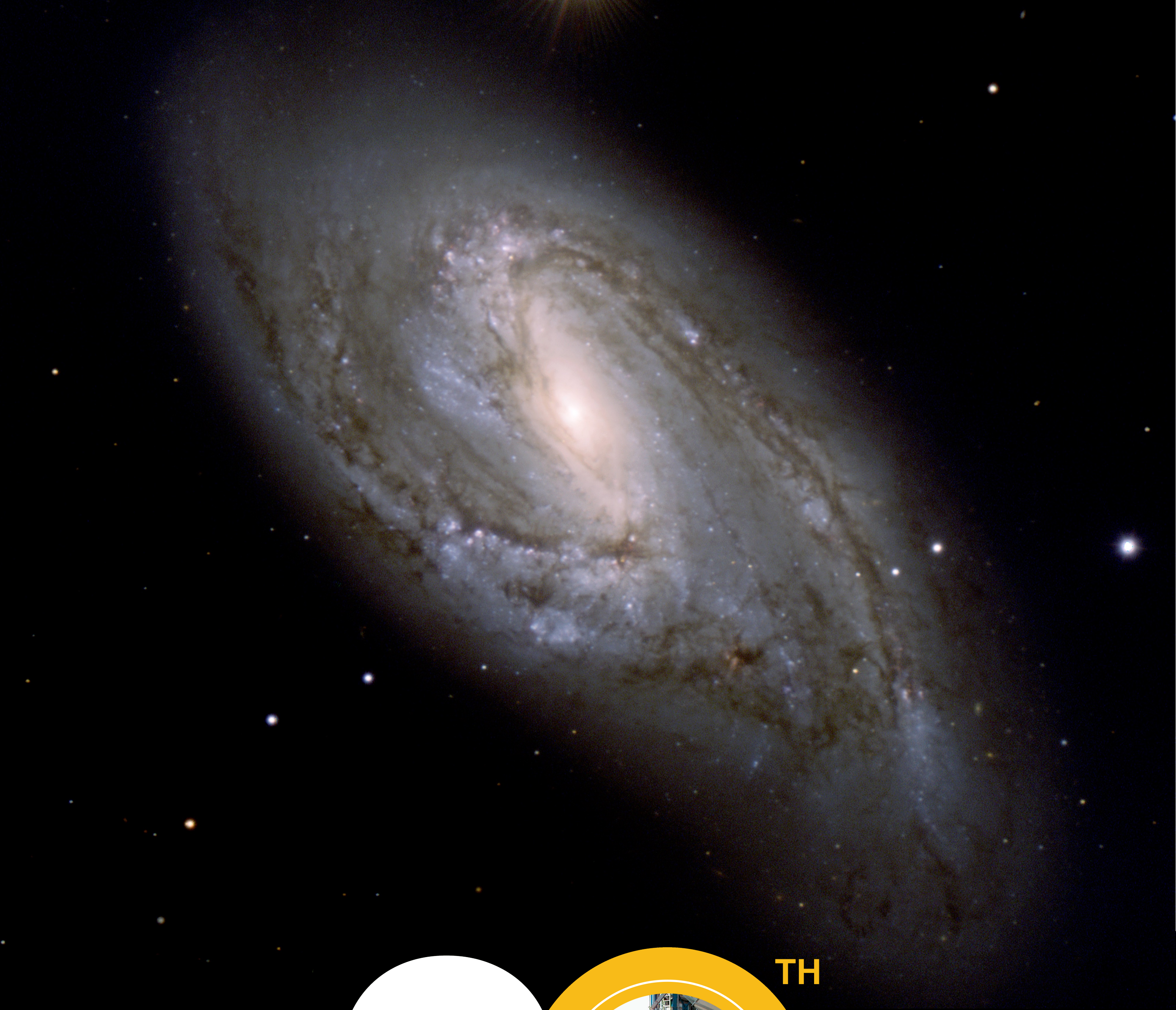

20TH ANNIVERSARY OF SCIENCE EXPLORATION WITH FORS

Abstract Booklet
March 12, 2019

Front cover: Messier 66

> “Of all instruments at Paranal, FORS is the Swiss Army knife.”

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In April 1999, the first of the twin workhorses of the Very Large Telescope, FORS1, started regular science operations. In September 1999 its twin, FORS2 arrived on Paranal and entered regular service on UT2 Kueyen in April 2000. Over the years, the two FORS instruments provided unique data, leading to many astronomical discoveries, not to mention very well-cited papers. Both were in high demand and were among the most prolific of all Paranal instruments during the time when they were both offered. Though operations with FORS1 came to an end on 1 April 2009, a revamped FORS2 has continued down that same high-demand, high-productivity path.
In 2019, we will celebrate 20 years of first light for FORS2 and a cumulated operational life of 29 years for both instruments! This is the right time to take a moment and see what makes FORS such successful instruments.

12 March 2019 - ESO Supernova		
08:30	**Coffee and Registration**	
Chair: Ralf Siebenmorgen		
09:15	**Opening**	Xavier Barcons, ESO DG - *Welcome*
09:15		Gero Rupprecht - *FORS: How it all began*
09:30		Wolfgang Hummel - *FORS operations*
10:10	**Coffee Break**	
Chair: Michael Sterzik		
10:40		Oliver Hainaut - *Minor bodies in our solar system, as seen by FORS*
11:20		Nikolay Nikolov - *From hot gas-giants to cooler rocky exo-Earths*
12:00		Stefano Bagnulo - *Polarisation by scattering and biomarkers*
12:40	**Lunch**	
Chair: Luca Pasquini		
14:00		Veronika Schaffenroth - *Observing short-period binaries with FORS2 - possibilities and challenges*
14:40		Magda Arnaboldi - *Dynamics of galaxies and clusters with FORS*
15:00		Laura Pentericci - *Probing the reionization epoch with deep spectroscopy*
15:40		Ferdinando Patat - *Supernovae, gamma-ray bursts and GW counterparts with FORS*
Chair: Bruno Leibundgut		
16:20	**Discussion**	*The future of FORS*

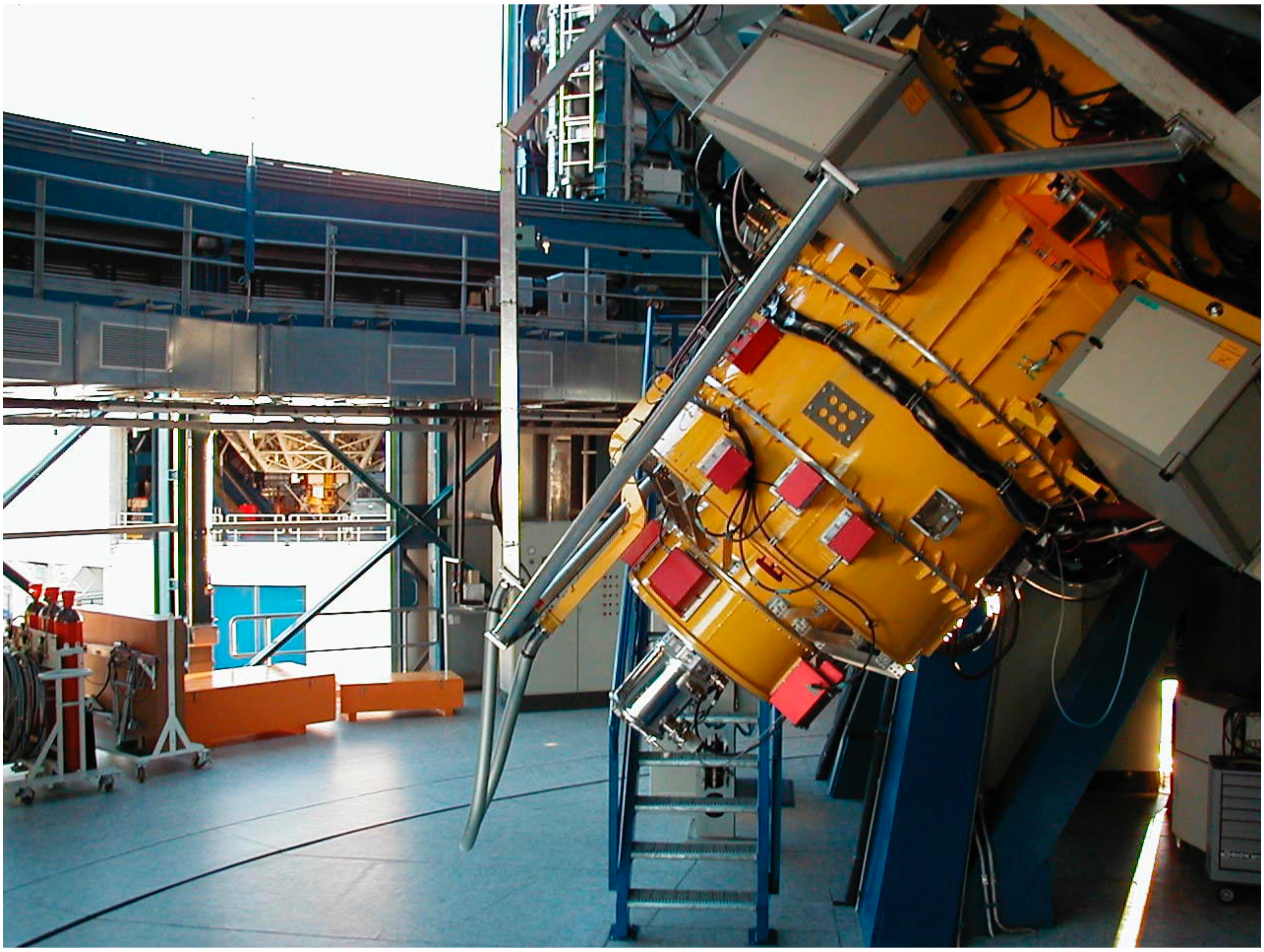
Abstracts

Gero Rupprecht: *FORS - How it All Began*

I will give a highly subjective account of the events leading to the design and construction of two of the most famous, most requested, and most reliable optical instruments on 8m-class telescopes: FORS1 and FORS2. I will also give a view behind the scenes of the project.

Wolfgang Hummel: *FORS operations*

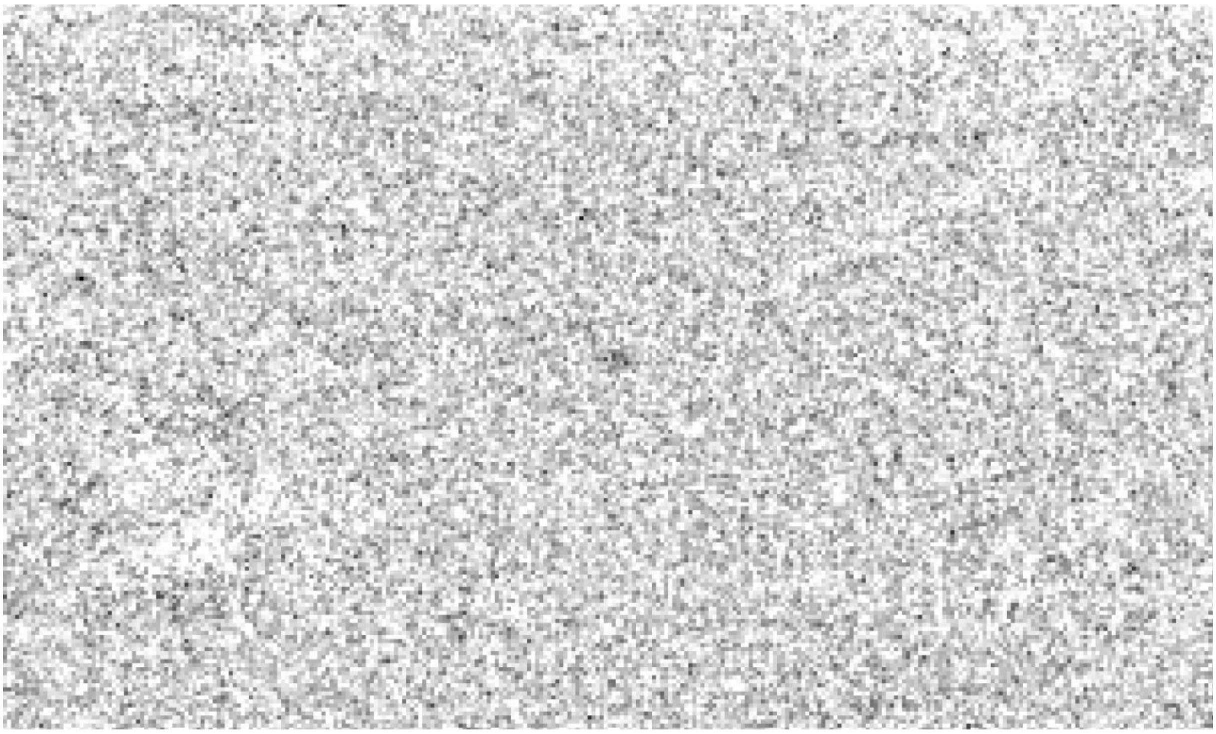
ESO operates the FORS instruments since twenty years. In my talk I will highlight the operational aspects of the FORSes during the last two decades. This includes an overview of its technical capabilities, the instrument specific procedures within VLT operations and the dataflow. I will describe the efforts taken be ESO to keep the FORSes competitive and the projects that lead to an improvement of the science data quality.



The two FORSes at Paranal.

Olivier Hainaut: *Minor bodies in our Solar System, as seen by FORS*

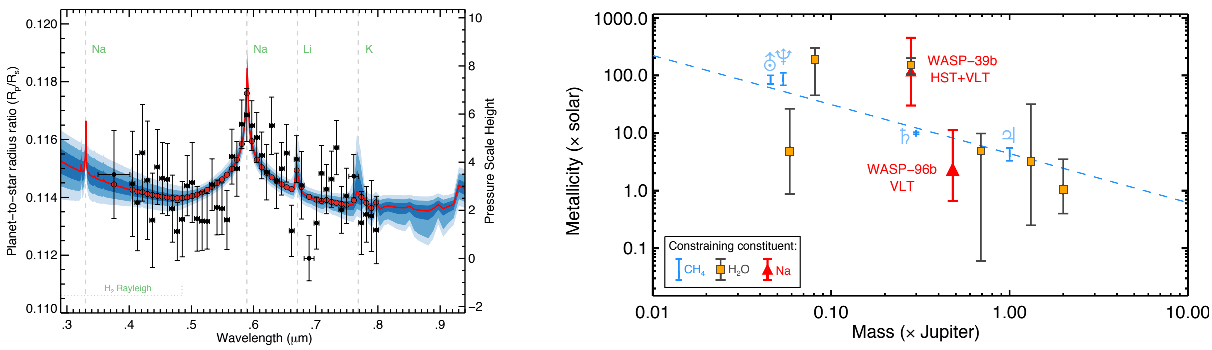
Discovered just a few years before the FORS twins started their long career, the Trans Neptunian Objects are a beautiful example of a population that was characterized thanks to the VLT. Two large programs and countless projects have shaped our understanding of these minor bodies. More generally, the power of the FORSes and the flexibility of the VLT are a excellent match to the challenges of faint, moving targets. Furthermore, thanks to the UTs' collecting area, the FORSes can measure extremely faint dust comae, revealing that some objects are actually comets. FORS' contribution to the planetary defence; record breaking observations of the faintest or most distant solar system bodies observed; crucial support to spacecraft visiting remote objects... I'll present a (strongly biased) selection of FORS' contribution to the study of the minor bodies in the Solar System.



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.

Nikolay Nikolov: *From hot gas-giants to cooler rocky exo-Earths: A pioneering survey of exoplanet atmospheres*

Over the past decade, transit spectroscopy of close-in exoplanets has started to reveal a large diversity of atmospheres and a prevalence of clouds and hazes, ranging in composition from alkali volatiles to metal oxide refractories. Currently, no obvious pattern of atmospheric chemistry has emerged to show how it links with the occurrence of clouds and hazes, planet formation and the physical properties of the host stars. Only large surveys, combined with previous results, will allow us to establish correlations and help elucidate the main processes responsible for the formation and evolution of the overall exoplanet population. While space-based observations play a leading role in the atmospheric exploration of exoplanets, significant progress has recently been made from the ground thanks to VLT FORS2. I will discuss results from the first comparative ground-based multi-object spectroscopy followup of cloud-free, cloudy and hazy exoplanets with atmospheric features detected with HST. By comparing and contrasting the VLT spectra with HST spectroscopy, we find that VLT FORS2 is an ideal instrument for exoplanet transmission spectroscopy. I will further present results from the first large-scale transmission spectral survey with FORS2 from hot gas giants down to cooler Earth-mass worlds. In particular, I will discuss the optical transmission spectrum of the ”hot Saturn“ WASP-96b, which exhibits the complete pressure-broadened profile of the sodium absorption feature enabling a precise absolute sodium abundance and atmospheric metallicity from the ground. With an absence of space-based optical capabilities beyond the HST lifetime, FORS2 can play a leading role in exploring the diversity of exoplanet atmospheres and by providing highly-complementary optical transmission spectroscopy for the upcoming infrared ARIEL, FINESSE and JWST enabling absolute atmospheric abundances.

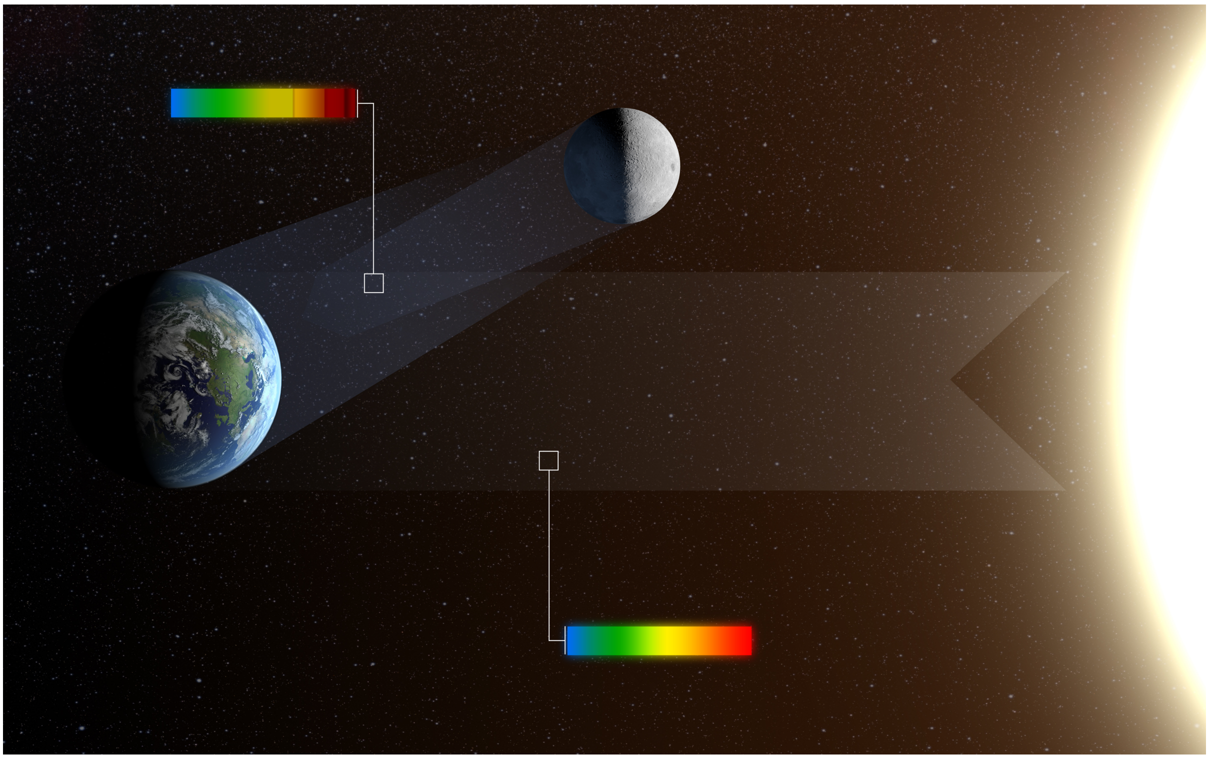


Left: Transmission spectrum of WASP-96b from FORS2 (black dots with 1σ error bars) compared to the best-fit model obtained from retrieval analysis (continuous line), with the 1σ, 2σ and 3σ confidence intervals (shaded regions). *Right*: Mass-metallicity diagram for Solar System planets and exoplanets. With its detected and resolved pressure-broadened Na line wings, WASP-96b is the first transiting exoplanet for which high-precision atmospheric metallicity has been constrained using data only from the ground. (Nikolov et al. 2018, Nature)

Stefano Bagnulo: Polarisation by scattering and biomarkers

After having inherited the polarimetric optics of its twin instrument FORS1, FORS2 has become the most heavily subscribed polarimeter in the Southern Hemisphere, and one of the most versatile, sensitive, and accurate polarimeters in the world, both in imaging and in spectro-polarimetric mode. Because it is mounted at the Cassegrain focus, the fraction of linear and circular polarisation of astronomical sources may be precisely measured in absolute value, with an accuracy up to a few units in 10^{-4}. Linear polarimetric measurements, in particular, allow a full characterisation of the continuum of the radiation scattered either by particles or by surfaces. FORS2 has been used for instance for the study of supernovae, to characterise the interstellar dust, and to explore the surface of the atmosphereless objects of our solar system, helping also to explain or even anticipate results from space missions. Of very special interest is the case in which the study of the polarised radiation reveals biomarkers, like the presence of O_2 in a planetary atmosphere. This is a result that has been achieved by FORS2, although on a planet that was already known to host life (Sterzik et al. 2012, Nature).

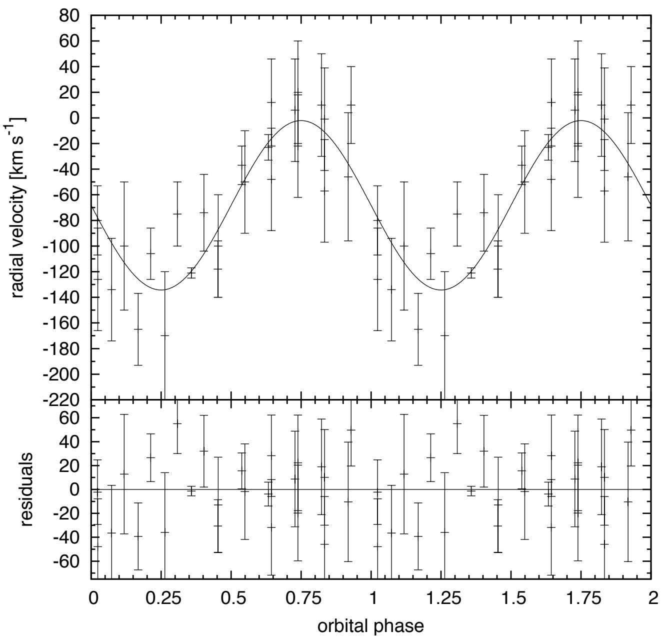
In this talk I will review some of the results that have been obtained with FORS2 (mainly in linear polarimetric mode) over the last decade. In many applications, FORS2 was used at the limit of the instrument+telescope capabilities, and I will discuss how the forthcoming instrument upgrade, as well as the design of future polarimeters, may be informed by the FORS experience.



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.

Veronika Schaffenroth: *Observing short-period binaries with FORS2 - possibilities and challenges*

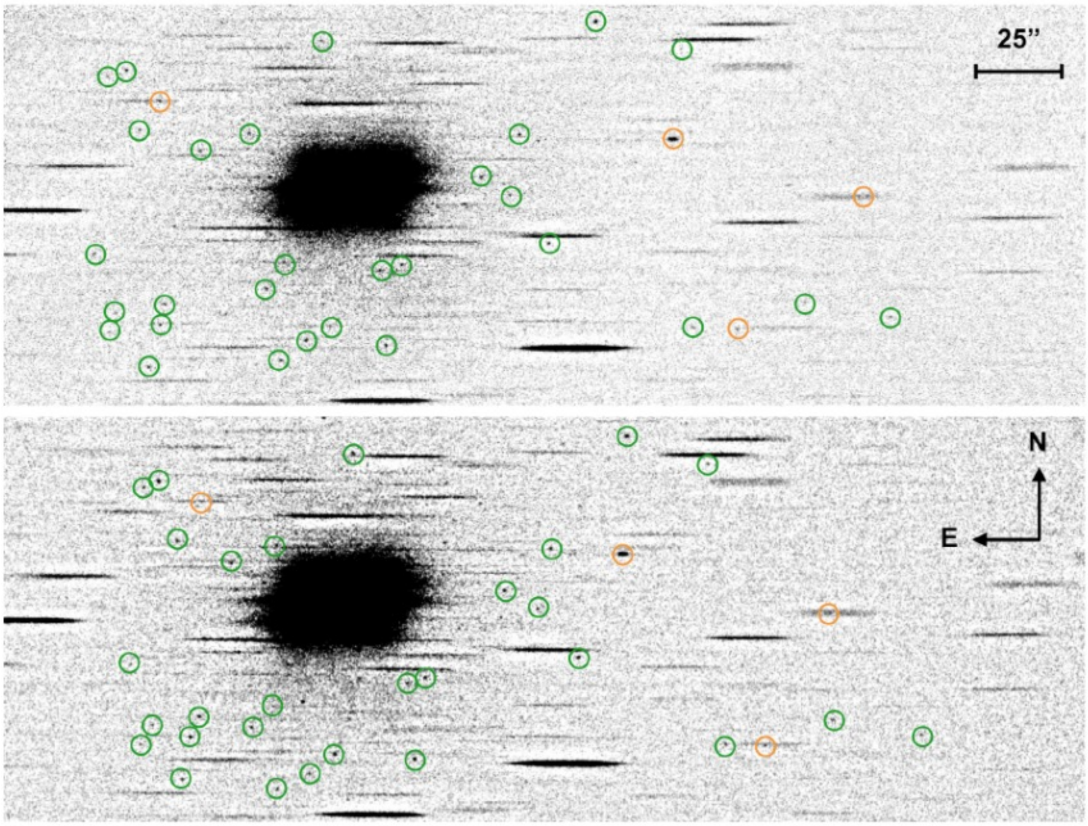
The FORS2 instrument is one of the most widely used and productive instruments on the Very Large Telescope. It can be used as a camera, polarimeter, multi-object spectrograph or long-slit spectrograph. The FORS optics is optimized for good image quality and good transmission over an extended wavelength range (330 nm to 1100 nm). It is still the only instrument providing low to medium resolution spectra in the optical at the VLT including also in the blue wavelength range below 400 nm. To observe blue, faint, short-period binaries, a telescope of the 8m-class is necessary, as the possible exposure time is limited. The spectroscopy mode of FORS2 is used mainly for deriving redshifts of faint galaxies or for taking multi-object spectra of stars in other galaxies or open clusters. However, the resolution of FORS2 is also sufficient to measure the radial velocity curves of close binaries. Here, I will give a review of binaries observed with FORS. I will emphasize on the introduction of the EREBOS (Eclipsing reflection effect binaries from the OGLE survey) project. This project aims at increasing the number of eclipsing post-common envelope systems studied significantly. We were awarded with an ESO Large program with FORS2 for this project. We are studying eclipsing post-common envelope systems consisting of hot subdwarf stars and cool low mas companions, which are found at periods between 0.05 to 0.5 days. Hot subdwarf stars are helium-core burning objects, which lost most of their envelope on the tip of the red giant branch. It is believed that binary evolution plays a major role in the formation of these systems. Short-period hot subdwarf binaries with cool, low-mass companions must undergo a common-envelope phase, as otherwise such short periods cannot be explained. With the help of spectroscopic follow-up combined with photometric observations, we are able to determine the mass, and hence the nature of the companion, as well as the primary star. We are hoping to answer especially the question, which minimum mass a companion must have to be able to eject the envelope of the primary star in a common envelope phase, but also to understand the poorly understood common-envelope phase better. Furthermore, I will discuss some challenges that we faced during the data analysis and how the future of observing binaries with FORS could look like.



Radial velocity curve of the 19.5 mag binary OGLE-GD-ECL-10384 (period = 1.86 h).

Magda Arnaboldi: *Dynamics of galaxies and clusters with FORS*

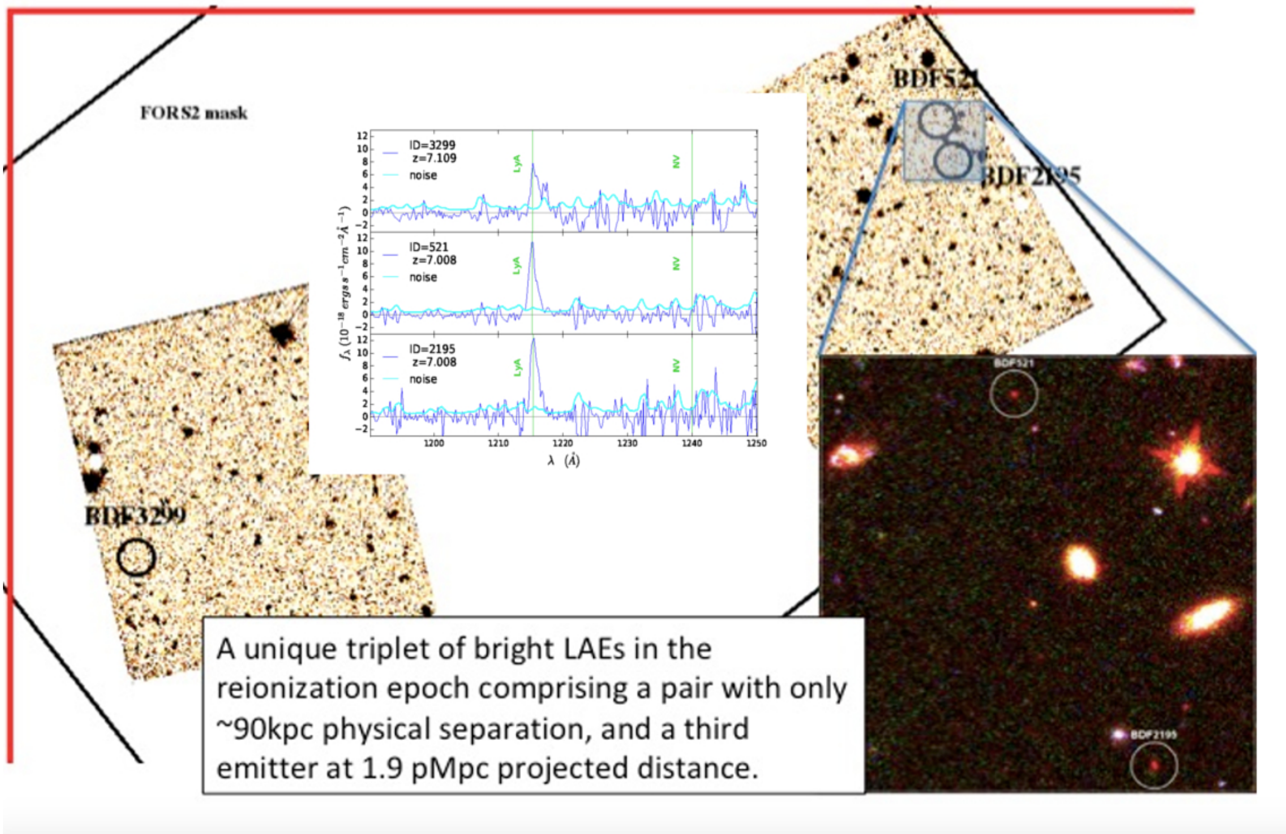
FORS1 and 2 have been key instruments in the quest of measuring the orbital motions of stars and the mass distribution in the outer halos of galaxies, and in the densest regions of the universe, the cluster cores. In addition to the standard long slit/MXU modes, which allow absorption line spectroscopy of the stellar continuum and of discrete tracers like globular clusters, the counter dispersed imaging (CDI) technique with narrow band filters has enabled FORS to become a unique survey facility optimized for the detection of emission line sources, like planetary nebulae, Ly-αand [OII] emitters. I will review the fantastic results achieved by FORS with CDI, in addition to the standard modes, on constraining the mass distribution and stellar populations of early type galaxies. I will conclude with the mapping of stellar motions in the Fornax and Hydra clusters' core, at 17 and 50 Mpc, based on the detection of bright emission lines from single stars, i.e. planetary nebulae, in these stellar systems, and the forward look.



Example of the FORS CDI technique. Zoomed in region of Field 3 of the Fornax cluster survey by Spiniello et al. 2018 MNRAS, 477, 1880. The top frame is the W0 exposure while the bottom frame is the counter-dispersed W180 exposure rotated back to be compared to the first. The big diffuse blob on the left center of each frame is NGC 1387 while the other horizontal strikes are stars. The two images have been corrected, registered and calibrated, in a way that the galaxy and the stars appear in the same position. Only planetary nebulae and point-like emitters have different x-positions in the two panels because of their line-of-sight velocity. Additional background line emitters, like the [OII] emission from galaxies at z~0.347, or Lyman-α galaxies at z~π are identified either because the [OII] doublet is resolved, thanks to the adopted 1200V grism, or the presence of a continuum. Some emitters are circled (PNe in green, background objects in orange) in the above image to give illustrative examples. From Spiniello et al. 2018, MNRAS 477, 1880.

Laura Pentericci: *Probing the reionization epoch with deep spectroscopy*

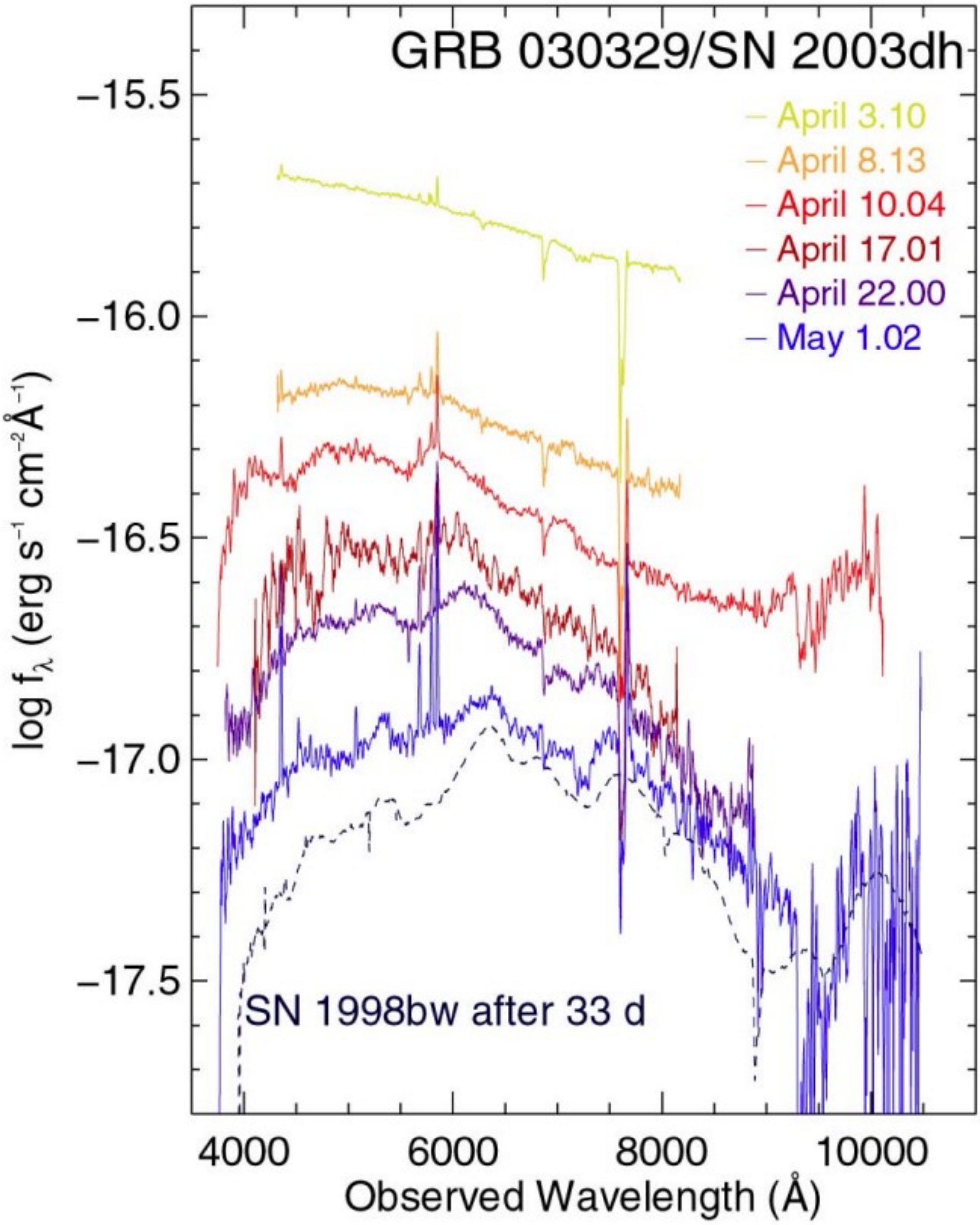
Two of the most outstanding issues in modern astrophysics are what reionized the Universe and when and how did the first objects form. The past decade has seen impressive progress in our understanding of these problematics surely multi objects spectroscopy has played a key role since it has allowed us to securely identify and study galaxies up to the earliest epochs. Multi object spectrographs have thus become the work-horse instruments of many observatories: the FORS2 spectrograph (together with its precursor FORS1) contributed with many significant discoveries in this area, allowing us to identify a large population of Lyman alpha emitting galaxies up to z>7. The Lyalpha line offers a powerful probe to study both reionization and the process of galaxy formation: it is an efficient tool for identifying young actively star forming galaxies and can provide a robust measure of how much neutral hydrogen is present in the environment of the galaxies, thus being a reionization test that complements the Gunn-Peterson trough observations in quasar spectra.
I will review the most recent observational results on high redshift galaxies, namely Lyalpha emitters and Lyman break galaxies and the current constrains that we can place on the reionization epoch using the first statistical samples of spectroscopically confirmed z=7 star forming galaxies, the evolution of the luminosity functions and of the clustering strength of Lyalpha emitters.



A unique triplet of bright LAEs in the reionization epoch comprising a pair with only ~90kpc physical separation, and a third emitter at 1.9 pMpc projected distance.

Ferdinando Patat: *Supernovae, Gamma-ray Bursts and GW Counterparts with FORS*

The FORSes have provided the astronomical community with a very powerful and versatile tool for transient astronomy. In my talk I will review the main results obtained with these instruments in the field of Supernovae, Gamma-Ray bursts and, more recently, on the electromagnetic counterparts of Gravitational Waves events. In the light of these results I will also try to outline a possible future for these instruments in the study of explosive transients.



FORS1+2 spectral sequence of SN2003dh/GRB030329 (Hjorth, J. et al., 2003, Nature, 423, 847). These data provided the ultimate confirmation of the association between long GRBs and Type Ic supernovae, clearly showing the spectroscopic transition between the early afterglow and an hyper energetic supernova event.

List of Participants

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