The Messenger

No. 138 – December 2009

VISTA image release
X-shooter extragalactic science
Neutron star astronomy
APEX/LABOCA deep survey

First Release of Images from VISTA

The new ESO survey telescope VISTA (the Visible and Infrared Survey Telescope for Astronomy) was recently commissioned at Paranal and has just released its first public images.

VISTA was conceived and developed by a consortium of 18 universities in the United Kingdom led by Queen Mary, University of London and became an in-kind contribution to ESO as part of the UK's accession agreement. The telescope is described in Emerson et al. (2004, 2006). Project management for the telescope design and construction was the responsibility of the Science and Technology Facilities Council's UK Astronomy Technology Centre (STFC, UK ATC). Provisional acceptance of VISTA was formally granted by ESO at a ceremony at ESO Headquarters in Garching, Germany, attended by representatives of Queen Mary, University of London and STFC on 10 December 2009. VISTA will now be operated by ESO.

VISTA has a 4.1-metre primary mirror with a 1.65 degree field of view. On account of the speed of the primary (F/0.98), the largest mirror to be manufactured with such a low focal ratio, the figuring and polishing of the primary was a formidable task. The secondary is 1.24 metres in diameter. As a survey telescope it has only one instrument, a camera composed of 16 2048 × 2048 infrared detectors. The Raytheon VIRGO HgCdTe detectors have 0.34-arcsecond pixels and a single "pawprint" covers an area of 0.6 square degrees. By combining six offset images, a full field coverage of 1.5 × 1.0 degrees is achieved. The camera was designed and built by a consortium including the Rutherford Appleton Laboratory, the UK ATC and the University of Durham. Figure 1 shows a view of the telescope with the camera in the process of being removed. The camera has five broadband filters *Z*, *Y*, *J*, *H* and *Ks*, with an option for user-provided filters.

The front cover shows a colour-composite image of the dusty star-forming H II region NGC 2024 in the Orion Cloud region, called the Flame Nebula (image from the ESO press release). Figure 2 shows a 1 × 1.4 degree region of the Fornax galaxy cluster, with NGC 1399 and NGC 1365 both visible. The VISTA science verification (SV) programme[1] consists of two mini-surveys: one Galactic, on the theme of star formation and very low mass stars and brown dwarfs in the Orion region; and one extragalactic, on the stellar halo in NGC 253. The SV data will be processed using the VISTA Data Flow System run jointly by the Cambridge Astronomical Survey Unit (CASU) and the Wide Field Astronomy Unit Edinburgh (WFAU), and the reduced data will be publicly released.

VISTA will be dedicated to large surveys and a five-year programme of six public surveys has been assigned. Observations will begin soon. They range from surveys of variable stars in the Milky Way, a survey of the Magellanic Clouds, a southern hemisphere survey and a large area galaxy survey, and two deep small field surveys. Details of these surveys can be found in Arnaboldi et al. (2007).

References

Arnaboldi, M. et al. 2007, The Messenger, 127, 28
Emerson, J. P. et al. 2004, The Messenger, 117, 27
Emerson, J. P. et al. 2006, The Messenger, 126, 41

Links

[1] http://www.eso.org/sci/activities/vltsv/vista/index.html

Credit: ESO/G. Hüdepohl

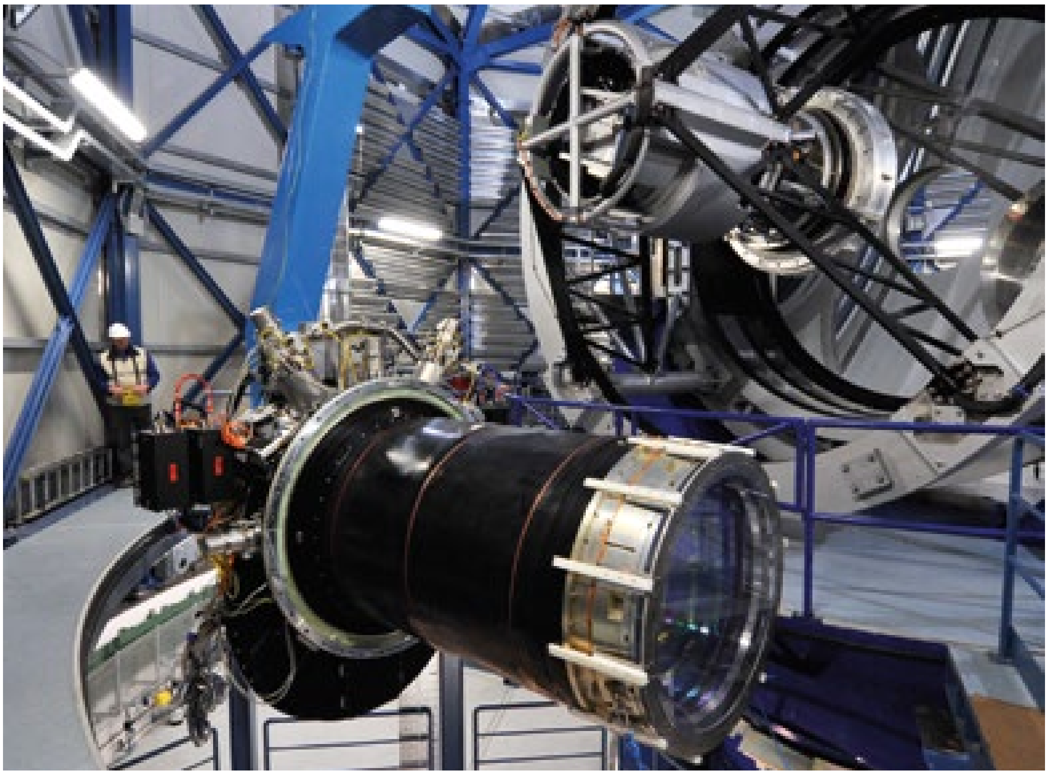


Figure 1 (left). The VISTA infrared camera being removed to allow the primary mirror to be recoated in September 2009.

Figure 2 (right). VISTA colour image (from *Z*, *J* and *Ks* filters) of the Fornax galaxy cluster. At the lower left is the barred-spiral galaxy NGC 1365 and to the upper right the central bright elliptical NGC 1399. The total exposure time per pixel was about 25 minutes.

Credit: ESO/J. Emerson/VISTA
Acknowledgement: Cambridge Astronomical Survey Unit

X-shooter Starts Operation at the Paranal Observatory: A New Opportunity for Extragalactic Astronomy

Joël Vernet[1]
Sandro D'Odorico[1]
Lise Christensen[2]
Hans Dekker[1]
Elena Mason[1]
Andrea Modigliani[1]
Sabine Moehler[1]

[1] ESO
[2] Excellence Cluster Universe, Technische Universität München, Germany

X-shooter, the new three-arm spectrograph at the VLT promises to be a powerful tool for high quality observations of targets of intermediate and faint magnitude at any redshift. The instrument capabilities are summarised and several examples of its use for the spectroscopy of intermediate and high redshift objects presented.

X-shooter at the start of operations

X-shooter is the first of the second generation Very Large Telescope (VLT) instruments and replaces the workhorse FOcal Reducer and low dispersion Spectrograph (FORS1), which has been successfully in use for more than a decade. It is located at the Cassegrain focus of the Kueyen Unit Telescope (UT2). The consortium that built X-shooter consists of ten institutes in Denmark, France, Italy and the Netherlands. ESO delivered the detector's systems and the cryogenic system controller and undertook the final integration, first in Garching and then at the telescope. The instrument was completed in five years at a cost of 6 million euros and ~ 70 person-years. Details on the consortium and the instrument have been included in previous *Messenger* articles (Vernet et al., 2007; D'Odorico, 2008) and can be found on the ESO website[1].

X-shooter consists of a central structure (backbone), which supports three prism-cross-dispersed échelle spectrographs optimised for the ultraviolet–blue (UVB), visible (VIS) and near-infrared (NIR) wavelength ranges. At the entrance of each spectrograph there is a slit unit, equipped with 11-arcsecond-long slits of different widths. The light beam of the telescope after the focus is directed to the UVB and VIS arms and transmitted to the NIR spectrograph cryostat by two dichroics in series. It is also possible to use an image slicer in the focal plane that reformats a 1.8 × 4 arcsecond field on the sky into a 0.6 × 12 arcsecond-long slit. X-shooter simultaneously collects the full spectrum of the target from 300 to 2500 nm with an efficiency of between 15 % and 35 %, including the telescope and the atmosphere (see Figure 1a, b and c for the UVB, VIS and NIR efficiencies respectively). The spectral resolution varies between 3000 and 17000 depending on the slit width and wavelength range, as shown in Table 1. The optical image quality is between 1 and 2 pixels on the detector over the full range.

In the first two commissioning runs, in November 2008 and January 2009, only the UVB and VIS arms could be tested. The instrument was operated in its full configuration with the NIR arm from March 2009. It has lived up to expectations in terms of image quality, spectral resolution and simple and robust opera-

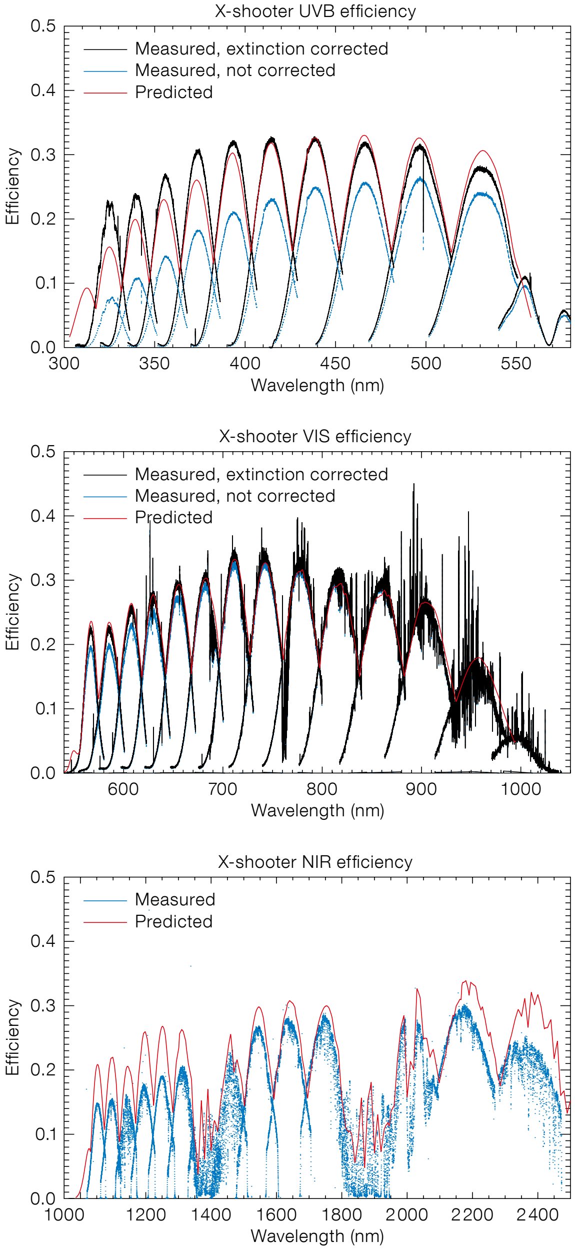


Figure 1a, b, c. The three plots show the predicted efficiency at airmass 1.0 (red lines) versus observed efficiencies (blue lines) of the instrument+telescope for all orders of the échelle spectra. For the UVB and VIS arms the correction of extinction to airmass 1.0 is also shown (black lines). For the NIR arm the prediction includes an estimate of telluric absorption at airmass 1.0. These measurements are based on observations of the flux standard GD71 obtained in June 2009.

UVB			VIS			NIR		
Slit width (arcseconds)	R $\lambda/\Delta\lambda$	Sampling (pixels/FWHM)	Slit width (arcseconds)	R $\lambda/\Delta\lambda$	Sampling (pixels/FWHM)	Slit width (arcseconds)	R $\lambda/\Delta\lambda$	Sampling (pixels/FWHM)
0.5	9100	3.5	0.4	17400	3.0	0.4	11300	2.0
0.8	6200	5.2	0.7	11000	4.8	0.6	8100	2.8
1.0	5100	6.3	0.9	8800	6.0	0.9	5600	4.0
1.3	4000	8.1	1.2	6700	7.9	1.2	4300	5.3
1.6	3300	9.9	1.5	5400	9.7	1.5	3500	6.6
IFU (1.8 × 4 arcseconds)	7900	4.1	IFU	12600	4.2	IFU	8100	2.8

Table 1. Offered resolution, *R*, and sampling as a function of slit width, and for the integral field unit (IFU).

tion. The overall efficiency is essentially as predicted, except for the *J*-band where it is ~ 30 % below the original goal, due to losses that can only be partly explained by scattering in the ZnSe cross-disperser prisms.

Following an open call there were two successful Science Verification (SV) runs in August and September 2009. A summary of the SV programmes is available[2]. Data from the commissioning and the SV runs have been made publicly available through the ESO archive and can be used to become familiar with the data format and to plan future observations.

The possibility of collecting the full spectrum from the atmospheric UV cut-off to the *K*-band at intermediate resolution in a single shot is an attractive option for a variety of scientific programmes, from the study of Solar System bodies to the search for emission galaxies at high redshift. In the first two proposal calls, where X-shooter was offered for general use (April and October 2009), it was the second most requested instrument at the VLT after FORS.

Examples of X-shooter observations

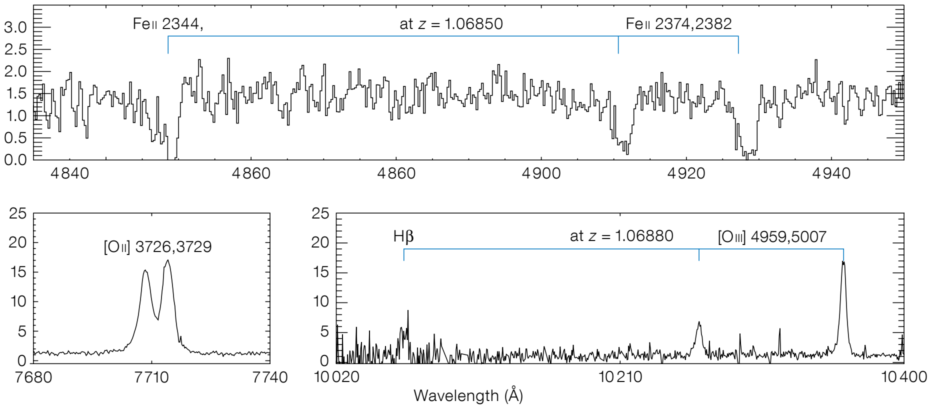
We present here examples of X-shooter observations from the commissioning runs which illustrate the capability of the instrument in extragalactic astronomy. The examples were also used as test cases for the data reduction software. All data shown here have been reduced, up to a 2D rectified, merged, wavelength-calibrated and sky-subtracted spectrum, with the data reduction pipeline, developed by the X-shooter consortium and integrated into the Data Flow System by ESO. The pipeline is used at the Paranal Observatory for online visualisation of the data and at ESO Headquarters in Garching for quality control and for reduction of the service observations. A preliminary version will be made available to the users of the instrument in Period 84.

An emission line galaxy at intermediate redshift

One of the key scientific drivers of X-shooter was the capability to collect a useful spectrum of a target of unknown redshift already in the discovery observation, thanks to its large spectral coverage. This capability — which is also the origin of the name of the instrument — was very much in mind for observations of gamma-ray bursts, where the rapidly-declining brightness calls for “shooting” an exposure of the target as soon as it is identified. This advantage however becomes equally useful in the observations of faint galaxies at unknown redshift. During commissioning, two lensed galaxy candidates from the Cassowary survey[3] (Belokurov et al., 2007) were observed. X-shooter spectra confirmed the nature of both candidates from several emission and absorption lines distributed over the three arms of the instrument. The first target, CASSOWARY 20, resembles an Einstein Cross and is a blue star-forming galaxy at $z = 1.433$ (Pettini et al., 2009).

Here we present, in Figure 2, data of another system, a star-forming galaxy at $z = 1.0688$ lensed by a pair of foreground galaxies at $z = 0.388$ (Christensen et al., in preparation). In the X-shooter spectrum we identify 20 different emission lines from [O II] 3727 Å to He I 10830 Å. Even Hα, which is located in the region between the *J*- and *H*-bands, where the transmission is ~ 10 %, could be measured. Furthermore, in the 40-minute exposure it is still possible to identify UV absorption lines that are from the species Si II, Al III, Fe II, Mg II and Mg I. The resolution of X-shooter allows the strong emission lines to be decomposed into two components that are separated by ~ 50 km s^{-1}, a narrow one with a width of 50 km s^{-1} and a wider component of width 128 km s^{-1}. The interstellar medium absorptions are blueshifted by 43 km s^{-1} relative to the systemic redshift of the source, as determined by the emission lines.

Figure 2. Sections of the UVB, VIS and NIR arm spectra of a lensed star-forming emission line galaxy. This spectrum was the confirmation observation of a candidate from the Cassowary survey (Belokurov et al., 2007). The target was observed with 2 × 1200 s on-target, aligning the slit between the two brightest images (V ~ 21 mag) of the lens.



High redshift quasars

B1422+231 ($z = 3.62$) is one of the brightest quasars in the sky ($V \sim 16.5$ mag), and is highly amplified by gravitational lensing. The X-shooter integration of total time 4800 s was split over 4 × 1200 s exposures and gives a final signal-to-noise ratio of between 50 and 100 over most of the spectral range. Two of the lensed quasar images, separated by 0.5 arcseconds, were aligned along the slit and the extracted spectrum refers to the sum of the two.

The resulting X-shooter spectrum (Figure 3) has resolutions of 6200, 11 000 and 8100 in the UVB, VIS and NIR spectral regions respectively. At this resolution it is possible to study both narrow emission and absorption lines, from the gas in the quasar environment and from the intervening galaxies. The quasar continuum can be accurately traced even in the Lyman-α forest. The major advantage is the simultaneous coverage of a large wavelength interval. For this $z = 3.62$ quasar, the region from the Lyman continuum to redwards of the [O III] 5007 Å line can be investigated simultaneously. With a standard optical or infrared spectrograph only limited regions of the spectrum could be studied in a single exposure, with the potential risk of introducing errors in the final compilation of data taken at different times and under different weather conditions. With X-shooter it is now possible to circumvent these obstacles. The recovery of accurate profiles of several emission lines permits accurate determination of the redshift of the quasar, to be compared with the redshifts of the interstellar medium absorptions. Similarities and differences in the restframe UV and optical regions have allowed us to gain a better understanding of the accretion processes in the centre of the quasar.

A second example of a quasar observation is for the $z = 5.99$ SDSS QSO J130608.26+035626.3 ($z = 19.5$ mag, $J = 18.8$ mag). For objects from $z = 3.5$ up to $z = 6.5$, X-shooter permits Lyman-α to be obtained simultaneously in the visual arm up to a resolving power of 11 000 (allowing a good tracing of the emission line profile) and absorption systems up to the *Ks*-band to be identified at a reso-

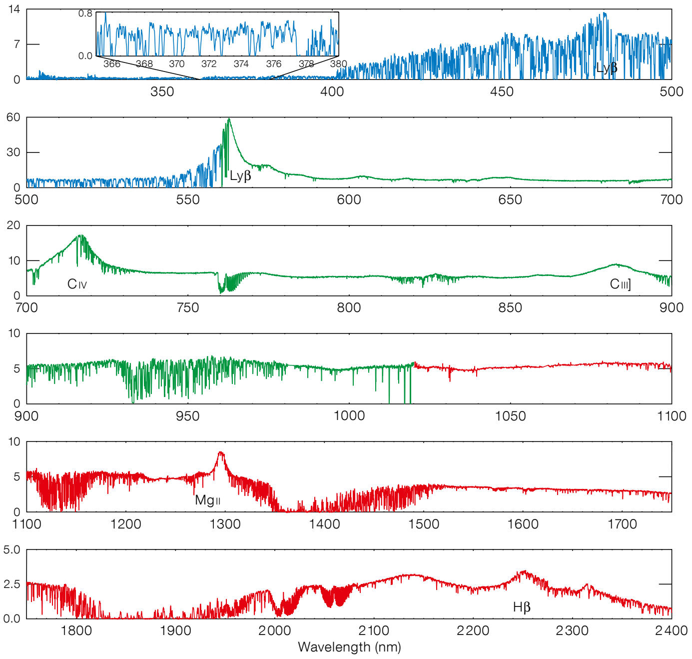


Figure 3. Spectrum of the lensed quasar B1422+231. The blue part of the spectrum shows the UVB, the green the VIS, and the red the NIR data in units of 10^{-16} erg s^{-1} cm^{-2}. No correction for telluric lines has been applied.

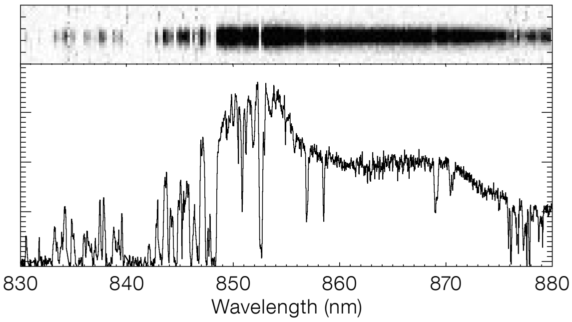


Figure 4a. Part of the extracted visual arm spectrum of the $z = 5.99$ SDSS QSO J130608.26+035626.3, encompassing the region of the Lyman-α emission. The upper panel shows the 2D, sky-subtracted, rectified and merged spectrum, the lower panel the corresponding 1D spectrum. The total integration time consisted of three 1800-s exposures nodded along the slit. The resolution is 8800.

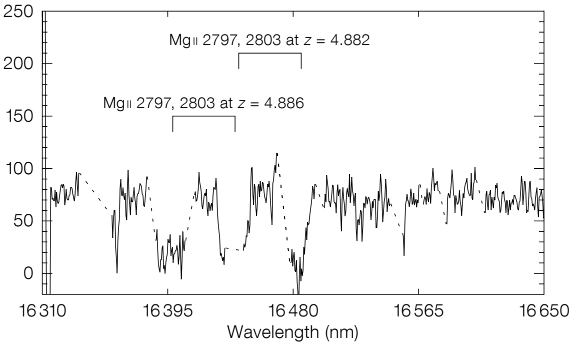


Figure 4b. A section of the *H*-band spectrum of the SDSS QSO J130608.26+035626.3, from the same integration detailed in Figure 4a. It shows a region with the highest redshift Mg II absorption systems as identified by Jiang et al. (2007). The resolution is 5600, or about eight times better than that of the discovery paper, permitting the measurement of column densities. The parts of the spectrum that have been interpolated at the position of strong OH sky lines are shown by a dotted line.

lution of up to 8000. This is illustrated in Figures 4a and b.

Acknowledgements

Without the X-shooter consortium, this new capability of the VLT would not have happened. We would like to acknowledge their expert and dedicated effort. We would also like to thank Jens Hjorth, Max Pettini and Vasily Belukurov for suggesting the test observations which are presented in this article.

References

Belokurov, V. et al. 2007, ApJL, 671, L9
D'Odorico, S. 2008, The Messenger, 134, 12
Jiang, H. et al. 2007, ApJ, 134, 1150
Pettini, M. 2009, arXiv0909.3301v1
Vernet, J. et al. 2007, The Messenger, 130, 5

Links

[1] http://www.eso.org/sci/facilities/paranal/instruments/xshooter
[2] http://www.eso.org/sci/activities/vltsv/xshootersv/
[3] http://www.ast.cam.ac.uk/research/cassowary/

ALMA First Fringes at 5000 m Altitude

The first two fully equipped ALMA antennas were transported to the ALMA Operations Site (AOS) at 5000 m altitude in September and October 2009 as planned. Figure 1 shows one of the antennas on its way to the AOS. After single dish functional tests, the two antennas were connected together (see Figure 2) as an interferometer using the ALMA production components previously installed inside the AOS Technical Building on Chajnantor at 5000 m. On 1, 2 and 5 November 2009, stable fringes were detected on the 160 m baseline at 3 mm, 1.3 mm and 0.85 mm. Figure 3 shows the amplitude and phase measured for the source 0538-440 at a frequency of 235.5 GHz and Figure 4 for the extragalactic radio source 3C454.3 at 345.8 GHz. The two-antenna array was remotely controlled from the Operations Support Facility (OSF) Technical Building at 2900 m altitude. In the near future further antennas will be added to the array in preparation for the start of early science operations in 2011.

More details at http://www.eso.org/public/events/announcements/aos_interferometer/.


Credit: ALMA (ESO/NAOJ/NRAO), A. Quintana/J. Olivares (ALMA)

Figure 2 (above). Fringes were obtained between these two antennas at the 5000 m ALMA Operations Site.

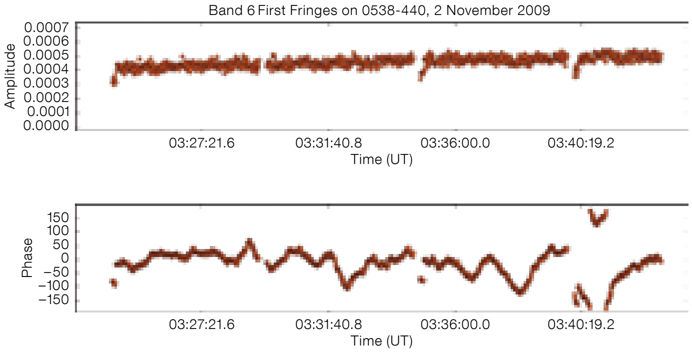


Figure 3 (left). Fringes at 235.5 GHz (ALMA Band 6) — amplitude and phase measured for the radio source 0538-440.

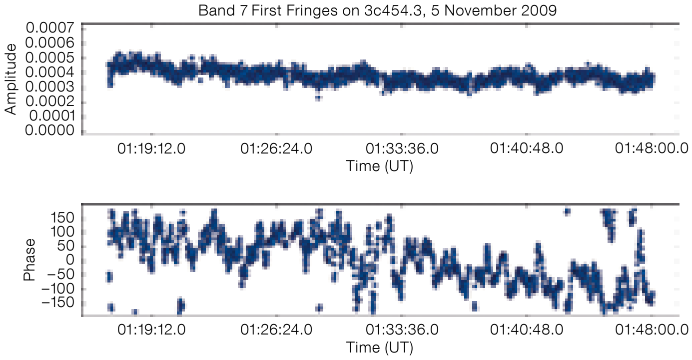


Figure 4. Fringes at 345.8 GHz (ALMA Band 7) — amplitude and phase measured for the radio galaxy 3C454.3.


Credit: ALMA (ESO/NAOJ/NRAO)

Figure 1. The transporter Otto is shown carrying one of the antennas from the OSF to the AOS. See Kraus et al. 2007 (*The Messenger*, 132, 23) for more information on the ALMA transporters.

A Tenth Birthday Present for UVES: A CCD Upgrade of the Red Arm

Jonathan Smoker[1]
Nicolas Haddad[1]
Olaf Iwert[1]
Sebastian Deiries[1]
Andrea Modigliani[1]
Suzanna Randall[1]
Sandro D’Odorico[1]
Gaël James[1]
Gaspare Lo Curto[1]
Pascal Robert[1]
Luca Pasquini[1]
Mark Downing[1]
Cédric Ledoux[1]
Christophe Martayan[1]
Thomas Dall[1]
Jakob Vinther[1]
Claudio Melo[1]
Andrew Fox[1]
John Pritchard[1]
Dietrich Baade[1]
Hans Dekker[1]

[1] ESO

During July 2009, a new MIT CCD, Zeus (previously part of the EMMI spectrograph), was installed in UVES to replace Nigel, the high-wavelength part of the red CCD mosaic. The main characteristics of Zeus are reported.

The Ultraviolet and Visual Echelle Spectrograph[1] (UVES) is the VLT’s high resolution optical spectrograph located at the Nasmyth B focus of the VLT Unit Telescope 2 (Kueyen). It is a cross-dispersed echelle spectrograph designed to operate with high efficiency from the atmospheric cut-off at 300 nm to the long-wavelength limit of the CCD detectors (about 1100 nm). The maximum resolution is 80000 and 110000 in the blue and red arms respectively (for details, see Dekker et al., 2000). The instrument was installed at the Paranal Observatory in 1999. The red arm detector consisted of a mosaic of an EEV CCD (named Sting) at lower wavelengths and an MIT/LL CCD (called Nigel) at higher wavelengths. The latter was the first device from Massachusetts Institute of Technology Lincoln Laboratories (MIT/LL) to become available to ESO via a best effort development programme led by the University of Hawaii. The next generation of MIT/LL CCDs that ESO received and installed (for example for the ESO Multi-Mode Instrument [EMMI] and the FOcal Reducer and low dispersion Spectrograph [FORS2]), were of superior quality. Upgrading the CCD mosaic in UVES has long been on ESO’s agenda. The opportunity finally arose to carry it out with the decommissioning of EMMI and the availability of an MIT/LL CCD (named Zeus) from that instrument. Ten years after its installation, UVES is still an instrument very much in demand (it occupies fourth position in the list of most-requested VLT instruments). The installation of the new CCD significantly increases the performance at the red end of its spectral range, which is interesting for both stellar and extragalactic work.

Readout Mode	Gain Zeus : Nigel (Electrons per ADU)	Readout Noise Zeus : Nigel (Electrons rms)
225 kHz, 1 × 1, low gain	1.41 : 1.50	3.7 : 3.8
225 kHz, 1 × 2, low gain	1.41 : 1.50	3.7 : 3.8
625 kHz, 1 × 1, low gain	1.41 : 1.50	4.7 : 4.9
50 kHz, 2 × 2, high gain	0.46 : 0.57	2.1 : 3.4

Table 1. Common readout modes for MIT/LL CCD Zeus compared with Nigel. The saturation level is now ~ 65000 ADUs compared with ~ 45000 ADUs for Nigel.

Characteristics of Zeus

Zeus is a deep depletion 2k × 4k CCD (MIT serial number 4-10-2), with pixel size of 15 μm and nominal thickness of 40 μm, compared with the old CCD Nigel, which had a thickness of 20 μm. For the replacement of Nigel, the UVES red cryostat was shipped to Garching and hence only the blue arm of UVES was available between 1 May and 15 July 2009. In Garching the quantum efficiency (QE) of the old mosaic was measured, Nigel was replaced by Zeus, and the QE of the new mosaic obtained. The readout modes are the same as previously offered and the most commonly used ones are listed in Table 1.

Due to variation in the packaging of the CCDs, the gaps between the two parts of the mosaic are now ~1250 μm at the bottom, close to the readout register, and ~1470 μm at the top. This introduces tilts in the dispersion direction of arc or sky lines of +0.35 pixels for the EEV and −0.05 pixels for the MIT, when a 10-arcsecond-long slit is used. The spectral format has also slightly changed, requiring upgrades to the exposure time calculator and UVES pipeline. Versions 4.4.7 and higher of the pipeline will reduce both old and new mosaic observations.

The cosmetics of Zeus are excellent. The most obvious defects are three bad columns in the 50 kHz, 2 × 2 high gain (HG) readout mode with peak values of between 1 and 50 ADU above the bias level and a glow of about 10 ADU peak visible in the first 200 pixels in 625 kHz, 1 × 1 low gain (LG) and 50 kHz, 2 × 2, HG. The MIT/LL CCD is linear to better than 0.7 % up to ~ 55000 ADU in 50 kHz, 2 × 2, HG and 225 kHz, 1 × 1, LG, with a saturation level of ~ 65000 ADU compared with ~ 45000 ADU for Nigel.

Owing to the fact that Zeus is a thick CCD, the fringing is much reduced compared with Nigel. Figure 1 shows a comparison of the extracted spectrum of a B-type star without flatfielding for Nigel and Zeus.

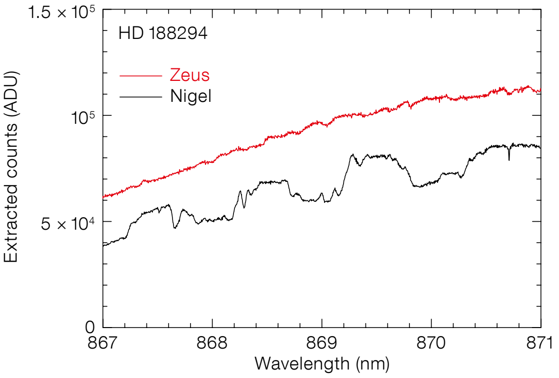


Figure 1. Part of the spectrum of the same fast-rotating star HD 188294 obtained with Nigel and Zeus. The greatly reduced fringing with Zeus is apparent. No flatfielding has been performed.

The QE for Zeus was measured both in the laboratory and on-sky by the use of standard stars. The efficiency of Zeus is approximately 84 % at 800 nm, 64 % at 900 nm and 18 % at 1 µm. Figure 2 shows the ratio of the Zeus/Nigel QEs. Between ~ 500–700 nm the efficiencies of the two CCDs are very similar, however redwards of 700 nm there is a steady increase in throughput, reaching a factor of ~ 1.6 at the wavelength of the calcium triplet at 860 nm and increasing to a factor of ~ 2 at 900 nm.

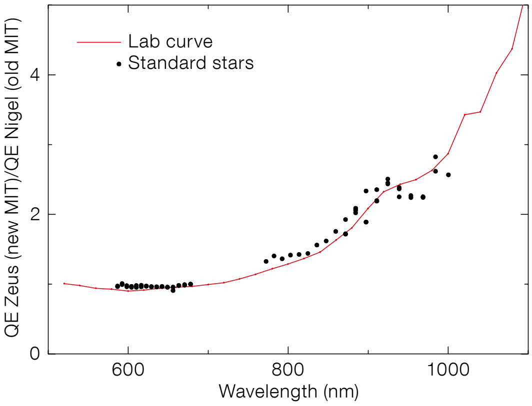


Figure 2. Ratio of quantum efficiencies of Zeus and Nigel derived from laboratory measurements and standard stars.

Although the move to the thick CCD has brought enormous benefits in terms of reduced fringing and increased QE, there is a (small) price to pay. The first issue is a higher cosmic ray count, which has increased by ~ 70 % with respect to the value in Nigel. A cosmic-ray removal test using *lacosmic* in IRAF found, in 3600 s of integration time, that ~ 0.27 % of pixels were affected by cosmic rays. The second issue is increased remanence after oversaturation caused by strong argon lines in the ThAr arc calibrations redward of ~ 660 nm. These can last for several hours and the pre-existing policy of not allowing such attached calibrations at night during service mode will be strictly enforced. The Paranal Instrumentation team, in cooperation with the Optical Detector Team Garching, is investigating the possibility of mitigating this problem by using a special readout mode to get rid of the remanence before the next science or calibration image.

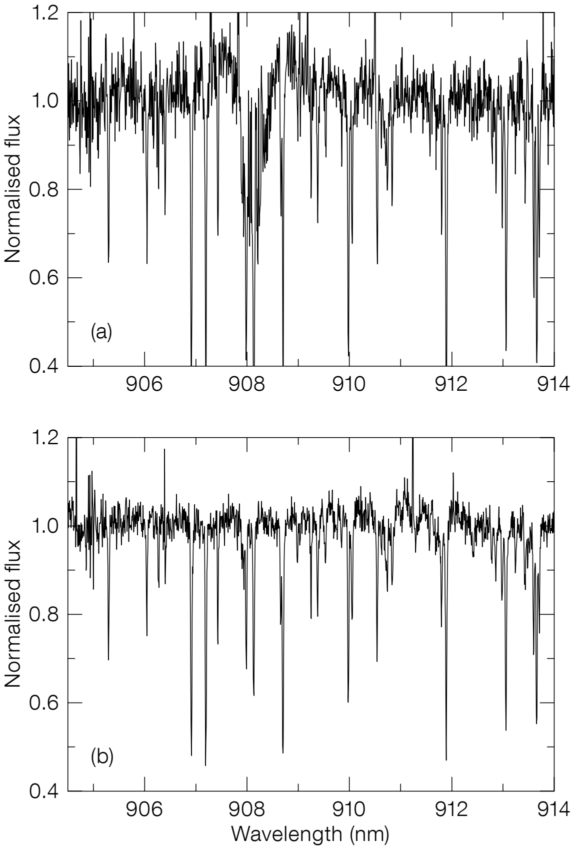


Figure 3. (a) Exposure of 4500 s with a 0.9-arcsecond slit towards the quasar QSO 1331+1704 with the old CCD mosaic from 904.5–914 nm. (b) A repeated observation with the same exposure time, but with the new mosaic. The narrow telluric lines were weaker in the later observations.

Zeus — on-sky tests

A number of on-sky test exposures were taken of fast-rotating stars previously observed with Nigel in the Paranal Observatory Project (Bagnulo et al., 2003). All data are publicly available in the ESO archive[2]. The extracted profiles and spectral resolution are similar in Nigel and Zeus, indicating little change in the point spread function before and after the upgrade.

Additionally, the quasar QSO 1331+1704 was observed. This quasar had previous observations from the first UVES commissioning. Figure 3 shows a comparison of the old and new observations at a wavelength of around 910 nm with equal exposure times. The improvement in the signal-to-noise ratio of the spectrum is immediately apparent. We note that the EEV CCD spectra (bluest part of the red mosaic) for the two epochs are very similar, indicating that the improvement is not due to better observing conditions, but to the new CCD.

In conclusion, the on-sky tests confirm the laboratory measurements and indicate that the replacement of the CCD has lived up to expectations, enhancing the longest wavelength data from UVES.

References

Bagnulo, S. et al. 2003, The Messenger, 114, 10
Dekker, H. et al. 2000, SPIE, 4008, 534

Links

[1] UVES: http://www.eso.org/sci/facilities/paranal/instruments/uves/
[2] ESO archive: http://archive.eso.org/eso/eso_archive_main.html

ISAAC Moved to a New Home

Linda Schmidtobreick[1]
Pedro Mardones[1]
Roberto Castillo[1]

[1] ESO

In August 2009, ISAAC was relocated from UT1 to UT3 to adjust the difference in the pressure factor of the two telescopes. The move went more smoothly than expected and the instrument was delivered in a very good state. A short report on the event is presented.

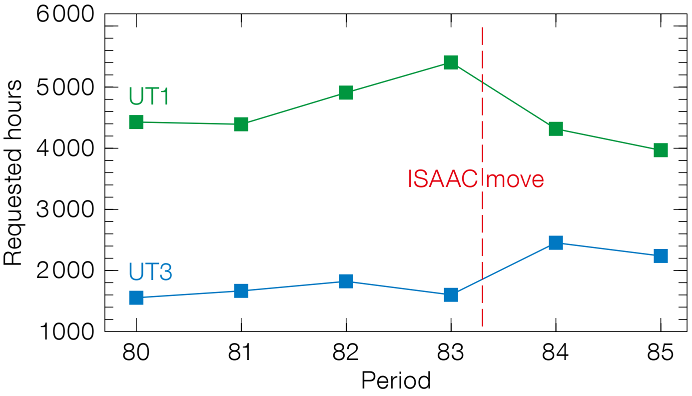


Figure 1. The number of hours requested for VLT UT1 and UT3 in recent observing periods (since October 2007).

ISAAC (Infrared Spectrometer And Array Camera) was one of the first instruments to be operated on Paranal and used to be located at the Nasmyth B focus of the VLT Unit Telescope 1 (UT1). It is still highly in demand, as are the other UT1 instruments, FORS2 and CRIRES, and so the requested number of hours on UT1 reached a record value of 5405 in Period 83. In contrast, UT3 was in rather low demand, as can be seen from the statistics in Figure 1. It was hence proposed that ISAAC should be relocated to UT3 to balance the pressure factors on the two telescopes better, and after an initial feasibility check the decision was made in favour of the move.

Planning started with the involvement of the Instrument Operation Team and various engineering groups in Paranal and Garching, but it was not at all clear if the move would go smoothly. One major problem that was anticipated was the retrieval of the co-rotator unit. This is the part that connects the instrument to the control electronics cabinets. It is responsible for keeping the cables and hoses untwisted when the instrument rotates in order to compensate for the rotation of the image field. This co-rotator unit was attached in a way that seemed to make it impossible to remove simply. Instead, plans were made for a complete dismantling of this unit and subsequent re-assembly at UT3. It seemed like sheer luck that on the day when ISAAC was taken off, it was found that the co-rotator unit could be removed as a whole. With a bit of tilting and pushing it was actually possible to remove it and hence a full week of work was saved and a great weight was lifted from the minds of everyone involved. A good team spirit and the dedication and vigilance of all the people involved resulted in a swift and successful conclusion of the work. Two weeks ahead of schedule, ISAAC was attached to UT3, the Hawaii detector cleaned, all technical functions tested, and the instrument handed over to the instrument scientists for the re-commissioning.

All tests were performed without encountering major problems, but there were some positive surprises instead. The big flakes on the Hawaii detector that had previously been interfering with observations had disappeared; hence all restrictions concerning offsets, nod-throw and jittering boxes could be removed. The image quality seems to have improved, i.e. the elongation of point source images is now considerably reduced. Four weeks after the instrument was taken off UT1, the first science observations were made with ISAAC: a time-critical transient of a planet was monitored in the fast photometry mode. All in all, we consider the move a complete success, not least because the original motive, the adjustment of the pressure factors, was achieved as well, as the statistics in Figure 1 show.

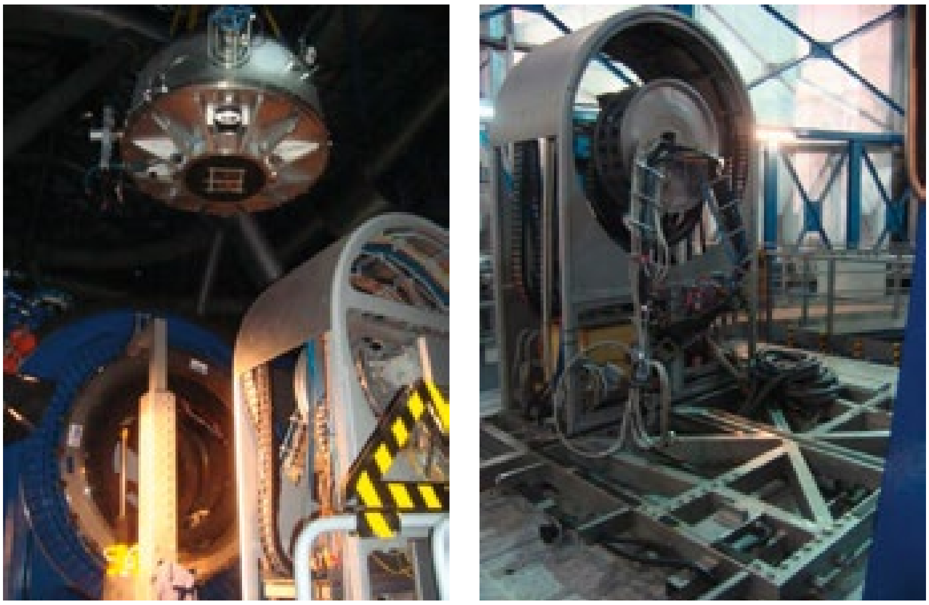


Figure 2. ISAAC, the silver round box in the upper part of the left image, is being taken out from its place at UT1. The right photo shows the co-rotator unit.

A Sneak Preview of the E-ELT Design Reference Science Plan Questionnaire Results

Markus Kissler-Patig[1]
Aybüke Küpcü Yoldaş[1]
Jochen Liske[1]

[1] ESO

The European Extremely Large Telescope is in its detailed design phase until the end of 2010. During this period, the telescope design is being consolidated and instrument and operation concepts are being studied. The scientific users are feeding back requirements into the project in numerous ways. One of them, the Design Reference Science Plan, was an opportunity for the entire community to provide direct feedback to the project. Here, we summarise the first results from this study. The full report will appear in the first half of 2010.

As the detailed design phase of the European Extremely Large Telescope (E-ELT) progresses at a rapid pace, the scientific users are continuously injecting requirements into the project. The E-ELT Project includes a science office staffed by around ten researchers (the majority being post-docs, i.e. young future users of the facility), and it is continuously assisted on scientific issues by an external Science Working Group (SWG), established in early 2006, and comprising about 20 senior researchers from the community. A Design Reference Mission (DRM) was set up by the SWG and served as reference for about 20 high priority science cases that have been simulated in detail (the first reports are available on the project web pages[1]). The outcome of these science cases is being used to drive the telescope and instrument requirements.

However, a very broad, direct input from the community was missing until a year ago. This was the reason for launching the E-ELT Design Reference Science Plan (DRSP) at JENAM 2008 in Vienna. The DRSP is meant to be a large collection of science cases provided directly by the future users of the E-ELT. The DRSP aims at exploring the full range of science cases for which the E-ELT will be used. Ultimately, it will help to define the boundaries of the parameter space over which the E-ELT will operate. It will be used to guide the performance optimisation of the telescope, the prioritisation of the instruments, as well as to plan the science operations modes.

In order to collect input from the community efficiently, the DRSP was set up as a web questionnaire, guiding the users through the submission of a dummy proposal for the E-ELT. The questionnaire prompted for the science case (title, abstract, category, …), the identity of the authors (institute, stage of career, …) before going into the details of the targets, spatial requirements, spectral requirements, type of instrumentation required, operations requirements, synergies, etc. A detailed presentation of the questionnaire can be found in the contribution of Aybüke Küpcü Yoldaş to the Design Reference Mission Workshop 2009 (see Hook et al., 2009) and available on the E-ELT science web pages[2].

The questionnaire was available to the community from September 2008 until June 2009. During that period, 188 science cases were submitted by 157 principal investigators from 105 institutes across Europe. This well exceeded our goal of collecting at least 100 cases. The entries have been collected in a large database and are being analysed statistically. A report, with the analysis, as well as the entries for all those cases that agreed to publication, will be produced and published in the first half of 2010. Here, we provide a sneak preview of the first statistics.

Synopsis of questionnaire results

Proposals were received from all ESO member states. The UK, Germany and Spain feature prominently, followed by Italy and France. The distribution of questionnaire returns by ESO member state is detailed in Figure 1. The number of returns for ESO is partly inflated by the E-ELT Science Office, which, in addition, "submitted" all those DRM cases not already covered by the community. About two thirds of the PIs were faculty members, the other third being made up of postdoctoral researchers (see Figure 2 for the breakdown).

The proposals were classified in the four categories established for the ASTRONET Roadmap[3]. Three quarters of the proposals were shared between the categories, "How do galaxies form and evolve?" and "What is the origin and evolution of stars and planetary systems?" (see Figure 3 for the project categories and the distribution of the returns).

On the technical side, all instruments that are being currently studied in Phase A have been requested and almost all equally, with a slightly higher number of proposals for the only mid-infrared instrument (METIS), and a slightly lower one for the most specialised instrument: the planet-finder. The full breakdown by re-

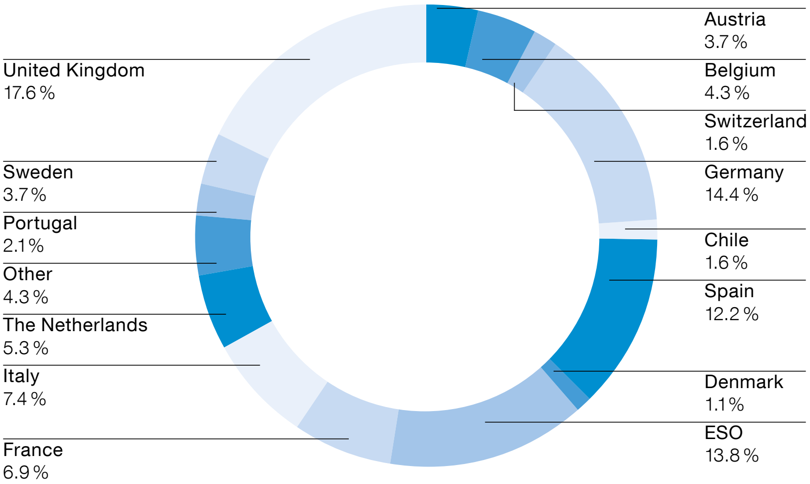


Figure 1. Pie chart showing the E-ELT DRSP questionnaire responses divided by ESO member state of the respondees.

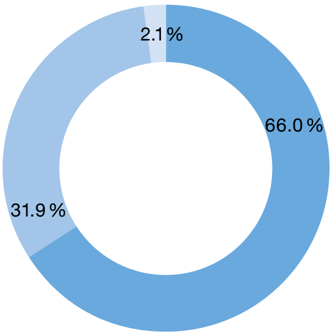


Figure 2. Distribution of academic status of respondees to the DRSP questionnaire.

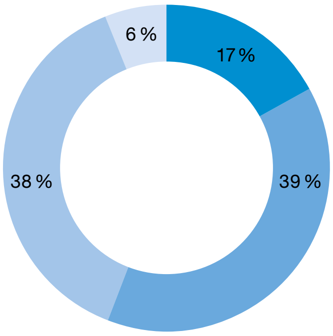


Figure 3. The division of the DRSP responses into four E-ELT Project categories.

quested instrument is given in Figure 4 and a list of the E-ELT instruments can be found in Spyromilio et al. (2008). Only a very few proposals requested capabilities not included in the current studies, confirming that the suite of instruments presently under investigation covers the entire needs of the community. In terms of spatial resolution, the largest share goes to diffraction-limited imaging.

Not surprisingly, given that the spatial resolution of the E-ELT exceeds that of the James Webb Space Telescope (JWST) by a factor of seven at infrared wavelengths, some ambitious science ideas were unleashed. However a quarter of the proposals requested seeing-limited image quality (see the summary of proposals by spatial resolution in Figure 5). This trend is to be expected, partly because, towards the blue end of the wavelength range, much better spatial resolution will not be available (at least in the first few years of operation), and partly because some high resolution spectroscopy cases did not require high spatial resolution, but rather are intending to use the E-ELT as a giant light-collecting bucket (its 1200 m^2 far exceeds the ~ 50 m^2 of a single VLT Unit Telescope). The field of view selectable in the questionnaire ranged from 1 × 1 arcseconds to 10 × 10 arcminutes and the distribution of the requests is shown in Figure 6, with 85 % requesting 1 arcminute or less, and 60 % requesting a field of view of 1 arcminute or less.

The range of requested spectral resolutions is very wide, covering from R ~ 100 to R > 100 000. About a quarter of the proposals requested broad- or narrowband imaging. Peaks are seen in the requested spectral resolution near the "standard" near-infrared resolutions

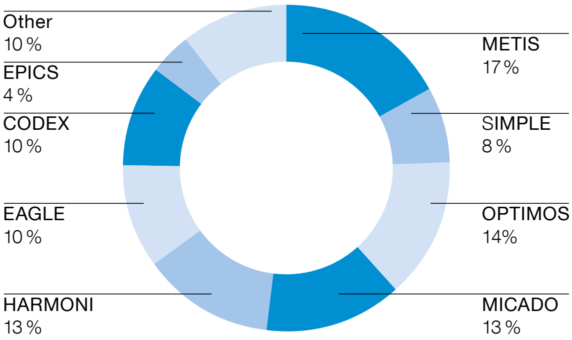
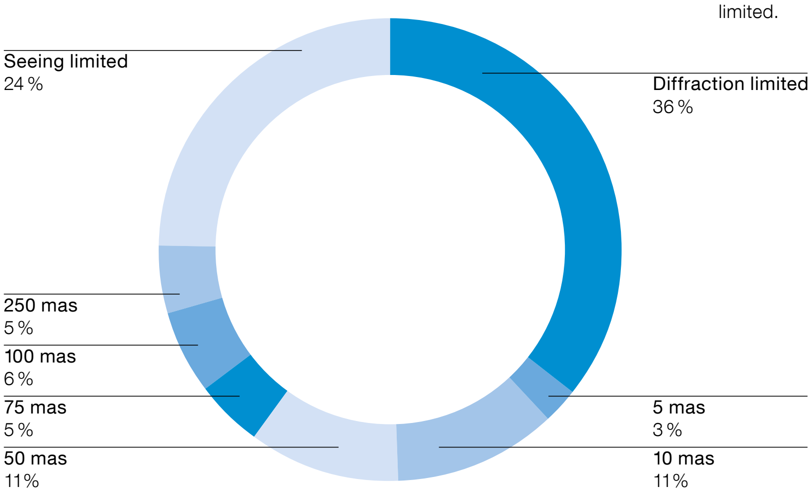


Figure 4. Breakdown of responses to the DRSP questionnaire by the eight E-ELT proposed instruments and an "other" instrumentation category.

Figure 5 (below). The spatial resolution in milliarcseconds (mas) of the proposed DRSP projects broken down into diffraction-limited, six size bins and seeing-limited.



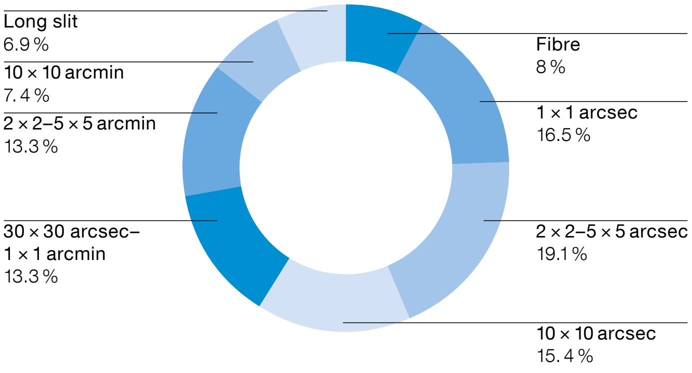


Figure 6. Distribution of proposed E-ELT observations by field of view (six categories) and including fibre and long slit.

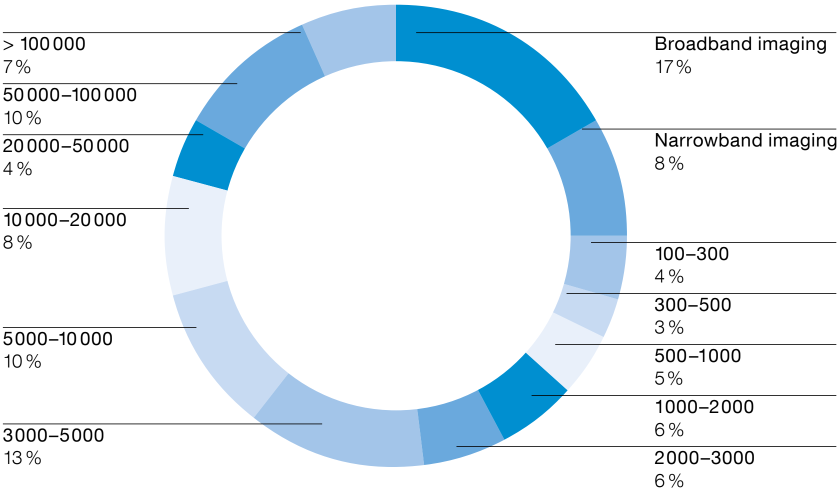


Figure 7. Pie chart of the requested spectral resolution for E-ELT DRSP proposals divided into broadband imaging, narrowband imaging and eleven ranges.

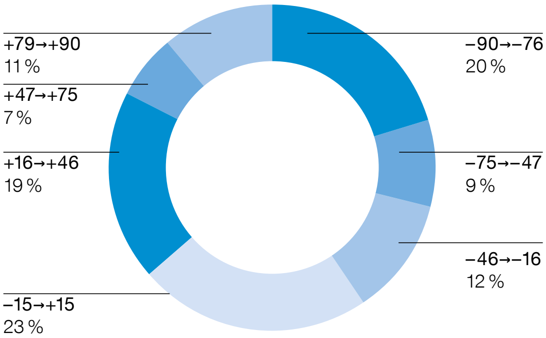


Figure 8. Distribution of requested declinations for the targets from the E-ELT DRSP questionnaires.

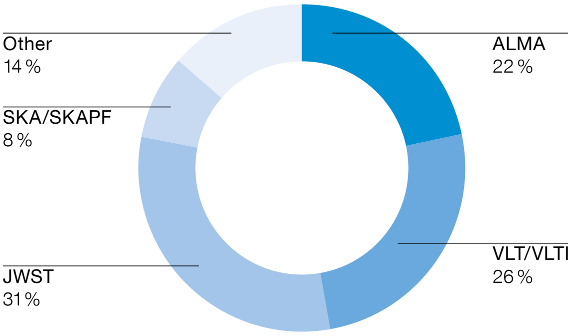


Figure 9. The current and future facilities with which the proposed E-ELT DRSP observations have a synergy.

(3000–10 000) and above $R \sim 50\,000$ (see Figure 7).

The targets of the proposals have a very uniform distribution in right ascension. In terms of declination, targets in the southern hemisphere (declination < 15 degrees) prevail over the targets in the northern hemisphere (declination > –15 degrees), as is clear from Figure 8.

Finally, the authors were asked to indicate whether their proposal would work in synergy with another facility (Figure 9). More than a third of the proposals mentioned JWST, about a third mentioned the Atacama Large Millimeter/submillimeter Array (ALMA), and the next most mentioned facilities are the VLT/VLTI and the Square Kilometre Array (SKA) (incidentally all located in the southern hemisphere).

So far, the proposals have provided valuable feedback, strengthened some of the project requirements and guided the project on scientific issues. The project is extremely grateful to the community for their numerous inputs to the DRSP and thanks all those potential future users who have taken time to support the project through the DRSP.

References

Hook, I. et al. 2009, The Messenger, 137, 51
Spyromilio, J. et al. 2008, The Messenger, 133, 1

Links

[1] E-ELT DRM Science Cases: http://www.eso.org/sci/facilities/eelt/science/drm/cases.htm
[2] E-ELT Design Reference Missions and Science Plan workshop proceedings: http://www.eso.org/sci/facilities/eelt/science/drm/workshop09/
[3] ASTRONET Roadmap: http://www.astronet-eu.org

A colour image of the southern H II region RCW 38 taken with the MPG/ESO 2.2-m telescope and the Wide Field Imager. Exposures in *B*, *V*, *R* and H-alpha filters were combined to form this colour image. RCW 38 is situated at a distance of 1.7 kpc and is a young H II region. Recent VLT NACO observations have revealed an embedded young cluster in the core; see ESO Photo Release 29/09 for more details.

The Application of FORS1 Spectropolarimetry to the Investigation of Cool Solar-like Stars

Heidi Korhonen[1]
Swetlana Hubrig[2]
Zsolt Kővári[3]
Michael Weber[2]
Klaus Strassmeier[2]
Thomas Hackman[4]
Markus Wittkowski[1]

[1] ESO
[2] Astrophysical Institute Potsdam, Germany
[3] Konkoly Observatory, Budapest, Hungary
[4] Observatory, University of Helsinki, Finland

The low resolution spectropolarimetric observations obtained with FORS1 at the VLT have often been used for investigating magnetic fields in hot stars. Here we describe the first investigation of the magnetic field over the stellar rotation in a cool late-type star, FK Com, based on FORS1 spectropolarimetry. We measure the mean longitudinal magnetic field from nine circularly polarised spectra, and study its behaviour over the stellar rotation. The magnetic field measurements are compared to a simultaneous stellar surface temperature map obtained with Doppler imaging techniques. These observations reveal two cool spots on the surface, and indicate that the main cool region coincides with the maximum value of the mean longitudinal magnetic field. Additionally, only 0.25 in phase apart from the main spot, the secondary spot is located at a similar phase to the field minimum. The observations can be interpreted as two spots having different magnetic field polarities, implying that the starspot configuration on FK Com is similar to that observed in the Sun.

The solar surface shows a varying number of sunspots. Currently, during the longest and deepest solar activity minimum of the space age, these cooler patches of the solar surface are very rarely seen, whereas a few years ago, during the solar activity maximum, many spots were constantly visible. A century ago the magnetic origin of sunspots was discovered by Hale (1908), explaining why sunspots were dark. In a sunspot the magnetic field acts as a valve, hindering the normal heat transportation from the solar interior and forms an area with temperatures of approximately 2000 K less than that of the unspotted solar surface.

With current telescopes and instruments it is not possible to obtain direct, spatially resolved images of a stellar surface, except in the few special cases of nearby supergiants. In general, indirect methods have to be used for recording the surface structures on stars, and in most stars the magnetic activity is so low that it is impossible to obtain any spatial information on the starspots using present technology.

Doppler imaging (e.g., Vogt et al., 1987) is a method that can be used for the detailed mapping of stellar surface structures. If the stellar surface has a non-uniform temperature distribution, the radiation from different parts of the stellar surface will depend on the local temperature. This produces a distortion in the spectral line, and this distortion moves across the line profile as the star rotates. In Doppler imaging, high resolution, high signal-to-noise spectroscopic observations at different rotational phases are used to measure these distortions. The measurements from different rotational phases are combined to produce a map of the stellar surface temperature (such as shown in Figure 1).

The Doppler imaging studies have taught us that starspots on active stars are different from sunspots (for a review, see Strassmeier, 2009). Firstly, the starspots that can be resolved using Doppler imaging are much larger than sunspots, and are often even larger than the Sun. Also, sunspots occur close to the solar equator, usually within 35° of it, whereas the starspots can be located at much higher latitudes, even at the rotational poles. Figure 1 shows Doppler images of two magnetically active K giant primaries of RS CVn-type binaries, ζ Andromedae and IM Pegasus. The spectra used in the Doppler imaging have been obtained using the high resolution Ultraviolet and Visual Echelle Spectrograph (UVES) at the Kueyen Unit Telescope of the VLT. ζ And shows hints of a spot at the rotational pole and a belt of spots close to the equator. On IM Peg the activity concentrates at the middle latitudes. UVES spectra and Doppler imaging techniques have also been used for spatially resolving hot spots caused by accretion shocks on the rapidly rotating T Tauri-type star MN Lupi (Figure 2).

FK Com: an enigmatic prototype

FK Comae-type stars were first defined as a new group of stars in the early 1980s (Bopp & Stencel, 1981). They are magnet-

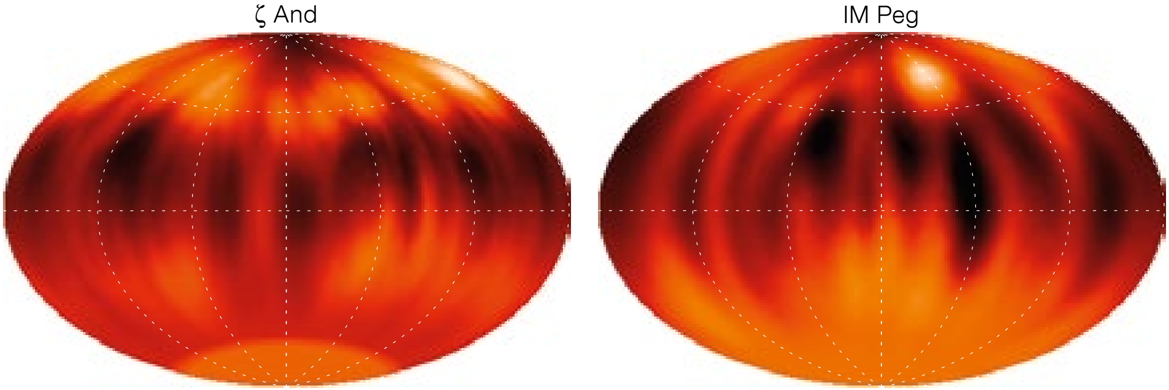


Figure 1. Examples of surface temperature maps of two K giants, ζ And and IM Peg, obtained from UVES spectra. The darker colour denotes lower temperature.

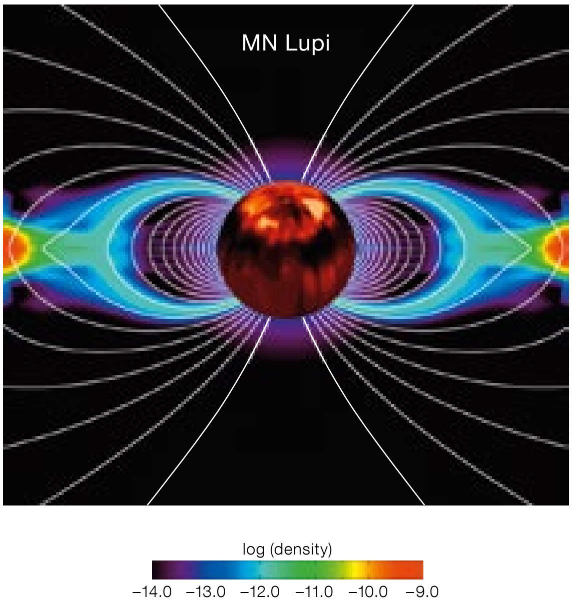


Figure 2. Doppler imaging results of MN Lupi together with numerical simulation results for the magnetic field and the density of the accretion disc. The bright high latitude spots seen in the Doppler image are not traditional starspots, but are thought to be the impact locations of the accreting material funnelled by the magnetic fields onto the star (from Strassmeier et al., 2005).

ically very active late-type giants with rotation periods of only a few days. Spectroscopic observations of these stars do not reveal any sign of the presence of a companion. The photometric and spectroscopic characteristics of FK Comae-type stars are very similar to those of the active RS CVn-type stars, e.g., ζ And and IM Peg described above. But the RS CVn-type stars are close binary systems in which tidal effects produce synchronous rotation, and therefore also rapid rotation, whereas FK Comae-type stars are thought to be single.

Among the late-type single giants, $v\sin i$ values larger than about 10 km/s are extremely rare. Thus, the anomalously rapid rotation of FK Comae-type stars demands an explanation. Three main theories have been put forward for their nature: post-main-sequence stars, whose rapid rotation is provided by core angular-momentum transport; coalescing binaries that accrete material from an unseen companion; or coalesced W UMa-type binaries. The last scenario is the most likely one to explain the observed characteristics of the FK Comae-type stars. If the coalescence is really the cause of the rapid rotation in these stars, it could have interesting ramifications for the internal structure and dynamo operation of these stars, and thus also on their magnetic activity.

FK Com itself, with its $v\sin i$ value of 160 km/s, is the fastest rotator of the FK Comae-type stars, and thus also the most active among them. The spectrum of FK Com is peculiar, showing Hα and Ca II H&K emission and variable Balmer line profiles. Its visual brightness varies by 0.1–0.3 magnitudes in the *V*-band with a period of approximately 2.4 days. These variations are interpreted as being caused by large starspots on the surface. Several surface temperature maps of FK Com have been obtained over the years using Doppler imaging techniques. These surface temperature maps mainly show high latitude spots with spot temperatures approximately 1000 K less than that of the unspotted surface (see, e.g., Korhonen et al., 2007).

An unexplained phenomenon

Long-term photometric observations show that the spots on FK Com tend to concentrate on two active longitudes which are about 180 degrees apart (Jetsu et al., 1993). These active longitudes alternate in strength and a switch in the longitude of the main spot activity occurs every few years. Figure 3 shows examples of *V*-band light curves from the 1990s showing one of these so-called flip-flop events. The cycle length of the flip-flop phenomenon in FK Com has been estimated to be 6.4 years (Korhonen et al., 2002), i.e., one flip-flop occurs on average every 3.2 years. After its discovery in FK Com, the flip-flop phenomenon has also been reported in RS CVn-type binaries and young solar-type stars, and it has been suggested that it also occurs in the Sun (see, e.g., Berdyugina & Tuominen, 1998; Usoskin et al., 2005).

The flip-flop phenomenon has strong implications for the dynamo theory. The behaviour of the global solar magnetic field can be explained by an axisymmetric mean-field dynamo without any longitudinal structure. In more rapidly rotating stars, the higher order non-axisymmetric modes become excited, forming two active regions that are 180° apart, i.e., equivalent to the two permanent active longitudes, as seen in many active stars. Not only is the magnetic configuration different in the axisymmetric and non-axisymmetric modes, but so are their oscillatory properties. The solar-type axisymmetric modes show clear cyclical behaviour, whereas the non-axisymmetric modes do not oscillate. To explain the flip-flop phenomenon, both properties — non-axisymmetric field configuration and oscillations — are needed. To constrain the dynamo models and to properly understand the mechanism behind the flip-flops, it is crucial to obtain measurements of the magnetic field behaviour at the two permanent active longitudes.

Spectropolarimetric investigation of FK Com

To investigate the magnetic field of FK Com, and especially the polarities of the active longitudes, we have obtained low resolution ($\lambda/\Delta\lambda = 2000$) spectropolarimetric observations using FORS1 with VLT Kueyen. The observations were obtained in April 2008 and show a distinct signal in the circular polarisation, as is seen in Figure 4. We have obtained nine separate observations at different rotational phases of FK Com. The mean longitudinal magnetic field, which is measured from the circularly polarised spectra, shows a clear variation over the stellar rotation. Figure 5 shows the magnetic field behaviour over the rotation, with the maximum value of the mean longitudinal field $<B_z> = 272 \pm 24$ G occurring at the phase 0.08 and the field

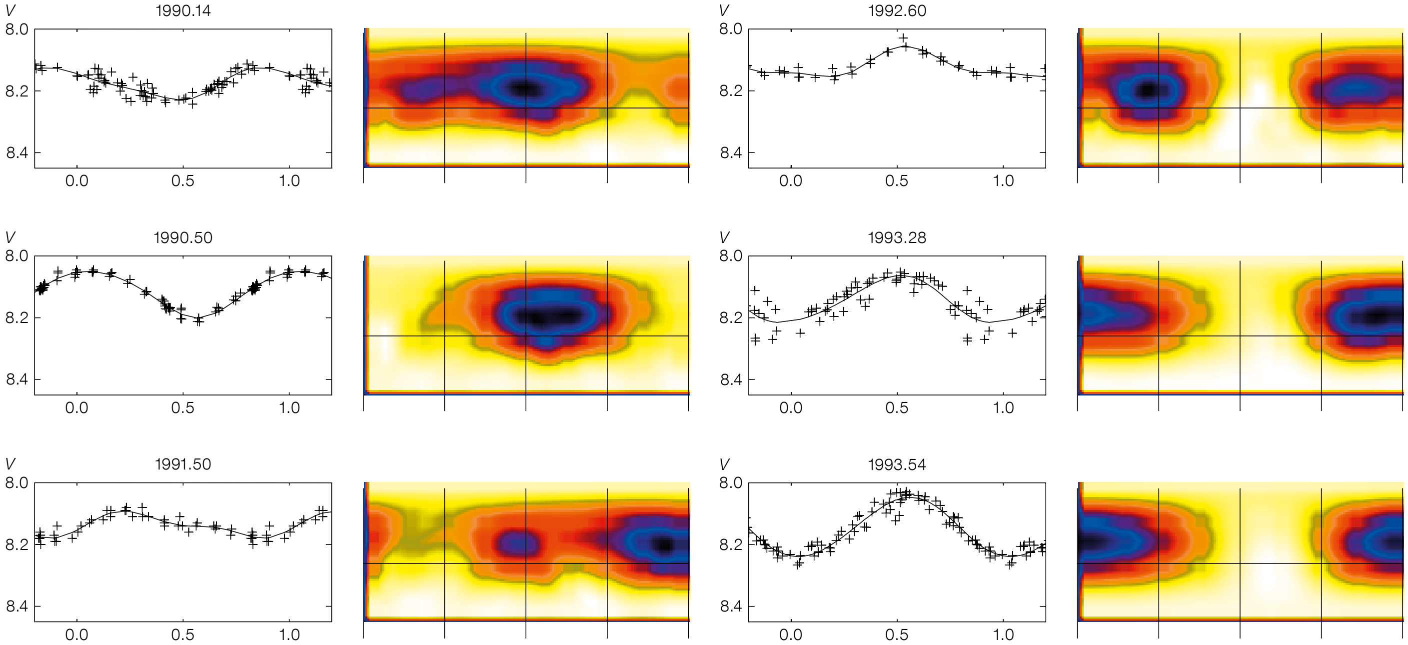


Figure 3. *V*-band light curves of FK Com and the spot filling factor maps obtained from them. The photometric observations are from 1990–1993. In the light curves the crosses are the observations and the solid line the result from the inversion. In the light-curve inversion maps the darker colour indicates a larger spot filling factor. Note that these maps are not Doppler images, and only give information on the longitudinal distribution of the spots. A flip-flop event is clearly seen in the data. In 1990 the spots concentrate around the phase 0.5 and in late 1991 change to a configuration with an active region at phase 0.0 (1.0) (from Korhonen et al., 2002).

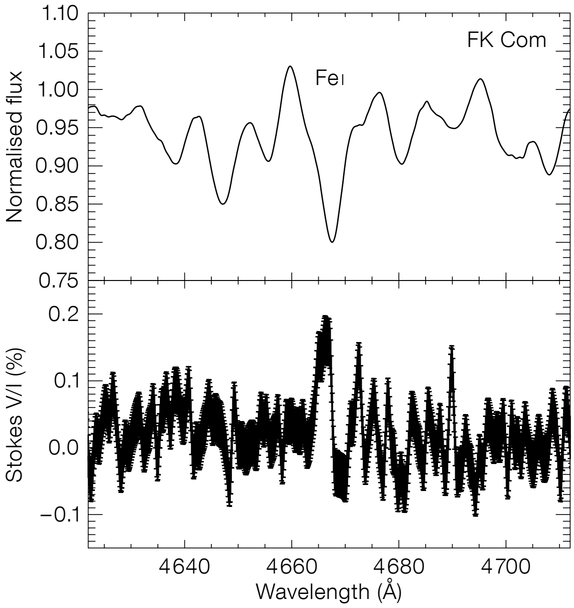
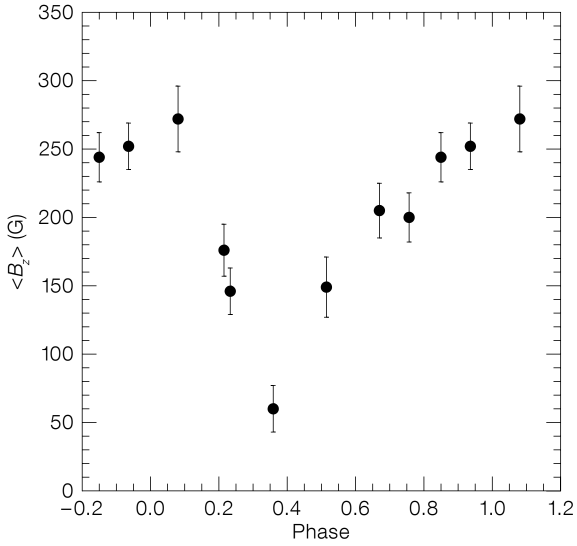


Figure 4 (left). FORS1 Stokes I (integral light) and Stokes V (circularly polarised) spectra of FK Com. In the plot the spectrum around the iron line, Fe 466.8 nm, is shown (from Korhonen et al., 2009).

Figure 5 (below). The mean longitudinal magnetic field measured from the FORS1 circularly polarised spectra plotted over the rotational phase.



minimum $<B_z>$ = 60 ± 17 G at the phase 0.36. None of the observations show negative magnetic field polarity.

To be able to compare the field behaviour to the starspot locations, we have also carried out contemporaneous high resolution spectroscopy using the STELLA robotic telescope of the Astrophysical Institute Potsdam and the Instituto de Astrofísica de Canarias, located on Tenerife. These spectra have been used to obtain a surface temperature map of FK Com simultaneous with the magnetic field measurements from the FOcal Reducer and low dispersion Spectrograph (FORS1). Figure 6 shows the surface temperature map in which the

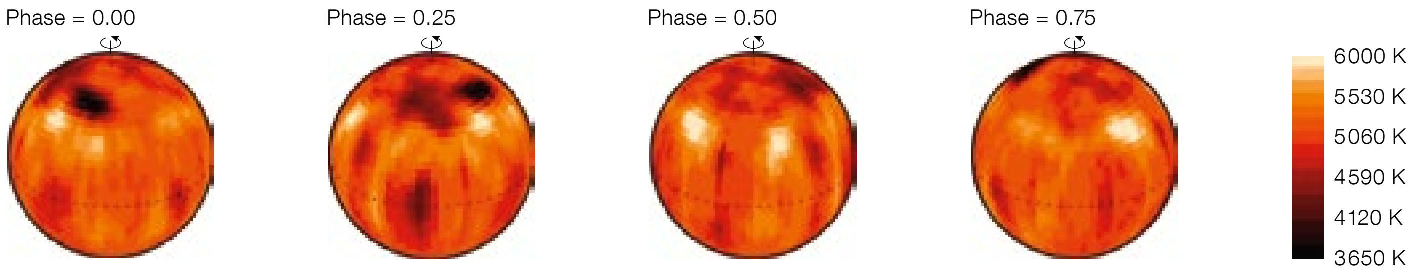


Figure 6. The surface temperature map of FK Com obtained from the STELLA data using the Doppler imaging technique. The stellar surface is shown at four different rotational phases, 0.25 in phase apart. The colour indicates the surface temperature.

coolest active region is seen at the phases 0.00–0.14 and a secondary active region at the phases 0.21–0.35. Both of the active regions occur at high latitude, but the weaker region, located at phases 0.21–0.35, also extends towards the equator.

The maximum of the longitudinal magnetic field occurs at the same rotational phase as the coolest spot seen in the surface temperature map. Also, the field minimum at the phase 0.36 coincides with the secondary active region seen on the surface at phases 0.21–0.35. It seems that the behaviour of the mean longitudinal magnetic field in FK Com is correlated with the starspots, and that the main spot on the surface, at phase 0.1, has a positive magnetic field polarity. The observed minimum, and also the very fast change from the maximum in the mean longitudinal magnetic field to the minimum, could be explained by the secondary active region having a negative magnetic field polarity. The negative field would partly cancel the positive field emerging in the dominant spot.

If the spot at the phase 0.1 does indeed have a different polarity from the one at phase 0.3, then this configuration closely resembles the one that is commonly observed in the Sun. Sunspots usually occur in pairs where the two components have different polarities. Also, in the Sun, the leading spot (the one in the pair that is first in the direction of rotation) is more compact, and the following one is more fragmented. In Doppler images the compact spot would be seen as a cooler spot and the fragmented one would have a higher average temperature, as is seen in the Doppler image of FK Com (Figure 6). In the solar case, the spots in a pair are connected by magnetic loops. The earlier X-ray observations of FK Com also hint at loops connecting two nearby spots (Drake et al., 2008), also indicating that the two spots on FK Com could have different spot polarities.

The low resolution FORS1 spectropolarimetric observations show some evidence that the two main spots on FK Com have different magnetic field polarities. However, these spots are only 0.25 in phase away from each other and have to be viewed as residing on the same active longitude. Thus, even though the FORS1 observations have provided an interesting view of the possible spot polarity configuration analogous to the solar case, they have not been able to answer the question on the active longitude polarities on FK Com. Partly this is due to the fact that during our observations the second active longitude did not show spots. One has to keep also in mind that the low spectral resolution observations do not provide a detailed insight into the magnetic surface structures. To answer the question on the spot polarities at the two permanent active longitudes properly, high resolution spectropolarimetric observations would be needed. Also, these high resolution observations should be carried out before and after a flip-flop event to study the possibility of the active longitudes changing polarity during the flip-flop, as predicted by some models (e.g., Tuominen et al., 2002).

Closing remarks

We have shown that the low resolution spectropolarimetry with FORS1 can also be used to investigate magnetic fields in cool stars, and not only for hot stars, as has previously been the case (see Hubrig et al., 2009). The recent change of polarimetric capabilities from FORS1 to FORS2, which has a more red-sensitive CCD, will be beneficial for studying the cooler, redder stars. Also, until now ESO has not had a high resolution spectrograph with polarimetric capabilities, which is needed for studying the stellar surface in greater detail. This situation will improve dramatically with the commissioning of the polarimetric mode of the HARPS high resolution spectrograph on La Silla. This facility will open a new frontier for the ESO community for studying stellar magnetic fields until the E-ELT comes online. A high precision spectropolarimeter on the E-ELT could address cosmic magnetism in many more objects than just the brightest and most prominent stars.

References

Berdyugina, S. V. & Tuominen, K. 1998, A&A, 36, 25
Bopp, B. W. & Stencel, R. E. 1981, ApJ, 247, L131
Drake, J. J. et al. 2008, ApJ, 679, 1522
Hale, G. E. 1908, ApJ, 28, 315
Hubrig, S. et al. 2009, The Messenger, 135, 21
Jetsu, L. et al. 1993, 278, 449
Korhonen, H. et al. 2002, A&A, 390, 179
Korhonen, H. et al. 2007, A&A, 476, 881
Korhonen, H. et al. 2009, MNRAS, 395, 282
Strassmeier, K. G. 2009, A&AR, 17, 251
Strassmeier, K. G. et al. 2005, A&A, 440, 1105
Tuominen, K. et al. 2002, AN, 323, 367
Usoskin, I. G. et al. 2005, A&A, 441, 347
Vogt, S. S. et al. 1987, ApJ, 321, 496

Neutron Star Astronomy at ESO: The VLT Decade

Roberto Mignani[1]

[1] Mullard Space Science Laboratory,
University College London,
United Kingdom

In this review I summarise some of the most important results obtained in ten years of VLT observations of isolated neutron stars. More general reviews are presented in Shearer (2008) and in Mignani (2009), to which the reader is referred for a complete reference list.

Forty years have gone by since the optical identification of the Crab pulsar (PSR B0531+21), and 25 isolated neutron stars (INSs) of different types have now been identified, including the classical rotation-powered pulsars[1]. ESO observations historically played a pivotal role in the optical studies of INSs (Mignani et al., 2000). Indeed, one can go as far as saying that neutron star optical astronomy developed thanks to the seminal work carried out with ESO telescopes. The ESO contribution naturally continued with the advent of the Very Large Telescope (VLT) in 1998. At that time, in response to a Call to the Community, my collaborators and I proposed ESO optical observations of INSs as a possible test case for the Science Verification of the VLT Unit Telescope 1 (UT1). Our proposal was accepted and the first INS in the VLT record was observed with the Test Camera on 17 August 1998. Our results were promptly published (Mignani et al., 1999) in a special issue of *Astronomy & Astrophysics Letters* dedicated to the UT1 Science Verification. Remarkably, ours was historically the first *submitted* publication based on a VLT observation. Thereafter, the VLT began to make its own contribution to the optical studies of INSs, very much as its predecessor, the New Technology Telescope (NTT), had in the previous decade, marking a new era in neutron star astronomy.

VLT observations of rotation-powered pulsars

As the first class of INSs detected in the optical, and the most numerous (Lorimer, 2009), rotation-powered pulsars (simply pulsars throughout this section) were the most natural targets for the VLT. In particular, thanks to its unprecedented collecting power, the VLT has allowed the first polarimetric and spectroscopic observations of pulsars fainter than $V \sim 22$ to be carried out.

Phase-averaged polarimetry of young pulsars (< 10 000 years old) was performed in 1999, as a part of the commissioning for the first FOcal Reducer and low dispersion Spectrograph (FORS1). These observations yielded the optical identification of PSR B1509-58 from the measurement of a ~ 5 % polarisation of its counterpart. Moreover, these observations allowed the phase-averaged polarisation of the Vela pulsar to be measured, the first measurement for this object, and PSR B0540-69 in the Large Magellanic Cloud (LMC). In particular, by comparing the VLT polarimetry data with high resolution optical and X-ray observations from the Hubble Space Telescope (HST) and Chandra, respectively, it was possible to correlate the map of the synchrotron emission from the supernova remnant (SNR) with its polarisation structure. Thus, polarisation measurements provide deep insights into the highly magnetised relativistic environment around pulsars and offer a unique test bed for neutron star magnetosphere models. Interestingly, the phase-averaged polarisation of the Vela and Crab pulsars are much lower than predicted by different models. Moreover, the FORS1 observations showed, for the first time, the existence of an apparent alignment between polarisation direction in the Vela pulsar, the axis of symmetry of the X-ray arcs and jets observed by Chandra, the pulsar proper motion, and its rotation axis (Figure 1). This alignment, also observed in the Crab pulsar, suggests a connection between the pulsar's magnetospheric activity and its dynamical interaction with the synchrotron nebula.

Spectroscopy of the Vela pulsar was performed for the first time with FORS1. Spectroscopy is crucial for the characterisation of pulsar optical spectra, which, in most cases, are from multiband photometry, often compiled from the literature, and thus highly inhomogeneous. The FORS1 observations showed that the Vela optical spectrum is characterised by a featureless power-law continuum, as expected from pure synchrotron radiation (e.g., Pacini & Salvati, 1983), confirming that the optical spectra of young pulsars are dominated by magnetospheric emission. FORS1 spectroscopy was also performed for PSR B0540-69, but the background from the surround-

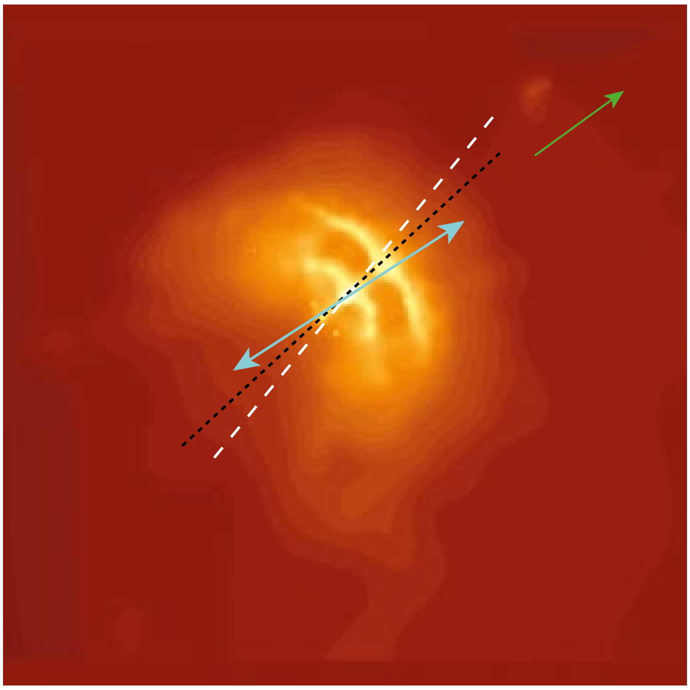


Figure 1. Chandra X-ray image of the Vela pulsar (centre) and its nebula. The white dashed and black dotted lines are the axis of symmetry of the nebula and the computed pulsar spin axis, while the green and light blue arrows are the pulsar proper motion and the polarisation direction, respectively (Mignani, 2009).

This photograph shows star trails through a complete night at Paranal including both dusk and dawn, 11 hours of total exposure. It should be "read" in the following way: the exposure starts with dusk visible to the right (west), is followed by the clockwise apparent rotation of the stars around the south pole and concludes with the dawn light to the left (east) of the image. During the exposure, the VLT telescopes are observing the night sky while the Sun continues its path below the horizon. The image was taken from the top of the Paranal meteo post.

Image courtesy and copyright Stéphane Guisard
(see www.astrosurf.com/sguisard).

ing, compact (4 arcseconds diameter) SNR did not allow a clean measurement to be obtained. The optical spectrum is more complex for middle-aged pulsars, like the ~ 100 000 year old PSR B0656+14. Indeed, the FORS1 optical spectrum shows the signatures of two different components: a power law, ascribed to synchrotron radiation, as in younger pulsars, and a blackbody, ascribed to cooling radiation from a fraction of the neutron star surface. Similar two-component spectra are observed in soft X-ray emission, which allows the study of spectral breaks in the synchrotron emission and the mapping of regions at different temperatures on the neutron star surface, offering a unique opportunity to investigate the neutron cooling process and the structure of the neutron star interior.

On the other hand, timing observations of pulsars have rarely been performed. Although the FORS2 high time resolution (HIT) mode allows timing observations, its time resolution (2.3–600 ms) is too low to sample the light curve of fast-spinning pulsars like the Crab (33 ms) adequately, which still remains the only pulsar observed (see ESO Press Release 40/99). Indeed, in most cases, timing observations of INSs have been performed with guest instruments like ULTRACAM.

Observations with the Infrared Spectrometer And Array Camera (ISAAC) have been important in the study of pulsar emission in the near-infrared (NIR). *JHK*-band photometry of the Vela pulsar clearly showed that the IR emission is also of synchrotron origin, as in the optical, with the spectral fluxes nicely fitting the extrapolation of the FORS1 optical spectrum. This is at variance with the younger Crab pulsar, for which ISAAC multiband photometry showed evidence of a unique spectral break in its optical-to-IR synchrotron emission, possibly attributed to synchrotron self-absorption. ISAAC and NAOS–CONICA (NACO) observations allowed the IR spectrum of the mysterious emission knot ~ 0.4 arcseconds southeast of the Crab pulsar, whose connection with the pulsar is unclear, to be studied for the first time. The anti-correlation between the power-law spectra of the two objects, however, suggests that the knot is not produced by the pulsar.

One of the most interesting VLT contributions in neutron star astronomy has been in the study of the long-term evolution of their optical luminosity. According to the magnetic dipole model, the luminosity of pulsars is expected to decrease due to the neutron star spin down, an effect originally predicted by Pacini & Salvati (1983) in the optical band, but never convincingly measured so far. A first tentative measurement of this "secular decrease" was obtained with the NTT (8 ± 4 thousandths of magnitude per year). More recently, a new measurement performed with FORS1 data (2.9 ± 1.6 thousandths of magnitude per year) narrowed the magnitude of the effect by 60 %, thus imposing tighter constraints on theoretical models.

Apart from studying optically identified pulsars, the VLT competed with the HST to obtain new identifications, performing deep observations for several of them with both FORS1 and FORS2. In addition to PSR B1509-58, the VLT identified the optical counterparts of two much older pulsars: PSR B1133+16 (5 million years old) and PSR J0108-1431 (166 million years old) and confirmed the proposed identification of PSR B0950+08 (17.3 million years old) through multiband photometry. The optical counterpart to PSR B1133+16 was discovered from FORS2 observations performed in 2003, which detected a dim source (B = 28.1 mag) at the pulsar radio position. A possible counterpart (U = 26.4 mag) to PSR J0108-1431 was indeed spotted in 2001 by FORS1 observations, barely detected against the halo of a nearby elliptical galaxy (see Figure 2), but it was not recognised as such until its proper motion was measured by Chandra. These observations showed that the position of the candidate was consistent with the backward proper motion extrapolation of the pulsar and, thus confirmed its identification *a posteriori*. Optical/UV studies of old pulsars (> 100 million years) are crucial to understanding the latest stages of neutron star thermal evolution. Indeed, these old neutron stars are expected to have cooled to temperatures of ~ 10 000–100 000 K, making their surfaces too cold for thermal emission to be detectable in the X-ray band, but still hot enough to be detectable in the optical/UV. The detection of such radiation is thus the only way to test the long-term predictions of cooling models and to investigate possible reheating mechanisms in the neutron star interior, which are more efficient in the optical/UV.

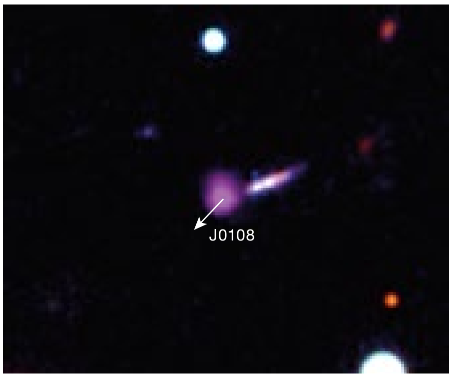


Figure 2. Composite FORS1 (red, blue and white) and Chandra (purple) image of the PSR J0108-1431 field. In the X-ray image, the pulsar is the source at the centre, in the optical it is the dim source north of the elliptical galaxy. The offset is due to the pulsar proper motion (arrow) between the FORS1 (August 2001) and Chandra (January 2007) observations (Chandra Press Release 26/02/2009).

VLT observations of other types of INSs

Rotation-powered pulsars are only one example of the many INS types that have been observed by the VLT. Indeed, high energy observations unveiled the existence of several INS types that differ from rotation-powered pulsars in many respects. First of all, they are typically radio-silent, while the latter are radio-loud. Moreover, their multiwavelength emission is not powered by the star rotation, but by other mechanisms, not yet completely understood. VLT observations of these INSs have contributed enormously to the study of their nature and to the determination of the characteristics that distinguish them from rotation-powered pulsars.

ROSAT All Sky Survey observations in 1990 discovered seven X-ray sources, with dim (at least by the X-ray astronomy standards of the early 1990s) and purely thermal X-ray emission (blackbody temperatures kT ~ 50–100 eV) and with very high X-ray-to-optical flux ratios. These sources were associated with X-ray emitting INSs at a distance of < 500 pc, as the low X-ray absorption (hydrogen column densities $N_H \sim 10^{20}$ cm^{-2}) suggested, and promptly nicknamed X-ray Dim INSs, or XDINSs (Haberl, 2007). The lack of magnetospheric X-ray emission and of associated SNRs suggested that the XDINSs were at least a few million years old, perhaps old enough (> 500 million years old) to be once-active radio pulsars. The origin of their thermal X-ray emission was unclear, however. Depending on the actual XDINS age, it might have originated either from a still cooling neutron star surface, or from a neutron star surface re-heated by accretion from the interstellar medium (ISM).

VLT observations were crucial in this respect. The NTT identification of the optical counterpart to the XDINS RX J0720.4-3125 (B = 26.7 mag) paved the way for the measurement of its proper motion with the VLT. This yielded the neutron star space velocity, which, for the most likely values of the distance, turned out to be too high (> 100 km/s) to be consistent with ISM accretion. A similar conclusion, inferred from the HST proper motion measurement of RX J1856.5-3754, thus made XDINSs new targets to study neutron star cooling. The measurement of X-ray pulsations (3–12 s), likely from hot polar caps, hinted at a possible non-uniform temperature distribution on the neutron star surface, with the colder and larger regions observable in the optical, as in the case of the middle-aged rotation powered-pulsars. This helped to spur on the search for the optical counterparts of XDINS, both with HST and the VLT. Recently, FORS1 and FORS2 observations identified likely counterparts to RBS 1774 and to RX J0420.0-5022. Searches for XDINS in the NIR have been performed with ISAAC and with the Multi-conjugate Adaptive optics Demonstrator (MAD), but with negative results.

FORS1 optical spectroscopy of RX J1856.5-3754 and multiband photometry of RX J0720.4-3125 showed optical spectra closely following Rayleigh–Jeans, suggesting that their optical emission is thermal and, indeed, possibly coming from a colder and larger region on the neutron star surface. This might be true also for other XDINSs, although still unconfirmed (Mignani, 2009). Since the inferred XDINS rotational energy loss is too low (~ 10^{30} erg s^{-1}), however, it is unlikely that their optical emission is powered by the star rotation as in young radio pulsars. For RBS 1774, its relatively high optical flux may be related to the huge magnetic field (~ 10^{14} Gauss), inferred from the observation of an X-ray absorption feature. Confirmation of this interpretation, might establish a link between RBS 1774 and a family of much younger INSs: the magnetars.

Magnetars (of which about 15 are known to date) represent one of the most interesting INS families. They have spin periods of 1.5–12 s, longer than those of most rotation-powered pulsars, and period derivatives of 10^{-13}–10^{-10} s s^{-1}. For a pure magneto-dipolar spin down, this yields ages of only ~ 1000–10 000 years and magnetic fields of ~ 10^{14}–10^{15} Gauss, typically a factor of 10–100 higher than those of rotation-powered pulsars. Historically, magnetars were identified in two families of high energy sources (Mereghetti, 2008): the Soft Gamma-ray Repeaters (SGRs), first discovered in 1979 through their recurrent soft gamma-ray bursts, and the Anomalous X-ray Pulsars (AXPs), discovered in the 1980s through their persistent X-ray emission. SGRs and AXPs are likely linked by their extreme magnetic fields. According to the magnetar model, the torque from these extreme fields rapidly spins down the neutron star, while the field decay explains the persistent X-ray emission, much larger than can be accounted for by neutron star rotation; crustal fractures induced by the field drifting explain the X-/gamma-ray bursts. However, other models were developed in parallel, based on accretion from low-mass companion stars or from debris discs formed by the supernova explosion, which could at least explain the persistent X-ray emission. Depending on the accretion regime, a disc extending to the neutron star magnetosphere might contribute to its spin down, which would mean that the inferred magnetic field values would be overestimated. Thus, SGRs and AXPs would not be magnetars at all but more ordinary INSs.

Optical observations have obviously been crucial in testing different models. Unfortunately, the field crowding towards the Galactic Plane, where most magnetars reside, and the high interstellar extinction (up to $A_V \sim 30$) have only allowed high-resolution NIR NACO observations. Since magnetars are variable at high energies, their counterparts can be pinpointed by the detection of correlated IR variability. This was only possible through prompt, i.e. within a few hours or days, Target of Opportunity observations in response to triggers from high energy satellites. In this way, IR counterparts were identified for SGR 1806-20, and possibly SGR 1900+14, and for the AXPs 1E 1048.1-5937, XTE J1810-197, 1E 1540.0-5408 (Figure 3), and possibly also for 1E 1841-045, amounting to most of the magnetars identified in the NIR. These observations ruled out the presence of both a companion star and of

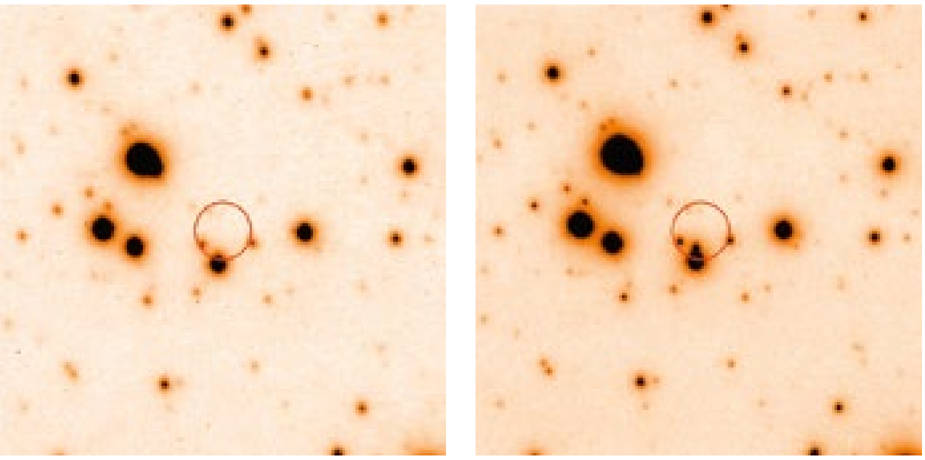


Figure 3. NACO *Ks*-band images (10 × 10 arcseconds) of the magnetar 1E 1540.0-5408 field taken in July 2007 (left) and in January 2009 (right). The variable object in the error circle (0.63 arcseconds) is the magnetar IR counterpart (Mignani, 2009).

a disc extending down to the magnetospheric boundary, thus supporting the magnetar model.

The origin of magnetar NIR emission, however, is still uncertain. Interestingly, the ratio between the magnetar NIR luminosity and the rotational energy loss is a factor of > 100 larger than for radio pulsars (Mignani, 2009), suggesting that it is not powered by rotation but, rather, by their larger magnetic fields (Figure 4). Alternatively, the IR luminosity could be due to reprocessing of the X-ray radiation in a passive disc, which might have been detected in the mid-IR by Spitzer around the AXPs 4U 0142+61 and 1E 2259+585. Determining the source of the magnetar IR emission would thus represent an important test of both the magnetar and supernova models. However the NACO phase-averaged upper limit on the polarisation of the AXPs 1E 1048.1-5937 and XTE J1810-197 is inconclusive (Israel et al., in preparation). At the same time, the detection of optical pulsations from the AXP 1E 1048.1-5937, obtained with ULTRACAM at the VLT did not yield conclusive evidence either. The disc reprocessing scenario, however, is incompatible with the uncorrelated IR-to-X-ray variability of the AXP XTE J1810-197.

IR observations might also help to clarify the link between magnetars and other INS types. In particular, the detection of transient radio emission from the AXPs XTE J1810-197 and 1E 1540.0-5408 suggests that they might be related to the recently discovered class of radio-transient INSs called Rotating Radio Transients, or RRATs (McLaughlin, 2009). These sources (about 20 known to date) feature extremely bright radio bursts lasting only 2–30 ms, which tend to repeat at intervals of minutes to hours. NACO observations pinpointed a possible counterpart to the RRAT J1819-1458 (Rea et al., submitted), whose IR emission fits the magnetar characteristics very well (see Figure 4) and might strengthen a possible link between the two INS classes.

The radio-silent INSs (about ten known to date) at the centre of young (~ 2000–40 000 year old) SNRs are very much at variance with magnetars. Originally discovered by the Einstein Observatory, more of these sources were discovered by ROSAT, while Chandra made the spectacular discovery of a new source at the centre of the Cas A SNR. The nature of these sources, also known as central compact objects, or CCOs (De Luca, 2008), is puzzling. Their association with young SNRs suggests that they are young INSs, but they show no evidence of magnetospheric activity, either in the form of power-law X-ray spectra or of pulsar wind nebulae as, for example, in the Crab pulsar. X-ray pulsations have been detected (0.1–0.4 s) with period derivatives $< 10^{-13}$ s s^{-1}, implying magnetic fields $< 5 \times 10^{11}$ Gauss, in just three cases for CCOs. CCOs might thus be neutron stars born spinning close to their present period and with very low magnetic fields, which might have accreted from a debris disc. Deep optical/IR observations of CCOs have been performed mainly with FORS1 and NACO, but no likely candidate counterparts have been found. NACO has identified a possible IR counterpart for the CCO in the Vela Jr. SNR, but its nature is as yet undetermined. Interestingly, the Vela Jr. CCO also features an optical nebulosity detected both in the *R*-band and at Hα which might be a possible bow-shock produced by the neutron star motion through the interstellar medium. Most puzzling of all, is the source in the RCW 103 SNR, which is very different from the other CCOs, featuring a six-hour X-ray period and spectacular long-term X-ray flux variations. It might be a magnetar, braked by a magnetic field $> 10^{15}$ Gauss, or a very rare example of a neutron star in a binary system born in a SNR. A search for correlated periodic or long-term X-ray and IR variability, however, did not pinpoint a likely counterpart, the upper limits being consistent with both a very low-mass (later than spectral type M5) star or with a debris disc.

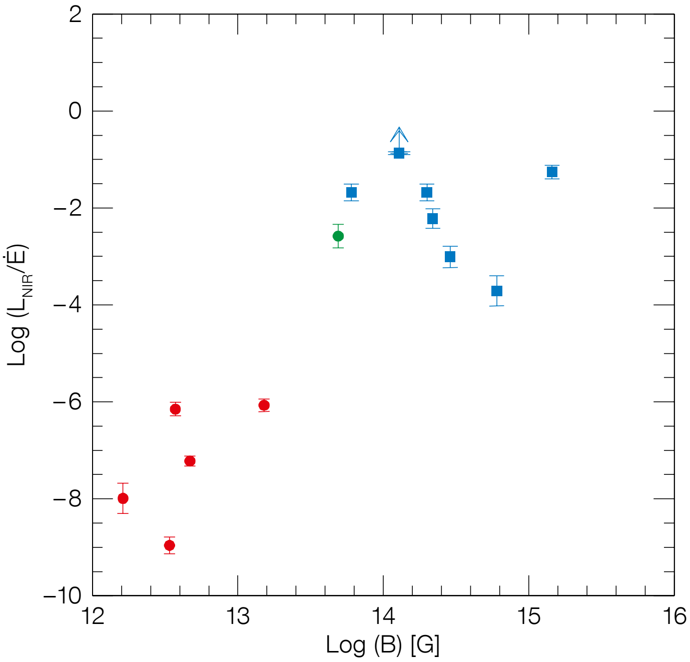


Figure 4. IR luminosity/rotational energy loss ratio (Ė) as a function of the magnetic field for rotation-powered pulsars (red), magnetars (blue), and rotating radio transients (green).

Prospects

VLT observations (see Table 1 for a qualitative summary) have played a major role in the study of the many INS types, the emission processes in their hypermagnetised magnetospheres and of neutron star cooling. While in the years to come the VLT will still be a leading facility in neutron star optical astronomy in its own right, it will also be a pathfinder for E-ELT observations. Following on from the VLT, the E-ELT should be able to yield about a hundred new INS identifications, reducing the current gap between optical and high energy observations (Becker, 2009; Abdo et al., 2009). Many identifications will likely come from follow-ups of observations with the new megastructure facilities, like the Square Kilometre Array (SKA) in the radio band. Moreover, the E-ELT will allow those observations that still represent a challenge for the VLT to be carried out easily for the faintest INSs, enabling more in-depth investigations to complete the seminal work of the VLT. Forty years after the identification of the Crab pulsar, the optical study of INSs is still a very active field, where ESO has marked important milestones in the last 20 years, first with the NTT (Mignani et al., 2000) and now with the VLT. The E-ELT will be able to take up this legacy, opening a third era in neutron star astronomy.

Name	Age	Mag	D (kpc)	A_V	Instruments	Modes
Crab	3.10	16.6 (*V*)	1.73	1.6	FORS1/ISAAC/NACO	IMG, HITI
B1509-58	3.19	25.7 (*R*)	4.18	5.2	FORS1	IPOL
B0540-69	3.22	22.0 (*V*)	49.4	0.6	FORS1	LSS
Vela	4.05	23.6 (*V*)	0.23	0.2	FORS1/ISAAC	IMG, IPOL, LSS
B0656+14	5.05	25.0 (*V*)	0.29	0.09	FORS1	LSS
B1133+16	8.89	28.0 (*B*)	0.35	0.12	FORS1	IMG
B0950+08	7.24	27.1 (*V*)	0.26	0.03	FORS1	IMG
J0108-1431	8.3	26.4 (*U*)	0.2	0.03	FORS1	IMG
RX J0720.4-3125	6.27	26.7 (*V*)	0.30	0.3	FORS1/FORS2/ISAAC	IMG
RBS 1774	6.57	27.2 (*B*)	0.34	0.18	FORS1/FORS2	IMG
RX J1856.5-3754	6.60	25.7 (*V*)	0.30	0.12	FORS1/ISAAC/MAD	IMG, LSS
RX J0420-5022	–	27.5 (*B*)	0.35	0.07	FORS1/FORS2/MAD	IMG
1E 1547.0-5408	3.14	18.2 (*K*)	9	17	NACO	IMG, IPOL, LSS
SGR1806-20	3.14	20.1 (*K*)	15.1	29	ISAAC/NACO	IMG
1E 1048.1-5937	3.63	21.3 (*K*)	3.0	6.10	NACO, ULTRACAM	IMG, IPOL
XTE J1810-197	3.75	20.8 (*K*)	4.0	5.1	NACO	IMG, IPOL

Table 1. VLT detections of INSs with optical counterparts (identifications in bold). INSs (blue: radio pulsars; red: XDINSs; green: magnetars) are sorted according to the logarithm of the spin-down age.

References

Abdo, A. A. et al. 2009, ApJ, submitted, arXiv:0910.1608v1

Becker, W. 2009, in *Neutron Stars and Pulsars*, ASSL, 357, 91

De Luca, A. 2008, in *40 Years of Pulsars*, AIP, 983, 311

Gold, T. 1968, Nature, 218, 731

Haberl, F. 2007, Ap&SS, 308, 181

Lorimer, D. L. 2009, in *Neutron Stars and Pulsars*, ASSL, 1, 289

McLaughlin, M. A. 2009, in *Neutron Stars and Pulsars*, ASSL, 357, 41

Mereghetti, S. 2008, A&A Rev., 15, 225

Mignani, R. P., Caraveo, P. A. & Bignami, G. F. 1999, A&A, 343, L5

Mignani, R. P., Caraveo, P. A. & Bignami, G. F. 2000, The Messenger, 99, 22

Mignani, R. P. 2009, in *Neutron Stars and γ-ray Bursts*, AIP, in press, arXiv:0908.1010

Pacini, F. 1968, Nature, 219, 145

Pacini, F. & Salvati, M. 1983, ApJ, 274, 369

Shearer, A. 2008, in *High Time Resolution Astrophysics*, ASSL, 351, 1

Notes

[1] According to the magnetic dipole model (Pacini, 1968; Gold, 1968) radio pulsars are powered by the neutron star rotation. Hence, the measurement of the pulsar period and period derivative yield an indirect estimate of the neutron star age, rotational energy loss and dipolar magnetic field.

Colour image of a rim of the supernova remnant RCW 86 showing the numerous shock-ionised filaments. This is a composite of a broadband kev Chandra image (blue) and a FORS2 Hα filter image (red). More details can be found in the ESO Science Release 23/09.

The LABOCA Survey of the Extended Chandra Deep Field South (LESS)

Ian Smail[1]
Fabian Walter[2]
Axel Weiss[3]
(for the LESS consortium*)

[1] Department of Physics, Durham University, United Kingdom
[2] Institute for Computational Cosmology, Durham University, United Kingdom
[3] Max-Planck-Institut für Radioastronomie, Bonn, Germany

We present the latest results from the LABOCA Extended Chandra Deep Field South (ECDFS) Submillimetre Survey (LESS), a joint 300-hour ESO–MPG survey of the 30 × 30 arcminute ECDFS field using the LABOCA camera on the 12-metre APEX telescope. This survey provides an important new waveband for comparison to previous studies of galaxies and active galactic nuclei (AGN) in the ECDFS, and one which is particularly sensitive to obscured starburst galaxies out to very high redshifts ($z < 8$). We highlight the identification in the LESS map of the highest redshift submillimetre galaxy currently known, as well as high significance statistical detections of a variety of star-forming galaxies and AGN, their clustering and evolution with redshift within the ECDFS.

One of the most significant findings of the IRAS survey was the identification of a population of ultraluminous infrared galaxies (ULIRGs, galaxies with far-infrared luminosities > 10^{12} $L_\odot$ or star formation rates of > 100 $M_\odot$ yr^{-1}) that emit the bulk of their bolometric luminosity at far-infrared wavelengths (Sanders & Mirabel, 1996). Surveys in the submillimetre and millimetre wavebands over the past decade (with the SCUBA camera on the James Clerk Maxwell Telescope at 870 μm or MAMBO on the IRAM 30-metre telescope at 1.2 mm) have shown that ULIRGs are much more common at high redshift compared to the local Universe (e.g., Smail et al., 1997; Coppin et al., 2006; Austermann et al., 2009), with indications from the first redshift surveys of an increase by a factor of 1000 out to $z \sim 2$ in the comoving volume density of luminous submillimetre galaxies (SMGs; Chapman et al., 2005). Therefore luminous obscured galaxies at high redshift could dominate the total bolometric emission from galaxies at those epochs. Such intense star formation would potentially build up significant stellar masses in a relatively short period of time and is thus capable of forming massive, evolved galaxies at high redshifts (e.g., Swinbank et al., 2006).

Surveys of the high redshift Universe in the submillimetre waveband are of particular interest due to the positive K correction from the dust spectrum in this waveband (Blain & Longair, 1993). Hence a source with a fixed far-infrared luminosity yields an almost constant flux density irrespective of redshift across $1 < z < 8$ — providing an efficient tool to survey for ULIRGs in the distant Universe. However, such submillimetre surveys have been hampered by the limited fields of view of the cameras, which have resulted in small survey areas and limited statistics of the detected sources. This situation has only very recently improved with the advent of the new Large APEX Bolometer Camera (LABOCA; Siringo et al., 2007; 2009) on the 12-metre APEX telescope (Figure 1), which features an impressive instantaneous 11.4-arcminute-diameter field of view providing a new opportunity for panoramic submillimetre surveys. Such surveys also benefit from APEX's location at one of the best astronomical sites worldwide: the ALMA high site at Llano de Chajnantor in Chile.

The LABOCA ECDFS Submillimetre Survey

LABOCA on APEX provided the opportunity to undertake the first sensitive and uniform panoramic survey of the extragalactic sky at 870 μm. This survey targeted the 2-Ms Chandra Deep Field South (CDFS; Luo et al., 2008) and the region immediately surrounding it (the Extended CDFS or ECDFS; Lehmer et al., 2005). This field has very low far-infrared backgrounds and good ALMA visibility and hence has become one of the preeminent fields for cosmological survey science. The ECDFS has been one of the prime targets for ESO's observatories over the past decade and hence a wealth of observations has been built up, pro-

Figure 1. The APEX telescope on Chajnantor. The LABOCA camera on APEX was used to obtain a deep map at 870 μm of the Extended Chandra Deep Field South for the LESS project. The wide field of view of LABOCA and the excellent site for the APEX telescope make this the most powerful facility for panoramic submillimetre surveys in the southern hemisphere.

viding a rich archive for the analysis of each additional dataset. As a result, the ECDFS is unique in the southern hemisphere in the combination of area, depth and spatial resolution of its multiwavelength coverage from X-rays through optical, near- and mid-infrared to the radio regime (e.g., Lehmer et al., 2005; Gawiser et al., 2006; Wolf et al., 2008; Caldwell et al., 2008). This field has also recently been observed in the far-infrared by the BLAST balloon experiment (Devlin et al., 2009) and will be one of the deepest fields observed by the Herschel Space Observatory. The ECDFS was thus a natural choice for the first large extragalactic survey to be undertaken with the new LABOCA camera on the APEX telescope.

Even though LABOCA's mapping speed dwarfs that of previous cameras at similar wavelengths, a complete survey of the ECDFS was still a major effort: a number of groups within ESO and the Max-Planck-Gesellschaft (MPG) communities proposed a joint public legacy survey of the ECDFS to the ESO and MPG time allocation committees. The LABOCA ECDFS submillimetre survey (LESS) covers the full 30 × 30 arcminute extent of the ECDFS. The completed LESS survey used a total of 310 hours of observing time and covers the full ECDFS with a uniform noise level of $\sigma_{870\,\mu m} \sim 1.2$ mJy beam^{-1} (Figure 2). LESS is thus the largest contiguous deep submillimetre survey undertaken to date. A total of 126 SMGs have been detected in this field. Due to the positive K correction in the submillimetre waveband this deep map is sensitive enough to detect individual starburst galaxies with star formation rates of $\sim 500\ M_\odot\ \mathrm{yr}^{-1}$ at $z < 8$. Moreover, the wide area and depth provide the largest reliable sample of SMGs in a single field yet obtained and provides a unique opportunity to tackle key questions about this enigmatic population.

Weiss et al. (2009) show that the differential source counts in the full field are well described by a power law with a very steep slope, $dN/dS \sim S^{\alpha}$ with $\alpha = -3.2$, similar to the results from previous surveys (e.g., Coppin et al., 2006). The ECDFS is known to have underdensities of various high redshift source populations (e.g., optically bright AGN and massive *K*-band selected galaxies) and indeed we find that the ECDFS exhibits a similar deficit of bright SMGs relative to previously studied blank fields, although the numbers of fainter SMGs, that dominate the extragalactic background light (EBL), are comparable to previous estimates. We have also taken advantage of our large contiguous field of view to investigate the clustering of SMGs in the ECDFS and find evidence for strong clustering on angular scales < 1 arcminute (~ 0.5 Mpc at the relevant redshifts) for the first time. Assuming a power law dependence for the correlation function and a typical redshift distribution for the SMGs we derive a spatial correlation length of 13 ± 6 h^{-1} Mpc. This strong clustering demonstrates that SMGs are a highly biased population in the early Universe and thus are likely to relate to the formation phase of massive galaxies.

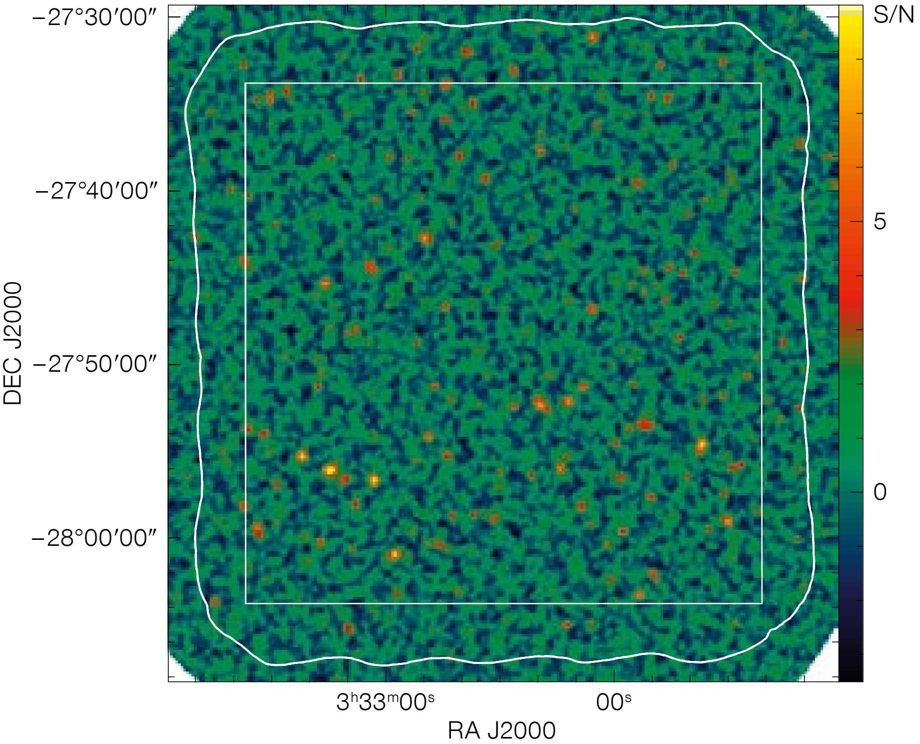


Figure 2. The submillimetre map of the ECDFS from the LESS project (Weiss et al., 2009) shown as a signal-to-noise map to highlight the uniformity of the coverage achieved by LABOCA and to give a visual impression of the distribution of the most significant sources. The white box shows the full 30 × 30 arcminutes of the ECDFS for which Hubble Space Telescope imaging and a large amount of supporting multiwavelength data exists. The white contour shows the 1.6 mJy beam^{-1} noise level which was used to define the field size for the source catalogue, yielding a search area of 1260 arcminutes^2.

The most distant submillimetre galaxy

To understand the physical processes driving the intense activity within the SMG population we need to identify counterparts to these sources at other wavelengths. Unfortunately the relatively coarse resolution of LABOCA — 19 arcseconds FWHM — along with the modest signal-to-noise of many of the detections and the expected high redshifts and dusty nature of the counterparts, all conspire to make the identifications challenging. At present the most efficient and reliable technique to locate the source of the submillimetre emission precisely is to exploit the close relation between radio and far-infrared emission from star-forming regions and hence use the higher spatial resolution of deep interferometric radio maps to identify counterparts to SMGs (Ivison et al., 2002). One of the first sources to be identified from the LESS map using this technique turned out to be the highest redshift SMG known to date: LESSJ033229.4 (see Figure 3). The submillimetre emission is identified with a radio counterpart for which archival optical spectroscopy gave a redshift of $z = 4.76$. Analysis of the spectral energy distribution of this galaxy shows that the bolometric emission is dominated by a starburst with a star formation rate of $\sim 1000\ M_{\odot}\ \mathrm{yr}^{-1}$, although a moderate luminosity AGN is also present in this galaxy. This mix of starburst and obscured AGN signatures is also characteristic of the bulk of SMGs at $z \sim 2$ and suggests that star formation and black hole growth may also be strongly linked in this population at $z \sim 5$.

Starbursts and growing black holes

An intimate link between AGN activity and luminous obscured starbursts is also suggested by the analysis of the submillimetre emission from the 900 X-ray sources across the CDFS and ECDFS using the LESS map (Lutz et al., 2009). The total sample is detected at $> 10\sigma$ significance, but more intriguingly we find distinct behaviour which suggests that there are two modes of AGN-star formation coexisting. For the bulk of the population, the X-ray properties of the AGN are only weakly coupled to their hosts, which have relatively modest star formation. In these systems, the period of moderately luminous AGN activity may not highlight a major evolutionary transition of the galaxy. The hints of more intense star formation and a more pronounced difference in star formation rates between unobscured and obscured AGN in our sample at the highest X-ray luminosities suggests that these luminous AGN may follow an evolutionary path, where obscured AGN activity and intense star formation are closely linked, possibly via a single physical process such as merging.

Submillimetre emission from “normal” galaxies

Most recently, we have employed the LESS map and the extensive multiwavelength observations available for the ECDFS to investigate the star formation activity in high redshift galaxy populations which are individually below the detection limit of our map. We achieve this through a stacking analysis of the submillimetre map using a sample of 8266 near-infrared selected ($K_{Vega} \leq$ 20 mag) galaxies, including 893 BzK galaxies (selected in *B-z v. z-K* colour space), 1253 extremely red objects (EROs) and 737 distant red galaxies (DRGs), all drawn from the Multi-wavelength Survey by Yale–Chile (MUSYC; Gawiser et al. 2006). In this way we obtain very strong statistical (10–20σ detection) constraints on the submillimetre emission from these different populations (Figure 4). For the BzK, ERO and DRG subsamples, which overlap to some degree and are all likely to be at $z \sim 1$–2, this implies an average far-IR luminosity of ~ 2–$6 \times 10^{11}\ L_{\odot}$ and star formation rates of ~ 40–$100\ M_{\odot}\ \mathrm{yr}^{-1}$. Splitting the BzK galaxies up into the photometrically-defined star-forming (sBzK) and passive (pBzK) subsets, the former is significantly detected while the latter is not (Figure 4), thus confirming that the sBzK/pBzK criteria do isolate obscured, star-forming and relatively passive galaxies. By mapping the stacked 870-µm signal across the *B-z v. z-K* diagram we suggest that the subset of sBzK galaxies which are also EROs are responsible for $> 80\,\%$ of the submillimetre emission from the entire sBzK population. In total we estimate that galaxies with $K \leq 20$ mag contribute $\sim 15\,\%$ of the 870-µm EBL, most of this arising below the detection limit of our submillimetre map. To study the evolution of this activity we further divide the $K \leq 20$ mag sample based on photometric redshift and derive the contributions to the EBL. We find a decline in the average submillimetre flux (and therefore IR luminosity and star-formation rate) by a factor ~ 2–3 times from $z \sim 2$ to $z \sim 0$. This suggests that the cosmic star formation history traced by far-infrared emission also exhibits a significant decline at $z < 1$, as indicated by UV tracers.

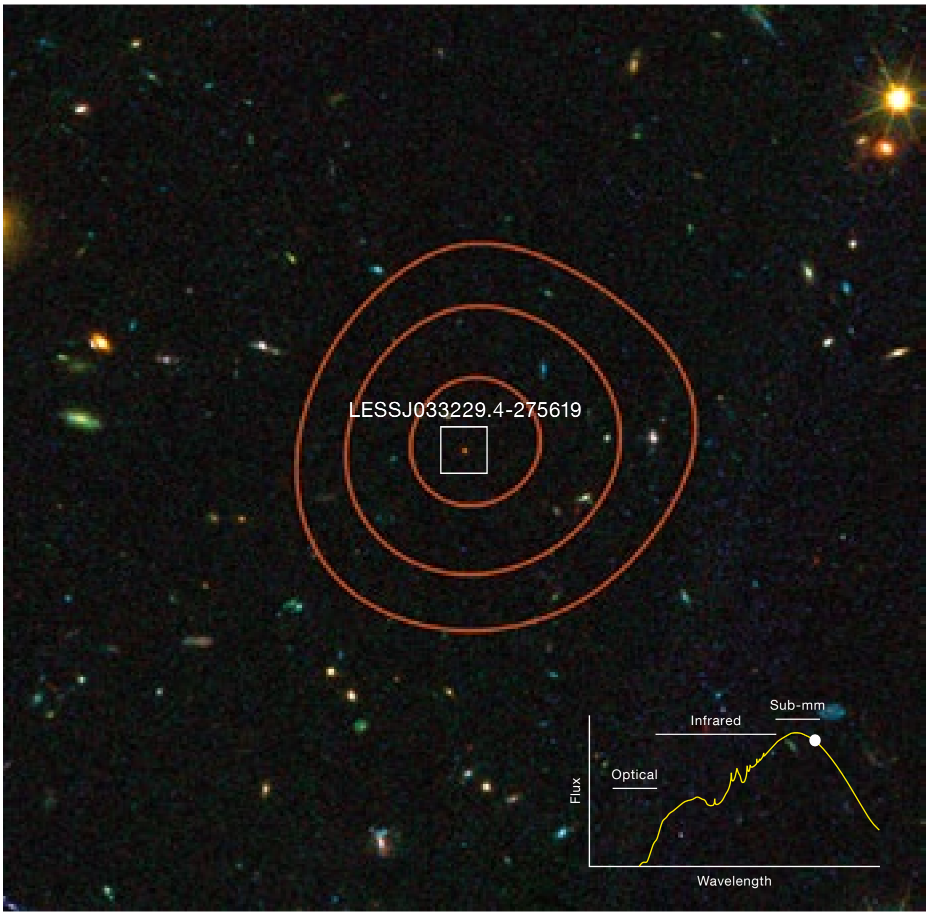


Figure 3. An early discovery from the LESS project was the highest redshift submillimetre galaxy (SMG) currently known (Coppin et al., 2009). The spectroscopic redshift, $z = 4.76$, for this galaxy was derived from some of the extensive archival observations available in the Extended Chandra Deep Field South. This system contains both a luminous, but dust-obscured, starburst and an actively fuelled supermassive black hole, underlining the strong link between black hole and galaxy growth in the SMG population. The best-fit spectral energy distribution demonstrates that most of the energy in this system escapes in the restframe far-infrared (the observed submillimetre band).

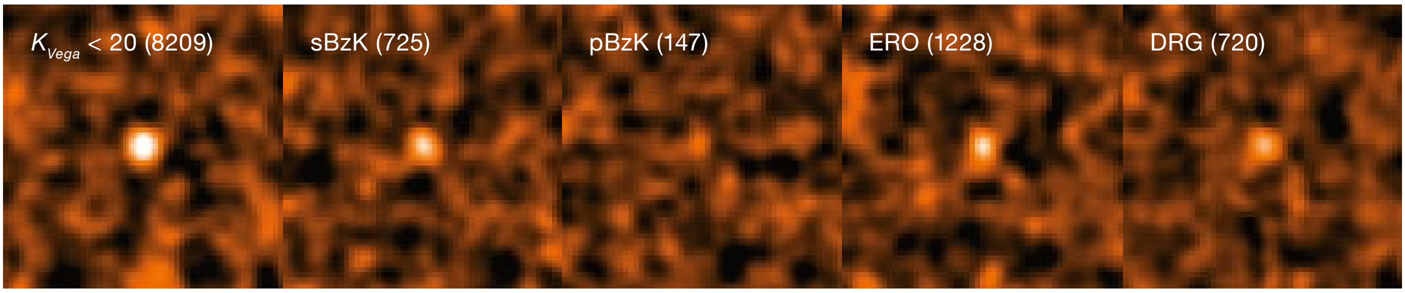


Figure 4. A demonstration of the science that can be derived from combining the LESS map with the rich multiwavelength archive in the Extended Chandra Deep Field South. These images show the average submillimetre emission from different photometrically-defined populations of faint, high redshift galaxies derived by stacking the emission at the positions of hundreds to thousands (number in brackets) of galaxies (Greve et al., 2009). From left to right they show the stacked emission from a simple magnitude-limited sample, the emission from star-forming BzK galaxies, from passive BzK galaxies, from Extremely Red Objects (EROs) and from Distant Red Galaxies (DRGs).

The future

This work has only just begun on exploiting the LABOCA map of the ECDFS, which will be released to the community through the ESO archive simultaneous with the publication of Weiss et al. (2009). Highlights of the ongoing work on the LESS project include a detailed comparison of the BLAST far-infrared maps of this region to the LABOCA submillimetre map. One goal of this comparison (and future work with Herschel) is to identify "drop-out" sources which are visible to LABOCA, but faint in the far-infrared and could conceivably be at very high redshifts, $z > 5$. The major element of our ongoing studies is a 200-hour VLT Large Programme that was awarded to obtain spectroscopic redshifts for the SMGs identified by LESS (as well as far-infrared targets selected from the Spitzer FIDEL survey). We therefore expect that APEX's contribution to studies of the ECDFS will continue to produce new and exciting science for a considerable period to come.

References

Austermann, J. E. et al. 2009, MNRAS, in press, arXiv:0907.1093
Blain, A. W. & Longair, M. S. 1993, MNRAS, 265, L21
Caldwell, J. A. R. et al. 2008, ApJS, 174, 136
Chapman, S. C. et al. 2005, ApJ, 622, 772
Coppin, K. E. K. et al. 2006, MNRAS, 273, 1621
Coppin, K. E. K. et al. 2009, MNRAS, 395, 1905
Devlin, M. J. et al. 2009, Nature, 458, 737
Gawiser, E. et al. 2006, ApJS, 162, 1
Greve, T. R. et al. 2009, ApJ, submitted, arXiv:0904.0028
Ivison, R. J. et al. 2002, MNRAS, 337, 1
Lehmer, B. D. et al. 2005, ApJS, 161, 21
Luo, B. et al. 2008, ApJS, 179, 19
Lutz, D. et al. 2009, ApJ, submitted
Sanders, D. & Mirabel, F. 1996, ARAA, 34, 749
Siringo, G. et al. 2007, The Messenger, 129, 2
Siringo, G. et al. 2009, A&A, 497, 945
Smail, I., Ivison, R. J. & Blain, A. W. 1997, ApJ, 490, L5
Swinbank, A. M. et al. 2006, MNRAS, 371, 465
Weiss, A. et al. 2009, ApJ, submitted, arXiv:0910.2821
Wolf, C. et al. 2008, A&A, 492, 933

Links

* More information about the survey, including the full list of co-investigators, is available at http://www.astro.dur.ac.uk/~irs/LESS.

Colour composite displaying the triggered star formation in the shell surrounding the HII region RCW 120, formed by combining submillimetre and optical images. The APEX LABOCA 870-µm emission from cold dust is visible as the blue clouds surrounding the core of ionised gas in red (image from the SuperCOSMOS H-alpha survey). See ESO Press Photo 40/08 for further details.

Two views of the ESO Open House day held on 24 October 2009.
Some of the total of around 4000 visitors viewing exhibits in the entrance hall (upper). A camera on the VLT platform showed real-time images from Paranal throughout the day. One of the two live question-and-answer sessions with Gianni Marconi on Paranal, moderated by Joe Liske, is shown (lower).

Report on the ESO Workshop

Detectors for Astronomy 2009

held at ESO Garching, Germany, 12–16 October 2009

Dietrich Baade[1]

[1] ESO

In the 1980s and 1990s, the developments in sensitivity, size, and effective image quality of semiconductor detectors progressed faster and with lower cost than any equivalent increase in the geometrical light-collecting power of optical/infrared telescopes could have achieved. Now, in the era of Extra Large Telescopes, where light-collecting power is again increasing and ever more sophisticated space-borne instruments are in preparation, the growing maturity of detectors still forms an important cornerstone of these large investments. The recent workshop brought together many of the world's leading detector developers, producers and users, as well as astronomers, to exchange ideas, questions and solutions with the aim of enabling detector systems to optimally support the exciting astronomy projects of the future.

After the workshops in 1991, 1993, 1996, 1999 (all in Garching), 2002 (in Hawaii) and 2005 (in Taormina, Italy), the seventh workshop in the series Detectors for Astronomy (DfA2009) returned to the ESO Headquarters in Garching. During the course of almost two decades, the title and scope of these workshops have evolved somewhat, but the emphasis has changed little. For the first time, the number of participants exceeded the capacity of the ESO auditorium, and the workshop was kindly hosted by the Max-Planck-Institut für Extraterrestrische Physik (MPE). During three full days and two half days, the 185 participants were presented with around 60 talks and 40 posters. In terms of attendance, this places DfA2009 in the top 10th percentile of the ~ 100 workshops held at ESO–Garching since ESO Headquarters was established there in 1980.

The approximately 50 % increase in attendance since DfA2005 signals the growing importance that the astronomical detector community assigns to these meetings. In fact, from the beginning, their format has been very special, in that they have brought together: (a) research laboratories, where much of the fundamental understanding and concepts are developed; (b) detector manufacturers, who run their own R&D programmes, but also cast research results into recipes for serial production and marketing; and (c) detector engineers at observatories, who are trying to deliver the best possible performance to astronomical users. Obviously, there are large overlaps in the expertise of these groups. This is the basis for a common understanding. But it is remarkable that the professional knowledge of none of the groups is a simple superset of any of the other two. Therefore, everyone can benefit and learn from everyone else. This makes such encounters extremely productive.

Figure 1. The DfA2009 participants facing a snow-cold sky outside the Max-Planck-Institut für Extraterrestrische Physik in Garching, where the workshop was held.

An additional thrill results from the fact that detectors, while indolently destroying photons after millions and billions of years of travel, do their utmost to preserve the information carried by the photons. After the detector electronics and software have assembled the detected signals, it is the very first moment that humans can reflect on these "messages" from very far away. Nothing gets closer to feeling the pulse of the Universe than the light-detection process. For this reason, the DfA workshops try to also include some scientific reports from observational experiments that are particularly dependent on the excellence of detectors. This time, cataclysmic variables observed at high temporal or spatial resolution, the quest for the identification of dark matter and energy, solar physics, the search for killer asteroids, cosmic shear, the use of supernovae as the accelerometers of the Universe, stellar diameter measurements from lunar occultations, the detection of TNT in high security areas, delay-time based 3D imaging, and many more, served to illustrate the difference between excellent and good detectors. Some of the forthcoming, or planned, advanced world-class facility observatories were also presented. It was interesting to see that such projects are now often proactive in identifying and securing the detectors they require. This planning especially applies to wavefront sensors for adaptive optics, but also to the development of curved detectors that would enable much better optical designs than a flat detector with a field-flattening lens.

Size, quantum efficiency and controllers

Back in 1991, the central questions (D'Odorico et al., 1991) concerned the maximum size of available charge coupled devices (CCDs), their UV-blue quantum efficiency, and the architecture and performance of controllers. These three topics, addressed from the DfA2009 perspective, are treated in the following, necessarily short, summary. During the eighteen years now covered by the DfA series, the scope of the workshops has long been extended to include

Figure 2. The 32 participants in the ESO Mini-Workshop on Large-size CCDs held at ESO Garching 18–19 June 1991. Twelve of them also attended DfA2009.

infrared (IR) arrays as well, the sizes of which have meanwhile grown, from the standpoint of the early 1990s, to unimaginable dimensions. For CCDs, from the first marketing of 2k × 2k chips (15-μm pixels) announced in 1991, the progress in size has been more moderate with 4k × 4k devices (also with 15-μm pixels) still being the largest thinned, backside-illuminated square formats readily found in the catalogues of all manufacturers. But results of successful on-sky tests obtained with a 111-million pixel detector were presented. Rather than in size, the growth has often been more in the diversity of chips, which in many cases can be further customised to match specific applications.

After the introduction of backside illumination and improved anti-reflection coatings, UV-blue sensitivity has long been very satisfactory. In the very near IR, CCDs and IR CMOS (complementary metal oxide semiconductor) technology are now competing: Deep-depletion technology permits thicker and thicker silicon devices to be used so that even at wavelengths close to 1 μm, where silicon is starting to become transparent, CCDs can detect up to 50 % of the light. Thick silicon also greatly reduces fringing, but at the price of increased sensitivity to particle radiation, and the point spread function needs careful attention. In this same wavelength region, IR CMOS detectors even achieve quantum efficiencies of 90 % or more. Their higher read noise and cost still prevent their usage at shorter wavelengths, but the rate of progress continues to be high.

The limits in space-borne projects on mass, volume, and power consumption are bringing about a paradigm shift from conventional controllers to ASICs (Application-Specific Integrated Circuits), which can often be mounted back-to-back with the sensor they are commanding. During the most recent Hubble repair mission, a conventional CCD controller of the Advanced Camera for Surveys was actually replaced with an ASIC originally developed for IR detectors. In a ground-based context, a number of talks also elaborated on the virtues of ASICs. But, as was also shown, conventional dedicated or general-purpose controllers can still offer some advantages if their bulkiness is not an issue. It will be interesting to see when custom-developed ASICs will become affordable.

A dream of many a detector physicist, engineer and astronomer is the noise-free detector. Electron-multiplying CCDs, avalanche photodiodes, and other technologies are coming ever closer to this ideal. Dead times, excess noise factors, and dynamic range still present challenges, but already permit routine application in specialised areas, most notably wavefront-sensing with laser and natural guide stars. Frame rates well above 1 kHz and the ability to discriminate between 100, 101 or 102 photon events were described. For scientific applications with very long exposure times, extremely low dark currents are of similar importance as low read noise and a “world-record” low value was reported.

Quite a few talks touched upon the optimisation of detectors under astronomical operating conditions; some were actually dedicated to this topic, mostly in conjunction with IR detectors. In the CCD domain, a major component was also the increased understanding of very low-level effects, such as pixel-size variations, e.g., as a function of proximity to the edge of the chip or of signal level, and the modelling of the interaction between light and silicon, including fringing. A concern for CCDs and CMOS devices alike is the coupling between charge in neighbouring pixels, so that any serious characterisation of detectors must include illumination with point sources. Optimisation is also one of the big challenges for large detector mosaics — now measuring up to more than 1 gigapixel, given the need to achieve much lower budgets for mass, power dissipation, etc. Several impressive examples were presented in great detail.

The level of precision, with which chemical and electrical profiles can be engineered and operated at sub-pixel dimensions, and the complexity of infra-pixel electronics (for CMOS devices) are stunning. So is their reproducibility from device to device as well as over millions of pixels. The much improved cleanroom technology has not only led to progress in these areas, but has given the term “chip cosmetics” a new meaning. Improved production yields lead to lower costs per pixel, but also permit larger devices to be made, so that the revenues of manufacturers do not suffer.

All in all, the talks and posters presented in less than one week may have been based on well over 1000 personyears of highly specialised work — a compression factor of order 10^5! Numerous discussions during coffee breaks, two well-attended poster sessions, demonstrations of ESO’s New General detector Controller (NGC), OCam, the Bonn shutter and TeePee, a nice welcome reception on Monday, and dinner at a Bavarian restaurant in Garching completed a very rich programme. Many participants commented explicitly on the openness with which authors also talked about the problems they had encountered. This was stated to be a very positive contrast to other major conferences. There was particular praise for the Broadband Introductory Course on Detector Technologies, run by James Beletic and Markus Loose.

In view of the high rate of progress in the very dynamic field of astronomical detectors, the DfA2009 proceedings will be published on the workshop web pages only[1]. At the time when this *Messenger* report appears, all presentations and some of the first papers will be available.

Acknowledgements

The workshop was only possible thanks to the dedication of the members of the SOC (James Beletic [co-chair], Randy Campbell, Donald Figer, Gert Finger [co-chair], Jean-Luc Gach, Satoshi Miyazaki, Peter Moore, Alex Short, Gregory Tarlé and Simon Tulloch), the LOC (Iris Bronnert, Maximilian Fabricius, Lu Feng, Nadine Neumayer, Ulf Seemann, and Christina Stoffer), the ESO IT Helpdesk, and many others, who provided logistical support. It was a tremendous advantage that the MPE kindly agreed to make their excellent facilities, so close to ESO Headquarters, available; this was largely handled by Maximilian Fabricius. When even careful preparation sometimes did not seem enough, Christina Stoffer's vast experience with ESO workshops kept everything on track, and the very positive spirit of all attendees made all tasks very pleasant. I thank all organisers and participants.

References

D'Odorico, S. et al. 1991, The Messenger, 65, 43

Links

[1] http://www.eso.org/sci/meetings/dfa2009/program.html

3D Movie Featuring ESO's Paranal Observatory

Lars Lindberg Christensen[1]

[1] ESO

The production companies parallax raumprojektion and fact&film have produced a unique 3D documentary about ESO's Very Large Telescope (VLT), in close cooperation with ESO, as part of its International Year of Astronomy 2009 activities. The film, *The EYE 3D — Life and Research on Cerro Paranal*, stars the young scientist and ESOcast host Dr J, aka Joe Liske. In June 2009, a German film crew, who specialise in making 3D movies, accompanied Dr J on a trip from ESO Headquarters in Garching to the landscapes of the Atacama Desert in the north of Chile, home of the VLT.

Along with stunning views of the telescopes and clear explanations of how such a technical masterpiece functions, the movie also follows the lives of people at Paranal: astronomers, engineers, physicists and technicians, showing just how everyone's work at the VLT contributes to the cutting-edge research about the Universe. The movie is aimed at a broad audience, from schoolchildren to science scholars. Its extraordinary 3D technique gives viewers a real sense of being at the centre of the action, taking them on virtual tours inside the telescope domes, or for a walk in the desert with Dr J.

The film was co-financed by the film subsidy agencies of the German federal states of Baden-Württemberg and Bremen, several charitable and public organisations and ESO. It has been appointed a Special Project of the International Year of Astronomy.

The EYE 3D, directed by Nikolai Vialkowitsch, had its world premiere on Wednesday, 28 October 2009, at the Film Festival in Biberach, Germany and is showing in 3D theatres across Germany, and later this year all over Europe. An international version in English language is available, and further translations in other European languages are in production.

More information at www.eso.org/public/events/special-evt/theeye/index.html.

Credit: parallax raumprojektion/ESO

Dr Joe Liske in the Atacama Desert in the movie *The EYE 3D*.

ESO Open House Day 2009

Lars Lindberg Christensen[1]
Britt Sjöberg[1]
Ed Janssen[1]

[1] ESO

On 24 October 2009 ESO opened its doors to the public as part of the annual campus-wide Open House event ("Tag der offenen Tür"). This year's Open House event was a resounding success, with a record-breaking attendance of around 4000 visitors. Dedicated ESO staff volunteered to spend part of their Saturday in the noble cause of improving ESO's connection with the taxpayer.

Nadine Neumeyer, an ESO Fellow, giving a talk to a packed auditorium about "Black holes in galaxy centres" during the ESO Open House event.

The many visitors barely had enough space to move from one exciting exhibit to the next and the talks in the auditorium were standing room only. An all-day live link to Paranal with a new webcam was very well received, and so was the portable planetarium, with the latest in high-tech digital fulldome projection showing ESO's ALMA planetarium show *In Search of our Cosmic Origins*. In the cafeteria samples of international cuisine were sold for the benefit of the ESO Charity Group and will find their way to charity projects in Chile.

Many families went home with infrared portraits and happy children with painted faces were roaming through the building. The lively conversations throughout the building also showed the interest of the visitors in astronomy, ESO and its technological achievements.

Similar events took place all over the Garching campus, where approximately 4000 people work and 8500 students study. The high concentration of scientific and technical research establishments found here gave the thousands of visitors from near and far a first-hand introduction to the Technical University Munich, several institutes of the Max Planck Society, the Ludwig Maximilian University Munich, the Bavarian Academy of Sciences, as well as many other renowned institutes and enterprises. The Garching campus is one of the largest centres for science, research and learning in Germany, with a sphere of activity reaching from fundamental research to development of promising high-tech applications. It continues to grow in size and diversity with new institutes and enterprises under construction, promising even bigger and more exciting Open House events in the future.

ESO Website is Now Available in Twelve Languages

Lars Lindberg Christensen[1]

[1] ESO

ESO is pleased to announce that important parts of its extensive website have been translated into eleven European languages, covering all ESO member states as well as some additional countries. Many more readers will now be able to learn all about ESO's impressive telescopes and projects in their own languages. These include the Very Large Telescope, as well as the Atacama Large Millimeter/submillimeter Array and the planned European Extremely Large Telescope. ESO press releases will also now be available in these languages, in addition to descriptions of ESO-related events taking place in the ESO member states.

This new service is courtesy of the ESO Science Outreach Network (ESON), a network of individuals in several countries — including all the ESO member states — who serve as local contacts for the media and the general public in connection with ESO developments, press releases, exhibitions and more. The ESON members also serve as useful contacts between the media and scientists in their respective regions, and as such are valuable ambassadors in the member states.

The new, dedicated websites are available for readers from Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and Switzerland, as well as for Chile. In addition, there are also ESON contacts in Ireland, the United Kingdom and the USA.

The ESON page with links to the mini-sites is at www.eso.org/public/outreach/eson/.

ESO Director General Visits the Vatican City

Lars Lindberg Christensen[1]

[1] ESO

On 30 and 31 October 2009 the ESO Director General, Tim de Zeeuw, was invited to visit the Vatican City, as part of an international group of renowned astronomers, on the occasion of the International Year of Astronomy 2009.

The visit included a tour of the Tower of Winds at the Vatican — the first location of the Vatican Observatory, built between 1578 and 1580 at the time of the Gregorian reform of the calendar — a visit to the Vatican Secret Archives, the Sistine Chapel and the astronomy exhibit AStrum 2009 at the Vatican Museum. On display in this exhibition of astronomy and instruments are 130 items, including Galileo Galilei's original handwritten notes detailing his observations of the Moon, and his publication *Siderius Nuncius* from 1610.

The highlight of the day was a private audience with Pope Benedict XVI who addressed the group. In his speech, the Pope said: "This celebration, which marks the four hundredth anniversary of Galileo Galilei's first observations of the heavens with a telescope, invites us to consider the immense progress of scientific knowledge in the modern age and, in a particular way, to turn our gaze anew to the heavens in a spirit of wonder, contemplation and commitment to the pursuit of truth, wherever it is to be found."

Credit: Photo Service L'Osservatore Romano

The ESO Director General Tim de Zeeuw meeting Pope Benedict XVI during a visit to the Vatican City. Between the Director General and the Pope are Fr. José Gabriel Funes, director of the Vatican Observatory (right), and Cardinal Giovanni Lajolo, president of the Governorate of the Vatican City State.

The Pope also expressed his "gratitude not only for the careful studies, which have clarified the precise historical context of Galileo's condemnation, but also for the efforts of all those committed to ongoing dialogue and reflection on the complementarity of faith and reason in the service of an integral understanding of Man and his place in the Universe".

The Pope also said: "The International Year of Astronomy is meant, not least to recapture, for people throughout our world, the extraordinary wonder and amazement which characterised the great age of discovery in the sixteenth century." He continued: "Who can deny that responsibility for the future of humanity, and indeed respect for nature and the world around us, and demand — today as much as ever — the careful observation, critical judgement, patience and discipline which are essential to the modern scientific method? At the same time, the great scientists of the age of discovery remind us also that true knowledge is always directed to wisdom, and, rather than restricting the eyes of the mind, it invites us to lift up our gaze to the higher realm of the spirit."

This visit was organised by the Governorate of the Vatican City State and the Vatican Observatory as part of their celebrations of the International Year of Astronomy 2009 by the Holy See.

Announcement of the ESO Workshop

Central Massive Objects: The Stellar Nuclei–Black Hole Connection

22–25 June 2010, Garching, Germany

The centres of massive galaxies are special in many ways, not the least because all of them are believed to host supermassive black holes. Since the discovery of key relations linking the mass of the central dark object with the large-scale properties of the dynamically hot galactic component, it has become clear that the growth of the central black hole is intimately connected to the evolution of its host galaxy. However, for lower-mass galaxies, the situation is much less clear. These galaxies, spanning a large range of Hubble types, typically host nuclear clusters of a few 10^6–10^7 solar masses. The presence of black holes and their relation to these nuclear clusters remains largely unknown.

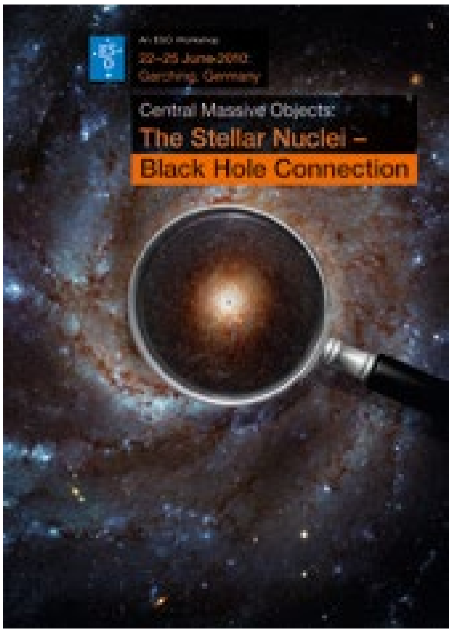
Recent studies have shown that nuclear cluster masses are coupled to the mass of their host galaxy, following a relation similar to that for supermassive black holes, suggesting that both types of central massive objects (CMOs) are closely related. Although nuclear clusters are more than the low-mass analogues of supermassive black holes, all CMOs very probably share some basic ingredients in their formation processes.

This workshop aims at bringing together a broad international audience in the combined field of galaxy nuclei, supermassive black holes and nuclear star clusters, to confront state-of-the art observations with cutting-edge models.

The key scientific questions for this workshop are:
- What is the evolutionary/causal connection between nuclear clusters and black holes?
- Are intermediate-mass black holes formed in nuclear clusters/globular clusters?
- Where do we stand observationally for black holes, nuclear clusters and intermediate-mass black holes?
- What can the Galactic Centre tell us about the nuclear cluster–black hole connection?
- How do the central massive objects relate to the host galaxies?
- What do theoretical models tell us about star formation in the extreme gravitational potential near the black hole and under the extreme stellar densities in galactic centres?
- What do theoretical models tell us about dynamics, evolution and migration of nuclear star clusters in galaxy centres?
- Do we understand the feeding of the central pc?
- How are nuclear clusters replenished with fresh gas?

The Scientific Organising Committee consists of: Eric Emsellem, Harald Kuntschner, Nadine Neumayer (all from ESO); Ralf Bender (LMU/MPE); Torsten Boeker (ESTEC); Elena Gallo (MIT); Reinhard Genzel (MPE); Ortwin Gerhard (MPE); Jenny Greene (Princeton); Simon Portegies Zwart (Leiden); Anil Seth (CfA); Roeland van der Marel (STScI) and Marta Volonteri (Michigan).

The registration deadline is 22 March 2010 and more details can be found at www.eso.org/sci/meetings/cmo2010.



New Staff at ESO

Rüdiger Kneissl

Since January of this year I have been working for ESO as an astronomer in Science Operations on the ALMA project. At the moment, while we are building ALMA, I spend a good fraction of my time on commissioning. It is exciting to see the project evolving so rapidly, from testing the first accepted antennas at the ALMA Operations Support Facility to interferometry at the Array Operations Site at 5000 m, and to be able to contribute at every step. The planning for operations is going on, along with progress on the completion of the instrument. Now we are detailing the processes for the first call for proposals and for the early science operations, which will follow.

Before joining ESO and ALMA, I worked in different places. After receiving my theoretical PhD from the University of Munich and the Max-Planck Institute for Astrophysics, I moved to Cambridge, England. There I learned about radio interferometry thoroughly, mainly on projects to measure the fluctuations in the cosmic microwave background (CMB) and to observe galaxy clusters via the Sunyaev–Zel'dovich (SZ) effect, with instruments such as the Cosmic Anisotropy Telescope, the Very Small Array and the Arcminute Microkelvin Imager. I also became involved in the Planck project, where I am now a scientist and a member of the High Frequency Instrument core team. At the University of California, Berkeley, and the Max-Planck Institute for Radioastronomy in Bonn I continued CMB studies with the SZ-camera we commissioned on the APEX telescope. Now on ALMA, in spite of the huge work load, I am still able to do

research in these projects, specifically aiming at combining observations in a useful way, for example monitoring Planck sources with APEX, which could be important ALMA calibrators. When ALMA becomes operational, I will be most interested in observations of high redshift galaxies and higher resolution imaging of SZ galaxy clusters, which I am currently modelling.

Coming to Chile was not an easy step, even without a family. My decision was driven mainly by work considerations, but living here, I am truly enjoying the welcoming and friendly culture of South America and the opportunity to travel around this spectacular region with its amazing landscapes.

Giorgio Siringo

My father was a school teacher, he taught mathematics and physics at a high school in Siracusa, in the very south of Sicily, where I grew up. He was really good at explaining everyday physics phenomena with simple words. My sister, my brother and I were fascinated by his tales revealing the magic of our Mother Nature, often embellished with anecdotes (mostly the fruits of his imagination, I presume) about Archimedes, Euclid or Fermi and Einstein (the last two were still alive when he was a student). He definitely had a strong "imprinting" effect: today my brother is a university professor of theoretical physics, my sister studied physics, but ended up teaching philosophy (which, in some senses, is not too far from physics) and I became an astrophysicist. I grew up during the Cold War, which, besides being a social threat, had the merit of providing an incredible boost to astronautics and technology development in general, making amazing projects like the manned missions to the Moon, the *Voyager* probes flying by Jupiter and Saturn, the MIR space station and the Space Shuttle possible. The popularity of those space missions and their great impact on the media (I'll never forget the emotions associated with the first marvellous false-colour pictures of Jupiter) attracted my attention even more to physics and astronomy and to the technology development that is necessary for their study.

I started my study of physics at the University of Catania, where I also studied astronomy at the local Institute of Astronomy, attached to the Observatory of the Italian National Research Council, at 1750 m on Mt. Etna. The limited number of university courses available in Catania pushed me to move to the (much larger) University of Rome "La Sapienza" where I joined the Experimental Cosmology Group G31. I was involved in ambitious projects aimed at measuring anisotropies and polarisation of the Cosmic Background Radiation (CBR) at millimetre wavelengths. During those years I studied cosmology and astrophysics, but I also learned how to build and operate a cryostat, to acquire and reduce data from 300-mK bolometers, or to measure the spectral transmission of a filter using a Fast Fourier Transform (FFT) interferometer. My university thesis is about a polarimeter using bolometers for ground-based measurement of the CBR polarisation to be operated at the MITO observatory, a 2.6-metre millimetre telescope at 3500 m in the Swiss–Italian Alps. We never measured any CBR polarisation, but it was an exciting experiment and my first experience of working on top of a high mountain, trying to concentrate while suffering from lack of oxygen. At that time I couldn't envisage that it was going to be my recurrent working condition.

I did my PhD at the University of Bonn, in Germany, where I worked for nine years in the bolometer group of the Max-Planck Institute for Radio Astronomy (MPIfR). My PhD thesis (here someone could argue that I have a limited imagination) is about a polarimeter for use with bolometers. This project, quite different from the one in Rome, was aimed at the observation of closer and brighter targets than the cosmic microwave background, such as Galactic molecular clouds, and designed as a sort of "polarisation plug-in" giving polarisation-sensing capabilities to the bolometer arrays produced by our group in Bonn. The polarimeter was successfully operated in combination with a bolometer array for the 870-micron atmospheric window on the Heinrich Hertz Telescope (HHT, also known as the Sub-Millimeter Telescope Observatory, SMTO), a 10-metre telescope, located at 3200 m on Mt. Graham in Arizona.

In May 2004 I went to APEX for the first time, working on the first-light instrument and for the first radio pointing model. It was the beginning of a very long series of trips to the 5000 m high plateau of Chajnantor as an MPIfR post-doc. In the following years I worked on the development, installation and commissioning of LABOCA and SABOCA, the facility bolometer cameras of APEX.

This year I had the great opportunity to join ESO as a staff astronomer at APEX. I live in Santiago and finally I don't have to fly from one hemisphere to the other to observe with the bolometer cameras that I installed there.

My father dreamt of being an astronomer: he studied physics, but when he finished at university, immediately after the Second World War, he had other priorities and decided to be a school teacher and a good father. I think he likes the idea that one of his sons works as astronomer, somehow making his dream come true.

Fellows at ESO

Giuseppina Battaglia

I have always been amazed by the monumental efforts we humans make to understand our own nature and the world around us. When I think of astronomy, I think of us, small humans on a small planet, trying, since the dawn of time, to decipher the mysteries of the Universe — notwithstanding our limited means — yet trying, striving to understand something so immense, so complicated and remote, and yet so fascinating, or probably so fascinating exactly because it is so unreachable. For me, this is what astronomy is about.

I took my first steps as a professional astronomer at the University of Bologna where I did my undergraduate studies. In 2002 I moved to Groningen, in the Netherlands, first for a few months to work on my Masters project, and then stayed for four years to start my PhD studies. The first project I carried out as a PhD student at the Kapteyn Astronomical Institute was a study on the dark matter content of the Milky Way, analysing the kinematics of objects in its stellar halo out to a very large distance from the Galactic Centre, 120 kpc! For the main part of my project I worked on a sample of dwarf spheroidal galaxies, nearby small satellite galaxies of the Milky Way, using spectroscopic data from VLT/FLAMES for hundreds of individual stars in these systems. I used these data to derive the dark matter content of these galaxies, among the most dark matter dominated systems known to date, and to study their chemical and kinematic properties. I cherish the years I spent in Groningen, not only for the highly stimulating and friendly work environment of the Kapteyn Astronomical Institute, but also because of the many people I met along the way who made me feel at home and made my time there unforgettable.

In 2007 I moved to Germany to join ESO as a fellow. Currently at ESO Garching I still like to pursue the kind of research I carried out for my PhD and I am extending it to the types of dwarf galaxies that are found at the outskirts of the Local Group, the dwarf irregulars and the so-called transition dwarfs, with the aim of understanding whether the different dwarf types that we observe today may be the descendants of similar progenitors, or are actually intrinsically different systems. As part of my functional duties at ESO I am performing simulations to explore the feasibility of resolved stellar population studies at large distances using the European Extremely Large Telescope (E-ELT), the project for the largest ground-based optical and infrared telescope in the world. Working at ESO not only gives me the chance to make my own small contribution to such an exciting project as the E-ELT, but also to be in one of the places where the future direction of European astronomy is decided and where a great part of the action takes place. Definitely a very interesting place to be!

Blair Conn

As an Australian coming to Chile there were a lot of familiar aspects of life waiting for me. I'd travelled a lot in Chile in 2001 and knew what to expect from the scenery and that, like Australians, Chileans are fairly laid back. The seasons weren't backwards and when gazing up at the night sky from La Silla, the stars were reassuringly like home and Christmas in summer is perfectly normal. Originally scheduled for Paranal, a hasty meeting was organised soon after I arrived and it was decided I'd go to La Silla to work on the Wide Field Imager at the MPG/ESO 2.2-metre telescope. In the three years since then I've had a wonderful experience at the La Silla Observatory and will miss it dearly.

As I sit here writing this, on the 9th of August, my last night as a support astronomer on La Silla, it certainly feels sad to be leaving this place. In all my visits here I've never grown tired of the mountains — they have this quiet majesty that creates a very special atmosphere of calm and tranquility. The gentle hues of the desert slowly turn red with the setting Sun and make it really feel like a privilege to be a witness to this transformation. But the real show is at night, when the Moon is yet to appear, and the Milky Way stretches across the entire sky in one vast ceiling of stars. I am pleasantly surprised that after all this time up here I'm still amazed at how beautiful it is. It is probably time to leave astronomy if I ever get cynical about the night sky.

Most people I talk to agree that La Silla is one of the special observatories of the world, remarking that it has a real family atmosphere amongst all who work and visit here, and I think it's true. There is always a smile and a laugh accompanying any task and my time working closely with the telescope operators and the engineering staff has been a great learning experience and lots of fun. They have really shown me what it means to work at an observatory. The small, but dedicated team, of La Silla astronomers have been a wonderful support when the going got tough or when a healthy dose of humour was needed. I have often relied on them to help me find solutions to the tricky problems that surface from time to time.

Before coming to Chile I was doing my PhD at The University of Sydney and now, as I move into my fourth year as an ESO fellow, I'm heading off to the Max-Planck-Institut für Astronomie in Heidelberg. There will be many new challenges ahead, least of all learning some German, and I'm excited about having the chance to live in Europe. I'm sure though that my time spent in Chile and especially here at the Observatory will stay with me. This place has become a second home to me and I'm already looking forward to when I can return.

Announcement of the ESO/ESA Joint Workshop

JWST and the ELTs: An Ideal Combination

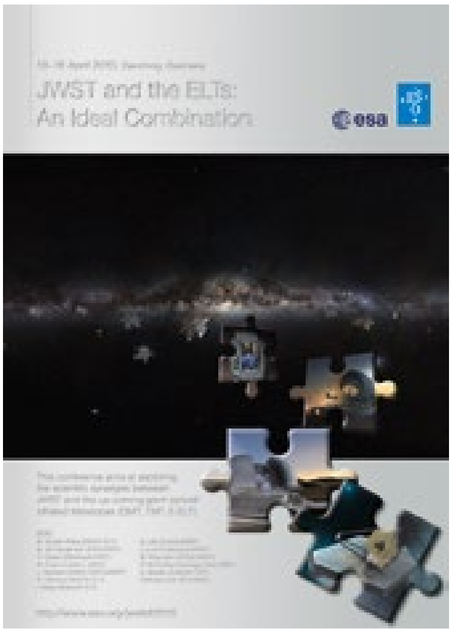
13–16 April 2010, Garching, Germany

ESA and ESO are jointly organising a workshop to explore synergies between the James Webb Space Telescope (JWST) and the extremely large telescopes (ELTs). The main goal of the workshop is to bring the JWST and ELT communities together, to identify the common science cases, and to outline instrumentation/upgrade priorities for the ELTs that would maximise the scientific return in key areas of scientific research requiring both facilities:
- The end of the Dark Ages: First Light and reionisation
- Assembly of galaxies
- The birth of stars and protoplanetary systems
- Planetary systems and the origins of life

The workshop is particularly timely, as it will feedback into the instrument suite selection of the ELTs. At the same time, JWST instruments are essentially complete and the joint telescope/instrument parameters well understood.

The Scientific Organising Committee is composed of: Markus Kissler-Patig (ESO/E-ELT); Mark McCaughrean (ESA/JWST); René Doyon (Montreal/JWST); Marijn Franx (Leiden/JWST); Jonathan Gardner (NASA GSFC/JWST); Roberto Gilmozzi (ESO/E-ELT); Isobel Hook (Rome/E-ELT); Simon Lilly (Zurich/JWST); Jonathan Lunine (Arizona/JWST); Matt Mountain (STScI/JWST); Pat McCarthy (Carnegie Observatory/GMT); Chuck Steidel (Caltech/TMT); Gillian Wright (UK ATC/JWST).

The deadline for registration is 15 January 2010 and more details can be found on the conference web pages at: www.eso.org/jwstelt2010.



Personnel Movements

Arrivals (1 October–31 December 2009)

Europe	
Bois, Maxime (F)	Student
Castro, Sandra Maria (BR)	Software Engineer
Cortesi, Arianna (I)	Student
Fontani, Francesco (I)	Fellow
Goddi, Ciriaco (I)	Fellow
González Gutiérrez, Juan Esteban (RCH)	Fellow
Krajnovic, Davor (HR)	Fellow
Krüger, Anna (D)	Administrative Assistant
Lagadec, Eric (F)	Fellow
Lewis, Steffan (GB)	Laser Engineer
Maury, Anaelle (F)	Fellow
McPherson, Alistair (GB)	Mechanical Engineer
Panic, Olja (BIH)	Fellow
Smiljanic, Rodolfo (BR)	Fellow
Trotta, Francesco (I)	Student
Unterguggenberger, Stefanie (A)	Student
Williams, Michael (GB)	Student

Chile	
Alamo, Karla Adriana (MEX)	Student
Arriagada, Oriel Alberto (RCH)	Electronic Engineer
Bayo, Amelia (E)	Fellow
Gadotti, Dimitri (BR)	Fellow
Huerta, Nicolas (RCH)	Software Engineer
Jilkova, Lucie (CZ)	Student
Kabath, Petr (CZ)	Fellow
Martin, Sergio (E)	Fellow
Mateluna, Reneé Cecilia (RCH)	Student
Ribes, Mauricio (RCH)	Instrumentation Engineer

Departures (1 October–31 December 2009)

Europe	
Biereichel, Peter (D)	Senior Software Engineer
Cullum, Martin (GB)	Former Head of Technical Division
Feng, Yan (VR)	Laser Physicist
Ferguson, Neil (GB)	Software Engineer
Gil, Carla (P)	Fellow
Gilmour, Rachel Emily (GB)	Fellow
Kotamäki, Miikka (FIN)	Mechanical Engineer
Misgeld, Ingo (D)	Student
Nittel, Frank (D)	Draughtsman
Robinson, Mark (GB)	Design Study Project Manager
Santangelo, Gina (I)	Student
Szyszka, Cezary (PL)	Student
Tanaka, Masayuki (J)	Fellow

Chile	
Asmus, Daniel (D)	Student
Caceres, Claudio (RCH)	Student
Di Cesare, Maria Alejandra (RA)	Operations Staff Astronomer (APEX)
Huertas-Company, Marc (E)	Fellow
Le Bouquin, Jean Baptiste (F)	Fellow
Leon, Gino (RCH)	Telescope Instruments Operator
O'Brien, Kieran (GB)	Operations Astronomer
Salinas, Ricardo (RCH)	Student
Sanhueza, Roberto (RCH)	Data Handling Administrator
Schütz, Oliver (D)	Operations Astronomer

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It is supported by 14 countries: Austria, Belgium, the Czech Republic, Denmark, France, Finland, Germany, Italy, the Netherlands, Portugal, Spain, Sweden, Switzerland and the United Kingdom. ESO's programme is focused on the design, construction and operation of powerful ground-based observing facilities. ESO operates three observatories in Chile: at La Silla, at Paranal, site of the Very Large Telescope, and at Llano de Chajnantor. ESO is the European partner in the Atacama Large Millimeter/submillimeter Array (ALMA) under construction at Chajnantor. Currently ESO is engaged in the design of the 42-metre European Extremely Large Telescope.

The Messenger is published, in hardcopy and electronic form, four times a year: in March, June, September and December. ESO produces and distributes a wide variety of media connected to its activities. For further information, including postal subscription to The Messenger, contact the ESO education and Public Outreach Department at the following address:

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

The Messenger:
Editor: Jeremy R. Walsh
Design, Layout, Typesetting:
Jutta Boxheimer
www.eso.org/messenger/

Printed by Peschke Druck
Schatzbogen 35, 81805 München
Germany

ISSN 0722-6691

Contents

Telescopes and Instrumentation

Astronomical Science

Astronomical News

Front Cover: One of the first public images from the VISTA telescope is shown. This colour composite of the star-forming H II region NGC 2024 was formed from images in *J*, *H* and *Ks* bands with a total exposure time per pixel of about 15 minutes. The image size is 26 × 36 arcminutes. Brackett-γ emission from ionised gas is visible in red. The bright star to the bottom of the image (north to the right, east top) is ζ Orionis (a multiple early-type star system), but the ionising source of NGC 2024 is the central embedded cluster. Credit: ESO/J. Emerson/VISTA. Acknowledgement: Cambridge Astronomical Survey Unit.