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Design and on-sky performance of the high-contrast imaging and spectroscopic modes of the new VLT/ERIS instrument

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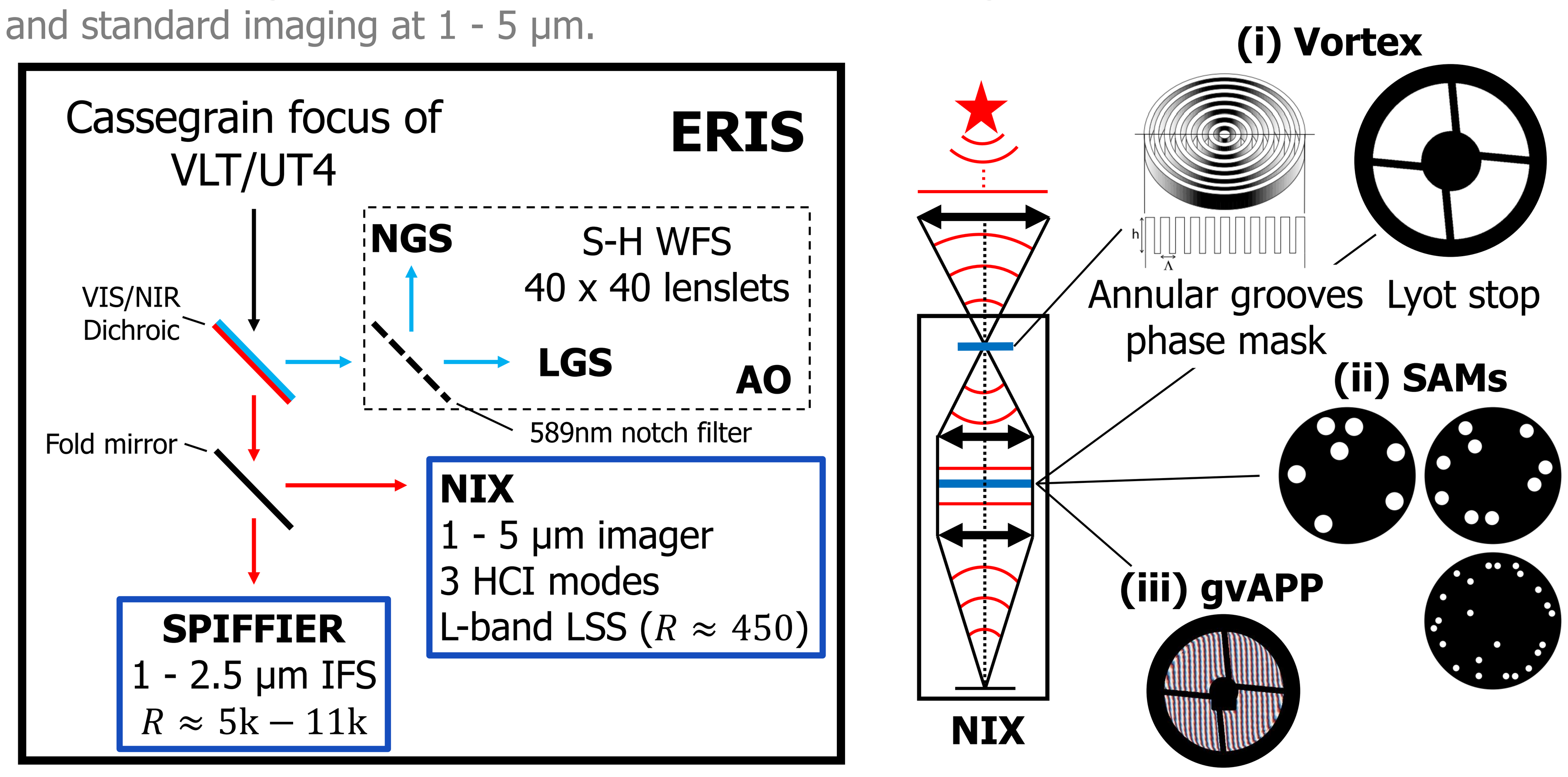
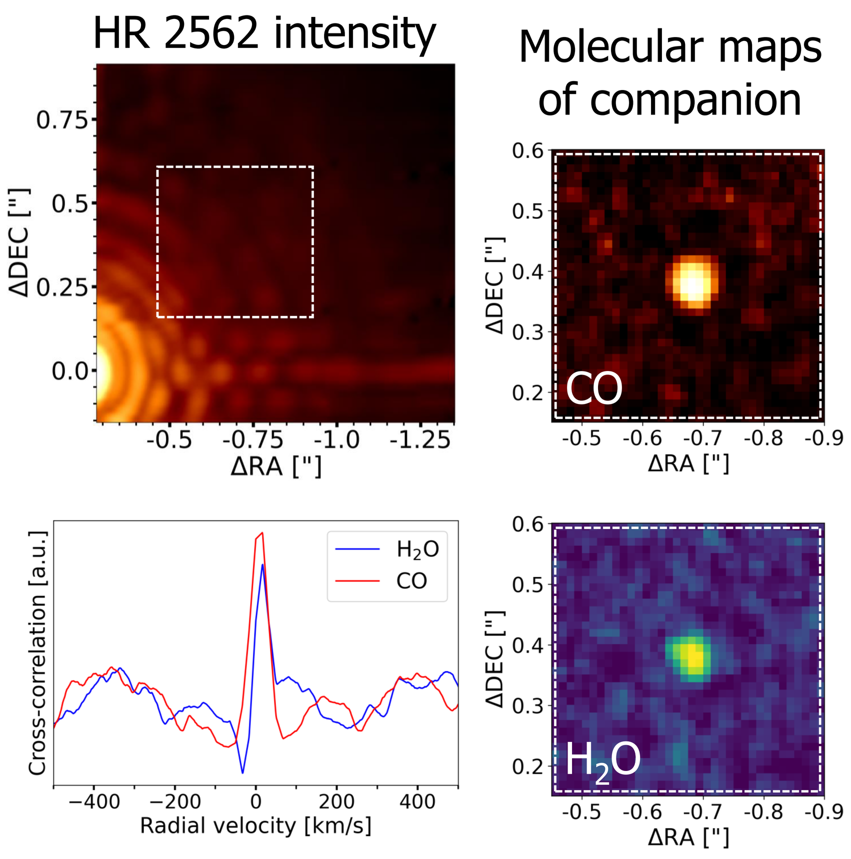
Overview of ERIS

The Enhanced Resolution Imager and Spectrograph (ERIS, [1]) is the **new near-infrared adaptive optics assisted instrument at the VLT**, replacing SINFONI and NACO. ERIS offers three high-contrast imaging modes: (i) a vortex coronagraph, (ii) a gvAPP coronagraph, and (iii) three Sparse Aperture Masks (SAM). On top of these, ERIS also offers integral field spectroscopy at 1 - 2.5 µm, long-slit spectroscopy in the L band, and standard imaging at 1 - 5 µm.



Integral Field Spectroscopy



The Integral Field Spectrograph ERIS/SPIFFIER can be used to study low-mass companions hidden by the stellar PSF by leveraging **cross-correlation spectroscopy** (CCS). This technique makes use of the fundamentally different spectra of the host star and its companions. After PSF subtraction, the **signal of the molecules** present in the atmosphere of the companion can be picked up by **cross-correlation with corresponding spectral templates**, creating so-called **molecular maps** [2,3]. More precise atmospheric constraints such as the p-T profile and the molecular abundances can be derived by embedding CCS into atmospheric retrievals, using e.g. CROCODILE [4].

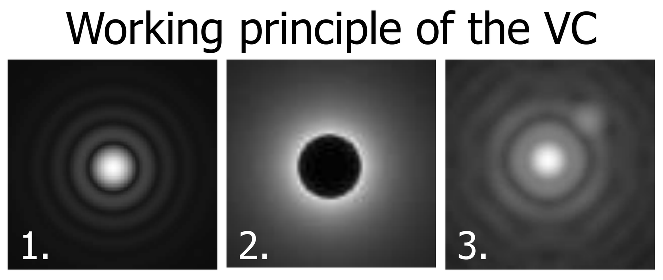
The HR 2562 system was observed as part of the ETH Zurich ERIS GTO, unveiling the **signatures of H_2O and CO** in the atmosphere of the 30M_J companion. Analysis is ongoing to measure its atmospheric C/O ratio via atmospheric retrievals.

More on this ERIS GTO program in my talk (n°969) on Friday!

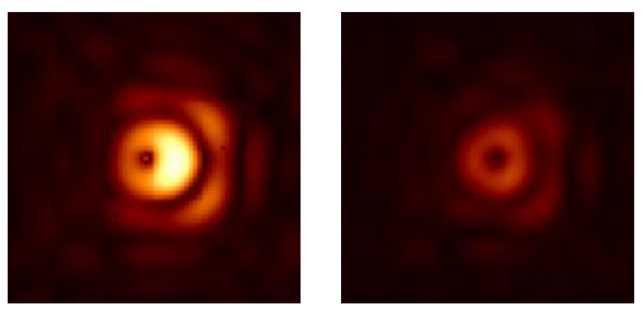
Vortex coronagraph

The vortex coronagraph (VC) consists of a **subwavelength grating** (Annular Grooves Phase Mask) placed in the focal plane diffracting the on-axis **stellar light** to the edge of the relayed pupil plane, where it is **blocked** by a Lyot stop [5]. Off-axis light, such as that produced by a companion, is largely unaffected with a transmission of >50% at 1 λ/D (i.e. 95 mas at L') from the vortex center. Two vortex masks are included in ERIS to account for the L and M bands.

Working principle of the VC



1. Stellar light in the focal plane (FP)
2. Diffracted light in the Lyot plane
3. Suppressed stellar light in the FP

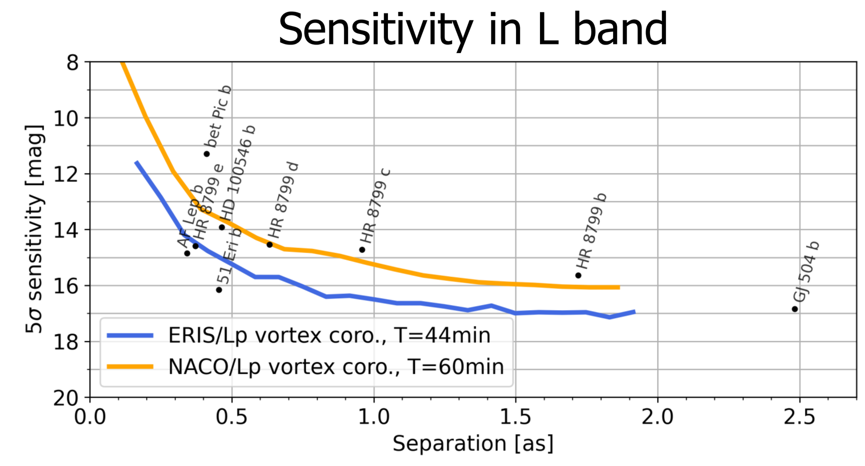


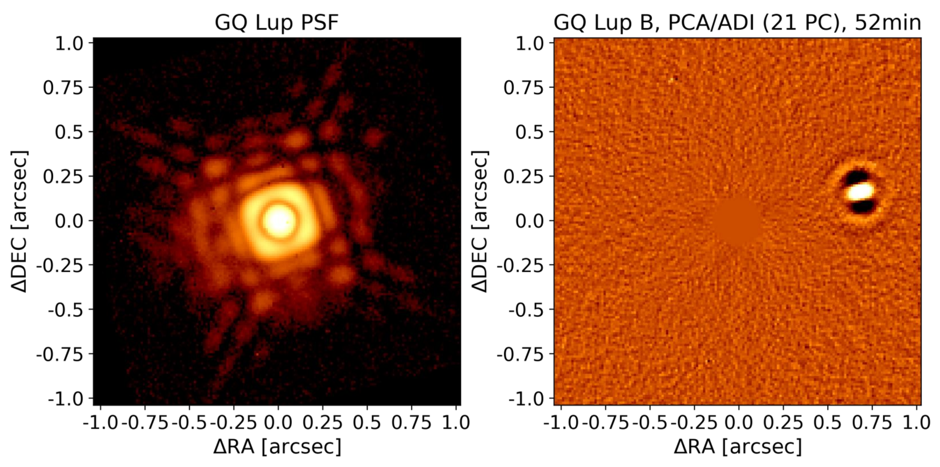
VC misaligned VC aligned

Since the suppression provided by the VC is highly dependent on pointing errors, it is supported by the **QACITS algorithm** [6]. QACITS monitors the changes in brightness of the residual stellar light and **sends corrections to the AO system**, reaching a **pointing stability better than 0.02 λ/D.**

The performance of the VC in the L band was measured during a 44min sequence on the star i Vel (L=4mag), reaching a **5σ detection limit of 17mag**. This is an **improvement of ~1mag compared to the NACO vortex**, for which we re-reduced similar datasets (similar magnitude and observing conditions).

Sensitivity in L band

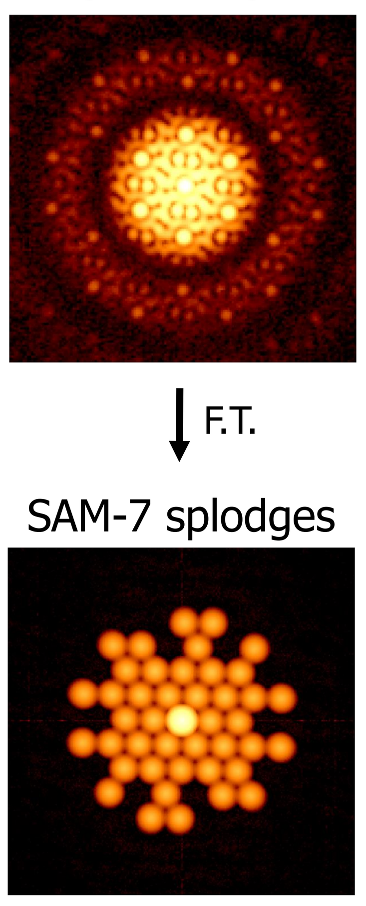




Additionally, we observed the young (2-5Myr) stellar system GQ Lup, which hosts a bright 10-40M_J companion [7]. The **companion is easily detected in our 1h sequence**, demonstrating both the functionality and sensitivity of the VC.

Sparse Aperture Mask

SAM-7 PSF

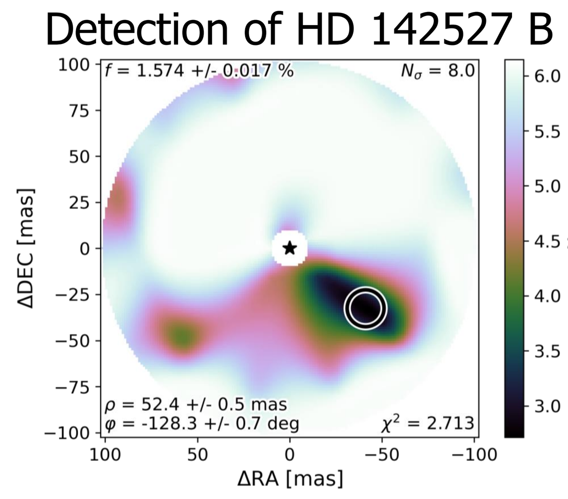


SAM-7 splodges

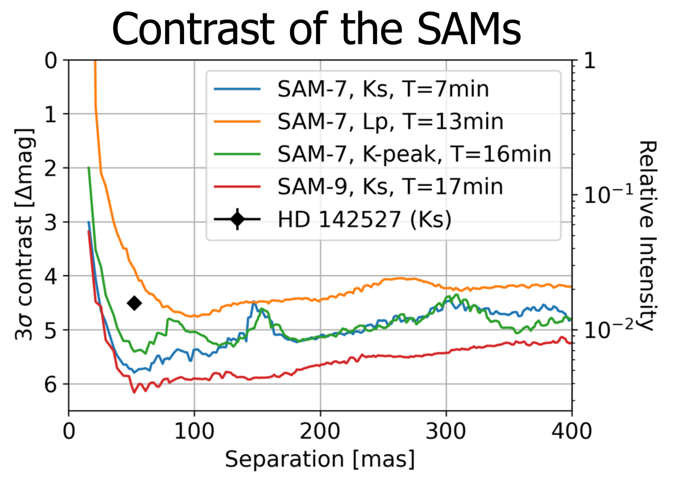
Sparse Aperture Masks (SAMs) transform the telescope into an **interferometer** with (partially) non-redundant baselines, thereby **improving the angular resolution** of the telescope **at the cost of throughput**. This makes the technique particularly suited to observe **binary stars** and small-scale **bright extended objects.**

We assessed the performance of the SAMs by measuring 3σ contrast curves and confirmed them by **detecting HD 142527 B**, a young M2.5 companion orbiting its primary star at ~14au [8].

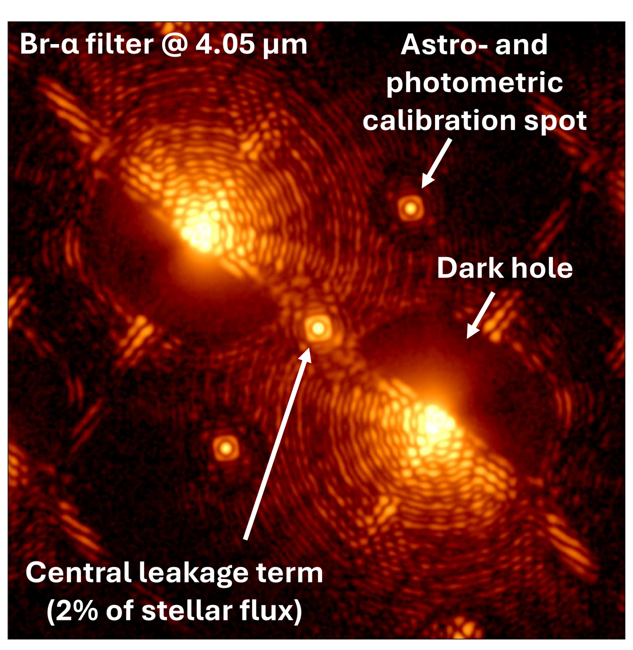
Detection of HD 142527 B



Contrast of the SAMs



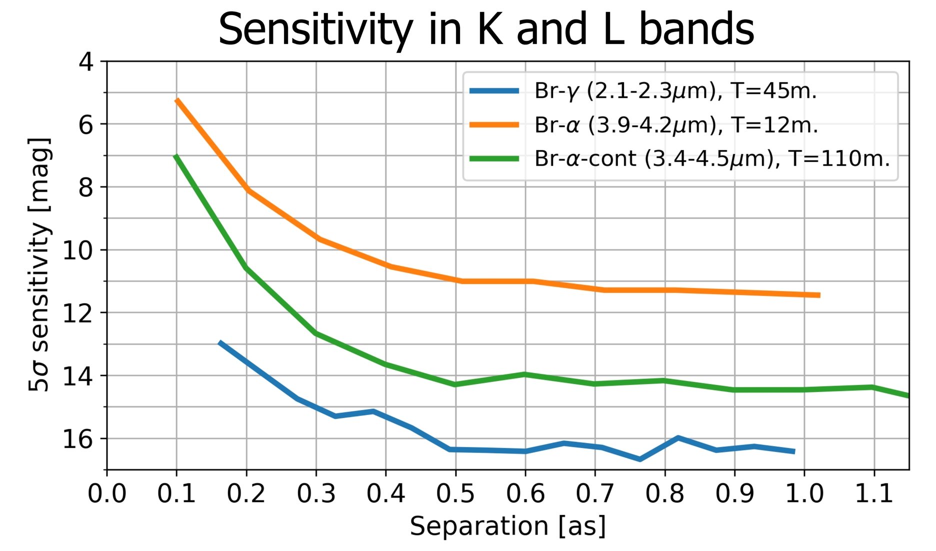
The gvAPP coronagraph



The grating vector-Apodizing Phase Plate (gvAPP) coronagraph is a pupil-plane optic that manipulates the phase using a half-wave liquid-crystal layer to cancel the starlight in the focal plane in so-called **dark holes**. The two circular polarization states receive equal but opposite phases, resulting in **two coronagraphic PSFs** with opposite dark holes [9]. This design offers a search space of nearly 360° between 2.2 and 15 λ/D to image faint companions and **enables chopping** to subtract the sky background as well as **photometric monitoring**. However, the gvAPP is limited to narrowband filters to avoid smearing of the PSF due to chromatic effects.

To measure the performance of the gvAPP, we executed deep observations of bright stars in three narrowband filters in the K and L bands offered by ERIS. We derived 5σ detection limits using fake planet injection. The **background limit is reached at 14.5mag** due to the combination of narrowband filters and high background at these wavelengths.

Sensitivity in K and L bands



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Acknowledgements

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This poster was proudly presented at Exoplanets V conference in Leiden, The Netherlands, 2024.

More from the Exoplanets & Habitability group at ETH Zurich

Emily O. Garvin's poster (n°1432) on Friday on better molecular mapping.
Helena Kuehnle's talk (n°1534) on Friday on the atmospheric characterization of the coldest brown dwarf with JWST.
Janina Hansen's talk (n°455) on Friday on detecting population-level CO2 trends with LIFE.

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