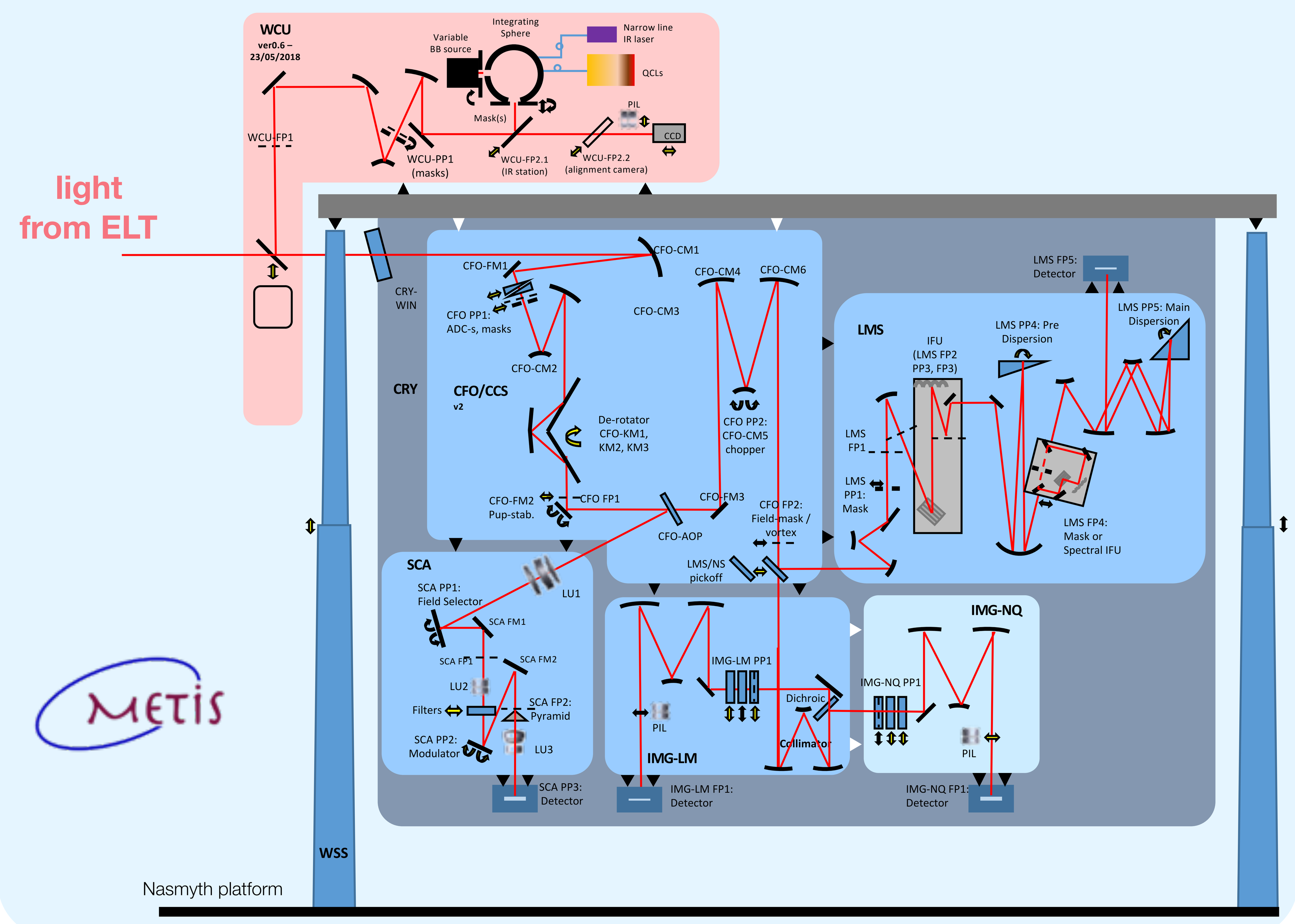
The game-changing promises of ELT/METIS for exoplanet imaging

O. Absil & the METIS consortium

METIS, the mid-infrared ELT imager and spectrograph, is one of the three first-generation instruments of the Extremely Large Telescope. It recently passed its preliminary design review, and is expected to see first light in 2027. Specifically designed to deliver high-contrast imaging capabilities, METIS features advanced coronagraphic concepts such as a ring-apodized vortex coronagraph and an apodizing phase plate. It also comprises a high-resolution (R=100,000) integral field spectrograph covering wavelengths from 3 to 5 μm, which can be combined with the coronagraphic observing modes. Using the full resolving power of the ELT thanks to a high-performance adaptive optics module, METIS promises to reach game-changing performance in the field of exoplanet imaging.

METIS design overview

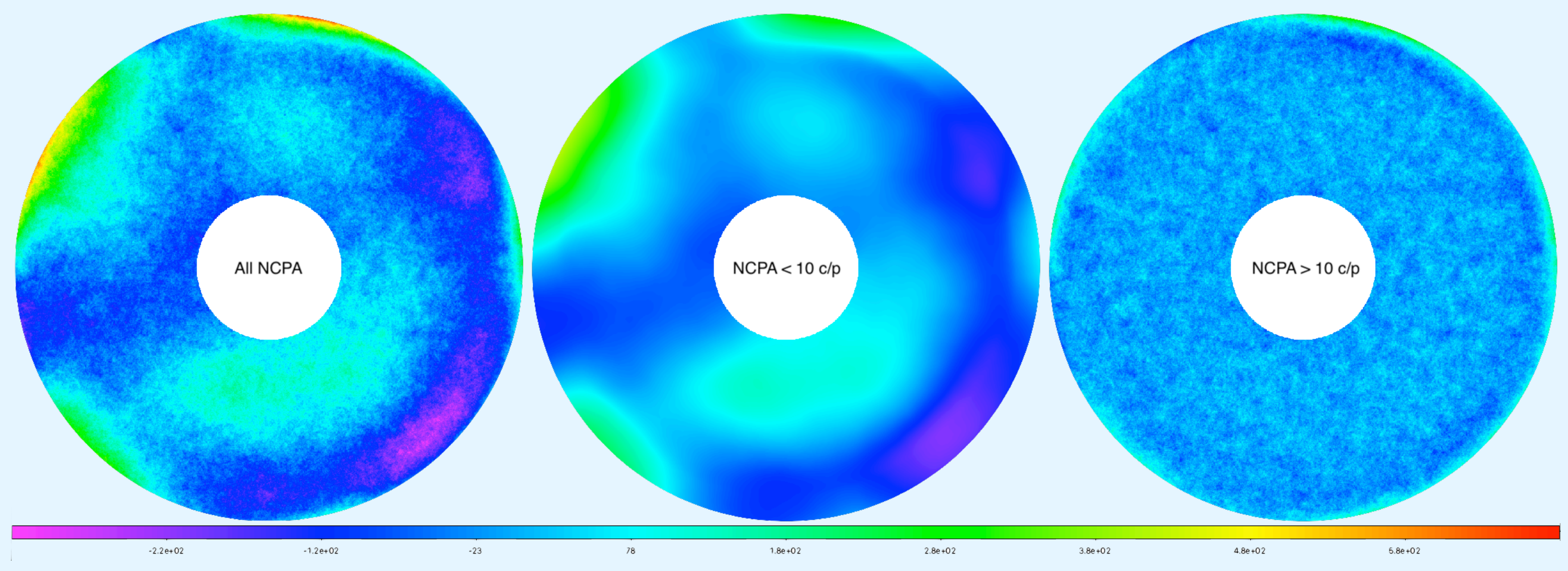


Non-common path aberrations

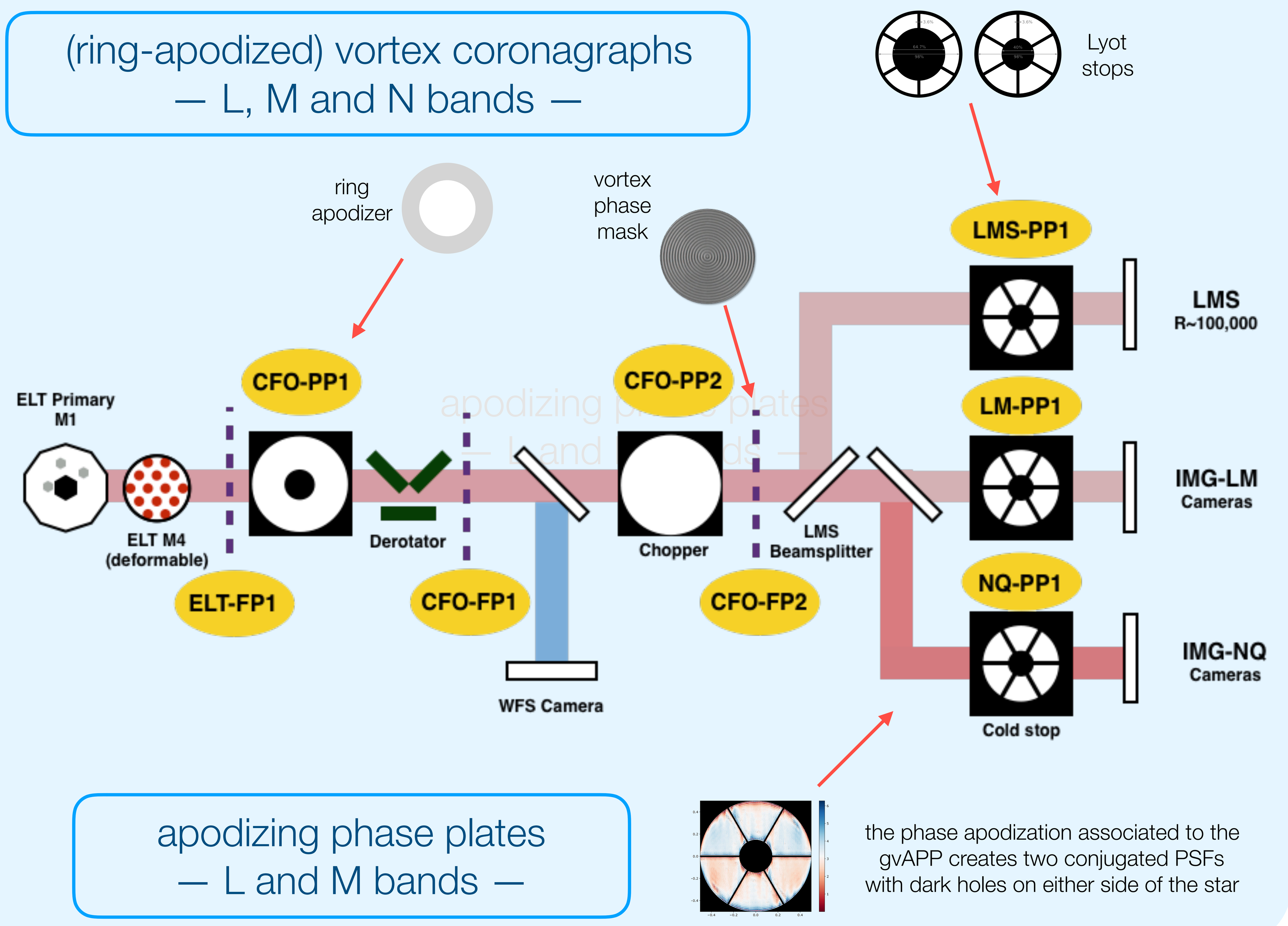
NCPA between the SCAO pyramid WFS (PyWFS) and the coronagraphic elements will be measured by two dedicated algorithms:

- The Quadrant Analysis for Coronagraphic Image Tip-tilt Sensing (**QACITS**, Huby et al. 2015) algorithm will measure the pointing error for vortex coronagraph operations based on the IMG focal-plane images, and will send an offset to the PyWFS modulator to change the SCAO set point.
- The Phase Sorting Interferometry (**PSI**, Codona et al. 2008) algorithm will measure aberrations in all HCI modes based on the short-exposure IMG focal plane images and on the SCAO WFS telemetry, and will send this information back to SCAO in order to change the reference slopes of the PyWFS.

At system level, the NCPA and their variations are minimized by design, thanks to the temperature-controlled, gravity-invariant design, and to the minimization of moving parts in the non-common path. NCPA are modeled with Monte-Carlo ray-tracing simulations, resulting in the phase maps below. These maps (and their possible fluctuations) are injected into our end-to-end HCI simulations to evaluate their effect on performance.

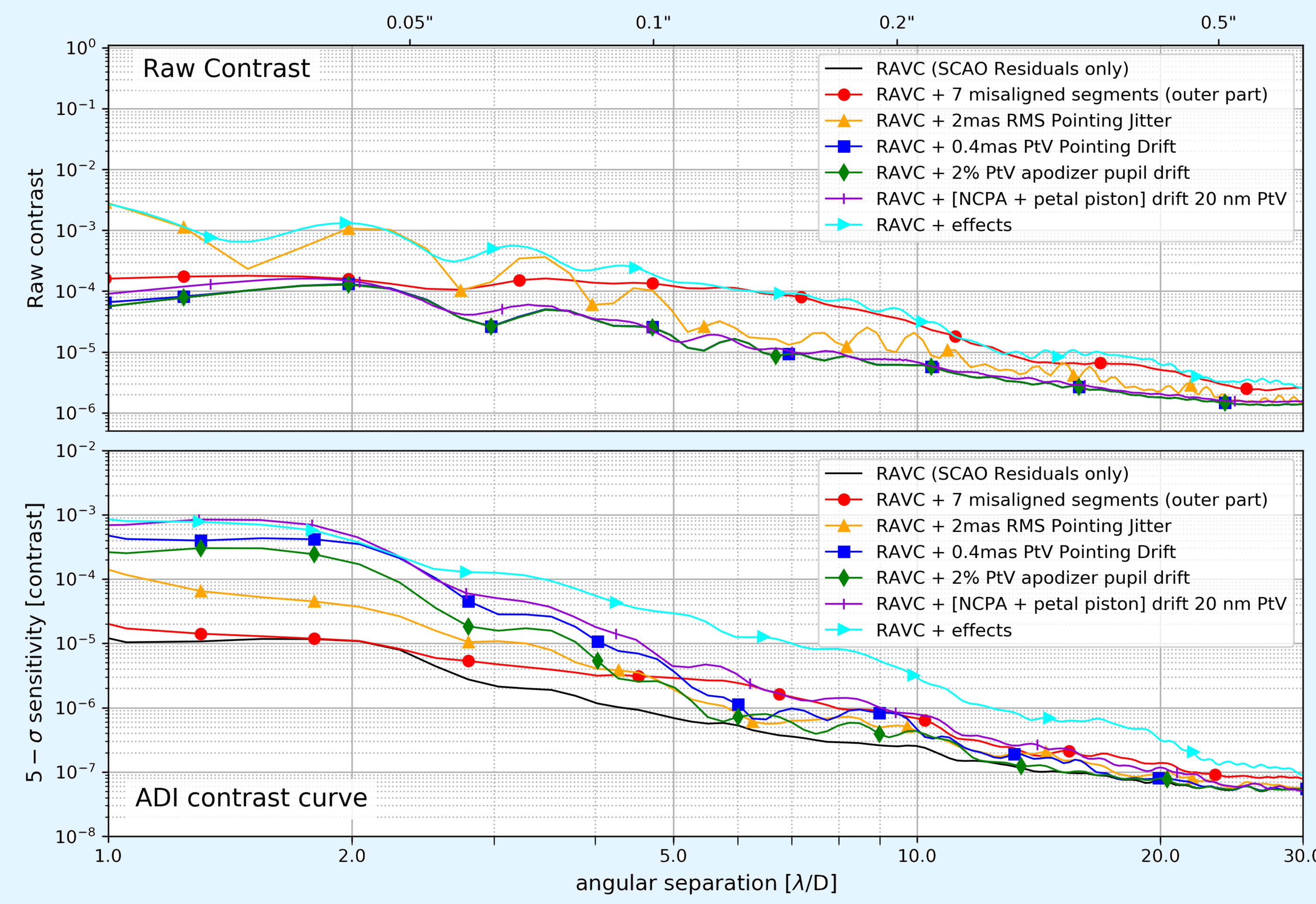


METIS HCI modes



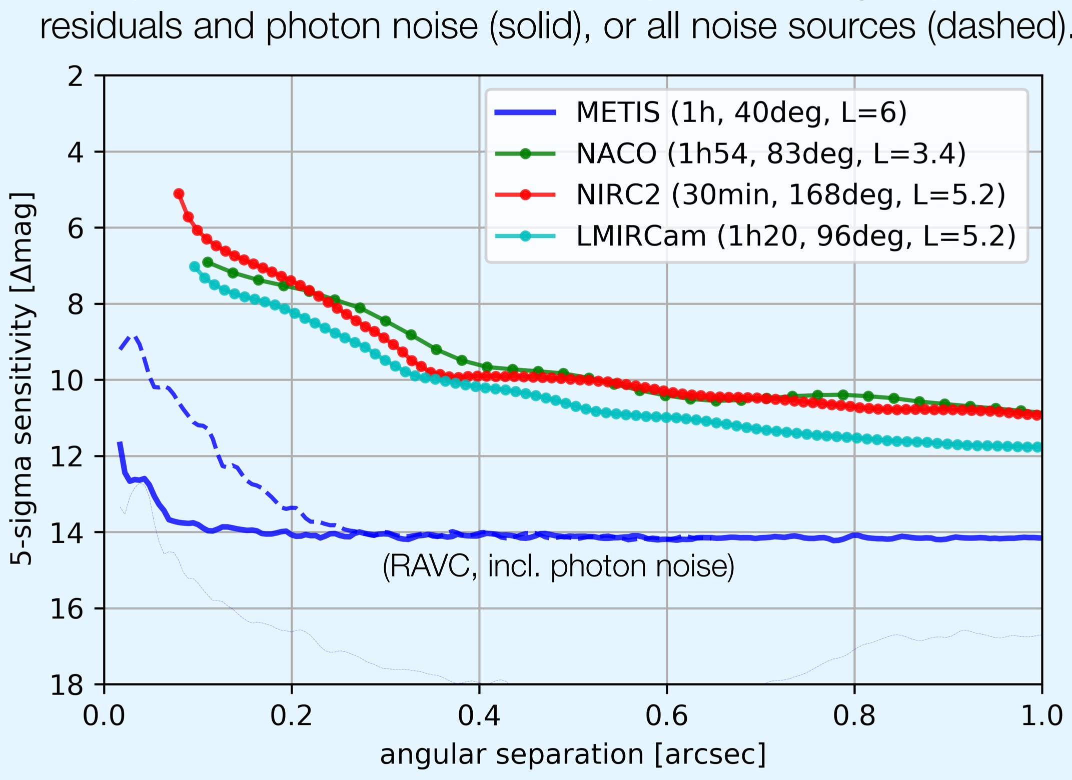
Expected performance

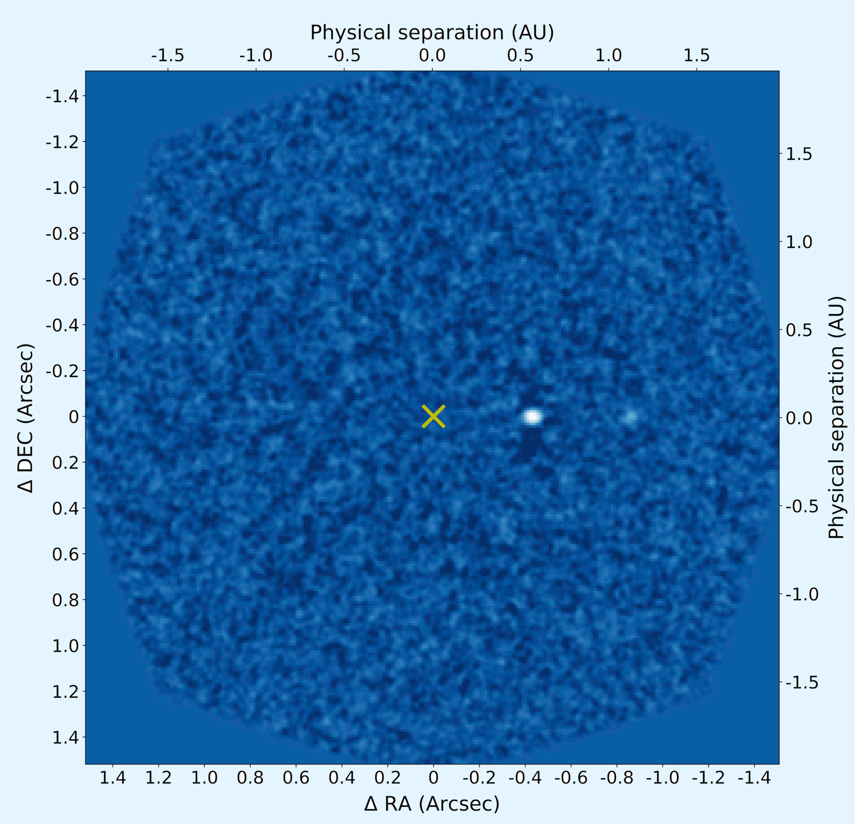
End-to-end performance simulations are performed with HEEPS (https://github.com/vortex-exoplanet/HEEPS), assuming a 1-h ADI sequence at L band with a 100 msec frame rate and 40° of parallactic angle rotation, using the Ring-Apodized Vortex Coronagraph. Shot noise is not included here to better highlight all individual contributions to the error budget. The SCAO simulations are performed with the COMPASS platform.



Simulated observations

Comparison with 10-m class telescopes, including only SCAO residuals and photon noise (solid), or all noise sources (dashed).





Left: Simulated N-band vortex coronagraph observation (5h ADI sequence) of alpha Centauri with two Earth-like planet (i.e., Erath radius and albedo) located respectively at 0.55 and 1.1 au from the star. Both planets are detected with SNR = 6 and 11.

Right: Simulation of the METIS IFU performance on the Proxima system at 3.8μm. Assuming a 1.1 R_{Earth} planet radius (albedo 0.3, 50% illumination), a coronagraph-aided contrast of 1:500 at 2 λ/D, and 10 hours of observing time, the planet is clearly detected in reflected light.