The Messenger

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ALMA Looks into Exocometary Belts
ALMA–CTAO Synergies
VLT Beyond 2030 and Call for White Papers

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Front Cover: This image shows the complex distribution of molecular gas in the Central Molecular Zone (CMZ) of the Milky Way. It was obtained with the Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner. This map is part of ACES — the ALMA CMZ Exploration Survey — a project designed to understand how gas condenses into stars in the extreme and chaotic environment at the heart of our galaxy. The survey has charted the distribution of dozens of different molecules, five of which are shown here in different colours: sulphur monoxide (cyan), silicon monoxide (green), isocyanic acid (red), cyanoacetylene (blue), and carbon monosulphide (magenta). The stars in the foreground of this image were observed at infrared wavelengths (*Y*, *Z* and *J* filters) with ESO's VISTA telescope as part of a different project. The actual density of stars in the CMZ is much higher than what is shown here, where we have opted to highlight the details in the molecular cloud. Note that the edges of the ALMA map appear somewhat sharp because the ALMA observations do not cover the entire rectangular area here. See the full extent of the map at: https://www.eso.org/public/images/eso2603a/

Credit: ALMA(ESO/NAOJ/NRAO)/S. Longmore et al.
Background: ESO/D. Minniti et al.

Only by working together as a team can all of ESO's 8-m telescopes become the Very Large Telescope Interferometer (VLTI) — and this image captures this teamwork perfectly. The photograph, taken by Juan Beltrán, an instrumentation technician at ESO's Paranal Observatory in Chile, marks the beginning of a new interferometry era.

J. Beltrán/ESO

Astronomical Science

ESO/A. R. G. do Brito do Vale et al.

This image shows the RCW 36 nebula, located about 2300 light-years away in the Vela constellation. Coincidently, this nebula, resembling a hawk, was also captured by a hawk — the HAWK-I instrument on the VLT.

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Exocometary Belts Transformed by ALMA

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Exocometary belts are belts of planetesimals lying in the cold outer regions of planetary systems — analogues of our Solar System's Edgeworth–Kuiper belt. Like extrasolar planets, these ice reservoirs are very common in extrasolar planetary systems. In the last 12 years, sensitive, spatially resolved observations enabled by the Atacama Large Millimeter/submillimeter Array (ALMA) have fundamentally transformed our understanding of these belts. ALMA has exposed their exocometary nature with detections of volatile gas linked to exocometary ice compositions and revealed a variety of radial and vertical (sub)structures often linked to ice/gas giants lurking below detectability at tens of au. These ALMA-enabled advances provide new insight into the composition, dynamics and diversity of exocometary belts, and their role in shaping outer planetary systems in the latest stages of planet formation and beyond.

Exocometary belts in outer planetary systems

With the rapid developments in exoplanet discovery in the past three decades, it is now common knowledge that most stars in our Galaxy are surrounded by rich and varied exoplanetary systems. Beyond the vast majority of discovered exoplanets, which lie in the inner ~au region of planetary systems, a significant fraction of stars in our Galaxy (at least ~20%, but potentially up to ~75%; Eiroa et al., 2013; Pawellek et al., 2021) also host belts of small bodies (planetesimals), dust and gas. These belts, commonly also referred to as debris discs, are extrasolar Edgeworth–Kuiper belt analogues (or exoKuiper belts), lying in the frigid outer reaches — at tens of au — of exoplanetary systems. Their widespread presence alone indicates that the planet formation process efficiently produces extrasolar planetesimals as well as planets. These planetesimals give us an insight on their formation, a key intermediate step in the making of planets. By forming at tens of au from their host star, these planetesimals are likely icy analogues of Kuiper Belt Objects and they release dust and volatile gas that makes them observable; this means that they can be viewed as 'exocomets' (Strøm et al., 2020; Fitzsimmons et al., 2024) and their natal belts as 'exocometary belts', the ice reservoirs of planetary systems.

The first landmark detection of dust in a belt was through the unresolved infrared excess it produces around Vega (Aumann et al., 1984); this was quickly followed by the first coronagraphic image of the edge-on belt around beta Pictoris (Smith & Terrile, 1984). The dust observed in these belts (typically ≳ 100 times lower in mass than their young protoplanetary disc counterparts) is short-lived, owing to the outward radiation pressure by photons from the typically intermediate-mass host stars. As such, it must be continuously produced through the collisional destruction of larger and larger solids, within a 'collisional cascade'. This cascade is likely to extend from observable, micron- to centimetre-sized grains to solids as large as about kilometre-sized planetesimals, which are required to sustain dust production over the main sequence age of belt-hosting systems.

One clear consequence of collisional evolution is mass loss from the belt over time, which in turn should cause the belts' infrared (IR) emission, typically peaking in the far-IR given dust temperatures at 10–100s of au around A–G-type stars, to decrease with system age. This is clearly observed in belt population studies in the mid-to-far IR with Spitzer and Herschel space-based surveys, which are most sensitive to the peak brightness of these belts (for example, Wyatt et al., 2007; Sibthorpe et al., 2018), as well as by the pioneering SCUBA-2 Observations of Nearby Stars (SONS) survey with the single-dish James Clerk Maxwell Telescope at submillimetre wavelengths (Holland et al., 2017). This also has the important implication that most of the brightest, well-studied belts are young, in the 10 to few 100 Myr era corresponding to the latest stages of planet formation, following from protoplanetary disc dispersal.

Millimetre/submillimetre-wavelength belt studies are key as they probe ~millimetre-sized, gravitationally bound grains. Contrary to the micron/tens of micron-sized grains probed both in the mid- to far-IR (via thermal emission) and optical/near-IR (via scattered starlight), millimetre-sized grains are large enough not to be affected by radiation forces. This makes them direct tracers of the location and dynamics of larger planetesimals. However, the low dust masses typical of detectable exocometary belts (~1–30 Moon masses) measured at millimetre-wavelenghts, and their relatively large on-sky extent (~1–16 arcseconds in diameter at 150–10 pc for an 80-au belt) result in low-surface-brightness emission which made millimetre-wavelength imaging very challenging with single-dish telescopes or small interferometers; this meant resolved millimetre studies of exocometary belts were limited to a few nearby systems (for example, Greaves et al., 1998; Hughes et al., 2008).

The exocometary (icy) nature of planetesimals in these belts was originally postulated based only on their observed dust temperature, and by association with our Solar System's Edgeworth-Kuiper belt. Evidence for ice was very indirect, through modelling of the belts' spectral energy distribution (for example, Lebreton et al., 2012) and evidence of volatile gas was limited to two systems with CO line detections: 49 Ceti and beta Pictoris (Zuckerman, Forveille & Kastner, 1995; Roberge et al., 2000). For a long time this led to the lack of significant amounts of gas being a defining feature of exocometary belts, in contrast to younger protoplanetary discs.

The Atacama Large Millimeter/submillimeter Array (ALMA) has profoundly transformed our view of exocometary belts and our ability to study them. This contributed significantly to the growth of the wider debris disc community, to the point of sustaining its own yearly/bi-yearly conference series, with its sixth edition since the first 2018 meeting in Victoria, Canada taking place this coming July 2026 at the University of Cambridge, UK[1]. Below, we highlight a few key ALMA-enabled breakthroughs, before reflecting on what the future might hold for this emerging sub-field of exoplanetary system science.

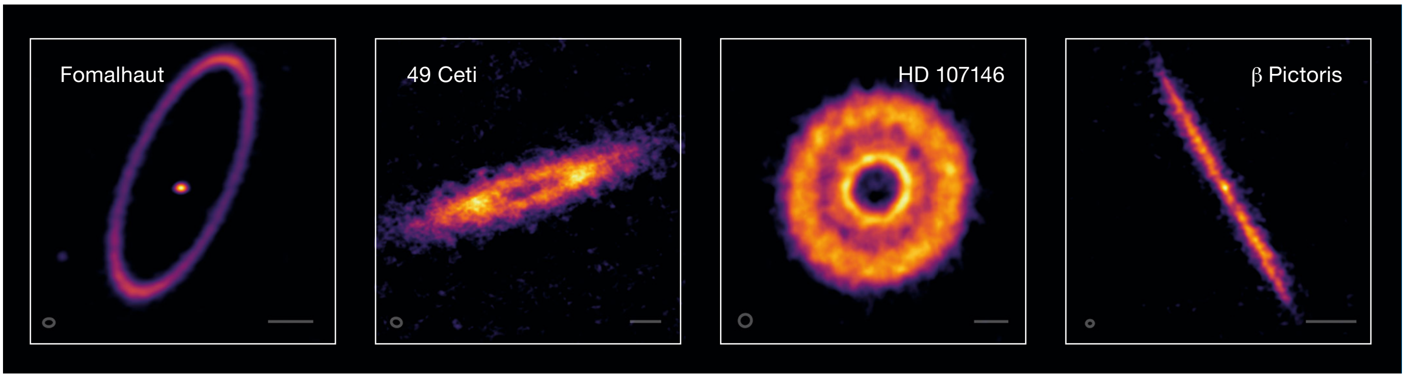

Figure 1. ALMA images of ~mm-wavelength dust emission from the exocometary belts around four nearby stars: Fomalhaut (MacGregor et al., 2017), 49 Ceti (Marino et al., 2026), HD 107146 (Marino et al., 2018) and beta Pictoris (Matrà et al., 2019). These reveal a variety of radial structure, from eccentric narrow rings to broad and gapped belts, to edge-on belts with complex vertical structure. The ellipse in the bottom left represents the spatial resolution of the data and the scale bar indicates a physical distance of 50 au.

Exocometary belt (sub-)structure: dynamical signatures of ice giants at 10s of au

ALMA's key enabling feature for exocometary belt studies has been the major increase in sensitivity it offers thanks to its collecting area, as well as its resolution in the 0.1–1 arcsecond range. A major scientific advance it brought about is the ability to image the dust continuum from millimetre-sized grains, gravitationally bound to the central star at unprecedented resolution, allowing us to detect structure at physical scales of a few to a few tens of au (Figure 1). These physical scales correspond to a few to a few tens percent of a belt's radius (distance from the star); accessing them with ALMA is transformational as these are the scales at which we expect to observe radial and vertical substructure produced by ice and gas giant planets. Following targeted pilot studies, the recently released ALMA Resolved exo-Kuiper belt Substructures (ARKS) ALMA Large Programme presents the most comprehensive view of (sub)structure in belts; we here highlight some of its findings as well as other key ALMA results.

Radial structure

ALMA moderate-resolution observations of 74 belts uniformly analysed as part of the REsolved ALMA and SMA Observations of Nearby Stars (REASONS) study show that a significant fraction of belts defies the classical picture of being a narrow ring such as Fomalhaut (Figure 1), instead being broad discs with a width more than half their radius (Matrà et al., 2025). Targeted studies of iconic systems such as HR8799 and Vega showed that at least some broad discs remain broad and smooth when imaged at higher resolution (Faramaz et al., 2021; Matrà et al., 2020); this is confirmed in around 40% of 24 systems in the ARKS Large Programme (like 49 Ceti; Figure 1 and Han et al., 2026). These broad belts are challenging to explain given the narrowness of rings observed in most young protoplanetary discs (Bae et al., 2023). The connection between the two evolutionary stages is therefore not as simple as one might expect, and other processes need to be invoked, such as migrating planets moving dust traps/rings and forming planetesimal discs across a wide range of radii (Miller et al., 2021) or scattering of planetesimals by a planet interior to the belts (Geiler et al., 2019).

On the other hand, the ARKS programme has established that about 50% of bright belts, when observed at sufficiently high resolution, show substructure in the form of multiple rings with gaps (for example, Marino et al., 2018), or bright rings on top of low-amplitude broad emission (Han et al., 2026). If interpreting gapped belts in the simple picture of a single static planet on a circular orbit carving the gap, the gap width measured by ALMA implies the presence of ~Neptune- to super-Jupiter-mass planets at 20–80 au in mature planetary systems. The vast majority of these remain below detectability with direct imaging (Milli et al., 2026; Bendahan-West et al., 2026), highlighting the role of belt substructure in revealing the influence of otherwise undetectable, long-period planets.

It is important, however, to recognise that these substructures may simply be inherited from protoplanetary discs (Marino et al., 2019), or created by alternative dynamical processes such as multiple planets, planet migration, mean motion resonances and secular interactions (for example, Pearce & Wyatt, 2015; Friebe, Pierce & Löhne, 2022). ALMA measurements of the sharpness of the inner and outer edges of planetesimal belts are a further indication of present or past interaction with planets (Pearce et al., 2024, Marino, 2021), though a fraction of the belts show shallow inner edges consistent with being produced by collisional evolution alone (Imaz-Blanco et al., 2023).

Vertical structure

A long-standing, fundamental challenge in the field has been weighing the mass in solids present within the belts; as mass is dominated by the largest objects in the collisional cascade, which are not observable directly, this is the same as asking how large the biggest planetesimals are — a key constraint for planetesimal formation models. ALMA has shed new light on this by allowing measurements of the belts' vertical structure, which can be linked to the velocity dispersion of dust particles imparted by the gravitational effect and therefore the mass/size of the largest solid bodies within the belts (for example, Quillen, Morbidelli & Moore, 2007). The first two pilot ALMA studies of edge-on belts discovered, on the one hand (Daley et al., 2019) that the largest bodies in the AU Mic belt must be less massive than ~1.8 $M_\oplus$. On the other hand, in the case of beta Pictoris (Figure 1; Matrà et al., 2019) ALMA revealed a complex vertical structure analogous to the two-component (dynamically hot and cold) population of classical Kuiper Belt Objects (for example, Brown et al., 2001). This points to the potential of planets interior/exterior to the belts to also contribute to the belt's vertical structure, as Neptune would have done by migrating outwards in our Edgeworth-Kuiper belt (for example, Nesvorný, 2015).

We now know from the ARKS programme (Zawadzki et al., 2026) — vertically resolving 13 systems — that belts show a wide variety of vertical thicknesses, with aspect ratios of ~0.003 to ~0.2 indicating that the largest bodies within the belts have radii in the range ~30–3000 km (between a large comet and Mars). However, ARKS has also shown complex structure similar to beta Pictoris for 10/13 belts, indicating that interaction with interior/exterior planets may be a common feature of exocometary belts. This corroborates the radial structure results, with ALMA showing overall that ice giants at tens of au commonly form in systems with bright belts, dynamically shaping planetary systems and likely producing volatile transport from these icy belt reservoirs.

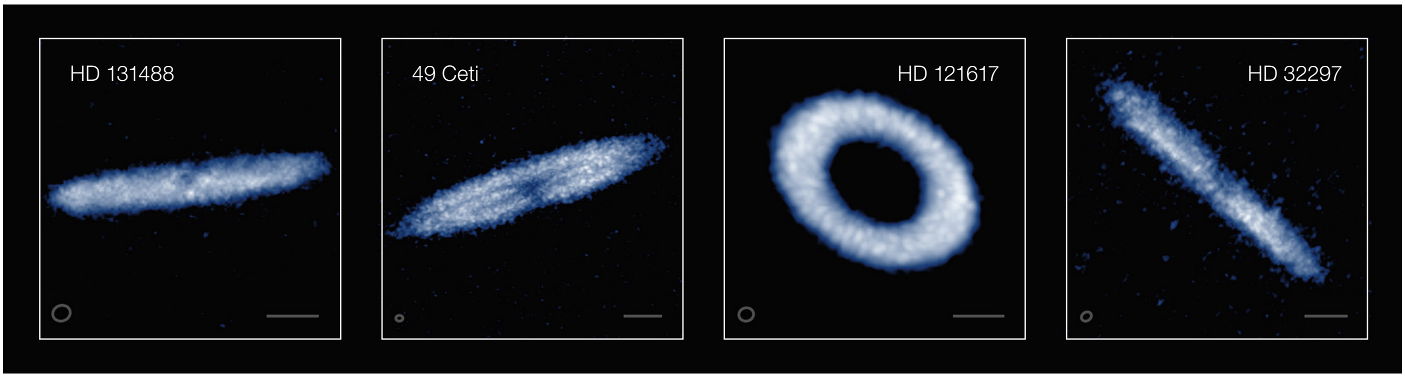

Figure 2. ALMA ARKS Large Programme images of ^{12}CO J = 3–2 (peak) line emission from the CO-rich exocometary belts around HD 131488, 49 Ceti, HD 121617 and HD 32297 (Mac Manamon et al., 2026), showing abundant optically thick emission co-located with, but typically more radially extended than, the belts traced by the millimetre dust. The ellipse in the bottom left represents the spatial resolution of the data and the scale bar indicates a physical distance of 50 au.

ALMA discovers volatile gas: exocometary release or planet formation leftover?

A key discovery enabled by the sensitivity of ALMA has been the detection of gas in the form of carbon monoxide (CO) and/or atomic carbon (CI) in around 25 exocometary belts, or about 30% of the ALMA resolved exocometary belt population. Small ALMA surveys focused so far on stars with belts known to be bright in dust emission. These show that the detectability of gas correlates with 1) age, in all but two CO-bearing belts in systems <50 Myr old (for example, Mac Manamon et al., 2026), and 2) luminosity of the central star, with around a 70% CO detection rate around A stars with bright exocometary belts (Moór et al., 2025). Amongst the detections, a dichotomy has arisen between CO-poor belts, with optically thin ^{12}CO and masses $< 10^{-3}\ M_\oplus$ and CO-rich belts with CO masses $> 10^{-3}\ M_\oplus$ (for example, Cataldi et al., 2023).

CO-rich belts tend to be bright and are amenable to high-resolution studies, with five of them observed at unprecedented spectrospatial resolution through the ARKS programme (Figure 2). ARKS confirmed that ^{12}CO emission is very optically thick (Brennan et al., 2026) and that it is typically broader than the belt as traced by dust (Mac Manamon et al., 2026); it also showed that dust may be significantly affected by gas drag in CO-rich systems (Marino et al., 2026; Weber et al., 2026; Milli et al., 2026).

The origin of this gas has been a matter of intense debate over the past decade. On the one hand, CO-poor systems like beta Pictoris have insufficient gas to shield themselves from the stellar and interstellar UV radiation field, leading to ~100-yr destruction timescales. This means that, like the dust, CO must be continuously replenished (Zuckerman & Song, 2012; Matrà et al., 2015) by exocomets within the belt. This led to the realisation that ALMA allows us to access the volatile component of exocomets released from exocometary ice. Assuming gas release over time through the same collisional cascade producing the dust, a CO+CO$_2$ mass fraction may be derived from the observed CO gas mass, revealing exocometary CO+CO$_2$ compositions similar to those of Solar System comets (Matrà et al., 2017, 2019). Rapid UV photodissociation unfortunately hinders a broader compositional comparison, as other molecules are typically much shorter-lived than CO, explaining non-detections in millimetre molecular surveys so far (Matrà et al., 2018; Klusmeyer et al., 2021).

The picture remains complicated, on the other hand, for CO-rich belts, as the CO exocometary production rates required to explain the observed high masses would be unreasonably high (Kóspál et al., 2013), implying that the CO must be shielded from photodissociation by itself or other species. In an exocometary release scenario, it is possible that CO gas released fast enough would produce enough atomic carbon to shield the CO itself, allowing it to accumulate and explaining observed CO-rich belts (Kral et al., 2019; Marino et al., 2020). However, the low CI/CO ratios recently measured by ALMA and the Hubble Space Telescope (Cataldi et al., 2023; Brennan et al., 2024) are challenging to explain in this exocometary production scenario.

This leads to the possibility that, instead, enough (undetectable) H_2 could be present as a shielding agent, raising the possibility that CO-rich belts may be long-lived remnants of Herbig Ae protoplanetary discs (Kóspál et al., 2013), with the gas therefore primordial in origin. This is supported by theoretical work indicating that the dispersal of protoplanetary discs around intermediate mass stars may take much longer than previously believed, and up to tens of Myr (Nakatani et al., 2021, 2023). However, the primordial H_2 scenario for CO-rich belts is also challenged by the high mean molecular weights derived by modelling high-resolution gas observations (Figure 2; Hughes et al., 2017; Brennan et al., 2026), and now by absorption observations with the upgraded CRyogenic high-resolution InfraRed Echelle Spectrograph (CRIRES$^+$) at the Very Large Telescope that show a CO/H_2 ratio $> 10^{-3}$ in a CO-rich belt, significantly higher than expected from protoplanetary disc or interstellar medium gas (Smith et al., 2026).

ALMA's key role for the community and the future quest for sensitivity

ALMA has enabled transformational progress in our understanding of exocometary belts in the outer regions of planetary systems; detailed targeted studies, the REASONS population study and now the ARKS Large Programme have given us access to key angular scales at sufficient sensitivity to meaningfully constrain exocometary belt physics, dynamically revealing interaction with otherwise undetectable ice and gas giant analogues at tens of au. ALMA has also opened a completely new direction and challenged the very definition of belts by discovering volatile CO and CI gas, verifying their exocometary nature and allowing us to access exocometary compositions.

Many mysteries remain, such as the origin of the CO-rich belts discussed here, as well as many unanswered questions, such as the occurrence and nature of belts closer to the star (potentially undetectable because they are faint) and those around low mass stars. Despite being the most common planetary systems in the Galaxy, their outer planetary systems remain completely unexplored (only one belt resolved by ALMA around $< 0.1\ L_\odot$ stars, with most studied belts in the A–F-type range). ALMA has characterised the brightest, largest and most massive belts, the tip of the iceberg and around 3–5 orders of magnitude more massive than our Solar System's Asteroid and Edgeworth-Kuiper belts.

The key need of the community is more surface brightness sensitivity for both continuum and line observations, as making progress from the current state of the art is not limited by ALMA's highest achievable resolution, but rather by its sensitivity. In the short term, deeper integrations and further characterisation of bright systems with current ALMA, as well as the moderate continuum sensitivity advance brought by the Wideband Sensitivity Upgrade will be beneficial to the community and will continue to provide interesting insights into exocometary belts as the ice reservoirs of planetary systems. These ALMA results will be enhanced by complementary observations at other wavelengths. JWST will lead the quest for directly imaged planets, but also for warmer dust and solid-state ice features (for example, Su et al., 2024; Xie et al., 2025), whereas the Extremely Large Telescope's Mid-infrared ELT Imager and Spectrograph (METIS) and Multi-AO Imaging CAmera for Deep Observations (MICADO) instruments will soon enable high-contrast imaging in the *M/N* band and for more compact/distant belts. In the longer term, however, moving from the tip of the iceberg to studying the most common exocometary belts requires a significant improvement in sensitivity as well as flexible resolution from a few milliarcsec to ~1 arcsec, making a next generation millimetre interferometer with a transformational increase in collecting area best placed to enable the next big leaps in exocometary belt science.

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Links

[1] Debris Disk Connections conference 2026: https://www.ast.cam.ac.uk/debris-disk-connections

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ERIS: A Snapshot of the Guaranteed Time Programmes

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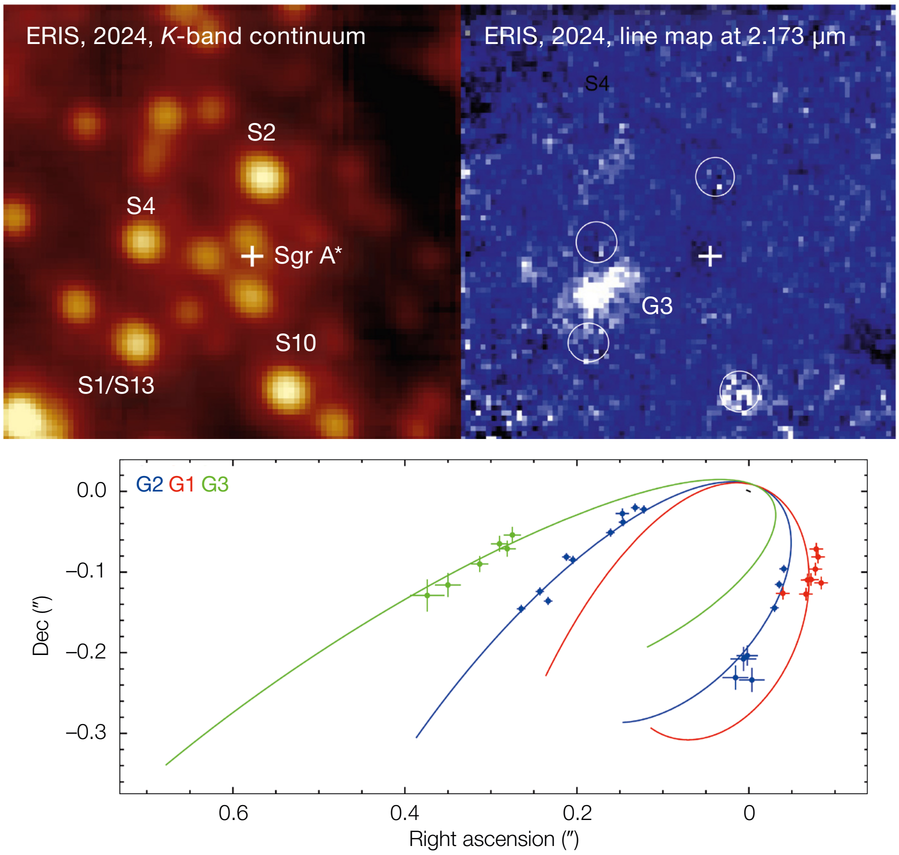
The Enhanced Resolution Imager and Spectrograph (ERIS) was conceived as a project to retain and enhance ESO's fundamental capabilities for diffraction-limited imaging and spectroscopy at ESO's Very Large Telescope. It significantly improves on the performance of two instruments that were being maintained beyond their operational lifetimes. The observational modes are integral field spectroscopy at 1–2.5 μm, imaging at 1–5 μm with several options for high-contrast imaging, and long-slit spectroscopy at 3–4 μm. ERIS has been in operation for the community since April 2023 and is very much in demand, regularly providing data quality that previously was only achieved in the best conditions. Here we highlight a snapshot of a few of the Guaranteed Time Observations projects, showing that the consortium is now engaged in an exciting science programme.

Figure 1. The integration team after successfully mounting ERIS to the Cassegrain focus of Unit Telescope 4 at the VLT. Adhering to the restrictions associated with the pandemic, both for travel and while at the observatory, made the whole process of integration and testing much more arduous than in normal times.

ERIS in a nutshell

The Enhanced Resolution Imager and Spectrograph (ERIS; Davies et al., 2023) is a Cassegrain instrument on Unit Telescope 4 of ESO's Very Large Telescope (VLT) that combines a new imaging camera (NIX), with a refurbishment and upgrade of the integral field spectrometer (SPIFFIER), and a new adaptive optics module that makes use of the Adaptive Optics Facility (AOF). Phase B of the project began at the end of 2014 with a mandate from the ESO Scientific Technical Committee that the project should be aiming for first light not later than 2020. This goal was, however, largely stymied by the pandemic, which led to a severe restriction of lab access, hampered participation at acceptance tests and curtailed travel. Despite these challenges, the instrument was shipped in 2021 and integration at the observatory began immediately after international travel restrictions were lifted. Commissioning was carried out during 2022 (Figure 1), with a first light announcement[1] and then science verification at the end of that year (Concas et al., 2023). ERIS was included in the Call for Proposals for Period 111, with guest observations beginning in April 2023.

Figure 2. The Galactic Centre in *K*-band continuum (top left) and 2.17-μm Brγ line emission (top right). The orbits of the three gas clumps are shown in the bottom panel, where they have been fitted simultaneously.



ERIS comprises several major sub-systems which are integrated in and around a central structure that attaches to the telescope adaptor-rotator:

- The Adaptive Optics module provides wavefront sensing and works with the AOF to correct atmospheric turbulence using the telescope's deformable secondary mirror. With a natural guide star it can provide Strehl ratios up to about 80% in the *K* band in median conditions; and with a single laser guide star (from any of the four AOF lasers) it can reach 60% in the *K* band in median seeing, and has been tested with tip-tilt stars as faint as 19 mag in the *R* band.
- The Calibration Unit allows internal calibration and registration of the wavefront sensors at optical wavelengths, and the two science instruments at 1–2.5 μm. Longer wavelength calibrations for NIX are performed on-sky.
- The integral field spectrometer SPIFFIER operates at 1–2.5 μm and provides 64 × 32 spatial pixels at 12.5 × 25 milliarcseconds over a 0.8-arcsecond field, 50 × 100 milliarcseconds over a 3.2-arcsecond field, or 125 × 250 milliarcseconds over a 8.0-arcsecond field. It offers two spectral resolutions, $R \sim 5000$ over full bands, or $R \sim 10\,000$ over half bands.
- The imager NIX operates at 1–5 μm and provides two pixel scales, 13 milliarcseconds over a 26.4-arcsecond field, or 27 milliarcseconds over a 55.4-arcsecond field. Imaging is offered with broad- and narrow-band filters, and with slow and fast speeds for reading the detectors. The observing modes include high-contrast imaging with a focal plane mask (annular groove, or vortex, mask) or pupil-plane masks (a grating vector apodised phase plate, or sparse-aperture masks), as well as long-slit for *L*-band spectroscopy at $R \sim 450$.

The consortium that designed and built ERIS together with ESO was led by the Max Planck Institute for extraterrestrial Physics, with the Italian National Institute for Astrophysics (INAF, at Arcetri, Teramo [now Abruzzo] and Padua), the UK Science and Technology Facilities Council (UK Astronomy Technology Centre, Edinburgh), the Swiss Federal Institute of Technology (ETH Zurich), and the Netherlands Research School for Astronomy (at Leiden). They provided the staff effort and contributed to the hardware costs, in return for which they were granted Guaranteed Time Observations (GTO). For these institutes the main science drivers were the Galactic centre, the evolution of galaxies, and exoplanets and their formation. The remainder of this article describes some of the initial results from the GTO programmes which are based on these themes.

Gas clouds in the Galactic centre

An unexpected and exciting discovery that for the first time provides a unified origin for all the reported detections of gas clouds in the Galactic centre (GC) was presented by Gillessen et al. (2026). The first detection of a gas cloud falling towards the GC just over a decade ago (Gillessen et al., 2012) led to a frenzy of activity to try and understand what it is and where it came from, and whether it would be dramatically disrupted as it passed close to SgrA*. In the end, there

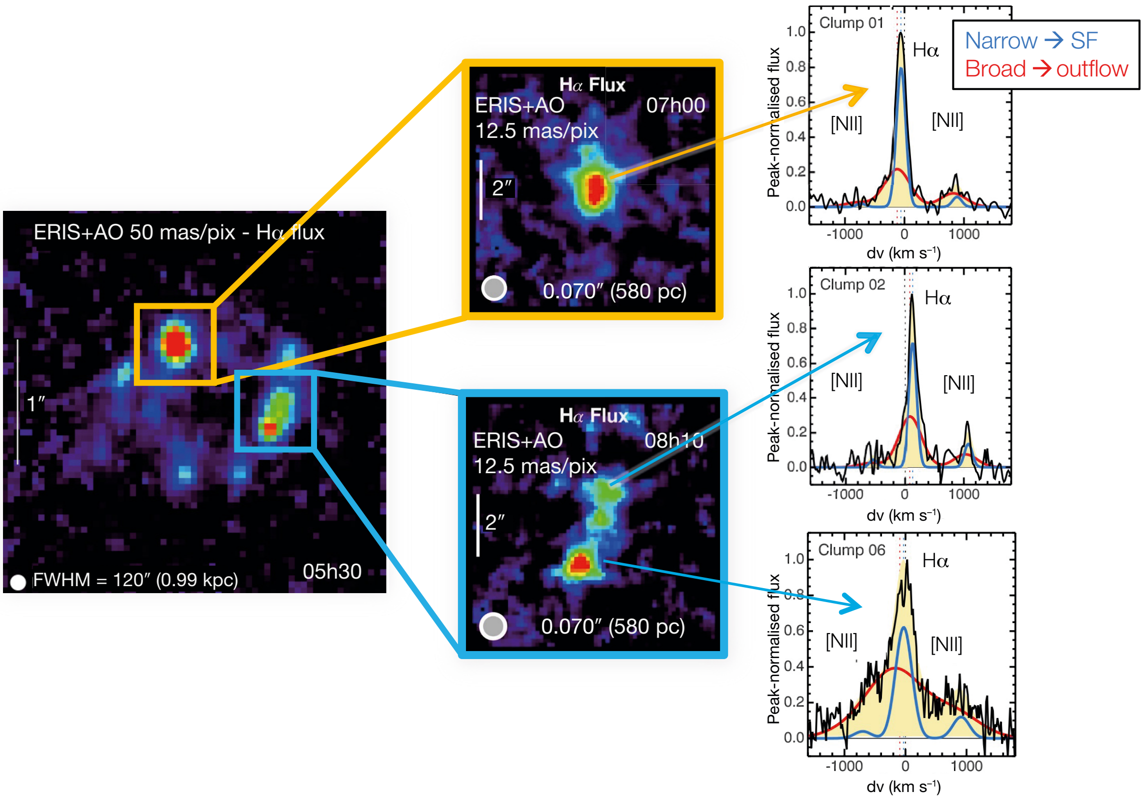


Figure 3. ERIS/IFS+AO Hα emission-line map of a clumpy galaxy at $z \sim 2.2$. The intermediate-resolution map obtained with the 50-milliarcseconds pixel^{-1} scale (left) reveals a large number of faint clumps that match up well with JWST continuum imaging, as well as two brighter conglomerates. High-resolution mapping using the 12.5-milliarcseconds-pixel^{-1} scale of these reveals their internal structures, and their spectral line profiles indicate both star formation and outflow.

was no firm consensus as to whether it was a pure gas cloud or had a stellar object at its centre, and it remained coherent even after pericentre which allowed the drag force of the interstellar medium to be measured. But it did lead to a retrospective realisation that a source emitting in the *L* band that had been noted a decade earlier was, after finding it in earlier Spectrograph for INtegral Field Observations in the Near-Infrared (SINFONI) datacubes, also a gas cloud with a similar orbit (Pfuhl et al., 2015). Now, within months of ERIS being pointed towards the GC, a third gas cloud on a similar orbit has been discovered via its Brγ emission, creating a series G1-2-3 (Figure 2).

Because the likelihood of finding three clouds on similar orbits is low, Gillessen et al. (2026) modelled them with the same orbit, only allowing the time and longitude of pericentre to vary between them. The remarkable success of this endeavour strongly points to a common origin for all three clouds. And, indeed, the location and time of apocentre, and its implied rotation rate, are a close match to the orbit of IRS 16SW. This source is a Wolf–Rayet eclipsing binary system that is known to have a stellar wind. Using smoothed-particle hydrodynamic simulations, the authors showed that in principle such a wind with a terminal velocity of 300–400 km s^{-1} could interact with the ambient interstellar medium and form a dense bow shock. This then fragments into clumps, a few of which can end up on orbits towards Sgr A*. Further confirmation of this hypothesis is needed to understand the entire process better. And as monitoring of the GC continues, the picture will become clearer, perhaps leading to discovery of a fourth gas cloud in the coming decade.

ERIS has also proven to excel when it comes to monitoring stellar orbits. The higher Strehl ratio compared to SINFONI has made it possible to classify a few faint stars in the direct vicinity of Sgr A*, which previously have not been accessible. The resulting radial velocities are very valuable: for stars with an astrometric acceleration, a single-epoch detection of the radial velocity uniquely determines the orbit. The high-resolution mode has also already yielded new insights: radial velocities of cooler stars with CO bandheads in the *K* band can be determined with accuracies of around 1 km s^{-1}. This also translates directly into being able to determine orbits, because a change in radial velocity — a radial acceleration — is as valuable as an astrometric one.

Zooming in on the clumps of cosmic noon galaxies

It is nearly two decades since near-infrared integral field spectroscopy showed the first evidence, by tracing spatially resolved line emission and kinematics, that a majority of star-forming galaxies at $z \sim 2$ were rotating discs, despite prominently clumpy morphologies especially towards rest-frame ultraviolet wavelengths. Subsequent deep adaptive optics observations of increasing numbers of star-forming galaxies at cosmic noon resolved the ionised gas, via the Hα and [NII] lines, on similar scales, revealing their detailed morphology and kinematics (Förster Schreiber et al., 2018 and references therein). However, probing the internal structure of the clumps themselves had to wait for the higher throughput and better adaptive optics performance of ERIS.

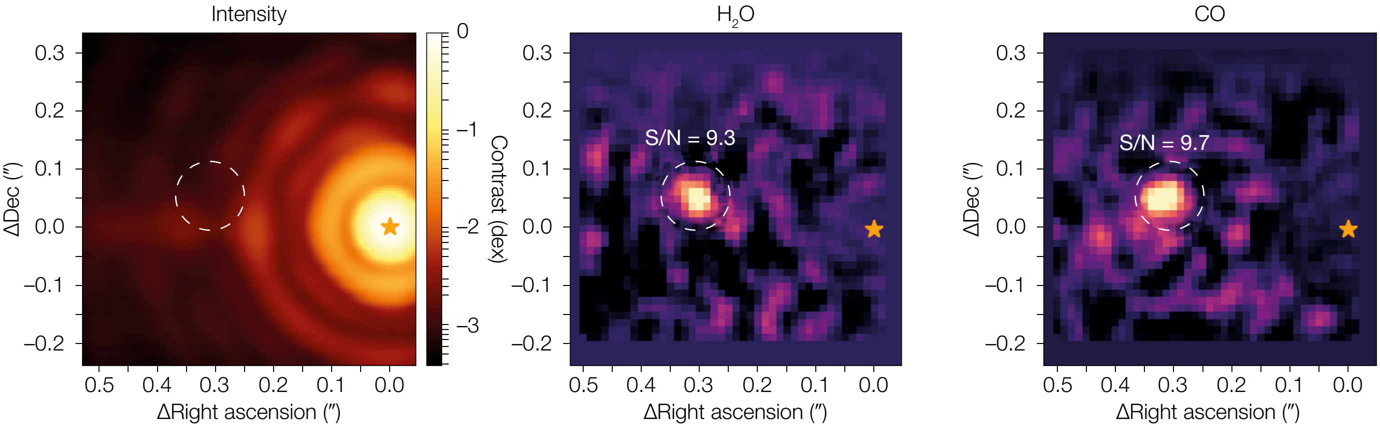


Figure 4. Molecular mapping of AF Lep b with integral field spectroscopy. Left: continuum image of the star, with the location of the planet marked. Centre & right: cross-correlation maps of the H_20 and CO respectively, showing a clear detection of the planet.

Very deep integrations, of 10–20 hours, together with careful compensation of the residual flexure and special techniques for reducing the impact of the OH night sky lines, have yielded data with spatial resolution close to 500 pc. They show that rather than all having condensed out of the global kinematics, the clumps exhibit a variety of structures with at most modest internal kinematic signatures and a wide range of masses, star formation rates and outflow rates (for example, Förster Schreiber et al., 2026). Data for one clumpy galaxy at $z = 2.19$ are featured in Figure 3. In this case the brightest clump has a compact core but also a rather smooth envelope extending out to a kiloparsec, and another clump appears to have two compact cores close to each other without a broader halo. In a third case, the ionised gas complex is resolved in a string of compact clumps that contrasts surprisingly with the shorter wavelength continuum images from JWST at comparable resolution, suggestive of a range of evolutionary ages. The spectral profile of the line emission reveals outflows that in one case dominate the line profile and can be traced to velocities exceeding 1000 km s^{-1}. The mass, star formation rate and outflow rate of this particular clump show that this extreme and off-centre star cluster may host an accreting black hole.

Molecular mapping of exoplanets

A very different application of integral field spectroscopy, that has been around for about a decade, is to directly test for the presence of molecules in the atmospheres of exoplanets, which simultaneously provides a measure of the radial velocity and hence helps pin down the orbital parameters. The first demonstration of how successful this technique can be with ERIS was made by Hayoz et al. (2025) for the young super-Jovian planet AF Lep b. This planet, which is at a distance of 27 pc and orbits an F8V star, has a mass of only 3.7 ± 0.5 M_{Jup} putting it among the lowest-mass exoplanets that have been directly imaged.

Achieving the result required developing techniques suited to this type of data to improve on the wavelength calibration provided by the pipeline. Using the $R \sim 11\,000$ resolution to exploit differences in spectral features between the star and its companion, the stellar spectrum was then removed from the data cube. The residuals contain key information about the planet's atmosphere, which can be extracted by cross-correlation with molecular spectral templates, making use of all the spectral channels simultaneously. Doing this for H_2O and CO yielded very significant detections in the same location (Figure 4), while CH_4 and CO_2 were not detected. Since the planet's temperature of 800 K would tend to favour CH_4 over CO, this result supports the hypothesis of chemical disequilibrium in which there is an upward stream from hotter deeper layers bringing molecules such as CO to the surface.

The cross-correlation technique simultaneously provides a measure of the radial velocity of the planet with respect to the star via the spectral location of its peak. The relative velocities associated with the two detected molecules are 8.9 ± 2.5 km s^{-1} and 6.1 ± 2.8 km s^{-1}. These values are consistent with an independent measurement from the High-Resolution Imaging and Spectroscopy of Exoplanets (HiRISE; Denis et al., 2025) instrument at the Very Large Telescope and unambiguously favour an orbital solution in which the planet was close to its maximum line-of-sight velocity, recently crossing the plane of the sky so that it is currently located behind the star. This means it is now possible to compute a phase curve for AF Lep b, which is important for planning future visible observations that probe the reflected light. A follow-up work (Hayoz et al., 2026) applying the same technique to 12 planetary-mass companions has ubiquitously detected H_2O and CO in their atmospheres, and enabled the detection of the ^{13}CO isotopologue in one of them. Combined with archival data, the new ERIS spectra were able to systematically constrain the atmospheric C/O ratio and metallicities of these companions, yielding insights into planet formation scenarios. And in addition the radial velocities and relative astrometry have improved the constraints on their orbital parameters.

A mid-infrared view of protoplanetary discs

Detecting embedded protoplanets remains extremely challenging because these young objects are deeply buried within their natal discs, where strong dust extinction and bright stellar residuals hinder direct detection. High-contrast imaging in the L' band offers a powerful way to overcome these limitations by reducing the impact of local extinction and enhancing the planet-to-star flux contrast, making it one of the most promising techniques to reveal forming planets. To enable this, ERIS has a grating vector Apodizing Phase Plate (gvAPP) mounted in the pupil plane, the laboratory and on-sky performance of which are thoroughly analysed by Kenworthy et al. (2026), and also an annular-groove phase mask (vortex coronagraph) mounted in the focal plane.

Using the gvAPP, Maio et al. (2025a) detected seven protoplanetary discs, including two without previous 4-μm detections. In a companion paper using the vortex mask, Maio et al. (2025b) focused on the HD 135344B system, a well-studied transitional disc located at 136 pc and characterised by a wide (~40 au) cavity, multiple optical/near-infrared spiral arms, and a striking azimuthal asymmetry at millimetre wavelengths. As shown in their press release[2], the ERIS data recover the known S1, S2, and S2a spirals, confirming the rich substructure of the disc. Beyond these previously identified components, the data reveal a new point source embedded in the inner disc at the base of the S2 spiral, located about 28 au from the star. The source displays an L'-band contrast of around 3×10^{-3}, and the multi-wavelength analysis suggests a mass $\gtrsim 2\,M_{\mathrm{Jup}}$ together with significant dust extinction ($A_V \gtrsim 10$ mag). Its strong L' emission combined with non-detections at shorter wavelengths is consistent with an actively accreting proto-planet surrounded by a circumplanetary disc. Additionally, a previously unrecognised spiral arm was identified to the northwest, further enriching the morphological complexity of the system. Taken together, these results point toward a physical connection between the detected protoplanet candidate and the surrounding disc substructures, and they provide compelling support for a planet-driven origin of the cavity and spirals in HD 135344B.

Active galactic nuclei: outflows, black hole binaries, and lenses

Active galactic nuclei (AGN) play a crucial role in shaping the evolution of galaxies at all cosmic times through various feedback mechanisms, with impacts on our understanding of galaxy evolution models, particularly at the low- and high-mass ends, and whether galaxies and their supermassive black holes (SMBHs) co-evolve. The extended sky coverage reached by ERIS allows larger populations to be observed at the diffraction limit, enabling a variety of opportunities, including spatially resolving ionised outflows at redshift $z = 2$–11 in galaxies where the molecular gas content is known, in order to assess whether the outflow properties correlate with the available gas reservoirs (Bertola et al., 2026). A second project aims to build a bridge between cosmological simulations of galaxy evolution and the predictions for gravitational wave events from SMBH mergers, by quantifying the incidence of the dual-AGN phase of galaxy evolution, when two or more SMBHs co-exist in a single post-merger galaxy. The merging timescales of these SMBHs can be up to several Gyr and during this phase the objects are revealed as pairs of AGN at close separations (1–6 kpc) inside a common host galaxy. The high angular resolution afforded by ERIS is used to classify the systems as dual or lensed AGN (Mannucci et al., 2023). Figure 5 shows an example of dual AGN separated by 2.2 kpc, with distinct spectra for the two QSOs (Zanchettin et al., 2026). Cases where the systems are identified as lensed QSOs also yield key results, as in the beautiful case of the most compact quadruply lensed QSO known, with an Einstein radius of only 0.2 arcseconds (D'Amato et al., 2026). The background QSO at $z = 2.79$ is lensed by a foreground galaxy at $z = 1.05$, the mass of which can be ascertained rather precisely as $2.3 \times 10^{10}\,M_{\odot}$. The high fidelity of the image allows the galaxy profile and luminosity to be measured, showing that it is an early-type galaxy. The mass-to-light ratio strongly favours a Chabrier IMF, providing one of the best IMF constraints to date on a low-mass galaxy at this redshift.

Final Note

The highlights above represent a current snapshot of some of the GTO projects that the ERIS consortium is pursuing. Contributing to the design, construction, and commissioning of an instrument requires a significant investment of effort over many years. The increasing number of partners in such projects means that an ever larger part of the community can benefit from the GTO which compensates that investment during the first few years of operation, sometimes through programmes that wouldn't necessarily be possible through the open time proposal channel. Similarly, the high demand for

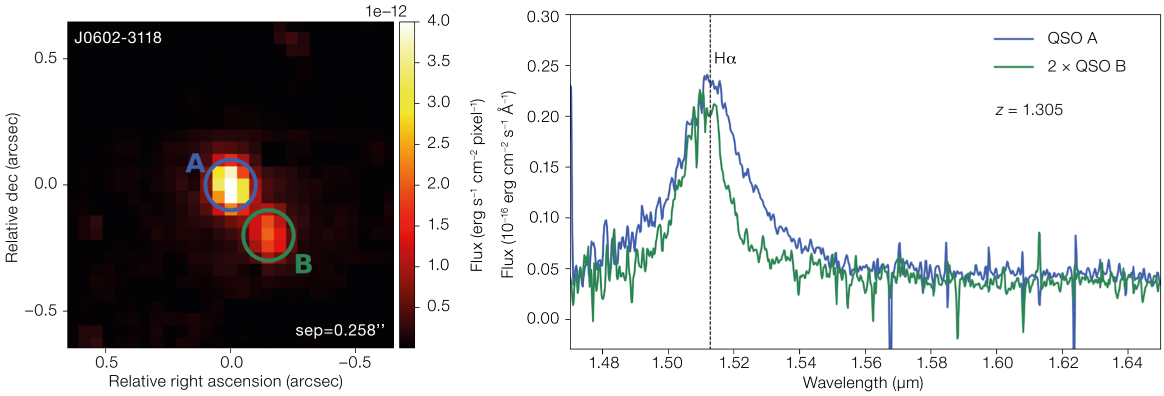


Figure 5. ERIS integral field spectroscopy provides an image (left) and spectra (right) of the two components of the dual AGN J0602-3118 at $z = 1.305$. Even for a projected separation between the two AGN of only 0.258 arcseconds, ERIS can obtain well-resolved spectra, allowing for a clear classification of the system.

ERIS shows that community is also benefitting from the novel capabilities of this new instrument.

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The consortium would like to thank the many people who have contributed to the project in numerous different ways, in some cases 'behind the scenes', both within the partner institutes and at ESO in Garching and at Paranal.

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Links

[1] Sharper infrared eyes for the VLT: ERIS sees first light https://www.eso.org/public/announcements/ann22015

[2] A disc and a planet candidate around the star HD 135344B https://www.eso.org/public/images/comparisons/eso2513a

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A. Trigo/ESO

This image shows the full scope of Paranal's beauty. Cerro Paranal in Chile's Atacama Desert, the mountain peak home to ESO's Very Large Telescope (VLT), is a site of many marvels. And this panoramic image taken by Chilean astrophotographer Alexis Trigo certainly captures them all. Right in front, one of the movable Auxiliary Telescopes (ATs) stands tall. While this "relatively" small 1.8-m telescope has its eyes shut, its bigger siblings, the Unit Telescopes (UTs), each with an 8.2-m mirror, are scanning the sky. The lasers emerging from the UTs each create a bright artificial star on the sky, so the shifts and swirls of the atmosphere can be measured and corrected to deliver sharp data.

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Multiplicity of Massive Stars at Low Metallicity: Early Results from the BLOeM Campaign

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Massive stars at low metallicity (*Z*) play a central role in shaping the high-redshift Universe, yet their multiplicity remains poorly constrained. The Binarity at Low Metallicity (BLOeM) campaign is a two-year survey of 929 stars in the Small Magellanic Cloud with the Fibre Large Array Multi Element Spectrograph (FLAMES) intrument at ESO's Very Large Telescope, providing the first large-scale spectroscopic monitoring of massive stars at low *Z* ($^1/_5$ *solar*). Analysis of the initial nine epochs reveals high intrinsic binary fractions (> 70%) on the main sequence and a steep decline in evolved objects. Analysis of the full dataset will yield orbital solutions, identify black-hole companions and allow a derivation of the initial mass function for single and binary stars at low *Z*.

Massive-star evolution at low metallicity

Massive stars are born with masses greater than eight times that of our Sun ($M_{\text{initial}} \geq 8\,M_\odot$). They end their lives in a sudden core collapse into neutron stars and black holes, often associated with a violent supernova explosion. These hot and luminous stars thus serve as a prominent source for mechanical, chemical and radiative feedback in their host galaxies. Surveys of the Large Magellanic Cloud (LMC) and our Milky Way galaxy have revealed unambiguously high multiplicity fractions. In particular, the majority of massive stars interact with a companion star before core collapse (for example, Sana et al., 2012; de Mink et al., 2014). Such binary interactions not only shape the properties of massive-star populations, but also produce unique phenomena such as stripped stars, X-ray binaries and gravitational-wave sources (for example, Langer, 2012; Marchant & Bodensteiner, 2024).

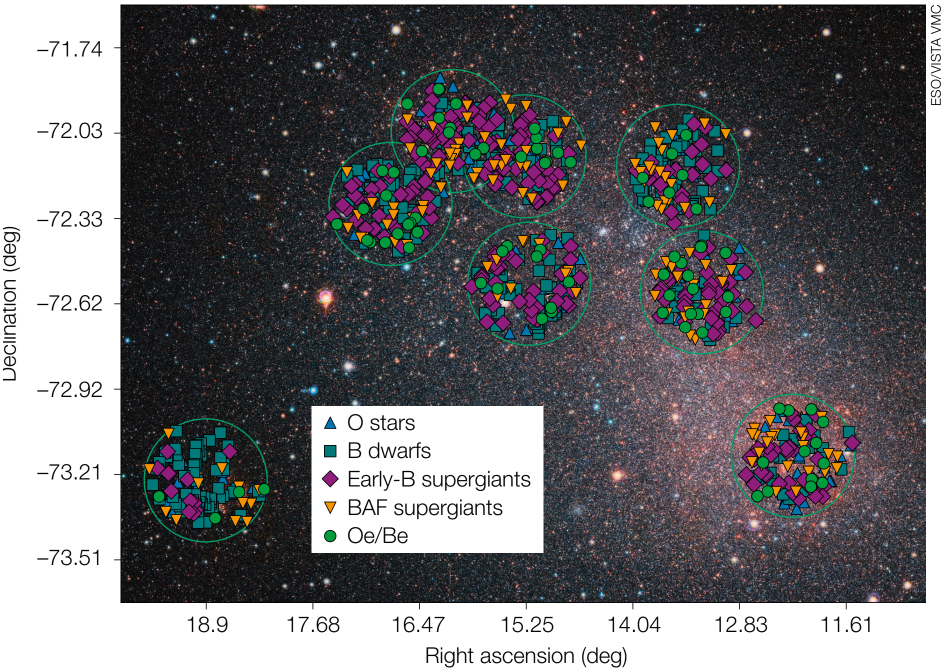

Figure 1. Distribution of the BLOeM targets in the SMC, distributed over eight FLAMES fields (indicated by green circles) and split by spectral types (see legend), overplotted on a VISTA *Y*-*J*-K_S false-colour image.

Massive stars with low metallicity (*Z*) are of particular interest as representatives of stellar populations in the early Universe. Their weaker winds are thought to lead to higher rotation rates and more massive stellar remnants. Such stars are predicted to dominate the progenitor population of black-hole and neutron-star mergers detected by gravitational-wave observatories, to produce long gamma-ray bursts and fast radio bursts and to shape the appearance of high-redshift galaxies through intense ultraviolet radiation (Bromm & Yoshida, 2011; Hopkins et al., 2014; Klessen & Glover, 2023). They likely played a role in reionising the early Universe and possibly in the formation of supermassive black holes. Yet our understanding of the multiplicity properties of massive stars and their evolution at low *Z* remains limited: How do binary fractions and orbital configurations vary with *Z*? Are evolutionary pathways and binary interactions fundamentally different at low *Z*? Does black-hole formation proceed differently?

The Small Magellanic Cloud (SMC; $Z \sim 20\%$ solar metallicity $Z_\odot$), hosting about 10 000 massive stars at a distance of 62 kpc, provides the nearest laboratory in which to obtain answers to these questions. The Binarity at Low Metallicity (BLOeM) campaign (Shenar et al., 2024) is an ESO Large Programme (PI: Shenar; dPI: Bodensteiner, programme ID: 112.25R7) designed to characterise the multiplicity of massive stars in the SMC through an unprecedented spectroscopic monitoring campaign with ESO's Very Large Telescope (VLT). BLOeM collected 25 epochs of spectroscopy with the Fibre Large Array Multi Element Spectrograph (FLAMES/GIRAFFE) between October 2023 and September 2025. By measuring radial velocities (RVs) across 25 epochs for two years, BLOeM enables the derivation of binary fractions and orbits, the detailed characterisation of stellar properties, the identification of dormant (i.e., X-ray-quiet) black hole companions, and the inference of the initial mass function of massive stars. While not pristine, the metal content of the SMC is the lowest at which a survey on this scale has been conducted to date.

This article summarises early results from the first nine epochs (Oct–Dec 2023), characterising the stellar content of the survey and providing the first systematic view of massive-star multiplicity across the SMC.

The BLOeM sample and survey

The 929 BLOeM targets were selected via an automated procedure from the Gaia Data Release 3 catalogue (DR3; Gaia Collaboration et al., 2023) within a radius of 2.6 degrees around the SMC centre, applying magnitude ($G < 16.5$ mag), colour ($BP–RP < 1$ mag), parallax and proper-motion cuts, and excluding Wolf–Rayet stars and red supergiants (see Shenar et al., 2024 for details). No other prior knowledge about the stars was assumed. The resulting sample is distributed across eight FLAMES fields, each 25 arcminutes in diameter, covering the main star-forming regions of the SMC (Figure 1).

All stars were observed with the FLAMES/GIRAFFE LR02 setting (3950–4570 Å; $R \sim 6200$), achieving signal-to-noise ≥ 20 (typically 70–100). The 25 epochs, which were scheduled for observing between October 2023 and September 2025, probe orbital periods up to ~1000 days, with the first nine epochs collected between October and December 2023. These nine epochs, which provide a 2–3-month baseline, were co-added to create high-signal-to-noise templates, enabling detailed spectral classification (Shenar et al., 2024).

The sample spans spectral types O4 to F5, with estimated initial masses from ~8 to 80 $M_{\odot}$. Among the OB stars, 82 exhibit Balmer emission, mostly attributed to rapidly rotating stars with decretion discs (OBe stars). Otherwise, it includes 139 O stars, 309 early B dwarfs/giants (B0-B3 V-III), 262 early B bright giants/supergiants (B0-B3 II-I), and 136 BAF supergiants (B5-F5 I). The sample also contains three B[e] supergiants, four X-ray binaries, three candidate magnetic stars (Of?p), two stripped-star candidates and around 100 eclipsing binaries. Bestenlehner et al. (2025) performed an initial quantitative analysis of the spectra (not yet accounting for binarity), enabling placement on the Hertzsprung–Russell Diagram (HRD), which is shown in Figure 2.

Because massive-star multiplicity is dominated by short-period systems (periods of days to months), the nine-epoch dataset already provides strong leverage on binary fractions, which are described below. However, identifying long-period, low-inclination and extreme mass-ratio binaries will only be possible with the full dataset, as will the complete orbital analysis and characterisation of companions.

Multiplicity of massive stars at low metallicity

The five subsamples described above probe distinct mass ranges and/or evolutionary phases and their distinct spectral characteristics require tailored measurement techniques. Their multiplicity analysis was therefore done separately. Stars exhibiting significant peak-to-peak RV variations above a chosen threshold (typically 20 km s^{-1}) were classified as binaries. Below we summarise the first results in evolutionary order from main-sequence OB stars and OBe stars to evolved supergiants.

Multiplicity across the main sequence: high also at low metallicity

The O-type stars and the early B-type dwarfs and giants together represent the core hydrogen-burning massive-star population in BLOeM, spanning initial masses from ~15 to 80 $M_{\odot}$ for O stars down to ~8 to 15 $M_{\odot}$ for early B-type dwarfs and giants. O-type stars dominate the ionising-photon output and are likely progenitors of the stellar-mass black holes, while early B-type stars are far more numerous, are likely progenitors of neutron stars and trace the bulk of massive-star formation by number. Their combined analysis therefore offers a comprehensive view of massive-star multiplicity across almost an order of magnitude in mass.

Sana, Shenar, & Bodensteiner et al. (2025) identified 62 binaries among 139 O-type stars, yielding an observed fraction of $f_{obs} = 45 \pm 4\%$. Accounting for observational biases, they derived an intrinsic (present-day) binary fraction of $f_{int} = 70^{+11}_{-6}\%$. This confirms, for the first time, that most O stars in the SMC reside in close binaries, consistent with Galactic and LMC results.

Villaseñor et al. (2025) conducted an equivalent analysis for the 309 early-B dwarfs and giants, identifying 153 binaries among them, corresponding to

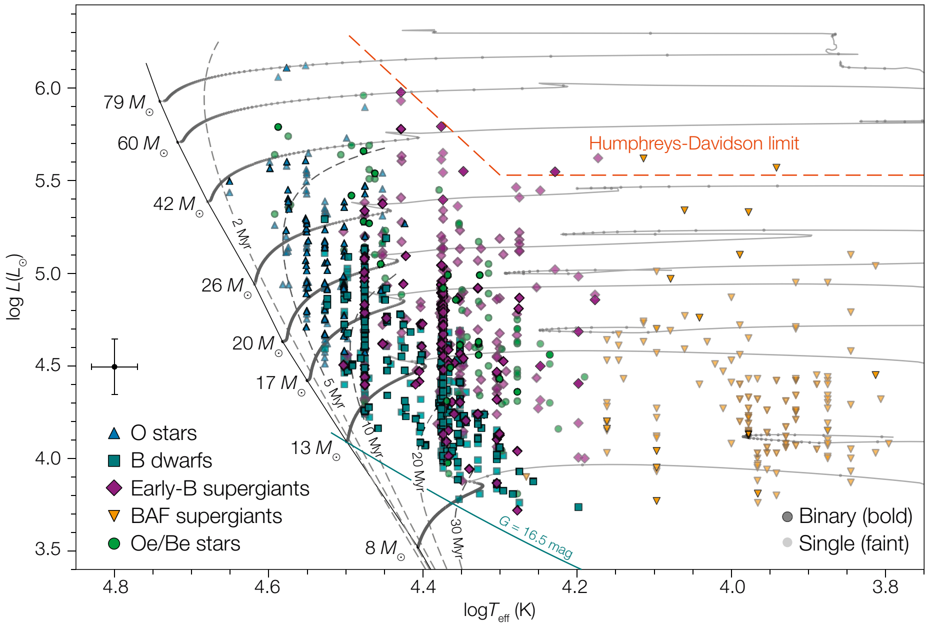

Figure 2. The BLOeM sample shown on a Hertzsprung-Russell diagram (adapted from Shenar et al., 2024), with parameters adopted from Bestenlehner et al. (2025) and Patrick et al. (2025). The assumptions underlying the evolutionary tracks are described by Shenar et al. (2024); dots along the tracks show equidistant time steps of 0.05 Myr. Objects classified as binary candidates from the nine-epoch multiplicity analysis are marked in bold. A very high binary fraction is observed in OB systems, which decreases sharply for the evolved stars in the sample.

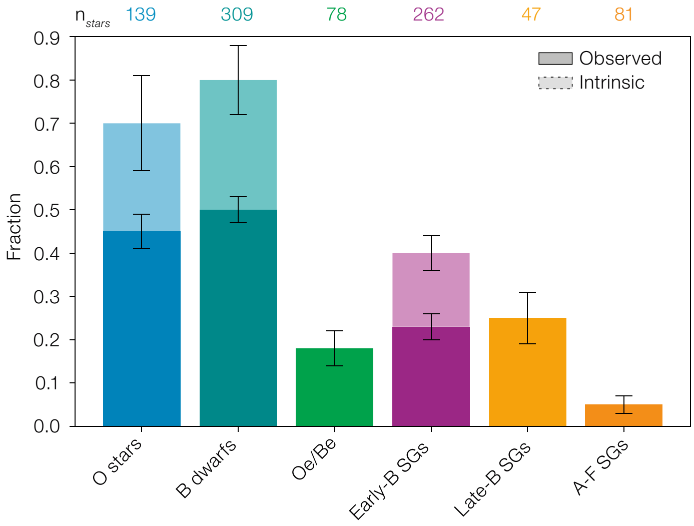

Figure 3. Overview of the binary fractions measured for the different subsamples probed by BLOeM. Results for O stars, B dwarfs, OBe stars, early B supergiants and late BAF supergiants are taken from Sana et al. (2025), Villaseñor et al. (2025), Bodensteiner et al. (2025), Britavskiy et al. (2025) and Patrick et al. (2025). We do not provide bias-corrected binary fractions for likely products of binary interactions (OBe & BAF sample) since knowledge of their underlying orbital-parameter distributions is lacking. Total sizes of the samples are noted above the respective bars.

f_{obs} = 50 ± 3% (see also Moe & Di Stefano, 2013). Bias correction yielded the remarkably high intrinsic fraction of f_{int} = 80 ± 8%, the highest reported for B-type stars at any metallicity. This may hint at an increasing binary fraction toward lower metallicity, though it is consistent with Galactic and LMC results, within errors.

Together, these two subsamples demonstrate that close binarity is common among main-sequence massive stars at 20% of solar metallicity, with intrinsic fractions of 70–80% across the mass range 8–80 $M_\odot$. This is the strongest indication so far that such systems are also common in the metal-poor early Universe, where gravitational-wave mergers originate.

Multiplicity of classical OBe stars: products of past mass accretion?

The OBe subsample contains 82 stars, mostly characterised by rapid rotation and Balmer emission from decretion discs. Mounting evidence suggests they are binary-interaction products that have accreted mass and angular momentum (for example, Bodensteiner, Shenar & Sana, 2020). In that case, most OBe stars are expected to be classified as single, either because their binary system was disrupted in a supernova explosion or because their companions easily evade detection (i.e., being helium stars or compact objects).

Bodensteiner et al. (2025) reported f_{obs} = 18 ± 4%, increasing to f_{obs} = 32 ± 5% when including candidate binaries. No bias correction was attempted, owing to uncertain underlying orbital properties. The relatively low binary fraction is potentially consistent with the interpretation of this sample as previous mass accretors, but intrinsic variability may have contaminated the results. The full dataset of 25 epochs will be essential to obtaining a robust final picture and characterise potential companions to these objects.

Multiplicity of B-type supergiants: unexpected residents of the Hertzsprung gap

The sample of early B bright giants & supergiants (B0-B3 II-I) comprises 262 stars. Standard single-star models predict few stars in this part of the HRD (Figure 2): the so-called Hertzsprung gap is expected to be traversed rapidly during post-main-sequence expansion. The large number of B supergiants observed in the SMC stands in stark contrast to models and is therefore puzzling.

One possibility is that many are binary-interaction products (for example, mergers, mass accretors, stripped stars), which would lower the expected binary fraction (for example, Podsiadlowski, Joss & Hsu, 1992; Menon et al., 2024). Alternatively, their presence could indicate that the main sequence extends to cooler temperatures at low *Z* (for example, Vink et al., 2010; de Burgos et al., 2025). Either way, knowledge of their intrinsic binary fraction is key to unlocking the true nature of blue supergiants.

Britavskiy et al. (2025) reported f_{obs} = 34 ± 3% and f_{int} = 40 ± 4% for this sample, lower than for their OB progenitors, but too high for a population dominated solely by merger products. This may indicate that the sample is a mixture of evolved main sequence objects and binary-interaction products. The full 25-epoch dataset is essential for firm conclusions.

Multiplicity of BAF supergiants: blue loop stars or binary-interaction products?

The coolest BLOeM subsample consists of 128 B, A and F supergiants (B5 to F5). Their nature is uncertain: they may be a mixture of stars undergoing a so-called blue loop after reaching the red supergiant phase and the products of various types of binary interactions.

Patrick et al. (2025) analysed the first nine epochs for the BAF sample. The exceptional RV precision (~ 0.1 km s^{-1}) reported by the authors makes this sample highly susceptible to binary detection. Adopting the 20 km s^{-1} threshold, no binaries are detected within the sample. Relaxing the threshold to 5 km s^{-1}, the observed fractions are 25% and 5% in late-type B and AF supergiants, respectively. As few binary systems are known in this evolutionary phase, to compare with BLOeM results Patrick et al. (2025) assumed an underlying orbital parameter distribution typical of main sequence binary systems. The resulting lack of short-period binaries observed within the BAF sample is inconsistent with a gradual evolution from main-sequence stars. These results imply that most BAF supergiants are products of binary interaction. The 25 epochs will be needed to probe longer periods or binaries with extreme mass ratios (for example, low-mass companions or neutron-star companions).

Towards a comprehensive picture of binarity at low metallicity

Figure 3 provides an overview of the results emerging from analysis of the first nine epochs. The most important BLOeM results with regard to multiplicity are:

- Close binaries are ubiquitous at low metallicity, with intrinsic fractions > 70% in OB-type systems.
- Stellar-evolution models require recalibration: a high density of stars in the Hertzsprung gap and a moderately high binary incidence among them are observed. This implies that the main sequence may extend to cooler temperatures than predicted by standard models, or that the gap is heavily contaminated by binary-interaction products — or both. A dedicated analysis of these results is underway.
- Most BAF supergiants and OBe stars are binary-interaction products, suggested by their drastically lower present-day binary fractions.

Unleashing the power of BLOeM in upcoming years

The first nine epochs already provide a transformative view of massive-star multiplicity in the SMC. With the full 25 epochs now obtained, BLOeM will soon deliver:

- A deeper binary identification sensitive to long-period (up to about 1000 days) and extreme mass-ratio systems (for example, low-mass companions and neutron-star companions).
- Orbital solutions for hundreds of massive binaries, yielding mass ratios and dynamical masses and including about 100 eclipsing systems.
- Characterisation of companions, via dynamical constraints and techniques such as spectral disentangling.
- A first sample of dormant black holes at low Z, providing constraints on black-hole formation, natal kicks and supernova mass ejections (see Willcox et al., 2025).
- A derivation of the initial mass function for binaries and single stars.

Additional studies are underway of rotational velocities, abundance patterns, detailed stellar parameters, runaway stars and individual exotic systems. In addition, a complementary FLAMES/GIRAFFE survey of the BLOeM targets was recently conducted to secure single-epoch observations of the diagnostic He II 4686 and Hα lines, enabling the detection of wind features and additional magnetic stars and OBe stars within the sample (PI: Mahy, ID: 115.28A9).

Together, these efforts will illuminate the origins and properties of stellar-mass black holes and neutron stars, gravitational-wave progenitors, and massive stars in general in conditions approaching those of the early Universe.

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The KMOS Spectroscopic Public Surveys

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We summarise the steps leading to the call, selection, approval and start of operations of the *K*-band Multi Object Spectrograph (KMOS) Spectroscopic Public Surveys. Following the ESO Scientific and Technical Committee's recommendation, the process, which began in 2024, resulted in two KMOS public surveys, EMPOWER (extragalactic) and VVVX–GalCen (galactic). They began data acquisition in January 2026 and will collect data over the next three years. The survey management plans detailing the observing strategies, data reductions and data releases will be published on the ESO web pages.

First phase with submission of letters of intent

Following a recommendation by the ESO Scientific and Technical Committee, ESO issued a call for Letters of Intent for public surveys (PSs) with the *K*-band Multi Object Spectrograph (KMOS) on the Very Large Telescope in July 2024. This call was part of a multi-staged approach that first stimulated the community to identify consortia with novel scientific cases for KMOS and interest in pursuing a PS project. It then enabled the identification of synergies, which prompted the consolidation of similar ideas into compelling scientific proposals with legacy value for the broader astronomical community.

A PS is understood to be an observing programme in which the investigators commit to produce and make publicly available, within a defined time, a fully reduced and scientifically usable data set that is likely to answer major scientific questions and be of general utility and broad interest to the astronomical community. The raw data are made public immediately. A KMOS PS was envisaged to be an observing programme requesting up to 200 observing nights to be allocated over six semesters, with observations in both visitor and service mode. The KMOS instrument was offered with a guaranteed minimum of 20 working arms. Owing to the difficulty of using mosaic mode if individual arms fail/are missing, it was decided not to offer the mosaic mode in this call.

The deadline for submission of Letters of Intent for PS with KMOS was on 15 October 2024. The Public Survey Panel (PSP), chaired by Miguel Mas-Hesse, reviewed the Letters of Intent and suggested integrations and possible merging of projects with similar aims and observing strategies.

Nine Letters of Intent were submitted for the KMOS PS, covering a broad range of scientific topics, from Galactic (young stellar objects, star clusters, nuclear stellar discs of the Milky Way), through near-field cosmology (nearby clusters) to the evolution of disc galaxies at higher redshifts. The total time requested amounted to an oversubscription of a factor five of the total time available with KMOS. The proposed targets were well spread in right ascension and observations generally requested good seeing conditions ranging from 0.7 to 1.0 arcseconds.

Submission and selection of the KMOS PS proposals

The PSP triaged and ranked the Letters of Intent and proposed suitable mergers; the PIs of the Letters of Intent were informed of the outcome in February 2025. The PSP selection led to the rejection of five projects. Two projects targeting the Galactic plane and two extragalactic projects were invited to submit proposals, with the recommendation that they be merged into one Galactic project and one extragalactic project. One Galactic PS proposal and two extragalactic PS proposals were submitted by 17 April 2025. ESO could commit to one

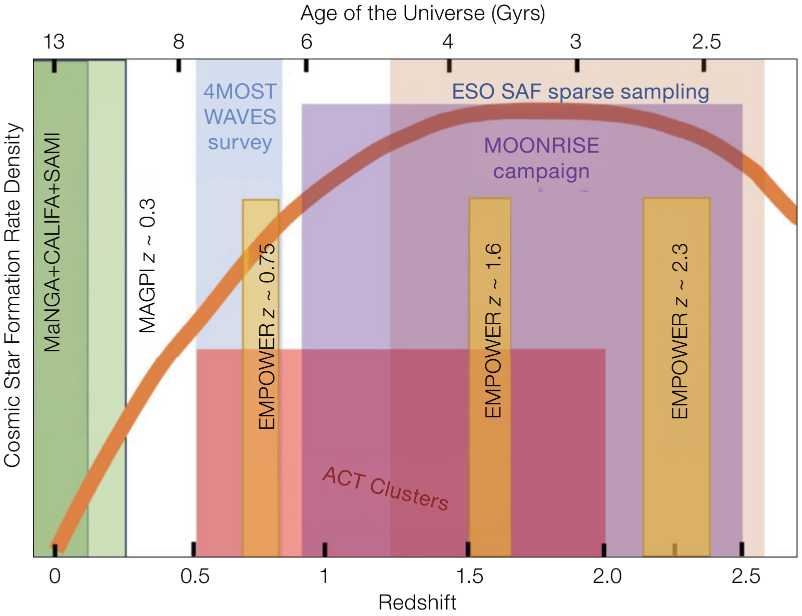

Figure 1. Redshift distribution of IFU (in black) and existing and upcoming spectroscopic surveys (in color). The EMPOWER redshift slices are indicated by the orange regions. The solid orange line indicates the evolution of the cosmic SFR density.

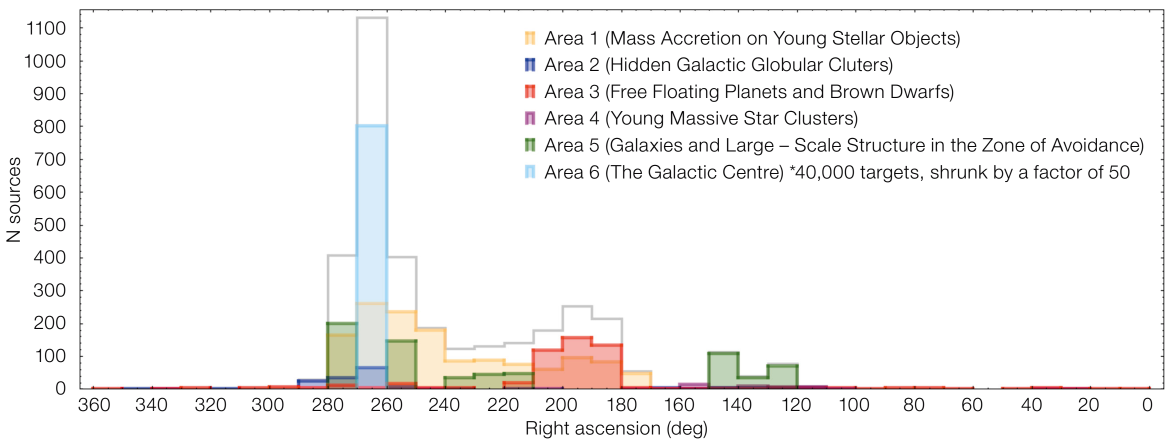

Figure 2. VVVX–GalCen Spectroscopic Survey targets for high-priority observations from different science areas (labelled 1 to 6), distributed along right ascension (RA). Area 6 has a total of 40 000 targets. Its histogram has been shrunk by a factor of 50 for visualisation purposes.

extragalactic project only. The period 116 Observing Programmes Committee (OPC), held in May 2025, recommended the implementation of the Galactic project and one of the two extragalactic projects. Any conflicts of interest were considered by including only non-conflicted members in the discussions and voting, as is routinely done in the OPC.

The two KMOS PS are[1]: the extragalactic survey — Emission line Mapping of the galaxy POpulation in the cosmic WEb enviRonments (EMPOWER), PI Paola Popesso (ESO) and the Galactic survey, the KMOS VVVX–GalCen Spectroscopic Survey, PIs Matias Gomez Camus (Andres Bello University, Chile) and Francisco Nogueras-Lara (Institute of Astrophysics of Andalucía [IAA-CSIC], Spain). The selected teams were invited to prepare a survey management plan (SMP), approval of which by ESO is mandatory before final acceptance of a PS.

The following conditions apply to the KMOS PS:

- No proprietary time is granted; raw data will become public immediately after observation and available to the world via the ESO Science Archive Facility (Romaniello et al., 2023).
- The ESO Science Archive Facility is going to be the repository of the survey products, both raw and science data products, and will provide the primary access to these products for the ESO community. Survey data products are to be prepared according to the ESO science data product standard and submitted in agreement with the policies for ESO Phase 3 (Arnaboldi et al., 2011). The teams are responsible for processing and validating the data products. Regular survey data product releases are expected every year.
- Progress of the approved KMOS PS is to be reviewed regularly by ESO on the basis of the yearly reports submitted by the teams. Corrective steps will need to be identified in cases where the survey execution is delayed or the data product delivery schedule cannot be maintained.

In what follows, we provide a brief overview of the main science goals and observing strategies of the extragalactic and Galactic KMOS PSs.

EMPOWER is a transformative PS that will expand the ESO KMOS Science Archive Facility with deeper and new observations. This ambitious integral field unit (IFU) campaign will target around 900 galaxies with $M_* > 10^{10}\,M_\odot$ across three key epochs, at $z \sim 0.75$, $z \sim 1.6$, and $z \sim 2.3$, which span the decline, peak and early rise of the cosmic star formation rate (SFR) density. EMPOWER is designed to answer fundamental questions in galaxy evolution: when and where do galaxies quench their star formation? What roles do mass, active galactic nucleus feedback and environment play in regulating star formation? How does the cosmic web shape these processes across cosmic time? EMPOWER will answer these overarching questions by sampling the full galaxy evolution parameter space — including stellar mass, SFR, nuclear activity and position within the Cosmic Web. It will deliver deep spatially resolved maps of dust-corrected SFR, metallicity, and ionised gas kinematics out to galaxy outskirts. By fully charting a galaxy's journey across both cosmic time and environment, EMPOWER will enable the broadest possible range of science for the community, standing as a true legacy resource for extragalactic astronomy. In Figure 1 we show the redshift distribution of IFU (in black) and existing and upcoming spectroscopic surveys (in colour).

The KMOS VVVX–GalCen Spectroscopic Survey builds on two very successful observational efforts: the wide-area, multi-epoch VVV/VVVX near-infrared survey and the high-resolution GALACTICNUCLEUS imaging of the innermost regions of the Galaxy. This is a diverse multipurpose survey aiming to serve the wider astronomical community. Its scientific objectives are to characterise eruptive young stellar objects and their environments across the southern disc, identify and measure the physical parameters for Galactic globular clusters hidden by extinction, confirm and measure nearby free-floating planets and brown dwarfs, characterise numerous young massive star clusters across the Galactic disc, classify nearby and distant galaxies and galaxy clusters in the zone of avoidance, revealing the large scale structure in the background, and conduct the first high-completeness spectroscopic study of the Galactic centre, revealing its star formation history, dynamics and structure. In Figure 2 we show the number of Galactic sources distributed in right ascension.

Observations for the KMOS PSs will be executed either in designated Visitor mode (remotely), in Visitor mode on

Paranal or in Service mode; the total allocation is 140 nights for the Galactic VVVX–GalCen Spectroscopic Survey and 145 nights for the extragalactic EMPOWER PS.

Next steps for the KMOS PS proposals

Following the selection of the KMOS PS proposals, the teams were invited to submit their SMPs. Given the extensive participation of ESO staff astronomers in the KMOS PS teams, the discussion of the SMP took into account potential conflicts of interest by including only non-conflicted members in the discussion and voting. Similar policies will apply should it come to actions during the surveys' operations, such as, for example, monitoring the progress of a survey.

Once the SMPs are approved they will be published on the dedicated ESO web page[1]. They detail the target selection, observing strategy, data releases and team composition. The start of data acquisition for the KMOS PSs was 1 January 2026. The runs scheduled in P116 are all carried out in visitor mode. They provide the opportunity for the survey teams to work hands-on with their observations, gaining experience in light of the very large allocation they will have in the future.

The two KMOS PSs join the successful endeavour of the previous 17 ESO PSs (Arnaboldi et al., 2019), which are now completed and whose scientific impact and legacy value led to tens of data releases[2] and the publication of nearly 2000 refereed highly cited (~100 000 citations) scientific papers. They will run in parallel to the 4-metre Multi-Object Spectroscopic Telescope (4MOST) PS whose science goals and strategy are illustrated in the 4MOST Survey Management Plan[3].

Acknowledgements

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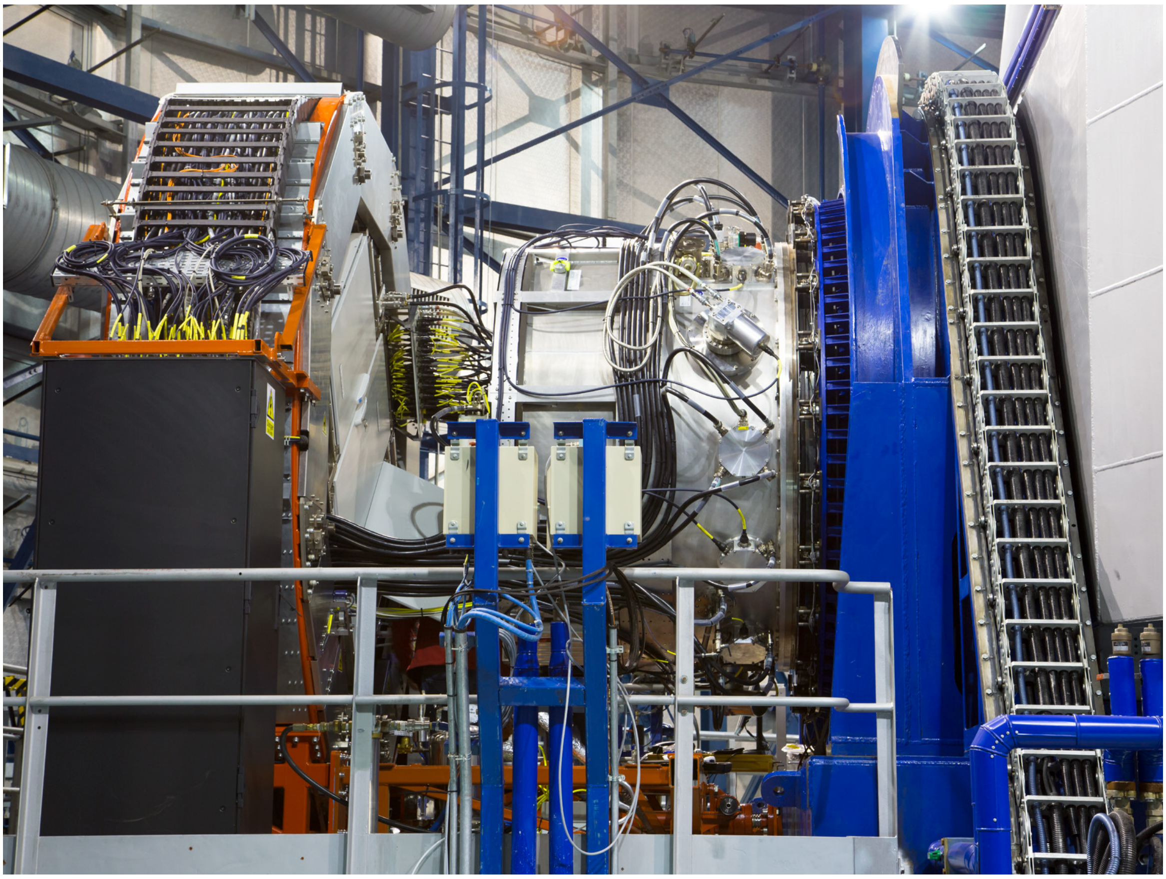
Arnaboldi, M. et al. 2019, The Messenger, 178, 10
Romaniello, M. et al. 2023, The Messenger, 191, 29

Links

[1] KMOS public surveys: https://www.eso.org/sci/observing/PublicSurveys/KMOS-surveys-projects
[2] ESO Phase 3 data releases: https://eso.org/rm/publicAccess#/dataReleases
[3] 4MOST Survey Management Plan: https://www.eso.org/sci/observing/PublicSurveys/4MOSTsmp



ESO/G. Lombardi (glphoto.it)

The KMOS instrument mounted on ESO's Very Large Telescope at the Paranal Observatory in Chile. KMOS is unique as it will be able to observe not just one, but 24 objects at the same time in infrared light and to map out how their properties vary from place to place. It will provide crucial data to help understand how galaxies grew and evolved in the early Universe — and provide it much faster than has been possible up to now. KMOS was built by a consortium of universities and institutes in the United Kingdom and Germany in collaboration with ESO.

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ALMA–CTAO Synergies

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This article aims to raise awareness within the ESO astronomical community of the scientific opportunities offered by the upcoming Cherenkov Telescope Array Observatory (CTAO), highlighting cases where combining the millimetre/submillimetre capabilities of the Atacama Large Millimeter/submillimeter Array (ALMA) with the CTAO's very-high-energy (~TeV) observations enables new avenues for discovery. Many astrophysical sources and environments exhibit emission processes detectable in both regimes; however, the synergies extend beyond shared emission mechanisms and include broader physical processes and observational connections linking millimetre/submillimetre and TeV energies.

Motivation

Construction of the Cherenkov Telescope Array Observatory (CTAO) is progressing at the southern site near the Paranal Observatory, hosted by ESO. Together with the northern site in La Palma, Spain, the CTAO will provide full-sky coverage and unprecedented sensitivity for astronomical observations at very high energies (20 GeV – 300 TeV; with 1 TeV = 1.25×10^{-9} nm = 2.4×10^{17} GHz), improving by at least an order of magnitude over current instruments (Hoffmann & Zanin, 2023). With the commencement of science verification, early science and subsequent full operations, ESO Member States will have access to 10% + 10% guaranteed observing time at the northern and southern CTA sites, respectively.

This suggests that the ESO community should begin preparing projects that make use of the CTAO, with ESO encouraging — though not exclusively — the submission of proposals that exploit synergies with other ESO facilities. Building such a community requires increasing the awareness of high-energy astrophysics, much as ESO did successfully for the Atacama Large Millimeter/submillimeter Array (ALMA), whose sensitivity revolutionised millimetre astronomy; the sensitivity leap offered by the CTAO will play a similar role at high energies.

Given the shift toward a genuinely multi-wavelength and multi-messenger research landscape (for example, Mészáros et al., 2019; Murase & Bartos, 2019; Padovani, 2024), leveraging synergies with ESO facilities will be essential for realising the full scientific potential of the CTAO. While the time-domain community has long operated in this coordinated framework, it has also faced challenges — especially for time-critical observations — as a result of limited community awareness of the operational requirements (for example, Middleton et al., 2017; Díaz Trigo, Maccarone & Tetarenko, 2024). This has motivated the development of Joint Programmes across facilities, with high-energy observatories such as Chandra and XMM-Newton (Schartel & Santos-Lleo, 2025) adopting such approaches early, having recognised the potential for additional scientific output through the use of complementary facilities, especially for rapid multi-wavelength follow-up of energetic, variable events. Strengthening community preparedness and awareness will therefore be fundamental for enabling timely responses in the era of time-domain astronomy.

This article highlights selected scientific cases in which the combined use of the CTAO and ALMA can significantly advance our understanding across many areas of astronomy, potentially leading to major breakthroughs in physics and astrophysics. It also outlines the operational steps needed to fully exploit these synergies.

Physical processes in play

Gamma rays (γ-rays) are produced by several physical processes which are categorised in two groups: leptonic processes — thermal bremsstrahlung, inverse Compton scattering, synchrotron emission — and hadronic processes, resulting from inelastic collisions with interstellar material, the dominant emissions being the decay into two γ-rays of the π^0 meson ($\pi^0 \rightarrow \gamma\gamma$) and the inelastic proton-proton interactions via the decay chain of charged π ($\pi \rightarrow \mu + \nu_\mu \rightarrow e\ \nu_e$). Each of the different processes has certain characteristics that can be used to identify the underlying production mechanism once the γ-rays are observed. It is relevant to notice here that the concomitant detection of neutrinos would indelibly mark the hadronic nature of the emission process.

In this article we focus on astrophysical sources and environments where non-thermal emission mechanisms such as synchrotron radiation are detectable at both high (2×10^{10} – $3 \times\times 10^{14}$ eV) and low (10^{-4} – 3×10^{-3} eV) energies, i.e. targets of the CTAO and ALMA, or where the high-energy radiation influences processes at lower energies via ionisation. In this article we will focus our attention on a few examples that are of particular relevance (in the authors' view).

Science opportunities

The origin of cosmic rays, their effects on the initial conditions of star formation, the initial mass function

Cosmic rays (CRs) are a population of non-thermal, relativistic charged particles that pervade the interstellar medium (ISM) of the Milky Way and external galaxies. They are produced primarily in supernova remnants and accelerated by shocks.

The collapse of gas and the onset of star formation within dense, dark molecular clouds — regions where ultraviolet and optical photons cannot penetrate — are regulated by CRs. In these deeply dust-enshrouded environments, CRs serve as the dominant ionisation source, driving the chemistry, setting the gas temperature and facilitating coupling with magnetic fields. Consequently, a close connection is expected between a galaxy's star formation activity and its CR content. In principle, this relationship can be indirectly constrained through observations of the non-thermal emission processes generated by CRs, which span a broad range of frequencies. The millimetre and radio bands trace the CR electron population via synchrotron radiation. However, reliance on these bands alone is challenging, as radio emission depends sensitively on the properties of the galactic magnetic field. In contrast, combining

γ-ray observations with simultaneous measurements of star formation tracers provides a powerful and complementary framework for investigating the star formation process.

One of the most original proposals to investigate this issue is the combined measurement of the γ-ray flux and spectrum of CRs in star-forming regions — specifically in dense molecular clouds — using the CTA, together with observations of emission lines from various isotopologues of carbon monoxide ($^{12}C^{16}O$ or CO), ^{13}CO, and $C^{18}O$, obtained with ALMA. These isotopologues trace the relative ^{13}C and ^{18}O abundances produced by successive generations of stars (i.e., Zhang et al., 2018a, b).

In very dense molecular clouds, as well as in the extreme environments of compact starbursts within merging galaxies, the CR energy density is expected to be up to a thousand times higher than that in the Milky Way. Under such conditions, CRs can substantially alter the fragmentation of molecular hydrogen (H_2) clouds, leading to the formation of fewer low-mass ($< 8\ M_\odot$) stars and resulting in a top-heavy stellar initial mass function (IMF). A systematic variation in isotopologue abundance ratios across galaxy-scale molecular hydrogen reservoirs would indicate a departure from the canonical IMF observed in normal star-forming galaxies, suggesting that CR-regulated initial conditions for star formation naturally influence the shape of the stellar IMF (Papadopoulos, Thi & Viti, 2004; Papadopoulos & Thi, 2013).

Related to this topic is the influence of CRs on the evolution of protoplanetary discs. CRs have long been predicted to be the dominant source of ionisation at the midplane of the inner disc (for example, Gammie, 1996). However, ALMA studies of molecular spatial distributions in disc samples suggest that the ionisation rate may be lower than that of the ISM and may vary among discs of similar mass ranges, possibly owing to differences in magnetic field configurations or turbulence (for example, Aikawa et al., 2021). This result could be further explored through direct measurements of CR ionisation rates in discs.

The Galactic disc and centre

A survey of the Galactic plane is one of the key scientific projects planned by the CTA science collaboration (Abe et al., 2024). The Galactic plane is expected to host a large population of very high-energy sources — pulsar wind nebulae, young and interacting supernova remnants (SNRs), compact binary systems — as well as diffuse emission from CR interactions. In these sources, γ-rays are produced through inelastic interactions between CRs, accelerated by the SNR shock, and the surrounding matter in the molecular cloud (via π^0 decay). The H.E.S.S. Collaboration (2018) has shown that the diffuse γ-ray emission from the Galactic centre (GC) is spatially coincident with the dense, molecular clouds traced by the CS molecule, as detected by the Nobeyama 45-metre dish (Tsuboi, Handa & Ukita, 1999) and later by tens of observations with ALMA also targeting other gas tracers (Miyawaki et al., 2021 and references therein), extending over a projected distance of 140 pc before fading beyond that point (H.E.S.S. Collaboration, 2018). This γ-ray emission provides strong evidence for a CR source located in or near the GC, with the CR energy profile consistent with a continuous accelerator operating within the central 200 pc.

Complementary ALMA programmes (for example, Sano et al., 2020) have targeted supernova remnants and found evidence for γ-ray production at shock fronts along molecular-cloud edges, consistent with shock–CR interactions. These results may indicate that CRs contribute significantly to the local energy density, influencing the chemistry and physics of star-forming regions.

The additional information provided by ALMA polarisation measurements will help to constrain the magnetic field structure and hence the diffusion of CRs. By mapping how dust emission is polarised, ALMA gives a direct look at field orientation and relative strength. This information is key to inferring magnetic field geometry to the level of scattering and turbulence that shape cosmic ray diffusion. This tightens the physical model and reduces uncertainty in how particles spread from their sources.

Relativistic jets and shocks associated with accretion around neutron stars, black holes and explosive events

Relativistic jets are highly collimated streams of plasma ejected at relativistic speeds from the vicinity of very compact astrophysical objects such as accreting neutron stars and stellar-mass black holes in X-ray binaries or supermassive black holes. Despite extensive studies performed in the past decades, their launching and quenching mechanisms remain unknown. Jets are expected to be sites of extreme particle acceleration and therefore TeV emitters. However, although most TeV sources are active galactic nuclei (AGN), with flux-limited samples dominated by blazars, AGN in which we are looking directly into the relativistic jet[1], the exact sites of particle acceleration remain unknown. Combined millimetre and TeV observations promise to shed light on this topic. In AGN, millimetre VLBI observations allow the region closest to the black hole to be mapped, including the jet launching area (The Event Horizon Telescope Collaboration, 2019; Lu et al., 2023). Simultaneous observations at TeV energies can then constrain the site of TeV emission by using temporal correlations within millimetre and TeV variability (Akiyama et al., 2015; Algaba et al., 2024) and may extend the relation observed between millimetre and GeV γ-rays for some sources (for example, Leon-Tavares et al., 2011; Ramakrishnan et al., 2016; Kim et al., 2024) to even higher energies. Interestingly, in X-ray binaries, the TeV emission sites have recently been localised to structures in the lobes, far from the centre of the system where the jets are formed (Abeysekara, 2018; LHAASO Collaboration, 2024), and associated at least in two cases with jet termination shocks associated with jet–ISM interaction observed in radio or millimetre emission (Gallo et al., 2005; Tetarenko et al., 2018).

Relativistic ejecta are also observed in long-duration γ-ray bursts (GRBs), bright flashes of γ-rays associated with stellar core collapse events and followed by fading afterglow emission caused by the interaction of the relativistic ejecta with surrounding gas. In the basic picture (see Figure 1), this interaction produces a forward shock in which electrons can be accelerated to relativistic speeds and then emit synchrotron radiation. Temporal evolution of the spectral energy distribution sets important constraints on this model and, in particular, radio and millimetre data have revealed the need to include an additional synchrotron component that is due to a reverse shock propagating back into the jet (Laskar et al., 2013, 2019). Emission at TeV energies has so far been detected only from a handful of GRBs, with the most energetic photon reaching 13 TeV (in GRB 221009A; LHAASO Collaboration, 2023; Abe et al., 2025a). However, these few events already show that TeV emission cannot be simply explained by inverse Compton emission from particle acceleration at the forward shock, suggesting that emission from the reverse shock may be needed (Laskar et al., 2023; Zhang et al., 2024). These models also indicate that the observed evolution of the reverse shock signature at radio/millimetre wavelengths is sensitive to the angular structure of the jet's energy and speed, with further implications for the expected TeV emission from such outflows (Zhang et al., 2024, 2025). Simultaneous monitoring from radio to γ-rays is required to disentangle the two potential emission components, and early radio/millimetre follow-up (within hours to days) is fundamental for capturing and characterising the reverse shock emission.

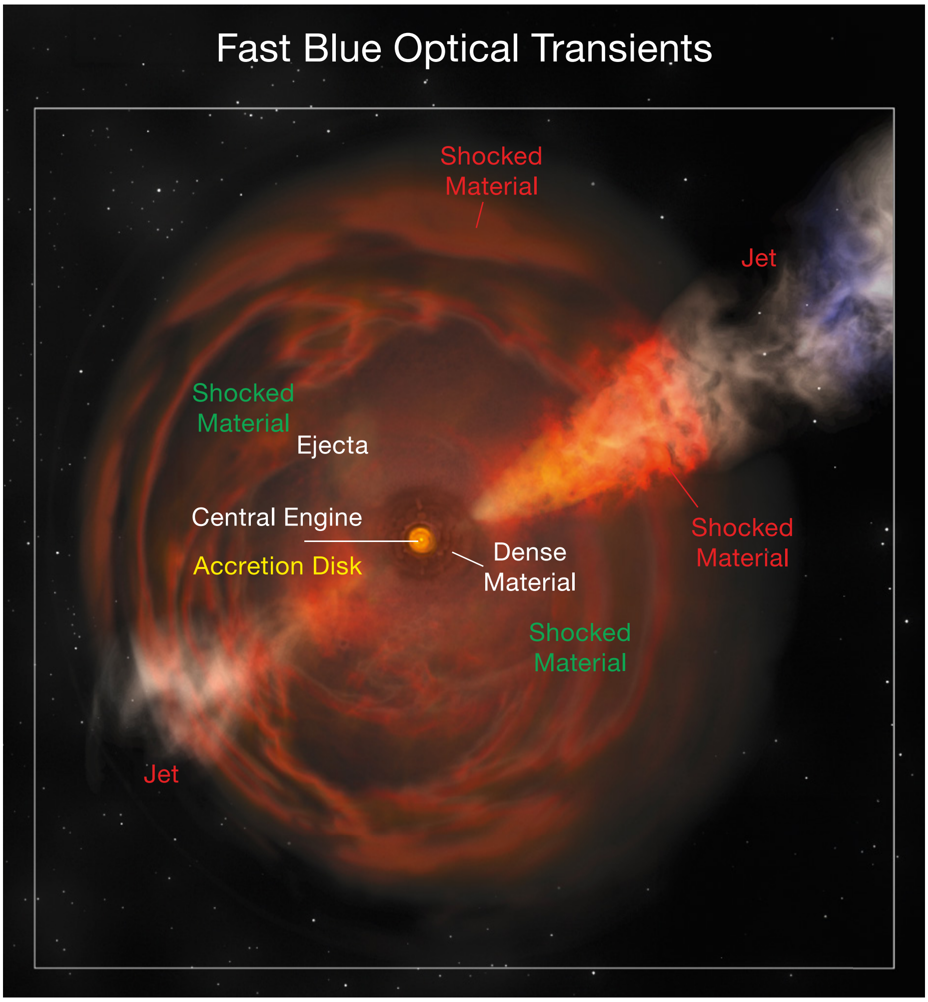

Figure 1. An artist's impression of relativistic ejecta associated with stellar core collapse events and followed by fading afterglow emission, caused by the interaction of such relativistic ejecta with surrounding gas. This simplified picture (adapted from an NRAO public image[2]) shows a forward shock accelerating relativistic electrons, which in turn emit synchrotron radiation. In objects like GRBs, radio and millimetre data suggest an additional synchrotron component that is due to a reverse shock propagating back into the jet . TeV emission also seems to suggest the presence of a reverse shock in addition to the inverse Compton emission from particle acceleration at the forward shock (see text for details).

Besides being sites of particle acceleration in general, shocks are also known to be sites of dust production, best observed via infrared (IR) and millimetre observations. A link between both may be being observed in novae or thermonuclear eruptions on the surfaces of white dwarves in binary systems. Gamma-rays up to TeV energies have recently been detected in the recurrent nova RS Ophiuchi (Acciari et al., 2022; H.E.S.S. Collaboration, 2022; Abe et al., 2025b), representing the first detection of TeV emission in this class of sources. While dust formation in novae has long been established through IR emission accompanied by optical dips that are due to obscuration, the sites of formation are less clear. However, correlations found in a subset of novae with double-peak radio lightcurves between the first peak attributed to synchrotron emission and an optical dip indicating dust formation could now indicate that shocks are the common site of dust production (Derdzinski, Metzger & Lazzati, 2017) and particle acceleration (Chomiuk et al., 2021). Simultaneous IR/millimetre and γ-ray monitoring observations, together with high-spatial-resolution IR/millimetre observations could help confirm this hypothesis.

Finally, millimetre observations are now also helping to elucidate the origin of γ-rays in the so-called γ-ray binaries, a sub-class of binaries with a massive star orbiting a compact object and broadband non-thermal emission peaking above 1 MeV. As an example, multi-band ALMA observations of the nearby source PSR B1259-63/LS 2883, consisting of a pulsar in an eccentric orbit around a Oe-type companion star with an equatorial decretion disc, have been crucial in disentangling the changes in synchrotron emission at low frequencies and the circumstellar disc at high frequencies as the pulsar passes through or near the disc of the companion star, when the interaction of the pulsar wind and the stellar environment leads to enhanced high-energy emission (Fujita et al., 2024).

The significant increase of sensitivity offered by the CTAO should also enable the detection of TeV energies from additional transient and variable sources (Abe et al., 2025c), thus further complementing studies of the non-thermal emission at radio and millimetre wavelengths, which will remain key for locating the acceleration sites and shocks.

Challenges

Operational models built for traditional astronomy struggle because they do not account for the fast reaction and tight coordination required today; communication often lags and events can fade away before observatories can respond. Technical systems cannot always keep up with the physical timescales involved. Data reduction adds more friction, especially when teams must work through large, uneven datasets.

Ground-based telescopes face visibility limits that vary by site, which makes simultaneous coverage difficult; space assets can run into the same problem. Time allocation procedures were never designed for rapid multi-messenger campaigns, so observing time rarely lines up with the needs of the science. Data processing still leans heavily on specialists in each wavelength, and archives do not always provide the key physical quantities in forms that are easy to use or cross compare.

Strong coordination with multi-messenger facilities is essential. That includes neutrino detectors like IceCube and gravitational wave observatories such as the Laser Interferometer Gravitational wave Observatory (LIGO), Virgo, the Kamioka Gravitational Wave Detector (KAGRA), the Laser Interferometer Space Antenna (LISA) and the planned Einstein Telescope.

The first steps toward modernising operational models are straightforward. Large facilities need to join the fast alert networks already used across the multi-messenger community. They also need joint observing programmes with Target of Opportunity capabilities that allow quick action when an event appears. Facilities must coordinate schedules in real time so they can follow fading sources at the same moment, not hours later. Alongside this, data reduction tools must be built for highly variable objects and should provide light curves and other essential products in real time. These changes create the foundation for facilities to work together and fully exploit the scientific power of synergetic observations.

Outlook

The synergetic use of astronomical facilities enables tackling some of the scientific questions that are unreachable by a single facility, thereby opening the parameter space of scientific discovery. A key factor for a successful synergetic use of two (or more) facilities is the matching of some technical capabilities such as sensitivity or angular resolution or their complementarity, for example spectroscopy and imaging. The second key factor is the complementarity of the facilities for the study of physical processes. In this article we have given an indication of the scientific cases that we expect to open new avenues for discovery when investigated with ALMA and the CTA. We also point to some operational changes that are needed for realising this potential, particularly — although not exclusively — in the cases that involve highly variable phenomena, and encourage ALMA and the CTAO to start a discussion now on how to implement such changes to be ready when the CTA comes online.

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Links

[1] TeV catalogue: https://www.tevcat.org/
[2] NRAO public image: https://public.nrao.edu/gallery/nrao20df03b/

ALMA(ESO/NAOJ/NRAO)/S. Longmore et al. Background: ESO/D. Minniti et al.

The depicted object,on this image, known as Ve 7–27, was long believed to be a planetary nebula — the end phase of a sun-like star's life. But observations with the VLT's MUSE instrument have now captured the first detailed image of this object. It shows that Ve 7-27 is shooting energetic jets with knots or 'bullets' along them, which is typical for newborn stars. Instead of being the "last breath" of a dying star, Ve 7-27 is a newborn one.

Instrumentation

O. Castillo/ESO

This circular motion of the stars is caused by the rotation of the Earth around its axis. The point at which Earth's rotation axis extends to in the sky is called a celestial pole, which in today's image is the centre around which all these stars seem to move or trail — hence, the name circumpolar star-trail. Osvaldo was able to capture this hypnotising motion at ESO's Paranal Observatory in Chile. With the tip of one of the Auxiliary Telescopes almost perfectly aligning with the southern celestial pole, it seems as if the sky revolves around the telescope, making it the centre of attention.

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First Fringes for Asgard — Phase 1

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Asgard is a suite of visitor instrument modules for the Very Large Telescope Interferometer designed to deliver high-contrast interferometric capability at infrared wavelengths through the phased installation of adaptive optics, fringe-tracking and spectroscopic and nulling instrumentation. Phase 1 was integrated and installed in mid-2025, followed by a commissioning campaign exploiting the Auxiliary Telescopes. First-light results demonstrate the robust acquisition and stabilisation of fringes across all six baselines in both *K*-band sub-filters, with Heimdallr tracking achieved down to $m_K \approx 9.5$. Early on-sky tests also validate the wavefront correction functionality provided by the Baldr instrument. With Phase 2/3 instruments (BIFROST and NOTT) now entering the integration phase, Asgard is on track to provide the community with next-generation interferometric capabilities for high-angular-resolution and high-contrast science.

The vision of Asgard

The Asgard suite of visitor instruments[1] for ESO's Very Large Telescope Interferometer (VLTI) grew from an original proposal for a nulling beam combiner to obtain the highest possible contrast at resolutions beyond the spatial resolution of a single telescope. The most challenging science case was the detection of exoplanets at a contrast of around 10^5 (Defrère et al., 2018). In order to obtain sufficient control of starlight amplitude and phase to enable this science, novel fast, low-order adaptive optics and fringe-tracking systems were needed (Martinache & Ireland, 2018). This naturally led to the instrument partnering with an effort to push the VLTI to the shortest wavelengths (Kraus et al., 2019, 2022), finally resulting in the following suite of instruments (Figure 1) to be installed in a phased approach (Martinod et al., 2023):

- Solarstein (Phase 1): an internal four-beam pathlength-matched artificial source used for internal alignment and adaptive optics calibration.
- Baldr (Phase 1): a low-latency (~0.5 ms), second stage, low-order adaptive optics and pupil alignment system.
- Heimdallr (Phase 1): high-efficiency fringe tracking and calibrated complex visibility science in two sub-filters within the astronomical *K* band.
- BIFROST (Phases 2 and 3): spatially filtered interferometric beam combiner at low to high spectral resolution in the *Y*, *J* and *H* bands. Phase 3 includes an off-axis mode (up to 0.8 arcseconds on

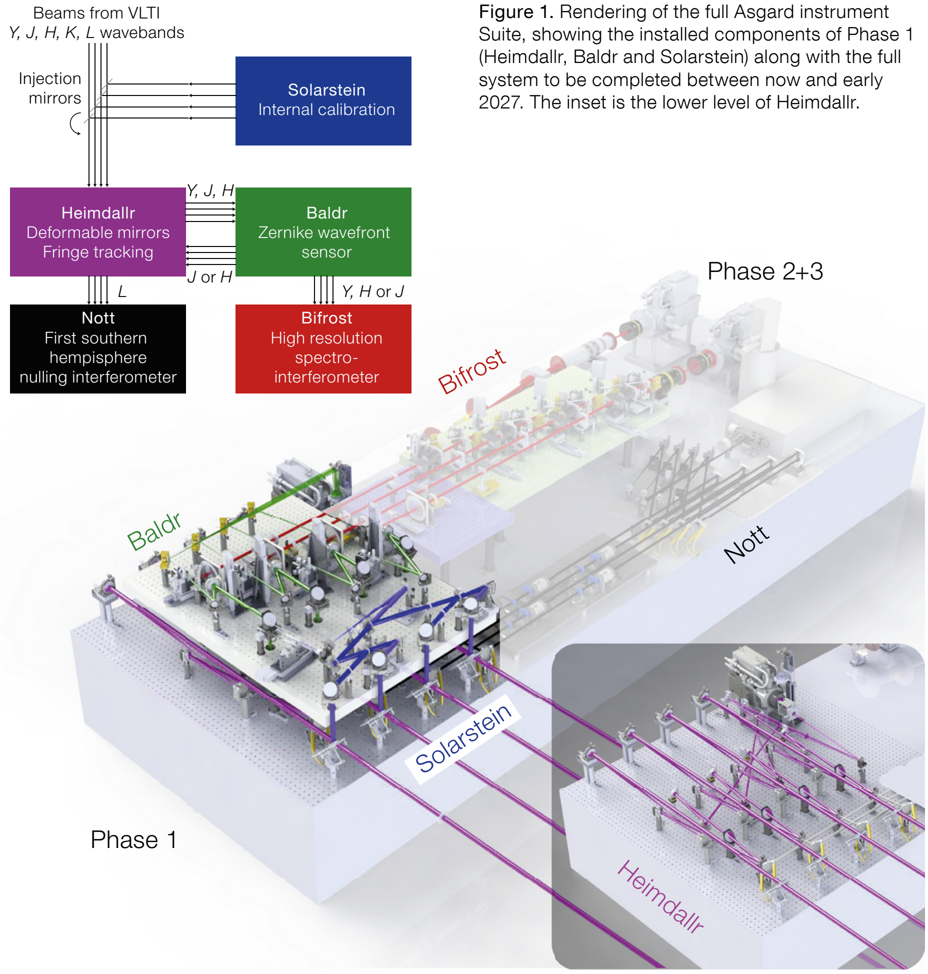

Figure 1. Rendering of the full Asgard instrument Suite, showing the installed components of Phase 1 (Heimdallr, Baldr and Solarstein) along with the full system to be completed between now and early 2027. The inset is the lower level of Heimdallr.

the Unit Telescopes or 4 arcseconds on the Auxiliary Telescopes) for high-contrast observations at small inner working angle.
- NOTT (Phases 2 and 3): nulling interferometry, including dispersion compensation using both prisms and a CO_2 cell, and double-Bracewell nulling.

The most challenging mode anticipated for Phase 3 (Periods 118 and 119) will be measuring the deepest nulls in an asymmetric double-Bracewell mode, while compensating for water vapour seeing using fringes from BIFROST. The science case motivating Asgard was submitted to the Observing Programmes Committee in March 2022 (P110) and officially approved by the Scientific Technical Committee in June 2023, following technical verification by ESO Paranal.

Phase 1 installation and description

Following assembly and integration of Australian and French components in Nice between October 2024 and April 2025, Solarstein, Heimdallr and Baldr (Taras et al., 2024) were inspected by ESO and shipped to Paranal for integration in July 2025. The instrument was installed on the former Astronomical Multi-BEam combineR (AMBER) table (Figure 2). Each beam features a fast (up to 4-kHz operation) 140-actuator deformable mirror used for the correction of wavefront error signals measured by Baldr and the initial fringe-tracking error signals measured by Heimdallr (before offload to delay lines), and for laboratory alignment diagnostics, using the sources inside Solarstein.

Interaction with VLT infrastructure occurs through one interface computer running VLT2024 software, which controls the underlying hardware via a linux-based module control unit. Communication is via high-speed CameraLink and USB2 over fibre, as well as low-speed ethernet, with 24-V DC supplies only to the cooled electronics box in the laboratory. All data are read out using a single C-Red One camera.

Since the ESO inspection in Nice, a small number of modifications have been made: both the camera and the low-voltage electronics box (which includes an internal fan) are vibrationally isolated from the optical table in order to eliminate the nearly 100-nm RMS fringe motion that was initially seen at Paranal, and actively rotating LiNbO3 plates were added for *K*-band polarisation compensation.

As a visitor instrument, all electronics in the laboratory including the C-Red One are designed to be rapidly powered on and off, with an approximately two-hour start-up procedure from a fully powered down and warm state, increasing to four hours including manual alignment checks.

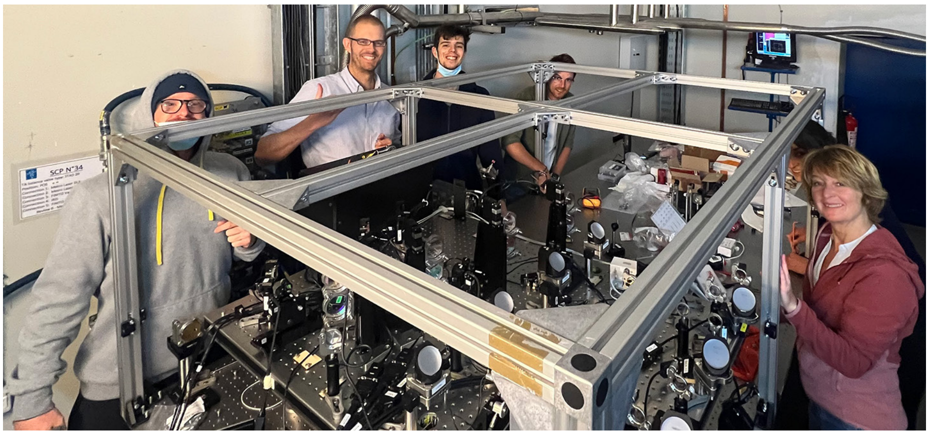

Figure 2. Core Asgard team members installing the outer enclosure in the VLTI laboratory on the visitor table — once panels were in place, it became more difficult to see inside in a single photo!

Commissioning and initial performance

The first commissioning run took place from 10 to 19 September 2025. It used the VLTI Auxiliary Telescope array in three different configurations: ‘small’ (A0, B2, D0, C1), ‘intermediate’ (A0, B2, C1, J2) and ‘extended’ (A0, G1, J2, K0), and took advantage of the New Adaptive Optics Module for Interferometry (NAOMI) AO correction. In all cases, Heimdallr was able to acquire up to four telescope beams and find fringes on all six baselines within both the *K1* and *K2* sub-filters (see Figure 3) on a timescale of minutes, leveraging the very high reliability of the VLTI infrastructure. Fringe stabilisation was first achieved using instrument internal delay lines, but now relies on the facility delay lines by way of a feedback loop mechanism updating every 10 ms.

The analysis of commissioning data is ongoing and it is therefore too early to present metrics of system performance. However we can report the demonstration of the system’s ability to acquire and maintain fringe lock using group delay tracking, for stars as faint as $m_K = 9.5$ (at 125 Hz, using our engineering-correlated double-sampling mode of the C-Red One — the more flexible and sensitive up-the-ramp mode is still being commissioned). Phase delay tracking with less than 80 nm RMS per telescope and at $m_K = 8$ was also achieved.

In addition to point sources ranging in magnitude from 0 to 9.5, our observations also included several partially resolved objects, such as well-known binaries, to establish the non-trivial instrumental field-dependence of response that is a consequence of the 2D remapping of the VLTI beams. Our commissioning targets also included several verification targets, in particular Gaia binaries, establishing benchmarks for key science programmes of Heimdallr.

Tests during commissioning revealed that Baldr’s AO and tip–tilt loop is highly sensitive to small alignment drifts between its internal reference elements (source, phase mask and cold stop). These effects were not apparent in laboratory testing, where the internal geometry is fixed. On sky, additional VLTI level focus offsets and higher-order residuals introduce subtle cross-couplings that can amplify tiny misalignments and destabilise the loop. Despite this, early tests already show

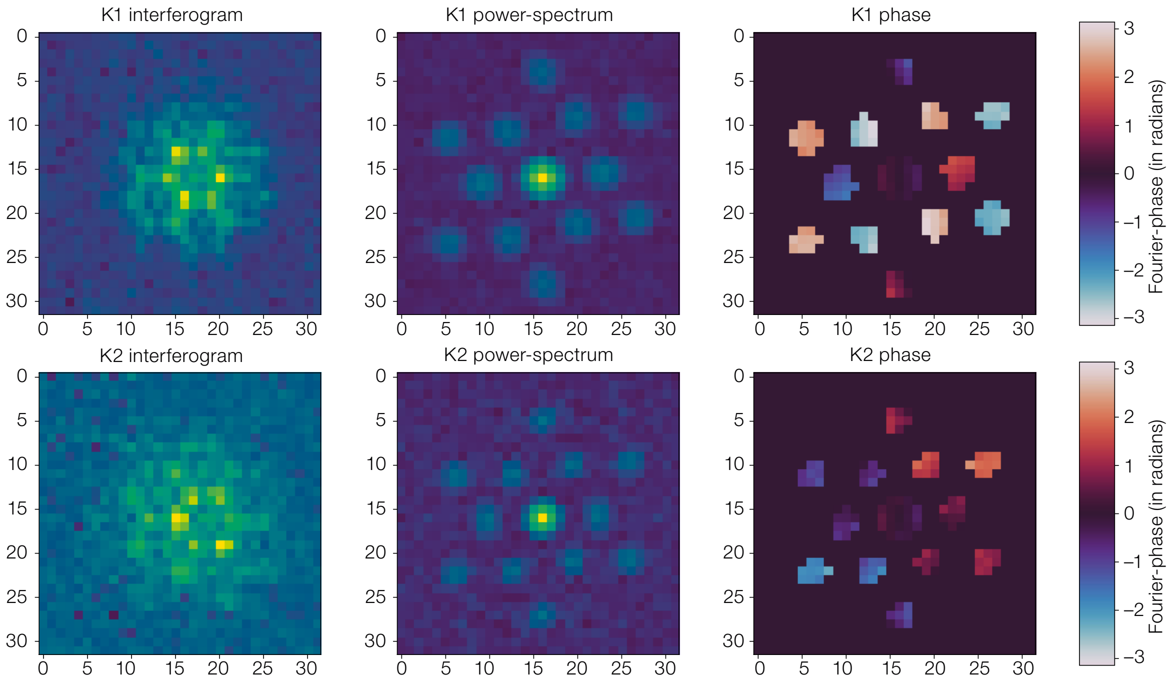

Figure 3. Simultaneous K1 (top row) and K2 (bottom row) interferograms acquired by the C-Red One detector at 1 kHz frame rate, and their respective 2D Fourier transform (visibility and phase). The fringe tracking algorithm of Heimdallr uses the K1 and K2 phase to estimate the real-time phase and group delay of the fringes. Higher order phase structures visible across Fourier splodges contain a combination of common and inter-beam tip-tilt error signals (that would otherwise lead to coupling losses in a single-mode recombiner) that can be used to control the system's deformable mirrors.

measurable improvement when Baldr is closed-loop on sky: measurements with Heimdallr showed 20% RMS reduction in image spread between open and closed loop runs (Figure 4). Ongoing work to establish a stable on-sky reference and calibrate the internal–external optical offset is expected to significantly increase the robustness and performance of Baldr's standard wavefront-correction mode. In subsequent commissioning we anticipate replacing the 'faint' mode with a fast tip-tilt-only mode.

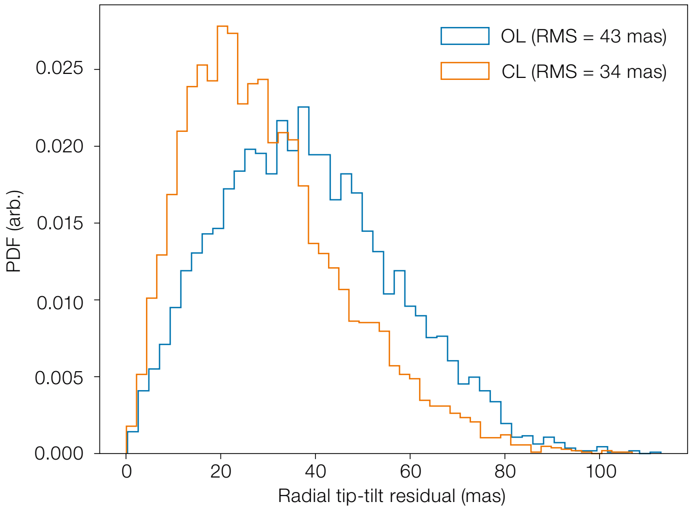

Figure 4. On-sky radial tip–tilt residuals of the Heimdallr PSF, measured out of loop and detrended, showing the reduction achieved when Baldr is switched from open loop (OL) to closed loop (CL) with the first stage AO NAOMI running on the AT's. Although promising already, Baldr is only partly commissioned, with the second run in February 2026.

Next steps and community access

Phase 1 science began in March 2026, and Phase 2 is now underway, with a successful installation of BIFROST and first Y to H band fringes in March/April 2026. This included UT operation with atmospheric dispersion compensators. Completion of BIFROST and NOTT phase 2 is scheduled for August and September 2026.

The Asgard consortium is committed to facilitating community access at the earliest opportunity. For the P117 call, submissions were invited via an Expression of Interest form to an Asgard-internal sifting panel that selected proposal ideas that (a) seem technically feasible, (b) make the best use of Asgard's unique capabilities, and (c) show the best complementarity with the Asgard core science themes. We received four responses that were all selected and developed to full proposals. Following this successful test-trial, we will again welcome proposals from the community in P118[2].

Acknowledgements

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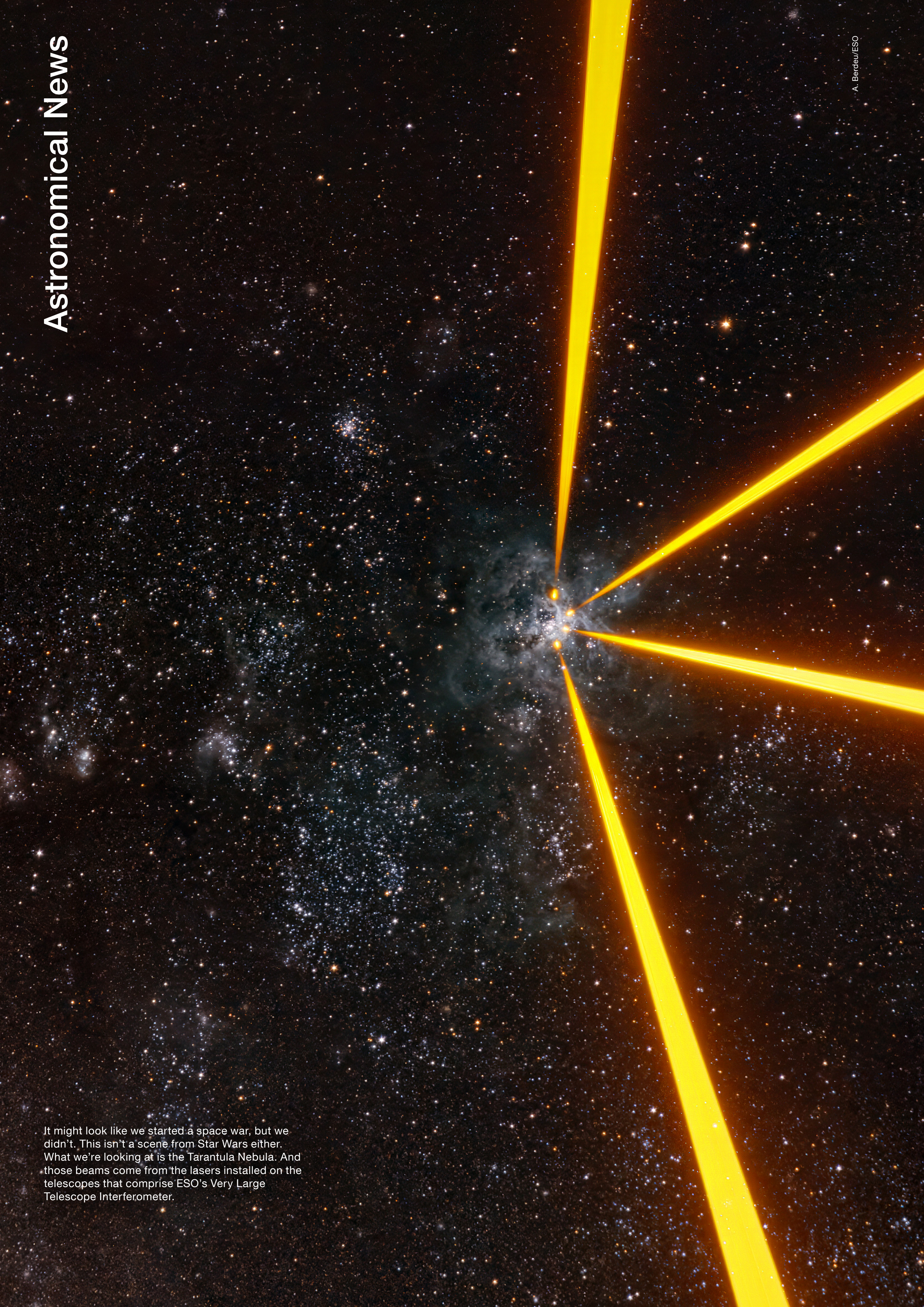
[1] Asgard instrument suite: http://asgard-vlti.org/
[2] Asgard community access: https://asgard-vlti.github.io/community.html

Astronomical News


A. Berdeu/ESO

It might look like we started a space war, but we didn't. This isn't a scene from Star Wars either. What we're looking at is the Tarantula Nebula. And those beams come from the lasers installed on the telescopes that comprise ESO's Very Large Telescope Interferometer.

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ESO Expanding Horizons White Papers Call: Current Status

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In July 2024 ESO launched the Expanding Horizons process to help the organisation define its next major undertaking after the Extremely Large Telescope. The first step of this process is to identify the major scientific questions that will drive the research of the astronomy community in the 2040s. A call for White Papers was issued to encourage discussion of Expanding Horizons as broadly as possible across the community, and to help the Senior Science Committee identify these key future astronomical questions. This article gives an overview of the submitted White Papers.

Introduction

The goal of the Expanding Horizons process (Brinchmann et al., 2025) is to trigger dialogue about the key scientific questions that will face astronomy, and the disruptive technologies required to address them, in the 2040s. This in turn will help ESO in the selection of the next major facility to be developed once ESO's Extremely Large Telescope is completed. Since the initial announcement of the Expanding Horizons process, ESO has taken every opportunity to advertise it as broadly as possible, through an extensive communication campaign, via its web portal[1], local media campaigns, presentations at National Astronomy Meetings, the European Astronomical Society, and on-demand at other meetings.

An important part of the process is the role played by the Senior Science Committee (SSC)[2], appointed by ESO to give independent and unconflicted advice to the executive and the ESO Council on the scientific ambitions and technical feasibility of the new programme.

To further encourage community engagement in the Expanding Horizons process, ESO and the SSC issued a call in Q3 of 2025 for White Papers from the European astronomical community, specifically to outline the key science questions that will likely face European astronomy in the 2040s.

By the 15 December 2025 deadline 208 White Papers had been received by ESO. These span the gamut of astronomical science, ranging from niche themes to the broadest of scientific range, amply demonstrating the diversity and richness of ambition of European astronomy. As announced in the call, although the White Papers will not be made public by ESO, authors have been encouraged to disseminate their contributions by submitting to, for example, arXiv. Currently, approximately half of these papers have already appeared on the archive.

Scientific ambitions

The SSC analysed all of the White Papers and met in person on 5 February 2026 to discuss their content in detail.

The primary focus of the discussion was on the scientific ambition and impact of the proposed science, but attention was also paid to whether the proposed science could be partially or fully addressed by other upcoming facilities. In addition, the technological readiness and promising future technological developments were also considered.

The White Papers spanned a wide range in style, from papers purely focused on scientific questions to others arguing mostly for a facility. Despite the numerous single science cases, there were clear areas of coherence where many White Papers were submitted – sometimes needing different kinds of facilities to reach similar science goals.

Overall, the papers fell into five broad categories with roughly the same number submitted in each:

- Cosmic Expansion and Gravity
- Origin of the Elements
- Matter Under Extreme Conditions
- Galaxy Assembly and Regulation
- Planetary Systems and Habitability.

Demographics of the submissions

As part of the submission process two optional questions were included (for statistical purposes only) to help ESO better understand the demographics of our community. Respondents could provide the career stage and the gender of up to the first three leading co-authors of each White Paper. As a result, such demographic data were submitted for 96% of the White Papers.

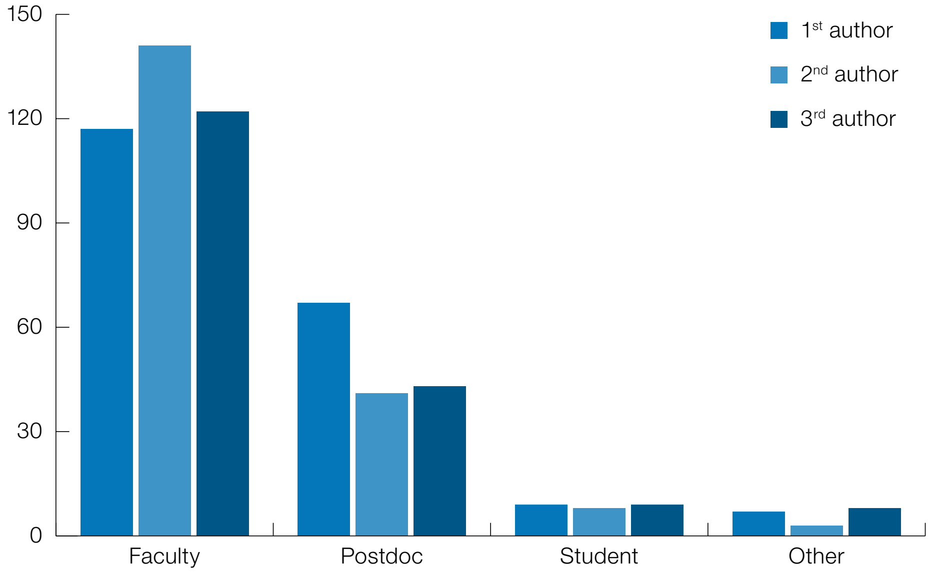

Figure 1. Career stage of up to the first three leading authors of White Papers

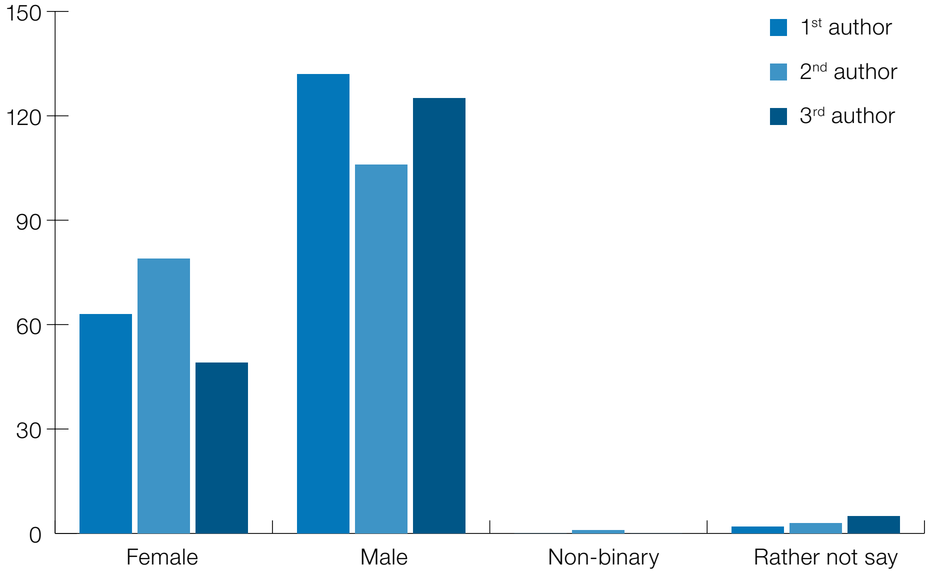

Figure 2. Gender of up to the first three leading authors of White Papers

Figure 1 demonstrates that even though most of the White Papers were led by senior astronomers, an encouraging number of lead authors were at the postdoc stage of their career. This is a key demographic considering the long-term timescale of the facility that is to be selected following the Expanding Horizons process.

Next steps

Informed by the submitted White Papers, ESO and the SSC are now organising the first in a series of community workshops, scheduled for 13–17 July 2026, to be held in person at ESO's Headquarters in Garching near Munich.

The primary goal of the "Expanding Horizons: What are the astronomical challenges of the 2040s" workshop[3] is to get the broadest engagement possible across the community, concerning both the science drivers as outlined in the White Papers, and facility needs.

The SSC hopes the workshop will help to identify overlapping goals and tools, as well as synergies across different scientific themes, leading to consolidation around specific facility concepts that will deliver the strongest scientific return to the European astronomical community.

Another important aspect of the meeting will be the discussion of the types of novel technical innovations that will be necessary to realise the new facility.

The structure of the workshop is currently envisioned to consist of a series of plenary talks covering the major scientific themes, interspersed with technology development talks, along with more dedicated splinter meetings.

It is expected that during this workshop ESO will launch the Call for Ideas for its next programme, ahead of the deadline for Letters of Intent, due on 1 December 2026. Further information will be provided on the Expanding Horizons website[1] and in particular in the FAQ section.

References

Brinchmann, J. et al. 2025, The Messenger, 195, 5

Links

[1] Expanding Horizons website: https://next.eso.org/
[2] Expanding Horizons Senior Science Committee: https://next.eso.org/ssc/
[3] Workshop Expanding Horizons: What are the astronomical challenges of the 2040s webpage https://www.eso.org/sci/meetings/2026/ExpH.html

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J. Looten/ESO

" ...by the beauty of it all, to the point of forgetting everything around me," says Julien Looten, a French astrophotographer. During his visit to ESO's Very Large Telescope in Cerro Paranal, Chile, he captured this extraordinary image which reveals the astonishing impression he gained of one of the world's darkest skies on Earth.

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Report on the ESO workshop

VLT Beyond 2030 and Call for White Papers

held at ESO Headquarters, Garching, Germany, 26–30 January 2026

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The VLT Beyond 2030 conference gathered participants from the community and ESO experts to present and discuss science and technological ideas for the future of both the Very Large Telescope (VLT) and its interferometer (VLTI). An effort was made to pair participants with science and engineering backgrounds so as to optimise cross-field fertilisation and initiate 'out-of-the-main-room' discussions. The well-attended conference reflected the continued interest within our community in developing new projects for the VLT/I and the will to use this facility to answer key science questions that are likely to be crucial in the decades to come. This article presents a summary of the overall points of focus during the conference and also serves as the opening of the call for White Papers with a deadline of 15 January 2027. Proposers are encouraged to fast-forward to the years beyond 2030 to identify essential areas of research so that together we can shape a long-term roadmap for the VLT/I.

Motivation

ESO operates optical/near-infrared telescopes on its La Silla and Paranal observatory sites and is a partner in the Atacama Large Millimeter/submillimeter Array (ALMA). The Extremely Large Telescope (ELT) on Cerro Armazones is under construction, expected to start operations at the end of the decade. ESO is a partner in the Cherenkov Telescope Array (CTA) which will start operations in the coming years. In addition, ESO provides resources such as user support and science archives to empower the community to make the best use of the facilities offered. The existing and planned ESO facilities cover a large parameter space across the electromagnetic spectrum, angular, spectral and time resolution, multiplexing and observing methods (Brinchmann et al., 2025a). In particular, Paranal observatory was developed specifically to host the Very Large Telescope (VLT) and its interferometer (VLTI) some 30 years ago. The VLT/I instrumentation has been developed over many years and continues to benefit from developments and upgrades.

The VLT Beyond 2030 process aims to maintain the VLT/I at the forefront of astrophysical research in the decades to come. This is distinct from the Expanding Horizons[1] process (Brinchmann et al., 2025b), the goal of which is to select the next ESO facility after the ELT. The development of the VLT/I instruments follows planning that is discussed with the ESO governing bodies to derive the best synergies amongst facilities. As part of this process, ESO organised a conference, named VLT Beyond 2030, at its headquarters in Garching near Munich (Germany) in January 2026. The programme[2] covered many topics and included extensive discussion sessions to promote ideas and thought-provoking exchanges beyond the invited and contributed contributions. This article provides a short, non-exhaustive summary of the meeting and also serves as the opening of the call for White Papers.

Bird's eye view

At the start of the conference, the ESO senior management reminded everyone of what a privilege it is to be able to observe, and hence our duty to protect our skies from multiple types of pollution from the ground, including light, dust and vibration. Later in the conference, light pollution from space, as generated by, for example, satellite constellations, was also discussed. While recent events have been positive in this respect[3], the astronomical community will have to keep high on its agenda an effective and coordinated dialogue with stakeholders to preserve the purity of the sky for the good of astronomical research and, more broadly, of human knowledge.

The start of the conference also included various presentations on the impact of future VLT/I instrumentation on sustainability. As our society is facing major environmental challenges, future projects will have to monitor and minimise their environmental impact. In addition, the consortia building the instrument beyond 2030 are invited to encourage diversity in their teams. While the timescale envisioned naturally provides opportunities for early-career scientists to contribute, a good mix of gender and minority representation would be an obvious asset for future projects.

Figure 1. VLT/I Beyond 2030 workshop banner.

The first day of the conference provided overviews of both ground- and space-based facilities at multiple wavelengths. It is becoming obvious that a number of future missions’ science goals cannot be fulfilled without coordinated follow-up from the ground. A discussion session dedicated to these topics concluded that an assessment of the ground-based segment as early as at the proposal stage, perhaps by having representatives of the partner agency taking part in the review process, would be the best way to coordinate such essential efforts efficiently. The role of public surveys in that context was also highlighted. Ultimately, this coordination would greatly benefit from synchronised roadmapping exercises, which would take into account similar timescales and scope.

All week, speakers stressed the several aspects unique to the VLT/I which should be not only preserved but also further developed. This included coherent and intensity interferometry and a blue coverage which remains competitive with respect to the ELT thanks to both a three-mirror design and the chosen mirror coatings. Similarly, the availability of four Unit Telescopes (UTs) makes the VLT/I unique in terms of survey power with respect to the next generation of giant telescopes, perhaps providing a means to select targets to then follow up with the ELT. It was highlighted that gathering statistics is going to be key for cosmology-related research in particular. Importantly, the VLT/I and even the Auxiliary Telescopes provide a valuable testbed for new technological developments and on-sky tests. Discussions included the idea of also awarding technological-development time (in addition to science time) on the VLT/I and driving new discovery by enabling technological breakthroughs. Some of these could be done via the recent new possibility of requesting Guaranteed Time Observations as part of an ESO Tech Dev project.

Some of the conference discussions highlighted that part of the future needs are at the level of the facility itself. Ideas included equipping all UTs with multiple laser guide stars and deformable mirrors to enable the use of adaptive optics (AO) for most future instruments while lowering the pressure on UT4. Furthermore, there were suggestions to provide a clear roadmap on the VLT/I instrumentation plan in the next decades to ensure scientifically valuable monitoring programmes can be sustained without instruments being unexpectedly decommissioned. Indeed, an obsolescence programme which preserves the efficient operation and maintenance of both successful current instruments and the telescopes themselves appears important. Finally, questions on how rapidly emerging private observatories might be integrated in the current system were also debated.

Scientific perspectives

The science landscape in the 2030s and beyond is paved with many challenging questions. Several conference attendees stressed that catering for multimessenger astronomy, especially as we stand on the verge of an era of booming numbers of transient triggers, will become increasingly important. Multimessenger astronomy beyond the 2030s will also require rapid access to real-time and archival data from multiple observatories to rapidly identify and follow up on crucial targets. This may necessitate a rethink of how we communicate alerts and design databases, a field in which ESO could play a coordinating role. As the number of astronomical objects classified as transients increases, the need for spectroscopic observations across the electromagnetic spectrum becomes more obvious and public surveys or alternatives might play a role in coordinating the community requests. In synergy with multiple other facilities targeting new messengers, including very high-energy photons, neutrinos or gravitational waves, the VLT/I is bound to have a role to play in these areas of research.

Cosmologists are still pursuing an understanding of the nature of dark energy and dark matter, while the so-called Hubble tension remains an uncomfortable challenge to our understanding of the largest scales of the Universe. Big Bang nucleosynthesis and related topics, such as the cosmic lithium problem, helium-4 abundance and deuterium over hydrogen abundance, have seen progress in recent years. High on the agenda is a measurement of the mass of neutrinos for which progress will likely require synergy with other experiments. Possible contributions by the VLT to these topics in the years to come include measurements of the variation of fundamental physical ‘constants’ at a level predicted by some theories and the so-called Sandage test measuring the expansion of the Universe through redshift drift. In the field of galaxy formation, a refined understanding and characterisation of the baryon cycle which connects the intergalactic medium with galaxies (dubbed intragalactic science) and stellar- and black hole-driven feedback processes will likely be key in 2030 and beyond. Some of the current VLT instruments have recently contributed crucial results to these fields and more are expected in the decades to come. The physics of black holes, especially the massive objects observed at high redshift, is another important area of development, with both ALMA and the VLT providing important spectroscopic results. The search for the elusive Population III stars is another active research domain. The epoch of reionisation and the fraction of ionising photons escaping galaxies also represent a dynamic field of research.

In the booming field of exoplanets, the role of spectroscopy was emphasised, highlighting that planet detection relies critically on long time series. A rapidly expanding sub-field is aiming to characterise the hot and cold atmospheres of exoplanets as a key component of both their chemical abundance and dynamics. It was stressed that a mono-mode fibre instrument at red wavelengths would enable us to search for habitability in Earth-mass planets orbiting late M-dwarfs. On the other hand, high-contrast imaging enabled by coronagraphy, coupled with AO and advanced software post-processing, offers the prospect of effective direct imaging approaching the fundamental limit. In particular, machine learning and predictive control of the AO systems provide a promising avenue for the future. Despite the limitations related to telescope availability and timescale for tailored instruments, the more than two orders of magnitude gain from the ELT with respect to the VLT in terms of direct imaging was stressed. As for other fields, the uniqueness of the VLT at shorter wavelengths remains. Exoplanet spectroscopy and astrometry would also

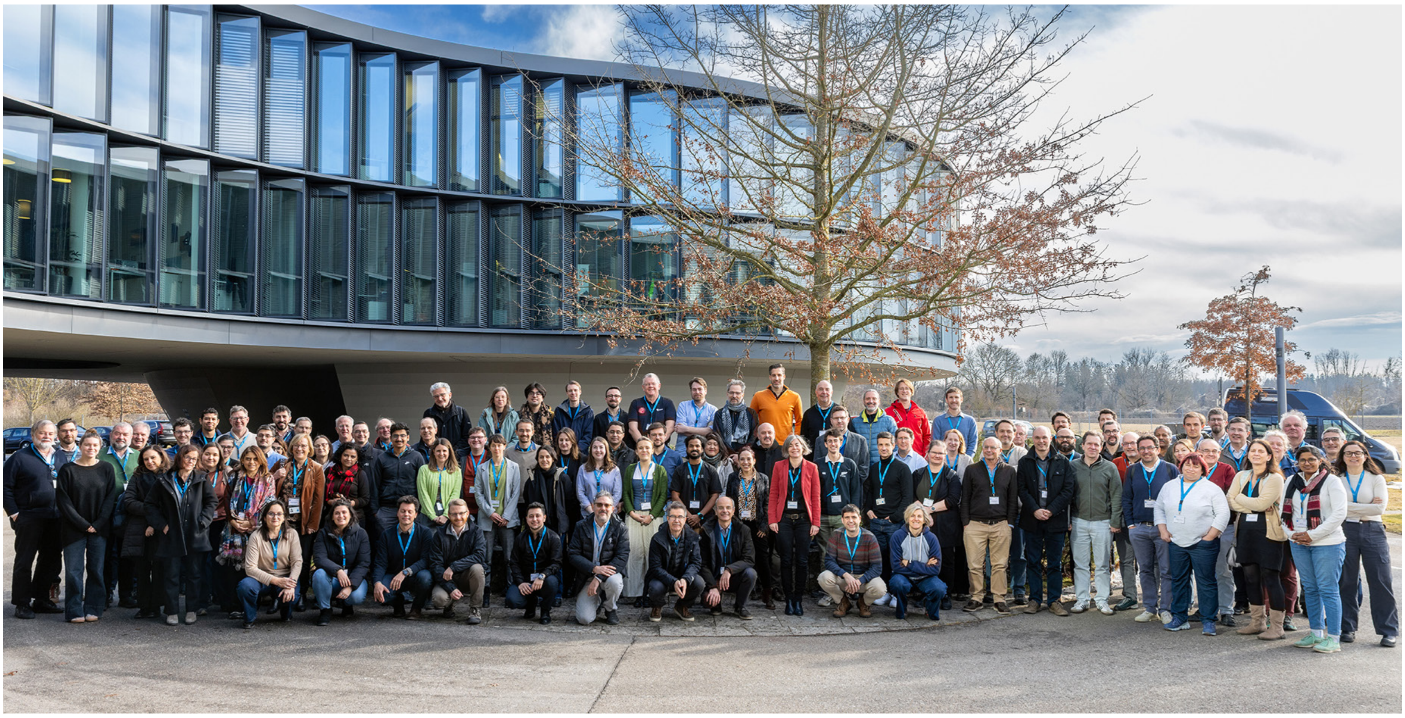

Figure 2. Many participants braved the harsh German winter to take part in the conference.

remain competitive with the VLTI, by expanding to shorter wavelengths and higher spectral resolution. Additionally, integral field spectroscopy in reflected light at the VLT could harvest potential biosignatures of the most promising targets. Finally, an improved understanding of planetary systems across time and space will be an important component of research in the field.

On the massive stars front, many questions will be addressed in the coming years including: i) probing the formation and evolution of binaries and other multiples; ii) quantifying the effect of metallicity; and iii) characterising stellar feedback. Open questions about star formation include population studies, accretion and ejection processes, disc physics and determining the universality of the initial mass function. Likewise, stellar structure, as probed through astroseismology and including magnetospheres, will likely be an area of development alongside studies of stellar remnants. Equally important is work on the origin of elements and nucleosynthesis as well as hierarchical galaxy assembly — including testing the lambda-cold-dark-matter scenario outside our Milky Way, but also establishing the number of merging events and nucleocosmochronology using chemical abundances to measure the ages of the oldest stars.

Other topics not developed in detail at the conference include the Solar System and its giant planets, also comprising comets and other fast-moving objects, as well as so-called galactic archeology.

Parameter space

One way to envision the next generation of instruments is naturally to expand the parameter space which will then likely enhance the discovery potential. Natural parameters to advance include i) spectral resolution, ii) angular resolution, iii) astrometic accuracy, iv) wavelength coverage, v) field of view, vi) multiplexing, vii) time-domain, viii) wavelength accuracy, ix) optimised transmission and x) contrast. Building on highly successful current instruments, pushing single-object, high-resolution spectroscopy to redder wavelengths on both the VLT and La Silla telescopes was proposed in various forms by several contributors. Likewise, current multi-object spectrographs cover a wide range of scientific topics from galactic archeology to the high-energy sky, galaxy evolution and even cosmology. The need for very high-resolution multi-object spectroscopy, an ESO legacy, was raised on several occasions, stressing in particular the role it might play in following up past & future European space missions. In the last decades, large-field integral field spectrographs (IFUs) have transitioned from single-object instruments to panoramic facilities catering for a large variety of science fields by providing massive spectroscopy in dense fields, both for extended sources and in deep fields. As we are entering an era of wide and deep photometric surveys (with facilities like Euclid, Vera C. Rubin Observatory and the Nancy Grace Roman space telescope), the need for matching spectroscopic surveys becomes even more obvious. Transmission remains a key element of such an instrument, in turn requiring optimisation of mirror coatings as well as further developments in the area of volume-phase holographics. Moving to redder wavelengths with such a wide-field instrument would offer a new parameter space. The challenges will be to cut the cost per spectrograph while providing a compact, and hence a more manageable, design. It was argued that, simply put, IFUs provide “spectroscopy of everything”.

In addition to these, other boundaries of the parameter space were proposed during the week. Various conference participants emphasised that line fidelity (which is different from wavelength accuracy) and simultaneity in terms of wavelength and also continuous spatial coverage are areas of potential advances. Additionally, brokers to triage the interesting targets before triggering a rapid response mode and appropriate data flow to enable quick access to the data are key aspects of the parameter space. Speakers also highlighted the power of low-surface-brightness sensitivity of extended sources as a tool to challenge the lambda-cold-dark-matter model. Polarimetry at various wavelengths, where multiple proofs of concept already exist, was felt to be an important tool to improve on our physical understanding of a wide number of astrophysical sources, ranging from planets, stars and local galaxies to supernovae and active galactic nuclei.

Key technological developments

From its inception, the conference aimed at associating scientific prospects beyond 2030 with innovative technologies at various levels of maturity. The science organisation committee suggested pairs of reviewers with either scientific or technological expertise on topics which might mutually benefit each other. This setup naturally highlighted a number of important current and future developments which will likely turn out to be essential for the VLT/I beyond 2030. Work on detectors and controllers is an obvious area of development, including the potential for low-noise, high quantum efficiency and curved detectors to enable instruments with larger fields of view. Maintaining supply chains of various sub-systems (detectors, thorium hollow-cathode lamps, etc) was also felt to be important. A discussion session reported a need for an increase in the maturity of accurate wavelength calibration from both (pressure-controlled) hollow-cathode lamps and laser frequency combs to new technologies, including electro-optic modulators and silicon chips. Panelists also stressed the challenges of interfacing these calibration units with the instrument/telescope. It was pointed out that for exoplanet research a laser frequency comb was not needed every night so that one system could be used by several telescopes and/or UTs. Reports of using a filter-tilter in front of the telescope optics to enable narrow-band filtering without degrading the flux transmission were also provided. Equally important are future developments in the field of AO, including tip-tilt correction to enable full-sky AO, more powerful laser guide stars enabling laser splitting, or orbiting artificial stars offering brighter sources with no cone effects and no need for stabilisation, as well as stable deformable mirrors. Intensity interferometry offers the potential to resolve 50-microarcsecond scales by combining the VLT and the 4-metre Visible and Infrared Survey Telescope for Astronomy (VISTA) telescope in Paranal, while robotic fibre positioners have been shown to be smaller and faster and to offer more accurate positioning, allowing for high-fibre-density instrument design. Virtually imaged phased array dispersers might enable a path towards ultra-high ($R > 300\,000$) spectral resolution, while the potential of astrophotonics, including for OH line suppression, has been highlighted. Clearly, more compact instruments would offer the benefits of lower costs, requiring fewer resources and lighter associated logistics.

Thinking outside the box

Beyond these technological developments, several participants emphasised the importance of adapting the VLT/I operation model to new needs, including high flexibility. This encompasses rapid follow-up of the many transients soon to be available, monitoring targets over several years and enabling a route for possible high-gain, high-risk proposals.

It was stressed several times that, beyond hardware, successful science projects also benefited from innovative software. While data reduction software at ESO has reached a high level of maturity, the instruments to be operated in the next decade likely will have to provide equally robust data analysis software to maximise the science outputs in a multi-wavelength environment. It was stated that this is particularly true for upcoming panoramic IFUs for which essentially every observation is a survey. The ever-increasing value of an easy-access, interoperable and public archive was also stressed. In an era of large data sets, the role of machine learning based on foundation models to harvest such archives is likely to become increasingly relevant. Importantly, it was highlighted that some of the astrophysical measurements to be made beyond 2030 are limited by flux calibration, highlighting the need for better spectrophotometric featureless standard stars and also for improvements to poorly constrained laboratory measurements of atomic data, which prove nonetheless key to deriving the composition and abundance of various elements. Research in these areas needs to be supported and promoted to enable the best scientific output.

Conference demographics

The Scientific Organising Committee (SOC) sought fair representation from the community. The SOC aimed for a balanced ratio of female to male speakers for invited and contributed talks compared to the ratio among participants. As a result, the SOC itself was composed of 5/6 F/M (45% female), while the invited speakers were 6/13 F/M (46% female) and the session chairs 10/22 F/M (45% female). The proposed contributed talks (79 total) were split 16/59/4 F/M/”prefer not to say” (20% female) while the actual contributed speakers (35 total) were 9/24/2 F/M/”prefer not to say” (25% female).

Attendees came from six continents (all but Antarctica), with the following percentages: 83.4 % Europe (Germany, Italy, France, Netherlands, Switzerland, Austria, UK, Sweden, Spain, Portugal, Denmark, Ireland, Belgium [r], Czechia [r], Poland [r], Finland [r], Hungary [r]); 6.3 % South America (Chile, Brazil); 4.9 % Australia; 2.4 % Asia (India, Iran [r], Turkey); 1.5 % North America (US, Canada) and 1.5% Other (where r = remote participants only).

The conference had a high oversubscription rate and attendance was over 140 in-person participants and typically 50 on-line attendees[4].

Call for White Papers

As part of the VLT Beyond 2030 process, ESO is issuing a call for White Papers for new instruments for the VLT/I, with a deadline of 15 January 2027. The process aims to keep the VLT/I at the forefront of astrophysical research in the coming decades. The White Papers will be assessed by ESO and community representatives. The assessment phase will take place during 2027, leading to a phase A which will start in 2028 at the earliest. ESO will contribute hardware budget up to 10 million Euros per instrument.

A web page[5] provides detailed information about the format of the White Papers. Two separate documents need to be prepared: one focusing on science and the second one providing further technical information. The second document shall include specifically the following sections: i) instrument design elements; ii) technological developments; iii) consortium structure; iv) a management plan including a risk assessment; v) a budget plan; and vi) impact (societal, environmental, etc.) Together the two documents (in pdf format) should have a maximum of 50 pages, including figures but excluding references. The number of pages split between the two documents is up to the proposers. Submission instructions for these materials will be provided on the dedicated webpage[5].

All are invited to submit a White Paper, regardless of whether they have attended the conference or not. Projects at different levels of maturity are welcome as ESO aims to use this material to establish a roadmap for the VLT/I beyond 2030.

Conclusion

Clearly, the week-long conference provided a forum in which to forge new connections between various experts, with the hope that these initial conversations will develop in well-shaped ideas by the deadline for the White Papers. The flexible format of the call is meant to encourage ambitious and transformational project proposals at various stages of maturity as ESO aims at using this material to establish a roadmap for the VLT/I beyond 2030. Ultimately, the VLT/I Beyond 2030 process aims to keep the VLT/I at the forefront of astrophysical research in the coming decades.

Acknowledgements

We would like to thank the SOC for shaping an exciting conference programme. We are further grateful to the Local Organising Committee for volunteering their expert support to the organisation of the conference. Special thanks go to Denisa Tako for professional help and steadily good mood.

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Links

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[5] Call for White Papers: https://www.eso.org/sci/meetings/2026/VLT_beyond_2030/whitepaper_call_vltbeyond2030.html

L. Sbordone/ESO

Have you ever wondered how a telescope keeps its mirrors in the best condition to observe the cosmos? In this image, a truck carefully carries one of the mirrors of ESO's Very Large Telescope (VLT), wrapped to protect it from the harsh environment of Chile's Atacama Desert. Its destination is the recoating facility that keeps the mirrors of this telescope perfectly shiny.

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Report on the ESO workshop

Galaxy Ecosystems Under the Microscope: Lessons from Highly-Resolved Studies

held at ESO Headquarters, Garching, Germany, 7–11 July 2025

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In the past decade, our approach to studying galaxies has undergone a remarkable transformation. By focusing on the most nearby systems, we can now probe the fundamental building blocks of galaxies — molecular clouds, H II regions and star clusters, along with fully resolved galaxy structures such as nuclear stellar discs, bars, and spiral arms — in unprecedented detail. The Galaxy Ecosystems Under the Microscope (GalRes25) workshop brought together over 110 participants from institutes in 18 countries at ESO Headquarters in Garching from 7 to 11 July 2025 to exchange the latest results from these highly resolved studies. Over the course of around 60 talks and 50 posters, participants explored how galaxies assemble their baryonic components, how star formation and feedback regulate their evolution, and how small-scale physics connects to global galactic properties. Sessions on gravitational lensing extended this discussion to the high-redshift Universe, setting the stage for future high-definition studies of galaxies both near and far with the Atacama Large Millimeter/submillimeter Array's Wideband Sensitivity Upgrade, the Square Kilometre Array, ESO's Extremely Large Telescope, and upcoming Very Large Telescope instruments such as BlueMUSE and the Multi-conjugate-adaptive-optics-Assisted Visible Imager and Spectrograph (MAVIS).

Workshop motivation and context

Galaxy evolution is driven by processes that unfold on parsec scales — gas inflows, turbulence, stellar feedback and cloud collapse. For decades such detail was accessible only in the Milky Way and its nearest companions. Recently, however, the field has experienced a major leap forward: by targeting the very nearest galaxies, we can now resolve their internal structure and directly study the interplay between gas, dust and stars on the scales where these processes occur (Figure 1). Observations from ESO facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA) and the Very Large Telescope, and complementary facilities such as JWST, the Hubble Space Telescope, the Canada France Hawaii Telescope's SITELLE spectrograph and MeerKAT have made this possible, while simulations have evolved to match this level of physics. GalRes25 was organised to take stock of these advances, bringing together observers and theorists to exchange results, confront challenges and build a coherent view of galaxies as interconnected ecosystems.

Conference structure & themes

Galaxy assembly: baryonic growth histories

Spatially resolved observations have made it possible to distinguish the assembly history of individual galaxy components. By studying the relative contributions of various processes, such as *in-situ* versus *ex-situ* formation, we can uncover the imprints left on a galaxy's structural components and piece together its life story.

This theme saw presentations on the assembly of galactic structures such as bars and nuclear discs, the role of mergers in galaxy growth and the buildup of dust in galaxies. Multi Unit Spectroscopic Explorer (MUSE) campaigns including Generalising Edge-on galaxies and their Chemical bimodalities, Kinematics and Outflows out to Solar environments (GECKOS), Time Inference with MUSE in Extragalactic Rings (TIMER), and Bulge Assembly in Nearby Galaxies (BANG) are providing detailed insights into the stellar populations of the galaxies, especially their centres. A strong representation by the dynamical modelling community ensured much discussion about the use of orbital superposition methods to diagnose galaxy structure and assembly histories.

Regulation of star formation and feedback

A central theme of the workshop was the regulation of star formation and the impact of stellar feedback in nearby galaxies. Using spatially resolved, multi-wavelength data from surveys, including Physics at High Angular resolution in Nearby GalaxieS (PHANGS) and the Local Group *L*-Band Survey (LGLBS), talks traced how gas becomes gravitationally bound, forms stars and is then disrupted, ionised or expelled by those same young stars.

Figure 1. Workshop motivation was provided by results such as this[1]. This stunning image of NGC 253 captured with MUSE provides context for parsec-scale science – individual star-forming regions, supernova remnants, outflows and the central galactic region are all spatially resolved in this image. The physical drivers of these phenomena (and many more) were the backbone of the science agenda of GalRes25.

Figure 2. A: Participants trying to find their groups for the poster quiz session. B: The eventual winners of the Poster Quiz, team Germans Analysing Luminous Realms of Extragalactic Schnitzel (GALRES), who also received a bonus point for the best team name!

This theme explored the internal structure of H II regions, the life cycles of molecular and dense gas, and both radiative and mechanical feedback — from ionising radiation to winds and supernovae — and showed how these processes vary across different galactic environments. A recurring focus was the full ‘star formation cycle’: how efficiently galaxies convert gas into stars, on what timescales, and how rapidly feedback returns energy and momentum to the interstellar medium. Together these results emphasise that star formation is not a simple on/off process but a tightly regulated cycle in which gas flows, environment and feedback continuously shape when, where and how galaxies continue forming stars.

Connecting scales: from parsecs to kiloparsecs

While galaxies are governed by processes that occur locally on scales of tens to hundreds of parsecs, the connection between these small-scale processes and global galaxy properties remains unclear. This theme aimed to link previous results from kiloparsec-scale surveys such as Mapping Nearby Galaxies at APO (MaNGA) and Calar Alto Legacy Integral Field Area (CALIFA) to more highly resolved studies of small samples of nearby galaxies. Progress is being made on the stellar populations front, the cold gas front (including comparisons between the Kiloparsec Investigations of Local Objects And Star-formation [KILOGAS] and the mm-Wave Interferometric Survey of Dark Object Masses [WISDOM] ALMA surveys), and star formation quenching, from global to cloud scales. The importance of a multiwavelength approach to the multiscale problem of galaxy evolution was a theme that ran through the week, though it was particularly highlighted in the invited and contributed talks on this theme. A key takeaway from this theme was the concept that the scale at which one needs to resolve a science object should be directly influenced by the science question.

Gravitational lensing: a high-z window

The final theme of the workshop focused on strong gravitational lensing, which effectively turns very distant galaxies into ‘nearby’ laboratories. The extreme magnification in these systems boosts both apparent brightness and spatial resolution, allowing us to apply the same tools we use in the Local Universe — mapping gas, star formation, feedback and metal enrichment — to galaxies only a few hundred million years after the Big Bang. Highlights included new results on the Waz Arc (COOL J1241+2219), whose highly magnified structure can be dissected in detail, and early findings from the JWST LEnsing and Galaxy Growth: Observing Substructures (LEGGOS) programme, which resolves individual clumps in lensed galaxies and traces how they assemble, interact and enrich their surroundings across cosmic time.

Innovative formats and event highlights

In addition to plenary sessions, GalRes25 championed interactive discussion groups, where participants worked in small mixed teams to encourage exchange between observers, theorists and instrumentalists. Randomly selected teams also competed in the poster quiz (Figure 2), a lively session in which groups were quizzed on the scientific content of the posters. The quiz proved both educational and entertaining and was repeatedly highlighted in participant feedback as one of the most enjoyable portions of the week. We again congratulate the winning team — Germans Analysing Luminous Realms of Extragalactic Schnitzel (GALRES) — for their superior knowledge and innovative team name (Figure 2b).

Participation and diversity

The GalRes25 Scientific Organising Committee (SOC) worked to ensure gender balance within both the organising committees and the invited speaker list. The final attendance (Figure 3) comprised 54% women, 41% men and 5% other genders or undisclosed, representing institutions across 18 countries (including nine Member States, Chile and Australia).

Figure 3. Conference picture of the participants in front of the ESO Supernova planetarium and visitor centre, Garching.

A strong emphasis was placed on supporting attendance at the workshop, with a significant portion of the budget allocated to reducing registration fees, enabling travel support for invited speakers and supporting junior participants (10 fee waivers). In addition, a hybrid format further expanded participation, with 16 colleagues attending online throughout the week.

Legacy

Talk slides are available on Zenodo[2].

Acknowledgements

We sincerely thank all the members of the GalRes25 SOC, which comprised Eric Emsellem, Francesca Fragkoudi, Eva Schinnerer, Francesco Belfiore, Luca Cortese, Stephanie Tonnesen, Amelia Fraser-McKelvie, Enrico Congiu, Ashley Barnes and Camila de Sá Freitas. The Local Organising Committee were instrumental in the success of this workshop, comprising Denisa Tako, Lukas Neumann, Lennart Boehm, Tomas Rutherford, Daudi Mazengo, Eric Emsellem, Nicolas Guerra Vargas, Felipe Schmidt Lohmann, Tamsyn O’Beirne, Ashley Barnes, Camila de Sá Freitas, Amelia Fraser-McKelvie and Enrico Congiu.

We thank ESO for workshop funding and logistical support, all session chairs, and all conference participants for their open and enthusiastic engagement throughout the week.

Links

[1] MUSE image of NGC 253: https://www.eso.org/public/news/eso2510/

[2] Workshop slides: https://zenodo.org/communities/galres2025

ESO/A. Feltre, F. Belfiore, G. Cresci et al.

This image is a closeup of the nearby Triangulum galaxy, also known as Messier 33, located about 3 million light-years away. This festive-looking image, taken with ESO’s Very Large Telescope (VLT), reveals the diversity and complexity of the gas and dust between the stars in great detail.

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Report on the ESO workshop

AO4ELT8: First Edition of AO4ELT in Chile

held at Viña del Mar, Chile, 27–31 October 2025

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Adaptive optics is one of the major challenges that the future extremely large telescopes face, and it's essential to reach their scientific goals in terms of accuracy and sensitivity. It's crucial for the entire scientific community working on the topic to gather and share ideas about the latest advances in this field. This is achieved through the Adaptive Optics for Extremely Large Telescopes (AO4ELT) conference, which has been held every two years since 2009. After the success of the seventh AO4ELT conference organised by the Optics Department of ONERA (the French aerospace lab) and the Marseille Astrophysics Laboratory, the Optoelectronics Laboratory (OPTOLAB) and Pontifical Catholic University of Valparaiso (PUCV) have joined the AO4ELT organisation to host the eighth conference in the series (AO4ELT8). The event was held in the city of Viña del Mar, Chile, between 27 and 31 October 2025.

The eighth Adaptive Optics for Extremely Large Telescopes (AO4ELT8)[1] conference brought together international experts in adaptive optics (AO) to share advances supporting the upcoming generation of extremely large telescopes (ELTs), including ESO's Extremely Large Telescope (ESO's ELT), the Giant Magellan Telescope and the Thirty Meter Telescope. Held over five days, the programme consisted of plenary lectures, focused technical sessions and extensive poster presentations, reflecting both the rapid evolution and the interdisciplinary expansion of AO technologies.

The conference began with a broad view of "The Adaptive Optics Renaissance", highlighting how AO has become essential not only for ground-based astronomy but also for fields such as optical communication and defence. Subsequent plenaries addressed new wavefront-correction frontiers, cross-domain synergies and AO technologies poised to shape the next decade. Parallel sessions explored the most active domains in AO research. Key topics included the design status of major AO systems for first-light instruments at ESO's ELT (the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph [HARMONI], the Multi-AO IMaging Camera for Deep Observations [MICADO], the Mid-infrared ELT Imager and Spectrograph [METIS], the Multiconjugate adaptive Optics Relay For ELT Observations [MORFEO], the ArmazoNes high Dispersion Echelle Spectrograph [ANDES]), wavefront sensing and reconstruction, vibration mitigation, turbulence characterisation, and AO system control. Special attention was given to machine learning, with sessions dedicated to deep neural networks for wavefront reconstruction, predictive control, point spread function modelling and real-time telemetry analysis.

Figure 1. Conference photo

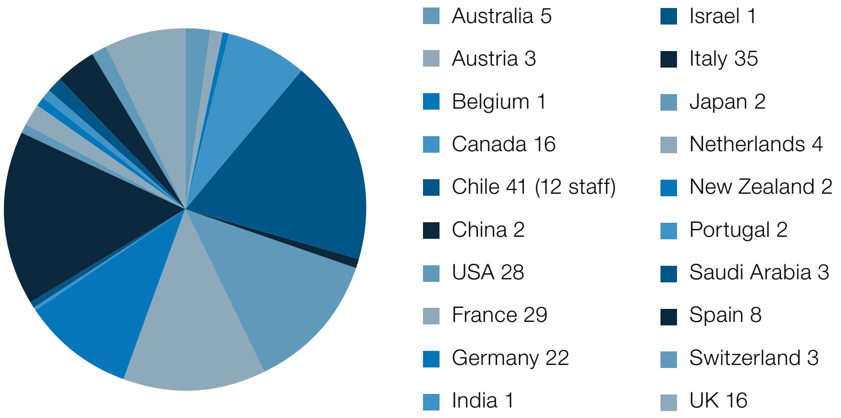

Figure 2. Number of participants per country.

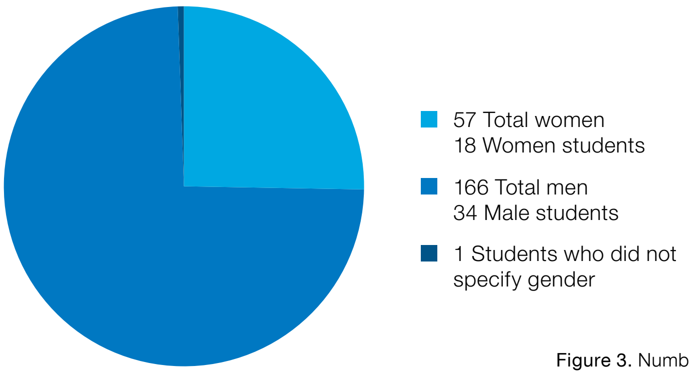

Figure 3. Number of participants by gender.

A strong emphasis was placed on pathfinder systems and testbeds, demonstrating the maturity of AO concepts ahead of implementation on ELT-scale platforms. Contributions showcased progress from major observatories such as Keck, Subaru, Gemini, ESO’s Very Large Telescope, and the Large Binocular Telescope, including on-sky demonstrations, laboratory validation and real-time control developments.

The conference featured more than 150 poster presentations, covering a diverse array of topics, including laser guide star systems, wavefront sensor prototypes, AO control architectures, atmospheric turbulence studies, high-contrast imaging methods and applications outside astronomy such as satellite communication and space surveillance. The poster sessions provided a complementary venue for detailed technical exchange and interdisciplinary discussion.

Over the week, some common themes emerged: AO systems for ELTs are reaching final design reviews; AI-driven approaches are transforming wavefront sensing and control; and integrated simulations are enabling more reliable performance prediction. Together, these developments highlight both the maturity and expanding scope of AO research showcased throughout AO4ELT8. The contributions demonstrated significant progress in AO system design for ELT-class instruments, the growing influence of machine learning across all aspects of AO operation, and the emergence of AO as a critical enabling technology beyond classical astronomy. As the extremely large telescopes approach first light, the field is undergoing rapid evolution and entering a phase of unprecedented capability, poised to deliver transformative scientific, technological and interdisciplinary impact.

Demographics

Like many workshops, the Scientific Organising Committee (SOC) sought fair representation from the community. To this end, we voted on 14 invited speakers, and four plenary sessions, using the sole criterion of who would give the best review of each topic. The result was a 71:29 ratio of male to female.

Attendees (Figure 1) came from five continents (all but Africa & Antarctica), the numbers as shown in Figure 2. The gender breakdown of participants is shown in Figure 2.

The talk selection was made blindly (one SOC member removed names and identifying information about the authors and then abstained from voting), so we conclude that the method likely worked to address gender biases. We also had a decent level of participation from young researchers, with around 24% of attendees being students. We also provided six student travel scholarships funded by OPTICA2.

The workshop had a high level of participation, with approximately 224 participants. We attribute this to both the compelling nature of the subject matter, which draws researchers at all career stages, and to the generous support that kept the cost of attendance relatively low.

Acknowledgements

We would like to express our sincere appreciation to all the sponsors whose support was essential to the realisation of this conference. Their generous contributions enabled the organisation of this event and facilitated the exchange of ideas and research within our community. We gratefully acknowledge their commitment and assistance.

Links

[1] Conference website: https://ao4elt8.pucv.cl/
[2] OPTICA website: https://www.optica.org/

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Report on the ESO workshop

LISA 10 — Library and Information Services in Astronomy

held at ESO Vitacura, Santiago, Chile, 3–7 November 2025

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The 10th LISA conference (LISA 10) took place at ESO Chile in early November 2025. The theme, Research Equity and Access in the Age of AI, highlighted the rapidly evolving landscape of scholarly communication in astronomy. Artificial intelligence, open access mandates, and expanding data archives are transforming scientific practice and information in an increasingly interdisciplinary research environment. Through presentations, posters, and discussions, LISA 10 explored how these developments are redefining the management of astronomy information work and the role of librarians.

Introduction

LISA 10[1] was the latest in the LISA (Library and Information Services in Astronomy)[2] series of international community-driven conferences that bring together astronomy librarians, information professionals, data specialists, archivists, documentalists, publishers and scientists to discuss issues relevant to information management in astronomy and related sciences. The series began in 1988 and has been held every three to four years since LISA II (held at ESO in Garching in 1995).

Astronomy librarians traditionally have been a small but global and yet well-connected community. LISA conferences have always been special as they are the foremost international meeting in our profession, enjoying high visibility and recognition (Figure 1).

Day 1: AI/ML, the UAT and the evolving role of libraries

Astronomy, like many other sciences, is seeing artificial intelligence (AI) and machine learning (ML) advance rapidly. This was reflected by the first conference session which showed how ML is entering scientific workflows, from identifying features in astronomical images to detecting the use of observational data in scientific papers. These projects illustrated AI's potential to support data curators. Librarians and publishers addressed the ethical aspects of AI, stressing the need for policies to guide responsible use of AI- and ML-based tools.

Several presentations examined the Unified Astronomy Thesaurus (UAT), its use as a training tool and its integration into systems such as the ADS/SciX database. Speakers emphasised that shared, consistent metadata standards remain essential even as automated indexing expands.

In an invited talk, Rafael Castillo and Cristián Calabrano of the University of Chile described the university's emerging open science ecosystem, shaped by years of policy development and practical experience to create a science environment that is valued by researchers.

The day concluded with a look at how astronomy libraries may evolve in a rapidly changing society, a theme that recurred throughout the conference.

Figure 1. LISA 10 conference photo at ESO Vitacura.

Day 2: Open access and research equity

Day 2 discussions focused on open access (OA), open science and the future of publishing. Astronomy has long been a leader in open data practices and manuscript sharing, but journal publishing in other sciences has taken different directions, creating a complex publishing landscape shaped by publishers’ business models, funder mandates and community-led dissemination.

Speakers presented a range of OA models, including the Astronomy & Astrophysics (A&A) adaptation of the collaborative Subscribe to Open (S2O) model, and the Open Journal of Astrophysics (OJAp) which relies on the arXiv platform to operate an overlay journal without author-facing Article Processing Charges (APCs). Presenters also discussed OA trends in India, the use of transformative agreements to fulfill national OA mandates in Italy and how stakeholders can shape the future of scientific publishing. While the principles of openness enjoy broad support, achieving an equitable, transparent and sustainable publishing ecosystem remains challenging.

A highlight was a lively presentation by invited speaker María Soledad Bravo-Marchant from the Consorcio para el Acceso a la Información Científica Electrónica (CINCEL), who offered a comprehensive look at SciELO Chile, an open access journal platform managed by the Agencia Nacional de Investigación y Desarrollo (ANID). Her talk illustrated how national initiatives can enable sustainable platforms for quality OA publishing, especially in contexts where commercial APC-based models are prohibitive.

A set of presentations addressed the importance of data linking and best practices for data publication and parallels between earth sciences and astronomy, underscoring the importance of interoperability and standardised citation. Additionial talks highlighted very successful virtual exhibitions, initiatives to improve access to astronomical knowledge and national strategies for open science training in Chile.

In the late afternoon participants visited the historic Manuel Foster Observatory on San Cristóbal Hill (Figure 2). Originally built by Lick Observatory astronomers and now a national monument managed by the Pontificia Universidad Católica de Chile, the site provided an excellent link between traditional and contemporary astronomy — a perfect end to the day.

Day 3: Open science, systems, and data

The third day of LISA 10 examined the infrastructures necessary to make open science a reality. Starting from bibliometric analyses and impact studies, the focus turned to data archives, with presentations from NASA’s Mikulski Archive for Space Telescopes (MAST), the Strasbourg astronomical Data Center (CDS) and the NASA/IPAC Extragalactic Database (NED) at Caltech. These talks showcased the complex and meticulous work carried out by data specialists and documentalists, applying their expertise in data curation, linking, standardisation and long-term preservation.

Several talks highlighted the growing demands of data stewardship. As astronomy generates increasingly complex datasets, the roles of librarians and documentalists have evolved from custodians to connectors responsible for identifying, contextualising and shaping the standards used across the core services of our profession. A joint presentation of colleagues from the CDS and NED demonstrated the extensive efforts required to harvest data from astronomical papers; the talk also illustrated the logistical challenges for the conference organisers in scheduling a session that accommodated speakers in Paris and California, with an online audience extending towards India and beyond.

Invited speaker Chris Erdmann from SciLife Lab in Sweden offered a cross-disciplinary perspective. Based on his extensive experience in both astronomy and the life sciences, he compared Findability, Accessibility, Interoperability and Reusability (FAIR) tools, platforms and implementation strategies in the two fields, emphasising that astronomy’s long-standing open data culture provides a strong basis for open science principles that extend beyond data to include software, research methods, infrastructures and the application of responsible metrics.

The day concluded with the conference dinner at a spectacular location in the Cajón del Maipo, Roan Jasé, providing home-cooked food, a tour of the site’s educational resources, including a 12-inch refractor telescope used for school classes and other visitors, and ample opportunities for conversations among participants and hosts.

Day 4: Stewarding astronomical knowledge and the changing roles of libraries

The final day began with invited speaker Álvaro López, who provided an overview of the national open science efforts in Chile, connecting high-level policy with the practical challenges faced by librarians, educators and researchers. His talk brought together many of the conference’s core themes, including openness, infrastructure, and the importance of equity.

Case studies from the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in India as well as UC Berkeley and the U.S. Naval Observatory in the USA illustrated how astronomy libraries worldwide are navigating evolving landscapes of print and digital collections, constrained staffing resources and changing user expectations. Additional talks focused on digitising centuries-old scientific correspondence, recovering the names and contributions of women in scientific archives, revising collection development in an increasingly electronic environment, and strategies to establish legacy collections. These presentations highlighted both the adaptability of information professionals, their creativity in reaching diverse user groups and their attention to historical collections at a time when the establishment of new facilities and the application of cutting-edge technology often take precedence.

Speakers also addressed the ever-changing role of astronomy librarians. Several presentations throughout the conference made it clear that the profession is not experiencing a revolution, but rather an evolution, in which we apply the tools of our trade, along with our skills and expertise, in the digital era.

The conference concluded with a historical retrospective on the LISA series by

Figure 2. Excursion to Manuel Foster Observatory, San Cristóbal Hill, Santiago de Chile

colleagues who have participated in (almost) all meetings since the first one in 1988 (not called LISA I as no one then knew there would ever be a second). Over time, LISA conferences have grown to become a globally recognised forum which continues to strengthen the community's mission: to collaborate and unite human expertise to advance information management in astronomy.

Following the core conference, some participants enjoyed a self-paid trip to visit ESO's Paranal Observatory, which allowed them a glimpse of the Extremely Large Telescope from a distance. The combination of cutting-edge technology and the seemingly endless Atacama Desert left everyone deeply impressed!

Looking ahead

LISA 10 provided a lively picture of a profession in transition. AI promises new capabilities, but requires ethical frameworks. Data systems are growing in complexity, yet the expertise needed to curate and connect information is often hidden behind user-friendly interfaces. Open access publishing offers the possibility of universal research participation, but inadequately formulated policies and mandates have exacerbated existing inequalities. Today's science ecosystem requires close collaboration among librarians, data specialists, publishers and researchers. LISA 10 confirmed that even in an age of automation and global digital infrastructures, the core of scholarly communication continues to be defined by humans.

At the end of LISA 10, a group of colleagues volunteered to host the next event. Such an early commitment had not happened before in the history of the conference series and it showed the importance and value the meetings continue to have for the community. Long live LISA!

Demographics

Traditionally, LISA conferences have enjoyed participation from colleagues around the globe. LISA 10 welcomed 80 online (52.5%) and in-person (47.5%) participants from 16 countries, including Latin America (Chile, Mexico), Europe (Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, The Netherlands, UK), North America (Canada, US) as well as South Africa and India. The Scientific Organising Committee invited four speakers (one female, three male) from Chile and Sweden. As can be expected in our profession, a large fraction of the presentations was delivered by female speakers (almost 70%), while male speakers presented approximately 30% of the talks.

Acknowledgements

This conference would not have been possible without the scientific organising committee chairperson, Jenny Novacescu, formerly at the Space Telescope Science Institute, who could not attend LISA 10 for personal reasons. A heartfelt Thank You to Jenny for everything she has done to make LISA 10 happen!

In order to ensure full inclusion, in particular of colleagues from our host country Chile, LISA 10 provided a simultaneous interpretation service that ensured that presentations in English or Spanish were understandable to non-native speakers of either language. We would like to thank the interpreters for their excellent work.

The organisers gratefully acknowledge the generous support of the conference sponsors: American Association for the Advancement of Science, EDP Sciences, ESO, IOP Publishing, Open Fifth, the Royal Astronomical Society and the SPIE Digital Library.

The LISA 10 conference proceedings (presentation slides and posters) are available via a dedicated collection at Zenodo[3].

Links

[1] LISA 10 homepage: https://www.eso.org/sci/meetings/2025/LISA10.html

[2] LISA conferences: https://www.eso.org/sci/libraries/lisa.html

[3] LISA 10 presentations and posters: https://zenodo.org/communities/lisa10/

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Report on the ESO workshop

Why Galaxies Care About AGB Stars V: 3D Winds In The Cosmic Matter Cycle

held at CEPAL headquarters in Santiago, Chile, 17–21 November 2025

Claudia Paladini [1]

[1] ESO

The fifth workshop in the Why Galaxies Care About AGB Stars series brought together researchers working on asymptotic giant branch (AGB) stars, stellar populations and galaxy evolution, with the aim of fostering collaboration and advancing our understanding of the role of AGB stars in the cosmic matter cycle. The workshop covered a broad range of topics, from stellar interiors and mass loss to circumstellar chemistry and the impact of AGB stars on unresolved stellar populations and galaxies across cosmic time. With recent breakthroughs in high-angular-resolution imaging, multi-wavelength observations and three-dimensional modelling, the meeting provided a timely overview of the current state of the field and a forum in which to discuss future prospects in the ESO's Extremely Large Telescope era and beyond.

Motivations

Through their stellar wind, asymptotic giant branch (AGB) stars return newly synthesised elements and dust to the interstellar medium, acting as major contributors to the cosmic dust cycle and influencing the formation of subsequent generations of stars and galaxies. Despite their importance, significant uncertainties remain in our understanding of the physical processes governing AGB evolution, including mass loss, convection, pulsation, nucleosynthesis, binarity and circumstellar dust formation.

Since the first meeting of the Why Galaxies Care About AGB Stars series in Vienna in 2006, the field has undergone rapid development. Advances in observational capabilities, particularly in high-angular-resolution techniques, have allowed astronomers to resolve the surfaces, atmospheres and winds of nearby AGB stars in unprecedented detail. At the same time, progress in three-dimensional stellar modelling has begun to bridge the gap between simplified one-dimensional evolutionary and stelllar atmosphere models and the complex, dynamic reality of AGB atmospheres.

The fifth edition of the workshop was motivated by the need to reassess the role of AGB stars in light of these developments and to place recent observational and theoretical results into a broader astrophysical context. A particular emphasis was placed on the connection between stellar-scale processes and their large-scale consequences, from shaping circumstellar envelopes to the contribution of AGB stars to galaxy evolution across cosmic time.

The workshop was held at the headquarters of the Economic Commission for Latin America (CEPAL) in Santiago. Holding the meeting in Chile, home to some of the world's most advanced astronomical facilities, underscored the close link between the scientific topics of the workshop and the observational infrastructure that enables this research.

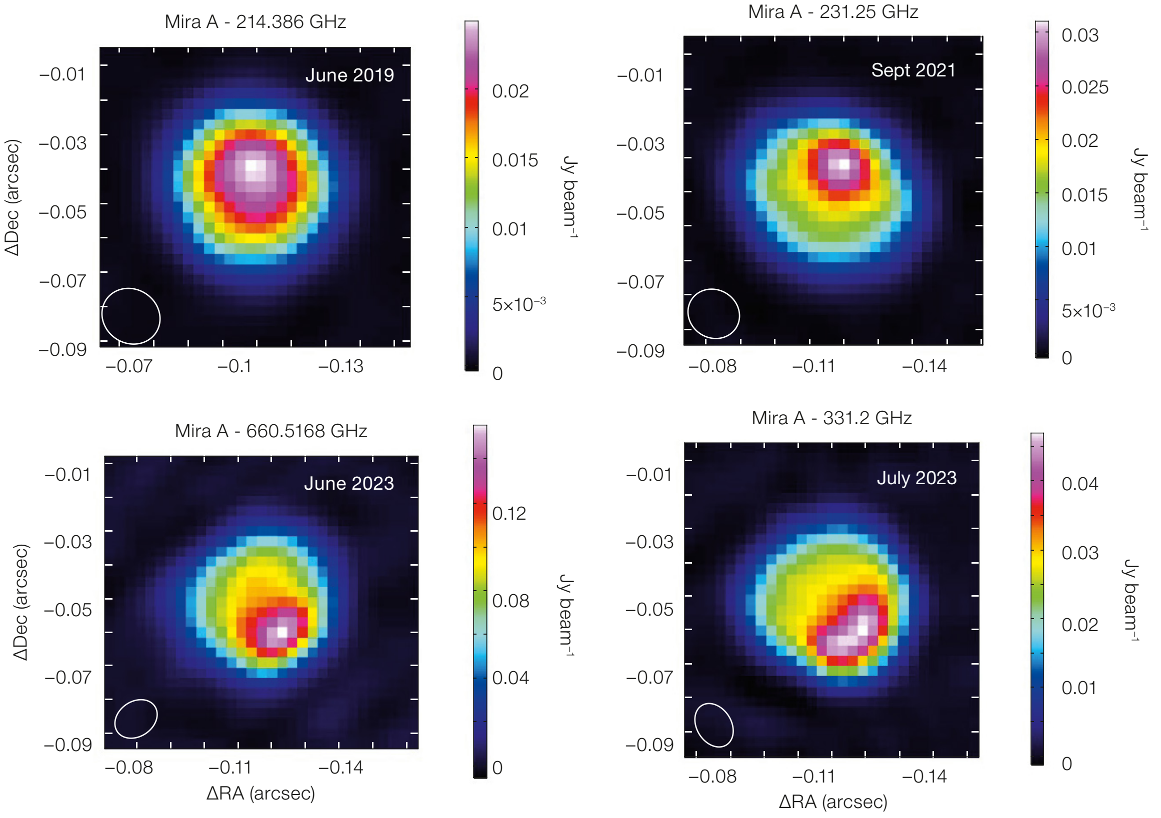

Figure 1. High-resolution ALMA images of the evolved star Mira A at different epochs and frequencies, revealing compact bright regions on the submillimetre stellar surface that may be linked to shocks and mass-loss processes (Andriantsaralaza et al., in preparation).

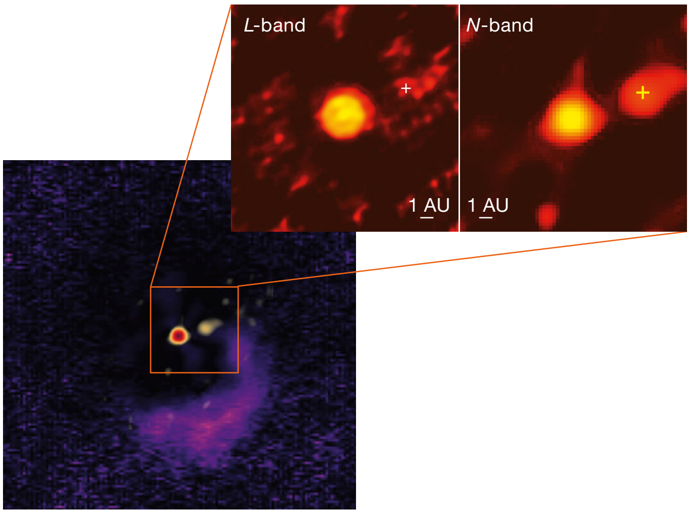

Figure 2. High-resolution Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE) images of π^1 Gru showing atmospheric elongation and the onset of a spiral induced by a close companion (cross); the MATISSE data (red-yellow colour scale and inset) are overlaid on Spectro-Polarimetric High-contrast Exoplanet REsearch instrument (SPHERE) observations (Drevon et al., 2026; Montargès et al., 2025).

Scientific highlights of the meeting

The meeting opened with a moment of remembrance for colleagues who passed away since the previous workshop: Inma Domínguez, Roberto Gallino, Paola Marigo and Karl Menten. Their scientific contributions have had a lasting impact on the study of AGB stars and related fields, as well as on the careers of many participants.

The scientific programme[1] covered the following topics: stellar structure and evolution; stellar interiors and nucleosynthesis; dynamic processes such as convection, pulsation and dust formation; circumstellar envelopes and astrochemistry; binarity, planets and discs around AGB stars; evolution beyond the AGB phase; the role of AGB stars in the cosmic matter cycle; resolved and unresolved AGB populations in stellar systems; galaxy evolution, including the first generations of AGB stars.

Progress was reported in extending nucleosynthesis calculations across a wide metallicity range, updating s-process yields, and refining treatments of mixing and dredge-up, while uncertainties related to mass loss and binary effects remain major challenges.

A central theme of the workshop was the recognition that AGB stars must be understood as inherently three-dimensional and time-dependent objects. The traditional picture of spherically symmetric winds driven by steady pulsation and radiation pressure on dust is increasingly challenged by observations revealing complex morphologies, asymmetries and the frequent influence of companions. High-angular-resolution observations have demonstrated that convection, pulsation, shocks, dust formation and binarity jointly shape extended AGB atmospheres and winds, with direct consequences for mass loss, chemical yields and circumstellar dust properties. Multiple period–luminosity relations of AGB variables were discussed as well-established sequences of pulsation modes, supported by stellar structure and three-dimensional models, with particular attention given to the still poorly understood long secondary periods (convection+pulsation versus binarity, or a combination of the two). The programme reflected a notable shift in community focus over the past decade, with binarity now recognised as a key ingredient in interpreting AGB mass loss, circumstellar structure and late stellar evolution. At the same time, speakers emphasised the need for caution in attributing all observed phenomena solely to binary interactions.

Several contributions highlighted the importance of linking detailed studies of nearby benchmark stars, such as Mira, R Dor, and π^1 Gru, with results from large surveys. While individual objects provide essential physical insight, surveys conducted with facilities such as Gaia, the Atacama Large Millimeter/submillimeter Array (ALMA), and JWST, and future observatories including Vera C. Rubin Observatory and ESO's Extremely Large Telescope (ELT) are required to place these results in a broader population and galaxy-evolution context.

The transition beyond the AGB phase was also discussed, with post-AGB stars considered primarily in the context of their AGB progenitors and as laboratories for studying the outcome of binary interaction and disc formation. This perspective reflects a long-standing focus within the post-AGB community that now connects naturally with the evolving emphasis on binarity in AGB research.

AGB stars were further discussed as probes of stellar populations and galaxy evolution. New results demonstrated their potential for tracing star formation histories and contributing to distance scale studies, including applications of the *J*-region AGB method as a distance indicator, with possible implications for addressing the Hubble tension. The detection of dusty AGB stars out to tens of megaparsecs opens new opportunities for studying galaxy evolution in diverse environments.

The scientific highlights of the meeting were reflected in the workshop awards. The best talk presenting ALMA data was awarded to Miora Andriantsaralaza for her study of the archetypal AGB star Mira (Figure 1), while the best Very Large Telescope (VLT) talk was awarded to Julien Drevon for his MATISSE observations of π^1 Gru (Figure 2). The best student talk was awarded to Toon De Prins for his talk entitled "Here be substructures: An interferometric imaging voyage to the inner rims of dusty post-AGB discs". The best poster prize was awarded to Mats Esseldeurs for his work on π^1 Gru, presenting (sub)millimetre interferometric evidence for a close companion orbiting an AGB star (Esseldeurs et al., 2026).

Main conclusions & ways forward

The discussions throughout the week highlighted both the significant progress achieved in recent years and the challenges that remain. A key conclusion was that mass loss, long treated as a parametrised ingredient in stellar evolution models, must increasingly be addressed

Figure 3. Workshop photo.

as an emergent process arising from the interplay of convection, pulsation, dust formation and sometimes binarity.

While three-dimensional simulations are providing essential physical insight, the community remains dependent on one-dimensional models for population and galaxy-scale applications, owing to the high computational cost of multidimensional modelling. Using detailed simulations to guide the simplified prescriptions required for population studies was identified as a key priority.

Looking ahead, participants discussed the transformative role of current and future facilities in a dedicated discussion inspired by the ESO Expanding Horizons process[2]. Upgrades to ALMA, longer baselines and more telescopes at the VLT Interferometer and the advent of the ELT will enable unprecedented studies of AGB atmospheres and winds, while large surveys from Gaia and Vera C. Rubin Observatory will continue to reshape our understanding of AGB populations. It was also emphasised that not all key science requires the highest angular resolution, and that sensitive single-dish radio observations remain essential for studies of AGB mass loss and circumstellar envelopes, where recovering the total emitted flux from extended circumstellar material is critical. In this context, the importance of coordinated observational efforts across facilities and spatial scales was highlighted. Ensuring that theoretical models evolve in step with observational capabilities emerged as an important requirement for the coming years.

Demographics

The Scientific Organising Committee (SOC) sought fair representation from the community and aimed to construct a balanced and inclusive scientific programme. For each topical session, several invited speakers were proposed, with the final selection made by the SOC solely on scientific merit. The resulting list was dominated by women, reflecting the outcome of the voting process rather than any predefined gender-based criteria.

The selection of contributed talks was performed blindly, based exclusively on the submitted abstracts. One member of the SOC removed names and identifying information before the abstracts were evaluated and abstained from voting, ensuring that the selection process focused purely on scientific content.

The workshop attracted a total of 116 participants, including 16 remote attendees (Figure 3). Approximately 40% of the participants were women and non-binary. In terms of career stage, the audience consisted of roughly 50% staff scientists, 25% students, 22% postdoctoral researchers and about 3% retired researchers.

Acknowledgements

The organisers thank the members of the SOC and the Local Organising Committee for their dedication in shaping the programme and ensuring the smooth running of the meeting. We are grateful to all speakers and participants for their contributions, and to the ESO and JAO workshop support for making the workshop possible. The organisers also acknowledge H. Olofsson, M. Groenewegen and Franz Kerschbaum for their long-standing leadership of the Why Galaxies Care About AGB Stars workshop series and for entrusting us with the organisation of this edition.

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Montargès, M. et al. 2025, A&A, 699, A22
Esseldeurs, M. et al. 2026, Nat Astron, 10, 124

Links

[1] Workshop programme: https://www.eso.org/sci/meetings/2025/whygalaxiescareaboutAGB.html
[2] ESO Expanding Horizons website: https://next.eso.org/

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Report on the ESO workshop

ExoELT-2025 Community Workshop: Planetary Formation & Exoplanets in the ELT Era

held at Headquarters, Garching, Germany, 17–21 November 2025

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The ExoELT-2025 community workshop, held at ESO's headquarters in Garching, Germany, in November 2025, brought together more than 170 participants to review the scientific readiness of ESO's Extremely Large Telescope (ELT) for studies of planet formation and exoplanets ahead of its first light by the end of this decade. The workshop presented the status and performance of the ELT and its instruments and discussed key science cases, ranging from planet-forming discs and protoplanets to exoplanet demographics and atmospheric characterisation. The unique capabilities of the ELT as regards spatial resolution, sensitivity and instrument versatility were highlighted, together with strong synergies with existing and future ground- and space-based facilities. The workshop fostered community coordination, promoted early-career researchers and identified priorities and challenges for maximisng the scientific return of the ELT.

Motivations

Understanding how giant and rocky planets form and evolve, their internal structure and that of their atmosphere, represents one of the major challenges of modern astronomy, directly linked to the ultimate search for life by 2040. In 2029, ESO's Extremely Large Telescope (ELT) will collect its first light from the sky. The high angular resolution and the huge collecting capacity combined with the extreme sensitivity of the instruments will allow unprecedented observations of regions of planet formation and exoplanetary systems. In light of this, the ESO community has developed a key expertise in the study of the initial conditions of planet formation, the search for exoplanets, the atmospheric characterisation of giant and rocky exoplanets and the search for biomarkers. This community includes various international laboratories and scientists who are also heavily involved at a technical and scientific level in the construction, scientific preparation and operation of instruments for the ELT and who have the opportunity to play a key role in ensuring a global return and shared success in the exploitation of the ELT.

In this context, the ExoELT-2025 community workshop[1] "Planetary Formation and Exoplanets in the ELT era" was held at ESO's headquarters in Garching, Germany, from 17 to 21 November 2025. The workshop attracted about 170 participants (Figure 1) with three main objectives:

- informing the ESO community about the status, schedule, modes and performances of the ELT and its suite of instruments (the Multiconjugate adaptive Optics Relay For ELT Observations [MORFEO], the Multi-AO Imaging Camera for Deep Observations [MICADO], the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph [HARMONI], the Mid-infrared ELT Imager and Spectrograph [METIS], the ArmazoNes high Dispersion Echelle Spectrograph [ANDES] and the planetary camera and spectrograph [PCS]) with specific interests in this science theme,
- presenting and revisiting together the science that will be addressed by the ELT, the scientific cases, samples, strategies of observation, calibration, data analysis and interpretation tools of the programmes dedicated to the study of planet formation and exoplanets,
- fostering collaboration and synergy within the community to harmonise our efforts, tools and strategies for the preparatory work on the ELT programmes dedicated to this topic within the framework of the guaranteed time and the open time. This includes in particular work on source selection, simulation and data analysis tools and calibrations, preparatory observations involving different observational techniques and also synergies between our programmes and those of of ground-based observatories and space missions (the Atacama Large Millimeter/submillimeter Array [ALMA], Gaia, the Very Large Telescope Interferometer [VLT/I-2030], JWST, the PLAnetary Transits and Oscillations of stars [PLATO] spacecraft, the Atmospheric Remote-sensing Infrared Exoplanet Large survey [ARIEL] spacecraft, the Nancy Grace Roman Space Telescope [Roman], the Square Kilometre Array, etc.). The key is to optimise the scientific return for our community and our observation programmes in guaranteed and open time on the ELT.

Demographics and remote access

The workshop aimed to attract young students while actively promoting gender equity and enhancing the visibility of junior researchers through opportunities such as contributed and review talks. Particular emphasis was placed on fostering scientific exchange by encouraging questions and answers, stimulating open discussions and creating meaningful social interactions throughout the event. To ensure broad participation and accessibility, remote attendance was made possible via MS Teams, with Slido enabling interactive Q&A sessions and Slack supporting continuous communication and collaboration among participants. These objectives are clearly reflected in the distribution of registered participants, as shown in Figure 2, as well as in the overall structure of the workshop programme, and represent a significant success for the organisers.

Summaries of sessions

The first session of the workshop was dedicated to presenting the current status of the ELT project, including updates on the construction site, the dome and telescope assembly, and the procurement and delivery of key opto-mechanical components. An overview of the current schedule leading to the ELT's first light in 2029 was also provided. This was followed by a presentation on the implementation of the new operational scheme at ESO and Paranal, aimed at fully integrating the ELT into observatory operations in the coming years. The session continued with status updates and key science drivers presented by the instrument consortia focused on planet formation and exoplanet science. These presentations covered the full suite of ELT instruments, beginning with MICADO and METIS, followed by HARMONI, MORFEO, and ANDES, and concluding with PCS. The second session concluded with a series of synergy talks highlighting the

Figure 1. ExoELT-2025 community workshop participants.

complementarity between the ELT science drivers and existing and future facilities, including the VLT/VLTI, ALMA, and space missions such as Gaia and JWST, as well as upcoming missions like PLATO, ARIEL, and the coronagraph instrument on Roman.

The third and fourth scientific sessions addressed key astrophysical questions related to planet formation. They began with studies of the evolution and chemistry of planet-forming discs, progressed to the physical processes driving planet formation and then focused on disc substructures and the detection and characterisation of protoplanets. The unique capabilities of the ELT, particularly its unprecedented spatial resolution that will enable access to planet-forming regions within 10 au, its high sensitivity and the versatility of its instrumentation in terms of wavelength coverage, spectral resolution, and observing modes, were highlighted as transformative. These capabilities will enable detailed exploration of the links between circumstellar discs and their environments, extend our understanding of the demographics of disc substructures across different star-forming regions and down to lower stellar masses and allowing the physics of accretion and the formation of young planets to be probed while they are still embedded in their natal environments.

The fifth session of the workshop took a complementary perspective by exploring instrumental solutions, performance improvements and synergies aimed at maximising the scientific exploitation of the ELT. Topics ranged from recent developments at the VLTI, including the GRAVITY+ project, to the latest performance assessments of the high-contrast imaging modes of the METIS and MICADO first-light instruments. The session also covered emerging technologies such as photonic lanterns and interferometric nullers, which could pave the way for future observing modes and instruments on the ELT. This session concluded with a hands-on tutorial attended by more than 50 participants, during which ELT observations were simulated using the Python-based ScopeSim[2] tool.

The sixth session reviewed the current state of the art in exoplanet demographics, drawing on population studies based on transit and radial-velocity surveys at short orbital separations, complemented by direct-imaging surveys probing separations beyond 10 au. These results highlighted a critical gap in parameter space between 1 and 10 au, a region where the ELT is expected to provide a decisive breakthrough and substantially advance our understanding of planetary system architectures. In particular, the ELT will be uniquely suited to explore planet–disc and planet–planet interactions, as well as the morphology and mineralogy of debris discs in the near- and mid-infrared, a strong synergy with ALMA observations.

The seventh and eighth sessions focused on the transformative impact the ELT is expected to deliver even at first light with MICADO, METIS, and HARMONI to study the physics of exoplantary atmospheres. These instruments will enable detailed studies of the composition and dynamics of the atmospheres of close-in hot Jupiters, as well as temperate and cooler giant and sub-Jovian planets beyond the snow line, providing key insights into the processes governing exoplanet formation and evolution. Beyond the first generation of instruments, ANDES and PCS are expected to detect and characterise temperate terrestrial planets and to offer the first clues regarding the presence of conditions favourable for the emergence of life. The challenges associated with defining the most suitable target samples, optimising observing strategies and advancing theoretical and interpretative models were discussed in detail. Particular emphasis was placed on the importance of strong synergies with future space missions such as the Habitable Worlds Observatory (HWO) and the Large Interferometer for Exoplanets (LIFE), highlight-

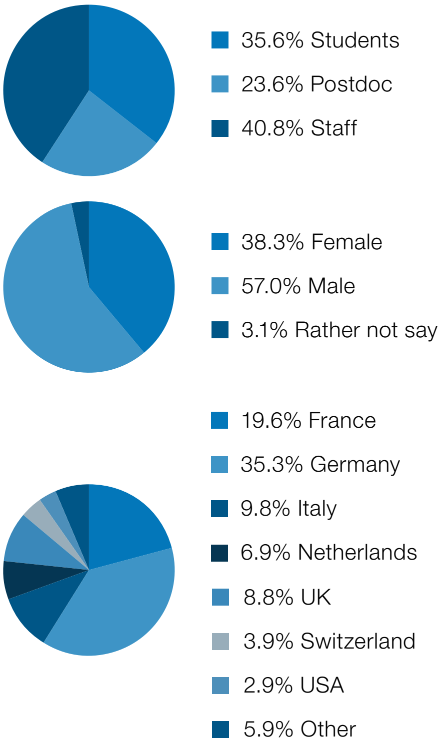

Figure 2. ExoELT 2025 Workshop participant demographics in terms of career, gender and nationality.

ing how coordinated ground- and space-based observations will be essential to fully exploit the scientific potential of the ELT and to achieve a comprehensive characterisation of exoplanetary systems.

Conclusions & perspectives

The ExoELT-2025 community workshop provided an excellent opportunity to bring together the community interested in the study of planet formation and exoplanets and to take stock of the current status of the ELT and its suite of instruments while placing them within a broader context of synergies with existing and forthcoming ground-based facilities and space missions. The workshop offered a comprehensive overview of key scientific themes and outstanding questions in the field, and helped identify the major challenges and priorities for the coming years. All presentations have been made available to the community[3]. In addition, the workshop played an important role in raising awareness among a large fraction of early-career participants of the future challenges and opportunities that the ELT will offer for exoplanet and planet-formation studies. Feedback collected through a short post-workshop survey was overwhelmingly positive, as regards both the scientific content and the overall organisation of the event. Participants expressed a strong interest in repeating this type of community workshop every three to four years, and suggested that future workshops include more hands-on and applied sessions focused on the preparation of observing programmes and proposal strategies in anticipation of the ELT's first light in 2029.

Acknowledgements

We would like to thank all participants for their active participation in the conference, which was crucial to making it such a success. We would further like to thank the members of our Scientific Organising Committee and Local Organising Committee for their fundamental and invaluable effort. We also thank ESO for funding the conference. A special thanks goes to Denisa Tako for her support with the organisational aspects of the conference.

Links

[1] ExoELT-2025 webpage: https://www.eso.org/sci/meetings/2025/exo-elt.html

[2] Link to ScopeSim tool: https://scopesim.readthedocs.io/en/stable/

[3] Link to all presetnations on Zenodo: https://zenodo.org/communities/exoelt2025/

ESO/G. Vecchia

This drone image, taken in April 2026, shows a stunning view above the dome of ESO's Extremely Large Telescope (ELT), under construction atop Cerro Armazones, a mountain in Chile's Atacama Desert. The sliding doors are partially open, showing the top of the telescope's main structure inside. The catwalks running along the edges of the sliding doors convey the sheer size of the 80-m high dome.

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Report on the

La Silla Observing School 2026

held at ESO Vitacura, Santiago, Chile, and ESO La Silla, Chile, 2–13 February 2026

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The La Silla Observing School, currently being held annually, comprises lectures and observations aiming at teaching students and early-career researchers various aspects of observational astronomy. Additionally, for this year's school, a group of public school teachers from communities near the ESO sites in Chile were also included with the aim of strengthening the bond between ESO and the local communities, as well as promoting astronomy to the younger generations. This year's school took place during the first two weeks of February 2026, starting with talks and lectures at ESO's Vitacura offices in Santiago, then continuing with four nights of observations at the observatory, using the ESO Faint Object Spectrograph and Camera 2 at the New Technology Telescope, the High Accuracy Radial velocity Planet Searcher and the Near Infra Red Planet Searcher at the 3.6-metre telescope and the PLATO-Spec instrument at the 1.52-metre telescope, culminating in three final days in Vitacura where the various groups analysed the data obtained and presented the results of their projects.

Introduction

Since 2016 ESO has hosted six observing schools at La Silla, aimed at senior Master's and doctorate students. The primary goal of the school is to give participants the necessary experience and know-how in observational astronomy, with a focus on ESO instrumentation and pipelines. They gain experience in identifying an interesting scientific problem to investigate, writing an observing proposal, preparing and planning observations using the p2 interface, performing these observations with their chosen instrument/s, reducing and analysing the obtained data using ESO pipelines and presenting their final results to their peers.

The La Silla Observing School 2026[1] (Figure 1) was opened to students worldwide; participants were required to fund their trips to and from Chile, while ESO provided lodging and transportation within Chile. In addition to the students, this year the school was opened to public school teachers from three regions around the two ESO sites in northern Chile, namely Atacama, Taltal and Coquimbo. The selection of the participating teachers was made by the corresponding regional governments, who chose eight teachers, spanning a wide range of educational levels and subjects. The purpose of this effort was to strengthen collaboration between ESO and the local communities in northern Chile, who for many decades have welcomed ESO so generously, as well as enriching Chilean basic education with specialised astronomical knowledge and enthusiasm, in the hope of inspiring future generations of astronomers from local communities. This group had exclusive access to the ESO 1.52-metre telescope, hosting the PLATOSpec[2] instrument (Kabáth et al., 2026), thanks to the consortium's offering time at the telescope to the school. Specific details of this aspect of the school are given later in this report.

The school started on Monday 2 February with two days of introductory lectures on the basic concepts of ground-based observing and telescopes, astronomical instrumentation, scientific detectors, imaging and spectroscopy, the La Silla instruments the High Accuracy Radial

Figure 1. Happy participants at the 6th La Silla Observing School upon arrival.

Figure 2. Group visit to the NTT.

velocity Planet Searcher (HARPS; Mayor et al., 2003), the Near Infra Red Planet Searcher (NIRPS; Bouchy et al., 2017) and the ESO Faint Object Spectrograph and Camera 2 (EFOSC2; Buzzoni et al., 1984), the Exposure Time Calculators, the p2 interface and Observation Blocks, data reduction and writing a proposal, as well as presentations of group projects and the participants themselves.

On Wednesday 4th, the group travelled to the observatory by bus, arriving in time for dinner, followed by views of the sunset and a safety talk, after which they briefly visited the control building. The following day included a tour of the 3.6-metre telescope and the New Technology Telescope (NTT; see Figure 2), followed by a short hike to the Swedish–ESO submillimetre telescope (SEST) and finishing the day by preparing for the upcoming observations in groups. During the following four nights, the groups performed their observations (Figure 3) under good sky conditions, with the only loss of time being due to an unexpected power cut for around one hour. On the final day at the observatory, an afternoon hike was organised to the petroglyphs close to the observatory site, a series of rock drawings dating back from 300 BCE to 700 CE. We had the good fortune to have Germán Rojas with us, one of the high school teachers participating in the school, who comes from the region and explained to all in great detail the significance of these drawings to the indigenous communities of the region (Figure 4).

On the 10th, the group travelled back to Santiago with many happy memories and lots of data to work on. The last three days of the school were dedicated to data analysis and a few further talks on optical and radio interferometry, ESO's Extremely Large Telescope, astronomy in Chile and possible career paths in astronomy and beyond. The school social dinner, which was held at a restaurant in the Providencia neighbourhood, was also organised at this time. On the final day of the school, the four groups presented the results of their observations to a wide audience, receiving many questions and positive feedback.

The working groups

The goal of the Group 1 project, led by ESO staff astronomers Anna F. Pala and Linda Schmidtobreick, was to provide the students with different examples of stellar variability. During the project, the students familiarised themselves with both spectroscopic and photometric data and learned about spectral features, radial velocities and stellar variability. The project was divided into four science cases: 1) Pulsating stars. HARPS and NIRPS were used to observe three Cepheids across different phases of their pulsation, to compare how the stellar spectral lines change in shape and depth during the pulsation period. The students also carried out a cross-correlation analysis of the data to derive the radial velocity,

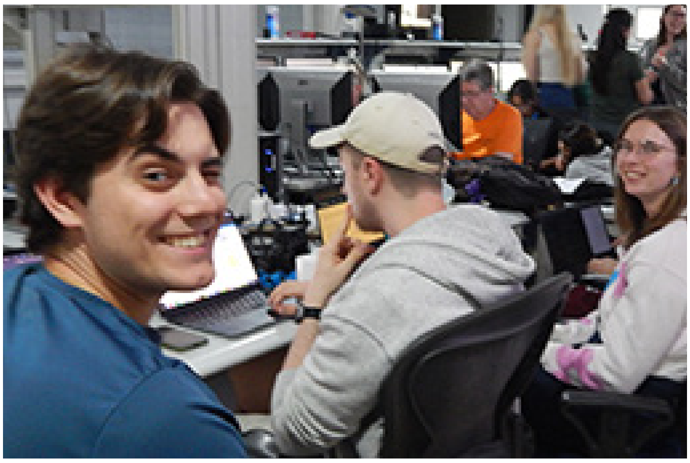

Figure 3. Happy students working hard at the control building.

which also revealed the presence of a possible binary companion in one of the three targets. 2) Binarity. Using the same instruments, two double white dwarf systems were observed — stellar binaries composed of two non-interacting white dwarfs. They obtained phase-resolved observations, which allowed them to reconstruct the radial velocity curve and derive an estimate of their orbital periods. 3) Variability in accretion discs. Using EFOSC2, the students obtained phase-resolved imaging of a cataclysmic variable — an interacting binary in which a white dwarf is accreting from a companion star via an accretion disc. The aim of the observations was to detect the double hump signature in the system lightcurve that would reveal the presence of possible spiral arms in the accretion disc. The extracted lightcurve revealed a periodicity consistent with the orbital period of the binary, but no clear signal ascribable to possible spiral arms was detected. 4) Nova eruptions. Narrow-band imaging of a nova shell around a cataclysmic variable was obtained. The size of the shell was calculated which, compared to previous observations in the literature, confirmed the free expansion of the ejecta. Finally, by combining the shell size and time since the eruption with the shell expansion velocity from the literature, the students derived the distance to the system, which was found to be in good agreement with the distance provided by the Gaia parallax.

Group 2 was led by ESO Fellow Camila de Sá-Freitas and the project aimed to characterise nearby barred galaxies using narrow-band Hα filters and long-slit spectroscopy with EFOSC2. Bars are prominent, common structures in the nearby Universe, present in around 2/3 of disc galaxies in the local Universe, and they act on galaxy evolution out to at least $z \sim 4$. Once formed, they affect their host galaxies in a range of ways, including redistributing angular momentum, funnelling gas inwards and forming a central rotation-supported structure known as nuclear disc. Historically, these structures are also known as discy bulges and/or a type of pseudo-bulge. de Sá-Freitas et al. (2025) found for a sample of nearby galaxies that the star formation rate density (ΣSFR) in the nuclear disc is tightly correlated with the age of the bar, such that younger bars relate to higher ΣSFR in the nuclear disc and older bars to lower ΣSFR. Since the SFR can be measured from the Hα emission flux, the idea of this project was to understand whether Hα emission correlates with bar age as well. We observed seven galaxies with known bar ages in both Hα narrow-band photometry and long-slit spectroscopy, positioning the slit along the bar. Each student focused on analysing a specific part of the project and the results are: there is a trend between Hα emission in the nuclear disc and the age of the bar, indicating that Hα narrow-band images might be used as SFR traces in future, broadly extrapolating bar ages; analysis of the global Hα emission with bar age showed that this could be an indication of quenching, although no significant trend was found; gas velocity was studied using Hα emission lines, allowing a preliminary characterisation of its velocity in the nuclear discs; and finally, observations of NGC1566, which represents a class of variable active galactic nucleus (AGN), showed that it has not varied since the last time it was studied, in 2020.

Group 3, nicknamed Unicorns and supervised by Henri Boffin and María José Rain, was devoted to the study of binary stars. Several projects were considered and followed up by some of the six students in this group. The first subgroup used HARPS to study the Rossiter–McLaughlin effect in binary stars to infer the relative inclination of the rotation axis of the primary with respect to the orbital plane. A detailed study of the contact binary system HD 115264 led to the conclusion that the primary is well aligned, likely as a result of strong tidal forces within the binary. The second subgroup analysed blue straggler stars (BSS) in open clusters, using both HARPS and

Figure 4. Visit to the petroglyphs with Germán Rojas giving a local’s perspective.

Figure 5. The teachers group outside the 3.6-metre telescope.

EFOSC2. With HARPS, they looked at some well-known long-period binaries with the aim of determining their chemical abundances, thereby confirming their membership of the cluster, as well as looking for any chemical anomalies that might be explained by mass transfer. EFOSC2 was used to derive radial velocities of rapidly varying BSS. For one of them — the star Rediet — the students clearly detected and analysed the radial velocity variations due to the second overtone pulsation, thereby confirming its delta Scuti character. Finally, one student used EFOSC2 to study planetary nebulae (PN), taking nice images of some of these intricate objects as well as obtaining time-resolved photometry and spectra of some others. In one case, the binary nature of the central star of the PN was confirmed, reflecting some previous estimates done with the Zwicky Transient Facility (ZTF). The work of these students was published in four Research Notes (Barone et al., 2026a; Divakaran et al., 2026; di Stefano et al., 2026; Steimle et al., 2026), with all being summerised by Barone et al. (2026b).

The group led by ESO Fellow Thallis Pessi aimed to discover and classify supernovae with the EFOSC2 instrument. Every day, tens of newly discovered astronomical transients are reported by all-sky surveys. The nature of these events is only completely understood after spectroscopic characterisation following their discovery. The main goal of the group was therefore to obtain spectra of recently discovered transients, in order to classify and constrain their true nature, especially looking for young supernovae resulting from the core-collapse of massive stars. The students searched for recent transients discovered by surveys such as the ZTF and the Asteroid Terrestrial-impact Last Alert System, planned observations and reduced and analysed the obtained spectroscopic datasets. Spectroscopic classification of the events was performed with Gelato (Harutyunyan et al., 2008) and SNID (Blondin & Tonry, 2007). In total, eight transient events were observed and classified by the students, including four type Ia and two type II supernovae, one AGN, and one unknown event with a blue featureless spectrum. These classifications were reported by the students in AstroNotes in the Transient Name Server (Lemus et al., 2026a,b). Remarkably, one of the type II supernovae, SN 2026cff, was discovered very early, within a few days of explosion (Pessi et al., 2026a). The students performed follow-up spectroscopic observations of this event during the four nights of the school, and noted that it presented a decrease in temperature, an increase in the integrated spectral luminosity, and an increase in the Hα luminosity (Pessi et al., 2026b).

The teachers group using PLATOSpec

For the first time, in this year's La Silla Observing School it was decided to also include a group of public school teachers from communities around the ESO sites in northern Chile (Figure 5). This was done with the aim of promoting astronomy to the youngest generations, while enhancing the visibility of ESO and its observatories among the communities who reside closest to the telescopes. To this end, a total of eight teachers were selected by three different municipalities, those being Taltal, Coquimbo and Atacama. The group of teachers participated in the school for the full two weeks, with ESO Fellow Abel de Burgos Sierra as their dedicated tutor. We had participation from: Colegio Pedro Pablo Muñoz (Dana Donoso & Manuel Arancibia) and Escuela José Santos Ossa (Karen Mondaca), both in La Higuera, Coquimbo; Liceo Pedro Troncoso Machuca (Camila Herrera & Karla Rivera) and Liceo Pedro Troncoso Machuca (German Rojas) in Atacama; and Liceo Juan Cortés-Monroy Cortés (Carolina Catalán & Bastián Olivares) in Taltal.

The teachers had exclusive access to the ESO 1.52-metre telescope, hosting the PLATOSpec high-resolution spectrograph, as well as a photometric camera (Figure 6). The spectrograph was built by Universidad Católica and the pipeline was developed at the Universidad Adolfo Ibáñez, both in Santiago, Chile. A specialised programme was prepared by Abel, who created several front-to-back scientific cases covering different astrophysical topics. The idea behind this was to provide the teachers with the necessary background, observational data and tools to be able to reproduce each case performed at the

1.52-metre telescope in their classrooms. To also allow them to experience how scientific observations are planned, and ultimately decide which targets to observe, an introduction to celestial coordinates, magnitudes and object visibility was provided during the first days at the ESO Vitacura offices. Once in La Silla, other aspects such as telescope and instrument control and procedures were covered, also including the calibration of the data, all of which were performed during the observations by the teachers themselves. In this way, the teachers got a realistic hands-on experience of what the lives of astronomers and operators are like at the observatories.

The scientific cases designed by Abel covered a wide range of topics. Some of the cases also included different levels of difficulty to adapt them to students of different ages. The main topics were: a) spectral-type classification of stars — isolated or in clusters — with very different temperatures using both photometry and spectroscopy; b) interpretation of colours in different nebulae and stellar clusters; c) morphological classification of several galaxies; d) understanding Doppler shifts from radial velocity measurements in isolated or known binary systems; e) interpreting images and spectra of Solar System bodies.

Figure 6. The teachers group at the 1.52-metre telescope before starting their observations.

During the observations the teachers were provided with a basic knowledge of photometry and spectroscopy, which allowed them to understand the raw and reduced data. The reduction of the spectra was done by the PLATOSpec pipeline and then Abel developed a portable program so that the teachers could visualise and make measurements on the spectra. The reduced imaging data were handed to the teachers in common image formats for easier use, to take back to their classrooms.

As a result of this initiative, the teachers have acquired an introductory but practical understanding of the work carried out at ESO and the astronomical observatories, bringing this knowledge directly to the communities in northern Chile who, despite their proximity to these facilities, may not always be familiar with the scientific activities happening in their own regions. Equally important is that they have gained the knowledge, skills and data necessary to help raise interest in astronomy and science among younger generations.

Demographics

The school was open to students worldwide and we received more than 200 applications, evenly distributed between male and female applicants, as well as across career stage. The selection was made by the tutors of the school, who did not have access to information on the names, gender, nationality, career stage or any other detail that could have potentially biased their evaluation during the selection process. Of the 21 selected students, we had 15 female and six male participants, coming from Germany, Italy, Portugal, France, Finland, the UK, Argentina, Colombia, India, Slovakia, Brazil and Chile. The selection was made based on the students’ background in astronomy, their motivation for participating in the school, their potential career gain from the school and the reference letters provided.

After the completion of the school, the feedback received from the participants was highly positive, with the students highlighting the quality of the talks given and the level of the organisation of the school. Possible improvements included other, more efficient modes of transport to and from the observatory.

Acknowledgements

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Links

[1] Workshop programme: www.eso.org/sci/meetings/2026/lasilla_school2026.html
[2] PLATOSpec website: https://stel.asu.cas.cz/plato

Notes

[a] The PLATOSpec consortium consists of the Astronomical Institute of the Czech Academy of Science, Thüringer Landesternwarte Tautenburg, Universidad Católica de Chile, Masaryk University Brno, Universidad Adolfo Ibáñez and the Institute of Plasma Physics of the Czech Academy of Sciences.

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Fellows at ESO

Martyna Chruślińska

We are almost certainly not entirely correct, and that is part of the game. This was one of the most important realisations that inspired me to pursue an academic career. During one of my first physics lessons at school, the teacher explained the scientific method by telling us about the history of science, showing the winding path that humankind took to reach the current understanding of the laws of nature. Seeing that science is the work of generations and that one person's 'best guess' or idea, even if proven wrong, can still be the starting point for another person to make a breakthrough gave me the courage to start thinking about those daunting questions that seem 'too big' to answer. The questions that bothered me the most turned out to fall within the realm of astronomy: How did the Universe come to be? And how did it end up full of galaxies rich in life-critical elements, not to mention dark matter? My interest in the subject grew further when I joined the nationwide astronomy club and started high school, where my physics teacher was a true astronomy enthusiast. I discovered that I enjoyed the challenging and creative process of solving problems for which there was no ready-made solution. I wanted to become a researcher, whatever that might entail.

I left my home city to study astronomy at the University of Warsaw in Poland. I was trying to find my way by doing projects on different topics (solar physics, magnetic reconnection, binary neutron stars, cosmological simulations of galaxy evolution – to name a few). I am grateful for these experiences and for the academics who could have just sent me away but devoted their time to guiding me back then. I was interested in almost everything. Luckily, the Universe helped me decide what to focus on: in 2015 we witnessed the historical first direct detection of gravitational waves from merging black holes. I became fully immersed in working with the group modelling the formation of such sources, and neutron star mergers became the subject of my Master's thesis. Soon after, the first signal from the merger of neutron stars was detected. This event prompted a successful search for an electromagnetic counterpart, engaging the global astronomical community and involving all major facilities. This discovery was made possible by large collaborations and research infrastructures, including the ESO telescopes, showcasing the importance of international collaborations in science.

It was a truly exciting time to work on the formation of gravitational wave sources and I started a PhD at Radboud University in the Netherlands in this area. The field of gravitational wave astrophysics was growing rapidly, new questions arose and my career evolved with them. My current aim is to understand the impact of cosmic chemical evolution on the formation of stellar-origin transients observed across the electromagnetic spectrum and detected via gravitational waves. To answer this question, I realised that I needed to expand my expertise. I turned to the chemical evolution of galaxies. This first led me to a postdoctoral fellowship at the Max Planck Institute for Astrophysics and then to ESO, where I am currently a fellow.

At ESO, I started new collaborations and I am learning about the observational side of galaxy evolution which is important for my research. Being part of a large, international, intergovernmental organisation has also taught me the importance of science diplomacy and strategic planning, so that the broad community can pursue ambitious goals in years to come despite an ever-changing scientific and geopolitical landscape.

Although I am no longer in my early teens, I still think of science as one large team effort spread over generations. I am proud that I can contribute my part, and as one of the scientists I looked up to as a student said, "I would consider my career a success if I wrote one paper that wasn't completely wrong".

Francesca Lucertini

My passion for astronomy has been driven by curiosity from a very young age. My family often recalls that when I was only six years old I was already asking for books about the Universe, and the stars in particular. It may sound like a cliché, but the first event I clearly remember that truly sparked my desire to study the Universe was the night of San Lorenzo, the traditional night of shooting stars.

I was born and raised in a small town on the east coast of Italy. At that time there were still isolated beaches free from light pollution. I remember lying on the sand and watching the sky, while my eyes slowly adapted to the darkness, allowing me to see more and more stars. In that moment I started wondering what else was out there and felt a deep desire to understand that apparently infinite Universe.

At that time I had no idea what it actually meant to become an astronomer or what the job involved. However, the path I wanted to follow always felt clear: attend a scientific high school and then enroll in a university programme in astronomy to study the stars.

I began my studies in astronomy at the University of Bologna. By the end of my Bachelor degree, I knew that I wanted to pursue a career in research. However, I found the programme in Bologna to be very theoretical and strongly focused on cosmology so, in order to follow a more observational path, I continued my career doing a Master in Astronomy at the University of Padova. It was in this context, during a laboratory course, that I had my first experience with a telescope at the Asiago Observatory. That experience confirmed my passion for observational astronomy.

Despite my determination to pursue a research career, I was not able to obtain a PhD position in Italy. With the support of my family, I decided to remain in Padova after completing my Master's degree, with the goal of turning my thesis into what would become my first scientific paper, while at the same time applying for PhD positions abroad. During that period, Giovanni Carraro encouraged me to look toward Chile and the many opportunities that this country offers in astronomy, including those at ESO.

I started my PhD at Andrés Bello University (in Santiago de Chile) in 2019 under the supervision of Lorenzo Monaco and the co-supervision of Elisabetta Caffau from the Université PSL in Paris. In my doctoral research, I used high-resolution optical and near-infrared spectroscopy to derive sulphur abundances in stars in the main components of the Milky Way (the bulge, the disc and the halo). Sulphur is a special and useful element for reconstructing the formation and evolution of galaxies, and it is also one of the elements essential for life. However, measuring sulphur in stellar atmospheres is challenging for several reasons, which is why it has been relatively little studied in the literature.

My first contact with ESO came in 2020, when I was selected to participate in the La Silla Observing Summer School. That experience made me realise that ESO and its observatories were not the symbol of an unreachable dream for a young PhD student in astronomy, but rather a concrete and tangible reality. I applied for and obtained an ESO Studentship in Chile, which allowed me to spend two years of my PhD under the co-supervision of Luca Sbordone. During this period, I expanded my experience in the analysis of chemical abundances in stellar atmospheres, working on elements beyond sulphur and becoming more and more specialised in Galactic archaeology studies.

During the ESO studentship, students are also expected to participate in a technical project at the VLT. After spending a week in Paranal studying the high execution efficiency of the UVES instrument, the enthusiasm I felt for my work and the pride in the path I had taken confirmed that I was in the right place. That feeling motivated me to apply for the ESO Fellowship, a position I obtained immediately after defending my PhD in 2023. Today I am still an ESO Fellow with duties at Paranal on UT3 and Instrument Fellow for CRIRES+. At the same time, I continue to expand our knowledge of sulphur by studying its behaviour in extragalactic systems and by analysing others peculiar elements that are useful for reconstructing the evolution of our galaxy.

I do not want to make my story sound like a smooth and easy path. I have never considered myself a genius in mathematics or physics, so my studies have often been challenging. Moving to Chile was not easy at the beginning, especially considering the social unrest in 2019 and the fact that I had to conduct the first part of my PhD in quarantine during the COVID-19 pandemic. However, I have been fortunate to receive constant support from my family, friends and excellent supervisors, who have always helped me nurture and sustain my passion and determination to continue pursuing my dream. For this reason, I look back with pride at the path I have taken and at the awards I have received for my research (including Best PhD Thesis 2024 and the ALUMNI UNAB 2025 award). At the same time, I try to share my story with young people who wish to pursue a career in research, to make them aware of the sacrifices that may lie ahead, but also to encourage them to persevere. If you truly want something, it is possible to achieve it.

After all these years, I am still that little girl who looks at the stars with fascination and curiosity, only now I do it from the VLT platform!

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In memoriam Thijs de Graauw (1942–2026)

Wolfgang Wild[1]

[1] ESO (retired)

On 20 April Thijs de Graauw passed away in Santigo de Chile at the age of 84.

Thijs was a world expert and pioneering leader in the field of millimetre and infrared astronomy and was known to many for his fundamental contributions to European space missions, as well as to ALMA.

He was the Principle Investigator of the Short-Wavelength Spectrometer (SWS) aboard the European Infrared Space Observatory (ISO) and the Heterodyne Instrument for Far Infrared (HIFI) at the international Herschel Space Observatory, leading the large international teams for both instruments from the conceptual phase through development (pioneering new developments more than once), prototyping, flight model construction all the way to spacecraft launch and scientific exploitation.

During the crucial construction phase of ALMA, from 2008 to 2013 he was the director of this large international sub/millimetre interferometer at 5000 metres altitude.

Thijs was a unique and special person. He was dedicated, modest, a strategic thinker and actor and had the exceptional capability of bringing together a wonderfully diverse group of people and channelling their strengths toward a common goal. He was guiding the collaborations with vision, humour and an unshakeable sense of direction. He was also a master of initiating and kicking off new developments anticipating future needs and the right direction much earlier than most other people.

At times he reminded me of an expedition leader, selecting the expedition team from all over the world for a long and difficult journey with possible hardships, defining the goals for the expedition (which in general in his words were “exploring the Universe”), setting out for a journey lasting many years and navigating around many difficulties and obstacles with great resourcefulness. He was very creative in finding solutions. Once during the development of HIFI, a cryogenic amplifier developer was urgently needed, but there was no budget and no time to hire someone. So he organised, via a professor of electrical engineering in Taiwan (whom he somehow knew), that the professor’s best student would come from Taiwan to Groningen for some time for this task. Of course, the development was successful.

During these long journeys he was a strong leader, motivating team members with his enthusiasm and optimism and providing support whenever needed. He had an immense work capacity and was absolutely committed to the goals. Once facing a difficult project situation with the risk of project failure, he said just four words to me quite unemotionally *“We don’t give up”* — and indeed he never gave up. After he retired in 2013, he stayed in Chile and supported and pursued several international projects. In particular, in his last years he developed and built a new and relatively inexpensive planetarium dome with the goal that *“no Chilean child grows up without looking at the stars”*, as he told me once. His intention was to build 100 planetariums throughout Chile.

Thijs had a great sense of humour. Thomas Klein (Director of La Silla Paranal Observatory) remembers that shortly after receiving his PhD and about to take on an important project role for the Herschel-HIFI instrument in his institute, he met Thijs for the first time at a consortium meeting in Pasadena. When he entered the meeting room Thijs approached him immediately, introduced himself as the PI of HIFI, and said: *“Thank you for joining the HIFI consortium. We were eagerly expecting you. This is a zoo where you will find all species you can think of — and I am sure you will discover new ones.”*

On another occasion at an early ALMA meeting in Leiden to discuss the ALMA receiver specifications and technology, Thijs’s expertise was questioned by a meeting participant with the words *“Well, who are you anyway in this field and what have you achieved in such projects?”*. Thijs just smiled and replied to the person *“I’ll send you my CV”*.

Thijs’s passing leaves a big hole. The infrared and millimetre community in Europe and worldwide owes Thijs a great deal. We are going to miss him terribly.