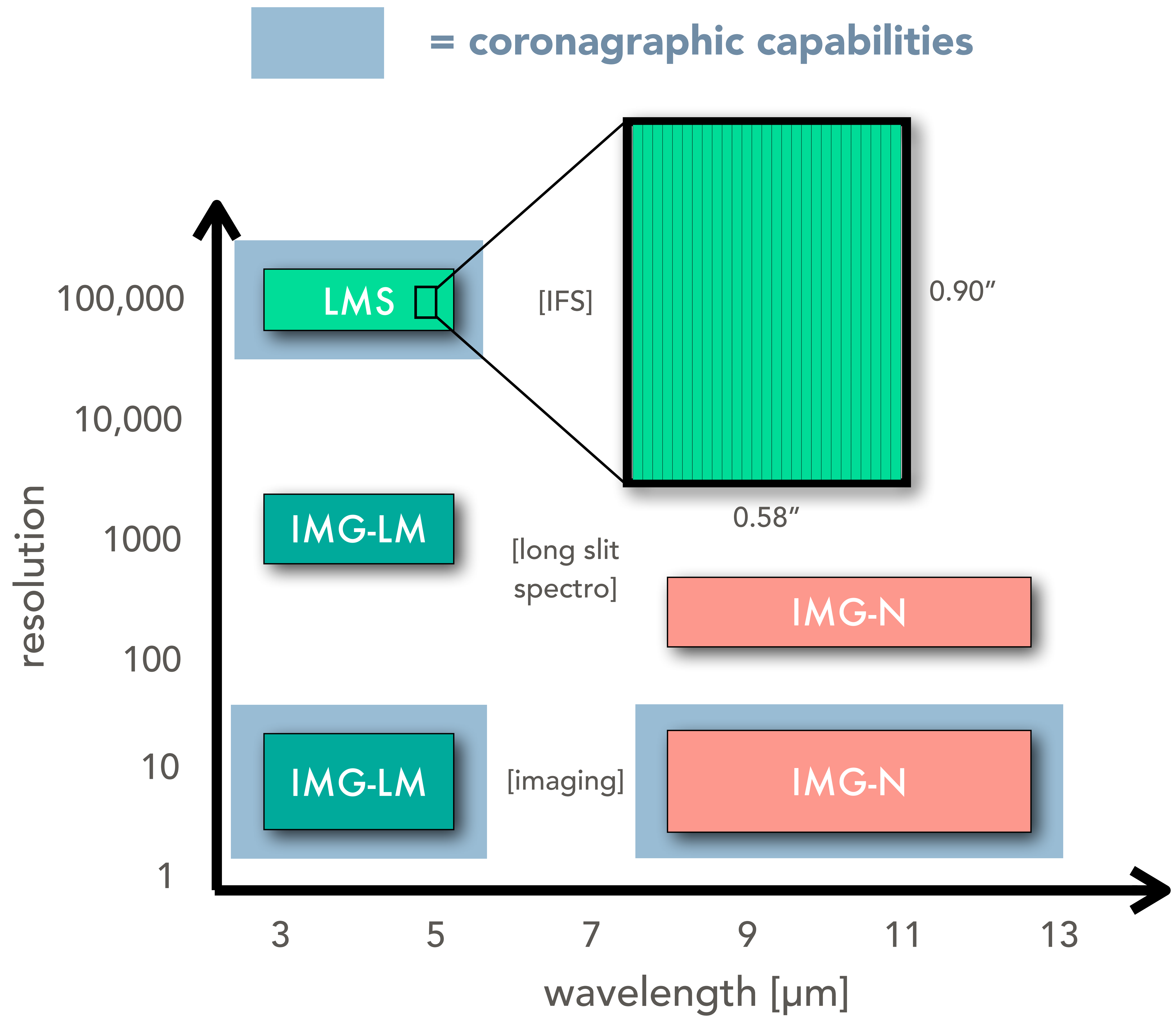
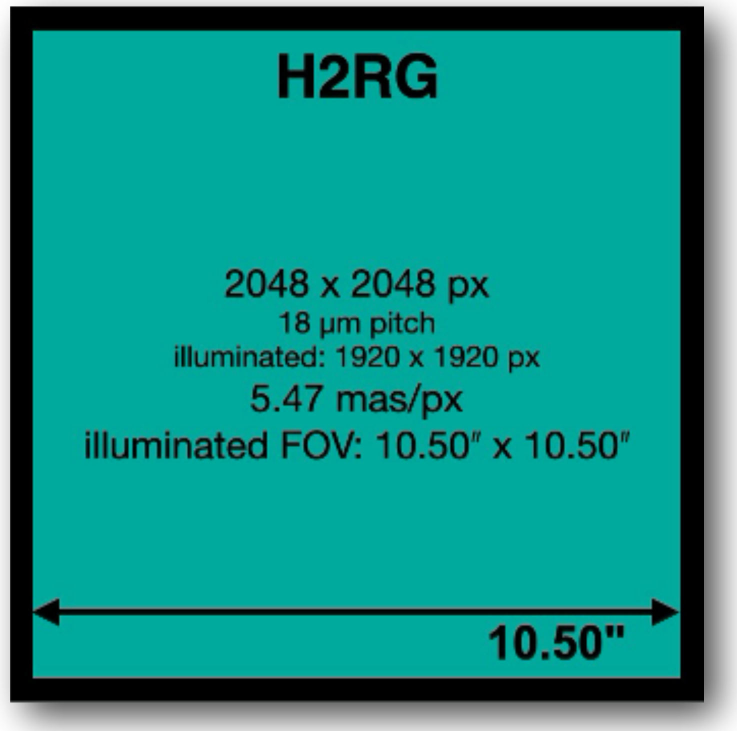
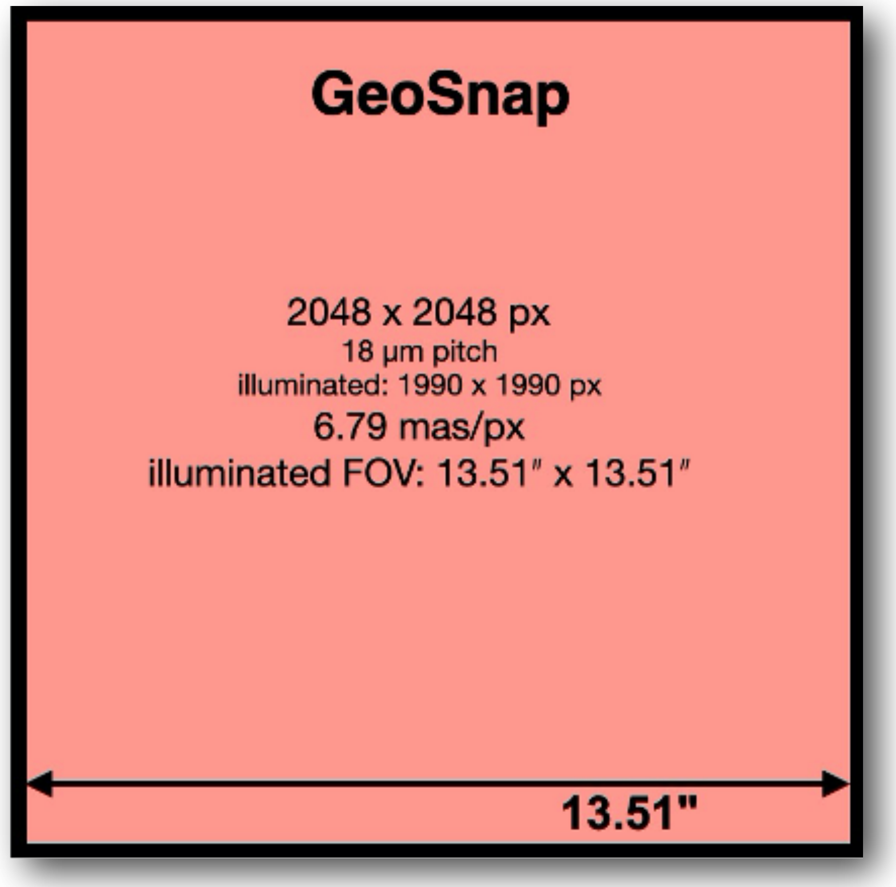
METIS high-contrast: expected performance and scientific potential

Olivier Absil
University of Liège

The METIS context







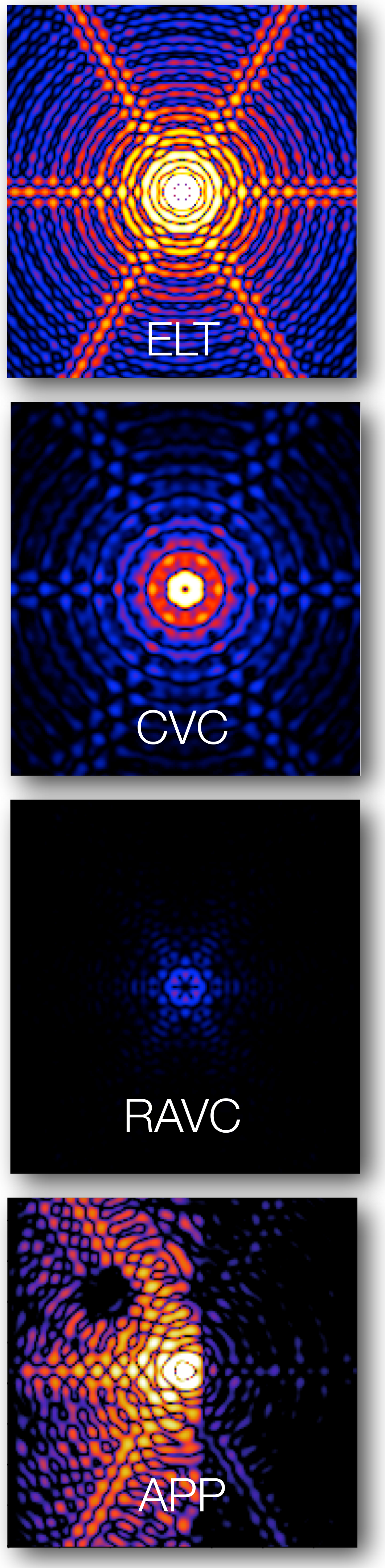
Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

Baseline coronagraphic modes

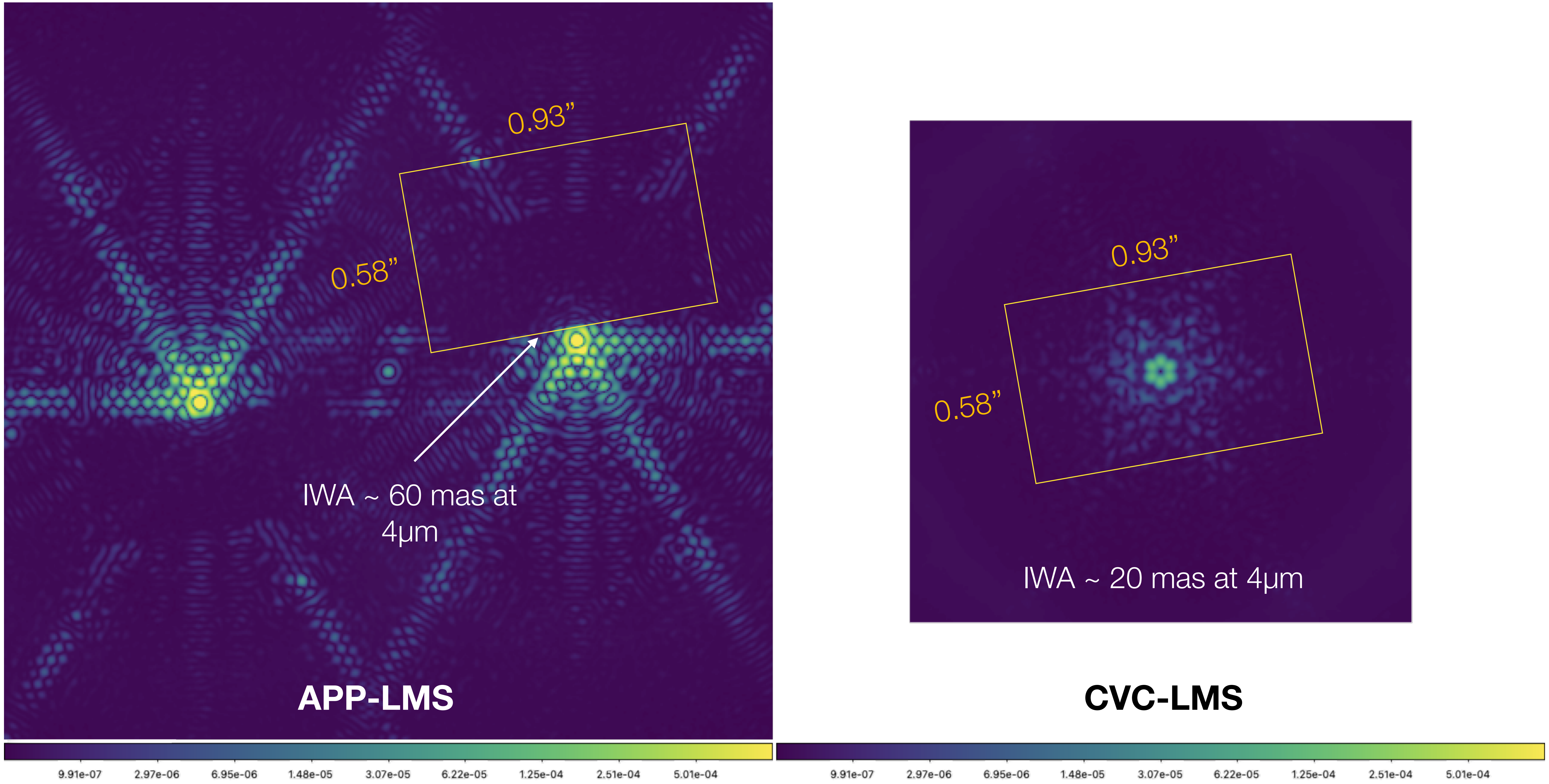
- Rationale
  - small IWA to compensate for longer wavelengths
  - high throughput to compensate for high thermal background
  - robust performance to cope with ELT uncertainties
  - high TRL in the thermal infrared
- Two main coronagraphic modes
  - (ring-apodized) charge-2 **vector vortex** for smallest IWA and highest throughput (LMN bands)
  - **grating-vector APP** for small IWA and robustness (LM bands)
- Choice also driven by consortium expertise



~% leakage

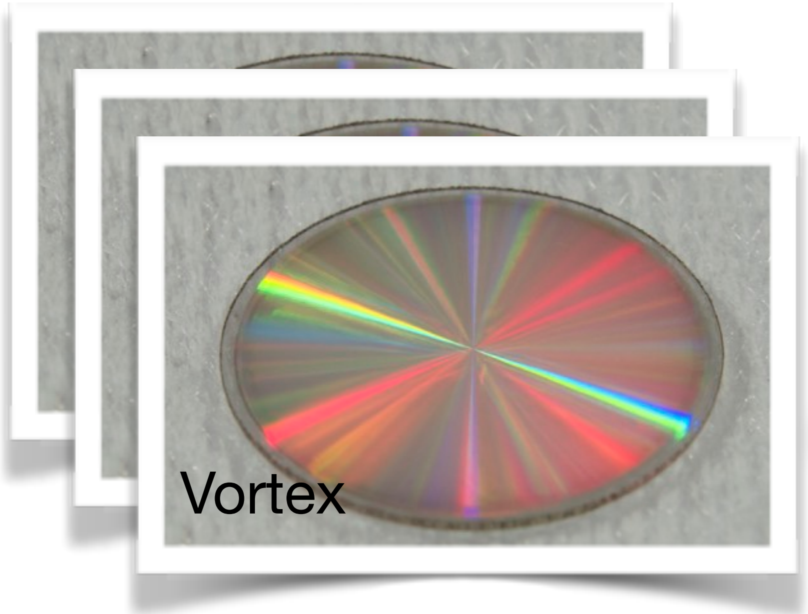
~‰ leakage

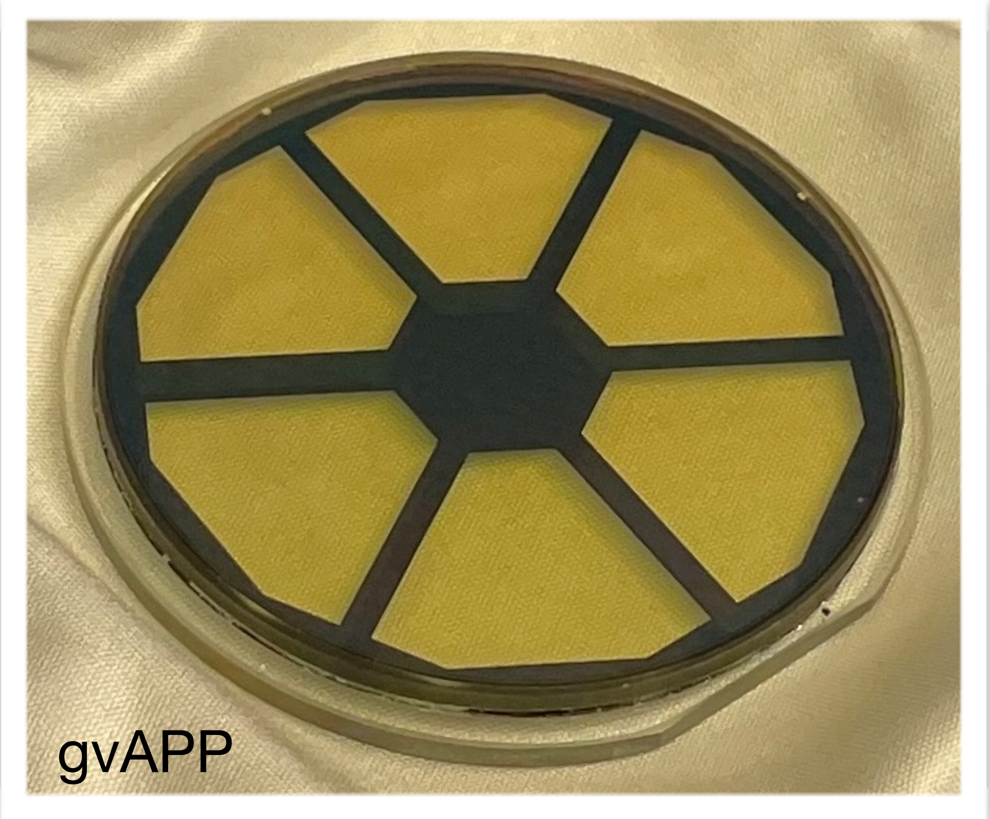
HCI + IFS modes

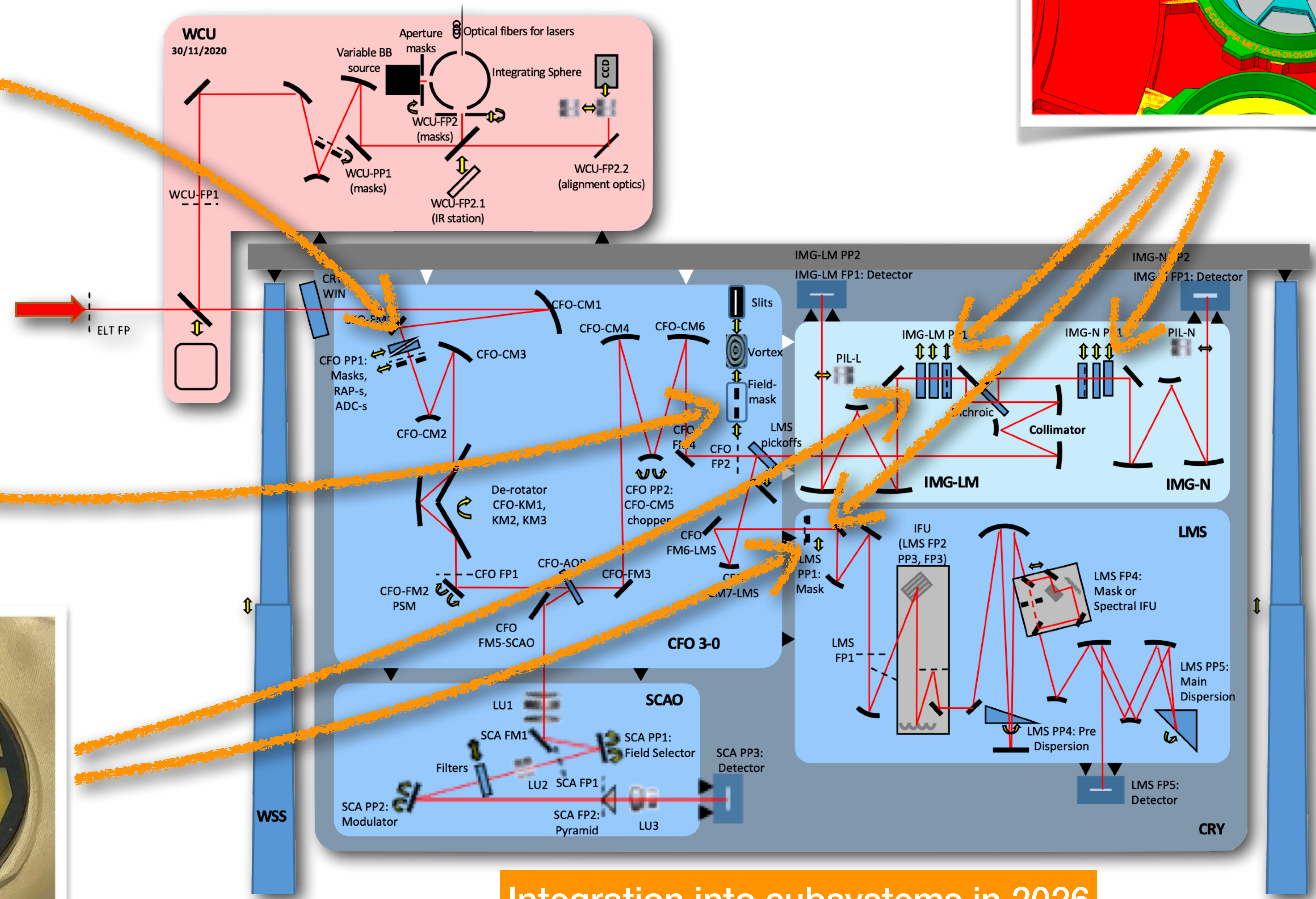


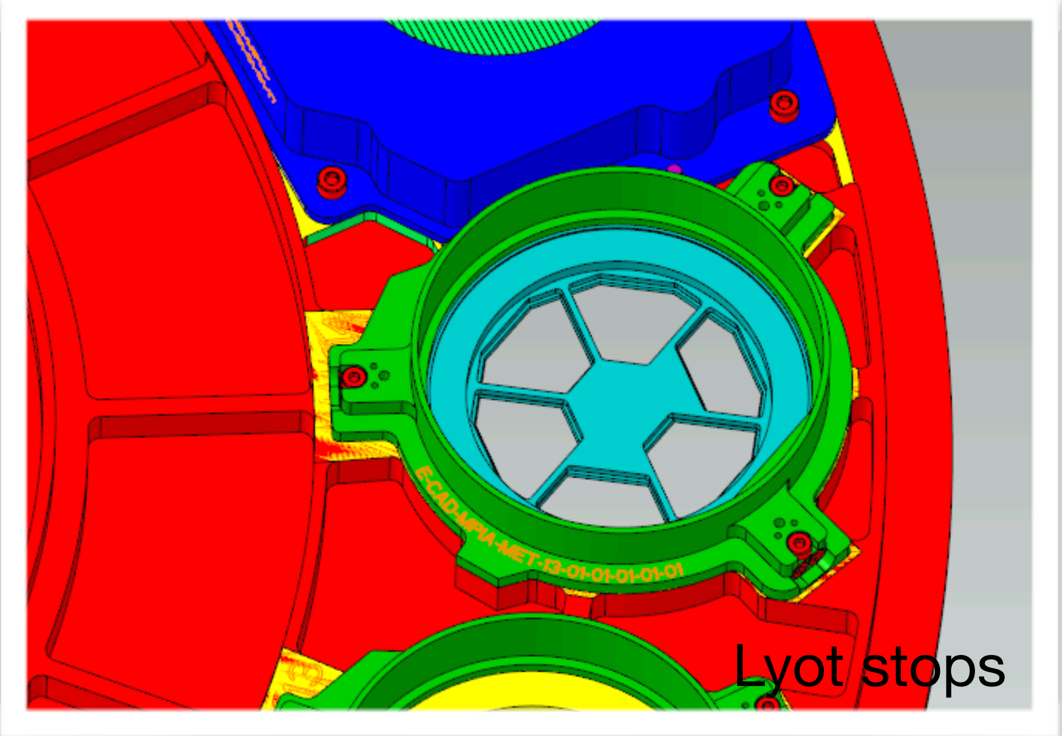
Expected raw contrast typically ranging from 10^{-3} to 10^{-5} inside the image slicer

MAIT status









Integration into subsystems in 2026

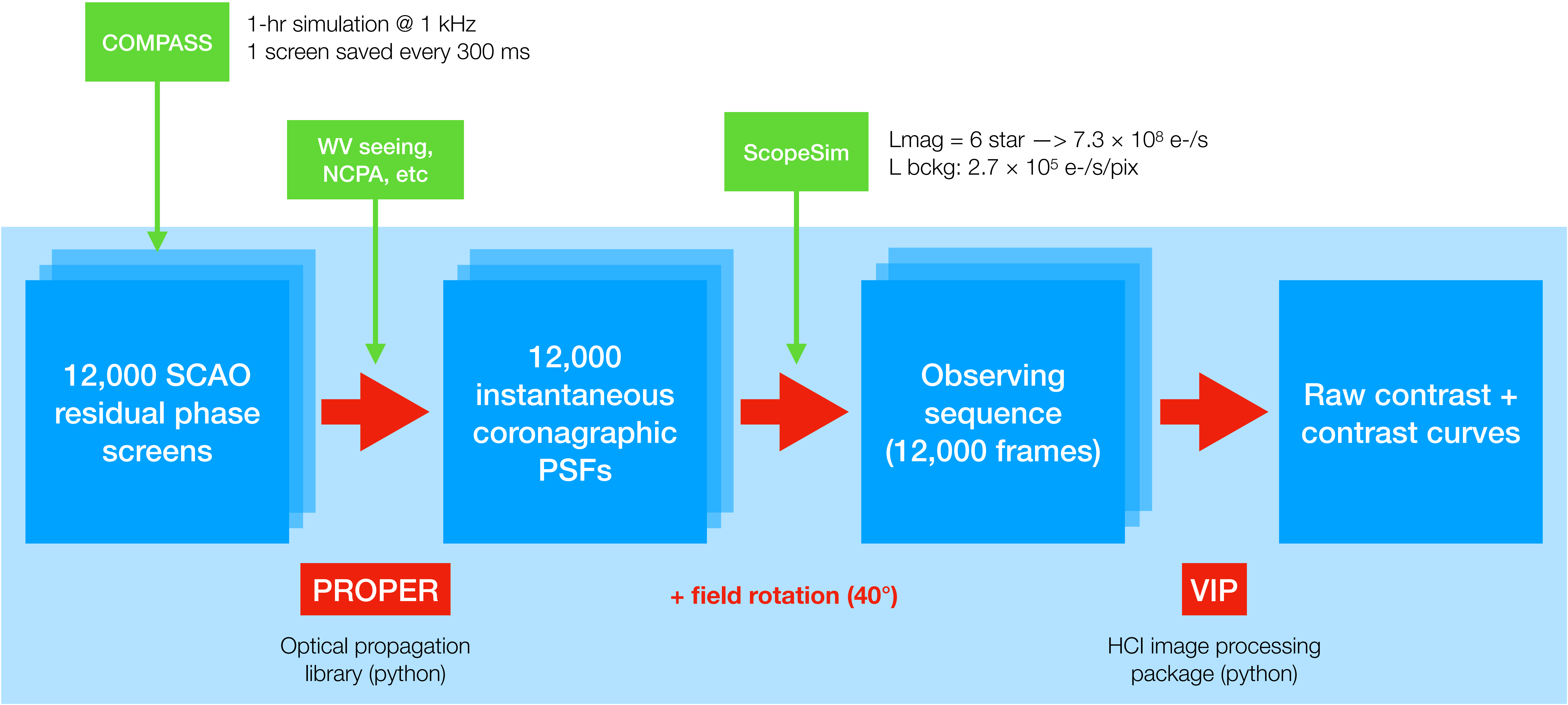
HCI system-level tests in 2028

Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

End-to-end simulations



HEEPS

(https://github.com/vortex-exoplanet/HEEPS)

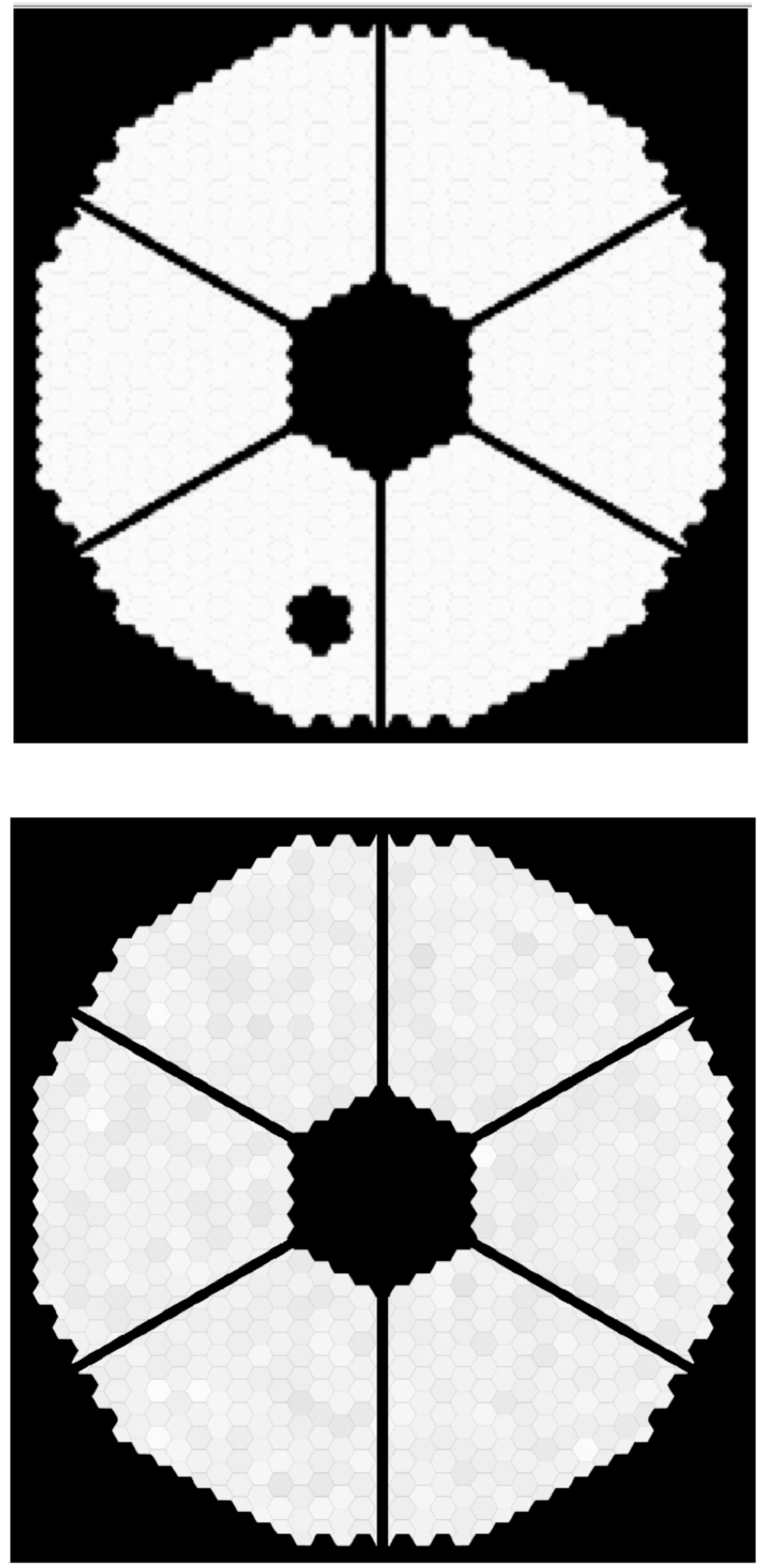
Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

Main simulated effects

- SCAO residuals
  - based on COMPASS METIS package
  - includes residual pointing jitter from wind load, residual petal piston, etc
- Other atmospheric effects
  - atmospheric dispersion: only turned on to design our two fixed ADCs
  - chromatic wavefront effects dominated by water vapour (see next slide)
- Pupil-related effects
  - ELT exit pupil stability
  - non-uniform ELT-M1 segment reflectivity & misaligned segments
- Miscellaneous
  - coronagraph imperfections, vortex center glow, finite stellar size, …



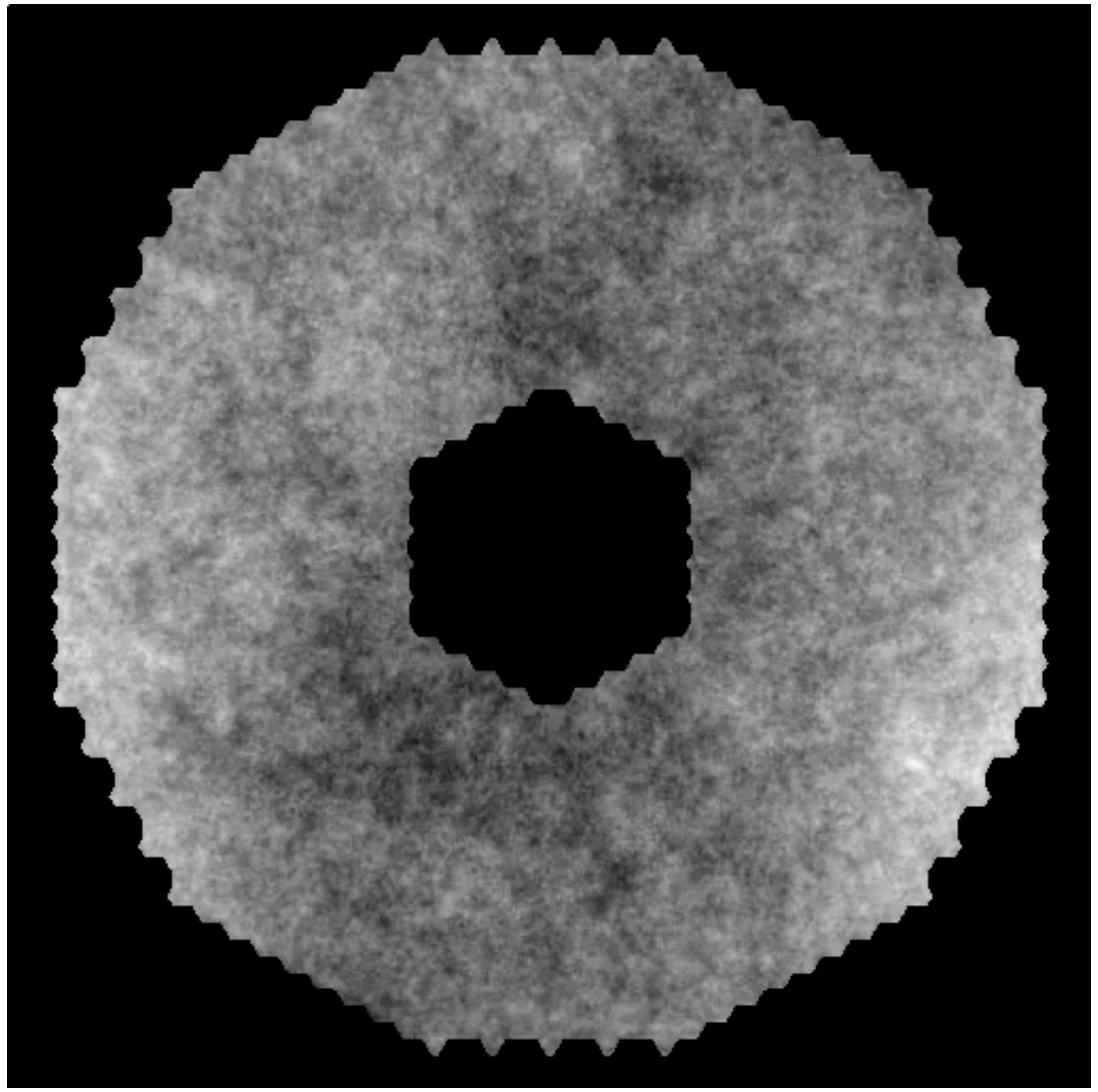
Non-common path aberrations

- Combination of static, quasi-static, and dynamic effects

- Phase aberrations
  - main dynamic source: water vapour seeing
  - main quasi-static source: chromatic beam wander

- Amplitude aberrations
  - quasi-static aberrations due to Talbot effect from chromatic beam wander (not controlled)

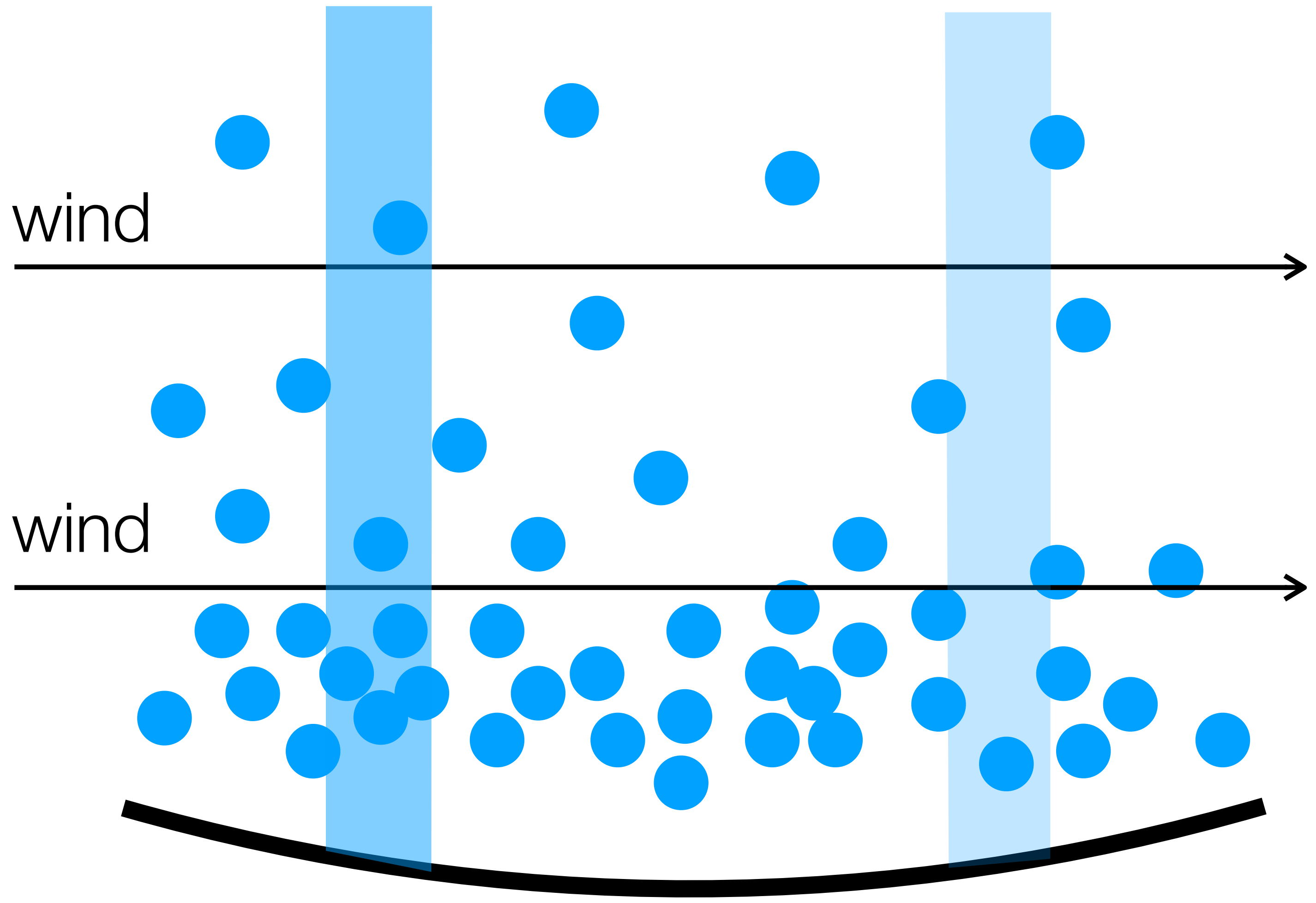
1h observing sequence around meridian

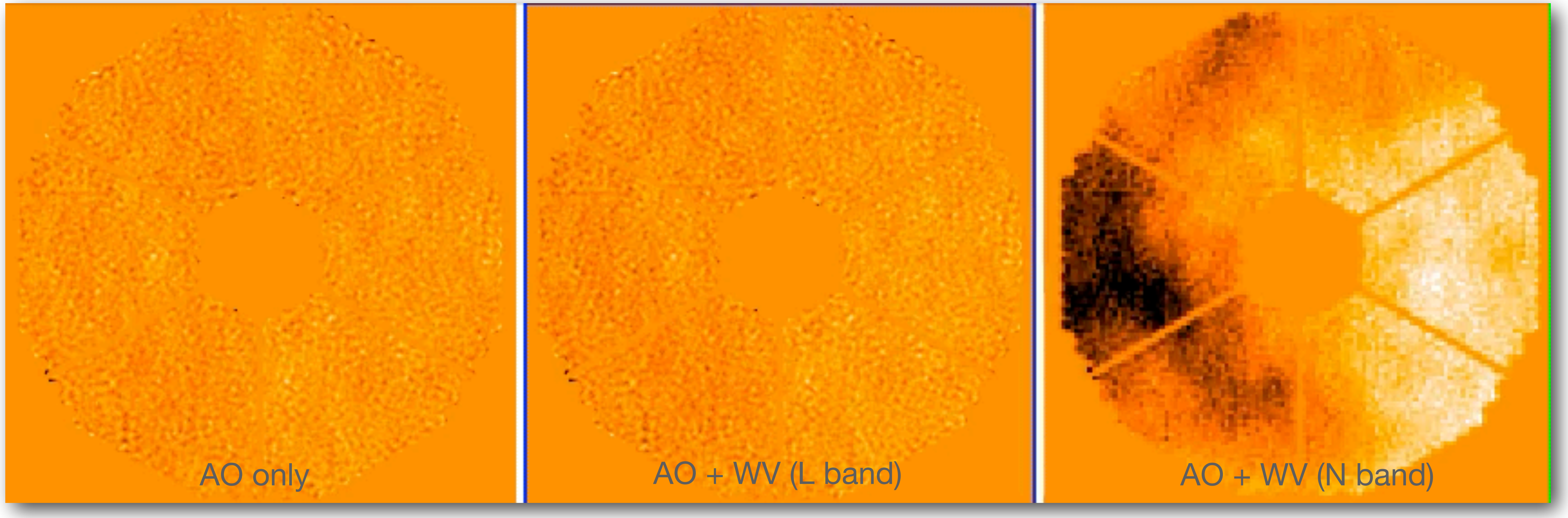


Median NCPA level ~ 100 nm
with ~ 30 nm variation due to CBW

Water vapour seeing

- Variable column density of water vapour above telescope
  - blown by wind —> WV seeing
- Highly chromatic in mid-IR
  - K-band SCAO correction not fully applicable to LMN bands
  - up to 300nm rms additional WFE at N





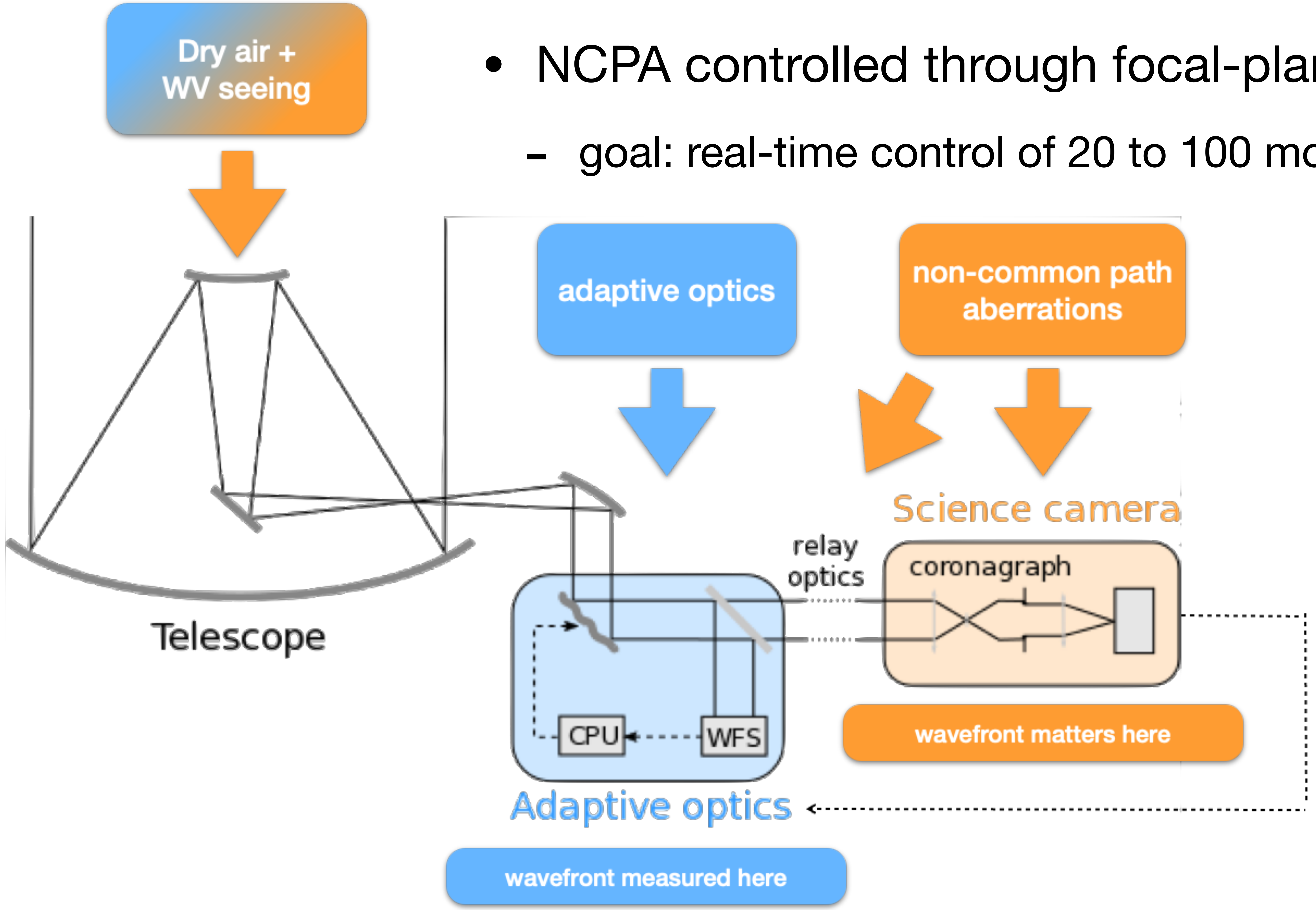
Mid Infrared E-ELT Imager and Spectrograph

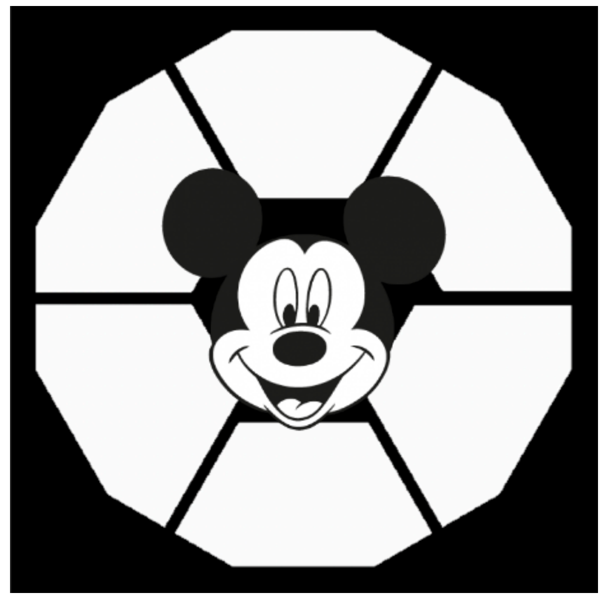
LIÈGE université

METIS

Wavefront control strategy

- SCAO (IR PyWFS+M4) provides > 90% Strehl (LMN bands)
- NCPA controlled through focal-plane wavefront sensing
  - goal: real-time control of 20 to 100 modes at 10 Hz





Asymmetric pupil focal-plane wavefront sensing

Mid Infrared E-ELT Imager and Spectrograph

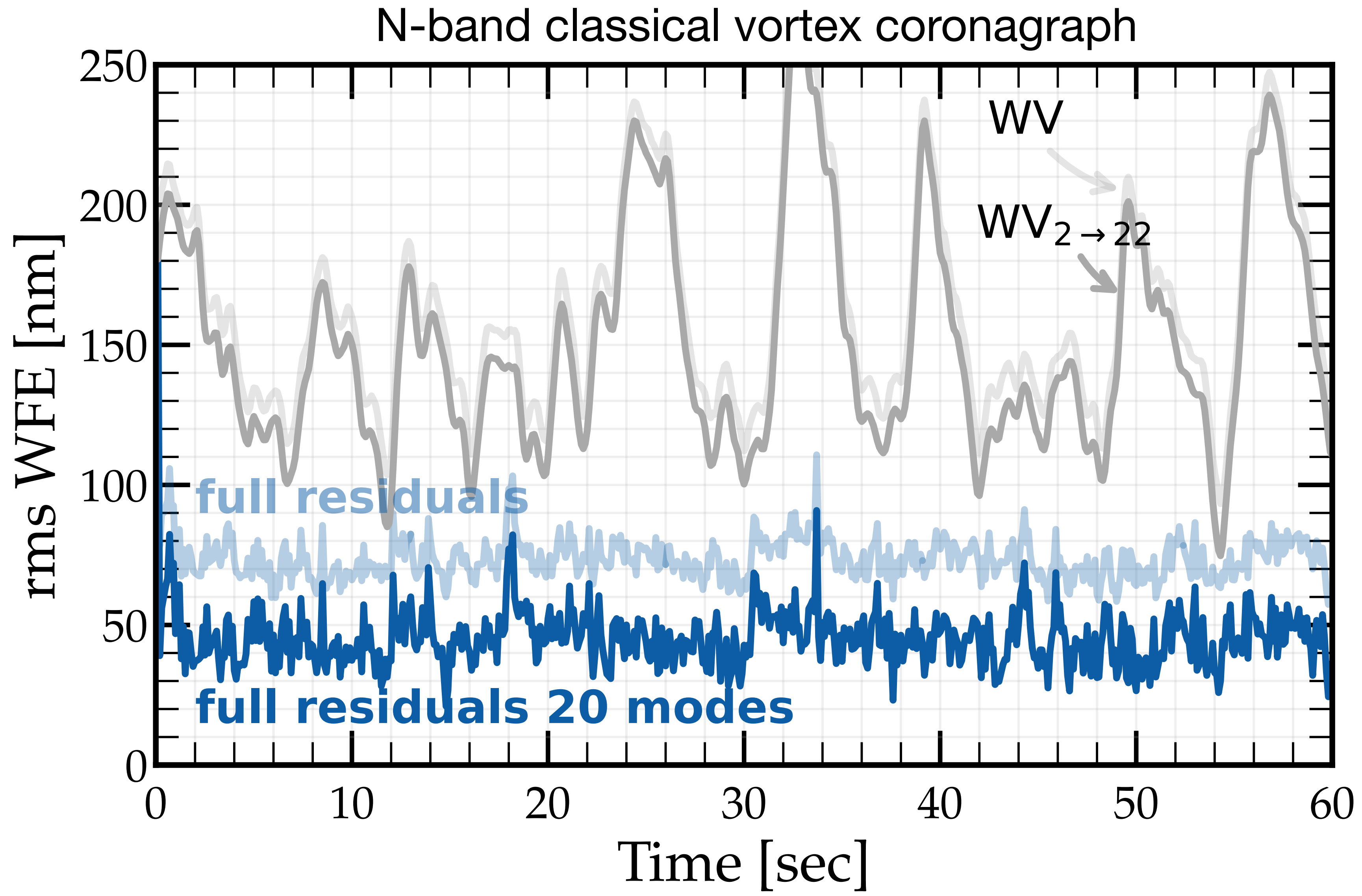
LIÈGE université

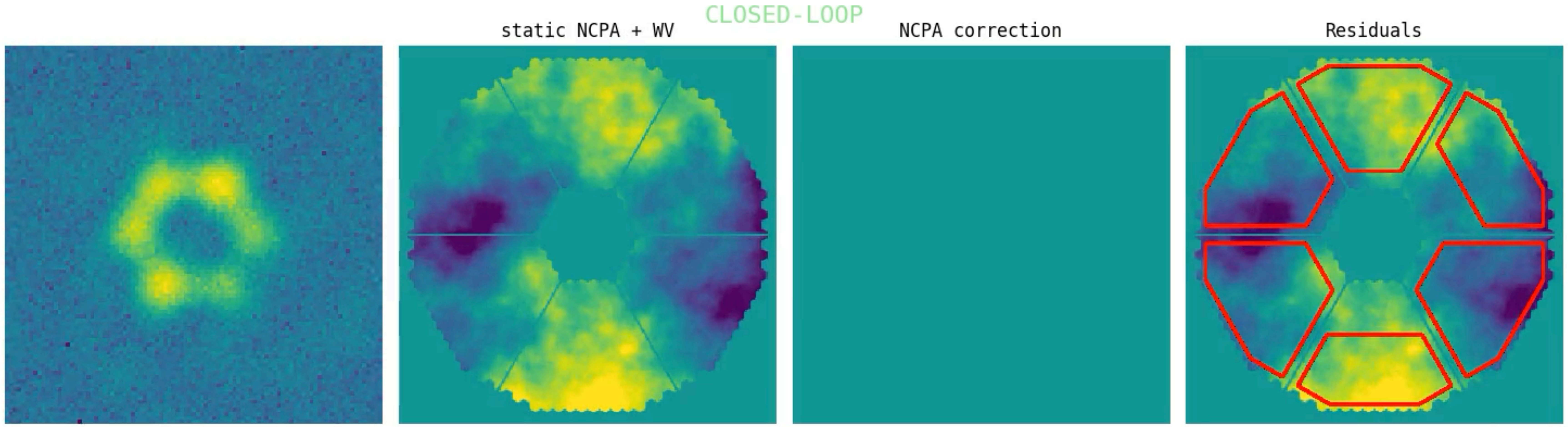
METIS

Asymmetric pupil WF sensing & control

- Three flavours of asymmetric pupil sensing
  - standard imaging: linear reconstruction (Martinache 2013)
  - APP: non-linear algorithm (Bos+2019)
  - vortex with asymmetric Lyot stop: nonlinear reconstruction with deep neural network (Orban de Xivry+2024)

- Control with simple integrator as baseline, but also exploring reinforcement learning



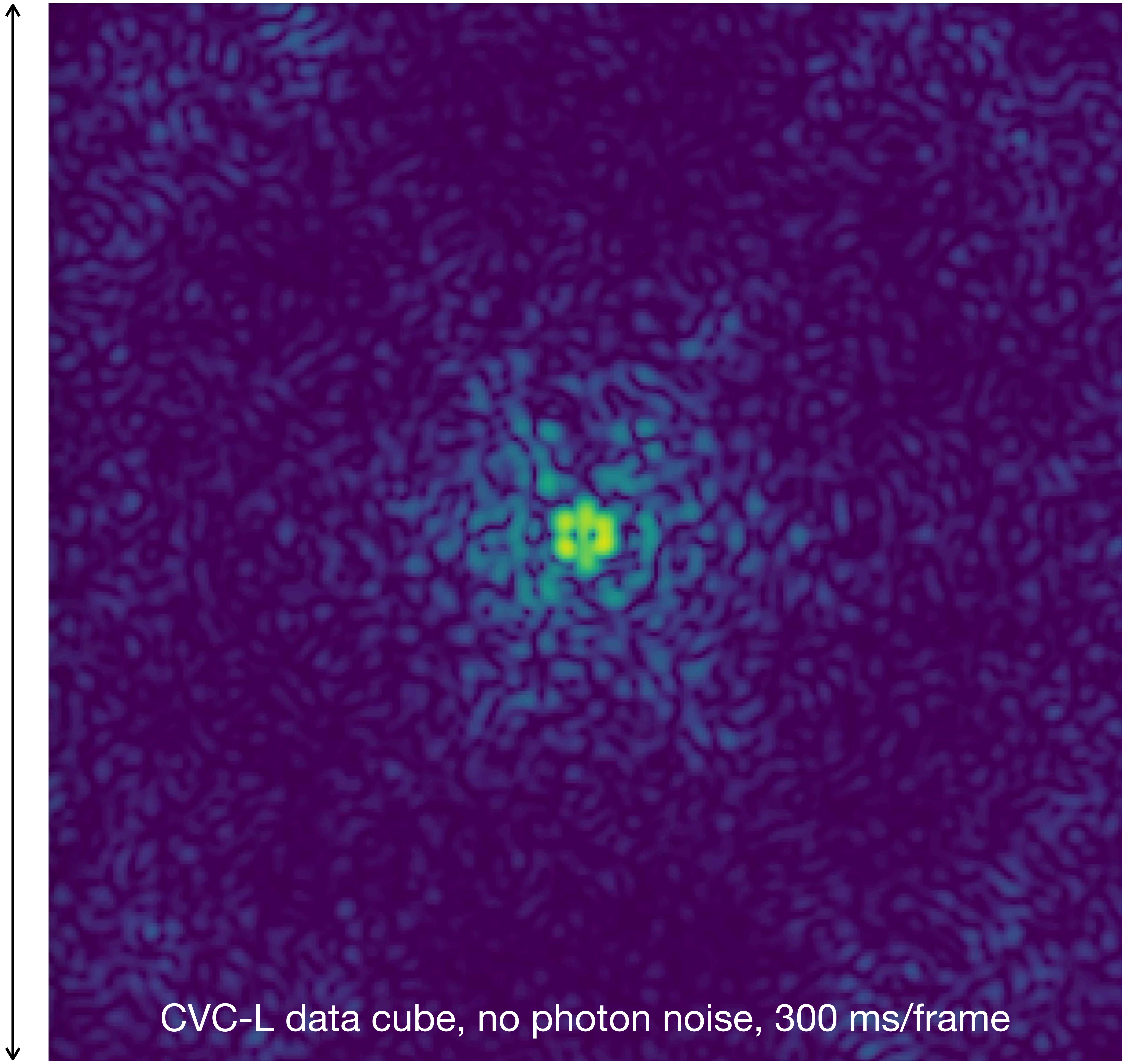


(Nmag = 0, 10 Hz closed-loop, 20 modes)

Mid Infrared E-ELT Imager and Spectrograph

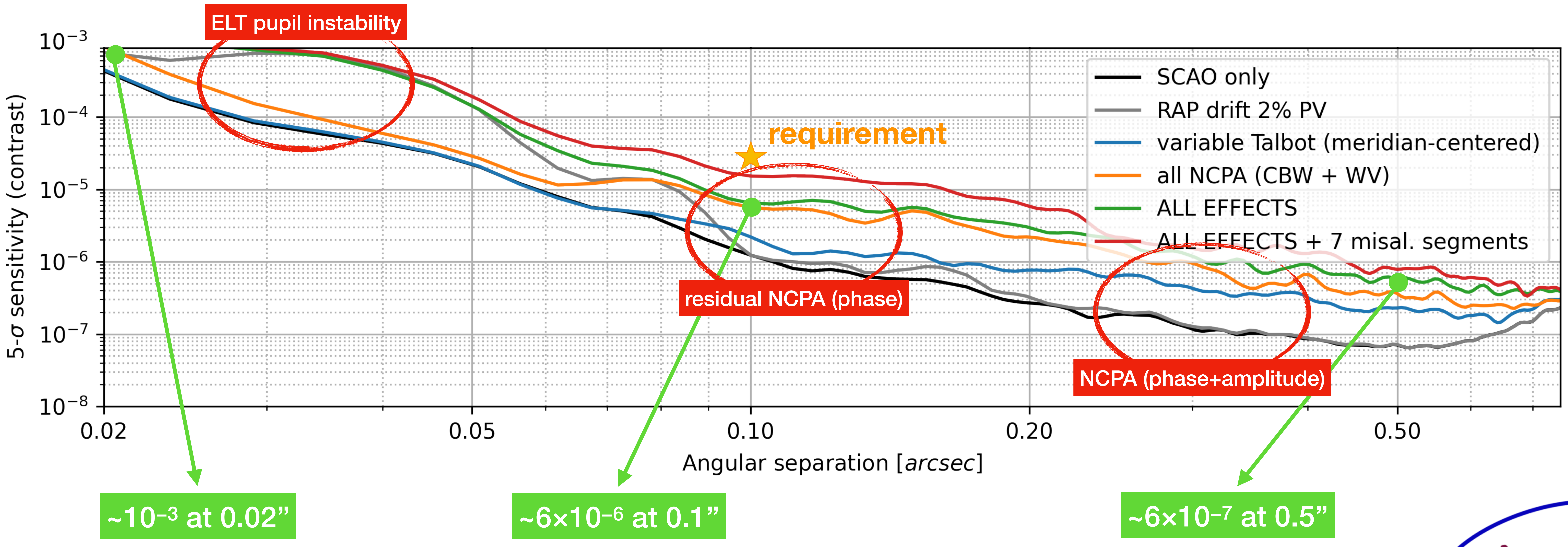
Mock data cubes

0.8”
(small part of the
full IMG FoV)



Final output: contrast curves

- Conservatively using median subtraction (classical ADI)
- Here: **L-band RAVC** for bright star / long integration time (no bckg noise)

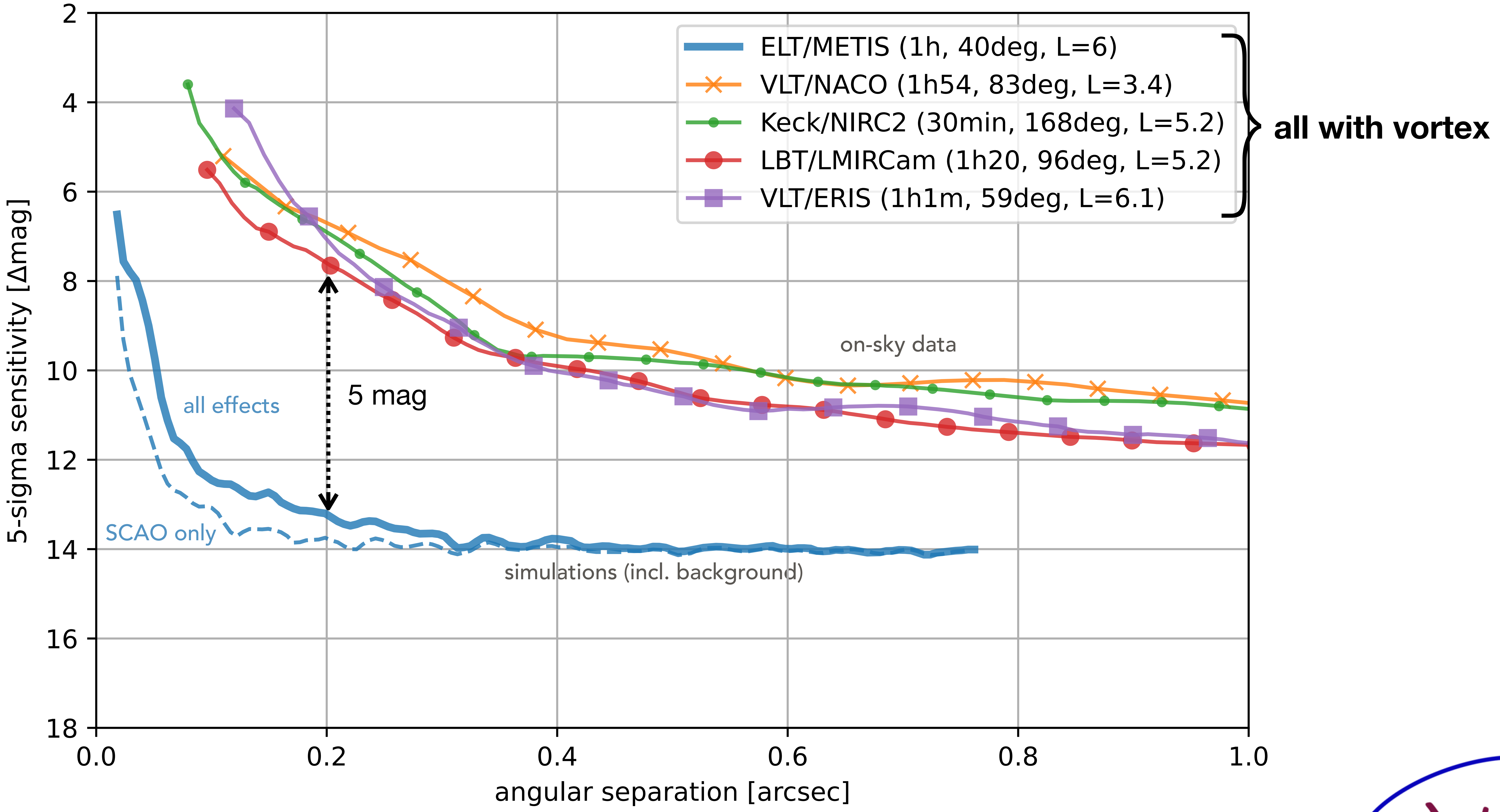


Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

Comparing with 10m-class telescopes

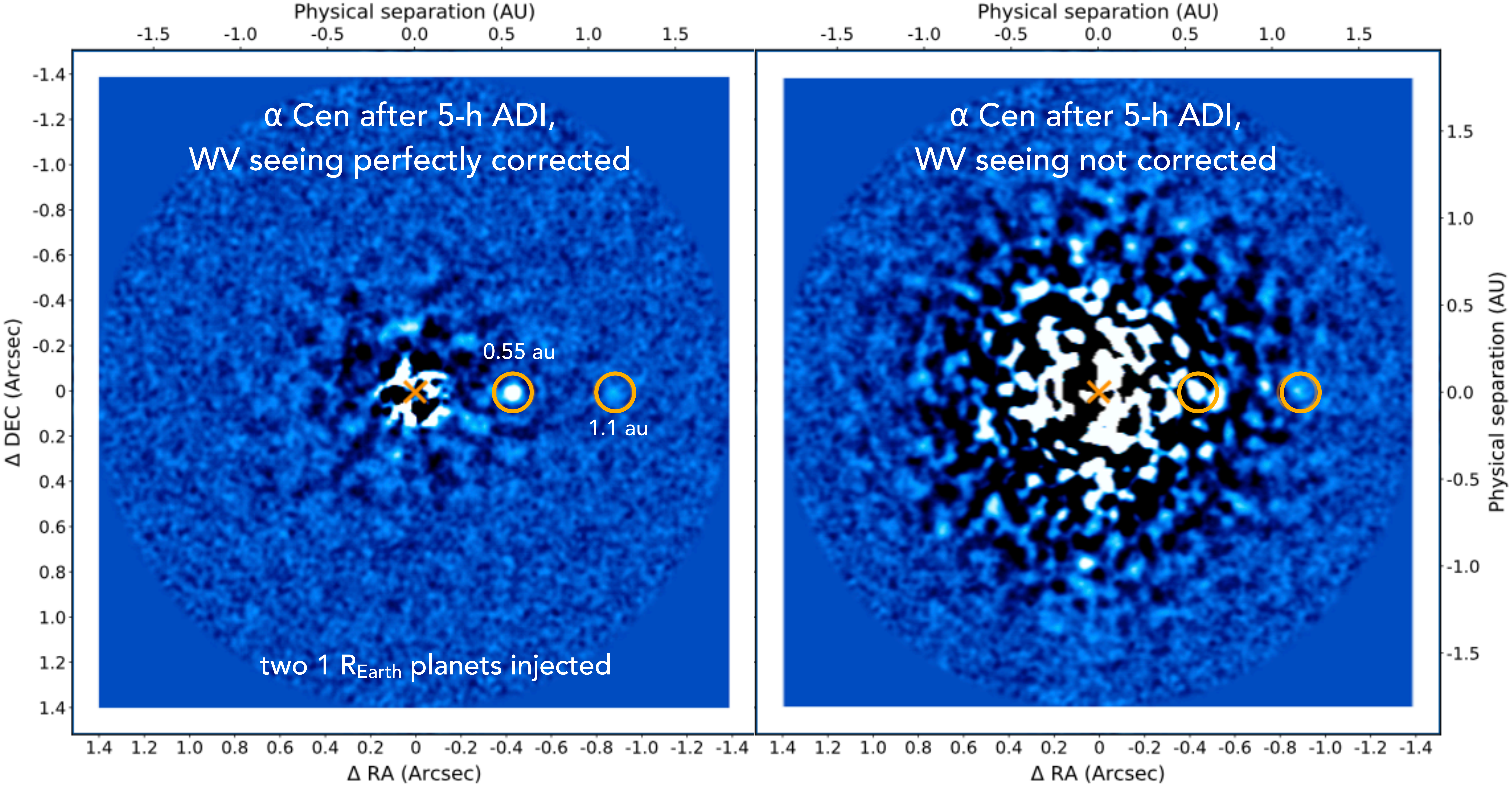


Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

Application: α Cen at N band

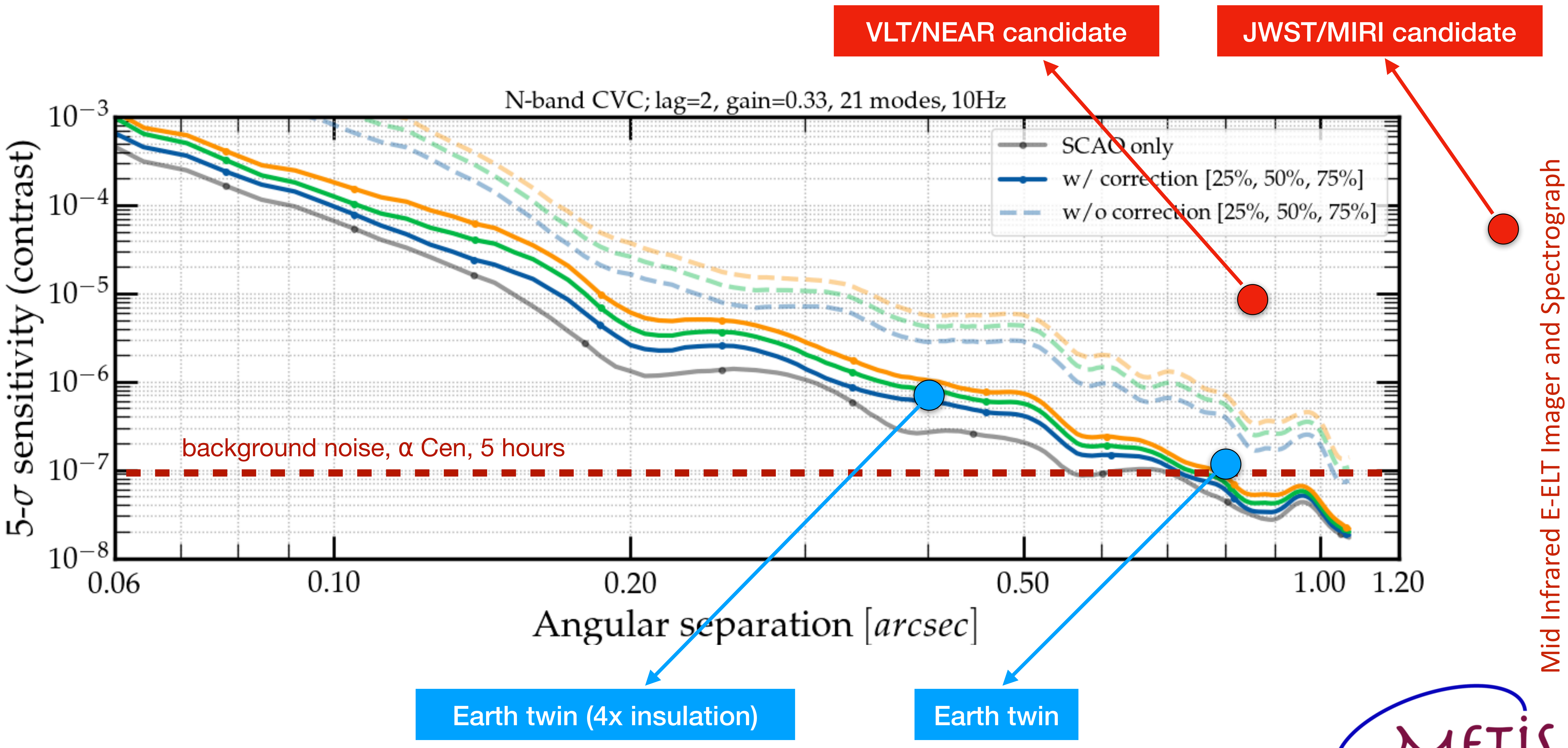


Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS

α Cen at N band: detection limits



LIÈGE université

METIS

Only 4 years to go…

Mid Infrared E-ELT Imager and Spectrograph

LIÈGE université

METIS