DOI: 10.18727/0722-6691/5420

First Fringes for Asgard — Phase 1

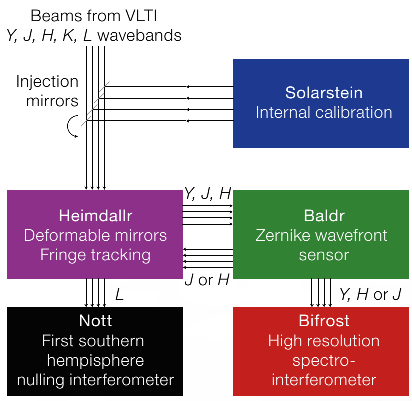
Michael Ireland[1]
Frantz Martinache[2]
Stefan Kraus[3]
Denis Defrère[4]
Adam Taras[5]
Benjamin Courtney-Barrer[1]
Xavier Haubois[6]
Nicolas Schuhler[6]
Fatme Allouche[6]
Julien Bernard[1]
Pierre Bourget[6]
Nick Cvetojevic[2]
Germain Garreau[4]
Juan Pablo Gil[6]
Connor Langford[5]
Romain Laugier[4]
Roxanne Ligi[2]
Grace McGuinness[1]
Marc-Antoine Martinod[2]
Sébastien Morel[6]
Laurent Pallanca[6]
Jyotirmay Paul[3]
Marcus Pavez[6]
Romain G. Petrov[2]
Sylvie Robbe-Dubois[2]
Gordon Robertson[5]
Owain Snaith[3]
Peter Tuthill[5]

[1] Australian National University, Canberra, Australia
[2] Côte d'Azur Observatory, Nice, France
[3] University of Exeter, United Kingdom
[4] KU Leuven, Belgium
[5] The University of Sydney, Australia
[6] ESO

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



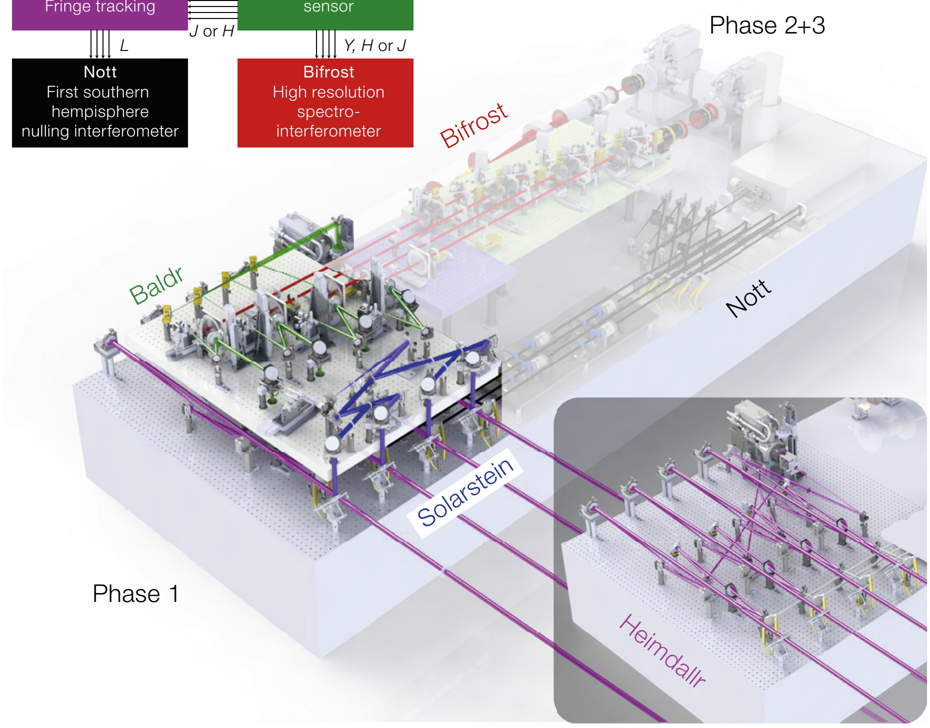


Figure 1. Rendering of the full Asgard instrument Suite, showing the installed components of Phase 1 (Heimdallr, Baldr and Solarstein) along with the full system to be completed between now and early 2027. The inset is the lower level of Heimdallr.

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.

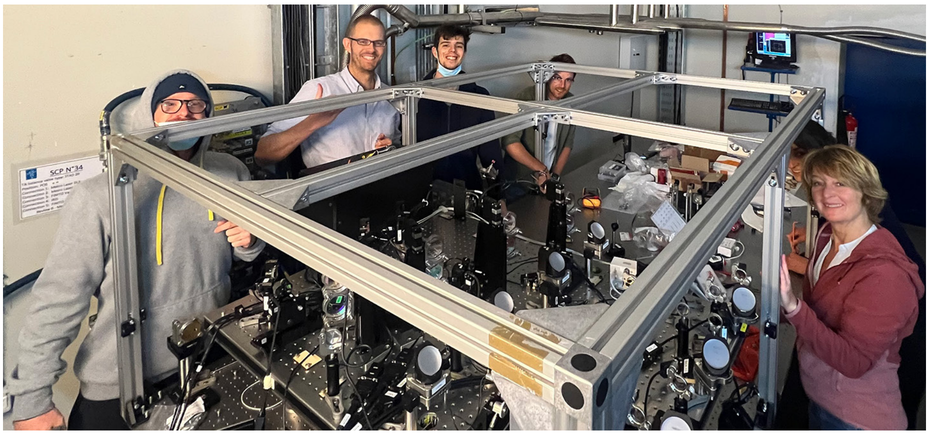


Figure 2. Core Asgard team members installing the outer enclosure in the VLTI laboratory on the visitor table — once panels were in place, it became more difficult to see inside in a single photo!

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

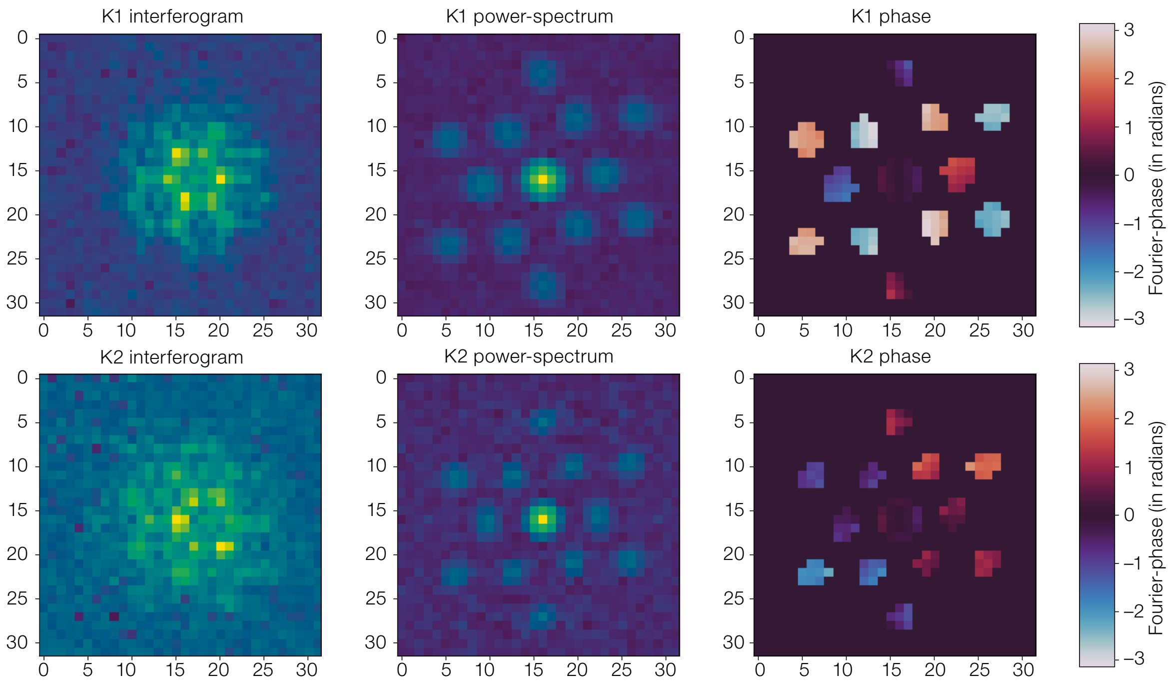


Figure 3. Simultaneous K1 (top row) and K2 (bottom row) interferograms acquired by the C-Red One detector at 1 kHz frame rate, and their respective 2D Fourier transform (visibility and phase). The fringe tracking algorithm of Heimdallr uses the K1 and K2 phase to estimate the real-time phase and group 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.

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].

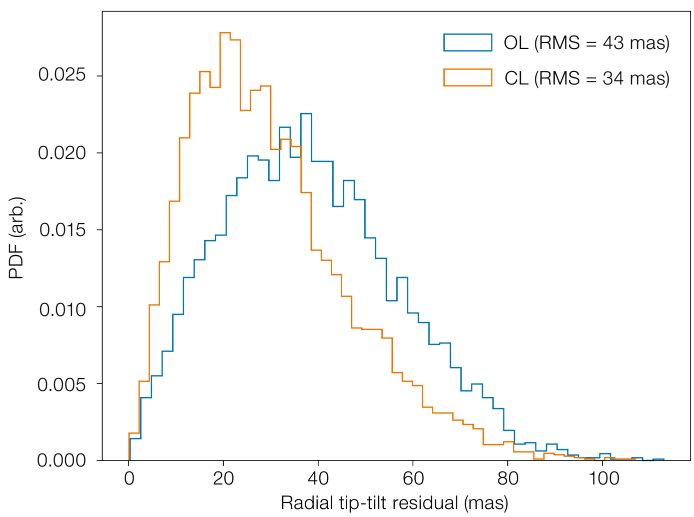


Figure 4. On-sky radial tip–tilt residuals of the Heimdallr PSF, measured out of loop and detrended, showing the reduction achieved when Baldr is switched from open loop (OL) to closed loop (CL) with the first stage AO NAOMI running on the AT's. Although promising already, Baldr is only partly commissioned,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

Acknowledgements

Asgard has been funded primarily through the Australian Research Council (LE220200126) and the European Research Council (Consolidator grants 101003096 and 866070). It has only been possible with assistance from numerous staff members of ESO in Chile.

References

Defrère, D. et al. 2018, Proc. SPIE, 10701, 107010U
Kraus, S. 2019, Zenodo 3356286
Kraus, S. et al. 2022, Proc. SPIE, 12183, 121831S
Martinache, F. & Ireland M. J. 2018, A&A, 619, A87
Martinod, M.-A. et al. 2023, JATIS, 9, 025007
Taras, A. K. et al. 2024, Appl. Opt., 63, 14

Links

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