The Messenger

No. 187 | 2022

The Close AGN Reference Survey (CARS)

Keeping Exoplanet Science Caffeinated with ESPRESSO

The Science Verification of CRIRES$^+$

The ALMA Science Archive Reaches a Major Milestone

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Contents

Astronomical Science

Instrumentation

Astronomical News

Front cover: This illustration shows a night-side view of the exoplanet WASP-76b. The ultra-hot giant exoplanet has a day side where temperatures climb above 2400 degrees Celsius, high enough to vaporise metals. Strong winds carry iron vapour to the cooler night side where it condenses into iron droplets. Further details about this result made thanks to observations with VLT/ESPRESSO can be found in Ehrenreich et al. (2020) and ESO press release eso2005.
Credit: ESO/M. Kornmesser

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The Close AGN Reference Survey (CARS): Data Release 1 and Beyond

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Françoise Combes[5]
Julia Scharwächter[6]
Irina Smirnova-Pinchukova[7]
Miguel Pérez Torres[12]
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Accretion of matter onto the supermassive black holes that live at the heart of most galaxies is one of the most energetic processes in the Universe. These active galactic nuclei (AGN), and the energy they expel, are believed to play a critical role in how galaxies evolve. Despite this, our understanding of how the energy emitted from the active nucleus couples to the rest of the galaxy is limited. The goal of the Close AGN Reference Survey (CARS) has been to construct a dataset that is tailored to answering this question. We have observed the brightest unobscured AGN at redshifts $0.01 < z < 0.06$ with the best astronomical observatories in the world, including the Multi Unit Spectroscopic Explorer (MUSE) at ESO's Very Large Telescope, the Atacama Large Millimeter/submillimeter Array (ALMA), the Very Large Array (VLA), the Hubble Space Telescope, and the Chandra X-ray Observatory. In this article we highlight the ongoing work of the CARS team, along with the recent data release and accompanying papers, before discussing what comes next for the survey.

The coupling of energy emitted from the accretion region within active galactic nuclei (AGN) to the host galaxies in which they reside is called AGN feedback. It is often invoked to explain the discrepancy between the luminosity of the observed galaxy population and what is predicted by simulations of the Universe. In particular, without some mechanism to regulate star formation in massive galaxies, simulations massively overpredict the number of bright galaxies. AGN feedback is thought to work in two primary ways. In the first case, when the AGN luminosity is larger than ~ 1/100 of the Eddington luminosity, the radiation pressure from the active nucleus propels gas from the host galaxy in galactic-scale outflows (Nesvadba et al., 2007; Liu et al., 2013a; Cicone et al., 2018) in what is termed quasar or radiative-mode feedback. In the second case, for low-luminosity AGN, mechanical energy from radio jets heats the surrounding environment and prevents the gas cooling to the temperatures required for star formation (see Nulsen et al., 2005; Cavagnolo et al., 2010; Wagner, Bicknell & Umemura, 2012; Gaspari et al., 2020 for a review). This is known as kinetic or radio-mode feedback. Each mode provides a mechanism that regulates star formation and cooling flows. This can be implemented to curtail galaxy growth in simulations, allowing us to more accurately model the observed population of galaxies.

Despite the enormous importance of AGN feedback in galaxy evolution, nailing down the exact mechanisms and effects has been notoriously difficult. This is due to a multitude of factors, including the difficulty of estimating star formation rates in AGN, the lack of multi-wavelength data, and poor spatial resolution. Concurrently, numerical simulations have a tough time resolving the full spatial/temporal scales of AGN feeding and feedback, involving over nine orders of magnitude in dynamical range. This is why we undertook the Close AGN Reference Survey[1] (CARS). The CARS sample contains the most luminous unobscured AGN in the nearby Universe (Husemann et al., 2022) surveyed across the electromagnetic spectrum at high spatial resolution. In other words, if we are going to be able to see AGN feedback at work anywhere, it should be in these data. The questions we aim the survey to answer are:

- How common are and what are the properties of multi-phase gas outflows?
- What is the relative role of radiative pressure vs. radio jet-driven outflows?
- Do we see evidence of suppression or enhancement of star formation?
- What is the timescale of AGN accretion and outflows?
- Are the effects of AGN feedback confined to the centres of galaxies or more global?
- Can we see signatures of AGN fueling on host galaxy scales?

So far the survey has produced 11 refereed papers, with two approaching submission (and various others in preparation). These have included serendipitous discoveries of changing-look AGN (McElroy et al., 2016; Husemann et al., 2016; Krumpe et al., 2017), detailed multi-wavelength analyses of AGN-driven outflows (Powell et al., 2018; Husemann et al., 2019), and several studies of star formation using multiple tracers (Busch et al., 2018; Neumann et al., 2019; Smirnova-Pinchukova et al., 2019). In this article we focus on three key papers, dealing with: (1) the integral field unit (IFU) sample and using black hole mass as a tracer of the mean AGN lifetime (Husemann et al., 2022); (2) characterising the spatial extent of AGN-driven ionised outflows (Singha et al., 2022); and (3) a systematic star formation rate estimation and exploration of the effect of positive and negative AGN feedback (Smirnova-Pinchukova et al., 2022).

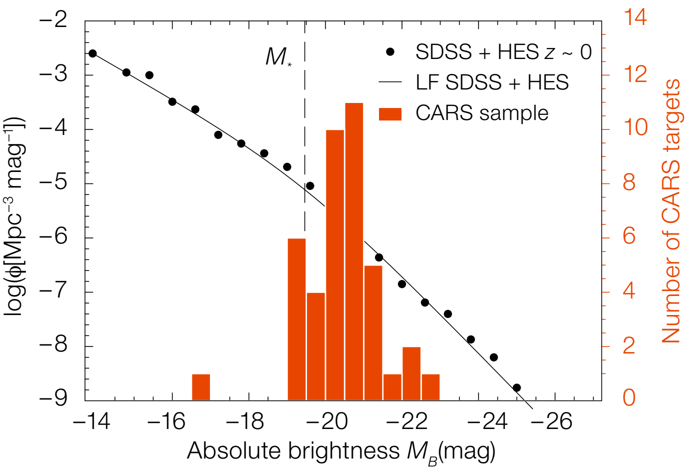


Figure 1. Histogram of the absolute magnitude of the chosen sample and the z = 0 type-1 AGN luminosity function (LF) derived from the Sloan Digital Sky Survey (SDSS) and the Hamburg/ESO Survey (HES).

The IFU sample and data release paper

CARS contains only unobscured AGN. In these galaxies the central engine is visible, meaning that the emission from the accretion disc and surrounding fast-moving clouds in the broad line region (BLR) can be observed directly. This is advantageous for two reasons. The first is that it allows for the masses of the central black holes and their accretion rates to be estimated from their central spectra. Secondly, it implies that the contribution of the AGN to the observations can be easily characterised as a point-source, as its sub-parsec size is completely unresolved in these observations. This means we can decompose the observations into AGN and host galaxy components, greatly aiding our further analysis.

The sample was selected from the Hamburg/ESO Survey (Wisotzki et al., 2000), which is a catalogue of ultraviolet-bright AGN. We applied a redshift limit of $z < 0.06$ to guarantee a minimum spatial resolution of 1 kpc, both to allow us to accurately decompose the host galaxy from the AGN and to reveal sufficient detail to achieve our science goals. The distribution of the targets is shown in Figure 1, where we see how the CARS galaxies compare to the overall unobscured AGN luminosity distribution.

Our integral field spectroscopic data — from instruments such as the Multi Unit Spectroscopic Explorer (MUSE) at ESO's Very Large Telescope (VLT) — provide spectra from across the entire spatial extent of the galaxies. To deblend the AGN from their host galaxies, we characterised the wavelength-dependent point spread function (PSF) by mapping the flux intensity of three prominent broad lines from the unresolved BLR using QDeblend3D[2]. We interpolated the PSF between the wavelengths of these lines and scaled to the central AGN spectrum to form an AGN datacube. An iterative algorithm was used to clean residual host galaxy light from the AGN spectrum before subtracting the AGN data cube. The process converges quickly and typically leads to a robust separation into an AGN and a host galaxy IFU datacube.

By examining images of the galaxies, the team classified the sample into disc-dominated, bulge-dominated, and irregular galaxies. Additionally, we noted whether galaxies displayed evidence of a bar or not. This analysis showed that 74% of the galaxies are discs, while only 14% are bulge-dominated. 12% of the sample was classed as irregular (meaning they were neither disc nor bulge dominated), but 40% show some signs of an interaction. We find that 50% of the overall sample have bars, and most of the disc galaxies do.

We used PyParadise[3] (see Walcher et al., 2015; Weaver et al., 2018; Husemann et al., 2019) to model the integral field data of the sample. This analysis is performed after the AGN emission has been removed, which allows us to look at the remaining gas and stellar emission from the host galaxy. PyParadise models the stellar absorption and gas emission features across the datacubes, allowing us to construct spatially resolved maps of these properties across the galaxies. We were able to take these measures one step further to classify the dominant ionising source in each spectrum using BPT diagrams (Baldwin, Phillips & Terlevich, 1981; Kewley et al., 2006), enabling us to see how far AGN ionisation extends and where star formation is the dominant ionising source.

We found a wide range of measured extended narrow line region (ENLR) sizes — from several hundred parsecs up to

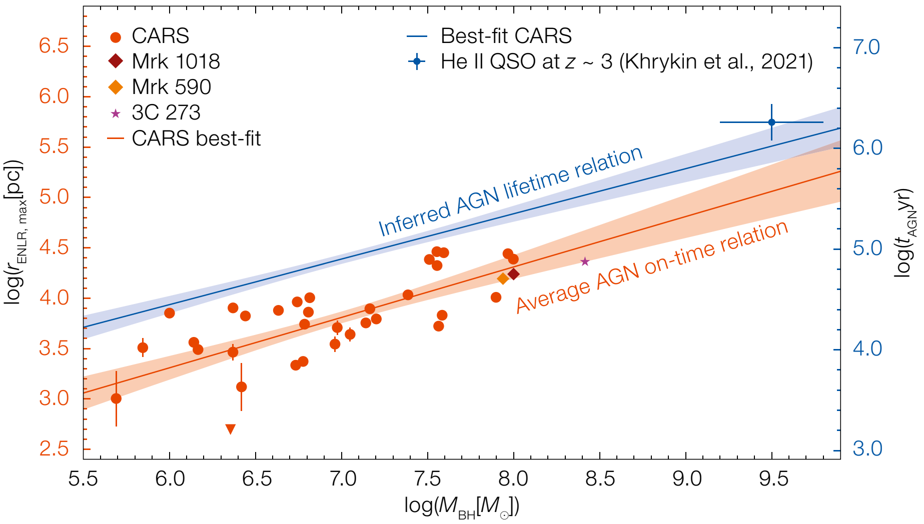
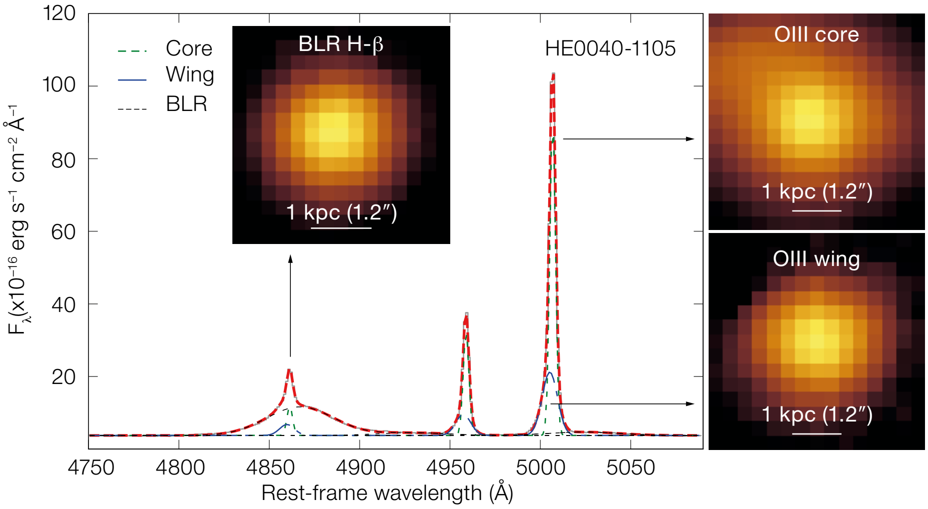


Figure 2. Maximum ENLR size as a function of black hole mass, with a linear best-fit relation shown (in red). The right axis shows the AGN lifetime; our inferred AGN lifetime relation is shown as the blue line.

Figure 3. The central figure shows the spectrum from the centre of this AGN (in black), the fit to the data (in red) and the fit split up into the core of the emission (green dashed) and broad emission from in the wings of the [OIII] line. The three images show intensity maps of the inner 3 arcseconds (2.5 kpc) of the three emission lines in the spectrum, as indicated by the arrows. The [O III] wing originates from a region only ~ 100 pc away from the unresolved BLR emission. The [O III] core component extends ~ 2.5 kpc away from the nucleus and leaves a clearly different light profile.



tens of kiloparsecs — and tested whether these are correlated with the luminosity of the AGN. However, we found that the ENLR-size–luminosity correlation is weak in the CARS sample. Surprisingly the strongest correlation was found between the maximum ENLR size and the mass of the black hole (shown in Figure 2), despite lacking an obvious direct connection. The simplest interpretation is that the maximum ENLR size is related to the timescale of the current AGN lifetime (t_{AGN}) — through the light travel time of ionising photons — which is correlated with black hole mass, M_{BH}. Hence, more massive black holes would statistically show longer periods of high accretion phases. We find a relationship of the form $t_{AGN} \sim M_{BH}^{0.5}$ using a Bayesian model, which agrees with the independent measurements for AGN lifetimes at higher redshifts which involve significantly more massive black holes. If such a relationship is confirmed, it implies that the released energy for AGN feedback will depend not solely on the luminosities of the AGN, but also on their actual time life that appears to scale with black hole mass.

Tracing the outflows

Spatially resolved spectroscopy across the entire galaxy provides ideal data from which to understand outflows, a key feature of our current model for AGN feedback. In Singha et al. (2022) we make use of the MUSE observations of the CARS galaxies to look for and characterise outflows driven by the active nucleus.

We used a method called spectro-astrometry (Bailey, 1998) which allows us to determine the location of any astronomical signature using spectroscopy. The unresolved BLR provides an excellent opportunity to model the PSF. The bright [O III] emission line in the optical regime is amongst the best signatures of outflows from AGN. Although ionised by the AGN, this gas is further away from the black hole, and as a result the resulting [OIII] emission line is usually narrow, unless an outflow is present. By modelling the asymmetry of broad underlying features in this line one can find evidence of outflowing gas, as shown in Figure 3. Where such signatures are present, we can determine whether the outflow is compact or extended. If the surface brightness profile of the [O III] wing is properly described by the PSF, we find the outflow to be compact, if not then it is extended. 23 out of the 36 AGN exhibit outflows which are unresolved by the IFU and are therefore compact, whereas for the other 13 sources, the outflows are resolved and therefore possibly extended on galactic scales (> 1 kpc).

This demonstrates that in an unbiased sample of nearby luminous AGN, compact (< 1 kpc) and extended (~ several kpc) outflows are both likely to occur. Our results are significant as they settle the long-standing debate in the AGN community about the spatial extent of outflows. Previous IFU studies focusing on the AGN-driven warm, ionised gas outflows (for example, Liu et al., 2013a; Harrison et al., 2014; Kang & Woo, 2018; and Wylezalek et al., 2020) found that kiloparsec-scale outflows are prevalent amongst luminous AGN. However, these studies did not account for PSF effects which cause centrally concentrated emission to be 'smeared' across the galaxy and appear as if it was spatially extended (Husemann et al., 2016).

The spectro-astrometric analysis further sheds light on the launching mechanism of these outflows. We find that the distributions of the BLR H-β luminosities, an indicator of the bolometric luminosity of the compact and the extended outflowing AGN, are almost identical. Our findings strongly indicate that the extensions of the AGN-driven outflows are not related to the AGN accretion properties. 1D spectroscopic analyses (such as Zakamska & Greene, 2014; Woo et al., 2016; Rakshit & Woo, 2018) and IFU observations (Liu et al. 2013b; Kang & Woo, 2018) suggested that the accretion properties of the AGN are related to the outflows and that outflows are mainly driven by AGN winds. Not only do our results show that the AGN accretion properties do not relate to the outflows, but also that they are launched from a region less than 100 pc from the nucleus, which is about a few orders of magnitude higher than the size of the AGN accretion disc (~ 10^{-5} pc). These findings imply that other parameters such as AGN lifetime or the radio properties of the AGN could be related to the outflows.

Star formation and AGN feedback

In Smirnova-Pinchukova et al. (2022), we present a complete census of the integrated star-forming properties of the galaxies in the survey. In order to

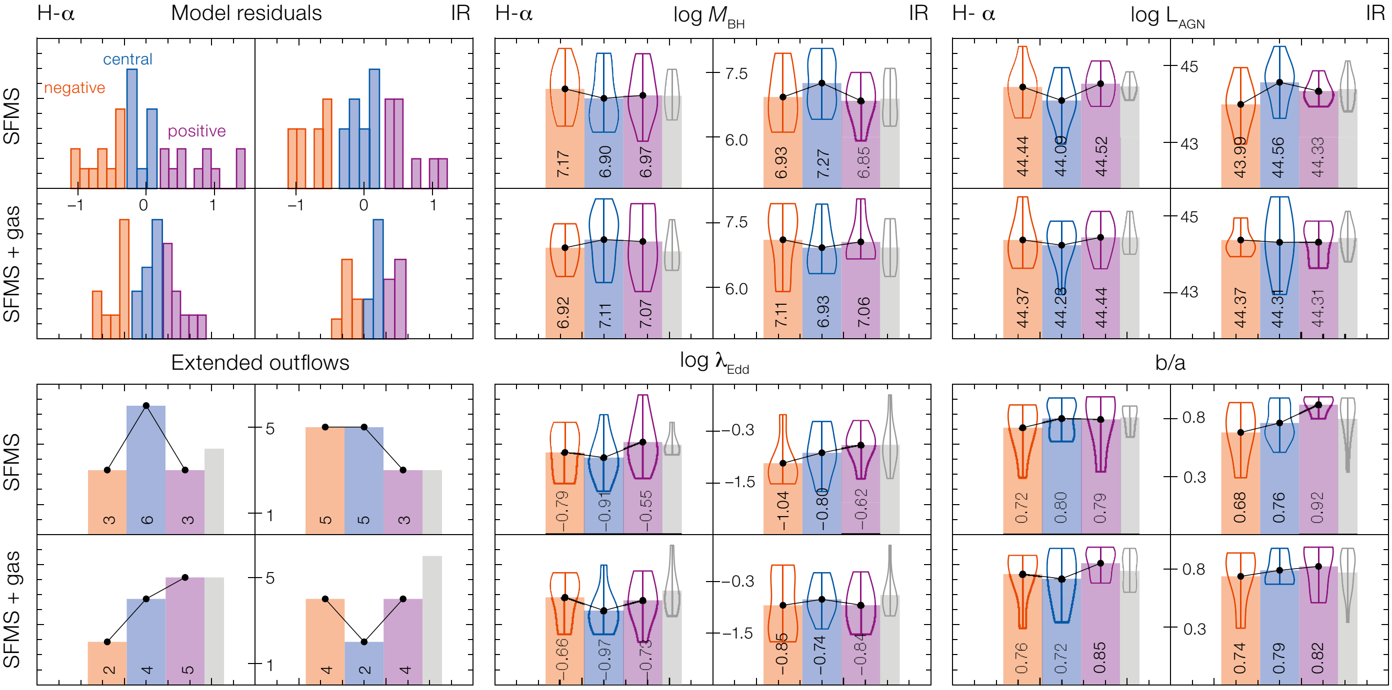


Figure 4. We compare the star formation rate residuals from the star forming main sequence (SFMS) and SFMS+gas models to AGN parameters using the H-α and infrared data (left and right of each panel). The top-left histogram shows the residuals, with negative in red and positive in purple. The rest of the panels compare the AGN parameters: logarithm of black hole mass, logarithm of AGN bolometric luminosity, number of galaxies with extended outflows, logarithm of Eddington ratio, and inclination (b/a).

understand how AGN affect star formation we first need to quantify the number of stars being formed, both now and in the past. To do this we combined the CARS MUSE data with dedicated observations from the James Clerk Maxwell Telescope, the Panoramic Near-Infrared Camera (PANIC) at Calar Alto observatory, the Dark Energy Camera (DECam), and the Stratospheric Observatory For Infrared Astronomy (SOFIA), in addition to archival broadband photometry to construct panchromatic spectral energy distributions (SEDs) from the far infrared to ultraviolet wavelengths. We then used AGNFitter (Calistro Rivera et al., 2016) to model the SEDs and predict the star formation rates and stellar masses. The spatially resolved spectroscopic data also allow us to use the H-α line as a measure of star formation, after the contribution from the AGN has been removed.

A control sample of inactive galaxies was used to probe the impact of AGN on star formation. We found no evidence that star formation is systematically lower in the AGN sample, and that there is no trend between star formation rate and luminosity of the AGN.

By using two different methods of measuring star formation we probe two different timescales. The far-infrared tells us the star formation rates on timescales of ~100 Myr while the H-α emission probes much more recent star formation (~5 Myr). These two measures allow us to determine whether star formation is increasing (meaning the H-α star formation rate is higher than the infrared one) or decreasing (vice versa). We find that declining star formation rates seem to be associated with the presence of an outflow, implying that feedback has an impact on star formation. Increasing star formation seems to be correlated with an ongoing interaction or a younger AGN phase.

Additionally, we find some evidence that the orientation of the central engine of the AGN with respect to the global axis of the host galaxy may impact the efficiency of feedback. Somewhat lower star formation rates are correlated with inclination (b/a) as shown in the bottom right panel of Figure 4. When the inclination is higher (meaning the galaxy is more edge-on) AGN radiation from the ionisation cone will encounter a larger cross section of the galactic disc, resulting in a greater feedback effect. This result is tentative and requires further investigation with larger samples.

Future directions

In this article we have focused on the optical IFU data from MUSE used in our three DR1 papers, but the interplay between AGN and their host galaxies cannot be disentangled using this alone. Recent work, such as that by Harrison et al. (2015) and Jarvis et al. (2019), has demonstrated the importance of radio-mode AGN feedback even in radio-quiet AGN. To investigate this, we will add very long baseline interferometry (VLBI) data to our arsenal. We also have yet to delve into the impact of feedback on the cold interstellar medium. We will leverage our ALMA observations here to reveal the impact of our AGN on both the diffuse and dense molecular gas.

Furthermore, to fully understand how AGN feedback begins on the smallest scales we need to zoom into the central (< 500 pc) region around the black hole to see how the energy released from the AGN couples with the surrounding medium. In the next phase of the survey, we will obtain high-angular-resolution observations with ESO's upgraded MUSE in its narrow-field mode, observations with the adaptive-optics-assisted Near-infrared Integral Field Spectrograph at Gemini North, and near-ultraviolet Hubble Space Telescope imaging to provide an unprecedented view of the very heart of the central engine of active galaxies. We hope that this and future data releases from the CARS team will serve as a legacy sample for AGN for years to come.

DR1 data access

The data release includes a query page[4], where the user can harness the power of the various datasets via customized SQL queries. The data are fully Virtual Observatory-compliant and can be accessed via the various table protocols of the Virtual Observatory. There you can find:

- 3D IFU observations along with higher-level data products from MUSE, the VIsible Multi-Object Spectrograph (VIMOS) at ESO's VLT and the Potsdam MultiAperture Spectrophotometer at Calar Alto Observatory;
- AGN spectral parameters;
- SED modelling;
- Characterisation of the warm, ionised outflows;
- Host galaxy parameters.

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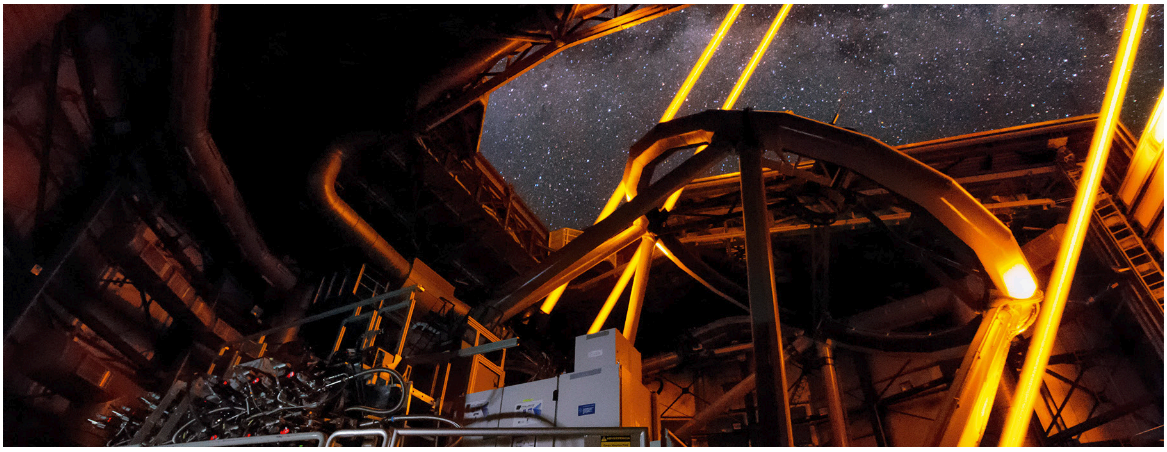
Links

[1] CARS survey: www.cars-survey.org
[2] QDeblend3D: http://www.bhusemann-astro.org/?q=qdeblend3d
[3] PyParadise: https://github.com/brandherd/PyParadise
[4] CARS query page: https://cars.aip.de/



Roland Bacon/ESO

Inside Unit Telescope 4 of the Very Large Telescope, the four lasers of the Laser Guide Star Facility — part of the Adaptive Optic Facility (AOF) — points to the skies during the first observations using the MUSE instrument. The sharpness and dynamic range of images using the AOF-equipped MUSE instrument will dramatically improve future observations.

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Keeping Exoplanet Science Caffeinated with ESPRESSO

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The ESPRESSO spectrograph at ESO's Very Large Telescope (VLT) has, since it began science operations in October 2018, revolutionised exoplanet science. The combination of the large VLT mirrors and the high resolution and stability of the spectrograph is enabling the detection of small, low-mass planets as well as detailed studies of the planets' atmospheres. In this article we present a brief overview of the first results from ESPRESSO and a hopeful glimpse towards the ultimate goal of reaching the radial velocity precision of 10 cm s^{-1} needed to detect an Earth-like planet.

The quest for temperate, rocky planets

Is life a common constituent of the Universe? This overarching question is currently driving the construction of telescopes (small, extremely large and space-based alike) and the development of new instruments. We know that planets themselves are very common; at least 50% of Sun-like stars have one planet, possibly more, around them (Fressin et al., 2013). Rocky planets seem to be one of the most predominant types of exoplanets out there, 10 times more frequent than giant gas planets when considering close-in orbits. However, when it comes to determining the occurrence of Earth-sized planets we are limited by current survey sensitivity, especially when probing orbital periods beyond 100 days (Fulton & Petigura, 2018).

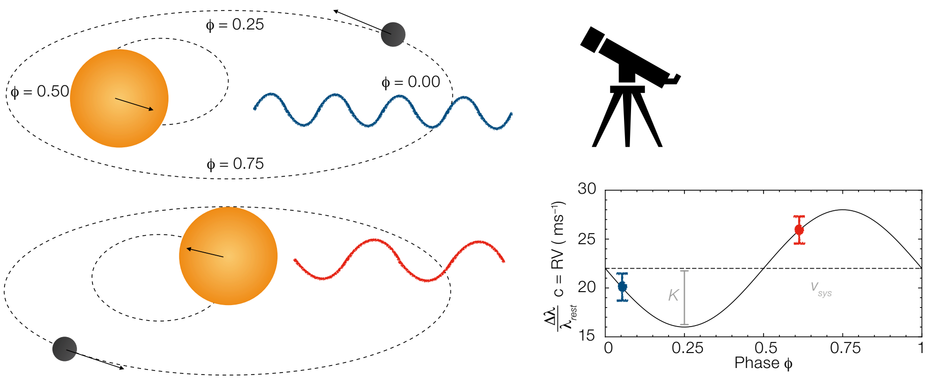


Figure 1. As a planet and star are orbiting their common centre of mass, the stellar light is red- and blue-shifted. The semi-amplitude of the stellar radial velocity shift, K_{RV}, is directly related to the mass ratio of planet and star, and the orbital period.

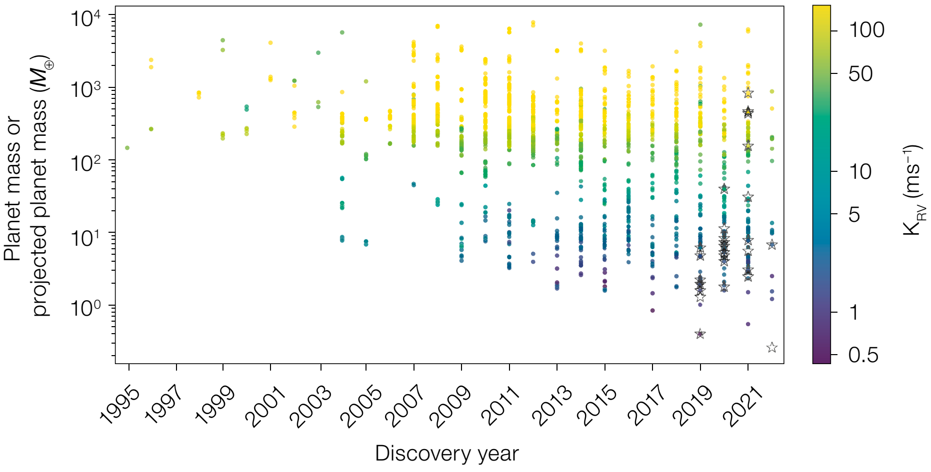
The radial velocity technique has, since the first discovery of an exoplanet around a main sequence star by Mayor & Queloz (1995), proven useful for discovering new exoplanets and measuring the masses of known transiting exoplanets. The wobble of a host star, induced by the gravitational pull of an orbiting planet, is translated into a periodic shift of the stellar absorption lines as the stellar light is red- and blue-shifted away from us and towards us, respectively, as seen in Figure 1. This subtle effect can be measured by high-resolution spectroscopy with stabilised instruments and reliable wavelength calibrations.

As new generations of instruments have entered the stage, astronomers have been able to push towards less and less massive planets. Figure 2 shows the masses of known exoplanets measured with the radial velocity technique (in Earth-masses; note the logarithmic scale) as a function of their discovery year. For systems where the orbital inclination is not known, the projected mass is used. Over the last 15 years, an almost linear evolution toward less massive planets has delivered the first Earth-mass exoplanets.

Extremely precise radial velocities with ESPRESSO

After the start of operations at ESO's Very Large Telescope (VLT) in October 2018, and a subsequent fibre upgrade in June 2019, the Echelle SPectrograph for Rocky Planet and Stable Spectroscopic Observations (ESPRESSO; Pepe et al., 2021) has started an era of extremely precise radial velocity measurements. Compared to its predecessor, the High Accuracy Radial velocity Planet Searcher (HARPS) on the ESO 3.6-metre telescope (Mayor et al., 2003), ESPRESSO benefits from a larger collecting area, wider wavelength range and better instrument stability and calibration. The instrument can be fed with light from any of the Unit Telescopes (UTs) at Paranal Observatory,

Figure 2. Exoplanet masses, or projected masses, based on radial velocity measurements versus the year of discovery. Note that the y-axis is in Earth-masses and is logarithmic. The colour scale is radial velocity semi-amplitude, K_{RV}. Masses determined with ESPRESSO are highlighted with stars, and empty stars are for planets not yet confirmed. Based on data from NASA Exoplanet Archive[1], April 2022.



or from all of them to mimic an effective collecting area corresponding to a 16-metre telescope. The 4-UT mode is offered with extragalactic astronomy also in mind, though in this article we will focus on the advances in exoplanet science only.

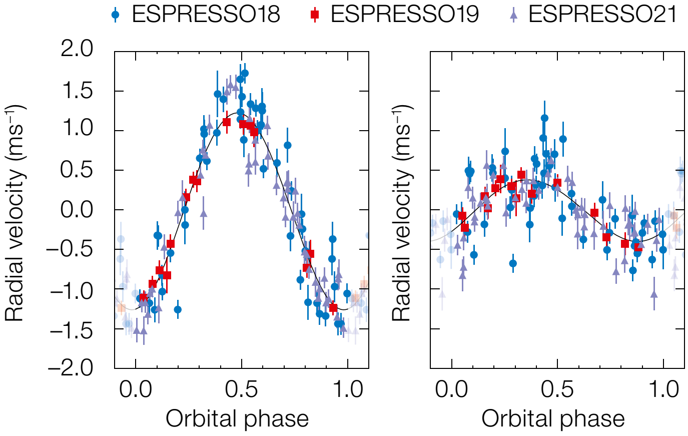


Figure 3. Radial velocity measurements of Proxima Cen from Faria et al. (2022). The two panels show the data phase folded on the epoch and period of the two detected planets along with the best fit model. The RMS of the residuals is just 0.26 ms^{-1}.

Unveiling the true nature of our closest neighbour

The nearest star to our Solar System, Proxima Centauri, has been monitored closely with ESPRESSO as part of an effort to discover low-mass planets in the habitable zones around nearby stars (Hojjatpanah et al., 2019). Proxima Centauri was known to host an Earth-mass planet, known as Proxima b, in an 11.2-day orbit (Anglada-Escudé et al., 2016) as well as a seven times more massive candidate on a 5-year orbit (Damasso et al., 2020). Using ESPRESSO, Suárez Mascareño et al. (2020) independently confirmed the orbit of Proxima b at 11.2 days, while also presenting hints of a third candidate in the system. This planet candidate was recently established by Faria et al. (2022) after collecting an additional season of ESPRESSO data. Based on three seasons of ESPRESSO data, Faria et al. (2022) find a minimum mass of 0.25 that of Earth for this close-in candidate, which is orbiting at a distance of just 0.029 astronomical units from its host star. The radial velocity data are shown in Figure 3, where the phase-folded data for the two planets with the best fit model are shown. The RMS of the residuals across the three seasons of observations is just 0.26 ms^{-1}.

With the discovery of a third rocky planet candidate around Proxima Centauri, our closest stellar system illustrates the potential for the discovery of low-mass planets around nearby stars. Given the low inherent luminosity of the host star, the three planets orbit just inward, within, and outward of the zone where liquid water could exist, commonly refereed to as the potential habitable, or goldilocks, zone.

When analysing the radial velocity observations from ESPRESSO and other spectrographs, one of the biggest challenges is separating the imprint of stellar activity from the signals caused by planets. The presence of active regions (for example, starspots) at the stellar surface creates radial velocity variations that can mimic a planet. This has been tackled using statistical methods combined with so-called activity indicators, which are auxiliary observations that measure the level of stellar activity (Pont, Aigrain & Zucker, 2011; Dumusque et al., 2017; Zicher et al., 2022). Furthermore, the large wavelength coverage and high radial velocity precision of ESPRESSO have made it possible to verify that signals are constant across the wavelength range (as planetary signals ought to be) and thereby to separate them from signals due to stellar activity.

Measuring the masses of transiting planets

Transiting exoplanets present unique opportunities for in-depth characterisation as we can potentially measure both their radius and mass as well as constrain full 3D orbits and determine atmospheric properties. The L 98-59 system contains three transiting planets (Kostov et al., 2019; Cloutier et al., 2019) as well as two additional candidates seen only in radial velocity measurements with ESPRESSO (Demangeon et al., 2021). L 98-59 b is a rocky planet with half the mass of Venus and is currently the lowest-mass planet measured using radial velocities.

Another interesting system for detailed studies is WASP-47, which has three inner transiting planets: a super-Earth at 0.79 days, a hot Jupiter at 4.16 days and a Neptune at 9.03 days (Hellier et al., 2012; Becker et al., 2015). Additionally, WASP-47 is known to host an outer giant planet with an orbital period of 1.6 years (Neveu-VanMalle et al., 2016), though it is uncertain whether it is in a transiting orbital configuration as seen from Earth. Recently, Bryant & Bayliss (2022) revisited the WASP-47 system using ESPRESSO and space-based photometry. Thanks to a high-cadence observing strategy they were able to refine the mass of WASP-47 e, the smallest, innermost planet in the system. Compared to the ensemble of known super-Earths, the density of WASP-47 e is found to be low, which could be caused by tidal interaction with the hot Jupiter in the system.

Probing exoplanet atmospheres with resolved spectral lines

In the few years that ESPRESSO has given us high-resolution data, it has also proven to be a powerful tool for characterising exoplanet atmospheres. With its high-fidelity spectra, many approaches to studying exoplanet systems were automated and various codes are now available to understand the 3D orbits and atmospheric constituents of exoplanets. Some examples are the CaRM code to learn more about the Rossiter-McLaughlin effect (Cristo et al., 2022), CHOCOLATE — a new chromatic Doppler tomography technique (Esparza-Borges et al., 2022), and the RRM revolutions approach (Bourrier et al., 2022) on GJ436 b, which lets us derive system parameters all the way down in size to Neptunes.

With all these new techniques, it is only a question of time before controversy arises. But who would have thought that the first

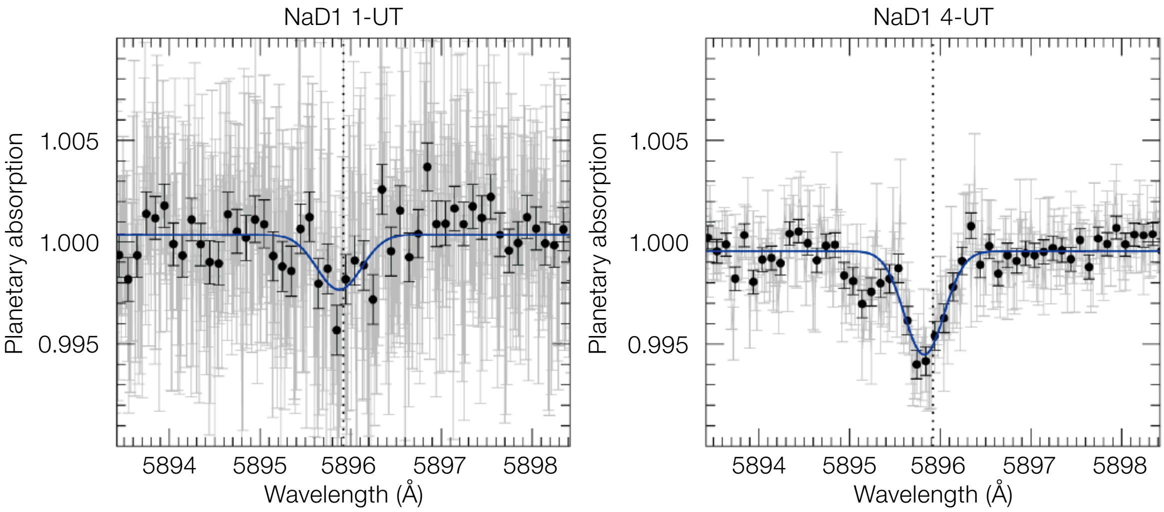


Figure 4. Sodium detection in WASP-121 b with ESPRESSO with one UT on the left and four UTs on the right. From Borsa et al. (2021).

bombshell dropping from ESPRESSO data would be related to the all-time favourite exoplanet, HD209458 b? Claimed as the first detected exoplanet atmosphere by Charbonneau et al. (2002), it has since been the poster child of atmospheric detections, with currently more than 75 peer-reviewed articles to its name. Yet, analysing ESPRESSO data taken over two individual transits revealed that the detections previously claimed for sodium, potassium, magnesium, iron and a handful of other molecules and atoms can be attributed solely to the distortion of the stellar lines by the Rossiter-McLaughlin effect (Casasayas-Barris et al., 2021).

While not as emotionally charged as the results for HD209458 b, ESPRESSO has also contributed to the understanding of the sub-Saturn WASP-127 b and the hot Jupiter WASP-19 b. For WASP-127 b, two independent studies of HARPS data came to different conclusions about the sodium detection strength. Allart et al. (2020) ultimately demonstrated with ESPRESSO data that WASP-127 b has a shallow sodium feature. Similarly, Sedaghati et al. (2021) added useful information to the ongoing study of WASP-19 b by providing various non-detections (for example, of Fe) and solidifying the detection of TiO, thus resolving the differences in the results obtained with FORS (Sedaghati et al., 2017) and IMACS (Espinoza et al., 2019).

Other atmospheric detections include sodium and potassium for the hot Jupiter WASP-117 b (Carone et al., 2021) and the confirmation of atmospheric sodium for the Neptune desert planet WASP-166 b (Seidel et al., 2022 and papers to follow).

But one of the first detection results from ESPRESSO directly turned out to be spectacular: Tabernero et al. (2021) re-observed the ultra-hot Jupiter WASP-76 b with ESPRESSO and confirmed the extremely broadened sodium signal as well as various other detections, starting off the race for ESPRESSO data on exoplanet atmospheres.

From static to time-resolved, from upper-limits to precise values: the ESPRESSO effect

WASP-76 b, the first ultra-hot Jupiter with a resolved sodium signature, provided the community with the most precise high-resolution dataset of any exoplanet atmosphere to date. The same dataset was analysed by Ehrenreich et al. (2020) who go beyond the integrated detection of elements. Instead of just claiming iron in its atmosphere, they trace iron as a function of phase, providing a time-resolved map of iron across the terminator of WASP-76 b. This leads them to a direct, time-resolved detection of a 5-km s^{-1} dayside-to-nightside wind in the lower atmosphere — a first in our understanding of exoplanet atmospheric dynamics. On the integrated transmission spectrum, the resolved sodium doublet opens the observational window on the exoplanet atmosphere to include even higher layers, probing all the way to the thermosphere. The same ESPRESSO dataset on WASP-76 b allowed the direct retrieval of 3D wind patterns by Seidel et al. (2021), who found exactly the same speeds for a dayside-to-nightside wind in the lower atmosphere as Ehrenreich et al. (2020) had done, confirming their observational results. Seidel et al. (2021) also find a vertical wind connecting the lower atmosphere to the photoevaporation-driven mass loss in the exosphere.

The journey with ESPRESSO to a more detailed understanding of exoplanet atmospheres has, however, only just begun. The 4-UT mode of ESPRESSO has recently provided the sharpest line shapes we have ever seen for a plethora of spectral lines, opening up a whole new world of time-resolved observations (Borsa et al., 2021; see Figure 4).

Acknowledgements

We thank João Faria for valuable comments and feedback on this article and for supplying the radial velocity figures for Proxima Centauri reproduced at Figure 3.

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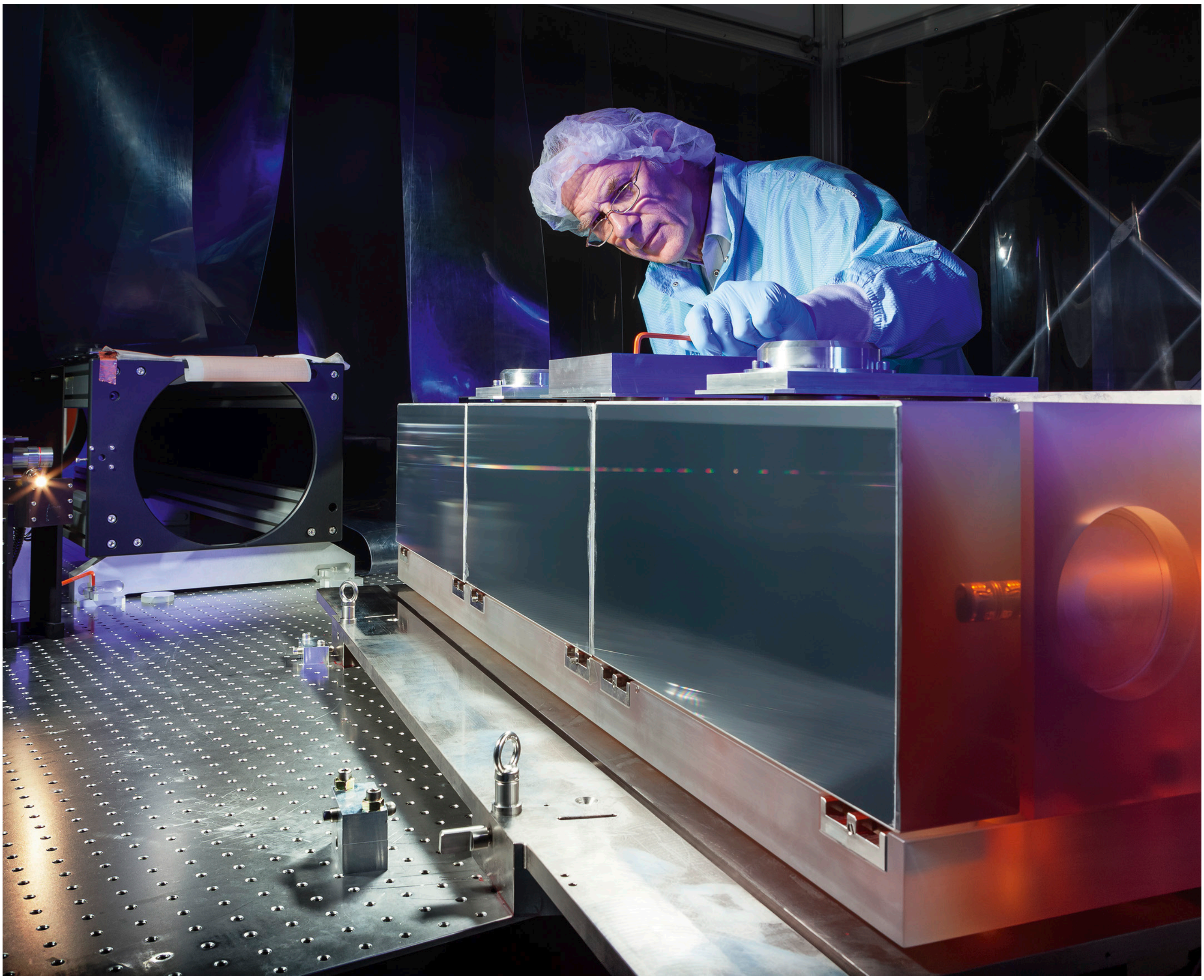
Links

[1] NASA Exoplanet Archive: https://exoplanetarchive.ipac.caltech.edu/


ESO/M. Zamani

The huge diffraction grating at the heart of the ultra-precise ESPRESSO spectrograph — the next generation in exoplanet detection technology — is pictured undergoing testing in the cleanroom at ESO Headquarters in Garching bei München, Germany.

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Exploring the Universe via the Wide, Deep Near-infrared Imaging ESO Public Survey SHARKS

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The ESO Public Survey Southern H-ATLAS Regions *Ks*-band Survey (SHARKS) comprises 300 square degrees of deep imaging at 2.2 microns (the *Ks* band) with the VISTA InfraRed CAMera (VIRCAM) at the 4-metre Visible and Infrared Survey Telescope for Astronomy (VISTA). The first data release of the survey, comprising 5% of the data, was published via the ESO database on 31 January 2022. We describe the strategy and status of the first data release and present the data products. We discuss briefly different scientific areas being explored with the SHARKS data and conclude with an outline of planned data releases.

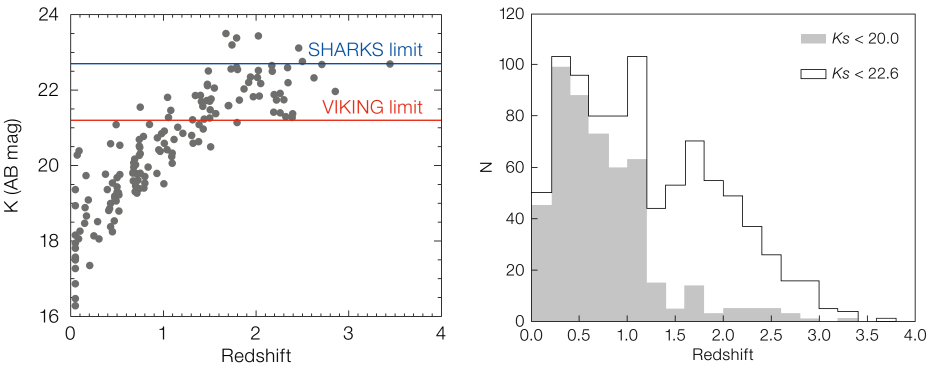


Figure 1. Left: *Ks*-band magnitude as a function of redshift for Herschel sources (from HerMES; Oliver et al., 2010) with Very Large Array counterparts in the Subaru Deep Field and the COSMOS survey. The VIKING survey is only able to detect H-ATLAS galaxies at $z < 1$. The much deeper SHARKS observations will enable detection of 90% of all star-forming, obscured, H-ATLAS sources, and also the most extreme populations at $z > 3$. Right: Photometric redshift distribution of counterparts of simulated SKA sources in the VIDEO survey, from McAlpine et al. (2012). This Figure shows that shallow *Ks*-band surveys only select the $z < 1$ radio population, whereas deeper surveys such as SHARKS are absolutely needed to select the $1 < z < 3$ population and the most extreme sources at $z > 3$.

Why another near-infrared survey?

The near-infrared (near-IR) wavelength range, a type of light imperceptible to the human eye, allows us to explore regions of the Universe that are either obscured by cosmic dust, too cold to be studied with telescopes observing in the visible, or at sufficiently high redshift that rest-frame optical/ultraviolet light is visible in the near-IR. Thus, this spectral range is key to understanding galaxies at both low and high redshifts. New wide-area surveys in the far-IR and radio promise to revolutionise this field of research, but currently we lack equivalent deep, wide-area, 2.2-micron (*Ks*-band) imaging (the most efficient near-IR passband in which to observe distant galaxies) to link the radio/far-IR sources to the optical and near-IR.

The Herschel ATLAS (H-ATLAS; Eales et al., 2010) is the largest Herschel Space Observatory open-time key project, having detected approximately half a million sources up to $z = 5$ with $S_{250\mathrm{micron}} > 28$ mJy over 600 square degrees of the sky. The discovery of distant, dust-obscured, star-forming galaxies in particular triggered a large number of pointed multi-wavelength campaigns. Clearly, at the depth of the VISTA Kilo-degree Infrared Galaxy (VIKING) Public Survey[a] (the deepest near-IR survey available over the South Galactic Plane (SGP) and Galaxy And Mass Assembly (GAMA) survey areas), only H-ATLAS sources at $z < 1$ have near-IR counterparts (Figure 1). However, more than 90% of the H-ATLAS sources at $1 < z < 3$ would be detected down to $Ks = 22.7$ mag (AB). Figure 1 also shows the redshift distribution of simulated Square Kilometre Array (SKA) radio sources in two different *Ks*-band magnitude ranges. It can be seen that shallow *Ks*-band observations/surveys such as VIKING only detect the $z < 1$ radio population, whereas surveys as deep as the VISTA Deep Extragalactic Observations (VIDEO; Jarvis, Häußler & McAlpine, 2013) will also detect the obscured sources at $1 < z < 3$ and some of the most extreme systems at $z > 3$. Therefore, the lack of wide and deep near-IR imaging on H-ATLAS fields motivated our team to propose a new public survey in 2015.

SHARKS survey and observations

The ESO Public Survey Southern H-ATLAS Regions *Ks*-band Survey (SHARKS; PI: H. Dannerbauer; 198.A-2006) was approved as a second-generation survey with the 4-metre near-IR-optimised Visible and Infrared Survey Telescope for Astronomy (VISTA) and its near-IR, wide-field imager the VISTA InfraRed CAMera (VIRCAM) at ESO's Paranal Observatory. In total, the survey was granted 1200 hours planned initially over four years. The overall survey covers 300 square degrees down to a 5-sigma limit of $Ks = 22.7$ mag (AB-system, 2-arcsecond aperture) and will detect a total of approximately 20 million sources. Already more than 90% of the data has been taken since autumn 2016 and it is expected that the observations will be completed by the end of 2022. The SHARKS team is an international collaboration of more than 50 researchers, whose expertise covers all aspects related to the full and successful exploitation of the SHARKS dataset.

In all, we will have conducted roughly 200 pointings (mosaics) in three fields, GAMA12, GAMA15 and SGP (see Figures 2 and 3). Each pointing is visited seven times (seven observing blocks of ~ 55 minutes' duration each). Within each observing block 36 images are taken, each with 60 seconds integration time, with the rest of the observing block dedicated to overheads. The survey strategy aims to complete each mosaic before moving to another, therefore the epoch difference within a mosaic is in general around a month. The required sky conditions are: seeing < 1.2 arcseconds in the SGP field and < 1.0 arcseconds in the GAMA fields, airmass < 1.7 and clear sky.

Data reduction

The first SHARKS data release (DR1) has been produced by a collaboration between the Instituto de Astrofísica de Canarias (IAC) and the Wide-Field Astronomy Unit (WFAU) at the Royal Observatory Edinburgh. Images are processed and calibrated at the WFAU. In addition, we have implemented an improved sky subtraction method. We use images reduced at the Cambridge Astronomy Survey Unit (CASU) and corrected for reset, dark, linearity, flat-field, and sky-background stripe correction. The VISTA Data Flow System pipeline processing and science archive are described by Irwin et al. (2004), Hambly et al. (2008) and Cross et al. (2012). Details of the data processing and calibration are provided in a separate document describing DR1[1]. To summarise, the pipeline starts by retrieving the CASU processed images and ends by creating co-added mosaic images sampled to a pixel size of ~ 0.34 arcseconds. The images have been astrometrically and photometrically calibrated with respect to the Two Micron All Sky Survey (2MASS; Skrutskie et al., 2006) and source catalogues are obtained with the SExtractor code (v2.19.5; Bertin & Arnouts, 1996).

First data release

On 31 January 2022 we made the DR1, amounting to 5% of the SHARKS data, available to the scientific community via the ESO Science Archive Facility. The release contains both calibrated images and source catalogues, so the data can be immediately exploited by researchers worldwide. The images from the DR1 are distributed over the three SHARKS fields, where six of them are isolated and four of them cover a contiguous region in the SGP-East (SGP-E) field (see Figure 3). The total area of each mosaic is 2.03 square degrees. In the four contiguous pointings in the SGP-E field, there is an overlap of 1.03 square degrees (13%) within the mosaics, completing 7.06 square degrees (see Figures 3 and 4). In total, the unique area of DR1 is 19.24 square degrees (20.27 square degrees considering the overlap). The DR1 consists of 10 co-added images and individual *Ks*-band source catalogues. Photometry is given for 13 standard apertures, from 1 to 24 arcseconds, in the AB system. For extended sources, Kron (Kron, 1980) and Petrosian (Petrosian, 1976) fluxes — which account for much of the missing light — are also determined. In addition to the co-added images we provide normalised-weight images (normalised to effective gains in analogue-to-digital units) and pre-images related to each (weight) image. The SHARKS DR1 catalogue comprises more than 1.5 million sources down to a median depth of 22.7 (5-sigma, AB), and a median seeing of 1 arcsecond. We estimate that 90% are classified as galaxies and that the level of spuriousness is below 2%, concentrated around bright stars. The release is made up of ~ 18 GB of co-added images (including weights) and 700 MB of the catalogues, provided individually for each of the 10 mosaics. The document giving details of the released data[1] also describes data reduction and quality.

Legacy value

The SHARKS dataset is complemented by an excellent existing multi-wavelength dataset including observations from the Spitzer Space Telescope, the Atacama Large Millimeter/submillimeter Array (ALMA), the Australian SKA Pathfinder (ASKAP), the Low Frequency Array (LOFAR), the Dark Energy Survey (DES), the Subaru Telescope and the Hubble Space Telescope (see Figure 2). These data are a mix of individual pointed observations and large-area surveys. The SHARKS fields covered will also overlap with future Legacy Survey of Space and Time (LSST; optical) and Euclid (near-IR, but not *Ks*) deep observations, representing a perfect complementary dataset (see Figure 2). To summarise, the combination of the near-IR survey SHARKS with

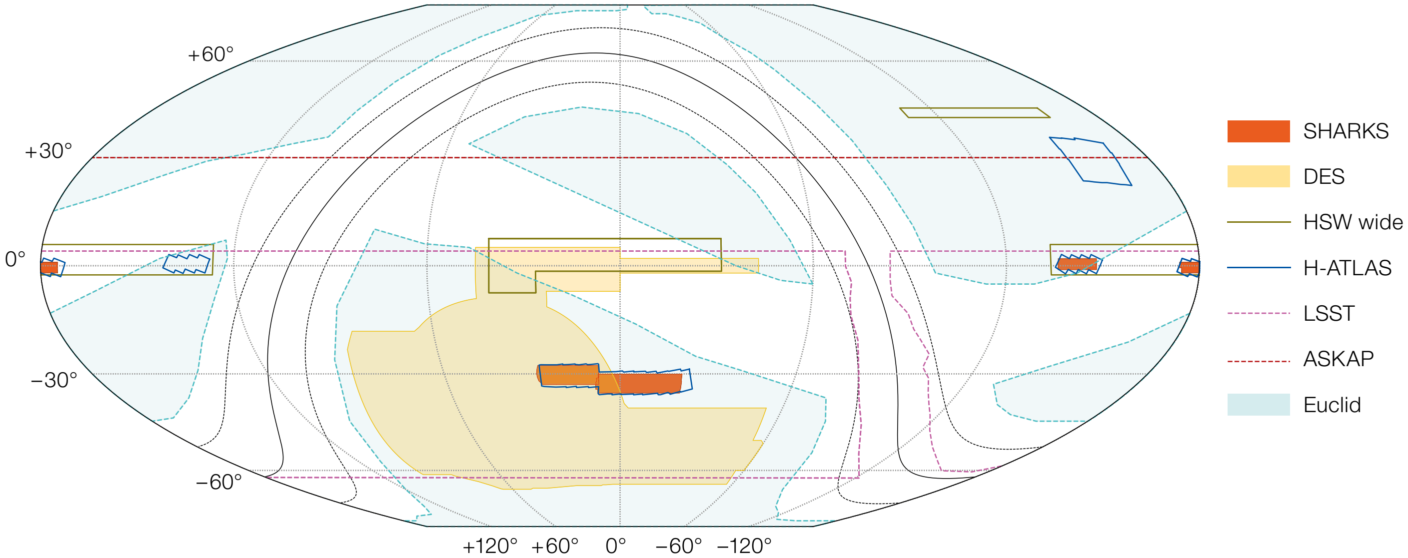


Figure 2. Coverage of the SHARKS fields by current and future surveys and missions.

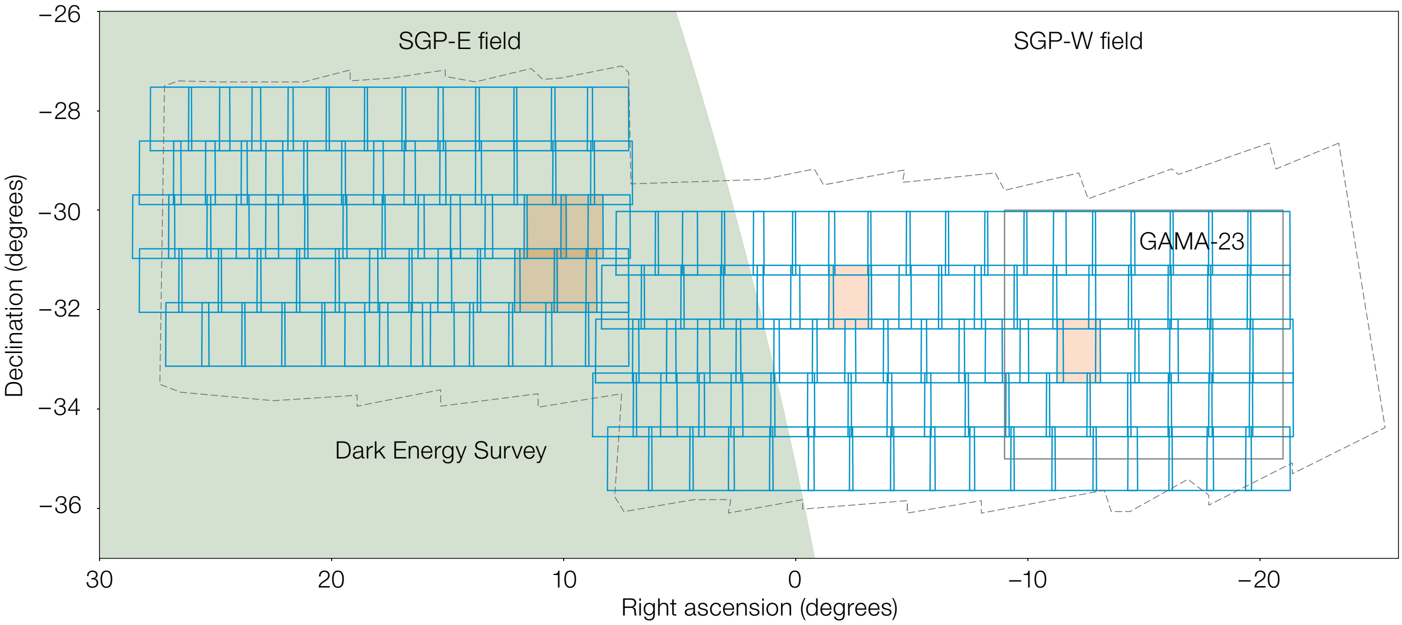


Figure 3. Spatial distribution of all observed and planned mosaics (in blue) in the SGP field. The H-ATLAS footprint is shown dashed, the GAMA-23h footprint is in black and the DES foorprint is shown filled in green. In red we show the mosaics of this field that were released in DR1.

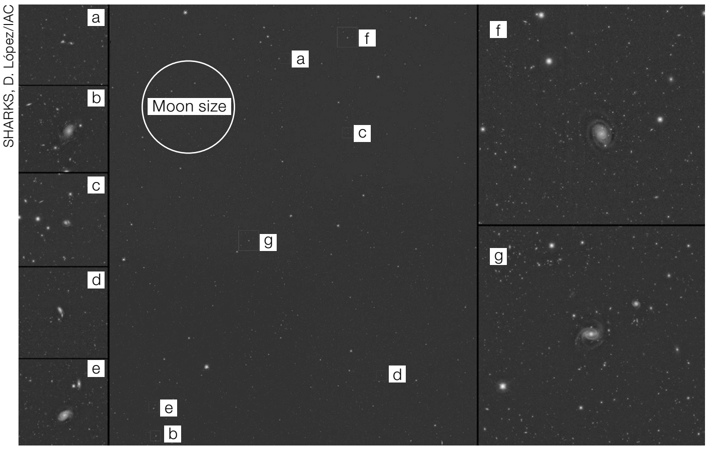
previous, current and future surveys at different wavelengths has a unique legacy value for future astrophysical studies.

Science outlook

The SHARKS data can be explored in different astrophysical areas, such as Solar System objects, stars, local and high-redshift galaxies and large scale structures. Thanks to the wide angular coverage of SHARKS, cosmic variance is negligible, and thus statistical studies of the evolution and formation of galaxies will provide robust and reliable conclusions. Using the four contiguous SGP-E fields from the DR1, we have derived the *Ks*-band number counts down to *Ks* = 22.7 mag (see Figure 5)[b]. This estimate is consistent with previous work by Daddi et al. (2000), giving us confidence in our data reduction and calibration. The larger part of the SHARKS survey has coverage in the optical from the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) and the DES. Adding the SHARKS imaging already improves photometric redshifts estimates for high-*z* sources significantly. In future, LSST and Euclid imaging will certainly further improve these estimates. The following topics related to galaxies can be exploited and searched for with the SHARKS data: the far-IR/radio correlation, rare objects, galaxy overdensities, lensed galaxies and QSOs. As shown in Figure 1, for about 90% of Herschel-selected sources, SHARKS will provide a counterpart identification, indispensable for deriving their distances, stellar masses and star formation rates. This is also true for sources selected from LOFAR and ASKAP radio surveys and ALMA observations. Currently the only region of sky with *Ks*-band imaging sufficiently deep to provide this level of identification completeness for far-IR/radio surveys is VIDEO. But at only 12 square degrees there will be little scope for probing extreme and rare sources. With 25 times more area, to the *Ks*-band depth required for radio identification, SHARKS would be ideal for finding the highest-redshift powerful radio sources with baryonic masses of $10^{12}\, M_{\odot}$ to $z = 10$ (Rocca-Volmerange et al., 2004).

Future plans

In the coming years at least two more ESO data releases are planned. In the second one, aimed for the beginning



SHARKS, D. López/IAC

Figure 4. Near-IR image of the SHARKS survey of a 7-square-degree large field (the four contiguous SGP-E fields from DR1), with the apparent size of the Moon as a reference. Boxes present representative galaxies in detail.

of 2023, we plan to release at least 50% of the data. In the third (and probably final) one, we will release all the observed fields. We also plan to include multi-wavelength information for each SHARKS *Ks*-band source. For future data releases we aim to use Gaia catalogues for astrometric calibration. In addition, the SHARKS team members at the IAC are working on a specific data reduction in order to reveal low-surface-brightness objects — such as Galactic cirrus, ultra-faint galaxies, outer parts of galaxies and intracluster light — in the near-IR. This work is based on previous work in the optical (Trujillo & Fliri, 2016) and will give us access to astronomical objects previously unexplored in this wavelength regime. Finally, we would like to note that more information about the survey, including the full list of SHARKS co-investigators, is available on our dedicated SHARKS webpage[2].

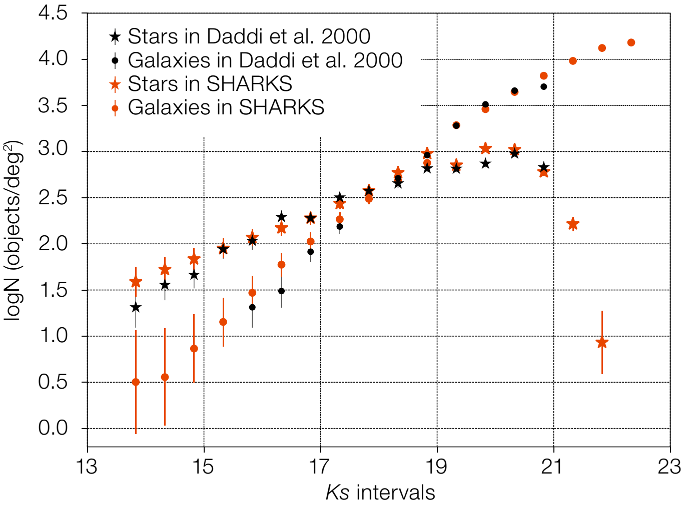


Figure 5. Comparison of *Ks*-band number counts of stars and galaxies derived for the four contiguous fields in SGP-E from SHARKS DR1 and work presented in Daddi et al. (2000). Our galaxy number counts match well with the previous study and we could even extend them to fainter magnitudes.

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Links

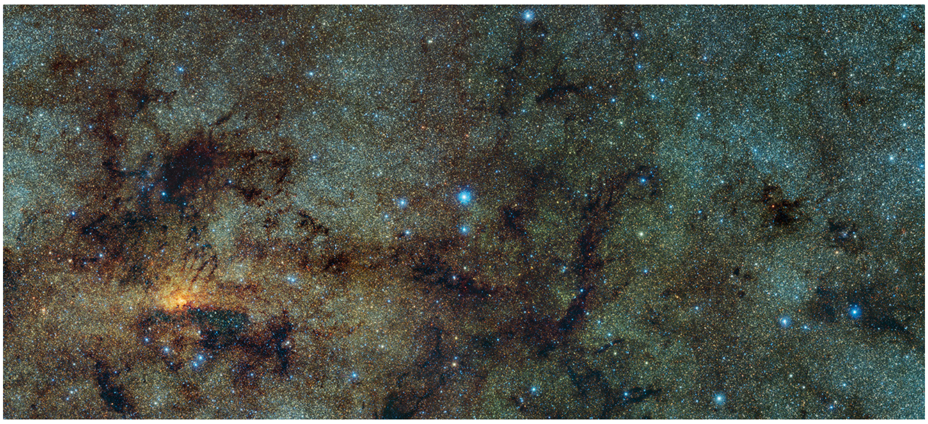
[1] DR1 description: https://www.eso.org/rm/api/v1/public/releaseDescriptions/179

[2] SHARKS webpage: http://research.iac.es/proyecto/sharks/pages/en/home.php

Notes

[a] The H-ATLAS fields were covered previously by the ESO Public Survey VIKING (Edge et al., 2013) at a significantly shallow level (*Ks* < 21.2 mag, 5-sigma, AB).

[b] This analysis was part of a bachelor’s thesis carried out by Sergio Saavedra Esquiviel of the Universidad de La Laguna. For details see: https://riull.ull.es/xmlui/handle/915/24098



ESO/VVV Survey/D. Minniti

This image, captured with the VISTA infrared survey telescope, as part of the Variables in the Via Lactea (VVV) ESO public survey, shows the central part of the Milky Way. While normally hidden behind obscuring dust, the infrared capabilities of VISTA allow the stars close to the galactic centre to be studied.

Instrumentation

An engineer working on the CRIRES⁺ (CRyogenic high-resolution InfraRed Echelle Spectrograph⁺) instrument, installed on one of the VLT’s Unit Telescopes (UTs). The instrument, which will search for potentially habitable super-Earth exoplanets, is installed on UT3.

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Science Verification of CRIRES⁺

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Science Verification (SV) observations with CRIRES⁺ were obtained between 15 and 19 September 2021. The SV team performed the observations jointly on Paranal and in Garching. The weather conditions were mostly good except for the last night when thick clouds prevailed for most of the night requiring adjustments for some observations. Most of the planned SV observing programme could be accomplished. Of 57 submitted proposals, 23 observing programmes were scheduled for a total of 47 hours of observations. The allocation assumed four observing nights (of ten hours each) and included a slight oversubscription. Sixteen projects could be completed, including the eight top priority programmes. Three programmes could only be partially executed, and four runs were not observed. Some of the first science results are presented.

Proposal solicitation and submission

The call for CRIRES⁺ SV proposals was issued on 16 June 2021[1]. With the call, the CRIRES⁺ SV Webpage[2] was launched. 57 proposals were received by the deadline on 7 July 2021 requesting in total 170 hours. The proposals were submitted through the regular P1 system in a special call. This is amongst the highest demands on recent instrument SVs. The SV team ranked the proposals according to scientific interest and the final selection was discussed at a meeting on 23 July 2021. 23 projects were selected for a total of 47 hours of execution time. Several proposals were rejected because they overlapped with submitted P108 proposals. One proposal requested time-critical observations outside the allocated SV nights and had to be rejected as well. The approved projects slightly oversubscribed the available time. The proposers were informed about the outcome of the selection on 3 August 2021. In parallel, the information was also made available to the Principal Investigators (PIs) through the Observing Programmes Office Webletter pages. The deadline for the submission of the Phase 2 material was 1 September 2021.

The largest number of requests were for exoplanet transit observations to characterise planetary atmospheres. Other topics included studies of circumstellar disc chemical composition, atomic gas in quasar absorption systems, obtaining the He isotope ratios towards the Orion Nebula, accretion and ejection of gas in discs around young stars, mass loss from post-red-supergiant stars, gas planets in the Solar System (Jupiter and Neptune), and abundance measurements in planetary nebulae and star clusters. Some of the first science results are presented below.

Observations

The CRIRES⁺ SV nights were scheduled for 15 to 19 September 2021. The schedule was determined by the CRIRES⁺ commissioning activities and had to remain flexible. In general, the atmospheric conditions were good except for high seeing during the first night and clouds during the last night. Observations could be obtained throughout the allocated CRIRES⁺ SV nights. In some cases, the observations had to be adjusted to the prevailing conditions and some data were obtained outside the requested observing constraints. CRIRES⁺ performed very well and only a small amount of time was lost for certain target acquisitions, caused by either crowded fields or mismatches in the filter/brightness combinations for the reference stars resulting in occasional deviations from the optimal observing schedule. No significant instrument problems were encountered during the four SV nights. The collaboration between the science operations on Paranal and the support team in Garching was excellent. A remote observing session from Garching was set up to train the CRIRES⁺ user support astronomers. There were very fruitful

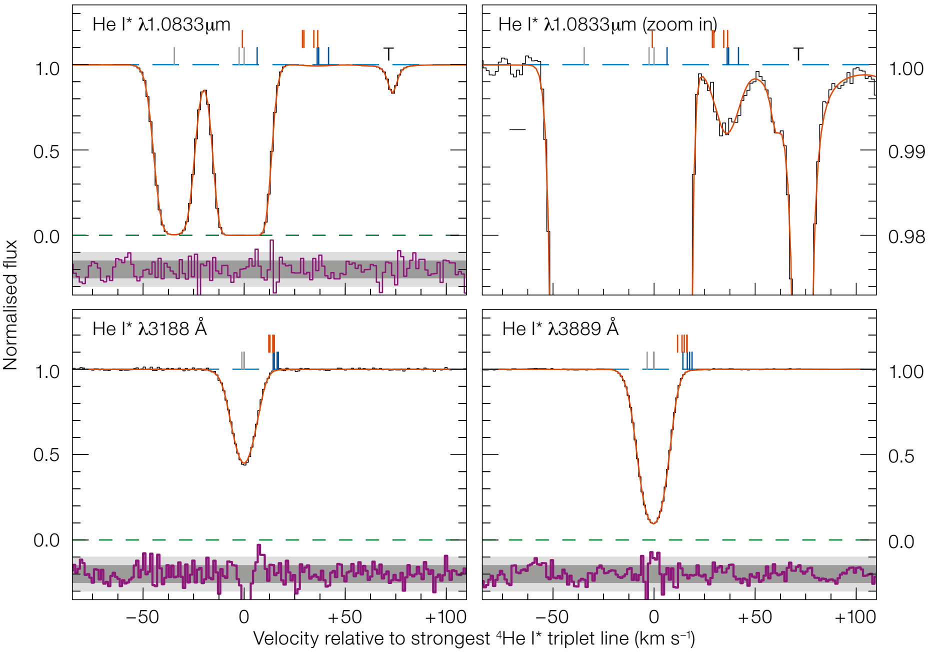


Figure 1. He I* absorption lines towards θ^2 A Ori. The top row shows the CRIRES⁺ observations and the bottom row archival data from the Ultraviolet and Visual Echelle Spectrograph (UVES). The ^{3}He I* lines are identified with the red and blue tick marks and are observed only in the CRIRES⁺ data. The grey tick marks indicate the positions of the ^{4}He I* lines and the 'T' marks a telluric line.

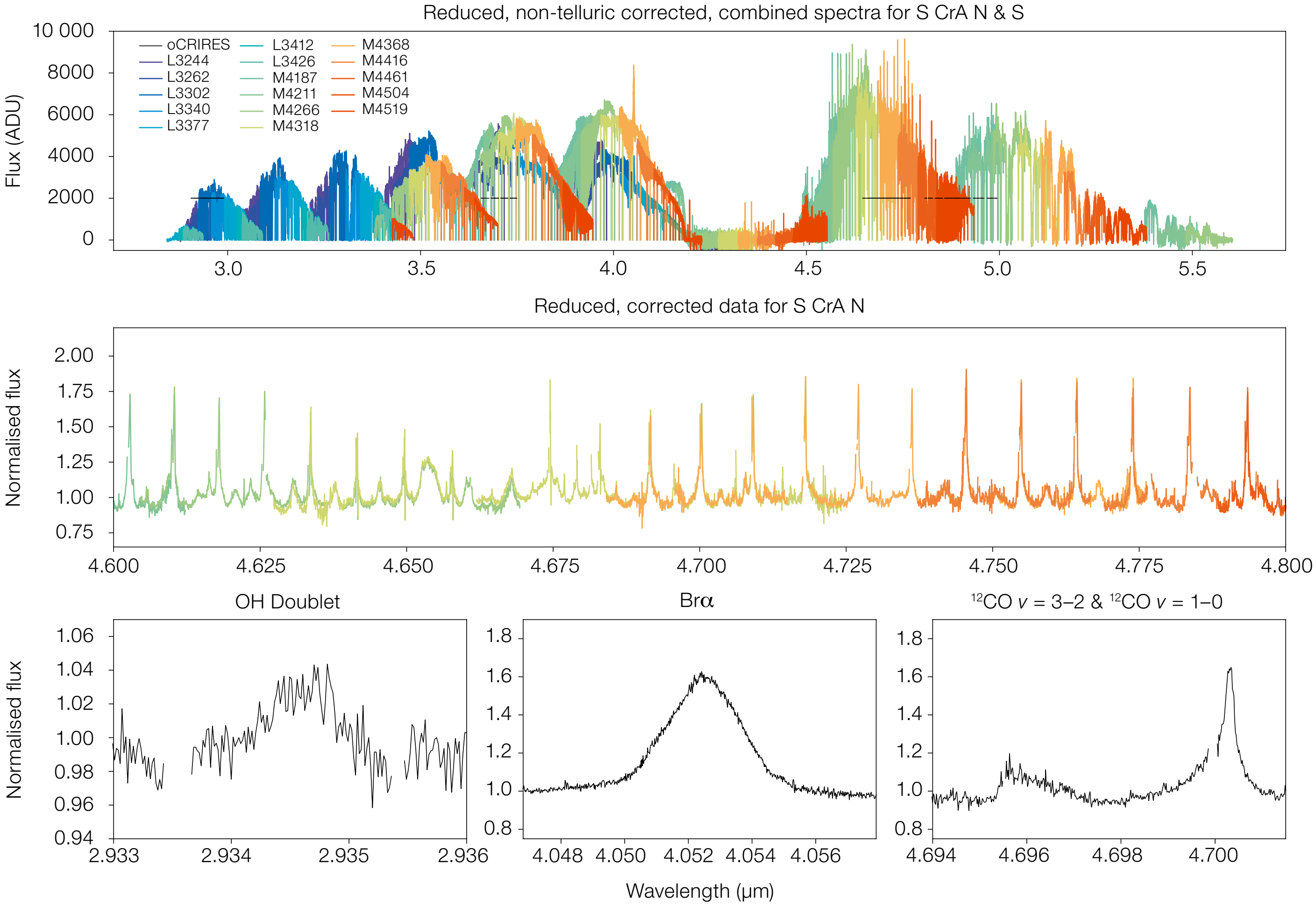


Figure 2. Top: The CRIRES^{+} pipeline reduced spectra for S CrA in all the *L*- and *M*-band settings. CRIRES data taken before the instrument upgrade as part of the ESO Large Programme 179.C-0151 are shown in black. Middle: The reduced and telluric-corrected spectra for S CrA N in a region rich with CO lines. Bottom: Examples of the spectral features seen in the data of S CrA N after combining any overlapping orders.

interactions between Paranal astronomers and Garching observers in regard to instrument operations.

Archive and data processing

All raw data are publicly available through the ESO science archive. The CRIRES^{+} SV webpage has been updated with direct links to the raw data in the archive. The preliminary version of the CRIRES^{+} data reduction pipeline was made available to the PIs through the notification notes they received shortly after the observations were obtained. In the meantime the CRIRES^{+} pipeline was released with the start of operations at the beginning of October 2021 and the link is provided through the CRIRES^{+} SV webpage as well.

First science results

Several PIs of successful CRIRES^{+} SV programmes very kindly shared their first results for presentation in this article. In some cases, manuscripts have already been submitted for publication.

Primordial ^{3}He

A brief period of nucleosynthesis, a few minutes after the Big Bang, created five nuclides in abundance. The relative abundance of these primordial nuclides provides our earliest probe of fundamental physics and cosmology. Historically, the most challenging of these nuclides to measure has been Helium-3 (^{3}He) and it has so far only been detected in the Milky Way. CRIRES^{+} was used to secure the first measurement of the helium isotope ratio (^{3}He/^{4}He) beyond the Local Interstellar Cloud. This is based on the observation of a meta-stable helium absorption seen against a bright star in the Orion Nebula (θ^{2} A Ori). This measurement requires high spectral resolution data with an extremely high signal-to-noise ratio (S/N). A precise value of ^{3}He/^{4}He = $(1.77 \pm 0.13) \times 10^{-4}$ was determined, which is just ~ 40 per cent above the primordial relative abundance of these isotopes, assuming the Standard Model of particle physics and cosmology, of ^{3}He/^{4}He$_{p}$ = $(1.257 \pm 0.017) \times 10^{-4}$. This novel measurement technique offers a new opportunity to study the physics of the early Universe, and the potential to detect ^{3}He in a more primitive environment beyond the Milky Way.

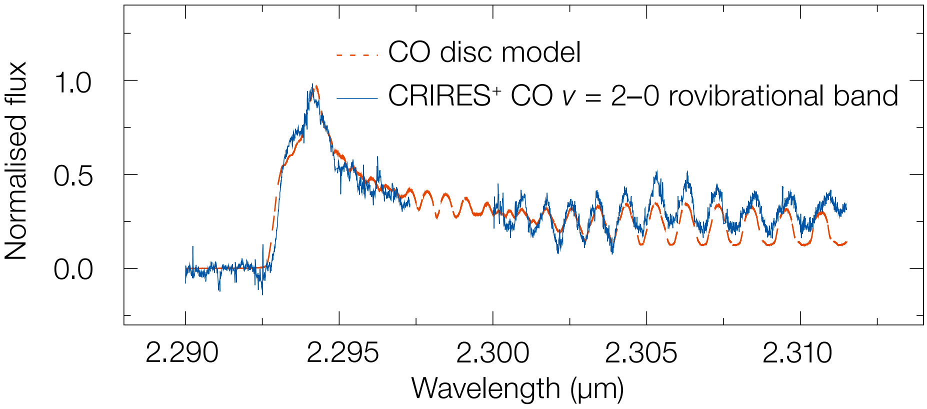


Figure 3. CRIRES$^+$ spectrum of the first CO overtone emission of the Herbig Ae star HD 36917 (blue spectrum). The spectrum is continuum subtracted and normalised to the peak of the bandhead. Preliminary results of a CO model are over-plotted as a red dashed line. The CO is modelled as a disc in Keplerian rotation at a temperature T = 3000 K, a CO column density of 3×10^{21} cm^{-2}, intrinsic line width of 0.5 km s^{-1}, and v_{rot} sin(i) ≈ 113 km s^{-1}. The CO emitting disc extends from around 0.3 au to 2 au from the central source.

Protoplanetary disc composition

High spectral resolution *L*- and *M*-band observations offer a unique probe into the kinematics, structure, and composition of the inner 10 astronomical units (au) of protoplanetary discs. A full spectral scan of the binary system S Coronae Australis (S CrA) in the *L* and *M* bands was observed with CRIRES$^+$. These observations tested the new spectral coverage of CRIRES$^+$ on a target that had been observed with CRIRES prior to its upgrade (Pontoppidan, Blake, & Smette, 2011; Pontoppidan et al., 2011; Brown et al., 2013; Banzatti et al., 2017). The full spectral scan provides complete coverage from 2.9 to 5.5 µm and the overlap of orders from different filters gives a unique opportunity to test which settings provide the highest quality data at a given wavelength. Spectral lines from H_2O, OH, HCN, and CO all fall within the coverage, along with several atomic hydrogen lines. This is the first complete high-resolution *L*- and *M*-band spectrum of any protoplanetary disc obtained to date.

CO disc

Most of our knowledge about the physical properties of protoplanetary discs is based on studies of the dusty disc beyond ~1–2 au. Very little is known about the innermost disc. Probing the inner disc is key as it can provide insights into the processes driving evolution and disc dissipation, as well as the initial conditions for planets forming in short orbits. One of the few observational probes of the innermost disc is the overtone emission of CO at 2.3–2.5 µm (for example, GRAVITY Collaboration, 2021). CRIRES$^+$ observations of the CO bandhead in the Herbig Ae/Be star HD 36917 characterise the properties of the gas emitting the CO bandheads. By modelling the spectrum with a CO disc model, physical properties of the CO emitting gas (temperature and CO density) and its kinematics (for example, rotational velocity) can be derived. The intrinsic line widths of the individual J-components are determined, which potentially constrain the angular momentum transport. Important information about the physics of the inner gaseous disc, for which no model is currently available, can be obtained.

Alpha-enhanced star in the Galactic centre

The Nuclear Star Cluster (NSC) lies behind 30 magnitudes of optical extinction at the centre of the Milky Way. This compact

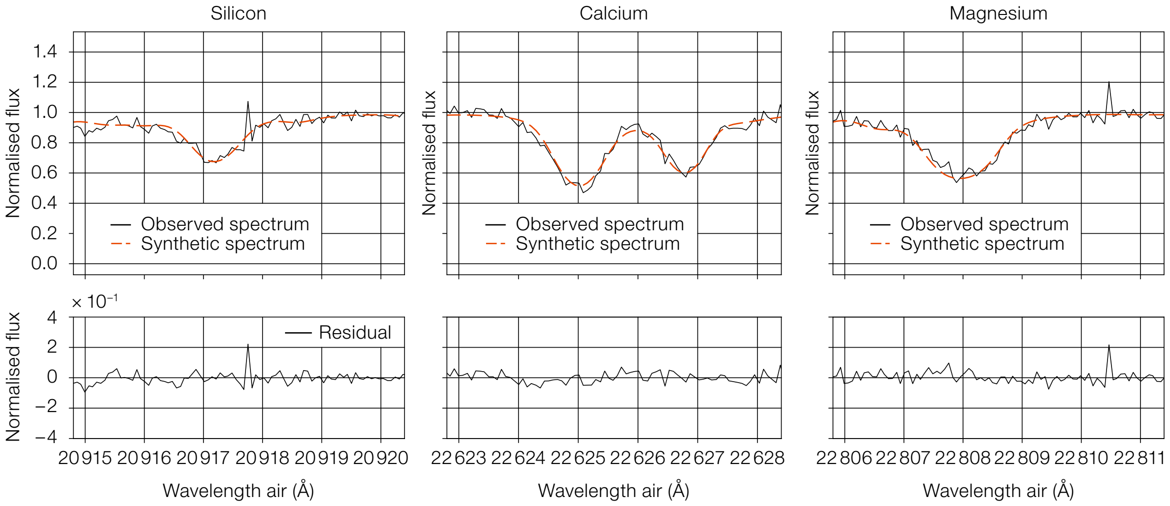


Figure 4. Synthetic spectrum showing the goodness of fit for three α-elements, namely Si, Ca and Mg. The synthetic spectrum was generated using the stellar parameters from Thorsbro et al. (2020).

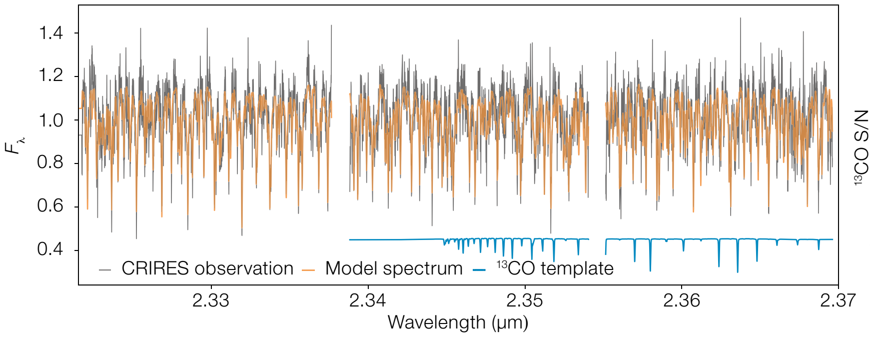


Figure 5. CO lines in a brown dwarf spectrum. Left panel: The CRIRES+ data are shown in black, the model in orange, and the positions of the ^{13}CO lines are indicated in blue (left panel). Right panel: The detection of the ^{13}CO lines.

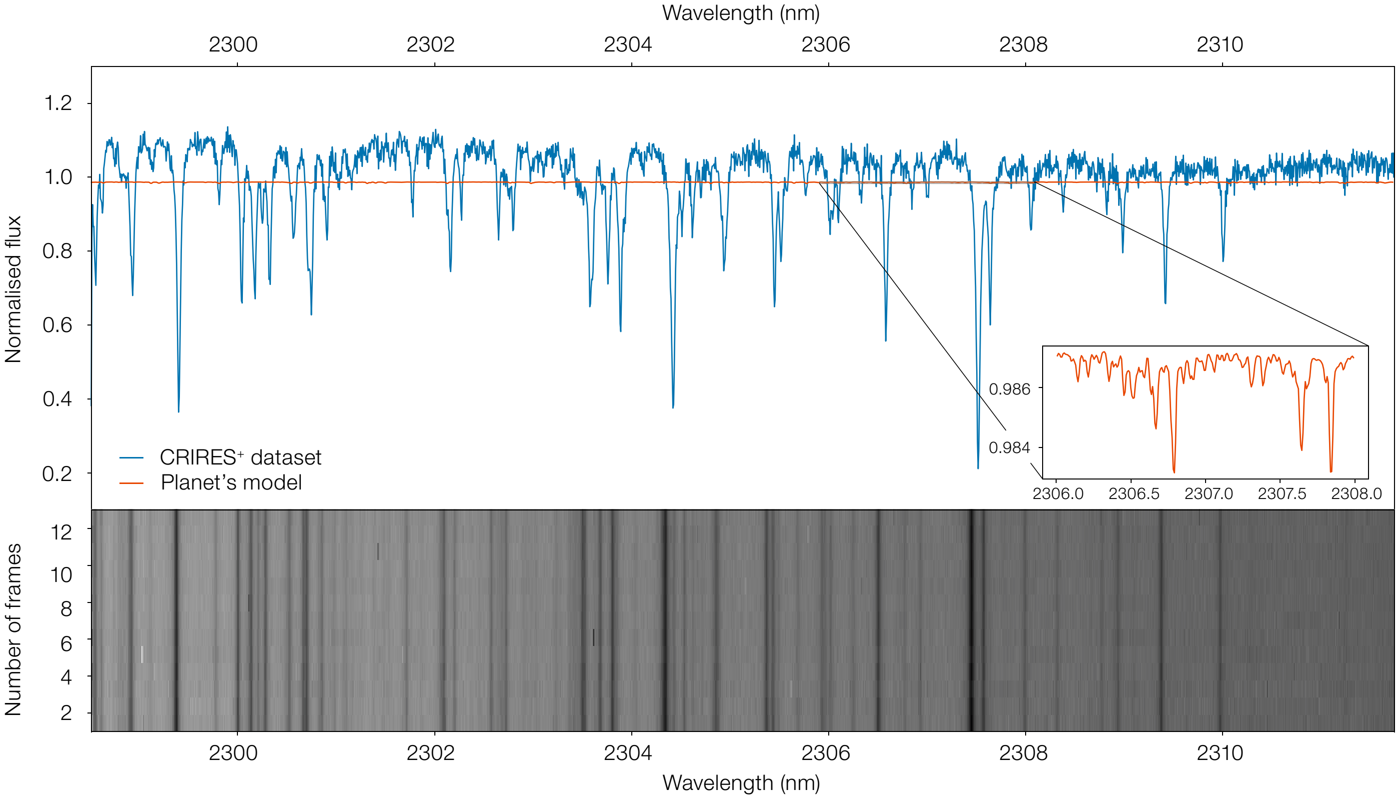


Figure 6. Example of extracted spectrum of Wasp-20b with the CRIRES+ pipeline. Top: Comparison between the raw dataset (blue line) and a synthetic spectrum of Wasp-20b (red line), obtained from a 1D model. Small box: Zoom of a section of the planet's spectrum. The signal of the planet is completely drowned by the telluric absorption, the stellar signal and the instrumental noise, which are still present in the raw dataset and are hundreds of times stronger. Bottom: Consecutive frames of the same spectrum are ordered along the y-axis. The strongest contaminating signals (i.e., telluric absorption and stellar signal) occur always at the same wavelength, resulting in straight black lines.

structure, with an effective radius of about 4 pc, consists of several million stars, appears to be very old (> 10 Gyr), and contains very metal rich stars. The formation history of the NSC is an open question. It could be the surviving core of multiple globular clusters or parts could be formed in situ and/or contain stars that have migrated from the inner Milky Way disc.

A star in the NSC was observed with CRIRES+ in the *K* band using the K2192 setting with a 0.2-arcsecond slit width (R ~ 100 000). The star had previously been observed with the NIRSPEC spectrograph on the KECK II telescope (Thorsbro et al., 2020) with R ~ 23 000. That observation determined stellar parameters of T_{eff} = 3359 ± 150 K, log g = 0.64±0.3, and [Fe/H] = 0.25±0.15. The preliminary reductions of the CRIRES+ observation confirm these parameters. Thorsbro et al. (2020) find a silicon abundance for the star at [Si/Fe] = 0.25 ± 0.15, which is remarkable as [Si/Fe] ~ 0.10 ± 0.15 for local disc stars, suggesting that at least silicon could be enhanced for NSC stars. The CRIRES+ preliminary results indicate [Si/Fe] = 0.20 ± 0.10, [Ca/Fe] = 0.20 ± 0.10, and [Mg/Fe] = 0.15 ± 0.10. This yields an average for α-elements close to 0.20. The CRIRES+ data strengthen the evidence for enhanced α-elements.

Brown dwarf spectrum

CRIRES$^+$ provides a great opportunity to link atmospheric characterisation to the formation history of exoplanets and brown dwarfs. The high spectral resolving power of CRIRES$^+$ facilitates the search for isotopologue features in emission spectra of planetary-mass objects. A *K*-band spectrum of the low-mass, young brown dwarf 2MASS J03552337+1133437 was obtained with a half-hour observation at a spectral resolution of $R \sim 80\,000$. The spectrum is shown as a black line in Figure 5 (left panel). The isotopologue ^{13}CO is detected at S/N ~ 6.5 (right panel) through the cross-correlation between the observation and the ^{13}CO template. A retrieval analysis was performed to generate the best-fit model spectrum (orange line) and constrain atmospheric properties of the L dwarf, in particular the carbon-to-oxygen abundance ratio, and the C and O isotope ratio in the atmosphere, which are potential probes of formation pathways of planets and brown dwarfs (Zhang et al., 2021; Zhang, Snellen & Mollière, 2021). In the future, analyses such as presented here can be conducted on a wide range of planetary-mass objects to unveil planet formation history.

Exoplanet spectra

The transit of WASP-20b, a hot Saturn planet, was observed for five hours on 16 September 2021. The planet has an equilibrium temperature close to 1400 K and orbits its host star in less than 5 days. The calibration and extraction of spectra were performed with the new CRIRES$^+$ pipeline, but at this point of the analysis the planetary spectrum is still completely hidden by the stellar signal and the telluric lines. A direct comparison is given in the top panel of Figure 6, where one of the extracted spectra (blue line) is over-plotted onto a synthetic spectrum of Wasp-20b (red line), obtained from a 1D model. The amplitude of the synthetic spectrum is many times smaller than the observed spectrum, which is dominated by telluric features.

Contrary to the planet's signal, which undergoes larger Doppler shifts during the night, the contaminators are stationary or quasi-stationary, which means that they always occur at the same wavelength. Figure 6 (bottom panel) displays the spectra from different observations ordered by time along the y-axis. The stable telluric and stellar features result in straight black lines. A principal component analysis is used to separate the velocity shifts and to disentangle the spectrum of the planet from all the other signals so as to detect molecular features in its atmosphere.

A second observation concerned the exoplanet system MASCARA-1b (Talens et al., 2017). It was observed with CRIRES$^+$ during a transit from phase ≈ 0.33 to 0.42, with 107 exposures (where phase = 0 and phase = 0.5 correspond to central transit and secondary eclipse, respectively). The goal was to detect C+O-bearing molecular species using Doppler-resolved cross-correlation spectroscopy (Snellen et al., 2010). This works by first removing the stellar and telluric lines from the data, and then cross-correlating the 'residual' spectra with spectral templates containing the signal of interest, in this example H_2O (resulting in cross-correlation functions as a function of v_{sys}). The cross-correlation signals are then summed as a function of time, assuming a range of values for the planetary velocity amplitude K_p.

The CRIRES$^+$ pipeline was used to extract 'raw' spectra for each spectral order as a function of time. These spectra are shown in the upper plot of Figure 7, before performing some standard pre-processing (including outlier rejection and blaze correction — middle panel of Figure 7). The SysRem algorithm (Tamuz, Mazeh & Zucker, 2005) was employed to remove the stellar and telluric lines (bottom panel of Figure 7) and to generate a planetary template spectrum assuming only H_2O in the atmosphere. The spectra were then cross-correlated with the template spectrum (over a velocity range of –150 to 150 km s^{-1}), before being summed over the planetary velocity for a range of K_p (from –300 to 300 km s^{-1}). The detection significance was then determined by dividing through the K_p v_{sys} map by the noise (after excluding regions around the peak and near $K_p = 0$). We found a peak detection of > 4σ near the expected K_p

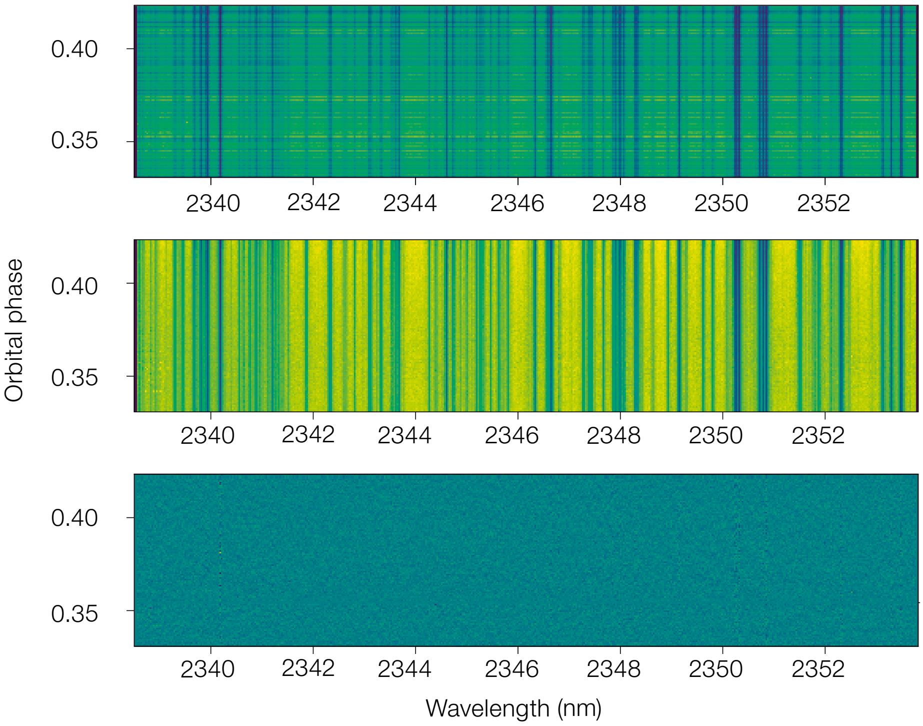
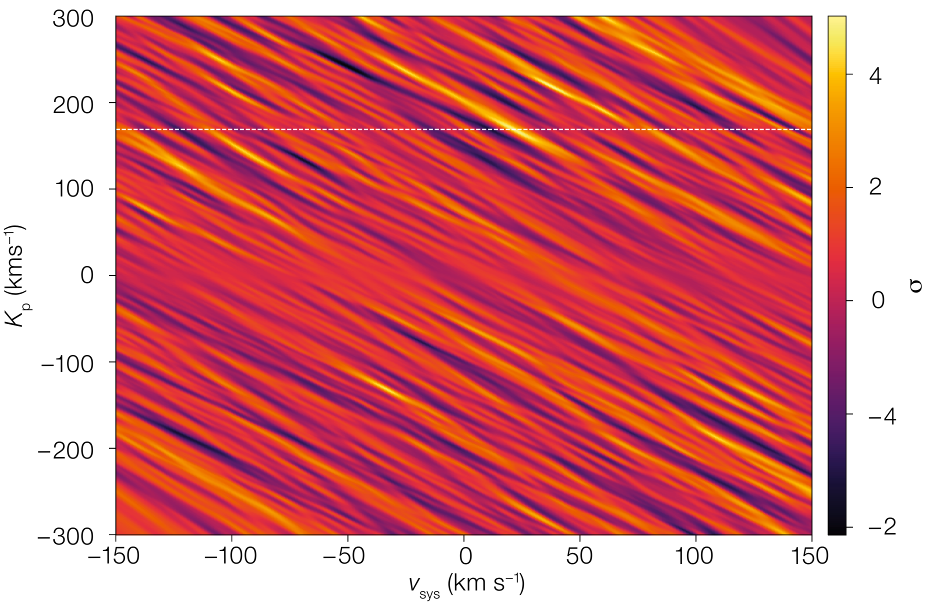


Figure 7. Top panel: Raw spectra for a single CRIRES$^+$ order as a function of time/orbital phase. Middle panel: Spectra after initial pre-processing including blaze correction. Bottom panel: Final 'residual' spectra after removing the telluric features using SysRem.

Figure 8. K_p–v_{sys} map of the of the summed cross-correlation signal for a H_2O template. The plot shows a tentative detection of water near the expected K_p and v_{sys} at > 4σ; however, refinements of the model templates are continuing in order to confirm the signal.



and v_{sys} indicating the probable detection of water. Further work is required to confirm the signal, as well as to search for other molecular species. See Gibson et al. (2020, 2022) for further details of the data processing and model templates.

Radial velocity of an exoplanet host star

Hot Jupiters are gaseous giant planets, orbiting their host stars in tight orbits at typical distances of a few percent of an au. The formation and evolution processes of hot Jupiters remain under debate. It is thought that these planets form at large orbital distances beyond the snowline, much like the Solar System giants, and subsequently undergo inward migration via disc–planet interaction or, alternatively, dynamical planet–planet scattering or star–planet interactions via the Kozai–Lidov mechanism (Kozai, 1962; Lidov, 1962). These mechanisms produce systems with distinct distributions of the alignment of stellar rotational axis and planetary orbit normal.

HIP 65Ab is an extreme hot Jupiter. With a mass of 3.2 M_{Jup}, it orbits its K4-type host star in an exceptionally short 0.98-day orbit, yielding a grazing transit geometry, potentially indicative of an oblique orbit (Nielsen et al., 2020). While in transiting systems the planetary radius can be determined via photometric transit light curves, radial velocity (RV) measurements of the stellar reflex motion remain indispensable for determining the planetary mass; by means of the Rossiter–McLaughlin effect (Rossiter, 1924; McLaughlin, 1924) the orbit obliquity can also be measured.

A spectral transit time series of HIP 65Ab was obtained to measure the stellar reflex motion and potentially the Rossiter–McLaughlin effect in HIP 65A in the *K* band. The observations cover a complete planetary transit, lasting only 45 minutes, and take advantage of the absorption gas-cell installed in CRIRES$^+$ serving as a reference standard for RV measurements. RV measurements were obtained using the VIPER pipeline (Zechmeister, Köhler & Charmathi, 2021). The observations suffered from adverse weather conditions (thick clouds) which caused strong interference by telluric lines and prevented the requested adaptive optics operations, resulting in a severely

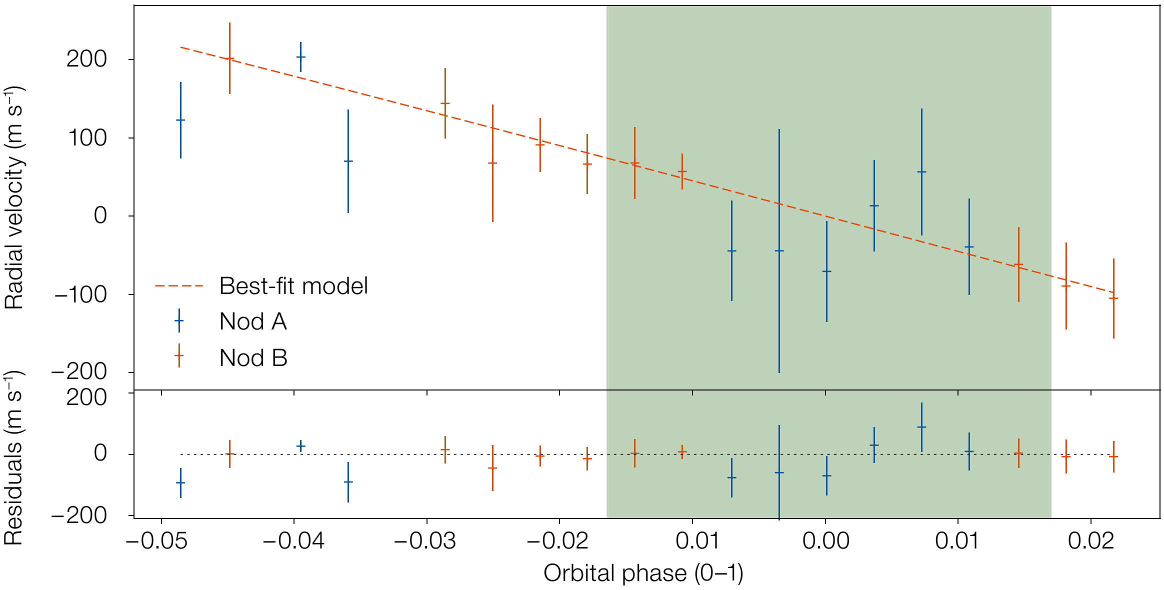


Figure 9. Radial velocity change of the host star HIP 65A during a planetary transit. The green area indicates first and fourth contact.

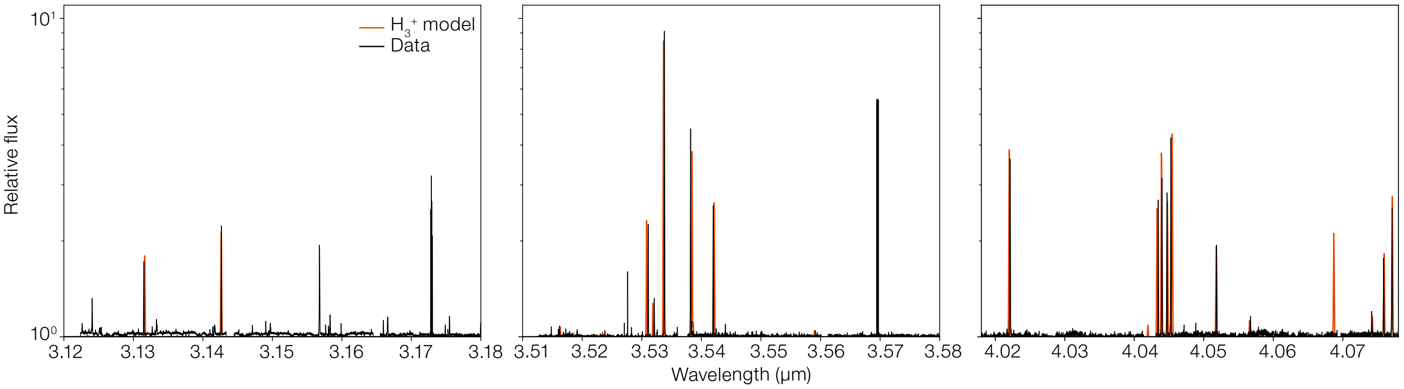


Figure 10. Selected wavelength regions of CRIRES$^+$ data from Jupiter's auroral region (black). A large number of emission lines from H_3^+ are clearly visible. A model based on the linelist from Neale, Miller & Tennyson (1996) is shown for comparison (red).

diminished S/N of the spectra. While this prevents a meaningful analysis of the Rossiter–McLaughlin effect, the result clearly shows the stellar reflex motion of HIP 65A (Figure 9) corresponding to a RV semi-amplitude of 715 ± 90 ms^{-1} determined with CRIRES$^+$ alone.

Neptune

Neptune was observed on 19 September 2021 in selected spectral regions between 1.48 μm and 5.15 μm. The goal was to assess Neptune's atmospheric composition and to better constrain emission from carbon monoxide (CO) and the trihydrogen cation (H_3^+) in the upper atmosphere and absorption from methane near the tropopause. The adaptive optics system was unable to lock on to the extended disc of Neptune, resulting in seeing between 0.28 and 0.77 arcseconds. Thick clouds also moved in during the observations, reducing the sky transparency and data quality.

The CRIRES$^+$ spectra resolve Neptune's ~ 2.3-arcsecond-diameter disc. In the *H* band, (1.582 μm central wavelength), brightness variations across the disc are seen with a distinctly greater radiance along the northern edge of the planet. Spatial variation across the disc is particularly evident between 1.52 μm and 1.64 μm where methane absorption is weakest. With increasing wavelength, the disc grows fainter. This behaviour suggests that there is a significant difference in the altitude of the highest clouds between the south and north. This is likely due to scattering from a discrete cloud near the tropopause in Neptune's northern hemisphere. In the *K* band, scattering from the bright northern regions extends to wavelengths < 2.15 μm, but no signal is evident from most of the disc. This discrete reflectance declines in intensity with increasing wavelength, with no signal evident between 2.15 μm and 2.48 μm. This is consistent with sunlight scattered by the high-altitude clouds becoming increasingly attenuated by molecular hydrogen collisional-induced absorption (CIA). Some signal is observed again between 2.48 μm and 2.53 μm, where H_2-CIA is reduced. Careful analysis of the reflectance *K* band and *H* bands together will be used to potentially constrain the methane abundance near Neptune's tropopause (Roman, Banfield & Gierasch, 2018).

Only a very faint signal is observed in the *L* band at the shortest wavelengths (≤ 2.9 μm). No obvious H_3^+ lines are detected. There appears to be a faint, indistinct planetary signal across much of the raw spectrum in the *M* band. The radiances appear rather flat and featureless, which may be the result of a combination of thermal emission and scattering from Neptune's upper troposphere. There is no obvious evidence of the 4.7 μm CO fluorescence feature previously detected in AKARI satellite spectra (Fletcher et al., 2010). If the CO fluorescence is indeed now absent, it may be indicative of temporal changes in the CO abundance or solar activity. However, the telluric absorption and emission are very prominent at these wavelengths, and further work is needed to improve the reduction and calibration for analysis.

Jupiter

Auroral H_3^+ line emission was first observed in 1989 in Jupiter and since then detected in Saturn and Uranus. It is a prominent indicator for auroral geometry and a sensitive probe of the planetary atmosphere and magnetosphere, and it plays an important role in the dynamics, heating, cooling and chemistry of the Solar System planets. The data will provide a benchmark for future research in Solar System planetary atmospheres and for the search for H_3^+ in exoplanets. H_3^+ spectroscopy provides new opportunities for characterising exoplanet atmospheres from ground-based observatories and in non-transiting planets.

Hydrogen Brackett and Pfund series in supergiant stars

Two rare, massive post-red-supergiants, IRAS 17163-3907 and IRC+10420 (Koumpia et al., 2020; Oudmaijer & de Wit, 2013), were observed in the *M* band at four different settings (M4416, M4368, M4318, M4266). All settings combined provide a very good wavelength coverage between 3.4 and 5.3 μm. These observations make it possible to probe powerful hydrogen diagnostic lines of the Bracket and Pfund series of hydrogen, as well as the CO (*v* = 1-0) rovibrational transitions (see Figure 11). The emission lines probe material originating in a region at typically thousands of kelvin, while absorption occurs in cooler regions, at several hundred kelvin. Both are present in the spectrum of IRC+10420, which in addition shows P-Cygni signatures in its CO emitting gas, indicative of an expansion. This is the first time IRAS 17163-390 has been observed spectroscopically in the *M* band, which besides its extreme spectral similarities to IRC+10420 at shorter wavelengths, appears to show generally stronger hydrogen recombination lines, but weaker CO absorption. The very high spectral resolution, of order 80 000, will permit the authors to derive the velocity of the outflowing material, and also to determine the temperatures and densities of the regions where mass-loss takes place using LTE and non-LTE radiative transfer modelling. The wind/outflow velocity distribution traced with the warm CO emission will constrain the outflow velocity very close to the yellow hypergiant and therefore the most recent mass-loss rates and kinematic timescales.

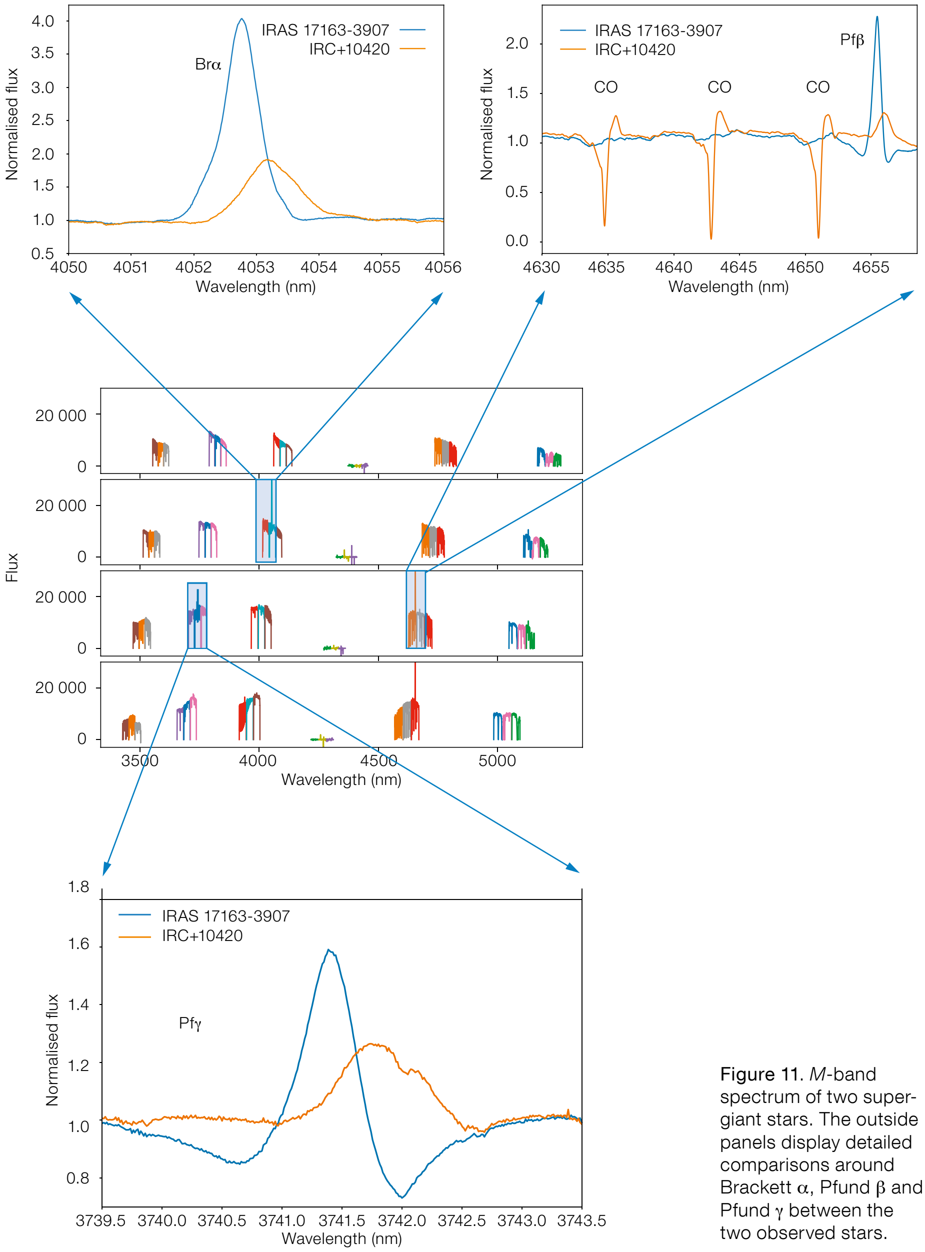


Figure 11. *M*-band spectrum of two supergiant stars. The outside panels display detailed comparisons around Brackett α, Pfund β and Pfund γ between the two observed stars.

Conclusions

CRIRES$^+$ SV can be considered a success. The scientific results presented are an initial sample of the science CRIRES$^+$ will address in the future. It will be an excellent tool with which to examine and characterise exoplanet atmospheres, stellar discs and stars. The instrument is now in full operation.

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Links

[1] Call for CRIRES$^+$ SV proposals: https://www.eso.org/sci/publications/announcements/sciann17414.html
[2] CRIRES$^+$ SV: http://www.eso.org/sci/activities/vltsv/crirespIussv.html

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The ALMA Science Archive Reaches a Major Milestone

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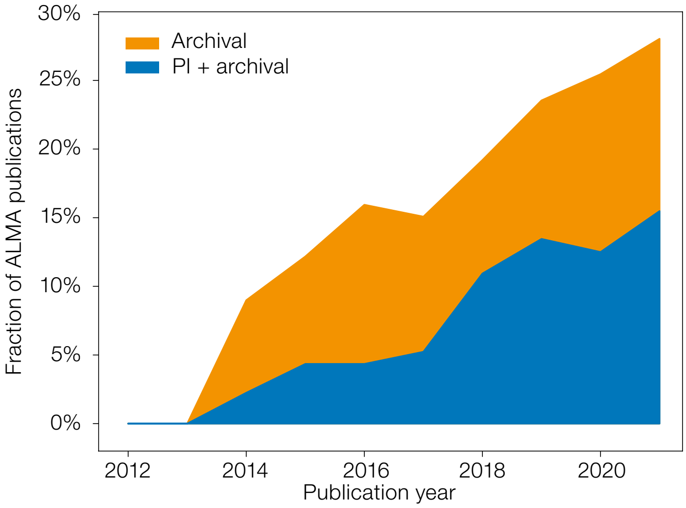


Figure 1. The fraction of ALMA publications with archival context (excluding Science Verification data) is shown as a function of the publication year. The fraction of publications making use of ALMA archival data together with proprietary PI data is shown in blue. Stacked on top is the fraction of publications making exclusive use of ALMA archival data, shown in yellow. Overall, the fraction of ALMA publications with archival context has been continually rising, reaching 28% in 2021.

Science archives are cornerstones of modern astronomical facilities. In this paper we describe the version 1.0 milestone of the Atacama Large Millimeter/submillimeter Array Science Archive. This version features a comprehensive query interface with rich metadata and visualisation of the spatial and spectral locations of the observations, a complete set of virtual observatory services for programmatic access, text-based similarity search, display and query for types of astronomical objects in SIMBAD and NED, browser-based remote visualisation, interactive previews with tentative line identification and extensive documentation including video and Jupyter Notebook tutorials. The development is regularly evaluated by means of user surveys and is entirely focused on providing the best possible user experience with the goal of helping to maximise the scientific productivity of the observatory.

The big picture

Science archives form an integral part of modern observatories. They contribute substantially to the success of an observatory by helping to maximise the scientific output and come with a very favourable cost-benefit ratio; they enable independent scientific research using existing data, and particularly facilitate modern multi-wavelength astronomy as well as studies of time-variable sources. In addition, science archives are the guardians of the fundamental requirement of science to allow for the reproducibility of scientific results, they give access to data for scientists in developing countries (Peek et al., 2019), and they are also used for the proposal preparation process, citizen science, and outreach.

In 2021 28% of all Atacama Large Millimeter/submillimeter Array (ALMA) publications made use of archival data of Principal Investigator (PI) observations, and that fraction is continuously growing (Figure 1). Once high-quality data are generated and processed at an observatory, the main effort in building a valuable and effective science archive is related to data curation, i.e., the extraction, correction, homogenisation, computation and explanation of metadata, as well as the presentation to the users in the form of the reliable search, download, interoperability and analysis functionalities.

The work done on the ALMA Science Archive (ASA) is strictly prioritised according to the overall positive impact anticipated for the users, following ALMA's principle to be easily accessible to all astronomers, very much including those outside the millimetre/submillimetre community. We closely track the wishes of the users both quantitatively (Figure 2) and qualitatively, and have recently finished analysing and discussing, one comment at a time, all 43 pages of comments from the last ALMA user survey dedicated to the ASA. That survey explicitly asked for “wild” and “out-of-the-box”

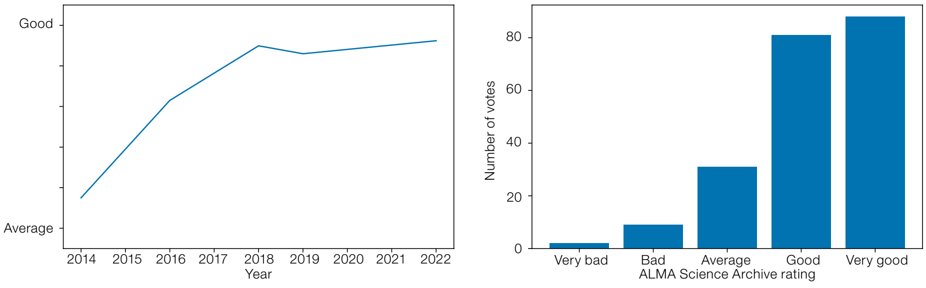


Figure 2. In regular user surveys users are asked to provide comments, but also to rate various aspects of ALMA. While the overall usability of the ALMA Science Archive, rated as “very bad”, “bad”, “average”, “good” or “very good”, has progressed significantly over the years, there is still room for improvement (left). The right-hand plot shows the rating distribution for the ASA query interface as of 2019.

ideas. We also use such ideas, and others, in DesignThinking (DT) workshops, which are a valuable and modern tool for our entirely user-experience-centred design approach.

One of the surprising general outcomes of those DT workshops was how important it was for users to be able to perform tasks quickly, over just being able to perform the tasks at all or even over being able to perform them easily. We call this need “fastronomy”. We believe that it will gain more importance in the next decade within astronomy and we make it a pillar of our own design strategy.

Allowing users to perform their tasks rapidly is even more challenging as the astronomical data taken grow exponentially with time (Stoehr, 2019). Therefore, a continued effort has to be made to keep up the pace by ensuring that all tools scale accordingly, and in particular to solve what is the real Big Data problem: reducing the fraction of data that astronomers have to actually look at. This effort will inevitably come with increased responsibility on the part of the observatories and will probably have to rely substantially on artificial intelligence techniques in the long-term future (Stoehr, 2019).

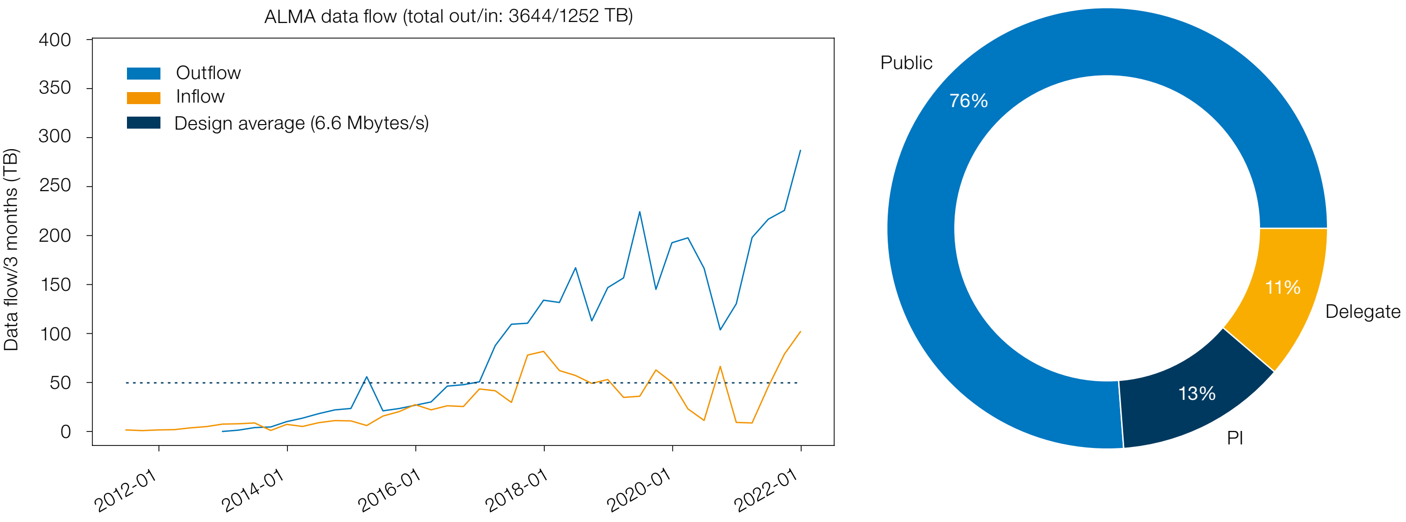


Figure 3. The left panel shows the data inflow (observations and data products) and data outflow (data download) per quarter. The dashed line indicates ALMA’s current design average data rate. The right panel shows which fraction of the data were downloaded when they were public compared to the fractions of the downloads made during the proprietary period by the PI as well as by a person to whom the PI has delegated access to the data.

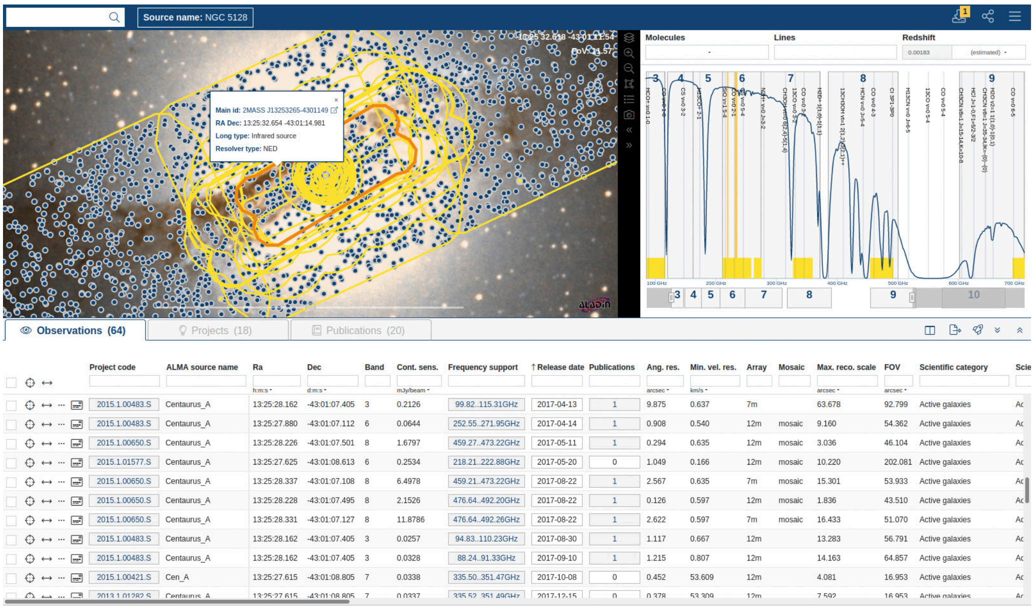
Currently the ASA query interface is accessed from 6000 distinct IP addresses each quarter. The ASA holds data from about 53 000 science observations distributed over 49 million files, totalling 1.3 PB in size. About 50 to 100 TB of data are served to the users every month with a healthy ratio of data downloaded by users versus data ingested from the telescope; this ratio is currently about a factor of three (Figure 3, left). The vast majority of the data are already out of their 12-month proprietary period when they are downloaded (Figure 3, right). So far, ALMA data have been used in over 2700 publications.

In the remainder of this paper, we describe our recent work which led to the milestone of the ASA we call version 1.0. Please refer to some of our previous work for astronomical archives in general (Stoehr, 2019), for the ALMA Science Archive (Stoehr et al., 2017) or for the principles of user interface design (Stoehr, 2017).

Features

The ASA query interface[1] offers search-as-you-type and instantaneous results from the entire multidimensional metadata cube, i.e., unscoped access to all 49 columns. That metadata cube contains extensive information about the observations, but also information about the corresponding projects and about the ALMA publications, for example authors or abstracts. The latter is possible because the library and information services at ESO, the National Radio Astronomy Observatory (NRAO) and the National Astronomical Observatory of Japan (NAOJ) carefully track each publication and record the data that have been used (for example, Grothkopf, Meakins & Bordelon, 2018), which authors are required by policy to specify in the publication’s acknowledgment section. Queries can combine search constraints on any of those three metadata categories. We offer users the possibility of uploading a list of targets or coordinates, showing the number of times a particular dataset was used in a publication, allowing modification of the layout of the interface to fit the users’ needs, enabling column reordering as well as sorting the entire data holdings and providing a bookmark to the current search and settings that users can save or share with colleagues. In all our designs the goal is always to show only the most relevant information while at the same time allowing experts to drill down to the metadata level they need.

Substantial effort has been put into combining the values of the raw data into one row per observed source, and allowing for searches on highly relevant scientific properties, i.e., real physical parameters of the observations, such as the estimated continuum and line sensitivity



Main id: 2MASS J13253265-4301149
RA Dec: 13:25:32.654 -43:01:14.981
Long type: Infrared source
Resolver type: NED

Project code	ALMA source name	Ra (h:m:s)	Dec (d:m:s)	Band	Cont. sens. (mJy/beam)	Frequency support	↑Release date	Publications	Ang. res. (arcsec)	Min. vel. res. (km/s)	Array	Mosaic	Max. reco. scale (arcsec)	FOV (arcsec)	Scientific category
2015.1.00483.S	Centaurus_A	13:25:28.162	-43:01:07.405	3	0.2126	99.82..115.31GHz	2017-04-13	1	9.875	0.637	7m		63.678	92.799	Active galaxies
2015.1.00483.S	Centaurus_A	13:25:27.880	-43:01:07.112	6	0.0644	252.55..271.95GHz	2017-04-14	1	0.908	0.540	12m	mosaic	9.160	54.362	Active galaxies
2015.1.00650.S	Centaurus_A	13:25:28.226	-43:01:07.501	8	1.6797	459.27..473.22GHz	2017-05-11	1	0.294	0.635	12m	mosaic	3.036	46.104	Active galaxies
2015.1.01577.S	Centaurus_A	13:25:27.625	-43:01:08.613	6	0.2534	218.21..222.88GHz	2017-05-20	0	1.049	0.166	12m	mosaic	10.220	202.081	Active galaxies
2015.1.00650.S	Centaurus_A	13:25:28.337	-43:01:07.108	8	6.4978	459.21..473.22GHz	2017-08-22	1	2.567	0.635	7m	mosaic	15.301	53.933	Active galaxies
2015.1.00650.S	Centaurus_A	13:25:28.228	-43:01:07.495	8	2.1526	476.64..492.20GHz	2017-08-22	1	0.126	0.597	12m	mosaic	1.836	43.510	Active galaxies
2015.1.00650.S	Centaurus_A	13:25:28.331	-43:01:07.127	8	11.8786	476.64..492.26GHz	2017-08-22	1	2.622	0.597	7m	mosaic	16.433	51.070	Active galaxies
2015.1.00483.S	Centaurus_A	13:25:28.162	-43:01:07.405	3	0.0257	94.83..110.23GHz	2017-08-30	1	1.117	0.667	12m		13.283	56.791	Active galaxies
2015.1.00483.S	Centaurus_A	13:25:28.162	-43:01:07.405	3	0.0328	88.24..91.33GHz	2017-09-10	1	1.215	0.807	12m		14.163	64.857	Active galaxies
2015.1.00421.S	Cen_A	13:25:27.615	-43:01:08.805	7	0.0338	335.50..351.47GHz	2017-10-08	0	0.452	53.609	12m		4.081	16.953	Active galaxies
2013.1.01282.S	Centaurus_A	13:25:27.615	-43:01:08.805	7	0.0337	335.52..351.49GHz	2017-12-15	0	0.378	53.309	12m		7.592	16.953	Active galaxies

Figure 4. The ASA query interface features search-as-you-type, a sky view, a spectral coverage viewer, a result table, and much more. All objects from SIMBAD and NED falling into any of the regions of the ALMA observations are displayed and even the object-types can be queried for.

(using the ALMA sensitivity calculator with parameters of the observed raw data), the integration time, the frequency resolution, or the expected spatial resolution and maximum recoverable spatial scale. To achieve homogeneity and consistency of the metadata, at each major software release all metadata are fully recomputed from the original raw data.

In addition to AladinLite[2], the query interface makes extensive use of modern web technologies, in particular the Angular web[3] framework as well as ElasticSearch[4]. We have implemented virtual scrolling on top of those technologies to offer a natural user experience and full scalability. Help is provided throughout the interface by means of tooltips, video tutorials[5] and the extensive Science Archive Manual[6].

Text similarity search

Users are often interested in projects or publications similar to the one they are looking at, but discovering those used not to be straightforward. To this end, the ASA has now implemented a state-of-the-art text-similarity-based recommender system (suggestion and proof-of-concept: Alejandro Barrientos) on all projects and publications. The "you might also be interested in" lists can be placed into a new browser tab allowing the users to add further search constraints.

Astronomical context

Many ALMA observations are not just 2D images but are full 3D datacubes, which are challenging to present on the interface. We have developed a spectral coverage viewer to show the exact extent of the frequency coverage of each observation, and even the extent for entire projects and/or publications. From the values PIs enter into the ALMA Observing Tool (OT) when preparing their proposals, we estimate the median redshift of the displayed results and then show the most relevant velocity-shifted spectral line transitions with the possibility of seeing more transitions by zooming-in further, or limiting the drawn lines to predefined categories (for example, Hot Cores) or species.

The spatial location and extent of all ALMA observations are displayed in the Aladin Sky view. In addition, observations can be directly selected from that view. The result table automatically scrolls to the corresponding position. Also through the sky view we provide additional astronomical context; we have implemented a slider that allows users to fade smoothly through the entire frequency spectrum where selected background data from sources such as the Digitized Sky Survey, the Spectral and Photometric Imaging REceiver (SPIRE) on the Herschel Space Observatory or the Atacama Cosmology Telescope/Planck maps are downloaded from the Strasbourg astronomical Data Center (CDS7) in HiPS format and displayed on the fly. Users can also select additional backgrounds from the layers icon.

At high zoom levels, the ASA sky view also displays all SIMBAD[8] and NED[9] sources that fall into any of the regions observed by ALMA. Tooltips show information about the sources and provide links to NED and SIMBAD for further details.

Object type search

The ability to query by object type (for example, "Active Galaxy Nucleus" or "Galaxy pair") rather than a specific target, together with any other search constraint, is challenging to implement but is motivated by an important use case, demonstrated by user feedback. A new feature enables this type of object-type search now that the metadata from SIMBAD and NED have been retrieved and fully integrated into the ALMA database (Figure 4).

By default all regions are returned where a source of that particular type is in the field of view, regardless of whether or not ALMA may have actually detected it. In addition to that default setting, we have tried to identify the "best match" object

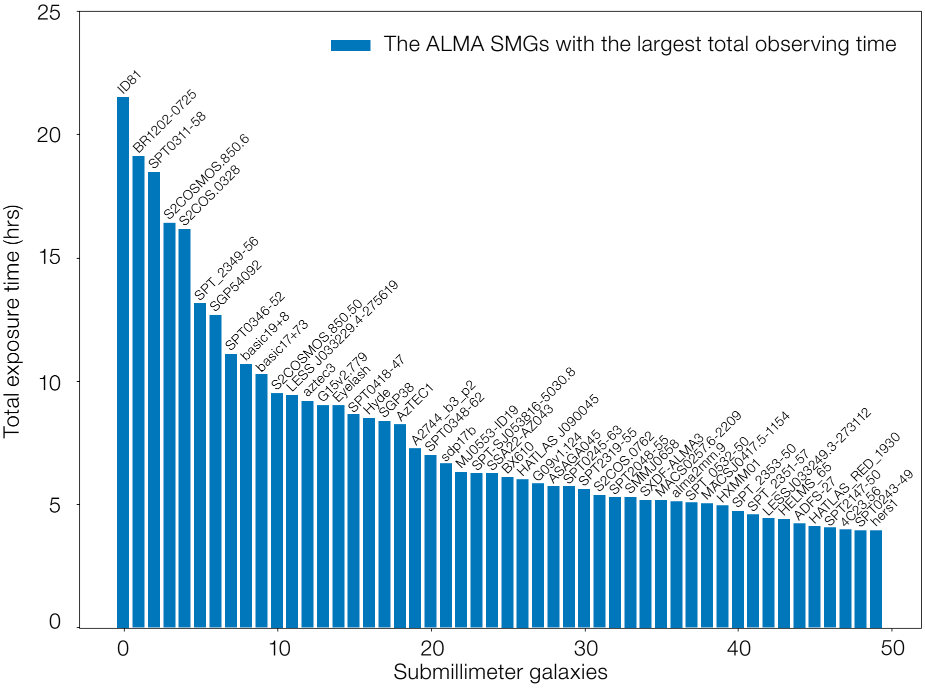


Figure 5. The ASA can be accessed via a web interface but also completely programmatically, i.e., through VO protocols and standards. We provide Jupyter Notebooks which show, for example, that with a few lines of Python this plot can be created, identifying submillimeter galaxies (SMGs) that have been observed most with ALMA, adding up the observing time across all observing cycles.

out of the many SIMBAD or NED objects falling into each of the ALMA observation footprints by taking into account the observed emission strength, source name and position on the sky given by the PI. Users can thus select object types and restrict the search to those that have likely been the main targets of the observations. In the sky view display, these best matching objects are marked in yellow.

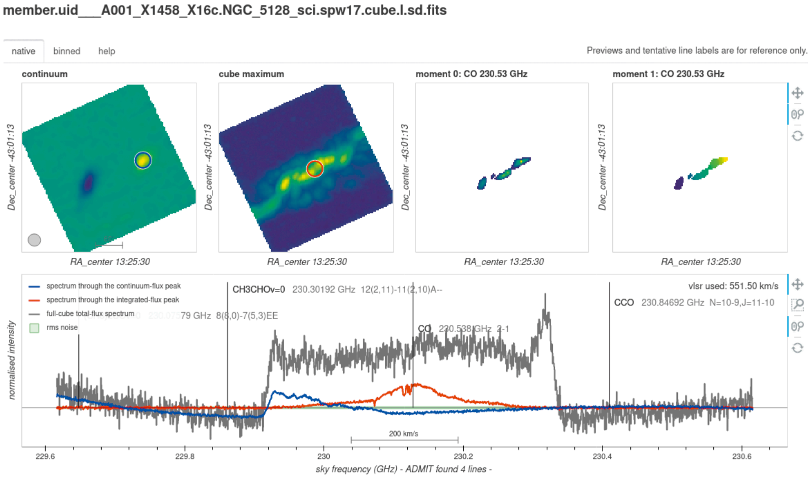
Virtual observatory

The ASA is now fully interoperable through virtual observatory (VO) standards. Using the rocket icon on the query interface, the query results can be broadcast through the VO SAMP protocol to other VO tools like Aladin[10] and Topcat[11]. The results can also be exported directly as VO Tables.

Moreover, the ASA provides a simple image access through the SIAv2 protocol[12], ObsCore[13] access through the TAP protocol[14], data exploration and download through the DataLink protocol[15], and also — our most recent addition — cutouts of FITS cubes and images via the SODA protocol[16]. These standardised interfaces can all be discovered through the registry services of the IVOA[17] and allow users to access the ASA in a fully programmatic way, including for data mining and machine learning, with the tools of their choice. We provide extensive Jupyter Notebook tutorials[18] demonstrating access to the ASA through the VO protocols using Python (Figure 5).

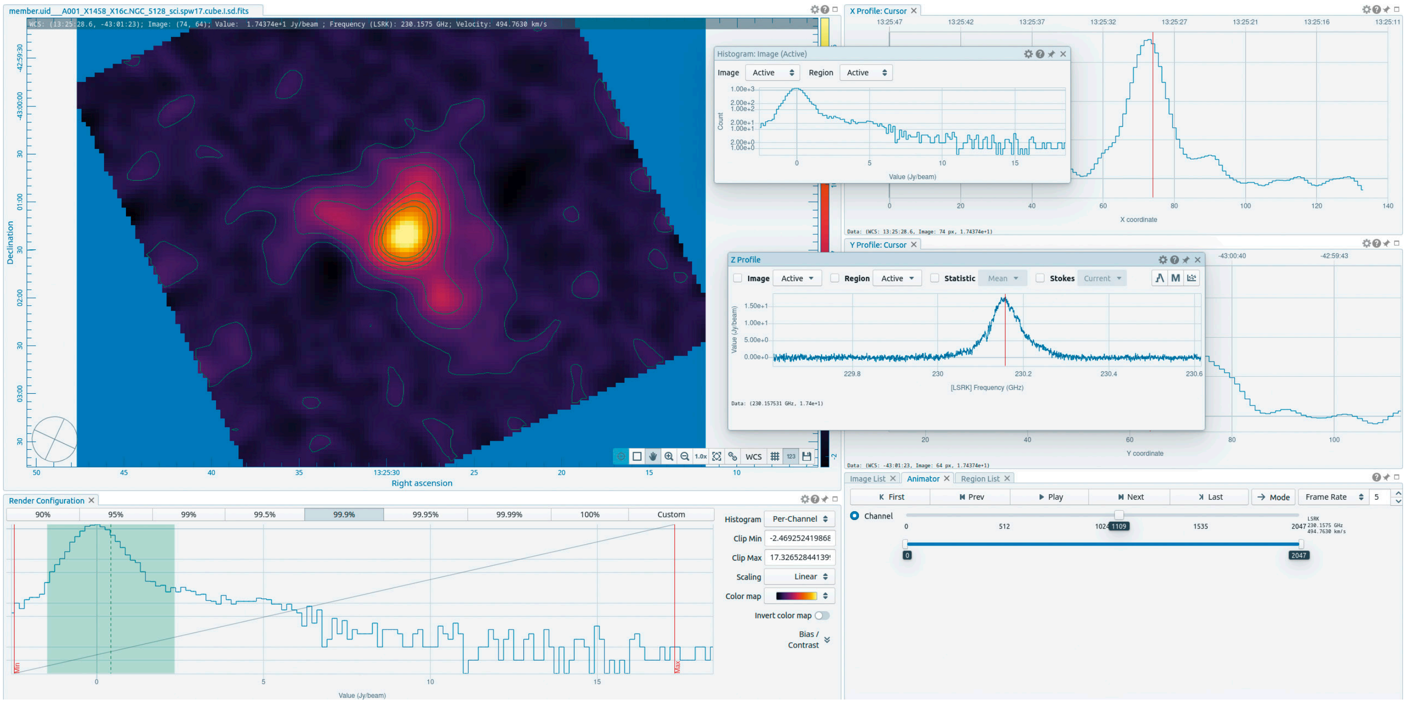
Previews

Previews — quick-look images allowing users to grasp the content of the data files at a glance — are a highly desired ingredient of modern astronomical archives. A particular challenge for ALMA is to provide previews that give the maximally useful essence of large 3D data cubes with up to 3800 spectral channels. After substantial experimenting, we opted for previews as shown in Figure 6. The previews are static and fully self-contained interactive html files. Users can zoom and pan the images and spectra for which we make use of the bokeh.org[19] library. Data products can be separated into two parts, the continuum emission (the flux for a pixel that is constant throughout the entire data cube) and the line emission (the remainder after the continuum was subtracted). Just collapsing (averaging) the line emission to create a two-dimensional image often erases the structure of the emission that sometimes can be concentrated into only a few spectral channels. We find that the


member.uid___A001_X1458_X16c.NGC_5128_sci.spw17.cube.I.sd.fits

Previews and tentative line labels are for reference only.

Figure 6. The ALMA previews show the continuum emission, the peak flux image (also called moment-8), and the moment-0 and moment-1 maps of the strongest detected line. In the lower part, three cuts through the datacube are presented. We use the ALMA Data Mining Toolkit (ADMIT) to identify spectral features and to tentatively label them. Those features are overplotted as vertical lines. Tabs provide access to the same analysis but binned by a factor of 16 in the spectral dimension, as well as to an extensive help. All panels are interactive and allow for zooming and panning.



WCS: (13:25:28.6, -43:01:23); Image: (74, 64); Value: 1.74374e+1 Jy/beam ; Frequency (LSRK): 230.1575 GHz; Velocity: 494.7630 km/s

Data: (230.157531 GHz, 1.74e+1)

Histogram: Per-Channel
Clip Min: -2.469252419868
Clip Max: 17.32652844139
Scaling: Linear
Invert color map

Figure 7. ALMA has implemented 1-click remote visualisation of all FITS files in the ASA using the feature-rich and sophisticated CARTA software. Powerful servers at each of the ALMA ARCs serve the minimally necessary data to the user's web browser providing a real-time user experience, even for extremely large data cubes.

peak-flux image (for each pixel the largest value along the spectral axis, (sometimes also called "moment 8") gives the most useful representation of the line emission.

In addition to showing those images, we run the ALMA Data Mining Toolkit (ADMIT)[20] over the data cubes. That software, originating in an ALMA development project, tries to find spectral lines in the data cube and — if provided with a guess for the relative velocity or redshift of the observed source — to identify them and label them with the molecule and transition tentatively responsible for the line emission. We use the following algorithm to provide the velocity to the ADMIT software. If a velocity was given by the PI in the ALMA OT, that velocity is used. If no velocity was given, we look for other existing ALMA observations of the same source and use the velocity if a value is available. If not, we try to match the observed source with a source from SIMBAD and NED and use the velocity from those services. If none is available, we check to see if the PI has entered the lines they were looking for in the OT and compute the velocities from that information. This process provides guesses of velocities for about 80% of all FITS files.

Three spectra across the cube are shown in the spectral panel of the preview. In the case that strong lines have been detected, the moment-0 and moment-1 images of the strongest line are displayed. The same plots do also exist in a binned version on the preview which makes the detection of weak broad lines easier. Finally, a help tab provides detailed descriptions of the content.

While not all lines can be detected and the line labels are tentative, using ADMIT across all FITS files is the first step towards automated data-annotation of ALMA data, i.e., the first step towards what is expected to be the next frontier for non-survey-type astronomical archives (Durand, private communication): describing the actual content of the data rather than only the observations themselves. Automatically described content has the potential to hugely speed up the data-exploration process and is thus fully inline with the "fastronomy" concept.

CARTA

The Cube Analysis and Rendering Tool for Astronomy (CARTA)[21] is an extremely powerful and feature-rich science-grade visualisation tool with a fast-paced and well-funded development process (Figure 7). The same software can be installed as a standalone desktop application or run partly on a server at a facility like ALMA and partly on the user's machine, creating a very fast user experience. Users can then connect to the server remotely and visualise archival images or cubes directly in their web browser without having to download the data at all. But they can still experience a fully seamless user experience identical to their CARTA desktop installation. In the client server setup, the server is located very close to the data and performs all the data access and pre-processing such that only the absolute minimum information has to be sent over the internet to the users. The result is that FITS cubes, even those above 1TB in size, can be opened in seconds, and visualised and analysed in real-time. Next to the spectral coverage viewer and the previews, CARTA is our third pillar helping with the 3D data challenge. In collaboration with the CARTA team, ALMA has deployed one server instance at each of the three ALMA Regional Centres (ARCs) on dedicated hardware (64 cores, 512 GB RAM, as well as a powerful GPU). One-click visualisation is available for users directly from the preview window of the query interface or from the Request Handler interface, again part of “fastronomy”.

Request Handler

Once data of interest have been selected, they can be downloaded. Unless data are still protected by the proprietary period, typically 12 months, all interaction and download can happen anonymously. The Request Handler window allows users to see the products for the selected data showing the minimum matching number of products per default. With tabs, users can decide to view larger parts of the product hierarchy. The products can also be selected in categories or filtered by name. All files can be downloaded individually or conveniently packaged into .tar files.

As ALMA data can be large, we offer download through a script that carries out the download in five parallel streams. This script can also be executed elsewhere, for example on a processing cluster. The user can decide whether or not the data should be unpacked and, if so, whether or not the directory structure of the dataset shall be preserved.

The Request Handler provides products created by ALMA as well as externally contributed products, like the products from the Additional Representative Images for Legacy (ARI-L) project (Massardi et al., 2021) and products provided by the PIs of Large Programmes.

Outlook

The development of the ASA is of course not stopping at the version 1.0 milestone. On the contrary, in addition to the constant adaptation of the ASA to changes in ALMA’s capabilities and policies, a number of new features are in the near-term development plan, the largest one being the integration of processing of all ALMA FITS products with ADMIT into the ALMA data workflow at the Joint ALMA Observatory (JAO). As a result, the metadata of detected and then tentatively labelled lines can be made available for queries.

Additional resources would enable the implementation of ambitious ideas for the long-term evolution of the ALMA data flow and of the ASA, including: high-level data products; user-initiated remote creation of calibrated measurement sets; user-initiated remote imaging and data combination; regular automated bulk reprocessing of the data holdings with the latest version of the ALMA pipeline; and a fully fledged ALMA Science Platform including access to graphics processing units for machine learning.

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Links

[1] ASA web interface: https://almascience.org/aq
[2] Angular web framework: https://angular.io
[3] AladinLite: https://aladin.u-strasbg.fr/AladinLite
[4] Elastic search: https://www.elastic.co
[5] ASA video tutorials: https://almascience.org/alma-data/archive/archive-video-tutorials
[6] ASA manual: https://almascience.org/documents-and-tools/latest/science-archive-manual
[7] CDS: https://cds.u-strasbg.fr
[8] SIMBAD: http://simbad.u-strasbg.fr/simbad
[9] NED: https://ned.ipac.caltech.edu
[10] Aladin: https://aladin.u-strasbg.fr
[11] Topcat: http://www.star.bris.ac.uk/~mbt/topcat
[12] SIAv2: https://www.ivoa.net/documents/SIA/20151223
[13] ObsCore: https://www.ivoa.net/documents/ObsCore/20170509/index.html
[14] TAP: https://www.ivoa.net/documents/TAP/20190927
[15] DataLink: https://www.ivoa.net/documents/DataLink
[16] SODA: https://www.ivoa.net/documents/SODA/20170517/index.html
[17] EuroVO Registry: http://registry.euro-vo.org/evor
[18] ASA Jupyter Tutorials: https://almascience.eso.org/alma-data/archive/archive-notebooks
[19] Bokeh library: https://bokeh.org
[20] ADMIT: https://admit.astro.umd.edu
[21] CARTA: https://cartavis.org

The Eta Aquariids meteor shower, which peaked in early May this year, was captured in this stunning image by astrophotographer Petr Horálek. It was taken near San Pedro de Atacama, a Chilean town about 50 km away from the Chajnantor observatory site, where APEX and ALMA, astronomical facilities co-owned by ESO, are located. The Eta Aquariids meteors are caused by leftover debris from Halley’s comet and make up the bright, arrow-like darts of light in the photo. But don’t stop there: this image is literally full to the brim of astronomical phenomena. See an annotated version of this image on https://www.eso.org/public/images/potw2227b/

ESO/P. Horalek

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Early-Career Scientific Visitor Programme at ESO Chile and Garching

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The ESO Offices for Science in Garching and Santiago have introduced a special programme to support short-term visits by early-career scientists of any nationality, to enable them to gain some research experience at ESO.

Named the Early-Career Scientific Visitor Programme, the programme is a flexible channel through which young astronomers can enrich their professional profile with short-term research experience. With it ESO aims to support young astronomers who have been particularly disadvantaged by the COVID-19 pandemic. Moreover, ESO seeks to promote scientific interaction with its community and research institutions worldwide and enhance ESO's role as an astronomical centre of excellence.

The selected candidates will receive support for travel and lodging for the period of the visit, office space and a computer terminal with an account.

Students enrolled in a PhD programme in astronomy or related discipline and young post-doctoral researchers up to three years after their PhD are eligible to apply to the Early-Career Scientific Visitor Programme.

Early-career visitors will be able to spend from one to four months working on their research project at ESO. They will have the opportunity to participate in a vibrant scientific atmosphere and to promote their own research. Through this programme visitors will have the chance to look for potential collaborators and foster scientific interactions with an international community.

Whilst visiting ESO the early-career scientists will have the unique opportunity to meet ESO experts who are deeply involved in the development and operation of the ESO facilities at La Silla Paranal Observatory as well as the Atacama Pathfinder EXperiment (APEX), and the Atacama Large Millimeter/submillimeter Array (ALMA), and in the organisation of ESO proposal submission, data processing and archive research. It will also be a good opportunity to meet the experts who are building instruments and ESO's Extremely Large Telescope (ELT).

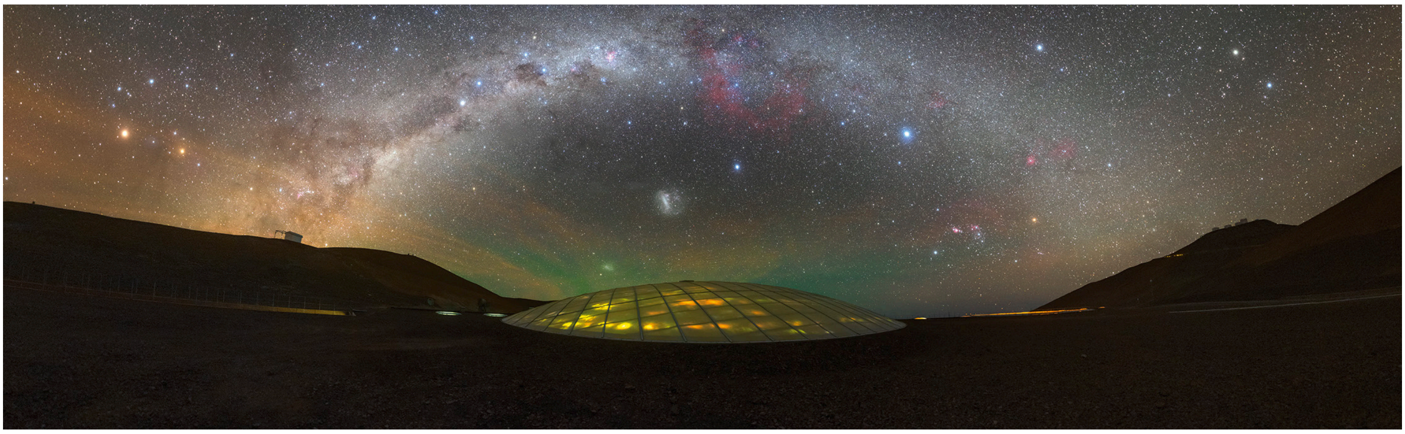
Early-career astronomers interested in applying to this programme should coordinate in advance with an ESO scientific staff member or Fellow who will act as contact point and will support the visit. Applicants can also contact the chair of the ESO visiting committee asking for assistance to find possible ESO collaborators who can act as host of the visit.

The Offices for Science encourage interested candidates to submit their applications at any time of the year and at least four months before the visit so as to properly arrange the logistics. Candidates will be evaluated on the basis of their scientific excellence, the scientific project proposed for the visit, and its feasibility in terms of goals against the requested duration of the visit.

More information about the programme, eligibility and instructions for applications can be found on the dedicated webpages for visits to Garching[1] and Chile[2].

Links

[1] Programme webpage for visits to Garching: https://www.eso.org/sci/activities/garching/personnelvisitors/Policy_Early-Career_Scientific_Visitors_Garching.html
[2] Programme webpage for visits to Chile: https://www.eso.org/sci/activities/santiago/personnel/ecsvp.html



P. Horálek/ESO

Once used as the otherworldly lair for a James Bond villain, the ESO Residencia usually serves a far less sinister purpose! Since construction was completed in 2002, it has been a home from home for the astronomers, engineers and technicians working at ESO's Paranal Observatory in Chile. The sleek building sits 2400 metres above sea level in the Mars-like Atacama Desert, just a few kilometres from Cerro Paranal — the mountain that hosts ESO's Very Large Telescope (VLT) and Visible and Infrared Survey Telescope for Astronomy (VISTA).

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Report on the ESO Workshop

The Present and Future of Astronomy (ASTRO2022)

held online, 14–18 February 2022

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Being one of the most fascinating and ancient sciences, astronomy has always played a special role in society. In 2022 ESO organised an online conference to offer the community a platform to discuss astronomical topics of sociological and philosophical relevance in a professional atmosphere. The talks touched on several crucial aspects, moving from the methodology of science to the use of metrics, to the importance of diversity in evaluation processes, and to the link between astronomy and society.

Monday, 14 February 2022	Methodology of science in the modern world
Tuesday, 15 February 2022	The funding of astronomy
Wednesday, 16 February 2022	Assessment and metrics
Thursday, 17 February 2022	Mental health and impostor syndrome
Friday, 18 February 2022	Astronomy and society

Table 1. The programme of the ASTRO2022 conference.

Science plays a crucial role in modern society. Scientists foster knowledge and produce results that have often immediate impact on people's lives. In this context, astronomy plays a privileged role. While having an extraordinary impact on the imagination of many people, astronomy enables researchers to use cutting-edge technology to explore the Universe and its beauty. In this way, astronomers can play a crucial role in science education. The development of large, international and collaborative organisations like ESO and their research facilities at the forefront of technology brings many broader societal benefits[1].

Driven by a genuine passion for their work, the community of professional astronomers is permeated by a continuous exchange of technical expertise, basic knowledge and scientific discoveries that crosses most cultural barriers. Diversity, personal development and returns to society are important aspects of our profession too.

Astronomical research is communicated mostly through well-established networks of professional journals, conferences, workshops, public presentations and teaching. Scientific publications play a crucial role not only in the development and sharing of knowledge but also in the sustainability of the research activity itself. It is not uncommon practice to use publication-related metrics in evaluation, assessments of performance and hiring processes. This fact has in recent years put significant pressure on researchers at all career stages, with the risk that the productivity of each individual might gain more relevance than the quality of the research.

ESO organised an online workshop where the astronomical community was invited to discuss, with the help of professionals from other disciplines, including social sciences, the above points and potential for improvements. Driven by the positive experience of the ESO Cosmic Duologues and Hypatia series (Beccari & Boffin, 2020, 2021), we have now learned to what extent online seminars can be an efficient way to engage and reach out to the astronomical community, even under the severe restrictions imposed by the COVID-19 pandemic.

The workshop (ASTRO2022) was announced in November 2021. The community was invited to participate either by registering for the conference or by following the event live on YouTube. By the deadline on the 9 February 2022, 486 participants had registered. Of the registered participants, 52% were early-career scientists (35% PhD students and 17% postdoc). This clearly demonstrates the strong interest within the astronomical community as a whole, and particularly the youngest, in participating in a workshop critically assessing how science is done in the modern era. It is also important to note that 45% of the registered participants were female. While it is not easy to demonstrate whether these numbers are also representative of the effective demographic of the participants in the online event, we are proud to acknowledge that we achieved our goal of engaging a diverse group of people.

Five conferences in one: the programme

As said by several participants, this was a unique workshop that addressed essential themes of concern for every researcher. Each day was dedicated to a particular topic: Methodology of science in the

1. Focus groups and interviews with diverse stakeholders

Research success and career success are often incompatible with one another

Career success	≠	Research success
Quantity		Quality
Exceptional findings		Reproducible findings
Individual achievements		Collaboration
Competitive		Open sharing
Certainty of positive results		High risk innovative science
Sensational		Transparency, honesty, modesty

Aubert Bonn, N., Pinxten, W. (2021) *Research Integrity and Peer Review* 6, 1 and 3. DOI: 10.1186/s41073-020-00104-0 and 10.1186/s41073-020-00105-z

Figure 1. A slide from the presentation of Noémie Aubert Bonn showing the difference between the words characterising career and research success in the current times.

modern world; The funding of astronomy; Assessment and metrics; Mental health and impostor syndrome; Astronomy and society. It was said several times that each of these topics would have deserved a dedicated conference of its own. The videos of the event are available on YouTube[2] and some of the presentations have been made publicly available on Zenodo[3]. At the time of writing (March 2022), the videos have been viewed more than 3700 times.

In his introduction, Bruno Leibundgut from ESO underlined some of the key aspects that motivated the meeting: as professional astronomers, we are privileged to do the work we do and honoured by the trust that society places in us by investing research funds to create knowledge. It is a responsibility of the research community to reflect and take a critical look at the various aspects that crucially impact our work, like the use of metrics in hiring and in assessing, the importance of ensuring diversity to guarantee a healthy scientific environment, the use of funding, and the role of astronomy in education.

The conference started with a series of talks touching on the foundations of the scientific method from a philosophical perspective. It was remarkable to see almost 300 participants connected via either YouTube or Zoom during the first day. Given the large participation, there is no doubt that our community is willing to understand whether we still follow the fundamental principles of the scientific method as stated by Karl Popper in the last century. And the answer is certainly far from trivial. It is important, however, to realise that such studies exist, and that as researchers we need to take a step back and analyse our methods.

On the second day, the topic of the conference moved to the funding of astronomical research. Valentin Oprea described the opportunities provided by the European Research Council, while Thomas Zurbuchen highlighted the importance of ensuring diversity in hiring and funding at NASA. This last point was also the focus of the contributed talks and the discussion, reinforcing the need for greater diversity — in gender, professional profile, culture, and minorities, amongst others — in shaping healthy and successful scientific programmes. As explained by Francesca Primas, member of the ESO Diversity and Inclusion Committee, diversity is one of the ESO organisational goals and is present in various critical aspects, from playing a key role in shaping the Respectful Workplace policies aimed at fostering professional and respectful relationships at work, to the formulation of mid- and long-term goals to consolidate diversity and inclusion in recruitment and promotion processes.

The discussion on recruitment and assessment processes continued on the third day of the conference when, thanks to the talks by Stephen Curry and Noémie Aubert Bonn, the focus was the use of metrics. Noémie Aubert Bonn presented the results of a study aimed at identifying the perceived meaning of scientific and career success in a research environment. As shown quite remarkably in Figure 1, the keywords describing research success and career success are often incompatible. While the availability of large and complete databases has made it possible to perform accurate metric analyses in evaluation processes, it is a fact that the first modern concept of peer review was introduced at least two centuries ago, when the number of humans populating the planet was a factor of sixteen lower than it is today (see Figure 2). It is therefore a fair question to ask whether the peer review system as originally introduced still allows a solid and balanced evaluation of the scientific quality of manuscripts, and whether the introduction of metrics alleviates or exacerbates biases in the evaluation process. The San Francisco Declaration on Research Assessment (the DORA initiative[4]) presented by Stephen Curry, looks critically at these and other aspects of the evaluation process and aims to find new means to renovate the ways in which the outputs of scholarly research are evaluated and adapt to the requirements of a modern world (for example, by eliminating the use of journal-based metrics, and assessing research on its own merits).

The restrictions imposed by the COVID-19 pandemic had, in the course of 2020 and 2021, dramatic consequences for career development, especially for early-career scientists. The delicate balance between professional and personal life has been challenged by imposed social distancing, lockdown measures and isolation. Mental health and wellbeing have become more than ever crucial aspects of our personal and professional life which deserve awareness within the community. Ewa Pluciennicka and Sanne Feenestra presented the latest scientific insights into mental health and the impostor phenomenon in academia. As emphasised by the valuable contributions from all the Thursday speakers, it is imperative that institutions listen to the voices of the new generation of astronomers whose desires, needs and vision often challenge the established procedures and approaches in research. Family support, work-life balance, employment of personnel with disabilities, and support of researchers in developing countries are only a few of the aspects that must become the core of scientific and research policies[5]. As long as the growth of scientific knowledge and the horizon of a career in research are dominated by productivity and associated concepts like the number of publications and

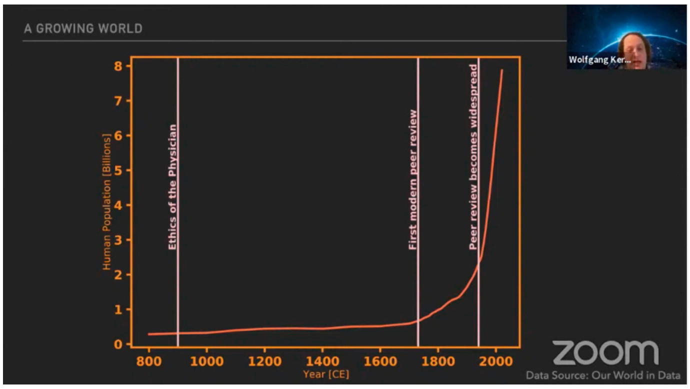

Figure 2. A slide from Wolfgang Kerzendorf’s presentation showing the increase of human population as a function of time. The vertical lines indicate three milestones on the road to the modern peer review process.

leadership, we risk forgetting what lies at the core of scientific progress: the individual scientist, their creativity and talent.

There are extraordinary and successful examples of how astronomy can be used to reach the general public, inspire the youngest generation and contribute to bringing more equality into the world. Sandra Benítez Herrera and Mirjana Povič showed how initiatives related to research collaborations, education, institutional development, human capacity building, policy development, and participation of women in science are powerful ways to stimulate creativity and increase the perception of science as an approachable discipline contribute to combat poverty and inequity in the world.

Closing remarks: more than "food for thought"

The ASTRO2022 conference offered to many participants a starting point to address, in a fast-changing world, important questions about the foundations of the scientific method and the modernity of science. Scientists have to ask themselves what their responsibility is and — in our context — what we, as professional astronomers, can do to exert a positive influence on society. The topics discussed in the five half-days touched on aspects that we all need to understand and accept. Diversity in science, wellbeing and work-life balance, sustainability, fair assessments, and quality-driven evaluations are aspects to be fully ingested and represented in science- and research-related policies and procedures. There is a profound desire in the scientific community and beyond to refocus our efforts onto people. A fair society in which every person can flourish based on their own talents, desires and creativity must be the goal of the changes in the way we do science in a modern world. The talks and discussions triggered during the ASTRO2022 conference were a promising start towards a new view of science in a modern world. Achieving this ambitious goal requires fair and open intergenerational exchanges with the support of multi-disciplinary expertise.

Acknowledgements

We would like to thank all the speakers and the community for their enthusiastic and professional participation in the live event and in the discussion sessions.

References

Beccari, G. & Boffin, H. M. J. 2020, The Messenger, 181, 34
Beccari, G. & Boffin, H. M. J. 2021, The Messenger, 185, 23

Links

[1] ESO's Benefits to Society publication: https://www.eso.org/public/products/brochures/brochure_0076/
[2] ASTRO2022 videos: https://www.youtube.com/c/ESOCosmicDuologues
[3] ASTRO2022 presentations: https://zenodo.org/communities/astro2022
[4] DORA: https://sfdora.org/
[5] For examples on work-family balance and issues affecting especially mothers, see the book "Mothers in Astronomy" by Paola Pinilla, https://misaladino.com/mothers-in-astronomy/

ESO/A. Ghizzi Panizza (www.albertoghizzipanizza.com)

This picture of the week shows four powerful laser beams leaving Unit Telescope 4, or 'Yepun', at ESO's Very Large Telescope (VLT) in Chile's Atacama desert. These form the VLT's 4 Laser Guide Star Facility, which enables astronomers to take extremely crisp images of the cosmos by employing a technology known as adaptive optics.

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The MAYA 2022 Conference: Propelling ALMA Early-career Astronomers into the Spotlight

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The first Meeting for ALMA Young Astronomers (MAYA) organised by the European ALMA Regional Centre (ARC) network (Hatziminaoglou et al. 2015) took place online from 2 to 4 March 2022. It was a successful and inspiring event, well attended, with 40–80 participants at any one time. After two years of limited opportunities for socialising because of the COVID-19 pandemic, the event was aimed at gathering together early-career scientists, primarily graduate students and junior postdocs, and giving them the chance to present their work based on ALMA data to their peers, to interact with each other, and to build new collaborations and projects.

Planning the first MAYA

The idea of organising a conference for young scientists, focusing on ALMA science, had already been in the air for some time. It was discussed further at the end of November 2021 by the European ARC network visibility group, consisting of staff working in the different European ARC nodes. As is often the case, setting a date for the event was challenging. Conflicts with other calendar constraints had to be avoided as much as possible, in particular the critical period of a couple of weeks just before the ALMA deadline. On the other hand, organising the conference some time before the deadline arguably offered a good opportunity to build some momentum for the preparation of ALMA proposals, possibly with new ideas and new collaborations. We formed a Scientific Organising Committee (SOC) from members of the network visibility group. Eventually a time slot in early March 2022 emerged, which left us with only three short months for advertising the conference, allowing enough time for registration and abstract submission, reviewing the abstracts, building a programme, and finally giving the speakers about two weeks notice before the actual start of the conference. The excellent, friendly working atmosphere within the SOC allowed us to overcome this challenge and eventually transform the MAYA concept into a successful event.

Figure 1. The MAYA logo, including the Lamat Mayan star, symbol of fertility, abundance, and a new beginning.

Building a programme

The conference was originally planned to run over three days, with two sessions of two hours each per day. We received 180 registrations (Europe: 76%; North America: 9%; Asia: 7%; South America: 5%; unknown: 3%; from more than 30 different country affiliations. See Figure 2 for a pie-chart of the main contributors) and nearly a hundred submitted abstracts for oral presentations. Those numbers exceeded all our expectations and clearly highlight the community's interest in such events and the need for opportunities for a whole generation of students and young researchers to present their work in a scientific conference setting.

We decided that a format with talks of 15 minutes, followed by five minutes of questions, was the best compromise between a fair cadence of talks, enough time for the speaker to properly present their work, and time for questions and discussion. However, this setup was imposing a drastic abstract selection to match the original schedule. After considering parallel sessions, which we gave up on because of the complexity of the organisation and the crowded schedule readability, we eventually decided to extend the session duration to three hours, with a short break in the middle, allowing for 50 live talks. The participants with non-selected abstracts were given the opportunity to upload prerecorded talks to the European ARC YouTube channel. All talks (live and prerecorded) are now available in a combined MAYA2022 playlist[1].

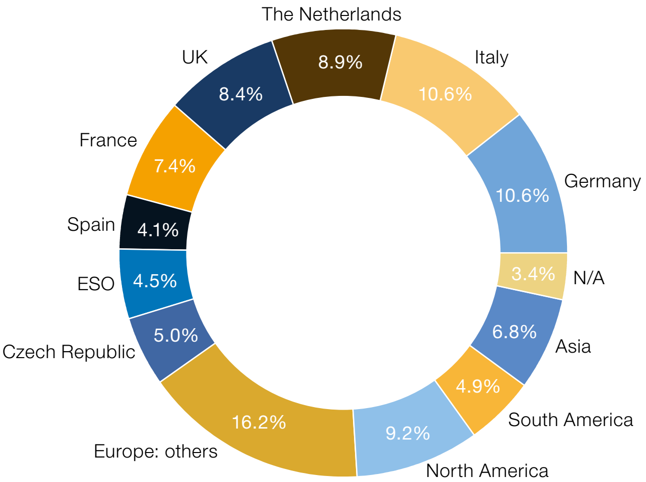

Figure 2. Distribution of registered participants' affiliation by main countries/regions. More than 30 different country affiliations were represented.

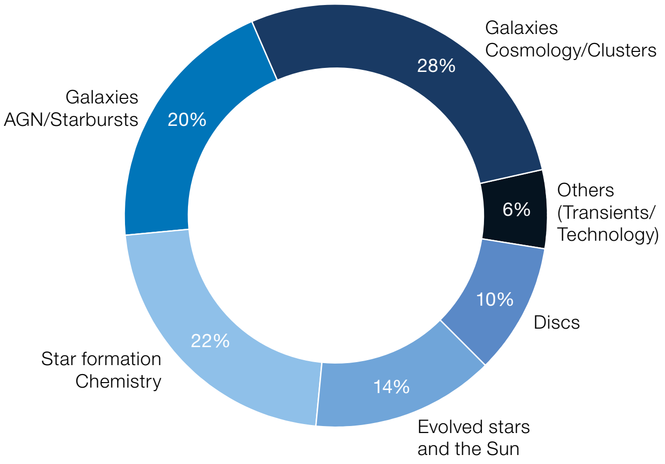

Figure 3. Topic distribution of the live talks.

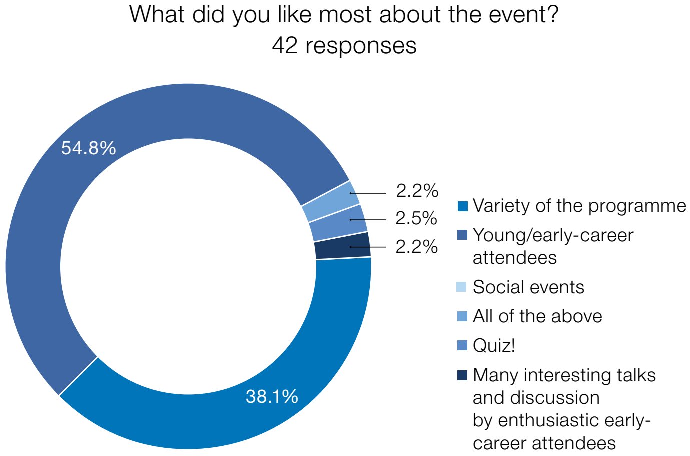

Figure 4. Excerpt from the questionnaire feedback.

The abstract selection and construction of the programme were hugely challenging, given the impressive quality of all the abstracts and the broad range of science topics. We decided to organise sessions with mixed topics (Figure 3), in order to expose participants to science fields other than their own, switching, for example, from ALMA solar science to chemistry in proto-planetary discs and to star formation in high-redshift galaxies in one session. According to the participant feedback, this setup and the programme variety were much appreciated (Figure 4).

We also had the pleasure of welcoming two invited talks. Leonardo Testi (ESO) spoke about the Joys and Tribulations of Building a Transformational Observatory. Leonardo presented an inspiring overview of the challenges of building a revolutionary telescope like ALMA. In particular, he included many anecdotal details with a taste of humour. Violette Impellizzeri (Allegro node) presented an overview of the European ARC network and the services the network provides. She discussed the in-person or virtual face-to-face support provided by the nodes for proposal preparation, data reduction and analysis, and archival science mining. In addition, Violette introduced the various activities and resources provided by the ARC network, such as schools, ALMA days, and tutorials (such as, for example, the Interactive Training in Reduction and Analysis of INterferometric data series, ITRAIN, also available as a playlist[2] on the European ARC YouTube channel). She also highlighted the computational support provided by the nodes for ALMA data handling and the development of software tools to support users with their ALMA science.

The MAYA meeting was organised on the Zoom platform. To make it as convivial as possible, we avoided the Zoom Webinar format and encouraged participants to keep video mode open. During talks, questions could be entered in the Zoom chat, and the Slack platform was used as a complementary communication channel for follow-up discussions on questions and conference announcements. All questions were gathered into Slack and addressed by the respective speakers.

Stimulating interactions during an online meeting

Besides the traditional series of talks, we wanted to incorporate various social activities to create a relaxed atmosphere and increase the chance for participants to interact with each other.

The first activity was a quiz game, run in several parts during the coffee breaks. All the questions were related to ALMA, covering its different components like the antennas, receivers, correlator, etc. However, the answers were of different flavours: for example, participants had to guess the equivalent surface of a 12-metre ALMA antenna in the special unit of a ping-pong table area (answer: 27) or the total amount of energy that would be collected by the array after 30 years of observation of a 1-Jansky source (answer: about the potential energy of a snowflake falling from a height of one meter). The top five winners were offered gifts in the form of ALMA mounted images from the ESO Webshop or an ALMA LEGO® antenna.

We also organised social events in the evenings for discussion and playing online games. Although we were worried that this would increase the length of already long days, it turned out that this was a wonderful way to relax and get to know each other better. Several games were proposed, like inviting others to guess a word from a drawing[3]; astronomy-related terms like "gravitational lens" or "white dwarf" turned out to be challenging and a lot of fun for both the artist and the guessers! We also played a "GeoGuesser" on geostatic[4]. In this game, the players are dropped somewhere on Earth on Google Street View,

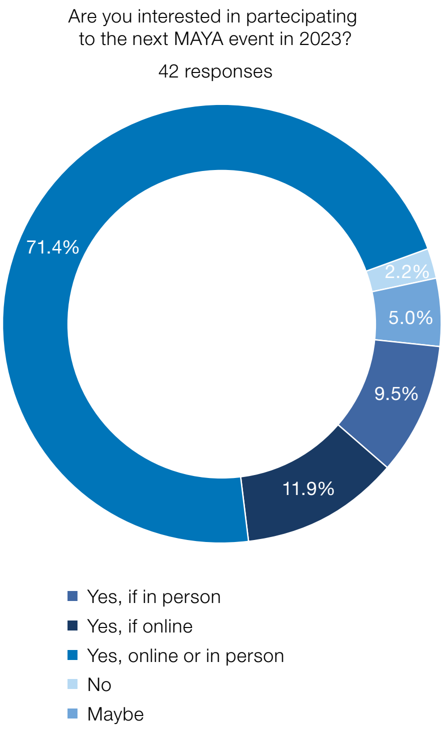

Figure 5. Excerpt of the questionnaire feedback.

and they have to guess where they are by exploring the surroundings. Depending on the location, this can be much more tricky than it seems. We found out that it was a great advantage to have international participants in the team, with various cultural backgrounds. This helped participants to quickly recognise road signs in various languages, or building styles: a perfect example of "together we are stronger".

Concluding remarks

After such an overwhelming success, very positive feedback, and the fun of organising the first event, we are already thinking about a future MAYA. The main question is whether to hold it online or on site. An online meeting has the advantage of reaching more people, especially from countries that are still developing their ALMA science exploratory capacity. It is also easier to organise, removing general logistics issues related to finding an appropriate venue and catering. On the other hand, on-site has the immense benefits of immediate and easy-going social interaction, which is so important for young scientists. However, according to the results of the feedback questionnaire, there is no strong preference for either on-line or on-site (Figure 5). The words of Baron Pierre de Coubertin still apply: "*The important thing is to participate.*"

Certainly, this first MAYA proved that there is a desire on the part of young astronomers to interact, communicate, share results, and establish contacts. The future generation of ALMA scientists is already there, mature, enthusiastic, and very dynamic — and already producing amazing science results.

References

Hatziminaoglou, E. et al. 2015, The Messenger, 162, 24

Links

[1] MAYA2022 playlist: https://www.youtube.com/playlist?list=PLSPuDgClX-pYJkZ3VEd_SewcPkPh-5BpyE
[2] ITRAIN playlist: https://www.youtube.com/playlist?list=PLSPuDgClX-pbJTT8Q9KdBVFsVBsl-zlu2p
[3] The drawing game: https://skribbl.io/
[4] Geostatic: https://geotastic.net/home

ESO/José Francisco Salgado (josefrancisco.org)

Four antennas of the Atacama Large Millimeter/submillimeter Array (ALMA) gaze up at the star-filled night sky, in anticipation of the work that lies ahead. The Moon lights the scene on the right, while the band of the Milky Way stretches across the upper left.

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Fellows at ESO

Ana Escorza

My interest in astronomy is older than I can remember, but I could have never imagined it would take me this far professionally or geographically. When I was young, I thought that looking at the night sky was just a nerdy hobby; but now I get to do that from the Paranal platform while taking a break from my actual job as a VLT night astronomer. It's a dream.

I was born in Calahorra, a small city in the north of Spain. The region, La Rioja, is quite empty, mainly being full of farms and vineyards. The cities nearby are not too large either, so light pollution is moderate and the sky is quite enjoyable. I always looked up with curiosity, but I was just very curious about everything. I never really planned to make a living from looking at the stars. At school, I was a good student. I was interested in all the sciences, but also in history and literature, which made it quite difficult for everyone, including me, to guess where I would end up. The story started changing with a school trip.

At some point in the early 2000s, my school took me and my classmates to Borobia, a tiny town 100 kilometres away that I had never heard of until then. There, they had a small observatory built mainly for outreach purposes, and through their 42-cm Schmidt–Cassegrain telescope "El Coyote", I saw Jupiter's moons, Saturn's rings, and a few nebulae and globular clusters for the first time. That was it! It might sound stereotypical, but that day I went back home saying that I wanted to work in a place like that when I was older. Working in Paranal was still beyond my wildest dreams though.

A few years later I started a physics degree in Zaragoza. Although the university did not have a specialisation in astronomy, I did get the chance to fulfil teenager-Ana's life goal. I did a summer internship in Borobia and I spent a summer doing science communication with the very same telescope that had changed my view of the sky a few years back. During my degree I also did an exchange year in Southampton, where I could take more astronomy courses than in my home university, and I was granted a summer research position at the Institute of Astronomy in the Canary Islands. These experiences put me definitively on the astronomy track. However, my physics degree in Zaragoza was very theoretical, and I did not feel ready to jump into real research just yet. This is how I ended up in Belgium, looking for another international adventure and pursuing the master's degree in astronomy and astrophysics at KU Leuven, a programme that was very much focused on observational astronomy research.

Belgium is where the story really changed. KU Leuven took a physicist who had no idea what she could do with her degree and made an astronomer with ambitions and big plans for her future. During my master's, I got the opportunity to operate my new favourite telescope, the Mercator telescope. I jumped from a 42-cm to a 1.2-m telescope, and from using my eyes as my only instruments to using HERMES, one of the most wonderful spectrographs available (no offence to my dear ESO instruments). Once I graduated, the path to follow was crystal clear, as it had never been before. I was sure for the first time that I wanted to do a PhD in astronomy and, if possible, I wanted to do it in Belgium. I applied for a couple a vacancies to fulfil this new life goal and in 2015 I started a dual PhD in astronomy in a collaborative programme between KU Leuven and the Université Libre de Bruxelles.

My PhD focused on barium stars, a class of chemically peculiar stars formed as products of the interactions between asymptotic giant branch stars (old red giants) and their companions in binary systems. Most of the research I have led concerns these systems, but I am interested in any fun or weird multiple system, especially if the stellar components are interacting or did so in the past. During my PhD, I also developed an interest in teaching and a passion for science communication. I may be biased, but I think that astronomy is one of the prettiest sciences, and we astronomers should use that gift to advocate for the other branches of science. With this mentality, I have participated in and organised all kinds of outreach events, at all kinds of venues and for all kinds of audiences. In case you are curious, my personal favourites are events like Pint of Science and Astronomy on Tap. Bringing scientists to pubs to talk to the locals about ground-breaking science with everyday vocabulary is one of the most rewarding science communication experiences I have had, even more rewarding if there is Belgian beer involved, of course.

Going back to the story that brought me to write this piece, and almost reaching the end, in October 2019 I started applying for postdocs. With a mounted image of Paranal in my living room and with enough ambition and ideas to continue my career with my own grant, the ESO fellowships were the first two postdoc applications I wrote. I got the offers just before Christmas, on the same day that I submitted my PhD thesis. I became a Doctor in Astronomy on 3 March 2020, a week before Europe locked down, and a few months later I moved to the other side of the world. Now I am an ESO Fellow in Chile with duties in Paranal, where I operate Antu and Kueyen (UT1 and UT2). I have a couple of nerdy hobbies now: drinking a coffee while enjoying the sunset from the Paranal platform and looking up at the sky in between observations when my new favourite 8-metre telescopes give me a break.

Thomas Wevers

When reading (auto-)biographies or histories of famous (as well as less famous) astronomers, they usually start with how they already knew what they wanted to do later in life while they were only children/teenagers. This is not one of those stories; ending up with a career in astronomy was more due to serendipitous events and chance than a well-thought-out plan.

I started following the Latin track in high school, but quickly realised that this was not for me, so after two years I switched to a science track. I was always interested in how stuff works, and spent a lot of time trying to find out how everyday objects, say a fridge, a combustion engine or a car, work. It always seemed to boil down to some law of physics or other, so I included as much physics in my courses as possible — the other sciences did not seem to have this degree of applicability to everyday life.

Given my interests in how nature works, I chose to do a bachelor's degree in physics at the small university closest to home (Hasselt University, in Belgium). Near the end of this degree, I was convinced that I would take a master's in nuclear physics. However, a course on this subject taken during an Erasmus exchange to Montpellier, France — which I thought would be my favourite topic, but turned out the opposite — made me change my mind. Just a few weeks before I had to sign up for a master's specialisation, I had no idea what to choose.

I came across the astronomy programme of the KU Leuven, which included an observing course on their small telescope in the Canary Islands. This was the most "hands-on" experience I could find among all potential physics specialisations. Without having done an astronomy course worth the name during my bachelor's degree, I decided to take my chances and enrolled for a master's in astronomy.

My master's thesis involved modelling observations of post-AGB binary stars, and while I really liked astronomy, I did not see myself continuing in any of the (mainly stellar astrophysics) topics covered during the master's (except for the observing part!). A lecture series on high energy astrophysics given by a professor from The Netherlands changed my perspective, and I applied for a PhD position to work with this professor in Nijmegen in The Netherlands. The idea was to create a pipeline to reduce Gaia's fast cadence photometry, identify transient events and see what we could find. In practice, the Gaia launch and verification period lasted throughout the first year of my PhD. Having two very creative and supportive supervisors, I ended up working on everything ranging from white dwarfs to X-ray binaries and tidal disruptions of stars (also called spaghettification events) around supermassive black holes. This latter research topic still keeps me busy today.

I was lucky to be able to spend a significant amount of time during my PhD travelling, to observatories (~ 15 trips to La Palma and Chile) as well as conferences and meetings, so I got very familiar being a visitor at telescopes — and curious about how they work from the "other side".

After finishing my PhD, I moved to do a postdoc in Cambridge, in the UK (working on Gaia transients and the aforementioned spaghettification of stars). During those three years, my curiosity about how the telescopes and instruments themselves work and are organised remained: what technologies are behind them; how you design, build and operate an instrument; how you optimise the scientific output; and so on.

In order to experience this aspect of astronomy, ESO provides a great option for early-career astronomers with its fellowship. As an ESO Fellow I currently work on several aspects (characterisation, performance, etc.) of the Multi Unit Spectroscopic Explorer (MUSE) instrument, and I have learned a lot about all aspects of astronomy (for example, adaptive optics, which uses laser guide stars to correct the turbulence of the atmosphere). More generally, contributing to operating the VLT has opened a new world of astronomy that I had not quite realised existed, even after spending seven years working in the field. From a professional point of view, it has been an amazing experience.

Unfortunately, being part of a two-body problem (that of finding jobs for both partners in the same place) as an early-career researcher is still very much an underrated and often ignored aspect of academic life, even at a flagship institution such as ESO. As a result, my experience at ESO so far has had a rather stark black & white contrast between the professional and personal aspects. Given that the fellowship is explicitly targeted at early-career researchers, I'm hoping that ESO uses its position at the forefront of astronomy to address this problem in the near future, and leads the way towards a more sustainable career path for astronomers.

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Engineering Fellows at ESO

ESO's core missions are to build and operate state-of-the-art facilities for the advancement of astronomical research and to foster international cooperation in astronomy. A strong research and development programme is therefore at the core of ESO's activities. For this reason, for a few years ESO has established, in addition to the ESO fellowship programme for researchers in astronomy, an engineering fellowship programme. The profile of one of these ESO engineering fellows is presented here.

Cédric Taïssir Héritier-Salama

Writing this article was an interesting opportunity to reflect on how I became an adaptive optics researcher/engineer. What probably set the foundations for a career in science is the fact that I grew up in an area called la Vallée de Chevreuse in France — known to host many scientific research institutes — and that most of the people I knew were somehow related to a scientific institute, including some members of my family (I have an uncle working at NASA).

My first contact with astronomy occurred during a short internship in high school at the Institut d'Astrophysique Spatiale d'Orsay with L. D'Hendecourt; there I heard for the first time about the search for exoplanets. I remember that at the time I was very disappointed to hear that we had only a few pictures of them and that most of them had been detected indirectly! However, this internship really aroused my curiosity for our Universe, and this is probably when I first started to think about a career in astronomy.

To that end, I specialised in fundamental physics at the Paris-Saclay University. As part of my master's degree and thanks to the Erasmus programme, I got the chance to study in Rome for a year, at La Sapienza University. This year abroad definitely changed my life. A large part of this experience was personal as I was able to discover a new culture and a new language. Also, I decided to take a course in optics for astronomy to get a background in instrumentation, although I had chosen most of my classes to focus on astronomy. This is when I got introduced to a technique called adaptive optics (AO) that is used to compensate in real time for the optical aberrations induced by the atmosphere. This technique seemed magical to me and sounded quite fun to study. Therefore, I decided to specialise in instrumentation with the goal of working on AO instruments. The transition from fundamental physics ended up being quite smooth, although I had to get familiar with completely different tools and concepts. However, it became clear to me that the "magical" aspect of AO relied in fact on a deep understanding of optics, mechanics, automatic control, electronics, and algebra.

At the end of this year of specialisation I was able join ESO for the first time, to do my master's thesis with J. Paufique working on the NAOMI instrument for the VLTI. The goal was to characterise the performance of the new wavefront sensors (WFS) of the Auxiliary Telescopes to improve the flux available for interferometry purposes. A few years later, NAOMI became fully operational in Paranal and the feeling that I contributed to at least a small part of its success makes me very happy.

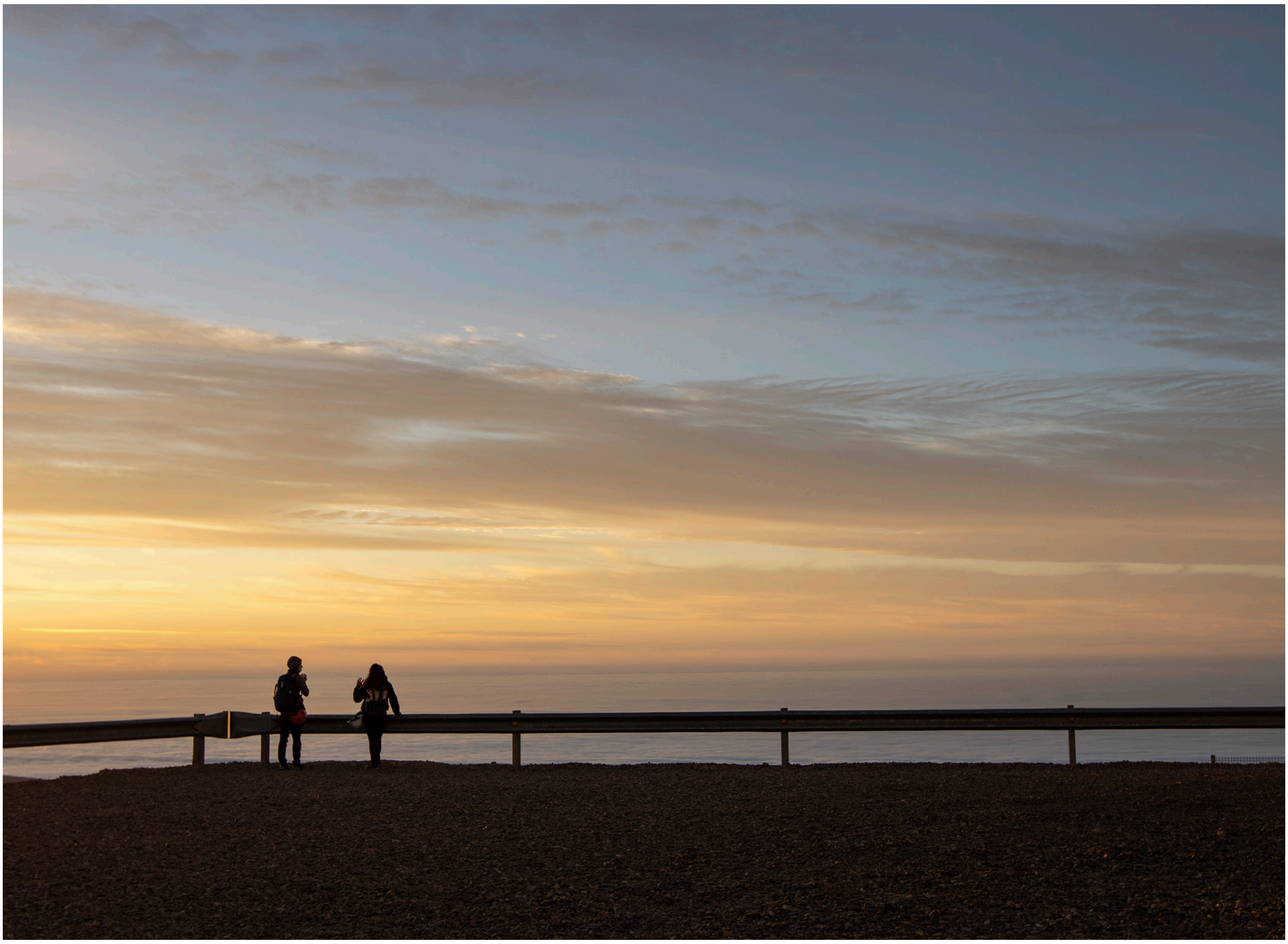
After this first technical experience, I was selected to do a PhD on the calibration of the future AO instruments of ESO's Extremely Large Telescope (ELT). This topic sounded very attractive to me as it would help minimise the instrument overheads due to imperfect calibrations and provide more time for the science. It really gave some practical sense to my work. Another very exciting aspect of this PhD is that four institutes were involved in the supervision (T. Fusco from ONERA, B. Neichel from LAM, S. Oberti from ESO and S. Esposito from INAF–Arcetri) and that I could spend a year in each country (France, Germany and Italy). This peculiar organisation ended up being valuable for my research and I am grateful that I have been able to interact with so many AO experts across Europe.

The goal of my PhD was to find ways to ensure that the calibration of the AO system stays nominal during the scientific observations, regardless of the fact that mechanical flexures might lead the adaptive mirror M4 to move frequently with respect to the WFS. In order to do that, I developed an algorithm called SPRINT to track the relative motions of one with respect to the other. Although parts of this method have been validated on existing telescopes, I will still have to wait many years to see how my piece of work will perform on the real ELT AO systems!

I wanted to carry on this research by investigating other effects that might affect the AO performance and stability due to the complexity of an ELT AO instrument (WFS specificity, pupil fragmentation effects, complexity of the M4 mirror, phasing of the primary mirror, etc.). The problem remains that these different effects may add up and could make the control of the instruments quite challenging. To study these topics, I was selected to be an ESO Engineering and Technology Research Fellow to try to come up with realistic performances of the AO systems while investigating possible ways to mitigate some of these effects. Although my research mainly benefits the AO instruments, being at ESO also allows me to interact with the teams working on the ELT itself which is very useful for understanding better how the instruments will be operated.

In fact, as an ESO Engineering Fellow my engineering duties are very close to my research interests as I am currently leading some activities to develop a common calibration strategy for all the ELT AO instruments. My everyday work includes mostly simulations of ELT AO systems, as well as investigating different wavefront control and reconstruction strategies and new wavefront sensing concepts. I am also involved in a R&D project called GHOST led by M. Kasper. This testbench aims to validate experimentally AO control strategies based on machine learning to improve the contrast of PCS, the future planet finder of the ELT.

Apart from work, if I am not busy playing team sports I am most certainly taking some time off from my computer to listen to and observe the nature around me. The spotting of a rare bird or a friendly encounter with an octopus in the Mediterranean Sea are simple things that always bring me joy.



ESO staff members enjoy the glorious sunset at ESO's VLT platform in the Atacama Desert, Chile.

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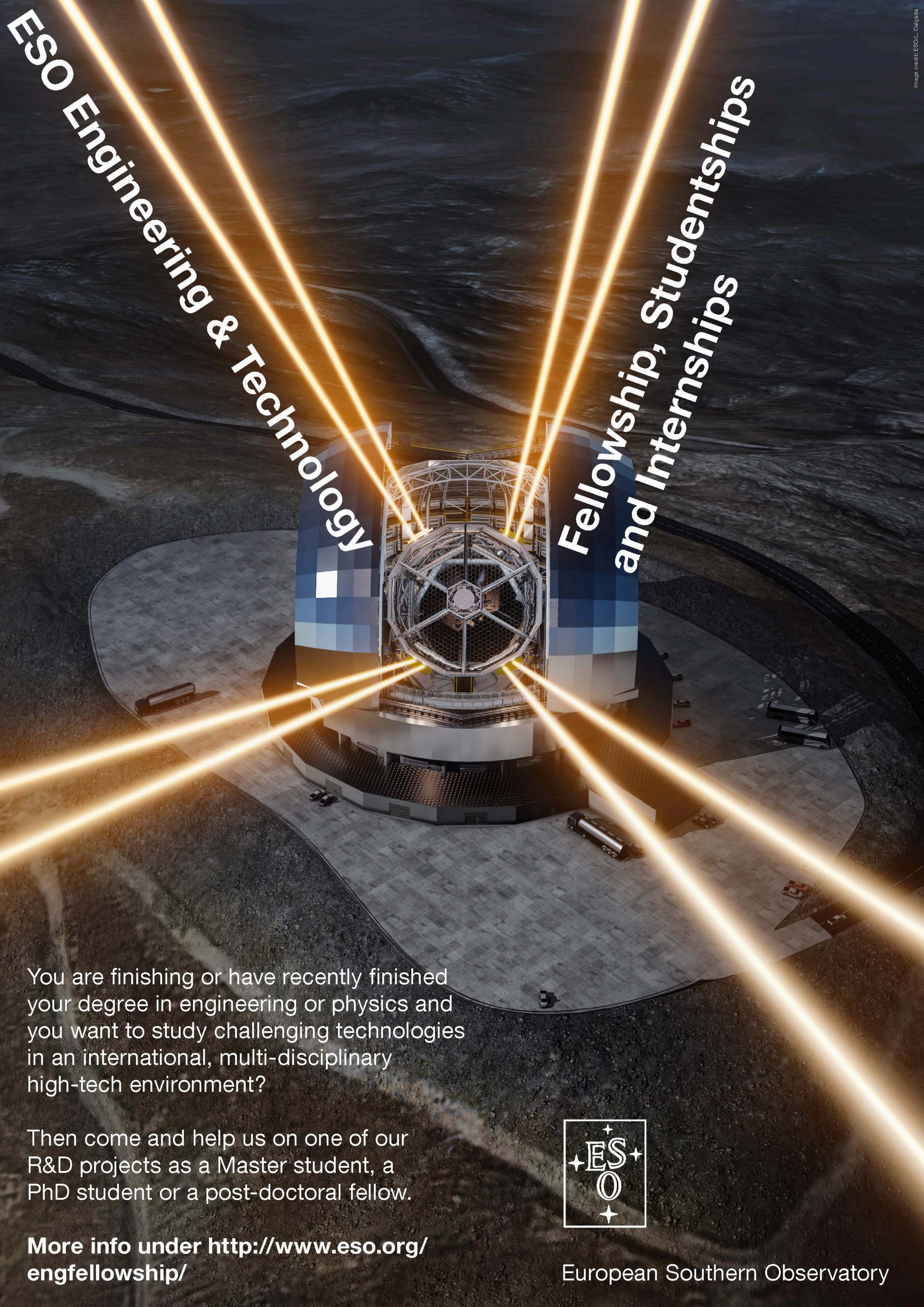

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