth, ALMA will represent a major step forward in the study of comets, asteroids and planets. ALMA's highest angular resolution at a distance of 1 AU corresponds to a linear resolution of less than ten kilometres.

Observations of comets with ALMA will greatly increase our understanding of their nature and origin, and complement the planned space probes that will be able to sample only a few comets. Over 20 molecular species have so far been discovered in comets. ALMA will make it possible to search for less abundant molecules, radicals, and new ions, and to investigate isotopic ratios in several species. Such studies will provide key information on the origin of comets and the formation of the Solar System. It will be possible to detect molecules in distant comets and study the evolution of their outgassing as they approach the Sun. The fast high-resolution imaging capability of ALMA will allow us to study structures in the inner coma of comets, and maps of the distribution of rotational temperatures of different molecular species will help us study the thermodynamics, excitation processes, and physical conditions in these objects.

Asteroids and cometary nuclei of small sizes, and even distant objects such as Centaurs and trans-Neptunian objects, will be detectable in the mm and sub-mm continuum. Together with observations in other wavebands, ALMA will allow us to probe the temperature of these objects at various depths and to measure their albedo and size. Imaging thermal emission from the planetary satellites, the Pluto/Charon system and the largest asteroids will provide clues to their thermal properties and the degree of heterogeneity of their surface.

ALMA will be able to map planetary atmospheres on short timescales. Maps of CO and HDO in Mars and Venus will give data on wind, temperature, CO and water distribution, and atmospheric dynamics on spatial scales comparable to regional weather scales. The analysis of meteorological and climatic variations in the atmosphere of Mars will be a valuable complement to future space missions. Searching for molecular trace species likely to be present in these planets, such as sulfur-bearing compounds in Venus and organic species in Mars, will become possible. Wide bandwidth capabilities will allow us to probe the deep atmosphere of Venus. Mapping HCN and CO, and searching for other nitriles on Neptune, will provide information on whether the origin of such molecules is internal or external. It will be possible to detect and map tropospheric species such as PH_3 in the Giant Planets. During very dry conditions at the high-altitude site proposed for ALMA, the mapping of H_2O and HDO on the four giant planets will provide clues on the origin of water.

ALMA will also observe the atmospheres of Pluto and the satellites of the giant planets. ALMA will be able to detect SO_2 and SO in the plumes of the volcanoes on Jupiter's moon Io and may discover other trace constituents. Mapping the millimetre lines of CO, HCN, HC_3N, and CH_3CN in the stratosphere of Titan with high spectral resolution will provide the vertical and latitudinal distributions of these constituents, giving better constraints on the photochemistry that occurs in Titan's atmosphere and its response to seasonal effects. ALMA will have sufficient sensitivity to detect and map CO, and perhaps other species, such as HCN, in the tenuous atmospheres of Pluto and Triton. This will provide clues on the nature of the interaction between their icy surfaces and their atmospheres.

The scientific reach of ALMA thus extends from the most distant objects in the Universe to details of the nearest objects in our solar system. It will be one of the major astronomical facilities of the 21st century.

4. Scientific and Technical Requirements

High angular resolution is of great importance both for observations of the distant Universe and for detailed studies of the processes of star and planet formation nearby in our own Galaxy. It is clear from HST observations that an angular resolution of at least 0.1″ is needed for high-redshift studies. Similarly, an angular resolution of 10 milliarcsec or better is required to resolve the gaps in protoplanetary disks created by forming planets, and such resolution should be achieved at least at the shorter (submillimetre) wavelengths accessible to ALMA. Both requirements imply baselines of 10 km or greater.

Such high angular resolution cannot be exploited without adequate sensitivity. The noise in brightness temperature increases as the square of the baseline. However, millimetre astronomy is the domain of *cold* matter, so the brightness temperatures to be observed are low. In the case of spectral lines, bandwidths are limited by the line widths, so increasing detector bandwidth does not help. Furthermore, modern receiver performance is approaching quantum limits and/or the atmospheric noise limits. Therefore, the only way to increase the sensitivity is to increase the collecting area of the array. An angular resolution of < 0.1″ can only be achieved for thermal lines with a collecting area approaching 10^4 square metres. The other main driver for very high sensitivity is the detection of the most distant galaxies in the Universe. If galaxies formed by successive mergers of sub-galactic objects, the highest possible sensitivity will be needed to detect the first luminous objects.

The large size and collecting area can only be achieved with a large array of antennas. The collecting area of an array can be enhanced by increasing the number of antennas, their size, or both. There were thus several trade-offs to be considered. Small antennas have higher precision and give better wide-field imaging. The use of large antennas maximises the collecting area, and reduces the number (and therefore cost) of receivers and the demands on the correlator. In view of the supreme importance of high sensitivity, the largest possible antenna size was chosen. The combination of pointing and surface accuracy required for efficient operation at submillimetre wavelengths (respectively 0.6″ and 25 μm rms or better) is difficult to achieve for antenna diameters greater than about 12 metres, so this determined the antenna size. An array of 64 12-metre diameter antennas provides a total collecting area of over 7000 square metres, satisfying the sensitivity requirements given above. This large number of antennas also provides excellent high-resolution imaging capability, which will be very important for the science objectives of ALMA. The 2016 independent baselines remove the need to use Earth rotation to provide aperture synthesis, and allows high resolution "snapshot" images of high fidelity.

Thus, the angular resolution and sensitivity requirements are satisfied by ALMA, an array of 64 12-metre diameter high-precision antennas extending over a region up to 12 km across. The receivers should provide complete wavelength coverage of the atmospheric bands over the range 0.3 to 10 mm; the dewars will be built to accommodate all ten receivers needed, and will be populated initially with the four of highest priority. Other requirements include wide instantaneous bandwidth (16 GHz per antenna), a flexible correlator system allowing spectral resolution as high as 5 kHz (0.01 km s^{-1} at 100 GHz), and a complete polarisation capability providing all Stokes parameters. The site must obviously be large, flat, and very high (to minimise the atmospheric attenuation at these wavelengths), and the 5000-metre high Llano de Chajnantor in the Atacama desert region of northern Chile is ideal. Even on such an exceptional site, atmospheric pathlength fluctuations are critical for imaging performance, and ALMA is designed with water vapour radiometers to compensate for these variations, as well as a fast switching capability to "freeze" the atmosphere.

More information on the ALMA project can be found in earlier issues of *The Messenger* (March 1996, March 1998; December 1998; and June 1999), and on the following websites:

http://www.eso.org/projects/alma/
http://www.alma.nrao.edu
http://www.nro.nao.ac.jp/~lmsa/index.html.

News from the 2p2 Team

L. GERMANY

Service Mode

The percentage of time allocated to service mode observations at the 2.2-m is increasing yet again in Period 69. We would just like to take this opportunity to remind the PIs of upcoming Service Mode programmes: please read the webpage describing our Standard Calibrations before submitting your Phase 2 package. It is different to the Standard Calibrations performed at the VLT. We now have 2xU filters, 2xB filters and 2xI filters but only one of each is part of the Standard Calibrations. Please check: http://www.ls.eso.org/lasilla/Telescopes/2p2T/E2p2M/WFI/CalPlan/StdCal/
to learn which of the filters is covered in the standard calibrations.

We also have a "Service Mode Tips" page at: http://www.ls.eso.org/lasilla/Telescopes/2p2T/E2p2M/WFI/SMTips.html
with suggestions on how best to organise your OBs and observing programmes in order to maximise the chances of them being executed.

New Filters

We have recently mounted a new B filter in the ESO/MPG Wide Field Imager. This filter has superseded the B/99 filter as part of the Standard Calibrations for service mode programmes. Service Mode PIs note: if you wish to use the B/99 filter for your programme, you can no longer request Standard Calibrations in your README file.

The zeropoints for this filter and for the new U360 filter can be found at: http://www.ls.eso.org/lasilla/Telescopes/2p2T/E2p2M/WFI/zeropoints/ and the transmission curves at: http://www.ls.eso.org/lasilla/Telescopes/2p2T/E2p2M/WFI/filters/

NGAS

To deal with the vast quantities of data that will be produced by ALMA and the new instruments to arrive at the VLT, the NGAS (Next Generation Archive System) project was initiated by ESO's Data Management Division. In this system, magnetic disks are used to store and transport the data between Chile and Garching, rather than the lower capacity CDs, DLTs and DVDs that are currently used.

Since the ESO/MPG Wide Field Imager already produces large amounts of data in a short period of time, the 2.2-m was chosen as the test bench for the implementation of the NGAS. We have been using this system since July 2001 with the final commissioning and acceptance of NGAS at the 2.2-m performed in December 2001. In the second half of 2001, the 2p2 team was sending both magnetic disks and DLTs to Garching for archiving; however, as of January 2002, only the magnetic disks of the NGAS now make the journey.

To learn more about the NGAS system please visit:
http://arcdev.eso.org/NGAST/

ESO 1.52-m Telescope

Fans of the Boller and Chivens spectrograph may be relieved (or perhaps sorry) to see the old HP1000 interface go and the new gui interface come online. The new system is more user-friendly and as of October 2001 has seen the end of an era as the big pizza-wheels (magnetic tapes) are no longer threaded – all data are now directly written to DAT tape. Never fear though – the HP1000 is still on hand, sleeping in the background, and the pizzas are ready to spin again if the new technology fails.

October 2001 also saw the end of the old REOSC control unit (which controlled dome movement and the windscreens) in the dome. For those of us who don't speak French, we can now read and understand the positions of the switches on the new control panel.

Danish 1.54-m Telescope

Service Mission

In November 2001, and in collaboration with a team from Copenhagen University Observatory, a complete maintenance and upgrade of DFOSC and the systems at the Danish 1.54-m telescope was undertaken.

The full report can be found at:
http://www.ls.eso.org/lasilla/Telescopes/2p2T/ D1p5M/RepsFinal/#dfosc

We would like to thank the team from Copenhagen University Observatory who came out to La Silla to work on this with us: Anton Norup Soerensen, Morten Liborius Jensen and Jens Klougart.

A view of the Residencia at sunset,

as seen from the Telescope Platform at the top of Paranal. A narrow path connects the top with the Residencia and invites to a nice 45-min downhill walk! Photo: Massimo Tarenghi.

The Messenger continues its publication of reports from the Chilean astronomical community with the Panorama of Chilean Astronomy by Professor Leonardo Bronfman, President of the Sociedad Chilena de Astronomía, followed by an article by A. Reisenegger et al. on the on-going investigation of the Shapley supercluster.

A Panorama of Chilean Astronomy

L. BRONFMAN, Universidad de Chile

President, Sociedad Chilena de Astronomía

Chile is becoming the astronomical capital of the world. The Atacama desert encompasses the best locations on Earth to build astronomical observatories. Paranal, Las Campanas, Tololo, Pachón, and La Silla are well-known places that contain top-quality optical astronomical facilities open to Chilean astronomers. In the last few years a new generation of astronomical facilities, the mega-telescopes, have been constructed in those sites: VLT, Magellan, and Gemini. In addition, there will be near San Pedro de Atacama at a height of 5000 m, the most powerful radio synthesis telescope of the world: the Atacama Large Millimetre Array (ALMA). This telescope will open up a new, unexplored, window of the electromagnetic spectrum for astrophysical studies. It will operate in an spectral range where clouds of cold gas which are the placental material of mostly every object we know in the universe, have their characteristic spectral signatures.

The privileged access of Chilean astronomers to this unparalleled suite of instruments provides them with a unique opportunity to address some of the most fundamental problems in modern astrophysics. In a time span of a few years ALMA will permit them to investigate the origins of celestial objects. To face these new challenges in the best possible way it has become necessary that the nation provides the astronomers with the proper environment and tools to undertake the research which should put them at the frontiers of astrophysics.

I. Recent Developments

The Chilean CONICYT (Consejo Nacional de Ciencia y Tecnología) recently approved a Centre of Excellence in Astronomy, within the FONDAP (Fondo Nacional de Desarrollo de Areas Prioritarias) programme. This Centre constitutes a new approach among astronomers to generate the conditions to boost Chilean astrophysics, and place it among the world leaders in the area. The Centre members will tackle, through the use of the currently available mega-telescopes, various problems of fundamental scientific importance, covering the origins of a broad range of objects. They will investigate origins from the largest scales, by studying aspects of galaxy formation and evolution, to the smallest scales, by studying aspects of the collapse of an individual star, facing candent problems such as: What did the universe look like 10 billion years ago? How do galaxies form? How do low-mass and high-mass stars form? Where do planets, complex molecules and the beginnings of life came from? Significant progress toward the main scientific goals of the Centre will only be achieved if individuals studying different aspects of origins in astrophysics are brought together for the fruitful and much needed interchange of different views and ideas.

The Centre's mission is to pave the way, through the research of their members and the education of the new generations of astronomers, for identifying and setting up the basis of the new problems to be tackled with the new generation of instruments to be set in Chile, in particular with ALMA. This world's largest array will produce some of the most exciting science in astronomy over the following 10–20 years. It will be the best instrument for detecting proto-galaxies at very high redshifts in the early Universe, as well as both protostars and proto-planetary disks in nearby star-forming clouds. With a resolution higher than the Hubble telescope, and a sensitivity 10 times larger than anything else currently in existence, it will be the largest and most powerful millimetre array in the world.

To accomplish its mission, the FONDAP excellence centre has set for itself the following strategic objectives in science, education, and outreach:

1. Transform the nature of Chilean astrophysics from individual research efforts into a coherent, co-ordinated and collaborative endeavour in science and education.
2. Place Chilean astrophysics in an internationally highly competitive position in several major areas of current interest.
3. Educate and train a new generation of young astronomers to take full advantage of the unique opportunities available in Chile to carry out world-class research, and help create career opportunities for young astronomers in Chilean institutions.
4. Make the Chilean public highly aware of work and discoveries by national astrophysicists and use astrophysical research as a model to promote national pride.

The Centre will be hosted by the Universidad de Chile at its Astronomy Department in Cerro Calán, and will have as associated organizations the Astronomy Department of the Pontificia Universidad Católica and the Physics Department of the Universidad de Concepción. In the next section I describe the present status of Astronomy in these institutions, as well as other recent centres.

II. Existing Institutes

Universidad de Chile

Astronomy is one of the scientific disciplines with the longest tradition at the Universidad de Chile. It began in 1852, when the Chilean Government established the National Observatory in association with the Universidad de Chile. During the early 60's the build up of modern international observatories (Cerro Tololo, Cerro La Silla, and Cerro Las Campanas) prompted the Universidad de Chile to create the Astronomy Department at the Observatorio Nacional, starting up the first programme of *Licenciatura en Astronomía* in 1966 and a decade later the current Magister in Astronomy programme. Many graduates of these programmes went to obtain their Ph.D. degrees in USA, Canada, and Europe, returning in the early 80's to the Department, making a deep impact in astrophysical research and teaching. Two of these early graduates, M.T. Ruiz and J. Maza, have obtained the National Science Prize. The present staff of the Astronomy Department includes 14 faculty members: M.T. Ruiz (Chair), H. Alvarez, L. Bronfman, L. Campusano, S. Casassus, E. Costa, G. Garay, P. Lira, S. López, J. May, J. Maza, D. Mardones, F. Noël, and M. Rubio, as well as 5 postdoctoral fellows. The Astronomy Department is part of the Facultad de Ciencias Físicas y Matemáticas, which attracts a freshman class of 500 from the top 2% of all graduating high school students, a most important asset. It is located at Cerro Calán, Santiago, in a large building with adequate teaching and research facilities, as well as the oldest and most complete astronomical library in the country.

The Universidad de Chile created in 1999, with support from Fundación Andes, the first Ph.D. programme in astronomy in the country. The programme has currently 8 students enrolled, and is expected to significantly increase the number of young scientists starting a career in Astronomy. To strengthen the areas of astrophysics not currently covered by the members of the Department, during the first few years of the programme part of the teaching is done in association with Yale University. It is expected that the programme will timely change its centre of gravity to the Universidad de Chile. A key for such change will be the incorporation to the staff of theoretical astrophysicists in the next two years, through a joint programme of the Physics and Astronomy Departments, with support of the Comité Mixto ESO-Chile. The Ph.D. programme was recently awarded an important grant from the Ministry of Education, through a MECESUP project, to hire new faculty and fund student fellowships over the next 3 years.

Research is carried on in a number of areas, including Quasars and AGNs (evolution of galactic nuclear regions and the formation of massive black holes); Large-Scale Structure and Cosmology; Starburst Galaxies (dwarf systems, metal-poor galaxies) ; High-Mass and Low-Mass Star Formation (galactic distribution, hot molecular cores, bipolar outflows, gas kinematics at high densities, embedded pre-main sequence stars); Supernovae; Faint Stellar Objects (faint white dwarfs, brown dwarfs, extrasolar planets, baryonic dark matter); ISM in the Galaxy and the Magellanic Clouds; Red Giants; Planetary Nebulae; and Solar Astrometry. Some research highlights are: (i) the discovery of the first free floating brown dwarf (Ruiz et al. 1997, *AJ* 491, 107); (ii) the Calán-Tololo supernovae survey (Hamuy et al. 1995, *AJ* 109, 1), which provided the first calibration of the relationship between the absolute magnitude of type Ia SNe at maximum and their rate of decline, and is the basis for studies of the expansion of the Universe; (iii) the first derivation of the mass and distribution of H_2 in the Galaxy using a complete CO survey (Bronfman et al. 1988, *ApJ* 324, 248); (iv) the first complete CO survey of the LMC (Cohen et al. 1988, *ApJ* 331, 95); (v) recent searches for infall motions toward young stellar objects (Mardones et al. 1997, *ApJ* 489, 719); and (vi) a thorough review on the environment and formation of massive stars (Garay and Lizano 1999, *PASP* 111, 1049).

The Astronomy Department is actively engaged in collaboration with a number of international institutions, presently holding agreements with the Association of Universities for Research in Astronomy (AURA), the Carnegie Southern Observatory (CARSO), the University of Florida, the National Radio Astronomy Observatory (NRAO), CalTech, the National Astronomical Observatory of Japan (NAOJ), and the Instituto Astrofísico de Canarias (IAC). A 45-cm telescope donated by the government of Japan, with a CCD camera 1k × 1k, will arrive at Cerro Calán in 2002, to be used for public outreach and student training. The Department operates the *Estación Astronómica Cerro El Roble*, with a 90-cm Maksutov telescope.

Pontificia Universidad Católica de Chile

The Departamento de Astronomía y Astrofísica (DAA) is part of the Physics Faculty of the Pontificia Universidad Católica de Chile (PUC). Astronomy at the PUC started in 1929 when the University received, as a donation, a 36-inch Mills telescope located then at the Observatorio Manuel Foster on the Cerro San Cristóbal in Santiago. The Institute for Physics and Astrophysics was founded to teach in these areas; the Institute later gave rise to the present Faculty of Physics. The Department of Astronomy and Astrophysics was created in 1996, and operates at the Campus San Joaquín in Santiago. The PUC is promoting the growth of astrophysics by the creation of faculty and postdoctoral positions, as well as undergraduate and graduate programmes of study: a *Certificado Académico* (minor), a *Licenciatura* (B.Sc.), a M.Sc., and a Ph.D in Exact Sciences.

The University, recognizing the major comparative advantages, has given high priority to astronomy. Since 1995 the number of members at the DAA has increased steadily. Currently, working at the DAA there are 8 faculties: L. Infante (chair), F. Barrientos, M. Catelan, A. Clocchiatti, G. Galaz, D. Minniti, H. Quintana and A. Reisenegger, as well as 8 postdoctoral fellows. All members at the DAA are heavily involved in research and teaching, both astronomy and physics. There are 8 graduate students and of the order of 100 undergraduate students. The DAA carries out research in both observational and theoretical astrophysics. Most of the research is based on observations at the telescopes of the international observatories operating in Northern Chile. A significant fraction of the Department's research projects involves collaborations with European, North American, Australian and other Latin American astronomers, with funding from several international agencies (NASA, NSF, etc).

The main areas of research are: Planetary Astronomy (search for extrasolar planets); Stellar Astronomy (supernovae, Be stars, Cepheid and RR Lyrae variables; distances, ages, and metallicities of clusters in the Galaxy and the Magellanic Clouds); Extragalactic Astronomy (dynamics of groups and clusters of galaxies, evolution and structure of Dumbell galaxies, structure and dynamics of superclusters, faint and low-surface brightness galaxies, gravitational lenses in clusters of galaxies, quasars, large-scale structure and cosmology); and Theoretical Astrophysics (stellar evolution, compact objects, extragalactic astrophysics and cosmology, hot gas and metals in clusters of galaxies, formation of structure in the Universe). DAA members have had important participation in the discovery of the accelerated expansion of the Universe; the disclosure of Ultra Compact Galaxies in clusters; the discovery and understanding of MACHOS; the detection of the overall collapse of the Shapley Superclusters; the strong clustering of galaxies in pairs and in small groups.

With the support of Fundación Andes, who also funds several fellowships, the DAA is involved in a partnership programme with the Department of Astrophysical Sciences of Princeton University (USA). This programme includes a joint postdoctoral prize fellowship in observational astronomy, faculty and graduate student exchange, joint organisation of international meetings in astrophysical areas of common interest, and the construction of an observatory in the outskirts of Santiago for student training. The PUC is one of four international affiliate members of AURA (Association of Universities for Research in Astronomy), and has built a number of partnerships with several academic institutions in Chile and abroad.

Universidad de Concepción

The astronomy group was created in 1995, as part of the Physics Department. Its current staff includes Douglas Geisler, Wolfgang Gieren, Ronald Mennickent, and recently Tom Richtler. There are 4 postdocs funded by the Comité

Mixto ESO-Chile, the Alexander Von Humboldt Foundation, and a NASA project. Research is funded mostly by FONDECYT, as well as by Fundación Andes and several international agencies.

Current fields of research include: Star clusters (galactic and extragalactic); Stellar populations (in the local group and other nearby groups of galaxies); Distance scale calibration (Cepheids, RR Lyraes, red clump stars, blue supergiants, PNLF, GCLF, SN Ia); Physics of stellar standard candles; Cataclysmic variables and accretion disks; Dwarf novae and long-term variables; Close binary evolution and brown dwarfs in binary systems; Old giants in the galactic halo; Galactic structure. A full account of the ongoing work can be found in Gieren et al. 2002 (*The Messenger* 106, 15)

The Universidad de Concepción recently created a Doctoral programme in physics, including astronomy. Presently there is one student enrolled in astronomy and several more are expected to enter the programme in 2002. In 2003 a *Licenciatura en Física con Mención en Astronomía* will begin.

Universidad Católica del Norte in Antofagasta

The Instituto de Astronomía at the Universidad Católica del Norte, of recent formation, operates the Observatorio Cerro Armazones, with two telescopes of 84 cm and 41 cm. In 2002, with the support of the Physics Department also from the Facultad de Ciencias, an undergraduate programme, *Licenciatura en Física con mención en Astronomía*, will start. The Institute operates, with the help of ESO, an important outreach centre, the *Centro de Divulgación de la Astronomía*, serving the northern Chile community. There is presently one full-time staff member, L. Barrera, and another one will be appointed this year with the help of the Comité Mixto ESO-Chile. The research carried on at the Institute includes Ground Support for Space Missions; Quasar Monitoring; Trans-Neptunian Objects; Craters and Meteorites in the II Region of Chile.

Universidad de La Serena

The Universidad de La Serena has created a new astronomy group at the Physics Department, with two staff members, A. Ramírez and H. Cuevas. Another one will be hired with the help of the Comité Mixto ESO-Chile. The Physics Department, traditionally devoted to teaching, is presently strongly supporting the development of research in astronomy. The group has further impact over the IV Region of Chile by providing the possibility of starting a career in astronomy to local students unable to move away from the region. Research is mostly oriented to Extragalactic Astronomy (intermediate red-shift clusters, X-Ray clusters).

III. The Next Decade

The FONDAP Centre of Excellence is expected to play a major role supporting the formation of human resources in astrophysics at different universities in Chile. The Ph.D., M.Sc., and/or B.Sc. programmes in astronomy at the Universidad de Chile, Pontificia Universidad Católica, and Universidad de Concepción will benefit strongly from the efforts of the astronomers associated with the Centre. They will offer graduate courses jointly to students of all institutions, supervise students from any institution, and visiting professors will be encouraged to have stays at more than one site. The Centre will also support and be involved in summer schools to attract the young, science-oriented minds, to astrophysics. The Centre is expected to become, in a ten-year frame, a world-wide recognised institution that provides graduate student training at the highest level of excellence and performs frontier research in astrophysics.

The Centre will encourage members to perform and be involved in the execution of large surveys. Chilean astronomers are in a unique position to do prominent surveys, maximising telescope time and fostering cross collaborations. This can be achieved by organising the Chilean community, and dedicating a fraction of the available (human and technical) resources. These surveys, along with the solid doctoral programmes at Chilean Universities, would perhaps become the long-lasting legacy of the new Centre. Its present members are G. Garay (Director), M.T. Ruiz (Subdirector), L. Bronfman, D. Geisler, W. Gieren, L. Infante, D. Mardones, J. Maza, D. Minniti, H. Quintana, and M. Rubio.

The first goal of the Centre is to broaden the research base in each astronomy site within the country, giving a particular emphasis to the development of research areas related to the study of the *origins* of celestial objects. The second, and equally important, goal of the Centre is to strengthen the teaching of theoretical astrophysics in all astronomy Ph.D. programmes in the country so that they will be fully conducted by Chilean universities.

There will be five main areas of astrophysics to be cultivated at the Centre. All of them have a distinct integrator: *The study of origins of celestial objects* ; and a common window for future progress: *Sub-millimetre wavelength observations with ALMA*. The advance in knowledge in any of these areas will have an immediate impact in the understanding of the others. Each of the areas will be led by a Principal Investigator (P.I.) which will be responsible for the proper advance to achieve the goals expected in his/her area of research. In what follows we shortly summarise the research areas, putting emphasis in the connectivity between them.

1. Birth and Evolution of Structures in the Universe (P.I.: L. Infante)

One of the greatest challenges in extragalactic astrophysics is to understand the formation and evolution of galaxies. Understanding the physics underlying the processes by which these structures formed and evolved is the main thrust of modern cosmology. To reconstruct the star-formation history of the Universe beginning with the early epochs of galaxy formation and reaching the present is one of the key questions in astrophysics. The Centre will carry out studies in the following topics:

• *Primeval galaxies*. – How, at the earliest epochs, the seeds observed in the cosmic microwave background radiation lead to the formation of the first galaxies (and stars), and how these primordial low-mass galaxies merge to produce the more massive systems we see today.

• *Galaxy clusters as tracers of Large-Scale Structure*. – Galaxies cluster on all scales by gravitational forces and this clustering evolves with time. As galaxies cluster on smaller scales, they interact more and more, leading to their growth via a merging process. How, during early times, clustering processes assemble larger galaxies by mergers of smaller or not fully developed ones, leading to the present-day large galaxies; and how gas with a mass an order of magnitude larger than those in galaxies, is trapped in the growing gravitational potential wells.

• *Starburst galaxies*. – The current generation of mega-telescopes and unique instrumentation will make possible the identification of hundreds of extreme star-forming galaxies at redshifts ~ 3 and higher, thereby initiating detailed studies of star-forming galaxies when the Universe was still young. These studies will permit to characterise and trace the evolution of starburst galaxies on a firm statistical basis and, in particular, to determine the peak epoch of star formation activity, helping to constrain structure formation models.

• *Globular Clusters and Galaxy Formation*. – Being the living probes of the earliest epoch when most galaxies formed, globular clusters (GCs) are an ideal tool for the study of galaxy formation. Centre members plan to obtain reliable age, chemical abundance, and kinematic information for globular cluster systems, which will provide critical clues to reveal the formation and chemical evolution history of galaxies, and will help to tightly constrain galaxy formation models.

• *Nearby galaxies*. – The nearest galaxies are key in the understanding of galaxy evolution, since they are the only galaxies that can be studied consistently on a star-by-star basis, providing direct information on the distribution of ages and metallicities. Their studies will help us to constrain the integrated-light population synthesis models used in the interpretation of distant galaxies not resolved into stars.

• *The Milky Way*. – Our own galaxy, the Milky Way, is a unique place to study in great detail the formation and evolution of galaxies. We can determine with exceeding resolution the interplay between its stellar, molecular, and neutral components, which should be representative of similar galaxies. Centre members are involved in the determination of the large-scale distribution of massive star formation in our own Galaxy, aiming to derive the best rendition of the spiral structure of the Milky Way, using the most adequate tracers, which will become a key stone for future comparison with the distribution in external galaxies at the scale of spiral arms.

2. Quasars and Active Galactic Nuclei (P.I.: J. Maza)

Being the most luminous objects of the Universe, quasars and active galactic nuclei are splendid, but puzzling, probes of the earlier stages of cosmic evolution. Members of the Centre will carry out research in three main topics of this fascinating area of astrophysics. They will seek to understand how the luminosity function for quasars evolves with time (or redshift), which is of paramount importance in order to understand how massive black holes can develop in galactic centres and how they become bright quasars. They will also investigate the mechanism of the enormous energy production in compact objects, including quasars, nuclei of giant elliptical galaxies, BL Lac objects, and cores of radio galaxies. In addition, they will undertake observations to determine the metal abundance of the faintest population of starburst galaxies, a project of utmost importance since it will permit to obtain the most accurate value of the primordial Helium abundance, a basic cosmological parameter. Once ALMA comes on line, the researchers in this field will get accurate measurements of the sub-millimetre emission from quasars and active galactic nuclei to clarify the relationship between these enormously energetic objects and to learn about the mechanism of their energy production. These measurements would be crucial to distinguish between the mechanisms leading to "radio-loud" and "radio-quiet" quasars.

3. The Extragalactic Distance Scale (P.I.: W. Gieren)

• *Cepheid variables as standard candles*. – Cepheid variables are thought to be one of the most reliable standard candles, and hence one of the most powerful distance indicators. There are, however, uncertainties, in particular the effect of metallicity on the Cepheid fundamental physical parameters and on their pulsation properties. To determine the effect of metallicity on Cepheid properties, Centre members will carry out a programme to discover Cepheid variables in nearby galaxies with steep metallicity gradients in their disk, and then calibrate the metallicity effect on the period-luminosity relationship. This programme is expected to lead to the first truly accurate empirical determination of the effect of metallicity on Cepheid-based galaxy distances.

• *The distance to the LMC*. – Although the knowledge of the distance to the Large Magellanic Cloud (LMC) is a key step in the determination of the distance ladder, its value is still a matter of debate. Centre members will employ the surface brightness technique calibrated on Cepheid variables, and at infrared wavelengths to minimise problems with interstellar absorption and metallicity to obtain the distance with a precision of 3%. Such a precision will mean a big leap forward in the calibration of the distance scale, and the Hubble constant.

4. Star Formation (P.I.: G. Garay)

A comprehensive theory of both high- and low-mass star formation is an essential requirement if we are to understand galaxy formation and evolution and the formation of Sun-like stars and planets. However, our knowledge of how stars form is still rudimentary. Several questions of a basic nature remain unanswered: (a) What motions occur before and during the gravitational collapse of a molecular cloud core to form stars? (b) How do stars acquire their main-sequence mass, or how does the collapse and accretion stop? and (c) What is the role of disk-like structures in the formation of single stars, binary stars, and planets? (d) How are high-velocity bipolar jets driven away from the central protostar? To address these questions, Centre members have identified 850 individual regions of massive star formation in the Milky Way, the most complete sample presently available.

• *Infall*. – Members of the Centre will study, at sub-millimetre wavelengths, the long-sought evidence of gravitational infall onto very young stars, to get a comprehensive view of the infall processes leading to either the formation of an isolated low-mass star, as seen in dark globules, or to the formation of a cluster of massive stars, as seen in dense molecular cores. Do low- and high-mass stars form in a self-similar way? or do they follow a different formation path, possibly due to differences in the initial conditions of the parental gas? In the latter case, which is the determinant physical parameter of the ambient gas that establishes the different modes of collapse? With ALMA they will study the kinematic of the infalling gas close to the forming star, the structure and kinematics of protostellar disks, and their role in the formation of binary stars and planets.

• *Outflows*. – One of the major astronomical results of the last two decades has been the discovery that star formation is accompanied by energetic, collimated mass outflow. The outflow mechanism is unknown and requires study on scales as close to the star as possible. High-velocity flows from recently formed stars will be observed with unprecedented sensitivity, helping to elucidate the mechanism that drives the outflow and its influence in limiting the growth of a star. They will also investigate how the outflow phenomena that appear in the earliest stages of star formation affect the physical and chemical properties of the environment.

• Star formation in the Magellanic Clouds. – The Large and Small Magellanic Clouds (LMC, SMC), being the two nearest external galaxies, provide the best opportunity for a detailed study of the stellar and interstellar matter component of any external galaxy. Understanding the process of formation of stars, their interaction with the surrounding gas and dust, the chemical enrichment, as well as the older population of stars in these galaxies, is the link between the knowledge in our Galaxy and the rest of the Universe.

5. Brown Dwarfs and Planetary System Studies (P.I.: M.T. Ruiz)

• *Brown Dwarfs*. – Sub-stellar objects, like brown dwarfs, are likely to provide unique information on the fragmentation processes that accompany the formation of a single star or a cluster of stars. Although the first free floating brown dwarf was discovered only five years ago, current surveys are showing that there are plenty of these objects, implying that we might be immersed in a sea of small dark bodies. How many and how massive are they? The answer to these questions will have an impact on the theory of stellar formation and might have some dynamical consequences for the galaxy as a whole. Using the new optical/IR mega-telescopes and their IR instrumentation it will be possible to investigate the physical characteristics of these objects, particularly those in orbit around nearby stars which will allow us to obtain their masses. ALMA will be a perfect instrument for the follow-up studies of brown dwarfs found in these studies.

• *Extrasolar planets and proto-planetary disks*. – One of the great appeals of astronomy is undoubtedly its potential to help us understand the origin of our planet. The Centre will foster the development of the area of planetary science, currently non-existent in the country, starting from available human resources. This would be accomplished by joining and developing searches for extrasolar planetary systems using modern techniques such as radial velocities, planetary occultations (transits) and micro-lensing. Once ALMA is available we will be able to undertake molecular line observations of the atmospheres of planets and other bodies which will give new knowledge of planetary "weather", the structure of atmospheric wind and the variations in chemical constituents. Studies of proto-planetary disks will be carried out using the recently available IR facilities. ALMA, with its sensitivity and resolving power, will be the ideal instrument to provide definite answers regarding the formation and evolution of proto-planetary disks. Their images will have enough detail to allow astronomers to see chemical variations in proto-planetary systems and to permit them to compare such systems with evolutionary models of our own solar system.

The present article could not have been written without the contribution of the FONDAP Centre of Excellence Director, Guido Garay, and of its P.I. Members. I thankfully acknowledge the contribution from M.T. Ruiz, Director of the Astronomy Department at Universidad de Chile; L. Infante, Chairman of the Pontificia Universidad Católica de Chile Department of Astronomy and Astrophysics; W. Gieren, Head of the Astronomy Group at the Universidad de Concepción Physics Department; L. Barrera, from the Instituto de Astronomía at Universidad Católica de Antofagasta; and A. Ramírez, from Universidad de La Serena.

Dynamics and Mass of the Shapley Supercluster, the Largest Bound Structure in the Local Universe

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Introduction

The Shapley Supercluster is the largest bound structure identified in the local Universe ($z < 0.1$). In this article, we discuss the role of superclusters as present-day "turning points" in the growth of structure in the Universe. We review observations of the Shapley Supercluster and their interpretation, particularly with regard to its dynamics and the determination of its mass, much of which has been done by our group, centred at Pontificia Universidad Católica de Chile. Finally, we describe our recent application of a spherical collapse model to the supercluster, and discuss possibilities of future progress.

1. Cosmological Structure Formation and Superclusters

Observations of the cosmic microwave background radiation show matter in the early Universe to be very uniformly distributed, with large-scale density perturbations as small as 1 part in 10^5 (Smoot et al. 1992). This is in strong contrast with the present-day Universe and its highly overdense condensations, such as galaxies and clusters of galaxies. A natural and widely accepted explanation for the growth of the density perturbations is that initially slightly overdense regions attract the surrounding matter more strongly than underdense regions. Therefore, the expansion of overdense regions is slowed down with respect to underdense regions, and the density contrast grows. Eventually, regions of large enough overdensity can stop their expansion altogether and start recontracting. Their collapse is then followed by a process of relaxation or "virialisation", after which the resulting object is in an approximate equilibrium state, in which its structure is only occasionally perturbed by merging with other objects. This state is well described by the *virial theorem* of classical mechanics, which states that in such an equilibrium state the gravitational potential energy of the object is proportional to the total kinetic energy of the smaller objects randomly moving inside it (stars in a galaxy, galaxies in a cluster of galaxies). This theorem allows to infer the mass of the object (which determines the gravitational potential) from the measured velocity dispersion and size of the collapsed structure.

Inflationary models for the early Universe predict a well-defined relation between the amplitude of the "initial" density fluctuations on different spatial scales. The prediction, corroborated by several sets of observations, implies that the fluctuations are largest on the smallest scales. Since fluctuations on all significant scales grow at the same rate, those on the smallest scales will first reach turnaround and virialisation. Thus, the chronological order of formation of objects proceeds from small to large, i.e., from globular clusters[1] to galaxies, groups of galaxies, and finally to galaxy clusters, the largest virialised known structures at present. The next larger objects, namely groupings of clusters of galaxies, or *superclusters,* should presently be undergoing gravitational collapse, whereas even larger structures should still be expanding and only slightly denser than average.

On the largest scales, the Universe is still undergoing a nearly uniform expansion. For a very distant galaxy, its *redshift factor* $1 + z$, defined as the ratio of the *observed* wavelength of a given line in the spectrum to the wavelength of the same line *at its emission,* is a good approximation to the factor by which the Universe expanded in all spatial directions while the radiation was travelling through it. From a Newtonian point of view, applicable to regions much smaller than the Hubble length[2], this is

[1]Structures much smaller than globular clusters cannot collapse spontaneously, since their gravitational attraction is not strong enough to overcome the pressure of the intergalactic gas. Therefore, stars are formed only within collapsing or already collapsed larger structures.

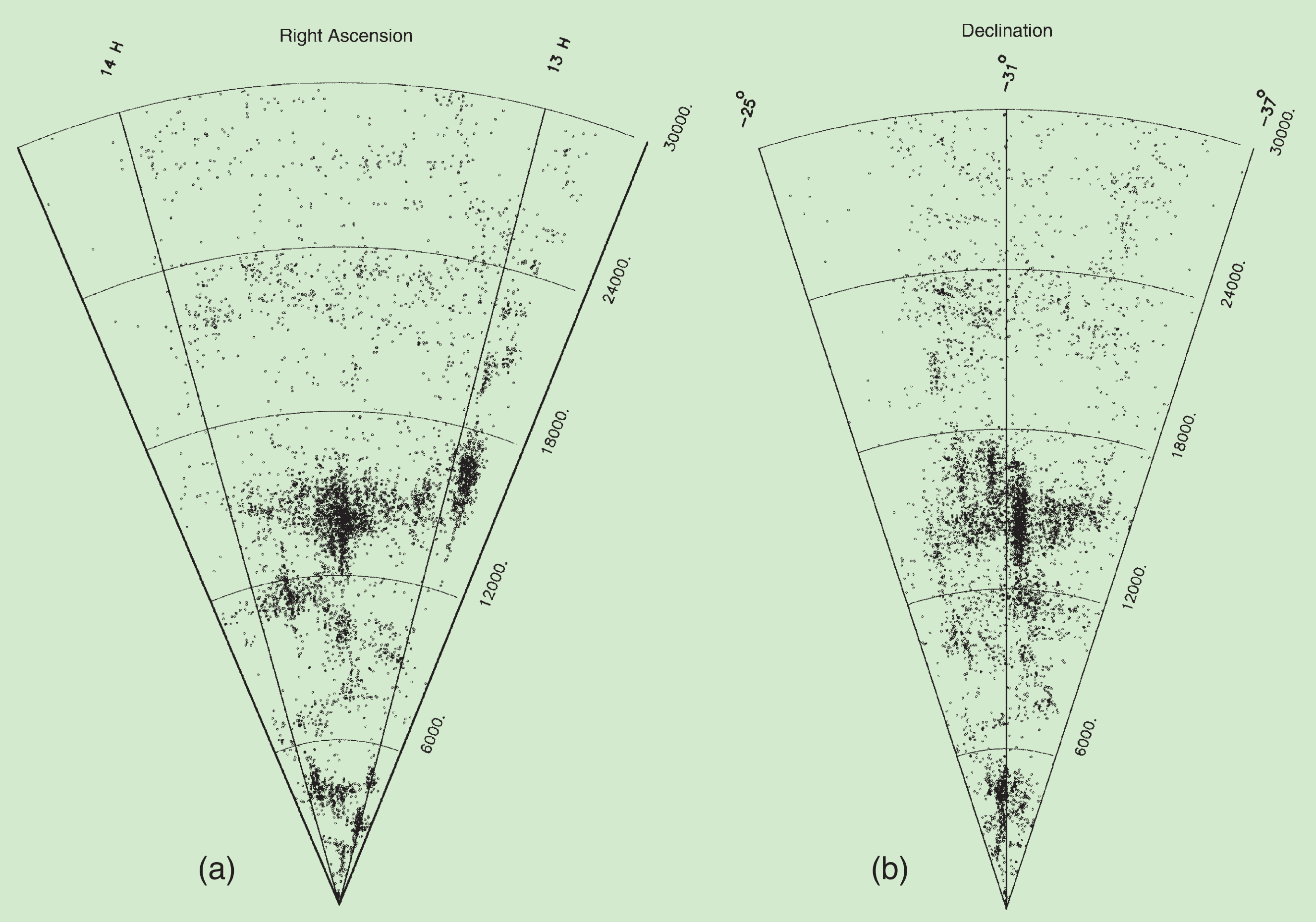

Figure 1: Two projections of the distribution of galaxies with measured redshifts in the region of the Shapley Supercluster. The radial co-ordinate, the recession velocity determined from the redshift, cz, measured in km/s, is an imperfect surrogate (see text) for the galaxy's distance to us, which would be at the vertex. The angle in panel (a) is right ascension α in hours (1 h = 15°), in panel (b) it is declination δ in degrees. Both angles are expanded relative to their true size.

equivalent to write the present-day recession velocity of the galaxy as $v_r = cz = H_0 d$, where c is the speed of light, z is the same as in the previous definition, H_0 is the *Hubble parameter* (see footnote 2), and d is the (Euclidean) distance between us and the object, therefore allowing us to (approximately) infer the distance from the measurement of z. Knowledge of an object's sky co-ordinates α and δ and its redshift z allow its approximate positioning in the three-dimensional space, and large catalogues of objects with this information can be used to trace the three-dimensional large-scale structure.

In virialised structures, on the other hand, there is no expansion, and redshift *differences* between constituent objects are due to the local kinematic Doppler effect resulting from relative motions within the structure, which are unrelated to their distance from us. In this limit, structure along the line of sight is difficult to discern, but the dispersion of redshifts allows to determine the object's mass, as discussed above.

In the intermediate regime, of interest here, the situation is much more murky. Deviations from the uniform expansion are large, some parts of a structure may be expanding while others are contracting at the same time, but no virial equilibrium has been reached. More detailed modelling is generally required to disentangle the three-dimensional morphology and the internal dynamics of the structure. If this can be done, one of its by-products are the masses of these structures, which can be used to constrain the spectrum of initial fluctuations, an important ingredient of all models of cosmological structure formation.

2. The Shapley Supercluster

According to recent catalogues of agglomerations of clusters of galaxies (Zucca et al. 1993; Einasto et al. 1997), the so-called Shapley Supercluster is by far the largest such structure in the local Universe, out to $z \sim 0.1$. Its core region was first pointed out by Shapley (1930), who noticed a *"cloud of galaxies in Centaurus that appears to be one of the most populous yet discovered, [...], oval in form with dimensions roughly 2.8° by 0.8°"*, and centred at the position of the very rich cluster Shapley 8 (Shapley 1933). It was later rediscovered, identified with an X-ray source, called SC 1326-311 (Lugger et al. 1978), and is now more commonly known as A3558 (Abell et al. 1989).

This structure gained attention when a dipole anisotropy in the cosmic microwave background radiation (CMBR) was detected and interpreted as due to the Earth's motion with respect to the homogeneous background frame defined by the CMBR (Smoot & Lubin 1979 and references therein). Correcting for small-scale, local motions, the velocity of the Local Group of galaxies[3] with respect to the CMBR is ≈ 600 km/s (e.g., Peebles 1993), approximately in the direction of the structure found by Shapley, but long forgotten. Initially, it was thought that this motion was produced by the gravitational attraction of the Hydra-Centaurus Super-

[2]The Hubble length is $c/H_0 \approx 5000$ Mpc, where H_0 *is* the "Hubble parameter", i.e., the present expansion rate of the Universe, and 1 Mpc *(megaparsec* = 3.086×10^{19} km = 3.261 million light-years, roughly the distance between our Galaxy and Andromeda or the size of a cluster of galaxies. The Hubble length is roughly the distance traversed by a light ray during the age of the Universe, much larger than the size of any of the structures being discussed here.

[3]This group contains our own Galaxy (the "Milky Way"), M 31 ("Andromeda"), and 20 or so smaller galaxies, such as M32, M33, and the Magellanic Clouds.

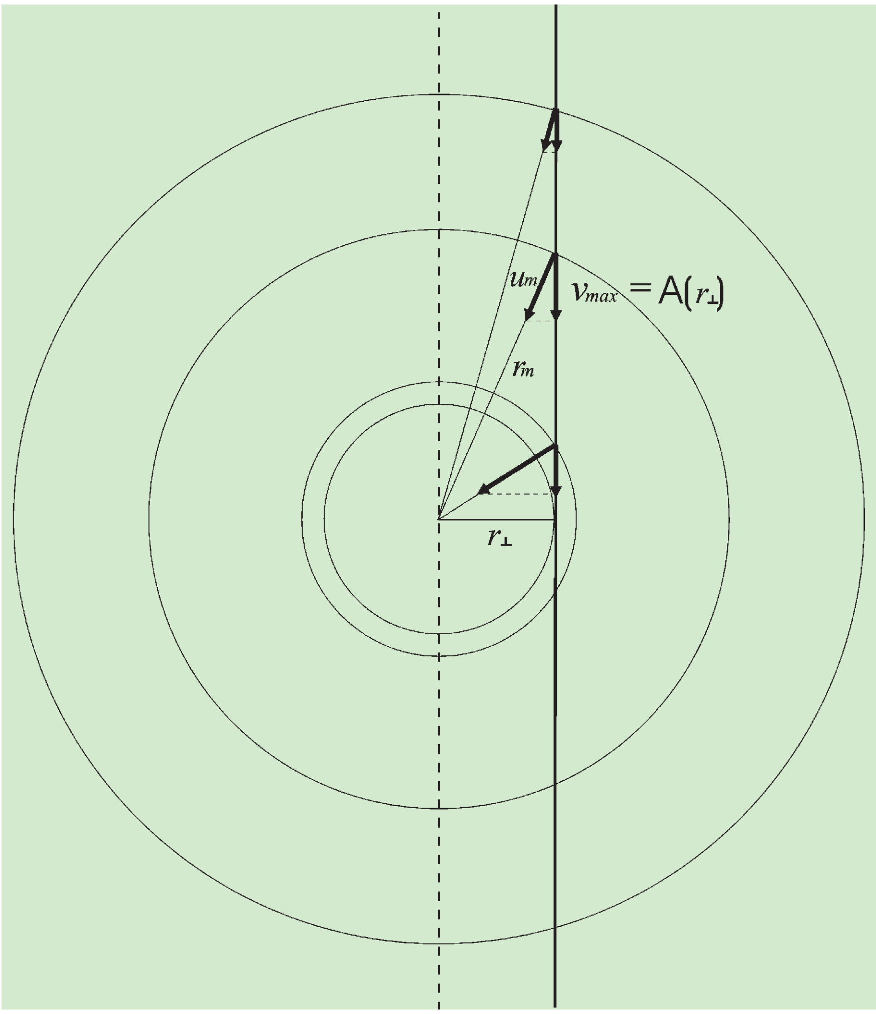

Figure 2: Schematic representation of the spherical collapse model. A discussion is given in the text.

cluster, at $cz \approx 3000$ km/s. However, Dressler et al. (1987) found a coherent streaming velocity beyond this structure, out to $cz \approx 6000$ km/s, implying that, if there was one single or dominant "attractor", this had to be further away. Melnick and Moles (1987), using redshift data gathered in "SC 1326-311" by Melnick and Quintana (1981) and preliminary data taken over a more extended region by Quintana and Melnick (later published in Quintana et al. 1995), showed that there is a much larger concentration at $cz \approx 14{,}000$ km/s, which they called the "Centaurus Supercluster", giving a first mass estimate for its central region, based on the virial theorem, as $2.5 \times 10^{15}\, h^{-1}\, M_\odot$ within 1° or $\sim 2.5\, h^{-1}$ Mpc,[4] and finding that this is far from the mass needed, by itself, to produce the required acceleration of the Local Group over the age of the Universe. Scaramella et al. (1989) pointed out that there is a large concentration of clusters in the direction of the Local Group motion, which they called "α-region", without reference to either Shapley or Melnick & Moles. It was Raychaudhury (1989) who pointed out that the concentrations found by all these authors were the same, and coined the name "Shapley Supercluster". He confirmed a strong concentration of galaxies in that direction, based on a much larger catalogue than that used by Shapley, estimated its total luminosity, L, and found that an enormous mass-to-light ratio,[5] $M/L \geq 6000 hM_\odot/L_\odot$, is required to produce the observed Local Group motion.

We will not attempt to review all the subsequent work carried out on the Shapley Supercluster, but only highlight a few contributions which are important to the present purpose. Spectroscopic observations, with the main purpose of obtaining redshifts, in order to determine masses and trace the 3-dimensional structure of the SSC, were carried out by several groups, but most intensively and systematically by two of them: Quintana and collaborators (Quintana et al. 1995, 1997, 2000; Drinkwater et al. 1999) and Bardelli and collaborators (Bardelli et al. 1994, 1998, 2000, 2001; early work reported in *The Messenger:* Bardelli et al. 1993). Since the SSC is at declination $\delta \approx -30°$, telescopes in Chile are ideally suited for its study. In fact, Bardelli and collaborators have made extensive use of the ESO 3.6-m for a detailed study of the very dense condensations around the clusters A 3558 and A 3528, whereas Quintana and collaborators mostly took advantage of the large field (1.5° × 1.5°) of the 2.5-m telescope at nearby Las Campanas, in order to cover a much wider area, ~ 8° × 10°. Their papers discuss quantitative and qualitative properties of individual clusters and the morphology of the SSC (under the assumption that redshifts indicate distances, at least on the global scale of the supercluster). The most detailed discussion so far of the latter was given by Quintana et al. (2000), who find the SSC to consist of several subcondensations with filamentary structures emerging and connecting them. Two projections of the "three-dimensional galaxy distribution" in right ascension α, declination δ, and recession velocity cz are given in Figure 1.

Different methods have been used to put bounds on the mass and density of parts of the SSC[6]:

(1) adding up the masses of individual clusters determined through the virial theorem (e.g., Quintana et al. 1995, 1997) or from X-ray observations (Raychaudhury et al. 1991; Ettori et al. 1997), which of course gives a lower bound on the total mass, as intercluster matter is not taken into account;

(2) estimates of the overdensity on the basis of galaxy counts on the sky, e.g., in 2 dimensions, having to make educated guesses as to the SSC's depth and the fraction of the observed galaxies belonging to the SSC as opposed to the foreground or background (Raychaudhury 1989);

(3) estimates of the overdensity from counts in 3-dimensional redshift space, assuming that the redshift is a good distance indicator (Bardelli et al. 1994, 2000), i.e., that the SSC is still in the initial expansion phase; and

(4) virial estimates applied to the whole or a large part of the SSC (Melnick & Moles 1987; Quintana et al. 1995; Ettori et al. 1997), which requires, at least conceptually, that the SSC has already ended its collapse phase and relaxed to an equilibrium state.

We emphasise that methods 3 and 4 place the supercluster at opposite ends of its dynamical evolution, which are both not correct according to the discussion in Section 2. For the sake of argument, consider a homogeneous structure exactly at turnaround. At that instant, there are no internal motions, and all galaxies within the structure are therefore at the same redshift. Analysing this structure with method 3,

[4] Here, $h = H_0/(100$ km/s/Mpc$) \approx 0.5 - 0.8$ is the standard parametrisation of our ignorance regarding the exact value of the Hubble parameter, and $M_\odot$, is the mass of the Sun, 2×10^{30} kg.

[5] $L_\odot = 4 \times 10^{26}$ watts is the luminosity of the Sun. The typical mass-to-light ratio of a cluster of galaxies is $\sim 300 hM_\odot/L_\odot$ (Peebles 1993).

[6] We will not go here into the still unresolved and perhaps somewhat academic question of what would be meant by "the whole SSC". See Quintana et al. (2000) for a recent discussion.

one would argue that there is a finite number of objects within a vanishing volume, and therefore an infinite density would be inferred. With method 4, the vanishing kinetic energy of the structure is taken to reveal a vanishing potential energy, and therefore a vanishing mass density. In practice, this state of zero motion is of course never realised, mostly because superclusters are never homogeneous, but always contain substructure (most prominently clusters of galaxies) whose internal velocity dispersions produce a spread in redshift space, in this way making both estimates give finite results. However, it is not fully clear whether these finite results are close to the true values to be determined[7]. So far, details in the definition of the volume to be considered appear to be more important than the choice of method. The average density within a large radius, ~ $10h^{-1}$ Mpc, around the SSC's centre generally comes out to be a few times the cosmological critical density $\rho_c = 3H_0^2/(8\pi G)$, not far from the density expected at turnaround (~ $5\rho_c$). This makes the discussion above particularly relevant, as more and more data on this and other superclusters are being accumulated.

3. Spherical Collapse Models

In order to avoid considering only the extreme limiting cases of pure Hubble expansion or a time-independent equilibrium state, Reisenegger et al. (2000) considered a simplified, spherical model that allows to calculate the full, nonlinear dynamical evolution from the initial (Big Bang) expansion through turnaround until the final collapse. This model, pioneered by Regos & Geller (1989) and applied by them to the infalling galaxies in the outskirts of individual clusters, treats the matter as composed of concentric spherical shells, each of which first expands and then contracts under the gravitational pull of the enclosed matter (composed of the smaller shells). If the structure has an outwardly decreasing density profile, the innermost shells will collapse most rapidly, and no crossing of shells will occur at least until the first shells have collapsed, so the mass M enclosed in each shell is a constant in time.[8] This allows the time evolution of any given shell's radius, $r(t)$, to be written in the familiar parametric form,

$$r = A(1 - \cos\eta); \quad t = B(\eta - \sin\eta); \qquad A^3 = GMB^2 \qquad (1)$$

(e.g., Peebles 1993, chapter 20), where A and B are constants for any given shell, determined by the enclosed mass M and the shell's total energy per unit mass, G is Newton's gravitational constant, and η labels the "phase" of the shell's evolution (initial "explosion" at $\eta = 0$, maximum radius or "turnaround" at $\eta = \pi$, collapse at $\eta = 2\pi$). As we are observing many shells at one given cosmic time t_1 (measured from the Big Bang, at which all shells started expanding, to the moment at which the structure emitted the light currently being observed), the speed of each shell can be written as

$$\dot{r} \equiv \frac{dr}{dt} = \frac{r}{t_1}\frac{\sin\eta(\eta - \sin\eta)}{(1 - \cos\eta)^2}. \qquad (2)$$

Equations (1) can also be combined to yield

$$M = \frac{r^3}{Gt_1^2}\frac{(\eta - \sin\eta)^2}{(1 - \cos\eta)^3}, \qquad (3)$$

the mass enclosed within the shell of current radius r. Therefore, having an estimate for t_1 (depending on the cosmological model), a measurement of the radial velocity $\dot{r}$ for each shell would

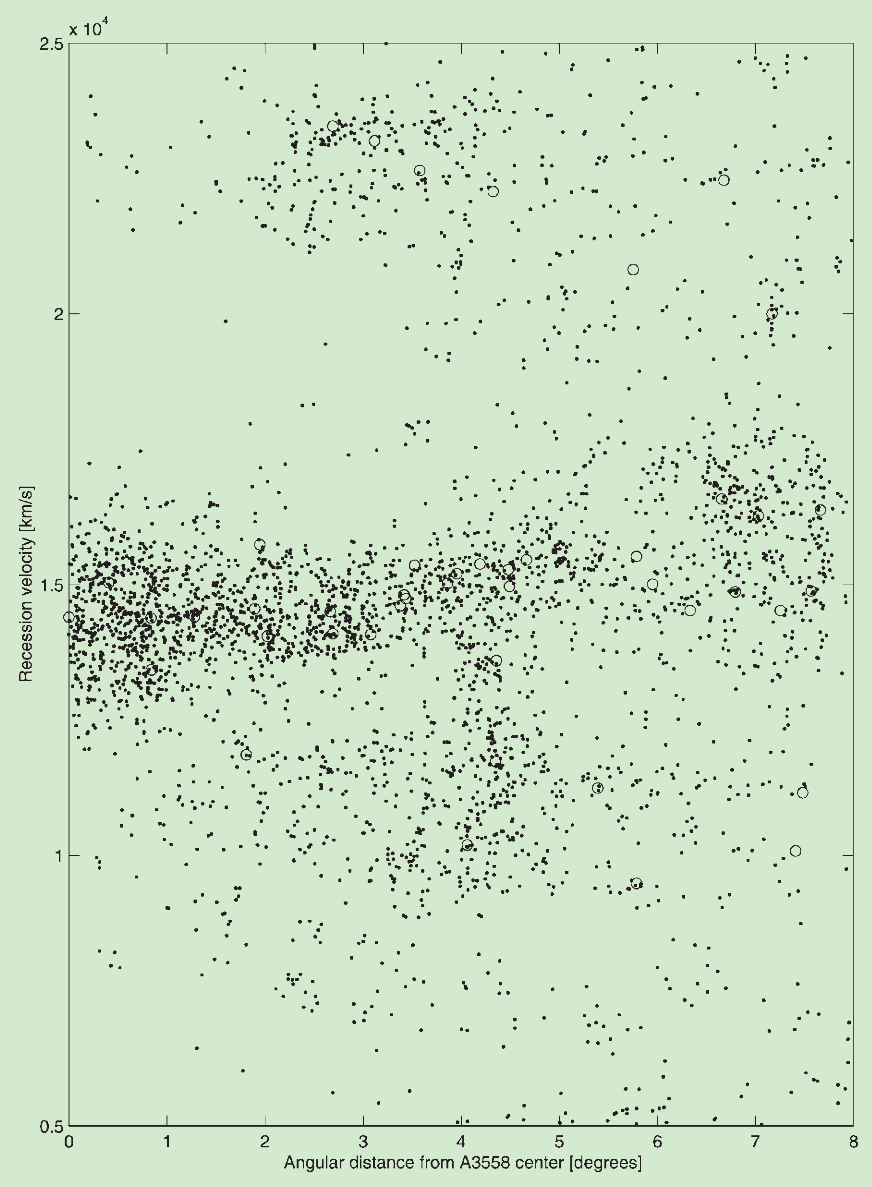

Figure 3: Distribution of galaxies and clusters of galaxies in the Shapley Supercluster, with reference to the central cluster A 3558. The abscissa represents the projected angular distance θ of each object to the centre of A 3558, related to the projected physical distance by $r_\perp = 2.5\ \theta$ [degrees] h^{-1} Mpc, where our distance to A 3558 is taken to be $cz/H_0 = 143\ h^{-1}$ Mpc. The vertical axis is the line-of-sight velocity, cz. Dots are individual galaxies, circles represent the centres of clusters and groups of galaxies. Note the dense region extending horizontally from the location of A 3558 (circle at $\theta = 0$, $cz \approx 14{,}300$ km s^{-1}), which is interpreted as the collapsing structure. (Figure reproduced from Reisenegger et al. 2000.)

[7]Simulations by Small et al. (1998) of superclusters near turnaround within popular cosmological models show at least the virial mass estimate to be surprisingly accurate. It remains to be determined how sensitive this result is to the dynamical state (or density) of the supercluster and to the amount of structure on smaller scales, and whether the galaxy overdensity method is similarly accurate.

[8]Since the density in a (proto-)cluster or supercluster is always much larger than the presently popular value of the "cosmological constant" or "exotic energy" density, the effect of the latter on the dynamics can be safely ignored, except in its contribution to the age of the Universe, i.e., the time available for the collapse to occur.

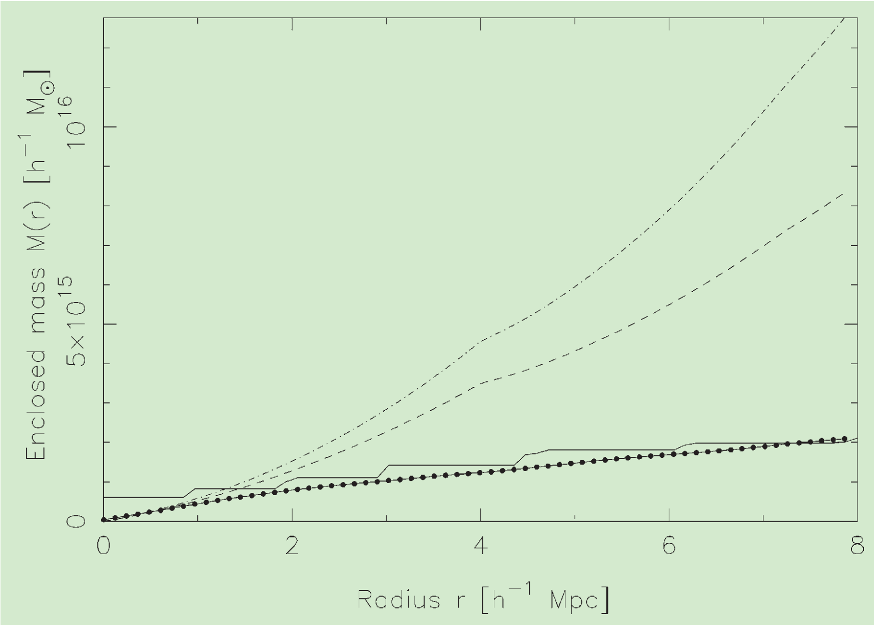

Figure 4: Enclosed mass as a function of radius around A 3558 given by different methods. The solid line is the sum of masses of clusters and groups within the given radius, taking their projected distance as the true distance to A 3558. The dashed and dot-dashed lines are upper bounds to the total mass based on the pure spherical infall model, for a Universe dominated by a cosmological constant and for a Universe with critical matter density, respectively. The solid-dotted line is the estimate from Diaferio & Geller's (1997) escape-velocity model. (Figure reproduced from Reisenegger et al. 2000.)

allow to solve for η and, thus, M for the same shell. Since redshift measurements yield velocity components along the line of sight, the determination of $\dot{r}$ is possible in an indirect and somewhat limited way, as follows.

Along a given line of sight through the collapsing structure, passing at a distance $r_\perp$ from its centre, there can be galaxies at different distances from the observer, whom we take to be at the bottom of Figure 2. A galaxy at the same distance as the centre of the structure falls towards the latter perpendicularly to the line of sight, and therefore has the same redshift as the centre. Galaxies *farther* away from the observer have a velocity component towards the observer, so their redshift is somewhat *lower* than that of the structure's centre. The opposite happens with galaxies closer to the observer (not shown), qualitatively inverting the redshift-distance relation familiar from Hubble's law. The redshift difference between a galaxy and the structure's centre is small both when the galaxy is close to the centre (because the velocity is perpendicular to the line of sight), and when it is far away (because the gravitational pull is weak), so it has to take its extreme (positive or negative) value at an intermediate distance from the centre (r_m in Fig. 2), thus defining two symmetric "caustics" in redshift space, of amplitude $v_{max} = A(r_\perp)$.

Note that, generally, there will be galaxies also outside the caustics, corresponding to the expanding Universe far away from the collapsing structure. However, the density at the caustics is formally divergent, and it should also be very high in the enclosed region, making the identification of the caustics relatively unambiguous. Figure 3 shows $r_\perp$ and cz for the galaxies in the SSC's (projected) central area. The dense region enclosed by the caustics clearly stands out.

The caustics amplitude, $A(r_\perp)$, is a decreasing function of $r_\perp$, related to the radial velocity, $\dot{r}(r)$, by a transformation akin to the Legendre transform familiar from thermodynamics and classical mechanics (Reisenegger et al. 2000, Appendix). This transformation can in general not be directly inverted. Given $A(r_\perp)$, one can in the general case only obtain an upper bound on $|\dot{r}(r)|$, and therefore an upper bound on the enclosed mass $M(r)$.

Furthermore, as Diaferio & Geller (1997) pointed out, even if the large-scale shape of the structure is roughly spherical, it is expected to have substructure with random velocities. These add to the purely radial infall velocities, washing out the caustics and expanding the redshift range covered by galaxies in the collapsing structure, which further increases the estimated mass. To cure this problem, they propose the alternative relation:

$$M(r) = \frac{1}{2G} \int_0^r A^2(r_\perp) dr_\perp. \qquad (4)$$

There is no rigorous derivation for this result, although it can be justified heuristically by assuming that $A(r_\perp)$ reflects the escape velocity at different radii, i.e., that all galaxies within the dense region are gravitationally bound to the structure. One has to assume further that the radial density profile lies between $\rho \propto r^{-3}$ and $\rho \propto r^{-2}$, as in the outskirts of simulated clusters of galaxies (e.g., Navarro, Frenk, & White 1997). Nevertheless, tests of this model in numerical simulations shows it to work quite well in the infall regions around clusters (Diaferio & Geller 1997; Diaferio 1999).

Figure 4 shows the enclosed mass as a function of radius, $M(r)$, as determined by the two methods discussed, together with a third determination, namely the cumulative mass of the clusters enclosed in the given projected radius. The cluster mass estimates, M_{500}, taken from Ettori et al. (1997) for the most important clusters, are masses within a radius enclosing an average density 500 times the critical density ρ_c. This is substantially higher than the standard "virialisation density" of ~ 200 ρ_c, and therefore gives a conservative lower limit to the total virialised mass, which may be increased by a factor ~ $(500/200)^{1/2} \approx 1.58$ for a more realistic estimate.

Given the simplifications and uncertainties involved, there seems to be fair agreement among the different mass determinations, and it seems safe to say that the mass enclosed by radius $r = 8h^{-1}$ Mpc lies between $2 \times 10^{15} h^{-1} M_\odot$ and $1.3 \times 10^{16} h^{-1} M_\odot$, corresponding to a density range $\rho/\rho_c \sim 3$–20. It is interesting, nevertheless, that Diaferio & Geller's method gives results that differ so little from the lower limit to the virialised mass in clusters. Therefore, if this method is applicable to the SSC, either there is very little mass outside the clusters of galaxies, or the cluster mass estimates are systematically high.

For comparison, the mass required at the distance of the SSC to produce the observed motion of the Local Group with respect to the cosmic microwave background is $M_{dipole} \approx 2.8 \times 10^{17} h^{-1} M_\odot$, where a standard value for the cosmological density parameter, $\Omega_m \sim 0.3$, has been assumed.[9] The mass within $8h^{-1}$ Mpc can therefore produce at most ~ 5% of the observed Local Group motion, which makes it unlikely that even the whole SSC would dominate its gravitational acceleration. On the other hand, consistent models of the density and velocity distribution on large scales (where density fluctuations are small) in the local Universe can now be built (e.g., Branchini et al. 1999). In these, the SSC figures prominently, although the Local Group motion originates from a combination of several "attractors".

[9] Ω_m is the ratio of the average mass density in the Universe to the critical density. The required M_{dipole} is proportional to $\Omega_m^{0.4}$.

4. Conclusions and Further Work

The SSC is undoubtedly a remarkable structure in a very interesting dynamical state, which deserves further study. A first attempt at a truly dynamical model of the supercluster has been made, but much further progress is possible, at least in principle. A large amount of information is available, namely the sky co-ordinates and redshifts of ~ 6000 galaxies (e.g., Bardelli et al. 2000; Quintana et al. 2000), an important fraction of which is still unpublished, and which is still being expanded, in order to fill in gaps and cover an even wider area (Quintana, Proust et al., in preparation), in order to assess whether a "boundary" of the supercluster can somewhere be discerned. Only a very limited part of the available information, namely the position of the caustics on the ($r_\perp$, z) plane, has been used in the present spherical collapse models. In principle, the galaxy density at each point on this plane can be used to refine the model, either constraining it more strongly by assuming that the galaxies trace the mass, or determining both the mass density and the galaxy density from the full two-dimensional information (Reisenegger et al., in preparation). However, this will require a uniform redshift catalogue, not available at present, since the available data are a collection of observations taken by different astronomers for different purposes. In order to assess the incompleteness of the present redshift catalogue, a complete and accurate photometric catalogue of the region is being prepared (Slezak et al., in preparation). A more homogeneous catalogue might also allow to attempt a three-dimensional, non-spherical model of the SSC, perhaps along the lines of recent work on recovering the initial density fluctuations from the present-day redshift-space density distribution in a mildly nonlinear density field (Goldberg & Spergel 2000; Goldberg 2001). Numerical simulations of superclusters can also be run in order to test and calibrate dynamical models to be applied to the SSC.

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Swimming pool of the Residencia

The swimming pool at the lowest floor of the Residencia was introduced into the project as a part of the humidification system. However, it also serves as an important psychological element that helps to overcome the harsh living conditions, especially for the permanent staff. Photo: Massimo Tarenghi.

To Be or Not to Be and a 50-cm Post-Mortem Eulogy

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Introduction

Be stars were discovered as early as 1866 by the famous Jesuit astronomer Angelo Secchi. Not only was γ Cas the first known Be star but the first star ever to be seen displaying emission lines. About half-way between then and today, the work by Otto Struve and others led to the picture that Be stars differ from supergiant B-type stars, which also feature emission lines, in that they are much less evolved, rotate extremely rapidly (up to 450 km/s at the equator), and their emission lines arise from a circumstellar disk.

Roughly 1–2% of the 10,000 visually brightest stars belong to this class, and only few other types of stars have been observed so intensively and over a similar period of time. Therefore, every addition to the arsenal of observing tools and facilities resulted in an at least proportional expansion of the empirical knowledge base about Be stars. This made it increasingly clear that the physics of the atmospheres of Be stars does not fundamentally differ from the one of other early-type stars. But various processes are more pronounced and interact with one another more strongly. This renders Be stars attractive laboratories for the exploration of early-type stars in general, which make the largest stellar contribution to the chemical and dynamical evolution of late-type galaxies.

The comparison with a laboratory is appropriate because variability on timescales of hours to decades is the common theme of virtually all investigations that are based on repeated observations of Be stars. Obviously, the role of actively controlled experiments is to be taken over by observational monitoring. With many modern observing facilities this is getting ever more difficult. Therefore, when the PI of the FLASH/HEROS spectrographs (e.g., Wolf, B., Mandel, H., Stahl, O., et al. 1993, *The Messenger,* No. 74, p. 19), Prof. Bernhard Wolf from Heidelberg, offered the opportunity of a long-term collaboration, we immediately jumped on it.

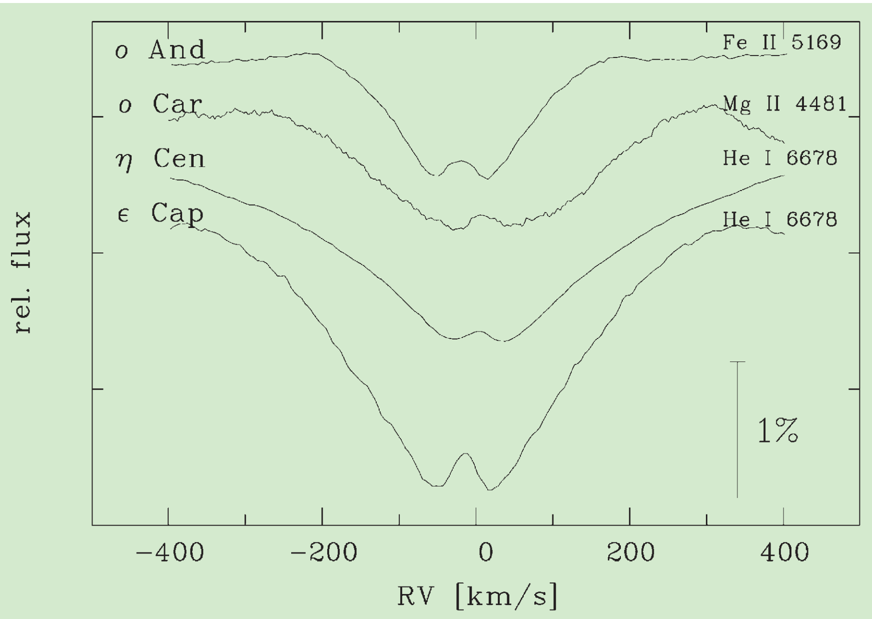

Figure 1: Central quasi-emission components (CQEs) in four different stars. The CQEs themselves are a purely circumstellar, geometric-kinematic phenomenon. The Fe II line is formed only in the disk; the other lines also have some photospheric contribution, which is broader due the rapid stellar rotation. The velocity has been reduced to the heliocentric scale with the CQEs marking the respective systemic velocities.

The wavelength coverage from the near-UV to the near-IR meant that both stellar and circumstellar phenomena could be studied simultaneously. With a CCD as detector, even a 50-cm telescope would suffice to obtain within 30 minutes spectra of 5th-magnitude stars with a signal-to-noise ratio of 100 and a spectral resolving power of 20,000. ESO's Observing Programmes Committee could be convinced to recommend the allocation of the ESO 50-cm telescope on La Silla for several runs of up to 3 months each. The time was to be shared among several projects, of which Be stars formed only one.

This has resulted in an until then unprecedented database of almost 2000 high-quality echelle spectra of three dozen Be stars (some 500 additional ones were obtained from northern-hemisphere observatories). Since meanwhile the ESO 50-cm telescope was de-commissioned in 1997 and after some temporary revival was terminally mothballed in 1999, a summary in *The Messenger* of the many exciting results that could be extracted may be appropriate. Before embarking on the story, we emphasise that the picture of Be stars sketched below is probably not representative of late-type Be stars, which are much more inert. Moreover, it is not complete because, for the sake of brevity, only a minimum of non-HEROS results is mentioned.

The Velocity Law in the Disks

A few broad-lined B stars were noted some years ago to show a weak central reversal, dubbed central quasi-emission (CQE), in some spectral lines (Fig. 1). From the comprehensive HEROS database, two points quickly became apparent: (i) All these stars are actually so-called shell stars, i.e. Be stars whose circumstellar disk ('shell') is intersected by the line of sight, thereby imprinting narrow and often very deep absorption lines onto the stellar spectrum. (ii) CQE's only occur in spectral lines that have also some component due to absorption in the disk. (The latter is cooler than the central star so that the two spectra do not have all spectral lines in common.)

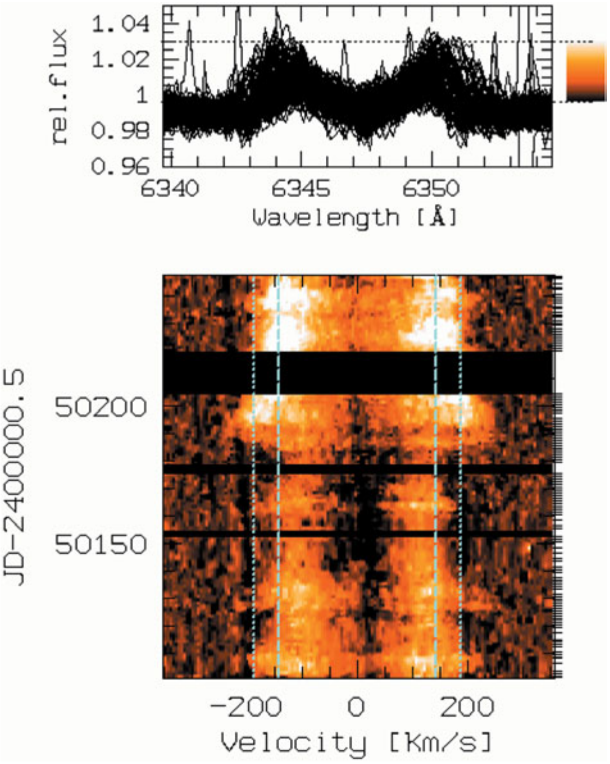

Figure 2: The evolution of the Si II 6347 emission line of μ Cen over an outburst cycle. The left and the right peak respectively form in the approaching and recessing parts of a rotating disk. The blue vertical lines mark the projected rotation velocity of the star (dashed) and the Keplerian velocity at the stellar surface (dotted), respectively. The initial occurrence of line emission at super-Keplerian velocities suggests that some of the matter was moving fast enough to escape the star. The subsequent reduction in separation of the two peaks shows that the ejecta were collected at large distances from the star, where the rotation velocities are lower, and merge with the disk.

Some Be stars erupt relatively mildly every few weeks. Others prefer one major outburst per decade, and there are all kinds of mixed cases. In stars with infrequent outbursts one can observe the incipient demolition of the disk at its inner edge. With time, a cavity eats into the disk, which can be replenished by one or more later outbursts (Fig. 3).

The HEROS spectra have not yet enabled us to elucidate the physical process(es) underlying these mass-loss events. Otto Struve still conjectured that the Be stars are rotationally unstable. Later, quantitative analyses have rendered this picture untenable. Not considering a small number of stars spun up by mass transfer from a companion, the HEROS database did not lead to the identification of stars with more than three quarters of the critical equatorial velocity. It only confirmed that rapid rotation is necessary but not sufficient for a B star to become a Be star.

Periodic Short-Term Variability

The first report about periodic line profile variability in any Be star appeared in *The Messenger* (1979, No. 19, p. 4). Many others have been published since (cf. Fig. 4). For a while, the proximity of the observed periods of 0.5 to 2 days to calculated rotation periods made co-rotating surface structures appear as a possible alternative to the original explanation as non-radial pulsation.

This provided a strong hint that the explanation of CQEs might already be contained in studies of the formation of shell absorption lines. Indeed, calculations by R. Hanuschik (1995, *A&A*, 295, 423) have shown that apparent central reversals arise from disks provided there is no significant radial motion. Because only quasi-Keplerian rotation can plausibly achieve such a well-tuned equilibrium, the velocity law at large could be deduced. Other studies had arrived at the same result before, but the evidence was always rather indirect. This confirmation was important because the problem with a Keplerian disk is that its specific angular momentum is larger than at the stellar equator even if the star were rotationally unstable. Models for the disk formation need to account for this.

The Disk Life Cycles

Be stars are too old for their disks to be fossils of the formation of the central stars. The stellar radiation pressure and intrinsic dynamical instabilities have cleared the circumstellar space a long time ago. So the disks must be 'decretion' disks, i.e. consist of matter lost from the central star. (In binaries, the disk matter may also originate from a Roche lobe overflowing companion. β Lyrae is the most prominent example. However, the existence of single Be stars and of Be stars in high-mass X-ray binaries with neutron star secondaries mandate other explanations.)

It was already known before that Be stars undergo outbursts. The HEROS spectra could further illustrate how common such phases of enhanced mass ejection are. More interesting is, however, that these events seem to basically follow one generalised temporal profile, which may be scaled up or down in strength and duration. This pattern includes that a significant part of the matter is ejected with super-critical velocities and eventually does manage to merge with the disk (Fig. 2).

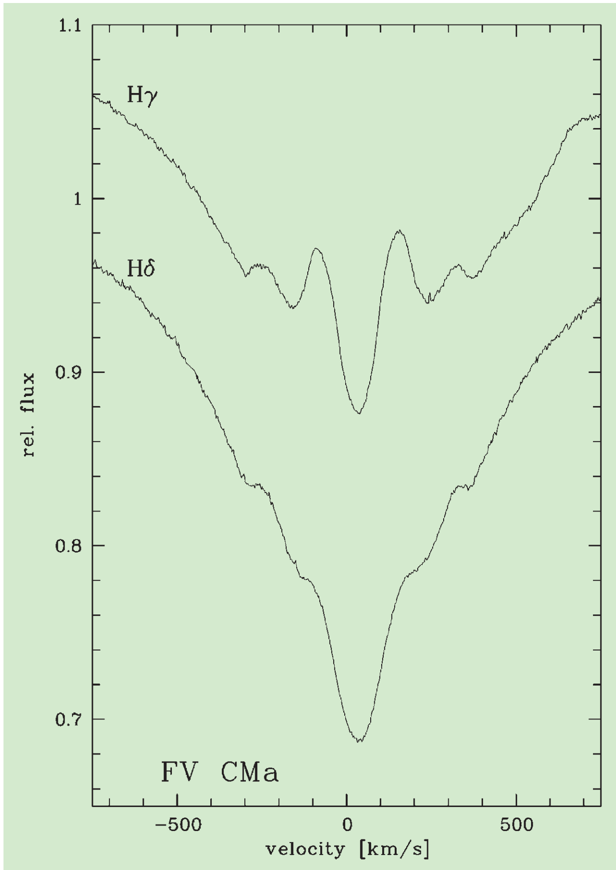

Figure 3: Two emission systems can be distinguished in these Balmer emission profiles of FV CMa. They indicate the simultaneous existence of two structural entities, which must be spatially separated from each other: The pair with the higher velocity separation rotates faster and is therefore closer to the star. Maybe the disk bears some resemblance with Saturn's rings although the geometrical thickness of the disk is a considerable fraction of the stellar diameter. However, the inner ring expands and eventually reaches the outer disk.

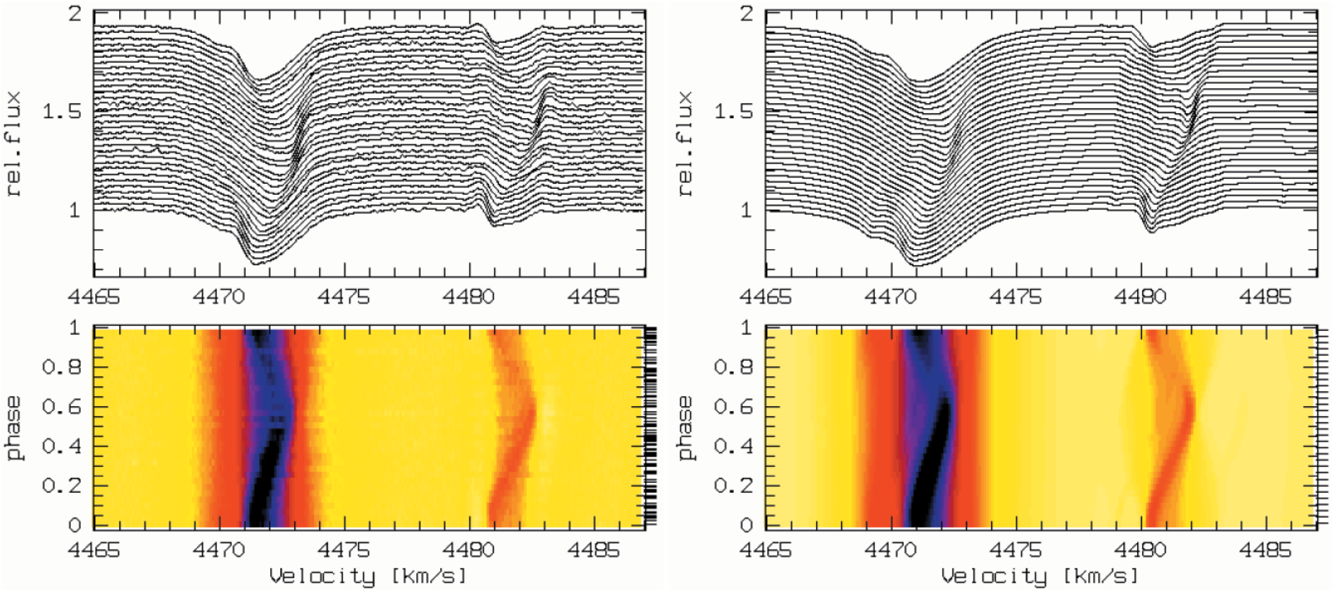

Figure 4: Observed (left) and modelled (right) line profile variability of He I 4471 and Mg II 4481 in ω CMa. The stellar and atmospheric model parameters are identical for both lines. And yet, the line-specific appearance of the observed lpv *is reproduced properly, like the forbidden component contribution on the blue side of He I 4471 and the relatively sharp absorption core of Mg II 4481. The helium line forms preferentially at higher stellar latitudes, where the temperature is higher. The dependency of also the pulsational velocity field on latitude, then, results in different variability. This sets tight constraints on the possible models.*

Since the velocity fields of most non-radial pulsation modes deviate from spherical symmetry by their own characteristic pattern, which furthermore is added to the large rotational velocity, the observed line profiles are crude 1-D maps of the stellar surface. The partial degeneracy of these maps is lifted by the different response of spectral transitions to the atmospheric conditions prevailing between the hot poles and the equatorial regions with their rota-

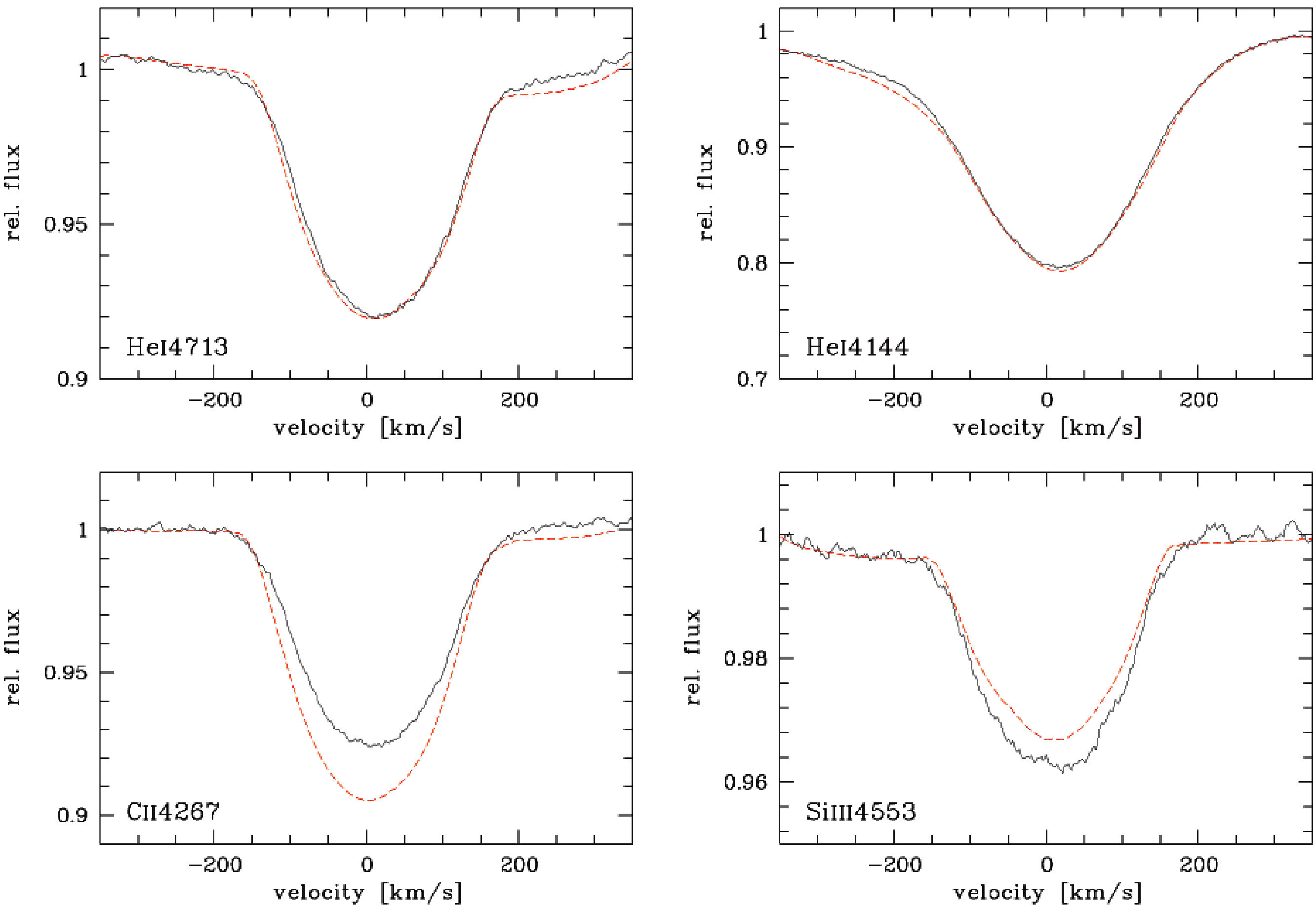

Figure 5: Selected time-averaged observed and modelled line profiles of μ Cen. Apart from crude initial guesses of the primary stellar parameters, the only input to the modelling procedure were the residuals *from the mean profile of He I 4713. And yet, also the mean profile is nearly perfectly matched by the model. The fit is nearly as good also for the other He I lines (unless contaminated by emission). Si III 4553, too, is still reasonably well reproduced while the applied LTE model is known to produce too strong C II 4267 absorption. These results encourage the idea that quantitative, absolute parameters can be derived from stellar pulsation modelling ('astero-oscillometry').*

tionally reduced effective temperature and gravity. HEROS was the first instrument to produce dense series of electronic high-resolution spectra covering the full optical wavelength range. Accordingly, this mapping potential could be fully exploited, especially since contamination by the disk is more readily recognisable when numerous lines can be compared. In this way, the pulsational nature of the line profile variability could be unambiguously established.

A separate *Messenger* article will describe the modelling techniques in more detail. However, it is worthwhile mentioning already here that by modelling the line profile *variability,* i.e. merely the residuals from the mean profiles, global stellar parameters can be derived. These, in turn, permit a model spectrum to be calculated, that matches the observed *spectrum* stunningly well (Fig. 5). Since nonradial pulsations of various kinds are very wide-spread among early-type stars, this might lay the foundation to an entirely new stellar analysis technique, which could be called astero-oscillometry.

Pulsation and Outbursts

The HEROS observations of Be stars initially focused on the 3rd-magnitude star μ Centauri, which seemed to undergo the (then still much more enigmatic) outbursts particularly often. In fact, this choice was highly fortunate as the later analysis of the Hipparcos all-sky database has not furnished any more active Be star than μ Cen. The real thrill, however, of this star unfolded with the discovery that its outbursts, which had been assumed to be stochastic, not only repeated periodically but with two periods, namely 29 and 52 days, which correspond to beat periods between the nonradial pulsation modes with the largest amplitudes.

Would this be the century-long sought key to the understanding of the Be phenomenon? At most partly: Late-type Be stars are not known to be periodically variable or to undergo outbursts and so need to be explained differently. Most of the repetition times of Hipparcos outbursts of Be stars are of the order of 100–200 days, sometimes more. To establish such timescales as periods requires observations with a time baseline of at least twice that length, whereas the ESO 50-cm was de-commissioned already in 1997. So, we were fortunate to be able to arrange for the relocation of HEROS from La Silla to other places and eventually, in 2000, to the 2-m telescope at the Ondřejov Observatory of the Czech Republic. However, in Ondřejov the weather is not much better than in Garching; and there are only very few bright, active equatorial Be stars, for which previous series of observations could be continued.

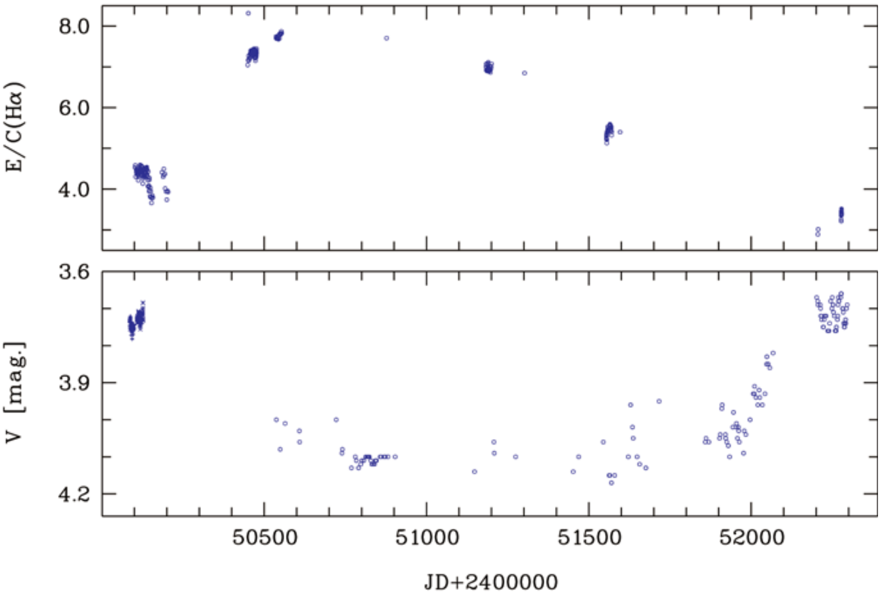

Figure 6: The ratio of the peak height of the Hα emission to the adjacent continuum (top) and the visual magnitude (bottom) of 28 CMa in series of observations covering 7 consecutive annual observing seasons.

Combining Past and Present

Comprehensive though the information contents of HEROS spectra is, it always represents only a small fraction of the complete facts. Accompanying other observations are therefore particularly valuable. Sometimes they can be secured even retroactively.

A simple joke claims: 'The world's largest telescope is when all people look into the same direction'. In fact the collective light-gathering power of all eyes of mankind exceeds even the one of the VLT and will be topped only by some ELT. By implication, the smallest telescope is the eyes of a single person. However, what has been largely forgotten since the days of a F.W.A. Argelander is that a well-trained pair of human eyes is a surprisingly good measuring instrument. So, we have recently teamed up with Argentine amateur astronomer Sebastian Otero (Liga Iberoamericana de Astronomia, Buenos Aires), who has taught himself the almost extinct art of visual photometry and, in a good night, reaches an accuracy of a few hundreds of a magnitude.

He has recently alerted us to a new outburst of the bright Be star 28 CMa. We had observed the previous major outburst with HEROS in 1996. But, then, there was no way to obtain accompanying photometry. Building up on our conclusion that outbursts of Be stars are very similar, we are now stitching the two only partly overlapping series of data together by occasionally 'borrowing' a new FEROS spectrum as a safeguard against the much longer timescale of 28 CMa than of the Be stars observed by us before.

The disk of 28 CMa is seen almost face-on. Stars with edge-on disks are known to fade during an outburst. The brightening of 28 CMa would therefore suggest, as has been argued by others before, that after an outburst the disk is in some area optically thick even in the continuum. This would divert light into directions above and below the disk. However, to explain an amplitude of 40% in this way is a real challenge.

Confusing SMC

Both pulsations and mass loss depend sensitively on metallicity. It would be extremely useful to check whether there are any systematic differences between Be stars in the Galaxy and the SMC. In some fields and clusters of the latter, one-half and more of all B-type stars show emission lines. Moreover, at least Be stars in NGC 330 are known to exhibit photometric short-term variability of the same kind as in the solar neighbourhood. By sacrificing a little bit in S/N and temporal resolution, the impressive throughput of VLT+UVES should permit the observation of stars that are 10,000 times fainter than the ones we had monitored with HEROS and the ESO 50-cm telescope, and thereby to reach NGC 330 spectroscopically.

We submitted a corresponding observing proposal, which apparently presented the picture emerging from the first sections of this article so affirmatively that the OPC concluded that we would not find any difference between Galaxy and SMC. This would not be interesting enough to confirm observationally with as scarce a resource as the VLT. Fortunately, the move of FORS2 from Kueyen to Melipal opened a special observing window with UVES

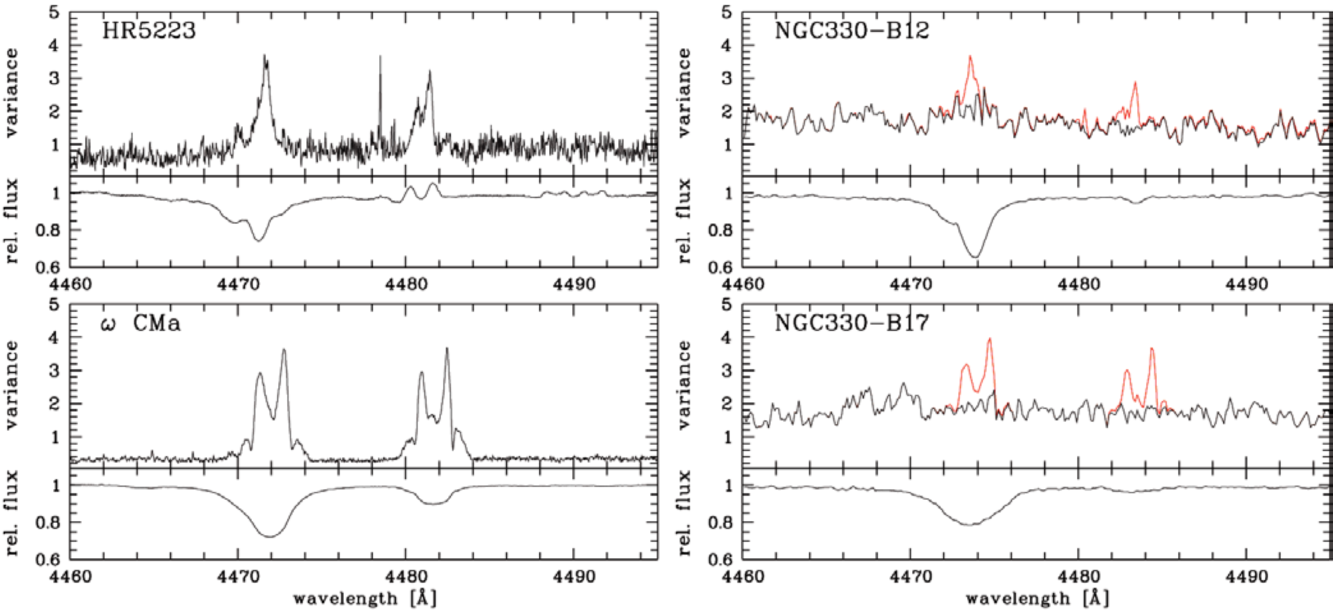

Figure 7: Mean line profiles and their temporal RMS variance of Galactic (left; observed from La Silla) and SMC (right; observed with the VLT and UVES) early-type, pole-on Be stars compared. The red overplot demonstrates the expected RMS variance if the SMC stars underwent the same variability as their Galactic counterparts. The differences in the strength of the Mg II 4481 line are due to the metallicity of the SMC, which is about 80% lower than in the Galaxy.

on Kueyen in August 2001, and the Director General's Discretionary Time Committee recommended some reconnaissance observations.

The results are shown in Figure 7: Not only is there a difference between Galactic and the two SMC Be stars we observed but the latter are not variable at all at a level that would have been easily detected in Galactic observations of the same quality! There is, of course, the possibility of this result being due to small number statistics. However, since we believe that this possibility is probably very small, we submitted a letter to some major astronomical journal. Only to be told by the first referee that our data were not interesting. This problem has meanwhile been fixed. But the puzzle of the Be phenomenon persists with some old questions answered and some new complexities added, and the expansion and analysis of the HEROS database continue.

Acknowledgements: We are indebted to too numerous people at the Landessternwarte Heidelberg and the European Southern Observatory (La Silla and Garching) to give credit to all of them individually. We have not forgotten the manifold technical, scientific, and administrative support.

Spectroscopy of Quasar Host Galaxies at the VLT: Stellar Populations and Dynamics Down to the Central Kiloparsec

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1. Scientific Context

Discovered more than 40 years ago, and in spite of tremendous theoretical and observational efforts, quasars and their host galaxies remain puzzling objects. It seems now established that at least all large galaxies harbour massive black holes (e.g., Magorrian et al. 1998), and that quasar-like activity may be a common but transient phenomenon in galaxy evolution. However, very little of the physical processes at work *during* such episodes of nuclear activity is actually understood. The following questions list some of the important issues still to be solved: What are the time-scales involved in the fuelling (or refuelling) of massive black holes? Does the material they burn come from mergers? Do all galaxies contain a black hole or only the most massive ones? What is the exact relation between galaxies and quasars? Is the feedback from a luminous Active Galactic Nuclei (AGN) onto its host galaxy important? Is it in the form of huge quantities of ionising radiation or does it manifest itself directly as mechanical outflows such as jets?

Quasar host galaxies have been studied almost exclusively by imaging. Examples of such work are numerous and use a broad variety of telescopes, instruments and post-processing techniques. The Hubble Space Telescope (HST) data of Bahcall et al. (1997) have shown that quasars occur in all types of galaxies. Stockton et al. (1998) used adaptive optics near-IR data to map the plumes and jets around the quasar PG 1700+518. Recent HST optical studies have established that high-luminosity quasars generally reside in big ellipticals, irrespective of radio properties (McLure et al. 1999, McLeod & Rieke 1995a, Disney et al. 1995). There also seems to be a trend that more luminous QSOs are hosted by more massive galaxies (McLeod & Rieke 1995b).

A more detailed and quantitative understanding of the physical conditions in hosts galaxies can only be obtained from spectroscopic observations. The data available in this field are very scarce, and although extensive quasar host spectroscopy was conducted already in the early 1980s (e.g., Boroson et al. 1985), they have never really been followed up with improved instrumentation and analysis techniques, except for a few isolated objects (among them 3C 48 being the probably best-studied case in this field – e.g., Chatzichristou et al. 1999, Canalizo & Stockton 2000. See also Crawford & Vanderriest 2000 for similar work with other objects).

Nearly all spectroscopic observations up to now were designed as long-slit, "off-nuclear" spectroscopy. Off-nuclear observations attempt to minimise contamination by the bright quasar, by placing the slit of the spectrograph a few arcsec away from it. While this surely contributes to minimise contamination by the quasar, it also minimises the signal from the host galaxy itself! In addition, only the outer parts of the host are probed, hence giving a biased idea of the overall stellar content, and loosing the dynamical information.

Recent developments in instrumentation and the advent of sophisticated post-processing techniques have made it possible to tackle in a new way the problem of light contamination by the central AGN. We describe in the present article the first results of a comprehensive VLT spectroscopic campaign which, at variance with the traditional approach, is designed as "on-axis" spectroscopy combined with spectra deconvolution. The case of the low-redshift quasar HE 1503+0228, at z = 0.135 is taken as an example and placed in a broader context which will involve optical and near-IR two-dimensional spectroscopy with instruments such as GIRAFFE, SINFONI and FALCON.

2. VLT Spectroscopic Observations

Our goal is to study the stellar and gas contents of quasar host galaxies as well as their dynamics, and to compare their properties with "normal" galaxies without quasar activity. This not only requires deep spectra with moderately high spectral resolution, but also accurate decomposition of the data into the individual spectra of the quasar and of its host galaxy. We have chosen to carry out our study for optically bright radio-quiet quasars selected from the Hamburg/ESO survey (Wisotzki et al. 2000). Our sample involves quasars with $M_B < -24$ and $z < 0.33$, for most of which we also have sharp H-band imaging obtained at the NTT with SOFI. The spectroscopic work in progress is based on the VLT/FORS1 observations of 18 of these objects, with ANTU at Paranal observatory. The 5 observing nights allocated in the context of the programmes 65.P-0361(A) and 66.B-0139(A) were all clear and with seeing often below 0.6 arcsec.

Decomposition of the quasar and host spectra requires knowledge of the instrumental Point Spread Function (PSF). We have therefore chosen the MOS mode of FORS1 in order to observe simultaneously the quasars and PSF stars in the field of view. One 19 arcsec long slit was placed on the quasar, several other slits were placed on PSF stars (note that there was always at least one PSF available), and the rest was used to observe galaxies in the immediate environment of the quasar. We show in Figure 1 part of the FORS1 field of view around HE 1503+0228, where are indicated the positions of two slits used for the quasar and for the only bright PSF star available in this field of view. Each object was observed with the three high-resolution grisms of FORS1 and the standard collimator (0.2 arcsec pixel), giving a mean spectral resolution of 700. The exposure time was 1200 seconds in each of the three grisms, in grey time.

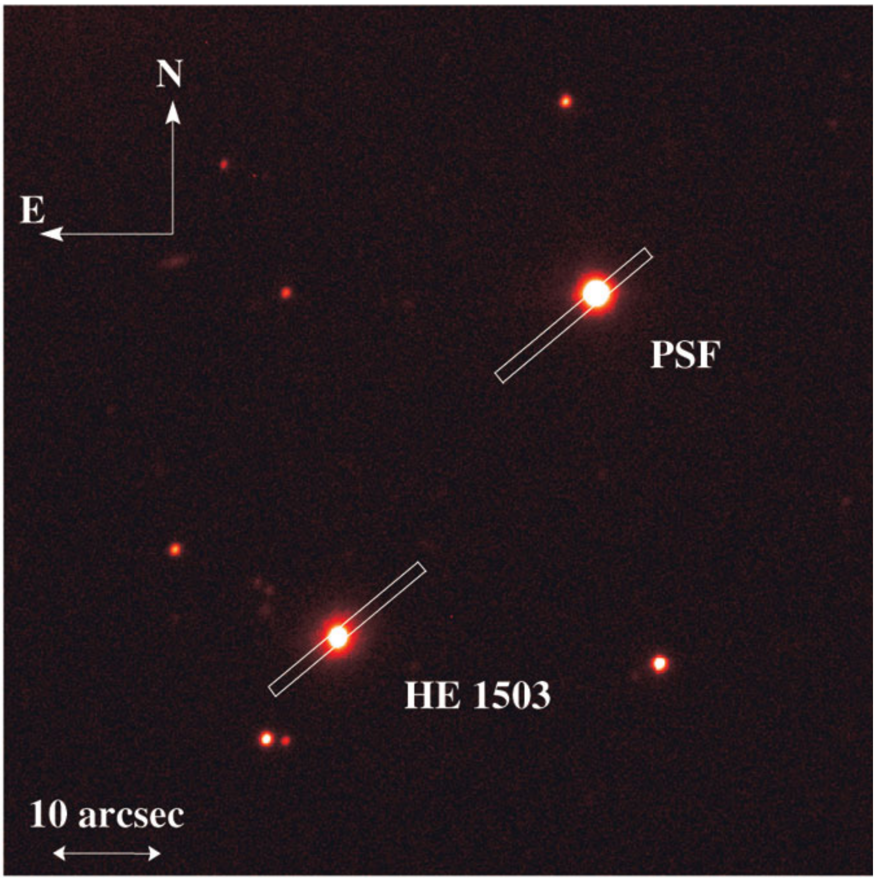

Figure 1: Part of the VLT/FORS1 pointing image. The seeing is 0.62″ on this 30-sec R-band exposure. The 1″ slits used to obtain the spectra of the target and of the PSF star are indicated.

3. Spectra Decomposition and Stellar Population

The method used for decontaminating the host's spectrum from the quasar light is an adaptation of the MCS image deconvolution algorithm (Magain et al. 1998) to spectroscopy (Courbin et al. 2000a). It uses the *spatial* information contained in the spectrum of one or several PSF stars in order to *spatially deconvolve* the science spectrum. This results in higher spatial resolution across the slit and in a spectrum which is decomposed into several channels. One of these channels contains the spectrum of extended objects, while there is one individual channel for each point source in the slit. In the application we already showed for the gravitational lens HE 1104-1805 (Courbin et al. 2000b and Lidman et al. 2001), there were two channels for each of the quasar images and the channel for the extended sources was used for the

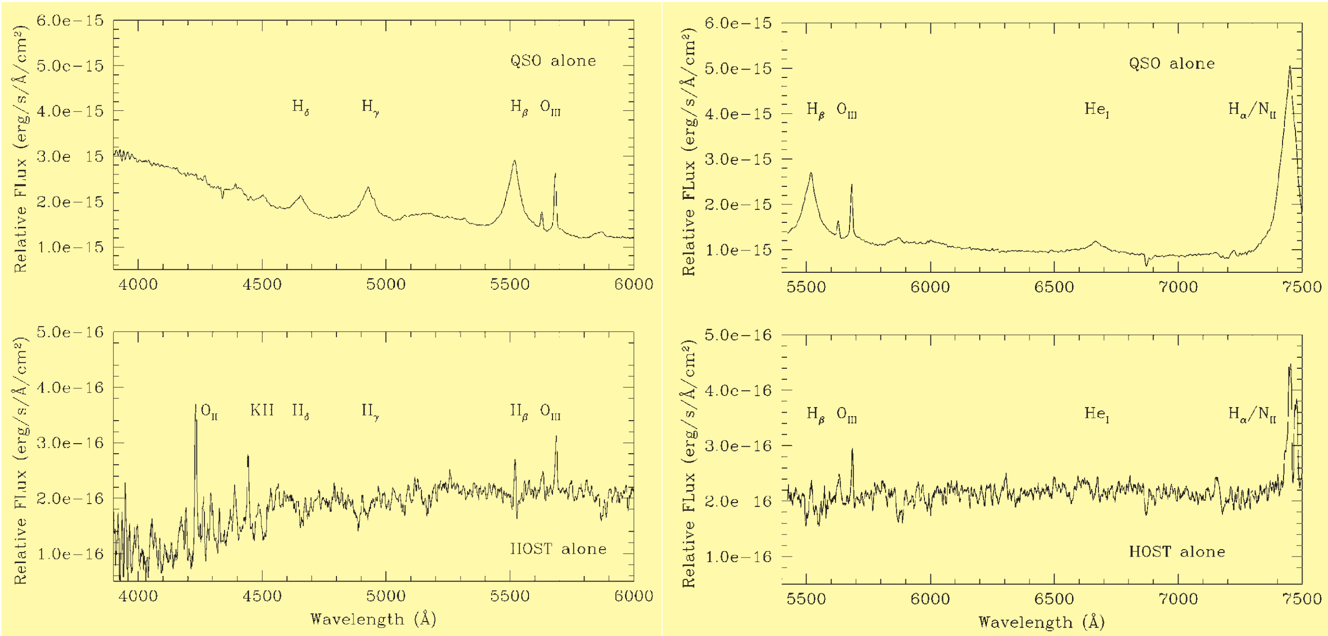
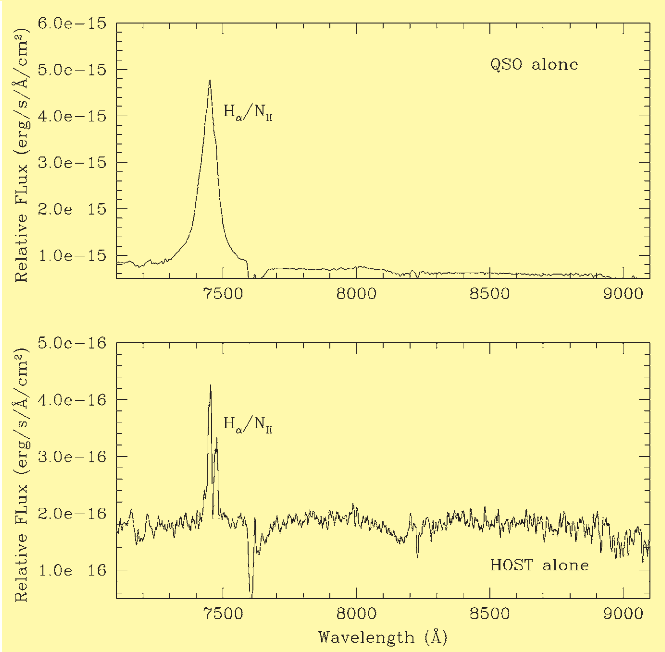

Figure 2: One-dimensional deconvolved spectrum of HE 1503+0228, at z = 0.13552, and its host galaxy. Each panel corresponds to one FORS1 grism and displays the individual flux-calibrated spectrum of the quasar and its host galaxy. Note that the spectrum of the host shows no trace of the AGN broad emission lines. These lines are seen narrow in the spectrum of the host. Note also the very good agreement in the deconvolution of the 3 grisms in the overlapping regions. The spatial resolution on the deconvolved 2D spectra is 0.4 arcsec.

lensing galaxy. For quasar hosts, there is one channel for the quasar and one for the host galaxy.

Figure 2 displays the integrated spectrum of HE 1503+0228. Each panel shows the deconvolved/decomposed data for the three FORS1 grisms. The quality of the decomposition can be judged from the many narrow emissions seen in the host and hidden in the quasar spectrum. In addition, there is no trace of residuals of the quasar broad emission lines in the spectrum of the much fainter host. Courbin et al. (1999) already showed from simulations that such a decomposition was possible, but there were no suitable MOS data at that time to test the method on real spectra.

Luckily, almost all regions of astrophysical interest in the spectrum of HE 1503+0228 are observed in two different grisms. This allows for double check of the deconvolution results and to build a composite spectrum from 4000 Å to 9500 Å, with higher signal-to-noise ratio in the regions where the grisms overlap. Note in Figure 2 the excellent agreement between the deconvolution done for each grism, in the regions of overlap. The data are plotted here as they come from the deconvolution process, without any adjustment to ensure a good match between the different grisms. Accurate spectrophotometry can actually be done on the deconvolved data.

The host galaxy spectrum we present here has a signal-to-noise that varies between 10 and 25 per Å from the bluest parts to the reddest. This allows the analysis of the stellar population. Measuring the emission and absorption lines in the spectrum of HE 1503+0228, and comparing them with that of normal spiral and elliptical galaxies (Kennicutt, 1992a, b, Tragger et al. 1998), we find that the spectrum of the HE 1503+0228 host is that of a normal early-type spiral galaxy. Its interstellar medium is ionised by star formation and only a tiny residual excitation can be attributed to the central AGN.

4. Dynamics of the Host

Many of the quasar hosts we observed (about 30–40%) display prominent narrow emission lines that sometimes extend over several arcseconds. These lines, and the fact that we observe with the slit centred on the quasar, allow us to derive the rotation curve of the host, from the outer parts of the galaxy, down to the central kiloparsec.

In the deconvolution process described above, the difference in spatial properties between AGN (point source) and the host galaxy (extended component) is used to separate the spectra of these two sources. A smoothing in the spatial direction is applied for this purpose to the extended component. However, such a method is not optimal for deriving velocity curves, as spatial smoothing (which is not precisely known as it varies with the local S/N) may modify the spectral position of the lines at a given spatial position, by averaging spatial components of different radial velocities. We have therefore designed another method, for extracting narrow emission lines in two dimensions, from the rest of the spectrum. The method decomposes the data in: (1) the narrow emission lines of the host, and (2) the low-frequency signal composed of the spectrum of the quasar plus the *continuum* of the host galaxy. The result of the process is shown in Figure 3, where the rotation of the galaxy is conspicuous.

The extracted emission lines are used to compute the rotation curve of the galaxy in HE 1503+0228 as shown in Figure 4. The first data point (green dots) is at only 0.5 kpc away from the AGN (assuming H_0 = 65 km s^{-1} Mpc^{-1}, Λ = 0, and Ω_M = 0.3). In order to infer the mass of the galaxy, and of its central regions, we use a three-component model including a central mass concentration, a thin disk, and a spherically symmetric halo of dark matter. Fitting this model to the data gives the blue line in Figure 4, which has to be corrected for the inclination of the galaxy and other geometrical effects (red curve). This inclination is estimated from our SOFI and FORS images. We find $i \sim 46 \pm 9°$. This is certainly the major source of uncertainty on the mass of the galaxy. A preliminary estimate of the mass we can infer for the host of HE 1503+0228 is $(1.3^{+0.4}_{-0.1})\ 10^{10}\ M_\odot$ within 1 kpc. The total mass of the galaxy, by integrating our mass models over the 10 kpc is $(1.4^{+0.5}_{-0.2})\ 10^{11}\ M_\odot$, or about the mass of a "normal" spiral galaxy.

5. Towards 2D Spectroscopy and High Spatial Resolution: GIRAFFE, SINFONI and FALCON

The study of quasar host galaxies is a fantastic application for high spatial resolution capabilities. We show from a very simple and short FORS/MOS observation that a distant quasar host galaxy can already be probed in spectroscopy down to the central kiloparsec, making it possible to infer in a quantitative way the mass of the galaxy and to compare its stellar population with other non-AGN galaxies.

Our observation was taken under average seeing at Paranal, about 0.6–0.7″ depending on the grism. A gain of a factor 10, as is obtained with adaptive optics, will allow for similar studies easily up to redshift 1 or slightly more. This means that we will be able to follow the evolution with time of the interactions between AGNs and their hosts. It also means that the nearest AGNs will be resolved into great detail, maybe down to the central parsec, where the dust torus and the outer parts of AGN accretion disks become visible (e.g., Marco & Alloin, 2000, Alloin et al. 2001).

Modern observatories, and in particular ESO, offer a broad range of instruments not only capable of high-resolution imaging at NGST-like resolution, but also capable of producing two-dimensional spectra at such a spatial resolution. GIRAFFE is a step towards high-resolution 2D spectroscopy, and will already allow us to map the whole velocity field (gas and stars) of low-redshift quasar-host galaxies. Stellar population gradients might be seen across the objects, and accurate mass determination will become possible by allowing for accurate determination of the inclination of the galaxy. At low redshift, GIRAFFE observations are simple. A 1-hour shot will already reveal the velocity field of the gas. Adding two hours to this will allow to follow the important Calcium absorption lines, hence the stellar velocity field.

From our FORS observations, we can safely predict that GIRAFFE will efficiently be used up to redshift 0.5, for an average seeing observation at Paranal. SINFONI is similar to GIRAFFE, but its adaptive optics system and its near-IR detector will allow to follow quasar hosts at much higher redshifts (up to z = 2), especially since laser guide stars will allow to access the entire sky or close to this, with the AO instruments.

On a longer term, FALCON, a near-IR integral field spectrograph using multi-conjugate adaptive optics, shall take place at the VLT. With its many Integral Field Units (IFU) and a local adaptive optics system (i.e., around each IFU) the instrument will be used to observe *simultaneously* quasars, PSF stars (for accurate post-processing techniques) and galaxies in the immediate vicinity of the quasar. The FALCON concept (Hammer et al. 2002) not only allows to map the velocity field of the quasar host, but also the one of each component of the groups or clusters of galaxies involved in the fuelling process of the central AGN.

The study of quasar host galaxies is therefore one more of the numerous areas that will highly benefit from high angular resolution now made possible in a systematic way on large telescopes, either by using AO or by applying post-processing techniques, or a combination of both.

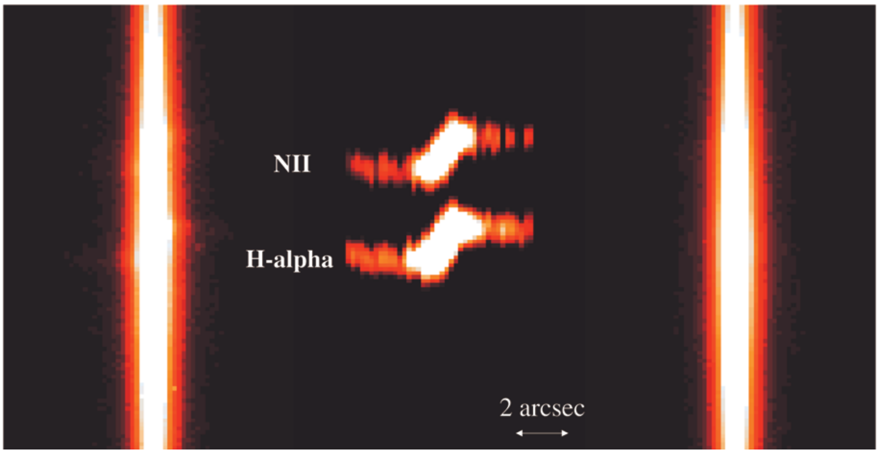

Figure 3: Example of emission lines extraction for the Hα and N II lines in the I grism. The original data are shown on the left. The middle panel shows the emission lines of the host galaxy alone, whereas the right part shows the sum of the quasar spectrum and of the continuum of the host galaxy.

Acknowledgements

We would like to thank the ESO staff for their very efficient help at the telescope during our two VLT runs, and in

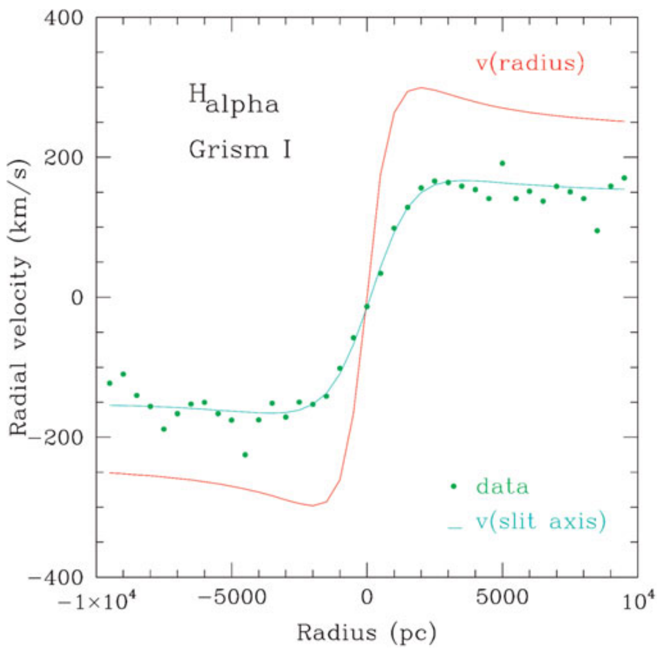

Figure 4: Rotation curve of the host galaxy of HE 1503+0228. The dots are the data points obtained using simultaneously the Hα and N II lines in the I-band grism. The blue curve is the fit of our three component galaxy model, and the red curve shows the fit after correction for the inclination of the galaxy and of a number of slit and seeing effects (see Courbin et al. 2002 for more details).

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The Crab Pulsar and its Environment

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1. Introduction

The Crab Nebula is a supernova remnant. The supernova exploded in 1054 AD, and was monitored by contemporary Chinese astronomers (see e.g., Sollerman, Kozma, & Lundqvist 2001). Today the nebula offers a spectacular view, with a tangled web of line-emitting filaments confining an amorphous part ghostly shining in synchrotron light. The beauty of the Crab makes it repeatedly appear in PR pictures, even from a southern observatory like the VLT (Fig. 1).

Figure 1: The VLT (UT2 + FORS2) view of the Crab nebula. A composite of images in B(blue), R and S II(red), taken in November 1999 as part of commissioning. ESO PR photo 40f.

At the heart of the nebula resides the energetic 33-ms Crab pulsar. This $m_V \sim 16$ object actually powers the whole visible nebula. The Crab nebula and its pulsar are among the most studied objects in the sky. This astrophysical laboratory still holds many secrets about how supernovae explode and about how pulsars radiate and energise their surrounding nebulae.

A main theme for pulsar research has been to understand the emission mechanism for the non-thermal pulsar radiation. This is still to be accomplished. No comprehensive model exists that can explain all the observed features of the radiation. Observationally, only recently was a broad range UV-optical spectrum of the pulsar published (Sollerman et al. 2000). We have now extended the study into the infrared (IR).

But even if most of the research on the Crab pulsar has concerned the radiation mechanism, almost all of the spin-down energy actually comes out in the particle wind. This is the power source of the Crab nebula. The stunning image of the pulsar environment obtained with CHANDRA (Fig. 2) captures a glimpse of the energetic processes at work. Direct evidence of the pulsar activity has long been seen in the system of moving synchrotron wisps close to the pulsar itself.

The detailed study of the wisps was started by Scargle (1969) using observations obtained before the authors of this article were born. Hester et al. (1995) used the HST to study the wisps at higher resolution, and presented their observations as the spectacular 'The Crab Movie'[1], where the constant activity in the region around the pulsar is highlighted.

The most stunning discovery in these HST images was the knot sitting just 0.6 arcseconds from the pulsar. At 2 kpc this amounts to a projected distance of only 1000 AU. Hester et al. interpreted this feature as a shock in the pulsar polar wind. Our IR observations also allowed us to have a look at these manifestations of the magnetic relativistic wind from the pulsar.

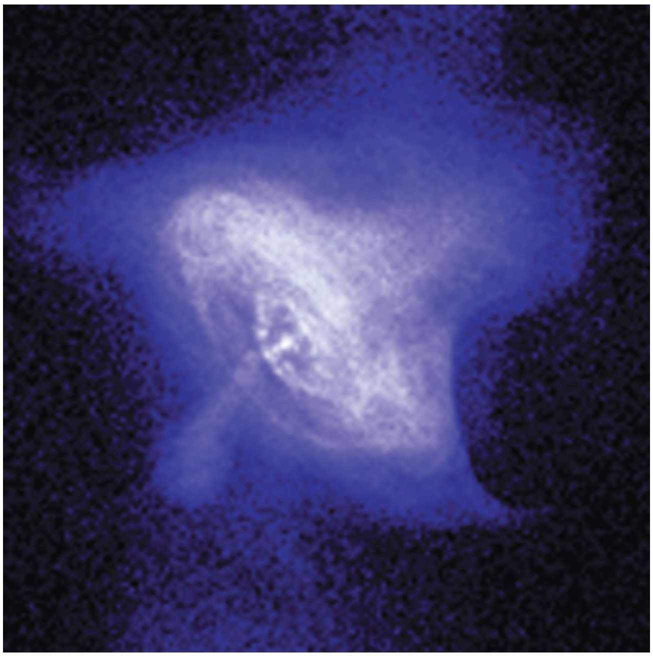

Figure 2: The CHANDRA X-ray view of the pulsar. The spectacular torus and a long jet is clearly seen in this space-based 45-minute exposure from August 1999. The field of view is 2.5 arcminutes. With some imagination, the same structures can be seen in the VLT 5-minute B-band image (Fig. 1). Photo NASA/CXC/SAO.

2. IR Photometry, Reductions and Results

IR imaging in the short wavelength (SW) mode of ISAAC was obtained in service mode on the VLT on October 13, 2000. The exposures were taken in *Js*, *H* and *Ks* with a total exposure time of 156 seconds per band. The main goal of these short exposures was to properly calibrate our IR spectroscopy. However, the image quality provided by Paranal also allowed a detailed view of the central region of the Crab nebula. The near-IR images are displayed next to each other in Figure 3.

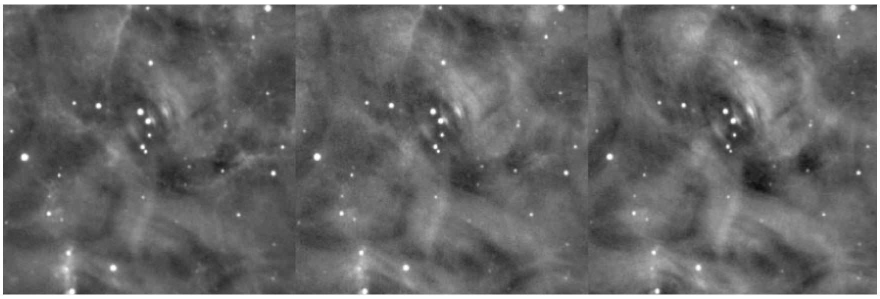

Figure 3: The central part of the Crab nebula in the infrared, Js, H and Ks. Observations with ISAAC on 13 October 2000. The pulsar is the lower right (South Preceding) of the two bright objects near the centre of the field.

Photometry was obtained of the Crab pulsar and some of the stars in the field using PSF-fitting (DAOPHOT). We estimate that our magnitude measurements of the pulsar are correct to about 0.05 magnitudes.

[1]http://oposite.stsci.edu/pubinfo/pr/1996/22.html

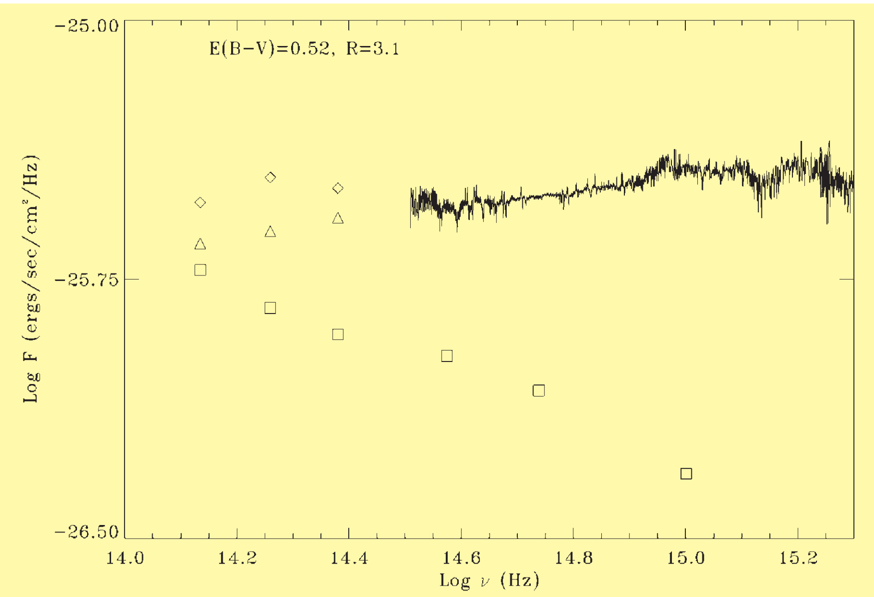

Figure 4: Spectral energy distribution of the Crab pulsar. The optical and UV data are from Sollerman et al. (2000). The diamonds show the IR flux as published by Eikenberry et al. (1997). The triangles are our new ISAAC measurements. Also shown (squares) are the fluxes of the knot, here multiplied by a factor ten. The optical data for the knot is from HST. All observed fluxes were de-reddened using R = 3.1 and E(B – V) = 0.52 (Sollerman et al. 2000).

In Figure 4 we plot our measurements as de-reddened fluxes together with the optical-UV data from Sollerman et al. (2000). We note that our IR fluxes deviate significantly from the most recent results published by Eikenberry et al. (1997). Our measurements give a fainter pulsar by some 0.3 magnitudes.

The pulsar magnitudes of Eikenberry et al. agree with those in the 2MASS point source catalogue. As our relatively isolated standards in the field show good agreement with 2MASS, we do not think the difference in pulsar magnitudes is due to an offset in the zero-point. Instead, our measurements of the Crab pulsar agree well with previous time-resolved photometry of the Crab (Penny 1982; Ransom et al. 1994). Such measurements generally use a large aperture and simply assume any non-varying contribution to be due to the background. By integrating under the pulsar light curve, they measure only the pulsating contribution of the flux. Our ISAAC photometry has excellent signal and image quality. In the complex region around the pulsar, this significantly improves the background subtraction. In particular, PSF subtraction excludes contributions from

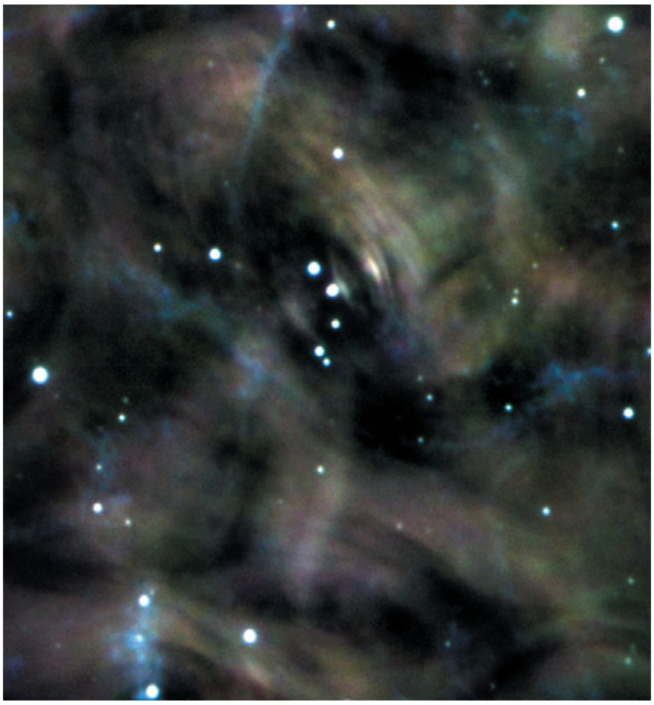

Figure 5: The Crab nebula in the infrared. This is a colour composite of the frames shown in Figure 3. North is up and East to the left.

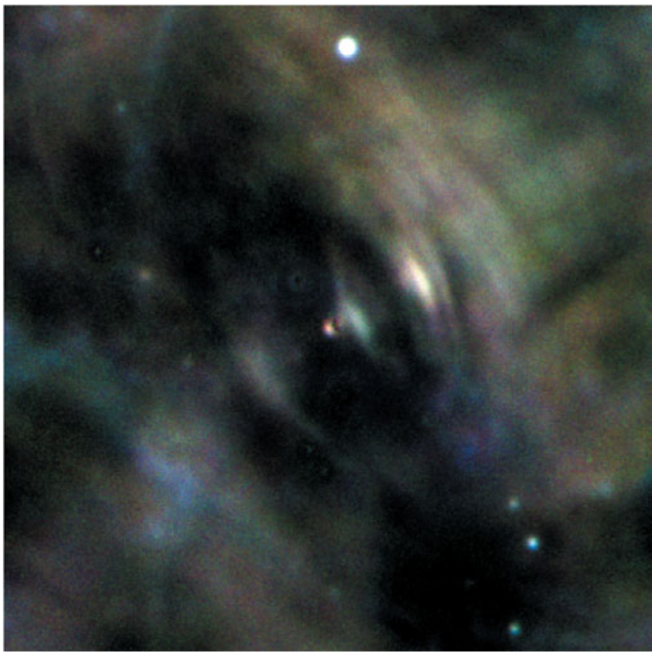

Figure 6: The centre of the Crab nebula in the infrared. After the central stars have been removed using PSF subtraction, the knot close to the pulsar position is revealed. The FOV shown in this ISAAC image is 55.6 arcseconds, as provided by the NAOS/CONICA C12S camera.

the wisps and the nearby knot. We believe that the difference with 2MASS is simply a matter of resolution, and that we are now able to subtract virtually all background from the pulsar.

The 3-colour image of the central parts of the Crab (Fig. 5) is colour coded with *J*s = blue, *H* = green and *K*s = red. In an attempt to keep some physical information in this image, the individual frames were scaled to make an object with a flat de-reddened F_V spectrum appear white.

This image shows the well-known features of the inner Crab. The wisps are clearly visible in higher detail than previously obtained in the IR. Some filaments are also seen, most strongly in the *J*s band. This is most likely due to the [Fe II] 1.26 μm emission line. The Ks band is instead dominated by amorphous synchrotron emission (Fig. 3). With suitable cuts the pulsar image appears slightly elongated. This is due to the presence of the knot first identified by Hester et al. (1995) on a HST image. To reveal this structure in our images we constructed and subtracted a PSF from the stellar images. After subtraction, the knot is clearly revealed in all three bands. A colour image made out of the PSF subtracted frames is shown in Figure 6. The image directly gives the impression that the knot is redder than for example the wisps.

Quantifying this we have estimated the magnitudes of the knot as well as of the nearby wisp 1. The knot was measured within an aperture of 0.9 arcseconds and the wisp was simply measured with an aperture of 1.2 arcseconds. The spectral energy distribution of the knot is shown in Figure 4. It is clearly red. In the *K*s-band the flux from the knot amounts to about 8% of the flux of the pulsar. The stationary wisp appears to have a flatter spectrum in this regime.

3. Optical Data from VLT and HST

To extend the wavelength region over which to derive the spectral characteristics of the inner Crab components, several optical images are available in the ESO and HST data archives.

The VLT PR image (Fig. 1) was taken with FORS2 on 10 November 1999, just two weeks after first light. On the five-minute *B*-band and the one-minute *R*-band exposures, we could PSF-subtract the pulsar to reveal the knot. The knot appears clearly in both frames, and amounts to a few per cent of the pulsar light at these wavelengths.

Data on the Crab pulsar are also available in the HST archive. Most of the observations are from Jeff Hester's comprehensive monitoring programme of the inner parts of the nebula, which has shown just how active the Crab nebula really is. These frames allow a detailed study of both the spectral and temporal properties of the knot. In August 1995 the region was observed in three filters (F300W, F574M, F814W). We measured the de-reddened spectral index for the knot to be $\alpha_V \sim -0.8$, which agrees well with our IR data (Fig. 4).

Furthermore, a wealth of data in the F574M filter allows a study of the tem-

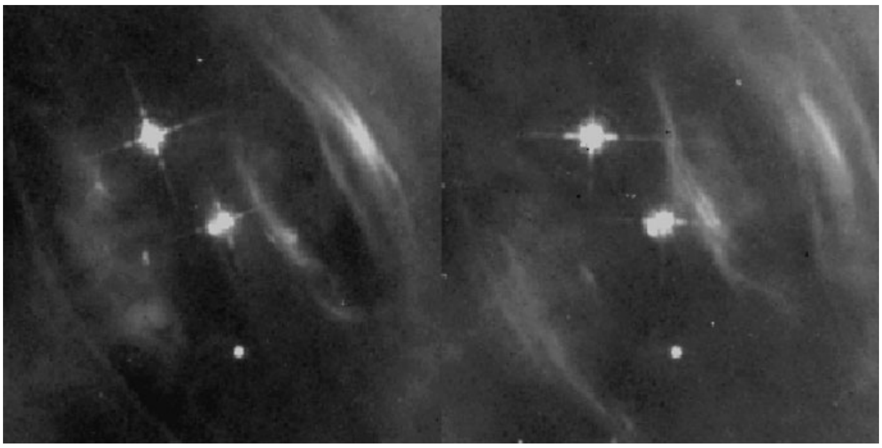

Figure 7: HST F547M images of the very centre of the nebula. The leftmost frame is obtained on March 1994, and the right frame on October 2000, simultaneous with our IR imaging. Note that the wisp structures are very dynamic, but that the knot seen south-east of the central pulsar has persisted over more than 6 years. The FOV is 20 arcseconds, North is up and East to the left.

poral behaviour (Fig. 7). First of all we note that the knot is indeed present in all frames. It thus appears quasi-stationary for more than six years, although the position appears to vary at the 0.1 arcsecond level. The de-reddened flux of the knot (Fig. 4) is measured to be 9×10^{-28} ergs s^{-1} cm^{-2} Hz^{-1} but variations of the flux by at least 50% are observed.

4. Discussion and Implications

For the pulsar itself we have added new information in the IR. Together with the optical-UV data in Sollerman et al. (2000) this significantly revises the observational basis for the pulsar emission mechanism. In fact, most of the theoretical efforts have been based on the old optical data from Oke (1969) and the IR continuation of Middleditch, Pennypacker & Burns (1983). Our new results call for a fresh look on the emission mechanism scenarios for young pulsars.

For the knot, we have shown that the structure is indeed quasi-stationary, and that the emission has a red spectrum. Few models are available for the knot. Lou (1998) presented a formation scenario in terms of MHD theory, while Shapakidze & Machabeli (1999) argue for a plasma mechanism. None of these scenarios predict a very red spectral distribution.

Another area where caution may be required is in the recent claims of weak and red off-pulse emission from the Crab pulsar in the visible (Golden, Shearer & Beskin 1999). It is clear that the knot close to the pulsar has to be seriously considered in these kinds of studies.

5. Future Plans

The Crab pulsar and its environment continue to be the prime astrophysical laboratory for the study of the pulsar emission mechanism and the spin-down powering of pulsar nebulae. Although much observational effort has been put into this object, a modern re-investigation is likely to clean up the many contradictory measurements. Optical imaging in good seeing would require only a few minutes with the VLT, and would directly determine the knot-subtracted spectral energy distribution. ISAAC in the LW range can in less than 3 hours clarify if the knot is significantly contributing to the emission at these frequencies, and would establish if the IR drop of the pulsar is real.

Most interesting is the possibility to monitor the very central parts of the pulsar environment with NAOS/CONICA. With a resolution superseding HST we will be able to monitor the structures close to the pulsar, with 2 pixels corresponding to merely 50 AU. This would provide an unique opportunity to study the structure and dynamics of the inner pulsar wind and its interaction with the surroundings.

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SOFI Discovers a Dust Enshrouded Supernova

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1. An IR Search for SN

Luminous Infrared Galaxies (LIRGs) are characterised by luminosities larger than 10^{11} $L_\odot$ mostly emitted in the far-IR spectral range. Since the discovery of a handful of these objects by Rieke & Low (1972), and afterward the extensive list produced by IRAS, the source of energy of the LIRGs phenomenon has been matter of debate. The radiation observed is mostly thermal emission by dust heated by some primary source. Dust extinction in LIRGs can exceed several magnitudes in the optical and this makes any optical study more difficult than in normal galaxies. Recent IR observations, mostly by ISO, allowed to shed new light on the problem and to identify the starburst (SB) activity as the main source of energy for most LIRGs (Genzel et al. 1998). However, the presence of obscured AGNs, which are elusive in the optical, has also been identified in a few cases raising again the issue on the relative contribution of active nuclei to the bolometric luminosity. Yet, if most of the lumi-

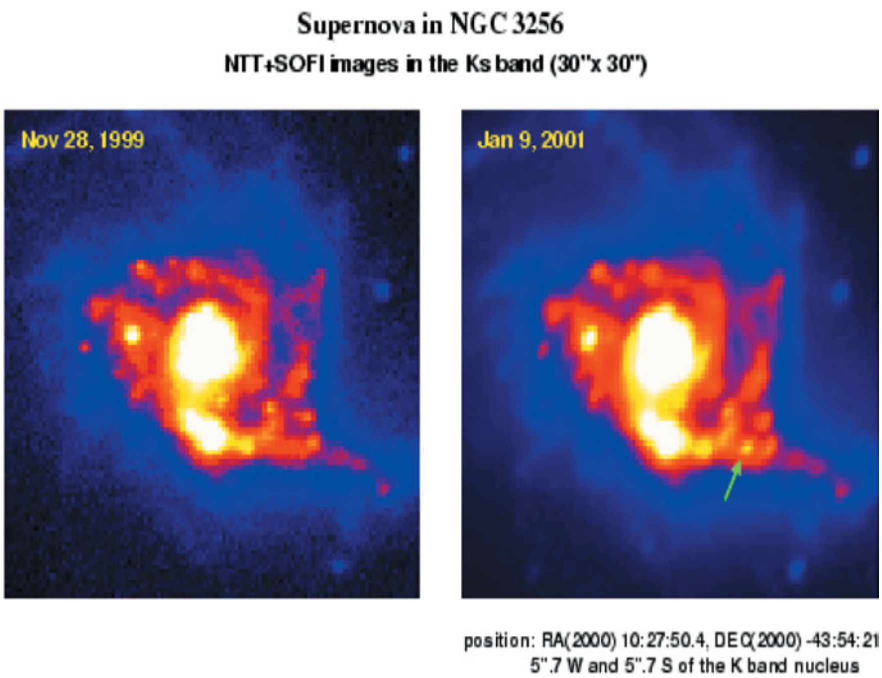

Figure 1: SN2001db is detected in the Ks image of NGC 3256 observed on January 9, 2001 with SOFI (right) when compared with an archival image (left).

nosity is powered by star formation, the SN rate should consequently be higher than in normal galaxies. Therefore measuring the SN rate in LIRGs is an indirect way to measure the star-formation rate.

Optical searches for SNe in standard starburst galaxies however failed in detecting the expected enhanced SN rate. This is most likely due to the large amount of extinction affecting these galaxies. A way around the problem is to observe in the near-IR where the dust optical depth is a factor of 10 lower than in the visible. The first attempts in this direction, however, have not been very promising (van Buren & Norman 1989, van Buren et al. 1994). LIRGs are an optimal sample for this kind of observations; in fact their huge luminosity requires star-formation rates up to a few 100 $M_\odot$ yr^{-1} and, consequently, a supernova rate up to a few SNe per year.

We started a monitoring campaign in the K (2.1μm) near-IR band of a sample of 35 LIRGs aimed at detecting obscured SNe. The survey started in late 1999 (not continuously) and carried on with the ESO NTT, the TNG (Galileo National Telescope) and the Kuiper/Steward Telescopes.

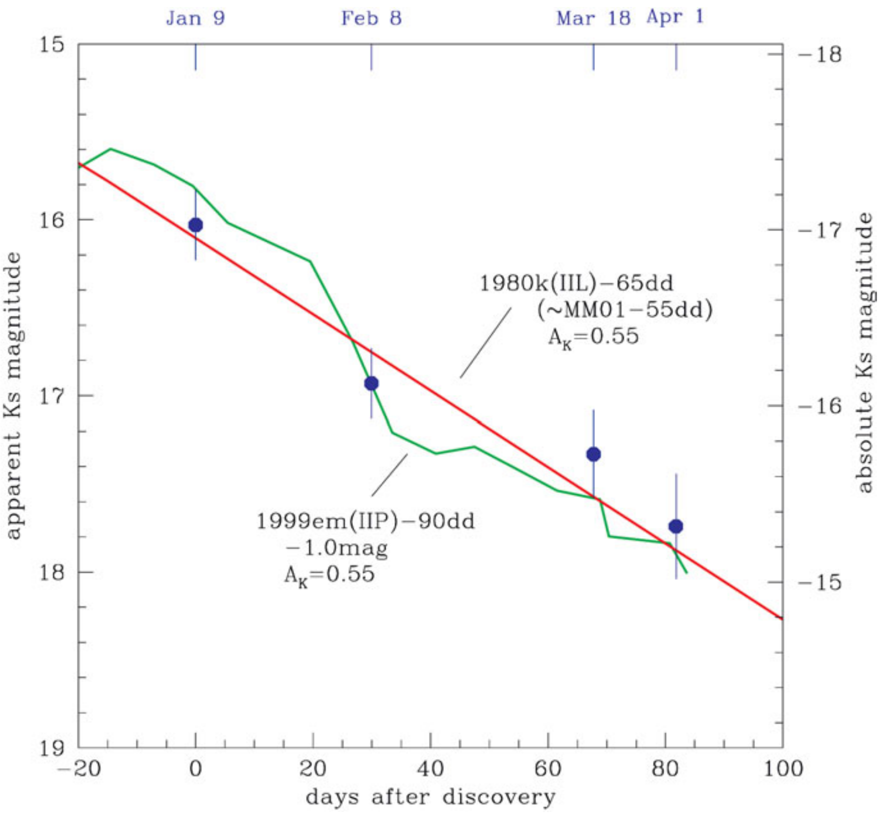

Figure 2: Ks light-curve of SN2001db (blue points) compared with template curves from the literature.

2. First Success with SOFI – SN2001db

A southern sample of galaxies was observed with SOFI at the NTT during period 66. A total of 6 nights, about one month apart from each other, were allocated. Images were obtained in the Ks filter using a total integration time on source of about 30 minutes per object. The data were reduced using the ESO Eclipse package and then compared with each other and with archival images.

The LIRG NGC 3256 was observed for the first time on January 9, 2001, and subsequently on February 8, March 18 and April 1. SN2001db was detected on the first image, after comparison with the following ones, at coordinates R.A.(J2000) = 10^{h}27^{m}50^s.4, Dec.(J2000) = –43 54′ 21″, 5″.7 to the West and 5″.7 to the South of the Ks nucleus. The Ks magnitude of the SN in the image of January is 16.03. In Figure 1 we show the archival SOFI image of NGC3256 (left) and the first image obtained in 2001 (right) where SN2001db has been detected.

In Figure 2 the infrared light-curve of SN2001db is compared with those of SN1980k and SN1999em taken as representative of type IIL and type IIP, respectively (data from Dwek 1983, Barbon et al. 1982, Hamuy et al. 2001). The light-curve has been extinguished by an A_K = 0.55 (see next section). The infrared observations can be roughly fit both with the light-curve of SN1980k offset by 65 days, and with the light-curve of the SN1999em offset by 90 days and 1.0 mag. The average K-band light-curve for type II SNe obtained by Mattila & Meikle (2001) is nearly identical to the SN1980k light-curve in Figure 2, but offset by 55 days. We estimate that the V-band magnitude of the SN was most likely fainter than 20 at its maximum and, therefore, it would have been missed by most of the optical SN search programmes.

After this discovery we immediately applied for Director Discretionary Time to spectroscopically confirm our finding at the VLT. An optical spectrum was obtained on May 16, 2001, with FORS1 at the ESO VLT-UT1 using grism GRIS_300V and 1″ slit yielding a spectral resolution of 500. The total integration time was 15 minutes. Most of the

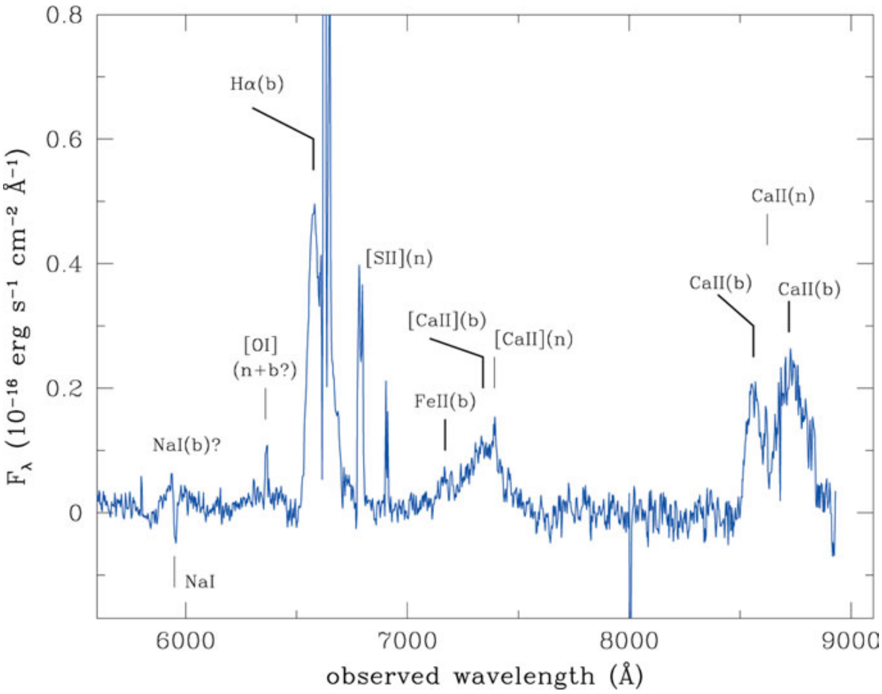

Figure 3: Optical spectrum of SN2001db observed with FORS1.

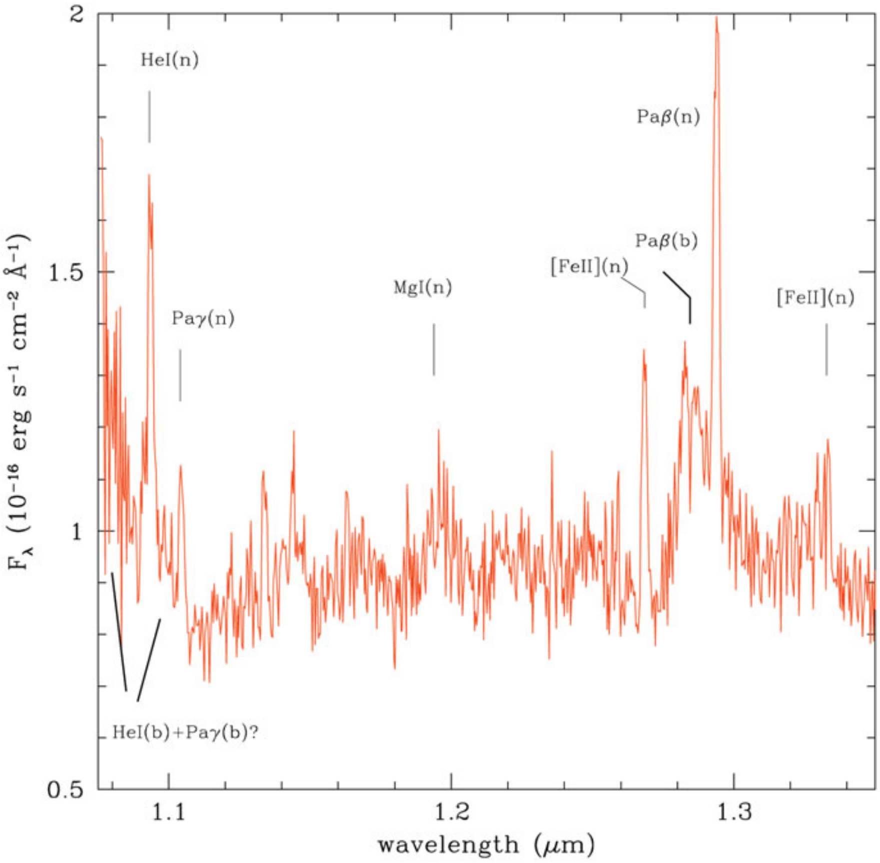

Figure 4: Near-Infrared spectrum of SN2001db observed with ISAAC.

emission lines detected are due to H II regions or SN remnants (see next paragraph) while the continuum is due to the background emission of the galaxy, however, the spectrum shows a clear broad component of Hα which is a clear signature of a type II SN. Hα has an asymmetric profile with a peak blueshifted by about 2000 km/s with respect to the parent galaxy. The FWHM is ~ 5000 km/s. Broad emissions at 7324Å and 8542Å–8662Å due to Ca II respectively are detected. In Figure 3 we show the optical spectrum subtracted of the underlying background. At the same redshift of the peak of the broad Hα we detect a Fe II 7155Å line. Finally the spectrum shows indications for two broad emission features at 5893Å (Na I) and 6300Å ([O I]).

A near-IR spectrum was obtained in the J band with ISAAC at the ESO VLT-UT1 on April 21, 2001 with a slit of 1 arcsec and the low resolution grating set at the 4th order, yielding a spectral resolution of 500. The total integration time was 45 minutes. The spectrum is shown in Figure 4. The broad component of Paγ is more prominent with respect to Hα and the profiles are almost identical. There are indications of a broad component of Paγ and He I 1.0083μm as well. It is worth noting that the strong [Fe II] emission relative to Pap (narrow) indicates that the underlying emission is not simply due to H II regions, but must be contributed significantly by SN remnants. No conclusive results on the SN sub-type (IIL vs. IIP) can be driven from the spectroscopic data.

3. Extinction

Extinction can be measured by using different methods. The ratio between the narrow components of Hα and Hβ is 12.0 which, for a Galactic extinction curve, gives an equivalent screen extinction A_V = 4.2 mag, or higher if assuming a mixed case. The Na I interstellar absorption doublet at ~ 5890Å has an equivalent width of 5.87Å that according to the relations of Barbon et al. (1990) implies an equivalent screen extinction $A_V \geq 3.0$–4.9 mag. To use the ratio of the broad components of Paβ and Hα to directly constrain the reddening of the SN requires the assumption that during the 25 days elapsed between the infrared and the optical spectrum the line flux has not changed significantly (e.g. Danziger et al. 1991). If this is true the observed ratio between the broad components is 1.73 which implies an extinction of A_V = 6.7 mag. for the case B theoretical ratio. There are, however, indications that a ratio higher than case B is more appropriate in SNe (Fassia et al. 2000, Xu et al. 1992) this would give A_V = 5.3 mag. In the case of variation of the emission line flux between the two observations, conservative estimates give a lower limit on the extinction of $A_V > 4.6$ mag. We assume $A_V \approx 5.6$ mag, with an uncertainty of about 1 mag.

SNe discovered in the optical are much less extinguished. In the compilations given by Schmidt et al. (1994) and by Mattila & Meikle (2001) the optical extinction is generally lower than $A_V <$ 1.5 mag, as shown in Figure 5 where the distribution of extinction for optically discovered SNe is reported. If these compilations are representative, then the extinction inferred for the IR SN2001db is probably the highest among the SNe so far discovered.

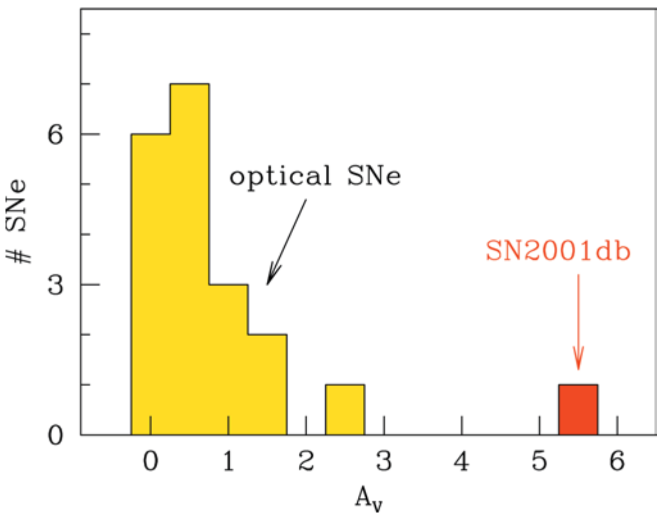

Figure 5: Distribution of the extinction for optically discovered SNe.

4. The IR SN Rate

So far, our programme has detected 4 SNe: two of them were detected also in the optical (SN1999gd and SN 2000gb); another SN (1999gw) was discovered at the TNG, but we could not obtain a spectroscopic identification; the fourth one is SN2001db discussed in this paper. The number of SN events found can be compared with the expected detection rate in the LIRGs of our sample. Assuming the conversion from blue luminosity to SN rate (all types) given in Cappellaro et al. (1999), i.e. SNr $\simeq 10^{-12}$ $(L_B/L_\odot)$ yr^{-1}, we would have expected to detect ~ 0.5 SNe. Since we have detected 4 SNe, we roughly infer a SN rate about an order of magnitude higher than estimated by the conversion inferred by optical surveys. This is quite different from the number of SNe expected from the far-IR luminosity. If most of the far-IR luminosity is due to star formation and we adopt the conversion from L_{FIR} to the SN rate given in Mattila & Meikle (2001), i.e. $SNr \simeq 2.7 \times 10^{-12}$ ($LFIR/L_{\odot}$) yr^{-1}, we find that our survey has missed about 80% of the expected SNe. This can be explained if most of the SNe are so embedded in dust that they are significantly obscured even in the near-IR or, alternatively, obscured AGNs may contribute substantially (~ 80%) to the far-IR luminosity of these galaxies. Finally, there is growing evidence that most of the starburst activity is located in the nuclear region (Soifer et al. 2001). If most SNe occur in the nucleus (i.e. within the central 2″), then our limited angular resolution would have prevented us to disentangle them from the peaked nuclear surface brightness of the host galaxies.

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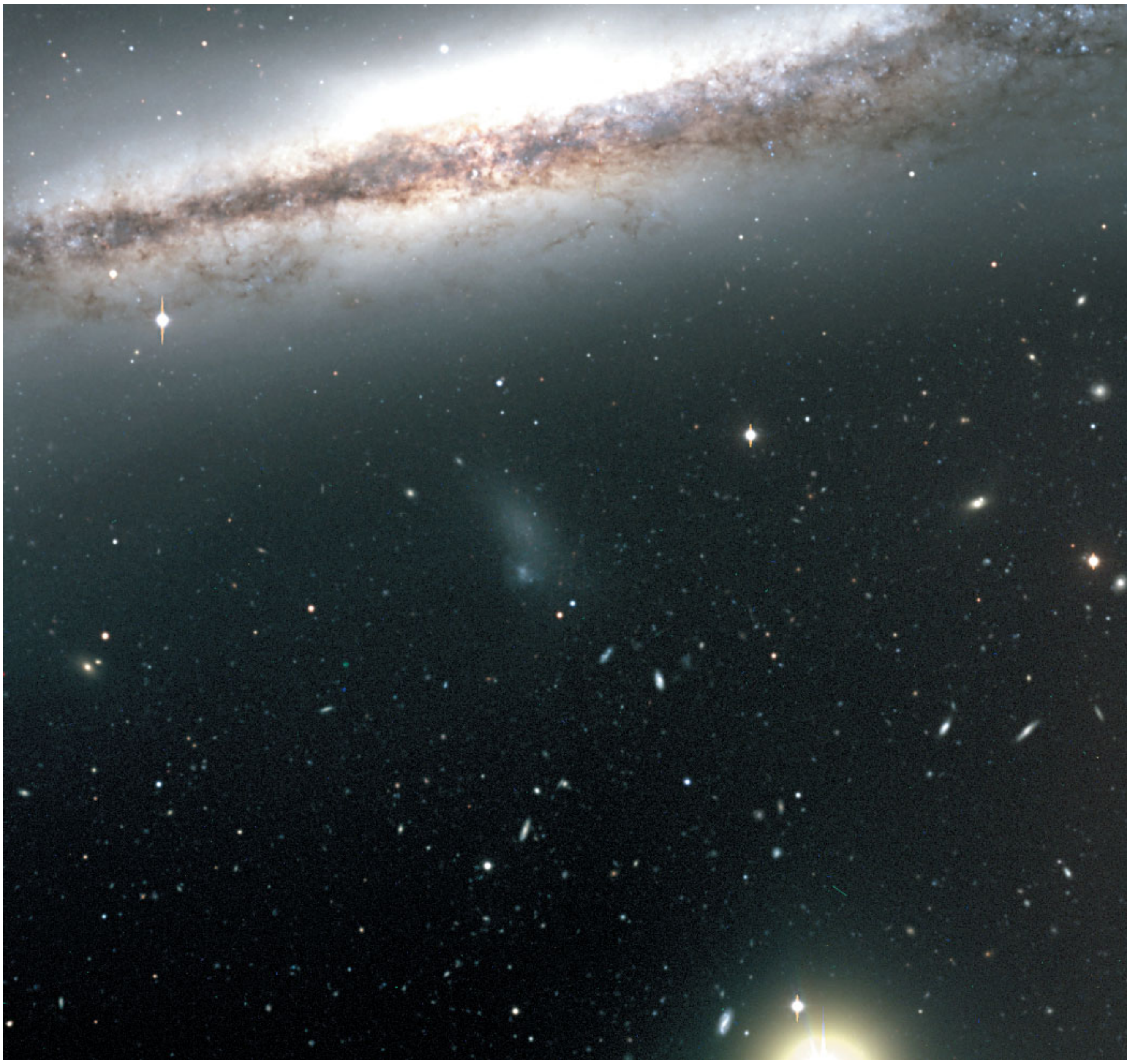
A Deep Look at an Active Galaxy

The image below shows the peculiar edge-on spiral galaxy NGC 3628. It is situated in the constellation Leo and forms a famous triplet of galaxies together with M65 and M66, also known as the Leo Triplet. Its distance is 35 million light-years/11 Mpc.

NGC 3628 is interesting in several respects: although classified as a spiral



galaxy of type Sbc (like our own Milky Way galaxy) its massive dust shows disturbances, possibly as a consequence of the fairly close proximity of the two other members of the Triplet. Furthermore, there seems to be a lot of star formation going on, as one can see in the upper right corner of the image, where numerous star-forming regions with young massive blue stars are visible. The box-like bulge of this galaxy (visible at the top of the image) is also remarkable and could indicate the presence of a central bar. A number of globular clusters can be seen as fuzzy reddish spots in the halo of the galaxy.

The field around NGC 3628 is rich in very faint galaxies, many of which can be seen in this image as slightly diffuse objects. Only a few foreground stars belonging to our own Milky Way are visible, sharp and point-like. However, the conspicuously blue star-like object just SSW of the diffuse patch that extends more or less along the minor axis of the main galaxy, is not a star but an X-ray emitting quasar at a redshift z = 0.995.

Of special interest in this picture is an elongated low-surface-brightness feature that seems to emerge along the minor axis of the large active galaxy. It appears to be part of a chain of objects that coincides very exactly with an X-ray filament associated with ejection of X-ray material from the centre of the galaxy, as shown by observations with the ROSAT and, very recently, the Chandra satellites.

The high image quality of FORS2 on VLT/Kueyen enables resolution of the various objects along this optical feature. A spectroscopic investigation is currently under way in order to study their possible physical relationship to events in this conspicuously disturbed, nearby galaxy.

Technical information: The colour image was composed from five individual exposures through Bessel B, V, R and I broadband filters. Exposure times were 120 + 600 sec in B, 300 sec in V, 600 sec in R and 600 sec in I. They were taken with FORS2 during the commissioning period in February 2000 and retrieved from the ESO Science Archive. The seeing on the different frames was between 0.64 and 0.8 arcsec. The size of the field is 6.8 × 6.8 arcmin; north is up, east to the left. Pre-processing was done with the FORS pipeline in Garching. Observations were carried out by G. Rupprecht, data reduction by F. Patat (both ESO/Garching), image composition by R. Hook and R. Fosbury (both ST-ECF), astronomical background provided by H. Arp (MPA).

G. RUPPRECHT

Coming Home at Paranal

Unique “Residencia” Opens at the VLT Observatory

(Taken from the ESO Press Release of 7 February 2002)

Summary

The Paranal Residencia at the ESO VLT Observatory is now ready and the staff and visitors have moved into their new home.

This major architectural project has the form of a unique subterranean construction with a facade opening towards the Pacific Ocean, far below at a distance of about 12 km. Natural daylight is brought into the building through a 35-m wide glass-covered dome, a rectangular courtyard roof and various skylight hatches.

Located in the middle of the Atacama Desert, the Residencia incorporates a small garden and a swimming pool, allowing the inhabitants to retreat from time to time from the harsh outside environment.

Returning from long shifts at the VLT and other installations on the mountain, here they can breath moist air and receive invigorating sensory impressions. With great originality of the design, it has been possible to create an interior with a feeling of open space – this is a true “home in the desert”.

Moreover, with strict ecological power, air and water management, the Paranal Residencia has already become a symbol of innovative architecture in its own right. Constructed with robust, but inexpensive materials, it is an impressively elegant and utilitarian counterpart to the VLT high-tech facilities poised some two hundred metres above, on the top of the mountain.

Ever since the construction of the ESO VLT at Paranal began in 1991, staff and visitors have resided in cramped containers in the “Base Camp”. This is one of driest and most inhospitable areas in the Chilean

This photo shows the Residencia, looking towards west. The linear construction used to fill the natural depression of the ground in this area is evident. The 35-m central dome protrudes from the “filled-in” valley. Photo: Massimo Tarenghi.

A panorama of the Reception Area with the entry to the Cantine in the background. The essential construction and the warm colour of the concrete walls are clearly visible and help to give the feeling of being “at home”. Photo: Massimo Tarenghi.

Atacama Desert, and eleven years is a long time to wait. However, there was never any doubt that the construction of the telescope itself must have absolute priority.

Nevertheless, with the major technical installations in place, the time had come to develop a more comfortable and permanent base of living at Paranal, outside the telescope area.

A Unique Architectural Concept

The concept for the Paranal Residencia emerged from a widely noted international architectural competition, won by Auer and Weber Freie Architekten from Munich (Germany), and with Dominik Schenkirz as principal designer. The interior furnishing and decoration was awarded to the Chilean architect Paula Gutierrez.

The construction began in late 1998. Taking advantage of an existing depression in the ground, the architects created a unique subterranean construction with a single facade opening towards the Pacific Ocean, far below at a distance of about 12 km. It has the same colour as the desert and blends perfectly into the surroundings. The Paranal Residencia is elegant, with robust and inexpensive materials.

Natural daylight is brought into the building through a 35-m wide glass-covered dome, a rectangular courtyard roof and various skylight hatches. The great originality of this design has made it possible to create an interior with a feeling of open space, despite the underground location.

Facilities at the Residencia

To the visitor who arrives at the Paranal Residencia from the harsh natural environment, the welcoming feeling under the dome is unexpected and instantly pleasant. This is a true “oasis” within coloured concrete walls and the air is agreeably warm and moist. There is a strong sense of calm and serenity and, above all, a feeling of coming home. At night, the lighting below the roofing closure fabric is spectacular and the impression on the mind is overwhelming.

The various facilities are integrated over four floors below ground level. They include small, but nice and simple bedrooms, offices, meeting points, a restaurant, a library, a reception area, a cinema and other recreational areas. The natural focal point is located next to the reception at the entrance. The dining room articulates the building at the –2 level and view points through the facade form bridges between the surrounding Paranal desert and the interior.

A functional and essential room of 16 m^2 with all communication connections allows staff and visitor to work and rest. Photo: Massimo Tarenghi.

Simple, but elegant furnishing and specially manufactured carpeting complement a strong design of perspectives. The Republic of Chile, the host state for the ESO Paranal Observatory, is present with its emblematic painter Roberto Matta.

Additional space is also provided for a regional art and activity display.

The staff moved out of the containers and into their new home in mid-January 2002. Today, the Paranal Residencia has already become a symbol of innovative architecture in its own right, an impressively elegant and utilitarian counterpart to the VLT high-tech facilities poised some two hundred metres above, on the top of the mountain.

A series of woollen, handmade rugs were specially designed by the Chilean artist Luz Méndes, with motives from astronomical images, spectra and interferogrammes obtained at the Paranal Observatory. They decorate the common space of the building. The one seen on this photo displays the Pavo interacting galaxies. Photo: Massimo Tarenghi.

From the Cantine it is possible to observe the preparation of the meals in a modern and well-equipped kitchen. Photo: Massimo Tarenghi.

Release of Scientific Data from VLTI Commissioning

Technical commissioning activities of the VLTI with the VINCI test camera and the 40-cm diameter siderostats with 16 m baseline and the ANTU and MELIPAL 8-m telescopes with 103 m baseline have been ongoing since first fringes on March 17, 2001 with the siderostats and on October 30, 2001 with the 8-m. A number of astronomical targets from various object classes have been observed in these two modes.

The observations were made to assess the compliance of the instruments with the technical specifications as well as to characterise performance of the facility in its first phase of development. In addition to these more technical tasks, a number of observations are certainly also useful for scientific purposes.

In order to fully involve the ESO community in analysing and understanding the data and its scientific and technical implications, ESO has decided to make these data available to this community through the archive.

The data were obtained in the period between March 17, 2001 and December 5, 2001 and have been deemed by the commissioning team and the VLTI Project Scientist to be of sufficient quality to warrant scientific work. The data are available directly on the ESO web (http://www.eso.org/projects/vlti/instru/vinci/vinci_data_sets.html).

Access to these data is restricted to astronomers in the ESO member countries. ESO welcomes community feedback on any aspect of the reduction, analysis and interpretation of these data. Please contact the VLTI project scientist (fparesce@eso.org), the VLTI group head (aglindem@eso.org) or the head of the Commissioning team (mschoell@eso.org) with your comments and for further information on this release. *F. PARESCE*

VLT Science Verification Policy and Procedures

Replicated from ESO web pages

1. Science Verification Observations

After the conclusion of Commissioning of a new VLT instrument, and prior to the start of regular operations, a series of **Science Verification** (SV) observations with such an instrument are conducted. SV observations may also be conducted in the case of a major instrument upgrade.

The equivalent of at least 11 VLT UT nights should be dedicated to SV observations.

SV Observations are conducted during the *dry runs* preceding the instrument regular operations. At the end of the scheduled dry runs, the VLT Programme Scientist submits to the Director General a report on the status of completion of the planned SV observations. If the corresponding set of data is judged insufficient to reach the goals of SV, the Director General may decide that further SV observations be executed during the first scheduled regular runs in Service Mode.

All SV Observations are conducted in Service Mode, but one or two members of the SV Team may be present at Paranal Observatory for a prompt reduction of the data, and the selection of the observations to be executed.

2. Goals of Science Verification

The goals of SV are manifold, and include:

- offering to ESO users first science-grade data from a new instrument
- demonstrating the scientific potential of the VLT+instrument
- fostering an early scientific return from the VLT+instrument
- experimenting any pipeline and reduction tools that may be available at the time of SV
- providing feedback to Operation (Paranal and Garching), Instrument Division, and Data Flow System, as appropriate
- the involvement of scientists from the ESO community in the prompt scientific exploitation of the data.

3. Science Verification Programmes and Data Policy

The SV Plan of an instrument is developed by a dedicated SV Team.

The PI(s) of the instrument subject to SV and the Instrument Science Team are involved in the definition of the SV plan.

The SV Programme is presented to the ESO Faculty for discussion.

The SV Programme is finally submitted by the VLT Programme Scientist to the Director General for approval.

SV observations of targets already included in GTO or approved GO programmes with the same instrument could be executed only with the agreement of the PI.

Raw and calibration SV data passing quality control are made immediately public via the ESO archive, following the “Data Access Policy for ESO Data”.

The SV Team will make efforts to release reduced SV data within two months from the conclusion of SV observations.

4. Selection Criteria for SV Programmes

SV Programmes are selected according to the following criteria: They should

- have outstanding scientific interest
- push the VLT+Instrument close to their limit
- address a scientific issue widely studied within the ESO Community
- result in a sufficiently complete dataset for its prompt exploitation to be scientifically rewarding
- use the core modes of the instrument
- help PIs and Co-Is of approved GO and GTO programmes to get promptly acquainted with the data from the instrument
- exploit complementarity with other public datasets (e.g. HDF-S/CDF-S/EIS, etc.), if appropriate.

5. The SV Team

5.1 Composition of the SV Team

A dedicated SV Team is assembled for each of the various SV phases, including Garching and Chile staff and fellows (typically up to 8–10 people).

In the selection of the SV Team members the VLT Programme Scientist will follow the following criteria:

- Strong scientific interest for the specific capabilities of the instrument
- Technical experience with the type of data being produced by the instrument
- Wide coverage of the main scientific areas that the instrument is designed to satisfy

To all activities of the SV Team will also be invited to participate:

- The Instrument PI and Co-PI, or one person designated by each of them
- The ESO Instrument Scientist
- The ESO and Consortium Instrument Pipeline experts

4.2 Duties of the SV Team

The duties of the SV Team include:

- Development and pre-selection of the SV projects
- Preparation of the OBs, and their delivery to Paranal Observatory prior to the instrument dry runs
- Maintenance of SV WEB pages, describing the SV plan well in advance of the SV Observations, and including informative lists of SV data as they become public
- Real time assessment of the SV data at Paranal Observatory (maximum 2 SV Team members)
- Reduction of the SV data
- Delivery through the SV WEB and the ESO Archive of the raw, calibration, and calibrated data
- On users request provide information on the data
- The SV Team can have access to the Commissioning data prior to SV observations.

5. Scientific Exploitation of the SV Data

The scientific exploitation of the SV data can start as soon as the data are publicly released.

The formation of groups and teams for the scientific exploitation of SV data is left to the initiative of the individuals.

SV Team members are encouraged to promptly use the data and to stimulate the participation of scientists from the community.

Authors are kindly asked to send to ESO (Office of the VLT Programme Scientist) at submission time copy of any paper that may result from the use of SV data, along with a concise technical report on the use of the data, pipeline, etc.

News from Santiago

The spectacular fringes obtained at VLTI, as well as the intensive ALMA preparatory work in Chile, have suddenly brought the “world of interferometry” to full attention of the astronomical community in Chile.

Astronomers not yet familiar with this type of observational technique have started to realise the originality, the strength and the astrophysical potential of aperture synthesis observations, both at radio and at optical/IR wavelengths.

On the side of the pioneers who have been developing the techniques of interferometry for almost 30 years now, it is time to advertise widely their tools and enrol young researchers in this fascinating adventure. On the side of the astronomical community at large, the fantastic improvement in spatial resolution brought by interferometry is very attractive and opens new avenues for solving astrophysical problems.

Therefore, the demand has been growing in Chile for some basic and practical information about interferometry: the principles, the instrumental solutions to be adopted according to the wavelength domain, and also the effective achievements of today’s interferometric instruments.

The idea of organising an “Interferometry Week” at ESO/Santiago was born almost two years ago and became a reality on 2002 January 14–16. After the traditional welcome (D. Alloin) and introductory remarks (M. Tarenghi), we could attend very well prepared and enlightening lectures on the basics of aperture synthesis (P. Lena), on interferometry in the radio domain and soon with ALMA (S. Guilloteau), on the science performed with millimetre interferometers (A. Dutrey), on optical/IR interferometry (A. Glindemann), on phase closure (M. Wittkowski), on the VLTI and its instrumentation (M. Schoeller) and, finally, on the science we can dream of with optical/IR interferometers (A. Richichi).

A large audience attended the tutorial, including a noticeable group of students from ESO/Chile, PUC and Universidad de Chile. At the request of the attendees, and thanks to the generous attention of the speakers, all presentations have been made available on a webpage and can be retrieved from: http://www.sc.eso.org/santiago/science/interf2002.html

Once more, we thank the lecturers and the attendees for a very interesting scientific meeting which, for some of us, has opened the door to new horizons in astronomical data and results. Many thanks also to the administration staff and to the team of the Office for Science in Santiago, in particular A. Lagarini, who have contributed in the organisation and the success of this “Interferometry Week”.

We hope that this first contact with interferometry (for some of the attendees) will be the start of exciting work and beautiful discoveries. *D. ALLOIN*

ESO Studentship Programme

The European Southern Observatory research student programme aims at providing the opportunities and the facilities to enhance the post-graduate programmes of ESO member-state universities by bringing young scientists into close contact with the instruments, activities, and people at one of the world’s foremost observatories. For more information about ESO’s astronomical research activities please see the ESO Science Activities webpage at URL http://www.eso.org/science/index.html .

Students in the programme work on an advanced research degree under the formal tutelage of their home university and department, but come to either Garching or Vitacura-Santiago for a stay of up to two years to conduct part of their studies under the supervision of an ESO staff astronomer. Candidates and their national supervisors should agree on a research project together with the potential ESO local supervisor. This research programme should be described in the application and the name of the ESO local supervisor should also be mentioned. It is highly recommended that the applicants start their Ph.D. studies at their home institute before continuing their Ph.D work and developing observational expertise at ESO.

The ESO studentship programme comprises about 14 positions, so that each year a total of up to 7 new studentships are available either at the ESO Headquarters in Garching or in Chile at the Vitacura Quarters. These positions are open to students enrolled in a Ph.D programme in the ESO member states and exceptionally at a university outside the ESO member states.

The closing date for applications is June 15, 2002.

Please apply by using the ESO Studentship application form available on-line at URL http://www.eso.org/gen-fac/adm/pers/vacant/studentship2002.html .

European Southern Observatory
Studentship Programme
Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
abeller@eso.org

The Third NEON Observing School

The Network of European Observatories in the North (NEON) is pleased to announce its third observing school, sponsored by the European Community, which will take place at Asiago Observatory (Italy) from

September 9 to 22, 2002

The school is organised jointly and alternately by Asiago Observatory (Italy); Calar Alto Observatory (Germany-Spain) and Haute-Provence Observatory (France), with additional tutorial assistance from ESO.

The purpose of the school is to provide opportunity to gain practical observational experience at the telescope, in observatories with state-of-the-art instrumentation. To this effect, the school proposes tutorial observations in small groups of 3 students, under the guidance of an experienced observer, centred around a small research project and going through all steps of a standard observing programme. Introductory lectures are given by experts in the field. The list of topics includes telescope optics, photometry, spectroscopy, data analysis, etc.… Special emphasis will be given this year on polarimetry. Additional topics cover VLT instrumentation, virtual observatories, wide-field imaging, etc.…

The school is open to students working on a PhD thesis in Astronomy, or young post-docs without previous observational experience, and which are nationals of a member State or an associated State of the European Union. The working language is English. Up to fifteen participants will be selected by the organising committee and will have their travel and living expenses paid if they satisfy the EC rules (age limit of 35 years at the time of the Euro Summer School).

Applicants are expected to fill in an application form (available on the Web site), with a CV and description of previous observational experience, and to provide a letter of recommendation from a senior scientist familiar with the work of the applicant.

The application deadline is April 20th, 2002.

Secretary of the school: Mrs. Françoise WARIN at IAP 98bis, Bd Arago F-75014 PARIS warin@iap.fr

Further instructions and full practical details can be found on the school Web site, which is hosted by the European Astronomical Society at:

http://www.iap.fr/eas/schools.html

You will also find there a description of activities in the previous schools, hosted in 2000 by the Calar Alto Observatory, and in 2001 by the Haute-Provence Observatory.

We expect the next school to be as great a success as were the previous ones!

Spread the word around your community.

Michel Dennefeld, Co-ordinator of the NEON school

“Life in the Universe” Winners on La Silla and Paranal

A. BACHER, ESO and Institut für Astrophysik, Leopold-Franzens-Universität Innsbruck

“Please fasten you seat-belts, we are descending to Santiago de Chile!” On board of the airplane are the winners of the “Life in the Universe” contest, Mihaly Kristof, Katalin Lovei, Adam Orban, Andras Sik and Tamas Simon. All are excited and for one it is the first flight in his life. What a chance!

“Life in the Universe”, a common educational project of ESA, ESO and CERN, had its final event during the European Week of Science and Technology 2001 in Geneva. The two first prizes are a trip to Korou, sponsored by ESA, and a visit to the ESO Observatories in Chile. In November 2001, the team from Hungary, who created an ingenious game called Entropoly, was chosen among 77 competing groups to be one of the two bests projects and it won the trip to Chile.

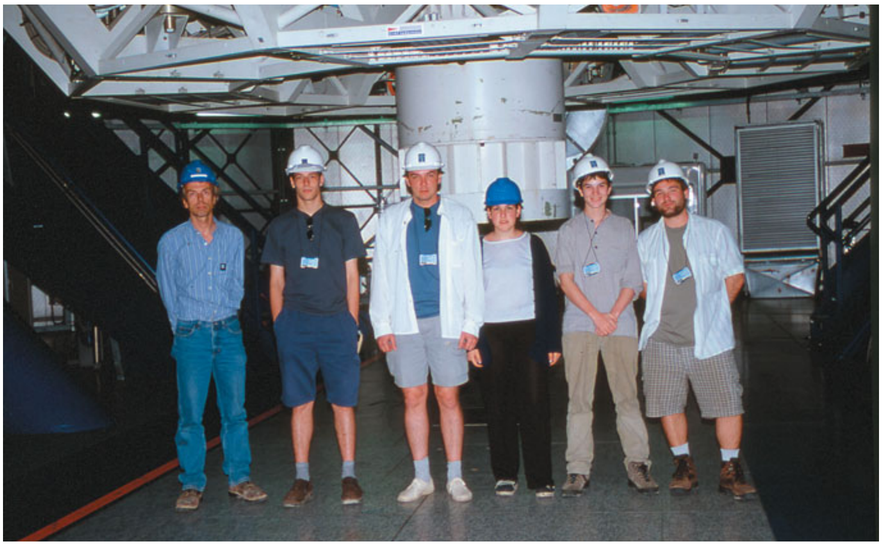
La Silla: Olivier Hainaut is explaining the 3.6-m telescope.

After a day of recovering from the 17-hour flight to Chile, we went to La Silla. Olivier Hainaut gave an inspired guided tour to the telescopes. From inside we could see the 3.6-m and the NTT. The concept of active optics was explained as well as all the different instruments including their purposes. For the winners, who have never before seen a telescope with a mirror larger than 1 m in diameter, it was a thrilling moment to experience such big telescopes moving.

In the night we could see astronomers working in the New Swiss Telescope and the NTT.

At the final event in Geneva, Michel Mayor gave a talk about extrasolar planets. It was very interesting for the winners to see the New Swiss Telescope where the images shown during that talk were obtained.

In the NTT we could follow a changing of the instrument from EMMI to SOFI. We did not only see how the images of the objects were taken, but we were also told why they are so interesting and what science the astronomer will do after data reduction.



VLT: The winners and Gerd Hudepohl in front of UT1.

The next destination was the Paranal Observatory. Humberto Varas was our guide and showed us the site. First we got a visit to UT1, ANTU, by day. The active optics system and the mounted instruments were explained. We also had a look into the control room, where the different purposes of the computers and monitors were illustrated.

After dinner we went again up on the mountain and we saw the opening of the telescopes. The winners were really excited seeing the "big brother" of the NTT moving. After sunset we stayed for a long time in the control room. We got explanations of the instruments mounted on each telescope as well as of the objects imaged that night. The Telescope Operators, the Staff Astronomers and the Visiting Astronomers kindly explained us their work.

Of course, on both observatories we had the possibility to ask questions, which was very important for the winners, not just hearing astronomers talking, but speaking directly to them.

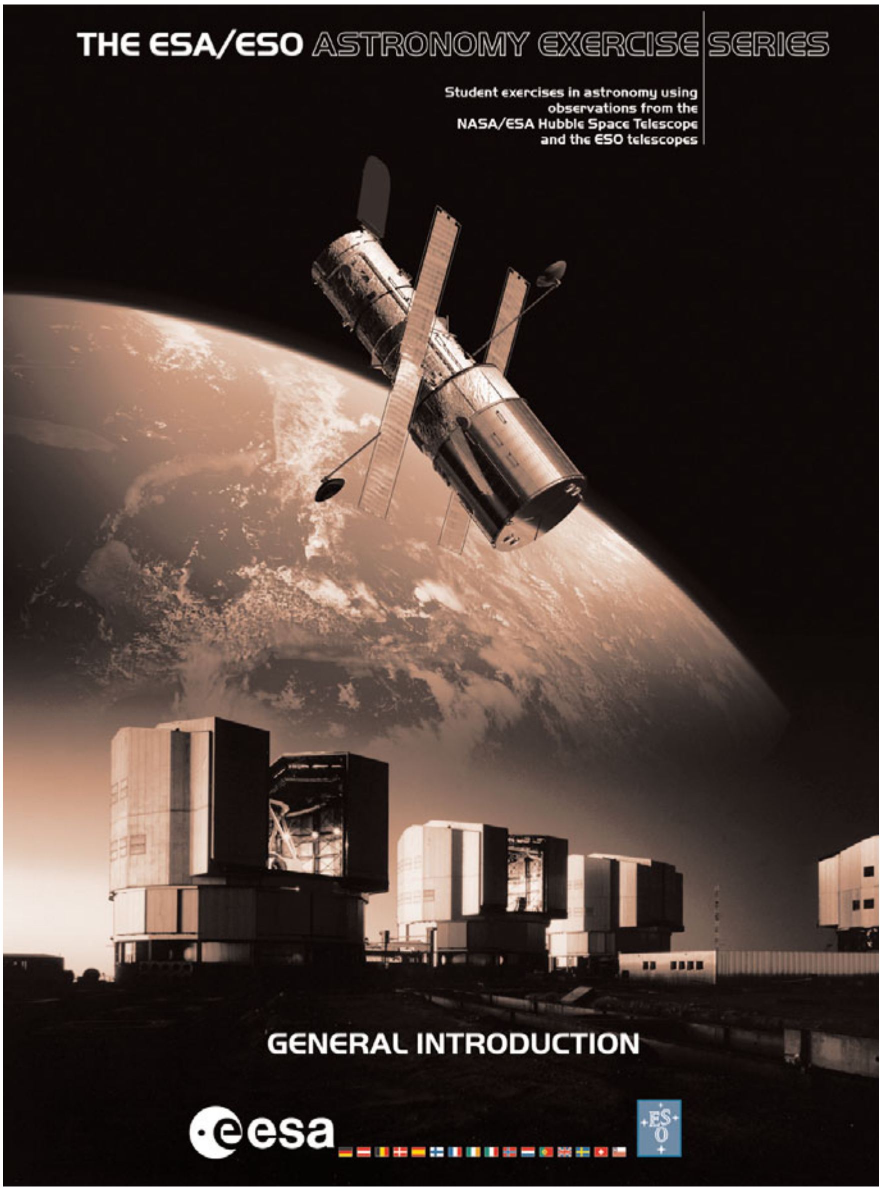
Although the long trip was very exhausting, we forgot it completely seeing the observatories. All are thankful to ESO for providing this nice prize and the opportunity to see the sites, where real frontline astronomy is done.

In the Footsteps of Scientists – ESA/ESO Astronomy Exercise Series

A. BACHER[1] and
L. LINDBERG CHRISTENSEN[2]

[1]ESO and Institut für Astrophysik, Leopold-Franzens-Universität Innsbruck;
[2]ST-ECF

The first instalments of the "ESA/ ESO Astronomy Exercise Series" has been published, on the web and in print (see also ESO PR 29/01). These exercises allow 16–19-year-old students to gain exciting hands-on experience in astronomy, making realistic calculations with data obtained by the NASA/ ESA Hubble Space Telescope and ESO's Very Large Telescope (VLT). Carefully prepared by astronomers and media experts, these exercises enable the students to measure and calculate fundamental properties like the distances to and the ages of different kinds of astronomical objects.



Cover of General Introduction. (European Space Agency and European Southern Observatory).

Focus on Basic Themes

The first four exercises focus on measurements of distances in the Universe.

The students apply different methods to determine the distance of astronomical objects such as the supernova SN 1987A, the spiral galaxy Messier 100, the Cat's Eye Planetary Nebula and the globular cluster Messier 12. With these results it is possible to make quite accurate estimates of the age of the Universe and its expansion velocity, without the use of computers or sophisticated software.

Students can also perform 'naked-eye photometry' by measuring the brightness of stars on two VLT images (taken through blue and green optical filters, respectively). They can then construct the basic luminosity-temperature relation (the "Hertzsprung-Russell Diagram") providing a superb way to gain insight into fundamental stellar physics.

Six Booklets

The following booklets have been published:

"General Introduction" (an overview of the exercise series),
"Toolkits" (explanation of basic astronomical and mathematical techniques),
"Exercise 1: Measuring the Distance to Supernova 1987A",
"Exercise 2: The Distance to Messier 100 as Determined by Cepheid Variable Stars",
"Exercise 3: Measuring the Distance to the Cat's Eye Nebula" and
"Exercise 4: Measuring a Globular Star Cluster's Distance and Age".

Each of the four exercises begins with a background text, followed by a series of questions, measurements and calculations. The exercises can be used either as texts in a traditional classroom format or for independent study as part of a project undertaken in smaller groups.

The booklets are sent free-of-charge to high-school teachers on request and may be downloaded as PDF files from the website. More exercises will follow in the future, e.g. measuring the velocity and distance to a transneptunian object.

Contact: info@astroex.org
Web: www.astroex.org

PERSONNEL MOVEMENTS

International Staff

(1 January 2002 – 31 March 2002)

ARRIVALS

EUROPE

DELMOTTE, Nausicaa (F), Student
DEPAGNE, Christophe (F), Student
GUIDOLIN, Ivan Maria (I), Associate
IAITSKOVA, Natalia (RU), Associate
PAUFIQUE, Jérôme (F), Engineer Adaptive Optics
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TAYLOR, Luke (GB), Associate
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CHILE

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LEDOUX, Cédric (F), Operations Staff Astronomer
MORELLI, Lorenzo (I), Student
PINTE, Christophe (F), Associate
RABELING, David (NL), Associate
RATHBORNE, Jill (AUS), Associate SEST

DEPARTURES

EUROPE

DEMOULIN-ARP, Marie-Hélène (F), Astronomer
DESSAUGES-ZAVADSKY, Miroslava (CH), Student
FARINATO, Jacopo (I), Support Engineer
GENNAI, Alberto (I), Control/Hardware Engineer
SANNER, Jörg (D), Associate
TRIPICCHIO, Alfredo (I), Associate
WEBER, Ingrid (D), Secretary

CHILE

GARCÍA AGUIAR, Martina (D), Mechanical Engineer

Local Staff

(1 December 2001 – 28 February 2002)

ARRIVALS

ESPARZA MORALES CRISTIAN, Telescope Instruments Operator, La Silla
FAUNDEZ MORENO LORENA, Telescope Instruments Operator, Paranal
LA FUENTE PE A EDUARDO, Telescope Instruments Operator, La Silla
PALACIO VALENZUELA JUAN CARLOS, Mechanical Engineer, Paranal
RIVERA MAITA ROBERTO, Temporary Site Testing, Paranal
SOTO TRONCOSO RUBEN, Software Engineer, La Silla
STRUNK SANDRA, Executive Bilingual Secretary, Paranal
VALENZUELA SOTO JOSE JAVIER, Instrumentation Engineer, La Silla

DEPARTURE

VERA ROJAS ESTEBAN, Electronics Engineer, Paranal

LIST OF SCIENTIFIC PREPRINTS

January–February 2002

1454. M.J. Neeser, P.D. Sackett, G. De Marchi, F. Paresce: Detection of a Thick Disk in the edge-on Low Surface Brightness Galaxy ESO 342–G017. I. VLT Photometry in V and R Bands. *A&A*.
1455. D. Elbaz, C.J. Cesarsky, P. Chanial, H. Aussel, A. Franceschini, D. Fadda and R.R. Charry: The bulk of the cosmic infrared background resolved by ISOCAM. *A&A*.
1456. T.-S. Kim, S. Cristiani and S. D'Odorico: The evolution of the physical state of the IGM. *A&A*.
1457. D. Fadda, H. Flores, G. Hasinger, A. Franceschini, B. Altieri, C.J. Cesarsky, D. Elbaz and Ph. Ferrando: The AGN contribution to mid-infrared surveys. X-ray counterparts of the mid-IR sources in the Lockman Hole and HDF. *A&A*.
1458. Y. Momany, E.V. Held, I. Saviane and L. Rizzi: The Sagittarius dwarf irregular galaxy: metallicity and stellar populations. *A&A*.
1459. A. Franceschini, D. Fadda, C.J. Cesarsky, D. Elbaz, H. Flores, G.L. Granato: ESO investigates the nature of extremely-red hard X-ray sources responsible for the X-ray background. *ApJ*.

MESSENGER INDEX 2001 (Nos. 103–106)

SUBJECT INDEX

TELESCOPES AND INSTRUMENTATION

REPORTS FROM OBSERVERS

OTHER ASTRONOMICAL NEWS

ANNOUNCEMENTS

AUTHOR INDEX

A

B

C

E

F

G

H

J

M

N

P

Q

S

T

U

Contents

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 nine countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Sweden and Switzerland. ESO operates at two sites. It operates the La Silla observatory in the Atacama desert, 600 km north of Santiago de Chile, at 2,400 m altitude, where several optical telescopes with diameters up to 3.6 m and a 15-m submillimetre radio telescope (SEST) are now in operation. In addition, ESO is in the process of building the Very Large Telescope (VLT) on Paranal, a 2,600 m high mountain approximately 130 km south of Antofagasta, in the driest part of the Atacama desert. The VLT consists of four 8.2-metre telescopes. These telescopes can also be used in combination as a giant interferometer (VLTI). The first two 8.2-metre telescopes (called ANTU and KUEYEN) are in regular operation, and the other two will follow soon. Over 1200 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 La Silla and Paranal observatories with the most advanced instruments. There are also extensive astronomical data facilities. In Europe ESO employs about 200 international staff members, Fellows and Associates; in Chile about 70 and, in addition, about 130 local staff members.

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

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