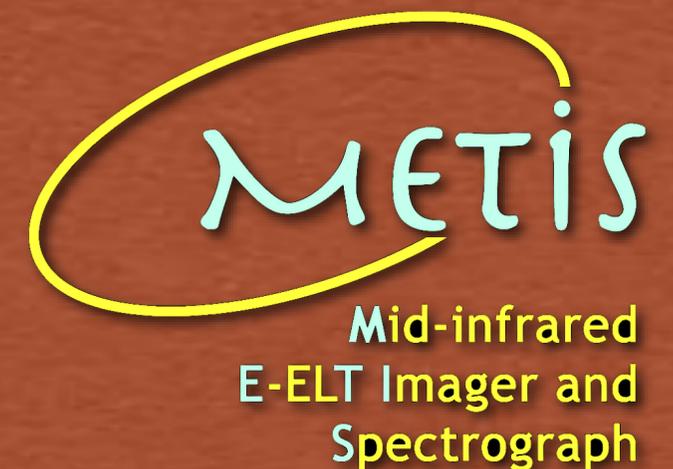


Non-Common Path Aberrations Strategy for the METIS High Contrast Imaging Modes

Gilles Orban de Xivry,
O. Absil, C. Delacroix, P. Pathak, M. Willson



First Generation Instruments @ ELT

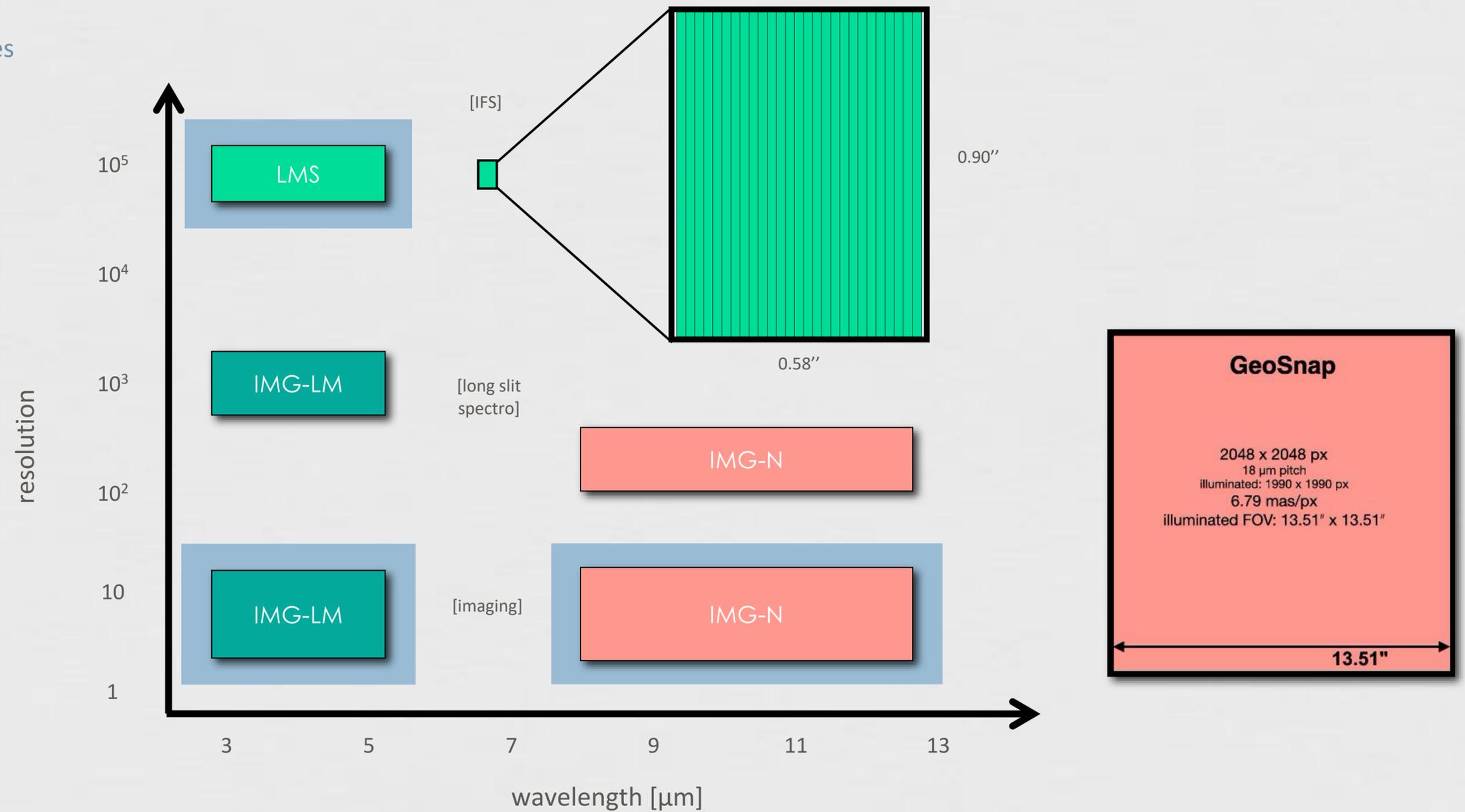


METIS instrument baseline

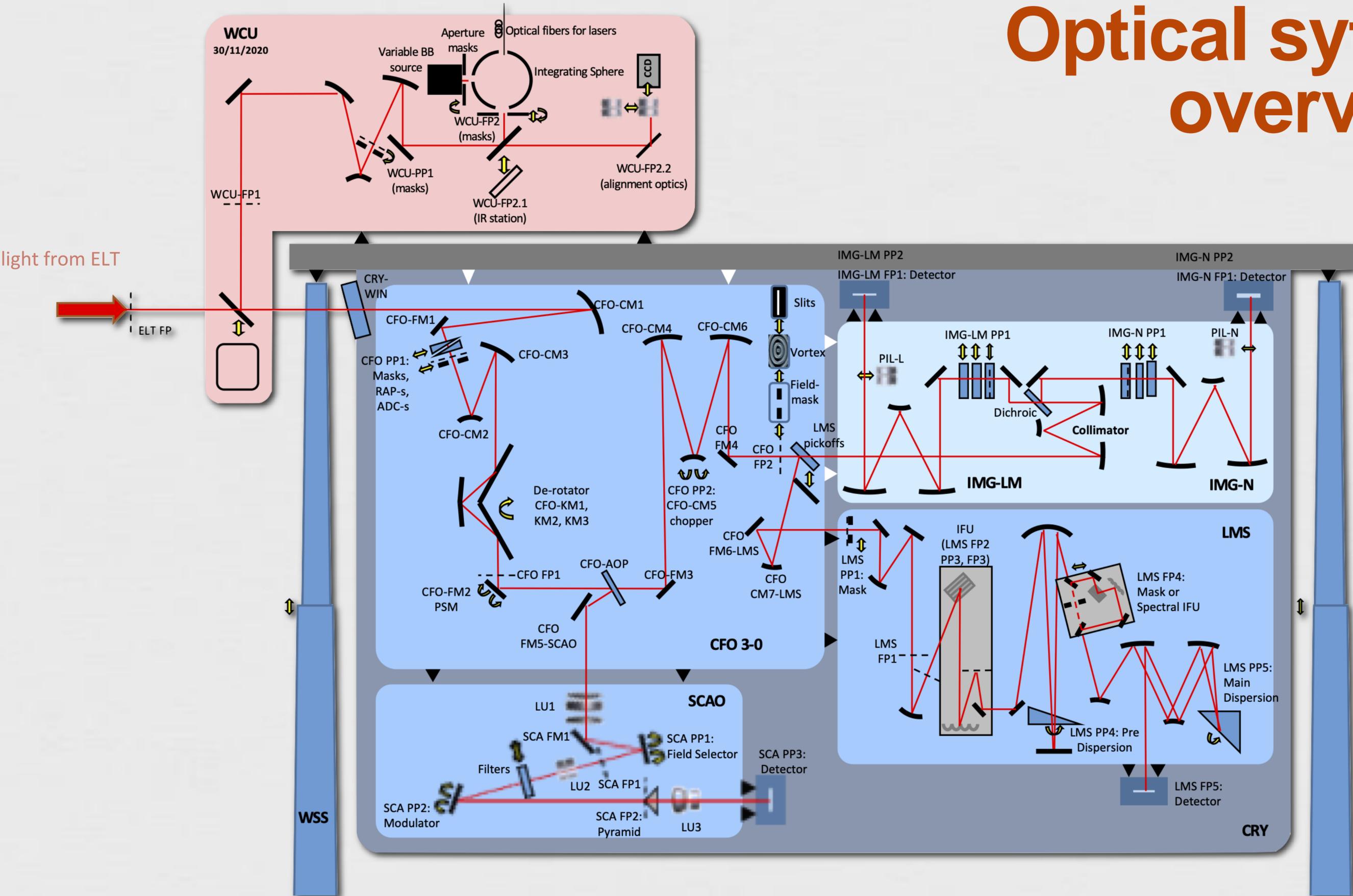
All modes work at diffraction limit of 38-m ELT using single-conjugate AO



= coronagraphic capabilities



Optical system overview



1:1 scale model



NOVA
METIS
Mid-Infrared
E-ELT Imager and
Spectrograph

Life-size optomechanical design of METIS, the Mid-infrared ELT Imager and Spectrograph

IT'S GOT
TO BE
BIG!

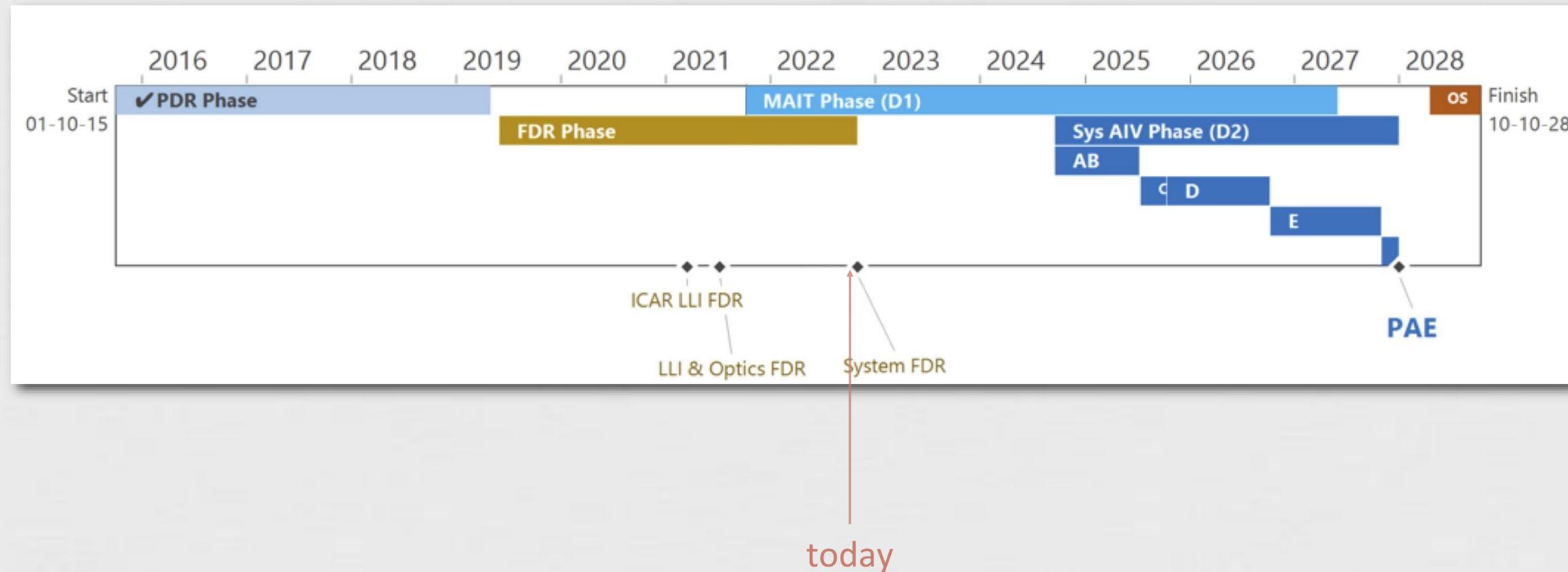
(and cold)

METIS PI

METIS Timeline

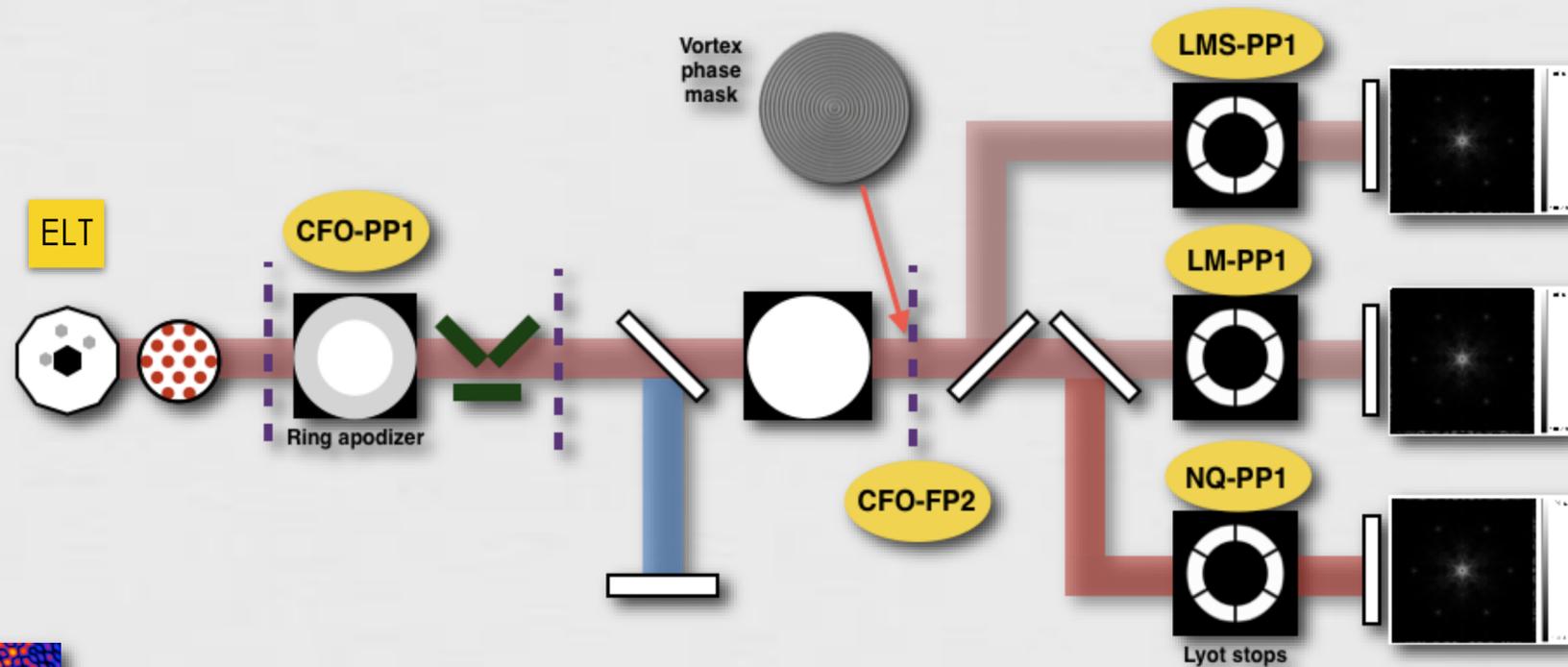
~ 670 FTE & 20 M€ hardware budget over 13 yrs

first light: end of 2028



High-Contrast Imaging Modes

(Ring-Apodized)
Vortex Coronagraph

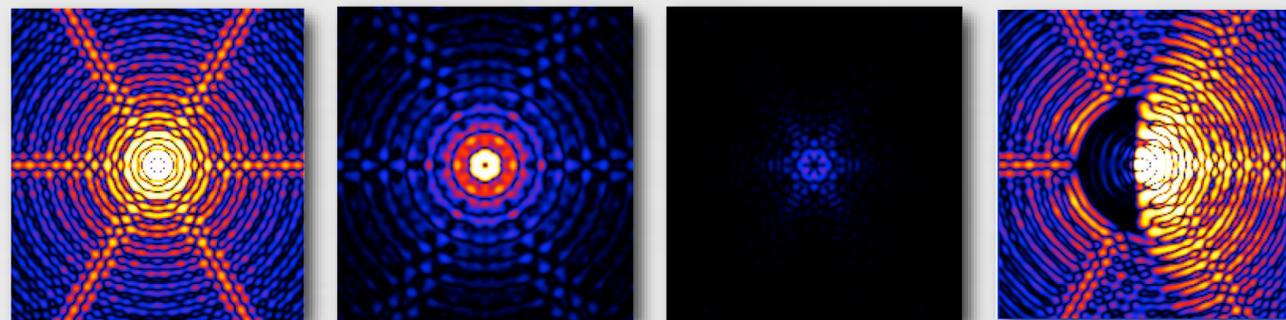


IMG (ELT)

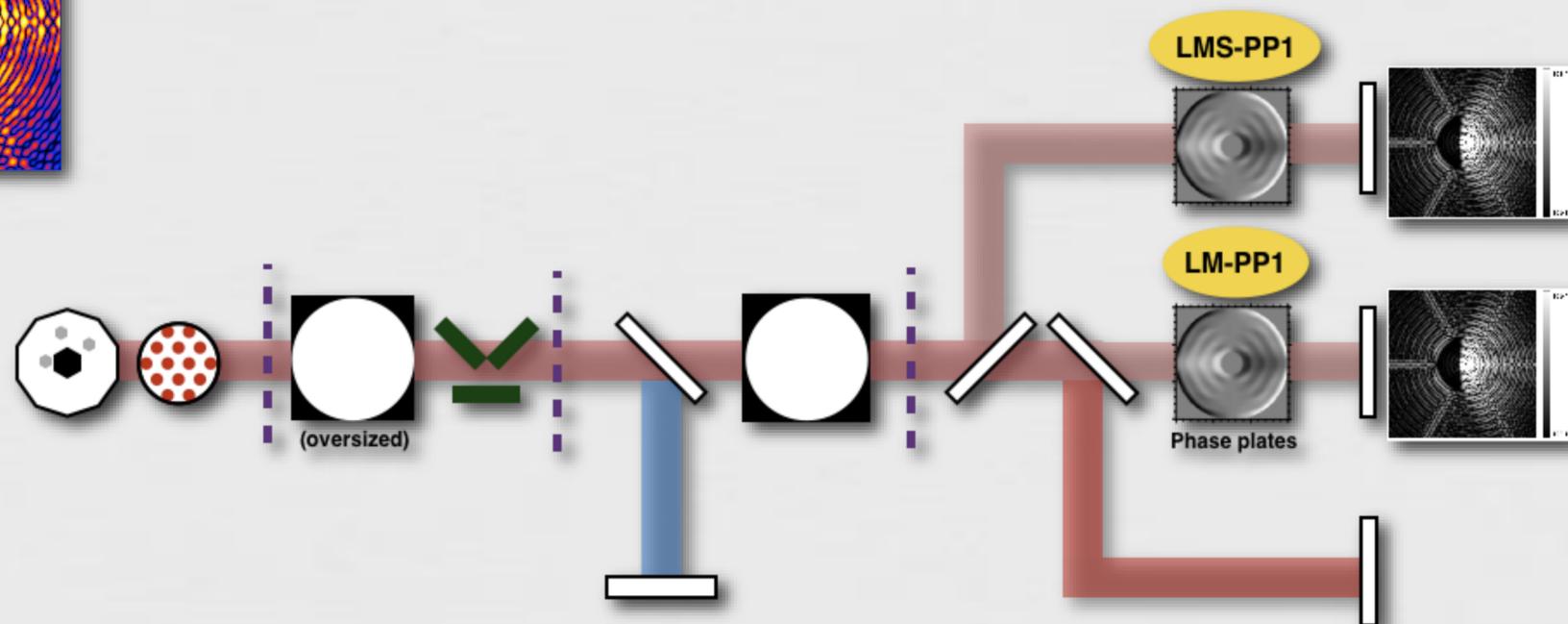
CVC

RAVC

APP

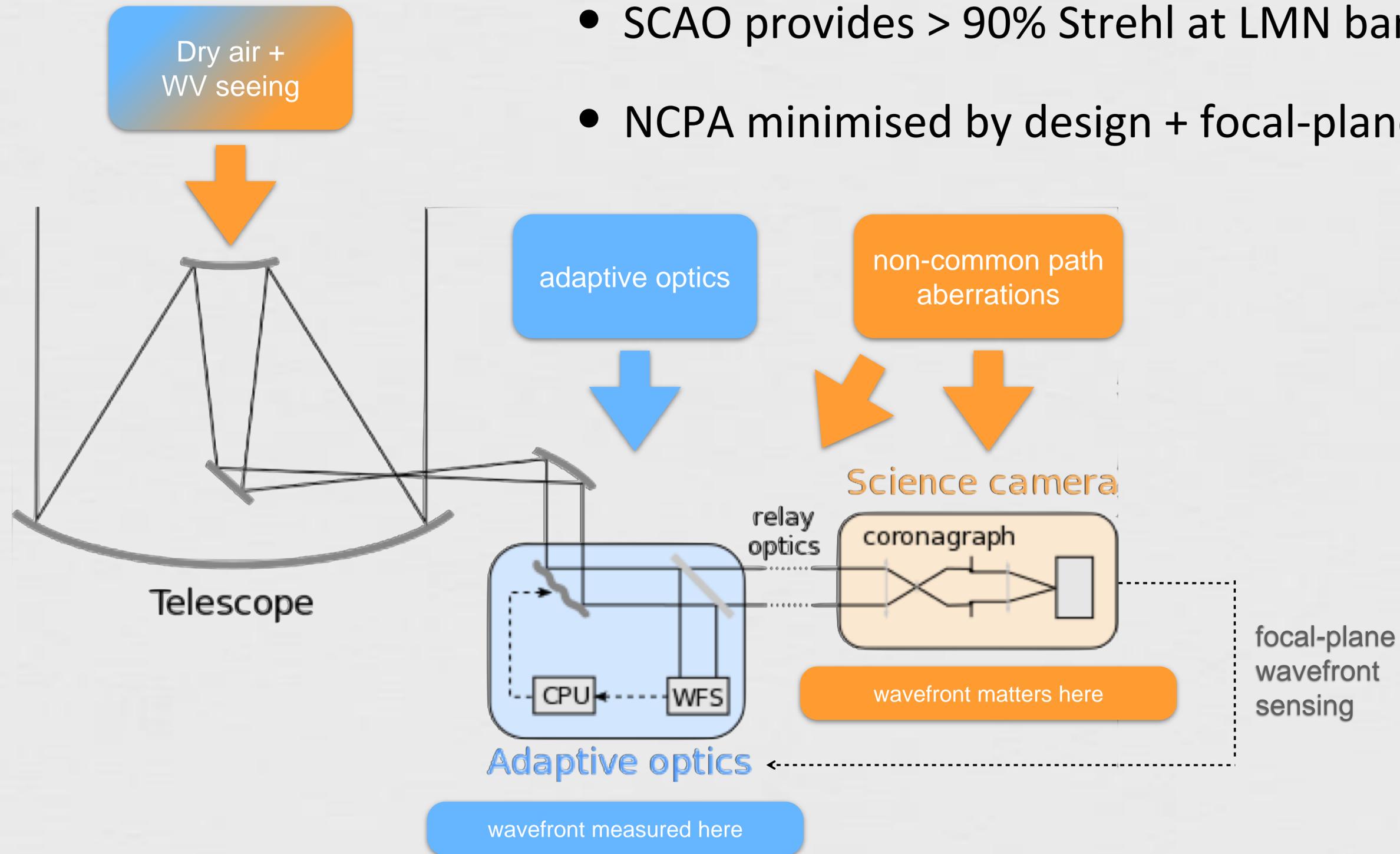


Apodizing
Phase Plate



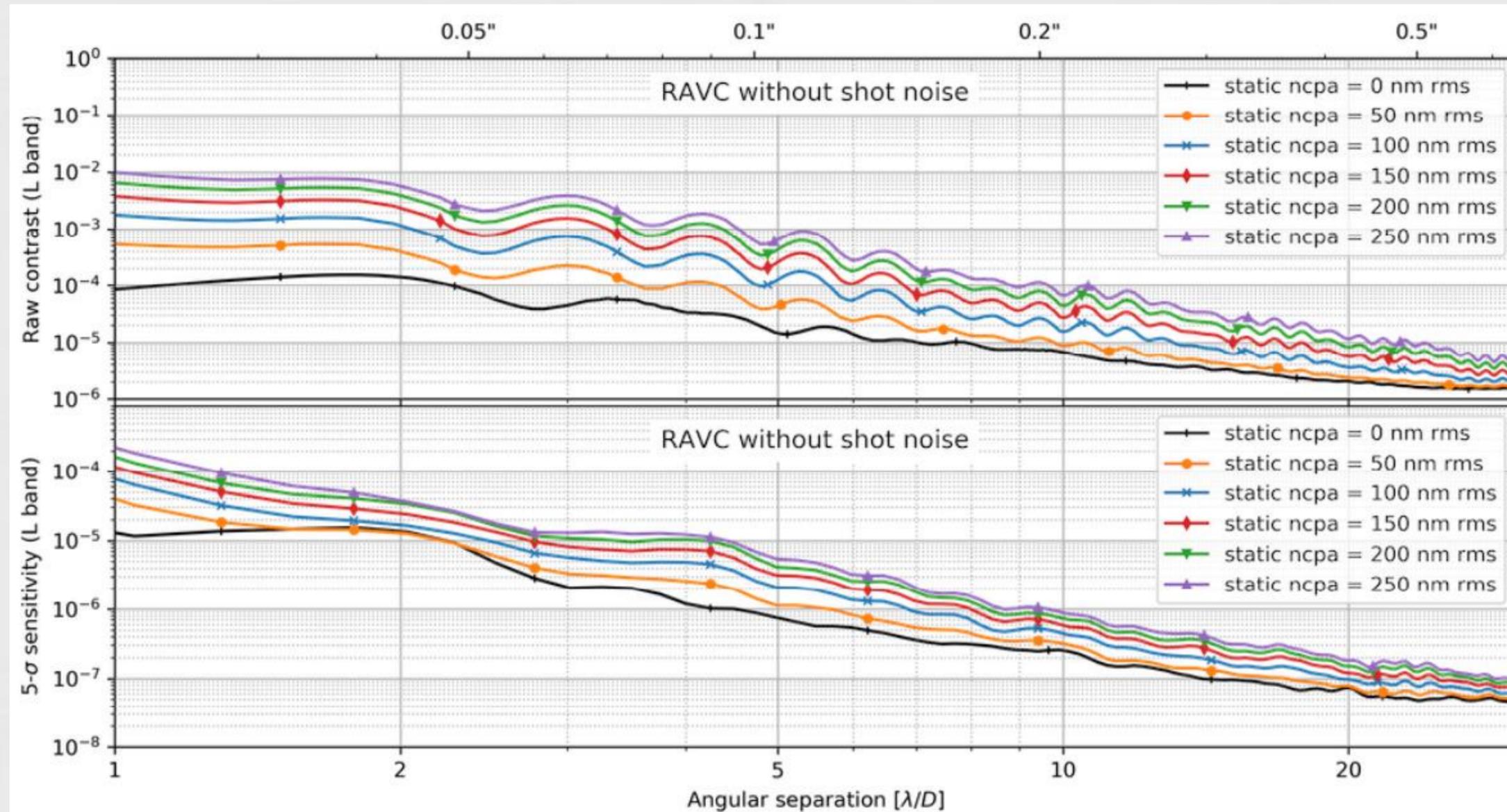
Wavefront Control Strategy

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

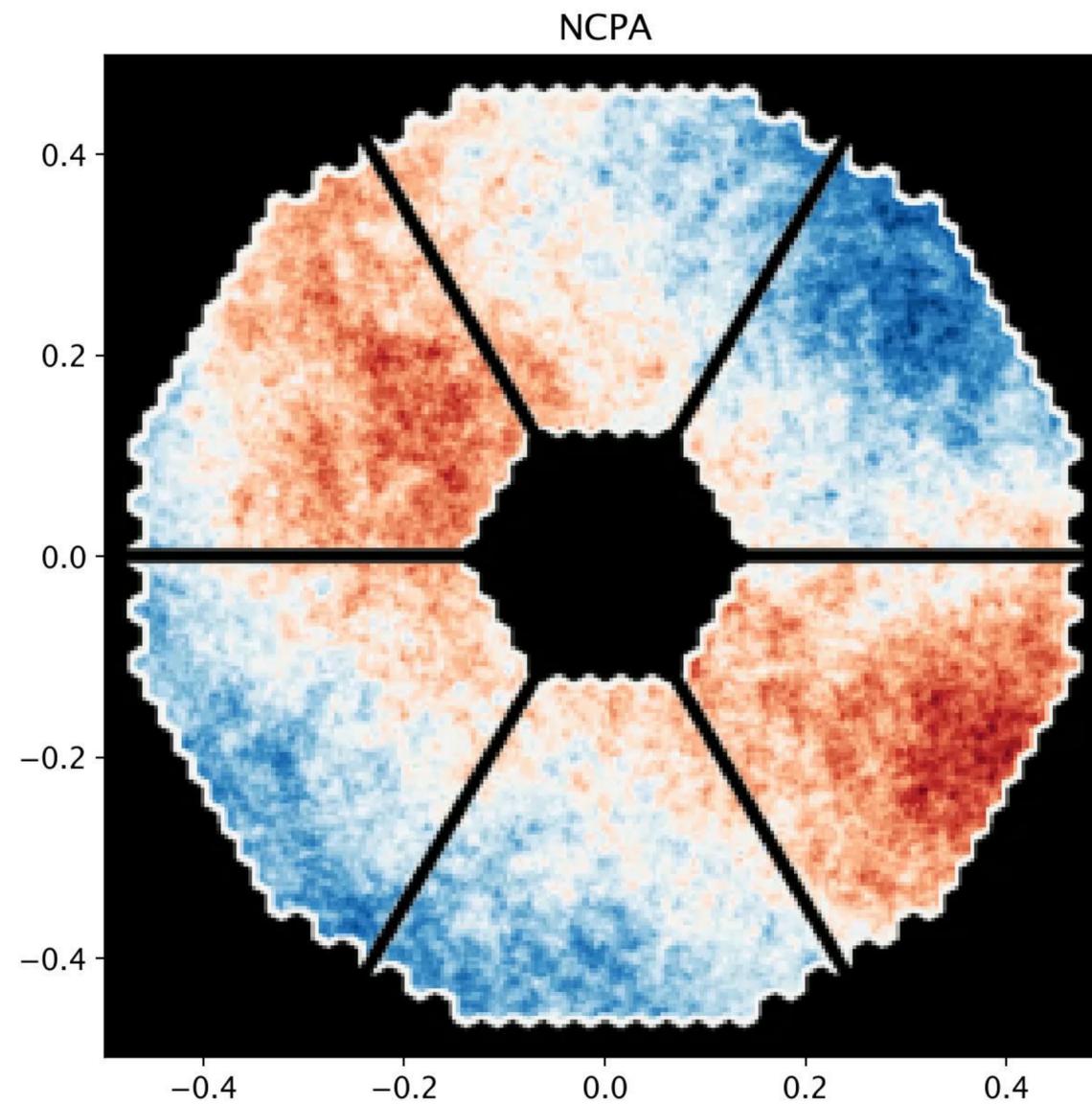


Static NCPA in METIS

Impact on contrast

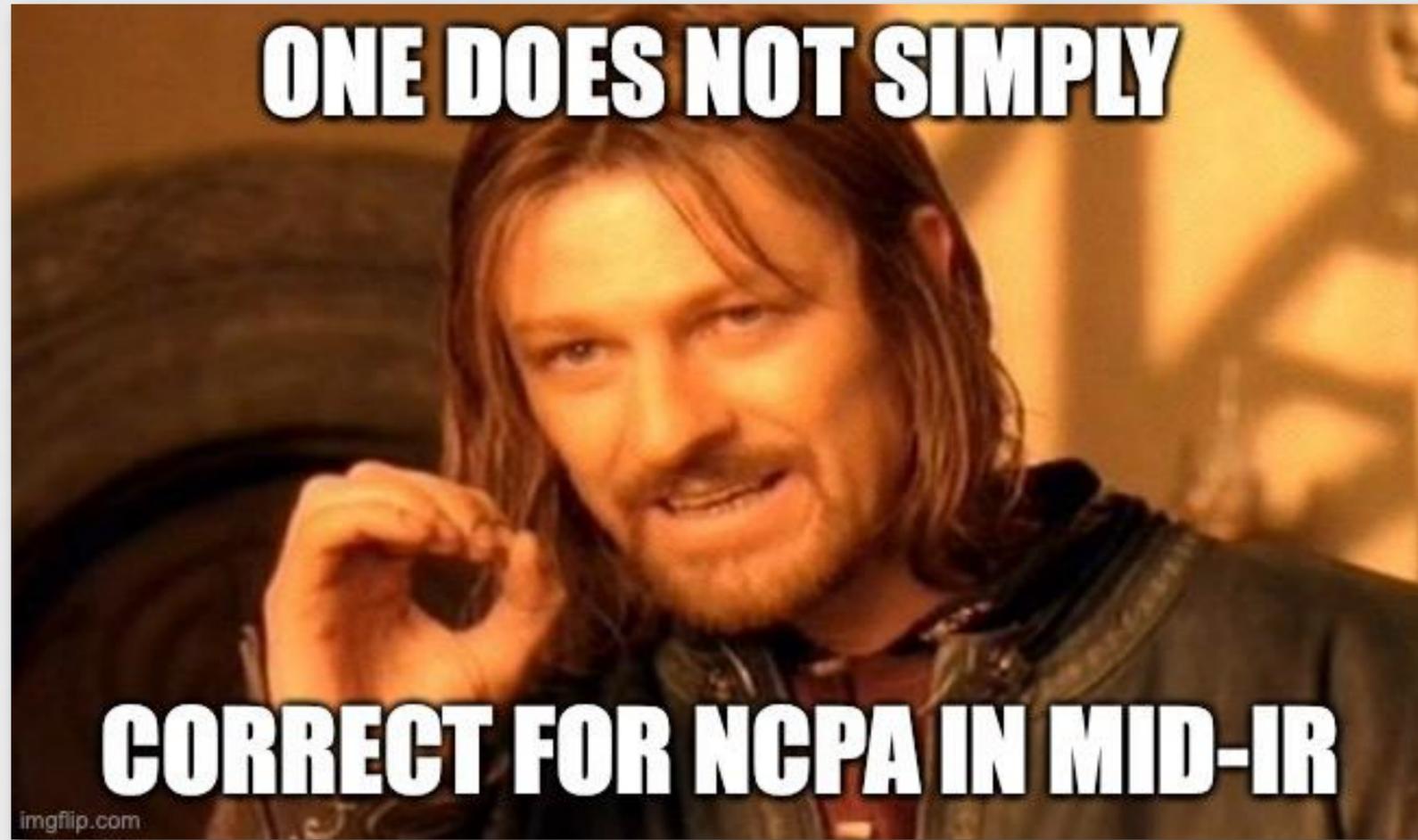


Quasi-static NCPA



- Static NCPA is ~ 100 nm rms

	LSF	HSF
Static	-	<40nm rms
Quasi-static (<0.01Hz)	20nm rms	20nm rms
Dynamic (>0.01Hz)	40nm	



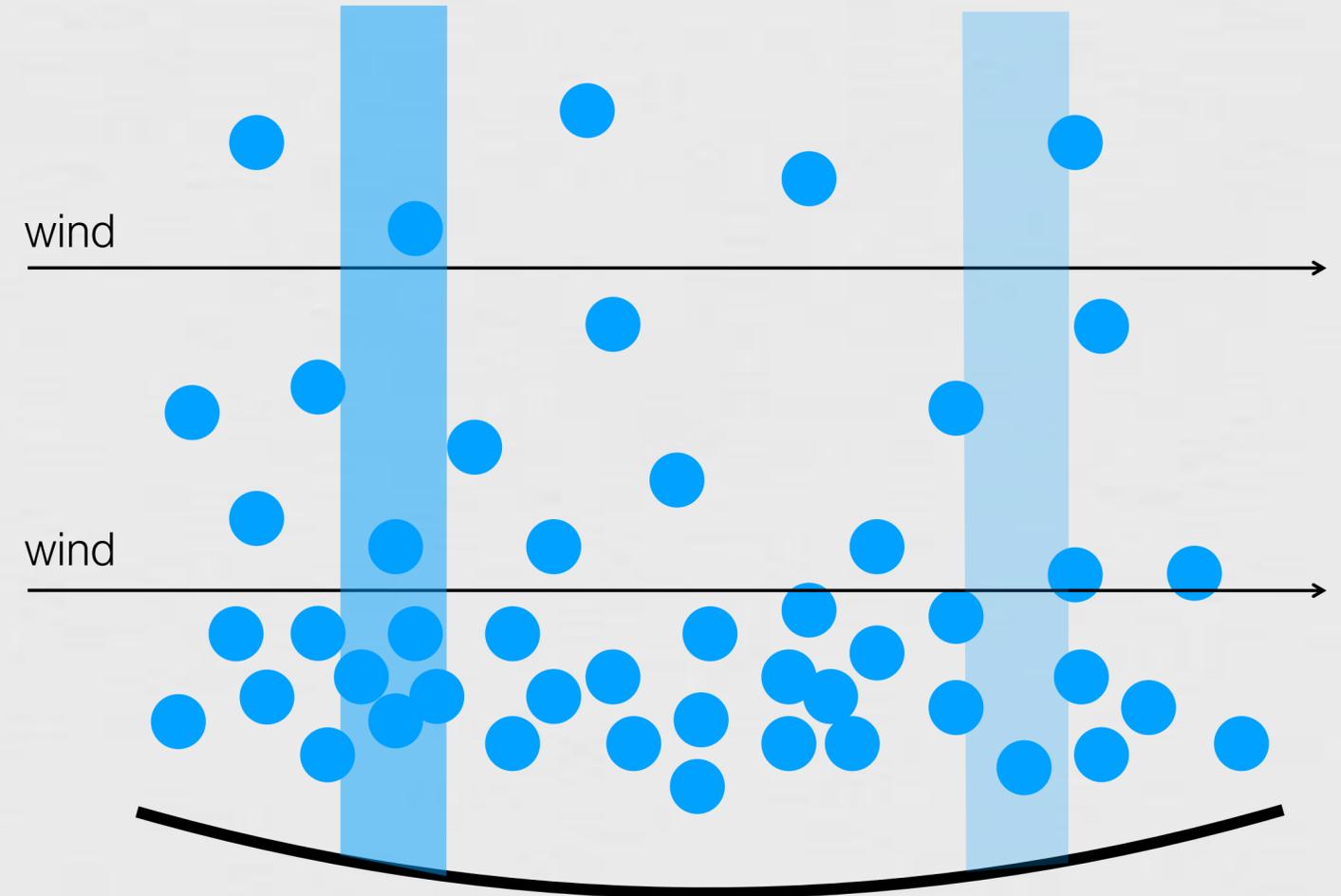
ONE DOES NOT SIMPLY

CORRECT FOR NCPA IN MID-IR

imgflip.com

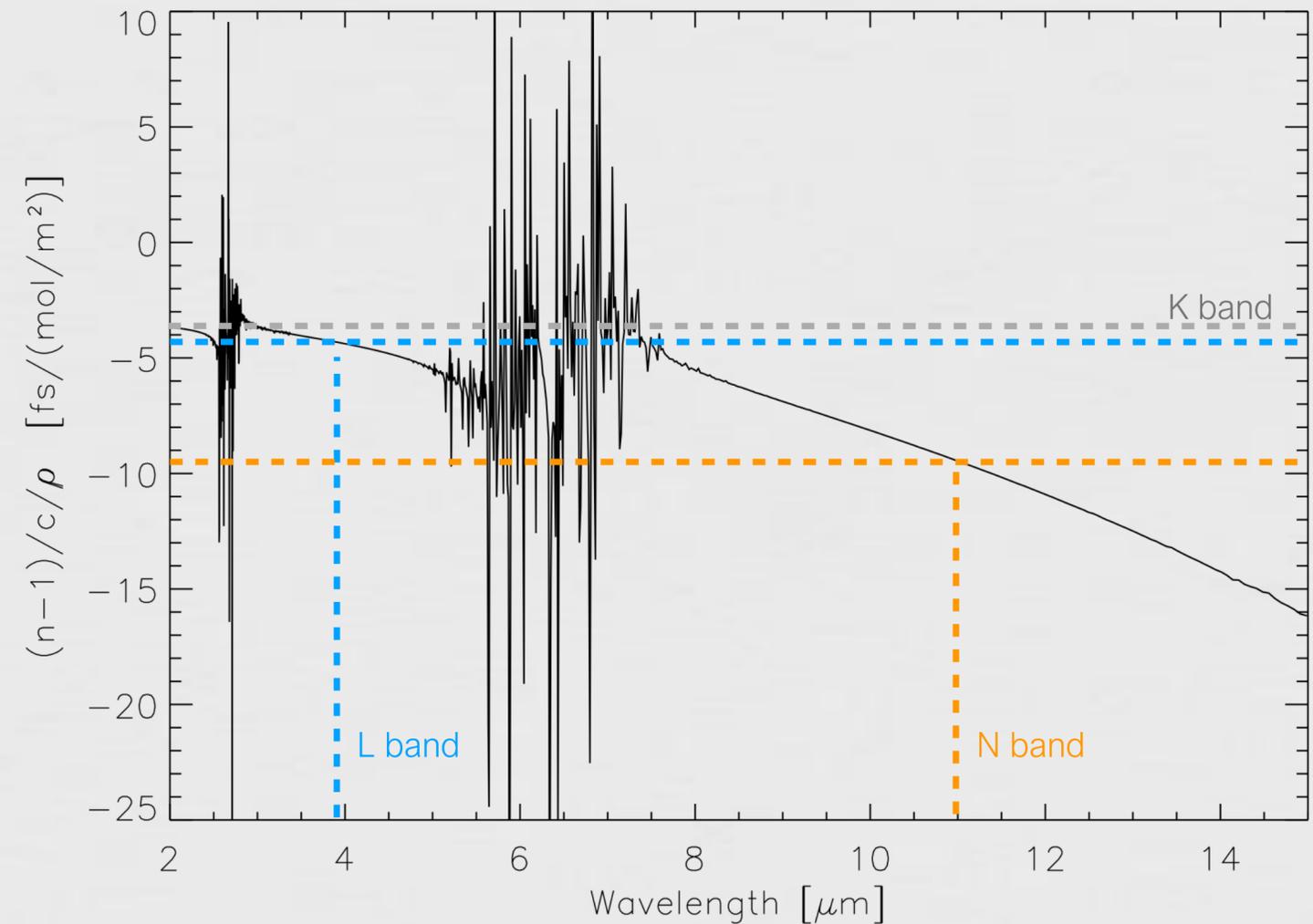
Water vapor seeing

- WV column density is variable
- Expected to follow Kolmogorov - von Karman spectrum
- Highly chromatic, especially in mid-IR
 - AO correction at K band not valid at L/N bands



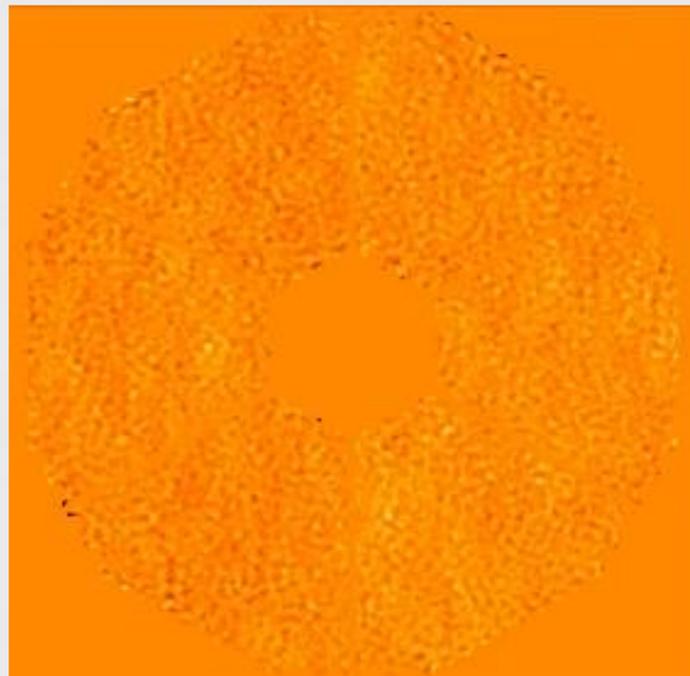
Additional path length: 'water displacing air'

- Holding P (and T) constant,
added humidity reduces dry air
- $\hat{n}_{\text{WDA}} = \hat{n}_{\text{WV}} - \hat{n}_{\text{air}}$
 - $\hat{n}_{\text{WDA}}(\text{L} - \text{K}) = 0.5 \text{ fs} / (\text{mol}/\text{m}^2)$
 - $\hat{n}_{\text{WDA}}(\text{N} - \text{K}) = 6 \text{ fs} / (\text{mol}/\text{m}^2)$



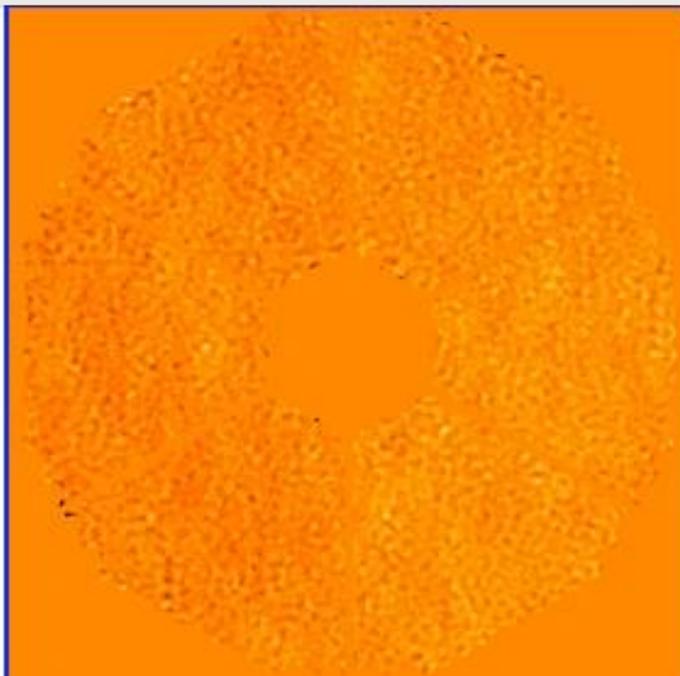
Adding WV to adaptive optics residuals

AO only



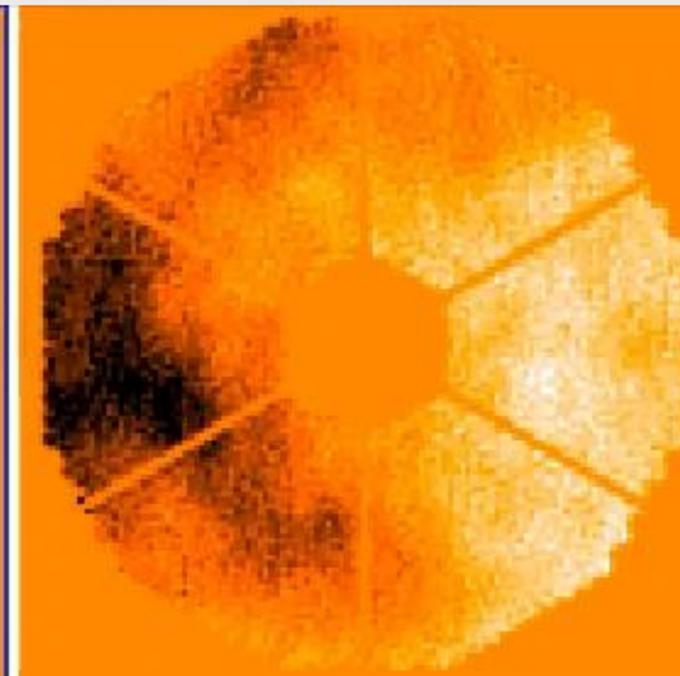
~140 nm RMS WFE

AO + WV (L band)



~25 nm RMS additional WFE

AO + WV (N band)

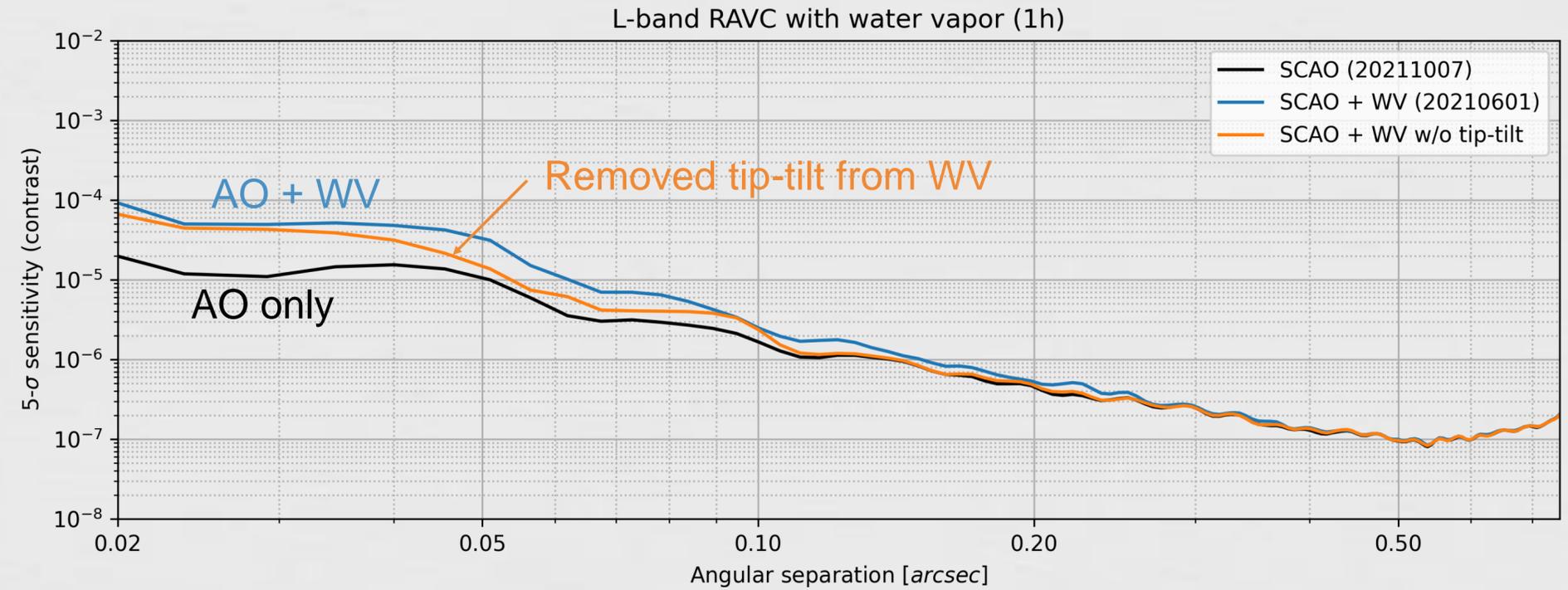


~300 nm RMS additional WFE

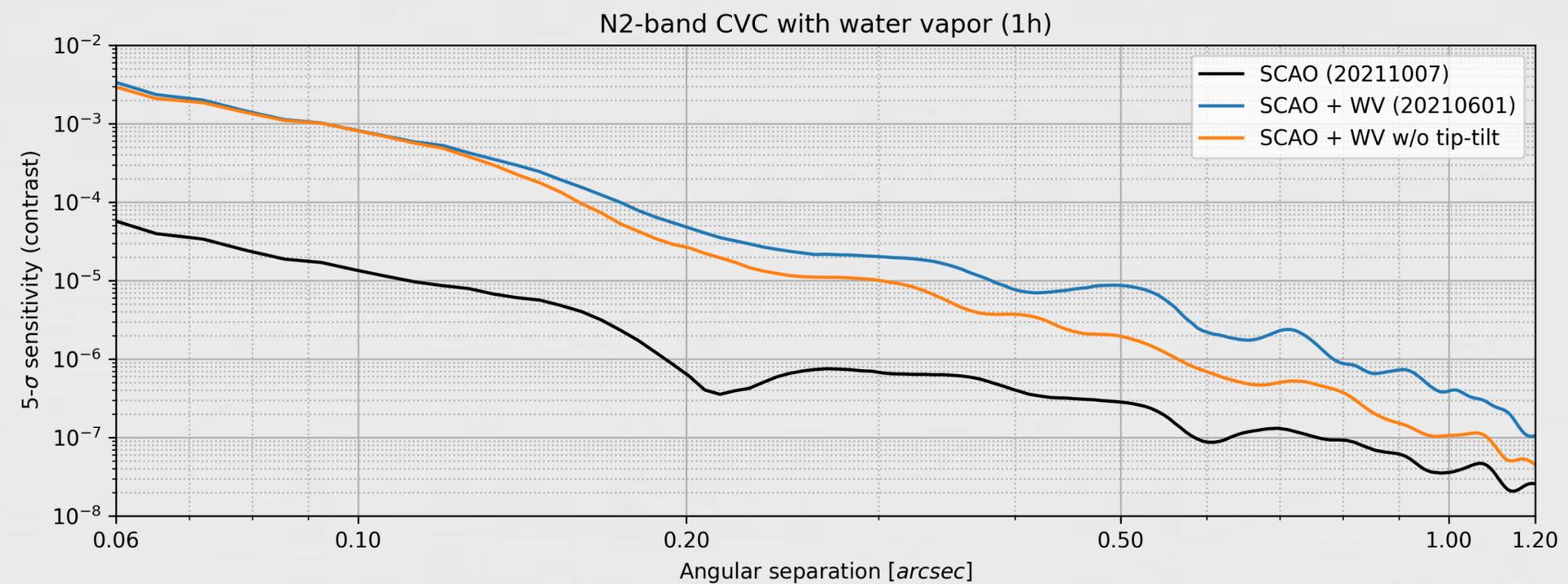
Strongly dominated by low spatial frequencies (Kolmogorov - von Karman)

Effect on HCI Performance

L band



N band

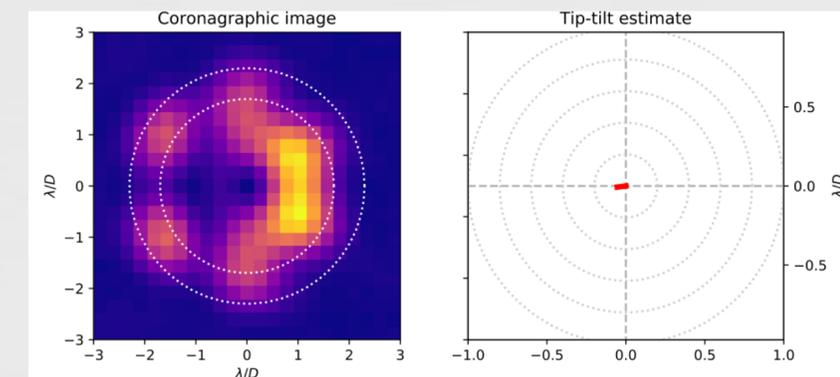
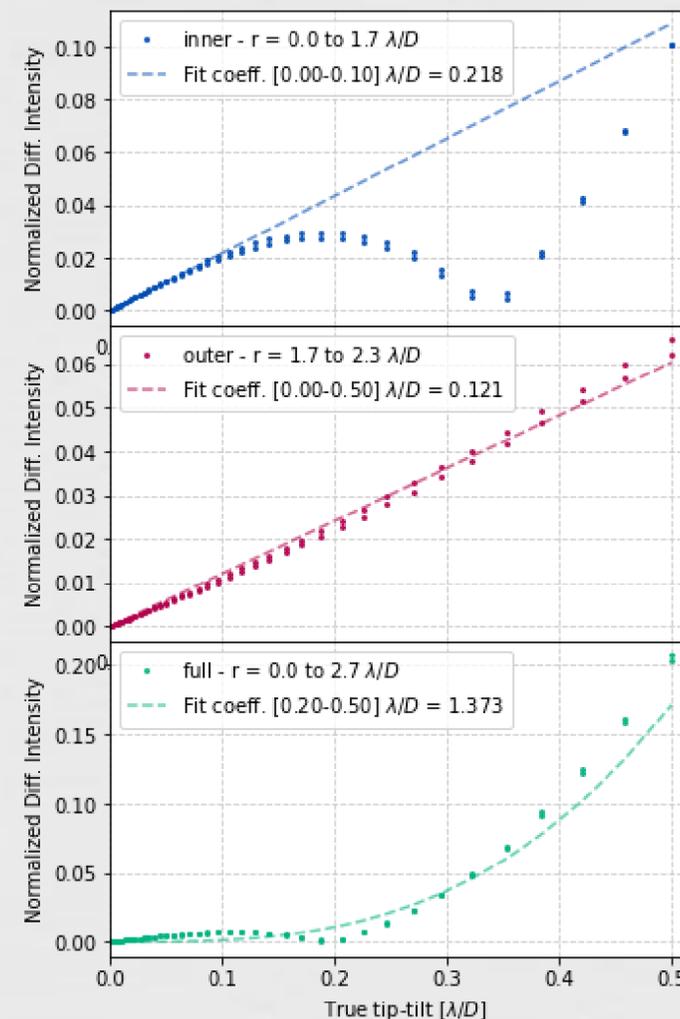
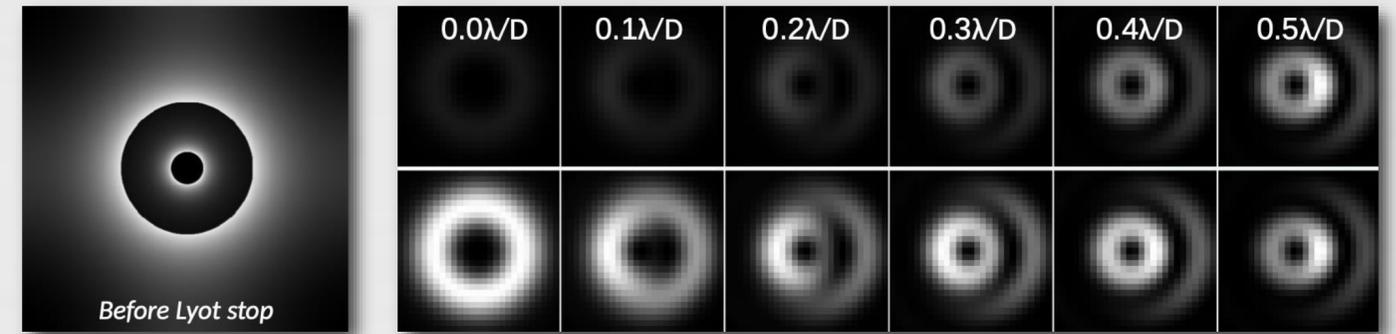


Mitigation plan for METIS

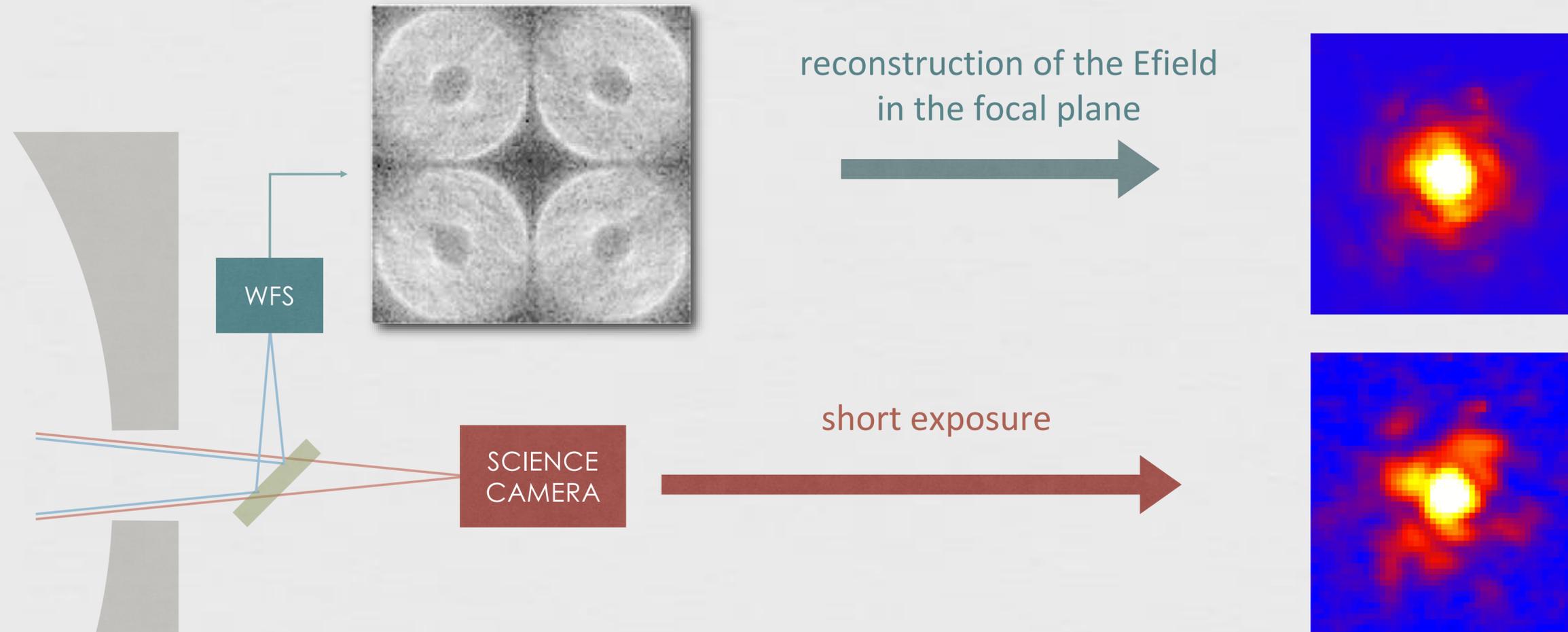
- Science images fed back to AO system for focal-plane wavefront sensing @ 1 Hz
- Pointing errors: **QACITS**
 - uses asymmetry in coronagraphic PSF
- Next ~100 Zernike modes: **Phase Sorting Interferometry**
 - uses phase diversity introduced by AO residuals
 - PSI output introduced as slope offsets in Pyramid WFS

Pointing Control with QACITS

- Tailored to vortex coronagraph
- Reconstruct pointing error with nonlinear model
- Demonstrated accuracy $\sim 0.01 \lambda/D$ On-sky : Keck, VISIR/NEAR, and soon on ERIS

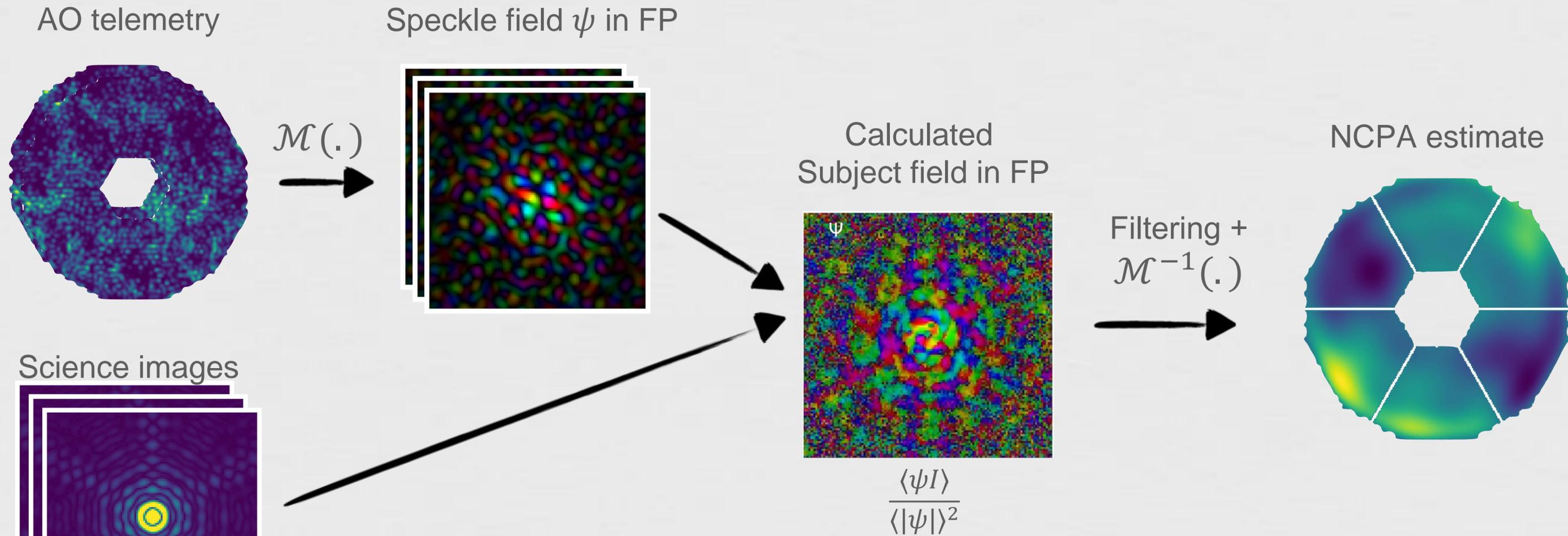


NCPA Control with PSI



- 100% duty cycle
- Reference beam or 'probes' are the known AO residual speckles
- Use SCAO residuals as source of diversity to infer pixel-wise amplitude and phase of NCPA

PSI algorithm in a nutshell



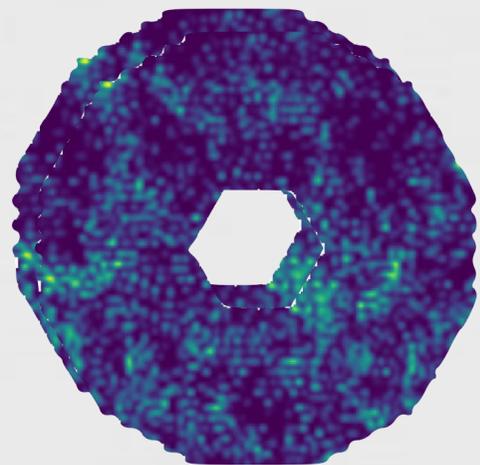
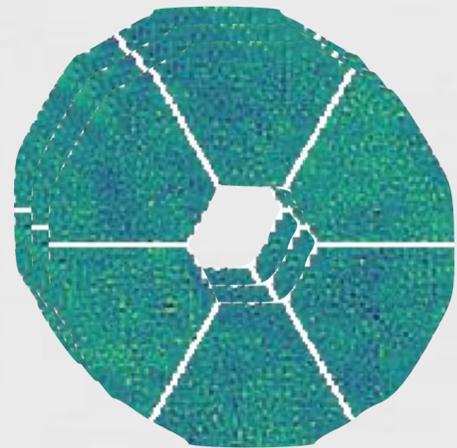
Typical numbers for METIS

PSI rate	1Hz
AO rate & telemetry	1kHz, 100Hz
Science DIT	100ms

METIS PSI simulation setup

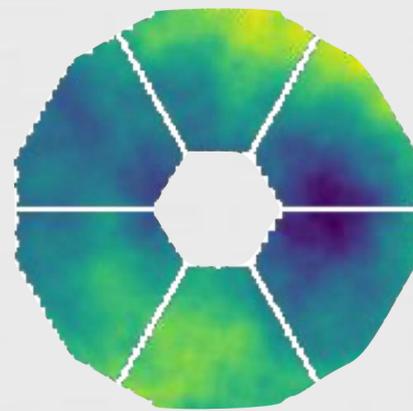
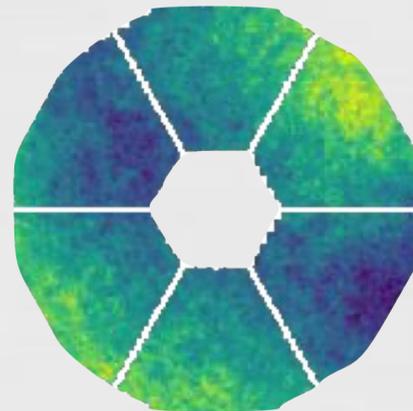
Run SCAO METIS COMPASS

- Save residual wavefront
- Save WF telemetry

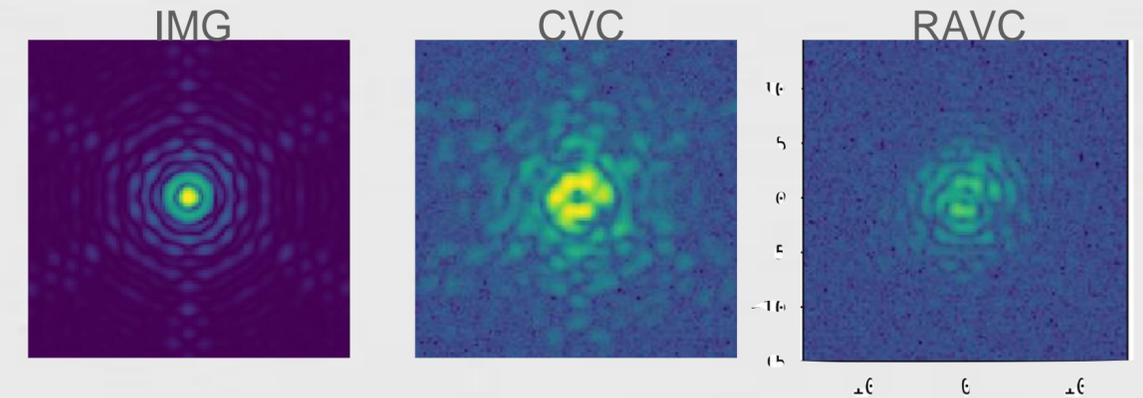


Add variable "NCPA"

- Phase map provided by Optics Team
- Water vapour seeing (Kolmogorov phase screens)



Simulate instrument mode and run PSI simulation



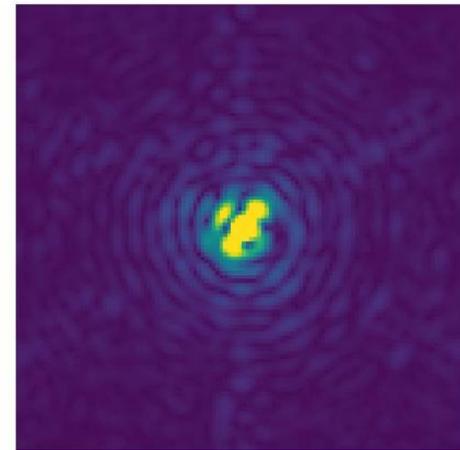
	L-band	N-band
Pupil plane diameter [px]	256	256
Resolution [px / (λ/D)]	4	9
Detector size [λ/D]	15	15 / 20
Wavelength	3.81e-6	11.33e-6
Flux zeropoint [e-/s]	8.999e+10	3.695+10
Background flux [e-/s/px]	8.878e+4	1.122e+8
Science DIT [sec]	0.1	0.04
Magnitude	6	0
Instrument mode	IMG or RAVC	IMG or CVC
Spatial filtering radius [λ/D]	10	10-17
PSI framerate [Hz]	1	0.1 - 1
Number of corrected Zernike modes	100	100

Results

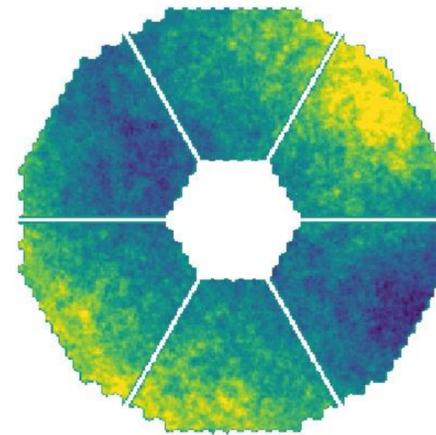
Illustrations

Level of aberrations exaggerated

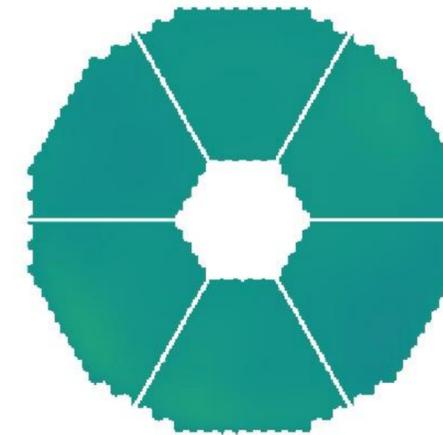
Static NCPA



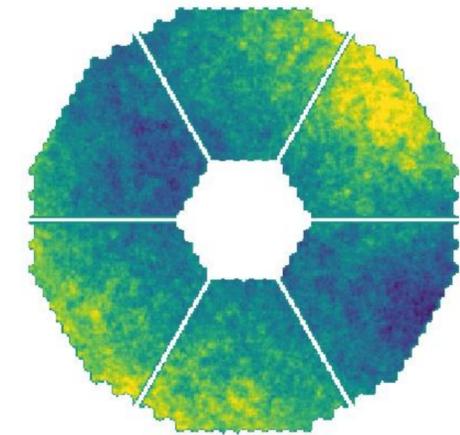
static NCPA



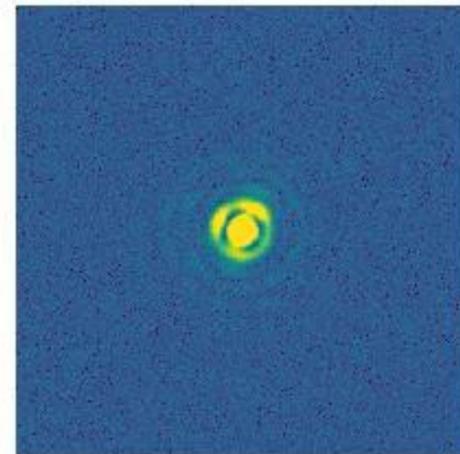
NCPA correction



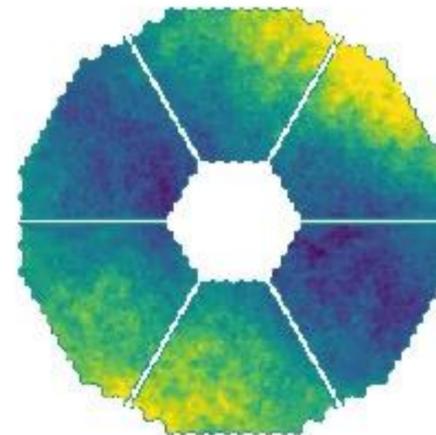
Residuals



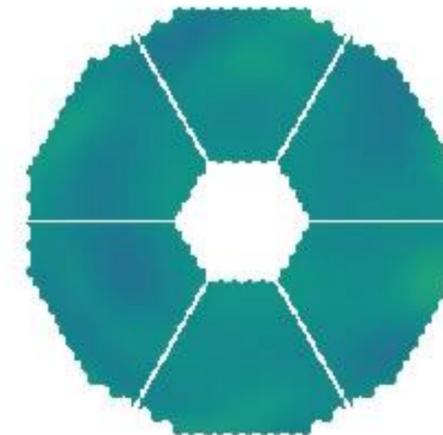
Static NCPA + Water vapour seeing



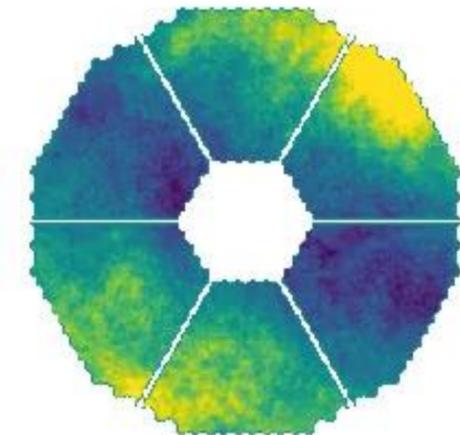
static NCPA + WV



NCPA correction



Residuals

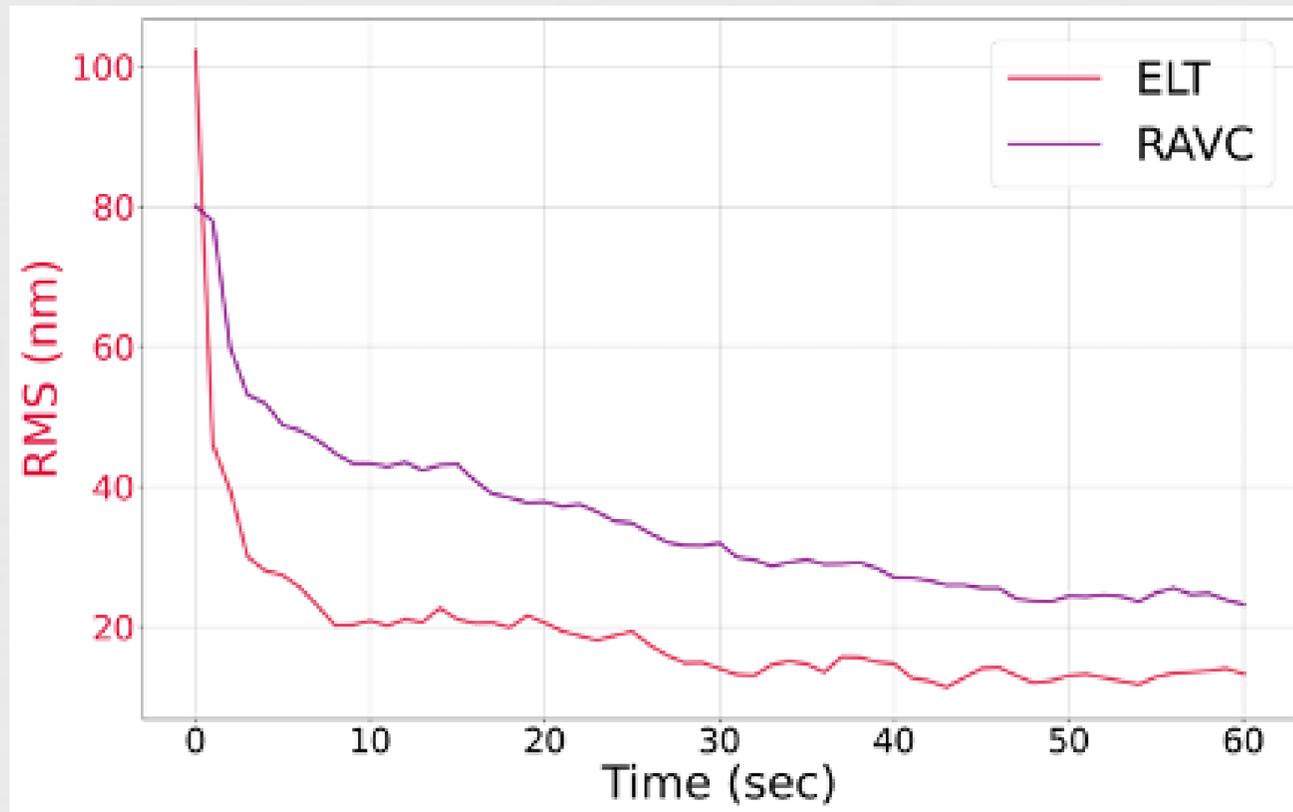


Results

RMS Plots

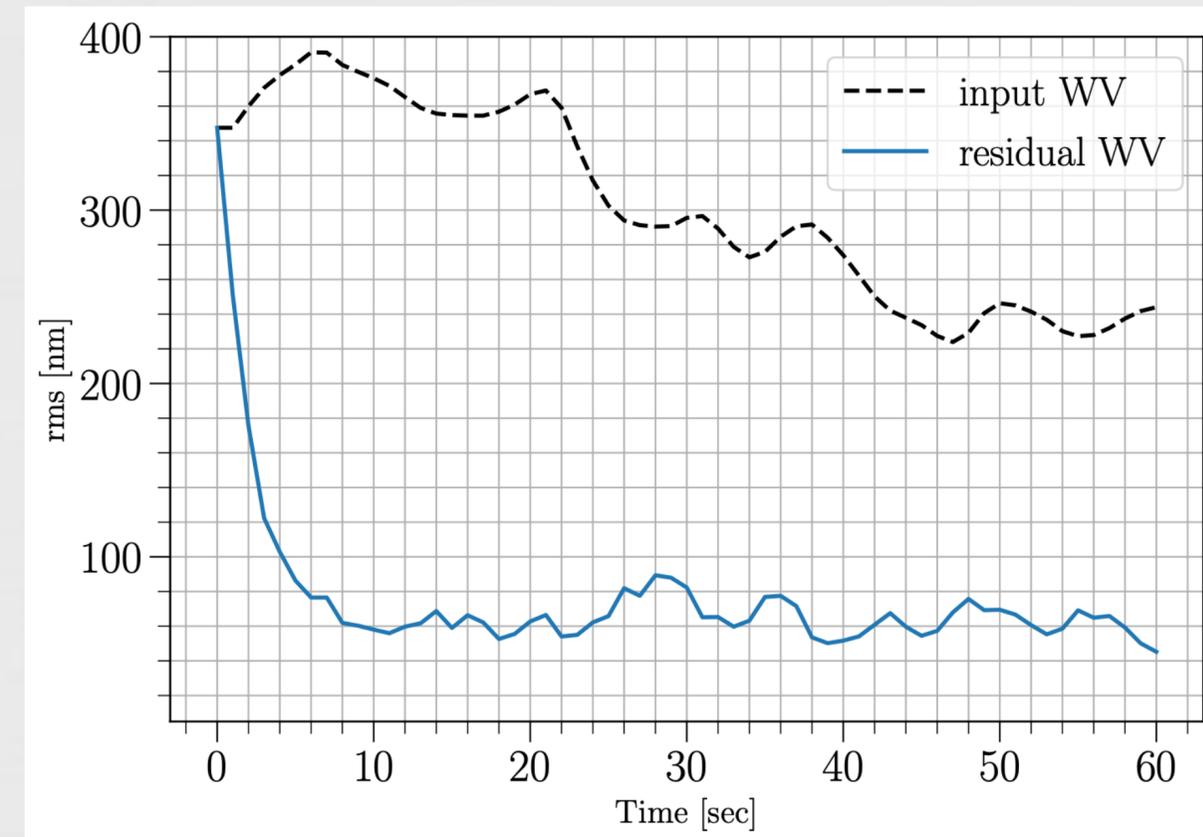
Static NCPA in L-band

*Reaching $< \sim 20\text{nm rms}$
for both IMG and RAVC*



N-band with “slow” (10x) water vapour

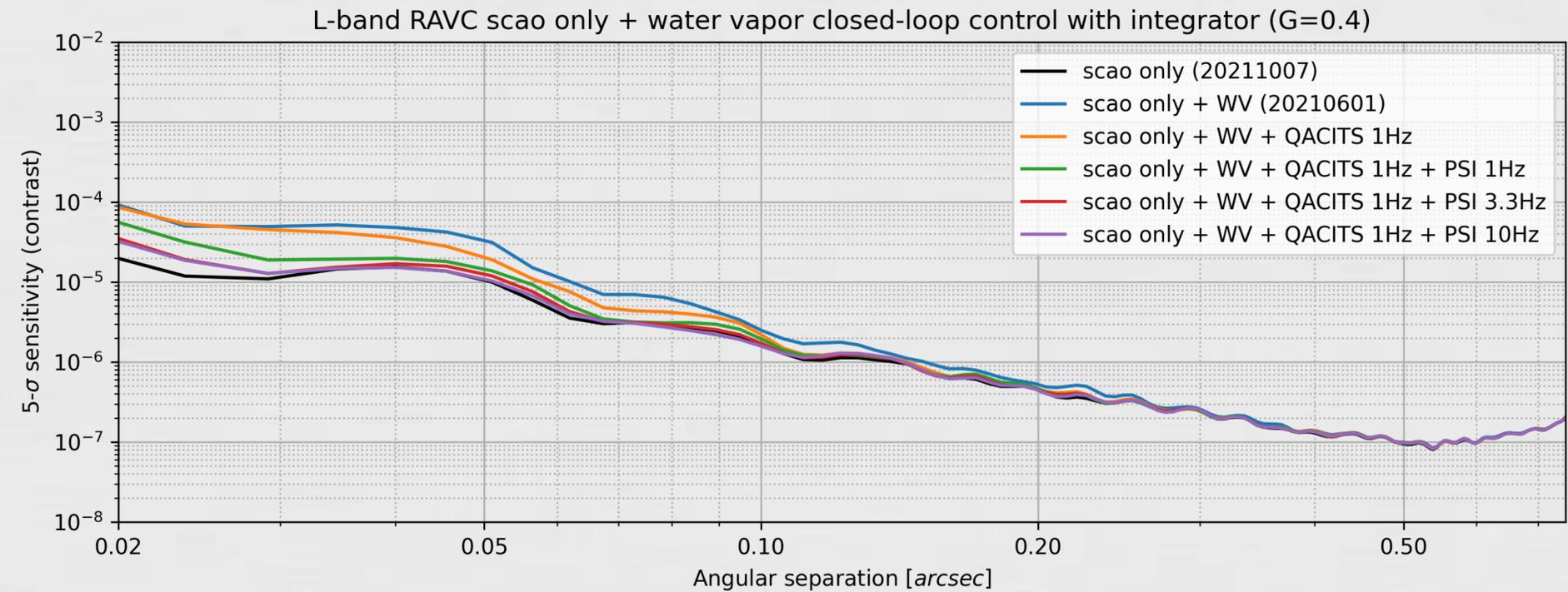
Reaching $< \sim 60\text{nm rms}$



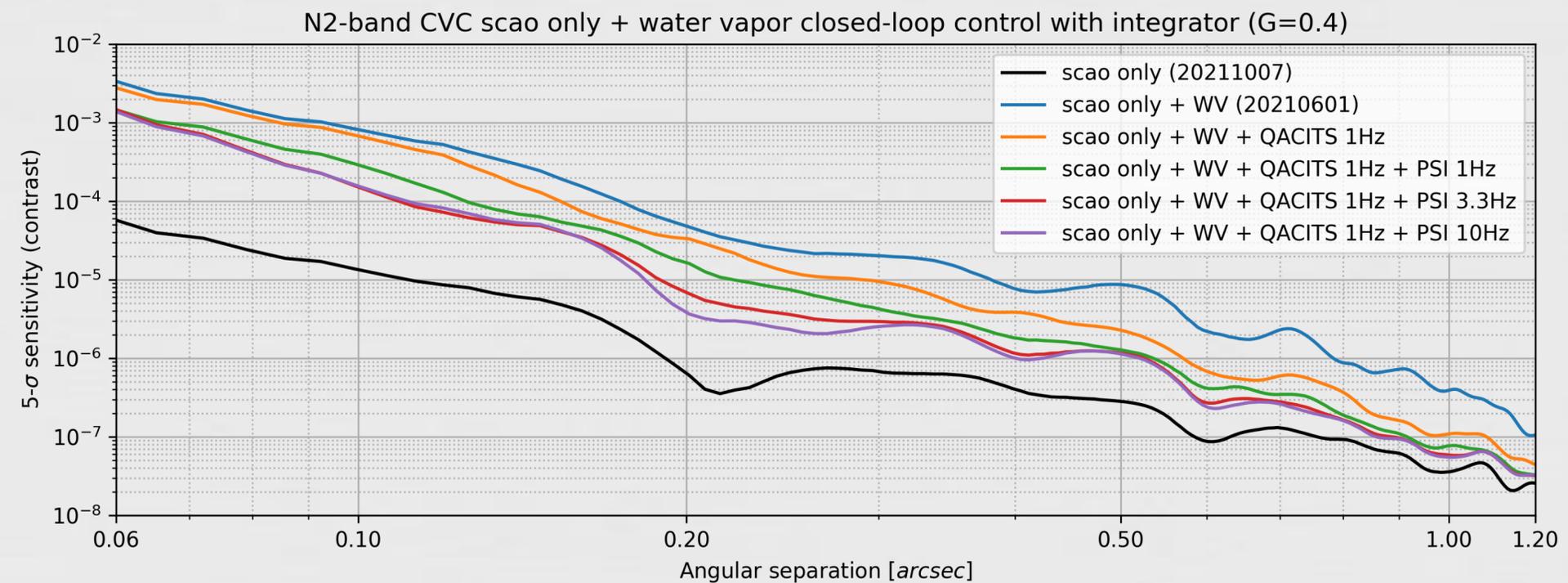
Probe field and subject beam cannot have the same temporal behaviour

Expected performance improvement

L band

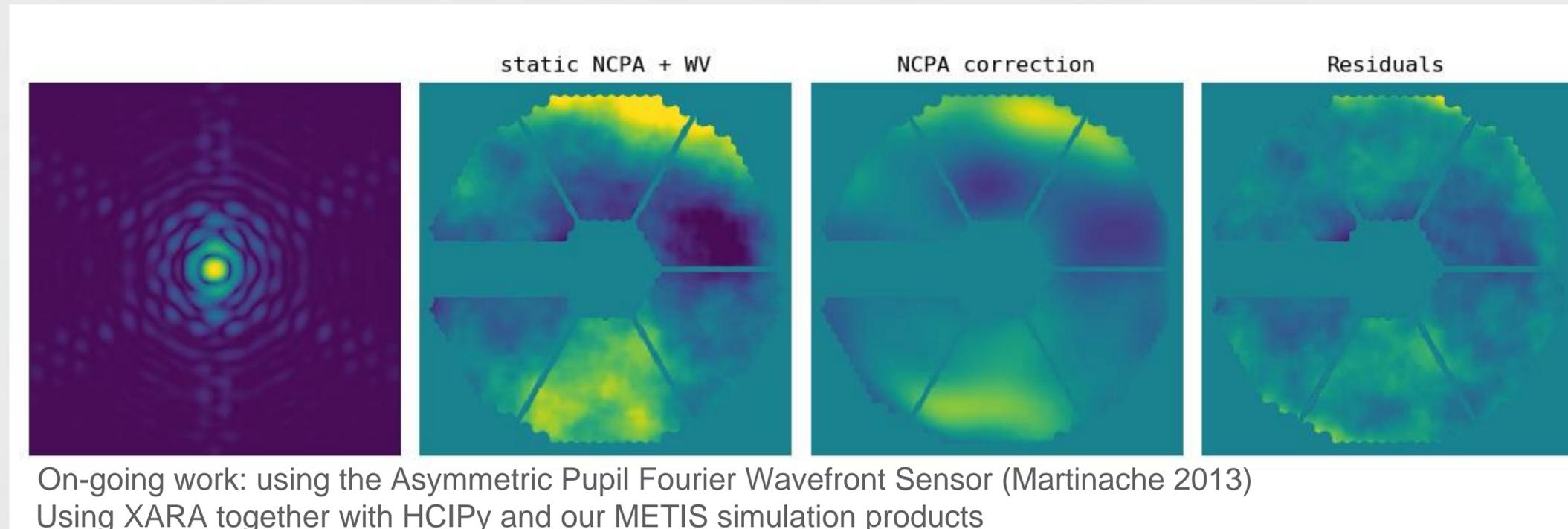


N band



An Alternative to PSI in N-band ?

Asymmetric mask (pupil or Lyot) to lift phase ambiguity



Key questions:

- Sensitivity limit (size of asymmetric arm, temporal aspect / WV rejection)
- Asymmetric Lyot stop + Vortex coronagraph

Expect the Unexpected!



(and let's keep our fingers crossed until then)

