### Acknowledgements

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### References

Hainaut, O. et al. 2018, The Messenger, 171, 8
ESO 1998, The VLT White Book, (Garching, Germany: European Southern Observatory)

### Links

1 Google Angular framework: https://angular.io
2 Semantic framework: https://semantic-UI.com
3 The GRAILS project: https://grails.org
4 CDS Sesame: http://cds.u-strasbg.fr/cgi-bin/Sesame
5 The ESO User Portal: http://www.eso.org/UserPortal
6 The format of the time constraints is described here: https://www.eso.org/p1demo/timeConstraintsHelp
7 Overheads table: https://www.eso.org/sci/facilities/paranal/cfp/overheads.html
8 The p1demo interface: https://www.eso.org/p1demo/proposals
9 A p1 video tutorial: https://www.eso.org/sci/observing/phase1/newP1tool/p1_shortIntroVideo_new.mp4
10 Global Research Identifier Database (GRID): https://www.grid.ac
11 E-mails can be sent to the p1 team at p1@eso.org
12 The p2 demo interface: https://www.eso.org/p2demo/login

### Notes

[a] The overheads are the same as in p2; if you are already familiar with the overheads that apply to your particular instrument setup, you can use the overheads table[7], otherwise it is recommended that you experiment with the p2demo[12].

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Report on the ESO Event

# 20th Anniversary of Science Exploration with FORS

held at the ESO Supernova, Garching, Germany, 12 March 2019

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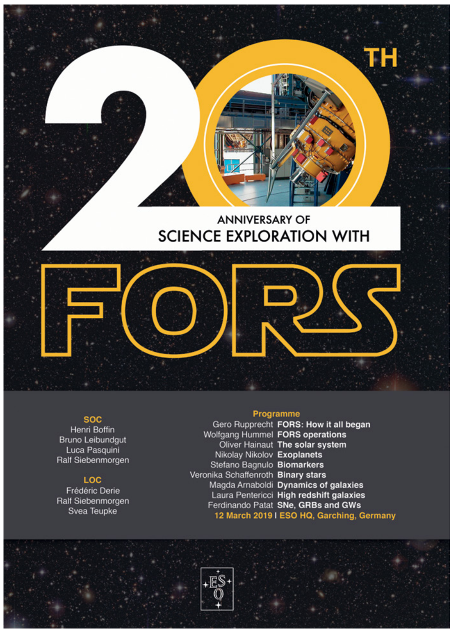
About 50 scientists belonging to the "Friends of FORS" family convened at the ESO Supernova Planetarium & Visitor Centre to celebrate 20 years of successful science exploration with FORS1 and FORS2. Scientific highlights from these instruments were discussed, covering various research areas ranging from interstellar bodies entering our Solar System, to the detection of exoplanets and biomarkers, interstellar medium dust polarisation, binary star velocities, galaxy dynamics, high-redshift galaxies near the re-ionisation epoch, and transient astronomical events such as supernovae, gamma-ray bursts, and gravitational waves. In addition to reviewing the amazing scientific achievements from the FORS instruments, a specific goal of the conference was to discuss ways in which to foster the high scientific impact of the instrument in the future. Various suggestions from the ESO community for upgrading the instrument were presented and discussed.

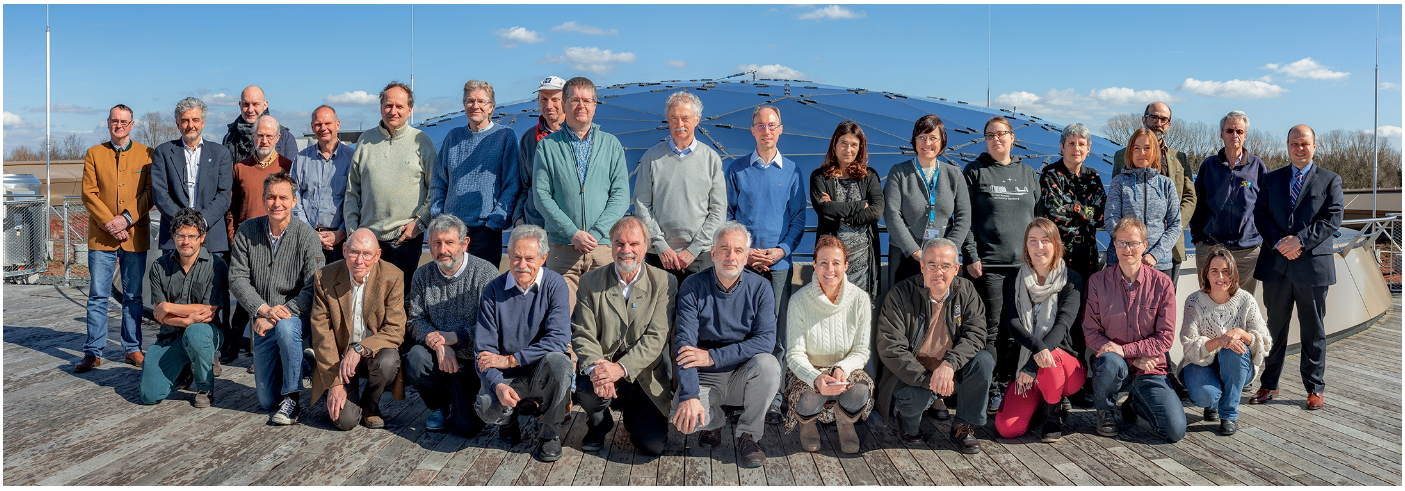
## A successful twin

The FOcal Reducer and low-dispersion Spectrpgraphs, FORS, are two multi-mode instruments mounted on a VLT Unit Telescope (UT) Cassegrain focus. They are offered in several modes: imaging, polarimetry, long slit, and multi-object spectroscopy. In April 1999, the first of the twin workhorses of the VLT, FORS1, began science operations. In September 1999 FORS2 arrived at Paranal, entering into regular service in April 2000. Over the years, the two FORS instruments have provided unique data leading to many astronomical discoveries. Both instruments are among the most prolific instruments worldwide. In March we celebrated the scientific discoveries made with these successful instruments in




Credit: N. Boffin

Figure 1. The conference poster.



a one-day event. The goal of the conference was to gather, consolidate and understand the wishes and needs of the astronomical community for upgrades that would ensure the high science productivity of FORS into the future.

## Instrument features

FORS is the "swiss army knife of the Paranal Observatory". FORS observations cover a wide wavelength range from 330 to 1100 nm at high sensitivity; the transmission is above 60% over 360–1100 nm, and reaches almost 80% around 440 nm. In imaging mode this leads to a typical magnitude limit of about 25.9 in *U* (with 1-hour integration; S/N ~ 5), 27.6 in *B* and 27.3 in *V* using an E2V detector, and — with the MIT detector — 26.6 in *R*, 25.8 in *I*, and 24.7 in *z*. The field of view is 6.8 × 6.8 arcminutes, which is the maximum unvignetted field of the Cassegran focus at the VLT. High image quality is ensured by a passive flexure compensation system.

The system includes a longitudinal atmospheric dispersion corrector (LADC) which acts up to about 60 degrees away from zenith, i.e., airmass ≲ 1.5–1.6. The astrometric precision reached is about 0.1 milliarcseconds using the high-resolution collimator. The instrument can also be used in spectroscopic mode with a magnitude limit between 23 and 24 in *V* as well as in imaging and spectroscopy polarimetry. FORS2 spectroscopy consists of three modes: classical long-slit spectroscopy with slits of 6.8-arcminute length and predefined widths between 0.3 and 2.5 arcseconds; multi-object spectroscopy using 19 slitlets with slit lengths of 20–22 arcseconds each; and arbitrary widths created by movable slit blades. Multi-object spectroscopy may also use masks with slitlets of almost arbitrary lengths, widths, shapes and angles in the Mask eXchange Unit mode (MXU). There are 15 grisms with resolutions from 260 to 2600 for a 1-arcsecond slit, which may be combined with three different order-separating filters to avoid second-order contamination.

## Science impact

Both FORS instruments have been in high demand since first light, and this has not changed; FORS2 is still among the most requested instruments at the VLT, with more than 100 proposals submitted in Period 102 (12% of all VLT proposals). In terms of refereed papers, the FORS instruments are the most productive instruments at Paranal; FORS1 led to 1022 refereed publications, and for FORS2 this number is 1511. In 2017 alone, FORS2 led to 106 refereed publications. Among these were three Nature papers highlighting innovative results: the first interstellar asteroid detected in the solar system (Meech et al., 2017; Micheli et al., 2018); the spectroscopic identification of a gravitational wave source (Pian et al., 2017); and the first detection of titanium oxide in the atmosphere of an exoplanet (Sedaghati et al. 2017; Nikolov et al. 2018). Over the years, FORS2 has led to 29 Nature papers and

Figure 2. The conference workshop photograph.

10 Science papers. Apart from those mentioned above, these papers cover a variety of topics, including asteroids, binary stars, neutron stars, supernovae, black holes, gamma-ray bursts, and quasars. All modes of FORS2 were used for these discoveries.

A presentation of early science with FORS can be found in Rupprecht et al. (2010). At that time, they 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"*. Amongst the most cited FORS2 papers, one finds the spectroscopic studies of the GOODS-South field (Vanzella et al., 2008; Popesso et al., 2009; Balestra et al., 2010) and of the Chandra Deep Field-South (Szokoly et al., 2004), which are based on MXU observations. In more recent years, the most cited papers are about Lyman-$\alpha$ emitters in the early universe (with MXU), spectropolarimetry of massive stars and dust, photometric studies of young stellar regions, astrometric studies of brown dwarfs and transmission spectroscopy of exoplanets.

## The workshop

In his welcome talk, the Director General presented some of his own science that had been carried out with FORS, identifying X-ray sources from XMM-Newton serendipitous surveys (Barcons et al., 2002).

He stressed the high scientific impact that FORS has delivered over the past 20 years. The first of several FORS project scientists from the past 20 years was Gero Rupprecht and, in a very emotional talk, he reflected on the early days of the instrument — during commissioning. He explained how FORS1 received the nickname of "yellow submarine" in the early days owing to its distinctive colour. Former Consortium member Wolfgang Hummel — now at ESO — highlighted the sophisticated operational model that had been put in place to make sure the best science is done with the instruments. He also presented a brief history of the various changes to the instruments.

The scientific presentations started with a review by Olivier Hainaut of the characterisation of minor bodies in our Solar System. Particular attention was given to 'Oumuamua, the first and currently only asteroid ever detected which is of interstellar origin.

Nikolay Nikolov presented the transmission spectroscopy technique, which is used to characterise the atmospheres of exoplanets, from hot gas giants down to cooler Earth-mass worlds. He stressed that the resulting FORS2 light curves were of space-based quality, making FORS2 the best ground-based instrument in the world for this kind of science. This is important as the VLT has access to fainter targets that have smaller signals than the Hubble Space Telescope does. Also, in the future all space-based instruments will only access the infrared and FORS2 will be needed to provide the optical counterpart observations, ensuring a unique role for FORS2 over the next 10–15 years.

Stefano Bagnulo showed how FORS2 spectro- and imaging polarimetry have been used in the study of supernovae, to characterise interstellar dust, and to explore the surfaces of Solar System bodies. Of special interest is the study of how polarised radiation reveals biomarkers, such as $O_2$, in a planetary atmosphere that is known to host life — i.e., the Earth (Sterzik et al., 2012)!

The challenges associated with observing short-period binaries were discussed by Veronika Schaffenroth. The FORS resolution is sufficient to measure radial velocity curves, and hence masses of close binaries — assuming the orbital inclination is known. One notable case involved using FORS observations to constrain the minimum mass a companion must have to be able to eject the envelope of the primary star in a common envelope (CE) phase. Such a phase, which is very poorly understood, is critical in creating very short period binary systems, some of which are thought to explode as Type Ia supernovae and to produce gravitational waves.

The dynamics of galaxies and clusters as revealed by FORS was presented by Magda Arnaboldi. The motions of planetary nebulae allow the mass distribution in the outer halos of galaxies, and in the cores of galaxy clusters, to be determined (McNeil et al., 2010; Spiniello et al., 2018). This requires the use of a special technique, called counter-dispersion imaging, which involves doing slitless spectroscopy, combined with narrowband filters and superposing two images taken 180 degrees apart. Thanks to this, it is possible to measure distances and radial velocities out to 25 Mpc.

An outstanding issue in modern astrophysics is what reionised the Universe and when and how the first objects formed. Laura Pentericci showed what was the main initial goal of FORS when conceived, i.e., deep spectroscopy to identify a large population of Lyman-$\alpha$ emitting galaxies up to $z > 7$ (Vanzella et al., 2008). She presented the deepest FORS2 spectrum ever obtained in the reionisation epoch — a 52-hour-long exposure that showed… nothing! This in fact indicates that reionisation might be a more extended process than previously thought and not yet completed at $z = 6$.

Figure 3. The FORS team during the preliminary design review in 1992.

Finally, Ferdinando Patat presented FORS as a versatile tool for transient astronomy and presented highlights of results obtained with the instruments in the field of supernovae, gamma-ray bursts and, more recently, on the electromagnetic counterparts of gravitational-wave events. The abstracts and presentations of the talks are available at the conference website[1] and a booklet[2] has been prepared that collects the highlights of 20 years of science exploration with FORS.

## The future

The conference summary focused on a discussion of the various upgrade options as presented. The need for a larger field of view was frequently raised; however, the unvignetted field of the VLT Casegrain focus is already in use. In terms of the telescope itself, an enhanced cleaning procedure to ensure optimal sensitivity of the ADC was requested. The instrument was designed for a 10-year lifetime (!), so a general overhaul of the mechanics and electronics is needed to ensure its smooth operation for the next 15 years. At the same time, the instrument will be upgraded so that it provides higher transmission in both the blue and red parts of the optical spectral range, without the need — as is currently the case — to exchange CCDs. The detector will come with better cosmetics and reduced systematics in the flat field. New grisms that provide flatter throughput and higher sensitivity will also be procured. The need for specific high-spectral-resolution grisms centered on the Na, K, and Li lines was also identified.

FORS polarimetry was reported to be excellent, though it could be further improved by reducing systematic errors such as the instrumental polarisation. A higher precision in Stokes V/I could be attained by considering a double-wedge device, allowing simultaneous observations of all four components of the Stokes vector rather than recording just the ordinary and extraordinary beams. In that respect, all the optical devices, including the collimator, will be verified and birefringence reduced where possible. An interest in imaging polarimetry with flat instrumental polarisation across the field was discussed. Besides bringing all software systems up to the current standards, the importance of the pipeline was stressed, including the need for science grade data products. Finally, it was also imperative to review all the operational constraints, such as for example the interdiction on taking arcs during the night at the position of the observations.

## Demographics

The Science Organising Committee sought fair representation from the community when voting to invite eight speakers. The end result was a male:female ratio of 4:3 among the invited science speakers.


### Acknowledgements

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### References


Appenzeller, I. et al. 1998, The Messenger, 94, 1
Balestra, P. et al. 2010, A&A, 512, A12
Barcons, X. et al. 2002, A&A, 382, 522
McNeil, E. K. et al. 2010, A&A, 518, A44
Meech, K. et al. 2017, Nature, 552, 378
Micheli, M. et al. 2018, Nature, 559, 223
Nikolov, N. et al. 2018, Nature, 557, 526
Pian, E. et al. 2017, Nature, 551, 67
Popesso, P. et al. 2009, A&A, 494, 443
Rupprecht, G. et al. 2010, The Messenger, 140, 2
Sedaghati, E. et al. 2017, Nature, 549, 238
Spiniello, C. et al. 2018, MNRAS, 480, 1163
Szokoly, G. P. et al. 2004, ApJS, 155, 271
Sterzik, M. et al. 2012, Nature, 483, 64
Vanzella, E. et al. 2008, A&A, 478, 83


### Links

[1] Workshop programme, abstracts, and online presentations are available at: https://www.eso.org/sci/meetings/2019/FORS2019.html
[2] FORS science overview booklet available at: https://www.eso.org/sci/meetings/2019/FORS2019/FORS20thyear_low.pdf

Image from first light FORS *BVRI* observations of the spiral galaxy NGC 1288 on the night of 15 September 1998.