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ESPRESSO
HARPS observation of the Venus transit
Spectroscopy of the Magellanic Stream
Science with ALMA Band 11

ESO

The ESO Product Data Management System — A New Home for ESO's Technical Documents

Maximilian Kraus[1]
Roberto Tamai[1]
Paul Jolley[1]
Guy Hess[1]

[1] ESO

Originally the technical archives at ESO grew organically and lacked a single coherent storage and access system. A search for a powerful product data management (PDM) system to unify the document archives of observatory, telescope and instrument technical material was initiated. After a careful assessment of the possible systems, it was decided to implement the *Kronodoc* system and its recent introduction as the ESO PDM system is described.

Technical archives at ESO

Over the years several tools have been introduced and used for the archiving and sharing of the ESO documents that staff, contractors and consortium partners produce and store for technical products and projects related to telescopes and instrumentation. This hybrid approach has worked well for most of the project teams, but the overall availability and control of the documents was not optimal. There has also been a central archive, called the Technical Archive, which developed from the documentation system set up for the Very Large Telescope (VLT) project and was located at ESO Headquarters in Garching. The VLT archive was originally planned for printed documents and drawings on paper, and was controlled using document lists. On Paranal a separate archive with a copy of the documents from Garching was set up.

In 2003 this paper-based Technical Archive (see Figure 1) was migrated to an electronic archive. New documents were only accepted as electronic files, and were accessible to ESO internal users on the intranet. The printed documents produced earlier and stored were scanned on demand and also made available on the intranet. In 2009, because of the urgent need for office space, the Technical Archive rooms were needed and all the paper documents were scanned by a specialised contractor and thereafter only stored electronically.

Staff at the La Silla Paranal Observatory had, in principle, access to this archive through the intranet. However, on account of a shortage of network bandwidth and speed, the search and download performance was not considered good enough. At the observatories technicians did not always have the documents available when they were needed, and problems remained in maintaining the documentation set in the event of changes or upgrades.

Over the years, and especially with the advent of the European Extremely Large Telescope (E-ELT) project, the need for a centralised archive for technical documentation became more and more evident. In addition, modern features like remote access, configuration control of documents and release workflows were necessary to support such a large and complex project efficiently. It was therefore decided to search for a replacement for the archiving systems.

Search for a new archiving system

Initially the search for an archiving system concentrated on a drawing management system, because it was perceived that drawing sets, with their parts lists and structures, are very complex to handle, and "normal" documents (for example, specifications) should be more straightforward to store and access. Several commercial systems were examined, but, after a detailed investigation, in each case a number of missing features or functions were identified and the candidate systems were considered unsuitable for the ESO research environment.

Contact with colleagues at the European Organization for Nuclear Research (CERN) was established and visits were arranged to learn first-hand from their experience. Many years ago CERN introduced their Equipment Data Management Service (EDMS[1]) system. After years of development and adaptation, EDMS has become a powerful tool and is in use for many projects at CERN, such as the Large Hadron Collider (LHC), and it is accessible worldwide to CERN partners. The CERN documentation experts shared their experience in the design of the EDMS configuration and also generously offered ESO access to their system. The ESO administrators were trained and worked for several weeks with CERN colleagues and in that way gained valuable information.

One major lesson learned from this exchange was that commercial systems designed for industry fit poorly into an open and creative research environment. This is also why CERN had heavily modified a commercial system and programmed a completely new user interface. CERN operates two completely different archives: one for the creation of drawings and another for the project teams, as they had learned that there are different working cultures and processes in the two areas, and integrating them would be difficult and cause many problems.

As a result of these exchanges, ESO investigated the suitability of the CERN EDMS system as a tool to operate the ESO Technical Archive. While these investigations were proceeding, we learnt about another commercial documentation management system from a small Finnish company, called *Kronodoc*. This company was created by engineers who used to work at CERN and helped to implement the CERN EDMS system within the framework of a Finnish in-kind contribution to CERN. Further information on this spin-off company has been published[2]. The *Kronodoc* system was investigated, and we immediately understood the similarities between it and the CERN EDMS.

During the investigation of the CERN system as a possible solution for ESO, we learnt about its many interesting features, but also recognised that EDMS is fully configured for use at CERN. It could only be adapted to ESO's needs in a very limited way, and there would still need to be some compensation for CERN's substantial efforts. The *Kronodoc* system took care of this limitation: it offered many of the interesting features of the CERN system, but with the flexibility to configure it for ESO's needs. So it was

Figure 1. Two views of the paper-based ESO Technical Archive: storage of folders in sliding cabinets (left); registered documents in suspension files (right).

decided to enter into a definition and testing phase, and a contract was concluded with the Dutch company BlueCielo, who had recently acquired the Finnish company *Kronodoc*[3].

Evaluation process

All the evaluations of possible ESO archiving systems were coordinated by the ESO Mechanical Department in the Technology Division, but other areas within ESO, such as the Instrumentation Division or the E-ELT Department, which also deal with projects, were involved so that they could also bring in their respective requirements.

During the system definition and evaluation phase, CERN's approach of separating the technical drawing and CAD (Computer Aided Design) data management system from the general technical documentation system was confirmed. It was decided to go for the drawing and CAD data management system from our CAD system provider, *AUTODESK*, on account of the complex interface between the CAD system and the drawing management system.

For the handling of the technical and project documentation, the *Kronodoc* system was found to be compliant. It had all the needed functionality: its flexible nature allowed it to be adapted to the needs of ESO, it was accessible from everywhere via a secure internet connection and its user interface was compatible with all computer platforms.

As a consequence two projects were started, first setting up the CAD and drawing management system for the Mechanical Department in May 2011, and then defining and configuring the PDM system in December 2011.

PDM

Why do we call our technical documentation system PDM? PDM is an acronym for Product Data Management. In the production industry, PDM systems are complex databases that can track and control the development of complex machines, plants or systems, in very great detail. An industrial PDM system handles thousands of parts, how they are assembled to form complex machines and can provide users with the relevant documentation at any time. Changes to processes are managed and any change initiated by a designer is scrutinised, and once accepted, the purchase department or workshop will be using the updated documents. Only then can the finished product be traced and the up-to-date documentation be available when the product is used.

At ESO the product creation process is usually not as complex as in the manufacturing industries; however there is the same need for complete and updated documentation when our products enter into their productive life. So we tried to achieve a similar goal: a database which can identify all our products from when they start their life as Phase A projects, through the start of operations at the observatory, tracking any modifications until they are retired from use. The system must provide all users with all documents relevant to our products at any moment of their life.

The majority of ESO's products are designed and produced by industry or consortia, and after testing, delivered to ESO. So there is no need for the ESO PDM system to cover the complex design and manufacturing environments. However, it is essential that we absorb all information created in industrial PDM systems and can access the documents delivered when products pass through their acceptance phase, making this data available to ESO project teams and observatory staff for operation and maintenance. The ESO PDM system is configured primarily for that purpose. In addition the PDM provides collaboration areas for project teams, where they can create and share working documents, and exchange documents with contractors and other partners in a controlled way.

After the contract with BlueCielo for the implementation of an ESO PDM system began, an intensive discussion and fact-finding process started. Over the years, in different areas of ESO, slightly different working cultures had developed, with different processes, or even different names for similar processes. It was necessary to bring all areas back to common standards so that they could be implemented in the automatic processes of a computerised tool. Representatives of all divisions were involved in discussions and brought up many topics where processes needed documentation and clarification. This coordination work will also continue after the implementation of the system.

In parallel with this preparatory work, a technical question needed clarification: how could colleagues in Chile get access to and find and retrieve documents. With the help of the ESO IT department, intensive tests were undertaken: the latency to a connection to Chile was simulated and the *Kronodoc* system was compared with other existing similar systems including the CERN EDMS. The performance of *Kronodoc*, based on a central server hosted in Finland, was found to be sufficient. Later this was also confirmed by direct tests from Paranal.

After the ESO's internal discussions about documentation processes, experts from the contractor were called in for workshops. The findings of the earlier discussions were explained to the external experts so that they could be implemented into the configuration of the documentation system. This exercise was completed as planned, owing also to the experience of the external experts in similar projects. Testing started, and the ESO PDM administrators were trained. Even during testing, the configuration needed to be adapted by the ESO administrators, because, as is usual in such projects, attempts to implement complex processes, which seemed to be logical in the planning phase, turned out to be too involved.

PDM into operation

As soon as a working system was available the data upload process began. Thanks to the good organisation of the existing archives, the VLT Technical Archive and the ELT Archive, the upload of the documents was achieved within a few months and was completed by the end of 2012.

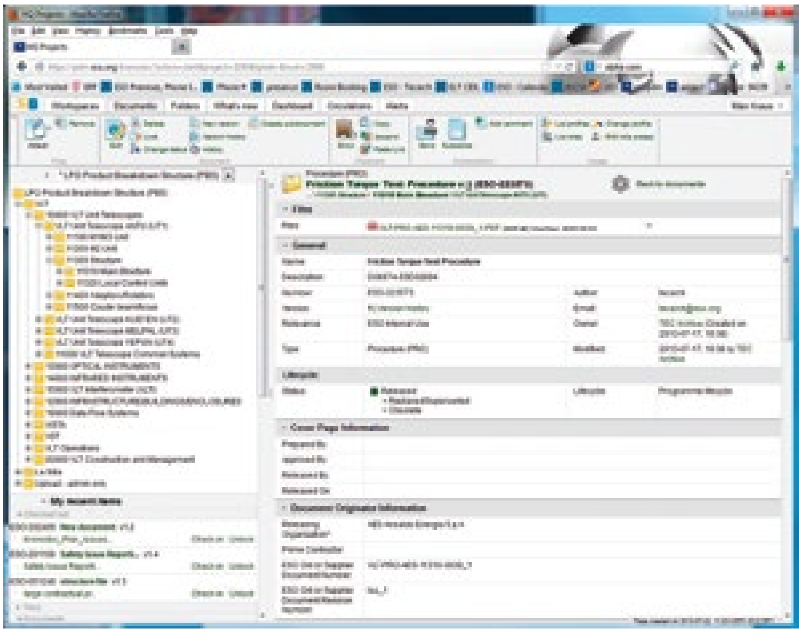

Figure 2. A screenshot of the user interface of the ESO PDM system.

By the beginning of 2013 the documents from the VLT archive, and also all documents from the E-ELT project produced in the study phases, were available in the system and users could access those documents (see Figure 2). After a general presentation, given first in Garching, and later at Paranal, the PDM system became available for the retrieval of all documents previously archived in the Technical Archive. The large volume of scanned documents from the paper archive can now be searched better due to the full-text search capabilities of the PDM system. All these documents are now available for registered users from any internet connection, and using any of the common computer platforms. User training sessions have been offered in Garching and are planned soon in Chile.

At the beginning of 2013 the team of PDM administrators was enlarged and is now preparing additional functionality, such as workspaces for project teams where team members can load documents on their own and share drafts with their colleagues. These workspaces will be created for subsequent project teams and more training on the additional PDM functions is being prepared and will be offered.

All the system selection and configuration work described has given an interesting insight into the growth of internal processes around our products and projects and thereby also into the, sometimes hidden, ESO cultures.

Links

[1] CERN EDMS: https://espace.cern.ch/edms-services/
[2] Story of *Kronodoc*: http://webhotel2.tut.fi/citer/Kronodoc-story.pdf
[3] Acquisition of *Kronodoc* by BlueCielo: http://www.bluecieloecm.com/bluecielo-acquires-majority-stake-finnish-software-company-kronodoc-oy.

Normal Programme Applications for HARPS are Most Welcome

Conny Aerts[1,2]
Gaitee Hussain[3]
Ferdinando Patat[3]

[1] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Belgium
[2] Chair, ESO Observing Programmes Committee
[3] ESO

As was the case for previous observing periods, the Observing Programmes Committee (OPC) has been happy to note the large diversity of topics, covering all aspects of astrophysics, in the observing proposals for Period 92 (covering October 2013 – March 2014). Exciting new ideas were prominently present and many were rewarded with telescope time.

A notable trend during the past few years has been the very efficient organisation of communities in need of long-term high-precision spectroscopic monitoring. They have requested observing time in the Large Programme category with HARPS (see Pepe et al., 2002) and its spectropolarimetric mode HARPSpol (described by Piskunov et al., 2010). Prime examples are the exoplanet community, the CoRoT asteroseismology teams, groups performing intensive polarimetric time series to search for and characterise magnetic fields in stars, and many more. Time-domain astronomy with ESO telescopes works optimally when forces are joined and targets are shared over the overall allocated time in order to achieve optimal time coverage and frequency precision.

A limiting factor of this type of community organisation seems to be a hesitation on the part of individual scientists, or small teams, to apply for normal HARPS programmes, under the unjustified assumption that almost all HARPS time is only reserved for Large Programmes. Table 1 shows the breakdown of HARPS allocations by Normal and Large Programmes over ten observing periods and demonstrates that, although the Large Programmes are very successful at winning observing time, Normal Programmes can be competitive. The limited number of Normal Programmes leads to an unwarranted limit on the diversity of scientific topics addressed by the HARPS facility. The ESO community is encouraged to submit proposals for Normal HARPS Programmes, addressing original and splendid science ideas for Period 93, and beyond.

References

Pepe, F., Mayor, M. & Rupprecht, G. 2002, The Messenger, 110, 9
Piskunov, N. et al. 2011, The Messenger, 143, 7

	Submitted Proposals			Requested Time (nights)			Scheduled Proposals			Allocated Time (nights)			Success Rates			
													Proposals		Time	
Period	Normal	Large	Total	Normal	Large	Total	Normal	Large	Total	Normal	Large	Total	Normal	Large	Normal	Large
82	27	1	29	240	15	285	15	1	17	118	15	163	0.56	1.00	0.49	1.00
83	22	9	33	160	149	334	7	3	12	58	82	160	0.32	0.33	0.36	0.55
84	25	5	32	195	142	362	5	2	9	46	94	168	0.20	0.40	0.24	0.66
85	25	2	29	182	103	312	5	1	8	42	93	162	0.20	0.50	0.23	0.90
86	30	3	35	236	124	386	5	0	7	44	95	165	0.17	n/a	0.18	0.77
87	23	3	27	155	125	295	9	1	11	55	98	168	0.39	0.33	0.35	0.78
88	26	5	32	217	133	365	5	2	8	34	100	149	0.19	0.40	0.16	0.75
89	20	4	25	112	161	288	9	0	10	44	114	173	0.45	n/a	0.39	0.71
90	17	5	23	102	144	261	5	2	8	31	122	168	0.29	0.40	0.30	0.85
91	17	10	27	109	186	295	13	3	16	85	85	170	0.76	0.30	0.78	0.46
92	19	6	26	106	138	259	9	2	12	41	104	160	0.47	0.33	0.39	0.75

Table 1. The time allocation statistics for HARPS in the last ten semesters (October 2008 – March 2014) for Normal and Large Programmes (LPs) is tabulated. From Period 82 the ESO 3.6-metre telescope was fully operated in visitor mode and HARPS was the only offered instrument. The time requested/allocated by/to scheduled LPs is spread across the requested semesters, while the time requested by rejected LPs is counted only for the semester in which the proposal was submitted; any requests in subsequent semesters are not counted. The total numbers listed include Guaranteed Time Observations (GTO).

ESO/H. H. Heyer

A panoramic view of La Silla covering almost 360 degrees, prominently showing the ESO 3.6-metre dome and the tower of the Coudé Auxiliary Telescope, illuminated by moonlight. The HARPS spectrograph in its vacuum enclosure is housed inside the 3.6-metre dome.

ESPRESSO — An Echelle SPectrograph for Rocky Exoplanets Search and Stable Spectroscopic Observations

Francesco Pepe[1]
Stefano Cristiani[4]
Rafael Rebolo[5]
Nuno C. Santos[6]
Hans Dekker[7]
Denis Mégevand[1]
Filippo M. Zerbi[2]
Alexandre Cabral[8]
Paolo Molaro[4]
Paolo Di Marcantonio[4]
Manuel Abreu[8]
Michael Affolter[9]
Matteo Aliverti[2]
Carlos Allende Prieto[5]
Manuel Amate[5]
Gerardo Avila[7]
Veronica Baldini[4]
Paul Bristow[7]
Christopher Broeg[9]
Roberto Cirami[4]
João Coelho[8]
Paolo Conconi[2]
Igor Coretti[4]
Guido Cupani[4]
Valentina D'Odorico[4]
Vincenzo De Caprio[2]
Bernard Delabre[7]
Reinhold Dorn[7]
Pedro Figueira[6]
Ana Fragoso[5]
Samuele Galeotta[4]
Ludovic Genolet[1]
Ricardo Gomes[3]
Jonay I. González Hernández[5]
Ian Hughes[1]
Olaf Iwert[7]
Florian Kerber[7]
Marco Landoni[2]
Jean-Louis Lizon[7]
Christophe Lovis[1]
Charles Maire[1]
Marco Mannetta[4]
Carlos Martins[6]
Manuel A. Monteiro[6]
Antonio Oliveira[3]
Ennio Poretti[2]
José Luis Rasilla[5]
Marco Riva[2]
Samuel Santana Tschudi[5]
Pedro Santos[3]
Danuta Sosnowska[1]
Sergio Sousa[6]
Paolo Spanò[2]
Fabio Tenegi[5]
Giorgio Toso[2]
Eros Vanzella[11]
Matteo Viel[4]
Maria Rosa Zapatero Osorio[10]

[1] Observatoire de l'Université de Genève, Versoix, Switzerland
[2] INAF–Osservatorio Astronomico di Brera, Merate, Italy
[3] LOLS, Faculty of Sciences, University of Lisbon, Portugal
[4] INAF–Osservatorio Astronomico di Trieste, Italy
[5] Instituto de Astrofísica de Canarias, La Laguna, Tenerife, Spain
[6] Centro de Astrofísica da Universidade do Porto, Portugal
[7] ESO
[8] CAAUL, Faculty of Sciences, University of Lisbon, Portugal
[9] Physics Institute of University of Bern, Switzerland
[10] Centro de Astrobiología, CSIC–INTA, Madrid, Spain
[11] INAF–Osservatorio Astronomico di Bologna, Italy

ESPRESSO is the next generation European exoplanet hunter, combining the efficiency of a modern echelle spectrograph with extreme radial velocity and spectroscopic precision. ESPRESSO will be installed in the Combined Coudé Laboratory of the VLT and linked to the four Unit Telescopes (UT) through optical coudé trains, operated either with a single UT or with up to four UTs for 1.5 magnitude gain. The instrumental radial velocity precision will reach the 10 cm s^{-1} level and ESPRESSO will achieve a gain of two magnitudes with respect to its predecessor HARPS. This is the first VLT instrument using the incoherent combination of light from four telescopes and, together with the extreme precision requirements, calls for many innovative design solutions while ensuring the technical heritage of HARPS.

The main scientific drivers for ESPRESSO are the search and characterisation of rocky exoplanets in the habitable zone of quiet, nearby G to M dwarf stars and the analysis of the variability of fundamental physical constants. As an ultra-stable high-resolution spectrograph however, ESPRESSO will allow new frontiers to be explored in most domains of astrophysics. The project passed its final design review in May 2013 and has entered the manufacturing phase. ESPRESSO will be installed at the Paranal Observatory in 2016 and is planned to begin operations by the end of that year.

Introduction

High-resolution spectroscopy has always been at the heart of astrophysics. It provides the data that bring physical insight into the behaviour of stars, galaxies, interstellar and intergalactic media. Correspondingly, high-resolution spectrographs have always been in high demand at major observatories, see, e.g., UVES at the VLT or HIRES at the Keck Telescope. As telescope apertures become larger, the capabilities of high-resolution spectrographs extend to fainter and fainter objects. Besides this increase in photon-collecting power, another aspect has emerged in recent years: the power of high-precision spectroscopy. In many applications there is the need for highly repeatable observations over long timescales where instrumental effects must be completely removed, or at least minimised. For instance, this is the case for radial velocity (RV) measurements, or, more generally, for the determination of the positions and shapes of spectral lines. In this respect, the HARPS spectrograph at the ESO 3.6-metre telescope (Mayor et al., 2003) has been a pioneering instrument. It has been widely recognised in the European astronomical community that a similar instrument on the VLT would be necessary.

The need for a ground-based follow-up facility capable of high RV precision was stressed in the ESO–ESA working group report on extrasolar planets (Perryman et al., 2005). The research area "*terrestrial planets in the habitable zone*" is one of the main scientific topics for the next few decades in astronomy, and one of the main science drivers for the new generation of extremely large telescopes (ELTs). The ESO–ESA working group report states: "High-precision radial velocity instrumentation for the follow-up of astrometric and transit detections, to ensure the detection of a planet by a second independent method, and to determine its true mass. For Jupiter-mass planets, existing instrumentation may be technically adequate, but observing time inadequate; for Earth-mass candidates, special purpose instrumentation (like HARPS) on a large telescope would be required." (Perryman et al., 2005, p. 63). The same concept is reiterated in the first recommendation: "Support experiments to improve RV mass detection limits, e.g., based on experience from HARPS, down to those imposed by stellar surface phenomena" (Perryman et al., 2005, p. 72).

Do the fundamental constants vary? This is one of the six big open questions in cosmology as listed in the ESA–ESO working group report for fundamental cosmology (Peacock et al., 2006). In the executive summary, the document states: "Quasar spectroscopy also offers the possibility of better constraints on any time variation of dimensionless atomic parameters such as the fine structure constant α and the proton-to-electron mass ratio. Presently there exist controversial claims of evidence for variations in α, which potentially relate to the dynamics of dark energy. It is essential to validate these claims with a wider range of targets and atomic tracers." This goal can only be reached with improved spectroscopic capabilities.

In this context the ESO Scientific Technical Committee (STC) recommended, at its 67th meeting in October 2007, the development of additional second generation VLT instruments, and its detailed proposal was endorsed by the ESO Council at its 111th meeting in December 2007. Among the recommended instruments, a high-resolution, ultra-stable spectrograph for the VLT combined coudé focus arose as a cornerstone to complete the current second generation VLT instrument suite. In March 2007, following these recommendations, ESO issued a call for proposals, open to Member State institutes or consortia, to carry out the Phase A study for such an instrument. The submitted proposal was accepted by ESO and the ESPRESSO consortium was selected to carry out the project for the construction of this spectrograph. The main scientific drivers for this project were defined by ESO as follows:

1. Measure high-precision RV to search for rocky planets.
2. Measure the variation of physical constants.
3. Analyse the chemical composition of stars in nearby galaxies.

The official project kick-off was held in February 2011. The design phase lasted about 2.5 years and ended with the final design review (FDR) in May 2013. The procurement of components and manufacturing of subsystems will last about 18 months. Early in 2015 the subsystems will be ready for integration in Europe. Acceptance Europe of the instrument will be held in late 2015. The transfer of the instrument to Paranal, installation and on-site commissioning is foreseen to take place in 2016. Acceptance Paranal is planned to take place at the end of 2016.

A new generation instrument for the VLT

Design concepts

ESPRESSO is a fibre-fed, cross-dispersed, high-resolution, echelle spectrograph. The telescope light is fed to the instrument via a coudé train optical system and within optical fibres. ESPRESSO is located in the Combined Coudé Laboratory (incoherent focus) where a front-end unit can combine the light from up to four Unit Telescopes of the VLT. The target and sky light enter the instrument simultaneously through two separate fibres, which together form the pseudo slit of the spectrograph.

Several optical tricks have been used to obtain high spectral resolution *and* efficiency despite the large size of the telescope and the 1-arcscecond sky aperture of the instrument. At the spectrograph entrance, the anamorphic pupil slicing unit (APSU) shapes the beam in order to compress it in cross dispersion and split it into two smaller beams, while superimposing them on the echelle grating to minimise its size. The rectangular white pupil is then re-imaged and compressed. Given the wide spectral range, a dichroic beam-splitter separates the beam into a blue and a red arm, which in turn allows each arm to be optimised for image quality and optical efficiency. The cross-disperser has the function of separating the dispersed spectrum into all its spectral orders. In addition, an anamorphism is re-introduced to make the pupil square and to compress the order height such that the inter-order space and the signal-to-noise ratio (SNR) per pixel are both maximised. Both functions are accomplished using Volume Phase Holographic Gratings (VPHGs) mounted on prisms. Finally, two optimised camera lens systems image the full spectrum from 380 nm to 780 nm on two large 92 mm × 92 mm CCDs with 10 µm pixels. A sketch of the optical layout is shown in Figure 1. The spectral format covered by the blue and the red chips is shown in Figure 2a and 2b and the shape of the pseudo slit is shown in Figure 2c.

The spectrograph is also equipped with an advanced exposure meter that measures the flux entering the spectro-

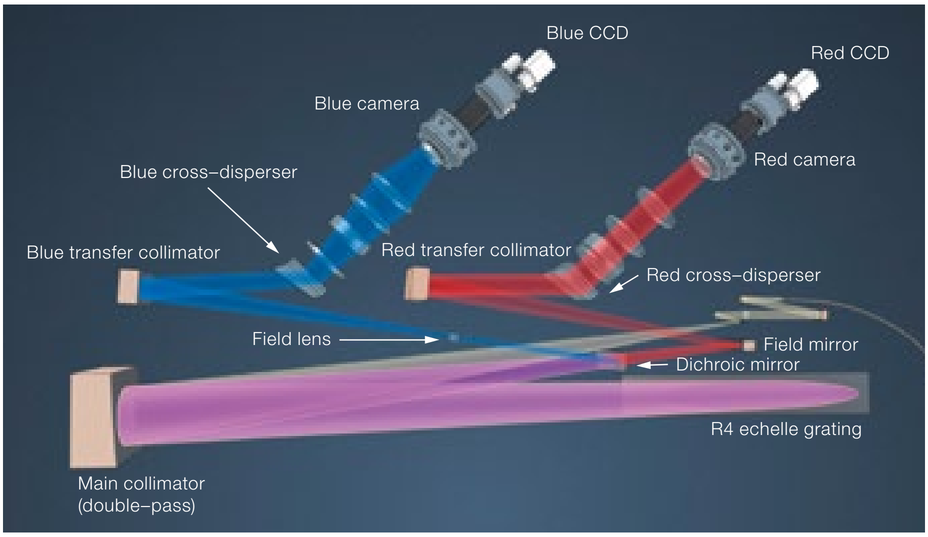

Figure 1. Layout of the ESPRESSO spectrograph and its optical elements.

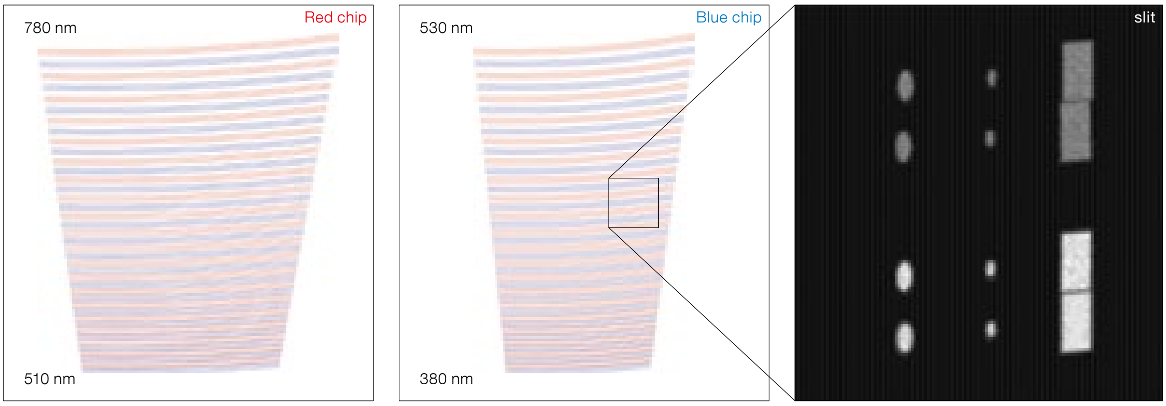

Figure 2. Shown left to right: Format of the red spectrum; format of the blue spectrum; zoom of the pseudo slit. This latter shows the image of the target (bottom) and sky fibre (top). Each fibre is re-imaged into two slices. The three sets of fibres, corresponding (from left to right) to the standard resolution 1-UT mode, ultra-high resolution 1-UT mode, and mid-resolution 4-UT mode, are shown simultaneously.

graph as a function of time. This function is necessary to compute the weighted mean time of exposure at which the precise relative Earth motion must be computed and applied to correct the RV measurement. The innovative design (based on a simple diffraction grating) allows a flux measurement and an RV correction at different spectral channels, in order to cope with possible chromatic effects that could occur during the scientific exposures. The use of various channels also provides a redundant and thus more reliable evaluation of the mean time of exposure.

Dealing with a large étendue

In order to minimise the size of the optics, particularly of the collimator and echelle grating, ESPRESSO implements an anamorphic optical element, the APSU, which compresses the size of the pupil in the direction of the cross dispersion. The pupil is then sliced in two by a pupil slicer and the slices are overlapped on the echelle grating, leading to a doubled spectrum on the detector. The shape and size of both the pupil and the fibre image is shown in Figure 3 for various locations along the optical beam of the spectrograph.

Without using this method, the collimator beam size would have been 40 cm in diameter and the size of the echelle grating would have reached 240 × 40 cm. The actual ESPRESSO design foresees the use of an echelle grating of "only" 120 × 20 cm and of much smaller optics (collimators, cross dispersers, etc.). This solution significantly reduces the overall costs. The drawback is that each spectral element will be covered by more detector pixels, given the two image slices and their elongated shape on the CCD. In order to avoid increased detector noise, heavy binning will be performed for faint object observations, especially in the 4-UT mode.

The opto-mechanics

ESPRESSO is designed to be an ultra-stable spectrograph capable of reaching RV precision of the order of 10 cm s^{-1}, i.e. one order of magnitude better than its predecessor HARPS. ESPRESSO is therefore designed with a totally fixed configuration, and for the highest thermo-mechanical stability. The spectrograph optics is mounted on a tri-dimensional optical bench specifically designed to keep the optical system within the thermo-mechanical tolerances required for high-

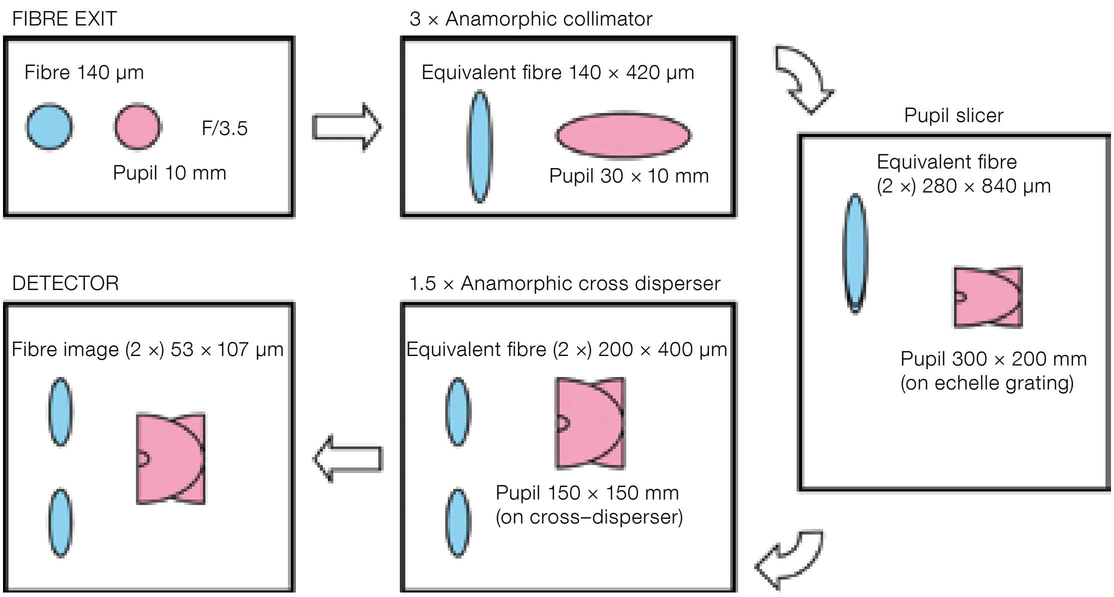

Figure 3. Conceptual description of pupil and fibre image at relevant locations of the ESPRESSO spectrograph.

precision RV measurements. The bench is mounted in a vacuum vessel in which a 10^{-5} mbar class vacuum is maintained during the entire duty cycle of the instrument. An overview of the opto-mechanics is shown in Figure 4.

The temperature at the level of the optical system is required to be stable at the mK level in order to avoid both short-term drift and long-term mechanical instabilities. Such an ambitious requirement is obtained by locating the spectrograph in a multi-shell active thermal enclosure system (Figure 5). Each shell will improve the temperature stability by a factor of ten, thus going from typically Kelvin-level variations in the Combined Coudé Laboratory (CCL) down to mK stability inside the vacuum vessel and on the optical bench.

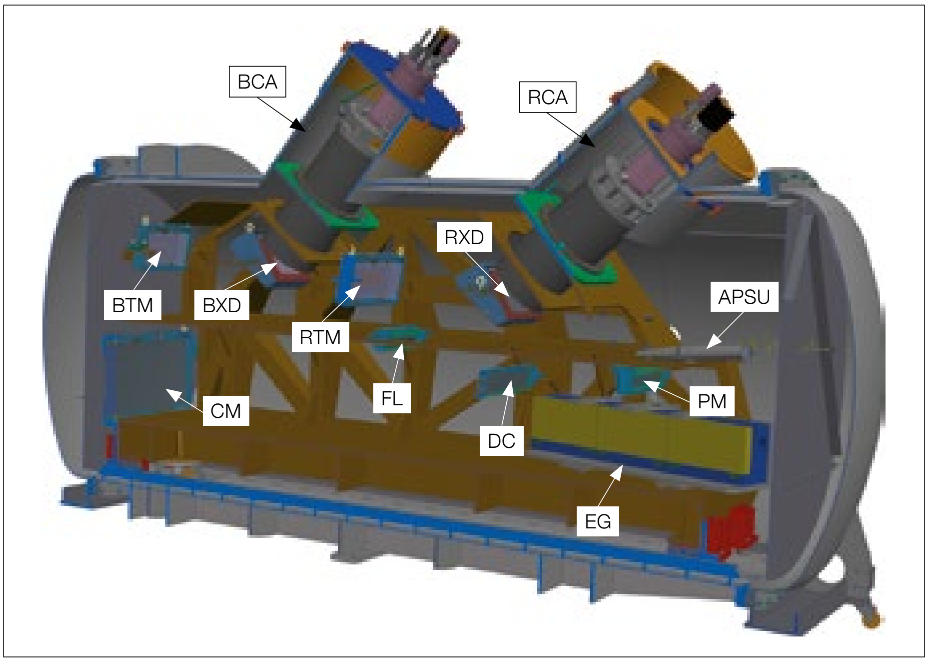

Figure 4. Opto-mechanical drawing of the ESPRESSO spectrograph is shown. Key to components: APSU: Anamorphic Pupil Slicer Unit; BCA: Blue Camera; BTM: Blue Transfer Mirror; BXD: Blue Cross Disperser; CM: Main Collimator; DC: Dichroic; EG: Echelle Grating; FL: Field Lens; PM: Field Mirror; RCA: Red Camera; RTM: Red Transfer Mirror; RXD: Red Cross Disperser.

New large-area CCDs

ESPRESSO also presents innovative solutions in the area of the CCDs, their packages and cryostats. One of the world's largest monolithic state-of-the-art CCDs was selected to properly utilise the optical field of ESPRESSO and to further improve the stability compared to a mosaic solution, as employed in HARPS. The sensitive area of the e2v chip is 92 mm by 92 mm, covering about 9k by 9k pixels of 10 µm size. Fast readout of such a large chip is achieved by using its16 output ports at high speed. Other requirements on the CCDs are very demanding, e.g., in terms of charge transfer efficiency (CTE) and all the other parameters affecting the definition of the pixel position, immediately reflected in the radial velocity precision and accuracy.

The CCDs are currently being procured by ESO from the e2v supplier. An engineering sample has already been received (see Figure 6). First warm technical light with the ESO custom-made components (NGC controller, cabling, cryostat electronics, firmware and mock-up mechanics) took place in July 2013.

The precision of 10 cm s^{-1} root mean squared (RMS) aimed at by ESPRESSO requires measuring spectral line position changes of 2 nm (physical) in the CCD plane, equivalent to only four times the silicon lattice constant! For better stability and thermal expansion matching, the CCD package is made of silicon carbide. The combination of the CCDs, the surrounding mechanics and precision temperature control inside the cryostat head

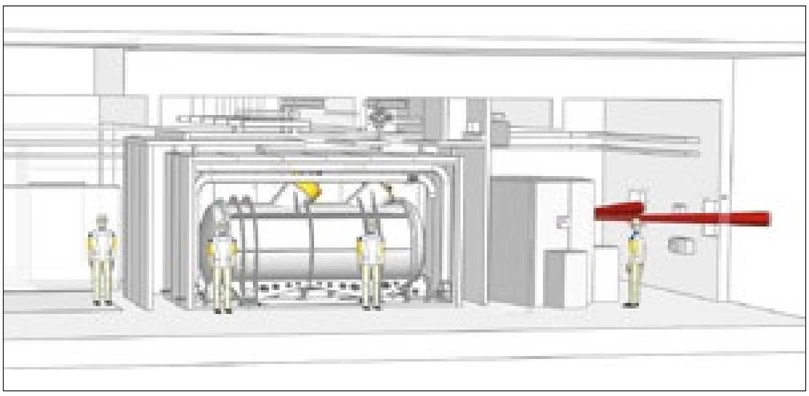

Figure 5. The appearance of ESPRESSO inside the Coudé Combined Laboratory with its vacuum vessel and multi-shell thermal control system shown.

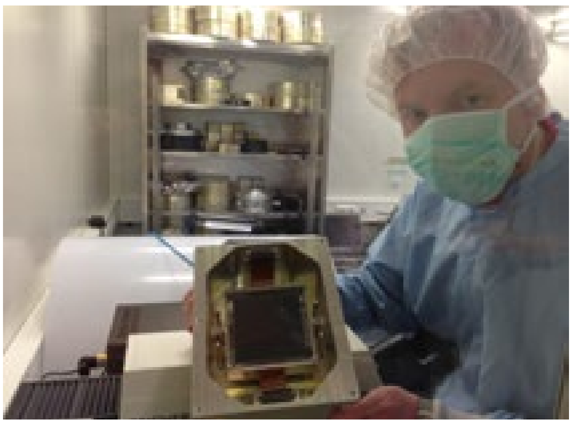

Figure 6. The first ESPRESSO e2v CCD is shown in its opened shipping container, being handled inside the ESO cleanroom.

and its cooling system, as well as the thermal stability and the homogeneous dissipation of the heat locally produced in the CCDs during operation, are of critical importance. ESO has therefore built a new "superstable" cryostat that has already demonstrated excellent short-term stability. A breadboard of the concept is currently being tested and the results will drive the design of the final ESPRESSO detector system.

Ultimate wavelength calibration and drift measurement

In order to track possible residual instrumental drifts, ESPRESSO will implement the simultaneous reference technique in a manner similar to HARPS (see, e.g., Baranne et al., 1996) where the spectrum of a spectral reference is recorded simultaneously on the scientific detector. All types of spectrographs need to be wavelength-calibrated in order to assign to each detector pixel the correct wavelength with a repeatability of the order of $\Delta\lambda/\lambda = 10^{-10}$. A necessary condition for this step is the availability of a suitable spectral wavelength reference. None of the currently used spectral sources (thorium argon spectral lamps, iodine cells, etc.) would provide a spectrum sufficiently wide, rich, stable and uniform for this purpose.

Therefore, the baseline source for the calibration and simultaneous reference adopted for ESPRESSO is a laser frequency comb (LFC). The LFC presents all the characteristics that are indispensable for precise wavelength calibration and provides a link to the frequency standard. The procurement of an LFC suited for ESPRESSO is ongoing and appears to be very promising. In parallel, ESO has been developing such a source for HARPS, in collaboration with other institutes and industrial partners (Lo Curto et al., 2012). As a back-up solution and in order to minimise risks, a stabilised Fabry Perot is also currently under development within the consortium.

1-UT or 4-UT? The astronomer's choice between an 8- or 16-metre equivalent telescope

ESPRESSO is an instrument designed for the incoherent combined focus of the VLT. Although foreseen in the original plan, such a focus has never been implemented at the VLT. But the use of a combined focus has been provided for, in terms of space left in the UT structures and ducts in the rock of the mountain. As part of the project agreement, the ESPRESSO consortium has been asked to furnish such a focus by providing the necessary hardware and software as part of the deliverables. The implementation of the coudé train requires substantial changes to the Paranal Observatory infrastructure which can only be achieved by developing the existing interfaces.

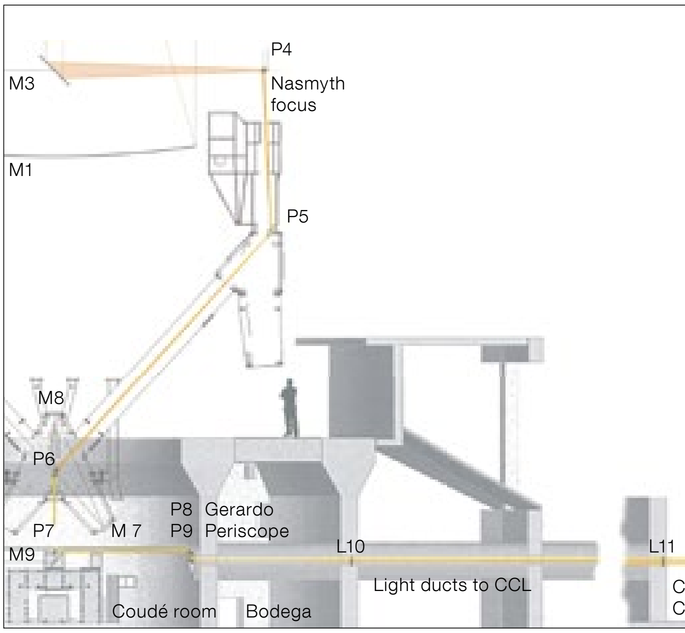

Figure 7. Coudé train of ESPRESSO and optical path through the telescope and the tunnels is shown schematically.

ESPRESSO will be located in the VLT CCL and, unlike any other instruments built so far, will be able to receive light from any of the four UTs. The light of the single UT scheduled to work with ESPRESSO is then fed into the spectrograph (1-UT mode). Alternatively, the combined light of *all* the UTs can be fed into ESPRESSO simultaneously (4-UT mode).

A trade-off analysis considering the use of mirrors, prisms, lenses and/or fibres, and possible combinations of them, suggested a full optical solution, i.e. using only conventional optics (no use of fibres) for transporting the light from the telescope into the CCL. In the chosen design, the coudé train intercepts the light with a prism at the level of the Nasmyth B platform and routes the beam through the UT mechanical structure down to the UT coudé room, and further to the CCL along the existing incoherent light ducts (see Figure 7). The selected concept to convey the light of the telescope from the Nasmyth focus (B) to the entrance of the tunnel in the coudé room (CR) below each UT unit is based on a set of six prisms (with some power). The light is directed from the UT's coudé room towards the CCL using two large lenses. The beams from the four UTs converge into the CCL, where mode selection and beam conditioning is achieved by the fore-optics of the front-end subsystem.

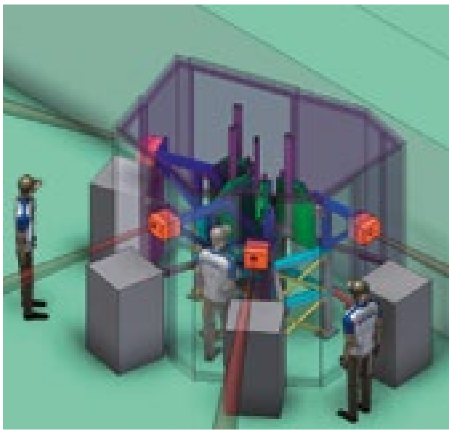

Figure 8. Top view of the ESPRESSO front end and the arrival of the four UT beams at the CCL is shown.

The front end transports the beam received from the coudé, once corrected for atmospheric dispersion by the atmospheric dispersion corrector (ADC), to the common focal plane on which the heads for the fibre-to-spectrograph connection are located. While performing such a beam conditioning, the front end applies pupil and field stabilisation. These two functions are achieved via two independent control loops each composed of a technical camera and a tip-tilt stage. Another dedicated stage delivers a focusing function. In addition, the front end provides the means to inject calibration light (white and spectral sources) into the spectrograph fibre if and when needed. A top view of the front-end arrangement is shown in Figure 8.

The fibre-link subsystem relays the light from the front end to the spectrograph and forms the spectrograph pseudo slit inside the vacuum vessel. The 1-UT mode uses a bundle of two octagonal fibres each, one for the object and one for the sky or simultaneous reference. In the high-resolution (singleHR) mode, the fibre has a core of 140 μm, equivalent to 1 arcsecond on the sky; in the ultra-high resolution (singleUHR) mode the fibre core is 70 μm and the covered field of view is 0.5 arcseconds. The fibre entrances are organised in heads that are brought to the focal plane of the front end when that specific bundle is used for observations, i.e., when that specific mode is selected.

In the 4-UT (multiMR) mode, four object fibres and four sky/reference fibres converge together from the four telescopes. The four object fibres will finally feed a single square 280 μm object fibre, while the four sky/reference fibres will feed a single square 280 μm sky/reference fibre. Also in the 4-UT mode the spectrograph will "see" a pseudo-slit of four fibre images, although they will be square and twice as wide as the 1-UT fibres.

Another essential task performed by the fibre-link subsystem is light scrambling. The use of a double-scrambling optical system will ensure both scrambling of the near field and far field of the light beam. A high scrambling gain, which is crucial to obtain the required RV precision in the 1-UT modes, is achieved by the use of octagonal fibres (Chazelas et al., 2011).

Modes and performance

The extreme precision required by the scientific goals of ESPRESSO will be obtained by adopting and improving well-known HARPS concepts. The light of one or several UTs is fed by means of the front-end unit into optical fibres that scramble the light and provide excellent illumination stability to the spectrograph. In order to improve light scrambling, non-circular fibre shapes will be used. The target fibre can be fed either with the light from the astronomical object or the calibration source. The reference fibre will receive either sky light (faint source mode) or calibration light (bright source mode). In the latter case — the famous simultaneous reference technique adopted in HARPS — it will be possible to track instrumental drifts down to the cm s^{-1} level. It is assumed that in this mode the measurement is photon-noise limited and that detector readout noise is negligible. In the faint-source mode detector noise and sky background may become significant. In this case, the second fibre will allow the sky background to be measured, while a slower readout and high binning factor will reduce the detector noise.

In summary (see Table 1), ESPRESSO will have three instrumental modes: singleHR, singleUHR and multiMR. Each mode will be available with two different detector readout modes optimised for low- and high-SNR measurements, respectively. In high-SNR (high-precision) measurements the second fibre will be fed with the simultaneous reference, while in the case of faint objects it may be preferable to feed the second fibre with sky light.

The observational efficiency of ESPRESSO is shown in Figure 9. In the singleHR mode a SNR of 10 per extracted pixel is obtained in 20 minutes on a V = 16.3 mag star, or a SNR of 540 on a V = 8.6 mag star. We have estimated that at the R = 134 000 resolution, this SNR value will lead to 10 cm s^{-1} RV precision for a non-rotating K5 star. For an F8 star, the same precision would be achieved for V = 8 mag. In the multiMR mode, a SNR of 10 on a V = 19.4 mag star is achieved with a single 20 minute exposure. A slight gain could be achieved with higher binning (2 × 8).

ESPRESSO's data flow

Following the very positive experience gained with HARPS, ESPRESSO has always been conceived as a "science-generating machine" rather than a "simple" standalone instrument. The final goal is to provide the user with scientific data that are as complete and precise as possible within a short time (minutes) of the end of an observation, thus increasing the overall efficiency and the scientific output of ESPRESSO. For this purpose an integrated view of the software cycle, from the preparation of the observations through instrument operation and control, to data reduction and analysis, has been adopted since early phases of the project. Coupled with a careful design, this approach will ensure optimal compatibility, ease of operations and maintenance within the existing ESO Paranal data-flow environment both in service and visitor modes.

The ESPRESSO data flow contains the following main subsystems:
– EOPS (ESPRESSO Observation Preparation Software): A dedicated visitor tool (able to communicate directly with the vOT — Visitor Observing Tool) to help the observer to prepare and

Table 1. Summary of ESPRESSO's instrument modes and corresponding performance.

Parameter/Mode	singleHR (1 UT)	multiMR (up to 4 UTs)	singleUHR (1 UT)
Wavelength range	380–780 nm	380–780 nm	380–780 nm
Resolving power	134 000	59 000	225 000
Aperture on sky	1.0 arcsec	4 × 1.0 arcsec	0.5 arcsec
Spectral sampling (average)	4.5 pixels	5.5 pixels (binned × 2)	2.5 pixels
Spatial sampling per slice	9.0 (4.5) pixels	5.5 pixels (binned × 4)	5.0 pixels
Simultaneous reference	Yes (no sky)	Yes (no sky)	Yes (no sky)
Sky subtraction	Yes (no simul. ref.)	Yes (no simul. ref.)	Yes (no simul. ref.)
Total efficiency	11 %	11 %	5 %
Instrumental RV precision	< 10 cm s^{-1}	~ 1 m s^{-1}	< 10 cm s^{-1}

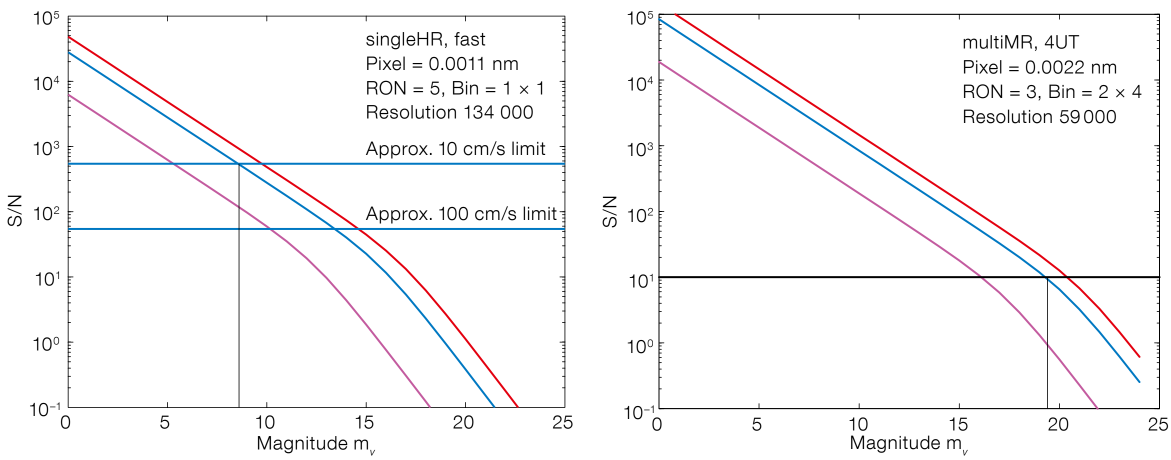

Figure 9. Achievable signal-to-noise ratio (SNR) plotted as a function of stellar visible magnitude for the singleHR (left) and the multiMR (right) modes. Red, blue and magenta curves indicate exposure times of 3600 s, 1200 s and 60 s, respectively.

schedule ESPRESSO observations at the telescope according to the needs of planet-search surveys. The tool will allow users to choose the targets best suited for a given night and to adjust the observation parameters in order to obtain the best possible quality of data.

– DRS (Data Reduction Software): ESPRESSO will have a fully automatic data reduction pipeline with the specific aim of delivering high-quality reduced data to the user. These data will be "science ready" a short time after an observation has been performed. The computation of the RV at a precision better than 10 cm s^{-1} will be an integral part of the DRS. Coupled with the need to optimally remove the instrument signature, to take account of the complex spectral and multi-HDU (header data unit) FITS format, to handle the simultaneous reference technique and the multi-UT mode, this will make the DRS a truly challenging component of the data flow chain.

– DAS (Data Analysis Software): Dedicated data analysis software will allow the best scientific results to be obtained from the observations directly at the telescope. A robust package of recipes tailored to ESPRESSO, taking full advantage of the existing ESO tools (based on the Common Pipeline Library [CPL] and fully compatible with Reflex), will address the most important science cases for ESPRESSO by analysing (as automatically as possible) stars and quasar spectra. (Among others, tasks that can be performed will include Voigt-profile line fitting, estimation of stellar atmospheric parameters, quasar continuum fitting and identification of absorption systems).

– Templates and control: Compared to other standalone instruments, the main reason for the complexity of the ESPRESSO acquisition and observation templates will be the possible usage of any combination of UTs, besides the proper handling of the simultaneous reference technique. Coupled with the fact that, at the instrument control level, PLCs (Programmable Logical Controllers) and new COTS (Component Off-The Shelf) Technical CCDs will be adopted instead of the (old) Versa Model Eurocard (VME) technology, ESPRESSO will contribute to opening a new path for the control systems of future ESO instrumentation. A general overview of the ESPRESSO control system is shown in Figure 10.

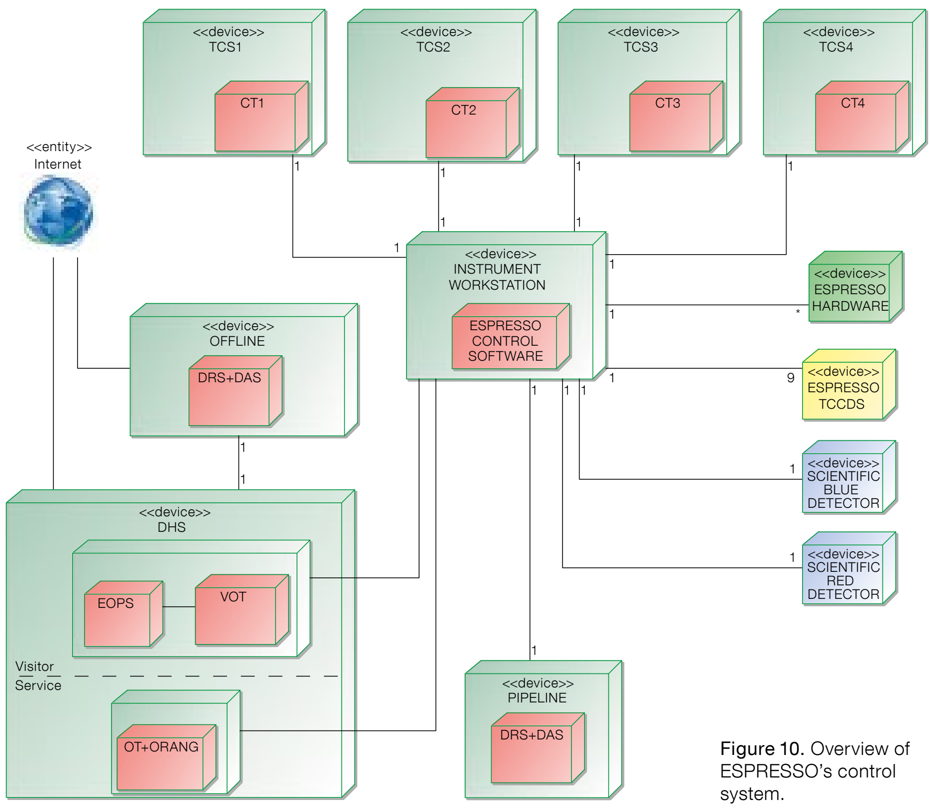

Figure 10. Overview of ESPRESSO's control system.

End-to-end operation

The implementation of the feed from the 4 UTs indirectly provides another major advantage for the singleHR mode: operational flexibility. In this mode, ESPRESSO can be fed by any of the four UTs, a possibility which significantly improves the scheduling flexibility for ESPRESSO programmes and optimises the use of VLT time in general. Scheduling flexibility is a fundamental advantage for survey programmes like RV searches for extrasolar planets or time-critical programmes like studies of transiting planets. The singleHR mode itself will thus greatly benefit from the implementation of the multiMR mode.

The overall efficiency and the scientific output of long-lead programmes can be considerably increased if an integrated view of the operations is adopted. Full integration of the data-flow system as described above is fundamental to allowing ESPRESSO to deliver full-quality scientific data less than a minute after the end of an observation.

Science with ESPRESSO

Searching for rocky planets in the habitable zone

Terrestrial planets in the habitable zones of their parent stars are one of the main scientific topics for the next few decades in astronomy, and one of the main science drivers for the new generation of extremely large telescopes. ESPRESSO, which is capable of achieving a precision of 10 cm s^{-1} in terms of RV, will be able to register the signals of Earth-like planets and massive Earths in the habitable zones (i.e., in orbits where water is retained in liquid form on the planet's surface) around nearby solar-type stars and stars smaller than the Sun.

Since 1995, research teams, using the RV technique, have discovered about 600 extrasolar planets, some with only a few times the mass of the Earth. Today, dozens of detected RV extrasolar planets have masses estimated at below ten Earth masses ($M_{\oplus}$), and most of them were identified using the HARPS spectrograph (e.g., Mayor et al., 2011). The rate of these discoveries is increasing steadily. The HARPS high-precision RV programme has shown that half of the solar-like stars in the sky harbour Neptune-mass planets and super-Earths, a finding also supported by the recent discoveries of the Kepler satellite (e.g., Howard et al., 2012). These exciting discoveries were made possible thanks to the sub-m s^{-1} precision reached by HARPS (Figure 11). Given the faint magnitude of the target star and/or the tiny RV signal induced by the planet, most of the observed objects would have remained out of reach of the existing facilities that were limited to 3 m s^{-1}. The most recent planet formation models support the current view that this emerging population is only the tip of the iceberg.

Considering the observational bias towards large masses, on the one hand, and the model predictions, on the other, a huge number of still-undiscovered low-mass planets is expected, even in already observed stellar samples. ESPRESSO is designed to explore this new mass domain and chart unknown territory (see Figure 12). This goal can only be obtained by combining high efficiency with high instrumental precision. ESPRESSO will be optimised to obtain its best RVs on quiet solar-type stars. A careful selection of these stars will allow the observations to focus on the best-suited candidates: non-active, non-rotating, quiet G to M dwarfs. The high efficiency of the instrument and an optimised observational strategy will permit demanding planetary systems and very low-mass planets to be characterised despite stellar noise. An impressive demonstration that this approach is realistic has been delivered recently with HARPS through the detection of a 1 $M_{\oplus}$ planet around the neighbouring star α Cen B (Dumusque et al., 2012).

With a precision of 10 cm s^{-1} (about a factor of ten better than HARPS), it will be possible to detect rocky planets down to Earth mass in the habitable zone of solar-type stars (for comparison the Earth imposes a velocity amplitude of 9 cm s^{-1} on the Sun). By extending the sample towards the lighter M stars, the task becomes even easier since the RV signal increases with decreasing stellar mass. Given its efficiency, spectral resolution and spectral domain, ESPRESSO will operate at the peak of its efficiency for a spectral type up to M4. An example of such capabilities is given by the discovery of HD 85512 b, a 3.6 $M_{\oplus}$ planet just at the edge of the habitable zone of a K5 dwarf (Pepe et al., 2011), see Figure 13. The discovery and the characterisation of this new population of very light planets will open the door to a better understanding of planet formation and deliver new candidates for follow-up studies by transit, astrometry, Rossiter–McLaughlin effect, etc.

Another important task for ESPRESSO will be the follow-up of transiting planets. It should be recalled that many KEPLER transit candidates are very faint and can hardly be confirmed by existing RV instruments. ESPRESSO will play a significant role in this respect. Most important yet, is the fact that other satellites like GAIA, TESS and hopefully PLATO will provide many new transit candidates, possibly

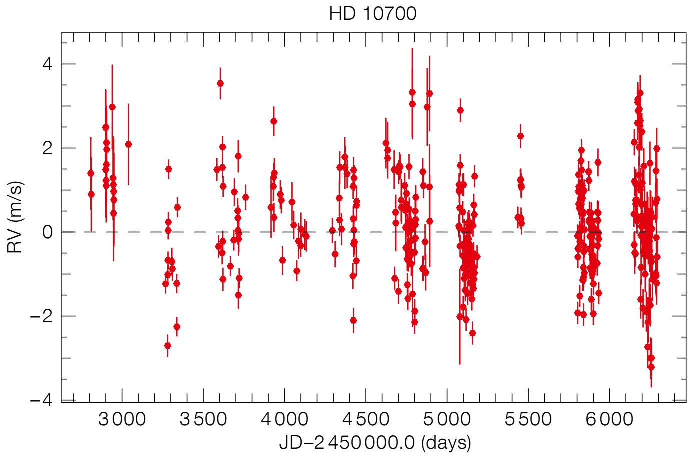

Figure 11. Ten years of RVs for Tau Ceti are plotted as measured by HARPS. The overall dispersion is 1 m s^{-1}. Time-binning of the data reduces the dispersion as expected with the square root of the number of observations down to 20 cm s^{-1}. Most important yet, is the absence of any long-term trend, thus proving the exquisite precision of HARPS.

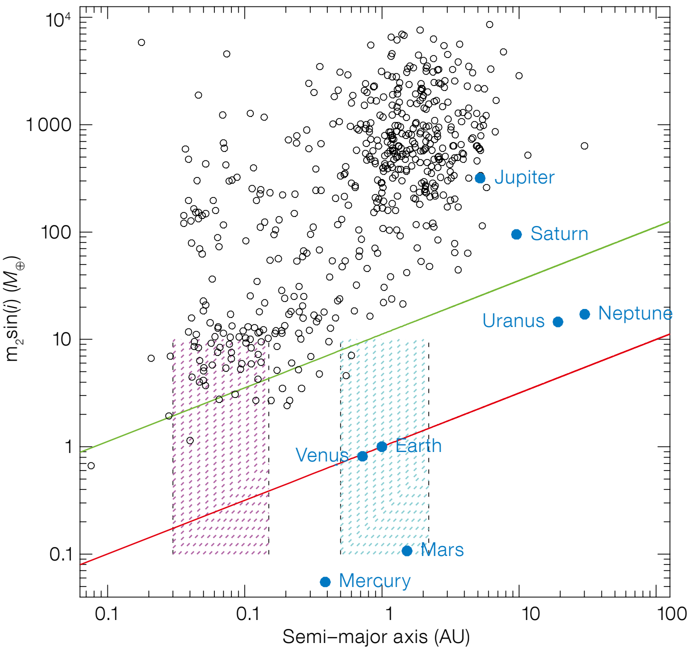

Figure 12. Detectability of planets orbiting a 0.8 $M_\odot$ star (red solid line) and a 1.0 $M_\odot$ star (green solid line) in the mass *vs.* semi-major axis plane expected for ESPRESSO. The detectability curves have been calculated assuming a velocity amplitude of 10 cm s^{-1} (for the 1.0 $M_\odot$ star) and 1 m s^{-1} (for the 0.8 $M_\odot$ star), zero eccentricity, and sin i = 1. Known RV planets of solar-type stars are plotted as open circles, and the planets of the Solar System (solid circles) are labelled. The "habitable zones" of 0.8–1.2 $M_\odot$ and 0.2–0.3 $M_\odot$ stars are indicated within the blue and pink dotted areas, respectively. These are regions where rocky planets with a masses in the interval 0.1–10 $M_\oplus$ can retain liquid water on their surface.

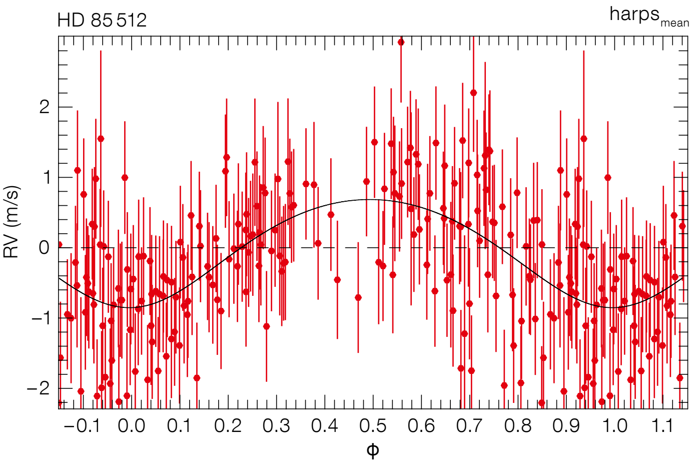

Figure 13. Phase-folded RV variation induced by the planet with a period of 58 days around the K5 dwarf HD 85512.

hosted by bright stars. ESPRESSO will be the ideal (and perhaps unique) machine to make a spectroscopic follow-up of Earth-sized planets discovered by the transit technique. Fast-cadence spectra of the most promising candidates will provide estimates of the maximum frequency of solar-like oscillations. The resulting seismic constraints on the gravity of the host stars and precise spectroscopic analysis will allow improvement in the determination of the mass and radius of the star and, therefore, of the planet (Chaplin & Miglio, 2013).

Besides being an exquisite RV machine, ESPRESSO will provide extraordinary and stable spectroscopic observations, opening up new possibilities for transit spectroscopy and the analysis of the light reflected and emited by the exoplanet. Several groups are currently investigating the extent to which this will be feasible in the visible and infrared spectral domains (see e.g., Snellen, [2013 a; b] and Martins et al. 2013). ESPRESSO should also certainly be considered as an important intermediate step towards the high-precision spectrographs on extremely large telescopes, such as HIRES for the European Extremely Large Telescope (E-ELT).

Do the physical constants vary?

The Standard Model of particle physics depends on many (~ 27) independent numerical parameters that determine the strengths of the different forces and the relative masses of all known fundamental particles. There is no theoretical explanation for their actual value, but they nevertheless determine the properties of atoms, molecules, cells, stars and the whole Universe. They are commonly referred to as the fundamental constants of Nature, although most of the modern extensions of the Standard Model predict a variation of these constants at some level (see Uzan, 2011). For instance, in any theory involving more than four spacetime dimensions, the constants we observe are merely four-dimensional shadows of the truly fundamental high dimensional constants. The four dimensional constants will then be seen to vary as the extra dimensions change slowly in size during their cosmological evolution. An attractive implication of quintessence models for dark energy is that the rolling scalar field produces a negative pressure and therefore the acceleration of the Universe may couple with other fields and be revealed by a change in the fundamental constants (Amendola et al., 2013).

Earth-based laboratories have so far revealed no variation in the values of the fundamental constants. For example, the constancy of the fine structure constant α is ensured to within a few parts in 10^{17} over a ~ 1 yr period (Rosenband et al., 2008). Hence its status as truly "constant" is amply justified. Astronomy has a great potential to probe the variability at very large distances and in the early Universe. In fact, the transition frequencies of the narrow metal absorption lines observed in the spectra of distant quasars are sensitive to α (e.g., Bahcall et al., 1967) and those of the rare molecular hydrogen clouds are sensitive to μ, the proton-to-electron mass ratio (e.g., Thompson, 1975).

With the advent of 10-metre-class telescopes, observations of spectral lines in distant quasi-stellar objects (QSOs) gave the first hints that the fine structure constant might change its value over time, being lower in the past by about 6 parts per million (ppm; see Webb et al., 1999; Murphy et al., 2004). The analysis of 153 absorbing systems from observations with VLT UVES (Figure 14) has revealed 4σ evidence for a dipole-like variation in α across the sky at the 10 ppm level (Webb et al., 2011; King, 2012). Several other constraints from higher-quality spectra of individual absorbers also exist, but none directly support or strongly conflict with the evidence for a dipole in α; possible systematic effects producing opposite values in the two hemispheres are not easy to identify.

In order to probe μ, H_2 absorbers need to be at $z > 2$–2.5 to place the Lyman and Werner H_2 transitions redward of the atmospheric cut-off. Only five systems have been studied so far, with no current indication of variability at the level of ~ 10 ppm (e.g., Rahmani et al., 2013). At lower redshifts, precise constraints on variation of μ are available from radio and millimetre-wave spectra of cool clouds containing complex molecules such as ammonia and methanol (see, e.g., Flambaum & Kozlov, 2007; Levskakov et al., 2013).

Extraordinary claims require extraordinary evidence and a confirmation of variability of α or μ with high statistical significance is of crucial importance. Only a high-resolution spectrograph that combines a large collecting area with extreme wavelength precision can provide definitive clarification. A relative variation in α or μ of 1 ppm leads to velocity shifts of about 20 m s^{-1} between typical combinations of transitions. ESPRESSO is expected to provide an increase in the accuracy of the measurement of these two constants by at least one order of magnitude compared to VLT with UVES or Keck and HIRES. More stringent bounds are also important and the ones provided already constrain the space of the parameters of various theoretical models that predict their variability.

A scientific Pandora's box

ESPRESSO combines unprecedented RV and spectroscopic precision with the largest photon-collecting area available today at ESO and unique resolving power (R ~ 200 000). ESPRESSO will certainly provide breakthroughs in many areas of astronomical research, many of which we cannot anticipate. Below we provide just a few examples.

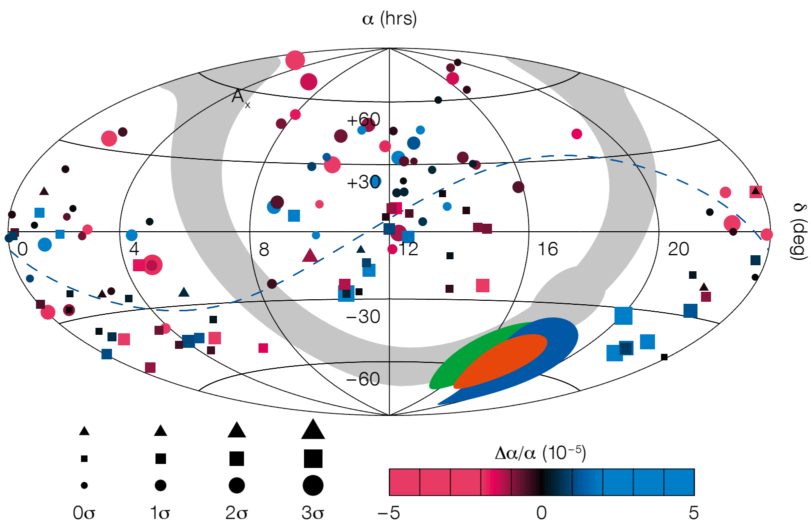

Figure 14. All-sky spatial dipole obtained from the combined VLT (squares) and Keck (circles) measurements of α (from Webb et al., 2011). Triangles are measurements in common to the two telescopes and the blue dashed line shows the equatorial region of the dipole.

Chemical composition of stars in local galaxies

One important piece of information in the understanding of galaxy formation is the chemical composition for local galaxies. In spite of the many successes in this field, the majority of local galaxies still lack detailed abundance information. There are about a dozen nearby galaxies observable from Paranal which, except for Sagittarius, have some chemical information, albeit generally for only a few stars and for a limited set of elements; for the faintest galaxies these results are based on low to medium resolution spectra. The Local Group galaxies all possess giant stars of magnitude $V = 20$, or fainter. Although some work has been done with UVES at the VLT, it is really difficult, if not impossible, to obtain accurate chemical abundances at these magnitudes. For galaxies that possess a young population, like Phoenix or Wolf–Lundmark–Melotte (WLM), one can rely on bright O and B supergiants. However, if one considers old metal-poor systems, like Bootes or Hercules, one has to rely on red giants. Although it is clear that most of the chemical information for local galaxies will have to come largely from the ELTs, ESPRESSO will provide the opportunity for a first, but important, glimpse into this area.

Metal-poor stars

The most metal-poor stars in the Galaxy are probably the most ancient fossil records of the chemical composition and thus can provide clues on the pre-Galactic phases and on the stars that synthesised the first metals. Masses and yields of Population III stars can be inferred from the observed element ratios in the most metal-poor stars (Heger & Woosley, 2010). One crucial question to be answered is the presence of Population III low-mass stars. For a long time, Population III stars were thought to be very massive, but the recent discovery of a very metal-poor star with [Fe/H] ~ −5.0 and "normal" C and N has presented an entirely new picture (Caffau et al., 2011). Several surveys searching for metal-poor stars are currently ongoing or are being planned, and thousands of extremely metal-poor stars with [Fe/H] < −3.0, of which several down to [Fe/H] ~ −5.0, and hopefully lower, are expected to be found. These stars will be within the reach of ESPRESSO, which will be able, in both the 1-UT and 4-UT modes, to provide spectra for exquisite chemical analysis.

Stellar oscillations, asteroseismology and variability

Stars located in the upper main sequence show non-radial pulsations that cause strong line profile variations. Asteroseismic study (i.e., mode identification) of these pulsating stars (γ Dor, δ Sct, β Cep, slowly pulsating B stars, etc.) provides constraints on the structure of massive stars (e.g., internal convection, overshooting, core size, extension of acoustic and gravity cavities, mass-loss phenomena and interplay between rotation and pulsation). ESPRESSO will allow the short exposures required to identify the high-frequency modes, currently achievable on a wide variety of stars only with photometry from space.

Galactic winds and tomography of the intergalactic medium

Spectroscopy of close, multiple, high-redshift quasars allows, in principle, recovery of the three-dimensional distribution of matter from the analysis of the H I Ly-α absorption lines. If the multiple lines of sight cross a region where there are known high-redshift galaxies, it is also possible to investigate the properties of outflows and inflows, studying the spectral absorption lines at the redshift of the galaxies and how they evolve with distance from the galaxies themselves. The main limitation to the full exploitation of this tomography of the intergalactic medium is the dearth of quasar pairs at the desired separation, and bright enough to be observed with the present high-resolution spectrographs at 10-metre-class telescopes. ESPRESSO, used in the 4-UT mode, would result in a gain of ~ 1.5 mag over UVES, translating into almost a factor 20 more observable quasar pairs with separation less than 3 arcminutes and emission redshift in the range $2 < z < 3$.

The expanding Universe

Sandage (1962) first argued that in any cosmological model the redshifts of cosmologically distant objects drift slowly with time. If observed, their redshift drift rate, *dz/dt*, would constitute evidence of the deceleration or acceleration of the Hubble flow between redshift *z* and today. Indeed, this observation would offer a direct, non-geometric, entirely model-independent measurement of the Universe's expansion history (Liske et al., 2008). The VLT, even in the 4-UT mode, probably does not have the capability to measure the tiny signal, which is at the level of a few cm s^{-1} yr^{-1}. However, it might provide the first accurate historical reference measurements and will, in any case, represent an important step forward, setting the scene for the next generation of high resolution spectrographs on ELTs.

Use of Guaranteed Time Observation allocation

In recognition of the capital and human investment, the consortium will be awarded Guaranteed Time Observations (GTO). Eighty percent of these observing nights will be invested in the search for and characterisation of rocky planets in the habitable zone of G, K and M stars in the 1-UT mode. Ten percent of the time will be dedicated to the determination of the possible variability of the fundamental constants. Depending on the magnitude of the targets, this programme will be carried out partially in the 1-UT and 4-UT modes. The remaining 10 % of GTO time will be reserved for outstanding science cases and allocated as a function of topical questions arising at the moment of the observations.

The ESPRESSO consortium

The ESPRESSO consortium is composed of:
- Observatoire Astronomique de l'Université de Genève, Switzerland (Project lead)
- Centro de Astrofísica da Universidade do Porto (Portugal)
- Faculdade de Ciências da Universidade de Lisboa (Portugal)
- INAF–Osservatorio Astronomico di Brera (Italy)
- INAF–Osservatorio Astronomico di Trieste (Italy)
- Instituto de Astrofísica de Canarias (Spain)
- Physikalisches Institut der Universität Bern (Switzerland)

ESO participates in the ESPRESSO project as an associated partner and is contributing the echelle grating, the camera lenses, the detector system and the cryogenic and vacuum control system.

Acknowledgements

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Optical to near-infrared image of the core of the Large Magellanic Cloud, 30 Doradus (NGC 2070). Near-infrared images (in *Y*, *J* and *K* filters) taken in the VISTA Magellanic Cloud public survey, were combined with *V*- and *R*-band images from the MPG/ESO 2.2-metre telescope. See Release eso1117.

ESO/M.-R. Cioni/VISTA Magellanic Cloud survey

The AMBRE Project: Stellar Parameterisation of ESO Archived Spectra

Patrick de Laverny [1]
Alejandra Recio-Blanco [1]
C. Clare Worley [1,2]
Marco De Pascale [1,3]
Vanessa Hill [1]
Albert Bijaoui [1]

[1] Laboratoire Lagrange, Université de Nice Sophia-Antipolis, CNRS, Observatoire de la Côte d'Azur, France
[2] Institute of Astronomy, Cambridge, UK
[3] ESO

AMBRE is a Galactic archaeology project set up by ESO and the Observatoire de la Côte d'Azur in order to determine the stellar atmospheric parameters for the archived spectra from the ESO spectrographs FEROS, HARPS, UVES and GIRAFFE. A total of about 230 000 spectra have now been homogeneously analysed and, for most (i.e., the slow-rotating FGKM-type stars), parameterised by their effective temperatures, surface gravities, global metallicities, α-element to iron abundance ratios and radial velocities. The determination of the stellar parameters is carried out using a pipeline that has been specifically developed for AMBRE. This pipeline is based on the MATISSE algorithm initially developed for the analysis of the Gaia Radial Velocity Spectrometer data.

AMBRE: A Galactic archaeology project

Our understanding of the formation and evolution history of the Milky Way has undergone a revolution within just the last decade, owing to the advent of large spectroscopic surveys. These target anything from several thousand up to a few tens of millions of Galactic stars. Past and future Galactic surveys will allow us to trace, with unprecedented detail, the chemical and kinematic history of the Galaxy through an extensive characterisation of its stellar populations, including the oldest low-mass stars formed at the earliest epochs (the fossils of Galactic archaeology). European astronomy plays an important role in such Galactic archaeology surveys and its place will be strengthened in the coming years due to the ESA/Gaia mission (with its Radial Velocity Spectrometer [RVS]) and the complementary ground-based project, the Gaia–ESO Survey (GES; Gilmore et al., 2012). Recio-Blanco (2012) provides more details about these Galactic surveys, including past and future ones.

In this context, the AMBRE project (AMBRE stands for Archéologie avec Matisse Basée sur les aRchives de l'ESO) was established by ESO and the Observatoire de la Côte d'Azur in 2009 to automatically and homogeneously parameterise stellar spectra archived at ESO. AMBRE analyses the stellar spectra collected with the four ESO high-resolution spectrographs FEROS, HARPS, UVES and GIRAFFE. In total, this dataset consists of more than 326 000 spectra that were collected between 2000 and 2011 (see Table 1).

The main goals of AMBRE are:
- To provide ESO with a database of stellar parameters (stellar radial velocity, effective temperature, surface gravity, mean metallicity and the [α/Fe] chemical index, together with their associated errors) for the archived spectra from the ESO high-resolution instruments. The goal is to make these parameters available to the community and to encourage future use of the ESO archive.
- To rigorously test automated parameterisation algorithms on large spectral datasets covering various ranges in wavelength and resolution, including those adopted by present and future Galactic spectroscopic surveys. The AMBRE project is, for example, connected to the work package that parameterises the Gaia/RVS spectra (DPAC/CU8/GSP-Spec). The AMBRE atmospheric parameters are available for use as standard or calibration data for GES and Gaia.
- To create chemical and kinematical maps of the different Galactic stellar populations in order to carry out Galactic archaeological analysis together with providing new constraints to stellar evolution models based on homogeneous and statistically significant data.

The analysis of the data from the first three spectrographs (FEROS, HARPS and UVES) has now been completed and the data products are under delivery to the ESO Science Archive through Phase 3. They are now publically available[1]. In the following sections we briefly describe the status of the AMBRE project, the pipeline analysis on which it is based and present some data produced by this project.

The AMBRE analysis pipeline

The spectra of FGKM-type stars archived by ESO are automatically and homogeneously analysed with a pipeline that has been specifically developed within the AMBRE project.

First, we received the reduced spectra for the four spectrographs from ESO. These spectra resulted from a re-analysis of the observed data by the ESO Data Management and Operations department using an improved reduction pipeline. This has ensured a very high homogeneity in the input data for the AMBRE project. Most of these reduced spectra can be retrieved from the ESO archives.

The AMBRE pipeline is based on the stellar parameterisation algorithm, MATISSE (Recio-Blanco et al., 2006), which was initially developed by the Observatoire de la Côte d'Azur for the analysis of Gaia/RVS spectra. It is a projection-like method that relies on a grid of synthetic spectra upon which the algorithm is trained. MATISSE has been applied to several Galactic archaeology projects, one of them being AMBRE. Other examples of the application of MATISSE are the stellar parameterisation of GIRAFFE spectra for the study of the CoRoT fields (Gazzano et al., 2010) and of the thick disc outside the Solar Neighbourhood (Kordopatis et al., 2011), as well as the last data release (DR4) of the RAVE Galactic Survey (Kordopatis et al., 2013). MATISSE is also one of the algorithms being used to characterise FGK-type stars in GES (UVES and GIRAFFE spectra).

Spectrograph	Number of spectra	Observations	Publication
FEROS	21 551	2005–2009	Worley et al. (2012)
HARPS	126 688	2003–2010	De Pascale et al. (2013)
UVES	78 593	2000–2010	Worley et al. (2013)
GIRAFFE	> 100 000	2004–2011	Under analysis

Table 1. The spectra samples for the AMBRE project.

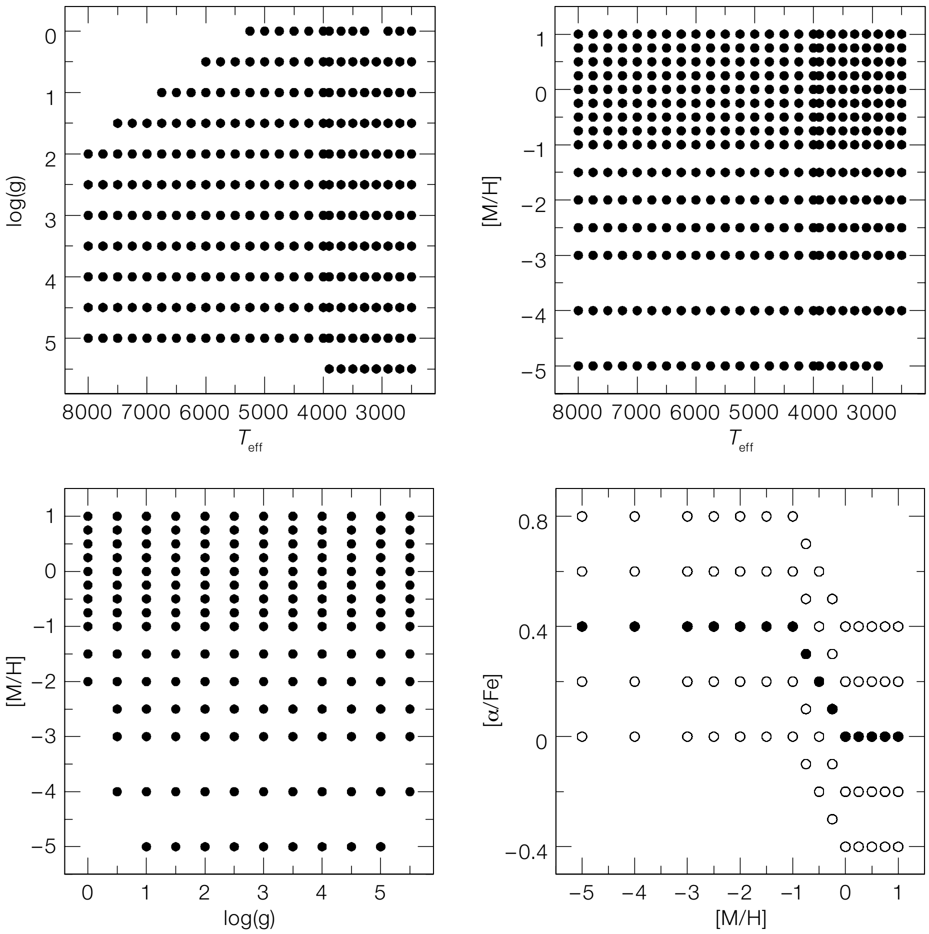

Figure 1. Distribution in the atmospheric parameter and [α/Fe] space of the FGKM-type synthetic spectra grid upon which the AMBRE pipeline is based (see de Laverny et al., 2012 for more details).

As a first step, a specific grid of about 17 000 synthetic spectra was computed for the AMBRE project (de Laverny et al., 2012). So that any of the spectral ranges and resolutions of the ESO spectrographs can be studied, this grid covers the whole optical domain for cool to very cool stars of any luminosity (from dwarfs to supergiants) with metallicities varying from 10^{-5} to 10 times the Solar metallicity. It also considers large variations in the chemical composition of α-elements with respect to iron. The parameter space covered by this grid is illustrated in Figure 1.

The analysis pipeline (see Figure 2) integrates spectral cleaning, signal-to-noise ratio (SNR) estimates, radial velocity determinations (including indicators sensitive to the projected rotational velocity) by cross-correlation with masks specifically built within the AMBRE project, radial velocity correction and iterative spectral normalisation procedures, and, finally, the automatic parameterisation of the spectra *per se*. Specific wavelength domains were also selected for each spectrograph in order to optimise the analysis computational time and accuracy (for instance, spectral ranges polluted by telluric features and the start and end of spectral orders with lower SNR are disregarded). This pipeline was first developed for the analysis of FEROS spectra (Worley et al., 2012) and it has been the testbed for producing the tools that are used in the analysis of UVES (Worley et al., 2013), HARPS (De Pascale et al., 2013) and GIRAFFE archived spectra.

The main products of this pipeline are the stellar radial velocity, the stellar atmospheric parameters (effective temperature, surface gravity and mean metallicity), and the enrichment in α-elements versus iron abundances ([α/Fe] chemical index)

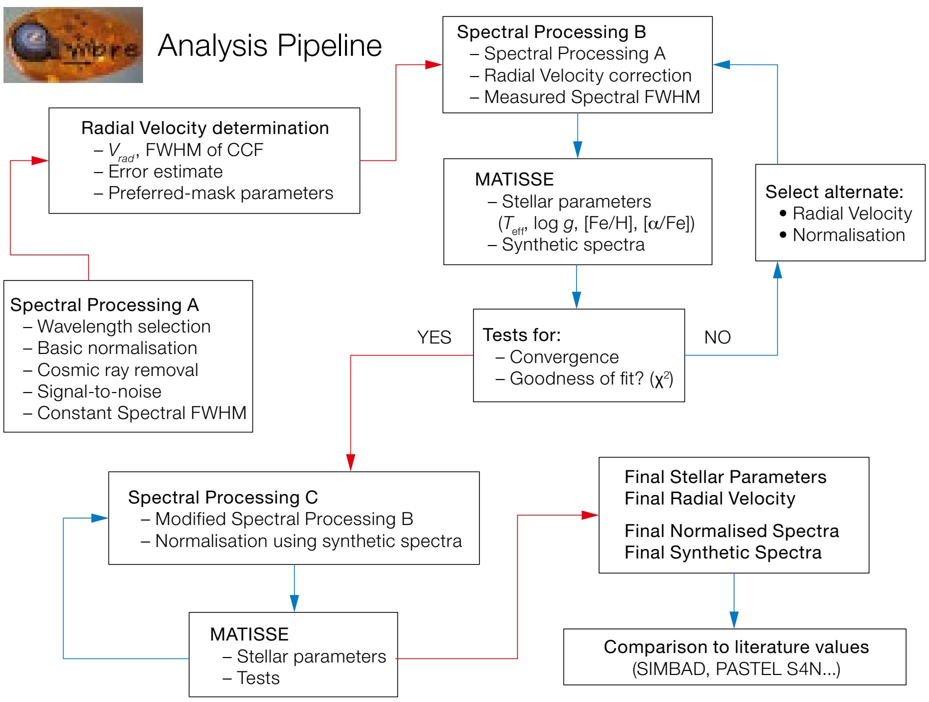

Figure 2. The AMBRE analysis pipeline as defined for the FEROS spectra and upon which the analysis of the archived spectra for the other three spectrographs is based (see Worley et al. [2012] for a detailed description).

together with their associated (internal and external) errors. Quality flags for these parameter estimates are also produced. We point out that external errors are estimated from the analyses of stellar atlases of well-known stars (the Sun, Procyon and Arcturus) and spectral libraries of reference samples (several hundreds of stars) found in the literature. Moreover, the analysis of the repeated observations by a given spectrograph allows us to estimate the internal errors of the adopted procedure (as an example, about 5% of the HARPS spectra correspond to the same stars — which may have been observed more than 20 times). Finally, typical total errors on the mean metallicity and the [α/Fe] ratios are around 0.1 dex and 0.05 dex, respectively, for spectra having SNR > ~ 25.

Results: AMBRE parameterisation of FGKM-type stars

We have presently analysed about 230 000 spectra archived by ESO and collected with FEROS, HARPS and UVES (see Table 1) and fully parameterised about two thirds of them. We adopted several selection criteria to construct the final tables of stellar parameters. These criteria are based on the different quality flags produced by our procedure resulting in the rejection of the low SNR spectra, hot and/or fast-rotating stars, and/or the detection of non-standard spectra (binaries, chemically peculiar stars and so on), for which the AMBRE analysis pipeline has not been developed.

We finally provided ESO with the stellar parameters of ~ 6 500 FEROS spectra (corresponding to ~ 3 100 different stars),

Table 2. The list of AMBRE data products for FEROS spectra that have been ingested into the ESO archives (taken from Worley et al. [2012]). Similar tables have been produced for the other spectrographs.

Keyword	Definition	Value range	Null value	Determination
DP_ID	ESO dataset identifier			
OBJECT	Object designation as read in ORIGFILE			
TARG_NAME	Target designation as read in ORIGFILE			
RAJ2000	Telescope pointing (right ascension, J2000)	deg.		
DEJ2000	Telescope pointing (declination, J2000)	deg.		
MJD_OBS	Start of observation date	Julian Day		
EXPTIME	Total integration time	sec.		
SNR	Signal-to-noise ratio as estimated by the pipeline	0–∞	NaN	
SNR_FLAG	Signal-to-noise ratio quality flag	C, R		C = Crude estimate from SPA*, R = Refined estimate from SPC#
EXTREME_EMISSION_LINE_FLAG	Detection of extreme emission lines	T, F		T = True: detection therefore no analysis carried out, F = False: no detection therefore analysis carried out
EMISSION_LINE_FLAG	Detection of some emission lines	T, F		T = True: some emission lines detected but analysis carried out, F = False: no detection therefore analysis carried out
MEANFWHM_LINES	Mean FWHM of absorption lines around 4500 Å	0–0.33	NaN	FWHM measured from spectral features (mÅ)
MEANFWHM_LINES_FLAG	Flag on the mean FWHM	T, F		T = True: *FWHM* > 0.33 or < 0.11. Default FWHM values used F = False: *FWHM* < 0.33, > 0.11
VRAD	Stellar radial velocity	−500 to +500	NaN	Units = km s^{-1}
ERR_VRAD	Error on the radial velocity	0–∞	NaN	If σ_{vrad} > 10, null value used for all stellar parameters. Units = km s^{-1}
VRAD_CCF_FWHM	FWHM of the CCF between the spectrum and the binary mask	0–∞	NaN	Units = km s^{-1}
VRAD_FLAG	Quality flag on the radial velocity analysis	0, 1, 2, 3, 4, 5	−99	0 = Excellent determination ... 5 = Poor determination
TEFF	Stellar effective temperature (T_{eff}) as estimated by the pipeline	3000–7625	NaN	Units = K. Null value used if T_{eff} is outside accepted parameter limits or if the spectrum is rejected due to quality flags
ERR_INT_TEFF	Effective temperature internal error	0–∞	NaN	Units = K. Square root of quadrature sum of internal errors ($\sigma(T_{eff})_{int,snr}$, $\sigma(T_{eff})_{int,vrad}$ & $\sigma(T_{eff})_{int,norm}$)
ERR_EXT_TEFF	Effective temperature external error	120	NaN	Units = K. Maximum expected error due to external sources
LOG_G	Stellar surface gravity (log *g*) as estimated by the pipeline	1–4.9	NaN	Units = dex. Null value used if log *g* is outside accepted parameter limits or if the spectrum is rejected due to quality flags
ERR_INT_LOG_G	Surface gravity internal error	0–∞	NaN	Units=dex. Square root of quadrature sum of internal errors ($\sigma(\log g)_{int,snr}$, $\sigma(\log g)_{int,vrad}$ & $\sigma(\log g)_{int,norm}$)
ERR_EXT_LOG_G	Surface gravity external error	0.2	NaN	Units = dex. Maximum expected error due to external sources
M_H	Mean metallicity [M/H] as estimated by pipeline	0-∞	NaN	Units = dex. Null value used if [M/H] is outside accepted parameter limits or if the spectrum is rejected due to quality flags.
ERR_INT_M_H	Mean metallicity internal error	0-∞	NaN	Units = dex. Square root of quadrature sum of internal errors ($\sigma([M/H])_{int,snr}$, $\sigma([M/H])_{int,vrad}$ & $\sigma([M/H])_{int,norm}$)
ERR_EXT_M_H	Mean metallicity external error	0.1	NaN	Units = dex. Maximum expected error due to external sources
ALPHA	α-elements over iron enrichment ([α/Fe]) as estimated by pipeline	−0.4–0.4	NaN	Units = dex. Null value used if [α/Fe] is outside accepted parameter limits or if the spectrum is rejected due to quality flags
ERR_INT_ALPHA	α-elements over iron enrichment internal error	0–∞	NaN	Units=dex. Square root of quadrature sum of internal errors ($\sigma([\alpha/Fe])_{int,snr}$, $\sigma([\alpha/Fe])_{int,vrad}$ & $\sigma([\alpha/Fe])_{int,norm}$)
ERR_EXT_ALPHA	α-elements over iron enrichment external error	0.1	NaN	Units = dex. Maximum expected error due to external sources
CHI2	chi^2 of fit between observed and reconstructed synthetic spectrum for MATISSE parameters	0–∞	NaN	Goodness of fit between final normalised and final reconstructed spectra
CHI2_FLAG	Quality flag on fit between observed and reconstructed synthetic spectrum for MATISSE parameters	0, 1, 2	−99	0 = Good fit ... 2 = Poor fit
ORIGFILE	ESO filename of the original spectrum being analysed			

Notes: * = Spectral Processing A; # = Spectral Processing C

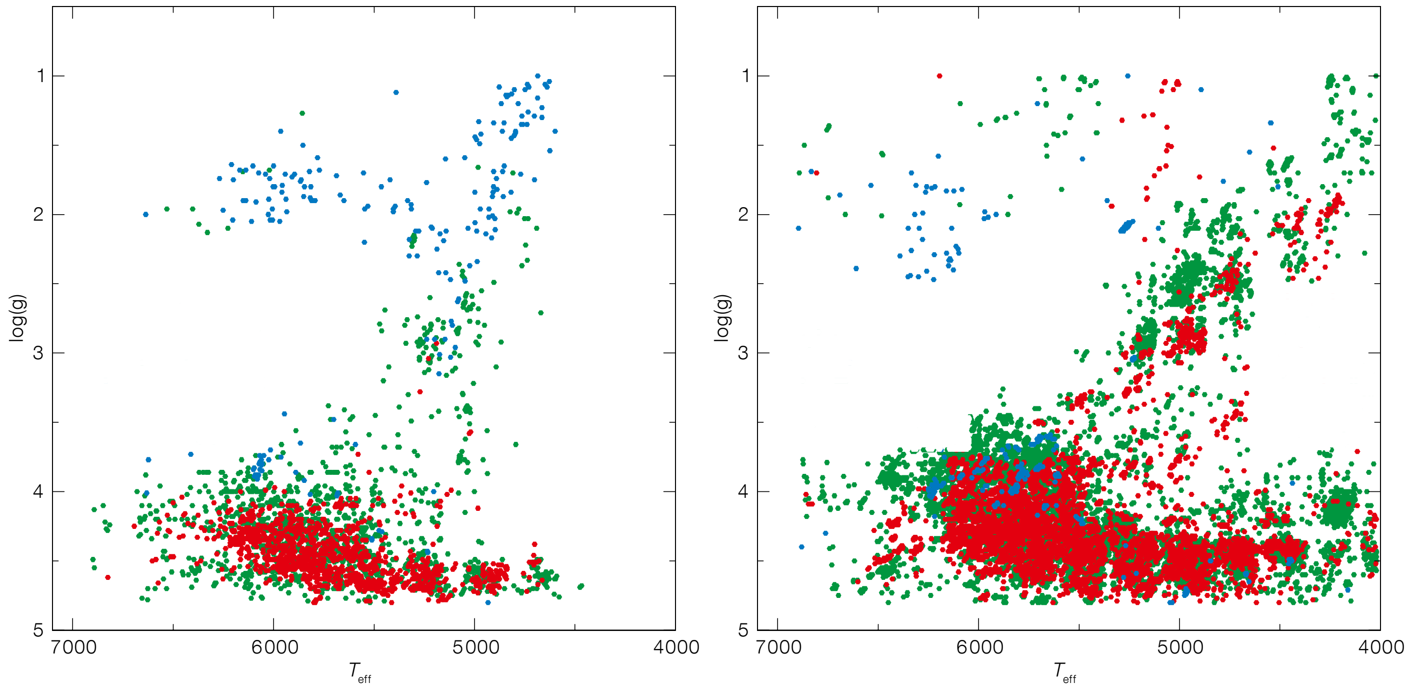

Figure 3. Hertzsprung–Russell diagrams of a sub-sample of the analysed spectra for FEROS (left panel, about 3600 spectra) and HARPS (right panel, ~ 75 000 spectra). Metal-poor stars ([M/H] < –1 dex) are plotted in blue, intermediate metallicity stars (–1 ≤ [M/H] < 0 dex) are in green and metal-rich stars ([M/H] ≥ 0 dex) in red.

~ 97 000 HARPS spectra (i.e. ~ 11 500 stars), and about 52 000 UVES spectra (around 25 000 stars). Radial velocities were determined for a larger sample of the spectra and are also part of the AMBRE products that have been sent to ESO. All these parameters have been ingested into the ESO archives (as Phase 3 Science Data Products) for storage and subsequent use by the scientific community. An example of all the derived data, their associated errors and different flags (32 entries in total) ingested into the ESO archives for a given spectrum can be seen in Table 2.

Finally, as an illustration of the AMBRE project results, in Figure 3 we show the Hertzsprung–Russell diagrams constructed from the derived stellar parameters of most of the FGKM-type slow-rotating stars analysed so far. These estimated stellar atmospheric parameters and chemical indices represent a huge amount of homogeneous and unique data that is ready to be exploited in terms of studies of stellar evolution and Galactic archaeology. We have already started some by-product analyses, such as the building of a catalogue of homogeneous projected rotational velocities of thousands of stars, the study of chromospheric indices in different types of stars, the mapping of the extinction of the interstellar medium, the heavy element content of stars in the Solar vicinity, and the separation of the thin/thick disc populations. Moreover, the AMBRE database is partly used as calibration data for the GES and Gaia surveys. We hope that the scientific community will make extensive use of the AMBRE database for a wealth of other astronomical projects.

Acknowledgements

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Links

[1] AMBRE data release: http://archive.eso.org/cms/eso-archive-news/first-data-release-from-the-matisse-oca-eso-project-ambre.html

HARPS Observations of the 2012 Transit of Venus

Paolo Molaro[1]
Lorenzo Monaco[2]
Mauro Barbieri[3]
Simone Zaggia[4]

[1] INAF–Osservatorio Astronomico di Trieste, Italy
[2] ESO
[3] Dipartimento di Fisica e Astronomia, Universitá degli Studi di Padova, Italy
[4] INAF–Osservatorio Astronomico di Padova, Italy

On 6 June 2012 the black disc of Venus passed across the Solar disc, taking nearly eight hours to complete the transit. The event was followed by millions of people worldwide. The transit of Venus is one of the rarest astronomical events, occurring approximately every 120 years. By means of HARPS spectroscopic observations, and using the Moon as a mirror, we detected the Rossiter–McLaughlin effect due to the eclipse by Venus of the Solar disc with a precision of few cm s^{-1}. The observation demonstrates that this effect can be measured even for transits of exoplanets of Earth size, or even smaller, provided enough photons can be collected by a very high resolution and extremely stable spectrograph, such as the planned HIRES instrument for the E-ELT.

A bit of history

In 1627, Kepler, in one of the first applications of the Copernican view of the cosmos, first predicted that there would be transits of the inner planets and the transit of Venus in 1631 in particular. However, Kepler had died in 1630 and Gassendi, who was the first to document a transit of Mercury, also missed the predicted transit since this transit of Venus could not be observed from Europe. However the young (22 years old) British astronomer Jeremiah Horrocks realised that transits of Venus occur in pairs separated by eight years, and in 1639 he and his friend William Crabtree were the humans to observe the phenomenon. Horrocks (1618–1641) wrote a poem commemorating the event:

... Thy return
Posterity shall witness; years must roll
Away, but then at length the splendid sight
Again shall greet our distant children's eyes.

Since then only six other transits have taken place in three epochs, namely 1762–1769, 1874–1882 and 2004–2012; there will not be another Venus transit until December 2117. As shown in Figure 1, taken from an old book by Proctor (1874), the cycle of the transits of Venus is precisely 243 years, so that of 2012 was similar to the one observed by James Cook from Tahiti in 1769 during his first voyage around the world, which led to the discovery of New Zealand and the Cook Islands. The observations by Cook and the astronomer Charles Green were recorded in a paper (Cook & Green, 1771) from which a figure is reproduced in Figure 2. In 1716 the Royal Astronomer Sir Edmund Halley, in an article entitled "A new Method of determining the Parallax of the Sun, or his Distance from the Earth", published in the Philosophical Transactions (Halley, 1716), suggested the use of observations of the transit of Venus to find a value for the distance of the Earth from the Sun, i.e. the astronomical unit (AU):

We therefore recommend again and again, to the curious investigators of the stars to whom, when our lives are over, these observations are entrusted, that they, mindful of our advice, apply themselves to the undertaking of these observations vigorously. And for them we desire and pray for all good luck, especially that they be not deprived of this coveted spectacle by the unfortunate obscuration of cloudy heavens, and that the immensities of the celestial spheres, compelled to more precise boundaries, may at last yield to their glory and eternal fame.

Astronomers did indeed organise major expeditions to the remotest parts of the world to obtain an estimate of the magnitude of the astronomical unit. From an initial value of about 10 million kilometres, as set by the ancient Greeks, the AU was increased to 120–155 million kilometres at the end of the 18th century and further refined by measurements during the transits of the 19th century to 149 341 924

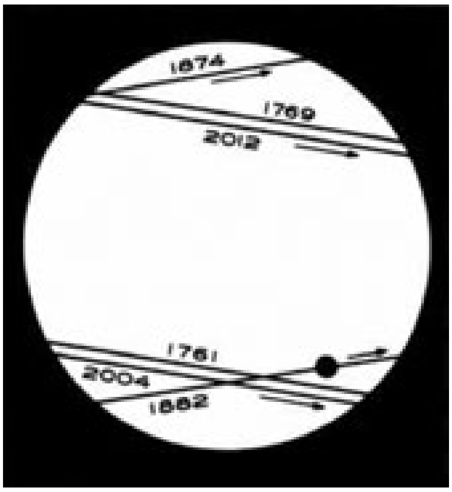


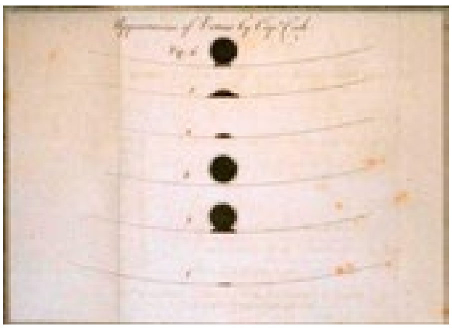
Figure 1. Sketch of the transits of Venus by Richard Antony Proctor (Proctor, 1874).

(± 96 076) kilometres, thanks to photographic recording (Harkness, 1888). A stunning video of the 2012 transit of Venus was captured by the Solar Dynamics Observatory and can be seen on the NASA website[1].

Science with the transit

In 1874 the young Kingdom of Italy organised an astronomical expedition to Madhapur, India, with the aim of observing the transit of Venus spectroscopically for the first time. In 1875 the Italian astronomer Tacchini sent a telegram from Calcutta: "First observations disturbed by small clouds – Good results spectroscopic and ordinary – Spectrum of Venus observed, details probably related to its atmosphere." (Pigatto & Zanini, 2001). We know today that this was not possible,

Figure 2. Drawing of the observations of the 1769 transit of Venus from Tahiti, taken from Cook & Green (1771).



since the atmosphere of Venus is too tiny to be detected in this way. However, after 138 years, on the occasion of the last transit, we found a new way to exploit spectroscopic observations of the transit of Venus by detecting the very small Rossiter–McLaughlin (RM) effect. When a body passes in front of a star the consequent occultation of a small area of the rotating stellar surface produces a distortion of the stellar line profiles, which can be measured as a drift of the radial velocity. The phenomenon was observed in eclipsing binaries by McLaughlin (1924) and Rossiter (1924) and in the Jupiter-like planets (Queloz et al., 2000), but becomes increasingly difficult to observe when the eclipsing body is as small as a planet and, in particular, for an Earth-sized planet such as Venus. The RM effect has been observed in about 60 extrasolar planets, providing important information on the angle between the sky projection of the orbital axis and the stellar rotation axis, and showing that several exoplanets have tilted orbits.

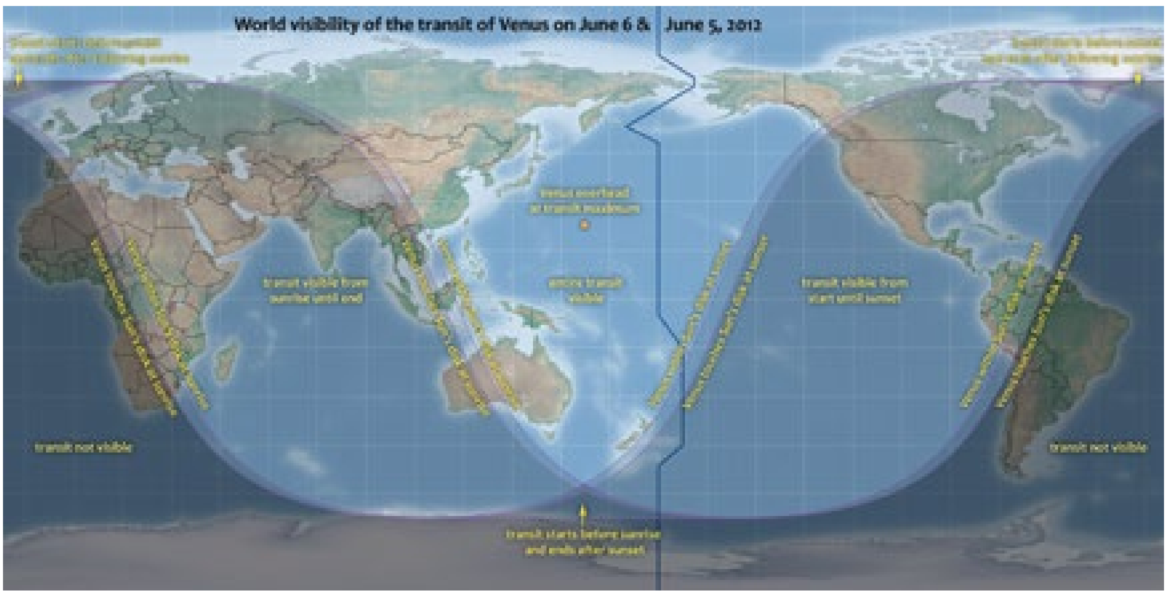
Most surprisingly, the integrated light of the Sun at high spectral resolution, which is needed to reveal the RM effect, is extremely difficult to obtain with direct observations. The simplest workaround is to collect the Solar light as reflected by the Moon or by other minor bodies of the Solar System. Chile was out of the visibility strip for the transit of Venus (c.f., Figure 3); a few weeks before the event we submitted a Director's Discretionary Time (DDT) proposal to observe the RM effect from Chile at night. The purpose was to detect the RM effect caused by the transit of Venus using the almost full Moon as a mirror (DDT 289.D-5015).

There are a few differences that have to be considered. Due to the different spatial location, the transit of Venus as seen from the Moon has a slightly different timing and projection on the Solar disc from that which is seen from Earth. The Moon was about eight degrees ahead of the Earth and Venus reached the Sun–Moon alignment with a delay of about two hours. The transit was also slightly longer than from Earth since the Moon was above the rotation plane of the Earth–Sun.

Our observations with HARPS began at 2 h:44 m UT on 6 June 2012 when the Moon reached about 40° above the horizon at about mid-transit and continued until the end of the transit, and for some time afterwards. The observations comprised a series of 245 spectra, each with an integration time of 60 s with 22 s of readout, and delivered a signal-to-noise ratio of ~ 400, each at 550 nm at a resolving power of R ~ 115 000. The first 227 observations cover the phases between about mid-transit to the end and for about two hours after the passage. Eighteen additional observations were also taken at twilight a few hours after the passage, and were used to fix the reference of the Solar radial velocity.

The radial velocities were obtained by the HARPS pipeline. Simultaneous spectra were collected with a reference ThAr lamp and used to correct overnight instrumental drifts, which were about 40 cm s^{-1} at the beginning and undetectable, i.e. less than 20 cm s^{-1}, after a couple of hours of observations. The relative motions of the Moon with respect to the Sun and the usual one due to the observer were accounted for. The barycentric radial velocities were then measured relative to the out-of-transit Solar radial velocity, which was measured as the mean value of all the out-of-transit observations and had a value of 102.53 ± 0.10 m s^{-1}. This latter quantity comprises the zero offset of the mask used in the cross-correlation by the HARPS pipeline, plus specific motions of the Sun on that day. The resulting radial velocities and their temporal evolution in phase with the transit are shown in Figure 4. The values show clearly the Solar 5-minute oscillations of the p-modes, but also a clear trend in phase with the passage of Venus in front of the receding hemisphere, with a half amplitude modulation of ~ 80 cm s^{-1}.

For the configuration of Venus, Sun, Moon and Earth it is possible to make a very accurate model for the RM effect, which considers Solar differential rota-



M. Zeiler, eclipse-maps.com

Figure 3. Visibility of the transit of Venus on 6 June 2012 as seen from the Earth. From the Moon it is slightly different, being longer and delayed by a couple of hours (see text).

tion, limb darkening and Solar axis inclination. The theoretical model is compared with the observations in Figure 4 as a continuous blue line. Note that this is not a fit to the data but an independent theoretical model of the RM effect. Once the p-mode oscillations have been filtered out, the radial velocity difference between the model and the observations is –4 cm s^{-1}. This offset can be entirely ascribed to our ability to establish the out-of-transit Solar radial velocity needed for the normalisation; this latter is known with an uncertainty of ~ 10 cm s^{-1}.

This is the smallest radial velocity effect ever detected with HARPS and it demonstrates that the RM effect can be detected despite the fact that the radial velocity change due to Venus is comparable to that of the Solar oscillation. The RM effect is one of the most promising ways by which astronomers plan to study exoplanets and new high resolution spectrographs at the E-ELT are also proposed for this purpose. The present observations show that an RM effect as small as those caused by Earth-like planets eclipsing their host star could be detected even in the presence of a comparable stellar jitter.

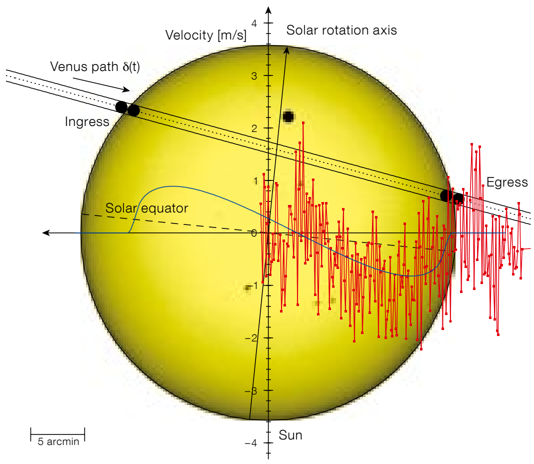


Figure 4. The Solar disc from the Solar Dynamics Observatory image of the Sun on 6 June 2012 with the path of the transit of Venus as seen from the centre of the Moon drawn in. Radial velocity measurements (the red points connected by the red line) from the 227 Solar spectra during the transit are shown (*x*-axis is time). The thin continuous blue line shows the theoretical RM effect. The radial velocities show clearly the 5-minute Solar oscillations as well as a decrease in the second part of the transit, up to 80 cm s^{-1}, due to the partial coverage of the receding Solar hemisphere by Venus.

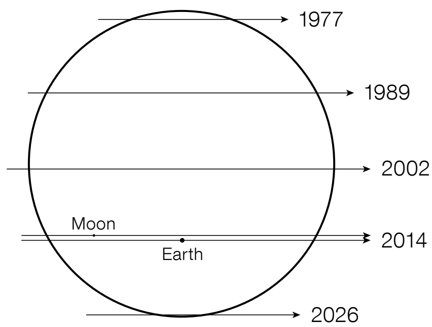


Figure 5. The tracks and dates of the Earth's transits across the Solar disc as seen from Jupiter are shown, adapted from a figure in Meeus (1989). For the transit in 2014, the Moon, at a distance of 1′ 47.4″ from Earth, is also shown. The Moon will produce its own eclipse of a small portion of the Solar disc, with an estimated RM effect of only ~ 2 cm s^{-1}.

Goodbye until 2117 (or is it?)

The next transit of Venus will occur in December 2117 so the observations described here cannot be repeated or improved by any other kind of instrument. The only other transit visible directly from the Earth in the next few years will be the one of Mercury on 9 May 2016, which occurs during the day in South America, between 11:12 and 18:42. However, we may not need to wait for 105 years for another similar opportunity. In the Solar System other transits can be seen from the other planets too, with only the exception of the innermost planet Mercury. More interestingly, the Earth too is seen transiting in front of the Sun from the outer planets. A transit occurs every time the heliocentric conjunctions take place near one of the nodes of their orbits. Accurate computations of the transits of all planets of the Solar System were made by Meeus (1989). He found that the Earth will be seen transiting the Sun from Mars in 2084. More interestingly the Earth will be seen transiting the Sun from Jupiter on 5 January 2014, and then again in 2026. As shown in Figure 5, where all the passages are drawn, the transit of 2026 will be a grazing one, quite unfavourable for any kind of observation. So effectively the transit occurring next year is a unique event, providing an opportunity to repeat the experiment, but with an Earth transit instead of that of Venus.

The predicted RM on this occasion will also be even smaller. From Jupiter the angular size of Sun is 369 arcseconds and of the Earth 4.2 arcseconds, so that the predicted modulation of the RM effect is only about about 20 cm s^{-1}. Interestingly, together with the Earth, the Moon will also produce a transit on the Solar surface. The transit of the Moon will be delayed by about four fours from the transit of the Earth.. The RM effect due to the Moon will only be about 2 cm s^{-1} and is probably beyond the limit of our technique. This is a unique configuration where we can possibly detect the RM effect of an Earth-size planet together with its moon. The presence of moons could be quite a common configuration among exoplanets and this will represent a sort of unique test-bench experiment. As for all unique experiments, a certain dose of good luck is required in order to have a clear sky. This is something that Jeremiah Horrocks certainly had when he first observed the transit of Venus through the cloudy English sky.

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Links

[1] Solar Dynamics Observatory Venus transit video: http://www.nasa.gov/mission_pages/sunearth/multimedia/venus-transit-2012.html

Following the G2 Gas Cloud towards the Galactic Centre

Jeremy Walsh[1]
Stefan Gillessen[2]
Reinhard Genzel[2,3]
Tobias K. Fritz[2]
Frank Eisenhauer[2]
Oliver Pfuhl[2]
Thomas Ott[2]
Marc Schartmann[2,4]
Alessandro Ballone[2,4]
Andreas Burkert[2,4]
George Hau[1]
Julien Girard[1]
Jared O'Neal[1]
Henri Bonnet[1]

[1] ESO
[2] Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
[3] Department of Physics and Astronomy, Le Conte Hall, University of California, Berkeley, USA
[4] Universitätssternwarte, Ludwig-Maximilians Universität, München, Germany

A gas cloud was detected within half an arcsecond of Sagittarius A* in 2011 in *L′*-band and subsequently in line emission of H and He. The emitting cloud can be traced back in time to 2002 and is in an orbit with a pericentre very close to the central massive black hole at the Galactic Centre. Named G2, the cloud is passing the pericentre from mid-2013 to probably mid-2014 and is being intensively monitored by many facilities. An update on the progress of G2 is reported, based on recent VLT observations with SINFONI.

The region around the compact radio source Sagittarius A*, the site of the massive black hole (BH) at the centre of the Milky Way, is of intense observational interest. Although the black hole is very underluminous in comparison with active galactic nuclei in distant galaxies, it presents a unique opportunity to study in detail the effects of strong gravity in the vicinity of a black hole. The advent of adaptive optics has enabled the astrometry of tens of stars in the central arcsecond to be followed over a period of 21 years to date and their orbits to be solved. The star with the most diagnostic power is a bright (K = 14 mag) short-period star, labelled S2, which has a period of 16 years and underwent a pericentre passage in 2002 (Genzel et al., 2010), with its next pericentre approach in 2018. Solving for the orbital elements of these stars around the BH enabled the mass of the central black hole ($4.3 \times 10^6 M_\odot$), and the distance to the Galactic Centre (8.3 kpc) to be well constrained (Gillessen et al., 2009).

The 3D orbits of the stars in orbit around the BH at the Galactic Centre (GC) require both astrometric and kinematic observations. Astrometric orbits of the GC cluster stars (the S stars; Gillessen et al., 2009) have been the province of speckle imaging and adaptive optics (AO) imaging, beginning with the SHARP 1 camera on the New Technology Telescope (NTT) and, since 2002, with the Very Large Telescope (VLT) NACO instrument (see Genzel et al. [2010] for a review) and with NIRC2 at the Keck Telescope (e.g., Ghez et al., 2008). The line-of-sight velocities of these stars have been mainly measured with AO-assisted integral field unit (IFU) spectrographs, such as SINFONI at the VLT and OSIRIS at Keck. The S-stars orbit Sgr A* on randomly oriented orbits. Further out, a population of massive, luminous stars orbit in a disc inclined to the line of sight. Frequent observations during the GC season (March to October for ground-based telescopes) have enabled the orbits of more stars to be refined over the years.

During the 2011 campaign a new moving object was detected, initially in *L′*-band (3.8 μm), but not in *K*-band, suggesting it was a source cooler than a star. Examination of SINFONI H+K grating spectra showed in addition emission lines of Brackett-γ (2.17 μm) and He I (2.06 μm) enabling its radial velocity to be measured (Gillessen et al. [2012] and ESO Release 1151[1]). It was christened G2 by Burkert et al. (2012), as the second gaseous cloud after the one found by Clénet et al. (2005) in the near vicinity of the GC.

The G2 gas cloud

Careful examination of imaging data prior to 2011 revealed that G2 could be detected in NACO *L′*-band AO images back to 2002 and that its proper motion was 42 milliarcseconds per year, or 1700 km/s at the distance of the GC (Gillessen et al., 2012). The properties of G2 were distinct from that of the stars orbiting the GC: line emission, continuum undetected in *H*- and *K*-bands, but continuum detections in *L′*-band and the *M*-band (4.7 μm); these properties are those expected of a dusty gas cloud. The ratio of the He I and H I emission lines is also similar to that of photoionised gas, further strengthening evidence for the gaseous nature of G2. Knowing where to extract the spectrum of G2 from its orbit allowed the radial velocities to be measured from the emission lines, including on SINFONI datacubes back to 2004, and the velocities were found to be increasing from 1250 km/s in 2008 to 1650 km/s in 2011 (Gillessen et al., 2012).

From the astrometry and radial velocities of G2 over this time period, the orbit was tightly constrained to be highly eccentric and the cloud was falling towards Sgr A* — and being tidally disrupted. From the initial orbital elements, a pericentre passage within 3000 Schwarzschild radii (R_s) of Sgr A* was estimated. The implications for black hole studies were profound: G2 would probe the accretion flow around the BH and even perhaps feed matter into the BH. The event might be observable in a variety of bands from the radio up to the X-ray regime. G2 thus became the subject of intense observational study covering most of the electromagnetic spectrum and with ground- and space-based telescopes.

The evolution of G2 was followed up in 2012 with a further NACO image and deep SINFONI observations (Gillessen et al., 2013a). The progress of G2 towards Sgr A* over the period 2008–2013 is shown in Figure 1. The addition of new velocity data showed further acceleration of G2 as it approached the GC, an even larger eccentricity for the orbit of 0.966 and a smaller pericentre distance of 2200 R_s. Although the emission lines were becoming broader, the flux of G2 in the Brackett-γ line remained similar to the value at earlier epochs. The date of pericentre passage was estimated as September 2013, allowing strategic observing proposals to be planned[2,3].

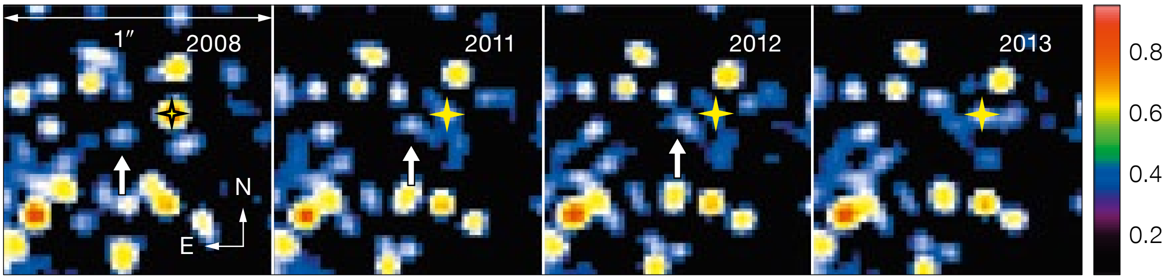

Figure 1. The progress of G2 in its course towards the Galactic Centre, Sgr A*, is shown in this sequence of restored NACO *L′*-band images over the period 2008 to 2013 (c.f., Gillessen et al. [2013a], Figure 1). The position of G2 is arrowed and the position of Sgr A* is shown by a cross.

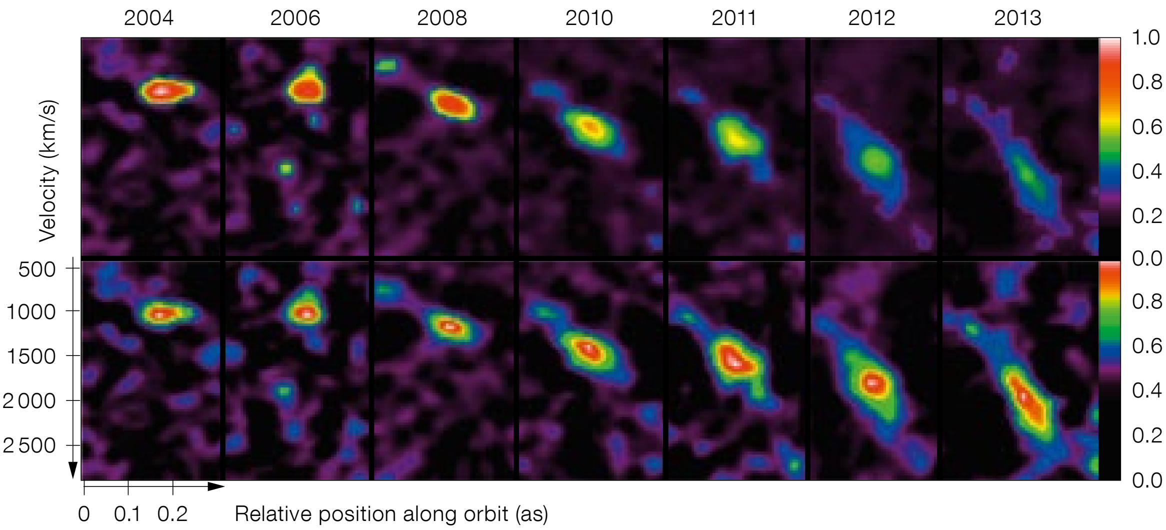

Figure 2. The evolution in the appearance of G2 in position–velocity diagrams extracted from SINFONI datasets is shown in two different scalings: upper row scaled to equal total luminosity; lower row scaled to identical peak luminosities. The increasing tidal shear with time is apparent (see Gillessen et al., 2013b).

2013 VLT campaign

NACO imaging in *L′*-band did not convincingly reveal the 2013 position of G2, on account of confusion. However very deep SINFONI data were obtained early in the 2013 GC season, in April: 24.4 hours of observational data, of which only 21% were rejected for lower Strehl ratios, made this the deepest integral field exposure of the Sgr A* region ever (Gillessen et al. [2013b] and ESO Release 1332[4]). On account of the high velocity of the G2 emission, the Paschen-α line (1.88 μm) could also be detected, shifted out of the strongest absorption of the Earth's atmosphere. Careful examination of earlier epochs revealed more detections of G2 in other datasets, enabling a total of 15 radial velocity measurements since 2004. Figure 2 shows a montage of the position velocity diagrams of G2 over this period: the evolution of a tidal shear on the knot emission is evident.

These observations are becoming more challenging as the cloud already presents low contrast emission against the diffuse emission from the whole GC region and the emission line of G2 is becoming broader as it is sheared by the gravitational field of the BH (Figure 2). Knowing the position from the astrometry, and the availability of IFU data, the spectrum can be extracted with a curved slit; by co-adding the three emission lines (two H lines, Brackett-γ and Paschen-α, and the He i line) a full position–velocity diagram along the orbit (Figure 3) reveals that emission is also detected with a blueshift of 3000 km/s, consistent with some gas having already undergone pericentre passage (Gillessen et al., 2013b). Thus the pericentre passage is an extended event of at least a year's duration with the bright head of G2 still before pericentre excursion in these observations.

Nature of G2

Although the recent SINFONI observations clearly reveal the course of G2 around the BH, there is still contention as to the nature of the cloud itself. A range of explanations, from the circumstellar shell of a low mass (T-Tauri) star or protoplanetary disc, a nova outburst, a stellar wind collision event, an instability in the gas of the Sgr A* accretion flow, have been advanced (see Gillessen et al., 2013a; also Phifer et al., 2013, Scoville & Burkert, 2013). In either case, it is clear that the observed phenomenology is that of a gas cloud being disrupted, and efforts to find a star inside have failed (Phifer et al., 2013). Also the 2013 VLT data are more consistent with a pure gas cloud model. A clue might be that G2 seems to be related to the disc of O and Wolf–Rayet stars that orbit the BH at radii larger than 1 arcsecond. As the pericentre passage begins to disrupt G2, the available options will be narrowed down. So far there is no evidence for hydrodynamic effects between the gas and BH at the Galactic Centre, but when the gas is at around 2000 R_s, interaction between G2 and the BH may become observable, both in X-ray and as a distortion from the, so-far, Keplerian orbit. The intense observing campaign this year and next year will be of unique interest for this first "experiment" with strong gravity and the infall of matter onto a massive BH.

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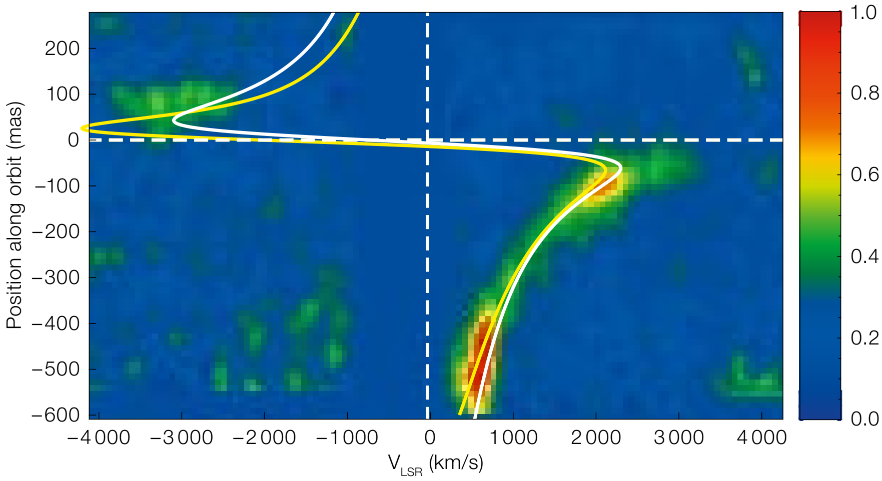

Figure 3. The full depth of the velocity–position diagram of G2 is revealed from the 24.4-hour 2013 SINFONI observation by extraction of the spectrum along the (curved) orbit path (from Gillessen et al., 2013b). The yellow line depicts the *L′*-band orbit which differs slightly from the Brackett-γ one (white line).

Links

[1] ESO Release 1151: http://www.eso.org/public/news/eso1332/
[2] MPE Galactic Centre pages: http://www.mpe.mpg.de/ir/GC
[3] Gas cloud Wiki: https://wiki.mpe.mpg.de/gascloud/FrontPage
[4] ESO Release 1332: http://www.eso.org/public/news/eso1332/

ESO/APEX & MSX/IPAC/NASA

A composite submillimetre and infrared image of the Sagittarius B2 region towards the Milky Way Galactic Centre. APEX ATLASGAL submillimetre-wavelength data are shown in red and are overlaid on mid-infrared images from the Midcourse Space Experiment (MSX) in green and blue. Sagittarius B2 is the bright orange-red region to the left of image centre. More details in Release eso0924.

The Magellanic Stream — A Tail of Two Galaxies

Andrew J. Fox[1]
Philipp Richter[2]
Bart P. Wakker[3]
Nicolas Lehner[4]
J. Christopher Howk[4]
Joss Bland-Hawthorn[5]

[1] Space Telescope Science Institute, Baltimore, USA
[2] University of Potsdam, Germany
[3] University of Wisconsin-Madison, USA
[4] University of Notre Dame, USA
[5] University of Sydney, Australia

Interactions between spiral galaxies and their dwarf satellites are often spectacular, producing extended streams of stripped gas and triggering new generations of star formation. The most striking local example lies in the outer halo of the Milky Way in the form of the Magellanic Stream. Extending for over 140 degrees, the Stream is a giant ribbon of gas trailing the orbit of the Large and Small Magellanic Clouds. Since its discovery over 40 years ago, the Stream has puzzled observers and theorists alike and raised many questions. New spectroscopic observations with the Hubble Space Telescope and VLT/UVES are addressing these questions and finding the origin of the Stream to be surprisingly complex.

Discovery of the Magellanic Stream

Radio observations in the early 1970s discovered an extended stream of H I 21-cm-emitting neutral gas emanating from the Magellanic Clouds and passing over a wide swath of the southern sky (Dieter, 1971; Wannier & Wrixon, 1972). Dubbed the Magellanic Stream, this object has been studied extensively with successive generations of sensitive radio telescopes (e.g., Putman et al., 2003; Brüns et al., 2005), and has been the subject of many simulations exploring its existence and properties. The nature of the mechanism(s) producing the Stream is still debated; the two leading theories are tidal stripping and ram-pressure stripping. In the tidal scenario, gravitational forces exerted by the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC) on each other pull gas out of their potential wells and create the Stream (e.g., Besla et al., 2010). In the ram-pressure model, drag forces exerted on the LMC and SMC as they pass through the extended gaseous halo of the Galaxy push gas out of their interstellar medium into the wake of their orbits (e.g., Mastropietro et al., 2005).

The Stream is split spatially into two principal filaments, which appear to wrap around each other, and is paired with a "Leading Arm" of material extending for ~ 60 degrees on the other side of the LMC and SMC. Since the Leading Arm lies in front of the direction of motion of the LMC and SMC, it cannot be created by ram-pressure forces, so at least this portion of the Magellanic System is thought to be tidally created. However, if the entire Stream were created by tidal forces, there ought to be a stellar component, yet such a stellar stream has never been observed, despite deep searches. Both origin mechanisms may therefore be at play.

Studying the Stream in absorption

While the radio data give exquisite quality maps of the neutral gas in the Stream, absorption-line spectroscopy of background targets is needed to reveal how much ionised gas and metal enrichment is present. Using ultraviolet (UV) spectra taken with the Cosmic Origins Spectrograph (COS) on board the Hubble Space Telescope (HST), together with optical spectra from VLT/UVES, we recently studied 14 active galactic nuclei (AGN) lying behind or near the Stream (a map of the Stream is shown in Figure 1, with the positions of several of the AGN marked). The resonance lines of the key elements for interstellar abundance measurements all lie in the UV, so the COS observations are necessary for constraining the Stream's metallicity. However, the UVES observations have the advantage of high velocity resolution (4.0 km s^{-1} full width at half maximum [FWHM] given the 0.6-arcsecond slit used), which allows the component structure of the cool gas in the Stream to be resolved. An example of the UVES data is shown in Figure 2, in which seven components of Ca II H and K absorption are seen in the velocity interval of the Stream toward the AGN

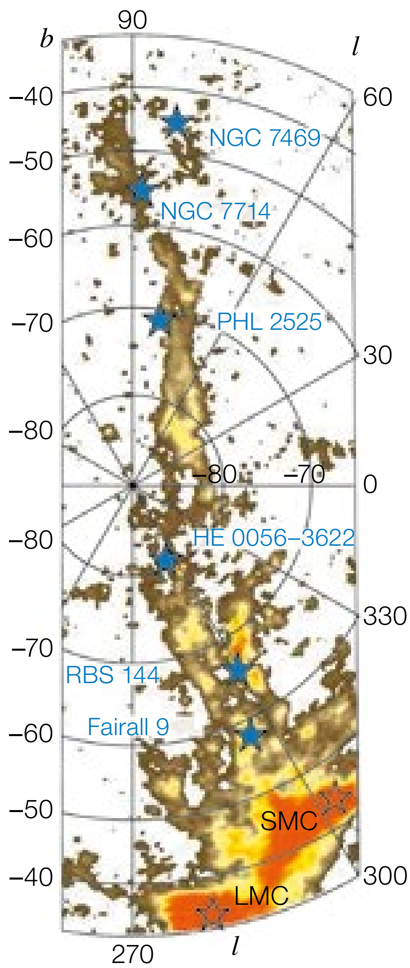

Figure 1. H I 21 cm map of the Magellanic Stream generated from the Leiden/Argentine/Bonn (LAB) survey, colour-coded by H I column density (from Fox et al., 2013). The map is shown in Galactic coordinates centred on the South Galactic Pole, with the LMC and SMC at the bottom. Background sources are indicated with stars. RBS 144 and Fairall 9 sample the two principal filaments of the Stream.

Fairall 9. This indicates that complex substructure and fragmentation is present in the gas. This substructure provides a valuable template for modelling the UV lines observed at lower resolution with COS (20 km s^{-1} FWHM).

The Stream's metallicity was derived in each direction by comparing the strength of the O I 1302 Å, S II 1250 Å or S II 1259 Å UV absorption lines to the strength of the H I (atomic hydrogen) 21 cm emission line measured from radio telescope observations. Neutral oxygen (O I) and singly ionised sulphur (S II) are chosen for these measurements since, in interstellar envi-

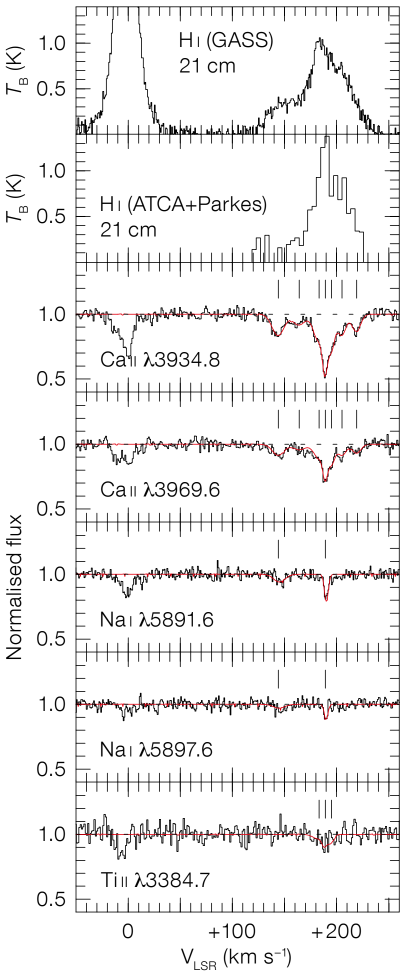

Figure 2. High-resolution VLT/UVES spectra of Ca II, Na I, and Ti II absorption lines in the direction of Fairall 9 (from Richter et al., 2013). Magellanic Stream absorption is visible in multiple components at local standard of rest (LSR) velocities between +130 and +240 km s^{-1}. The red lines indicate our Voigt-profile fit to the data. In the top panel, the Galactic All Sky Survey (GASS) 21 cm profile is included for comparison.

ronments, they are largely unaffected by ionisation and dust-depletion effects, so their ratios with H I provide robust metallicity indicators. We found the Stream's metallicity to be only ≈ 10% of the Solar value in three separate directions sampling most of its length (Fox et al., 2010; 2013; see Figure 3 upper panels), considerably lower than the current-day average metallicity of the SMC (≈ 20% Solar) and the LMC (≈ 50% Solar). However, the age of the Stream is estimated from tidal models to be around 2 Gyr (e.g., Besla et al., 2010), and to determine its parent galaxy, we need to know the LMC and SMC metallicity at that time in the past.

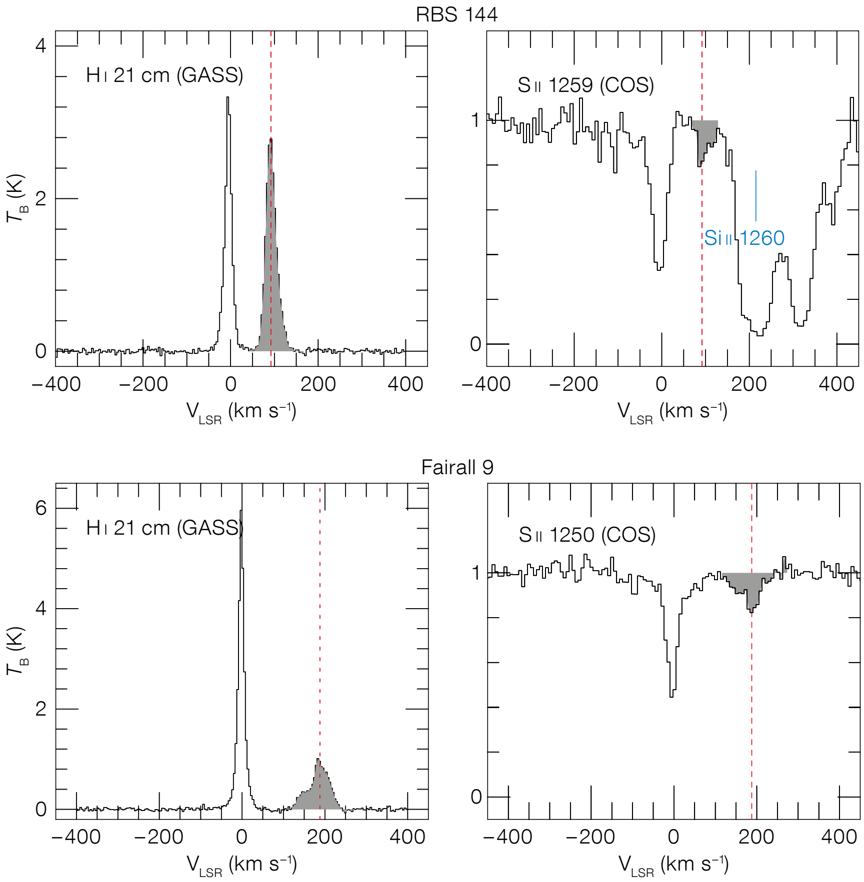

Figure 3. UV and radio spectra used to derive the metallicity of the Magellanic Stream towards RBS 144 (upper) and Fairall 9 (lower), two directions that lie only 8.4 degrees apart on the sky, yet trace two separate filaments of the Stream. The shaded regions show the Stream component, with the Milky Way component visible near 0 km s^{-1}. The abundance of sulphur in the Stream is only 10% Solar toward RBS 144, but 50% Solar toward Fairall 9.

Fortunately, information on the metallicity evolution of the Magellanic Clouds is available from their age–metallicity relations (Pagel & Tautvaisiene, 1998); these indicate that 2 Gyr ago, the SMC abundance was ~ 10% Solar, matching the value we measure in the Stream, whereas the mean LMC abundance at that time was much higher, at ~ 30–40% Solar. Our results thus support a scenario in which most of the Stream was stripped from the SMC (not the LMC), and has not self-enriched since its formation, because there is no evidence for ongoing star formation in the gas. In a sense, we have measured a fossil record of the Stream at the time of its birth in the SMC about 2 Gyr ago.

A second filament connected to the LMC?

However, a fourth sightline we studied (toward the AGN Fairall 9) tells a very different story (Richter et al., 2013; see also Gibson et al., 2000). In this direction, which lies close to the Magellanic Clouds on the sky, the sulphur abundance in the Stream is found to be 50% solar (Figure 3 lower panels), five times higher than the value measured in the other directions, and much higher than expected for gas that has been stripped from the SMC. Furthermore, the Fairall 9 direction traces a filament of the Stream that appears to connect kinematically to the southeastern corner of the LMC (Nidever et al., 2008). Our measurement of a higher metal abundance in this direction supports this claim, and points towards a dual origin for the Stream, with two interwoven strands of material, one pulled out of the SMC ~ 2 Gyr ago and another pulled out of the LMC more recently.

In both strands of the Stream, we measure a low nitrogen abundance relative to sulphur: in the LMC filament toward Fairall 9, we derive an N/S ratio of only 14% of the Solar value (Richter et al., 2013), and in the SMC filament toward RBS 144, we derive an upper limit of N/S < 17% Solar based on a non-detection in the N I 1200 Å triplet (Fox et al., 2013). Since nitrogen and sulphur have different nucleosynthetic origins, with nitrogen primarily produced in the asymptotic giant branch (AGB) phase of intermediate-mass stars, and sulphur largely released by core-collapse supernovae, the N/S ratio can be used as a clock, gauging how much time has passed since a burst of star formation occurred. The low N/S ratios measured in the Stream therefore indicate that both strands were stripped from their parent galaxy within ≈ 250 Myr of the initial burst of star formation, before the gas had time to become enriched in nitrogen.

Fuel for the halo or fuel for the disc?

A key remaining open question on the Stream concerns its fate — will it survive its journey through the Galactic halo to reach the disc, or evaporate into the million-degree corona? Continued star formation in spiral galaxies like the Milky Way is dependent on the replenishment of their fuel supplies, so the survival of gaseous tidal streams is of relevance to galaxy evolution in general. The strength of the evaporative interaction between the Stream and the hot corona depends on the density contrast between the two phases, which is poorly constrained observationally.

However, three separate lines of evidence indicate that the Stream is in the process of being evaporated: the presence of a highly ionised phase of gas seen in the UV absorption lines of C IV and O VI (Fox et al., 2010), which appear to trace the conductive or turbulent interfaces between the cool gas and the corona; the filamentary head–tail structures seen in radio data that are the hydrodynamic signatures of gas interaction (e.g., Nidever et al., 2008); and the results of simulations that explore the lifetime of the Stream to evaporative interactions (Bland-Hawthorn et al., 2007). Unless the evaporated material finds a way to re-cool and condense into the neutral phase, the eventual fate of the Stream may be to feed the halo, not the disc, of our Galaxy. The hot halo therefore plays an important role in controlling the passage of fuel supplies into the Milky Way.

Acknowledgements

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José Francisco Salgado/ESO

Night landscape and skyscape of the Paranal Observatory from the north. In the sky over the Observatory, the Large and Small Magellanic Clouds are clearly visible.

On 27 June 2013, the European Space Agency astronaut, Pedro Duque, visited ESO Headquarters. Duque, currently head of the Flight Operations Office at the Columbus Control Centre near Munich, is shown addressing ESO staff. More details in release ann13058.

The Bavarian State Minister of Sciences, Research and the Arts, Dr Wolfgang Heubisch, visited Paranal on 24–25 May 2013 and is shown (left) with the Director General Tim de Zeeuw.

ESO/G. Brammer

Report on the Workshop

Shaping E-ELT Science and Instrumentation

held in Ismaning and ESO Garching, Germany, 25 February–1 March 2013

Suzanne Ramsay[1]
Jochen Liske[1]
Paolo Padovani[1]
Jason Spyromilio[1]

[1] ESO

The workshop brought together astronomers from the ESO community, and beyond, with the aim of developing the science cases for the future instrumentation programme for the European Extremely Large Telescope (E-ELT). The two first-light instruments have already been chosen and the workshop focussed on the science cases for the following three instruments. After a review of the instrumentation programmes of E-ELT and the two other ELT projects, the sessions covered the scientific justifications for a mid-infrared instrument, a high resolution spectrograph and a multi-object spectrograph. A session was also devoted to future instrument concepts and other science cases. The workshop concluded with parallel discussions on the multi-object and high resolution spectrograph options and an open discussion.

ESO, working with its member community, has prepared an instrumentation roadmap for the E-ELT that describes in broad terms the instruments that will be delivered to the telescope over approximately the first five years of operations. The two first-light instruments were selected in 2011: an integral field spectrograph able to exploit the full range of image quality expected by the telescope, from natural seeing to the diffraction limit; and a near-infrared (NIR) camera working at the diffraction limit. Both will be fed by adaptive optics (AO) systems. The next three instruments on the roadmap are a mid-infrared (MIR) camera and spectrograph, a multi-object spectrograph (MOS) and a high spectral resolution spectrograph. Our intention, in organising the workshop, was to hear the community's ideas on the science goals for such instruments.

Such was the enthusiastic response to this meeting, that the first four days of the conference took place at the Bürgersaal in Ismaning, a location that gave sufficient space for the ~160 participants to meet together in one room. During these four days, invited and contributed talks were organised in five sessions, focussing on: (i) the status of the E-ELT, its first-light instrumentation and the status of the other ELT projects; (ii) mid-infrared (MIR) astronomy with the E-ELT; (iii) high resolution spectroscopy (HIRES); (iv) multi-object spectroscopy; and (v) future instrument concepts and science cases. A total of 57 presentations were delivered during these sessions. In addition, 37 posters were presented.

For the final day of the conference, we met at ESO Headquarters in Garching in parallel sessions. Informal discussions concerning ELT-MOS and ELT-HIRES were held in two splinter groups led by Monica Tosi and Gaël Chauvin for the high resolution spectrograph and Isobel Hook and Jordi Cepa for the multi-object spectrograph. Roughly half of the conference participants attended each of these splinter sessions. The outcomes of the splinter discussions were then presented to the plenum before wrapping up the conference with a final, open-themed discussion among all the participants. At the time of writing, the ESO E-ELT Science Office, working with the ELT Project Science Team, is taking the input from this workshop and other sources to define the requirements for the next capabilities on the E-ELT to follow on from the first-light instruments.

E-ELT projects and first-light science

Following an introduction from the ESO Director General, Tim de Zeeuw, an afternoon of presentations on the E-ELT project and instrumentation was complemented by presentations on the instrumentation plans for the Thirty Meter Telescope (TMT), by Luc Simard, and for the Giant Magellan Telescope (GMT), by George Jacoby. The revised instrumentation roadmap for the E-ELT was presented by Mark Casali. Following the launch of the contracts for the first-light instruments, the intention is that the procurement of the next three instruments will proceed in parallel. Detailed presentations on the first-light instruments were made by the principal investigators (PIs), Niranjan Thatte for the HARMONI integral field unit (IFU) spectrograph and Ric Davies for the MICADO camera. The MICADO camera is planned to be used with the multi-conjugate adaptive optics system, MAORY, the status of which was presented by the PI, Emiliano Diolaiti. A glimpse of two of the scientific programmes that will benefit from the first-light instruments was given by Chauvin, who discussed the potential for exoplanet science, and Seppo Mattila, who showed the future impact of adaptive optics observations on supernova research. The applications of an AO-fed camera on the E-ELT to the studies of blue compact dwarf galaxies and globular clusters were discussed later by Giuliana Fiorentino and Annalisa Calamida respectively.

The core of the workshop then consisted of sessions on the science cases for the three instrument concepts, summarised in following the sections.

Mid-infrared astronomy with the E-ELT

Based on the Phase A instrumentation studies, the MIR imager and spectrograph has been selected to be built for the E-ELT as one of the instruments to follow after the first-light pair. The concept and science cases for this instrument were presented in a review by the

PI, Bernhard Brandl. A review by Joana Ascenso and João Alves then covered the expected impact of the E-ELT on MIR studies of all stages of star formation from cores to star clusters. The third and final review talk was on MIR observations of evolved stars by Martin Groenewegen, confirming again the importance of the high spatial and spectral resolving power that will make MIR astronomy on an ELT a powerful complement to James Webb Space Telescope programmes.

The theme of stars and star formation was then taken up by the contributed talks, covering simulations of star cluster observations (Andrea Stolte), further exploration of the theme of evolved stars by Josef Hron and the potential for studies of high-mass young stellar objects (René Oudmaijer). Miwa Goto showed some of the advantages of IFU spectroscopy for studies of circumstellar discs. Exoplanet science is one of the cornerstones of the science case for the E-ELT. This was considered from two angles in the context of the MIR instrument by Wolfgang Brandner, who discussed the direct imaging of exoplanets, and by Ignas Snellen, who showed how the combination of high resolution MIR and NIR spectroscopy can allow the characterisation of exoplanetary atmospheres for a range of planets, possibly even for exo-Earths.

Galactic and extragalactic astronomy with HIRES

The Galactic and extragalactic cases for a future HIRES instrument were discussed in separate sessions on Tuesday afternoon and Wednesday morning. As might be anticipated, a wide range of science topics was presented.

The Galactic session was opened by an intriguing review from Jay Farihi on the archaeology of exoplanetary systems. The study of exoplanets also featured significantly in the interests of the contributing speakers, with a further talk on the possibilities of characterising exoplanet atmospheres from Nuno Santos, a presentation on the synergy between an ELT high spectral resolution spectrograph and the future Next Generation Transit Survey (NGTS) and CHaracterising ExOPlanets Satellite (CHEOPS) missions from Didier Queloz. The potential for detection of exoplanets in the Bulge and in external galaxies was presented by Eike Günther, who proposed investigating the fraction of stars hosting high-mass planets as a function of stellar density and galactocentric radius, testing the effect of environment on planet formation.

Closer to home, Paolo Molaro presented the detection of the Rossiter–McLaughlin effect in the transit of Venus in June 2012 and demonstrated that in principle this effect could be detected against the stellar jitter even for Earth-like planets (see Molaro et al., p. 22). As well as exoplanetology, a HIRES on the E-ELT will be important for the studies of stars themselves, as stressed by Livia Origlia, who showed first results from the NIR high resolution spectrograph recently installed at the Telescopio Nazionale Galileo (TNG), and also for the many physical processes accompanying star formation. Leonardo Testi showed that a HIRES will allow detailed study of winds from the outer disc, photo-evaporation from the inner disc, gas content and kinematics of the jet and inner disc, and the evolution of accretion of material from the disc onto the star.

During the extragalactic session, Valentina D'Odorico reviewed the importance of high resolution spectroscopy on an ELT for understanding the metal enrichment history of the intergalactic medium. The evolution of the abundance, ionisation state and spatial distribution of metals can discriminate between different mechanisms by which metals can theoretically be transported from galaxies into the intergalactic medium (IGM). In Max Pettini's review, he expanded on two cases for studying the most metal-poor objects in the Universe with high resolution spectroscopy. A HIRES on an ELT will provide full chemical fingerprints of old, extremely metal-poor stars in the Milky Way, and will also allow detailed study of the abundances of metals, including Fe-peak elements, in near-pristine gas (detected as very low-metallicity damped Lyα systems [DLAs]) at high redshift).

The contributed talks in the extragalactic session then covered key areas of the science expected from the E-ELT. Stefano Cristiani and Pauline Vielzeuf discussed the use of observations of the redshift drift and possible variations in the fine structure constant (α) and of the electron-to-proton mass ratio (μ). Martin Haehnelt reviewed the case for using faint but densely spaced background sources (quasi-stellar objects [QSOs] or Lyman-break galaxies) to probe, in absorption, the immediate environment of galaxies and to study the interplay between galaxies and the IGM. Sandra Savaglio highlighted super-luminous supernovae (SLSNe) as targets for intermediate to high resolution spectroscopy with the E-ELT. Apart from their significance as the end product of the evolution of very massive (50–250 $M_\odot$) stars, the comparatively slow evolution of SLSNe compared to gamma-ray bursts makes them excellent background sources for high-redshift interstellar medium studies.

In addition to the talks on individual science topics, Roberto Maiolino presented an overview of the science cases for a high resolution spectrograph.

Multi-object spectroscopy on the E-ELT

The session on MOS with the E-ELT took place on the Wednesday afternoon and continued on Thursday morning. A broad range of invited and contributed papers covered topics from the re-ionisation of the Universe to spectroscopy of extremely metal-poor stars.

James Dunlop reviewed the potential for MOS studies of the evolution of galaxies at high redshift ($6 < z < 10$) and their ability to re-ionise the Universe. Olivier Le Fèvre added to the case for E-ELT observations at these redshifts with a talk on the first phases of galaxy formation and assembly, showing that the E-ELT has the potential to provide large samples of observations at $z > 7$, enabling a robust statistical comparison with what is done today at $z \sim 2$–3. Jean-Paul Kneib discussed using lensing by massive galaxy clusters for studies of the first galaxies, while José Afonso showed that follow-up of future radio surveys, like the Low-Frequency Array (LOFAR), the Evolutionary Map of the Universe (EMU) and the Westerbork Observations of the Deep APERTIF Northern-Sky (WODAN), is another tool with which to probe galaxy formation. At lower redshift, Hector Flores argued that spatially resolved kinematics in $z > 1.5$–2 galaxies are required to study a large number of normal galaxies in order to investigate their star formation, dynamical state and the evolution of the fundamental scaling relations.

François Hammer and Jean-Gabriel Cuby discussed the use of both high-multiplex MOS spectroscopy and spatially resolved spectroscopy with lower multiplex, but supported by AO correction of the atmosphere, to observe the mass assembly of galaxies over the last twelve billion years. An instrument concept with potential to provide both these capabilities, and with science cases including the role of high-z dwarf galaxies in galaxy evolution, tomography of the IGM, resolved stellar populations beyond the Local Group and Galaxy archaeology with metal-poor stars, was presented by Chris Evans and Lex Kaper. Dimitri Gadotti further argued the case for observing the different components of galaxies (e.g., disc [thick/thin], bulge, bar, rings, etc.) with multiple, deployable IFUs.

The importance of a MOS instrument for stellar studies was first explored through review talks from Danny Lennon and Norbert Przybilla. Lennon covered the topic of massive stars, developing ideas of how their formation, evolution and death can be determined by MOS observations in nearby galaxies. Przybilla specifically discussed the study of supergiants out to the distance of the Virgo and Fornax clusters, which would be enabled by a MOS on the E-ELT. Locally, spectroscopic studies of the Galactic Bulge and its globular clusters can shed light on various possible scenarios of bulge formation and on the early phases of galaxy formation (Beatriz Barbuy). Much of the potential of the E-ELT extends this work to nearby galaxies, including resolved populations in the Local Group (talk by Thierry Lanz). With an ELT, Stefano Zibetti showed that studies of the formation and chemical evolution of stellar populations in galaxies can be extended to $z \sim 3$. Reaching the required sensitivity to absorption features that are diagnostics of age and metal content is currently extremely challenging at $z \sim 0.7$ with 8-metre-class telescopes. Studies of extremely metal-poor stars in external

Figure 1. The workshop participants in the entrance hall at ESO Headquarters.

galaxies, down to the main sequence turn off, can give us information on the critical metallicity needed to form low-mass stars and therefore on the mass distribution of the first generation of stars (Piercarlo Bonifacio). Ben Davies discussed using the chemical composition of large samples of stars at Mpc distances to obtain a more reliable determination of distances and metallicities than those based on Cepheids, or those derived from H II regions and colour–magnitude diagram fitting.

Future instrument concepts and science cases

The final formal session of talks on Thursday afternoon was open for presentations of instrument concepts and observing techniques that would either extend the ideas already under study for the HIRES and MOS instruments, or offer possibilities for the next instruments on the roadmap.

Roland Bacon presented the idea of a MUSE-like wide-field IFU spectrograph to survey for Ly-α emission from dense filaments of the IGM induced by the ultraviolet cosmic background. Martin Roth showed a concept for increasing the detectability of sources in highly crowded fields using crowded-field 3D spectroscopy — a technique analogous to crowded-field photometry — in a presentation which included tests of this technique on Potsdam Multi-Aperture Spectrophotometer (PMAS) data. Dainis Dravins explained how the large collecting area of the E-ELT could be used as an intensity interferometer and how this technique could potentially deliver science even during the construction phase of the telescope. Roberto Ragazzoni presented his ideas on adaptive optics using only natural guide stars on the E-ELT. The potentially important role of polarimetry was presented by Klaus Strassmeier. Finally, in a talk scheduled in the Wednesday morning session, Markus Kasper presented the roadmap towards the E-ELT Planetary Camera and Spectrograph, the workhorse instrument to reach the ultimate sensitivity for exoplanet characterisation.

Acknowledgements

This meeting would not have been possible without the hard work of the Science Organising Committee (SOC) and the Local Organising Committee. The SOC members driving the scope of the workshop and bringing together the busy and exciting programme were Giuseppe Bono, Johan Fynbo, Roberto Gilmozzi, Isobel Hook, Tom Herbst, Anne-Marie Lagrange and Monica Tosi. Jordi Cepa and Gaël Chauvin from the E-ELT Project Science Team helped lead the discussion sessions. The local arrangements and day-to-day organisation of the meeting was carried out by Noé Kains, Iris Bronnert, Samantha Milligan, Hans Pelz, Stephan Grohmann and Christina Stoffer. Additional help on the days of the meeting was provided by Leticia Ferrera, Loredana Spezzi and Marco De Pasquale. The authors gratefully acknowledge the invaluable assistance of all of these contributors to the success of the meeting as well as the enthusiastic participation of all the attendees, whether they presented talks, posters or simply contributed to the discussions.

Links

Webpages with the poster and oral presentations from the meeting are available at http://eso.org/sci/meetings/2013/eelt2013/program.html.

Report on the Workshop

Science with ALMA Band 11 (1.0–1.6 THz)

held at The Queen's College, University of Oxford, United Kingdom, 19–20 March 2013

Dimitra Rigopoulou[1,2]
Robert Laing[3]
Stafford Withington[4]
Georgios Magdis[1]
Sarah Graves[4]
John Richer[4]
Brian Ellison[2]

[1] Astrophysics, Department of Physics, University of Oxford, UK
[2] STFC, Rutherford Appleton Laboratory, UK
[3] ESO
[4] Cavendish Laboratory, University of Cambridge, UK

The workshop formed an important part of an ALMA Development Plan Study, funded by ESO, and covered the science cases for terahertz observations with ALMA. About fifty participants, mostly from Europe, but also from North America and East Asia attended. The meeting was very successful in identifying both extragalactic and Galactic science cases for all three accessible atmospheric transmission windows (centred at 1.04, 1.33 and 1.51 THz) and also discussed the potential of the ALMA site for terahertz observing.

Introduction

Beyond 1 THz there are three atmospheric windows accessible to ALMA on the Chajnantor Plateau. These are collectively known as Band 11, following on from the current ALMA naming scheme, in which Band 10 covers 787–950 GHz. The recent deluge of exciting results from the Herschel mission and, in particular, spectroscopic observations with the Heterodyne Instrument for the Far-Infrared (HIFI) and the Spectral and Photometric Imaging Receiver Fourier Transform Spectrometer (SPIRE-FTS) instruments, have revealed the tremendous scientific potential of observing in the THz bands. ALMA Band 11 has the potential to follow up these observations with high angular resolution. The angular resolution at 1.6 THz is ≈ 0.04 arcseconds for a fairly compact array configuration with a maximum baseline of 1 kilometre. In ALMA's most extended configuration, the resolution would be ≈ 3 milliarcseconds (although maintaining phase stability over such long baselines would then be a major challenge).

In 2010, a consortium of UK institutes proposed an ESO ALMA Development Study to re-examine the science case for Band 11. This was funded and work began in 2012 (in parallel, the Science & Technology Facilities Council [STFC] is funding technical development of mixers for Band 11). The consortium members are: Astrophysics, University of Oxford; STFC Rutherford Appleton Laboratory; and the Cavendish Laboratory, University of Cambridge. One of the key elements of the ESO study was a community workshop to develop the science case. This was held at The Queen's College, Oxford and further details are available at the meeting website[1].

The meeting began with status reports on ALMA and its development programme from Pat Roche and Robert Laing. Although the aim of the meeting was primarily to review the science case, this cannot be done without understanding the atmospheric limitations (which are considerable even at the ALMA site). Sarah Graves presented an overview of the site conditions, concentrating on transparency, atmospheric noise and sensitivity estimates (see Figure 1), and Scott Paine discussed atmospheric modelling using his Atmospheric Model (AM) code.

The science sessions of the workshop explored in detail the advances that the extension of ALMA's capabilities to THz frequencies would bring to the Observatory. Particular emphasis was placed on science applications that would uniquely benefit from the capabilities of Band 11. The workshop focussed on two main scientific areas: galaxies and the high-redshift Universe; star formation, stars and protoplanetary systems. Invited speakers reviewed the science in each area, followed by contributed talks, and there were extended discussion sessions.

Galaxies and the high-redshift Universe

In the extragalactic session, the case for [C II] observations from intermediate redshift ($0.3 < z < 1$) galaxies was given a clear priority (talks by Roberto Maiolino and Georgios Magdis). Cooling lines are very important as they allow the collapse of molecular clouds and the formation of stars; they also regulate the radiative equilibrium of the interstellar medium (ISM). The [C II] line at 158 μm is the main cooling line of the Milky Way. Recent observations of [C II] emission from nearby ($z < 0.4$) galaxies with Herschel (e.g., Figure 2) and distant galaxies with both Herschel and ALMA have established the importance of the [C II] intensity as a proxy for the star formation rate of a galaxy. Already in Cycle 0, [C II] has been detected from many galaxies at $3 \leq z \leq 6.5$ using ALMA Bands 6 and 7. Band 5 (currently

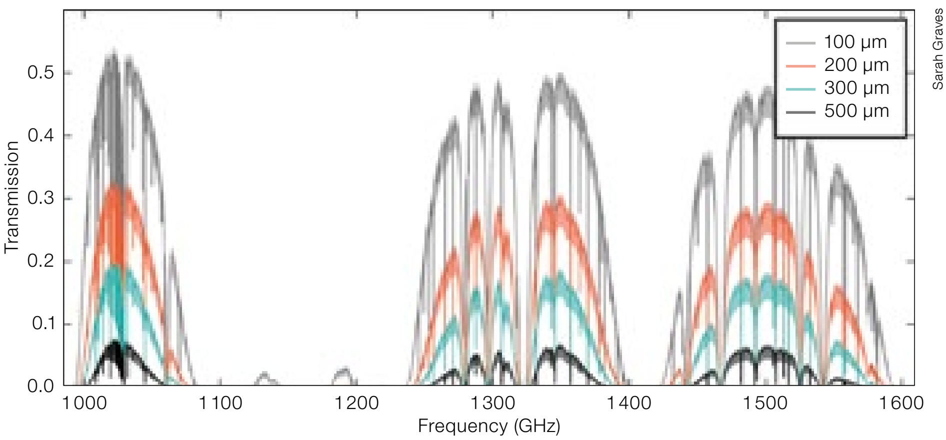

Figure 1. A plot of the transmission at the ALMA site in the three atmospheric windows that collectively make up Band 11. The transmission curves are shown for four different precipitable water vapour (PWV) columns of 100, 200, 300 and 500 μm. For average conditions on Chajnantor, the PWV column is < 270 μm for 5% of the time.

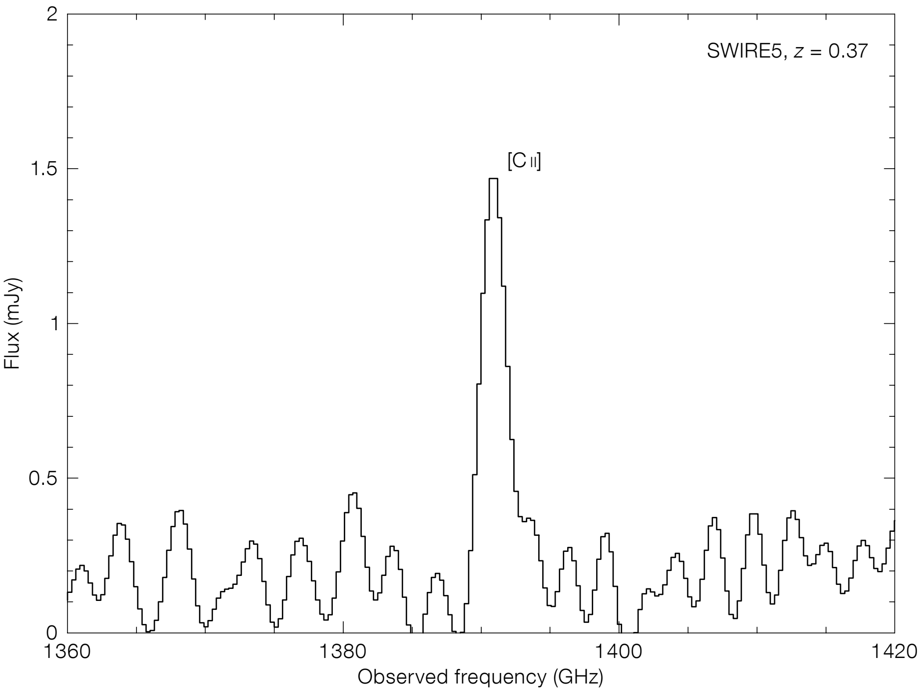

Figure 2. A spectrum of the [C II] line, rest wavelength 158 μm, from a galaxy at a redshift of 0.366, obtained with the SPIRE-FTS instrument on Herschel (from Rigopoulou et al., 2013).

under development) will extend [C II] detections into the early Universe (e.g., Laing et al., 2010). Band 11 has a complementary and critical role in studies of extragalactic [C II]. The redshift range $0.3 \leq z \leq 1$, covered for [C II] with ALMA Band 11, is a crucial phase in galaxy evolution: it is exactly in this range that the star formation density of the Universe increases steeply, becoming essentially flat at $z \geq 1.5$. [C II] observations of galaxies in this very energetic phase of the Universe will establish the long-sought link between the local and high-z Universe and allow us to form a "benchmark" for future studies of [C II] at very high redshifts.

ALMA Band 11 has another unique application: detection of molecular hydrogen (H_2) from primordial galaxies before the reionisation era (talk presented by Dimitra Rigopoulou). H_2 is the most abundant molecule in the Universe and plays a fundamental role in many astrophysical contexts (e.g., Dalgarno, 2000). It is found in all regions where the shielding of the ultraviolet (UV) photons, responsible for its photo-dissociation, is sufficiently large. H_2 makes up the bulk of the mass of the dense gas in galaxies and could represent a significant fraction of the total baryonic mass of the Universe. It is key to our understanding of the ISM, as its formation on grains initiates the chemistry of the interstellar gas. The role of H_2 emission as a contributor to the cooling of astrophysical media is even more significant in the early Universe.

The first generation of stars formed through gravitational collapse of primordial clouds induced by H_2 line cooling (e.g., Saslaw & Zipoy, 1967). How the first (Population III) stars formed out of primordial gas is indeed one of the most exciting questions in modern astrophysics. It has long been realised that the formation of molecular hydrogen plays a key role in this process, serving as an effective coolant at temperatures below 10^4 K, and the primary coolant of UV and X-ray irradiated gas in regions of low metallicity. Kamaya & Silk (2002) and Mizusawa et al. (2004) considered the H_2 rotational emission from primordial molecular cloud kernels to be associated with the formation of the first stars at the earliest epochs of $z \sim 20$. With Band 11, it will possible to detect the S(1) transition of H_2 (locally the strongest of the mid-infrared pure rotational transitions; e.g., Rigopoulou et al., 2002) in $z \geq 10$ galaxies. Based on the expected strength of these lines as predicted by various theoretical models, the detection of emission from primordial H_2 in early galaxies could be feasible with ALMA Band 11 with a few hours of observation.

Continuum observations with Band 11 will probe the dust emission on the long-wavelength side of the far-infrared peak for galaxies at $1 \leq z \leq 4$, putting constraints on the shape of the spectral energy distribution (SED) of the galaxies close to the peak of the star formation and active galactic nucleus (AGN) activity in the Universe. It should also be possible to trace the spatial distribution of the warm dust emission ($T_{dust} \sim 40$–70 K), providing clues about the heating mechanism. For higher-redshift galaxies, the shape of the SED in the poorly known rest-wavelength range of 40–80 μm will become measurable.

Star formation, stars and protoplanetary systems

Paola Caselli and Jose Cernicharo reviewed applications of ALMA Band 11 to the ISM and to star formation, respectively. In the area of star formation (particularly the study of the physical and chemical structures of molecular clouds), Band 11 provides access to a number of unique tracers of the densest regions. Deuterated nitrogen-bearing molecules (e.g., N_2D^+, NH_2D) are the best tracers of dense and cold gas. As we rely on such species to study the physical structure of clouds where star formation is going to take place (the pre-stellar cores), or where star formation has just started (protostellar envelopes in Class 0 sources), it is crucial to understand their formation and destruction paths. The main chemical processes affecting the deuterium fraction in dense clouds are the exothermic proton–deuteron exchange reaction $H^+ + HD \rightarrow H_2D^+ + H_2$ and the ortho-to-para ratio of H_2 molecules (as ortho-H_2 can drive the exchange reaction back, reducing the deuteration).

The only way to advance this field is to constrain the H_2 ortho-to-para ratio observationally, which relies on observations of species sensitive to this ratio (as ortho and para H_2 cannot be observed in cold gas). The most important species are: ortho-and para-H_2D^+, and

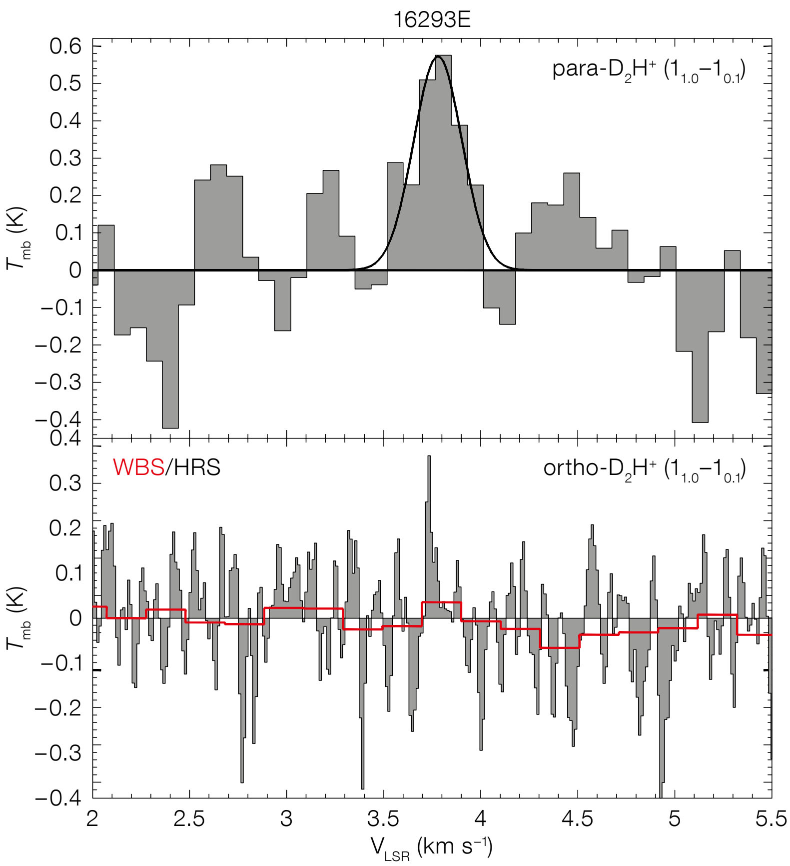

Figure 3. Upper: Spectrum of the para-D_2H^+ line at 692 GHz from the binary protostar IRAS 16293-2422 observed by the Caltech Submillimeter Observatory. Lower: The corresponding ortho-D_2H^+ at 1476 GHz, observed with Herschel HIFI (from Vastel et al., 2012).

ortho-and para-D_2H^+. The ortho-H_2D^+ line can be observed at 372 GHz (in ALMA Band 7), and para-D_2H^+ at 692 GHz (Band 9). The other two lines, para-H_2D^+ at 1370 GHz and ortho-D_2H^+ at 1476 GHz are both observable in Band 11 with relatively good (40–50%) atmospheric transmission. Figure 3 shows a detection of the 692 GHz line from the ground and the 1476 GHz line with HIFI from the same source. Additionally, the deuterated N-bearing molecule ND has its (2-1) transitions between 1018 and 1077 GHz and these are only accessible in Band 11. Together with detection of NH^+ (whose 1-1 transition is at 1012 and 2-2 at 1019 GHz), such observations will allow the astrochemistry community to set tight constraints on the chemical networks in star-forming clouds.

Continuum observations in Band 11 will allow measurement of the peak of the SED of cold protostars and prestellar cores at 1.5 THz, thereby greatly improving estimates of their temperatures and masses (talk by Derek Ward-Thompson). This is important because the cores have typical temperatures ~ 10 K, so all current ALMA bands sample the Rayleigh–Jeans tail of the SED. High-J CO lines and light hydrides trace the cavity walls and shocked gas in protostellar out-flows, enabling the study of UV and shock heating.

Michiel Hogerheijde reviewed the potential of Band 11 for studies of protoplanetary discs. The band will provide higher angular resolution than Band 10: this may be needed to resolve gas streams around (proto-)planets, which early ALMA results show to be complex and non-axisymmetric. Band 11 also traces higher excitation gas that can help to constrain the temperature structure of the disc and identify localised regions of heating such as shocks around (proto) planets. Finally, it may be possible to measure the ortho/para ratio of H_2D^+ in the disc mid-plane, as noted earlier for star-forming regions.

In the area of evolved stars, mapping of a number of THz water lines (e.g., at 1278 and 1296 GHz) and SiO lines that fall in Band 11 will allow a better understanding of the dynamics of individual clouds (presentation by Anita Richards). As the star is optically thick at large radii or lower frequencies, the THz regime allows the optical photosphere to be probed (currently only detectable at optical and shorter wavelengths), enabling measurement of the continuum brightness temperature and hence separating the photospheric and chromospheric contributions.

Synergies

In addition to the detailed discussions of Herschel results, which provided motivation for the entire meeting, observations taken in two THz windows at the Atacama Pathfinder Experiment (APEX) were also described (by Friedrich Wyrowski and Martina Wiedner), as were the synergies between ALMA Band 11, the Stratospheric Observatory for Infrared Astronomy (SOFIA), the Cerro Chajnantor Atacama Telescope (CCAT) and future far-infrared space observatories (presentations by Peter Schilke and Matt Griffin). The meeting concluded with presentations on the science case for Band 11 from an East Asian perspective by Norikazu Mizuno and Satoki Mathushita.

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We thank all the meeting participants for their enthusiastic participation and The Queen's College for gracious hospitality.

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Links

[1] Workshop web pages: http://www.physics.ox.ac.uk/almaband11

Report on the

2nd Solar ALMA Workshop

held in Prague, Czech Republic, 24 June 2013

Bartosz Dąbrowski [1]
Marian Karlický [1]

[1] Astronomical Institute, Academy of Sciences of the Czech Republic, Ondřejov, Czech Republic

The Czech node is one of the ALMA European Regional Centres and is the only one to support solar observations. The second workshop in the series is briefly described: the main themes were the scope of solar observation with ALMA, planning observations and the science that can be achieved.

The Atacama Large Millimeter/submillimeter Array (ALMA) is an international project of many institutions from Europe, East Asia, North America and Chile. Astronomers of the participating countries interact with ALMA via the ALMA Regional Centres (ARC). In Europe, the central node of the ARC is located at ESO and seven additional ARC nodes are spread across the continent. Of these, the Czech ARC node is the only one devoted to solar physics.

The 2nd Solar ALMA Workshop took place at the Faculty of Architecture of the Technical University in Prague and was attended by about 30 people from around the world. The main aim of this workshop was to bring together the ALMA-minded solar community to discuss solar observational issues with ALMA, solar science and planned observations with ALMA. This workshop was a natural continuation of the 1st Solar ALMA Workshop organised by the UK ARC node at the University of Glasgow in January 2013.

The format of the 2nd Solar ALMA Workshop divided into two parts: during the first part the talks were devoted mainly to simulations of solar ALMA observations; the second part featured a discussion. The programme is available on the workshop web page[1].

Observing the Sun with ALMA

Petr Heinzel and Miroslav Bárta presented a talk on observations of solar prominences with ALMA. They demonstrated that the fine structures in solar quiescent prominences can be well detected with the ALMA interferometer. Additionally, they simulated the visibility of fine structure in prominences and their brightness temperatures at various wavelengths, demonstrating the feasibility and usefulness of ALMA observations of solar prominences. Sven Wedemeyer discussed the ability to generate synthetic millimetre-scale maps of quiet Sun regions with ALMA. The temporal and spatial resolution of ALMA will allow ubiquitous small-scale features such as chromospheric fibrils, which outline magnetic fields, and propagating shock waves, their possible interaction, and other, yet-to-be-discovered, processes to be detected. In particular, the mapping of the magnetic field structure is crucial for addressing fundamental questions concerning heating and energy transport in the solar atmosphere.

Gregory D. Fleishman presented a contribution on the discovery of relativistic positrons in solar flares from microwave imaging and polarimetry. He concluded that new radio facilities, including the Jansky Very Large Array (VLA) and ALMA, which have the ability to image circular polarisation at the relevant high microwave/millimetre frequencies, will soon be able to routinely detect relativistic positrons in flares. This advance will provide invaluable information on the spectra of relativistic positrons, their spatial distribution and evolution in solar flares, thus allowing the nuclear component of the flare-accelerated particles to be much better constrained.

Maria Loukitcheva presented a talk about measuring the chromospheric magnetic field with ALMA. She showed estimates of the magnetic field at millimetre wavelengths in active and quiet Sun regions under the assumption that the radiation at these wavelengths is thermal free-free emission (Bremsstrahlung). She discussed these results in the context of future solar ALMA observations.

C. Guillermo Gimenez de Castro presented the Long Latin American Millimeter Array (LLAMA), a new submillimetre facility to observe the Sun. LLAMA is an Argentinian–Brazilian project to build and operate a 12-metre radio telescope that can observe from 45 to 900 GHz. It will have very long baseline interferometric (VLBI) capabilities. LLAMA will be installed in the Argentinian Puna de Atacama region at 4800 metres above sea level in the Salta Province, and less than 200 kilometres distant from ALMA. One of the last unexplored wavelength frontiers for solar flares is in the range of submillimetre to infrared wavelengths,

Bartosz Dąbrowski

Figure 1. The participants of the 2nd Solar ALMA Workshop in Prague pictured inside the Faculty of Architecture, Technical University.

and Pierre Kaufmann reported the detection of a bright 30 THz impulsive solar burst using a new imaging system.

Among others, Robert Laing presented a talk on the current status of ALMA and verification of the solar science capabilities. He gave a short report on the current status of ALMA and plans for Cycles 1 and 2 observations. The Joint ALMA Observatory is in the process of planning solar commissioning and science verification observations and he outlined the opportunities for the solar radio astronomy community to become involved.

The second part of the meeting was mainly devoted to a general discussion of different aspects of solar observations with ALMA. The introduction to this part of the workshop was given by Tim Bastian. There were discussions about ALMA commissioning and science verification activities in the context of one or more ALMA development proposals.

Bartosz Dąbrowski briefly presented the solar ALMA wiki platform. This is a special website (wiki form) devoted to the ALMA-minded solar community and it was created by the Czech ARC node. This wiki website is only available to registered users and those interested should contact Bartosz directly.

The workshop was immediately followed by the Community of European Solar Radio Astronomers CESRA2013 conference, which also included sessions on solar observation with ALMA.

Links

[1] Workshop webpage: http://www.asu.cas.cz/solar-workshop

Retirement of Massimo Tarenghi

Claus Madsen[1]

[1] ESO

Massimo Tarenghi, chronologically MPG/ESO project scientist, NTT project manager, VLT programme manager and first Director, ALMA Director and ESO Representative in Chile, has retired after 35 years at ESO. A brief summary of his achievements is presented.

Readers of *The Messenger* will be well aware that ESO has recently passed the 50-year mark of its existence. During those five decades, many people — astronomers, engineers, technicians and people of other professions – have worked for the organisation, some for a relatively short period, others for longer. Few people, however, have stayed with the organisation for 35 years or more. In such cases, it almost feels as if they belong permanently to "the house", and this certainly applies to Massimo Tarenghi, who retired on 1 September 2013.

Born in 1945, Massimo was awarded his PhD at the University of Milan in 1970. After post-doc assignments in Milan and Pavia, he became an ESRO Fellow at the Steward Observatory in the USA in 1973, but returned to Europe in 1975. Two years later, on 1 September 1977, he joined the newly established science group at ESO, at the time based in Geneva. This was also shortly after first light of the ESO 3.6-metre telescope, and, with his scientific interests in cosmology, he became one of the first official users of that telescope.

The ESO 3.6-metre and MPG/ESO 2.2-metre telescopes

Unsurprisingly, the telescope was still suffering from teething troubles. "I spent five nights observing — identifying [technical] problems," he later recalled. At the suggestion of André Muller, he continued working with the ESO 3.6-metre during technical time, testing the prime focus camera. Massimo is an incredibly energetic person with a wide range of interests, perhaps especially in technical matters, so it is no surprise that in parallel with his scientific work, he began to play an active role in the technical aspects of the telescope and its instrumentation. Thus he became an "instrument scientist" for the new ESO 3.6-metre prime focus automatic camera that was under development at ESO. "Automatic" meant remotely-controlled plate- and filter-changing, removing the need for the astronomer to ride in the prime focus cage of the telescope during observations.

With Italy and Switzerland expected to join ESO, it was decided to substantially increase the complement in the telescope park. The MPG/ESO 2.2-metre telescope was the first addition, followed by the 3.58-metre New Technology Telescope (NTT). It seemed natural for Massimo to become project scientist for this new 2.2-metre telescope, which had been built for the Max Planck Society for deployment in Namibia, but had never been installed there. Shortly afterwards, Massimo took over the task of project manager, leading the installation of the telescope at La Silla, not just in record time, but also on a shoestring budget. The 2.2-metre telescope saw first light in June 1983, and in 1984 Massimo led the first remote control experiments with this telescope.

From the NTT to the VLT

In 1983, he became project manager for the 3.58-metre NTT, which served as an important test-bed for many of the technologies that were to be fully used at the Very Large Telescope (VLT), including the active optics system developed by Ray Wilson. In 1989, at first light, the NTT produced the sharpest images of stellar objects ever obtained with a ground-based telescope (0.33 arcseconds; Wilson, 1989). At the inauguration of the telescope (Figure 1) the following year[1], Massimo was awarded the title *Commendatore della Repubblica Italiana* in recognition of his achievements in connection with the NTT.

Most importantly, the initial great success of the NTT proved that ESO was on the right track towards the VLT. And so was Massimo, who, from 1988, became involved in ESO's "big telescope" project — the VLT. In November 1991, he was appointed VLT Programme Manager and Head of the VLT Division. Over the years to come, he led the project to its successful conclusion — the first-light milestones for the four Unit Telescopes (UTs) and the first fringes to be obtained with the VLT Interferometer.

As for all large and innovative projects, the road towards realising the VLT was bumpy and paved with many challenges — be it of a financial, technical, political or legal nature. Despite these exigencies, some of them external to the project, Massimo kept his team focussed on the work at hand and delivered a fantastic telescope to the scientific community (see Figure 2). For all the difficulties, however, these tough years also offered high points, such as the UT1 first-light event on 25 May 1998 (ESO, 1998; and Figure 3). Speaking afterwards to members of the press assembled at ESO Headquarters, Massimo could hardly contain his enthusiasm, saying: "… the pleasure to do astronomy as I have in the last few days is incredible; you have to come here and spend a night with us, and I can tell you, you will have one beautiful night, one of the best nights of your life!" It clearly had been so for him.

Figure 1. Presenting the NTT to the public: a happy ESO team, including Massimo Tarenghi (right) at the press conference at ESO Headquarters on the occasion of the NTT inauguration on 6 February 1990.

Figure 2. Following the success of the VLT first light, ESO was awarded the Best of What's New prize for 1998 by the US *Popular Science* magazine. A proud Massimo Tarenghi received the prize at a ceremony in New York on 13 November 1998.

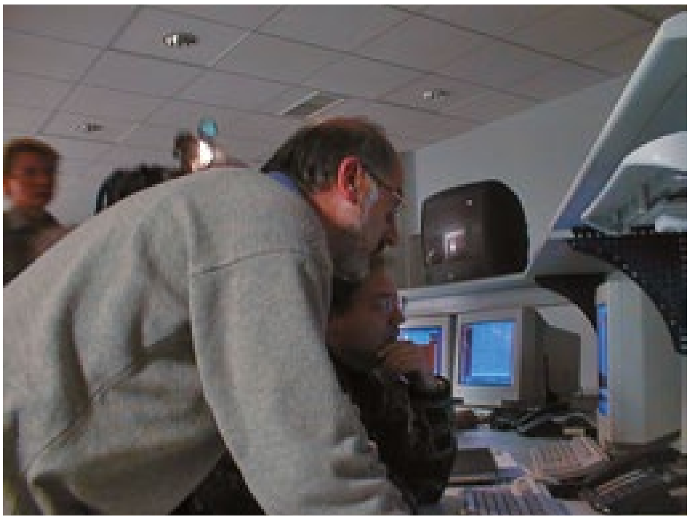


Figure 3. Massimo Tarenghi and Roberto Gilmozzi watching the first results during the night of UT1 first light on 25 May 1998.

ALMA

After the VLT's first light, Massimo continued as Director of the Paranal Observatory until 2002. However, if he had ever entertained the hope of leaving the stressful job of project management and returning to the role of an active researcher and enjoying the scientific fruits of the VLT, he might well have been disappointed. In June 2002 he became the ALMA interim project manager, moving to become ALMA Director in the spring of 2003. This was just when the first ALMA prototype antenna was being tested at Socorro, New Mexico, and in November 2003 the formal ground-breaking ceremony took place at Cerro de Chajnantor (Madsen, 2012). This period was an intense one of planning, design, manufacture and development of the site and Massimo successfully shepherded the project through these crucial stages. During this period Japan formally joined the North American and European partners and ALMA became the first truly global, ground-based astronomy project.

Figure 4. The award of the Grand Cross of the order of Bernardo O'Higgins was made to Massimo Tarenghi on 10 May 2013. He is shown here after having received the order from the Chilean Minister of Foreign Affairs, Alfredo Moreno.

ESO Representative in Chile

In 2008, Massimo handed over the ALMA project to his successor Thijs de Graauw. In turn, Massimo succeeded Daniel Hofstadt as the official ESO Representative in Chile. In this diplomatic function, he helped to pave the way for the European Extremely Large Telescope (E-ELT), working closely with the Chilean authorities and decision-makers to secure the new E-ELT site on Cerro Armazones. In his previous functions, Massimo may not have been known for his diplomatic skills, but as ESO Representative he passed the test with flying colours. In 2012 he was granted the Chilean nationality by "special grace" in a vote by the Chilean national congress[2] — awarded "in recognition of his great contribution to the development of astronomy in Europe and Chile". This extraordinary honour demonstrated his ability to act as a highly respected interlocutor, clearly representing ESO's interests, but always striving to reach solutions of mutual benefit.

His diplomatic successes notwithstanding, Massimo is arguably one of the most experienced project managers in ground-based astronomy in the world. He has excelled in this function, but occasionally it has required great personal sacrifice. For example, in 2003, unexpected but severe illness — and three operations — forced him to slow down for 2½ months. However, just two hours after the third operation, he participated in an ALMA board meeting from his hospital bed. As a hard-nosed manager, Massimo has often faced tough decisions, realising that such decisions must be taken by the person who is ultimately responsible, and understanding that project management is not a popularity contest. In this context he has often described himself as "a difficult person", but this view is hardly just. The truth is that through his hard work and undisputed successes, he has earned the deep respect of his colleagues in a way that only true professionals can appreciate. This respect is also reciprocal. Asked by a television journalist shortly before first light for VLT UT1, if he was nervous about the outcome, his answer was short and clear: "No, because I have confidence in my people."

Honours

Massimo has now completed his career at ESO, a sterling one indeed, and one which has led to the award of the Tycho Brahe Prize in 2013 by the European Astronomical Society[3]. It is a fitting reward. Tycho built Europe's largest and most prominent astronomical observatory of his time; Massimo, it can be argued, did the same in our time. More honours flowed (Figure 4) when he was awarded the Grand Cross, the highest rank of the order of Bernardo O'Higgins, by the Chilean Ministry of Foreign Affairs[4]. Yet he will not stop working. He is providing help to the European Research Council and continues to undertake other activities in the service of science.

Even if Massimo has formally left ESO, those who were privileged to work with him — *his people,* as he would put it — will think back with pride — and with one or two anecdotes to enjoy. In this sense, he will always remain a part "of the house". We wish him well for the time to come.

References

ESO, 1998, The Messenger, 92, 1

Madsen, C. 2012, *The Jewel on the Mountaintop — The European Southern Observatory through Fifty Years,* (Weinheim: Wiley-VCH)

Wilson, R. 1989, The Messenger, 56, 1

Links

1 NTT inauguration: http://www.eso.org/public/news/eso9003
2 Chilean nationality for Massimo Tarenghi: http://www.eso.org/public/news/ann12079
3 Massimo Tarenghi awarded Tycho Brahe prize: http://www.eso.org/public/news/ann13030
4 Massimo Tarenghi awarded Grand Cross by the Chilean Ministry of Foreign Affairs: http://www.eso.org/public/news/ann13045

Science Days at ESO

Jeremy Walsh[1]
Eric Emsellem[1]
Claudio Melo[1]

[1] ESO

The motivation for Science Days at ESO, when everyone has an opportunity to briefly present their current research, is outlined. The Science Day held in Garching in 2013 is briefly described as an example.

Science Day is the name given to the site-wide presentation of current astronomical science that is undertaken at ESO. There are quite naturally separate Science Days in Santiago and Garching, but the overall scheme of both is similar. Science Days have now become an established annual tradition and the first ones were held in November 2001, initiated by Danielle Alloin and Bruno Leibundgut.

The aim of the ESO Science Days is to display the range of science being done at ESO, to foster and encourage interactions leading to an enhancement of the research atmosphere and perhaps even initiating new collaborations. The set-up is simple and the aim is to accommodate talks for all participants. With about 90 astronomers (Faculty, Scientists, Students and Fellows) in Vitacura[1], including the researchers working at the Joint ALMA Observatory, and more than 100 in Garching[2], the task is intimidating. In Chile, this requires excellent coordination since science staff are regularly on *turnos* of a week or more at the mountain sites: this means staggering the Science Day over a few sessions. These Science Days are thus all the more important to bring science staff together and represent a unique opportunity to foster an active scientific life. At the Headquarters in Garching, the challenge is to have as many talks as possible in one day without tiring the audience by an overdose of science. Naturally, there is a strong social element to such gatherings, with a catered light lunch and a congenial drink at the end of the day included in the programme.

Science Day, Garching 2013

There has been a tradition of holding the Garching Science Days in the winter, usually November or February, with the consequence that the group photograph for the Garching events often involves standing in the snow. However, this year it was held in June (see Figure). It is needless and impossible to describe all the topics covered, but the range is always large. This year's Garching Science Day was no exception. With 74 presentations in one day, a five-minute limit per presentation had to be strictly enforced. Rather than being a constraint, this results in very dynamic and to-the-point presentations, where the enthusiasm of the speaker is very evident regarding her/his own science. There is of course only time for a few slides each, but there is always a call for questions after each presentation.

The presentations ranged from research developed out of functional work, such as the study of precipitable water vapour at Paranal, to progress reports on current projects, advertisement campaigns for a new survey or tool, to details and sidelines stemming from this research. With such a short format and receptive audience, it is sometimes tempting to delve "outside the box", such as the presentations on tachoastrometry and the rise of the savannah 30 million years ago on Earth. The range of science topics covered anything from earthshine to the highest redshift galaxies and included observations not performed with ESO telescopes, the development of software tools and a few theoretical investigations.

Figure 1. Group photograph from the 2013 Garching Science Day.

Research using the Paranal, La Silla, and now ALMA, sites was of course well represented.

Science Days have to be well organised, so all speakers have to deliver their presentations in advance and all run from the same computer. Of course the role of the chairs is particularly important to the smooth running of the day and this forms excellent training for Fellows and Students. For the end of the Science Day, the Bavarian tradition of *Bier und Brezen* has been adopted (borrowed from the closing session of workshops at the neighbouring Max Planck Institute for Extraterrestrial Physics). This year it was particularly encouraging that so many participants attended for the whole day, avoiding the increasingly common and taciturn practice of turning up one talk before one's own, and leaving one talk later. The gain for the participants is tremendous and the exposé of current high-level astronomical research can be a stimulating encouragement to one's own work.

Acknowledgements

Christina Stoffer has, since their inception, run the logistics of the Science Days in Garching, assembling the programme and ensuring that all the presentations are installed, and, not least, arranging the catering. We thank her very much for her dedication, without which such busy programmes would not be possible.

Links

[1] List of scientific staff in Chile: http://www.eso.org/sci/activities/santiago/personnel.html
[2] List of scientific staff in Garching: http://www.eso.org/sci/activities/garching/personnel.html

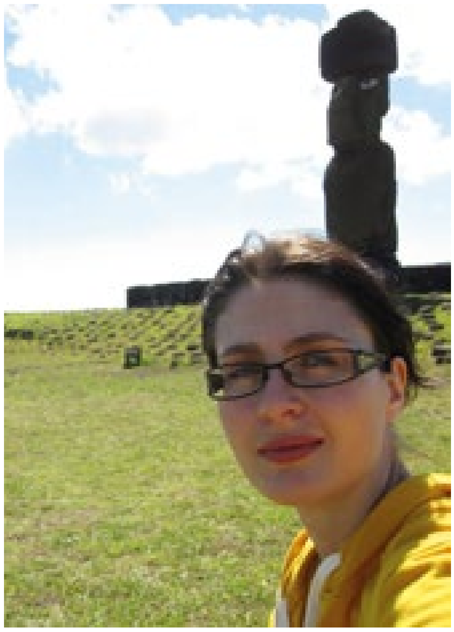
Fellows at ESO

Andrea Mehner

During my childhood, growing up in Berlin, I only remember seeing the Moon and very few stars. It wasn't until much later in life, at university, that I witnessed the beauty of a clear and dark night sky. I was born in East Berlin, and growing up there it was unimaginable that I would one day live in Chile and work for an astronomical organisation. However, even then, I had the desire to travel and see the world. In elementary school I was fascinated by maths and I decided to study mathematics in Moscow. This plan obviously never came to fruition. The Wall came down, and instead I had the opportunity to live in England, Spain, the United States and now Chile. Also, I did not study maths, but first physics, and then astrophysics.

During my university years, I wavered between nuclear physics and geophysics, before settling on astrophysics. The first astronomical event I took part in was the transit of Venus in 2004. At the end of the same year I saw Saturn's rings for the first time, through an amateur telescope in the Sierra Nevada, Spain. Back in Germany, Dr Eike Guenther inspired me to pursue a career in astrophysics. I attended some of his lectures and he displayed such an enthusiasm for the subject that I asked him to supervise my Diploma thesis at the Karl Schwarzschild Observatory in Tautenburg, Germany. Thanks to his enthusiasm, but also his entertaining stories about observatory trips, I developed a growing interest in astrophysics and astronomical observatories. During my thesis I had my first observing experiences at the observatories in Tautenburg, La Silla, and Calar Alto and enjoyed them so much that I became convinced that I would follow a career in an observatory.

In 2007, I moved to the Twin Cities in Minnesota, USA, to obtain my PhD. People may know Minnesota for its cold weather, its 10 000 lakes and its zillions of mosquitoes. Yet, there is also an astronomy department with small groups covering a rather large variety of topics. There I was confronted with Eta Carinae for the first time, one of the most massive and luminous stars in the Galaxy. I find this object so fascinating that I spend most of my time trying to understand the enigma it presents. In a nutshell, η Car is an evolved star with a mass of likely more than 100 $M_{\odot}$, which may end its life any moment, or, let's say, within the next


Andrea Mehner

10 000 years. The star shows intriguing variabilities on several time and magnitude scales. This object is also one of the most beautiful in the sky and has remained a mystery to researchers for many centuries. Hubble Space Telescope

images show η Car's bipolar lobes from material ejected in its Great Eruption in the mid-19th century in great detail.

Eta Carinae has been observed over the last few decades with a myriad of instruments and thus there are many high-quality archival datasets to play with. My work focuses on the nature of η Car and its variabilities, using mainly ultraviolet to near-infrared data. In recent years, I have broadened my research to evolved massive stars in general. I am interested in high-mass supernova progenitors and how they behave shortly before exploding. Objects of interest include luminous blue variables, Wolf–Rayet stars, and blue and red supergiants.

I feel privileged to have been awarded an ESO Fellowship. The past two years at ESO have been a unique and great experience. I value the insights I've gained with regard to the process of observational astronomy, observatory operations in general, the instruments, observing strategies, data quality, data reduction, and the final science output. I also greatly appreciate the ability to be connected to many research areas through the service mode observations. Since my first visit to Paranal I've been fascinated by this place. The telescope platform under an orange sunset is truly spectacular and makes you feel as if you've been transported to some serene distant world. It feels like a dream to play with one of the four monster telescopes that sit on top (I support Unit Telescope 2 with the instruments X-shooter, FLAMES, UVES). This girl from East Berlin is extremely grateful, somewhat fortunate, and, for sure, happy to work here at Paranal.

Timothy Davis

Timothy Davis

My path towards becoming an astronomer was a winding one, and only brainwashing, luck and good fortune bring me here to ESO today. I was born in Cambridge, UK, but grew up just north of London. My father has a doctorate in biochemistry, and my mother is a teacher, and so science was always around as I was growing up. My father would bring home chemicals from the lab to replace shop-bought cleaning fluids, and on one memorable occasion we had a liquid nitrogen cylinder sitting in the kitchen for weeks! I also had the (northern) constellations painted on my ceiling in glow-in-the-dark paint, so I went to sleep every night under the stars.

At school I did well in maths and science subjects, but it was aeronautics that really fascinated me. I would go to air shows any chance I got, and always dreamed of becoming an airline pilot. When it came to choosing my A-levels (the qualifications we take aged 16–18 in the UK, which determine your university options) I based my choices around maths and physics, as these are required for pilot training. My hope at that stage was to go to university, study something like aeronautical engineering, and then go on to pilot school.

It was in my A-level physics class that one of the first twists in the road that led me to ESO took place. We had an excellent teacher who filled us with enthusiasm for physics (as well as regaling us with tales of his adventures while teaching physics in Uganda, pre Idi Amin). I am sure he brainwashed us at some stage during those two years, as when the time came to apply to university, I chose physics without hesitation, as did ten out of my class of twelve students!

At the time I had no inkling that I would end up in astrophysics, and chose to do my degree at the University of Warwick in the UK. Warwick has a good reputation for physics, but at the time did not offer astrophysics. Luckily, during the time I was there they started an astrophysics group, and it was during a third-year course on galaxies that my interest in the subject really awakened.

I was fortunate enough to be allocated a masters project in the astrophysics group, studying X-ray evaporation of exoplanets. This first taste of real astronomical research was eye-opening, and this was when I first started considering studying for a PhD. I sent in various applications for PhD places around the UK, while simultaneously applying for "real world" jobs. In the end I decided to follow my passion over money, turning down a job as a nuclear physicist at Sellafield (the UK's nuclear reprocessing site) to start a PhD in astrophysics.

When applying for PhDs, I was unsure which area of astrophysics I wanted to enter. Warwick at the time had a very focussed department, studying binary stars and exoplanets, so I did not feel I had experienced enough subfields of astrophysics to narrow down my applications. I knew that I wanted to do an observational PhD, and in a field where I would be able to actually visit the telescopes! This led me to select a project investigating the properties of the molecular gas in early-type galaxies (using millimetre-wave single-dish telescopes and interferometers), under the supervision of Dr Martin Bureau at the University of Oxford.

Looking back, my three-year PhD went quickly, in a flurry of observing runs (at the IRAM 30-metre single-dish telescope and the CARMA interferometer), proposals, paper writing and talks. I spent four months visiting UC Berkeley to work with the CARMA group there, and also some time learning modelling techniques with the group in Nagoya, Japan.

Soon it was time to apply for postdocs, and as a European astronomer who was excited about ALMA, ESO seemed an obvious place to apply. Luckily I was selected, and started my Fellowship here in Garching in October 2011. I am really enjoying my time here so far. Munich is a fun city, with so much to see and do, and the scientific life at ESO is vibrant and fulfilling. As I write this I am sat in Chile, at the ALMA Operations Support Facility, waiting to begin my night as an Astronomer on Duty — an opportunity I couldn't have got at many other places in the world!

It's unfortunately already time to start looking for my next job. I don't know where I will end up, but my hope is to continue my astronomical career — building further on the lessons and experiences gained during the wonderful time I have spent here as an ESO Fellow.

Announcement of the ESO Workshop

3D2014 — Gas and Stars in Galaxies: A Multi-wavelength 3D Perspective

10–14 March 2014, ESO Headquarters, Garching, Germany

This workshop follows from the first ESO meeting on extragalactic 3D multi-wavelength astronomy held in 2008 and aims to bring together the optical/near-infrared, millimetre and radio extragalactic communities. The kinematics, mass assembly and evolution of galaxies has been explored in large samples in the optical and near-infrared by the SAURON/ATLAS3D and CALIFA surveys of nearby galaxies and the SINS and MASSIV surveys at z ~ 1–2. The second generation VLT instruments KMOS and MUSE are taking up science operations in 2013/14 and ALMA is conducting Cycle 1 observations and preparing for new observing modes. The timing is perfect to evaluate the scientific progress made since 2008 and topics to be addressed are centred on both gas and stars in and around galaxies at all stages of their evolution.

Targeted workshop themes include: dynamics of nearby galaxies, starbursts and interacting galaxies, supermassive black holes and active galactic nuclei, gas accretion and outflows, high redshift galaxies, cosmology and deep fields. In addition, tools to visualise and analyse multi-wavelength datacubes will be discussed. The format will include invited reviews, contributed talks and discussions, with short talk slots for younger researchers to present their work. Additionally three parallel user workshops for KMOS, MUSE and ALMA will be offered to raise awareness of ESO 3D instrumentation and introduce observation preparation, data reduction and analysis of different types of 3D observations.

The deadline for registration is: 1 December 2013.

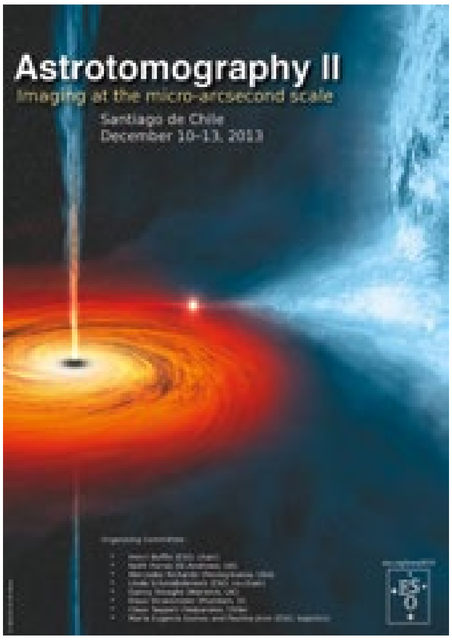
Details are available at:
http://www.eso.org/sci/meetings/2014/3D2014.html
or by email to: gal3d2014@eso.org

Announcement of the ESO Workshop

Astrotomography II — Imaging at the Microarcsecond Scale

10–13 December 2013, ESO Vitacura, Santiago, Chile,

N. Boffin



Astrotomography is a generic term for indirect mapping techniques that can be applied to a huge variety of astrophysical systems, ranging from planets, through single stars and binaries to active galactic nuclei. This workshop will consolidate the success of the first astrotomography workshop in 2000, bringing together people from different communities who employ similar techniques to construct indirect images at very high angular resolution. Given the increase in scientific output of astrotomography methods and the wider range of applications, it is thus timely to review the methods, the progress in the field and the harvest of new results, as well as to prepare the next generation of astronomers to use these tools.

The broad themes to be covered by the meeting will be:

1. Methods: computational techniques such as maximum entropy and regularised fitting;
2. Astrotomography techniques and new developments: e.g., eclipse mapping, spectral disentangling, Doppler tomography and modulated Doppler tomography, Zeeman–Doppler mapping, interferometric Doppler imaging;
3. New instruments and possibilities: e.g, EsPaDons, UltraCam, UltraSpec, X-shooter, instruments on extremely large telescopes;
4. Applications: e.g., structure of disc flows, tomographic constraints on black hole and neutron star masses, ultra-compact binaries, cataclysmic variables (magnetic and non-magnetic), X-ray binaries, exoplanets and active galactic nuclei.

The format of the meeting will consist of invited reviews, contributed talks on new results and plenary discussions. The last day is planned as a hands-on training workshop using various tomography methods and applying them to real data. PhD students and young postdocs are particularly invited to attend.

The abstract submission deadline is 30 September and registration deadline 31 October 2013.

More detailed information is available at:
http://www.eso.org/tomo2013
or by e-mail to: tomo2013@eso.org

ESO/H. H. Heyer

Personnel Movements

Arrivals (1 July–30 September 2013)

Europe	
Alvarado Gomez, Julian David (CO)	Student
Murray, John (GB)	Senior Mechanical Engineer
Sbarrato, Tullia (I)	Student
Tazzari, Marco (I)	Student
Voggel, Karina Theresia (D)	Student

Chile	
Klein, Thomas (D)	APEX Station Manager
Krühler, Thomas (D)	Fellow
Muñoz-Mateos, Juan Carlos (E)	Fellow

Departures (1 July–30 September 2013)

Europe	
Ascenso, Joana (P)	Fellow
Boissier, Jérémie (F)	Fellow
Dutra Ferreira, Letícia (BR)	Student
Echaniz, Juan Carlos (E)	System Engineer-Product Assurance
Fourie, Petrus Gerhardus (ZA)	System Engineer
Jeanmart, Kristel (B)	Procurement Officer
Kraus, Hans-Jürgen (D)	Administrative Clerk
Lourenco Correia, Joana Catarina (P)	Accountant
Lützgendorf, Nora (D)	Student
Meyer, Manfred (D)	Electronics Engineer
Morita, Yuka (J)	Secretary
Pineda, Jaime (RCH)	Fellow
Rosati, Piero (I)	Astronomer
Wagg, Jeffrey Franklin (CDN)	Fellow

Chile	
Alvarez, Fernando (RCH)	Head of Maintenance Department
Avanti, Juan Carlo (RCH)	Accountant
Brammer, Gabriel (USA)	Fellow
Calisse, Paolo Gherardo (I)	Test Scientist
Dias, Bruno (BR)	Student
Ihle, Gerardo (NL)	Head of the La Silla Observatory
Martin, Sergio (E)	Fellow
Mauersberger, Rainer (D)	Astronomer
Patru, Fabien (F)	Fellow
Serrano, Guido (RCH)	Procurement Officer
Snow, William (USA)	System Engineer
Tarenghi, Massimo (I)	ESO Representative in Chile
Wieching, Gundolf (D)	APEX Station Manager
Vega, Florine (RCH)	Contract Officer

Panorama of the Paranal Observatory by night. This 360-degree view was made by combining many individual images taken before morning twilight. The zodiacal light can be seen above the rising Moon and the Milky Way stretches across half the sky with the Large and Small Magellanic Clouds visible to the south. See Picture of the Week 9 November 2009 for details.

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

The Messenger:
Editor: Jeremy R. Walsh;
Design, Production: Jutta Boxheimer;
Layout, Typesetting: Mafalda Martins;
Graphics: Roberto Duque.
www.eso.org/messenger/

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Contents

Front cover: The contrasting line emission of the pair of H II regions, NGC 2014 (upper, to west) and NGC 2020 (lower, to east) is shown in a VLT FORS2 composite colour image. This region is to the northwest of 30 Doradus in the Large Magellanic Cloud. Broadband filter images in *B*, *V* and *R*, and narrowband images on the [O III] and Hα+[N II] emission lines were combined and emphasise the differing ionisation conditions in the two regions. NGC 2020, the blue, higher ionisation, ring nebula surrounds hot young stars while the red, lower ionisation and probably more heavily extincted, diffuse nebula is ionised by somewhat cooler stars. See Release eso1335 for more information.