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ERIS Science Verifications

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The Enhanced Resolution Imager and Spectrograph (ERIS) is the new near-infrared instrument at the Cassegrain focus of Unit Telescope 4 (UT4) of ESO's Very Large Telescope. Its Science Verification (SV) was scheduled from 2 to 6 December 2022 during which time conditions were mostly good. Most of the planned SV observing programme could be accomplished. Out of 87 submitted proposals 23 observing programmes were scheduled for a total of 40 hours of observations. The allocation had assumed observations in four nights (eight hours each) and included a slight oversubscription. Five of the seven top-ranked proposals could be fully completed, the other two received partial data. In total, eleven programmes could be completed, seven were partially observed and three programmes could not be started. Some smaller technical problems with the adaptive optics affected parts of the observations.

Brief instrument description

ERIS has two arms: SPIFFIER, the refurbished version of the Spectrometer for Infrared Faint Field Imaging (SPIFFI), and the Near Infrared Camera System (NIX). SPIFFIER is a medium-resolution integral field spectrograph covering the *J* to *K* bands. NIX is capable of imaging between the *J* and *M* bands, and offers coronagraphic and *L*-band long-slit capabilities. ERIS is designed to be used in conjunction with UT4's deformable secondary mirror and delivers diffraction-limited spatial resolution with Strehl ratios of better than 0.6 for $\lambda > 2$ μm. The atmospheric turbulence can be sensed with either a natural guide star, or a single artificial star generated with the Adaptive Optics Facility (AOF). ERIS replaces and expands the capabilities of the decommissioned Nasmyth Adaptive Optics System (NAOS) – COudé Near-Infrared CAmera (CONICA) combination (together known as NACO) and Spectrograph for INtegral Field Observations in the Near-Infrared (SINFONI) in a single instrument. A full description of ERIS can be found in Davies et al. (2023).

Proposal solicitation and submission

The call for ERIS Science Verification (SV) proposals[1] was issued on 16 September 2022. With the call, the ERIS SV webpage[2] was launched. Eighty-seven proposals were received by the deadline on 14 October 2022 requesting in total 215 hours. This was the highest demand for recent instrument SVs. The SV team ranked the proposals according to scientific interest and the final selection was discussed at a meeting on 3 November 2022. Twenty-three projects were selected for a total of 40 hours of execution time. Two proposals were rejected entirely, and one target was rejected from a third, because of conflicts with submitted P111 proposals. The approved projects oversubscribed the available time slightly to account for atmospheric conditions and target visibility. The proposers were informed about the outcome of the selection on 8 November 2022. Owing to a technical problem at the end of the last commissioning run in November 2022, NIX's pupil wheel mechanism was left fixed in the imaging position. This precluded the execution of any approved SV programme requesting use of the apodising phase plate coronagraph. Three projects were therefore not feasible, and the PIs were informed accordingly on 23 November. The Phase 2 deadline for the submission of the observing blocks was 25 November 2022.

Proposed scientific topics included galaxy structures across redshift space, kinematic searches for signatures of stellar-mass black holes or binary supermassive black holes in galaxy centres, observations of gravitational lenses, characterisation of emission-line objects, for example young stars, and searches for exoplanets using different high-contrast methods. Integral-field spectroscopy and high-contrast imaging were in high demand.

Observations

The ERIS SV nights were scheduled from 2 to 6 December 2022. In general, the conditions were quite good, i.e. mostly photometric and clear. The first night had poor seeing (up to 1.5 arcseconds), but substantially better observing conditions were encountered during the following three nights.

ERIS performed well, although some difficulties with the adaptive optics (AO) were experienced during the first night. The third night suffered from a loss of time that was due to an instrument cryogenic alarm, which needed to be investigated. The beginning of the last night was affected by a failure of the telescope guide camera, which delayed the start of observing by one hour. Some programmes were affected by glitches (for example errors associated with the Standards Platform for Adaptive optics Real Time Applications[3] (SPARTA); AO loop opening) and only received partial data. The collaboration between the science operations on Paranal and the support team in Garching (via the Garching Remote Access Facility) worked well and we also received technical support from the team at Arcetri Observatory who developed the AO subsystem for ERIS.

As in previous cases, ERIS SV provided an excellent opportunity to test and diagnose issues related to the operability of the instrument, especially the acquisition of faint targets and crowded regions. Valuable lessons were learned and provided the opportunity to implement fixes/changes before the instrument started regular operations with P111 (in April 2023).

Data processing

All raw data are publicly available through the ESO science archive. The ERIS SV webpage[2] provides direct links to the raw data in the archive. A preliminary version

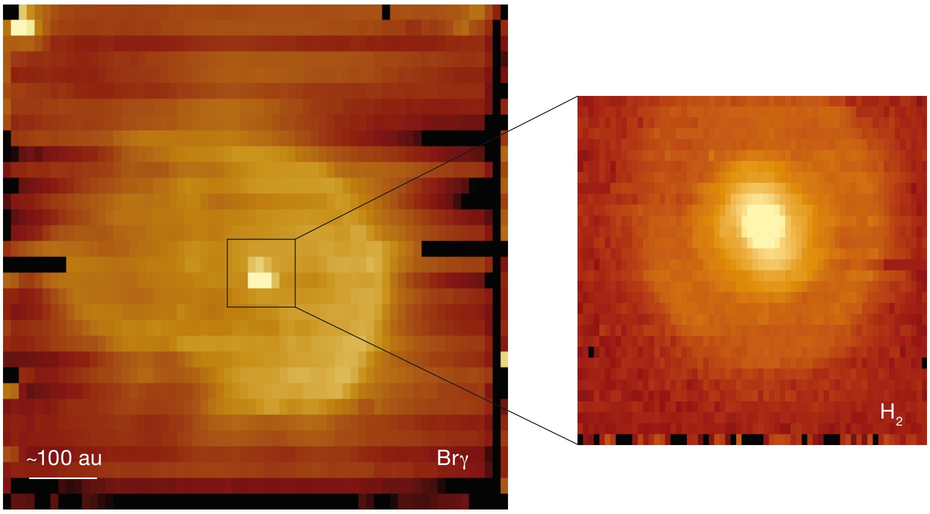


Figure 1. Two ERIS views of the planetary disc around θ^2 Ori A. The left image shows the Brγ emission in a field of view of 8 × 8 arcseconds, while the right image shows details of the planetary disc in H_2 in a field of view of 0.8 × 0.8 arcseconds. In both images north is up and east to the left.

of the ERIS data reduction pipeline was made available to the PIs through the SV Web page. In the meantime, the ERIS pipeline has been released[4].

Some early SV results

First results of some of the SV observations are presented below. They have been kindly provided by the research teams.

Protoplanetary discs

The evolutionary pathways of individual protoplanetary discs can differ, depending on the surrounding environment, especially in the presence of massive stars (see the review by Parker, 2020). The UV radiation from O-type stars in massive clusters can photo-evaporate discs and strongly affect their size, mass, and survival timescale (for example, Winter & Haworth, 2022).

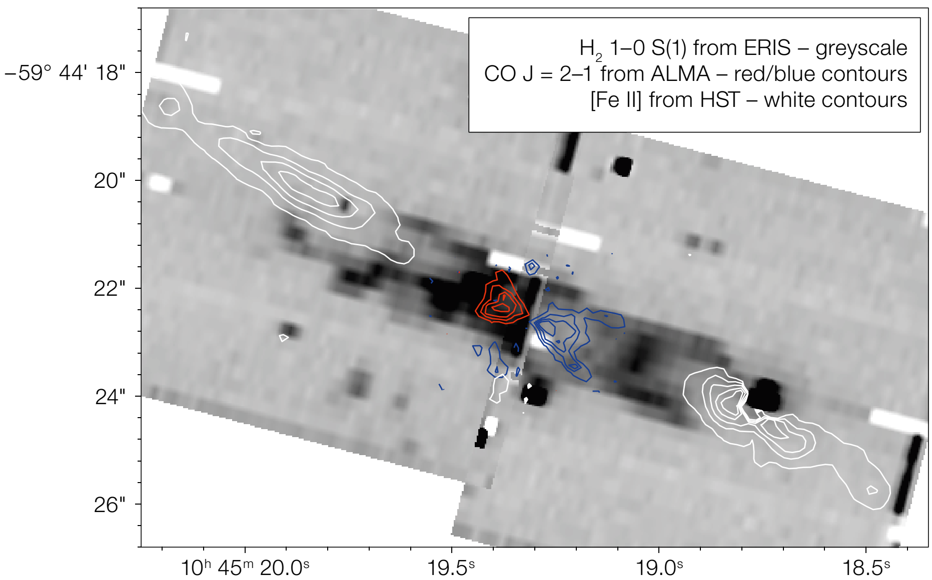
ERIS/SPIFFIER obtained a spatially and spectrally resolved image of the large irradiated protoplanetary disc (proplyd) 244-440 in the Orion Nebula Cluster (Figure 1). The proplyd, illuminated by the O-type star θ^2 Ori A, was observed with two spaxel scales: the larger field of view (8 x 8 arcseconds) covered the whole object, and the smaller one (0.8 × 0.8 arcseconds) zoomed-in to the central protoplanetary disc.

ERIS can resolve the various components of the proplyd in greater detail and better constrain their density and temperature than the instruments it replaces. The observations with ERIS are complementary to those with the Multi Unit Spectroscopic Explorer (MUSE) and the JWST and help to create a comprehensive view of the structure and physical conditions of 244-440.

Outflows from forming stars

Forming stars drive jets and outflows. These outflows are often detected in optical emission lines that are excited in shocks or molecules entrained in the outflow. In massive star-forming regions, jets and outflows are illuminated by external UV photons that dissociate molecules and ionise atoms, changing the observational picture. The template irradiated outflow is HH 900, located in the Carina star-forming region. The cold molecular outflow is clearly seen inside its natal globule in CO with the Atacama Large Millimeter/submillimeter Array (ALMA) but ends abruptly at the edge of the globule (Reiter et al., 2020). Outside the globule, classic jet-sensitive lines like Hα and [S II] seen with MUSE trace an ionised wide-angle outflow that extends smoothly from the end of the CO outflow and surrounds a collimated jet seen in [Fe II] (Reiter et al., 2019). ERIS/SPIFFIER reveals the transition between the purely molecular and fully ionised components where molecules in the outflow are rapidly dissociating (see Figure 2). Understanding this dissociating component is an important step towards accounting for the full mass-loss in irradiated jets and outflows. Results from this programme (Reiter et al., submitted to MNRAS) will guide the interpretation of

Figure 2. Outflow from the HH 900 tadpole at various wavelengths.



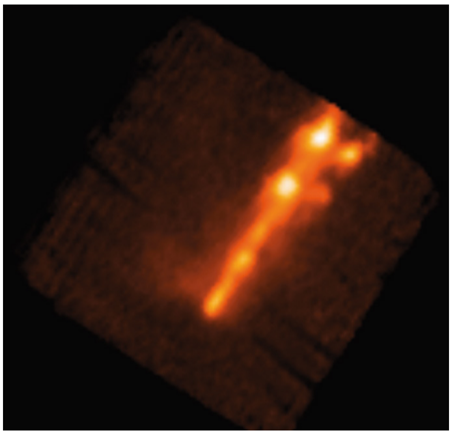


Figure 3. Image slice of the ERIS data cube in the 1.6435 μm emission line of [Fe II]. The knotty structure of HH1 jet is clearly visible. It is crossed in projection by the fainter HH501 jet. The field of view is 8 × 8 arcseconds. North is up, and east is to the left.

near-infrared observations of jets and outflows in massive star-forming regions (for example with the JWST) and provide a template for the further development of models of irradiated jets and outflows (for example, Estrella-Trujillo et al., 2021).

The prototypical jet HH1

Protostellar outflows play a crucial role in the formation and evolution of stars since they remove excess angular momentum from the star-disc system and return material into the surrounding cloud (Frank et al., 2014). The Herbig-Haro 1 (HH1) jet represents a prototypical Class 0 jet with interesting kinematical features. It has been traced in H_2 2.121 μm (for example, Garcia Lopez et al., 2008) and [Fe II] 1.64 μm (for example, Erkal et al., 2021) as close as 1–2 arcseconds from its driving source VLA1, a deeply embedded Class 0 protostar.

Observations were carried out with the SPIFFIER arm of ERIS, using the laser guide star (LGS) mode with a nearby star for tip-tilt corrections. The grating configurations J_middle, H_middle, and K_middle were observed, giving spectral resolutions of about 10 000, 10 400, and 11 200, respectively. The 250-milliarcsecond plate scale was used, giving spaxels of 125 × 250 milliarcseconds, and a total field of view of 8 × 8 arcseconds. In the three datacubes a total of 21 lines of [Fe II], eight lines of H_2, two lines of [Ti II], and one line each of [P II], He I and Paschen β could be detected. Figure 3 shows the HH1 jet in the strong 1.6435 μm line of [Fe II]. A series of five knots, connected by fainter inter-knot emission, is visible, extending in a north-westerly direction. The high spatial resolution of the image reveals that in fact there are two jets crossing each other in projection. The fainter HH501 jet becomes visible just north of the HH1 jet and is crossing it in projection. The series of knots along these jets are resolved into small bow shocks. The large number of iron lines and H_2 lines enables a detailed analysis of the increasing extinction towards the jet source VLA1 and of the excitation state of the outflowing jet gas with both its atomic and its molecular components.

Exoplanet characterisation

ERIS was operated in the LGS mode to resolve the young (~ 2.5 Myr) Taurus system 2M0347 consisting of a 0.15–0.18 $M_\odot$ star and a 3–5 M_{Jup} exoplanet. SPIFFIER produced datacubes in the *K* band providing the spatial and spectral diversity at R = 5000 resolution needed to remove the stellar halo, reveal the emission of the faint ($K \approx$ 17 mag) exoplanet (Figure 4), and look for molecular absorptions (H_2O, CO) in the atmosphere of the object. The observations demonstrate the potential of the instrument to capture images and spectra of substellar companions and circumstellar discs in the vicinity of stellar and substellar host stars.

Lensed galaxy spectrum

ERIS observed a strongly lensed hyper-luminous infrared galaxy, PJ0116–24, at z = 2.125 (Figure 5). The different galaxy images are aligned in a near-perfect circle. The galaxy has a magnified infrared luminosity of $L_{IR} \approx 1 \times 10^{14}\ L_\odot$ and an intrinsic star formation rate of *SNR* 1820 ± 460 $M_\odot$ yr^{-1} (Kamieneski et al., 2023), and it is a member of the rare class of hyper-luminous infrared galaxies that are usually thought to be extremely dust obscured.

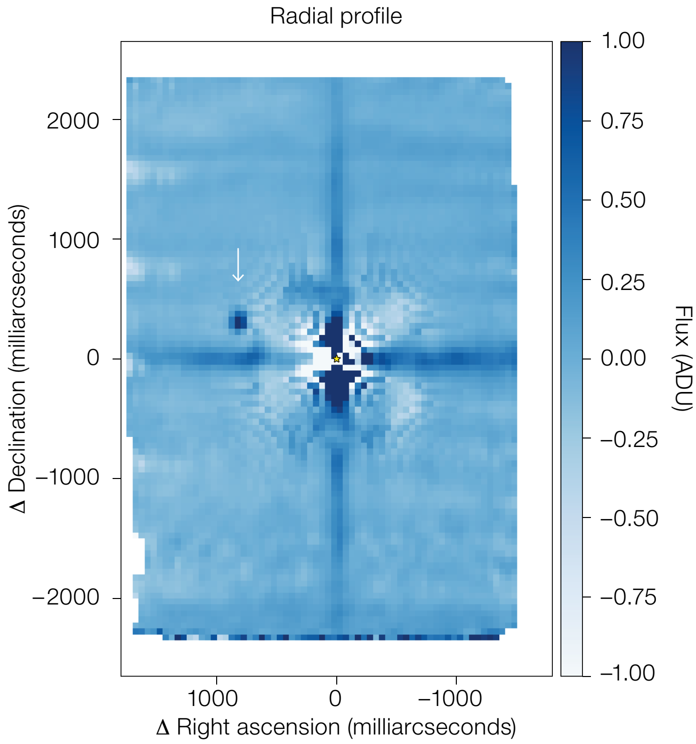


Figure 4. Detection of a 3–5 Jupiter-mass planet around 2M0347. The image is the collapsed cube of a SPIFFIER observation and will enable direct spectroscopy of the planet.

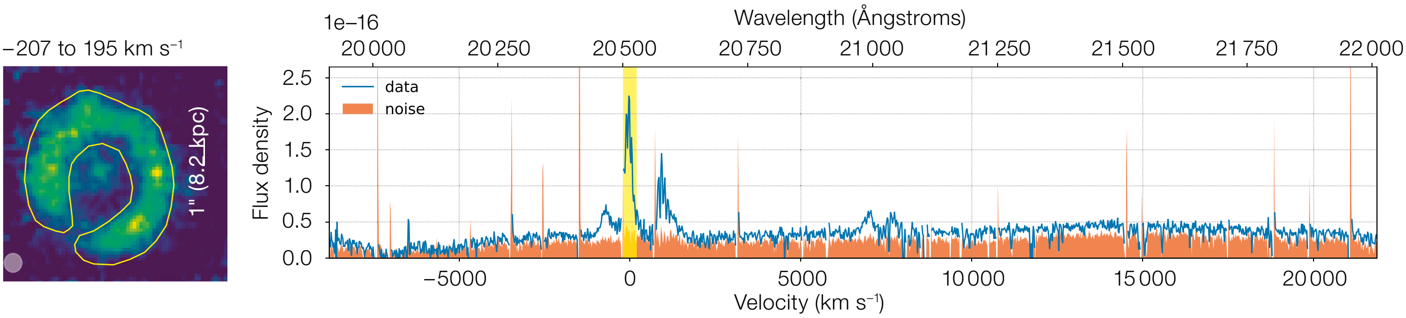


Figure 5. Left: ERIS Hα line integrated intensity image at a seeing-limited angular resolution with ~ 0.67 hours of on-source exposure in the *K* band. Right: ERIS *K*-band spectrum integrated over the highlighted area in the left panel. Prominent Hα, (N II) and (S II) lines are observed with a wide line width indicating outflows.

Summary

ERIS operations started with P111 in April 2023. The SV data give an early indication of what scientific topics can be addressed with near-infrared integral field spectroscopy with SPIFFIER and the imaging provided by the NIX camera. It can be expected that ERIS will continue to build on the successful campaigns of NACO and SINFONI.

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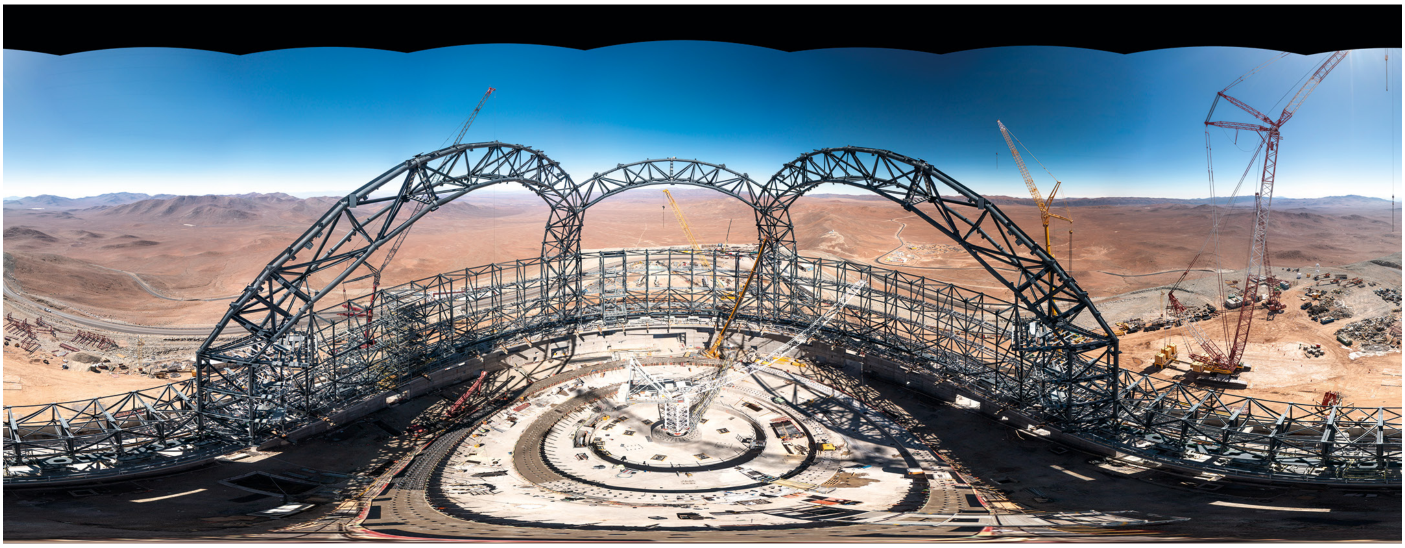
Links

[1] ERIS call for SV proposals: https://www.eso.org/sci/publications/announcements/sciann17516.html
[2] ERIS SV webpage: http://www.eso.org/sci/activities/vltsv/erissv.html
[3] SPARTA: https://www.eso.org/sci/facilities/develop/ao/tecno/sparta.html
[4] VLT instrument pipelines: http://www.eso.org/sci/software/pipelines/



A panoramic view taken from the top of the dome of ESO's Extremely Large Telescope (ELT) in early August, 2023. When completed, the dome will be 80 metres high, weigh more than 6100 tonnes and rotate 360 degrees on 36 trolleys.