AO4ELT7 - June 29th, 2023

Final design and performance of the METIS HCI modes

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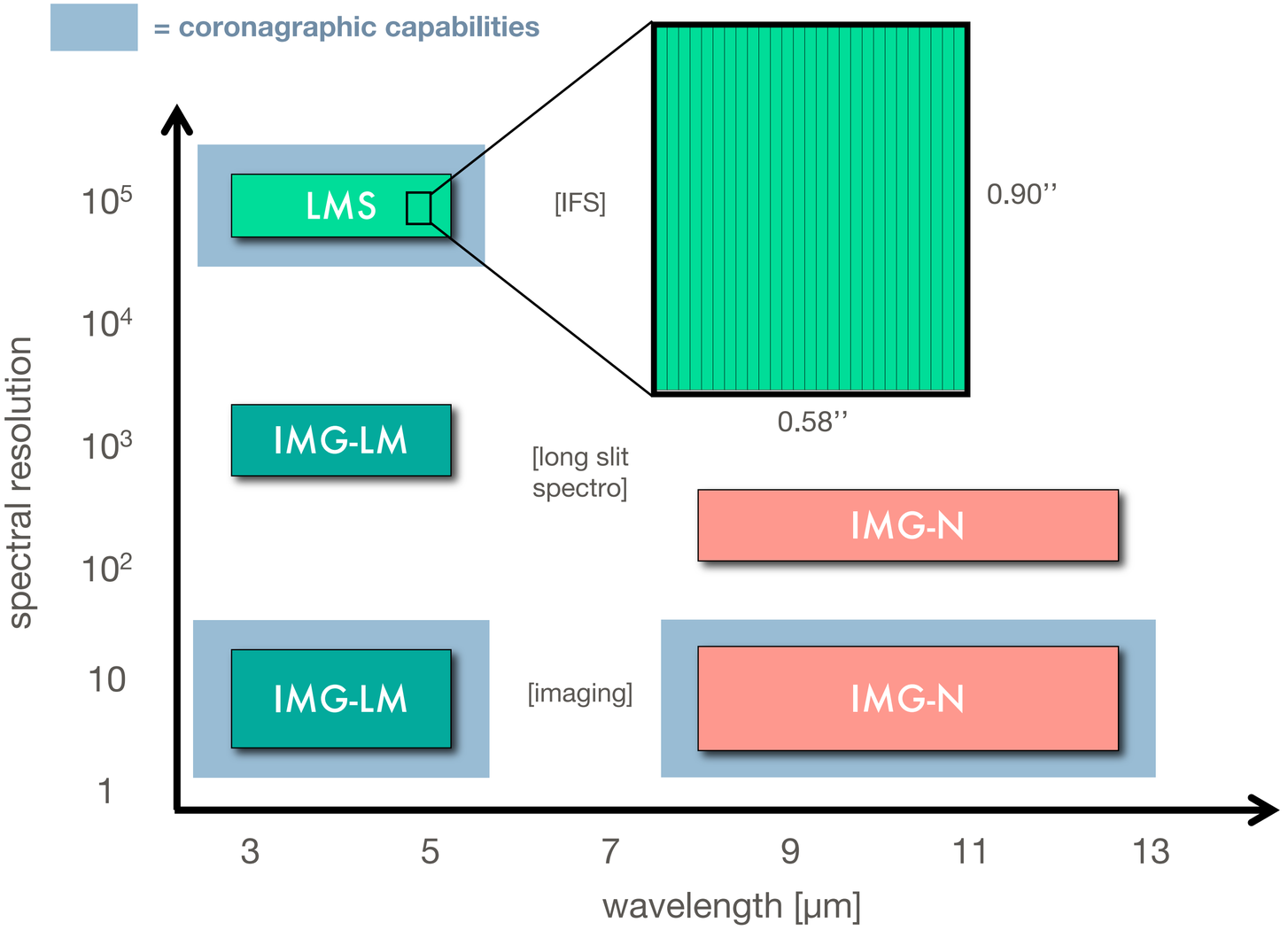
University of Liège

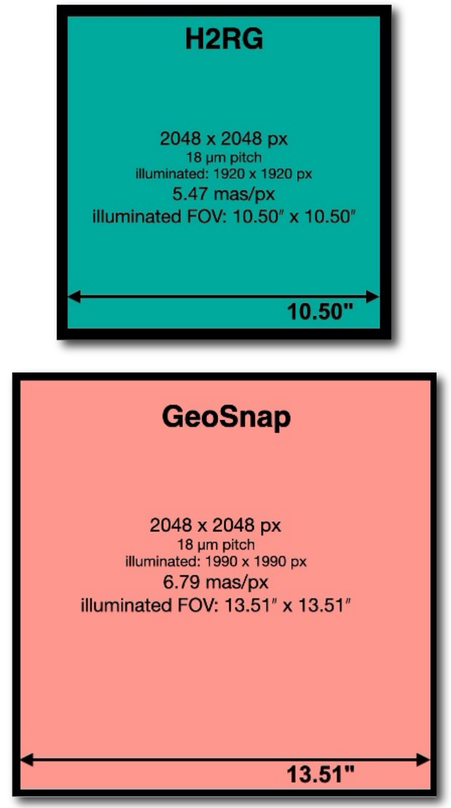
centra
center for astrophysics and gravitation

Science and Technology Facilities Council
UK Astronomy Technology Centre

METIS instrument baseline

ALL MODES WORKING AT ELT'S DIFFRACTION LIMIT USING SCAO

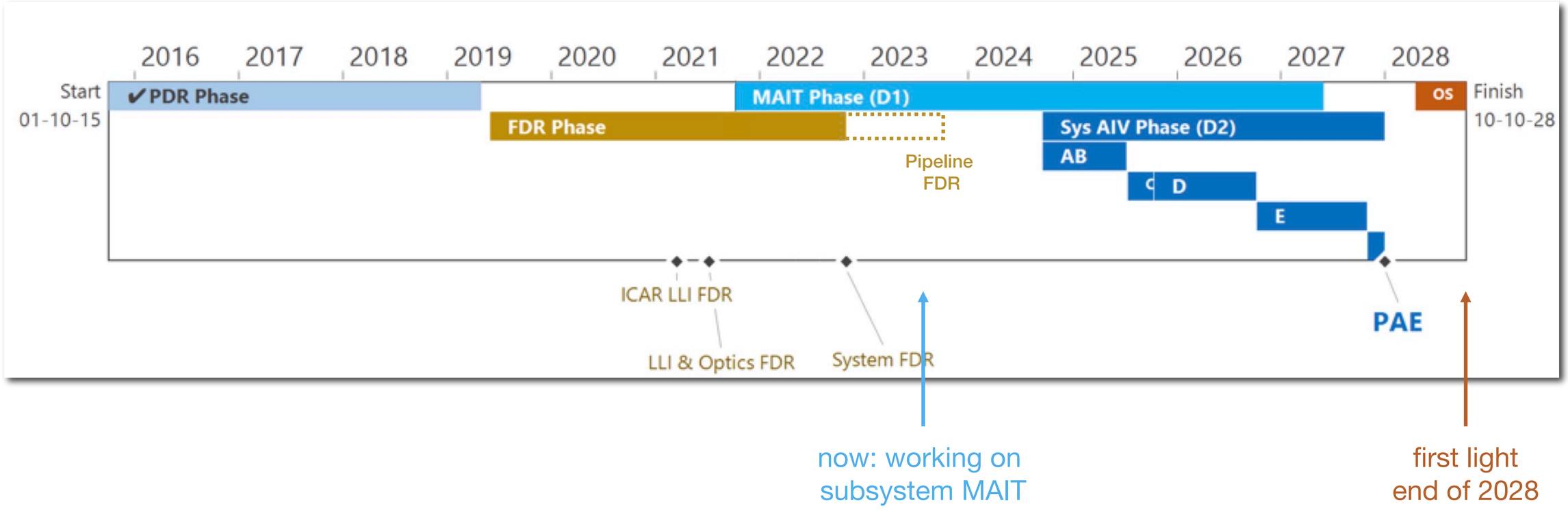




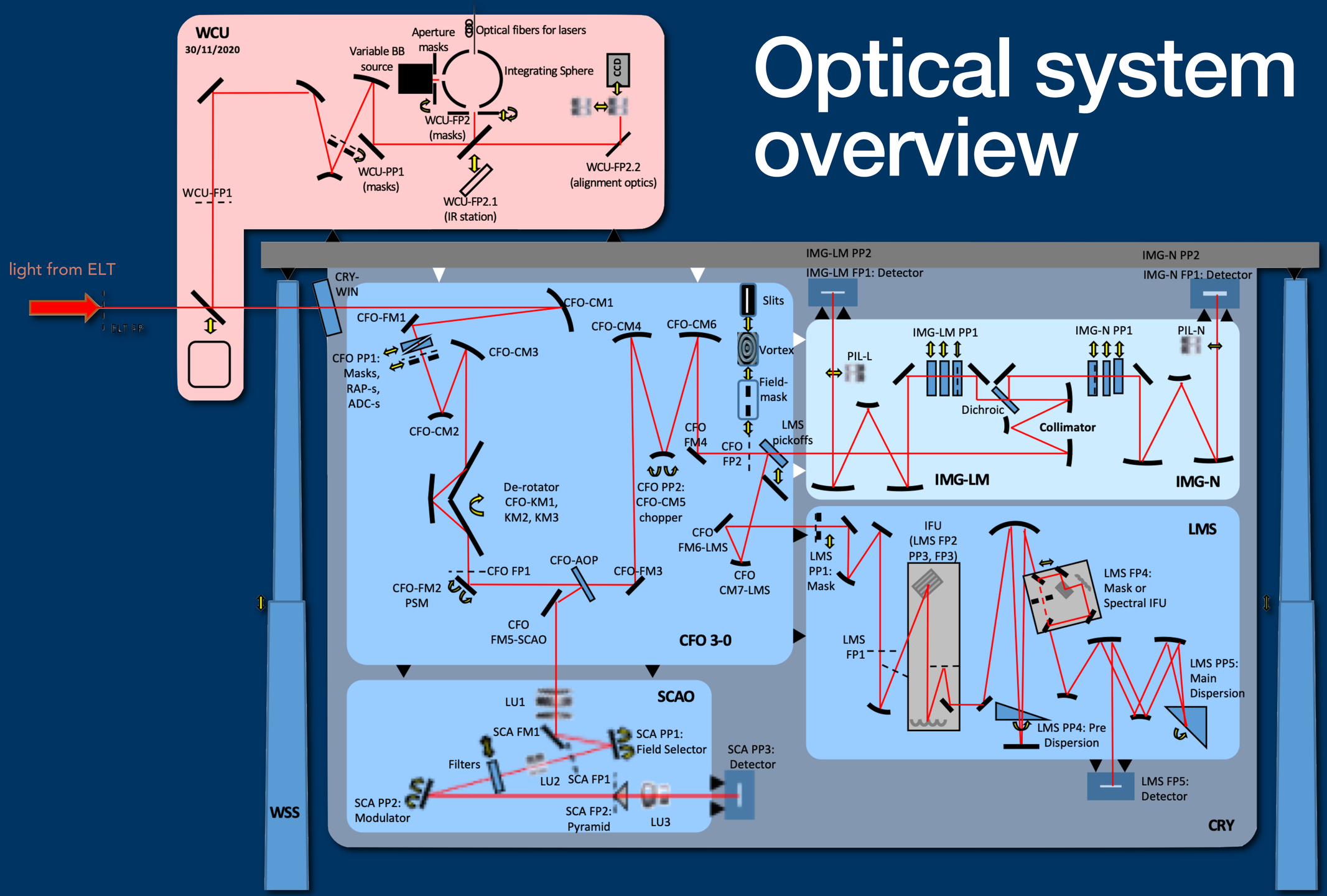
IMG detectors

METIS timeline

~ 670 FTE & 20 M€ hardware budget over 13 yrs



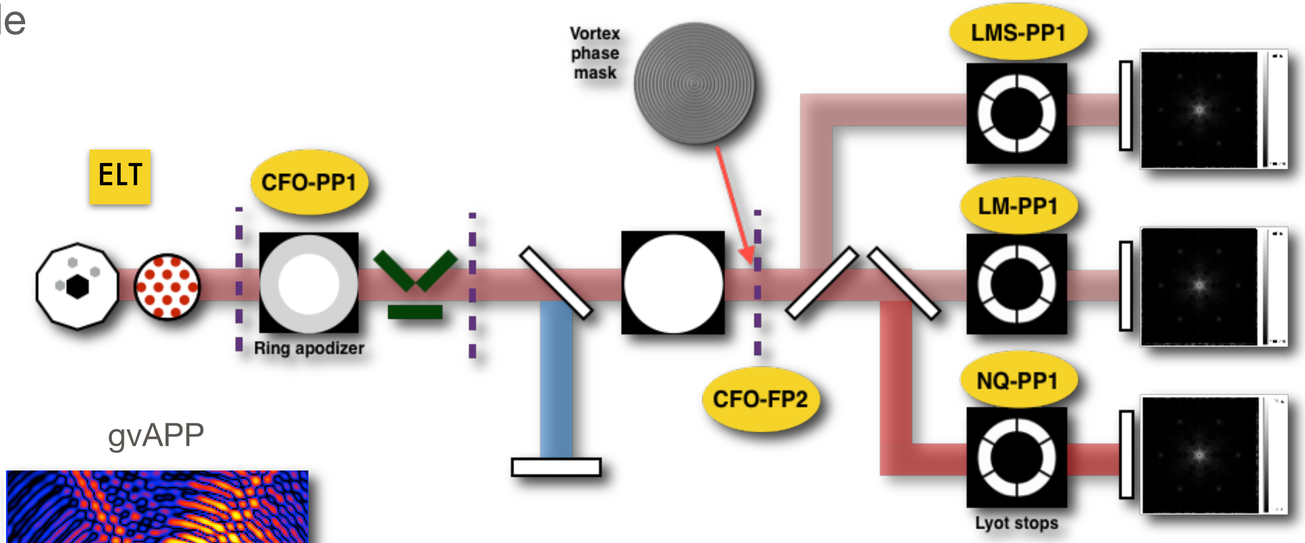
Optical system overview



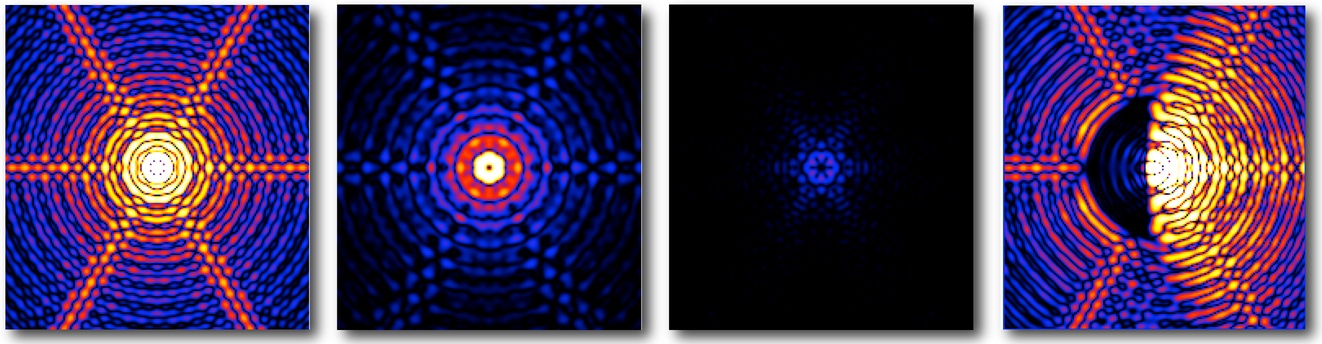
High-contrast imaging modes

All optimized to access small inner working angle

(Ring-Apodized) Vortex Coronagraph

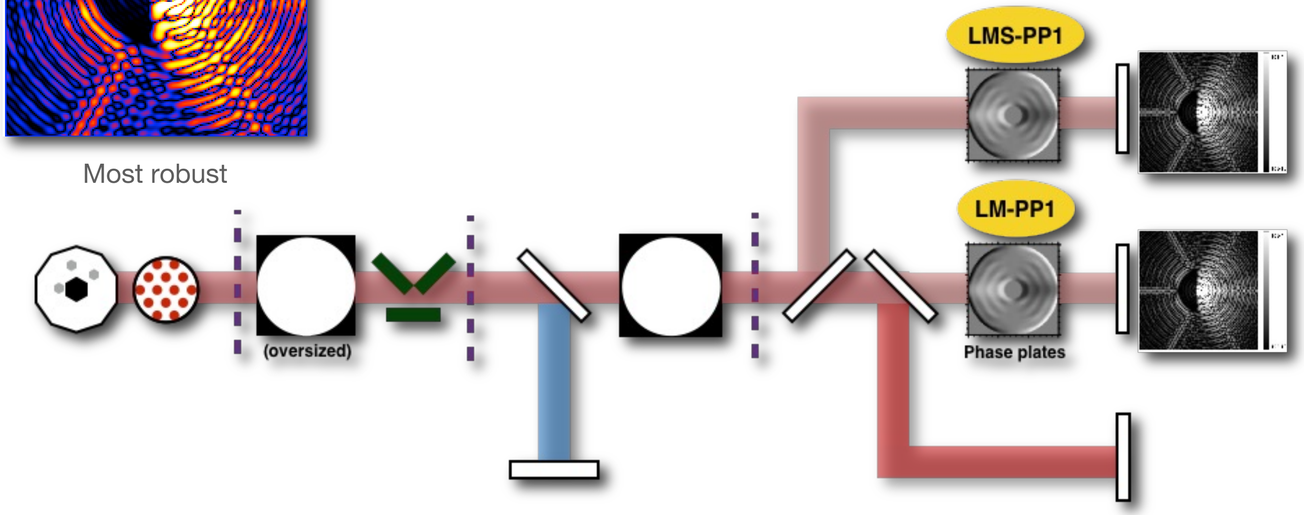


ELT | CVC | RAVC | gvAPP

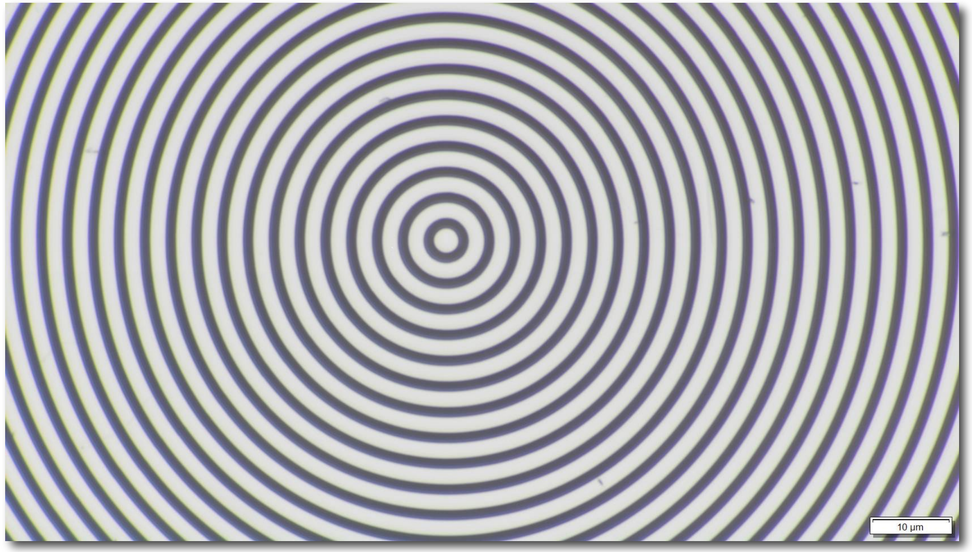


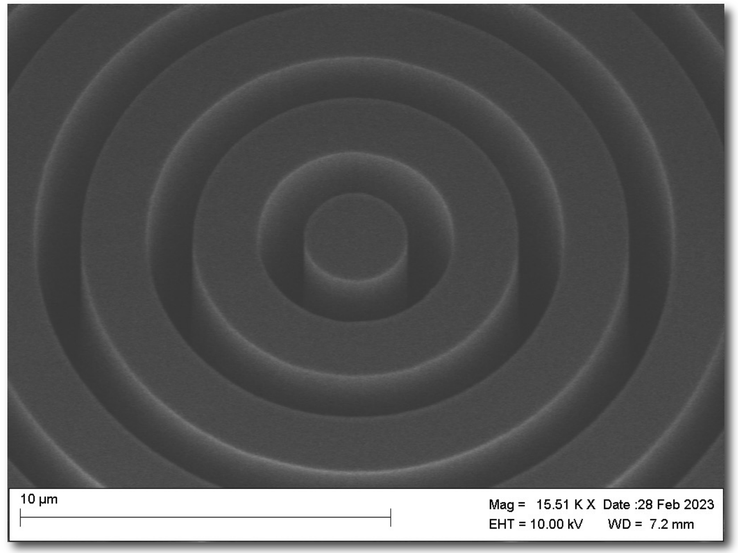
Highest thruput / Strehl | Best contrast | Most robust

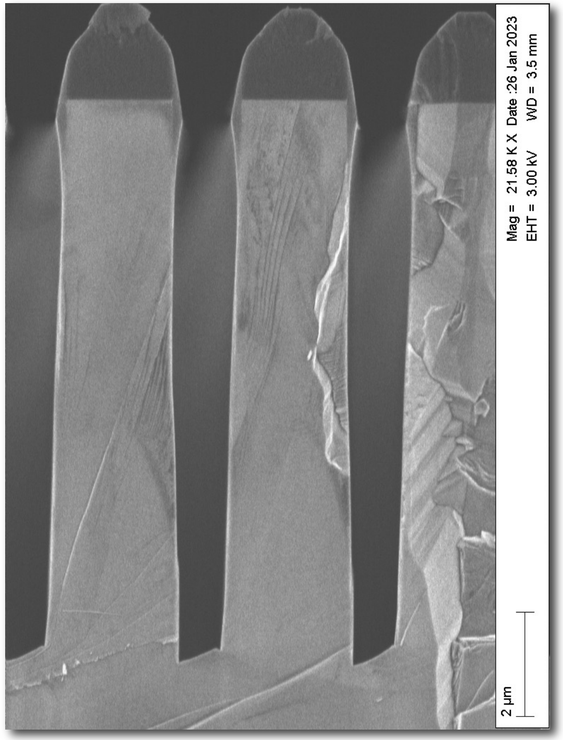
Apodizing Phase Plate

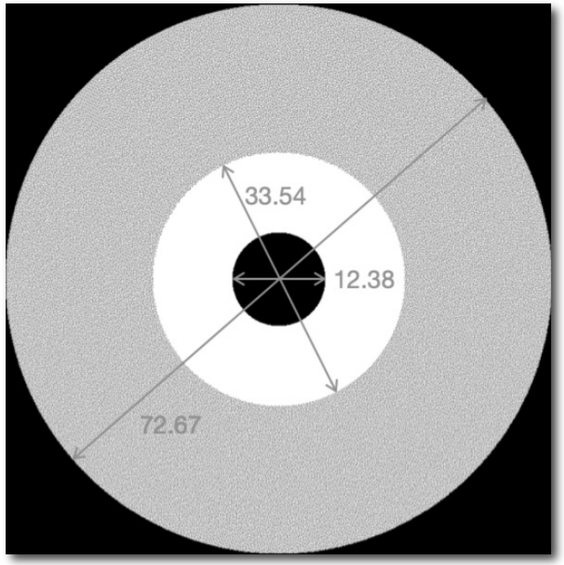


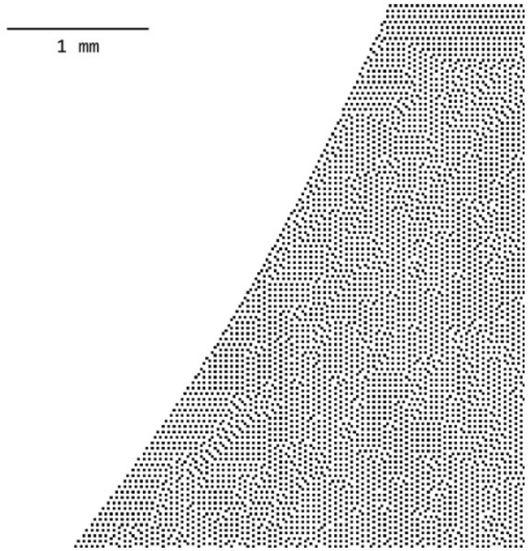
On-going procurements







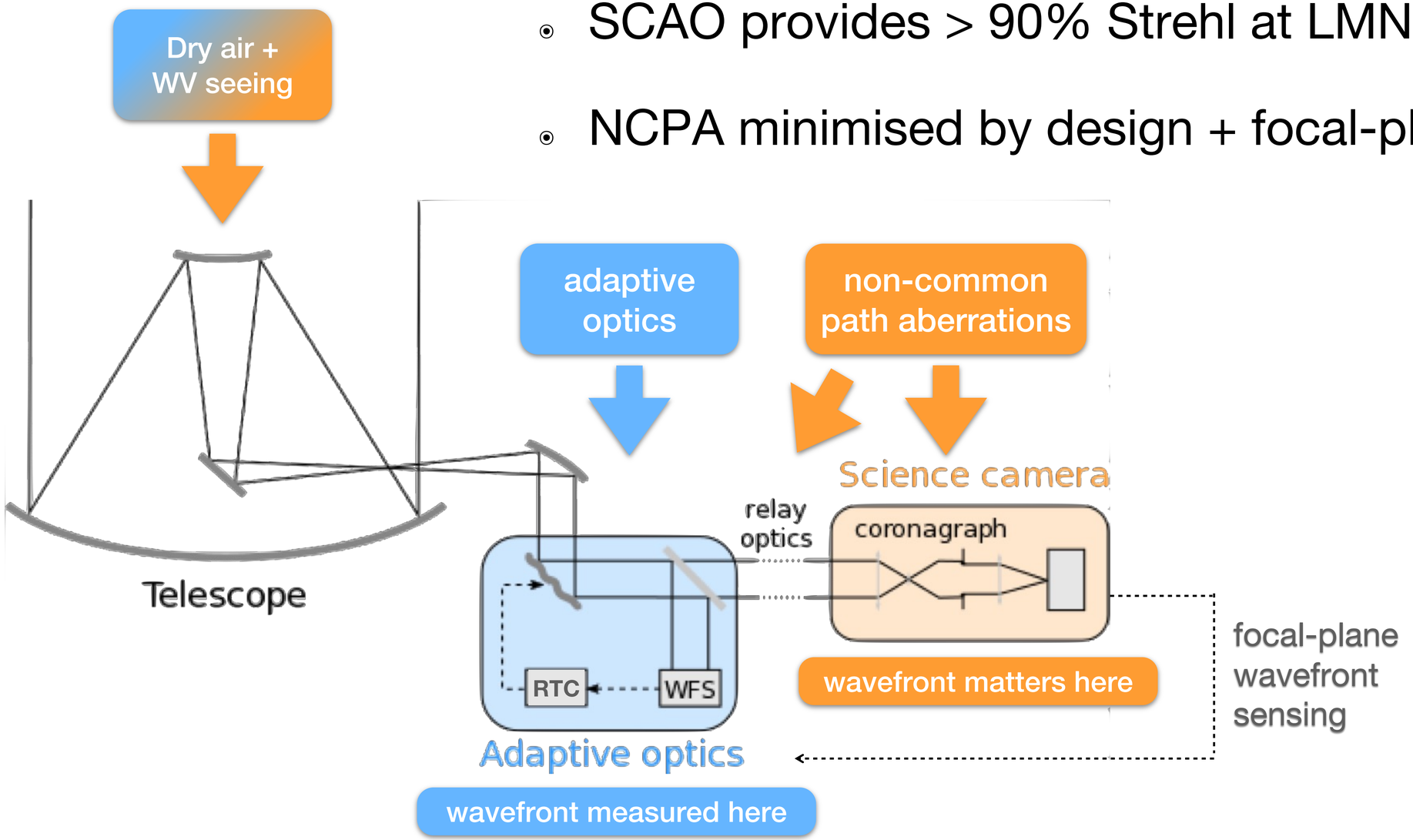




- Vortex phase masks: Uppsala Univ.
  - reactive ion etching on synthetic diamond
- Ring apodizer: Opto-Line
  - microdot chrome deposition on SiO-coated ZnSe substrate (on-going)
- Grating-vector APP: ColorLink Japan

Wavefront control strategy

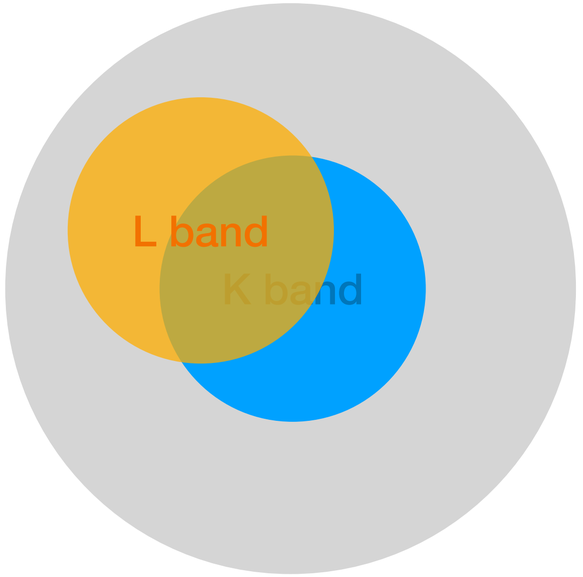
- SCAO provides > 90% Strehl at LMN bands
- NCPA minimised by design + focal-plane WFS

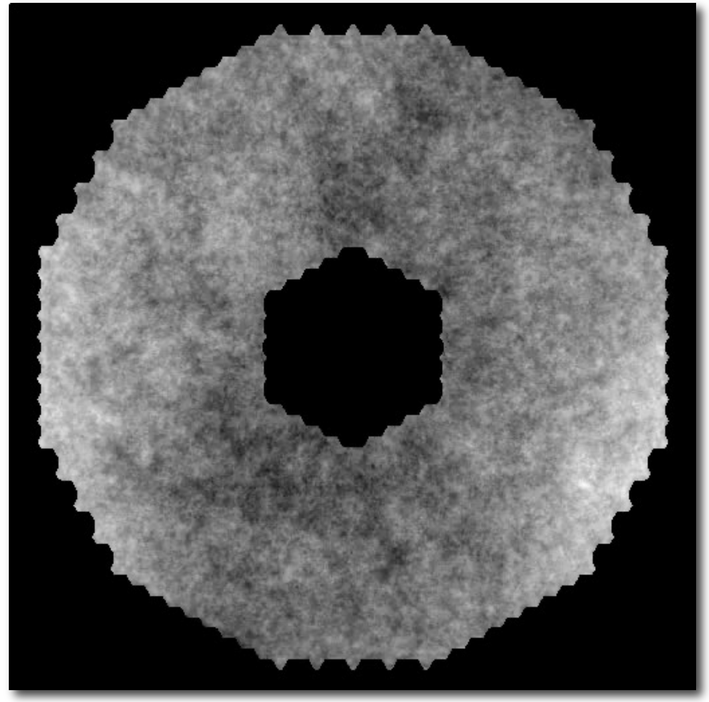


Sources of NCPA

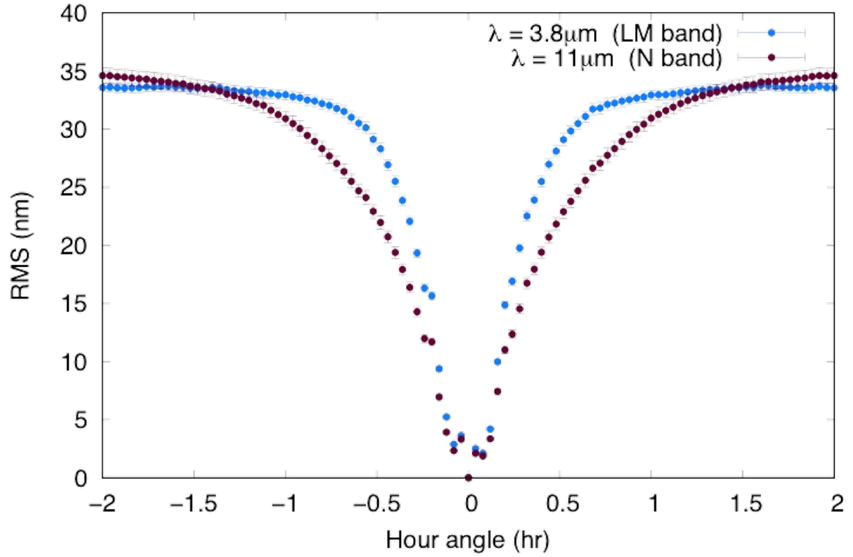
- Instrument
  - < 150nm rms of static NCPA
  - no internal turbulence
  - no gravity variation
  - very stable thermal environment
- Chromatic effects
  - atmospheric refraction causes ‘chromatic beam wander’
  - L-band IMG sees different WFE than K-band SCAO, slowly varying as telescope follows star across sky
  - ~30nm rms of NCPA variations

Boné et al. (in prep)



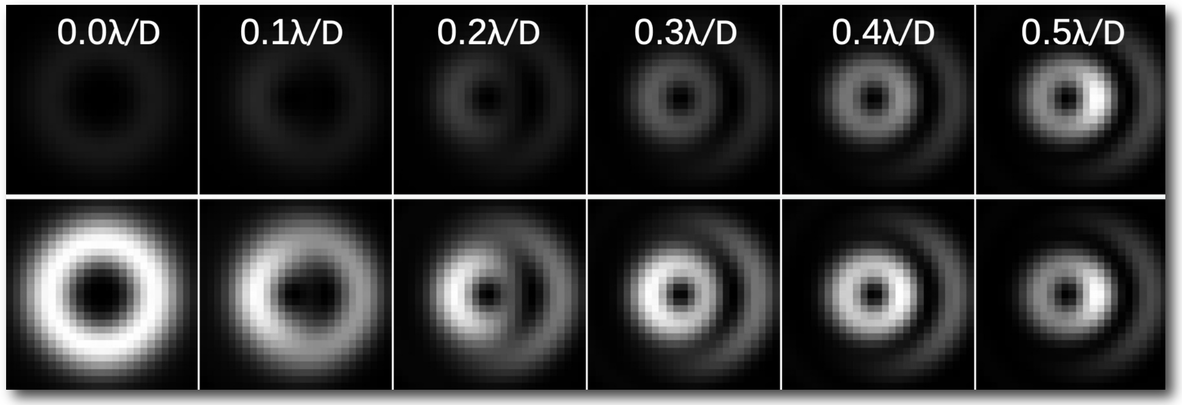


Differential NCPA vs time

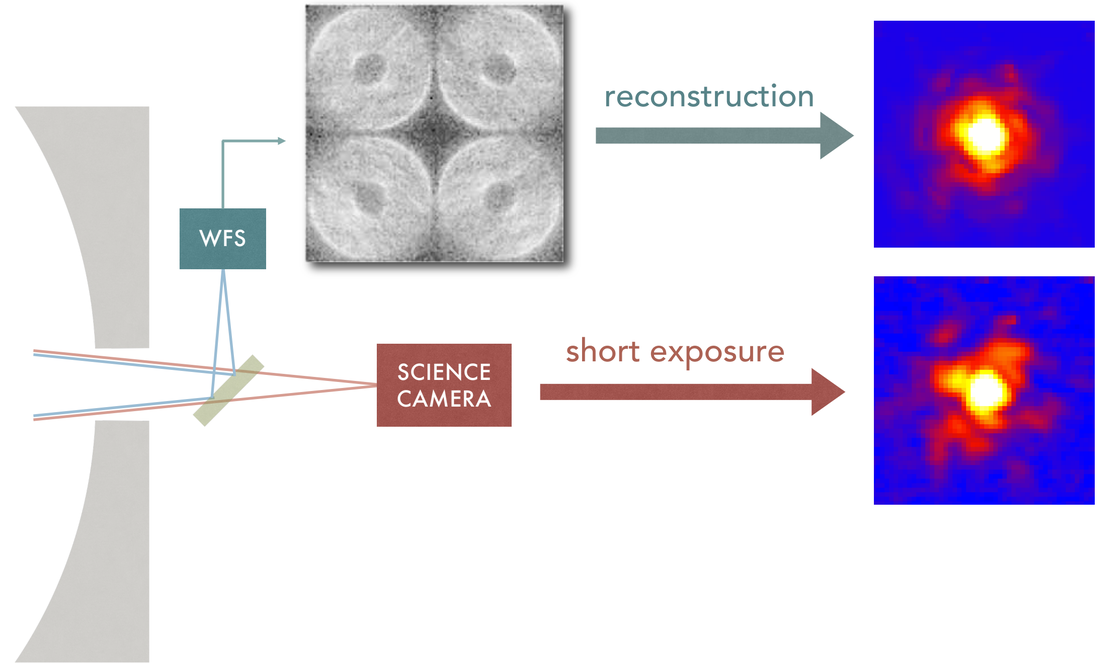


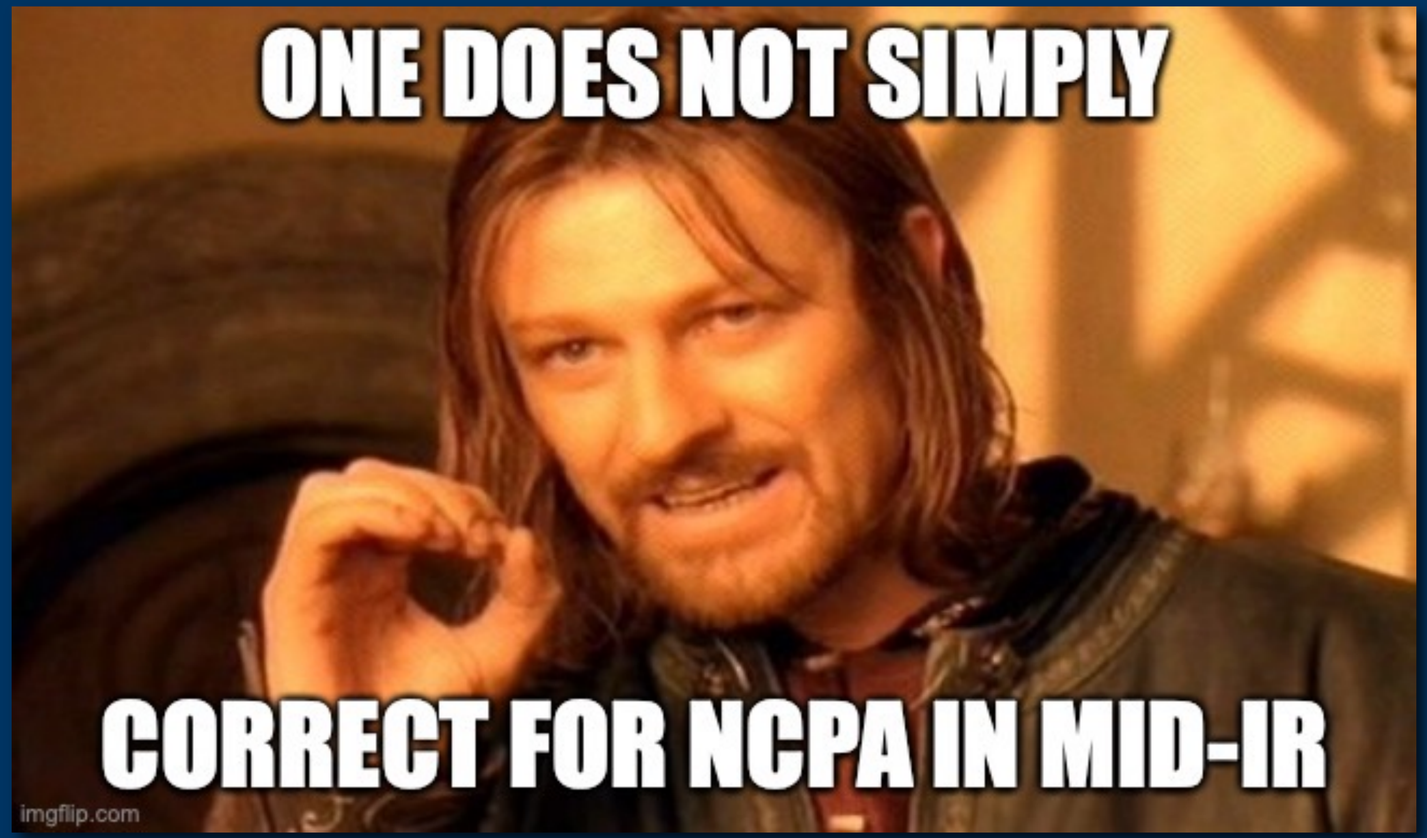
NCPA control strategy

- Cf Gilles' talk yesterday
- Pointing control with QACITS
  - 0.01 λ/D at 1 Hz



- Higher-order modes
  - baseline: Phase Sorting Interferometry
  - alternative being studied: Asymmetric Pupil WFS
  - goal: < 20 nm RMS at 1 Hz, for up to 100 modes




ONE DOES NOT SIMPLY
CORRECT FOR NCPA IN MID-IR
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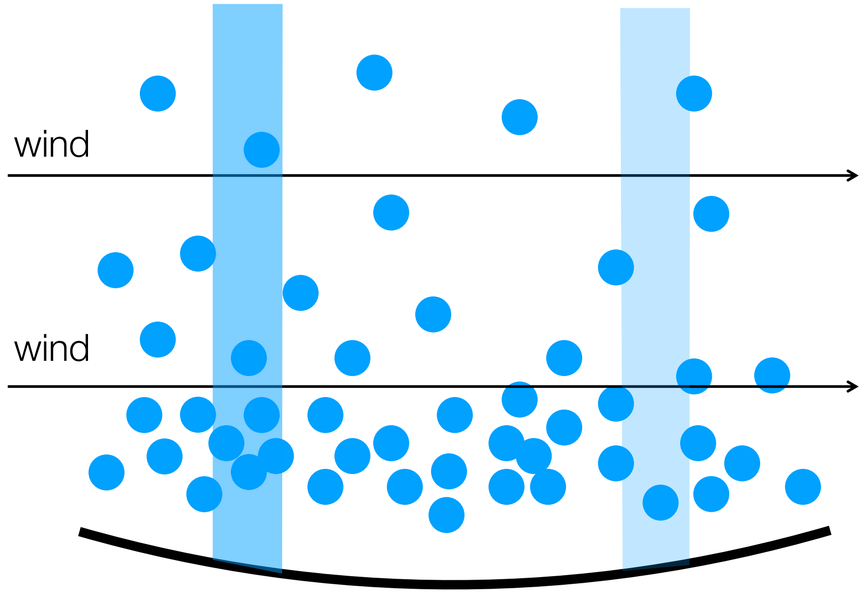
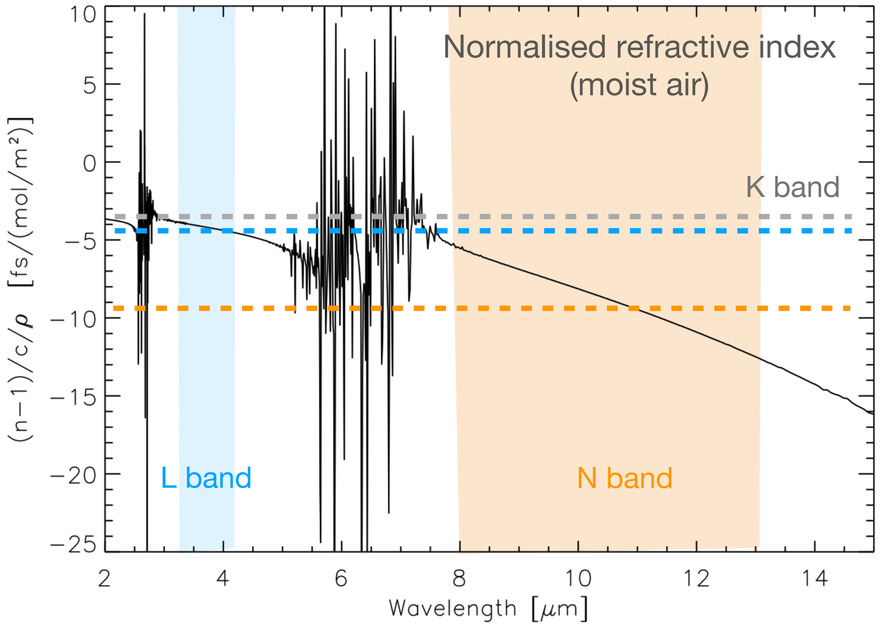
Water vapour seeing

- Inhomogeneous WV in atmosphere, blown by the wind
  - variable column density of water vapour above various parts of telescope

- Highly chromatic in mid-IR
  - K-band SCAO wavefront correction not fully valid at LMN bands



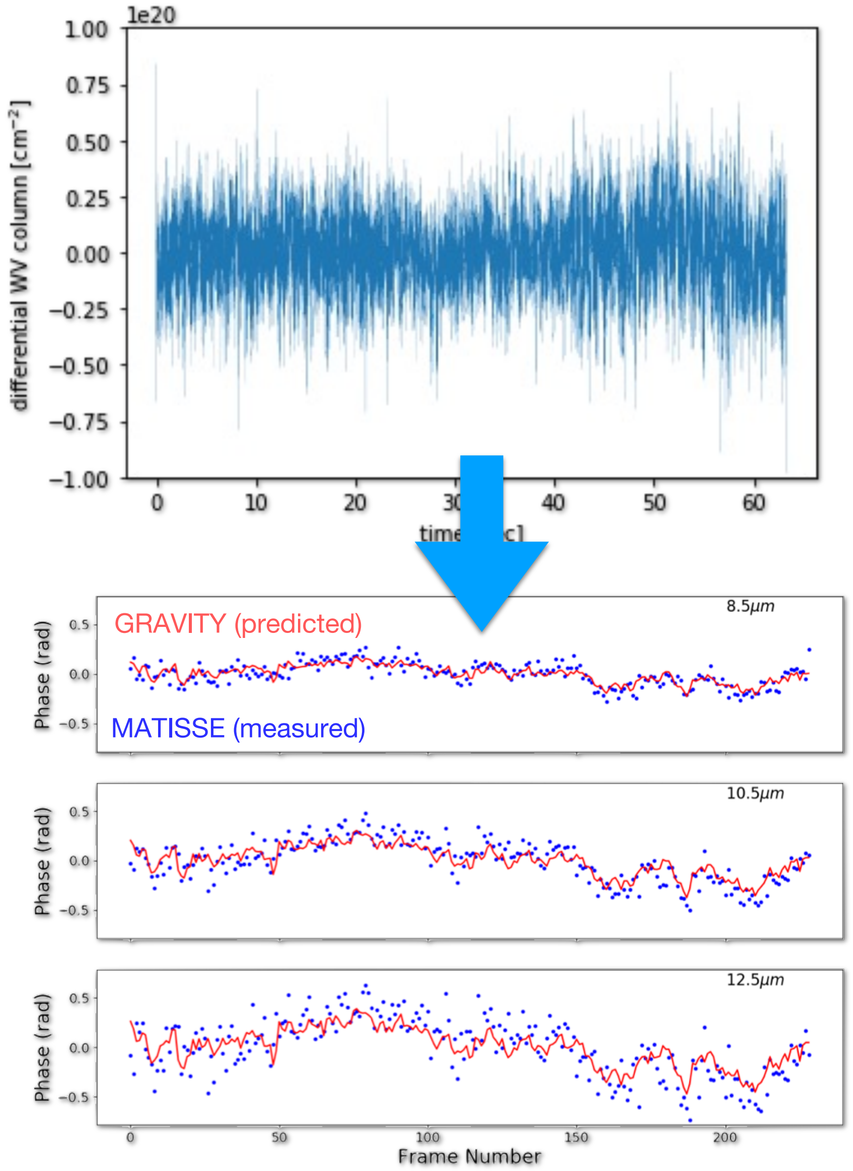


SEE PRASHANT'S POSTER

How strong is WV seeing at Armazones?

- VLTI/GRAVITY K-band fringe tracker: dispersed fringes to infer WV
- Validation of GRAVITY WV extraction
  - predict fringe position at N band
  - use MATISSE at N band to check prediction
- Currently exploring statistics

PWV (mm)	1.4 mm	2.0 mm	6.6 mm	7.0 mm
1-min rms WV column density (cm^{-2})	1.3×10^{19}	1.8×10^{19}	2.2×10^{19}	2.4×10^{19}

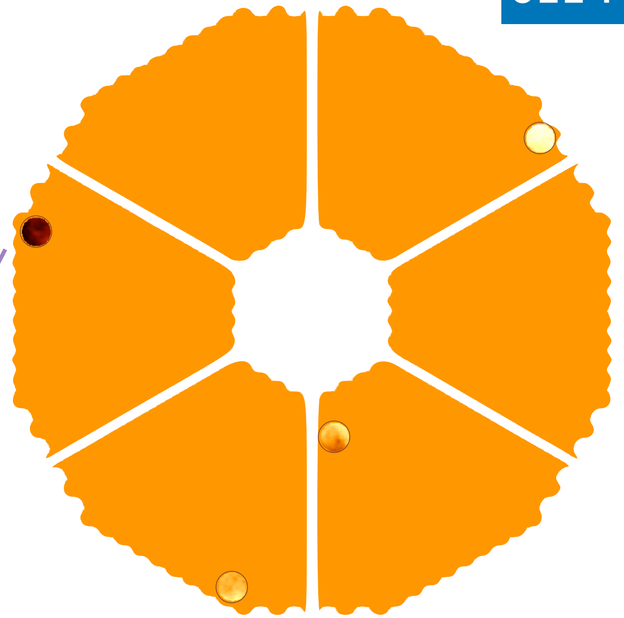


Berio et al. (in prep)

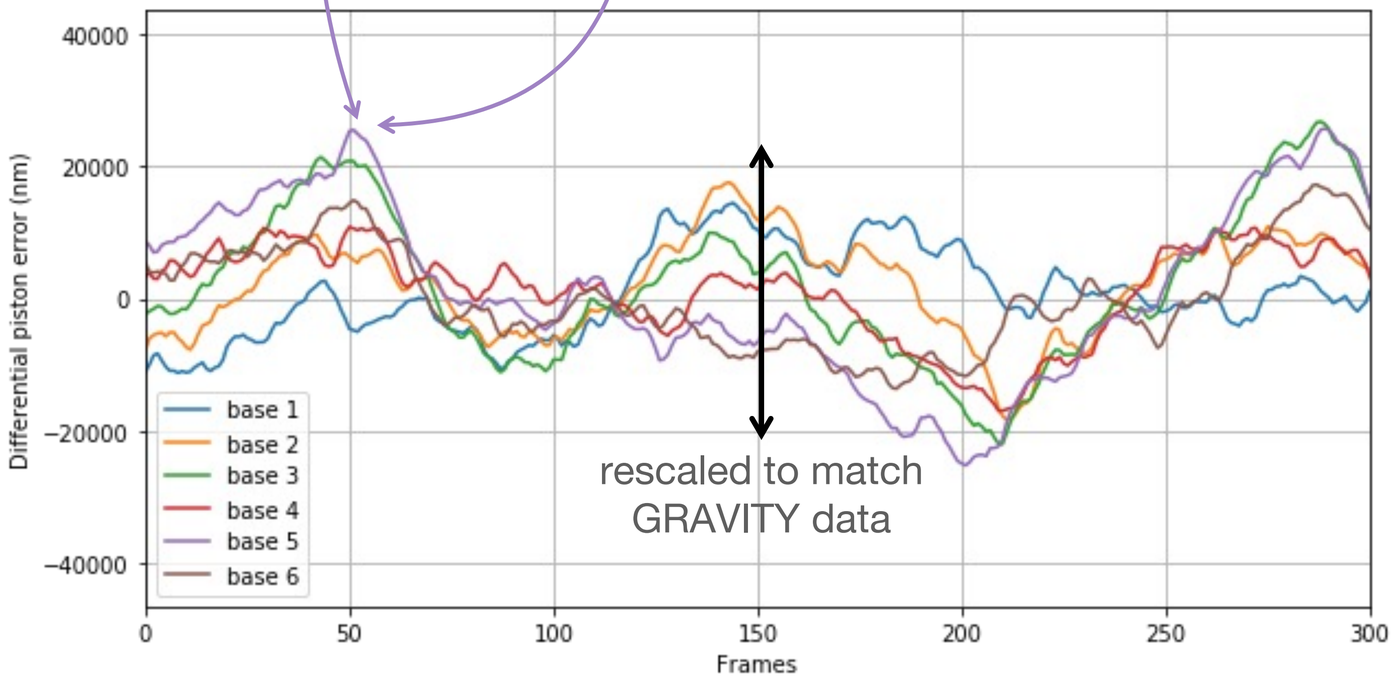
SEE PRASHANT'S POSTER

Simulating WV seeing

- Generate open-loop Kolmogorov turbulence phase screens on ELT pupil
- Extract VLTI-like sub-apertures and measure piston
- Scale phase screens to match WV-induced piston measured by GRAVITY
  - ~25 nm rms WFE at L band
  - ~300 nm rms WFE at N band

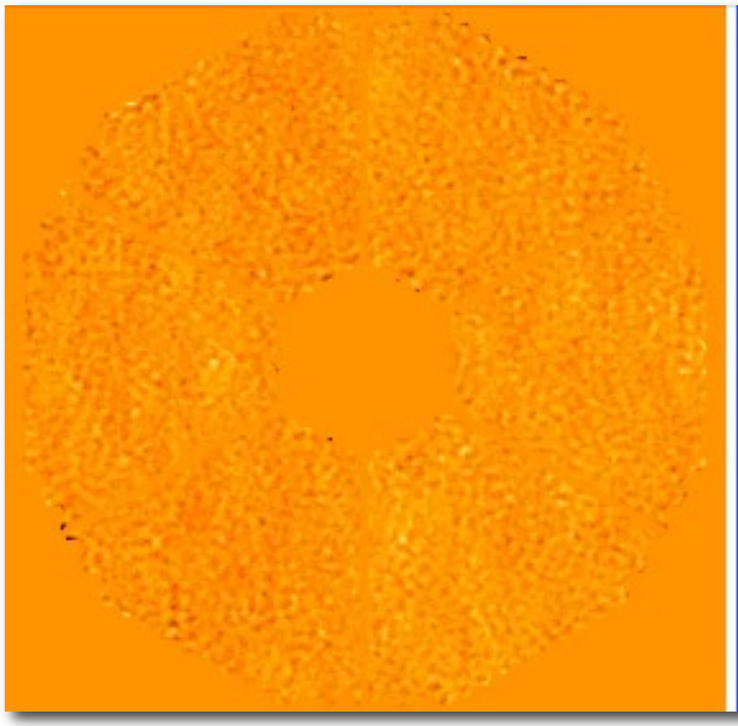


VLTI auxiliary telescopes footprint on ELT pupil (compact array)



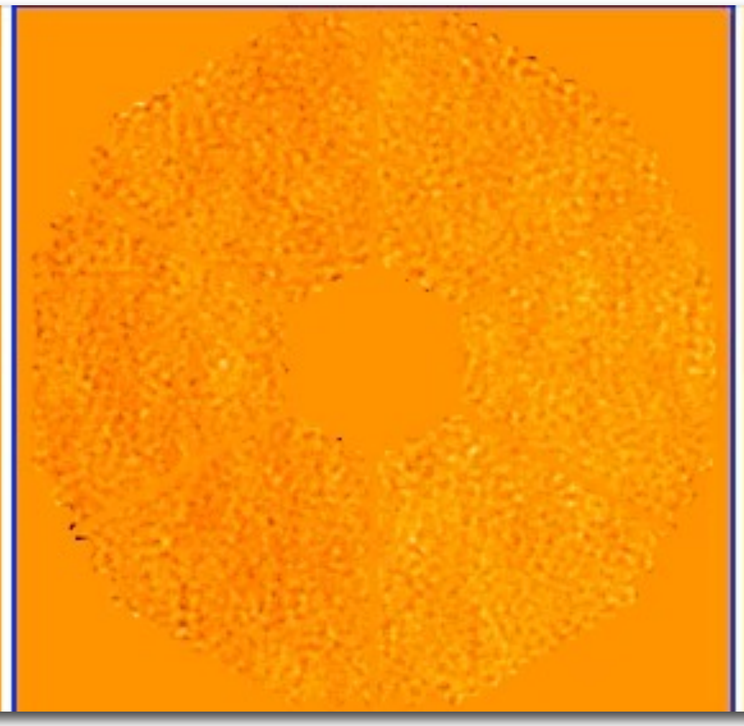
Adding WV seeing to AO residuals

AO only



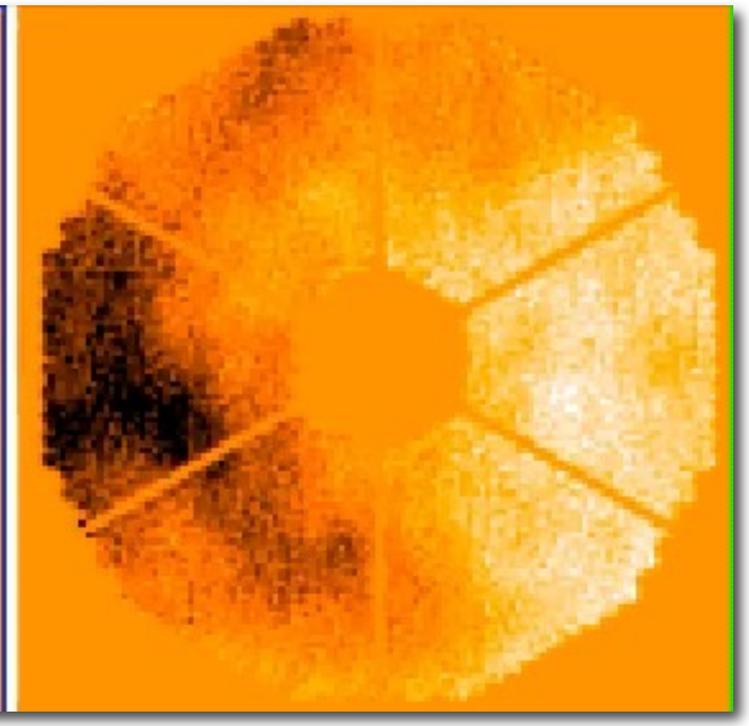
~140 nm RMS WFE

AO + WV (L band)



~25 nm RMS additional WFE

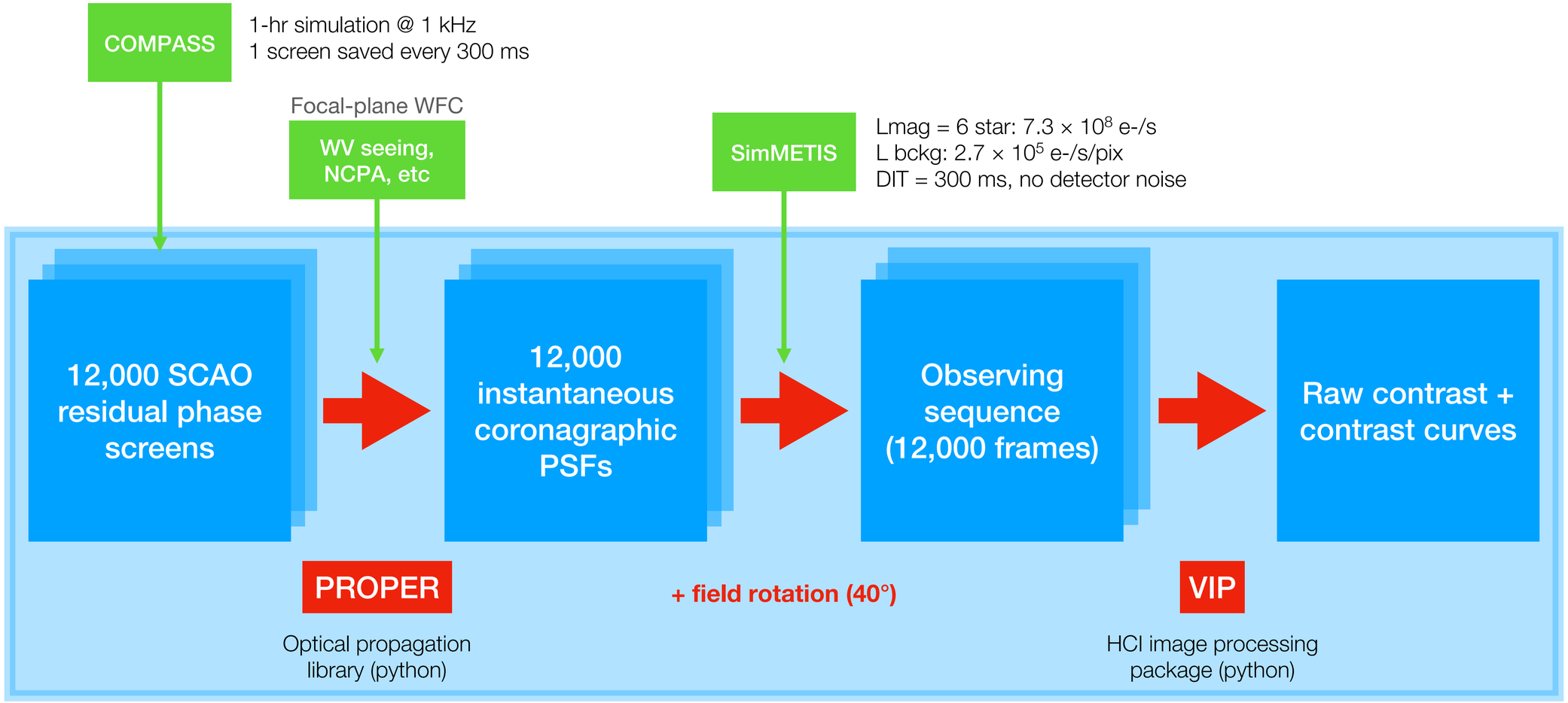
AO + WV (N band)



~300 nm RMS additional WFE

Strongly dominated by low spatial frequencies (Kolmogorov - von Karman)

End-to-end HCI simulations

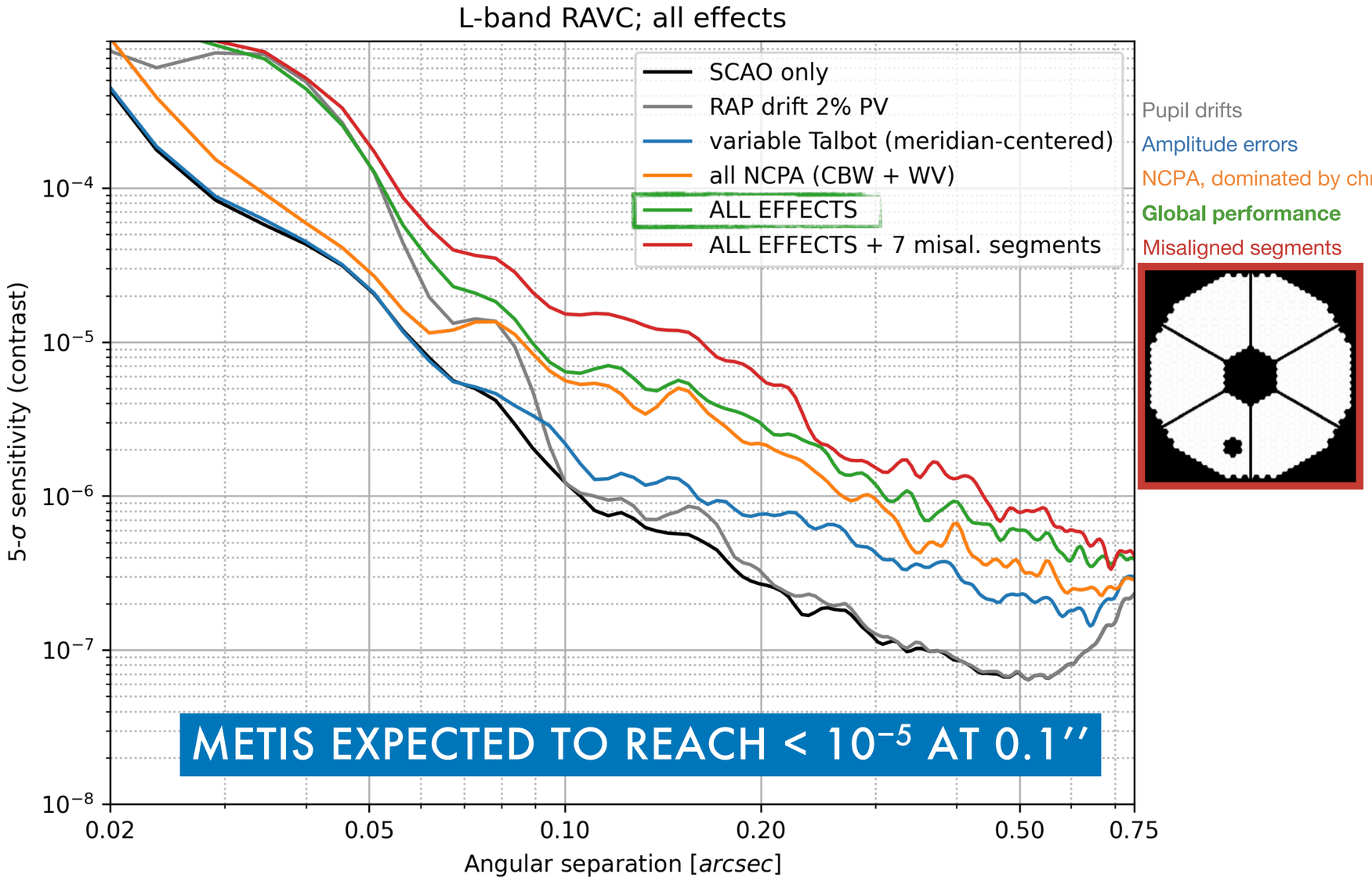


HEEPS

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

Carlomagno et al. 2020

Expected L-band performance



Pupil drifts

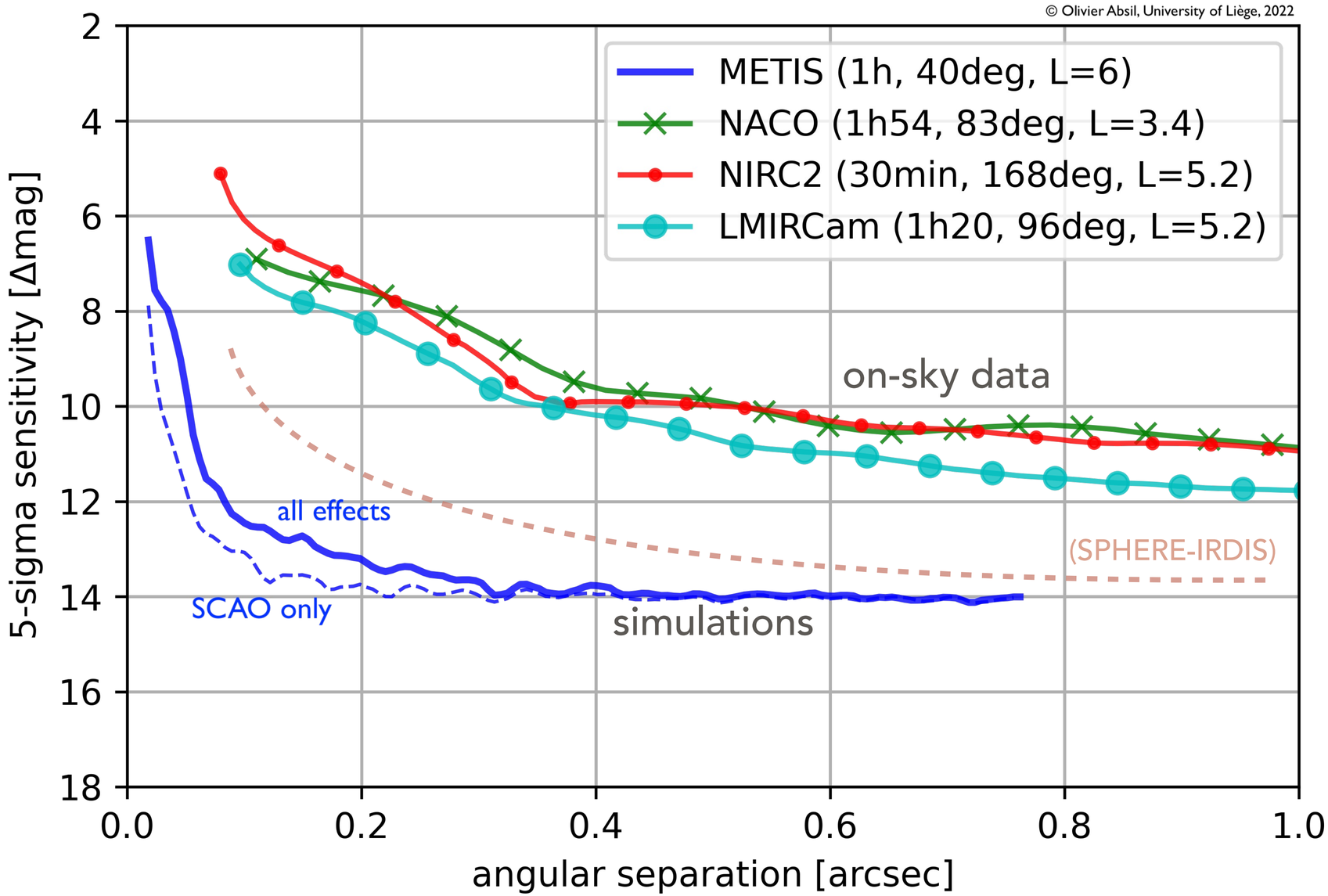
Amplitude errors

NCPA, dominated by chromatic beam wander

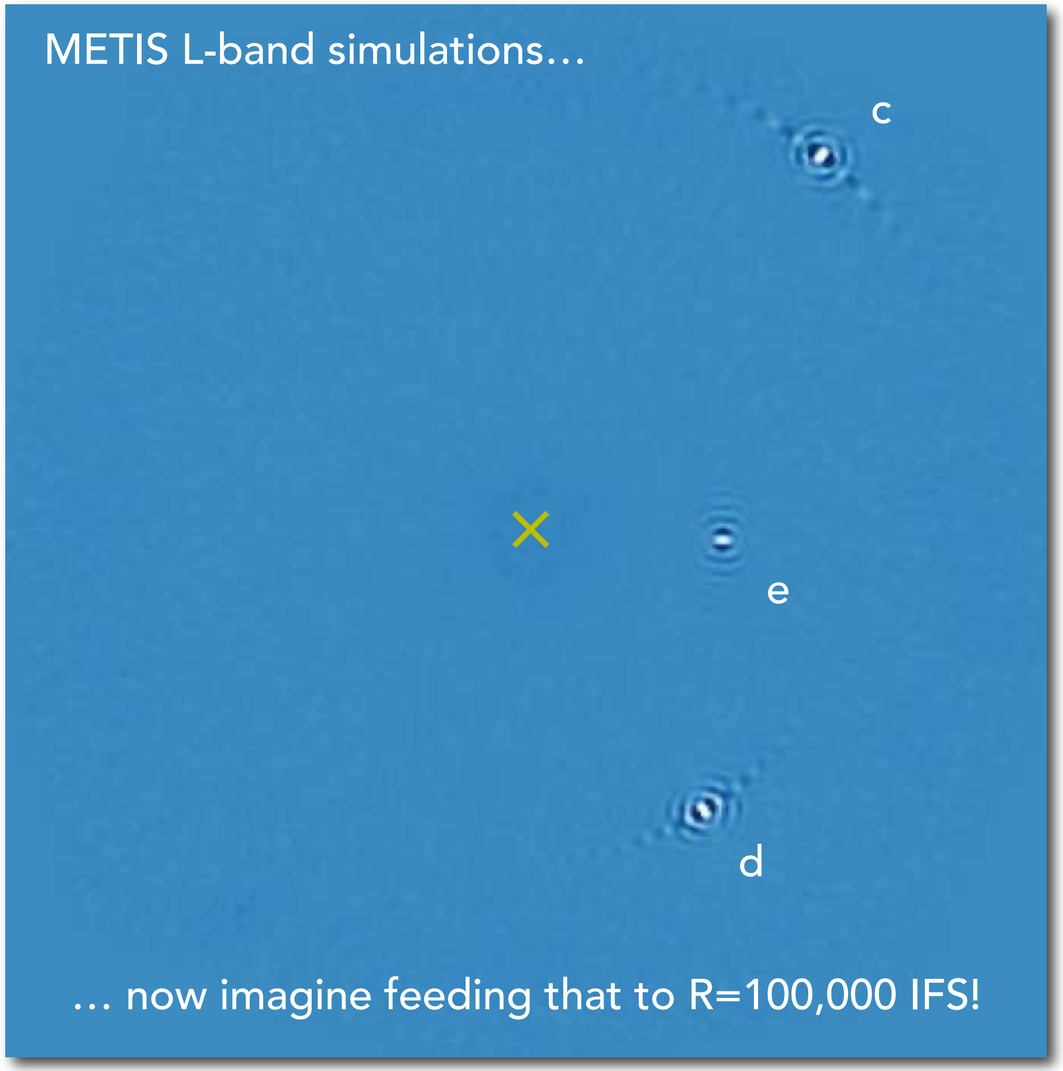
Global performance

Misaligned segments

METIS vs 10-m class telescopes @ L Band



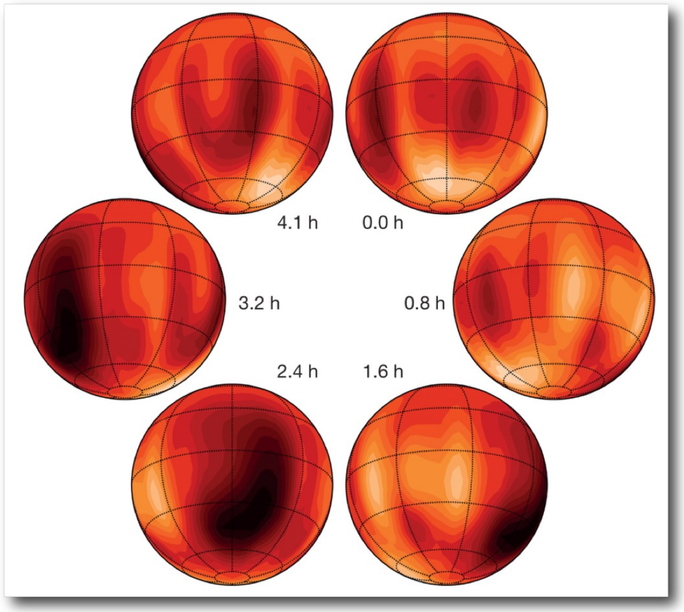
Famous systems, revisited…



2D maps of exoplanet atmospheres

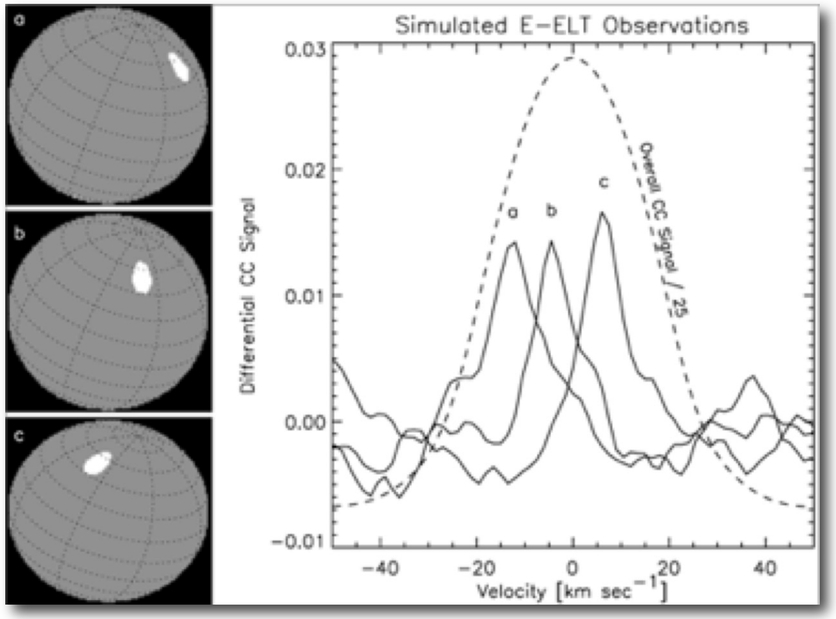
Doppler tomography with high-resolution IFS (R = 100,000)

From brown dwarf cloud maps…



Crossfield et al. 2014

to clouds in giant planets atmospheres!



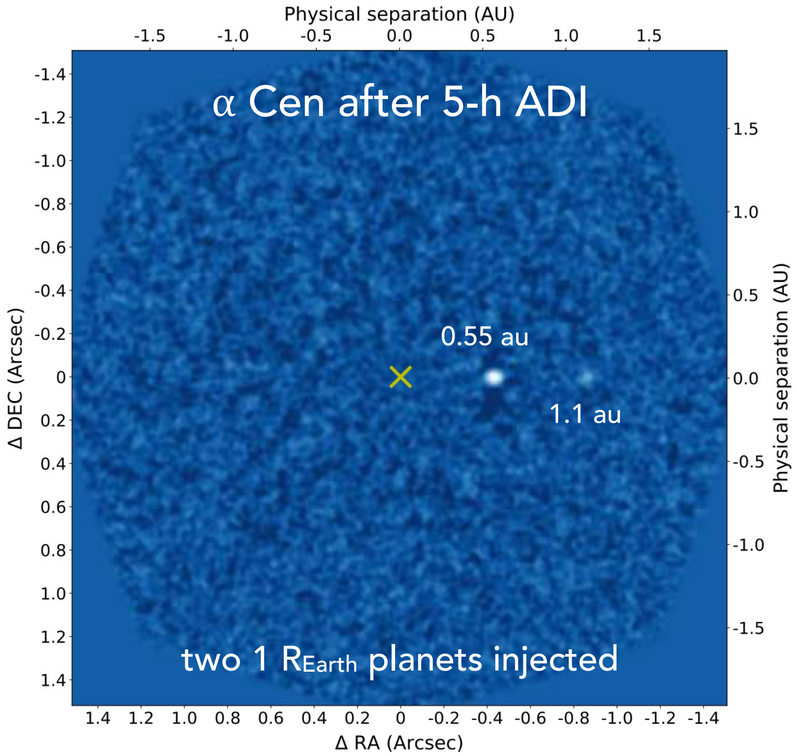
Snellen et al. 2014

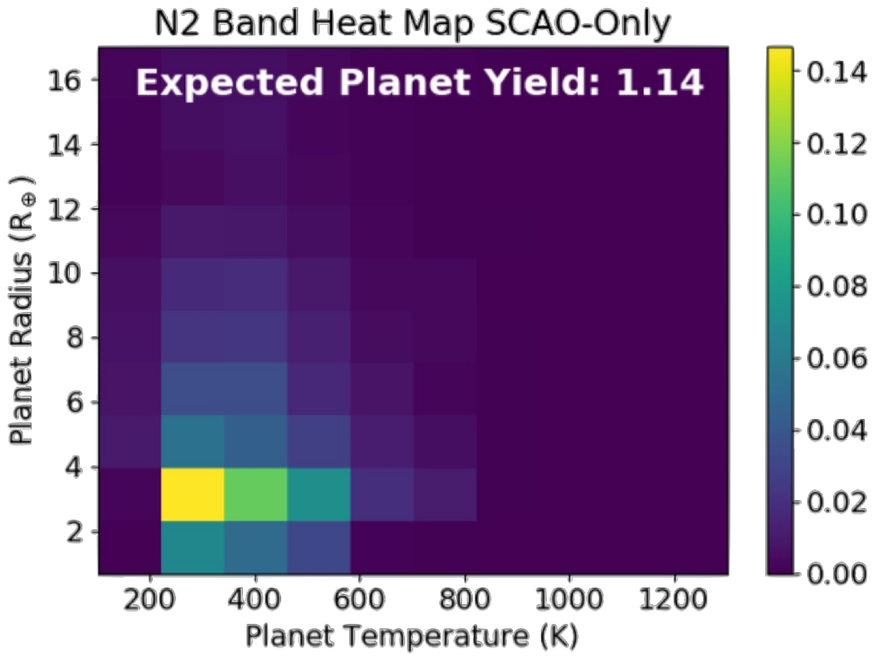
Your weather forecast on beta Pic b, starting 2029

Bowens et al. 2021

What about N-band exoplanet science?

- N band HCI: potential to probe thermal emission of temperate rocky planets
- Here assume SCAO + background limited performance
  - terrestrial regime potentially accessible around a handful of stars






METIS WOULD DETECT AN EARTH-LIKE PLANET AROUND ALPHA CENTAURI
HAVE YOU CONSIDERED WATER VAPOUR SEEING?
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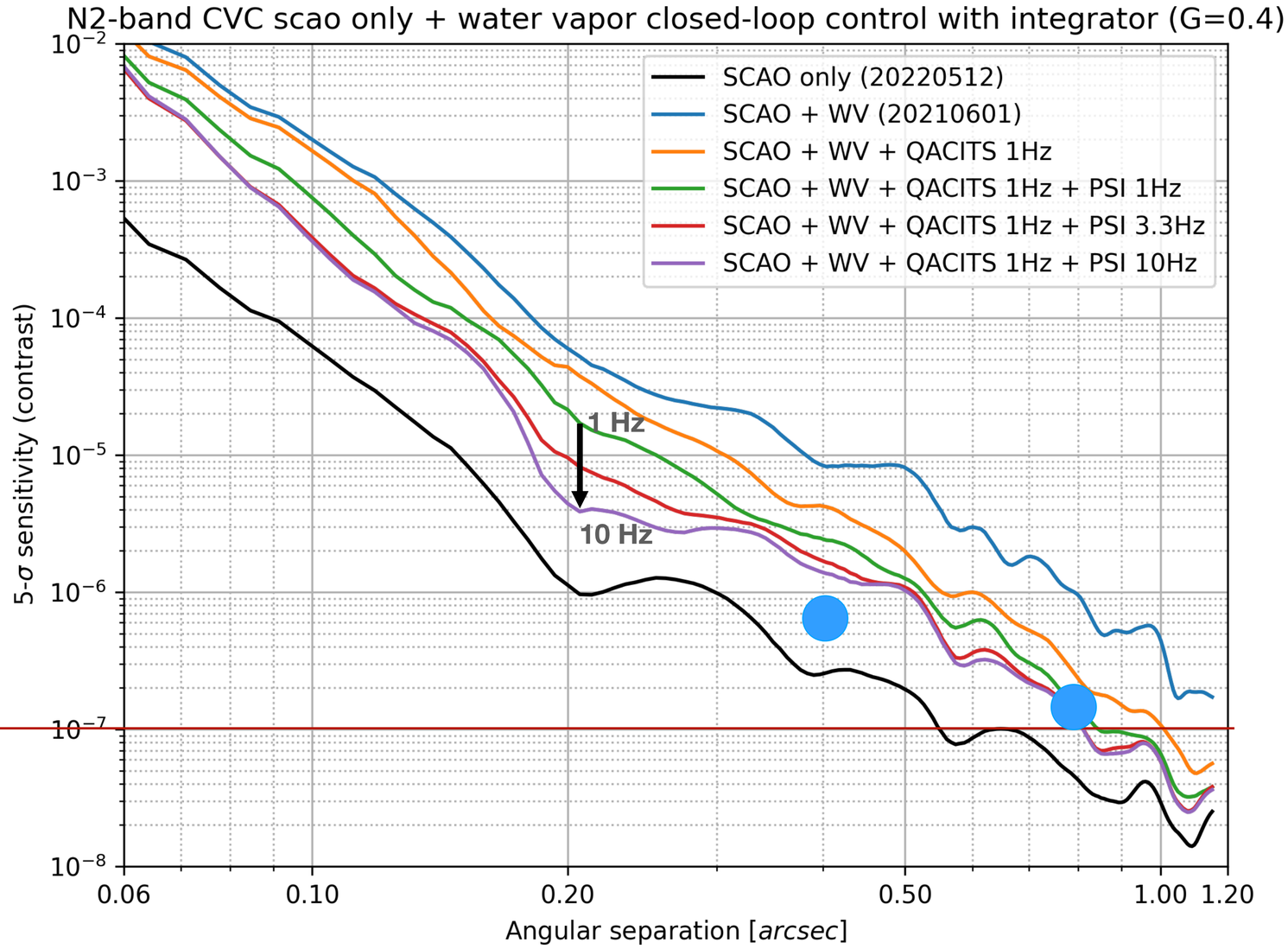
N-band simulations: impact of WV seeing

ABILITY TO MEASURE AND CORRECT FOR WV SEEING IN REAL TIME WILL DRIVE HCI PERFORMANCE



Only five more years to wait !!!

(let’s keep our fingers crossed until then)