Performance evaluation of mid-IR vortex coronagraphs with centrally obscured segmented pupils


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1. Objective and simulation setup

In its original design, the E-ELT/METIS mid-infrared imager and spectrograph incorporates a vortex coronagraph for the detection and characterization of exoplanets, with a required 5-sigma L-band contrast of 3e-5 (goal: 1e-6) at 5 lambda/D (goal: 2 lambda/D), with lambda/D~20 mas at L band. The AGPM (Annular Groove Phase Mask) is a vortex phase mask with impressive characteristics (small inner working angle, high throughput, achromaticity) and theoretically achieves perfect starlight cancellation for a circular pupil. However, a non-circular or obstructed pupil and non-flat input wavefront result in a starlight leakage, which degrades the performance of the vortex coronagraph.

2. Raw contrast for a perfect input wave front

Our model of the E-ELT includes the central obstruction, spiders and segmented aperture. We assume a perfect vortex coronagraph. In order to compensate for the non-circular pupil, several solutions have been analyzed. The Lyot Phase Mask (Ruane et al., 2015) is a phase-only optical element, placed at the Lyot stop, that can improve the performance of the vortex coronagraph in a defined area of the focal plane (here, 4 to 19 lambda/D). The Double Vortex (Mawet et al., 2011) is a multi-stage vortex coronagraph, with two focal plane vortex phase masks and two Lyot stops, that can reduce the residual light leakage without losing in throughput. The Ring-Apodized Vortex Coronagraph (Mawet et al., 2013) combines the vortex coronagraph with an amplitude ring apodizer in order to compensate for the central obstruction.

3. Raw contrast for SCAO-corrected phase screens

Natural guide star single-conjugated adaptive optics simulations under YAO have been used to evaluate the residual turbulence at the entrance of the METIS instrument (Feldt & Hippler, personal communication). We have used these screens to evaluate the performance degradation of the vortex coronagraph and the proposed solutions under typical observing conditions. Our simulations suggest that all concepts deliver similar ray contrasts in presence of atmospheric turbulence, except for very small angles where some differences can be noticed. Final contrasts taking into account post-processing still need to be computed and may show more differences.