The Messenger

No. 163 – March 2016

Observing the Sun with ALMA
Growth of the Science Archive community
QSOs behind the Magellanic Clouds
KMOS AGN survey at high redshift

The Signing of the ALMA Trilateral Agreement

Nikolaj Gube[1]
Tim de Zeeuw[1]

[1] ESO

The first Atacama Large Millimeter/submillimeter Array (ALMA) Agreement between ESO and the US National Science Foundation (NSF) entered into force on 25 February 2003, following various earlier approaches and contacts between different radio astronomy projects, and as a result of the visionary key decision to join the strengths and efforts of the North American, East Asian and European projects in Chile. Japan, through the National Institutes of Natural Sciences (NINS), formally joined the construction project a year later.

Since then, ALMA has developed tremendously. Sixty-six antennas have been built and commissioned, and now populate the Chajnantor Plateau in northern Chile. All the antennas are equipped with, and supported by, cutting-edge technologies, hardware and software; upgrades and the opening of more frequency bands continues to enhance the capabilities. All the necessary infrastructure, buildings and roads on the ALMA site and in Santiago have been constructed and — last, but surely not least — the technicians, engineers, scientists and administrative staff from all over the world and with many different cultural backgrounds have learnt to work together for the good of the project. The last remaining milestone — the Residencia — is in an advanced state of construction and due to be occupied later this year. There have already been more than three years of science observations — resulting in stunning discoveries, with more still being revealed.

Quite naturally for a project of this size and complexity, matters have evolved considerably from the early days when the ink of the first signatures on the agreement was not even dry. Also quite naturally, the initial agreements no longer fully reflect the current *modus operandi* of ALMA. NINS is now fully committed to ALMA operations, the ALMA Director's Council was created while other committees were disbanded, and ALMA has moved on from being a construction project to operations, and is on its way to a steady state. The ALMA parties ESO, NINS and NSF thus decided to review the high-level agreements and consolidate them in a single consistent agreement — the Agreement Concerning Operations of ALMA — which was signed in Tokyo on 15 December 2015.

ALMA (ESO/NAOJ/NRAO)

Figure 1. Signing of the ALMA Trilateral Agreement in Tokyo on 15 December 2015, by the three representatives of the ALMA partners. Left to right: Tim de Zeeuw, ESO Director General; Katsuhiko Sato, NINS President; F. Fleming Crim, NSF Assistant Director.

Text of the Speech by the ESO Director General, Tim de Zeeuw, at the Signing of the ALMA Trilateral Agreement

President Satoh, Professor Hayashi, Dr. Crim, distinguished colleagues and friends from NAOJ, NSF and ESO.

It is a pleasure to say a few words on behalf of ESO at today's ceremony, which marks the next phase in the intercontinental ALMA project, namely the signature of the Trilateral Agreement governing the operational phase, which sees all three Partners, NINS, NSF and ESO on an equal footing.

It is just over thirty years ago since the IAU Symposium 115, entitled Star-forming Regions, took place in the Hotel Metropolitan here in Tokyo in November 1985. The topic and timing were related to the coming online of the Nobeyama 45-metre telescope and interferometer, both of which were world-leading at the time. My wife Ewine and I were postdocs, and we participated in the Symposium. It was our first direct and very positive encounter with Japanese astronomy. The visit to the Nobeyama Radio Observatory was one of the highlights of the entire week!

In preparation for today's event, I looked again at the published proceedings from that Symposium, and discovered not only a detailed list of participants, but also three photos showing nearly everyone who attended. Amazingly, quite a few are here today! Many others also had key roles in making ALMA become a reality, or became leaders in other areas of astronomy! The cast included three future IAU Presidents (amongst whom of course Norio Kaifu), two Directors of NRAO (Paul Vanden Bout and Fred Lo), the first ALMA Director (again Vanden Bout), all three chairs to date of the ALMA Proposal Review Committee (Neal Evans, Anneila Sargent and Francoise Combes), members and chairs of the ALMA Board (Evans, Sargent, Ewine van Dishoeck, Shoken Miyama, Hideyuki Kobayashi, Masahiko Hayashi), future Directors General of NAOJ, NINS and ESO, the former Gemini and STScI Director and current AURA President (Matt Mountain), as well as many others.

Ewine and I subsequently attended the IAU General Assembly in Delhi and then took a tour of Rajasthan together with a few US colleagues and a small group of Japanese astronomers led by Kaifu, and including Masatoshi Ohishi and Hiroko Suzuki, who sadly passed away too soon.

S. Otarola/ESO

Figure 1. Night-time operations of ALMA on the Chajnantor Plateau.

In the years that followed, plans were made on three continents for a next generation facility, with much increased resolution and sensitivity. This naturally led to the idea of a large interferometer on a very high site, with the best high-frequency receivers that can be built. The power of a radio interferometer goes up with the square of the number of antennas, so by combining the individual plans in East Asia, North America and Europe into the worldwide ALMA partnership it was possible to build a much more powerful facility at an affordable cost.

Building the array in northern Chile on Chajnantor, half-way up into space, with the strong support of the Chilean government, was a fairly natural step for NSF, which funds optical observatories in Chile, and certainly for ESO, which operates the La Silla Paranal Observatory there. But Chile is very far away from where we are today. I admire the commitment of our Japanese and East Asian colleagues for taking the bold step to go for the best site worldwide and join ALMA.

ALMA construction was started as a bilateral project between NSF and ESO, and Japan joined soon after via bilateral agreements with each. This was a key step as it enabled ALMA to become a truly transformational facility. It also strengthened the partnership and enriched it with an additional scientific community and culture. Of course it also projected Japan straight into the global arena, building on the success of Nobeyama and of the Subaru Telescope on Hawaii.

As ALMA construction proceeded, it became clear that it would be very useful to replace the three bilateral agreements by a single Trilateral Agreement governing operations, which would take into account the experience gained during construction.

The development of the Trilateral Agreement was performed by a small group, consisting of Masa Hayashi and Satoru Iguchi for NAOJ/NINS, Dana Lehr and Phil Puxley for NSF, and the former Council President Xavier Barcons, Nikolaj Gube and myself for ESO. Nikolaj was the main keeper of the document and garnered credit from all involved. I am pleased he is here today, and want to express my thanks to him and all others in the team for the very constructive spirit in which the Trilateral Agreement was written, which has further increased the level of trust between the Partners.

The ALMA conference which took place in Tokyo last year demonstrated that the dream of a truly transformational facility for astronomy has become a reality. I am certain that the power and efficiency of the facility will continue to increase in the years to come. It is a testimony to the visionary and motivated individuals who laid the groundwork more than three decades ago, and turned it onto a reality. Who could have thought this in 1985 when many of us met during IAU Symposium 115 as young astronomers!

Telescopes and Instrumentation

An aerial view of the ALMA high site during daytime, showing a relatively close packing of the 12-metre antennas, with the ALMA Compact Array (the Morita Array) at upper right.

Clem & Adri Bacri-Normier (wingsforscience.com)/ESO

The Growth of the User Community of the La Silla Paranal Observatory Science Archive

Martino Romaniello[1]
Magda Arnaboldi[1]
Cristiano Da Rocha[2]
Carlos De Breuck[1]
Nausicaa Delmotte[1]
Adam Dobrzycki[1]
Nathalie Fourniol[1]
Wolfram Freudling[1]
Laura Mascetti[2]
Alberto Micol[1]
Jörg Retzlaff[1]
Michael Sterzik[1]
Ignacio Vera Sequeiros[1]
Myha Vuong De Breuck[2]

[1] ESO
[2] TERMA GmbH, Germany

The archive of the La Silla Paranal Observatory has grown steadily into a powerful science resource for the ESO astronomical community. Established in 1998, the Science Archive Facility (SAF) stores both the raw data generated by all ESO instruments and selected processed (science-ready) data. The growth of the SAF user community is analysed through access and publication statistics. Statistics are presented for archival users, who do not contribute to observing proposals, and contrasted with regular and archival users, who are successful in competing for observing time. Archival data from the SAF contribute to about one paper out of four that use data from ESO facilities. This study reveals that the blend of users constitutes a mixture of the traditional ESO community making novel use of the data and of a new community being built around the SAF.

The content of the ESO Science Archive Facility

The ESO Science Archive Facility[1] began operating in 1998, a few months ahead of the start of science operations of the Very Large Telescope (VLT); see Pirenne et al. (1998). It is the operational, technical and science data archive of the La Silla Paranal Observatory. As such, it stores all the raw data, including the ambient weather conditions, from the La Silla Paranal Observatory, i.e., the telescopes on Paranal, the ESO telescopes on La Silla and the Atacama Pathfinder Experiment (APEX) antenna on Chajnantor. Also available through the SAF are data from selected La Silla instruments, for example, the Gamma-Ray burst Optical/Near-infrared Detector (GROND), the Fibre-fed Extended Range Echelle Spectrograph (FEROS) and the Wide Field Camera (WFI), together with the raw data for the UKIDSS WFCAM survey obtained at the United Kingdom Infrared Telescope (UKIRT) in Hawaii.

Access to science data is initially limited to the Principal Investigators (PIs) of the observing programmes that generated them and to their delegates[2]. After the expiration of this proprietary period, which is typically one year, data are available to the community as a whole. Data have been accessible from the SAF worldwide since April 2005; prior to that they were limited to ESO Member States. Raw data from Public Surveys are public immediately, without any proprietary restriction. The non-PI use of data is the focus of the present article.

Over time, the SAF has grown to contain about 650 TB of data in 33 million files and ~ 23 billion database rows containing header keywords that describe the data themselves. Redundant copies of the archive contents provide protection against loss of data. The typical inflow to the SAF is about 12 TB of new data a month, while about 15 TB/month are served to science users.

The SAF contains the raw data as generated at the telescopes and selected processed data; the latter are either contributed by the community (see Arnaboldi et al., 2014) or generated at ESO (Romaniello et al., 2016). Raw data, as extracted from the SAF, need to be processed before they can be used for science measurements. This processing is required to remove the signature imprinted on the science signal by the Earth's atmosphere and the telescopes and instruments themselves and in order to calibrate the results into physical units. A user tool within the SAF associates the applicable calibration files to raw science data needed to perform this processing. ESO supports data processing by individual users by providing software tools that implement the relevant algorithms. The Reflex environment (Freudling et al., 2013) allows the data to be conveniently organised, so that they can be run through the processing steps to interactively assess the quality of the results and, if needed, iterate on them.

Processed data are also available from the Science Archive Facility. They can be used directly for scientific measurements, thus alleviating the need for users to do any data processing of their own. As mentioned above, the SAF is populated with processed data through two channels. On the one hand, data-processing pipelines are run at ESO for selected instrument modes to generate products that are free from instrumental and atmospheric signatures and calibrated in physical units. They cover virtually the entire data history of the corresponding instrument modes and are generated by automatic processing, without knowledge of a specific science case. Checks are in place to identify quality issues with the products. On the other hand, the community contributes data products generated with processing schemes optimised to serve specific science cases and that have, in most cases, been used for the results in refereed publications. These contributed datasets, which are validated in a joint effort between the providers and ESO before ingestion into the archive, often include advanced products like mosaicked images, source catalogues and spectra. Thorough user documentation, detailing the characteristics and limitations of the various collections of processed data, is also provided. This detail is particularly important, as it enables users to decide whether the data are suitable for their specific science goals.

The publication of such processed data in the SAF dates back to 25 July 2011, with the first products from Public Surveys with the VIRCAM infrared camera on the VLT Infrared Survey Telescope for Astronomy (VISTA) generated by the corresponding teams (Arnaboldi & Retzlaff, 2011). Processed data generated at ESO have been available since September 2013. All processed data are searchable homogeneously through the same archive interfaces.

In the following we discuss the growth of the user community of the ESO Science

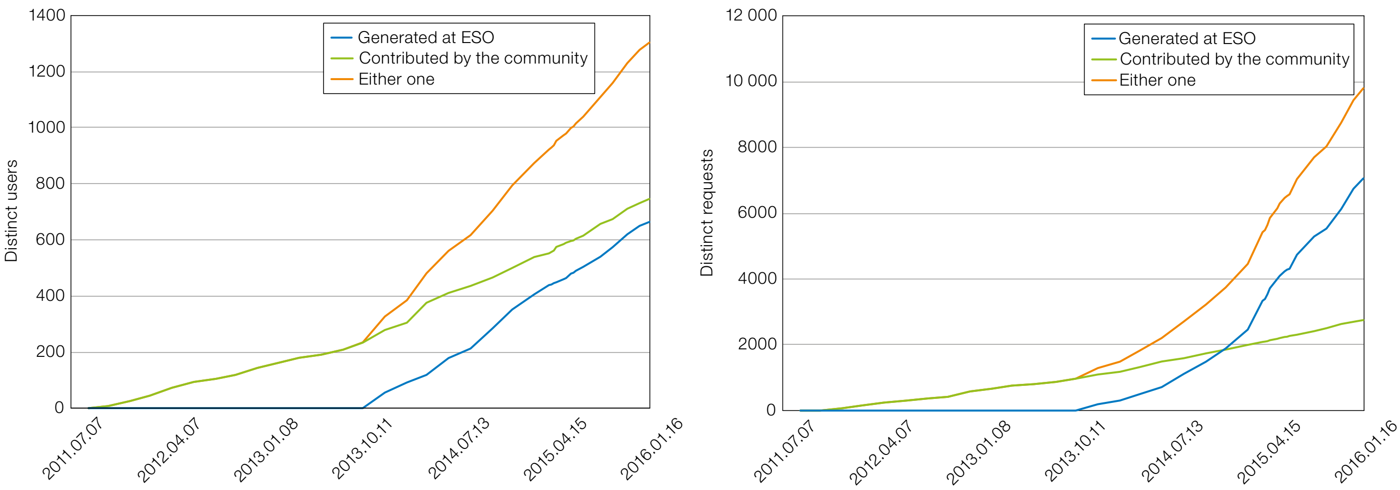


Figure 1. Access to SAF data products as a function of time plotted for distinct users (left panel) and distinct requests (right panel). In both panels the green line displays access to products contributed by the community (deployed on 25 July 2011), the blue line shows access to products generated at ESO (deployed on 10 September 2013) and the orange line is for access to either type of products.

Archive Facility by analysing access and publication statistics.

Use of the Science Archive Facility: A growing community

The community accessing data from the SAF is large and varied. Taking as a reference point the date of publication in the SAF of the first processed data from Public Surveys in July 2011, more than 4500 unique users have accessed archived non-proprietary data, raw or processed. To put this figure into context, in the same time period there were 2500 distinct PIs submitting proposals for observing time on the ESO telescopes (8700 Co-Investigators [Co-Is]), 1500 of whom were successful. Simply from a numerical point of view, accessing non-proprietary data that are readily available through the SAF is a resource for the ESO community comparable to the classical route of proposing customised observations. Moreover, the rate at which the SAF is accessed is accelerating: it took 11 years from mid-1998 to collect the first half of the current base of unique users, but only six to collect the other half. The current trend is to add about 50 new archive users per month, a trend that shows no sign of flattening off. In fact, the desire to download data, for which it is necessary to be registered to the ESO User Portal[3], is the driver for new registrations, at an average rate of 2–3 per day.

The most frequent uses of archive data include the preparation of new observations, both to check feasibility and to avoid duplications (when submitting observing proposals it is mandatory to demonstrate that suitable data are not already present in the archive), and making novel scientific use of the data beyond the original scope for which they were taken. New data are swiftly made available through the SAF to PIs of ongoing observing programmes for prompt science exploitation and to allow the observing strategy to be revised and refined, if needed. The time delay for raw data appearing in the SAF, and being available for download, is typically one hour from acquisition at the telescope for the La Silla Paranal Observatory, and 1–2 days for APEX.

Access to science-ready processed data

When compared to the eighteen-year history of the SAF, which started out in 1998 containing only raw data, systematic availability of processed data is a fairly recent addition, dating back to July 2011. The available science-ready processed data are listed[4], and links are provided for access to the data. Both the data products contributed by the community and those generated at ESO are in great demand by science archive users. From the first publication of data products in 2011 to January 2016, in excess of 1300 unique users have accessed products of either origin. (For comparison, this is more than 1.5 times the number of PIs and Co-Is of the Public Surveys currently running at ESO and, in the same period of time, the SAF had almost 3500 unique users accessing raw data). About 30 % of users who have accessed processed data have never downloaded raw data: they can therefore be seen as a net addition to the archive user community, drawn to it by the availability of processed data. Also, users keep returning to the SAF, submitting on average 6.5 data requests each.

The detailed distributions are shown in Figure 1, where access to SAF data products is displayed as a function of time. It should be recalled that processed data generated at ESO cover virtually the entire history of the corresponding instrument modes, without knowledge of any specific science use case. They are processed to remove instrumental and atmospheric signatures and to calibrate data in physical units. Data contributed by the community, on the other hand, generally go further in terms of processing level and are usually processed with a specific science goal in mind. In the left panel of Figure 1, the number of unique users accessing the SAF is plotted; in the right panel, the number of unique requests. Related to the latter, at least part of the reason why the number of accesses to processed data generated at ESO grows so much faster than those contributed by the community is attributable to the different publishing patterns.

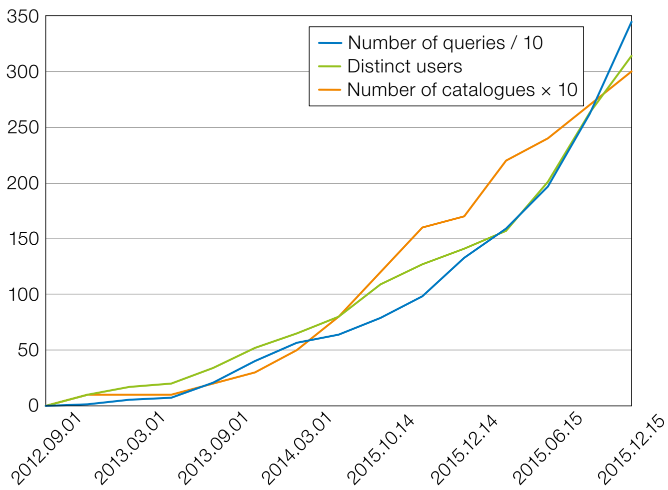


Figure 2. Access to the ESO Catalogue Facility is shown as a function of time. As of December 2015, the 30 catalogues available have been accessed by more than 300 unique users, at a pace that increases with time.

Data from external providers are published in batch releases and so the archive users, after data have been published, generally need just one request to retrieve the dataset in which they are interested. In contrast, reduced data generated at ESO feed the archive in a semi-continuous stream, which then leads users to submit several requests to retrieve the same amount of data.

Object catalogues are also very much in demand. They represent the highest level of processed data in that they contain the physical properties of celestial objects, such as magnitudes in different bands, shape parameters, redshifts or radial velocities, chemical abundances and stellar parameters. These properties can be queried through a dedicated interface (the ESO Catalogue Facility[5]) which allows complex constraints across the different parameters, dependent on the nature of the different catalogues, plus a unique identifier and celestial coordinates, which are always present. At the moment, all the catalogues currently available were contributed by providers in the community, mostly as a result of Public Surveys or Large Programmes. Access statistics to the ESO Catalogue Facility are summarised in Figure 2. As can be seen, all of the 30 catalogues currently available have been accessed by more than 300 unique users.

The science products that are most frequently accessed by the archive users are 1D spectra (about 1.5 million files), followed by single-band source lists (~ 130 000 files), images (~ 40 000 files) and object catalogues (~ 20 000 files). In excess of 1400 unique users access processed data in the ESO SAF, including images, spectra and object catalogues; a number that continues to grow. It is interesting to note that requests for the raw counterparts to processed data have so far remained constant, and not (yet?)

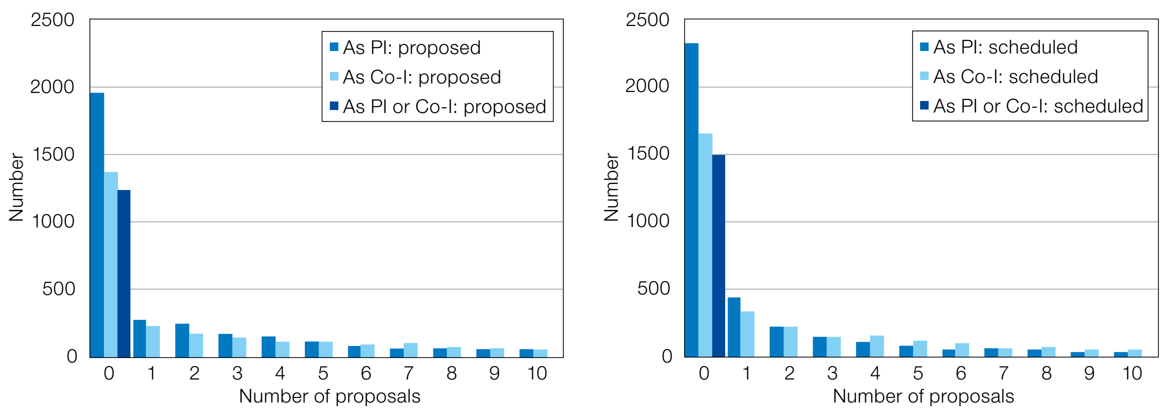


Figure 3. Number of proposals for telescope time submitted (left panel) and scheduled (right panel) by users who have accessed raw data from the ESO Science Archive Facility. Different shades of blue indicate the role of archive users in such proposals: PI, Co-I, or either.

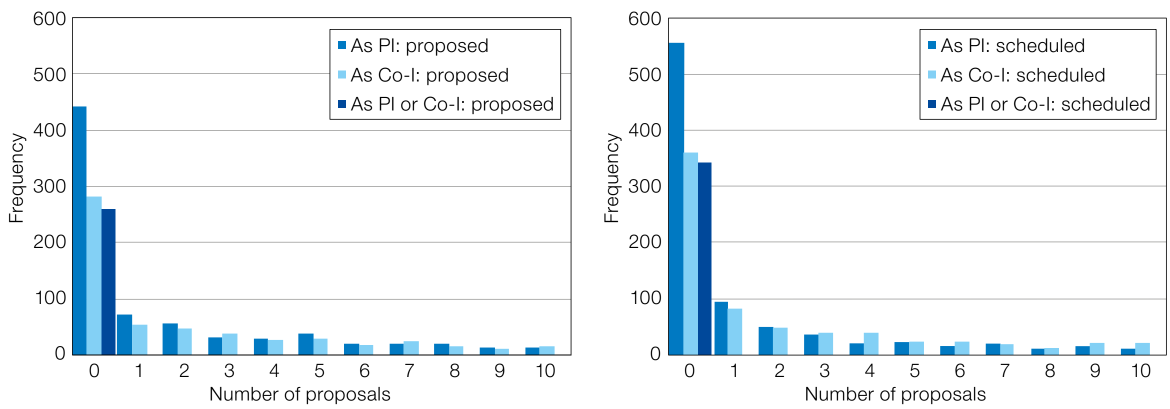


Figure 4. Same as Figure 3, but for users who have accessed processed data from the ESO Science Archive Facility.

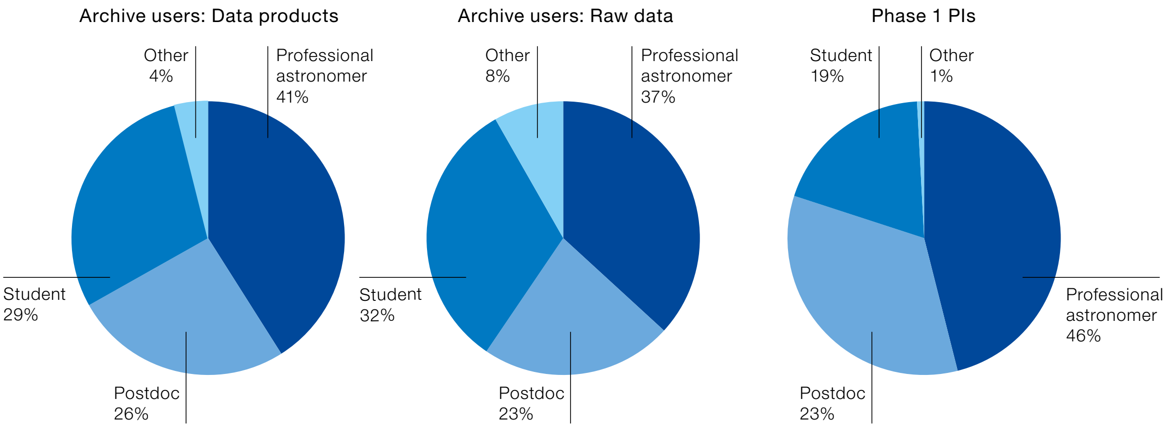


Figure 5. Distribution of the professional profile category of archive users, as entered by users themselves in their ESO User Portal account profile, is shown by type of archive request (left panel: for data products; middle panel: for raw data). For comparison, the professional category of PIs of Phase 1 observing proposals is shown (right).

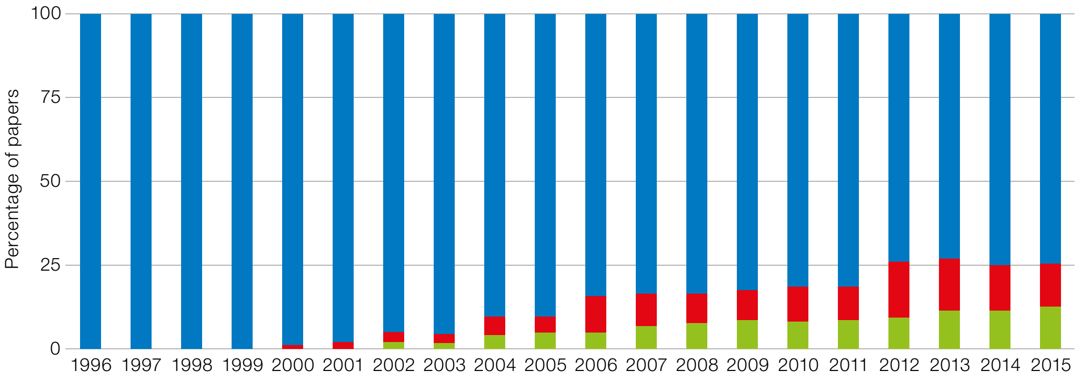


Figure 6. Archive data usage in refereed publications as a function of time. The blue bars represent the fraction of papers that only make use of data for which there is an overlap between the authors of the paper itself and the PI and Co-Is in the original observing proposals. The red bars represent the papers for which there is no such overlap and the green ones the papers that used data both with and without overlap.

declined as might have been expected. We will, of course, continue to monitor this trend in the future.

Observing proposals by archive users

The use of the archive expands the ESO science user community beyond its traditional boundaries of application for time to obtain observations specifically tailored to a given problem. This effect is shown in Figures 3 and 4, in which the number of observing proposals submitted and approved are displayed for archive users of raw and processed data, respectively. The numbers are similar in both cases and paint a very interesting picture: almost 30 % of archive users have never applied for their own observing time with ESO, neither as PIs nor Co-Is (dark blue bars). For them, the SAF is the one point of contact with ESO, from where they readily access the data they need for their science. It is also interesting to note that, among those who did submit proposals for observing time, only about 10 % of users who have downloaded archival data were consistently unsuccessful in being awarded observing time, as compared to about 30 % for the general population of those who have applied for telescope time. It seems, then, that being an archive user is also beneficial in order to write successful proposals!

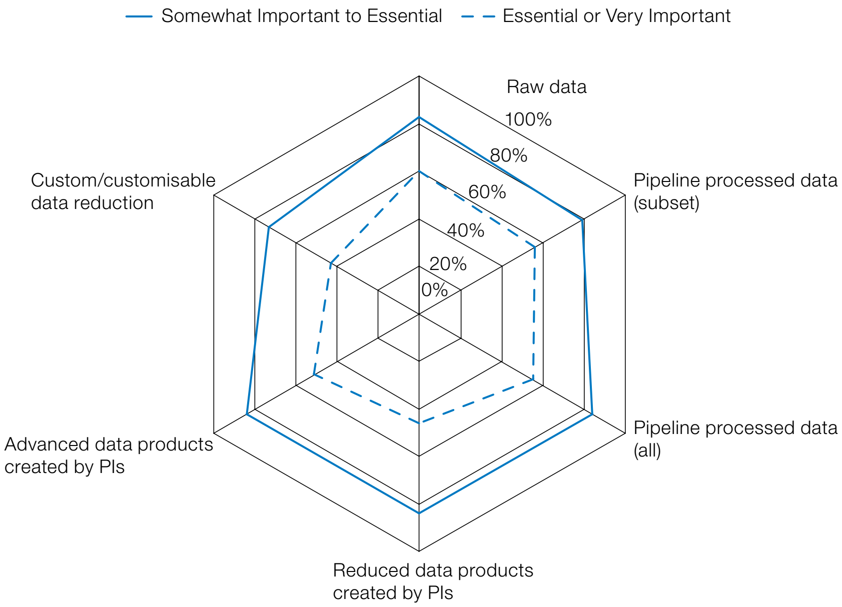
The demographics of archive users

In Figure 5 we contrast the professional category of users of the archive and of PIs of observing proposals, as entered by the users themselves in their User Portal account profile. The differences among archive users and PIs of observing proposals, which of course partly overlap, are not very large. Notwithstanding, there may be an indication that students constitute a larger share among the archive users compared to proposal PIs. The SAF is also an entry point to ESO (and observational astronomy!) for the younger generation, who will become the users of the future.

Archival refereed publications

Among the different uses of archival data, generating refereed publications is certainly one of the most important. As part of an effort to track publications from its facilities, the ESO Library classifies and tracks archival papers, defined as papers in which none of the authors was part of the original observing proposal that generated the data used in the paper itself. This definition is a conservative one and likely to underestimate the actual contribution of archive science to the total output of an observatory. It is, however, well defined and, therefore, well suited for comparisons among different data centres. The contribution of archival papers to the total output of ESO refereed papers is shown in Figure 6: after an initial gradual ramp up, archive papers have contributed to about 25 % of the output of refereed papers that make use of ESO data for the last several years.

A paper is classified as using archive data if none of its authors was PI or Co-I



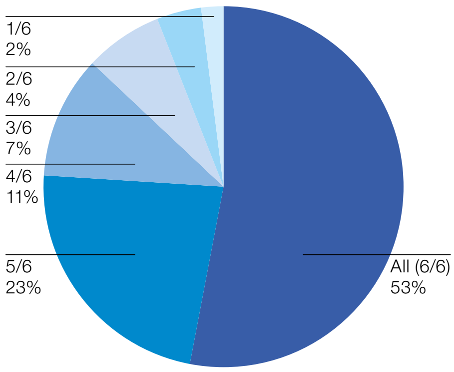


Figure 8. The number of data product types listed in Figure 7, whose archive access was rated between "Somewhat Important" to "Essential" according to the respondents to the "ESO in the 2020s" user poll (Primas et al., 2015).

Figure 7. Percentage of users that rate different types of archive data holdings as "Somewhat Important to Essential" (solid line) or "Essential to Very Important" (dashed line), based on the answers to the question "How important is access to the following sorts of archived data products in order to maximise your scientific productivity?" taken from the user poll "ESO in the 2020s". 1439 responses were received (Primas et al., 2015).

of the original proposal that generated the data itself, which corresponds to the sum of red and green bars in Figure 6. The source of the plot, and of many more interesting statistics and information, is the ESO Telescope Bibliography (telbib[6]), as curated by the ESO librarians. The inference is that about 25 % of archival papers use data never published by the team that proposed and was awarded time for the original observations. Seen from a different perspective, about 5 % of data from the La Silla Paranal Observatory, including APEX, are only published as archive papers.

Conclusions and outlook

During its lifetime, the Science Archive Facility has established itself as a powerful science resource for the ESO astronomical community, now contributing to about one paper out of four that use data from ESO facilities. This is the result of a mixture of the traditional ESO community making a novel use of the data and of a new community being built around the SAF itself. The growing importance of archival research is a trend that is expected to become increasingly important in the future, as highlighted by the recent ESO/ESA Workshop on science data management (see Romaniello et al., p. 46).

When asked "How important is access to the following sorts of archived data products in order to maximise your scientific productivity?" as part of the user poll ESO in the 2020s (Primas et al., 2015) none of the 1439 respondents indicated that archived data is "not important". Furthermore, the majority of respondents (53 %) think that archive access to all of the six data categories offered as choices are, and will remain, somewhere between "somewhat important" to "essential" for their research. The detailed responses are visualised in Figures 7 and 8.

In order to meet the challenges of astronomy in the future, ESO is actively developing the SAF in close collaboration with the community at large. This development is occurring both in terms of content and user services. On the first point, the quality and quantity of data products are being continuously enhanced. Services for data exploration, discovery and exploitation, within the SAF itself and in conjunction with other data archives are being developed to follow the evolution of astronomy into a multi-messenger, multi-wavelength, multi-facility science.

Acknowledgements

We would like to express our appreciation to our ESO colleagues in the Directorate for Engineering who have worked hard and successfully towards the development of the Science Archive Facility and to those in the ESO Library for tracking the use of ESO facilities in publications. Data end up in the archive at the end of a long and complex path that goes from the submission of observing proposals, through the definition and execution of the observations, to users who generate and return processed data for the benefit of the community at large: our thanks go to all those involved!

References

Arnaboldi, M. & Retzlaff, J. 2011, The Messenger, 146, 45
Arnaboldi, M. et al. 2014, The Messenger, 156, 24
Freudling, W. et al. 2013, A&A, 559, A96
Pirenne, B. et al. 1998, The Messenger, 93, 20
Primas, F. et al. 2015, The Messenger, 161, 6
Romaniello, M. et al. 2016, The Messenger, in prep.

Links

[1] ESO Science Archive Facilty (SAF): http://archive.eso.org
[2] Data access delegation can be granted though the ESO User Portal profile: http://www.eso.org/userportal
[3] ESO User Portal: http://www.eso.org/userportal
[4] List of Phase 3 data releases: http://www.eso.org/sci/observing/phase3/data_releases.html
[5] ESO Catalogue Facility: http://www.eso.org/qi
[6] ESO Telescope Bibliography (telbib): http://telbib.eso.org

FORS2 Rotating Flat Field Systematics Fixed — Recent Exchange of FORS LADC Prisms Improves the Long-known Flat-fielding Problem

Henri Boffin[1]
Sabine Moehler[1]
Wolfram Freudling[1]

[1] ESO

For many years the FORS2 instrument has suffered from artefacts in the flat fields caused by surface inhomogeneities on the longitudinal atmospheric dispersion corrector (LADC) that affected high-precision photometric and spectroscopic measurements. Recently, the FORS LADC prisms were exchanged, and our analysis of a large number of flat fields shows that this exchange has resulted in a significant decrease in the level of small-scale artefacts.

One of the most recent techniques used to probe the atmospheres of exoplanets is transmission spectroscopy, which relies on measuring how the transit depth of a planet crossing the disc of its host star varies with wavelength. Such measurements require extreme precision — at the level of 100 ppm — and can only be done with space- or large ground-based telescopes. After some pioneering work done by Bean et al. (2010) with the FORS2 instrument attached to the Very Large Telescope (VLT), this field was brought to a halt at ESO until very recently because FORS2 measurements produced unexpectedly high systematics in the differential light curves obtained with this instrument. These systematics turned out to be impossible to calibrate out reliably (see Boffin et al. [2015] for a more extended discussion).

In parallel, Moehler et al. (2010) studied the twilight flat fields obtained with the two FORS instruments and found structures that rotated with the field rotator, structures that had a significant impact on photometric measurements. These authors concluded that the origin of these structures was the LADC and developed a technique to minimise the impact of these artefacts on photometry. The current FORS2 calibration plan routinely acquires the necessary data for the implementation of this method (Bramich et al., 2012; Coccato et al., 2014). These structures were also at the origin of the systematics affecting exoplanet transmission spectroscopy.

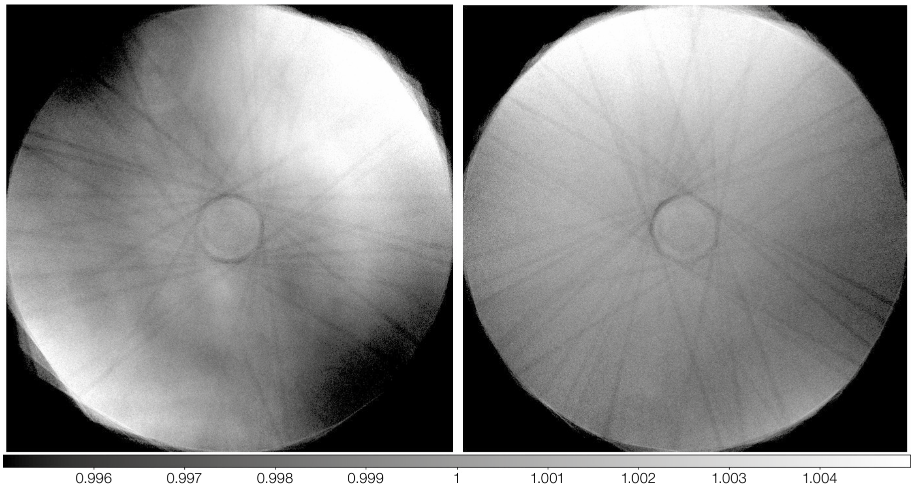


Figure 1. Comparison of rotator-angle dependent features in the FORS2 flat fields (i.e., corrected for detector/filter dependent features, see text for details) for the R_SPECIAL filter, before (left) and after (right) the prism exchange of the LADC. The scale represents artefacts on a scale between 0.995 (black) to 1.005 (white).

In order to improve the spectroscopic performance, the FORS2 LADC prisms were exchanged with the uncoated ones of FORS1 — which has been dismounted to leave space for other, second generation instruments at the VLT. The preliminary results were clearly very encouraging, as the red noise due to systematics significantly decreased after the exchange, making it possible to perform transmission spectroscopy with FORS2 again (Sedaghati et al., 2015).

As part of the regular calibration plan, sufficient data have been collected since the exchange of the prisms to allow us to look again at the level of rotating structures in the twilight flat fields of FORS2 and investigate whether they have largely disappeared. To this aim, we collected FORS2 twilight flat fields taken with the standard setup with the filters b_HIGH, v_HIGH, R_SPECIAL, and I_BESS. As part of the mitigation process, FORS2 twilight flat fields are now taken almost every four to seven nights (in the above filters at least) with a random rotator angle on sky.

We selected at most five frames per 5° angle range for rotator angles between ±180° (angles outside that range were adjusted by adding/subtracting 360°). We then combined the frames from the two detectors, after correcting each by its overscan bias, normalised each frame by its median and then median-stacked all the frames (per filter and detector) and normalised each frame by the corresponding stack to remove any rotator-independent structure. Each normalised frame was then rotated to a rotator angle of 0° and to a random rotator angle. Finally all rotator angle 0° and random rotator angle frames were again median-stacked.

This exercise was performed for frames observed between 1 February and 31 October 2014 (before the LADC prism exchange) and between 13 November 2014 and 4 August 2015 (after the LADC prism exchange). Figure 1 shows the result for filter R_SPECIAL. Note that the dark stripes come from the gap between the two detectors.

The frames are displayed in the contrast range of 0.995–1.005, i.e. ±0.5 %. The small-scale structures clearly visible in the old data are gone, leaving only a gradient across the field. This probably explains the improvement we have seen in the precision with which it is possible to perform transmission spectroscopy. The presence of the gradient indicates that photometry over the whole field still requires attention to the rotator angle and, therefore, that the current calibration plan should not be changed, as we still need to collect the data to be able to correct for rotation effects.

We will continue to monitor the structures in the twilight flat fields, to prevent users trying to perform observations at the level that is not attainable should the optics in FORS2 be degraded. As there is no longer a coating on the FORS2 LADC prisms, we do not expect, however, to encounter the same problem as before, which was due to a degradation of the anti-reflection coating. The result of our monitoring will be put on the ESO FORS2 public web pages[1].

Acknowledgements

We would like to thank Jonathan Smoker for a careful reading of the manuscript.

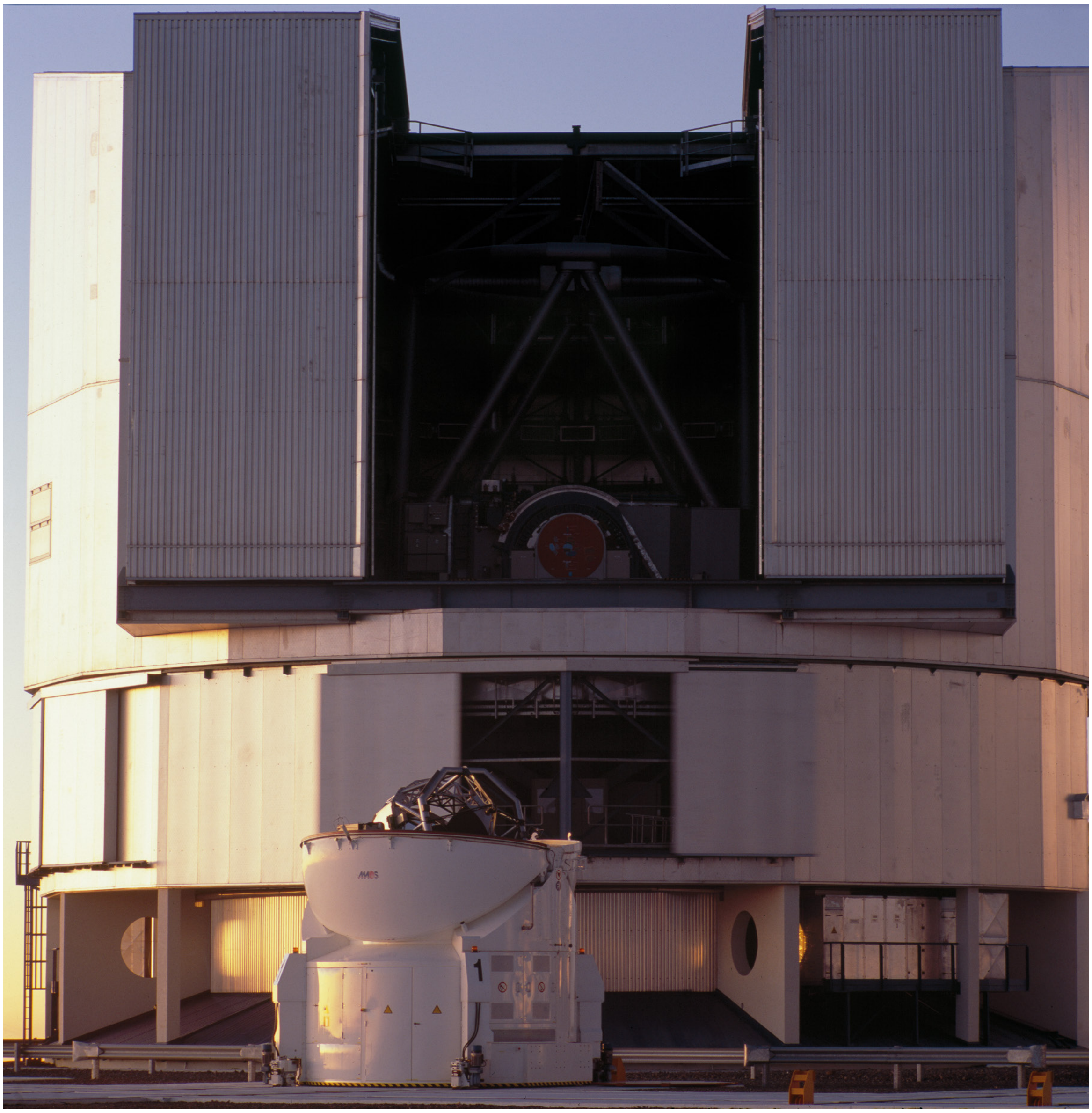
References

Bean, J. L., Miller-Ricci Kempton, E. & Homeier, D. 2010, Nature, 468, 669
Boffin, H. M. J. et al. 2015, The Messenger, 159, 6
Bramich, D. et al. 2012, The Messenger, 149, 12
Coccato, L. et al. 2014, MNRAS, 438, 1256
Moehler, S. et al. 2010, PASP, 122, 93
Sedaghati, E. et al. 2015, A&A, 576, L11

Links

[1] FORS2 News page: http://www.eso.org/sci/facilities/paranal/instruments/fors/news.html

ESO/H. H. Heyer



Unit Telescope 1 (Antu), the current location of the FORS2 instrument. In this photograph (from 2007), one of the Auxiliary Telescopes, belonging to the Very Large Telescope Interferometer (VLTI), is positioned in the foreground.

A Simpler Procedure for Specifying Solar System Objects in Phase 2

Benoît Carry[1,2]
Jérôme Berthier[1]

[1] IMCCE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ Paris 06, Université Lille, France
[2] Laboratoire Lagrange, Université de Nice Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur, France

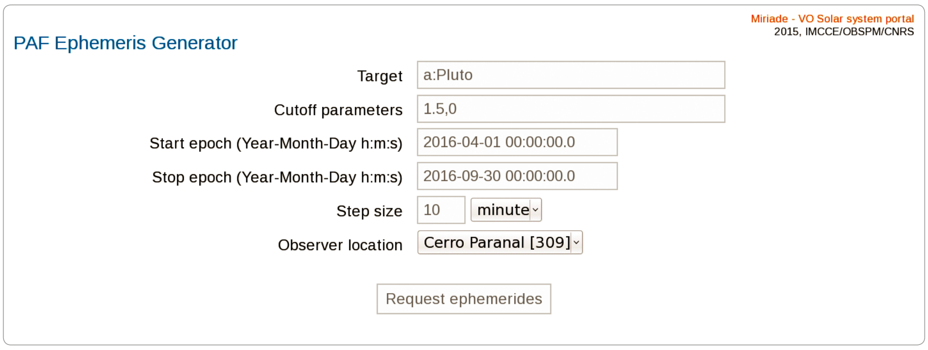


Figure 1. The PAF query form, hosted at IMCCE and ESO. Here, ephemerides are requested for (134340) Pluto, from Paranal, for the entire Period 97, with a time step of 10 minutes. The PAF parameters refer to the cut-off on the target airmass (≤ 1.5) and the Sun's elevation (≤ 0 degrees) for displaying ephemerides.

Observations of Solar System objects in Service Mode require a special procedure. Observers preparing Observing Blocks must submit a detailed ephemerides file for each target for the whole duration of the observability period, which can sometimes be the entire ESO Period. These ephemerides files are ASCII files and follow a strict format, compatible with the VLT parameter file format. We present a simple web service that is now available to replace the former two-step process.

ESO ephemerides requirements

As with many other telescopes, Very Large Telescope (VLT) observations done at a non-sidereal tracking rate require a special procedure at the VLT. In Visitor Mode (VM), each visiting astronomer is responsible for updating both the coordinates and the apparent motion of the target at the time of execution of an Observing Block (OB), prepared with the Phase 2 Proposal Preparation tool (P2PP). In this case, the choice of source of ephemerides, and its format, is at the discretion of the visiting astronomer.

The situation is different in Service Mode (SM), where the staff at Paranal execute OBs prepared weeks in advance by remote astronomers. The procedure set by ESO for Phase 2 preparation in the case of moving targets thus includes the submission of an ephemerides file together with each OB. Both the content and format of these ephemerides files are strictly defined. The ESO Phase 2 web pages[1] document these requirements thoroughly. We limit the description here to the core of these files.

For each OB, the ephemerides file lists the successive coordinates and apparent motion of the target, for the whole duration of its observability period. The apparent displacement of the target cannot exceed 30 arcseconds between two consecutive entries (3 arcseconds in the case of SINFONI, due to its much smaller acquisition field of view). As a result, such files may contain up to several thousand entries.

The coordinates are requested as topocentric astrometric equatorial coordinates, at J2000 equinox (International Celestial Reference Frame). The VLT telescope control system corrects for precession, nutation, annual aberration and atmospheric refraction, and coordinates should not be submitted as apparent coordinates.

Ephemerides computation at IMCCE

The Bureau des longitudes, created during the French Revolution by the law of Messidor 7, year 3 by the Convention Nationale, is the academy responsible for the definition of the French national ephemerides. The practical realisation of these ephemerides is entrusted to the Institut de mécanique céleste et de calcul des éphémérides (IMCCE). Aside from the official astronomical and nautical ephemerides publications[2], the IMCCE releases ephemerides computations through its website.

The ephemerides of planets and small Solar System objects (SSOs) are computed in a quasi-inertial reference frame, taking into account post-Newtonian approximations. The geometric positions of the major planets and the Moon are provided by Intégrateur Numérique Planétaire de l'Observatoire de Paris (INPOP) planetary theory (Fienga et al., 2014). Those of small SSOs (asteroids, comets, Centaurs, trans-Neptunian objects) are calculated by numerical integration of the *N*-body perturbed problem (Gragg–Bulirsch–Stoer algorithm: Bulirsch & Stoer, 1966; Stoer & Bulirsch, 1980), with the exception of the natural satellites, for which positions are obtained from dedicated solutions of their motion, e.g., Lainey et al. (2007; 2004a, b) for Mars and Jupiter, Vienne & Duriez (1995) for Saturn, Laskar & Jacobson (1987) for Uranus, and Le Guyader (1993) for Neptune. The typical accuracy of asteroid and comet ephemerides are at the level of tens of milliarcseconds, mainly due to the accuracy of their osculating elements.

In 2005, the IMCCE started to implement Virtual Observatory (VO) compliant interfaces in its ephemerides services (Thuillot et al., 2005). A web portal[3] describes the various services, such as Solar System object identification (SkyBoT: Berthier et al., 2006), or general ephemerides computation (Miriade: Berthier et al., 2009). All our services are accessible via web services (based on the SOAP and HTTP POST method) which allows interaction between the application and the services via HTTP request and web forms, and are integrated in several VO-compliant software packages, such as the widespread Aladin Sky Atlas (Bonnarel et al., 2000). We describe below an extension of the Miriade ephemerides generator to simply and quickly generate ephemerides files compliant with ESO Phase 2 requirements.

A simple solution for Phase 2 preparation

We have implemented the strict VLT parameter file format (PAF) as one of the possible outputs of the Miriade VO ephemerides generator. This makes it easy to generate a fully PAF-compliant ephemerides file by setting the *–pafParams* option within the Miriade web service.

In order to reduce the final number of entries, the service includes a test on two parameters: the target airmass and the Sun's elevation above the horizon. Only entries satisfying both conditions (target above a threshold airmass, and Sun below a threshold elevation) are reported by the service. The default thresholds are an airmass of 2.6 and an elevation of 0 degrees, i.e., sunset and sunrise.

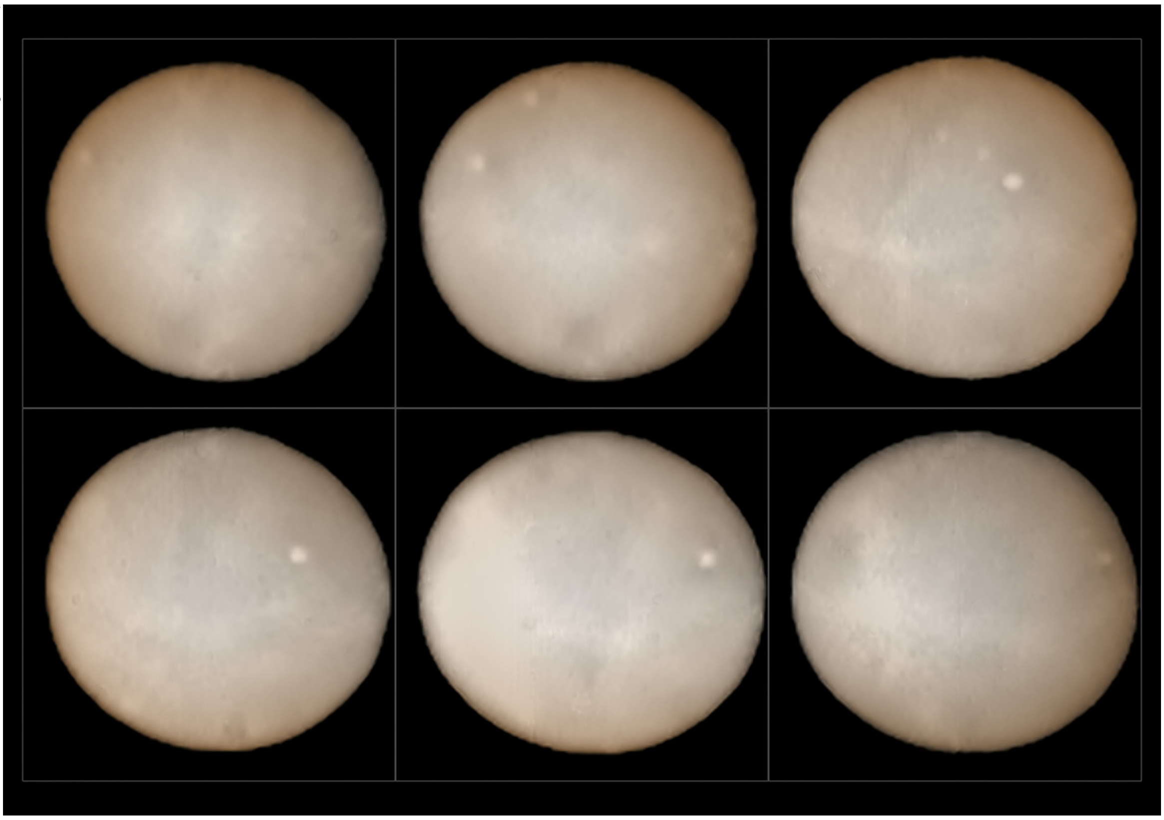
We have also developed a simple query form, hosted on both the IMCCE[4] and ESO[5] websites, in which users need only fill in the target (helped by the autocompletion Application Program Interface [API] of our SsODNet[6] service), the observatory (Paranal or La Silla), the time span and time interval of the ephemerides entries, and, optionally, the thresholds for entry selection (see Figure 1). The code source of this query form can be provided upon request[7], and copy-pasted into any web page, the computations being carried out at IMCCE.

References

Berthier, J. et al. 2009, European Planetary Science Congress 2009, 676
Berthier, J. et al. 2006, ADASS, ASP Conference Series, 351, ed. Gabriel, C., Ponz, D. & Enrique, S., 367
Bonnarel, F. et al. 2000, A&AS, 143, 33
Bulirsch, R. & Stoer, J. 1966, Numerische Mathematik, 8, 1
Fienga, A. et al. 2014, Scientific notes
Lainey, V., Arlot, J. E. & Vienne, A. 2004, A&A, 427, 371
Lainey, V., Dehant, V. & Patzold, M. 2007, A&A, 465, 1075
Lainey, V., Duriez, L. & Vienne, A. 2004, A&A, 420, 1171
Laskar, J. & Jacobson, R. A. 1987, A&A, 188, 212
Le Guyader, C. 1993, A&A, 272, 687
Stoer, J. & Bulirsch, R. 1980, *Introduction to numerical analysis*, (New York: Springer)
Thuillot, W. et al. 2005, BAAS, 37, 638
Vienne, A. & Duriez, L. 1995, A&A, 297, 588

Links

[1] Moving targets in Phase 2: https://www.eso.org/sci/observing/phase2/SMSpecial/MovingTargets.html
[2] Publications of IMCCE: http://www.imcce.fr/en/publications/publications_officielles.html
[3] IMCCE VO Web Portal: http://vo.imcce.fr/
[4] IMCCE ephemerides query form: http://vo.imcce.fr/webservices/miriade/?forms
[5] ESO Phase 2 ephemerides query form: http://www.eso.org/sci/observing/phase2/SMSpecial/MovingTargets.html
[6] SsODNet target name autocompletion: http://vo.imcce.fr/webservices/ssodnet/
[7] Query form source code: http://vo.imcce.fr/webservices/miriade/?clients



ESO, B. Yang and Z. Wahhaj

The two hemispheres of the dwarf planet Ceres are visible in this series of images, taken two weeks apart, made by the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument. Several transitory bright spots are seen, whose nature is not yet well understood. The NASA *Dawn* satellite is currently in orbit around Ceres. See Picture of the Week potw1536 for more detail.

The young reflection nebula IC 2631 illuminated by the bright Herbig Ae/Be star HD 97300 in the Chamaeleon I dark cloud at about 150 pc. HD 97300 has a rich circumstellar environment with C_{60} (Buckminsterfullerene) detected. This colour composite derives from *B*-, *V*- and *I*-band images taken with the MPG/ESO 2.2-metre telescope and the Wide Field Imager. See Release eso1605 for more details.

New Eyes on the Sun — Solar Science with ALMA

Sven Wedemeyer[1]

[1] University of Oslo, Norway

In Cycle 4, which starts in October 2016, the Atacama Large Millimeter/submillimeter Array (ALMA) will be open for regular observations of the Sun for the first time. ALMA's impressive capabilities have the potential to revolutionise our understanding of our host star, with far-reaching implications for our knowledge about stars in general. The radiation emitted at ALMA wavelengths originates mostly from the chromosphere — a complex and dynamic layer between the photosphere and the corona that is prominent during solar eclipses. Despite decades of intensive research, the chromosphere is still elusive due to its complex nature and the resulting challenges to its observation. ALMA will change the scene substantially by opening up a new window on the Sun, promising answers to long-standing questions.

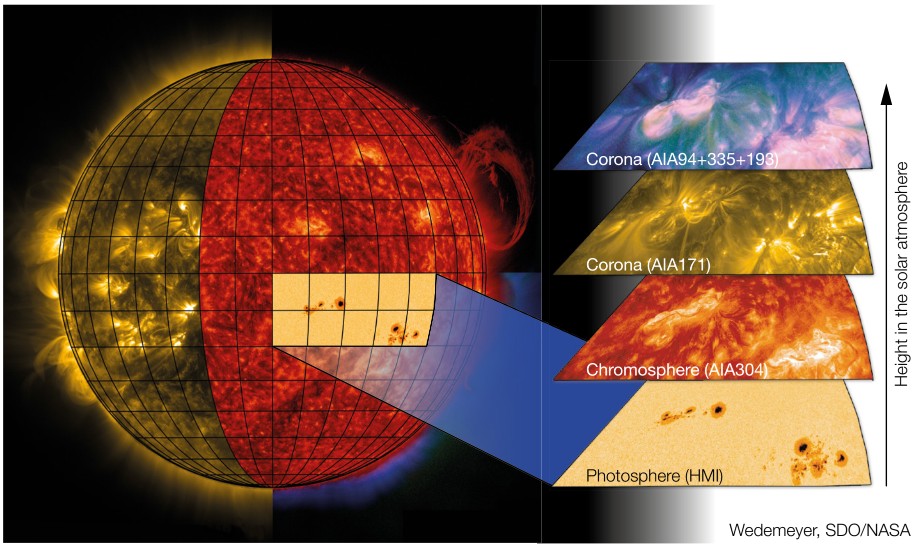


Figure 1. The Sun as seen with NASA's space-borne Solar Dynamics Observatory (SDO) on 20 December 2014, exhibiting a prominence on the top right limb of the solar disc. The images on the right side show close-ups of an active region observed in different filters, which essentially map plasma within different temperature ranges and thus at different height ranges in the solar atmosphere. The lowest panel shows the photosphere, whereas the top two images map the corona at temperatures of more than 6×10^5 K and at millions of Kelvin, respectively. ALMA will observe mostly the intermediate layer, the chromosphere, which is displayed in red.

The Sun — A dynamic multi-scale object

The impressive progress in ground-based and space-borne solar observations, together with numerical modelling, has led to a dramatic change in our picture of the Sun. We know now that the solar atmosphere, i.e., the layers above the visible surface, cannot be described as a static stack of isolated layers. Rather, it has to be understood as a compound of intermittent, highly dynamic domains, which are intricately coupled to one another. These domains are structured on a large range of spatial scales and exhibit a multitude of physical processes, making the Sun a highly exciting plasma physics laboratory.

High-resolution images and movies from modern solar observatories impressively demonstrate the Sun's complexity, which is aesthetic and challenging at the same time (see Figure 1). While most of the Sun is covered by quiet (or quiescent) regions, a few active regions are prominently apparent. They are characterised by strong magnetic field concentrations, visible in the form of sunspots, and produce flares, i.e., violent eruptions during which high-energy particles and intense radiation at all wavelengths are emitted. It is fascinating to realise that the Sun, a reliable source of energy sustaining life on Earth, is at the same time the source of the most violent and hazardous phenomena in the Solar System.

Observing the elusive solar chromosphere

The different radiation continua and spectral lines across the whole spectrum originate from different domains or layers within the solar atmosphere and probe different, complementary plasma properties. Consequently, simultaneous multi-wavelength observations, as obtained during coordinated campaigns with space-borne and ground-based instruments, are a standard in modern solar physics.

Unfortunately, only a few suitable diagnostic techniques for probing plasma conditions in the chromosphere are available. Amongst the most important, currently used, diagnostics are the spectral lines of singly ionised calcium (Ca II) and magnesium (Mg II), and Hα. Examples of observations of the chromosphere in the Ca II spectral line at 854 nm are shown in Figure 2 for different types of region on the Sun, all of them exhibiting a complicated structure shaped by the interaction of magnetic fields and dynamic processes.

The real problem, however, lies in the interpretation of these observations because these spectral lines have complicated formation mechanisms, which include non-equilibrium effects that are a direct result of the intricate nature of the chromosphere. This layer marks the transition between very different domains in the atmosphere of the Sun. Many simplifying assumptions that can be made for the photosphere no longer hold for the rarer chromosphere. There, the matter is optically thick for some wavelength ranges, but mostly transparent for others. The ionisation degree of hydrogen, the major ingredient of the Sun's plasma, is clearly out of equilibrium due to hot, propagating shock waves ionising the gas, but recombination does not occur instantaneously. Consequently, the observed intensities of chromospheric diagnostics usually depend on a large number of factors, which are non-local and involve the previous evolution of the plasma. Deriving the true plasma properties from an observable is therefore a complicated task with limited accuracy.

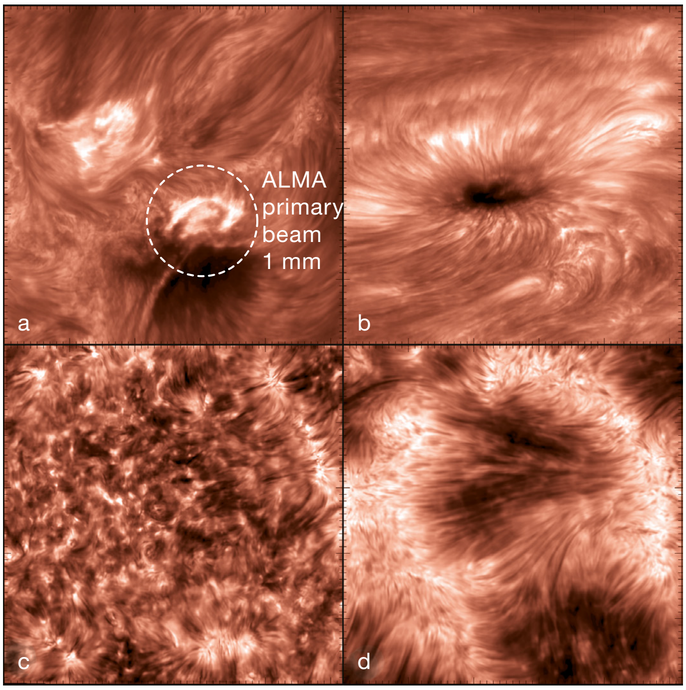


Figure 2. Chromospheric images taken in the core of the Ca II infrared triplet line at a wavelength of 854.2 nm, one of the currently most used chromospheric diagnostics. The observations were carried out with the Swedish 1-metre Solar Telescope. The field of view is about 1 × 1 arcminute (~ 1/30 of the solar diameter). (a) An active region with an ongoing medium-class flare (inside the circle). (b) The chromosphere above a sunspot close to the limb. (c) A quiet region inside a coronal hole close to the disc centre. (d) A decaying active region with a pronounced magnetic network cell close to the disc centre. Courtesy of L. Rouppe van der Voort (see also Wedemeyer et al., 2015).

The combination of the complicated, dynamic and intermittent nature of the chromosphere, with its non-linear relations between observables and plasma properties and the small number of useful diagnostics, have hampered progress in our understanding of this enigmatic layer. On the other hand, this challenge has driven the development of instrumentation and theory. Currently, ground-based observations with the Swedish 1-metre Solar Telescope (SST), aided by adaptive optics and advanced image reconstruction methods, achieve a spatial resolution of ~ 0.1 arcseconds, which corresponds to about 70 kilometres on the Sun. The next generation of solar telescopes with mirror diameters of the order of 1.5 metres currently, and 4 metres in the near future, will continue pushing towards smaller scales, which seems inevitably required in order to explain many observed solar phenomenon not yet understood.

ALMA and a new view of the Sun

The solar radiation continuum at millimetre wavelengths, as will be observed with ALMA, may provide answers to many open questions because it serves as a nearly linear thermometer for the plasma in a narrow layer of the solar chromosphere. In other words, the radiation at millimetre wavelengths gives direct access to fundamental properties such as the gas temperature, which are otherwise not easy to obtain. This unique capability comes, unfortunately, at a price, namely the comparatively long wavelength and the resulting low resolution for a given telescope size compared to optical telescopes. Resolving the relevant spatial scales on the Sun would require enormous single telescope apertures. The technical answer to this problem lies in the construction of large interferometric arrays composed of many telescopes, mimicking a large aperture and facilitating reliable imaging of an extended source like the Sun. Despite many noteworthy efforts in the past, only ALMA can now achieve imaging with an effective spatial resolution, which is, at the shortest wavelengths, close to what is currently achieved at visible wavelengths and thus is sufficient for investigating the small-scale structure of the solar chromosphere.

High-resolution imaging is only one of several key capabilities that make ALMA so interesting for solar observing. In addition, the high achievable temporal and spectral resolution and the ability to measure polarisation are crucial. Since the chromosphere changes on short dynamic timescales, long integration times result in smearing out the pattern, most notably on the smallest scales, which tend to evolve fastest. The first ALMA observations in Cycle 4 will already be able to allow for a time resolution of only 2 seconds, which enables the study of the complex interaction of magnetic fields and shock waves and yet-to-be-discovered dynamical processes — features that otherwise would not be observable. At the same time, the necessary high time resolution makes observing the Sun different from many other astronomical objects. Exploiting the Earth's rotation for improving the Fourier *u–v* plane coverage is not an option and thus other solutions are required for adequate imaging of solar features.

The continuum radiation received at a given wavelength originates from a narrow layer in the solar atmosphere with the height depending on the selected wavelength (see Figure 3). At the shortest wavelengths accessible with ALMA, i.e. 0.3 millimetres, the radiation stems from the upper photosphere and lower chromosphere, whereas the uppermost chromosphere is mapped at ALMA's longest wavelength (just short of 1 centimetre). Rapid scanning through wavelength, which might be achieved via rapid receiver band switching in the future, thus implies scanning through height in the solar atmosphere. Such observation sequences could be developed into tomographic techniques for measuring the three-dimensional thermal structure of the solar chromosphere — a true novelty with a significant scientific impact. The polarisation, which ALMA can measure, provides a measure of the longitudinal component of the magnetic field vector at the same time and in the same layer as the continuum radiation. In the same way, a scan through wavelength can be used to reconstruct the three-dimensional magnetic field structure in the solar chromosphere. Measuring the magnetic field in this layer is in itself a hot topic and has been tried many times.

Furthermore, the many spectral channels and the flexible set-up of the ALMA receiver bands opens up a number of new possibilities. Radio recombination and molecular lines at millimetre wavelengths

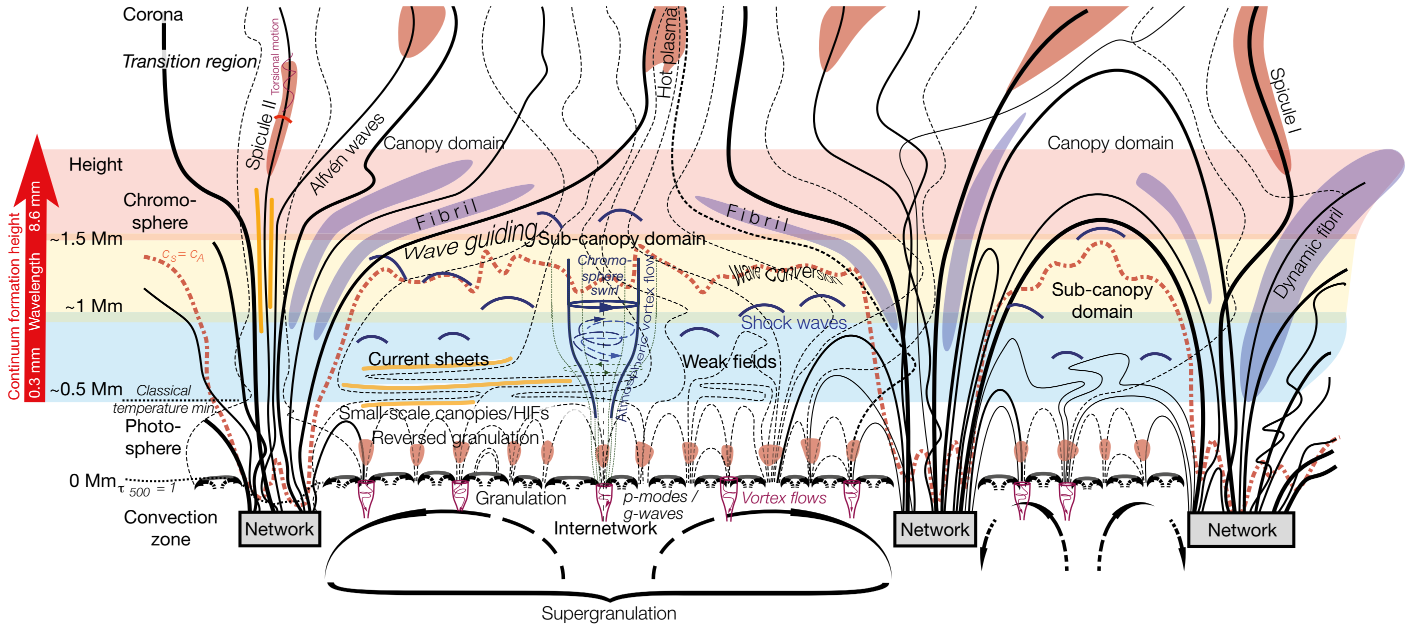


Figure 3. Schematic structure of the atmospheric layers in Quiet Sun regions, i.e. outside the strongest magnetic field concentrations, exhibiting a multitude of different phenomena. The black solid and dotted lines represent magnetic field lines. The arrow to the left and coloured bars illustrate the height range mapped by ALMA. Aspect ratio is not to scale. From Wedemeyer et al. (2015).

are expected to have a large diagnostic potential, providing complementary information about the thermal, kinetic and magnetic state of the chromospheric plasma and possibly adjacent layers. These unprecedented capabilities promise important new findings for a large range of topics and progress in fundamental questions in contemporary solar physics, although the details need to be investigated first.

Central questions in solar physics

The chromosphere plays an important role in the transport of energy and matter throughout the solar atmosphere and influences a number of currently poorly understood phenomena. Given ALMA's unique capabilities, there is little doubt that ALMA will advance our knowledge of the chromosphere in all its different flavours ranging from quiet solar regions to flares. In particular, substantial progress can be expected regarding central questions in contemporary solar physics, which we describe below.

Atmospheric heating

Since the late 1930s, it has been known that the gas temperature in the outer layers of the Sun rises, counter-intuitively, from a temperature minimum of around 4000 K at only a few hundred kilometres above the visible surface to values in excess of a million degrees Kelvin in the corona (Edlén, 1943; see Figure 5). The obvious conclusion is that the outer layers of the Sun are heated, but more than 70 years later it is still not clear exactly how. The same applies to the outer layers of other stars, too, making coronal and chromospheric heating a central and longstanding problem in modern astrophysics.

After many decades of research, a large number of processes are known, which could potentially provide the amount of energy required to explain the high temperatures deduced from observations. The question has therefore shifted to which processes exactly are the most relevant. It seems plausible to assume that a mix of different processes is responsible and that their heating contributions vary for the different types of region on the Sun, each of which have different magnetic field environments and thus different activity levels. Some processes provide continuous heating, producing a basal contribution, while others (e.g., flares, see below) have by nature a more transient effect and cause more variable and intermittent heating.

Next to magnetic reconnection processes and Ohmic heating, wave heating processes emerge as the most likely heating candidates outside flaring regions (see, e.g., De Pontieu et al., 2007). The waves can be primarily distinguished between acoustic and magnetohydrodynamic (MHD) waves, where the latter are subdivided into different wave modes, including for example Alfvén waves. MHD waves can in general contribute directly or indirectly to heating the atmospheric plasma, i.e., through perturbation of the magnetic field resulting in damping of the waves and the associated release of magnetic and kinetic energy. The consequences of this heating are, for instance, observed in the form of the ubiquitous spicules at the solar limb.

A large number of observations and theoretical models suggest further potential candidates for relevant heating mechanisms, for example magneto-acoustic shocks, gravity waves, (magneto-acoustic) high frequency waves, transverse kink waves, multi-fluid effects and plasma instabilities, to name just a few. The large number of possible heating mechanisms has made it difficult to determine which of them actually dominate and how their heating contributions depend on the type of region on the Sun. Knowledge of their characteristic properties, e.g., their spectral signatures, would in principle allow the different mechanisms to be identified,

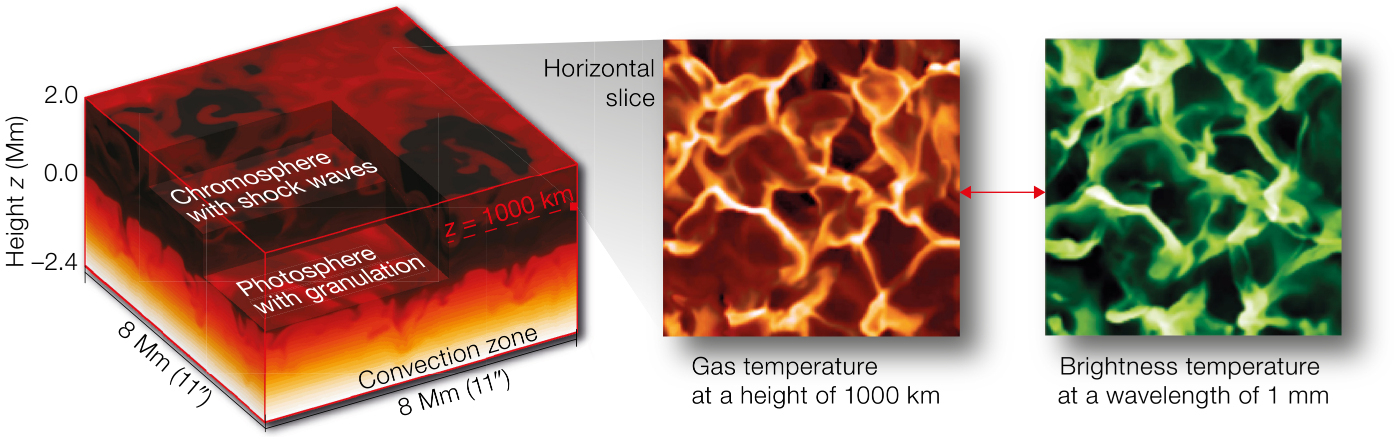


Figure 4. Illustration of a 3D numerical model of a small region in the solar atmosphere (left). The gas temperature in a horizontal cross-section in the chromosphere at a height of 1000 km (centre) corresponds closely to the brightness temperature at a wavelength of 1 mm (right) as derived from a detailed radiative transfer calculation involving the whole model atmosphere. The close match between patterns demonstrates that ALMA can serve as a linear thermometer for the chromospheric plasma.

the disentangling of their contributions and could reveal the sources and sinks of heating in the chromosphere through which all energy has to pass on its way into the corona. This crucial task, however, ultimately requires quantitative and precise measurements, which can produce datasets that completely and unambiguously describe the thermal, magnetic and kinetic state of the chromospheric plasma in a way that is time-dependent and in three spatial dimensions. ALMA has the potential to deliver just such impressive datasets, making it a potential game-changer that would take an essential step towards answering the chromospheric/coronal heating problem.

The answer to the heating problem would have direct implications for the nature of stellar atmospheres and their activity in general. Observations of the activity as a function of stellar type, e.g., by using the observed flux density in the Ca II H + K spectral lines as a chromospheric activity indicator, reveal a lower limit, known as basal flux (Schrijver, 1987). The exact source of this basal flux, however, is still debated. It is most likely the combined product of heating due to acoustic waves and processes connected to the atmospheric magnetic field. In this respect, the Sun may serve as a Rosetta Stone for deciphering the various contributions from the different phenomena to stellar activity, and ALMA would be the tool of choice.

Solar flares

ALMA will also be able to make substantial contributions to answering many open questions concerning solar flares, which can be considered as one of the major problems in contemporary solar physics and thus a very active field of research. While many details are as yet unknown, it is clear that solar flares are produced by the violent reconfiguration and reconnection of the magnetic field in the solar atmosphere. As a result, large amounts of energy, which were stored in the magnetic field prior to an event, are released explosively in the form of radiation and high-energy particles, which are accelerated to very high speeds. The emitted radiation covers the whole electromagnetic spectrum from gamma-rays and X-rays to radio waves. The strongest solar flares observed occur in active regions with strong magnetic fields and release energy on the order of a few 10^{32} ergs, equivalent to a few billion megatons of TNT (Emslie et al., 2005).

Not all flares are equally strong, but they span a large range of strengths. The much weaker micro- and nano-flares occur on small spatial scales and may contribute to the heating of the corona in a more subtle and continuous way. In contrast, the strongest flares are sometimes accompanied by coronal mass ejections (CME) and can lead to the ejection of solar plasma into interplanetary space. Such space weather events can have notable effects on Earth, ranging from beautiful aurorae to disruptions of

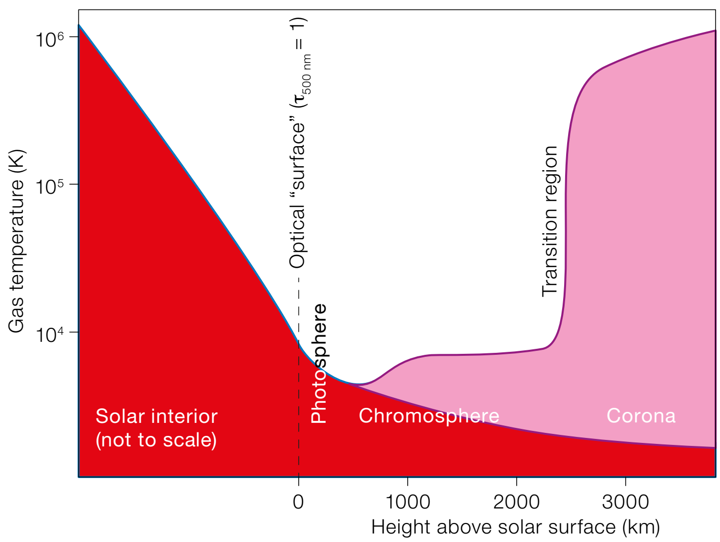


Figure 5. Schematic average gas temperature of the Sun as function of height. The lower curve illustrates how the temperature in the upper layers would decline without heating, whereas the upper curve is the actual average profile implied by observations.

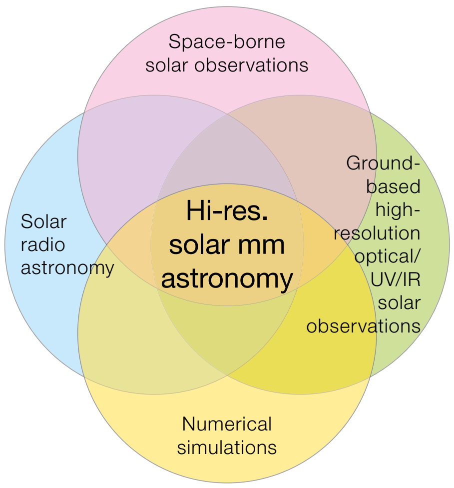


Figure 6. Shaping a new research field: high-resolution solar millimetre astronomy.

power grids (like the Quebec blackout in 1989) and the satellite infrastructure on which our modern society so sensitively depends.

The strong flares observed so far may not mark the upper end of the scale. The possible occurrence of super-flares is discussed (Maehara et al., 2012), which may release more energy than the infamous Carrington event of 1859. This powerful geomagnetic storm was the result of a CME hitting the Earth's magnetosphere associated with a strong solar flare, resulting in aurorae unusually far from the poles, visible in Hawaii, Cuba, Liberia and Queensland, but also responsible for the failure of telegraph systems. A CME of similar strength occurred in 2012 but luckily missed the Earth. Such super-energetic events are certainly rare, but they would have truly devastating consequences for modern society and must therefore be studied. Super-flares have been observed on other stars and red dwarf stars even exhibit mega-flares, which can be more than a thousand times stronger than their strongest (known) solar analogues and thus exceed the bolometric luminosity of the whole star in minutes (Hawley & Pettersen, 1991).

Open questions about solar and stellar flares on all scales concern, for example, the particle acceleration mechanisms and the source of the still-enigmatic emission component, which is observed at sub-THz frequencies. ALMA's high spectral, spatial and temporal resolution for observations in the sub-THz range, together with the ability to probe the thermal structure and magnetic fields in flaring regions, promise ground-breaking discoveries in this respect. Already the thermal free-free radiation, which is mostly due to electron-ion free-free absorption and H^- free-free absorption, provides much needed information. In addition, however, ALMA can also detect the non-thermal radiation component produced by gyro-synchrotron and gyro-resonance processes, which become important in the vicinity of strong magnetic fields and can thus provide important clues about the acceleration of charged particles during flares. Another intrinsic feature of flares, which can be exploited by ALMA, are quasi-periodic pulsations, which constrain the physical mechanisms behind the accumulation and release of magnetic energy and the acceleration of particles.

Solar prominences

ALMA is an ideal tool for probing the cool plasma in the solar atmosphere and will therefore be able to contribute to answering many still-open questions about solar prominences. Solar prominences are extended structures in the solar atmosphere that reach up from the visible surface into the corona (Vial & Engvold, 2015). Prominences appear bright when seen above the solar limb (Figure 1, top right) and as (dark) filaments when seen against the bright solar disc. The gas contained in a prominence is much cooler (some 10^4 K) and denser than the surrounding 10^6 K coronal plasma and is supported by magnetic fields against gravity.

Quiescent prominences exhibit large-scale structures that can measure a few 100 000 kilometres, thus stretching over a significant portion of the Sun. These prominences can remain stable for many days or weeks, making them one of the longest-lived solar phenomena. Their fine structures, on the other hand, change on timescales of a few minutes. In contrast, active prominences live for a much shorter time, exhibit large-scale motions and can erupt within hours. Erupting prominences can propel substantial amounts of magnetised plasma at high speeds into interplanetary space and are thus one of the primary sources of space weather. It is not clear what exactly triggers such eruptions. Among the processes, which may contribute and could be studied with ALMA, are (giant) solar tornadoes, which form at some of the legs of prominences. The rotation of the magnetic prominence legs builds up twist in the magnetic field of the overlying prominence, which may eventually cause a destabilisation of the whole structure.

Other important questions, which could be addressed with ALMA, concern: the thermal structure of prominence bodies with their spatial fine-structure, which is composed of fine sub-arcsecond threads; and the transition to the ambient coronal medium, with resulting implications for the energy balance of prominences. Equally, it is not yet settled what the elementary magnetic field structures are or how they connect to the field at the solar surface. In this respect, ALMA observations at high spatial and temporal resolutions will help to track the changes of the prominence plasma and the magnetic field, giving clues on how solar prominences form, how they evolve and eventually diminish or erupt.

The advantage of using ALMA lies again in the easier interpretation of the observations. The spectral lines in the optical and ultraviolet currently used for prominence observations are optically thick, so that detailed radiative transfer calculations are necessary for their analysis. In contrast, the prominence plasma is optically thin at ALMA wavelengths, which makes the interpretation much simpler and straightforward. In addition, observations of waves and oscillations in prominences provide essential information and constraints on the magnetic field structure. Prominences have already been seen with ALMA during test observations and will certainly be an exciting target both for high-resolution studies of their dynamic fine-structure and for mosaics capturing their large-scale structure.

Preparing the future

As in many other fields of astrophysics, numerical simulations have become an essential tool in solar physics. They help to simulate what ALMA might observe

(Figure 4). Such artificial observations of the Sun allow for the development and optimisation of observing strategies, which are quite different for the dynamic Sun than for most other ALMA targets. For this purpose, and in connection with solar ALMA development studies, an international network was initiated in 2014, which aims at defining and preparing key solar science with ALMA through simulation studies: SSALMON[1] (Solar Simulations for the Atacama Large Millimeter Observatory Network). The network has currently (as of early 2016) 77 members from 18 countries around the world. Furthermore, the SolarALMA project, funded by the European Research Council from 2016 to 2021 and hosted at the University of Oslo, aims at addressing the heating problem through a synthesis of ALMA observations and numerical simulations.

In essence, these developments illustrate that a new research field is emerging, which could be named high-resolution solar millimetre astronomy (schematically shown in Figure 6). This new field brings together solar radio astronomy, which was previously limited to lower spatial resolution, and ground-based and space-borne high-resolution observations at other wavelength ranges, combined with state-of-the-art numerical modelling. This is a truly golden era for studies of the solar chromosphere with many exciting scientific results expected for the coming years.

Acknowledgements

Future solar observing with ALMA is made possible due to the dedicated work of many colleagues as part of Commissioning and Science Verification/ Extension of Capabilities (CSV/EOC) activities carried out by the solar development teams of the North American, European and East Asian ALMA Regional Centres (ARCs) and the Joint Astronomical Observatory (JAO), and as part of recent SSALMON publications. Special thanks in connection with this article go to H. Hudson and N. Labrosse.

References

De Pontieu, B. et al. 2007, Science, 318, 1574
Edlén, B. 1943, Zeitschrift für Astrophysik, 22, 30
Emslie, A. G. et al. 2005, Journal of Geophysical Research (Space Physics), 110, A9, 11103
Hawley, S. L. & Pettersen, B. R. 1991, ApJ, 378, 725
Maehara, H. et al. 2012, Nature, 485, 478
Schrijver, C. J. 1987, A&A, 172, 111
Vial, J.-C. & Engvold, O. 2015, A&SS Library, Vol. 415, (Switzerland: Springer International Publishing)
Wedemeyer, S. et al. 2015, SSRv, Online First

Links

[1] SSALMON: http://ssalmon.uio.no

ESO/C. Malin

A meteor burning up in the Earth's atmosphere was captured on camera during a time-lapse exposure of the Atacama Large Millimeter/submilimeter Array (ALMA) at Chajnantor.

The Central Role of FORS1/2 Spectropolarimetric Observations for the Progress of Stellar Magnetism Studies

Markus Schöller[1]
Swetlana Hubrig[2]
Ilya Ilyin[2]
Matthias Steffen[2]
Maryline Briquet[3,2]
Alexander F. Kholtygin[4]

[1] ESO
[2] Leibniz-Institut für Astrophysik Potsdam (AIP), Germany
[3] Institut d'Astrophysique et de Géophysique, Université de Liège, Belgium
[4] Astronomical Institute, St Petersburg State University, Russia

The spectropolarimetric mode of the FOcal Reducer and low dispersion Spectrographs (FORS), which was first implemented in FORS1, and then moved to FORS2 seven years ago, has made it possible to probe the presence of magnetic fields in stars of different spectral classes at almost all stages of stellar evolution. While in the early days of FORS1, many of the observations were related to magnetic Ap/Bp stars and their progenitor Herbig Ae/Be stars, recent spectropolarimetric studies with FORS2 have involved more challenging targets, such as massive O- and B-type stars in clusters and in the field, very fast rotating massive stars with magnetospheres, Wolf–Rayet stars and central stars of planetary nebulae. The role of FORS observations for stellar magnetic field measurements is summarised and improvements in the measurement technique are described.

Magnetic fields in massive stars

During recent years a number of FORS2 magnetic studies have focused on the detection of magnetic fields in early B- and O-type stars. The characterisation of magnetic fields in massive stars is indispensable for the understanding of the conditions controlling the presence of those fields and their implications for stellar physical parameters and evolution. Accurate studies of the age, environment and kinematic characteristics of magnetic stars are also promising to gain new insights into the origin of these magnetic fields. While a number of early B-type stars were identified as magnetic several decades ago, the first magnetic field detection in an O-type star was achieved only 13 years ago, even though the existence of magnetic O-type stars had been suspected for a long time. The many unexplained phenomena observed in massive stars that are thought to be related to magnetic fields, like cyclical wind variability, Hα emission variation, chemical peculiarity, narrow X-ray emission lines and non-thermal radio/X-ray emission have all acted as indirect observational evidence for the presence of magnetic fields.

However direct measurements of the magnetic field strength in massive stars, using spectropolarimetry to determine the Zeeman splitting of the spectral lines are difficult, since only a few spectral lines are available for these measurements. In addition, these spectral lines are usually strongly broadened by rapid rotation and macroturbulence and frequently appear in emission or display P Cyg profiles. In high-resolution spectropolarimetric observations, broad spectral lines frequently extend over adjacent orders so that it is necessary to adopt order shapes to get the best continuum normalisation. Furthermore most of the existing high-resolution spectropolarimeters operate at smaller telescopes and cannot deliver the necessary high signal-to-noise (SNR) observations for the majority of the massive stars. In particular, O-type stars and Wolf–Rayet (WR) stars are rather faint. The Bright Star Catalog contains only about 50 O-type stars and very few WR stars.

Significant line broadening in massive stars appears to make the low-resolution VLT instrument FORS2 — and prior to that FORS1 — the most suitable instrument in the world to undertake the search for the presence of magnetic fields. FORS offers the appropriate spectral resolution and the required spectropolarimetric sensitivity, giving access to massive stars even in galaxies beyond the Milky Way. Only the Faint Object Camera and Spectrograph (FOCAS) at the Subaru Telescope has an operating spectropolarimetric mode and, pending the commissioning of the PEPSI spectrograph in polarimetric mode installed at the Large Binocular Telescope (LBT), no further high-resolution spectropolarimetric capabilities are available on any of the 8–10-metre-class telescopes.

We started the first spectropolarimetric observations of O-type stars with FORS1 in 2005. During a survey of thirteen O-type stars the discovery of the presence of a magnetic field was announced in the Of?p star HD 148937. The class of Of?p stars was introduced by Walborn (1973) and includes only five stars in our Galaxy. Of?p stars display recurrent spectral variations in certain spectral lines, sharp emission or P Cygni profiles in He I and the Balmer lines, and strong C III emission lines around 4650 Å. In recent years it has been shown that all Of?p stars are magnetic with field strengths from a few hundred Gauss to a few kG. Among them, only two Of?p stars, HD 148937 and CPD-28 2561, are observable from Paranal, and it is noteworthy that their first magnetic field detections were achieved through FORS1 and FORS2 observations (Hubrig et al., 2013).

All FORS1/2 observations of HD 148937 are presented in Figure 1, together with observations from the Echelle Spectro-Polarimetric Device for the Observation of Stars (ESPaDOnS), obtained at the Canada France Hawaii Telescope (CFHT) by Wade et al. (2012). This figure demonstrates the excellent agreement between the FORS2 and ESPaDOnS measurements, highlighting the outstanding potential of FORS2 for the detection of magnetic fields and the investigation of the magnetic field geometry in massive stars. Notably, while an exposure time of 21.5 hours at the CFHT was necessary to obtain seven binned measurements, the exposure time for the individual FORS2 observations accounted only for two to four minutes, and only 2.3 hours were used for our observations at six different epochs, including telescope presets and the usual overheads for readout time and retarder waveplate rotation.

Also our FORS2 measurements of the mean longitudinal magnetic field of the second Of?p star CPD-28 2561 were consistent with a single-wave variation during the stellar rotation cycle, indicating a dominant dipolar contribution to the magnetic field topology with an estimated polar strength of the surface dipole B_d

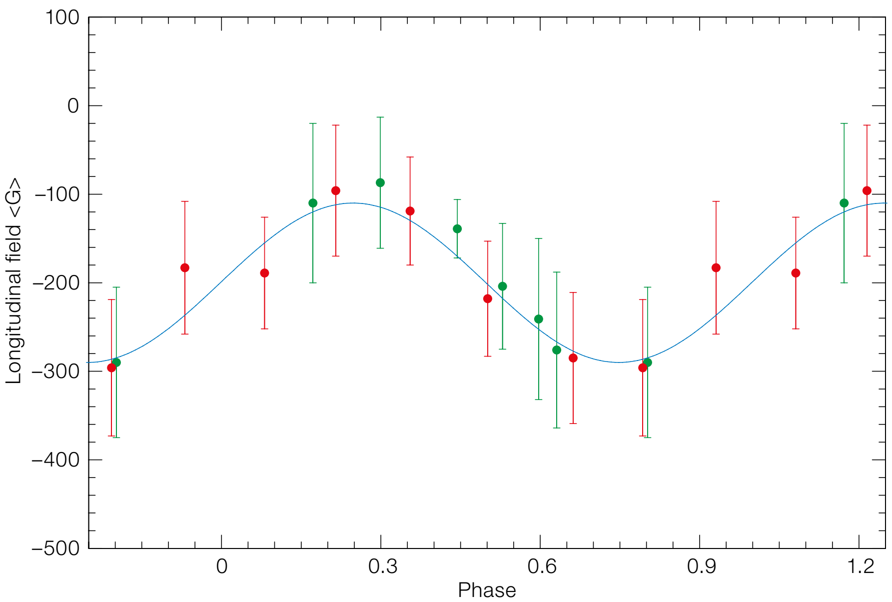


Figure 1. Longitudinal magnetic field variation of the Of?p star HD 148937 according to the 7.032-day period determined by Nazé et al. (2010). Red symbols correspond to ESPaDOnS observations (Wade et al., 2012) while green symbols are our FORS1 and FORS2 measurements (Hubrig et al., 2013). Note that the measurement errors for both ESPaDOnS and FORS1/2 observations are of similar order.

larger than 1.15 kG (Hubrig et al., 2015). We note that in our studies of these two Of?p stars, none of the reported detections reached a 4σ significance level. While 3σ detections with FORS2 cannot always be trusted for single observations, they are genuine if the measurements show smooth variations over the rotation period, similar to those found for the Of?p stars HD 148937 and CPD-28 2561.

The presence of magnetic fields might change our whole picture about the evolution from O stars via WR stars to supernovae or gamma-ray bursts. Neglecting magnetic fields could be one of the reasons why models and observations of massive-star populations are still in conflict. Magnetic fields in massive stars may also be important in studies of the dynamics of the stellar winds. A few years ago, our team carried out FORS2 observations of a sample of Galactic WR stars and one WR star in the Large Magellanic Cloud. Magnetic fields in WR stars are especially hard to detect because of wind broadening of their spectral lines. Moreover all photospheric lines are absent and the magnetic field is measured on emission lines formed in the strong wind. Remarkably spectropolarimetric monitoring of WR6, one of the brightest WR stars, revealed the sinusoidal nature of $\langle B_z \rangle$ variations with a period of 3.77 days and an amplitude of only 70–90 G (Hubrig et al., 2016).

Pulsating stars

Recent high-precision, uninterrupted high-cadence, space photometry using a number of satellites (e.g., the Wide Field Infrared Explorer [WIRE], the Microvariability and Oscillation of Stars [MOST], the Convection Rotation et Transits planétaires [CoRoT], Kepler and the Bright Target Exploter [BRITE]) have led to a revolutionary change in the observational evaluation of variability of massive stars. Supported by results from photometric monitoring, it is expected that a large fraction of massive stars show photometric variability, due to either β Cephei- or slowly pulsating B-type star (SPB) like pulsations, stochastic *p*-modes or convectively-driven internal gravity waves.

High-resolution spectropolarimetric observations of pulsating stars frequently fail to show credible measurement results if the whole sequence of sub-exposures at different retarder waveplate angles has a duration comparable to the timescale of the pulsation variability. As an example, even for the bright, fourth magnitude β Cep star ξ^1 CMa with a pulsation period of 5 hours, a full High Accuracy Radial Velocity Planetary Searcher (HARPS) sequence of sub-exposures requires about 30 minutes. In contrast one FORS2 observation of the same star lasts less than 10 minutes. Owing to the strong changes in the line profile positions and profile shape in the spectra of pulsating stars, a method using spectra averaged over all sub-exposures leads to erroneous wavelength shifts, and thus to wrong values for the longitudinal magnetic field.

For the first time, FORS1 magnetic field surveys of SPB stars and β Cep stars were carried out by our team from 2003 to 2008. As a number of pulsating stars showed the presence of a magnetic field, our observations implied that β Cep and SPB stars can no longer be considered as classes of non-magnetic pulsators. Notably, although the presence of magnetic fields in these stars has already been known for more than ten years, the effect of these fields on the oscillation properties is not yet understood and remains to be studied.

ξ^1 CMa, discovered as magnetic with FORS1 observations, is still the record holder with the strongest mean longitudinal magnetic field among the β Cep stars of the order of 300–400 G (Hubrig et al., 2006). Using FORS2 measurements obtained in Service Mode in 2009/10, we were able to detect rotational modulation of its magnetic field with a period of about 2.19 days and estimate a magnetic dipole strength of about 5.3 kG (Hubrig et al., 2011a).

Fully unexpected observations of this particular star with the XMM-Newton telescope revealed, for the first time, X-ray pulsations with the same period as the stellar radial pulsation (Oskinova et al., 2014). This first discovery of X-ray pulsations from a non-degenerate massive star stimulates theoretical considerations for the physical processes operating in magnetised stellar winds.

Our observations of pulsating stars also allowed the first detection of a magnetic field in another β Cep star, ε Lupi, which is a double-lined spectroscopic binary system and which recently received

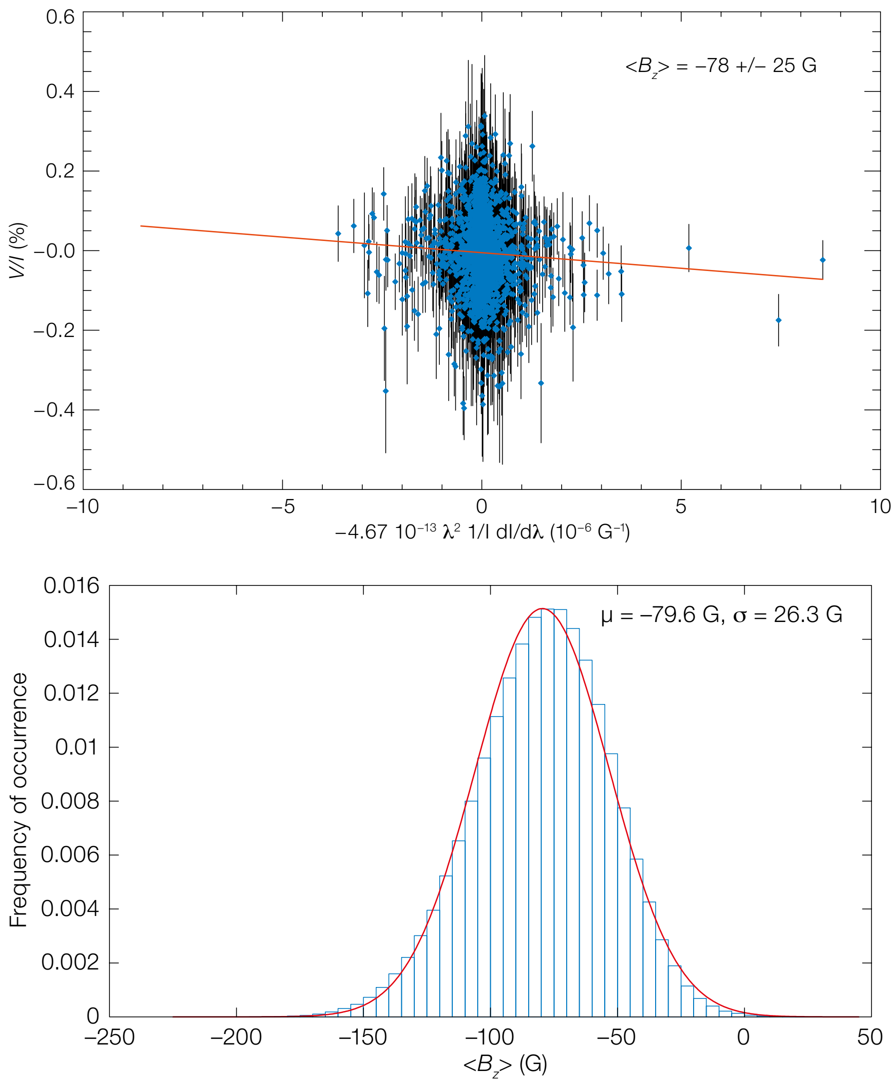


Figure 2. Hen 2-113: Monte Carlo bootstrapping regression detection of a $\langle B_z \rangle = -80 +/- 26$ G mean longitudinal magnetic field using uncontaminated stellar lines only (upper) and the corresponding (slightly non-Gaussian) distribution of $\langle B_z \rangle$ obtained from the Monte-Carlo bootstrapping technique (lower).

attention due to the presence of a magnetic field in both components. Since binary systems with magnetic components are rather rare, the detection of a magnetic field in this system using low resolution FORS1 spectropolarimetry indicates the potential of FORS2 for magnetic field searches in binary or multiple systems.

Diverse exotic targets

The spectropolarimetric capability of the FORSes has also been exploited by observations of a number of stars with a specific circumstellar environment, such as: the central stars of planetary nebulae (PNe) with different morphologies, including round, elliptical and bipolar; PNe central stars of WR type; Herbig Ae/Be stars with circumstellar discs showing magnetospheric accretion; and the X-ray binary Cyg X-1 containing a black hole.

First reports on magnetic fields in PNe using FORS1 measurements and claiming the detection of strong magnetic fields in two central stars could not be confirmed by improved analysis methods (Jordan et al., 2012). New FORS2 spectropolarimetric observations of a sample of 12 PN central stars achieved much lower detection limits than previous observations (Steffen et al., 2014). Our measurements have excluded the presence of a strong magnetic field in any of the central stars of our sample. However weaker fields of the order of 100 G were detected in the central star of the young elliptical planetary nebula IC 418 as well as in the WR-type central star of the bipolar nebula Hen 2-113.

We chose a subset of spectral lines originating exclusively in the photosphere and the wind of the central stars and not appearing in the surrounding nebular spectra for the measurements. Furthermore the pipeline for the spectral extraction includes by default background subtraction. In Figure 2 we present the Monte Carlo bootstrapping regression detection of a $\langle B_z \rangle = -80 +/- 26$ G mean longitudinal magnetic field in Hen 2-113 using uncontaminated stellar lines only. Since the majority of the central stars of planetary nebulae are very faint, only low-resolution FORS2 observations allow the detected magnetic fields of the central stars to be monitored with sufficient precision.

The first FORS1 observations of Herbig Ae/Be stars by our team date back to 2003. Models of magnetically driven accretion and outflows are not well developed for these stars due to poor knowledge of their magnetic field topology. On the other hand it is obvious that understanding the interaction between the central stars, their magnetic fields and their protoplanetary discs is crucial to our efforts to account for the diversity of exoplanetary systems. Only about 20 Herbig stars have been reported to host magnetic fields so far and our recent compilation of stars with published measurements of magnetic fields indicates that their field strength is predominantly below 200 G.

Among the sample of Herbig Ae/Be stars HD 101412 stands out due to its very slow rotation and the presence of chemical spots. Wade et al. (2007) measured a magnetic field of the order of +500 G using hydrogen lines and −500 G using metal lines with FORS1 from the same spectra. A subsequent study of Ultraviolet Visible EchelleSpectrograph (UVES) and HARPS spectra of HD 101412

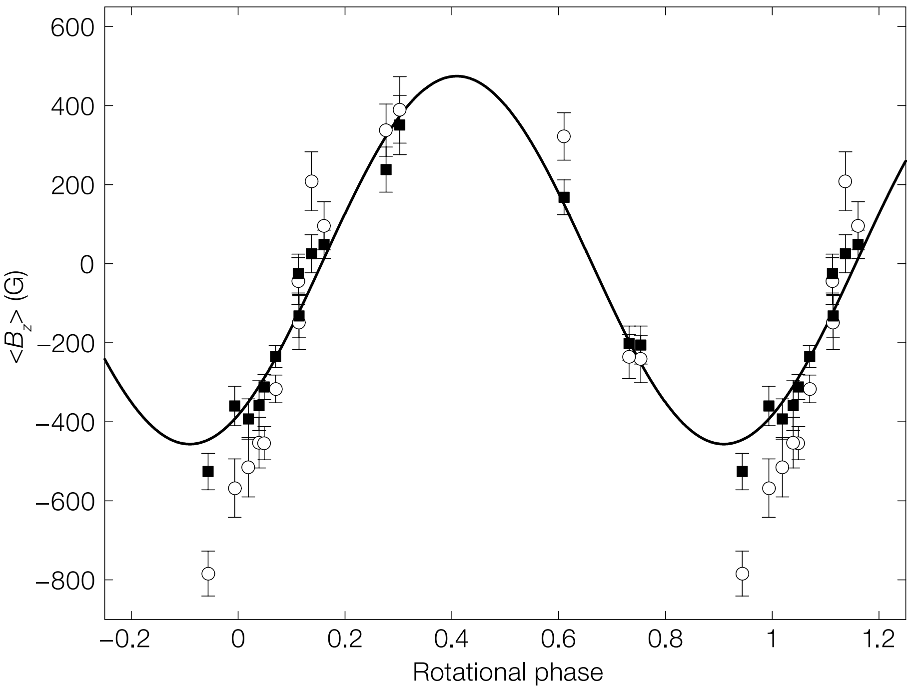


Figure 3. Phase diagram of HD 101412 with the best sinusoidal fit for the longitudinal magnetic field measurements using all lines (filled squares) and hydrogen lines only (open circles).

revealed the presence of resolved, magnetically split, lines, indicating a variable magnetic field modulus changing from 2.5 to 3.5 kG (Hubrig et al., 2010). Our multi-epoch FORS2 polarimetric spectra of this star, acquired over 62 days in Service Mode in 2010, have been used to search for a rotation period and to constrain the geometry of the magnetic field. The search for the rotation period using magnetic and photometric data resulted in *P* = 42.076 +/– 0.017 days (Hubrig et al., 2011b). In Figure 3 we present the corresponding phase diagram for all the available FORS2 mean longitudinal magnetic field measurements using either the whole spectrum or only the hydrogen lines, including the best sinusoidal fit to these data. The presence of a rather strong magnetic field on the surface of HD 101412 makes it one of the best candidates for studies of the impact of the magnetic field on the physical processes occurring during stellar formation.

Cyg X-1 is one of the brightest X-ray binary systems with an orbital period of 5.6 days. This system consists of an optical component — an O9.7Iab supergiant — and a black hole as an invisible component. Previous spectropolarimetric observations with FORS1 revealed the presence of a weak longitudinal magnetic field in the optical component (Karitskaya et al., 2010). The detected magnetic field showed variations over the orbital period of 5.6 days with an amplitude of about 100 G. This was the first successful attempt to measure a magnetic field in a binary with a black hole. However the character of the variability of the magnetic field has changed between the different years of observations, suggesting the existence of year-to-year variations. Quasi-simultaneous FORS2 monitoring of circular and linear polarisation over the orbital period is scheduled in observing Period 97. Such monitoring will provide us with unique information about the magnetic field topology and the processes taking place in a system containing a black hole.

Improvements in measurement technique

Since our last *Messenger* report on FORS1 observations (Hubrig et al., 2009), the measurement strategy has been modified in several aspects. The parallel and perpendicular beams are extracted from the raw FORS2 data using a pipeline written in the MIDAS environment by Thomas Szeifert, who was the first person to recognise the potential of FORS1 for surveying magnetic fields in stellar atmospheres, and he has supplied our team with the necessary knowhow. In the reduction process we perform a rectification of the Stokes *V/I* spectra and calculate null profiles, *N*, as pairwise differences from all available *V* profiles. From these profiles, 3σ-outliers are identified and used to clip the *V* profiles. This step removes spurious signals, which mostly come from cosmic rays, and also reduces the noise. A full description of the updated data reduction and analysis will be presented in a paper by Schöller et al. (in prep.).

The mean longitudinal magnetic field, $\langle B_z \rangle$, is defined by the slope of the weighted linear regression line through the measured data points, where the weight of each data point is given by the squared signal-to-noise ratio of the Stokes *V* spectrum. The formal 1σ error of $\langle B_z \rangle$ is obtained from the standard relations for weighted linear regression. This error is inversely proportional to the root mean square (RMS) signal-to-noise ratio of Stokes *V*. Finally we apply the factor $\sqrt{(\chi^2_{min}/\nu)}$ to the error determined from the linear regression if larger than 1.

Since 2014 we have also implemented the Monte-Carlo bootstrapping technique, where we typically generate *M* = 250 000 statistical variations of the original dataset and analyse the resulting distribution $P(\langle B_z \rangle)$ of the *M* regression results. The mean and standard deviation of this distribution are identified with the most likely mean longitudinal magnetic field and its 1σ error respectively. The main advantage of this method is that it provides an independent error estimate.

A number of discrepancies in the published measurement accuracies have been reported by Bagnulo et al. (2015a; see also Bagnulo et al., 2015b), who used the FORS1 pipeline to reduce the full content of the FORS1 archive. The same authors have published a few similar papers in recent years suggesting that very small amounts of instrument flexure, negligible in most of the instrument applications, may be responsible for some spurious magnetic field detections and that FORS1 detections may be considered reliable only at a level greater than 5σ. However no report on the presence of flexure from any astronomer observing with the FORS instruments has ever been published in the past. The authors also discuss the impact of seeing if the exposure time is comparable with the atmospheric coherence time (which they incorrectly assume to be in seconds and not in milliseconds). Not until their most recent work have these authors presented the level of intensity flux for each spectrum and reported which spectral regions were used for the magnetic field measurements. However no fluxes for left-hand and right-hand polarised spectra are available separately, thus it is not possible to reproduce their measurements. We note that small changes in the spectral regions selected for the measurements can also have a significant impact on the measurement results.

Since the measurement accuracies predominantly depend on photon noise, an improper extraction of the spectra, for instance the use of smaller extraction windows, would explain why Bagnulo et al. disregarded 3σ detections by other authors. If the levels of flux for each subexposure compiled in the catalogue of Bagnulo et al. (2015a) are inspected, it shows that their levels are frequently lower, down to 70%, in comparison with those obtained in our studies. It is obvious that the detection of weak magnetic fields is particularly affected if the extracted fluxes are low. From the consideration of the signal-to-noise ratios presented by Bagnulo et al., we also noted that emission lines are not taken into account during the measurements. The reason for this is not clear as there is no need to differentiate between absorption and emission lines: the applied relation between the Stokes *V* signal and the slope of the spectral line wing holds for both types of lines, so that the signals of emission and absorption lines add rather than cancel.

In order to increase the reliability of FORS2 magnetic field detections, but also to carry out a quantitative atmospheric analysis and probe spectral variability, it is certainly helpful to follow up FORS2 detections with high-resolution HARPS observations. To our knowledge the only collaboration that uses FORS2 and HARPS to monitor magnetic fields is the BOB (B-fields in OB stars) collaboration (Morel et al., 2014), which is focused on the search for magnetic fields in massive stars. Combining observations with different instruments has allowed the BOB collaboration to report the presence of magnetic fields in a number of massive stars during the last couple of years. As an example, the first detection of a magnetic field in the single slowly rotating O9.7V star HD 54879 was achieved with FORS2 and was followed up with HARPS observations. These observations show that HD 54879 is so far the strongest magnetic single O-type star detected with a stable and normal optical spectrum (Castro et al., 2015).

References

Bagnulo, S. et al. 2015a, A&A, 583, A115
Bagnulo, S. et al. 2015b, The Messenger, 162, 51
Castro, N. et al. 2015, A&A, 581, A81
Hubrig, S. et al. 2006, MNRAS, 369, L61
Hubrig, S. et al. 2010, Astron. Nachr., 331, 361
Hubrig, S. et al. 2009, The Messenger, 135, 21
Hubrig, S. et al. 2011a, ApJ, 726, L5
Hubrig, S. et al. 2011b, A&A, 525, L4
Hubrig, S. et al. 2013, A&A, 551, A33
Hubrig, S. et al. 2015, MNRAS, 447, 1885
Hubrig, S. et al. 2016, MNRAS, in press
Jordan, S. et al. 2012, A&A, 542, A64
Karitskaya, E. A. et al. 2010, IBVS, 5950, 1
Morel, T. et al. 2014, The Messenger, 157, 27
Nazé, Y. et al. 2010, A&A, 520, A59
Oskinova, L. M. et al. 2014, NatCo, 5E4024
Steffen, M. et al. 2014, A&A, 570, A88
Wade, G. A. et al. 2007, MNRAS, 376, 1145
Wade, G. A. et al. 2012, MNRAS, 419, 2459
Walborn, N. R. 1973, AJ, 78, 1067

ESO/B. Tafreshi (twanight.org)

Star trails at Paranal over three of the Auxiliary Telescopes of the Very Large Telescope Interferometer (VLTI).

The QUEST–La Silla AGN Variability Survey

Régis Cartier[1]
Paulina Lira[2]
Paolo Coppi[3]
Paula Sánchez[2]
Patricia Arévalo[4]
Franz E. Bauer[5,6]
Ricardo R. Muñoz[2]

[1] School of Physics & Astronomy, University of Southampton, United Kingdom
[2] Departamento de Astronomia, Universidad de Chile, Chile
[3] Department of Astronomy, Yale University, USA
[4] Instituto de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Chile
[5] Instituto de Astrofísica, Pontifícia Universidad Católica de Chile, Chile
[6] Space Institute, University of Tennessee, Tullahoma, USA

It is widely believed that supermassive black holes reside at the centres of every massive galaxy. When actively accreting they are known as Active Galactic Nuclei (AGNs). Most commonly, their presence is exposed by the radiation generated by the accretion of matter toward their centres. This radiation can show dramatic flux variations on timescales from minutes to years that can be observed across the full electromagnetic spectrum from X-ray to radio wavelengths. Although the exact origin of AGN variability remains unclear, such variability can be used as an efficient tool to find them and to understand the origin and demographics of flux variations. To this end, we have undertaken an AGN variability survey using the QUEST camera on the ESO 1.0-metre Schmidt Telescope at La Silla. The QUEST–La Silla AGN Variability Survey aims to discover thousands of new AGNs, and provide highly sampled light curves to study the ultraviolet/optical flux variations to a limiting magnitude of *r* ~ 21.5 mag.

The long-term variability of active galactic nuclei is mainly the result of modulations in the flux emitted by the accretion disc, although changes in the hot X-ray emitting corona or a possible jet can also drive variations at shorter timescales.

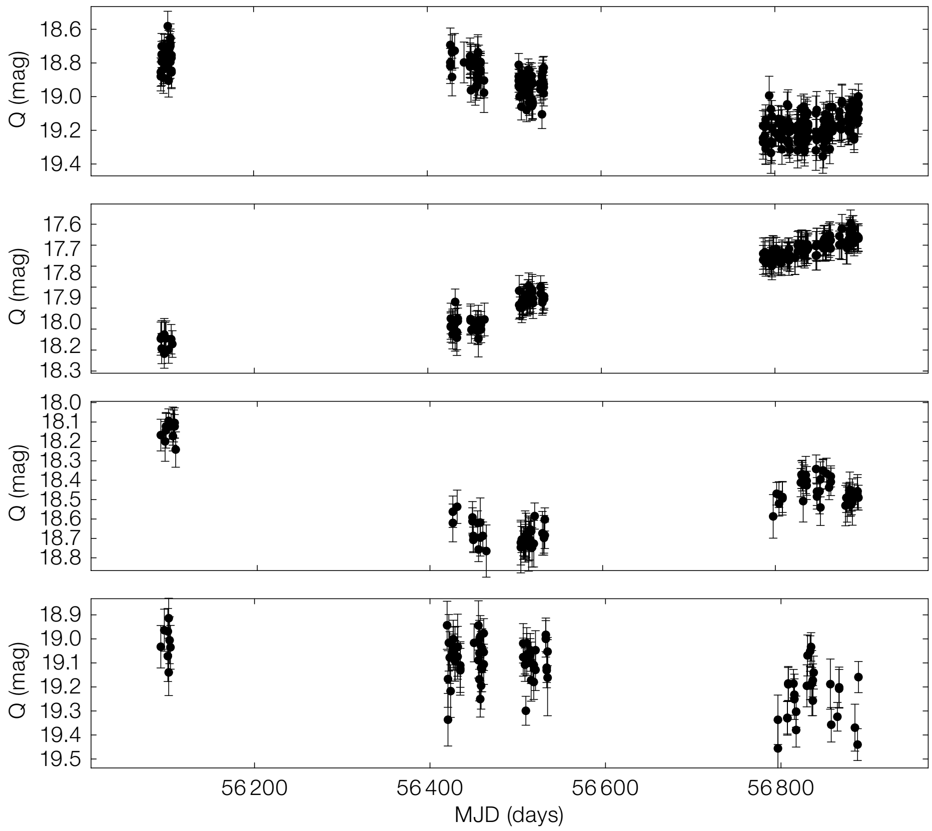


Figure 1. Light curves of QSO candidates in the redshift range $2.5 < z < 3.0$. Selection is based on a combination of colour and variability parameters by our machine-learning algorithm (Cartier et al., 2016). These QSO candidates would be missed by traditional selection methods using colours alone.

Monitoring studies are fundamental to gather information about the extreme physical conditions in the accretion discs near supermassive black holes (SMBHs). The aims of the QUEST–La Silla AGN Variability Survey are: (1) to test and improve variability selection methods for AGNs and to find AGN populations missed by other optical selection techniques; (2) to obtain a large number of well-sampled light curves, covering timescales from days to years; and (3) to study the link between the variability properties (e.g., characteristic timescales and amplitudes of variation) and physical parameters of the systems (e.g., black-hole mass, luminosity, and accretion rate).

Traditionally, optical selection of AGNs has made use of the fact that they show an ultraviolet (UV) excess in their spectral energy distribution when compared to stars (Schmidt & Green, 1983). The UV-excess technique, and more recent selection methods based on optical colours, are very efficient at finding AGNs in regions of colour space where the AGN density is higher than the densities of stars or galaxies. However, such selection methods miss a significant fraction of AGNs with peculiar colours (e.g., red quasi-stellar objects [QSOs]) or AGNs located at a redshift range ($2.5 < z < 3.0$) where their optical colours are similar to those of stars (Fan, 1999). The fact that AGNs are highly variable makes their selection by means of variability a very promising technique to find them, either with or without considering their colours (see some examples in Figure 1). Variability selection has successfully identified a large number of new QSO candidates, and is one of the main goals of the survey.

To expedite follow-up, the QUEST–La Silla AGN Survey monitored sources in several extragalactic survey fields, such as the Cosmological Evolution Survey (COSMOS), Extended Chandra Deep Field South (ECDF-S), ELAIS-S1, the X-ray Multi-Mirror Mission (XMM) Large

Felipe Murgas

Figure 2. Panoramic view of the La Silla Observatory: the telescopes from background to foreground are: the 3.6-metre, the New Technology Telescope (NTT), the 1-metre ESO Schmidt, the MPG/ESO 2.2-metre, the Danish 1.54-metre, and the MarLy 1-metre.

Scale Structure Survey (LSS) field, and Stripe-82. These regions have extensive and deep multi-wavelength ancillary data from XMM-Newton, Chandra, GALEX, the Hubble Space Telescope (HST), Herschel, Spitzer, and ground-based photometry and spectroscopy, providing valuable constraints on the spectral energy distributions (SEDs), galaxy hosts and environments of the AGN candidates. Additionally, these fields have nearly simultaneous observations in the near-infrared (NIR) performed by the Visible and Infrared Survey Telescope for Astronomy (VISTA) at the Paranal Observatory, which provides information about how the outer and colder portions of the accretion disc and its vicinity vary in relation to the inner parts probed at optical wavelengths.

The telescope and site

To carry out a high cadence variability survey to a limiting magnitude of ~ 21.5 mag, we require a large-format camera that can instantaneously sample a large field of view on a 1-metre or larger telescope at a good observing site. The QUEST2 camera, installed in 2009 on the prime focus of the ESO 1-metre Schmidt telescope at the La Silla Observatory, was the perfect choice. The 160-megapixel array of the QUEST2 camera is well-matched to the large field of view of the ESO Schmidt telescope, which is one of the largest Schmidt configurations in the southern hemisphere (equivalent to the area of 64 full Moons). This unique combination allows an efficient time domain survey to be carried out.

The location of the telescope at the La Silla Observatory is also a perfect complement. La Silla has excellent seeing, a high fraction of clear nights, is very dry and has some of the darkest night skies on Earth (see Figure 2).

In 2009, the ESO Schmidt telescope was fully robotised by the astronomy department of Yale University, and the observations are coordinated by a master scheduling programme (Rabinowitz et al., 2012). At La Silla, the ESO 3.6-metre telescope operator decides when the conditions are appropriate for opening the telescope, and the control software automatically closes the dome whenever the MPG/ESO 2.2-metre telescope is closed, when the Sun rises or when the telescope operator sends a command to close. Since 2011, the telescope has been observing in queue mode for our survey. However, during 2011 and 2012, we had several observing gaps due to problems with the dome wheels of the telescope. The wheels were replaced during 2012, and since 2013 the observations have been taken more regularly.

The QUEST camera and filter response

The camera consists of 112 charge coupled devices (CCDs) arranged in four rows, or fingers, of 28 CCDs each, covering 4.6 by 3.6 degrees (north–south by east–west) on the sky. The fingers are flagged A, B, C and D, and the columns of CCDs from 1 to 28 (see Figure 3 for the layout). Each CCD has 600 × 2400 pixels of 13 × 13 μm and a pixel scale of 0.882 arcseconds per pixel. There are gaps between fingers of 0.43 degrees, such that to obtain a full coverage of the 4.6 × 3.6 degree field of view one must acquire two exposures offset by 0.5 degrees in right ascension (RA). One single pair of exposures is

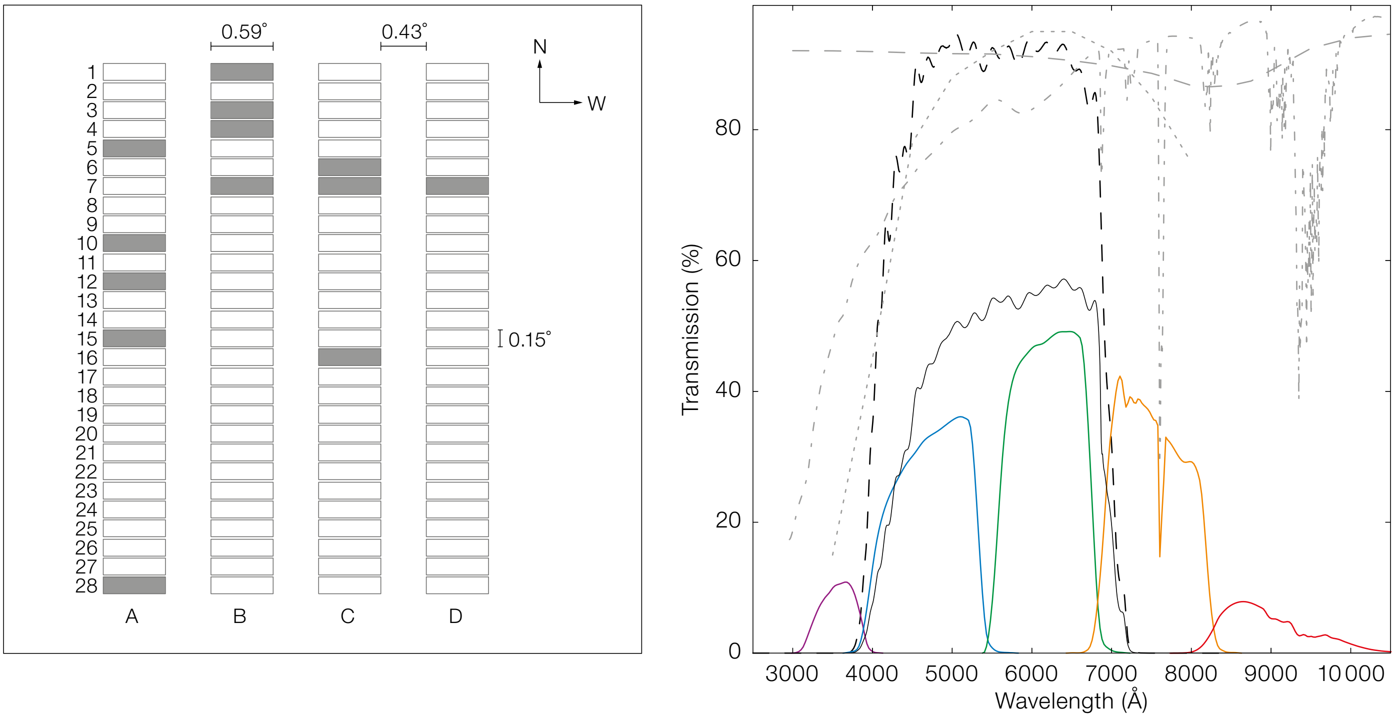


Figure 3. Left-panel: Layout of the QUEST camera array; the camera consists of four fingers of 28 CCDs. The fingers are flagged as A, B, C and D, and the columns from 1 to 28. The gaps between adjacent fingers are 0.43 degrees, and the projected size on the sky of each CCD is 0.59 × 0.15 degrees. In grey we highlight non-functional CCDs. Right-panel: System response of the *Q*-band (solid black) and SDSS bandpasses (in colours) at an airmass of 1.3. We also show the QUEST filter (dashed black; Rabinowitz et al., 2012), the 1-metre ESO Schmidt mirror reflectivity (dashed grey), the sky transmission at an airmass of 1.3 (dot-dashed grey), and the -camera quantum efficiency (dotted grey). From Baltay et al. (2007).

sufficient to cover all of the aforementioned fields, aside from the XMM-LSS field that requires two pairs.

About 16 % of the detector area is non-functional because the CCDs are either permanently off, randomly turn on and off, or have large defective areas, all of which hamper the astrometric solution, owing to the low number of stars detected and the potential for false detections. The effective sky area covered by the functioning CCDs is ~ 7.5 square degrees.

The QUEST–La Silla survey uses a broad *Q*-band filter spanning 4000 to 7000 Å. This bandpass was designed to avoid the fringing often present in the redder images obtained as part of the Palomar-QUEST survey (Baltay et al., 2007). The *Q*-band system response is similar to a broad SDSS ($g + r$) filter (see Figure 3).

Nearly simultaneous near-infrared light curves from VISTA surveys

In addition to the rich multi-wavelength set of data already available, most the survey fields have been observed repeatedly since 2009 in the near-infrared with the 67-megapixel camera (VIRCAM) mounted on the 4-metre wide field VISTA telescope at the Paranal Observatory. The VISTA near-infrared light curves of the COSMOS, ECDF-S, ELAIS-S1, and XMM-LSS fields (see Figure 4) provide nearly simultaneous complementary coverage with the optical data obtained by the QUEST2 camera, and were obtained as part of the UltraVISTA (McCracken et al., 2012) and VISTA Deep Extragalactic Observations (VIDEO; Jarvis et al., 2013) Public Surveys.

Little is known about AGN variability at infrared wavelengths, and our study of VISTA near-infrared light curves is a novel advance in the field (Sanchez et al., 2016). At low redshifts, the near-infrared samples the cooler portions of the accretion disc and the dusty torus that surrounds it. At higher redshifts it provides restframe optical constraints to complement the restframe UV ones obtained by QUEST2. By using both surveys, we expect to have a complete picture of how the emission from the accretion disc is reprocessed by the surrounding dust in obscured AGNs. This can be investigated for AGN with a variety of obscuration levels (i.e., types 1–2), to understand what roles structure, composition and orientation might play.

Status and future of the QUEST2 survey

The QUEST–La Silla AGN variability survey has been collecting data for six years, and the last photometric campaign will be completed by mid-2016. The data reduction process is now robust and well-characterised (i.e., non-linearity correction, photometric system and astrometric solution; see Cartier et al., 2015), and data obtained through 2014 have been reduced for most fields.

Our observing strategy has been to obtain between two to five observations per night to remove spurious variability due to artefacts, to potentially study intra-night AGN variability, and to produce stacked images reaching fainter magnitudes. Individual images reach a limiting magnitude between $r \sim 20.5$ mag and $r \sim 21.5$ mag for an exposure time of 60 or 180 s, respectively.

A reliable variability selection method, based on machine-learning techniques, has been developed (Cartier et al., 2016), and is now being used to find new QSO candidates. During 2015, we began a spectroscopic campaign to classify variable AGN candidates with peculiar colours (likely AGN at $2.5 < z < 3.0$). Our goals here are to: (1) test our selection method; (2) increase our training sample of variable objects with peculiar colours to improve our machine-learning algorithm; and (3) significantly increase the number of known QSOs at this redshift range, in order to obtain a more reliable luminosity function of QSOs at $2.5 < z < 3.0$.

Over the past six years, our project has successfully introduced and trained students in the fields of time-domain astronomy and photometric techniques. Since 2011, four undergraduate students have developed research projects related to the survey and are now pursuing PhDs on topics related to time-domain astronomy. The initial implementation, characterisation and first results of the survey led to the completion of one PhD thesis, while the analysis of the six-year dataset and the spectroscopic follow-up campaign will constitute part of a second thesis under completion.

As part of our survey we have collected light curves not only of AGNs but also of several other interesting transients (see example in Figure 5). Once the survey is completed, we will make our light curves and spectra publicly available to the community.

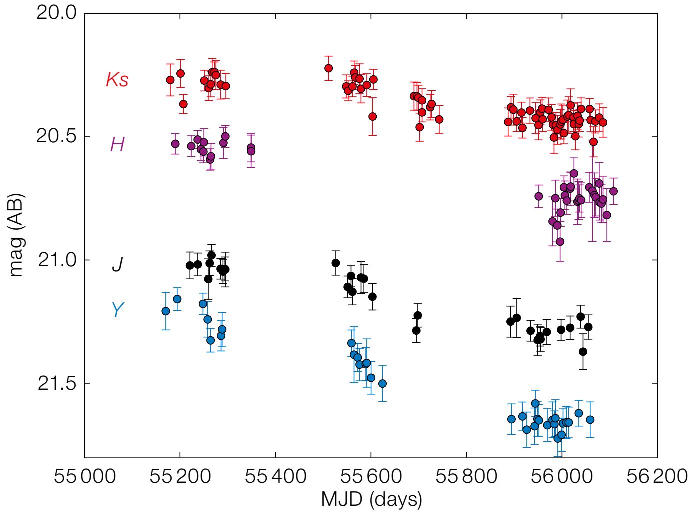


Figure 4. Near-infrared light curve of an AGN obtained by the UltraVISTA survey (McCracken et al., 2012) in one of our fields. NIR light curves for a complete set of AGN in the QUEST–La Silla AGN Variability Survey will be presented in Sanchez et al. (2016).

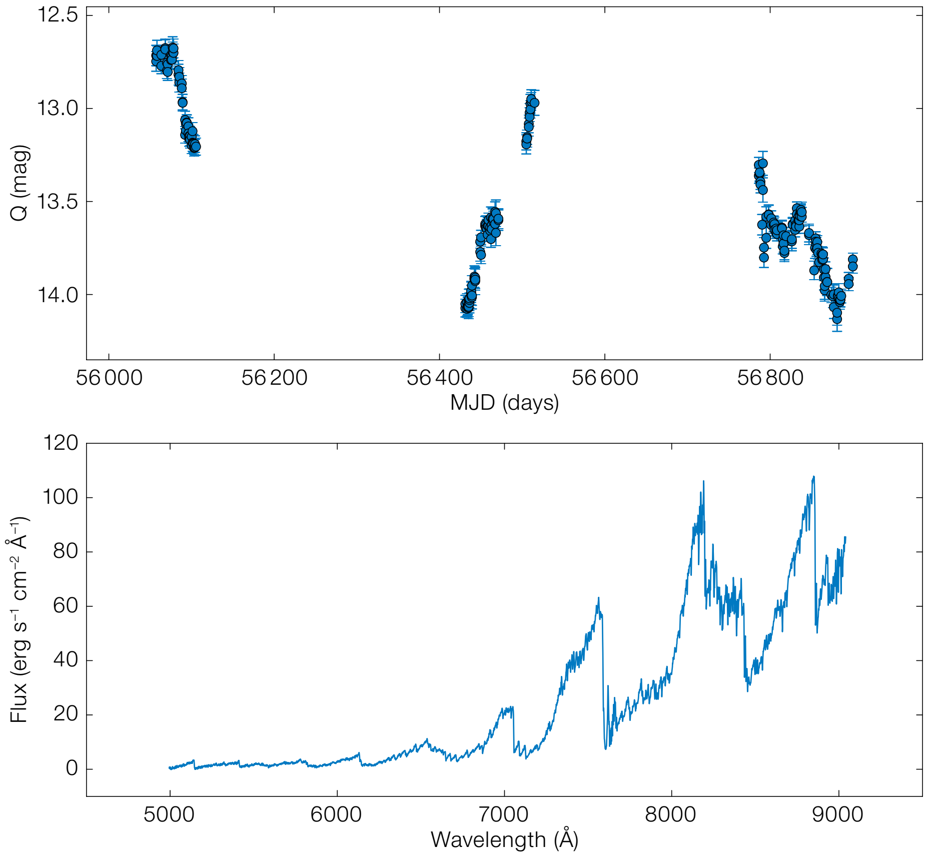
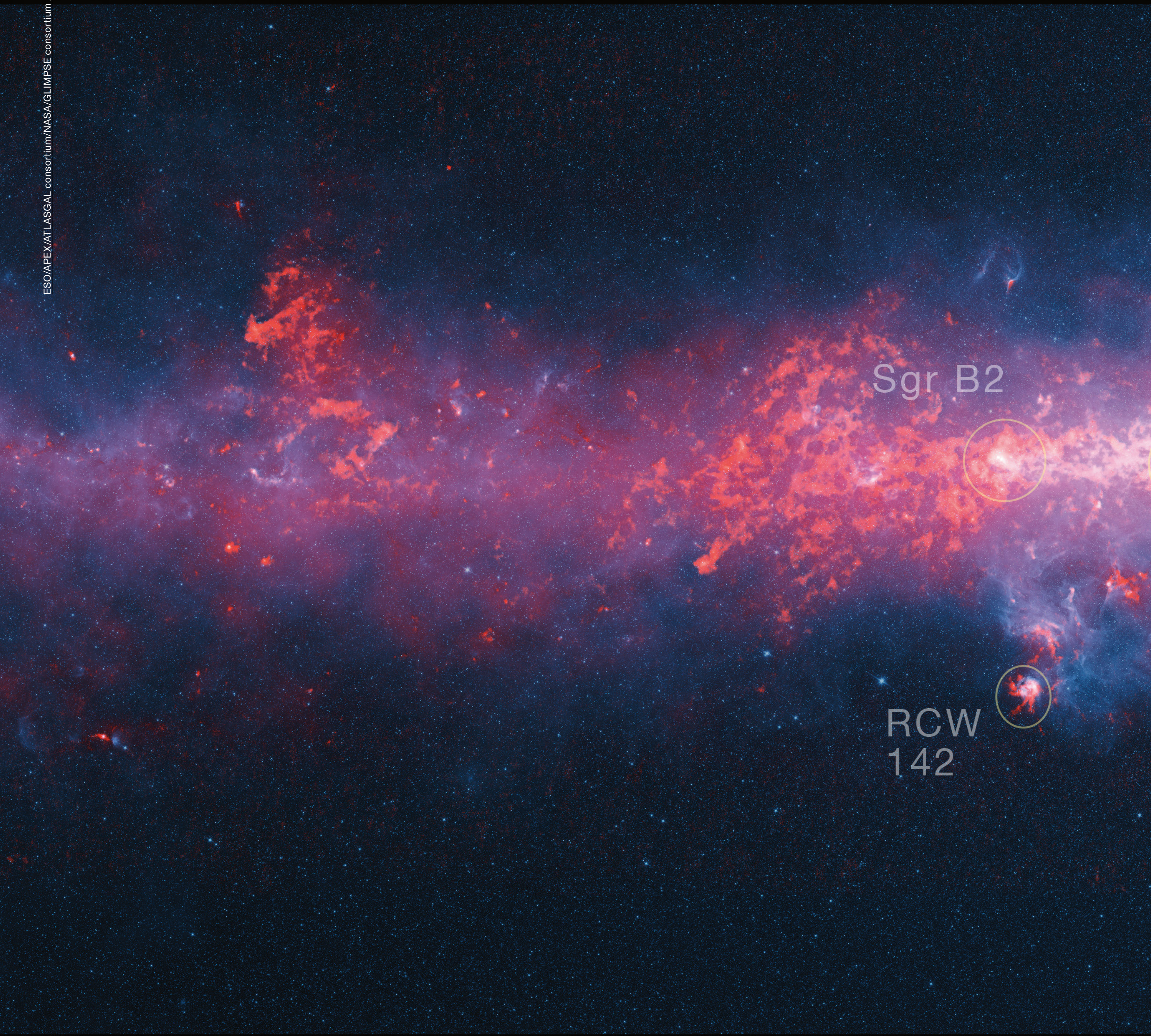


Figure 5. QUEST light curve (upper) and spectrum (lower) of a very red (low temperature) variable star, possibly a Mira star. The spectrum was obtained using the COSMOS instrument on the Blanco 4-metre telescope at Cerro Tololo Inter-American Observatory under poor weather conditions.

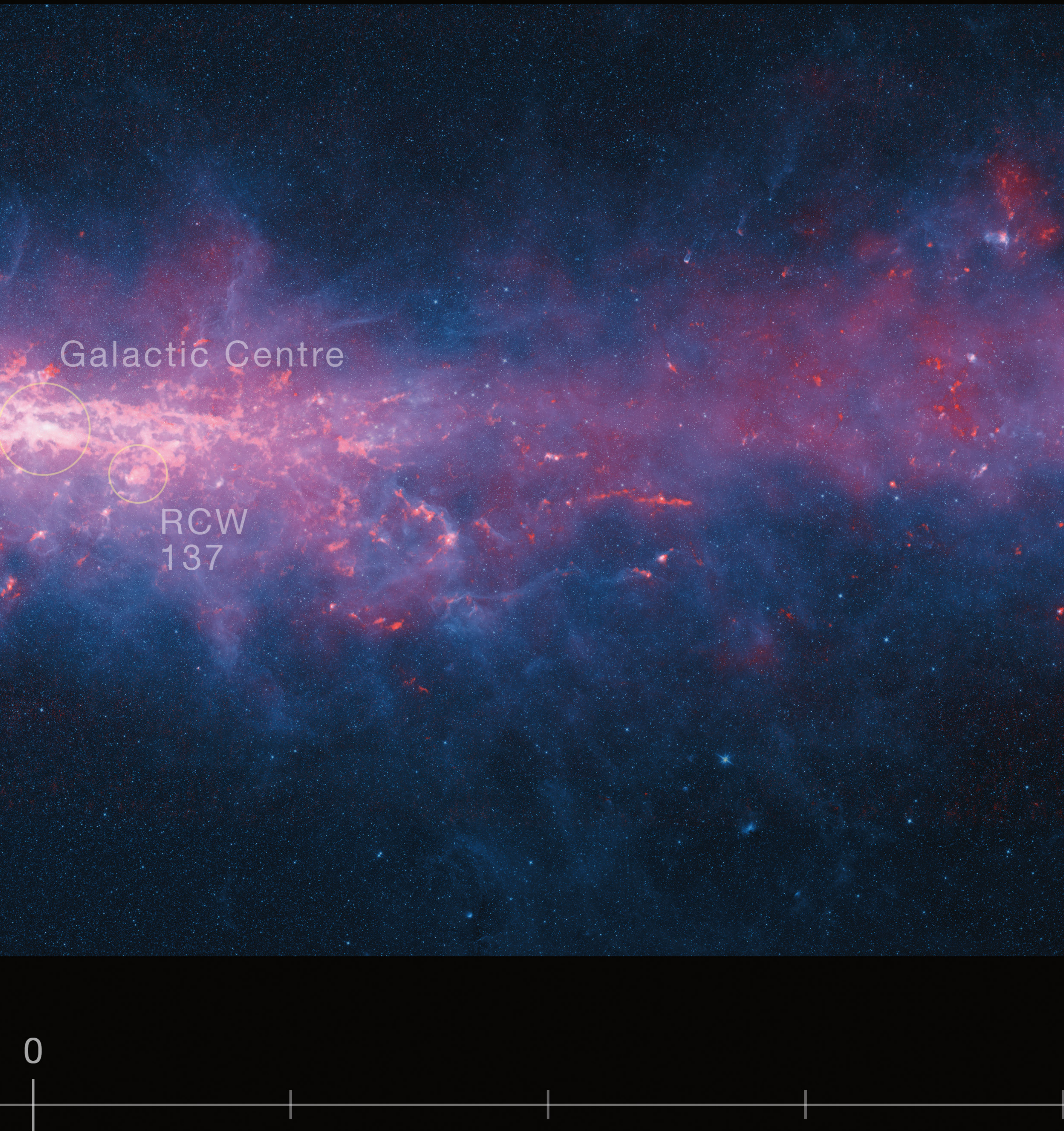
References

Baltay, C. et al. 2007, PASP, 119, 1278
Cartier, R. et al. 2015, ApJ, 810, 164
Cartier, R. et al. 2016, in prep.
Fan, X. 1999, AJ, 177, 2528
Jarvis, M. J. et al. 2013, MNRAS, 428, 1281
McCracken, H. J. et al. 2012, A&A, 544, 156
Rabinowitz, D. et al. 2012, AJ, 144, 140
Sanchez, P. et al. 2016, in prep.
Schmidt, M. & Green, R. F. 1983, ApJ, 269, 352

ESO/APEX/ATLASGAL consortium/NASA/GLIMPSE consortium/ESA/Planck



The Galactic Centre region from the APEX Telescope Large Area Survey of the Galaxy (ATLASGAL) image. Here an extent of only +/– 4 degrees in longitude about the Galactic Centre is shown. APEX data, wavelength 0.87 millimetres, are coded red; the background blue image shows infrared emission (3.6, 4.5 and 8.0 μm), mapped by the NASA Spitzer Space Telescope as part of the GLIMPSE survey; the extended pink structures come from far-infrared (850 μm) data from the ESA Planck satellite. Several prominent features are labelled. See Release eso1606 for details and access to the full image.


Galactic Centre
RCW
137
0

Towards a Fundamental Astrometric Reference System behind the Magellanic Clouds: Spectroscopic Confirmation of New Quasar Candidates Selected in the Near-infrared

Valentin D. Ivanov[1]
Maria-Rosa L. Cioni[2,3,4]
Kenji Bekki[5]
Richard de Grijs[6,7,8]
Jim Emerson[9]
Brad K. Gibson[10]
Devika Kamath[11]
Jacco Th. van Loon[12]
Andrés E. Piatti[13,14]
Bi-Qing For[5]

[1] ESO
[2] Universität Potsdam, Institut für Physik und Astronomie, Germany
[3] Leibniz-Institut für Astrophysik Potsdam (AIP), Germany
[4] University of Hertfordshire, Physics Astronomy and Mathematics, United Kingdom
[5] ICRAR, The University of Western Australia, Crawley, Australia
[6] Kavli Institute for Astronomy and Astrophysics, Peking University, Beijing, China
[7] Department of Astronomy, Peking University, Beijing, China
[8] International Space Science Institute – Beijing, China
[9] School of Physics and Astronomy, Queen Mary University of London, United Kingdom
[10] E. A. Milne Centre for Astrophysics, Department of Physics & Mathematics, University of Hull, United Kingdom
[11] Instituut voor Sterrenkunde, K. U. Leuven, Belgium
[12] Lennard-Jones Laboratories, Keele University, United Kingdom
[13] Observatorio Astronómico, Universidad Nacional de Córdoba, Argentina
[14] Consejo Nacional de Investigaciones Científicas y Técnicas, Buenos Aires, Argentina

Quasi-stellar objects (quasars) located behind nearby galaxies provide an excellent absolute reference system for astrometric studies, but they are difficult to identify because of fore- and background contamination. We have embarked on a programme to expand the quasar reference system behind the Large and Small Magellanic Clouds, the Magellanic Bridge and Magellanic Stream. Hundreds of quasar candidates were selected, based on their near-infrared colours and variability properties from the ESO VISTA Magellanic Clouds (VMC) Public Survey. A subset of 49 objects was followed up with optical spectroscopy with FORS2. We confirmed the quasar nature of 37 objects (34 new identifications) that span a redshift range from *z* ~ 0.5 to 4.1.

Quasi-stellar objects (quasars) are active nuclei of distant galaxies, undergoing episodes of strong accretion. Typically, the contribution from the host galaxy is small, and they appear as point-like objects with strong emission lines. Quasars are cosmological probes that serve as background "beacons" to explore the intervening interstellar medium, but they also are distant, unmoving objects used to establish an absolute astrometric reference system on the sky. The smaller the measured proper motions (PMs) of foreground objects are, the more useful the quasars become — as is the case for nearby galaxies. Quasars behind these galaxies are hard to identify because of foreground contamination, the additional (patchy) reddening inside the intervening galaxies themselves, and the galaxies' relatively large angular areas on the sky. The latter point underscores the need to carry out dedicated wide-field surveys, sometimes covering hundreds of square degrees, to find a sufficient density of background quasars. The Magellanic Clouds are an extreme case where these obstacles are notably enhanced.

The VISTA survey of the Magellanic Clouds

The ESO Public Survey with the VLT Infrared Survey Telescope for Astronomy (VISTA) of the Magellanic Clouds (VMC; Cioni et al., 2011) covers 184 square degrees around the Large and Small Magellanic Clouds (LMC, SMC), the Magellanic Bridge, and the Stream (Figure 1). The magnitude limit is to *Ks* = 20.3 mag (signal-to-noise ratio ~ 10; Vega system) in the *YJKs*-bands; 12 separate epochs in the *Ks*-band, spread over at least a year are also taken. The main survey goals are to study the star formation history and the geometry of the Magellanic Cloud system, as well as its cluster and variable-star populations.

The VMC is carried out with VISTA (Emerson et al., 2006), a 4.1-metre telescope on Cerro Paranal, equipped with the VISTA InfraRed CAMera (VIRCAM; Dalton et al., 2006), a wide-field near-infrared camera producing ~ 1 by 1.5 degree images across the 0.9–2.4 μm wavelength range. The VISTA data are processed with the VISTA Data Flow System (VDFS) pipeline (Irwin et al., 2004) at the Cambridge Astronomical Survey Unit[1]. The data products are available through the ESO Science Archive[2] or the specialised VISTA Science Archive (VSA; Cross et al., 2012).

Quasar candidate selection

Cioni et al. (2013) derived selection criteria (Figure 2) to identify candidate quasars based on both the locus of 117 known quasars in a (*Y*–*J*) versus (*J*–*Ks*) colour–colour diagram and their *Ks*-band variability behaviour. The diagram was based on average magnitudes obtained from deep tile images created by the Wide Field Astronomy Unit (WFAU[3]) as part of the VMC data processing, using version 1.3.0 of the VDFS pipeline.

Figure 2 shows the colour–colour diagram demonstrating the colour selection of our quasar candidates. The regions (marked with letters) where known quasars are found and the locus of the planetary nebulae (Cioni et al., 2013) is indicated. The blue crosses (×) indicate VMC counterparts to the spectroscopically confirmed quasars (Cioni et al., 2013), selected adopting a maximum matching radius of 1 arcsecond (the average separation is 0.15 ± 0.26 arcseconds).

The selected candidates for our study are included in Ivanov et al. (2016); for the quantitative description of the selection criteria, see Cioni et al. (2013). Extended sources were included in our search to ensure that low-redshift quasars with considerable contributions from their host galaxies were not omitted. Their extended nature is marginal, because they are dominated by their nuclei, and they are still useful for quasar absorption-line studies. The 68 brightest candidates were selected to homogeneously sample seven VMC tiles where quasars had not yet been found. The total number of

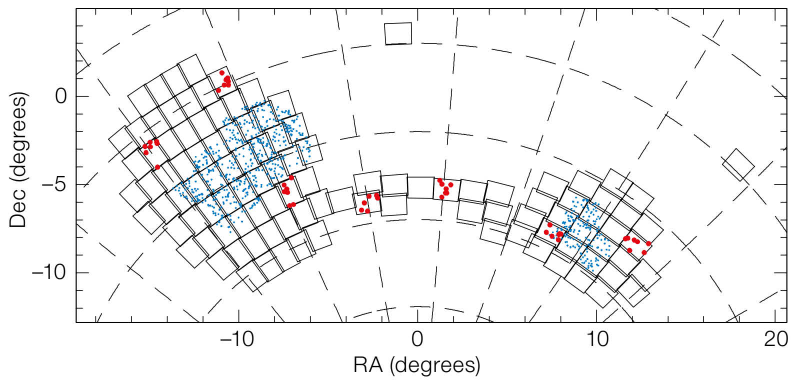


Figure 1. VMC footprints on the sky (shown as contiguous rectangles). The spectroscopically followed-up quasar candidates are marked in red, and confirmed quasars from Kozlowski et al. (2013) in blue. The dashed grid shows lines of constant right ascension (spaced by 15°), and constant declination (spaced by 5°). Coordinates are given with respect to (RA, Dec) = (51°, −69°).

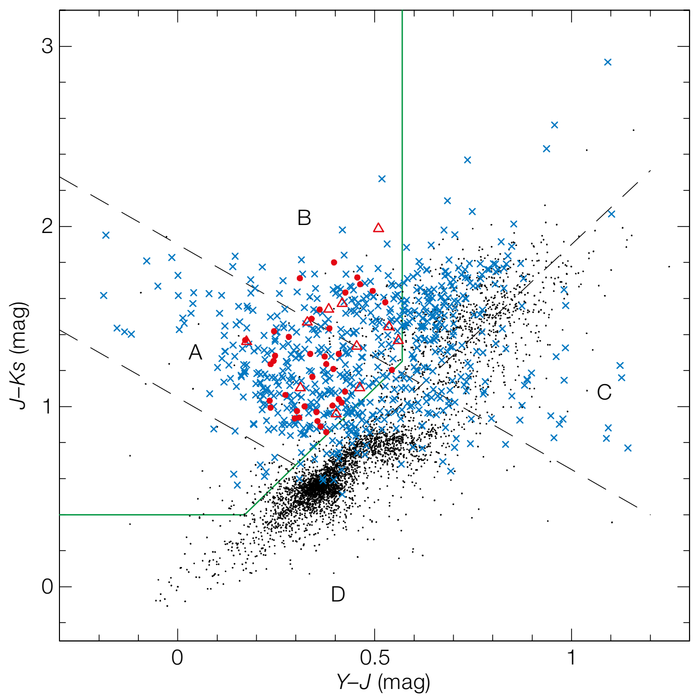


Figure 2. Colour–colour diagram showing the colour selection of our quasar candidates. The dashed black lines identify the regions (marked with letters) where known quasars are found, while the green line marks the blue border of the planetary nebulae locus. The spectroscopically followed-up quasars are marked with solid red dots, while the non-quasars are marked with red triangles. Blue crosses (×) indicate the location of the VMC counterparts to the spectroscopically confirmed quasars from Kozłowski et al. (2013). Black dots are randomly selected LMC objects (with errors in all three bands of < 0.1 mag), to demonstrate the locus of "normal" stars, as well as background galaxies in regions B and C.

candidates could increase greatly if fainter objects are considered.

Spectroscopic follow-up observations

Follow-up spectra of 49 candidates were obtained with the FOcal Reducer and low-dispersion Spectrograph (FORS2; Appenzeller et al., 1998) on the Very Large Telescope in long-slit mode, with the 300V+10 grism, delivering spectra over λ = 445–865 nm with a spectral resolving power R ~ 440 (1.3-arcsecond slit). Two 450 s exposures were taken for most objects, except for some fainter objects, for which the exposure times were 900 s. The signal-to-noise ratio (S/N) varies among the spectra, but it is typically ~ 10–30 at λ ~ 6000–6200 Å. The observing details are given in Ivanov et al. (2016). The data reduction was carried out using the ESO pipeline, version 5.0.0. Various IRAF[4] tasks from the onedspec and rv packages were used in the subsequent analysis. Some reduced spectra are shown in Figure 3.

Prominent emission lines were identified, from which the quasar redshifts were measured. For most line centres the typical formal statistical errors are $\Delta\lambda$ ~1 Å, which translates into redshift errors $\Delta z < 0.001$. These are optimistic estimates that neglect wavelength calibration errors. We evaluated the latter by measuring the wavelengths of 45 strong and isolated sky lines in five randomly selected spectra. We did not find any trends with wavelength and a root mean square (rms) error of 1.57 Å was determined. This translates into a redshift uncertainty of Δz ~ 0.0002 for a line at 7000 Å, near the centre of our spectral coverage. To evaluate the real uncertainties, we compared the redshifts derived from different lines of the same object. The average difference for 35 pairs of lines, for quasars with multiple lines, is effectively zero: $|z_i – z_j| = 0.006 \pm 0.007$.

For objects with multiple lines we adopted the average difference as redshift error, adding in quadrature the wavelength calibration error of $\Delta z = 0.0002$. This addition only made a difference for a few low-redshift objects. For quasars for which only a single line was available, we conservatively adopted as redshift errors $\Delta z = 0.005$ for objects at $z < 1$ and $\Delta z = 0.015$ for more distant objects. Finally, as external verification, in the Sloan Digital Sky Survey (SDSS) rest frame composite spectrum we re-measured the redshifts of the same lines that were detected in our spectra, obtaining values below $z = 0.0001$, as expected.

Results

The majority of the observed objects are quasars: 37 objects appear to be *bona fide* quasars at z ~ 0.47–4.10 (10 are located behind the LMC, 13 behind the SMC and 14 behind the Bridge area), showing some broad emission lines, even though some spectra need smoothing for display purposes. The spectra of the three highest-redshift quasars exhibit Lyα absorption systems; a few quasars (e.g., SMC 3_5 22, BRI 2_8 197, etc.) show blue-shifted C IV absorption, perhaps due to winds from active galactic nuclei. We defer a more detailed study of individual objects until the remainder of the sample have been followed up. Our success rate is ~76 %, testifying to the robustness and reliability of our selection

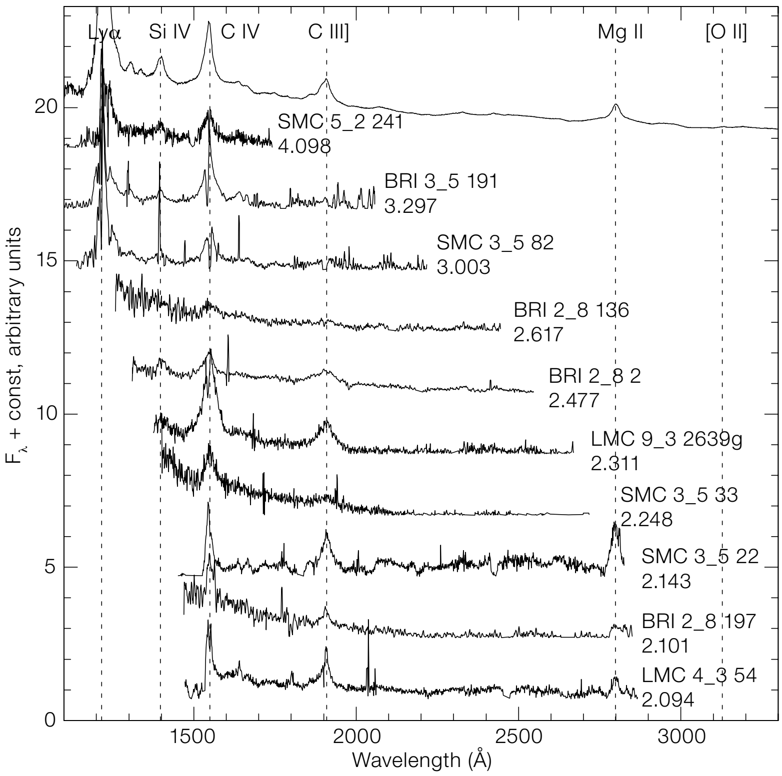


Figure 3. Example spectra of the quasar candidates sorted by redshift, shifted to restframe wavelength. The spectra were normalised to an average value of 1.0, and shifted vertically by offsets of two, four, etc., for display purposes. The SDSS composite quasar spectrum (Vanden Berk et al., 2001) is shown at the top.

criteria. Many of our quasars are present in the GALEX and SAGE–SMC (Surveying the Agents of Galaxy Evolution – Small Magellanic Cloud) source catalogues. The confirmed quasar SMC 5_2 241 has a candidate radio counterpart: SUMSS J002956–714640 at 2.8 arcseconds separation, detected in the 843 MHz Sydney University Molonglo Sky Survey.

Many quasars with redshifts $z \leq 1$ were classified as extended sources by the VDFS pipeline, supporting our decision to include extended objects in the sample: they are either contaminated by the host galaxy or by chance alignment with foreground objects from either the LMC or the SMC. Four extended objects are contaminating low-redshift galaxies: LMC 9_3 2728g, LMC 8_8 655g, and LMC 8_8 208g show hydrogen, some oxygen and nitrogen in emission, but no obvious broad lines, so we interpret these as indicators of ongoing star formation rather than nuclear activity; while LMC 8_8 341g may also show Hβ in absorption. In addition, LMC 8_8 341g has a recession velocity of ~ 300 km s^{-1}, consistent within the uncertainties with LMC membership, making it a possible, moderately young LMC star cluster. After target selection we realised that three of our candidates (SMC 5_2 203, SMC 3_5 24, and SMC 3_5 15) were previously confirmed quasars, and two others (LMC 9_3 137 and LMC 4_3 95g) were previously suspected quasars.

Three point-source-like objects are most likely emission-line stars: LMC 4_3 95, LMC 4_3 86, and SMC 3_5 29. The spectra of LMC 8_8 422g, LMC 4_3 3314g, and LMC 9_3 3107g do not offer any solid clues as to their nature. Some BL Lacertae (BL Lacs) — active galaxies believed to be seen along a relativistic jet emanating from the active nucleus — are also featureless, but they usually have bluer continua than the spectra of these three objects. A possible test is to search for rapid variability, typical of BL Lacs, but the VMC cadence is not well-suited for such an exercise, and the light curves of the three objects do not show any peculiarities. Finally, the spectra of LMC 4_3 1029g and LMC 8_8 376g are too noisy for secure classification.

Prospects

Cioni et al. (2013) estimated that the VMC survey may find a total of approximately 1830 quasars. The success rate of 76 % reached here brings this number down to some 1390. The spectra of the candidates in seven tiles, of the 110 tiles that make up the entire VMC survey, yielded on average ~ 5.3 quasars per tile. Scaling this number up to the full survey area yields ~ 580 quasars. This is a lower limit, because only the brightest candidates in the seven tiles were followed up, so the larger number is still a viable prediction.

This project is still at an early stage, but once spectroscopic confirmations have been achieved, the identified quasars will provide an excellent, independent reference system for detailed astrometric studies of the Magellanic Clouds system, complementing Gaia. In addition, the homogeneous, multi-epoch observations of the VMC survey, combined with the large quasar sample, open up the possibility to investigate in detail the mechanisms that drive quasar variability, for example, with structure functions in the near-infrared, following the example of the SDSS quasar variability studies.

References

Appenzeller, I. et al. 1998, The Messenger, 94, 1
Cioni, M.-R. L. et al. 2011, A&A, 527, 116
Cioni, M.-R. L. et al. 2013, A&A, 549, A29
Cross, N. J. G. et al. 2012, A&A, 548, 119
Dalton, G. B. et al. 2006, SPIE Conf. Ser., 6269, 30
Emerson, J. et al. 2006, The Messenger, 126, 41
Ivanov, V. et al. 2016, A&A, in press, arXiv:1510.05504
Irwin, M. J. et al. 2004, SPIE Conf. Ser., 5493, 411
Kozlowski, S. et al. 2013, ApJ, 775, 92
Vanden Berk, D. E. et al. 2001, AJ, 122, 549

Links

[1] Cambridge Astronomical Survey Unit (CASU): http://casu.ast.cam.ac.uk/
[2] ESO Science Archive: http://archive.eso.org
[3] Wide Field Astronomy Unit (WFAU): http://www.roe.ac.uk/ifa/wfau/
[4] The Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA), under a cooperative agreement with the US National Science Foundation.

The KMOS AGN Survey at High Redshift (KASHz)

Chris Harrison[1]
Dave Alexander[1]
James Mullaney[2]
John Stott[3,1]
Mark Swinbank[4,1]
Vinod Arumugam[5]
Franz Bauer[6,7,8]
Richard Bower[4,1]
Andrew Bunker[3,9]
Ray Sharples[10]

1 Centre for Extragalactic Astronomy, Durham University, United Kingdom
2 Department of Physics and Astronomy, University of Sheffield, United Kingdom
3 Astrophysics, Department of Physics, University of Oxford, United Kingdom
4 Institute for Computational Cosmology, Durham University, United Kingdom
5 ESO
6 Instituo de Astrofisica, Pontifica Universidad Catolica de Chile, Santiago, Chile
7 Millenium Institute of Astrophysics, Santiago, Chile
8 Space Science Institute, Boulder, Colorado, USA
9 Kavli Institute for the Physics and Mathematics of the Universe, The University of Toyko, Japan
10 Centre for Advanced Instrumentation, Durham University, United Kingdom

The KMOS AGN Survey at High Redshift (KASHz) is an extensive observational programme to obtain spatially resolved spectroscopy of distant galaxies that host rapidly growing supermassive black holes (i.e., active galactic nuclei [AGN]). By exploiting the unique capabilities of KMOS we will spatially resolve the ionised gas kinematics in around 200 such galaxies. A fundamental prediction of galaxy formation models is that AGN inject considerable energy into their host galaxies and ultimately destroy or remove star-forming material via outflows. However, until now, observational constraints of this prediction have been limited to only a small number of distant galaxies. KASHz will provide the strongest constraints to date on the prevalence, properties and impact of ionised outflows in the host galaxies of distant AGN. The survey is described and our first results presented.

Matching models with observations: AGN to the rescue

Over the last three decades, the growth of supermassive black holes (i.e., AGN) have moved to the forefront of galaxy evolution research. Historically, these energetic phenomena were considered rare, yet fascinating, objects to study in their own right. However, observations now indicate that all massive galaxies have hosted AGN activity during their lifetimes. Furthermore, the most successful models of galaxy evolution are unable to reproduce fundamental observations of local massive galaxies and galaxy clusters without implementing energetic feedback processes that couple AGN to the gas in their host galaxies, and beyond.

How can growing supermassive black holes be so critical in galaxy formation and evolution when they are a billion times more compact than the galaxies in which they reside in? Simply put, AGN are incredible energy sources. For example, accreting material to create a black hole like the one at the centre of the Milky Way (i.e., a mass equivalent to around $4 \times 10^{6}\ M_{\odot}$) could liberate 7×10^{52} Joules of energy (equivalent to 10^{35} times the energy released by the most powerful nuclear weapons ever made). Theoretically, even if a small fraction of this energy is able to couple to the gas, all of the host galaxy's gas could become unbound. Inevitably at least some of gas is going to be heated and/or driven away in outflows. This material could otherwise have gone on to form stars and therefore the AGN has had a direct impact on the future evolution of its host galaxy.

Such effects are required in cosmological models of galaxy evolution to reproduce realistic populations of galaxies (e.g., Vogelsberger et al., 2014; Schaye et al., 2015); however, whilst theoretically attractive, observations are required to refine or refute these models. As we will describe in this article, our new large survey using the *K*-band Multi-Object Spectrograph (KMOS) mounted on the Very Large Telescope (VLT) will play a key role in providing observational constraints on the prevalence, properties and impact of outflows in the host galaxies of distant AGN.

Previous observations of AGN-driven outflows

For several decades it has been known that AGN drive gas away in fast outflows. Ultraviolet and X-ray spectroscopy have revealed that ultra-fast outflows in the proximity of accreting supermassive black holes are extremely common and may even be ubiquitous (e.g., Ganguly & Brotherton, 2008). However, of more direct relevance to the evolution of galaxies is the growing amount of observational evidence of outflows extending out to much larger scales, where they can have a direct impact on the star-forming material inside the host galaxies. This evidence mostly comes from spatially resolved spectroscopy, where emission or absorption lines can be used to trace the movements of the gas over these spatial scales. A variety of such observations of nearby and distant sources have revealed gas in molecular, atomic and ionised phases that appears to be being driven out of galaxies (e.g., Rupke & Veilleux, 2013; Harrison et al., 2014; Cicone et al., 2014). While these effects appear to be common across all galaxies with ongoing star formation, there is growing evidence, at least in the local Universe, that the most extreme outflows are associated with ongoing AGN activity (e.g., Cicone et al., 2014).

For our work, we are particularly interested in warm (~ 10^{4} K) ionised outflows, which can easily be traced using restframe optical emission lines such as [O III] and Hα. An emission-line profile that is broad (from a few 100s to ≈ 1000 km s^{-1}) and/or asymmetric is strong evidence for outflowing material. Due to large optical spectroscopic surveys, such as the Sloan Digital Sky Survey (SDSS), which contains one-dimensional spectra of millions of galaxies, it is possible to search for such features in huge samples of nearby galaxies at late cosmic epochs (i.e., redshifts of $z \lesssim 0.4$; see Figure 1).

For example, Mullaney et al. (2013) constrained the prevalence of outflow features in the restframe optical emission lines for ≈ 24 000 AGN host galaxies exploiting the SDSS survey. Spatially resolved spectroscopy can then be performed using optical integral field units (IFUs) to measure key properties of subsets of

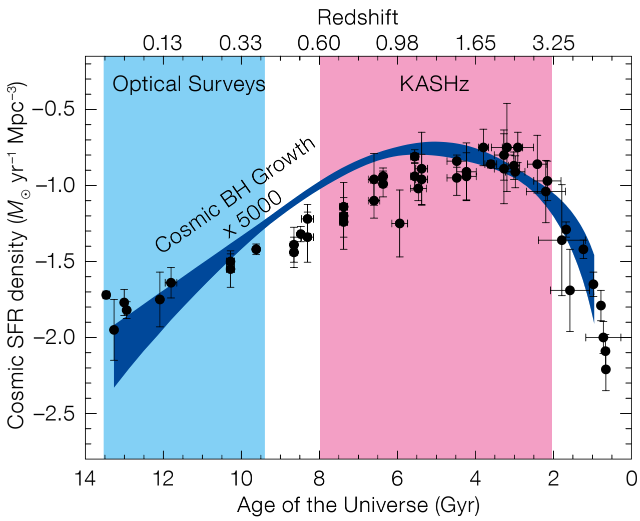


Figure 1. Volume-averaged star formation rate (SFR) density (circles; Madau & Dickenson, 2014) and scaled-up black-hole (BH) growth (curve; Aird et al., 2010) versus age of the Universe and redshift. The highlighted region shows the epochs covered by: (1) most optical spectroscopic surveys of warm ionised outflows (e.g., Mullaney et al., 2013); and (2) our new KASHz survey. Our first paper (Harrison et al., 2016) covers the peak epoch of BH and galaxy growth.

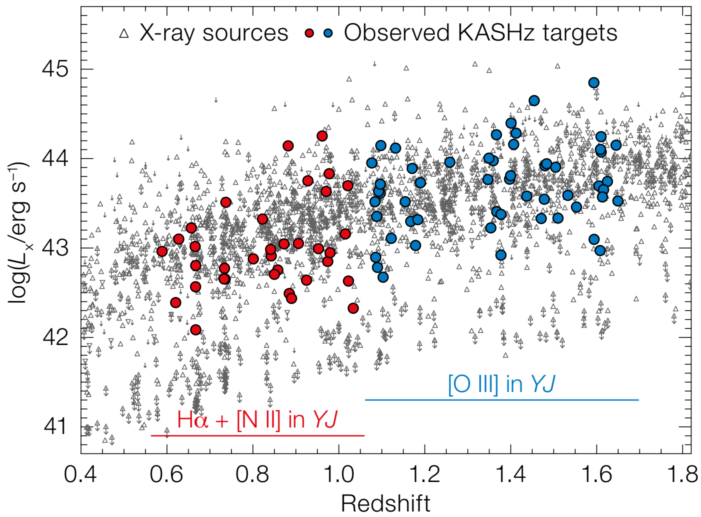


Figure 2. X-ray luminosity versus redshift for X-ray sources in the four deep fields covered by KASHz. The X-ray AGN with KMOS or SINFONI IFU data that appear in our first KASHz paper are highlighted with filled symbols.

these outflows, such as their spatial distribution and energetics (e.g., Harrison et al., 2014). Crucially, these IFU observations (and other multi-wavelength follow-up observations) can then be placed in the context of the parent population as a whole, making it possible to understand how representative these observations are and to compare them to cosmological simulations of galaxy evolution that predict such outflows.

The need for KMOS

As described above, a lot of work has been done using optical spectroscopy of low-redshift galaxies (i.e., at late cosmic epochs) to understand the prevalence and properties of galaxy-wide ionised outflows. However, much less work has been done at high redshift (i.e., early cosmic epochs; $z \approx 1$–3). This is largely due to the fact that the key restframe optical emission lines for the required analyses are shifted to near-infrared wavelengths for these distant galaxies. There has been some successful work on small numbers of objects using near-infrared IFUs, such as SINFONI on the VLT (e.g., Cano-Díaz et al., 2012; Cresci et al., 2015). However, until recently, it has been difficult to obtain large samples of near-infrared spectroscopy due to a lack of instrumentation. This has resulted in a significant deficit in our understanding of AGN feedback and outflows, because AGN activity and star formation are at their peak during early epochs ($z \approx 1$–3) and outflows may be most prevalent (see Figure 1).

Therefore, it has not been possible to constrain the prevalence and properties of ionised outflows in the high-redshift AGN and galaxy population as a whole. This is where KMOS comes to the rescue (Sharples et al., 2013). KMOS, which has been in operation at the VLT since November 2012, has 24 near-infrared IFUs that can be moved independently inside a 7-arcminute field of view. It is therefore ideally suited to rapidly build up large samples of high-redshift AGN host galaxies with high quality spatially resolved spectroscopy of the restframe optical emission lines (e.g., Bower & Bureau, 2014; Wisnioski et al., 2015). We have been exploiting the unique capabilities of KMOS to carry out such a survey — the KMOS AGN Survey at High Redshift (KASHz).

The KMOS AGN Survey at High Redshift

KASHz is designed to ultimately obtain spatially resolved emission-line kinematics of 100–200 high-redshift ($z \sim 0.6$–3.6) AGN. These data will primarily be obtained using KMOS guaranteed time observations, led by Durham University. This will be supplemented with archival data obtained using SINFONI, the single-object near-infrared IFU. The overall aim of KASHz is to provide insight into the feeding and feedback processes occurring in the host galaxies of high-redshift AGN by using IFU data to measure the ionised gas kinematics traced by the Hα, [O III], Hβ, [N II] and/or [S II] emission lines. The key aspect of KASHz is to exploit the unique capabilities of the multiple IFUs in the KMOS instrument to perform such measurements on larger, more uniformly selected samples of high-redshift AGN than was possible in previous studies that used single IFU instruments. This approach will make it possible to draw conclusions on the overall high-redshift AGN population and to place previous observations of a few sources in the context of the parent population of AGN. Until now, this sort of approach has only been possible for low-redshift AGN. Furthermore, our sample will provide an excellent characterisation of the parent population that can be used for efficient, multi-wavelength follow-up observations.

KASHz observations and first results

The first results from KASHz were published in Harrison et al. (2016). This study contains KMOS guaranteed time observational data from ESO Periods 92 to 95, as well as archival SINFONI data. This first study is of z = 0.6–1.7 AGN that were selected using X-ray wavelengths in the redshift range z ~ 0.6–1.7 (see Figure 2) and observed in the *YJ*-band. X-rays are excellent for identifying AGN because, for the most luminous emitters ($L_X > 10^{42}$ erg s^{-1}), they are largely uncontaminated by other processes (e.g., star formation) and X-rays are less affected by intervening absorbing material compared to optical and ultraviolet light. To select our targets, we made use of the well-studied extragalactic fields of the Chandra Deep Field South (CDFS-S), the Cosmological Evolution Survey (COSMOS), the UKIDSS Ultra Deep Survey (UDS) and SSA22. These fields have been covered by deep multi-wavelength observations, including high-quality X-ray observations, making them ideal for selecting AGN with known redshifts, as well as charactering the host galaxy properties of these rapidly growing black holes.

Harrison et al. (2016) contains data for 89 X-ray AGN, of which 79 were observed with KMOS (new data) and 10 were observed with SINFONI (archival data). Of these, 54 were selected to observe the [O III] emission-line doublet and 35 were selected to observe the Hα and [N II] emission lines (see Figure 2). Crucially, these targets have X-ray luminosities that are representative of the parent X-ray AGN population and therefore can be used to understand the emission-line kinematics of this population as a whole. This is an improvement over most previous IFU studies of high-redshift AGN that have observed small numbers of highly selected targets, making it difficult to understand how representative they are.

The KMOS observations were carried out using an ABA sequence (where A is on-source and B is on-sky). Each target was observed with on-source integration times between roughly 1.5 and 2.5 hours. These first KASH*z* observations were very successful. When only considering the 82 targets with reliable archival redshifts, 72 of them (88 %) were detected in emission lines. Example KMOS data are shown for three targets in Figure 3. The lower panels show galaxy-integrated [O III] emission-line profiles and the upper panels show two-dimensional spectra, over the same wavelength region, for each of the 14 KMOS IFU slices. From only these examples, it can be seen that there is a wide variety in the shapes of the emission-line profiles as well as their spatial extents and velocity structure.

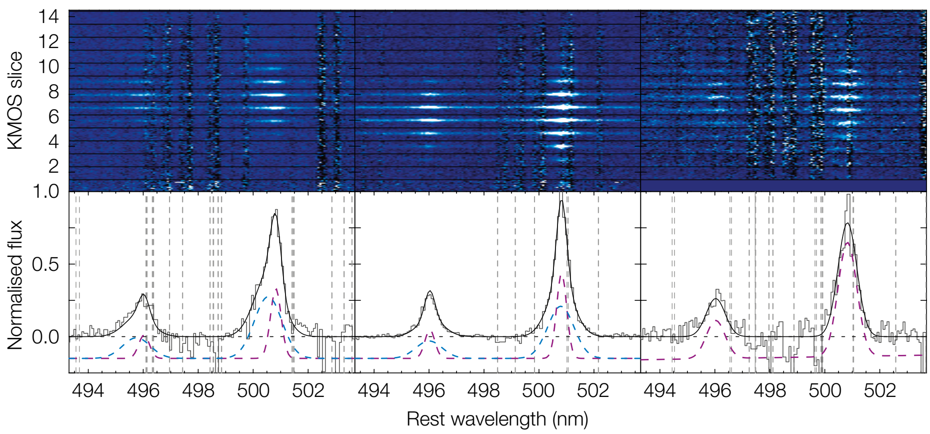


Figure 3. KASH*z* data for three example AGN-host galaxies centred around the [O III] 4959, 5007 Å emission-line doublet. Upper: The two-dimensional spectra from each of the 14 KMOS IFU slices. Lower: One-dimensional spectra created by summing over the spatial pixels within each IFU. The vertical dotted lines show the position of skylines. The black curve shows the fits to the emission-line profiles. Broad asymmetric emission-line profiles are indicative of warm, ionised outflows (see blue dashed curves); red dashed lines show the narrow emission line fits.

The first two examples in Figure 3 show broad underlying components in their [O III] emission-line profiles, indicating the presence of warm ionised outflows in the host galaxies of these X-ray AGN. The power of our survey is that we can constrain the prevalence of these ionised outflows in the context of the overall AGN population, following on from our work and of other groups at low redshift (see Figure 1). Furthermore, KASH*z* will enable us to assess how representative are the high-redshift AGN outflows that have been previously studied with near-infrared IFUs.

The prevalence of ionised outflows in high-redshift X-ray AGN host galaxies

One of the key aims of KASH*z* is to constrain the prevalence of ionised outflows in the host galaxies of high-redshift AGN. Following a similar approach to the Mullaney et al. (2013) study of z < 0.4 AGN, we set out to assess how common broad and asymmetric [O III] and Hα emission-line profiles are. These broad and asymmetric emission-line profiles are key indicators of warm, ionised outflows (see Figure 3). For example, Figure 4 shows a cumulative distribution of the overall [O III] velocity widths of the KASH*z* AGN extracted from the galaxy-integrated spectra (examples in Figure 3). These velocity widths are calculated by taking the velocity width between the 10th and 90th percentiles of the emission-line fluxes. Velocity widths of greater than 600 km s^{-1} are attributed to outflowing or highly turbulent material because even the most massive galaxies rarely reach these velocities from galaxy dynamics alone (see shaded region in Figure 4). We find that half of the sample observed in [O III] exhibit these or greater velocities. This finding implies that around half of X-ray luminous AGN host warm, ionised outflows that dominate their emission-line gas. Outflows that are less dominant in the overall kinematics will be even more common.

We have compared the prevalence of warm, ionised outflows in our high-redshift AGN sample with a luminosity-matched sample of z < 0.4 AGN taken from Mullaney et al. (2013). We observed a remarkable similarity between the distributions of ionised gas velocities between the two samples (see Figure 4). This result implies that, for a fixed black hole accretion rate, these outflows are very similar at both early and late epochs. However, due to a higher fraction of galaxies hosting rapid black hole growth at early times (see Figure 1), our results imply that the most extreme ionised outflows were more prevalent in the past.

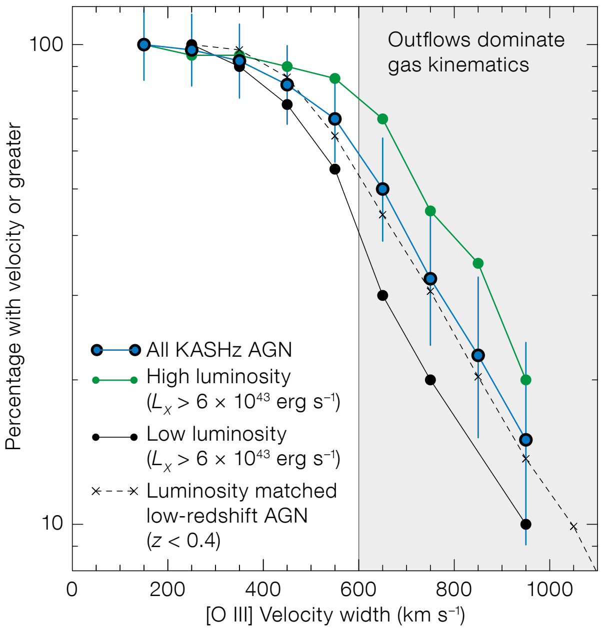


Figure 4. Cumulative histogram of the [O III] emission-line velocity widths for the z = 1.1–1.7 KASHz AGN observed so far, and a luminosity matched sample of low redshift AGN. Very high velocities of > 600 km s^{-1} indicate that the warm, ionised gas kinematics are dominated by outflows or high levels of turbulence (shaded region).

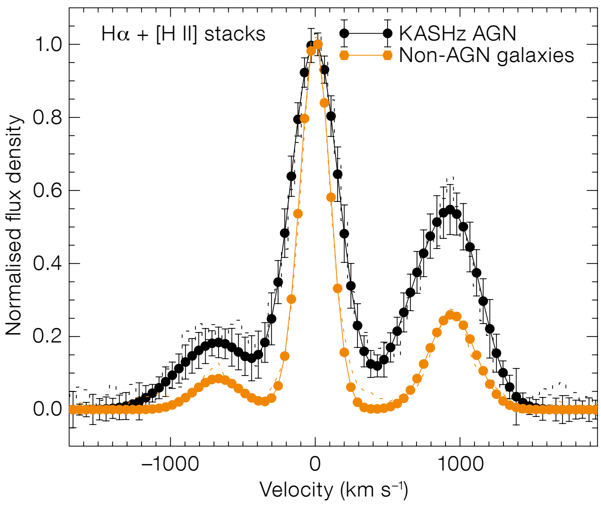


Figure 5. Stacks of the Hα and [N II] emission-line profiles for the z = 0.6–1.1 KASHz AGN observed so far (black curve) and a redshift-matched comparison sample of star-forming galaxies (orange curve) taken from the KROSS survey (Stott et al., 2016).

The drivers of ionised outflows

One of our key questions is what drives the most powerful outflows in high-redshift galaxies? We provide some initial insight in Harrison et al. (2016). For example, we found that high-velocity outflow features are about twice as common in the half of the sample with the most powerful (luminous) AGN compared to the less powerful half. Comparison of the green and black lines in Figure 4 demonstrates this result. This finding provides some evidence that the prevalence of outflows is increased in the host galaxies of the most rapidly accreting black holes.

We also compared the Hα and [N II] emission-line profiles of our AGN with a redshift-matched sample of star-forming galaxies with no clear signs of ongoing AGN activity (see Figure 5), taken from the KMOS Redshift One Spectroscopic Survey (KROSS; Bower & Bureau, 2014; Stott et al., 2016). The emission-line profiles are clearly broader in the host galaxies of the luminous AGN, implying that the prevalence of ionised outflows is increased. This effect still appears to hold true when taking into account the different galaxy masses of the two samples (see Harrison et al. [2016] for details). We can look forward to more direct evidence of the physical processes that drive these ionised outflows (e.g., radio jets versus AGN-driven winds, etc.) in future papers which exploit the full KASHz sample as well as multi-wavelength complementary datasets.

Ongoing work and prospects

We have presented the background and first results of KASHz. However, this is an ongoing project. By combining the excellent quality IFU data from KMOS and SINFONI, with the archival data available for our targets, we will be able to investigate a wide array of scientific questions. These include, how do the morphologies and energetics of the identified outflows compare to host galaxy and AGN properties, such as accretion rates, masses and star formation rates and what physical processes drive these outflows? These are key questions to address in order to constrain models of galaxy formation. Furthermore, as the observations continue, we are building up a larger sample of objects that, as well as increasing the parameter space covered by these objects, will provide the strongest statistics to date on the prevalence, properties and impact of ionised outflows in the host galaxies of high-redshift AGN.

Acknowledgements

Based on observational data obtained under ESO programmes: 086.A-0518; 087.A-0711; 088.A-0316; 60.A-09460; 092.A-0884; 092.A-0144; 092.B-0538; 093.B-0106; 094.B-0061 and 095.D-0035. Support is acknowledged from STFC, grant code ST/L00075X/1.

References

Aird, J. et al. 2010, MNRAS, 401, 2531
Bower, R. & Bureau, M. 2014, The Messenger, 157, 38
Cano-Díaz, M. et al. 2012, A&A, 537, L8
Cicone, C. et al. 2014, A&A, 562, A21
Cresci, G. et al. 2015, ApJ, 708, 419
Ganguly, R. & Brotherton, M. S. 2008, ApJ, 692, 758
Harrison, C. M. et al. 2014, MNRAS, 441, 3306
Harrison, C. M. et al. 2016, MNRAS, 456, 1195
Madau, P. & Dickinson, M. 2014, ARA&A, 52, 415
Mullaney, J. et al. 2013, MNRAS, 433, 622
Rupke, D. S. N. & Veilleux, S. 2013, ApJ, 768, 75
Schaye, J. et al. 2015, MNRAS, 446, 521
Sharples, R. et al. 2013, The Messenger, 151, 21
Stott, J. et al. 2016, MNRAS, submitted
Vogelsberger, M. et al. 2014, MNRAS, 444, 1518
Wisnioski, E. et al. 2015, ApJ, 799, 209

ESO/Felipe MacAuliffe

ESO/M. Zamani

(Upper) The tenth anniversary of astronomical research with the Atacama Pathfinder EXplorer (APEX) telescope was celebrated in January 2016. Shown are visitors at the telescope during the celebrations. See Announcement ann16008.

(Lower) Signing of the agreement between INAF (Italy) and ESO for the design and construction of the MAORY adaptive optics system for the European Extremely Large Telescope on 10 December 2015 at ESO Headquarters. See Announcement ann15093.

Light Phenomena over the ESO Observatories I: Airglow

Lars Lindberg Christensen[1]
Stefan Noll[2]
Petr Horálek[1]

[1] ESO
[2] Institute for Astro- and Particle Physics, University of Innsbruck, Austria

Airglow, the faint light emitted by the Earth's atmosphere, has in recent years been frequently photographed in large field images taken at ESO's observatories. The nature of the airglow is briefly described and example images are shown, capturing the variety of the displays.

On a moonless night at the La Silla Observatory, in the Atacama Desert of northern Chile, it should be very dark, but at times, strange green and red colours can be seen shimmering in the night sky. Although visible, albeit faintly, to the unaided eye, these unusual lights are very prominent in long exposures captured by commercial digital single-lens reflex (SLR) cameras. An example is shown in Figure 1. To the untrained eye, these lights may appear to be some kind of peculiar low-latitude auroral phenomenon, but they are actually the emission of airglow — light emitted by the Earth's atmosphere. This optical phenomenon prevents the night sky from ever becoming completely dark (Roach & Gordon, 1973; Patat, 2004, 2008; Noll et al., 2012), even in the absence of astronomical sources.

The formation of airglow

The first airglow emission line was identified in 1868 by the Swedish scientist Anders Ångström, but it took until the 1920s to understand that airglow differs from aurorae (Mc Lennan, 1928; Roach & Gordon, 1973). Since the 1950s airglow has been extensively studied by ground-based instruments (photometric and spectroscopic), by instruments aboard rockets and satellites and by laboratory experiments (Khomich et al., 2008).

These research efforts have revealed that the Sun is constantly showering the Earth's atmosphere with ultraviolet light, which photodissociates molecular oxygen (O_2) into individual atoms during the daytime and triggers a chain of complex chemical reactions after sunset. Atomic oxygen (O) cannot efficiently recombine and therefore has a long lifetime in the upper atmosphere. It represents a store of chemical energy that is also available at night. O_2, O, sodium (Na), and the hydroxyl radical OH can then be produced and excited by further reactions and collisions, causing them to emit radiation by chemiluminescence (Roach & Gordon, 1973; Khomich et al., 2008; Noll et al., 2012, 2015a, 2015b).

Astronomers are used to subtracting airglow emission lines from ground-based spectra. The airglow lines extend from the near-ultraviolet to the near-infrared regime (Rousselot et al., 2000; Hanuschik, 2003; Noll et al., 2012), and are characterised by clusters of numerous narrow emission lines. This structure is especially common in the near-infrared, where the strongest airglow lines are found (OH bands) and give rise to background patterns that present interesting challenges if they have to be removed (Noll et al., 2014). An example is presented by exposures from the VLT Infrared Survey Telescope for Astronomy (VISTA), in which the OH airglow structures move between the dithered exposures of the widely spaced array of CCD chips. This effect is especially visible until about two hours after twilight[1].

Observations of airglow

Airglow is very faint, but the strongest appearances of the phenomenon can be visible to the naked eye as an unexpected faint structure on the stellar background. To the naked eye, the colours of this airglow are invisible, but sensitive wide-angle photographs reveal the fine green and reddish shades of the phenomenon. Sometimes airglow presents itself as just a faint tinge of colour on the horizon, but it can also appear as a melange of changing colourful shapes (Figure 1).

The green layer of airglow lies about 100 kilometres above the ground and can easily be observed from the International Space Station (Figure 2). A much fainter reddish tint of luminescent atmosphere resides above the green layer, at altitudes between 150 and 350 kilometres. Both layers are related to atomic oxygen, but their different altitudes cause the green emission to peak much closer to the horizon (Noll et al., 2012).

The extent, colour and brightness of airglow is influenced by many different factors, including the time and location of the observation (Roach & Gordon, 1973; Khomich et al., 2008; Patat, 2008; Noll et al., 2012). The red oxygen glow, for example, tends to be brightest at the start of the night, but after midnight, it can be very weak. However sporadic bursts of airglow emission can occur at any time.

Airglow can also appear in formations called gravity waves (Taylor et al., 1997; Khomich et al., 2008), as illustrated by Figure 1, lower right. These propagating air pressure oscillations are mainly formed in the lower atmosphere (e.g., by air flows over mountains) and can then rise to high altitudes. Here, their amplitudes can increase to widths greater than those of the airglow layers due to very low air pressure and the conservation of wave energy and momentum. In turn, this affects the intensity of the airglow and characteristic moving ripples in the airglow can be formed (Figure 1).

Airglow increase

The origin of the airglow is now fairly well understood, but why are we seeing it more often in images taken at ESO sites in Chile over the past five years (see Figures 3, 4 and 5)? Has airglow become more common? Could it be caused by global changes in weather patterns? The answer is not yet clear, but the recent rapid development of digital cameras seems to play an important role as they allow for fainter details to be picked up in the night sky more frequently.

Identical cameras, however, have been found to capture dramatically different skies just weeks apart. Airglow changes with solar activity, so the 11-year solar cycle can have an impact on the brightness of the airglow. The current solar cycle (Cycle 24) peaked in 2014, although

P. Horálek/ESO

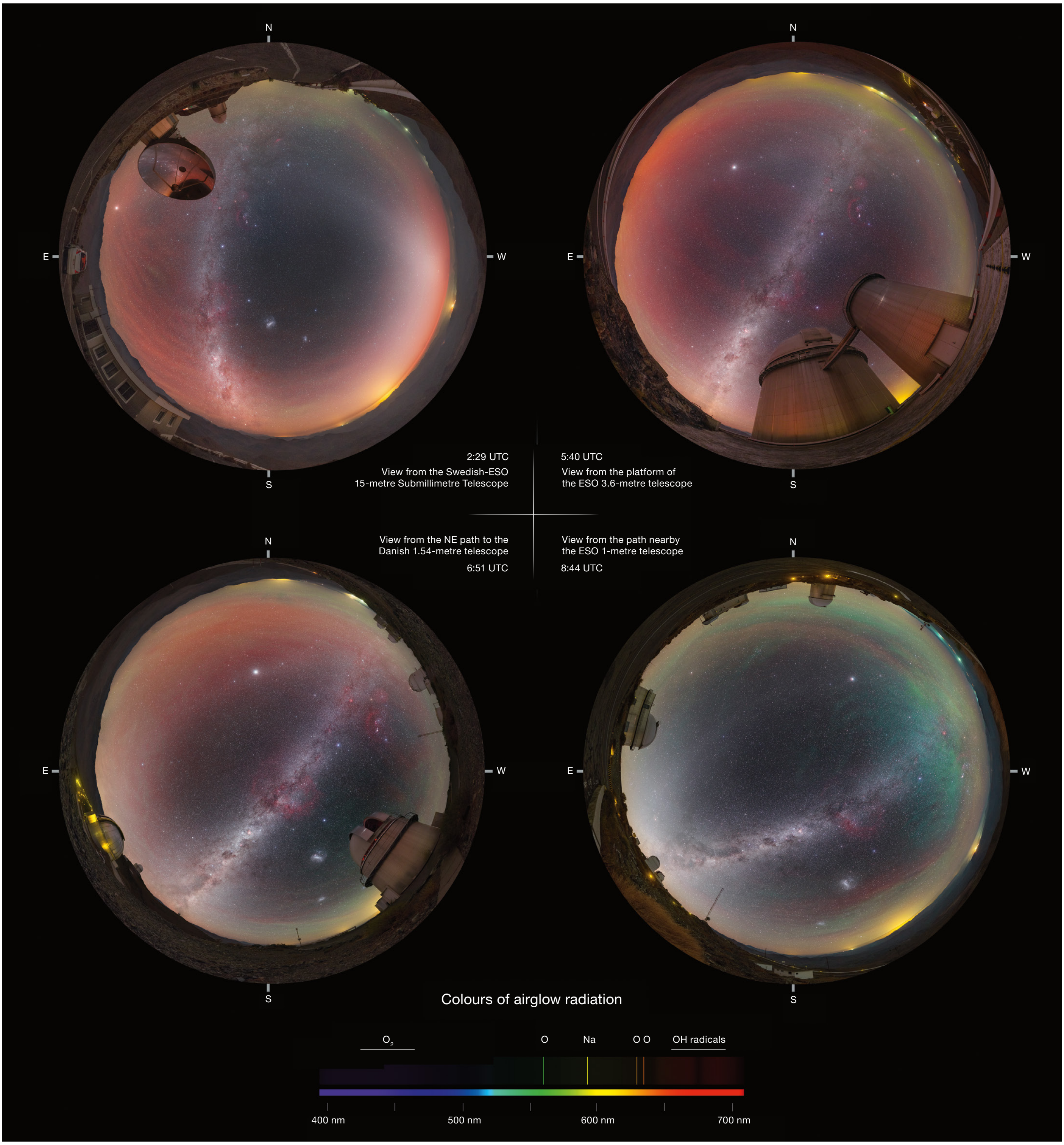


Figure 1. One night at the La Silla Observatory (20 January 2015) exhibiting different displays of green and red airglow seen in deep fisheye images spanning 360 degrees azimuth and 120 degrees altitude. In the lower right image, gravity waves can be seen forming ripples in the greenish layer of airglow.

ISS/NASA

Figure 2. This unique photograph, taken from the International Space Station, shows the airglow layers above the city lights of Brisbane, Australia.

Y. Beletsky (LCO)/ESO

Figure 3. Red and green airglow dances above ESO Photo Ambassador Babak Tafreshi as he prepares his camera to capture the night sky.

Y. Beletsky (LCO)/ESO

Figure 4. An example of airglow display at Cerro Paranal with the VLT in the foreground.

Y. Beletsky/ESO

Figure 5. Flaming red airglow photographed over the Paranal Observatory. The three 1.8-metre Auxiliary Telescopes, part of the Very Large Telescope Interferometer, can be seen in the foreground.

it was amongst the weakest maxima on record (Hathaway, 2015). It seems that the solar maximum could be partly responsible for the increase in airglow captured in images from ESO's observatories in recent years (Noll et al., 2012).

It is also worth mentioning that ESO's observatories in Chile are located below the South Atlantic Anomaly (Heirtzler, 2002). Here, the Earth's magnetic field — which prevents charged particles from reaching the surface — is reduced and thus more particles from the Sun penetrate the atmosphere. This anomaly can affect the red airglow, which originates in the Earth's ionosphere (see Figure 5), although the geomagnetic latitude is more crucial for the observed variability.

One way or another, airglow has become a regular feature in the magnificent celestial displays witnessed over the ESO sites. Even at one of the darkest places on the planet, the sky never becomes completely dark.

Acknowledgements

The authors acknowledge interesting conversations with Bob Fosbury.

References

Hanuschik, R. W. 2003, A&A, 407, 1157
Hathaway, D. H. 2015, Living Rev. Solar Phys., 12, 4
Heirtzler, J. R. 2002, JASTP, 64, 1701
Khomich, V. Y. et al. 2008, *Airglow as an Indicator of Upper Atmospheric Structure and Dynamics*, (Berlin: Springer)
McLennan, 1928, *Bakerian Lecture. The Aurora and Its Spectrum*, Royal Society Proc. A, 120, 785
Noll, S. et al. 2012, A&A, 543, A92
Noll, S. et al. 2014, A&A, 567, A25
Noll, S. et al. 2015a, *Atmospheric Chemistry and Physics*, 15, 3647
Noll, S. et al. 2015b, ACPD, 15, 30793
Patat, F. 2004, The Messenger, 115, 18
Patat, F. 2008, A&A, 481, 575
Roach, F. E. & Gordon, J. L. 1973, *The Light of the Night Sky*, (Dordrecht: Reidel)
Rousselot, P. et al. 2000, A&A, 354, 1134
Taylor, M. J. et al. 1997, JGR, 102, 26283

Links

[1] Sky brightness record from VISTA VIRCAM imaging: http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/sky-brightness-variation

Light Phenomena over the ESO Observatories II: Red Sprites

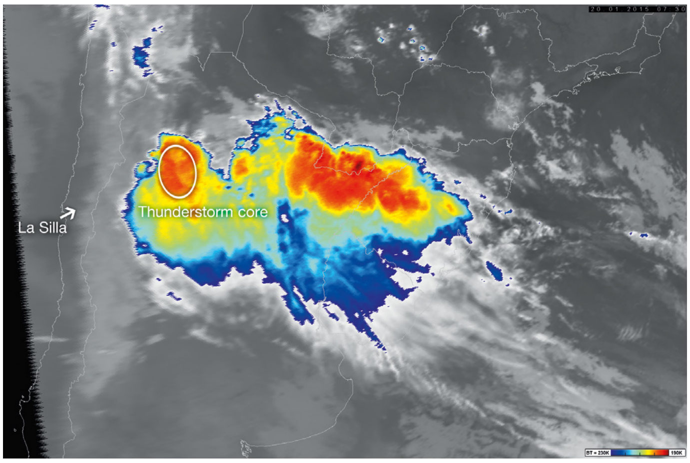
Petr Horálek[1]
Lars Lindberg Christensen[1]
József Bór[2]
Martin Setvák[3]

[1] ESO
[2] Research Centre of Astronomy and Earth Sciences, GGI, Hungarian Academy of Sciences, Budapest, Hungary
[3] Czech Hydrometeorological Institute, Prague, Czech Republic

A rare atmospheric phenomenon, known as red sprites, was observed and captured on camera from the La Silla Observatory. This event signalled the first time that these extremely short-lived flashes of red light, originating in the Earth's upper atmosphere, were photographed from a major astronomical observatory. Further images of red sprites from the La Silla Paranal Observatory sites are presented and the nature of red sprites is discussed.

Petr Horálek/ESO

Figure 1. (Above) Red sprites caught on extremely deep digital camera images from the La Silla Observatory on 20 January 2015. The time of each exposure is indicated.



EUMETSAT; Martin Setvák/CHMI; Petr Horálek/ESO

Figure 2. This image from the EUMETSAT's Meteosat-10 (Meteosat Second Generation, MSG-3) satellite was taken on 20 January 2015 at 7:30 UTC. The storm cell above which the sprites were observed (Figure 1) is marked.

On 20 January 2015, ESO Photo Ambassador Petr Horálek was photographing the Milky Way at the La Silla Observatory, when a series of short-lived flashes of red light appeared above the horizon and caught his eye. Using a digital camera, adapted for better near-infrared performance by removing the infrared blocking filter, a series of features known as red sprites was successfully photographed (see Figure 1). Red sprites have not been extensively imaged, and the image in Figure 1 marked the first time that they had been captured from a major astronomical observatory.

Subsequent investigation revealed the origin of the sprites to be a cluster of massive thunderstorms over northern Argentina on the eastern foothills of the Andes. Figure 2 shows the Meteosat-10 satellite image of this thunderstorm; the storm's activity reached its maximum at the time this image was recorded. The red sprites were photographed from La Silla around the same time. The core of the thunderstorm is marked in Figure 2 and was located about 560 kilometres from La Silla.

A week later at Paranal, just a few hours before daybreak on 27 January 2015, the first author once again spotted the unmistakable tendrils of red sprites, and this time photographed several over an almost two-hour period (see Figure 3). From the camera's perspective, they appeared to come from the direction of the rising Galactic Bulge of the Milky Way. In reality they originated from another huge complex of storms over the Andes at approximately the same location in Argentina, this time about 620 kilometres away. Figure 4 shows the Meteosat-10 image of this storm. The most spectacular red sprites were photographed from Paranal from 8:30 to 9:10 UTC. The core of the thunderstorm is marked in Figure 4 and is located about 550 kilometres from the Paranal Observatory.

The storms were so strong that another display of their activity was observed and documented. High in the atmosphere, gravity waves generated by these storms (Siefring et al., 2010) formed ripples in the greenish layer of airglow about four hours before the red sprites appeared (Figure 5).

The first observations of red sprites

The existence of transient luminous events, or TLEs, was predicted by the Scottish physicist Charles Wilson (1869–1959) in 1920. He was the inventor of the

P. Horálek/ESO

Figure 3. The unmistakable tendrils of multiple red sprites imaged by ESO Photo Ambassador Petr Horálek from ESO's Paranal Observatory on 27 January 2015. Two exposures were combined, with the upper sprite occurring at 7:46:43 UTC and the lower at 8:07:25 UTC. In the foreground is one of the 1.8 metre VLT Auxiliary Telescopes.

EUMETSAT; Martin Setvák/CHMI; Petr Horálek/ESO

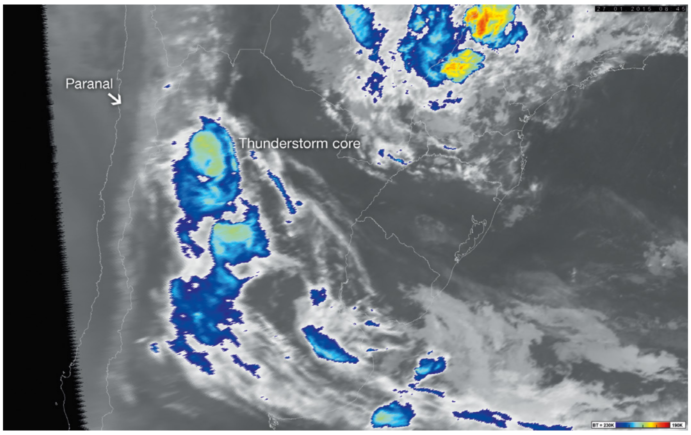


Figure 4. Image taken by the Meteosat-10 satellite on 27 January 2015 at 8:45 UTC as the thunderstorm's activity decreased. The weakening storm cell, above which the sprites in Figure 3 were observed, is indicated.

Wilson cloud chamber for the detection of elementary particles, and he was awarded the Nobel Prize in 1927 for his development of a method of visualising electrical particle tracks in condensed vapours. Unfortunately, Wilson did not live to witness the experimental confirmation of his theory.

The interest in TLEs has grown since 1989, when they were first detected with auroral cameras in Minnesota, USA (Franz et al., 1990), and interest has increased following imaging from the NASA Space Shuttle and the International Space Station (ISS); see Jehl et al. (2013) and Yair et al. (2013). Astronauts on the ISS have a particularly good vantage point and have recorded red sprites with digital cameras (Figure 6). The appearance of red sprites shortly follows the occurrence of the corresponding lightning stroke; both kinds of flashes are often captured on the same image that is taken from space.

A few years after the discovery of red sprites, the NASA Compton Gamma Ray Observatory managed to observe gamma bursts originating above thunderstorms — another consequence of tropospheric lightning activity (Fishman et al., 1994).

What causes red sprites to appear?

In thunderstorms, most cloud-to-ground discharges are called negative lightning, as they transfer negative charge to the ground. However, up to 5 % of all discharges are positive cloud-to-ground

Petr Horálek/ESO

Figure 5. Gravity waves in the airglow above Paranal, just a few hours before the red sprites shown in Figure 3 were photographed over the distant storm.

ISS/NASA

Luis Calçada/ESO

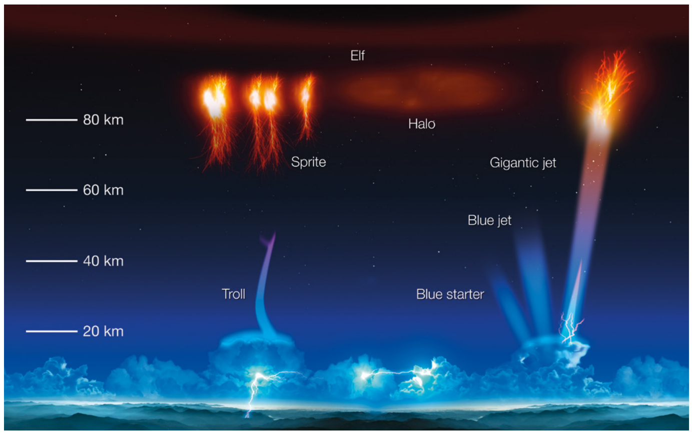


Figure 6. Red sprite photographed from the International Space Station above Southeast Asia in April 2012.

Figure 7. The family of TLE phenomena is depicted. Adapted from an illustration by Frankie Lucena.

lightning that transfer positive charge from the thundercloud to the ground. Up to ten times more energetic than negative lightning, positive lightning seems to be what makes the Earth's atmosphere produce red sprites and some of the other TLE phenomena, commonly known as upper-atmospheric lightning (Boccippio et al., 1995).

Red sprites are a manifestation of complex high-altitude electrical discharge processes (Pasko et al., 2012; Siingh et al., 2012). They typically show up over large and powerful thunderstorms that are strong enough to trigger gravity waves in the upper atmosphere. These unusual flashes are formed at altitudes up to 90 kilometres and get their distinct red hue from the excited nitrogen molecules in the atmosphere. They show up as figures composed of channels, beads and puffs (Bór, 2013). Red sprites are caused by electrical discharge fronts that move rapidly in the high-altitude electric field generated by tropospheric lightning[1].

There are many different species of TLEs (see Figure 7). The nomenclature of TLE phenomena is usually based on their shape and colour in the sky: blue jets, which occur at heights of 15–45 kilometres above the ground; red sprites at heights 50–85 kilometres; and elves at around 90–100 kilometres altitude (Pasko et al., 2012; Marshall & Inan, 2007). The vertically longest TLE phenomenon is the gigantic jet, which starts from the cloud tops and ends around 90 kilometres above the ground (Siingh et al., 2012). It has been speculated that similar phenomena could occur on other planets in the Solar System (Yair et al., 2009).

Red sprites are the most frequently photographed type of upper-atmospheric lightning phenomena on Earth. In photographs, they appear rather dim and the exact time and location of their appearance in the sky is unpredictable. They show up for only a fraction of a second, making them difficult to document and study. However with a wide-aperture lens and a clear view to the horizon in the direction of a powerful thunderstorm, together with low light pollution, they can be imaged with commercial cameras.

The La Silla and Paranal Observarory sites provide ideal conditions for photographing TLE phenomena. The observatories are located at more than 2000 metres above sea level and the dry and transparent air allows the phenomena to be observed at great distances and very low above the horizon. During midsummer (January–February), South America is rich in strong thunderstorm systems, especially above Brazil and Argentina. Due to the extremely low levels of light pollution above the ESO sites and the unimpeded view to the east, there is a good chance of capturing such phenomena with digital cameras, despite the very large distances to the thunderstorms. Recording the same red sprites from La Silla and Paranal simultaneously would enable the determination of their height and size by triangulation.

Red sprites are not yet completely understood and any new image showing them is valuable to atmospheric scientists studying these phenomena. Now ESO has been able to contribute to this intriguing puzzle of the Earth's atmosphere.

Acknowledgements

The contribution of József Bór was supported by the National Research, Development and Innovation Office, Hungary (NKFIH), K115836, and by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. We are grateful to Bob Fosbury for comments.

References

Boccippio, D. J. et al. 1995, Science, 269, 1088
Bór, J. 2013, J. Atmospheric & Solar-Terrestrial Physics, 92, 151
Fishman, G. J. et al. 1994, Science, 264, 1313
Franz, R. C., Nemzek, R. J. & Winckler, J. R. 1990, Science, 249, 4964, 48
Jehl, A., Farges, T. & Blanc, E. 2013, J. Geophysical Research: Space Phys., 116, 454
Marshall, R. A. & Inan, U. S. 2007, Geophysical Research Letters, 34, L05806
Pasko, V. P., Yair, Y. & Kuo, C.-L. 2012, Space Sci. Rev., 168, 475
Siefring, C. L. et al. 2010, J. Geophysical Research, 115, A00E57
Siingh, D. et al. 2012, Space Sci. Rev., 169, 73
Yair, Y. et al. 2009, J. Geophysical Research, 114, E09002
Yair, Y. et al. 2013, J. Atmospheric & Solar-Terrestrial Physics, 102, 140

Links

[1] The BBC documentary *Exploring the Edge of Space* features spectacular footage of red sprites: http://www.youtube.com/watch?v=lqeqWOQQe2Y

Report on the ESO–ESA Workshop

Science Operations 2015: Science Data Management

held at ESO Headquarters, Garching, Germany, 24–27 November 2015

Martino Romaniello[1]
Chistophe Arviset[2]
Bruno Leibundgut[1]
Danny Lennon[2]
Michael Sterzik[1]

[1] ESO
[2] ESAC, Villafranca de Castillo, Madrid, Spain

During four intense days, more than 100 astronomers, software engineers, science operation and data management experts gathered for the second installment of the ESO–ESA workshop series "Science Operations: Working together in support of science". Two years ago, the inaugural meeting of the series at the European Space Astronomy Centre in Madrid provided an overview of all of the different aspects of Science Operations. This year's gathering was focused on science data management, and an overview of the presentations and a summary of the discussions is provided.

Introduction: Science data management for European astronomy

ESO and the European Space Agency (ESA) generate a significant fraction of science data from ground and space for the European astronomical community (and beyond). These data feed both direct principal investigator (PI) demands and use by the community-at-large through powerful science archives. The objective of the workshop was to present and discuss the various approaches to science data management, with the goals of:
- comparing and improving processes and approaches;
- fostering innovations;
- enabling a more efficient use of resources;
- establishing and intensifying collaborations, specifically exploring ways to enhance the value of the data through common strategies and practices;
- establishing ways to collect community feedback and gauge the success and limitations of implemented solutions;
- exploring synergies and mutual support of science operations for ground and space missions.

Specific topics included quality assurance of science data and related calibrations, data reduction and analysis, and science archives (content and user services).

Some 45 talks and 20 posters were presented. All of the talks and a selection of the posters are accessible via the workshop web page[1] (individual talks have links to the Zenodo platform[2] to provide permanent Digital Object Identifiers [DOIs] that are citable and discoverable). The programme was structured around broad groups of topics, or tracks. Here we will follow these tracks, rather than the purely chronological order of the presentations. (In the electronic version of this article, clicking on the name of the presenter leads to the corresponding presentation.)

Introductory overviews

The proceedings were opened by welcome addresses from Andreas Kaufer, ESO Director of Operations, and Martin Kessler, Head of the Operations Department at the European Space Astronomy Centre (ESAC). In presenting broad overviews of the goals and perspectives of the two organisations, they highlighted the central role that science data management plays in enabling the scientific exploitation of the missions/observatories. Christophe Arviset from ESA and Martino Romaniello from ESO expanded on this introduction. In particular, Arviset presented the new approach that ESA is taking to integrate the development of all archives under the same organisational unit in order to foster close collaboration between astronomers and software engineers. This approach also allows individual mission archives to be embedded within a more general context, enabling and facilitating multi-mission scientific archive searches (e.g., the ESASky interface, described below). Romaniello described ESO's efforts towards an integrated approach to science data management, ensuring that instruments are working properly, that the science content can be extracted from the data and, finally, the science data delivered to our users, PIs and archive researchers alike.

Impressive statistics on archive access and data usage were shown for both ESA and ESO to corroborate the growing role of archive science in the astronomical landscape. Examples cited were: more than 50 % of the refereed publications that use Hubble Space Telescope (HST) data are based on archival data; the user base of processed data products from the ESO Science Archive Facility has grown to a grand total of more than 1200 individuals (and counting).

Archives and data centres

Felix Stoehr introduced ALMA science data management, which may be considered as an evolution of the Very Large Telescope (VLT) approach, but with important differences (e.g., the Science Archive is at the heart of the ALMA dataflow: quality assessment is made and based on the actual science goals of the PIs, rather than on relying on the instrument characterisation and modelling). Stoehr also offered thought-provoking ideas on the evolution of astronomy as a science, from being photon-starved to having to deal with a deluge of data.

Roland Walter brought in experience from high-energy astrophysics in demonstrating the power of legacy datasets to generate new discoveries, especially when analysed in ways that the original researchers could not have anticipated. A range of examples was given, from the new discovery of an accretion event by the black hole in the galaxy NGC 4845, to a detailed study of the wind velocity field of a nearby star. An archival stacked image corresponding to an exposure time of no less than 35 years was particularly impressive!

In a series of talks spread over different sessions, Denis Mourard, Françoise Genova, Giovanni Lamanna and Johannes Reetz elaborated on the wider European context of science data management. With initiatives like ASTRONET, the Horizon 2020 Astronomy European Strategy Forum on Research Infrastructures (ESFRI) and Research Infrastructure Cluster (ASTERICS) project and the European data initiative (EUDAT), it is clear that attention, at a continental level, is high with regard to astronomical science data management and the quest for synergies across disciplines. This found a nice echo

Figure 1. Delegates of the Science Operations 2015 (SciOps2015) ESO/ESA Workshop pose for a photo on the bridge connecting buildings at ESO Headquarters in Garching, Germany.

in the talks by Fréderic Hemmer from the European Organization for Nuclear Research (CERN), where managing the data is a significant challenge at all levels, and a crucial one for its exploitation, and by David Schade and Séverin Gaudet. The latter presented the nationwide Canadian Advanced Network for Astronomical Research (CANFAR) e-infrastructure and the transformational effect it has had on the role of data centres like the Canadian Astronomy Data Centre (CADC).

The requirements, and associated challenges, of processing, calibrating to an astrometric precision of order 10 microarcseconds, and archiving the 10^{12} measurements for one billion stellar sources and spectra delivered by the ESA *Gaia* satellite were the focus of talks by Antonella Vallenari, Fred Jansen, José Luis Hernandez-Munoz (presented by William O'Mullane), Marco Riello and Juan Gonzalez-Núñez. In order to meet these challenges, a pan-European cooperation, the Data Processing and Analysis Consortium (DPAC), has been put in place, through which over 1000 staff years have been channelled since 2006, mostly supported through national funding.

A similar scheme of distributed data centres for processing, archiving and distributing data is being put in place for the next big ESA astronomy mission, Euclid, the topic of the presentation by Marc Sauvage. With the aim of characterising the properties of the accelerating Universe in its components (dark matter and dark energy) and the dominant large-scale force (gravity), the mission will collect shape parameters for 1.5 billion galaxies and 30 million photometric redshifts to an accuracy of Δz of 0.001. Preparations are well underway, so that implementation can begin for the start of the nominal mission in 2021. The topic of distributed data management systems, or data federations, was also the focus of the presentation of Edwin Valentijn. The case in point is the AstroWise information system, currently in operation with OmegaCAM on the VLT Survey Telescope (VST) and the Multi Unit Spectroscopic Explorer (MUSE) on the VLT. The multi-disciplinary versatility of AstroWise was highlighted, though its applications to the Low Frequency Array for Radio astronomy (LOFAR) telescope, life science projects and business applications.

Continuing the topic of data centres, Mike Irwin traced the multi-decennial history of the Cambridge Astronomical Survey Unit (CASU), from digitising United Kingdom Schmidt Telescope (UKST) and Palomar Observatory Sky Survey (POSS) photographic plates to supporting surveys on cutting-edge current facilities (e.g., VIRCAM on the VLT Infrared Survey Telescope for Astronomy [VISTA], OmegaCAM on the VST, WFCAM on the United Kingdom InfraRed Telescope [UKIRT], MegaCAM on the Canada France Hawaii Telescope [CFHT], SuprimeCAM on the Subaru telescope, DECAM on the Cerro Tololo Inter-American Observatory [CTIO], etc.) and future (4MOST on VISTA, WEAVE on the William Herschel Telescope [WHT]) facilities. Key to its success is to have people in the team who actively do science with the data as this is the only way to understand the relevant details.

The activities of the Wide Field Astronomy Unit (WFAU) in Edinburgh were presented by Nicholas Cross. Most of the data received is processed at CASU, and WFAU specialises in building and operating survey science archives. Imaging surveys carried out on WFCAM on UKIRT, VIRCAM at VISTA and OmegaCAM on the VST account for most of its current work, which also includes operating the archive for the Gaia–ESO spectroscopic Public Survey. Again, the importance of staff understanding the science, the data and the archive system itself was highlighted as critical for its ultimate success.

The Centro de Astrobiología (CAB) Data Centre is the most important Spanish astronomical data centre and was the focus of the presentation by Enrique Solano. Among others, it contains the scientific archives of the Gran Telescopio Canarias (GTC) and the Calar Alto Observatory (CAHA). It draws its *raison d'être* and success from a tight connection with its community of data providers, professional astronomers and amateurs and the general public, providing them with added-value services on top of the data. José Manuel Alacid introduced the GTC Public Archive. It provides access to both raw and science-ready data, which are provided both by the community and generated in-house. The archive has been designed in compliance with the standards defined by the International Virtual Observatory Alliance (IVOA) to guarantee a high level of data accessibility and handling and, indeed, receives more accesses through Virtual Observatory protocols than through web interfaces.

Mark Allen presented the activities of the Centre de Données astronomiques de Strasbourg (CDS), which since 1972 has been collecting useful data on celestial objects in electronic form, and then improving the data by critical evaluation and combination, before distributing the results to the international community and conducting research using these data. The CDS has grown to be a reference data centre for astronomy that delivers critically evaluated, professionally curated information and whose services, e.g., SIMBAD, Vizier, Aladin and X-Match, provide added value to scientific content in order to support the astronomy research community.

The archives of several ESA astronomy and planetary missions were presented in the talks by Santa Martinez and Iñaki Ortiz de Landaluce (BepiColombo), Deborah Baines (the new European HST archive), Eva Verdugo (the Herschel Science Archive), Xavier Dupac (the Planck Legacy Archive), Tanja Lim (ExoMars) and Michele Armano (Laser Interferometer Space Antenna [LISA] Pathfinder). Bruno Merín showcased the brand-new ESASky astronomy multi-mission interface, which was recently released in its beta version, and which brings access to all ESA astronomy missions under one roof, allowing for easy access to multiwavelength targets across the entire sky.

Vicente Navarro introduced the activities carried out at ESAC to provide long-term preservation of data analysis software for four missions that are now in their legacy phase, namely ISOPHOT Interactive Analysis (PIA) for the Infrared Space Observatory (ISO) from 1995, the Science Analysis Software (SAS) for the X-ray Multi-Mission Mission (XMM) Newton satellite from 1999, the Herschel Interactive Processing Environment (HIPE) from 2009 and EXIA for the European X-ray Observatory SATellite (EXOSAT), dating back to 1983. Tailored solutions for expert and standard users are provided in the form of virtual machines and web interfaces, respectively.

Ivan Zolotukhin presented an interesting example of citizen science, through which a new web application was built to efficiently expose the 3XMM-DR5 catalogue from the XMM-Newton mission. By providing convenient access to previously existing data products, in its few months of public operations the interface has already tackled different science cases and led to a variety of results, including the discovery of new cataclysmic variables, of the first non-recycled pulsar and of the second cooling neutron star.

Science data management

Science data management at ESO was discussed in some detail in the talks by Steffen Mieske and Burkhard Wolff (data quality assurance and instrument trending), Reinhard Hanuschik (quality-controlled generation of science data products for archive publication), Wolfram Freudling (user science data reduction), Jörg Retzlaff (Phase 3, i.e. the publication of science data products through the ESO Science Archive Facility) and Nausicaa Delmotte (validation of Phase 3 data). Isabelle Pércheron elaborated on the experience of bringing the PIONIER VLT Interferometer instrument from a (very successful) visitor instrument to one that is offered to the whole community, fully integrated into ESO dataflow operations. Marina Rejkuba described how ESO supports its community in preparing and designing observations in order to maximise their science return as well as the overall efficiency of the observatory. Pascal Ballester reported on scientific software development at ESO, discussing the lessons learned and evolution of the process for the next generation of tools and observing facilities.

Peter Weilbacher presented the MUSE instrument, a wide-field integral field spectrograph that started science operations about one year ago at the VLT. The availability of a mature science pipeline from the beginning has allowed science results to be generated from the very complex data that the instrument produces. At the same time, a development path was identified and implemented to take into account what was being learnt from the actual data, as opposed to the expectations from pre-operation simulations.

Steven Crawford presented the data management activities at the Southern African Large Telescope (SALT). The 11-metre-diameter telescope is operated entirely in queue mode and is designed to explore the time domain. The challenge of operating it on a small budget is met by leveraging existing software and user expertise, ultimately yielding a rate of refereed publications comparable to other 8–10-metre-class telescopes.

Providing a glimpse of the ground-based future, Gijs Verdoes Kleijn's talk focused on the science data management of the European Extremely Large Telescope's (E-ELT) first-light instrument, the Multi-Adaptive Optics Imaging Camera for Deep Observations (MICADO), an optical and near-infrared imager and spectrograph. Key to being able to handle data from such a system, composed not only of the instrument itself, but also a highly complex, time-variable telescope and Earth's atmosphere, is to model it thoroughly. In this way the instrument, telescope and atmosphere status can be determined at once, and then the science information extracted from the astronomical source.

Arguably the ultimate outcome in the life cycle of science data is that of generating refereed publications. The NASA Astrophysics Data System (ADS) has long been used as a source of information about the scientific literature in astronomy and physics. Alberto Accomazzi reported on recent efforts at ADS to widen the range of available scientific resources to include datasets linked to the publications, observing proposals and software used in refereed astronomy papers. Perhaps not surprisingly, well-linked data papers, which are easy to discover by a broad audience, ultimately have a higher impact by receiving more citations.

Tracking the publication record of ESO facilities was the focus of the presentation by Uta Grothkopf on the ESO Telescope Bibliography (telbib). telbib is a database of refereed papers published by the ESO user community that links data in the ESO Science Archive Facility with the published literature, and vice versa. After careful curation, the rich metadata provide parameters for reports and statistics that allow the performance of ESO's facilities to be investigated and to help understand trends and developments in the publishing behaviour of the user community. telbib is an invaluable tool to guide future developments.

Concluding discussion

Andreas Kaufer and Danny Lennon wrapped up the workshop by offering points for discussion on the themes that emerged during the workshop itself:
– Quality assurance is critical in building trusted content, which, in turn, is critical to having the community embrace archives for science use.
– There is likely room for both centralised and distributed data reduction, depending on the project. The role of observatories to support this is probably going to increase as data volume and complexity increase.
– The content of science archives should be trusted and ready for science.
– Archive services should be oriented to users in order to increase the ease of utilisation and the discoverability of data, with tools to enhance the scientific return of the (ground and space based) facilities.

The debate that followed was too varied to be represented here in any detail, but it surely highlighted the richness and enormous scientific potential that science data management increasingly has in the present and future landscape in astronomy.

The great response to the workshop, with more than 100 people attending, testifies to the timeliness of a broad discussion on science data management in astronomy. It provided a forum for people to exchange ideas and compare approaches through which both the similarities and the differences were identified, not only concerning the problems in this particular area that we are facing as a community, but also in the ways in which they can be addressed. The workshop will hopefully give momentum to a dialogue, or, better said, dialogues, that will carry on and deepen in the future and foster collaborations for the benefit of the astronomical user community at large.

Prospects

Astronomy as a science is going through a very interesting phase of change, driven by the fast-growing amount and complexity of data. Analysis of multi-wavelength, multi-messenger data will no doubt grow in importance, as will the need to minimise the transfer of large volumes of data by processing them *in situ*. In an increasing number of cases the focus is shifting from primarily working with one's own data obtained directly at the telescope to complementing, or even replacing this data entirely, with data accessed from powerful archives filled and curated by dedicated professionals. In some cases the archives are filled with data originally obtained for observing proposals on specific individual projects, while in other cases, as for the Sloan Digital Sky Survey (SDSS) or the Large Synoptic Survey Telescope (LSST), data are conceived from the onset for archive use by the community at large. This transition has many similarities with the one that saw classical observing being more and more replaced by service or queue mode for ground-based observatories. As was the case for the observing transition, the success of the data transition will critically depend on two pillars: building the trust of the user community in the data they will receive; and providing a streamlined, science-oriented user experience. Data and archive service providers will have to adapt to and participate in defining these changes.

After the introductory general workshop two years ago (Primas & Hanowski, 2013), the success of this ESO–ESA workshop, focused on a specific topic, confirms the validity and potential of the formula. Discussions have already started on possible topics for the next installment in the series: see you in two years at ESAC!

Acknowledgements

We would like to warmly thank the Local Organising Committee (Véronique Ziegler, Adam Dobrzycki, Michael Naumann and Rein Warmels) and Simon Lowery and Judy Asher for IT support. ESA's support in providing food and refreshments to sustain the long hours of (fruitful!) discussions is gratefully acknowledged. Special thanks go to Alberto Accomazzi for taking time off from his Thanksgiving holiday to be with us for his presentation.

References

Primas, F. & Hanowski, N. 2013, The Messenger, 154, 67

Links

[1] Workshop web page: https//www.eso.org/sci/meetings/2015/SciOps2015.html
[2] Zenodo DOI platform: http://zenodo.org/

A 360-degree panorama of the Very Large Telescope Control Room at night.

Report on

European Radio Interferometry School 2015

held at ESO Headquarters, Garching, Germany, 6–10 September 2015

Robert Laing[1]
Anita Richards[2]

[1] ESO
[2] Jodrell Bank Centre for Astrophysics, University of Manchester, United Kingdom

The sixth European Interferometry School (ERIS2015) was held at ESO for the first time. As usual the school was aimed at graduate students and early-career postdocs, but this year the emphasis was on enhanced wide-bandwidth interferometers covering metre to submillimetre wavebands. More than 100 participants attended ERIS2015. The topics of the school are briefly described here. They covered a wide range, from an introduction to radio interferometric techniques through packages for data reduction and analysis to hands-on workshop sessions and proposal writing.

This was the sixth European Radio Interferometry School, a series which started in 2005 with the organisation undertaken, in turn, by major European radio astronomy centres. Previous schools have been run by Manchester University; the Max-Planck-Institut für Radioastronomie (MPIfR), Bonn; Oxford University; INAF–Istituto di Radioastronomia (held in Rimini); and the Netherlands Institute for Radio Astronomy (ASTRON)/Joint Institute for VLBI in Europe (JIVE). With the Atacama Large Millimeter/submillimeter Array (ALMA) coming into full operation and the availability of space in the new Headquarters Building, we felt that it would be appropriate for ESO to organise ERIS in 2015.

ERIS provided five days of lectures and tutorials on how to obtain scientific results from radio interferometry at metre to submillimetre wavelengths. It was primarily intended for graduate students and beginning postdoctoral fellows. The emphasis was on the generation of new and greatly enhanced interferometers that have recently become available to European astronomers, including the Low Frequency ARray (LOFAR), the extended Multi-Element Radio Linked Interferometer Network (eMERLIN), the European VLBI Network (EVN), the Jansky Very Large Array (JVLA), ALMA and the Institut de Radioastronomie Millimétrique (IRAM) Plateau de Bure/the NOrthern Extended Millimeter Array (NOEMA). The school also covered the use of archive data and looked forward to the Square Kilometer Array (SKA) and its precursors.

The programme was developed from those of earlier ERIS schools, with an increased emphasis on wide-bandwidth interferometers and on the use of the Common AStronomy Applications (CASA) package for data-reduction tutorials (the Astronomical Image Processing System [AIPS] was still used, but only for Very Long Baseline Interferometry [VLBI] data). We felt that it was essential for the students to learn techniques appropriate to modern arrays from the start, but took the decision to switch from older, narrowband data with some trepidation as the sizes of the tutorial datasets increased substantially, causing problems with distribution and processing speed. Students were expected to bring their own laptops with the standard software already installed; support was available from ESO and the National Radio Astronomy Observatory (NRAO, USA) to help with installation problems and ESO provided a number of loan laptops. In the end, we believe that the change was well worth the additional effort.

We decided that any attempt to cover the science enabled by radio interferometry in depth would take too long and was, in any case, better integrated with perspectives from other techniques. The school therefore started with two lectures on the fundamentals of radio interferometry (a gentle introduction for beginners, followed by a more mathematical underpinning) and an overview of modern radio interferometers. The programme went on to cover the generic data-reduction process for radio interferometry through a mix of lectures and hands-on tutorials. The main areas were: editing and removal of radio-frequency interference; calibration of continuum, spectral-line and polarisation data; imaging and deconvolution; and extraction of information from images or datacubes. The special problems of observing at very high (ALMA) and low (LOFAR) frequencies were also covered. Parallel tutorials allowed students to follow their own interests in advanced topics or to continue working on the basic tutorials.

One aspect of radio interferometry that prospective users often find obscure is the choice of instrument, frequency, spectral configuration and observing time. As well as lectures on the concepts, we also held a special tutorial in which students divided into small groups to write the technical case for an observing proposal on a topic of their choice. These proposals were presented at the end of the school. This exercise, which we first introduced at the Oxford ERIS, proved to be popular, and resulted in some excellent proposals.

On reflection, after the school, it became clear to us that the techniques of (sub) millimetre and centimetre-wave interferometry have now converged and can be taught together quite effectively. There are some obvious differences, mostly connected with the malign effects of the atmosphere at shorter wavelengths, but the main data-reduction steps are identical and the same package, CASA, can be used for both. However, wide-field imaging at low frequencies does require a different approach, because of the size of the datasets and the need for specialised software. This might argue for a different split in topics for future interferometry schools.

Lectures and most tutorials for ERIS 2015 took place in the new Eridanus auditorium, with parallel tutorials being held in neighbouring meeting rooms. There were 113 students (a new record for ERIS — see Figure 1). Of these, 95 came from EU member states and the rest were from Switzerland, the Russian Federation, Turkey, Brazil, Chile, Colombia, Korea, Japan, India and South Africa. The majority were doctoral or masters students or early-career postdoctoral researchers. A few more senior participants attended the school: established researchers changing field, radio astronomy software developers and observatory support staff. Thirty-seven participants were female (33 %) and a significant proportion were non-white.

Figure 1. Participants at ERIS 2015 photographed outside the new ESO Headquarters building.

Social events included two buffet suppers at ESO (one a magnificent Bavarian barbecue). These were each followed by evening science lectures, by Katherine Blundell from the University of Oxford on the Galactic microquasar SS433 and by Tim de Zeeuw on the work of ESO. Both events proved very popular with the students and the nature of the questions suggested that we had (on average, if not for every individual) provided the right amount of alcohol beforehand. We decided that forcing the students to visit the local LOFAR station on their "free" afternoon was a bad idea, given the competition from other attractions in Munich, and gave them a U-Bahn ticket for the central zone instead. All arrived promptly at ESO the next morning, so this was probably the right decision!

Further information, including all of the lectures, tutorial scripts and datasets can be found at the school home page[1].

Acknowledgements

The meeting was co-sponsored by ESO and Radionet3, an EU Integrated Infrastructure Initiative to coordinate access, development, and training for radio astronomy facilities in Europe[2]. RadioNet3 has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 283393. We are grateful to the members of the Local and Scientific Organising Committees and to all of the lecturers, tutors and ESO helpers for their work in designing and presenting a coherent programme. Many other people helped to make the school a success. We would particularly like to thank: Tim de Zeeuw and Katherine Blundell for their after-dinner talks; Berkan Maruthadiyan and Tamas Tutundiscz for audio-visual and laptop support; Ana Vukovic for keeping us supplied with coffee; Andrea Dinkel and colleagues for sorting out the finances; and Wolfgang Wild for agreeing to the substantial ESO contribution. Finally, at every meeting there is usually one person without whom the whole organisation would have fallen apart. In our case, this was Elena Zuffanelli, who worked long and hard to make the school a success.

Links

[1] ERIS 2015 school home page: http://www.eso.org/sci/meetings/2015/eris2015.html
[2] Radionet3: http://www.radionet-eu.org

The AstroMundus–ESO Connection

Liz Humphreys[1]
Gaitee Hussain[1]
Andy Biggs[1]
Hau-Yu Lu[1]
Eric Emsellem[1]
Annalisa De Cia[1]
Alexis Lavail[1]
Jason Spyromilio[1]

[1] ESO

The AstroMundus Programme is an E+ Erasmus Mundus Joint Masters Degree course in astronomy and astrophysics offered by a consortium of European universities and research institutes. In 2014 and 2016, AstroMundus Masters students visited ESO and participated in proposal-writing sessions, during which groups of students speed-wrote complete ALMA proposals, before presenting them to a pseudo Time Allocation Committee providing on-the-spot feedback. The AstroMundus visit of 25–26 January 2016 is described.

Nine students from the AstroMundus Programme[1] visited ESO during the afternoon of Monday 25 January 2016, with a welcome and introduction to ESO given by Eric Emsellem. Annalisa De Cia, Alexis Lavail and Jason Spyromilio then took the students on a tour of ESO, including the assembly hall where they could gain an insight into instrument development activities (see Figure 1), and a chance to see components of the European Extremely Large Telescope (E-ELT) and the upgrade work on the Very Large Telescope (VLT) instrument CRIRES+.

The following morning was devoted to a single topic: how to write a good proposal. The sessions started with short talks by Liz Humphreys and Gaitee Hussain, outlining the mission (to speed-write an Atacama Large Millimeter/submillimeter Array [ALMA] proposal), introducing ALMA and explaining the important points of proposal-writing. Hau-Yu (Baobab) Lu, an ESO Fellow, then presented one of his successful ALMA proposals and explained what information he had included in the proposal, and why.

The students then split into three groups to prepare their own ALMA proposals. Each group was provided with a technical assistant with ALMA expertise (Andy Biggs, Baobab Lu and Liz Humphreys), who could help them to prepare the technical case and guide them in the use of the ALMA Observing Tool (OT). The topics of the proposals were pre-selected by these technical assistants, based on exciting ALMA results that the students could use as a basis for their work. The topics were: protoplanetary discs, based on the iconic ALMA HL Tau image (ALMA Partnership, Brogan et al., 2015); the high-redshift Universe, based on ALMA observations of normal galaxies at $z \sim 7$ (Maiolino et al., 2015); and astrochemistry, based on the finding that the disc of the nearby low-mass star MWC 340 has a comet-like composition (Oberg et al., 2015). Each group needed to prepare a complete science case (up to four pages) and provide the technical information required by the ALMA OT. A justification of the technical setup in the OT was also required. Due to the short time available, the students were allowed to write their science case in the form of bullet points.

After a very hectic and enjoyable 2.5 hours, filled with discussions on how to set up observations, how to make science cases unique and compelling, and brainstorming memorable proposal titles, the students completed their mission to submit their proposals by the deadline. Each team of students then gave a ten-minute presentation of their proposals, highlighting the important scientific and technical aspects. The Time Allocation Committee, comprised of Biggs, Humphreys, Hussain and Lu, then gave feedback on the proposals' strengths and weaknesses. We were thoroughly impressed by what the students were able to achieve in such a short time.

Based on the quality of their work and their enthusiasm for the task at hand, we are sure we will see AstroMundus graduates using ESO and ALMA facilities in the near future. One current example is Aleksandar Cikota, an AstroMundus graduate who is a PhD student at ESO and the International Max-Planck Research School (IMPRS). Aleksandar was a participant in the first AstroMundus-ESO speed-proposal writing session held in 2014.

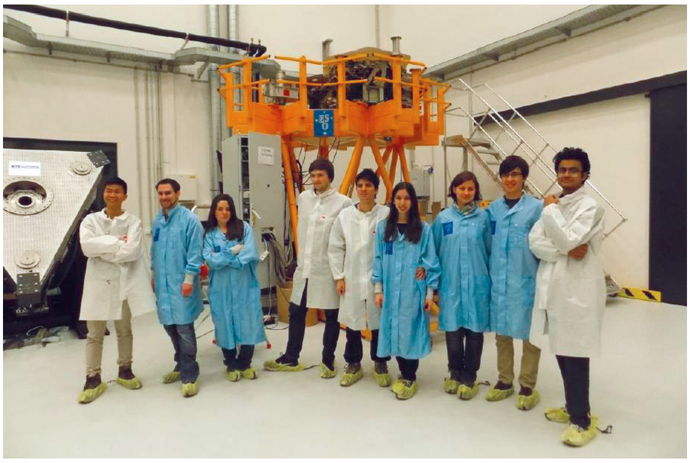


Figure 1. The nine Masters students, who participated in the AstroMundus 2016 visit to ESO, shown in the Assembly Hall.

Figure 2. Participants in the 2016 AstroMundus–ESO speed-writing proposal session. The technical assistants, and some members of the Time Allocation Panel, are also present: Baobab Lu (first on the left), Andy Biggs and Liz Humphreys on the far right.

References

ALMA Partnership, Brogan, C. et al. 2015, ApJ, 808, L3
Oberg, K. et al. 2015, Nature, 520, 198
Maiolino, R. et al. 2015, MNRAS, 452, 54

Links

[1] AstroMundus programme: http://www.astromundus.eu

Information on the AstroMundus Programme

The E+: Erasmus Mundus Joint Masters Degree (EMJMD) course in astronomy and astrophysics (AstroMundus Programme) is offered by a consortium of universities. The institutes participating in AstroMundus include the host University of Innsbruck (Austria), the universities of Belgrade (Serbia), Göttingen (Germany), Padova and Rome Tor Vergata (Italy). Associated partners are: the Astronomical Observatory of Belgrade; Istituto Nazional Di Fisica Nucleare – Gran Sasso Science Institute (Italy); and the Max Planck Institute for Solar System Research (Germany). All students start at the University of Innsbruck and then continue their studies, getting the chance to work in at least two of the four countries participating in the programme.

Gert Finger Becomes Emeritus Physicist

Tim de Zeeuw[1]
Christian Lucuix[1]
Michèle Péron[1]

[1] ESO

Gert Finger has retired after almost 33 years service and he has been made the first Emeritus Physicist at ESO. An appreciation of some of his many achievements in the development of infrared instrumentation and detector controllers is given. A retirement party for Gert Finger was held in February 2016.

Gert Finger obtained a PhD degree in physics at the ETH (Eidgenössische Technische Hochschule) in Zürich in March 1983, and a few months later joined ESO as an infrared instrumentation engineer with duty station in Garching.

At that time, the state-of-the art detector in the nearinfrared had a single pixel, providing indium antimonide (InSb) photometers for the nearinfrared and bolometers for longer wavelengths. ESO had started to develop the Infrared Spectrometer (IRSPEC), a general purpose 1–5 μm spectrograph for the New Technology Telescope (NTT), under the leadership of Alan Moorwood. Together with Manfred Meyer, Gert developed a multiplexed readout for a 1 × 32 element linear InSb detector array. This was a major step forward in infrared astronomy, both for the concept and in terms of the performance achieved (Moorwood et al., 1986).

Soon the first two-dimensional arrays became available, based on a 58 × 62 pixel readout architecture from Santa Barbara Research Center (SBRC). But Europe had no access because of export restrictions from the USA. A Mullard infrared CCD and various other detectors were installed in the Infrared Array Camera (IRAC), but problems with the injection threshold of these detectors affected the performance for astronomical applications. After some years InSb detectors based on the SBRC 58 × 62 array became available in Europe and in 1991 IRSPEC was retrofitted with this detector and a rather advanced Virtual Machine Environment (VME) based readout system (Moorwood et al., 1991).

IRAC was succeeded at the MPG/ESO 2.2-metre telescope by its sibling IRAC2 which used a 256 × 256 HgCdTe (1.0–2.5 μm) detector, the first of its kind at ESO. The Infrared Spectrometer And Array Camera (ISAAC) for the Very Large Telescope (VLT) was originally designed for 256 × 256 format detectors, but was readily modified to receive the new 1k × 1k HgCdTe detector arrays; one arm of ISAAC was fitted with a Hawaii detector and the second one with an Aladdin detector, a quasi-proprietary device which then had become available to the community. To achieve the efficient readout of these much larger detectors, the IRACE controller was developed by Gert together with Manfred Meyer, helped by Joerg Stegmeier and Leander Mehrgan.

As a spin-off, and also to bridge the gap to the time when ISAAC was operating on the VLT, SOFI (Son OF Isaac) was built for the NTT in order to replace IRSPEC, which suffered from rather strong internal background noise. SOFI arrived on La Silla (in 1997) a year earlier than ISAAC at the VLT, and it is still heavily in demand by the community. *K*-band low resolution spectroscopy provides an example of the enormous impact of these detector developments: in 1998 SOFI was four orders of magnitude more sensitive than the single pixel circular variable filter (CVF) spectrophotometer in operation at the ESO 3.6-metre telescope in 1980, while having twenty-fold spectral resolution and ~ 400 simultaneous spectral elements, while the CVF allowed only sequential access.

Subsequent instrument and detector developments on the VLT have been more rapid, with CONICA, the VLT Imager and Spectrometer for the Mid-infrared (VISIR), the CRyogenic InfraRed Echelle Spectrometer (CRIRES) with its mosaic of 4096 × 512 pixel Aladdin III detectors (soon to be upgraded to 2048 × 2048 arrays) and the High Acuity Wide Field *K*-band Imager (HAWKI) with brand-new 2k × 2k Hawaii-II RG sensors. The most recent generation of standard detectors are the Hawaii IV RG (4k × 4k) and will be used by the Multi-Object Optical and Near-infrared Spectrograph (MOONS) on the VLT, and potentially also in instruments for the European Extremely Large Telescope (E-ELT).


Gert Finger

In the meantime, the next technological leap in the detector controller area, the New Generation Controller (NGC), caught up with the detector developments. In 2012–14 the upgraded VISIR, and then the *K*-band Multi-Object Spectrograph (KMOS), were the first instruments to benefit from what is now the standard, and probably the most advanced, detector controller available today.

Gert also contributed to collaborative detector programmes, such as the one with the University of Hawaii and also directly with manufacturers, for example in the development of the SAFIRA detector with SELEX. The first application of the SAFIRA detectors was for the infrared wavefront sensors for GRAVITY, a crucial component of the instrument. There was always the expectation that at some point there would be quasi-noiseless infrared detectors and Gert propelled the development of a second generation for operation at 90 K. The success of the E-ELT critically depends on these detectors for wavefront sensing.

Retirement party

A retirement party for Gert was held at ESO Headquarters on 1 February 2016, attended by his friends and colleagues; the party included some remote appreciations by detector physicists from the USA. In recognition of Gert's tremendous achievements, which have also substantially contributed to ESO's programme and reputation, he was awarded the official status of Emeritus Physicist at ESO.

The introduction of the Emeritus Physicist position, of which Gert is the first recipient, is a way of recognising and honouring individuals who have played a major role in the development of ESO during their career. Emeritus Physicists are able to continue with their research activities, for example by participating in meetings in their areas of expertise, or giving presentations at conferences. The similar position of Emeritus Astronomer has existed for some five years at ESO (see Primas et al., 2010). However, since ESO is made up of people doing many other jobs in addition to astronomers, the Emeritus roles have now been extended to include both Emeritus Physicists and Emeritus Engineers.

Acknowledgements

The expert help and reminiscences of Frank Eisenhauer, Ulli Kaufl, Katjuscha Lockhart, Sandro D'Odorico and Jeremy Walsh are greatly appreciated.

References

Finger, G. et al. 2014, Proc. SPIE, 9148, 914817
Moorwood, A. et al. 1986, The Messenger, 44, 19
Moorwood, A., Moneti, A. & Gredel, R. 1991, The Messenger, 63, 77
Primas, F., Casali, M. & Walsh, J. 2010, The Messenger, 141, 50

Fellows at ESO

Melissa McClure

I grew up in the university town of Ithaca, NY in the USA, which provided a great atmosphere for promoting my curiosity about science. However, my particular interest in astronomy got off to a somewhat bumpy start. In elementary school, our science teacher's attempt to encourage my interest in the Solar System backfired when describing how the rubble left over from the tidal disruption of a protoplanet by Jupiter may have formed the Asteroid Belt. Having recently been chastised on the topic of sharing with other children, I felt that Jupiter had clearly cheated the rules and informed the teacher that "I don't like grabby people, and I don't like grabby planets!".

Fortunately, the terrestrial planets maintained their charm, and by the time I reached high school I had progressed from reading *The Magic School Bus: Lost in Space* to collecting news clippings about the Earth and Mars. During my first year of high school, testing began on the prototype for the future *Spirit* and *Opportunity* Martian rovers. As part of the mission's outreach programme, each of the four principal US universities selected one of their local area high schools to participate in the field tests of the prototype, *FIDO*. We were the high school selected by Cornell University. This was my first opportunity to see scientists in action and also to see how a large "collaboration" can work to accomplish a huge and complicated task. At the time (1999–2000) it was very exciting just to teleconference over the internet with the three other groups in order to plan out our test mission (driving the rover through the Mojave Desert) and then watch it being executed. I was hooked!

When starting college at the University of Rochester in 2003, I was still unsure about whether to pursue geology or astrophysics. After taking an introductory course with Professor Bill Forrest, I decided to go the astrophysics route, and ended up badgering him to let me work in his research group. My first project was reducing ground-based near-infrared photometry from the NASA InfraRed Telescope Facility (IRTF) in support of a future Spitzer InfraRed Spectrograph (IRS) programme on discs by the Spitzer

Melissa McClure

instrument team. I continued working with Bill on these data, mid-infrared photometry from the United Kindom InfraRed Telescope (UKIRT), and eventually the Spitzer IRS spectra themselves during the academic year and over summer breaks, culminating in a Bachelor's degree thesis on the physical conditions in low-mass embedded protostars.

By this time, our group had acquired a significant number of IRS spectra, and I spent the two years following my Bachelor degree working for Professor Dan Watson as the primary data reducer for the team. It was a great way to learn about both infrared astronomy and star formation, and by the end of the first year I knew I wanted to apply to graduate school. In 2008, I started the PhD programme at the University of Michigan working with Professor Nuria Calvet on spatial variation in dust composition and distribution in protoplanetary discs. Using the D'Alessio irradiated accretion disc code, I produced detailed disc-structure models with varying dust compositions (silicates and water ice), grain sizes, and radial distributions to compare with medium-resolution infrared spectroscopy from Spitzer, Herschel, and ground-based near-infrared telescopes. There is suggestive evidence for spatial variation in the composition and distribution of these different dust species, particularly water ice, which could affect the composition of planets forming at different locations in these discs. However, all of these observations were spatially unresolved.

During my PhD, I travelled to Chile a few times a year to use the Magellan telescopes at Las Campanas Observatory and became familiar with the other astronomical facilities there, including the ESO sites. When applying for postdocs, ESO stood out as a good place to get involved with high-contrast imaging, which could be used to spatially resolve some of the compositional gradients in the discs in which I was interested, as well as detecting the location of the "grabbiest", i.e. most massive, protoplanets. In particular, I was excited by the next generation Very Large Telescope (VLT) instruments, like the Spectro-Polarimetric High-contrast Exoplanet Research instrument (SPHERE), and upgrades to the VLT Imager and Spectrometer for the mid InfraRed (VISIR). After starting at ESO, I joined the SPHERE instrument team, participating in Science Verification and helping to verify the science quality of products produced by the reduction pipeline. Now I am in the process of consolidating my observing plans into a programme to address a number of research questions during the remainder of my Fellowship.

The whole experience of developing into a professional astronomer has been really rewarding, and I feel privileged to be involved with exciting research at the forefront of planet formation. My opinions about Jupiter, and grabby planets in general, have also shifted over time. Now I can acknowledge that sometimes the grabbiest planets are the most interesting, because they can most easily show us the inner workings of the mechanisms for planet formation in discs!

Julien Milli

I had many interests as a kid, and astronomy was only one of them, along with volcanology, geology, natural sciences and the environment in general. Some holidays spent in the Auvergne, a chain of extinct volcanoes in the centre of France, and many years later at the Piton de la Fournaise, one of the most active volcanos in the world, triggered my interest in Earth sciences. I remember bringing back many samples of basalt and olivine, and I even had the chance to see one eruption when I was there. I was fascinated by these natural phenomena and very curious to understand them at the same time.

I discovered astronomy a little bit earlier, thanks to an evening astronomy class organised by an amateur in his free time. The class was followed by observations with a small telescope. The first thing I remember was how cold it was, standing outside, in a little village in the Alps, at night, in winter, waiting to put an eye to the eyepiece! But then, how rewarding it was to discover for the first time the wonders of the Orion Nebula! This amateur astronomer taught us many tricks to help identify the stars and constellations, and I would later put them into practice whenever I had the opportunity to enjoy a dark night sky.

In high school, I loved mathematics and physics, and I am very grateful to my teachers, who encouraged me a great deal. I kept reading a lot about astronomy and space exploration, but also about birds, and the environment and its protection. It was hard to pick one career path with so many interests; I therefore decided to study at a general engineering school, L'Ecole des Mines, in Paris. There, I could keep studying geology, but unfortunately astrophysics classes were scarce, and I had to wait until an Erasmus semester in Dublin to take my very first astrophysics class — on stellar evolution. On the other hand, my knowledge on sustainable development and energy grew. I finally ended up starting my career as an engineer in a plant assembling wind turbines in northwest Germany, and kept astronomy as a hobby. But better late than never, after a year the hobby finally took over — I had missed physics too much and decided to become an astrophysicist for good!

Julien Milli

Astronomy has the beauty of encompassing almost all fields of physics, which makes it much more interesting than solving the mechanical issues of a wind turbine, in my opinion. I did not regret it. I spent a wonderful year while studying for a Master's in Astronomy in Paris, I met some of my best friends there, and many teachers passed on to me their enthusiasm for science. Observational astronomy was what I liked most. For one of my Master's projects, I observed Orion with an infrared camera mounted on a 40-centimetre telescope during cold winter nights in Meudon on the outskirts of Paris! I was however moving in a good direction: the little Newtonian telescope from my first contact with astronomy had turned into a decent 40-centimetre Cassegrain under a dome with a nitrogen-cooled detector. The comfort of a warm control room would come later! I was particularly attracted by high-angular-resolution astronomy and planetary systems, an area that had developed tremendously in the years since the discovery of the first exoplanets by direct imaging in 2008.

I decided to work on a PhD topic closely linked to the development of a future high-contrast instrument SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch). At the time, direct imaging of exoplanets was gaining much attention, but imaging of discs at high-angular resolution from the ground was still trailing behind, with new observational challenges to face, but also very interesting disc physics to be unveiled. This topic would become the focus of my research for the next three years. I studied discs around main sequence stars, called debris discs, because they contain asteroid-like objects called planetesimals that collide and generate small dust particles that we can detect through scattered stellar light. I moved to Grenoble, where the SPHERE instrument was being integrated during the first year of my PhD. I then spent the next two years in Chile, thanks to the ESO Studentship programme, participating in the on-sky commissioning. My PhD topic covered simultaneously instrumentation, observations and the physics of discs and light scattering. Understanding the whole life cycle of astrophysical data, from the design of an instrument to the measurements produced and their interpretation is really a plus, and I am very grateful to my two brilliant advisors, David Mouillet and Dimitri Mawet, for providing me with guidance during that time.

I dedicated much effort to two debris discs, β Pictoris, the first disc resolved in imaging in 1984, and HR4796, a narrow dust ring with peculiar geometric and physical properties. From the observations obtained with high-contrast instruments, such as NAOS–CONICA (NaCo) and SPHERE, I tried to constrain the physical and chemical properties of the grains. In other words, I tried to deduce their composition and their shapes and sizes, based on the way they scatter starlight. I also study the overall morphology of the discs, to discover asymmetries or dust enhancements that could hint at the presence of gravitational perturbers, which may be planets that still cannot be detected with the current instrumentation.

I see myself as a geologist of extrasolar systems, combining my two passions for astronomy and Earth sciences. I still frequently bother planetary science colleagues to compare our approaches and results on extrasolar dust on the one hand, and asteroids, comets or Zodiacal dust on the other hand, to better understand exoplanetary systems. During my thesis work in Chile, I liked the scientific environment at ESO and loved observations. In addition, Chile is an amazing country for a mountain lover and geology enthusiast like myself. I spent a lot of my free time climbing mountains or volcanoes and enjoying the landscapes, flora and fauna of the Andes. As a result, when the possibility of staying a bit longer for a Fellowship occurred, I seized the opportunity and signed up for another couple of years at ESO as a Fellow.

I am now part of the Unit Telescope 3 (UT3) team, assigned more specifically to SPHERE. Travelling more regularly to the Paranal Observatory, I am very happy to work with all the Paranal crew — astronomer colleagues, engineers and telescope operators — all the people who make our job possible in this isolated place. The silence of the desert and the wonders of the Paranal night sky are an unforgettable experience. Aside from my observing duties, I keep studying my preferred debris discs by maintaining strong links with my colleagues in Europe and the USA. I recently started a survey with SPHERE to try to understand why debris disc detections are so scarce in scattered light, whereas about 20 % of stars host a debris disc if we believe their infrared excess. The complementarity between my duties on SPHERE and my science is a great strength and the reason why I appreciate working at ESO during this exciting time for exoplanetary science. I think many discoveries will come in the near future, and I am very happy to be part of this team operating this advanced instrument!

Adam Ginsburg

I grew up in Colorado, USA and turned to astrophysics as the result of a high-school science-fair project on modelling planetary orbits to search for their habitable zones. Positive experiences in my high-school physics class led me to study astrophysics at Rice University in Houston, Texas. I became interested in repeatedly exploding stars like Eta Carinae and have since maintained an interest in beautiful, well-resolved astronomical images. The flat terrain in Texas led me back to the mountains, which, along with the desire to make awesome images of the sky, motivated me to become an observer.

After finishing my degree at Rice, I spent a summer in the Research Experience for Undergraduates Program, at the National Radio Astronomy Observatory, looking deeply into Very Large Array (VLA) data. I spent the next year travelling and then working as a researcher at Denver University, identifying post-asymptotic-giant-

Adam Ginsburg

branch stars in the Spitzer Surveying the Agents of a Galaxy's Evolution (SAGE) survey.

In 2007, I began my PhD studies at the University of Colorado. I worked with John Bally on observational studies of molecular outflows and high-mass star-forming regions. I reduced the data for the Bolocam Galactic Plane Survey, the first unbiased survey of the Galactic Plane in the millimetre regime, which drove my thesis. I found the most interesting aspect of this survey work was what we didn't see, which led to the conclusion that the most massive clusters probably do not have a "starless" stage before they form: instead, they grow by consuming material from a large, spread-out molecular cloud or by the merger of smaller subclusters.

One of the recurring themes in my work has been the creation and improvement of the computational tools needed to do astronomical research. As an undergraduate I learned about the Image Reduction and Analysis Facility (IRAF), which is an extremely powerful toolkit with a sometimes clunky interface. While writing a large data reduction pipeline as a student, I became involved in the Astropy Project, which has made a huge suite of tools available and accessible.

After my PhD, I came to ESO in Garching as a Fellow. I am involved in the ALMA Regional Centre, where my duties involve both observing and software development. Working with a small international collaboration, I have developed a suite of tools for use with ALMA data[1]. During the first year of my Fellowship, I dedicated most of my effort to producing a large 300-hour survey of the Central Molecular Zone of the Galaxy with the Atacama Pathfinder EXplorer (APEX) telescope. I used this data to measure the temperature of the Galactic Centre's densest gas, and we found that it was uniformly warmer than observed elsewhere in the Galaxy.

I have continued my observational projects on the study of the structure and properties of high-mass clusters, which are some of the most active regions in the present-day Universe, and of the Galactic Centre. These objects also represent the most visually striking features on the sky, but they can only be observed in the radio. As I will soon move on from ESO, I look forward to continuing my work with ALMA and other radio telescopes to understand the nature of star formation and the origin of high-mass stars.

Links

[1] Software tools for radio astronomy: radio-astro-tools.github.io

Personnel Movements

Arrivals (1 January–31 March 2016)

Europe	
Bouchtita, Sonia (FR)	Accountant
Förster, Andreas (DE)	Optical Engineer
Gonzalez Fernandez, Ariadna Irene (ES)	Student
Kosmalski, Johan Pierre-Dominique (FR)	Optical Engineer
Mroczkowski, Anthony (US)	Astronomer/Submillimetre Instrument Scientist
Tulloch, Simon Mark (UK)	Detector Engineer
Zivkov, Viktor (DE)	Student

Chile	
Guieu, Sylvain (FR)	Optical Physicist
Neumann, Justus (DE)	Student
Ramirez, Jorge (CL)	Electronic Engineer

Departures (1 January–31 March 2016)

Europe	
Finger, Gert (AT)	Applied Physicist
Guerou, Adrien (FR)	Student
Rodón, Javier Adrián (AR)	Fellow

Chile	
Ertel, Steve (DE)	Fellow
Hill, Tracey (AU)	Fellow

ESO

European Organisation for Astronomical Research in the Southern Hemisphere

ESO Studentship Programme 2016/2017

The research studentship programme of the European Southern Observatory provides an outstanding opportunity for PhD students to experience the exciting scientific environment at one of the world's leading observatories for a period of up to two years.

ESO is the foremost intergovernmental astronomy organisation in Europe. Its approximately 110 staff astronomers, 40 Fellows and 50 PhD students conduct frontline research in fields ranging from exoplanets to cosmology, offering one of the most vibrant and stimulating scientific settings anywhere in the world.

ESO's studentship positions are open to students enrolled in a PhD programme in astronomy or related fields. Students accepted into the programme work on their doctoral project under the formal supervision of their home university, but they come to ESO to work and study under the co-supervision of an ESO staff astronomer, normally for a period of between one and two years. Studentships may be hosted either at ESO Headquarters in Garching (Germany) or at ESO's offices in Santiago (Chile), where up to two positions per year are provided for students enrolled in South American universities.

Applicants and their home institute supervisors should agree upon and coordinate their research project jointly with their prospective ESO supervisor. For this purpose the ESO supervisor should be contacted well in advance of the application deadlines (1 May and 15 November 2016). A list of potential ESO supervisors and their research interests can be found at http://www.eso.org/sci/activities/personnel.html. A list of PhD projects currently being offered by ESO staff is available at http://www.eso.org/sci/activities/thesis-topics.html.

ESO Chile students have the opportunity to visit the observatories and to get involved in small technical projects aimed at giving insights into the observatory operations and instrumentation. Such involvement is also strongly encouraged for Garching students. In addition, students in Garching may attend and benefit from the series of lectures delivered in the framework of the International Max-Planck Research School on Astrophysics. ESO students have also the possibility to join in many outreach activities.

Students who are already enrolled in a PhD programme in the Munich area (e.g., at the International Max-Planck Research School on Astrophysics or a Munich University) and who wish to apply for an ESO studentship in Garching, should provide a compelling justification for their application.

If you are interested in enhancing your PhD experience through an extended stay at ESO, then please apply by completing the web application form available at http://jobs.eso.org/.

Please include the following documents in your application:
- a cover letter;
- a Curriculum Vitae, including a list of publications, if any;
- copies of your university transcript and certificate(s) or diploma(s);
- a summary of your master's thesis project (if applicable) and ongoing projects, indicating the title and the supervisor (maximum half a page);
- an outline of the proposed PhD project, highlighting the advantages of coming to ESO (recommended one page, maximum two);
- the names and contact details of your home institute supervisor and the ESO local supervisor. They will be automatically invited to submit a recommendation letter, however, applicants are strongly advised to trigger these invitations (using the web application form) well in advance of the application deadline;
- a letter from the home institute that: i) guarantees financial support for the remaining PhD period after the termination of the ESO studentship; ii) indicates whether the prerequisites to obtain the PhD degree at the home institute have already been met.

All documents should be typed in English (but no translation is required for the certificates and diplomas).

Depending on the number of available positions, there might be up to two application rounds per year, with closing dates for applications of 1 May 2016 and 15 November 2016. Review of the application documents, including the recommendation letters, begins immediately following the deadline. Incomplete or late applications will not be considered.

Candidates will be notified of the results of the selection process within two months following the deadline. Studentships considered in the May round will normally begin between August 2016 and March 2017; students for the November round in March–August 2017.

Further information

For more information about the studentship programme please see: http://www.eso.org/studentship.

For a list of current ESO staff and fellows, and their research interests, please see: http://www.eso.org/sci/activities/personnel.html.

A list of PhD projects currently being offered by ESO staff can be found at: http://www.eso.org/sci/activities/thesis-topics.html.

Details on the employment conditions and benefits are available at: http://www.eso.org/public/jobs/conditions/students/.

For any additional questions, please contact:
For Garching: Eric Emsellem, Tel. +49 89 32006914, email: eric.emsellem@eso.org.
For Chile: Claudio De Figueiredo Melo, Tel. +56 2 4633032, email: cmelo@eso.org.

Although recruitment preference will be given to nationals of ESO Member States (Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and United Kingdom), and, for Chile, to students enrolled in a South American university, no nationality is in principle excluded.

The post is equally open to suitably qualified female and male applicants.

Annual Index

ESO/APEX/ATLASGAL consortium/NASA/GLIMPSE consortium/ESA/Planck

A detail of part of the APEX Telescope Large Area Survey of the Galaxy (ATLASGAL) image of the Galactic Plane around longitude 345 degrees. See the image on p. 30–31 for a view of the Galactic Centre from ATLASGAL. The Plane crosses the middle of the field and the Galactic latitude extent +/– 1.6 degrees is shown. At higher latitude (upper) the prominent ring feature is IC 4628 and at negative latitude the brightest emission region is RCW 117. Both are H II regions enclosing areas of high-mass star formation, and IC 4628 is excited by the B-type star HDE 322417. See Release eso1606 for more details.

Annual Index 2015 (Nos. 159–162)

Subject Index

The Organisation

Telescopes and Instrumentation

Astronomical Science

Astronomical News

ESO/A. Santerne

Star trails in and beyond the antenna of the (now decommissioned) Swedish–ESO Submillimetre Telescope (SEST) at La Silla, with the 3.6-metre telescope dome in the background.

Author Index

ESO/F. Char

Star trails towards the south celestial pole circle around Yepun, VLT Unit Telescope 4.

ESO, the European Southern Observatory, is the foremost intergovernmental astronomy organisation in Europe. It is supported by 16 countries: Austria, Belgium, Brazil, the Czech Republic, Denmark, France, Finland, Germany, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom. ESO's programme is focused on the design, construction and operation of powerful ground-based observing facilities. ESO operates three observatories in Chile: at La Silla, at Paranal, site of the Very Large Telescope, and at Llano de Chajnantor. ESO is the European partner in the Atacama Large Millimeter/submillimeter Array (ALMA). Currently ESO is engaged in the construction of the European Extremely Large Telescope.

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

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: Smara Alonso.
www.eso.org/messenger/

Printed by FIBO Druck und Verlags GmbH, Fichtenstraße 8, 82061 Neuried, Germany

ISSN 0722-6691

Contents

Front cover: The barred spiral (SBab) galaxy, NGC 986, is shown in a FORS2 image. This impressive and nearby (distance about 20 Mpc) spiral galaxy is almost face-on and has a large dense gas-rich bar revealed by CO observations. The image was formed from exposures in *B*, *V*, *R* broadband filters and a narrow Hα filter. The prominent star-forming regions along the two spiral arms, flaring from the ends of the bar, are excited by hot and massive young stars and are bright in emission lines, such as Hα. More details under ESO Picture of the Week potw1605.