20TH ANNIVERSARY OF SCIENCE EXPLORATION WITH FORS

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"Of all instruments at Paranal, FORS is the Swiss Army knife."

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Twenty years ago, in 1999, the first of the two FORS instrument started regular operations. If FORS1 was removed after 10 years of operations, its twin, FORS2, is still very much in use, being one of the most demanded instruments at the Very Large Telescope, despite its age. This booklet aims at celebrating these two formidable workhorses by putting together, after a description of the instruments and their productivity, a subjective collection of ESO press releases dealing with them. The first set of press releases present the history of the instruments, while the remaining ones showcase some of the astounding achievements that they allowed. In between, a few among the most iconic images ever produced by FORS1 and FORS2 are shown. The list of scientific papers on which the science press releases were based is given at the end, together with a few of the Messenger articles that described the instruments.

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Unless indicated, all images are credit ESO.

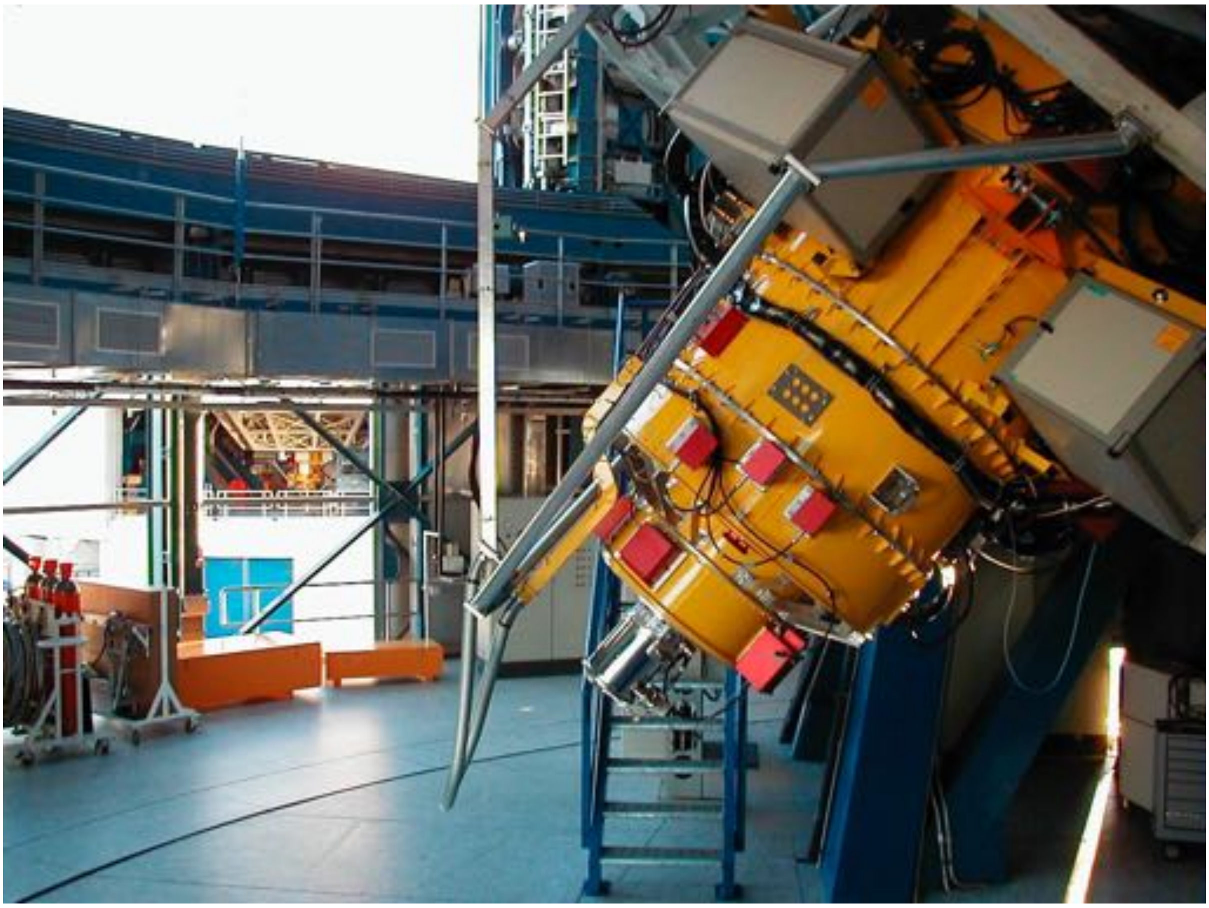
The Horsehead Nebula

The FORS Instruments

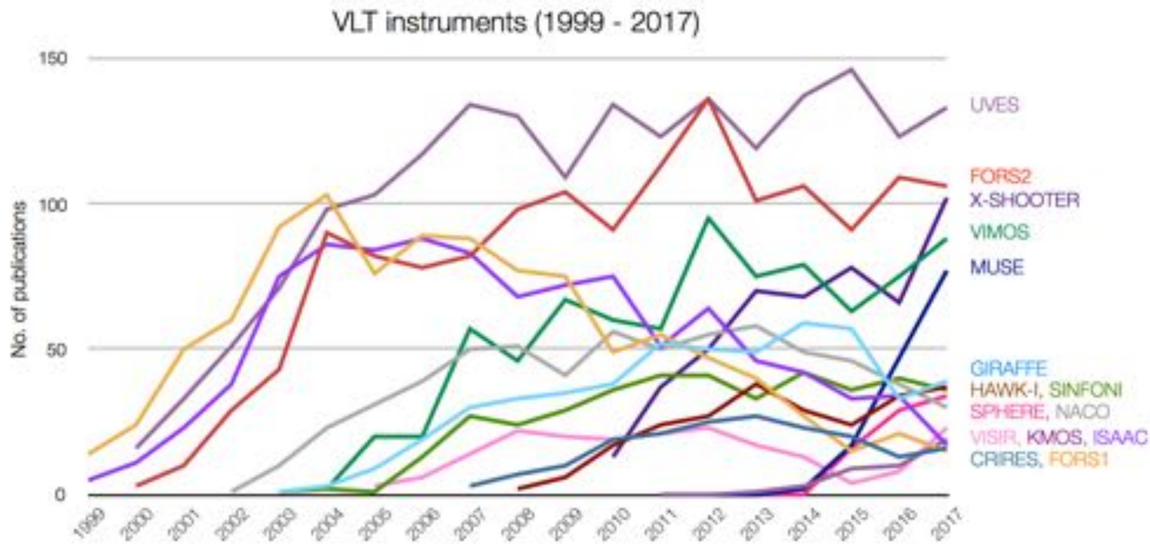
FORS — the FOcal Reducer and low dispersion Spectrograph — came in two copies, as some of the earliest instruments for the Very Large Telescope at Paranal. FORS1 had First Light in September 1998, starting regular operations in April 1999, with FORS2 following in April 2000. FORS1 was retired in 2009, and FORS2 refurbished to combine elements from both FORSes. Both instruments have been in high demand, and this hasn't changed much: FORS2 is still among the most demanded instruments at the VLT with 102 proposals submitted in P102 (or 12% of all VLT ones).

FORS2 is currently the Swiss army knife of the Paranal Observatory as an instrument covering the wide wavelength range from 330 nm to 1100 nm, with a very great sensitivity, over a field of view of 6.8 x 6.8 arcmin^2. It is also characterized by a superior image quality (in part due to a passive flexure compensation system) and is furthermore equipped with a Longitudinal atmospheric dispersion corrector (LADC) which acts up to about 60 degrees away from zenith (i.e. airmass 2). The astrometric precision reached is about 0.1 milli-arsecond using the high-resolution collimator. The instrument can also be used in spectroscopic mode with a magnitude limit between 23 and 24, as well as in polarimetric mode (imaging or spectroscopy). Built by a consortium of German institutes, its name is thus a clear understatement, as these instruments should have been called *FORFISMOSPOL*, for FOcal Reducer Fast Imager and low dispersion Single and Multi-Object SpectroPOLarimeter!

FORS2 spectroscopy consists of three modes: classical long-slit spectroscopy with slits of 6.8' length and predefined widths



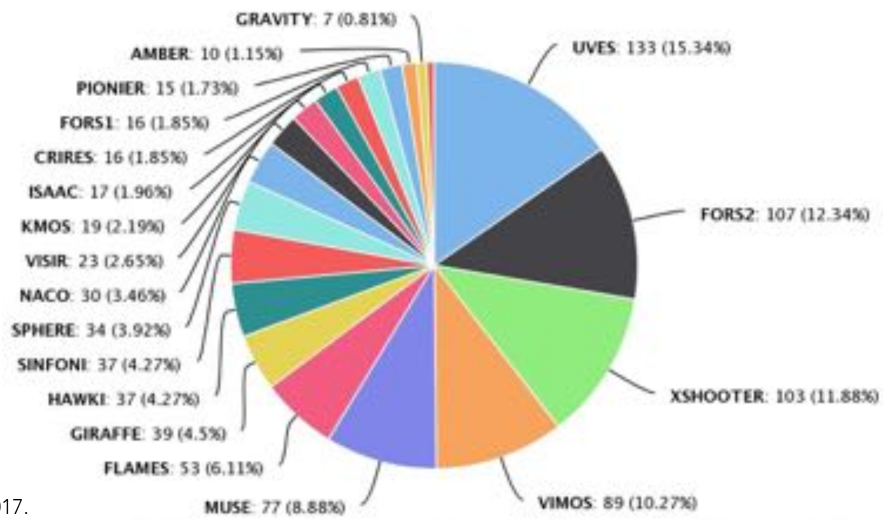
The two FORSes at Paranal.



Refereed publications using data from VLT instruments. FORS2 is still one of the most productive instrument.

between 0.3'' and 2.5'' (long-slit spectroscopy mode, [LSS]); multi-object spectroscopy with 19 slitlets of 20–22'' length each and arbitrary width created by movable slit blades (MOS mode); and multi-object spectroscopy using masks with slitlets of almost arbitrary length, width, shape and angle (MXU mode). There are 15 grisms with resolutions (for a 1''-slit) from 260 to 2600, which may be combined with three different order-separating filters to avoid second-order contamination.

The FORS instruments are among the most successful instruments in Paranal. Thus FORS1 led to 1022 refereed publications, while for FORS2 this number is 1511. In 2017 alone, FORS2 led to 107 refereed publications, putting it in second place of all La Silla Paranal instruments. Among these, there were 3 papers published in Nature, highlighting innovative science done with it: the first interstellar comet detected in the solar system (Meech et al. 2017, Nature 552, 378; see also Micheli et al. 2018, Nature 559, 223), the spectroscopic identification of the gravitational wave source (Pian et al. 2017, Nature 551, 67) and the first detection of titanium oxide in the atmosphere of an exoplanet (Sedaghati et al. 2017, Nature 549, 238; see also Nikolov et al. 2018, Nature 557, 526). Over the years, FORS2 led to 29 Nature papers and 10 Science papers. Apart from the above-mentioned topics, these papers dealt with a variety of topics, including asteroids,



Number of refereed publications per VLT instrument published in 2017.

binary stars, neutron stars, supernovae, black holes, gamma-ray bursts, and quasars. All the modes of FORS2 were used for these discoveries.

A presentation of the FORS science can be found in Rupprecht et al. (2010, Messenger 140, 2). At that time, it was already stated that "*If we look at the number of citations of VLT papers, it is symptomatic that at least one of the two FORS instruments was involved in eight of the ten most cited VLT papers.*"

Among the most cited FORS2 papers, one finds obviously the spectroscopic study of the GOODS-South field (Vanzella et al. 2005, A&A 434, 53; 2006, A&A 454, 423; 2008, A&A 478, 83; Popesso et al. 2009, A&A 494, 443; Balestra et al. 2010, A&A 512, A12) and of the Chandra Deep Field-South (Szokoly et al. 2004, ApJS 155, 271), which are based on MXU observations. Looking at the most recent years, the most cited papers are about Ly-alpha emitters in the early universe (MXU), spectropolarimetry of massive stars, photometry studies of young stellar regions, astrometric studies of brown dwarfs and transmission spectroscopy of exoplanets. Hence, again, this shows that all modes of FORS2 are used and lead to high impact science.

The fraction of modes used by FORS2 between 2009 and end 2016 is shown in the table below.

Mode	Number of OBs	% of total	Number of Runs	% of total
IMG	3521	27	437	31
LSS	4255	33	389	28
MOS	366	3	50	4
MXU	2395	19	222	16
IMG,PRE	634	5	117	8
PMOS	1707	13	142	10
IPOL	432	3	48	3
HIT	34	0.3	9	0.6
Total:	**12944**		**1414**	

Statistics on the usage of different FORS2 modes. IMG=imaging; IMG,PRE=pre-imaging for MOS and MXU; PMOS=spectro-polarimetry; IPOL=polarimetry imaging; HIT=high time-resolution imaging (now decommissioned).

It is interesting to note that much of the current science done with FORS2 differ from what was initially foreseen (e.g., FORS2 SV in Renzini & Rosati 1999, Messenger 98, 24) and therefore leads to different require–ments. For example, many current program–mes use relatively short exposure times (and some do time monitoring), where we are mostly photon-noise limited and where the read-out time of the CCD should be as small as possible.

NGC 3190

FORS: The Most Powerful Eye

5 February 1992

In 1991, and following a one-year preparatory phase after which a number of astronomical institutes were invited to participate in a tendering for two types of VLT instruments, ESO's Finance Committee agreed that contracts for these should be placed with two consortia of leading European astronomical institutes.

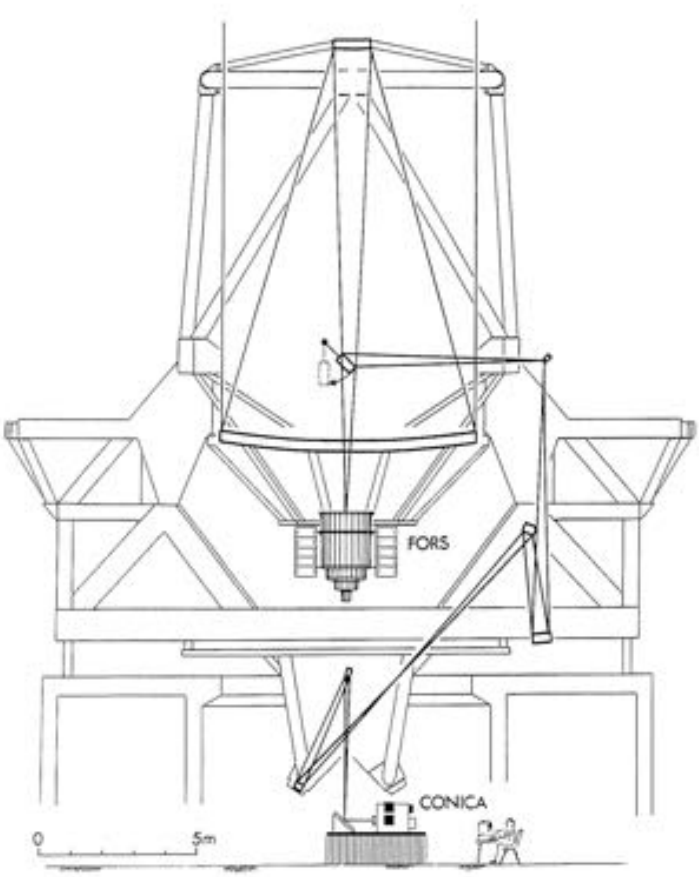
The selection process was very competitive and several proposals of high quality emanated from the community, all of which conformed with the very tough technical requirements. The stringent financial limits also played an important role in the present decision. The chosen consortia have proven merits in the instrumental field and can look forward to great challenges and opportunities during the coming years.

A consortium of the Heidelberg State Observatory and the University Observatories of Göttingen and Munich will construct two copies of a FOcal Reducer/low dispersion Spectrograph FORS, to be installed at the Cassegrain foci of VLT Unit Telescopes 1 (in 1996) and 3 (in 1998).

The contracts stipulate that ESO will pay for the hardware (about 6 million DM in all) and also exercise the quality control of the projects, while the institutes will provide the manpower, estimated to be about 170 man-years for the design, construction and testing. Moreover, the astronomers at the participating institutes will perform the first observations with the new instruments, immediately following a very thorough testing phase. They will therefore have the privilege of being the first to exploit the great potential of their instruments for important new discoveries, before other groups of European astronomers also begin to profit from the new facilities.

FORS (~2,000 kg) will be the real workhorse instrument for the VLT and will be produced in two copies to be installed at two of the 8.2-metre VLT Unit Telescopes. FORS will work in the visual part of the spectrum (320–1000 nm) and will refocus the collected light so that there will be a perfect match between the size of a stellar image and the individual image elements (pixels) of the very sensitive CCD detectors. This is necessary because the technique of adaptive optics does not (yet) work in visual light so the size of visual images will be determined by the instantaneous atmospheric turbulence (which is particularly small at the site chosen for the VLT observatory, the Paranal mountain in the Chilean Atacama Desert). In this way, FORS will permit a better concentration of the light so that the faintest possible objects can be observed. A special, "flexure-compensation" system will ensure that FORS will remain extremely stable during the very long exposure times anticipated for the detection and observation of such faint objects.

By means of various optical elements which can be inserted into the light beam, FORS can



CONICA and FORS at an 8.2-m VLT Unit Telescope

also perform low-dispersion spectroscopy, multi-object spectroscopy and polarimetry.
It is expected that FORS will be able to produce images of objects of magnitude 30 (about 4,000 million times fainter than what can be perceived with the unaided eye) during a cumulative exposure time of only 1 hour. The combination of several such exposures will show even fainter objects. Thus, there is little doubt that some of the first observational programmes with FORS will look significantly further out in space and correspondingly further back in time than what is possible with any existing telescopes. Very remote, young galaxies and quasars will be prime objects and statistical investigations of their distribution will provide a unique possibility to investigate the structure and evolution of the very young universe. It is also possible that FORS will be able to detect galaxies which are actually in the course of being formed.

Another major task of FORS will be to provide accurate distances of more nearby galaxies, in order to establish a firm basis for the cosmological distance scale. This will be done by detailed spectral observations of individual objects in these galaxies, for instance of globular clusters, planetary nebulae and exploding stars, novae and supernovae. With its ability to observe the spectra of up to 19 objects simultaneously, FORS will be a very efficient instrument for observations of this type.

It is expected that spectra sufficiently detailed to permit rather accurate abundance analysis can be obtained of stars of magnitude 20, i.e. in galaxies well beyond the Local Group at a distance of about 15 million light-years, that is much further than before possible. This will give a first indication of whether or not the chemical composition is the same as in our Milky Way, and therefore if the Universe is homogeneous on this scale.

First Major Astronomical Instrument Mounted on VLT

11 September 1998

After seven years of design and construction, and much preparatory work at Paranal, the first scientific instrument of the VLT, FORS1, was successfully mounted on the Cassegrain focus of the first 8.2-m VLT telescope (UT1) yesterday. FORS1 and its sister instrument, FORS2 (to be mounted at UT2 towards the end of 1999), have been designed to obtain images and spectra in the visual spectral region of the faintest possible objects.

FORS1 was assembled in the Instrument Area at the Paranal Base Camp and the operation began by the loading of FORS1 onto the Instrument Carriage. It was then hoisted onto the ESO 10-ton truck and slowly transported up the mountain to the UT1 enclosure in the morning of September 10. Here it was carefully lifted from the truck using the big M1 Lift Platform as a crane. It was driven inside the building and hoisted to the Azimuth platform with the enclosure crane.

Late in the afternoon, it was moved under the Cassegrain focus, then lifted and bolted to the flange inside the main mirror cell (M1 cell). The entire operation went very smoothly and this was a great moment for all involved!

There is still much work to be done before FORS1 will become fully operational. The detector must be prepared and installed, connections for power and communications have to be made and the proper functioning of all instrument components on the telescope under software control have to be carefully verified. Only then will FORS1, for the first time, 'see' the light from stars and galaxies and begin to explore the universe. If all goes well, FORS1 will produce its first test images within a few days.

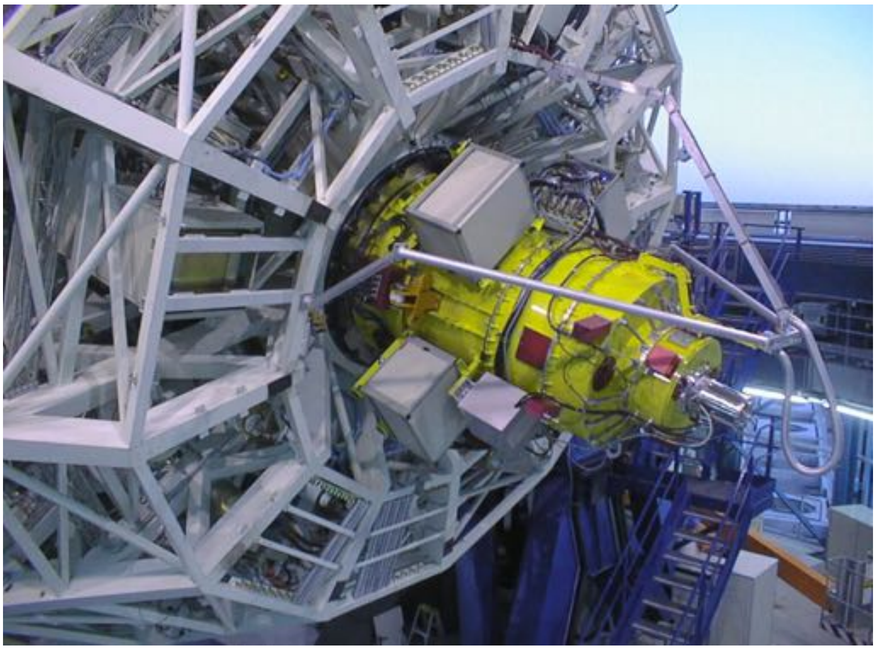
A Forceful Demonstration by FORS

23 September 1998

Following a tight schedule, the ESO Very Large Telescope (VLT) project forges ahead – full operative readiness of the first of the four 8.2-m Unit Telescopes will be reached early next year. On September 15, 1998, another crucial milestone was successfully passed on-time and within budget. Just a few days after having been mounted for the first time at the first 8.2-m VLT Unit Telescope (UT1), the first of a powerful complement of complex scientific instruments, FORS1 (FOcal Reducer and Spectrograph), saw 'First Light'. Right from the beginning, it obtained some excellent astronomical images. This major event now opens a wealth of new opportunities for European Astronomy.

FORS1, with its future twin (FORS2), is the product of one of the most thorough and advanced technological studies ever made of a ground-based astronomical instrument. This unique facility is now mounted at the Cassegrain focus of the VLT UT1. Despite its significant dimensions, 3 x 1.5 metres and 2.3 tonnes, it appears rather small below the giant 53 m^2 Zerodur main mirror. Profiting from the large mirror area and the excellent optical properties of the UT1, FORS has been specifically designed to investigate the faintest and most remote objects in the universe. This complex VLT instrument will soon allow European astronomers to look beyond current observational horizons.

The FORS instruments are 'multi-mode instruments' that may be used in several different observation modes. It is, e.g., possible to take images with two different image scales (magnifications) and spectra at different resolutions may be obtained of individual or multiple objects. Thus, FORS may first detect the images of distant galaxies and immediately thereafter obtain recordings of their spectra. This allows for instance the



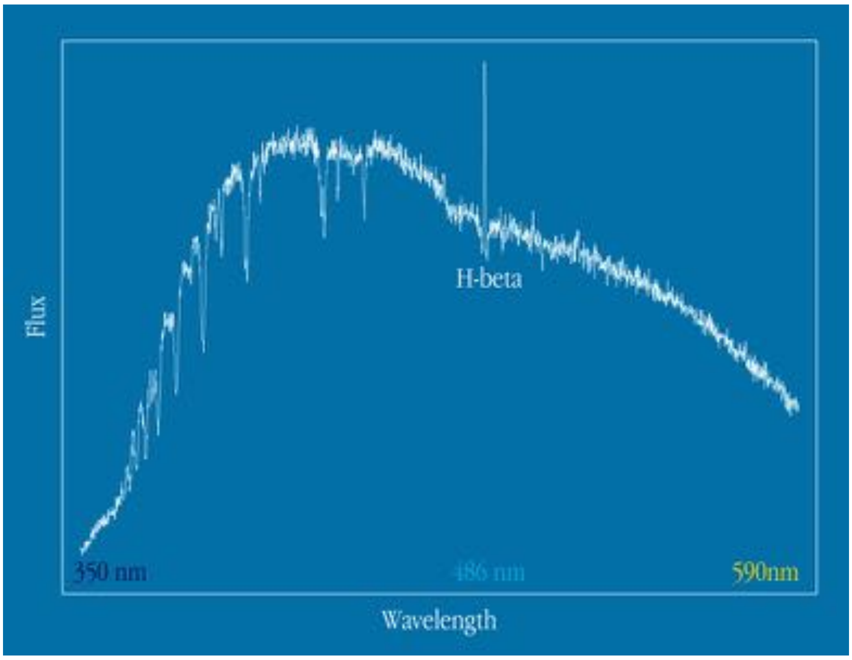
determination of their stellar content and distances.
As one of the most powerful astronomical instruments of its kind, FORS1 is a real workhorse for the study of the distant universe.

The FORS project is being carried out under ESO contract by a consortium of three German astronomical institutes, namely the Heidelberg State Observatory and the University Observatories of Göttingen and Munich. When this project is concluded, the participating institutes will have invested about 180 man-years of work.

The Heidelberg State Observatory was responsible for directing the project, for designing the entire optical system, for developing the components of the imaging, spectroscopic, and polarimetric optics, and for producing the special computer software needed for handling and analysing the measurements obtained with FORS. Moreover, a telescope simulator was built in the shop of the Heidelberg observatory that made it possible to test all major functions of FORS in Europe, before the instrument was shipped to Paranal.

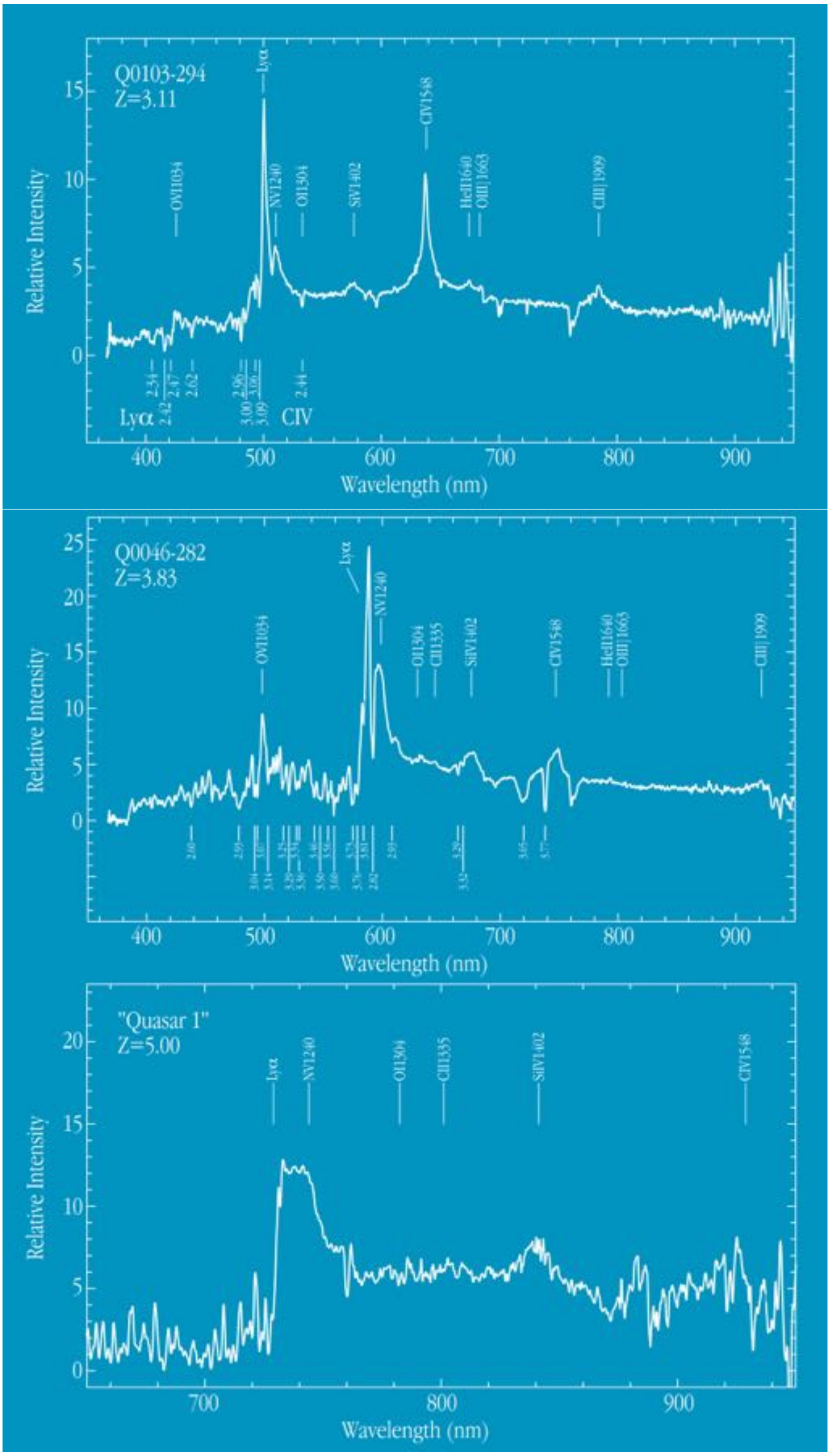
The University Observatory of Göttingen performed the design, the construction and the installation of the entire mechanics of FORS. Most of the high-precision parts, in particular the multislit unit, were manufactured in the observatory's fine-mechanical workshops. The procurement of the huge instrument housings and flanges, the computer analysis for mechanical and thermal stability of the sensitive spectrograph and the construction of the handling, maintenance and aligning equipment as well as testing the numerous opto- and electro-mechanical functions were also under the responsibility of this Observatory.

The University of Munich had the responsibility for the management of the project, the integration and test in the laboratory of the complete instrument, for design and installation of all electronics and electro-mechanics, and for developing and testing the comprehensive software to control FORS in all its parts completely by computers (filter and grism wheels, shutters, multi-object slit units, masks, all optical components, electro motors, encoders, etc.). In addition, detailed computer software was provided to prepare the complex astronomical observations with FORS in advance and to monitor the instrument performance by quality checks of the scientific data accumulated.



One of the first spectra of FORS1: Tracing of the spectrum of a Be star ('Be41') in the open cluster NGC 330 in the Small Magellanic Cloud.

In return for building FORS for the community of European astrophysicists, the scientists in the three institutions of the FORS Consortium have received a certain amount of *Guaranteed Observing Time* at the VLT. This time will be used for various research projects concerned, among others, with minor bodies in the outer solar system, stars at late stages of their evolution and the clouds of gas they eject, as well as galaxies and quasars at very large distances, thereby permitting a look-back towards the early epoch of the universe.



Spectra of three distant quasars taken with FORS1 in September and December 1998.

Next VLT Instrument Ready for the Astronomers

FORS2 commissioning period successfully terminated

8 February 2000

The commissioning of the FORS2 multi-mode astronomical instrument at KUEYEN , the second FOcal Reducer/low dispersion Spectrograph at the ESO Very Large Telescope, was successfully finished today. This important work — that may be likened with the test driving of a new car model — took place during two periods, from October 22 to November 21, 1999, and January 22 to February 8, 2000.

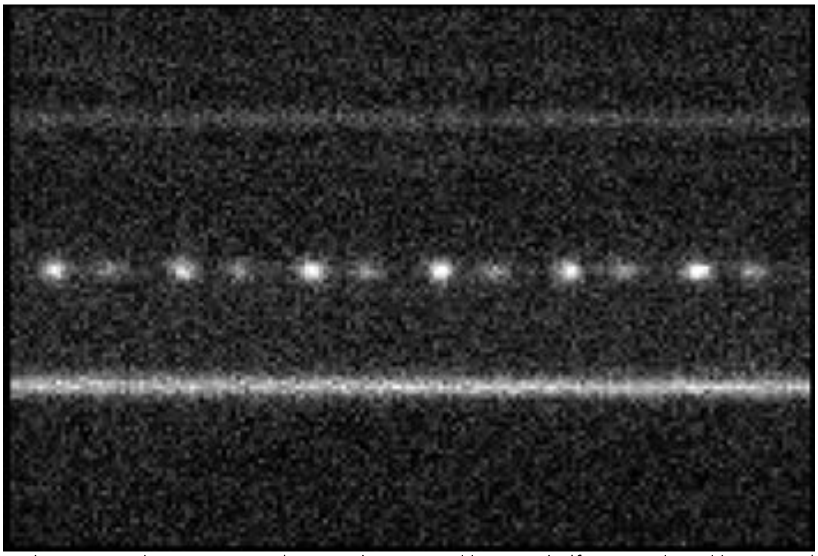
The overall goal was to thoroughly test the functioning of the new instrument, its conformity to specifications and to optimize its operation at the telescope. FORS2 is now ready to be handed over to the astronomers on April 1, 2000. Observing time for a six-month period until October 1 has already been allocated to a large number of research programmes.

The FORS Commissioning Team carried out a comprehensive test programme for all observing modes. These tests were done with 'observation blocks (OBs)' that describe the set-up of the instrument and telescope for each exposure in all details, e.g., position in the sky of the object to be observed, filters, exposure time, etc. Whenever an OB is 'activated' from the control console, the corresponding observation is automatically performed.

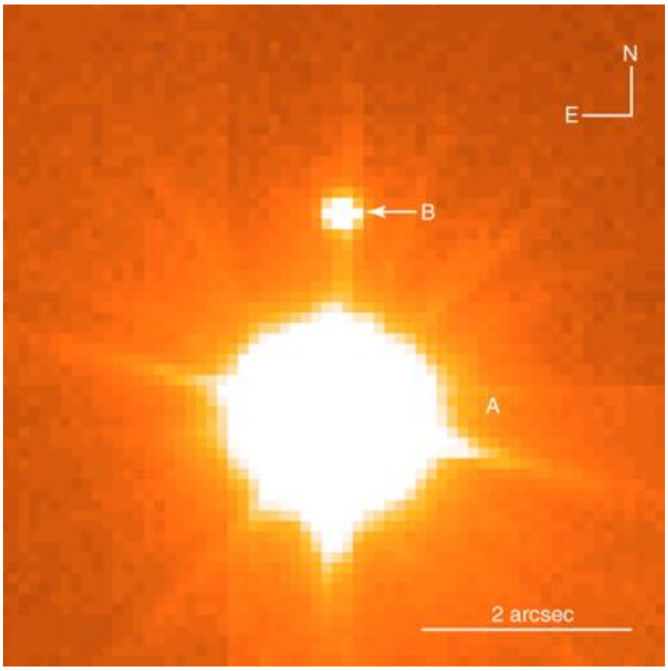
The FORS2 observing modes include direct imaging, long-slit and multi-object spectroscopy, exactly as in its twin, FORS1 at ANTU. In addition, FORS2 contains the 'Mask Exchange Unit', a motorized magazine that holds 10 masks made of thin metal plates into which the slits are cut by means of a laser. The advantage of this particular observing method is that more spectra (of more objects) can be taken with a single exposure (up to approximately 80) and that the shape of the slits can be adapted to the shape of the objects, thus increasing the scientific return. Results obtained so far look very promising.

To increase further the scientific power of the FORS2 instrument in the spectroscopic mode, a number of new optical dispersion elements ('grisms', i.e., a combination of a grating and a glass prism) have been added. They give the scientists a greater choice of spectral resolution and wavelength range.

Another mode that is new to FORS2 is the high time resolution mode. It was demonstrated with the Crab pulsar and promises very interesting scientific returns.



In this image, the continuous lines in the top and bottom half are produced by normal stars of constant brightness, while the series of dots represents the individual pulses of the Crab pulsar, one every 33 milliseconds (i.e. the neutron star rotates around its axis 30 times per second). It is also obvious that these dots are alternatively brighter and fainter: they mirror the double-peaked profile of the light pulses.



An image of TWA-5 A (lower, bright object) and TWA-5 B (upper), taken with the FORS-2 multi-mode instrument at the 8.2-m VLT/KUEYEN telescope on 21 February 2000. The integration time was 1 second through an *I*-band filter (wavelength 900 nm) with the high-resolution collimator. The image quality is 0.18 arcsec FWHM (full-width-half maximum). The lines emerging from the bright image are caused by optical reflection in the telescope.

The Tarantula Nebula in the Large Magellanic Cloud (LMC) as obtained with FORS2 at KUEYEN during the night of January 31 - February 1, 2000.


Crab Nebula

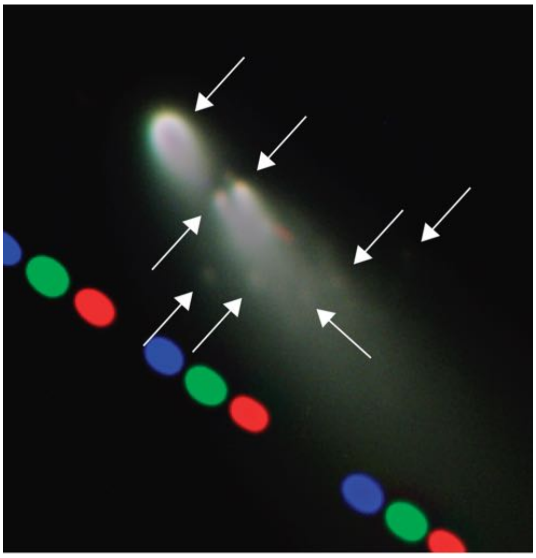
The Comet with a Broken Heart

VLT takes images of disintegrating comet 73P/Schwassmann-Wachmann 3

25 April 2006

On the night of April 23 to 24, ESO's Very Large Telescope observed fragment B of the comet Schwassmann-Wachmann 3 that had split a few days earlier. To their great surprise, the ESO astronomers discovered that the piece just ejected by fragment B was splitting again! Five other mini-comets are also visible on the image. The comet seems thus doomed to disintegrate but the question remains in how much time.

Comet 73P/Schwassmann-Wachmann 3 (SW 3) is a body with a very tormented past. This comet revolves around the Sun in about 5.4 years, in a very elongated orbit that brings it from inwards of the Earth's orbit to the neighbourhood of giant planet Jupiter. In 1995, when it was coming 'close' to the Earth, it underwent a dramatic and completely unexpected, thousand-fold brightening.



Observations in 1996, with ESO's New Technology Telescope and 3.6-m telescope, at La Silla, showed that this was due to the fact that the comet had split into three distinct pieces. Later, in December 1996, two more fragments were discovered. At the last comeback, in 2001, of these five fragments only three were still seen, the fragments C (the largest one), B and E. No new fragmentations happened during this approach, apparently. Things were different this time, when the comet moved again towards its closest approach to the Sun - and to the Earth. Early in March, seven fragments were observed, the brightest (fragment C) being of magnitude 12, i.e. 250 fainter than what the unaided eye can see, while fragment B was 10 times fainter still. In the course of March, six new fragments were seen.

Early in April, fragment B went into outburst, brightening by a factor 10 and on 7 April, six new fragments were discovered, confirming the high degree of fragmentation of the comet. On 12 April, fragment B was as bright as the main fragment C, with a magnitude around 9 (16 times fainter than what a keen observer can see with unaided eyes). Fragment B seems to have fragmented again, bringing the total of fragments close to 40, some being most probably very small, boulder-sized objects with irregular and short-lived activity.

The new observations reveal that this new small fragment has split again! The image clearly reveals that below the main B fragment, there is a small fragment that is divided into two and a careful analysis reveals five more tiny fragments almost aligned. Thus, this image alone shows at least 7 fragments. The comet has thus produced a whole set of mini-comets! Will the process continue? Will more and more fragments form and will the comet finally disintegrate? How bright will the fragments be when the comet will be the closest to the Earth, on 11 to 14 May, and how many new fragments will have appeared before the comet reaches its closest approach to the Sun, around 7 June? Fragment C of the comet should be the closest to Earth on 11 May, when it will be about 12 million km away, while fragment B will come as 'close' as 10 million km from Earth on 14 May.

Although this is the closest a comet ever approached Earth in more than twenty years - even Comet Hyakutake's smallest distance was 15 million km - this is still 26 times the distance between the Earth and the Moon and therefore does not pose any threat to our planet.

New Image of Comet Halley in the Cold

VLT observes famous traveller at record distance

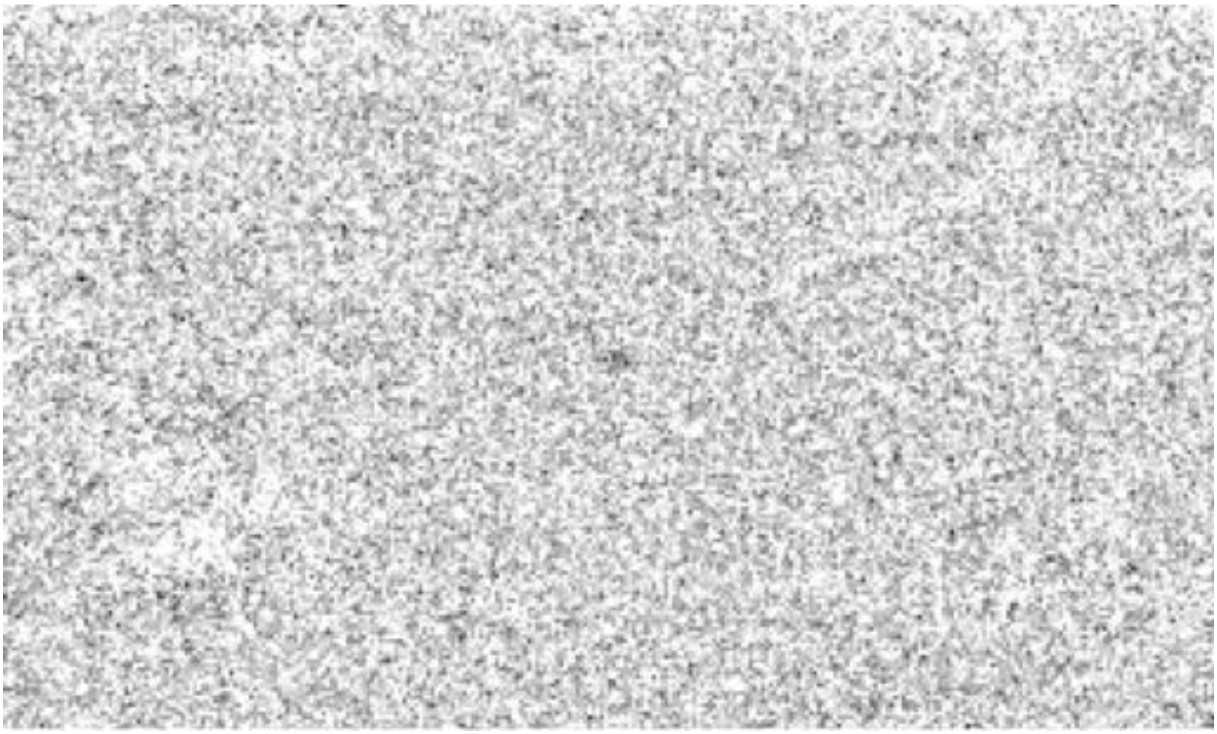
1 September 2003

Seventeen years after the last passage of Comet Halley, the ESO Very Large Telescope at Paranal (Chile) has captured a unique image of this famous object as it cruises through the outer solar system. It is completely inactive in this cold environment. No other comet has ever been observed this far — 4200 million km from the Sun — or that faint — nearly 1000 million times fainter than what can be perceived with the unaided eye. This observation is a byproduct of a dedicated search for small Trans-Neptunian Objects, a population of icy bodies of which more than 600 have been found during the past decade.

Remember Comet Halley — the famous 'haired star' that has been observed with great regularity — about once every 76 years — during more than two millennia? Which was visited by an international spacecraft armada when it last passed through the inner solar system in 1986? And which put on a fine display in the sky at that time?

Now, 17 years after that passage, this cosmic traveller has again been observed at the European Southern Observatory. Moving outward along its elongated orbit into the deep-freeze outer regions of the solar system, it is now almost as far away as Neptune, the most distant giant planet in our system.

At 4,200 million km from the Sun, Comet Halley has now completed four-fifths of its travel towards the most distant point of this orbit. As the motion is getting ever slower, it will reach that turning point in December 2023, after which it begins its long return towards the next passage through the inner solar system in 2062.



Faint, star-like image of Comet Halley (centre), observed with the ESO Very Large Telescope (VLT) at the Paranal Observatory on March 6-8, 2003. 81 individual exposures from three of the four 8.2-m VLT telescopes with a total exposure time of about 9 hours were combined to show the magnitude 28.2 object. At this time, Comet Halley was about 4200 million km from the Sun (28.06 au) and 4080 million km (27.26 au) from the Earth. All images of stars and galaxies in the field were removed during the extensive image processing needed to produce this unique image. Due to the remaining, unavoidable 'background noise', it is best to view the comet image from some distance. The field measures 60 x 40 $arcsec^2$.

The new image of Halley was taken with the Very Large Telescope. It was obtained as a byproduct of an observing program aimed at studying the population of icy bodies at the rim of the solar system. The image shows the raven-black, 10-km cometary nucleus of ice and dust as an unresolved faint point of light, without any signs of activity. The brightness of the comet was measured as visual magnitude $V = 28.2$, or nearly 1000 million times fainter than the faintest objects that can be perceived in a dark sky with the unaided eye.

The pitch black nucleus of Halley reflects about 4% of the sunlight; it is a very 'dirty' snowball indeed. We know from the images obtained by the ESA Giotto spacecraft in 1986 that it is avocado-shaped and on the average measures about 10 km diameter across. The VLT observation is therefore equivalent to seeing a 5-cm piece of coal at a distance of 20,500 km (about the distance between the Earth's poles) and to do so in the evening twilight. This is because at the large distance of Comet Halley, the infalling sunlight is 800 times fainter than here on Earth.

The measured brightness of the cometary image perfectly matches that expected for the nucleus alone, taking into account the distance, the solar illumination and the reflectivity of the surface. This shows that all cometary activity has now ceased. The nucleus is now an inert ball of ice and dust, and is likely to remain so until it again returns to the solar neighbourhood, more than half a century from now.

At 28.06 au heliocentric distance (1 au = 149,600,000 km — the mean distance between the Earth and the Sun), this is by far the most distant observation ever made of a comet. It is also the faintest comet ever detected (by a factor of about 5); the previous record, magnitude 26.5, was co-held by comet Halley at 18.8 au (with the ESO New Technology Telescope in 1994) and Comet Sanguin at 8.5 au (with the Keck II telescope in 1997). Interestingly, when Comet Halley reaches its largest distance from the Sun in December 2023, about 35 au, it will only be 2.5 times fainter than it is now. The comet would still have been detected within the present exposure time. This means that with the VLT, for the first time in the long history of this comet, the astronomers now possess the means to observe it at any point in its 76-year orbit!

The combination of the images from three 8.2-m telescopes obtained during three consecutive nights is not straightforward. The individual characteristics of the imaging instruments (FORS1 on ANTU, VIMOS on MELIPAL and FORS2 on YEPUN) must be taken into account and corrected. Moreover, the motion of the very faint moving objects has to be compensated for, even though they are too faint to be seen on individual exposures; they only reveal themselves when several (many!) frames are combined during the final steps of the process. It is for this reason that the presence of a known, faint object like Comet Halley in the field-of-view provides a powerful control of the data processing. If Halley is visible at the end, it has been done properly. The extensive data processing is now under way and the intensive search for new Transneptunian objects has started.

The field with Comet Halley was observed with the giant telescopes during each of three consecutive nights, yielding 81 individual exposures with a total exposure time of almost 9 hours. The faint comet is completely invisible on the individual images. Only by adding all frames does it appear. This is best done by 'subtracting' the images of all stars and galaxies from the individual exposures, before they are added. The photo of the previous page has been produced in this way and shows the image of Comet Halley more clearly. In total, about 20,000 photons were detected from the comet, i.e. about one photon per 8.2-m telescope every 1.6 second. However, during the same time, the telescopes collected about one thousand times more photons from molecular emission in the Earth's atmosphere within the sky area covered by the comet's image. The presence of this considerable 'noise' calls for very careful image processing in order to detect the faint comet signal.

The identity of the comet is beyond doubt: the image is faintly visible on composite photos obtained during a single night, demonstrating that the direction and rate of motion of the detected object perfectly matches that predicted for Comet Halley from its well-known orbit. Moreover, the image is located within one arcsecond from the predicted position in the sky.


NGC 2014
and NGC 2020

ESO Observations Show First Interstellar Asteroid is Like Nothing Seen Before

VLT reveals dark, reddish and highly-elongated object

20 November 2017

For the first time ever astronomers have studied an asteroid that has entered the Solar System from interstellar space. Observations show that this unique object was traveling through space for millions of years before its chance encounter with our star system. It appears to be a dark, reddish, highly-elongated rocky or high-metal-content object.

On 19 October 2017, the Pan-STARRS 1 telescope in Hawai‘i picked up a faint point of light moving across the sky. It initially looked like a typical fast-moving small asteroid, but additional observations over the next couple of days allowed its orbit to be computed fairly accurately. The orbit calculations revealed beyond any doubt that this body did not originate from inside the Solar System, like all other asteroids or comets ever observed, but instead had come from interstellar space. The object was reclassified as an interstellar asteroid and named 1I/2017 U1 (‘Oumuamua).

ESO’s Very Large Telescope was immediately called into action to measure the object’s orbit, brightness and colour more accurately than smaller telescopes could achieve. Speed was vital as ‘Oumuamua was rapidly fading as it headed away from the Sun and past the Earth’s orbit, on its way out of the Solar System.

Combining the images from FORS2 using four different filters with those of other large telescopes, the team of astronomers led by Karen Meech (Institute for Astronomy, Hawai‘i, USA) found that ‘Oumuamua varies dramatically in brightness by a factor of ten as it spins on its axis every 7.3 hours.

Karen Meech explains the significance: “*This unusually large variation in brightness means that the object is highly elongated: about ten times as long as it is wide, with a complex, convoluted shape. We also found that it has a dark red colour, similar to objects in the outer Solar System, and confirmed that it is completely inert, without the faintest hint of dust around it.*”

These properties suggest that ‘Oumuamua is dense, possibly rocky or with high metal content, lacks significant amounts of water or ice, and that its surface is now dark and reddened due to the effects of irradiation from cosmic rays over millions of years. It is estimated to be at least 400 metres long.

Preliminary orbital calculations suggested that the object had come from the approximate direction of the bright star Vega, in the northern constellation of Lyra. However, even travelling at a breakneck speed of about 95 000 km/h, it took so long for the interstellar object to make the journey to our Solar System that Vega was not near that position when the asteroid was there about 300 000 years ago. ‘Oumuamua may well have been wandering through the Milky Way, unattached to any star system, for hundreds of millions of years before its chance encounter with the Solar System.

Astronomers estimate that an interstellar asteroid similar to ‘Oumuamua passes through the inner Solar System about once per year, but they are faint and hard to spot so have been missed until now. It is only recently that survey telescopes, such as Pan-STARRS, are powerful enough to have a chance to discover them.

Artist’s impression of ‘Oumuamua.

VLT Rediscovers Life on Earth

By looking at the Moon

29 February 2012

By observing the Moon using ESO's Very Large Telescope, astronomers have found evidence of life in the Universe — on Earth. Finding life on our home planet may sound like a trivial observation, but the novel approach of an international team may lead to future discoveries of life elsewhere in the Universe.

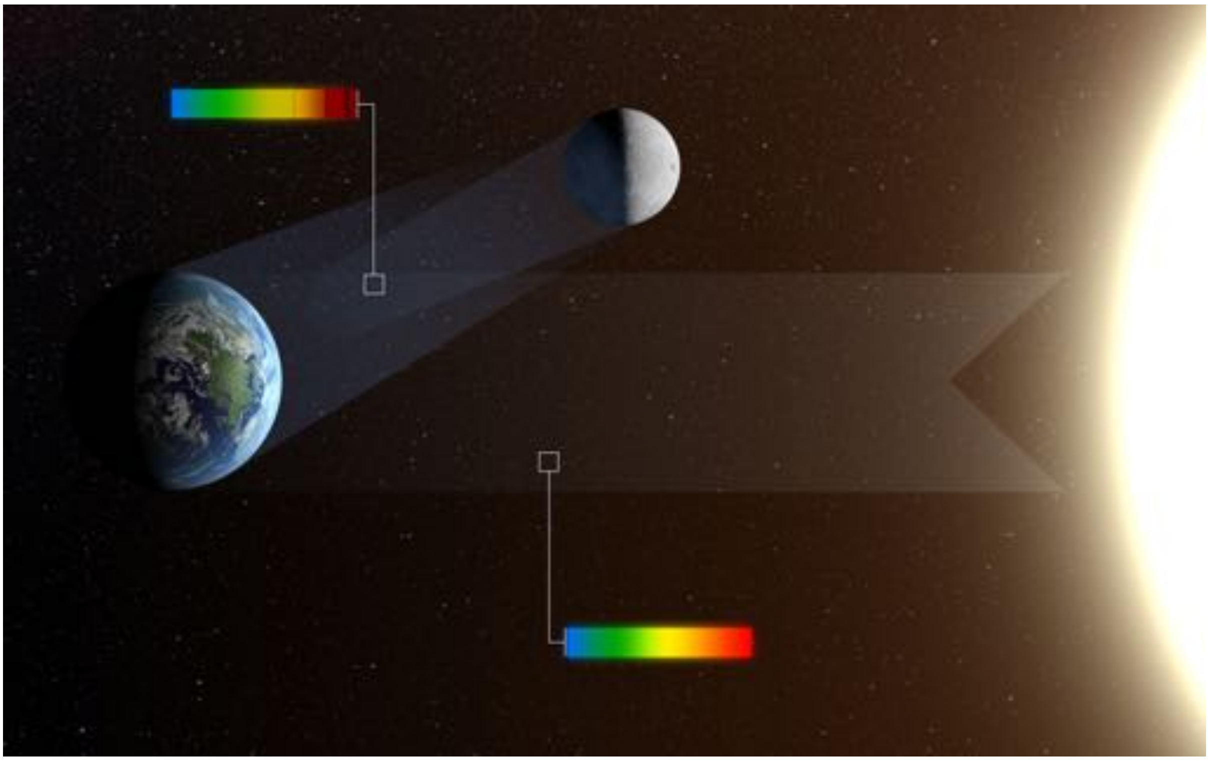
"*We used a trick called earthshine observation to look at the Earth as if it were an exoplanet,*" says Michael Sterzik (ESO), lead author of the paper. "*The Sun shines on the Earth and this light is reflected back to the surface of the Moon. The lunar surface acts as a giant mirror and reflects the Earth's light back to us — and this is what we have observed with the VLT.*"

The astronomers analyse the faint earthshine light to look for indicators, such as certain combinations of gases in the Earth's atmosphere, that are the telltale signs of organic life. This method establishes the Earth as a benchmark for the future search for life on planets beyond our Solar System.

The fingerprints of life, or biosignatures, are hard to find with conventional methods, but the team has pioneered a new approach that is more sensitive. Rather than just looking at how bright the reflected light is in different colours, they also look at the polarisation of the light, an approach called spectropolarimetry. By applying this technique to earthshine observed with the VLT, the biosignatures in the reflected light from Earth show up very strongly.

Co-author of the study Stefano Bagnulo (Armagh Observatory, Northern Ireland, United Kingdom) explains the advantages: "*The light from a distant exoplanet is overwhelmed by the glare of the host star, so it's very difficult to analyse — a bit like trying to study a grain of dust beside a powerful light bulb. But the light reflected by a planet is polarised, while the light from the host star is not. So polarimetric techniques help us to pick out the faint reflected light of an exoplanet from the dazzling starlight.*"

ESO/B. Tafreshi (twanight.org)



When the Moon appears as a thin crescent in the twilight skies of Earth it is often possible to see that the rest of the disc is also faintly glowing. This phenomenon is called earthshine. It is due to sunlight reflecting off the Earth and illuminating the lunar surface. After reflection from Earth the colours in the light, shown as a rainbow in this picture, are significantly changed. By observing earthshine astronomers can study the properties of light reflected from Earth as if it were an exoplanet and search for signs of life. The reflected light is also strongly polarised and studying the polarisation as well as the intensity at different colours allows for much more sensitive tests for the presence of life.

The team studied both the colour and the degree of polarisation of light from the Earth after reflection from the Moon, as if the light was coming from an exoplanet. They managed to deduce that the Earth's atmosphere is partly cloudy, that part of its surface is covered by oceans and — crucially — that there is vegetation present. They could even detect changes in the cloud cover and amount of vegetation at different times as different parts of the Earth reflected light towards the Moon.

"*Finding life outside the Solar System depends on two things: whether this life exists in the first place, and having the technical capability to detect it,*" adds co-author Enric Palle (Instituto de Astrofisica de Canarias, Tenerife, Spain). "*This work is an important step towards reaching that capability.*"

"*Spectropolarimetry may ultimately tell us if simple plant life — based on photosynthetic processes — has emerged elsewhere in the Universe,*" concludes Sterzik. "*But we are certainly not looking for little green men or evidence of intelligent life.*"

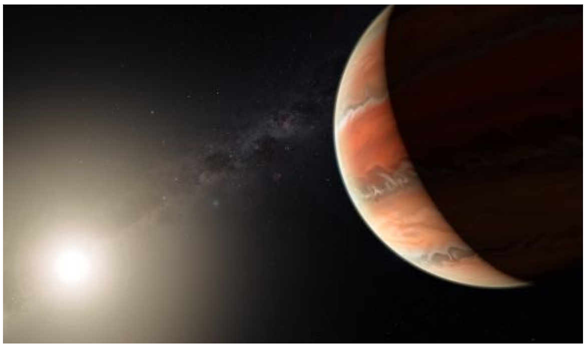
Credit: ESO/G.Hüdepohl (atacamaphoto.com)

The Medusa Nebula

Inferno World with Titanium Skies

ESO's VLT makes first detection of titanium oxide in an exoplanet

13 September 2017



Astronomers have detected titanium oxide in an exoplanet atmosphere for the first time. This discovery around the hot-Jupiter planet WASP-19b exploited the power of the FORS2 instrument. It provides unique information about the chemical composition and the temperature and pressure structure of the atmosphere of this unusual and very hot world.

A team of astronomers led by Elyar Sedaghati, an ESO fellow and recent graduate of TU Berlin, has examined the atmosphere of the exoplanet WASP-19b in greater detail than ever before. This remarkable planet has about the same mass as Jupiter, but is so close to its parent star that it completes an orbit in just 19 hours and its atmosphere is estimated to have a temperature of about 2000 degrees Celsius.

As WASP-19b passes in front of its parent star, some of the starlight passes through the planet's atmosphere and leaves subtle fingerprints in the light that eventually reaches Earth. By using the FORS2 instrument the team was able to carefully analyse this light and deduce that the atmosphere contained small amounts of titanium oxide, water and traces of sodium, alongside a strongly scattering global haze.

"*Detecting such molecules is, however, no simple feat,*" explains Elyar Sedaghati, who spent 2 years as ESO student to work on this project. "*Not only do we need data of exceptional quality, but we also need to perform a sophisticated analysis. We used an algorithm that explores many millions of spectra spanning a wide range of chemical compositions, temperatures, and cloud or haze properties in order to draw our conclusions.*"

Titanium oxide is rarely seen on Earth. It is known to exist in the atmospheres of cool stars. In the atmospheres of hot planets like WASP-19b, it acts as a heat absorber. If present in large enough quantities, these molecules prevent heat from entering or escaping through the atmosphere, leading to a thermal inversion — the temperature is higher in the upper atmosphere and lower further down, the opposite of the normal situation. Ozone plays a similar role in Earth's atmosphere, where it causes inversion in the stratosphere.

"*The presence of titanium oxide in the atmosphere of WASP-19b can have substantial effects on the atmospheric temperature structure and circulation,*" explains Ryan MacDonald, another team member and an astronomer at Cambridge University, United Kingdom. "*To be able to examine exoplanets at this level of detail is promising and very exciting,*" adds Nikku Madhusudhan from Cambridge University who oversaw the theoretical interpretation of the observations.

The astronomers collected observations of WASP-19b over a period of more than one year. By measuring the relative variations in the planet's radius at different wavelengths of light that passed through the exoplanet's atmosphere and comparing the observations to atmospheric models, they could extrapolate different properties, such as the chemical content, of the exoplanet's atmosphere.

This new information about the presence of metal oxides like titanium oxide and other substances will allow much better modeling of exoplanet atmospheres. Looking to the future, once astronomers are able to observe atmospheres of possibly habitable planets, the improved models will give them a much better idea of how to interpret those observations.

"*This important discovery is the outcome of a refurbishment of the FORS2 instrument that was done exactly for this purpose,*" adds team member Henri Boffin, from ESO, who led the refurbishment project. "*Since then, FORS2 has become the best instrument to perform this kind of study from the ground.*"

The VLT Unravels the Nature of the Fastest Binary Star

Two hot white dwarfs perform a tight dance

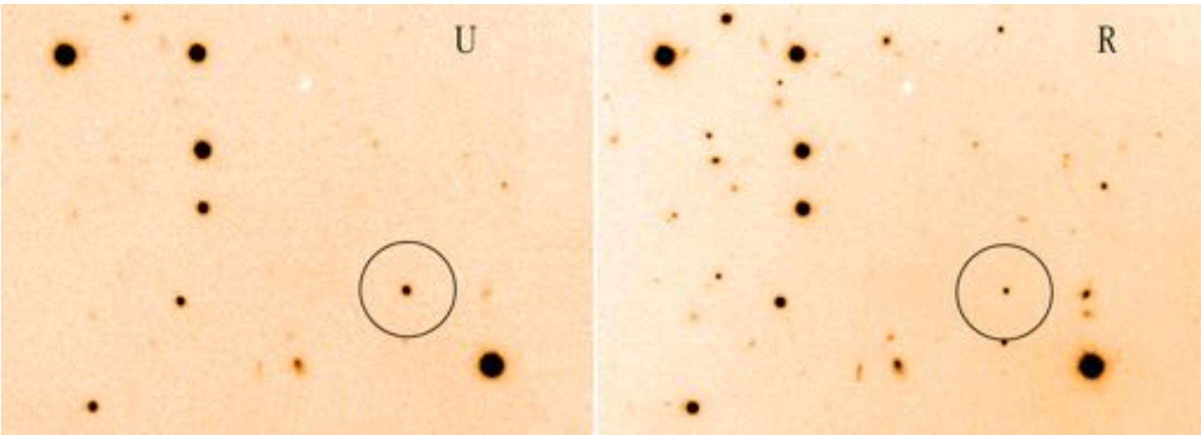
15 March 2002

Observations during the past two years have enabled an international group of astronomers to unravel the true nature of an exceptional binary stellar system. This system, designated RX J0806.3+1527, was first discovered as an X-ray source of variable brightness — once every five minutes, it ‘switches off’ for a short moment. The new observations have shown beyond doubt that this period reflects the orbital motion of two ‘white dwarf’ stars that revolve around each other at a distance of only 80,000 km. Each of the stars is about as large as the Earth and this is the shortest orbital period known for any binary stellar system. The VLT spectrum displays lines of ionized helium, indicating that the presence of an exceedingly hot area on one of the stars — a ‘hot spot’ with a temperature of approx. 250,000 degrees. The system is currently in a rarely seen, transitory evolutionary state.

One year is the time it takes the Earth to move once around the Sun, our central star. This may seem quite fast when measured on the scale of the Universe, but this is a snail's motion compared to the speed of two recently discovered stars. They revolve around each other 100,000 times faster; one full revolution takes only 321 seconds, or a little more than 5 minutes! It is the shortest period ever observed in a binary stellar system. This is the surprising conclusion reached by an international team of astronomers led by GianLuca Israel of the Astronomical Observatory of Rome, and based on detailed observations of the faint light from these two stars with some of the world's most advanced telescopes. The record-holding binary stellar system bears the prosaic name RX J0806.3+1527 and it is located north of the celestial equator in the constellation Cancer (The Crab).

The scientists also find that the two partners in this hectic dance are most likely a dying white dwarf star, trapped in the strong gravitational grip of another, somewhat heavier star of the same exotic type. The two Earth-size stars are separated by only 80,000 kilometers, a little more than twice the altitude of the TV-broadcasting satellites in orbit around the Earth, or just one fifth of the distance to the Moon.

The orbital motion is very fast indeed — over 1,000 km/s, and the lighter star apparently always turns the same hemisphere towards its companion, just as the Moon in its orbit around Earth. Thus, that star also makes one full turn around its axis in only 5 minutes, i.e. its ‘day’ is exactly as long as its ‘year’.



U- and *R*-filter images of the sky field around RX J0806.3+1527 (at centre of circle), obtained with the FORS2 multi-mode instrument on VLT KUEYEN. The object is brightest at the shorter wavelength (*U*-band) – reflecting its very high temperature. The image is reproduced from FORS2-exposures, obtained in November 1999 in the *U*- and *R*-bands, and both lasting 300 seconds. The field measures 2.0 x 1.5 $arcmin^2$.

The visible light emitted by this unusual system is very faint, but it radiates comparatively strong X-rays. It was due to this emission that it was first detected as a celestial X-ray source of unknown origin by the German ROSAT space observatory in 1994. Later it was found to be a periodically variable source. Once every 5 minutes, the X-ray radiation disappears for a couple of minutes. It was recently studied in greater detail by the NASA Chandra observatory.

The position of the X-ray source in the sky was localised with sufficient accuracy to reveal a very faint visible-light emitting object in the same direction, over one million times weaker than the faintest star that can be seen by unaided eye (*V*-magnitude 21.1). Follow-up observations were carried out with several world class telescopes, including the ESO Very Large Telescope (VLT) at the Paranal Observatory in Chile, and also the Telescopio Nazionale Galileo (TNG), the Italian 4-m class observatory at the Roche de Muchachos Observatory on La Palma in the Canary Islands.

The observations in visible light also showed the same effect: RX J0806.3+1527 was getting dimmer once every 5 minutes, while no other periodic modulation was seen. By observing the spectrum of this faint object with the FORS1 multi-mode instrument on the 8.2-m VLT ANTU telescope, the astronomers were able to determine the composition of RX J0806.3+1527. It was found to contain large amounts of helium; this is unlike most other stars, which are mainly made up of hydrogen.

"*At the outset, we thought that this was just another of the usual binary systems that emit X-rays*", says Gianluca Israel. "*None of us could imagine the real nature of this object. We finally solved the puzzle by eliminating all other possibilities one by one, while we kept collecting more data. As the famous detective said: when you have eliminated the impossible, whatever remains, however improbable, must be the truth!*"

Current theory predicts that the two stars, which are bound together by gravity in this tight system, produce X-rays when one of them acts as a giant 'vacuum cleaner', drawing gas off its companion. That star has already lost a significant fraction of its mass during this process. The incoming matter impacts at high speed on the surface of the other star and the corresponding area — a 'hot spot' — is heated to some 250,000 °C, whereby X-rays are emitted. This radiation disappears for a short time during each orbital revolution when this area is on the far side of the accreting star, as seen from the Earth.

Our Sun is a normal star of comparatively low mass and it will eventually develop into a white dwarf star. Contrary to the violent demise of heavier stars in a glorious supernova explosion, this is a comparatively 'quiet' process during which the star slowly cools while losing energy. It shrinks until it finally becomes as small as the Earth.

The Sun is a single star. However when a solar-like star is a member of a binary system, the evolution of its component stars is more complicated. During an initial phase, one star continues to move along an orbit that is actually inside the outer, very tenuous atmospheric layers of its companion. Then the system rids itself of this matter and develops into a binary system with two orbiting white dwarf stars, like RX J0806.3+1527.

Systems in which the orbital period is very short (less than 1 hour) are referred to as AM Canis Venaticorum (AM CVn) systems, after the first known binary star of this rare class. It is likely that such systems, after having reached a minimum orbital period of a few minutes, then begin to evolve towards longer orbital periods. This indicates that RX J0806.3+1527 is now at the very beginning of the 'AM CVn phase'.

With its extremely short orbital period, RX J0806.3+1527 is also a prime candidate for the detection of the elusive gravitational waves, predicted by Einstein's General Theory of Relativity. They have never been measured directly, but their existence has been revealed indirectly in binary neutron star systems. A planned gravitational wave space experiment, ESA's Laser Interferometer Space Antenna (LISA) that will be launched in about 10 years' time, will be sufficiently sensitive to be able to reveal this radiation from RX J0806.3+1527 with a high degree of confidence. Such an observational feat would open an entirely new window on the universe.

Cosmic Sprinklers Explained

Odd pair of aging stars sculpt spectacular shape of planetary nebula

8 November 2012

Astronomers using ESO's Very Large Telescope have discovered a pair of stars orbiting each other at the centre of one of the most remarkable examples of a planetary nebula. The new result confirms a long-debated theory about what controls the spectacular and symmetric appearance of the material flung out into space.

Planetary nebulae are glowing shells of gas around white dwarfs — Sun-like stars in the final stages of their lives. Fleming 1 is a beautiful example that has strikingly symmetric jets that weave into knotty, curved patterns. It is located in the southern constellation of Centaurus and was discovered just over a century ago by Williamina Fleming.

Astronomers have long debated how these symmetric jets could be created, but no consensus has been reached. Now, a research team led by Henri Boffin (ESO, Chile) has combined new Very Large Telescope observations of Fleming 1 (or Fg 1) with existing computer modelling to explain in detail for the first time how these bizarre shapes came about.

The team used FORS2 to study the light coming from the central star. They found that Fg 1 is likely to have not one but two white dwarfs at its centre, circling each other every 1.2 days. Although binary stars have been found at the hearts of planetary nebulae before, systems with two white dwarfs orbiting each other are very rare.

"*The origin of the beautiful and intricate shapes of Fleming 1 and similar objects has been controversial for many decades,*" says Henri Boffin. "*Astronomers have suggested a binary star before, but it was always thought that in this case the pair would be well separated, with an orbital period of tens of years or longer. Thanks to our models and observations, which let us examine this unusual system in great detail and peer right into the heart of the nebula, we found the pair to be several thousand times closer.*"

When a star with a mass up to eight times that of the Sun approaches the end of its life, it blows off its outer shells and begins to lose mass. This allows the hot, inner core of the star to radiate strongly, causing this outward-moving cocoon of gas to glow brightly as a planetary nebula. While stars are spherical, many of these planetary nebulae are strikingly complex, with knots, filaments, and intense jets of material forming intricate patterns. Some of the most spectacular nebulae — including Fg 1 — present point-symmetric structures. For this planetary nebula it means that the material appears to shoot from both poles of the central region in S-shaped flows. This new study shows that these patterns for Fg 1 are the result of the close interaction between a pair of stars — the surprising swansong of a stellar couple.

The pair of stars in the middle of this nebula is vital to explain its observed structure. As the stars aged, they expanded, and for part of this time, one acted as a stellar vampire, sucking material from its companion. This material then flowed in towards the vampire, encircling it with a disc known as an accretion disc. As the two stars orbited one another, they both interacted with this disc and caused it to behave like a wobbling spinning top — a type of motion called precession. This movement affects the behaviour of any material that has been pushed outwards from the poles of the system, such as outflowing jets. This study now confirms that precessing accretion discs within binary systems cause the stunningly symmetric patterns around planetary nebulae like Fg 1.

The deep images from FORS2 have also led to the discovery of a knotted ring of material within the inner nebula. Such a ring of material is also known to exist in other families of binary systems, and appears to be a telltale signature of the presence of a stellar couple.

"*Our results bring further confirmation of the role played by interaction between pairs of stars to shape, and perhaps even form, planetary nebulae,*" concludes Boffin.

First Signs of Weird Quantum Property of Empty Space?

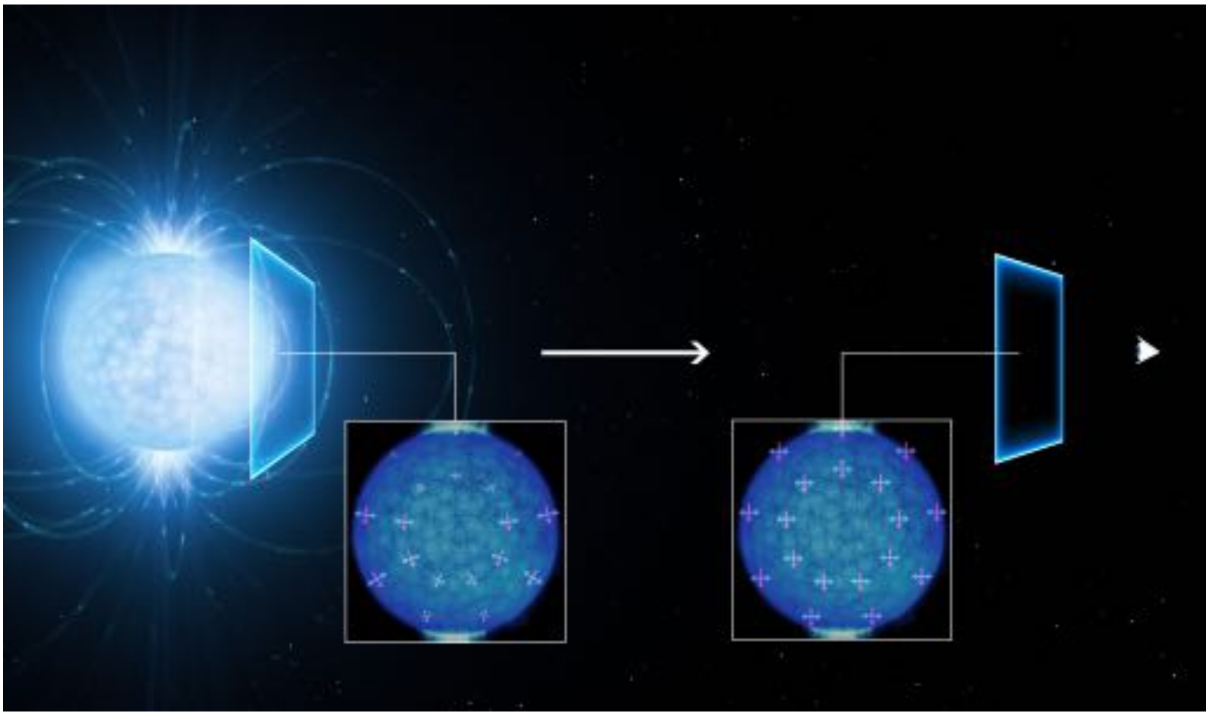
VLT observations of neutron star may confirm 80-year-old prediction about the vacuum

30 November 2016

By studying the light emitted from an extraordinarily dense and strongly magnetised neutron star using ESO's Very Large Telescope, astronomers may have found the first observational indications of a strange quantum effect, first predicted in the 1930s. The polarisation of the observed light suggests that the empty space around the neutron star is subject to a quantum effect known as vacuum birefringence.

A team led by Roberto Mignani from INAF Milan (Italy) and from the University of Zielona Gora (Poland), used the VLT to observe the neutron star RX J1856.5-3754, about 400 light-years from Earth. Despite being amongst the closest neutron stars, its extreme dimness meant the astronomers could only observe the star with visible light using the FORS2 instrument on the VLT, at the limits of current telescope technology.

Neutron stars are the very dense remnant cores of massive stars — at least 10 times more massive than our Sun — that have exploded as supernovae at the ends of their lives. They also have extreme magnetic fields, billions of times stronger than that of the Sun, that permeate



This artist's view shows how the light coming from the surface of a strongly magnetic neutron star (left) becomes linearly polarised as it travels through the vacuum of space close to the star on its way to the observer on Earth (right). The polarisation of the observed light in the extremely strong magnetic field suggests that the empty space around the neutron star is subject to a quantum effect known as vacuum birefringence, a prediction of quantum electrodynamics (QED). This effect was predicted in the 1930s but has not been observed before. The magnetic and electric field directions of the light rays are shown by the red and blue lines. Model simulations by Roberto Taverna (University of Padua, Italy) and Denis Gonzalez Caniulef (UCL/MSSL, UK) show how these align along a preferred direction as the light passes through the region around the neutron star. As they become aligned the light becomes polarised, and this polarisation can be detected by sensitive instruments on Earth.

their outer surface and surroundings. These fields are so strong that they even affect the properties of the empty space around the star. Normally a vacuum is thought of as completely empty, and light can travel through it without being changed. But in quantum electrodynamics (QED), the quantum theory describing the interaction between photons and charged particles such as electrons, space is full of virtual particles that appear and vanish all the time. Very strong magnetic fields can modify this space so that it affects the polarisation of light passing through it.

Mignani explains: "*According to QED, a highly magnetised vacuum behaves as a prism for the propagation of light, an effect known as vacuum birefringence.*"

Among the many predictions of QED, however, vacuum birefringence so far lacked a direct experimental demonstration. Attempts to detect it in the laboratory have not yet succeeded in the 80 years since it was predicted in a paper by Werner Heisenberg (of uncertainty principle fame) and Hans Heinrich Euler.

"*This effect can be detected only in the presence of enormously strong magnetic fields, such as those around neutron stars. This shows, once more, that neutron stars are invaluable laboratories in which to study the fundamental laws of nature,*" says Roberto Turolla (University of Padua, Italy).

After careful analysis of the VLT data, Mignani and his team detected linear polarisation — at a significant level of around 16% — that they say is likely due to the boosting effect of vacuum birefringence occurring in the area of empty space surrounding RX J1856.5-3754.

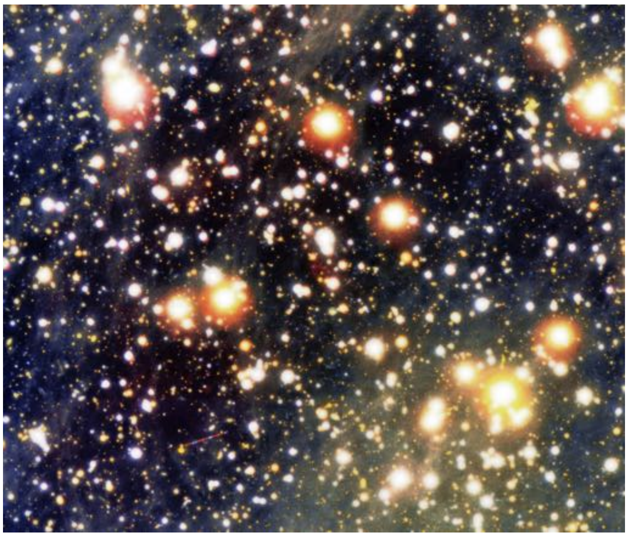
Vincenzo Testa (INAF, Rome, Italy) comments: "*This is the faintest object for which polarisation has ever been measured. It required one of the largest and most efficient telescopes in the world, the VLT, and accurate data analysis techniques to enhance the signal from such a faint star.*"

"*The high linear polarisation that we measured with the VLT can't be easily explained by our models unless the vacuum birefringence effects predicted by QED are included,*" adds Mignani.

"*This VLT study is the very first observational support for predictions of these kinds of QED effects arising in extremely strong magnetic fields,*" remarks Silvia Zane (UCL/MSSL, UK).

Mignani is excited about further improvements to this area of study that could come about with more advanced telescopes: "*Polarisation measurements with the next generation of telescopes, such as ESO's European Extremely Large Telescope, could play a crucial role in testing QED predictions of vacuum birefringence effects around many more neutron stars.*"

"*This measurement, made for the first time now in visible light, also paves the way to similar measurements to be carried out at X-ray wavelengths,*" adds Kinwah Wu (UCL/MSSL, UK).



VLT image of the area around the very faint neutron star RX J1856.5-3754.

Protostar HH 34 in Orion

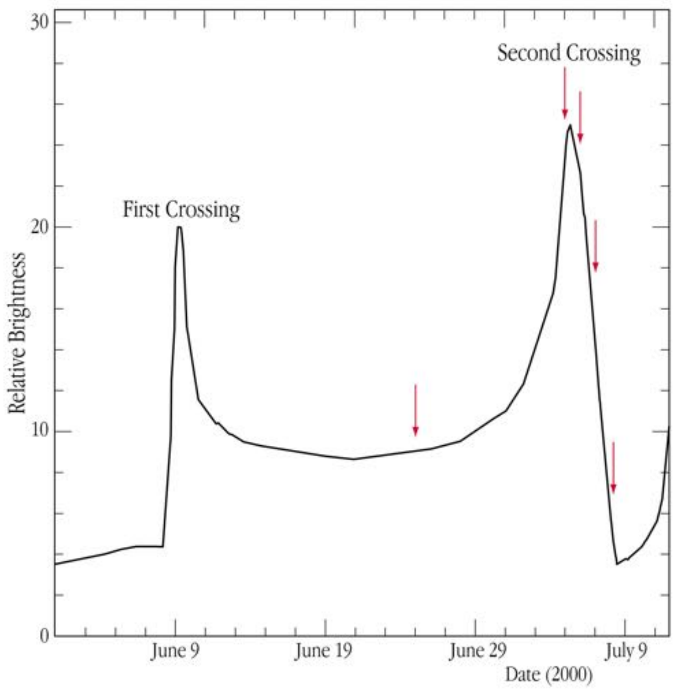
VLT Spectra 'Resolve' a Stellar Disk at 25,000 Light-Years Distance

Unique observations of a microlensing event

21 April 2001

Using FORS1 during a microlensing event, a team was able to obtain detailed spectra of the different parts of the remote star. In doing so, they managed to probe its gaseous atmosphere at different depths. This is the first time that it has been possible to obtain detailed, spatially resolved spectra across the full face of a normal star other than the Sun.

Like our Sun, stars are large gaseous spheres. However, while we are able to perceive the Sun's disk, all other stars are so far away that they normally appear as points of light. Only specialized observing techniques, like interferometry, are able to 'resolve' the images of nearby stars and to show them as extended balls of fire. But opportunities may sometimes arise that allow amazing observational feats in this field. Indeed, an international team of astronomers has just 'resolved' a single, normal star some 25,000 light years away, or about 1.6 billion times more distant than the Sun, by taking advantage of a multiple microlensing event. During such a rare event, the light from the remote star is amplified by the gravity of a faint object that passes in front of it, as seen from the Earth. In fact, this gravitational lens acts as a magnifying glass that focusses different parts of the star's image at different times.



Schematic representation of the lightcurve of the EROS-BLG-2000-5 microlensing event. It represents the changing brightness of a background star, as its light is being amplified by a binary gravitational lens that passes the line-of-sight from the Earth to the star. The ordinate indicates the factor by which the intensity increases during the various phases of the lensing event, as compared to the normal brightness of the star. The moment of the second 'caustic crossing' is indicated, during which the image of the star is substantially brighter. Spectral observations were made with the VLT at the times indicated by arrows.

On 5 May 2000, the EROS group announced an apparently normal microlensing event in a direction a few degrees from the Galactic Centre. The brightness of the background star was rising and the PLANET team began to monitor it during its regular operations. About one month later, on 8 June 2000, the MPS team noticed that the event, now designated EROS-BLG-2000-5, was undergoing an unexpected, sudden and significant brightening. PLANET observers immediately turned their full attention to it, monitoring it continuously from five different observing sites located at suitable longitudes around the Earth. The light curve changed dramatically while the source went through a first caustic crossing. On 10 June 2000, the PLANET team alerted the community that this particular event was indeed due to a multiple lens, thus indicating that another light maximum would follow at the second caustic crossing.

While continuing to monitor the light curve in order to predict the timing of this second event, the PLANET team contacted ESO with an urgent request to carry out a novel set of observations. The astronomers called attention to the unique possibility of performing detailed spectral observations during the second caustic crossing that could provide information about the chemistry of the stellar atmosphere of the magnified star. ESO concurred and within a day, their observing proposal was granted "Director's Discretionary Time" with the FORS1 spectrograph on the 8.2-m VLT ANTU telescope at the appropriate moment. Some spectra were taken of the background star while it was still magnified, but had not yet made the second caustic crossing. The star was now identified as a cool giant star, located some 25,000 light-years away in the general direction of the Galactic Centre (in the 'Galactic Bulge').

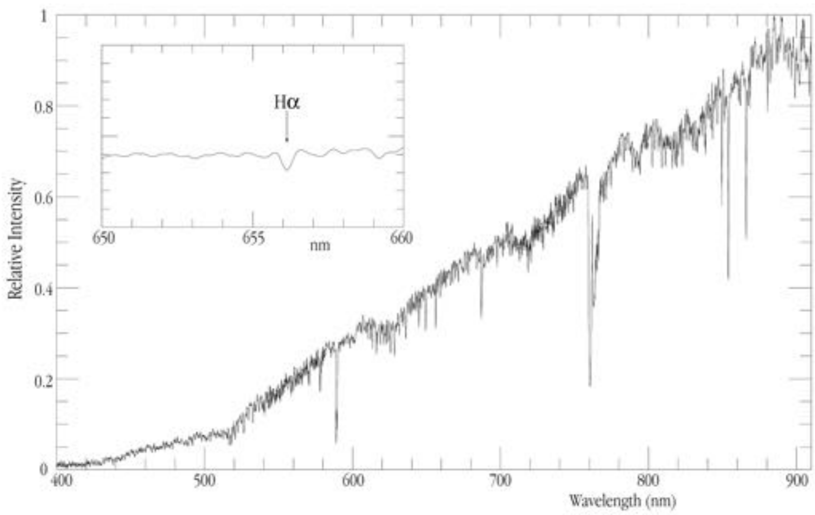
Then the team waited. Their predictions indicated that the second caustic crossing might last unusually long, several days rather than a more normal 10-20 hours. The observing plan was therefore changed to ensure that spectra could be taken on four consecutive nights during this caustic crossing. The light curve would then first brighten, and then drop dramatically.

During the four nights, the lens would successively magnify different areas of the disk of the cool giant star while 'the gravitational magnifying glass slowly moved across it', as seen from the VLT. First it would mostly be the light from the cool limb of the star that would be amplified, then the hotter middle of the disk, and finally the other, also cooler limb.

On each of the four nights beginning on July 4, 5, 6 and 7, 2000, ESO astronomers at Paranal performed two hours of service observations according to the detailed planning of the microlensing team. Spectra were successfully taken of the giant star with the multi-mode FORS1 instrument at the 8.2-metre VLT ANTU telescope at the moment of the second caustic crossing. The magnitude was about I=13 at the brightness peak, dropping about 2 magnitudes towards the end of the period.

In a first scientific assessment of these unique spectra, the team concentrated on an absorption line in the red spectral region (the 'H-alpha' line) that is produced by hydrogen in the stellar atmosphere. They found a clear change in the strength of this line of the source star during the four nights. No such variations were seen in the spectra of neighbouring stars that were observed simultaneously, providing a secure check that the observed changes are real.

The astronomers then went on to interpret this change. For this they performed various simulations by means of a computer model of the atmosphere of the cool giant star, applying the expected effects of the lensing and then comparing with the observed spectra. The observed changes of the H-alpha line during the caustic crossing agree well with the model calculations. During this event, the microlens magnifies successive areas of the stellar disk particularly strongly. To begin with, the light from the relatively cool, leading limb of the star dominates the registered spectrum — and here the absorption line strength drops slightly, exactly as expected. It then becomes stronger as the hotter areas near the middle of the disk 'come into focus' and then again decreases when the cooler trailing limb is strongly magnified. This is the first time that this effect has ever been measured for all phases of a caustic crossing.



Spectrum of EROS-BLG-2000-5, obtained with the FORS1 multi-mode instrument at the 8.2-m VLT ANTU telescope at Paranal on June 25, 2000, before the second caustic crossing described in the text. A small part of the spectrum around the H-alpha line at wavelength 656.2 nm is enlarged in the insert.

How to Steal a Million Stars?

VLT study reveals troubled past of globular cluster Messier 12

7 February 2006

Based on observations with ESO's Very Large Telescope, a team of Italian astronomers reports that the stellar cluster Messier 12 must have lost to our Milky Way galaxy close to one million low-mass stars.

"*In the solar neighbourhood and in most stellar clusters, the least massive stars are the most common, and by far*", said Guido De Marchi (ESA), lead author of the study. "*Our obser–vations with ESO's VLT show this is not the case for Messier 12.*"

The team, which also includes Luigi Pulone and Francesco Paresce (INAF, Italy), measured the brightness and colours of more than 16,000 stars within the globular cluster Messier 12 with the FORS1 multi-mode instrument. The astronomers could study stars that are 40 million times fainter than what the unaided eye can see (magnitude 25).

Located at a distance of 23,000 light years in the constellation Ophiuchus (The Serpent-holder), Messier 12 got its name by being the 12th entry in the catalogue of nebulous objects compiled in 1774 by French astronomer and comet chaser Charles Messier. It is also known to astronomers as NGC 6218 and contains about 200,000 stars, most of them having a mass between 20 and 80 percent of the mass of the Sun.

"*It is however clear that Messier 12 is surprisingly devoid of low-mass stars*", said De Marchi. "*For each solar-like star, we would expect roughly four times as many stars with half that mass. Our VLT observations only show an equal number of stars of different masses.*"

Globular clusters move in extended elliptical orbits that periodically take them through the densely populated regions of our Galaxy, the plane, then high above and below, in the 'halo'. When venturing too close to the innermost and denser regions of the Milky Way, the 'bulge', a globular cluster can be perturbed, the smallest stars being ripped away.

"*We estimate that Messier 12 lost four times as many stars as it still has*", said Francesco Paresce. "*That is, roughly one million stars must have been ejected into the halo of our Milky Way.*"

The total remaining lifetime of Messier 12 is predicted to be about 4.5 billion years, i.e. about a third of its present age. This is very short compared to the typical expected globular cluster's lifetime, which is about 20 billion years.

Centre of the globular cluster Messier 12 as observed with FORS1.

A Galaxy for Science and Research

European Commissioner captures stunning image of twisted spiral galaxy with ESO's VLT

9 November 2007

During his visit to Paranal, the European Commissioner for Science and Research, Janez Potočnik, participated in an observing sequence and took images of a beautiful spiral galaxy.

The visit took place on 27 October and the Commissioner observed with one of the FORS instruments.

"*Two hours bus ride from the nearest town, Antofagasta, in the middle of nowhere and at 2600 m altitude, rises a state of the art astronomical observatory at which scientists from across Europe venture to exploit some of the most advanced technologies and sophisticated techniques available within astronomy. One of the facilities is the VLT, the Very Large Telescope, with which, together with the other telescopes, scientists can study objects at the far edge of the Universe,*" wrote Potočnik on his blog.

Known until now as a simple number in a catalogue, NGC 134, the 'Island in the Universe' that was observed by the Commissioner is replete with remarkable attributes, and the VLT has clapped its eyes on them. Just like our own Galaxy, NGC 134 is a barred spiral with its spiral arms loosely wrapped around a bright, bar-shaped central region.

One feature that stands out is its warped disc. While a galaxy's disc is often pictured as a flat structure of gas and stars surrounding the galaxy's centre, a warped disc is a structure that, when viewed sideways, resembles a bent record album left out too long in the burning Sun. Warps are actually not atypical. More than half of the spiral galaxies do show warps one way or another, and our own Milky Way also has a small warp.

Many theories exist to explain warps. One possibility is that warps are the aftermath of interactions or collisions between galaxies. These can also produce tails of material being pulled out from the galaxy. The VLT image reveals that NGC 134 also appears to have a tail of gas stripped from the top edge of the disc.

So did NGC 134 have a striking encounter with another galaxy in the past? Or is some other galaxy out there exerting a gravitational pull on it? This is a riddle astronomers need to solve.

Studying galaxies like NGC 134 is an excellent way to learn more about our own Galaxy. NGC 134 was discovered by Sir John Herschel at the Cape of Good Hope and is located in the Sculptor southern constellation. The galaxy is located about 60 million light-years away — when the light that was captured by the VLT originally left the galaxy, a dramatic episode of mass extinction had led to the disappearance of dinosaurs on Earth, paving the way for the appearance of mammals and later specifically of humans, who have built unique high-tech installations in the Atacama desert to satisfy their curiosity about the workings of the Universe.

Still, NGC 134 is not very far away, by cosmological standards. It is the dominant member of a small group of galaxies that belongs to the Virgo or Local Supercluster and is one of the 200 brightest galaxies in our skies.

Black Hole Hunters Set New Distance Record

27 January 2010

Astronomers have detected, in another galaxy, a stellar-mass black hole much farther away than any other previously known. With a mass above fifteen times that of the Sun, this is also the second most massive stellar-mass black hole ever found. It is entwined with a star that will soon become a black hole itself.

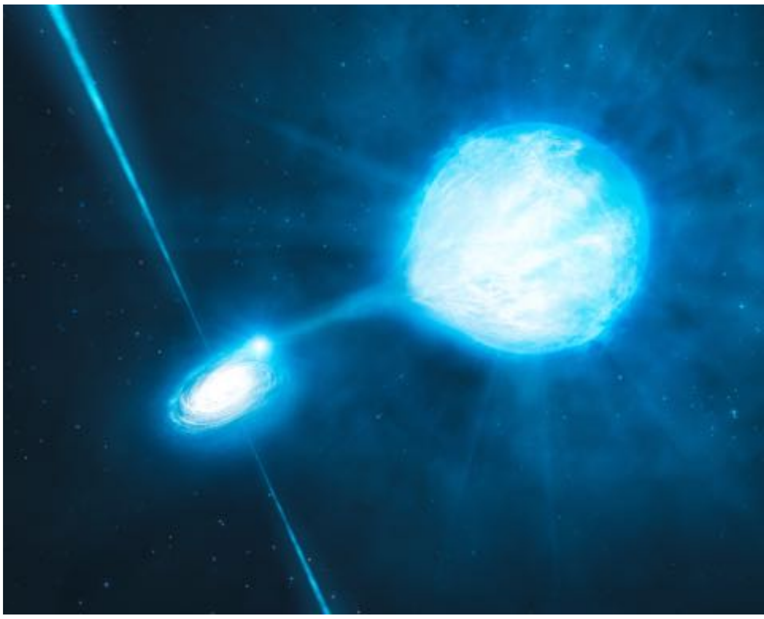
The stellar-mass black holes found in the Milky Way weigh up to ten times the mass of the Sun and are certainly not to be taken lightly, but, outside our own galaxy, they may just be minor-league players, since astronomers have found another black hole with a mass over fifteen times the mass of the Sun. This is one of only three such objects found so far.

The newly announced black hole lies in a spiral galaxy called NGC 300, six million light-years from Earth. "*This is the most distant stellar-mass black hole ever weighed, and it's the first one we've seen outside our own galactic neighbourhood, the Local Group,*" says Paul Crowther, from the University of Sheffield and lead author of the paper reporting the study.

The black hole's curious partner is a Wolf–Rayet star, which also has a mass of about twenty times as much as the Sun. Wolf–Rayet stars are near the end of their lives and expel most of their outer layers into their surroundings before exploding as supernovae, with their cores imploding to form black holes.

In 2007, an X-ray instrument aboard NASA's Swift observatory scrutinised the surroundings of the brightest X-ray source in NGC 300 discovered earlier with the European Space Agency's XMM-Newton X-ray observatory. "*We recorded periodic, extremely intense X-ray emission, a clue that a black hole might be lurking in the area,*" explains team member Stefania Carpano from ESA.

Thanks to new observations performed with the FORS2 instrument mounted on ESO's Very Large Telescope, astronomers have confirmed their earlier hunch. The new data show that the black hole and the Wolf–Rayet star dance around each other in a diabolic waltz, with a period of about 32 hours. The astronomers also found that the black hole is stripping matter away from the star as they orbit each other.



"*This is indeed a very 'intimate' couple,*" notes collaborator Robin Barnard. "*How such a tightly bound system has been formed is still a mystery.*"

Only one other system of this type has previously been seen, but other systems comprising a black hole and a companion star are not unknown to astronomers. Based on these systems, the astronomers see a connection between black hole mass and galactic chemistry: a higher concentration of heavy chemical elements influences how a massive star evolves, increasing how much matter it sheds, resulting in a smaller black hole when the remnant finally collapses.

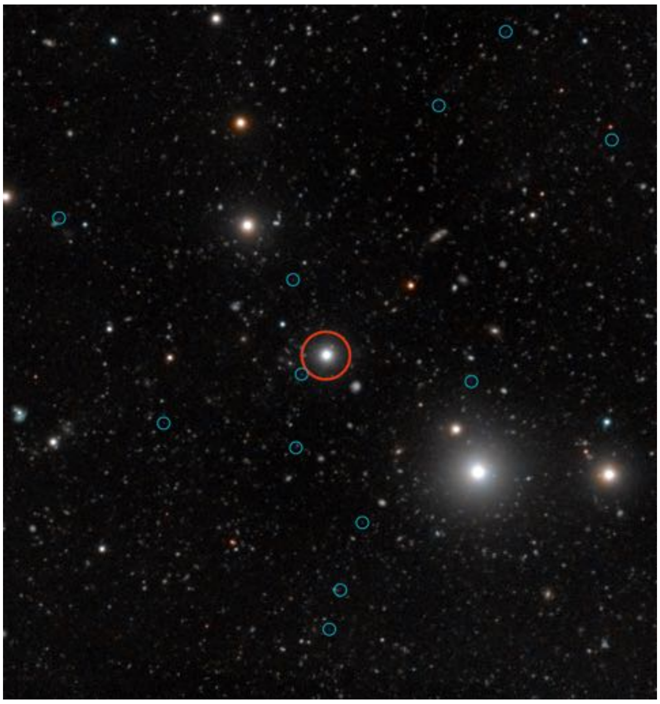
In less than a million years, it will be the Wolf–Rayet star's turn to go supernova and become a black hole. "*If the system survives this second explosion, the two black holes will merge, emitting copious amounts of energy in the form of gravitational waves as they combine,*" concludes Crowther. However, it will take some few billion years until the actual merger, far longer than human timescales. "*Our study does however show that such systems might exist, and those that have already evolved into a binary black hole might be detected by probes of gravitational waves, such as LIGO or Virgo.*"

Dark Galaxies of the Early Universe Spotted for the First Time

11 July 2012

For the first time, dark galaxies — an early phase of galaxy formation, predicted by theory but unobserved until now — may have been spotted. These objects are essentially gas-rich galaxies without stars. Using ESO's Very Large Telescope, an international team thinks they have detected these elusive objects by observing them glowing as they are illuminated by a quasar.

Dark galaxies are small, gas-rich galaxies in the early Universe that are very inefficient at forming stars. They are predicted by theories of galaxy formation and are thought to be the building blocks of today's bright, star-filled galaxies. Astronomers think that they may have fed large galaxies with much of the gas that later formed into the stars that exist today.



Because they are essentially devoid of stars, these dark galaxies don't emit much light, making them very hard to detect. For years astronomers have been trying to develop new techniques that could confirm the existence of these galaxies. Small absorption dips in the spectra of background sources of light have hinted at their existence. However, this new study marks the first time that such objects have been seen directly.

The team took advantage of the large collecting area and sensitivity of the Very Large Telescope (VLT), and a series of very long exposures, to detect the extremely faint fluorescent glow of the dark galaxies. They used the FORS2 instrument to map a region of the sky around the bright quasar HE 0109-3518, looking for the ultraviolet light that is emitted by hydrogen gas when it is subjected to intense radiation. Because of the expansion of the Universe, this light is actually observed as a shade of violet by the time it reaches the VLT.

"*After several years of attempts to detect fluorescent emission from dark galaxies, our results demonstrate the potential of our method to discover and study these fascinating and previously invisible objects,*" says Sebastiano Cantalupo (University of California, Santa Cruz), lead author of the study.

The team detected almost 100 gaseous objects which lie within a few million light-years of the quasar. After a careful analysis designed to exclude objects where the emission might be powered by internal star-formation in the galaxies, rather than the light from the quasar, they finally narrowed down their search to 12 objects. These are the most convincing identifications of dark galaxies in the early Universe to date.

The astronomers were also able to determine some of the properties of the dark galaxies. They estimate that the mass of the gas in them is about 1 billion times that of the Sun, typical for gas-rich, low-mass galaxies in the early Universe. They were also able to estimate that the star formation efficiency is suppressed by a factor of more than 100 relative to typical star-forming galaxies found at similar stage in cosmic history.

Discovering Teenage Galaxies

ESO's VLT takes the search for young galaxies to new limits

28 November 2007

Staring for the equivalent of every night for two weeks at the same little patch of sky with ESO's Very Large Telescope, an international team of astronomers has found the extremely faint light from teenage galaxies billions of light years away. These galaxies, which the research team believes are the building blocks of normal galaxies like our Milky Way, had eluded detection for three decades, despite intensive searches.

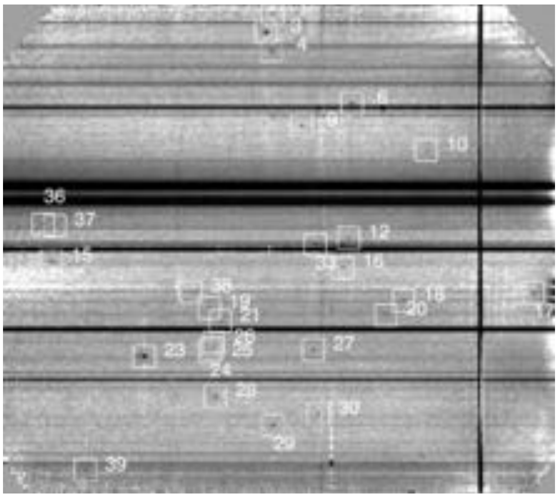
"*This is the first time that the sky has been searched to this depth and the unrivalled sensitivity of the picture taken with the VLT was key to succeeding,*" says Martin Haehnelt of the University of Cambridge, UK.

Experts have long speculated that galaxies like ours were created by the amalgamation of proto-galaxies early in the history of the Universe, but the light from these fragments was so faint that astronomers had struggled to prove they were there at all. Astronomers thought that the teenage galaxies must be out there because they were blocking part of the light from objects even further away in space.

"*Previous attempts have usually been frustrated by the difficulty of detecting extremely faint objects: the amount of time required even with an 8-metre class telescope like the VLT considerably exceeds typical observing time awards. We have thus exploited the periods of less good weather with the FORS2 spectrograph at the VLT, taking advantage of the service observing mode,*" says George Becker.

In service mode, ESO staff astronomers at Paranal are responsible for carrying out the actual observations, taking all the specific requirements into account.

"*We were actually trying to measure a faint signal from intergalactic gas caused by the cosmic ultraviolet background radiation. But as often happens in science, we got a surprise and found something we weren't looking for — dozens of faint, discrete objects emitting radiation from neutral hydrogen in the so-called Lyman alpha line, a fundamental signature of protogalaxies,*" explains Michael Rauch.



Two-dimensional spectrum obtained in 92 hours of exposure time, showing the line emitter candidates. The quasar absorption lines are visible close to the centre of the image.

The same small patch of sky, centred on a quasar, was observed between 2004 and 2006 for an unprecedented 92 hours, the equivalent of about 12 complete nights, allowing the astronomers to obtain a spectrum of the Universe when it was only 2 billion years old.

The result of this search is the detection of 27 faint objects. The weak light signal that the team has detected from these distant objects implies low star formation rates and a small amount of chemical enrichment, suggesting that they are indeed at an early stage of formation.

"*The properties of the emitters seem to provide an excellent match to those of 'Damped Lyman Alpha Systems', the main reservoir of neutral hydrogen in the far Universe,*" says Andy Bunker. "*The new observations confirm theoretical research proposing that galaxies like our own have formed by the amalgamation of small proto-galaxies early on in the history of the Universe,*" he adds.

"*What makes our discovery particularly exciting is that it opens the route to find large numbers of building blocks of normal galaxies and that we will now be able to study in detail how galaxies like our Milky Way have come together,*" concludes Martin Haehnelt.

Most Distant Quasar Found

29 June 2011

A team discovered the most distant quasar found to date. This brilliant beacon, powered by a black hole with a mass two billion times that of the Sun, is by far the brightest object yet discovered in the early Universe.

"*This quasar is a vital probe of the early Universe. It is a very rare object that will help us to understand how supermassive black holes grew a few hundred million years after the Big Bang,*" says Stephen Warren, the study's team leader.

Quasars are very bright, distant galaxies that are believed to be powered by supermassive black holes at their centres. Their brilliance makes them powerful beacons that may help to probe the era when the first stars and galaxies were forming. The newly discovered quasar is so far away that its light probes the last part of the reionisation era.

The quasar that has just been found, named ULAS J1120+0641, is seen as it was only 770 million years after the Big Bang (redshift 7.1). It took 12.9 billion years for its light to reach us.

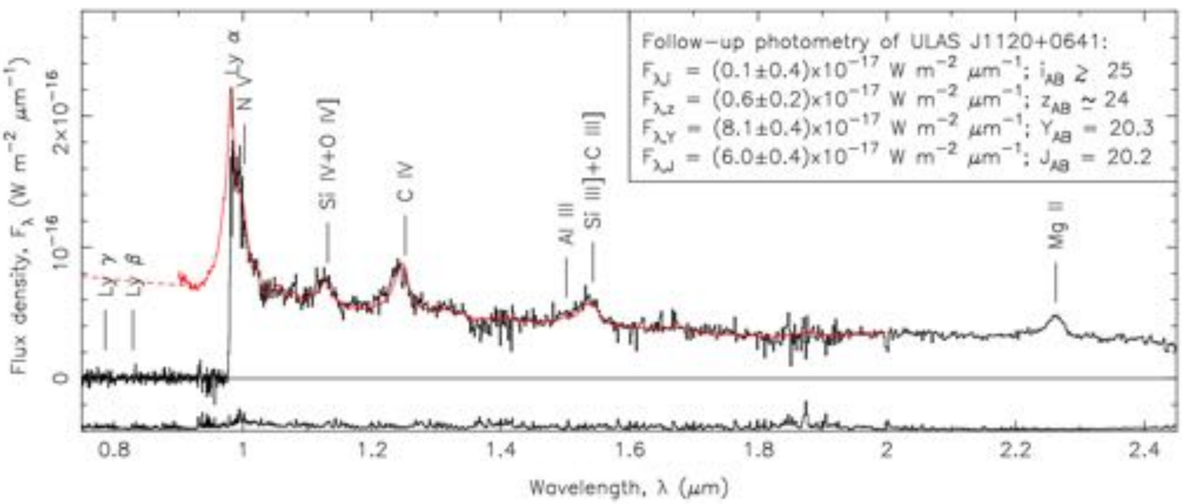
Although more distant objects have been confirmed (such as a galaxy at redshift 8.6), the newly discovered quasar is hundreds of times brighter than these. Amongst objects bright enough to be studied in detail, this is the most distant by a large margin.

The next most-distant quasar is seen as it was 870 million years after the Big Bang (redshift 6.4). Similar objects further away cannot be found in visible-light surveys because their light, stretched by the expansion of the Universe, falls mostly in the infrared part of the spectrum by the time it gets to Earth. The European UKIRT Infrared Deep Sky Survey (UKIDSS) which uses the UK's dedicated infrared telescope in Hawaii was designed to solve this problem. The team of astronomers hunted through millions of objects in the UKIDSS database to find those that could be the long-sought distant quasars, and eventually struck gold.

"*It took us five years to find this object,*" explains Bram Venemans, one of the authors of the study. "*We were looking for a quasar with redshift higher than 6.5. Finding one that is this far away, at a redshift higher than 7, was an exciting surprise. By peering deep into the reionisation era, this quasar provides a unique opportunity to explore a 100-million-year window in the history of the cosmos that was previously out of reach.*"

The distance to the quasar was determined from observations made with FORS2 and instruments on the Gemini North Telescope. Because the object is comparatively bright it is possible to take a spectrum of it.

These observations showed that the mass of the black hole at the centre of ULAS J1120+0641 is about two billion times that of the Sun. This very high mass is hard to explain so early on after the Big Bang.



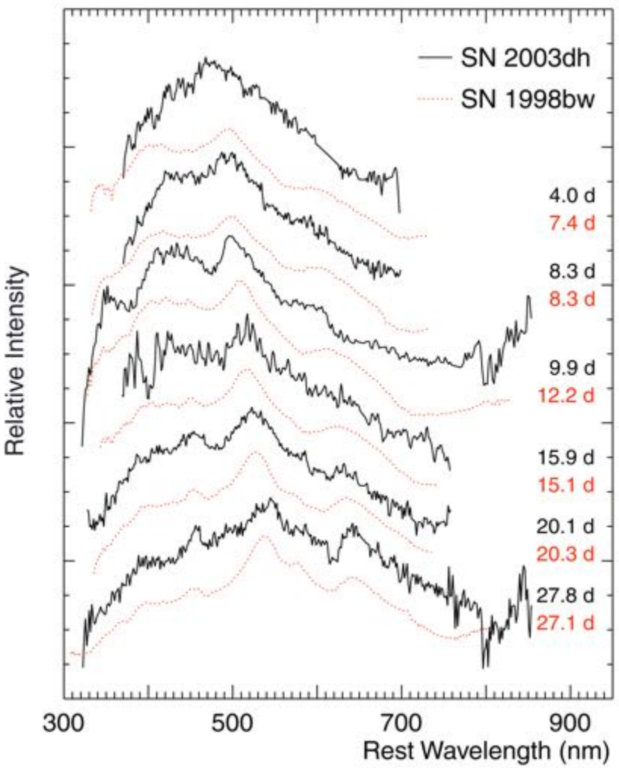
Spectrum of ULAS J1120+0641 (black) compared to a composite spectrum derived from lower-redshift quasars (red). Blueward of 1.005 μm the spectrum was obtained with FORS2.


Messier 61

Cosmological Gamma-Ray Bursts and Hypernovae Conclusively Linked

18 June 2003

A very bright burst of gamma-rays was observed on March 29, 2003 by NASA's High Energy Transient Explorer (HETE-II), in a sky region within the constellation Leo. Within 90 min, a new, very bright light source (the 'optical afterglow') was detected in the same direction by means of a 1-m telescope at the Siding Spring Observatory (Australia) and also in Japan. The gamma-ray burst was designated GRB 030329, according to the date. And within 24 hours, a first, very detailed spectrum of this new object was obtained by the UVES high-dispersion spectrograph on the 8.2-m VLT KUEYEN telescope at the ESO Paranal Observatory (Chile). It allowed to determine the distance as about 2,650 million light-years (redshift 0.1685). Continued observations with the FORS1 and FORS2 multi-mode instruments on the VLT during the following month allowed an international team of astronomers to document in unprecedented detail the changes in the spectrum of the optical afterglow of this gamma-ray burst.



Series of VLT-FORS-spectra, showing the spectral evolution of the hypernova (designated SN 2003dh) underlying the gamma-ray burst GRB 030329 (black curves). The red-dotted spectra are those of an earlier, nearby hypernova, SN 1998bw, observed with various ESO telescopes. The elapsed time (days in the rest frame of the object) since the explosion is indicated. There is a striking similarity between the spectra of the two hypernovae, also in their evolution with time.

The spectra show the gradual and clear emergence of a supernova spectrum of the most energetic class known, a 'hypernova'.

This is caused by the explosion of a very heavy star — presumably over 25 times heavier than the Sun. The measured expansion velocity (in excess of 30,000 km/s) and the total energy released were exceptionally high, even within the elect hypernova class. From a comparison with more nearby hypernovae, the astronomers are able to fix with good accuracy the moment of the stellar explosion. It turns out to be within an interval of plus/minus two days of the gamma-ray burst. This unique conclusion provides compelling evidence that the two events are directly connected. These observations therefore indicate a common physical process behind the hypernova explosion and the associated emission of strong gamma-ray radiation. The team concludes that it is likely to be due to the nearly instantaneous, non-symmetrical collapse of the inner region of a highly developed star (known as the 'collapsar' model). The March 29 gamma-ray burst will pass into the annals of astrophysics as a rare 'type-defining event', providing conclusive evidence of a direct link between cosmological gamma-ray bursts and explosions of very massive stars.

ESO-astronomer Palle Møller, is content: "*What really got us at first was the fact that we clearly detected the supernova signatures already in the first FORS-spectrum taken only four days after the GRB was first observed — we did not expect that at all. As we were getting more and more data, we realised that the spectral evolu–tion was almost completely identical to that of the hypernova seen in 1998. The similarity of the two then allowed us to establish a very precise timing of the present supernova event.*"

The Most Remote Gamma-Ray Burst

17 October 2000

Observations have enabled an international team of astronomers to measure the distance of a 'gamma-ray burst', an extremely violent, cosmic explosion of still unknown physical origin. It turns out to be the most remote gamma-ray burst ever observed. The exceedingly powerful flash of light from this event was emitted when the Universe was very young, less than about 1,500 million years old, or only 10% of its present age. Travelling with the speed of light (300,000 km/s) during 11,000 million years or more, the signal finally reached the Earth on January 31, 2000. The brightness of the exploding object was enormous, at least 1,000,000,000,000 times that of our Sun, or thousands of times that of the explosion of a single, heavy star (a 'supernova').

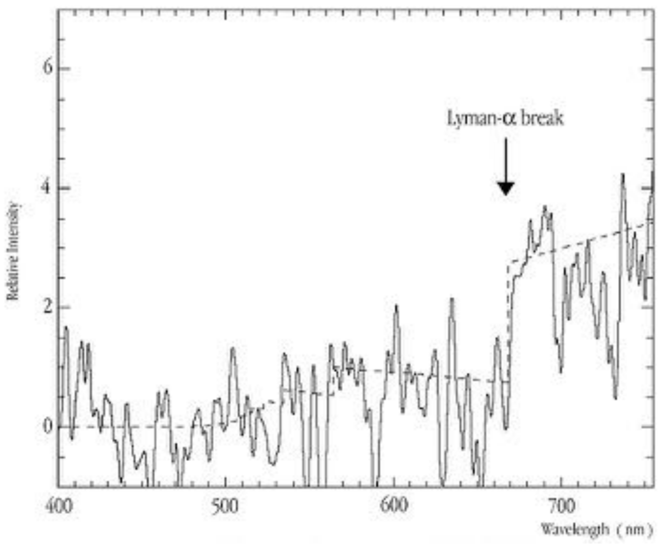
A gamma-ray burst was detected on January 31, 2000, by an international network of satellites (Ulysses, NEAR and Konus) via the InterPlanetary Network. It was designated GRB 000131 according to the date of the event. From geometric triangulation by means of the measured, exact arrival times of the signal at the individual satellites, it was possible to determine the direction from which the burst came. It was found to be from a point within a comparatively small sky area (about 50 arcmin^2 or 1/10 of the apparent size of the Moon), just inside the border of the southern constellation Carina (The Keel).

Follow-up observations were undertaken by a group of European astronomers. A comparison of several exposures with FORS1 during the nights of February 3-4 and 5-6 revealed a faint, point-like object that was fading rapidly — this was identified as the optical counterpart of the gamma-ray burst (the 'afterglow'). On the second night, the *R*-magnitude (brightness) was found to be only 24.4, or 30 million times fainter than visible with the unaided eye in a dark sky.

The observations showed that the light from the afterglow was very red, without blue and green light. This indicated a comparatively large distance and, assuming that the light from the explosion would originally have had the same colour (spectral distribution) as that of optical counterparts of other observed gamma-ray bursts, a photometric redshift of 4.35 to 4.70 was deduced.

An accurate measurement of the redshift — hence the distance — requires spectroscopic observations. A spectrum of GRB 000131 was therefore obtained on February 8, 2000. At this time, the brightness had decreased further and the object had become so faint (*R*-magnitude 25.3) that a total of 3 hours of exposure time was necessary with VLT ANTU + FORS1. The deduced photometric redshift of GRB 000131 predicts that a 'break' will be seen, caused by the strong absorption of light in intergalactic hydrogen clouds along the line of sight. The effect is known as the 'Lyman-alpha forest' and is observed in all remote objects.

As the spectrum shows, such a break was indeed found at wavelength 670.1 nm. Virtually all light at shorter wavelengths from the optical counterpart of GRB 000131 is absorbed by intervening hydrogen clouds. From the rest wavelength of the Lyman-alpha break (121.6 nm), the redshift of GRB 000131 is then determined as 4.50, corresponding to a travel time of more than 90% of the age of the Universe.



The spectrum of the afterglow of GRB 000131, obtained during a 3-hr exposure with FORS1 on February 8, 2000, when the object's magnitude was only *R* = 25.3. The 'Lyman-alpha break' at wavelength 670.1 nm is indicated.

Star Death Beacon at the Edge of the Universe

Astronomers find farthest known gamma-ray burst with ESO's VLT

12 September 2005

An Italian team of astronomers has observed the afterglow of a gamma-ray burst that is the farthest known ever. With a measured redshift of 6.3, the light from this very remote astro–nomical source has taken 12,700 million years to reach us. It is thus seen when the Universe was less than 900 million years old, or less than 7 percent its present age.

"*This also means that it is among the intrinsically brightest gamma-ray burst ever observed*", said Guido Chincarini from INAF-Osservatorio Astronomico di Brera and University of Milano-Bicocca (Italy) and leader of a team that made the study. "*Its luminosity is such that within a few minutes it must have released 300 times more energy than the Sun will release during its entire life of 10,000 million years.*"

Gamma-ray bursts (GRBs) are short flashes of energetic gamma-rays lasting from less than a second to several minutes. They release a tremendous quantity of energy in this short time making them the most powerful events since the Big Bang. It is now widely accepted that the majority of the gamma-ray bursts signal the explosion of very massive, highly evolved stars that collapse into black holes.

This discovery not only sets a new astronomical record, it is also fundamental to the understanding of the very young Universe. Being such powerful emitters, these gamma-ray bursts serve as useful beacons, enabling the study of the physical conditions that prevailed in the early Universe. Indeed, since GRBs are so luminous, they have the potential to outshine the most distant known galaxies and may thus probe the Universe at higher redshifts than currently known. And because gamma-ray burst are thought to be associated with the catastrophic death of very massive stars that collapse into black holes, the existence of such objects so early in the life of the Universe provide astronomers with important information to better understand its evolution.

The gamma-ray burst GRB050904 was first detected on September 4, 2005, by the Swift satellite, which is dedicated to the discovery of these powerful explosions. Immediately after this detection, astronomers in observatories worldwide tried to identify the source by searching for the afterglow in the visible and/or near-infrared, and study it. First observations by American astronomers with the Palomar Robotic 60-inch Telescope failed to find the source. This sets a very stringent limit: in the visible, the afterglow should thus be at least a million times fainter than the faintest object that can be seen with the unaided eye (magnitude 21). But observations by another team of American astronomers detected the source in the near-infrared *J*-band with a magnitude 17.5, i.e. at least 25 times brighter than in the visible. This was indicative of the fact that the object must either be very far away or hidden beyond a large quantity of obscuring dust. Further observations indicated that the latter explanation did not hold and that the GRB must lie at a distance larger than 12,500 million light-years. It would thus be the farthest GRB ever detected.

Italian astronomers forming the MISTICI collaboration then observed the object in the near-infrared with ISAAC and in the visible with FORS2. Observations were done between 24.7 and 26 hours after the burst. Indeed, the after–glow was detected in all five bands in which they observed (the visible *I*- and *z*-bands, and the near-infrared *J, H*, and *K*-bands). By comparing the brightness of the source in the various bands, the astronomers could deduce its redshift and, hence, its distance. "*The value we derived has since then been confirmed by spectroscopic observations made by another team using the Subaru telescope*", said team member Angelo Antonelli (Roma Observatory).

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NGC 3981

Back cover: Thor’s Helmet


Chamaeleon I