2024 Sagan Summer Workshop

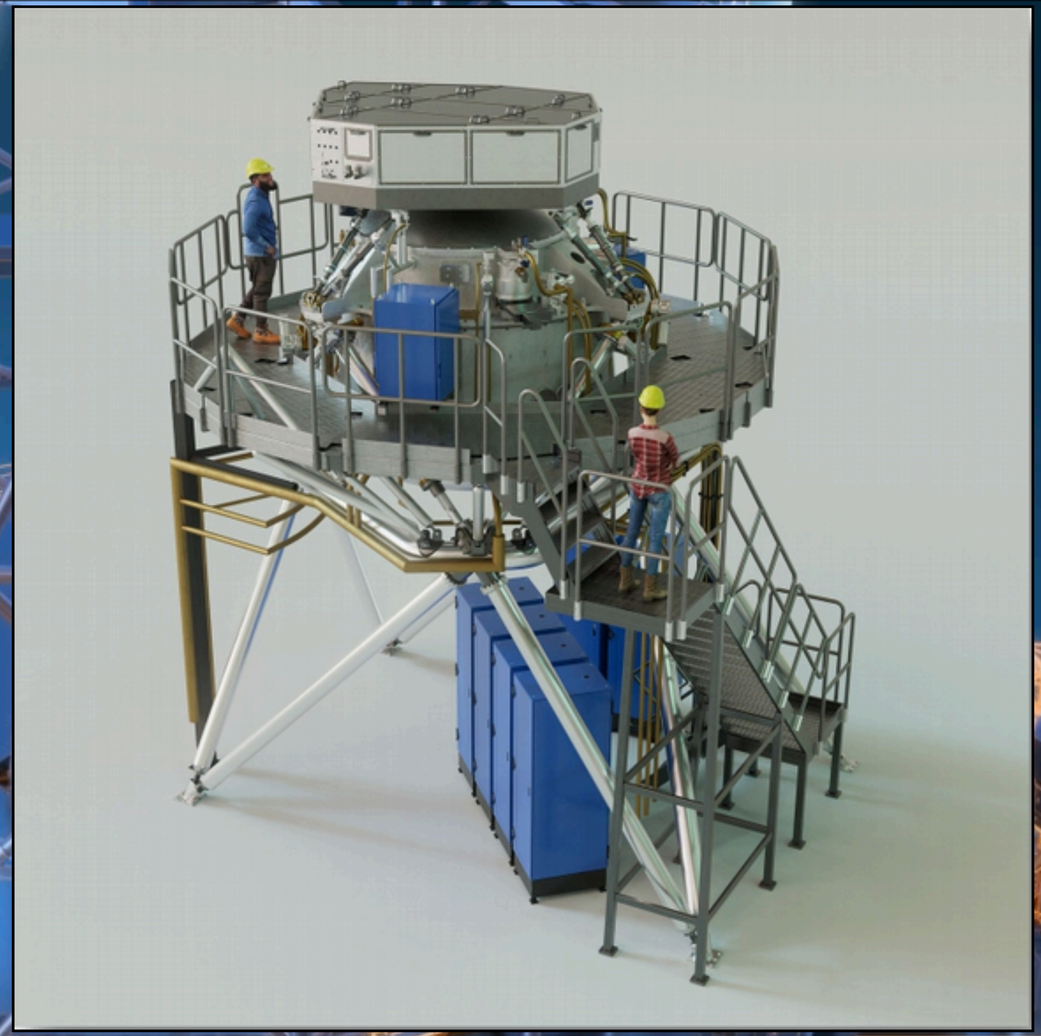
The ELT METIS instrument

Gilles Orban de Xivry & METIS consortium
University of Liège, Belgium

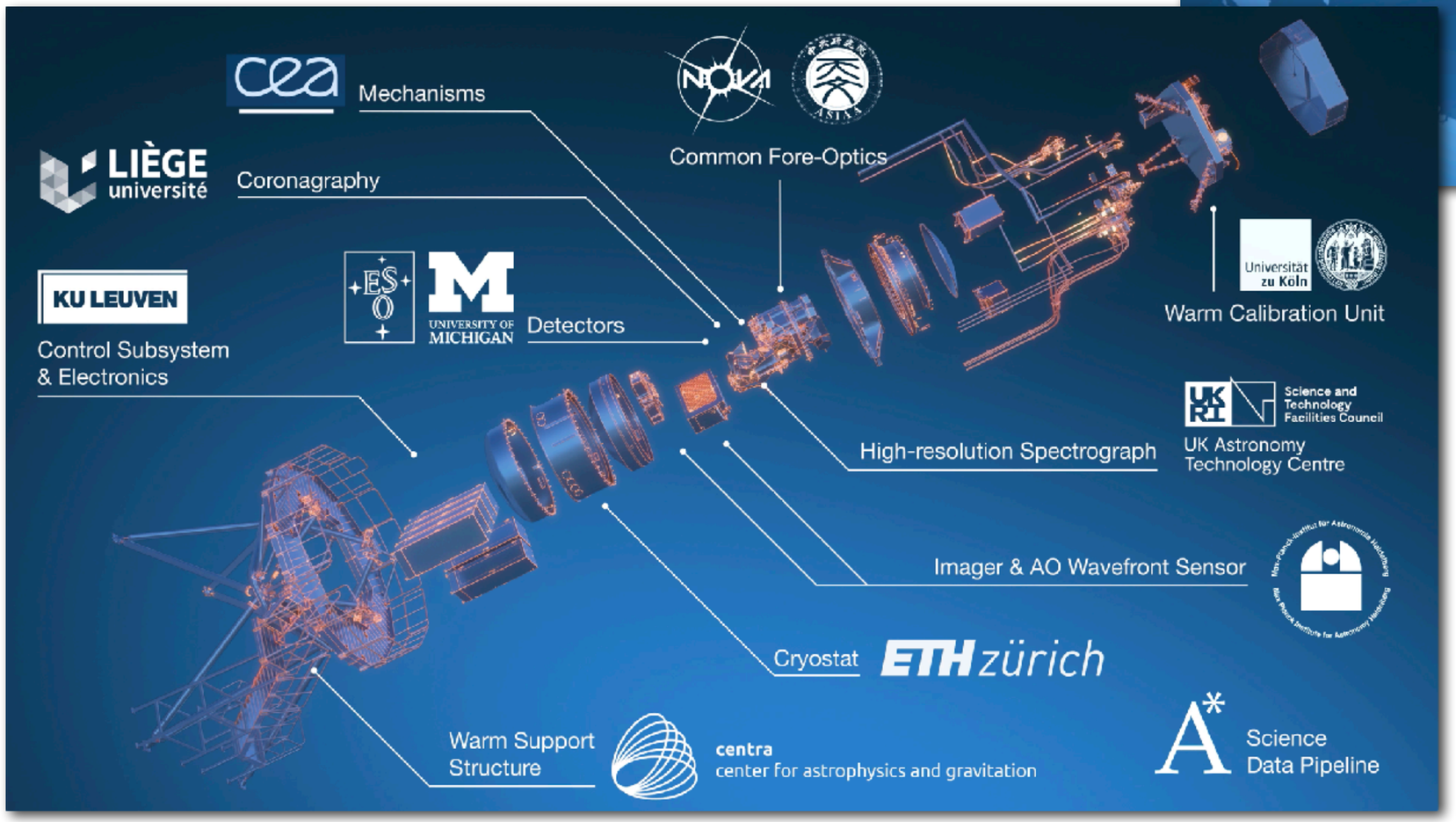
centra
center for astrophysics and gravitation

Science and Technology Facilities Council
UK Astronomy Technology Centre

Mid-infrared ELT imager and spectrograph



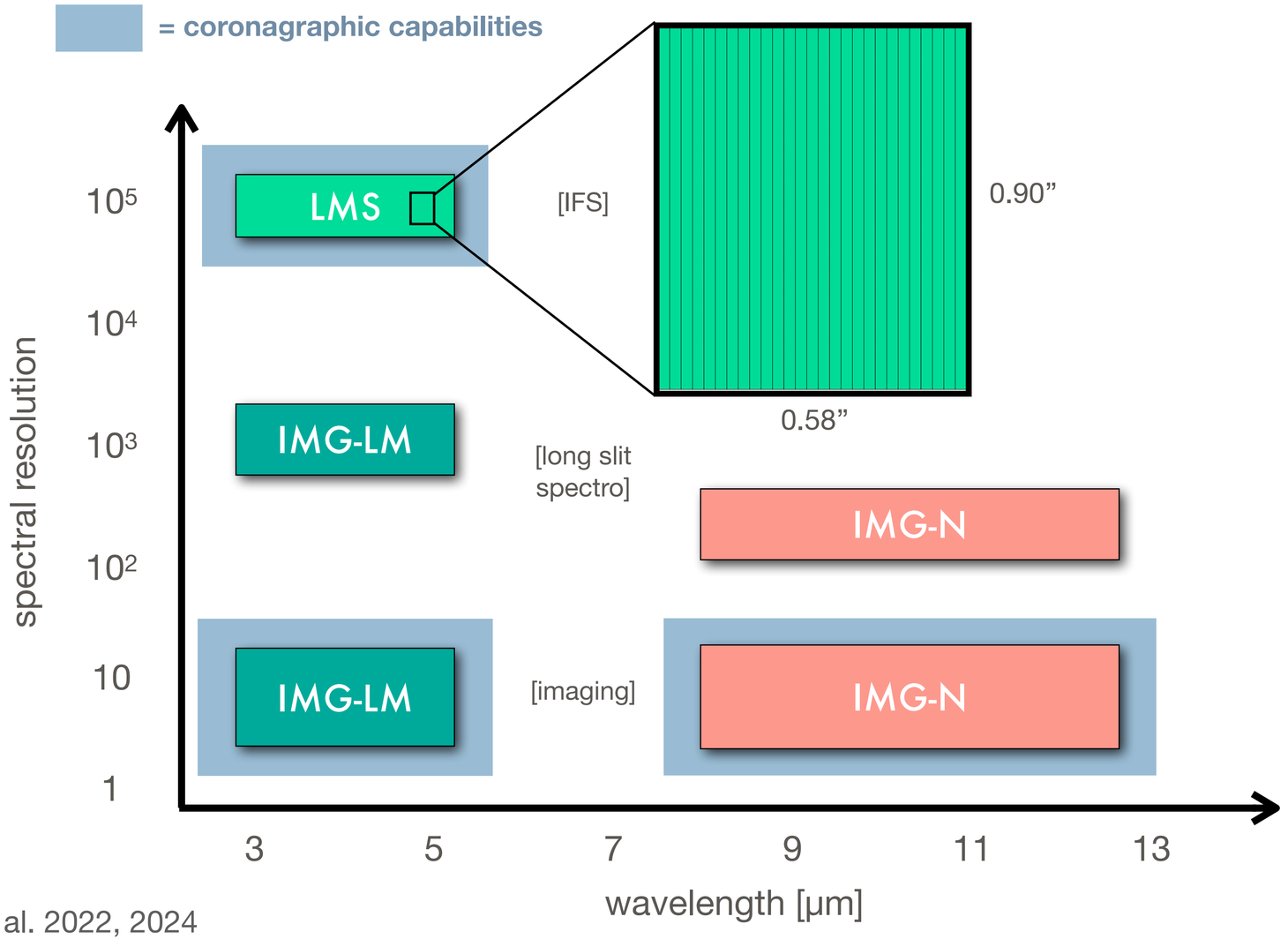
A consortium of 12 institutes

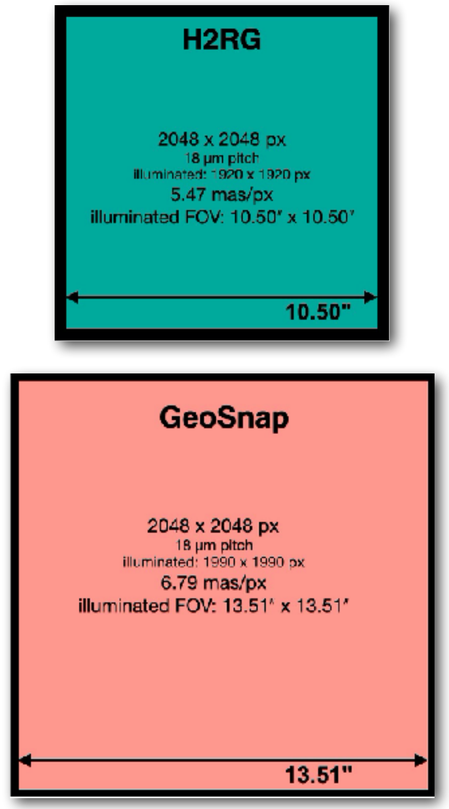


Altogether approximately:
~25 M€
~700 FTEs in labor

METIS instrument baseline

ALL MODES WORKING AT ELT'S DIFFRACTION LIMIT USING SCAO

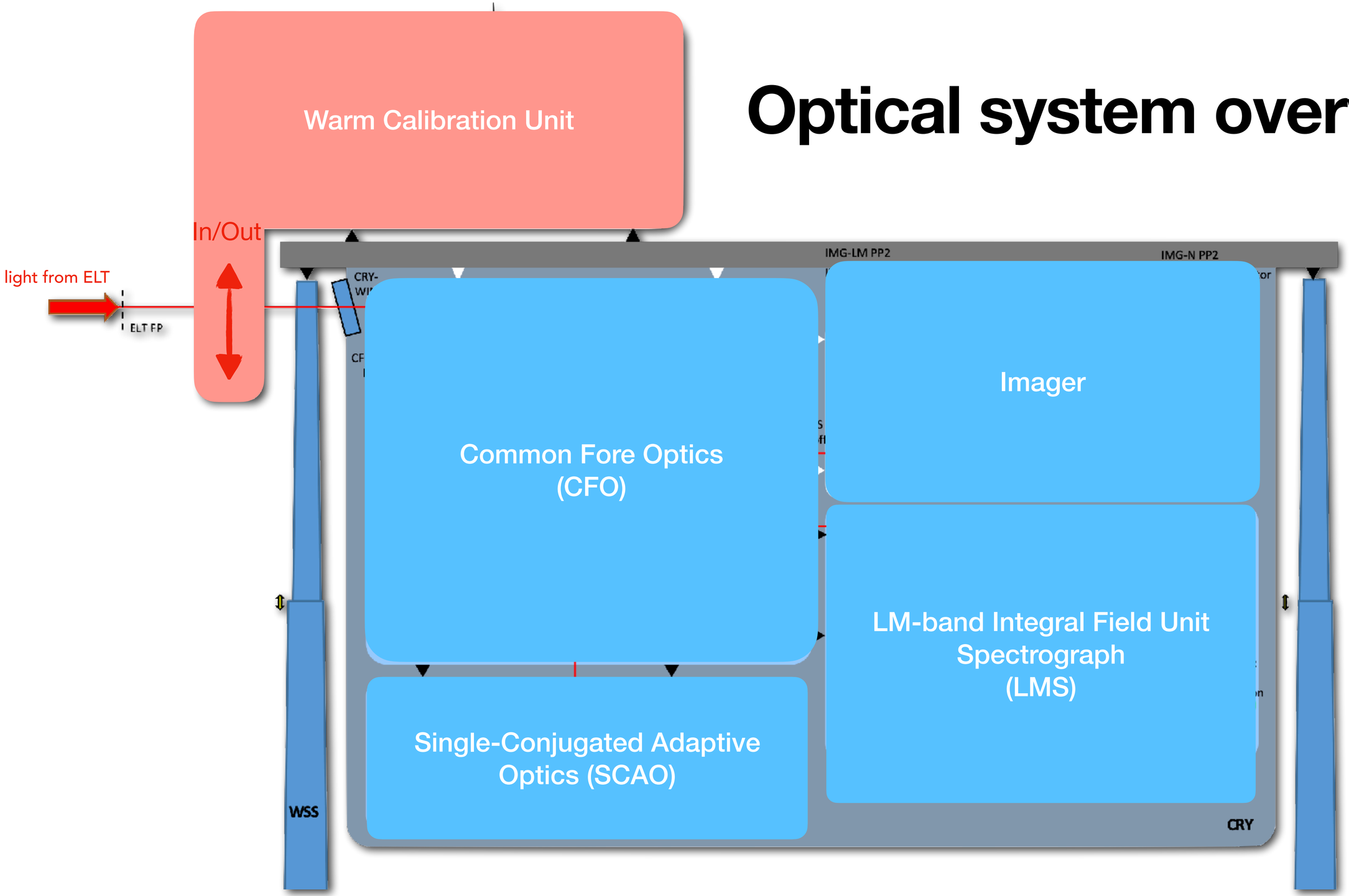




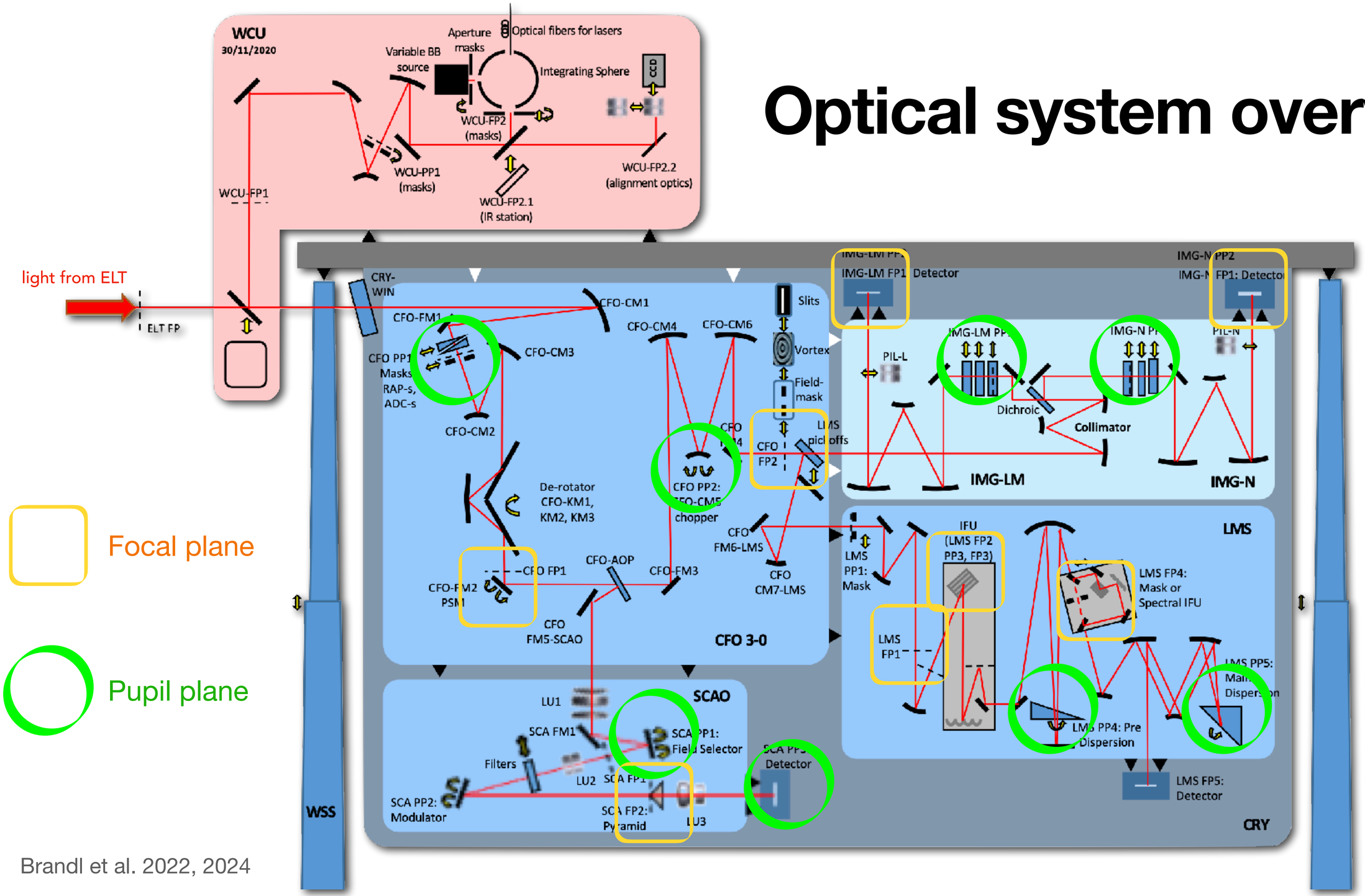
IMG detectors

Brandl et al. 2022, 2024

Optical system overview



Optical system overview

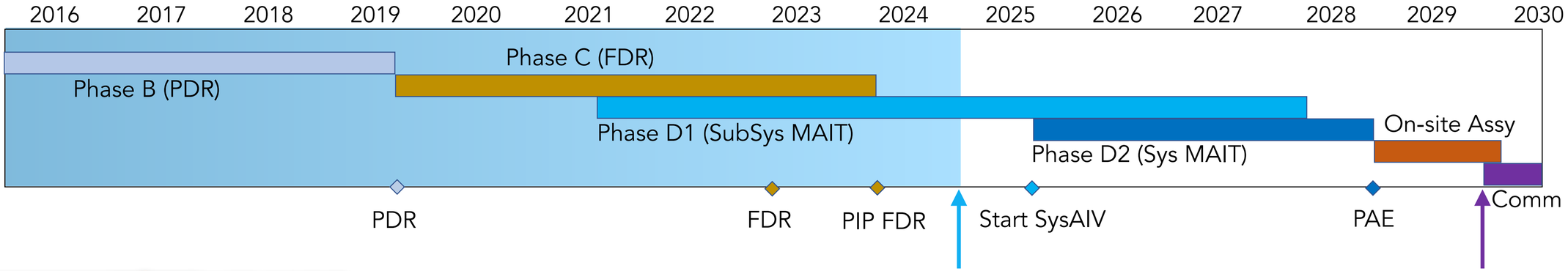


Focal plane

Pupil plane

Brandl et al. 2022, 2024

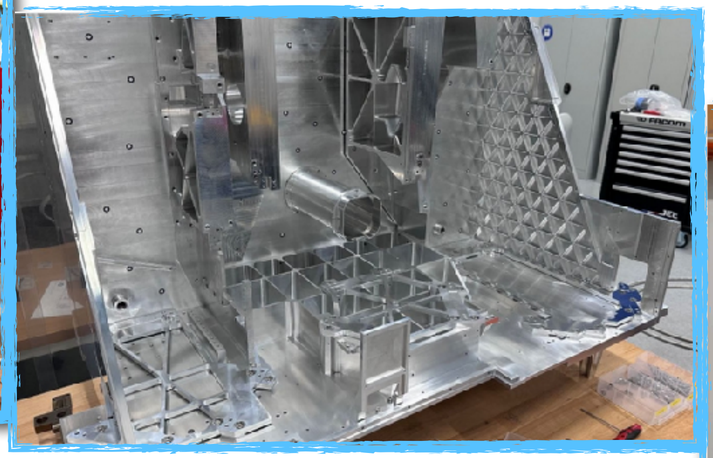
METIS timeline



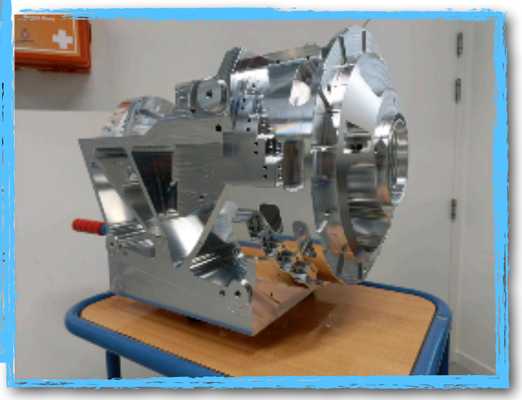
now: working on subsystems MAIT

first light mid-2029

Cryostat @ Zürich



Imager backbone @ Heidelberg



Derotator @ Dwingeloo

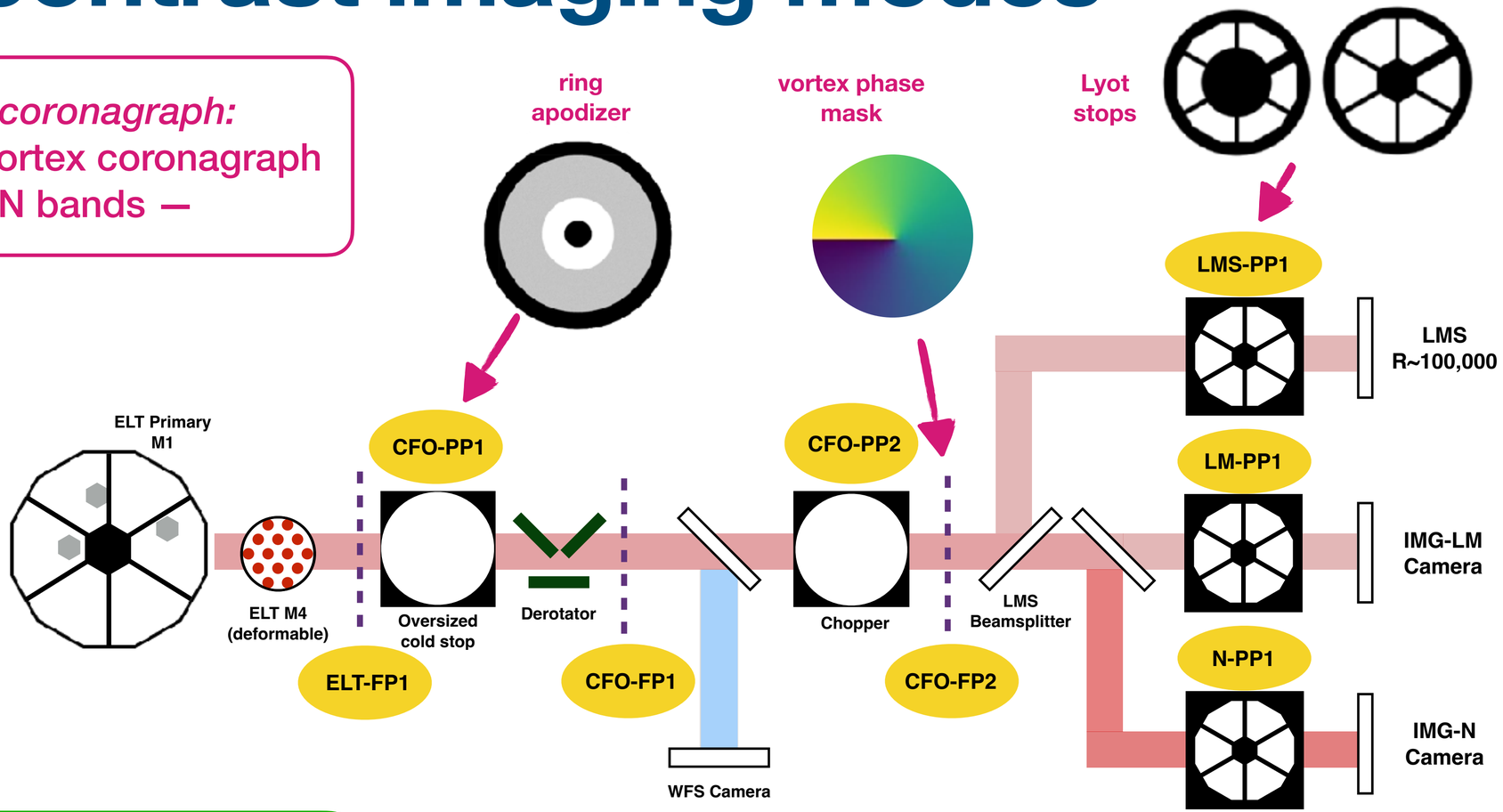
Integration hall getting ready @ Leiden

High-contrast imaging modes

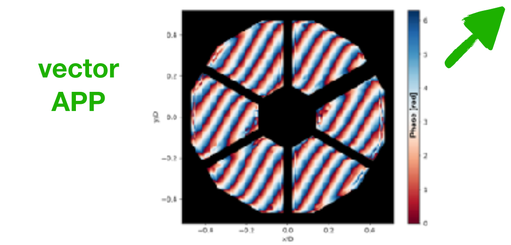
Focal plane coronagraph:
(ring-apodized) vortex coronagraph
— L, M & N bands —

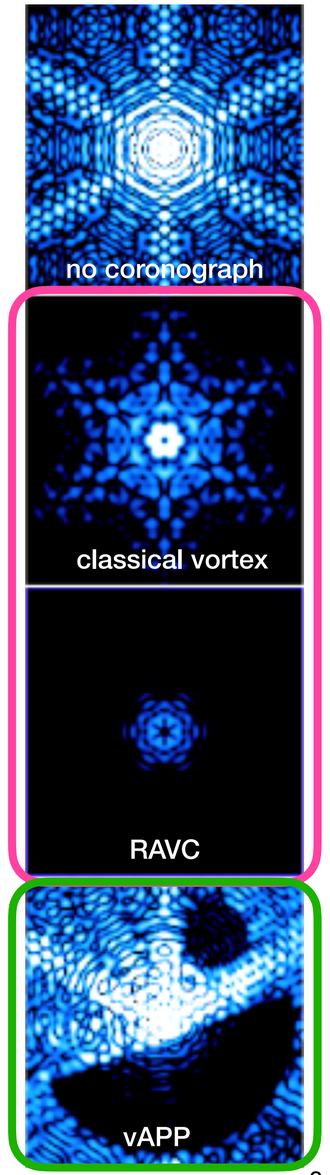
FP: focal plane

PP: pupil plane

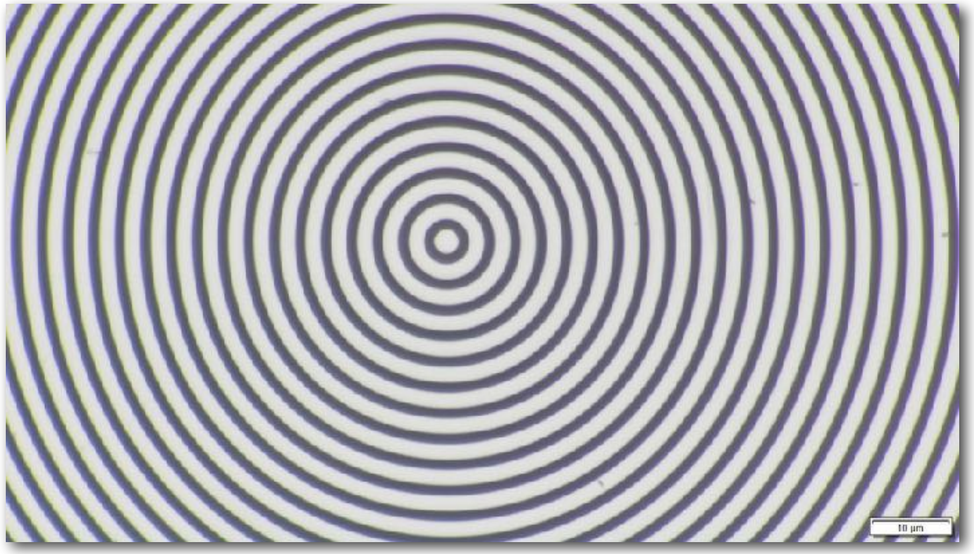


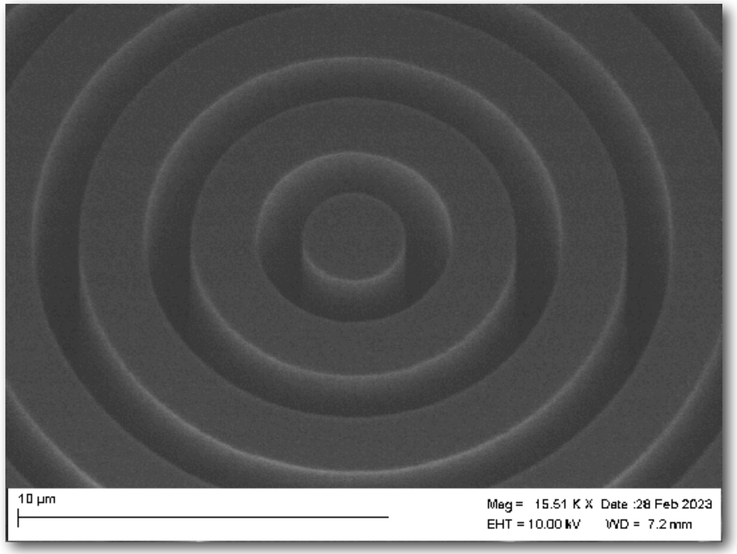
Pupil plane coronagraph:
apodizing phase plate
— L & M bands —

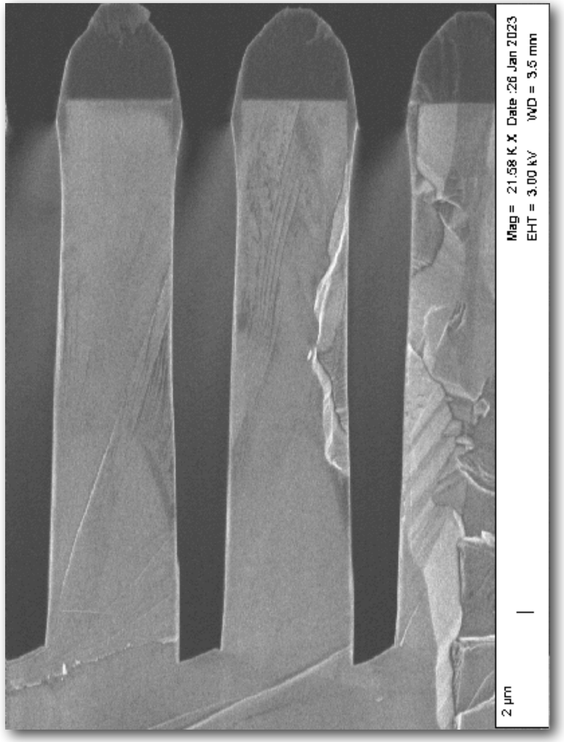


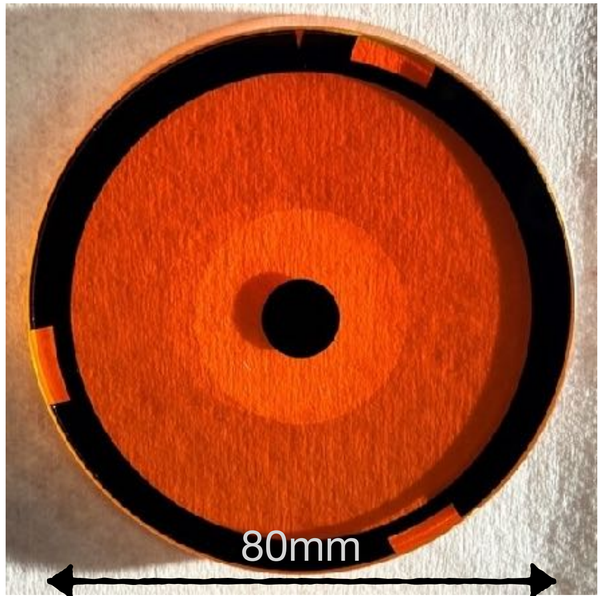


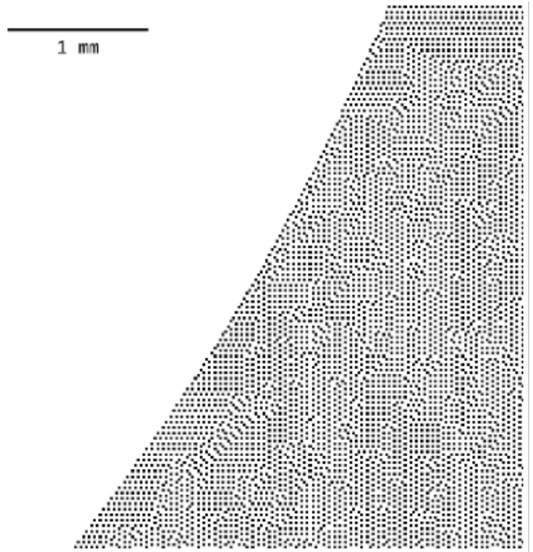
On-going procurements







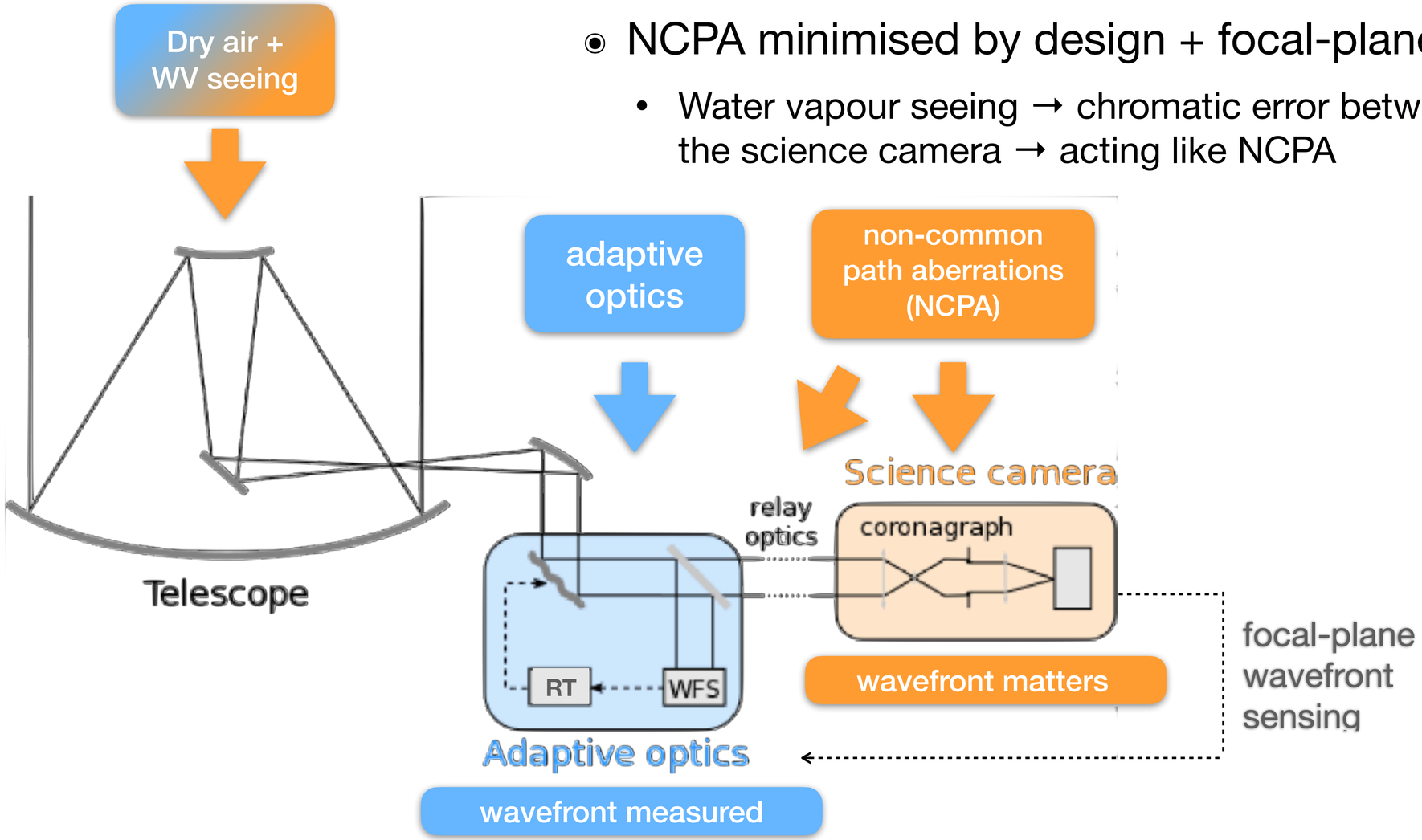




- Vortex phase masks: Uppsala Univ. (Forsberg et al. 2024, Delacroix et al. 2024)
  - reactive ion etching on synthetic diamond
- Ring apodizer: Opto-Line (König et al., 2024)
  - microdot chrome deposition on SiO-coated ZnSe substrate (on-going)
- Grating-vector APP: ColorLink Japan

Wavefront control strategy

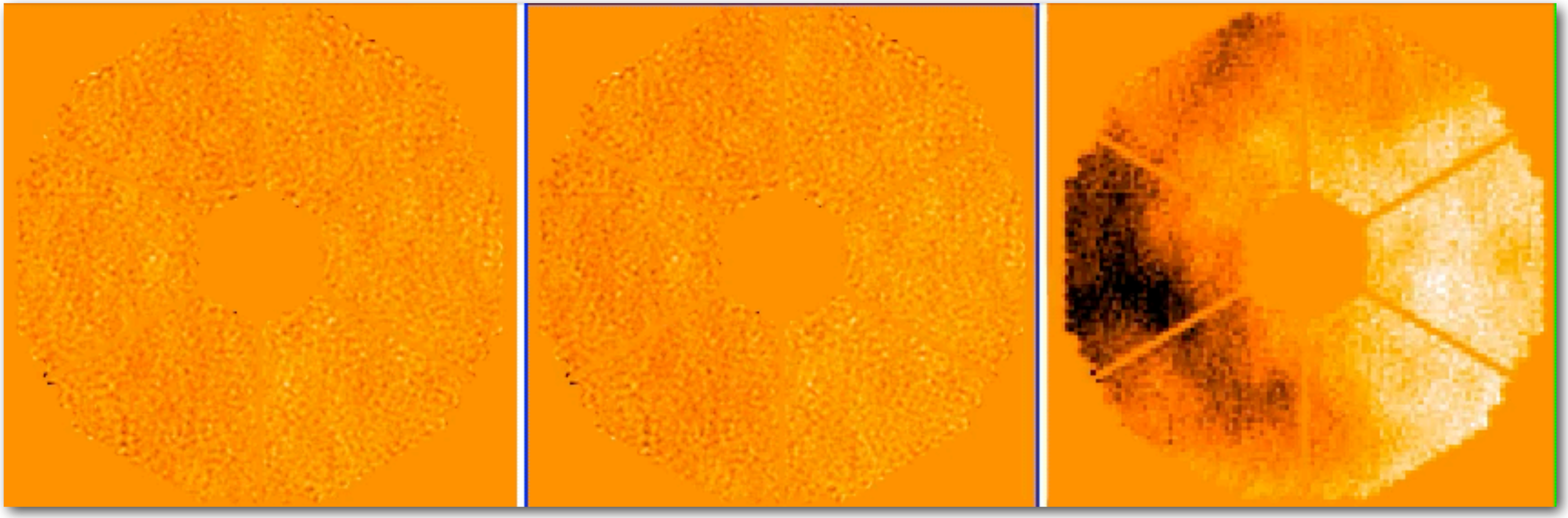
- SCAO provides > 90% Strehl at LMN bands
- NCPA minimised by design + focal-plane WFS
  - Water vapour seeing → chromatic error between the AO and the science camera → acting like NCPA



Adding WV seeing to AO residuals

METIS adaptive optics simulations

AO only | AO + WV (L band) | AO + WV (N band)



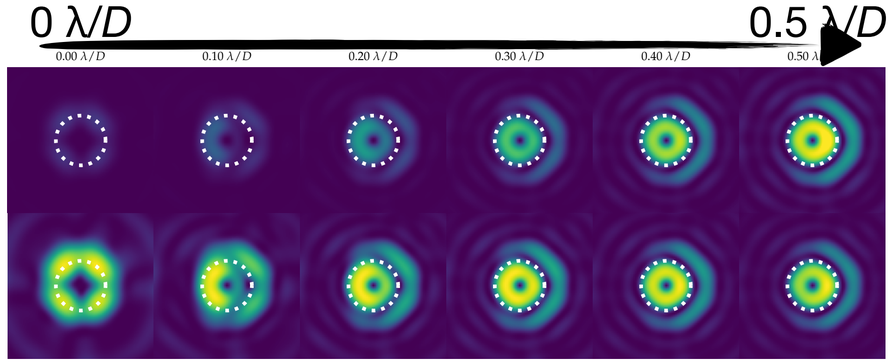
~140 nm RMS WFE | ~25 nm RMS additional WFE | ~300 nm RMS additional WFE

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

Absil et al., 2022

Focal plane wavefront sensing (FPWFS)

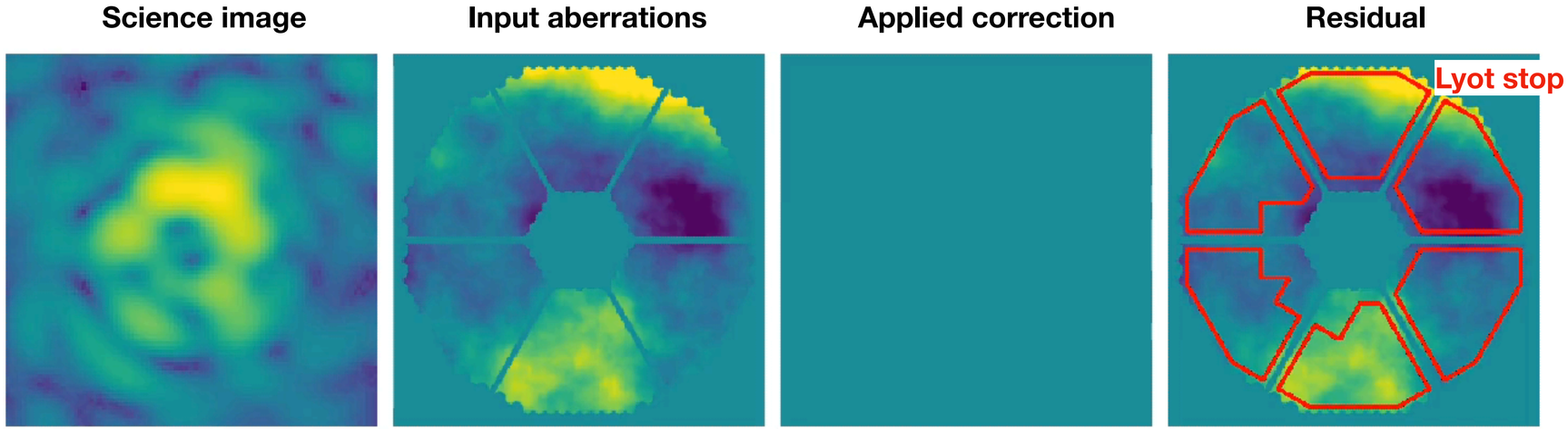
- Pointing control for the vortex coronagraph
  - ~0.01 λ/D at 1Hz



VLT/ERIS simulations

- Higher order modes
  - Asymmetric Lyot + supervised deep learning for reconstruction
  - 10Hz, 20 Zernike modes

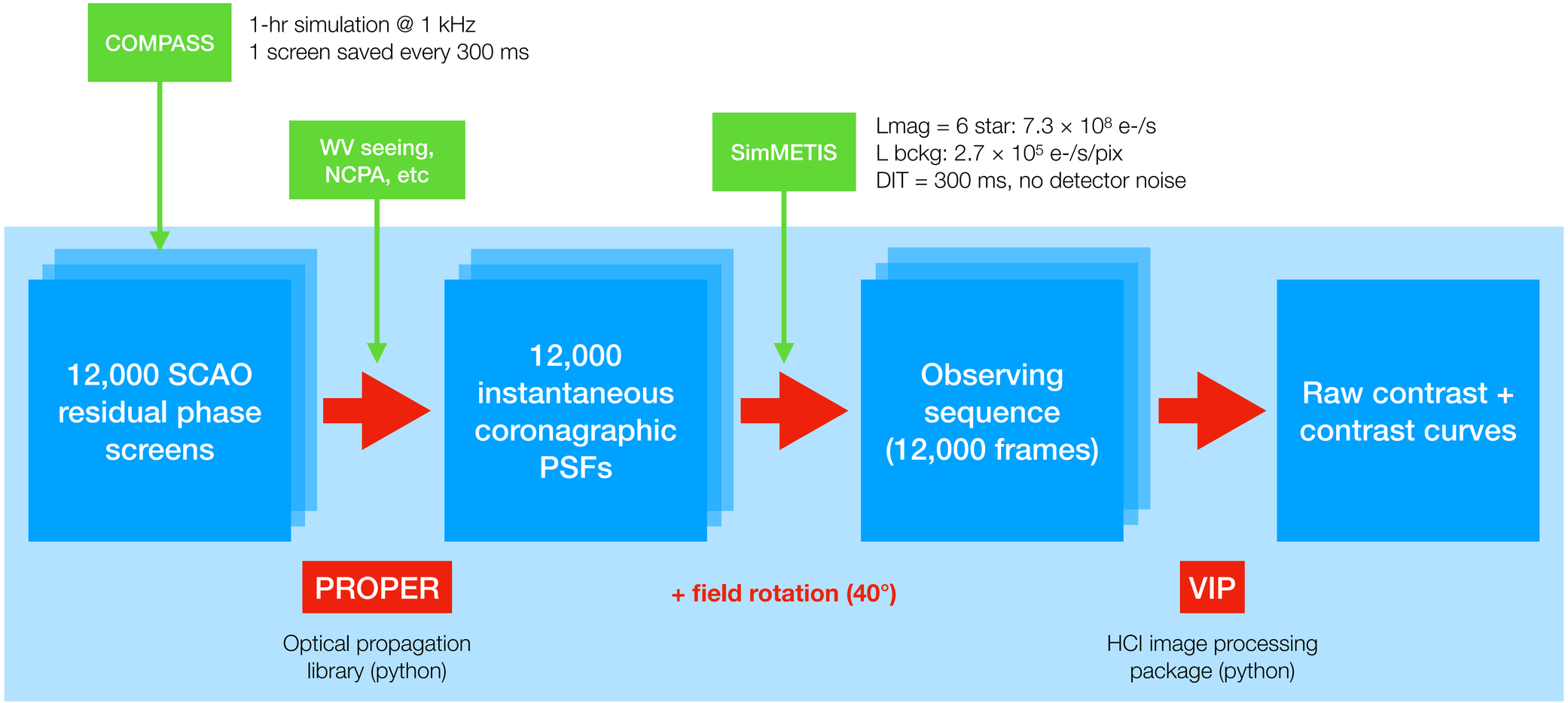
Asymmetric Lyot stop



Orban de Xivry et al., 2024a
Orban de Xivry et al., 2024b

METIS N-band vortex coronagraph; 10Hz correction rate, 20 Zernike modes

End-to-end HCI simulations

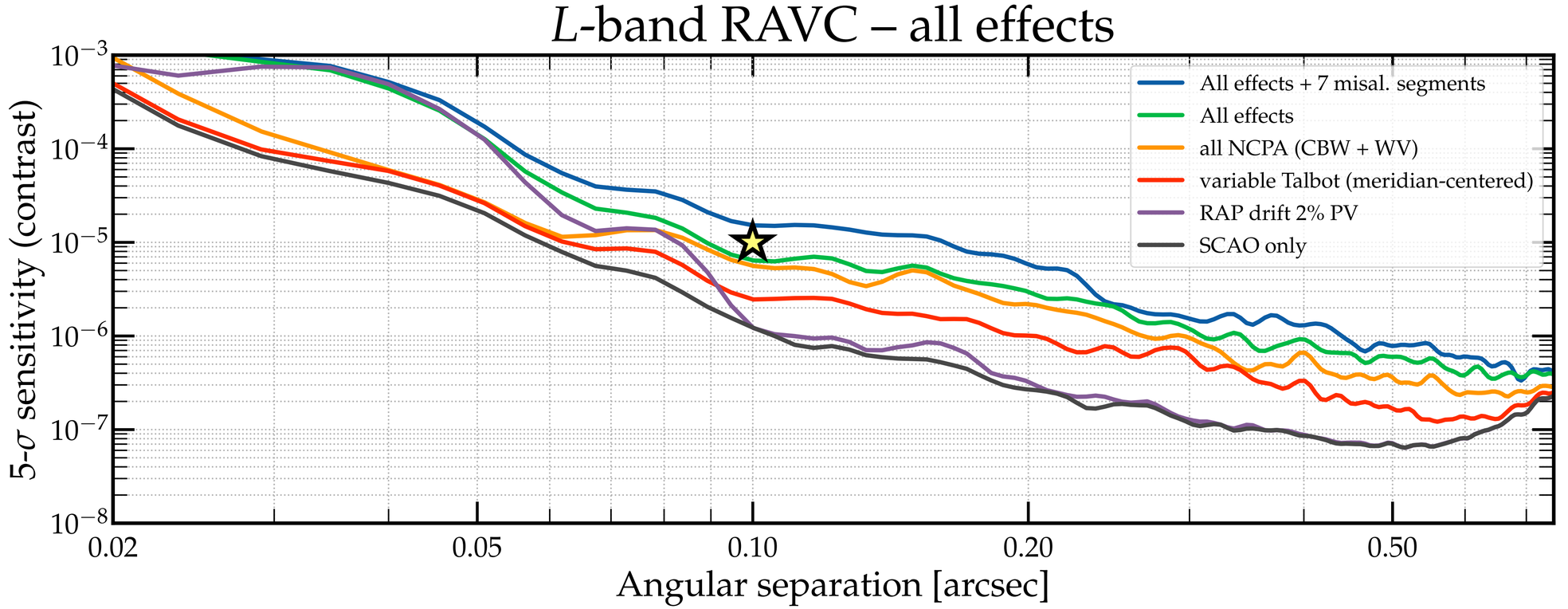


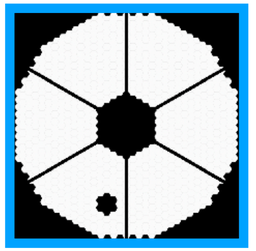
HEEPS

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

Delacroix et al., 2022

Expected L-band performance





Misaligned segments

Global performance

NCPA

Amplitude errors

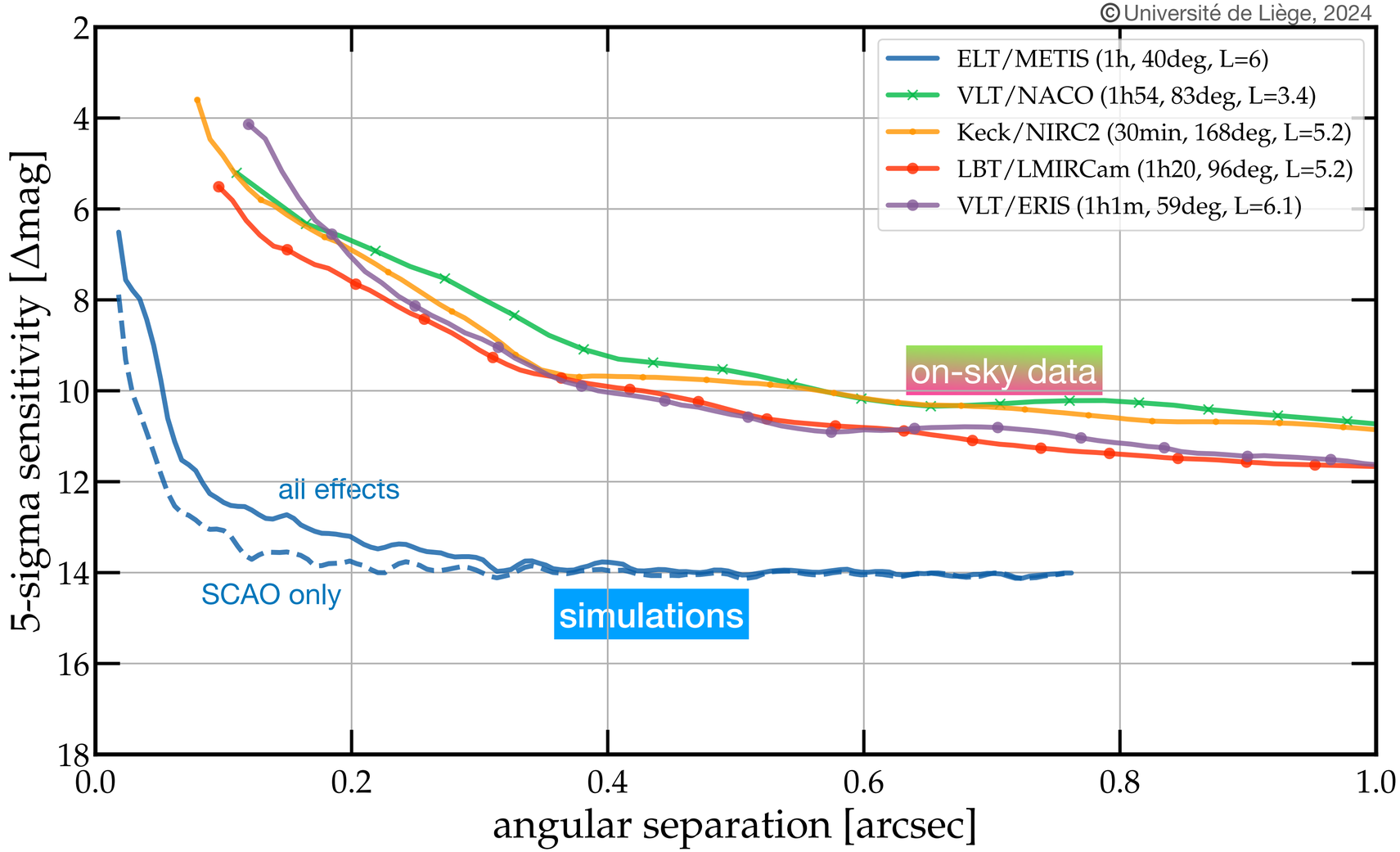
Pupil drifts

METIS SHOULD REACH < 10^{-5} AT 0.1″

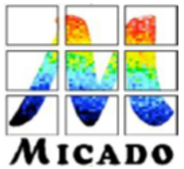
Delacroix et al., 2022
Carlomagno et al., 2020

METIS vs 10-m class telescopes

5-sigma sensitivity in L-band



METIS in the ELT context



Instrument	Main specifications		
	Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)
MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I*, *Z*, *Y*, *J*, *H*, *K* + narrowbands	0.8–2.45
	Single slit	*R* ~ 20 000	
HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45
METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L*, *M*, *N* + narrowbands	3–13
	Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*	
	IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L*, *M* bands *R* ~ 100 000	

Expected first light:

→ 2029

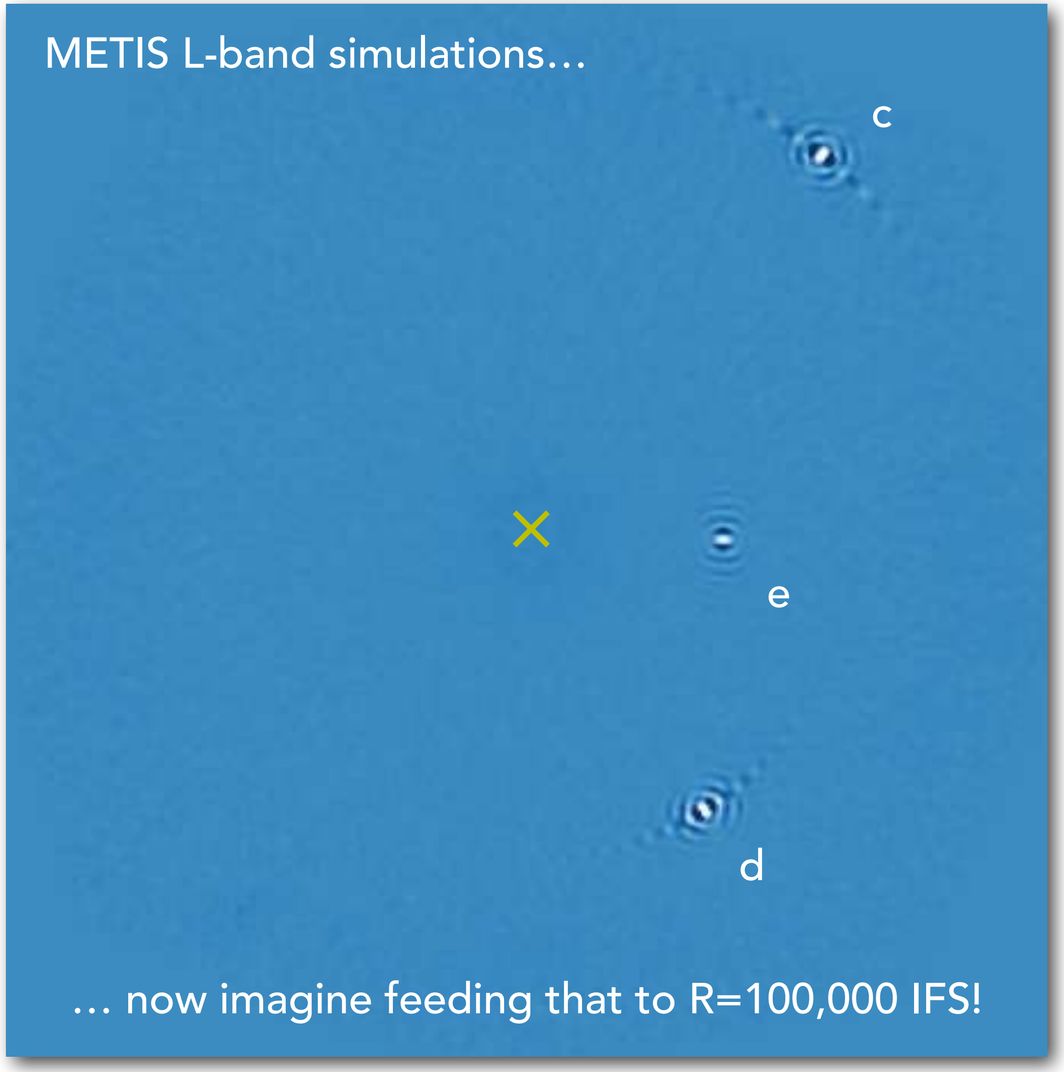
→ ~2031

→ 2029

All three instruments will have coronagraphic capabilities

Famous systems, revisited…

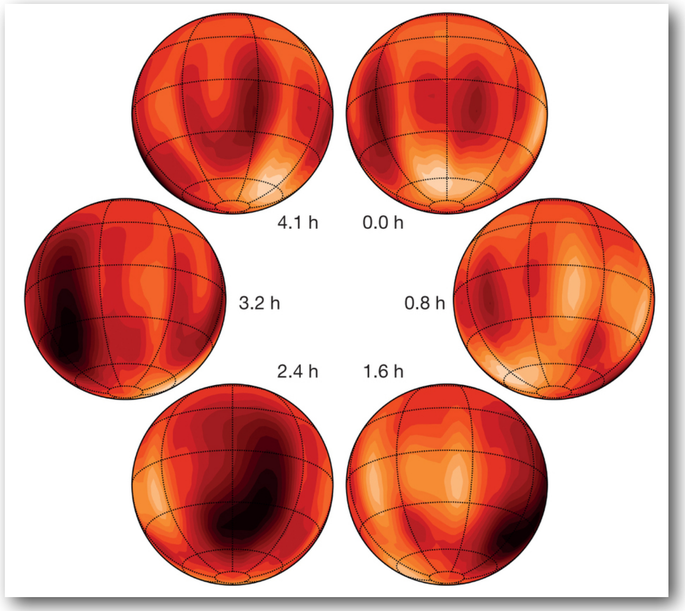
- Characterise planets with dynamical mass measurements
  - follow-up of Gaia and RV planets
  - METIS will detect a handful of each kind (Quanz et al. 2015, Wallace et al. 2021)
  - tidally heated super-eccentric planets also look promising (Dong et al. 2013)
- Follow-up directly imaged planets at R=100,000



2D maps of exoplanet atmospheres

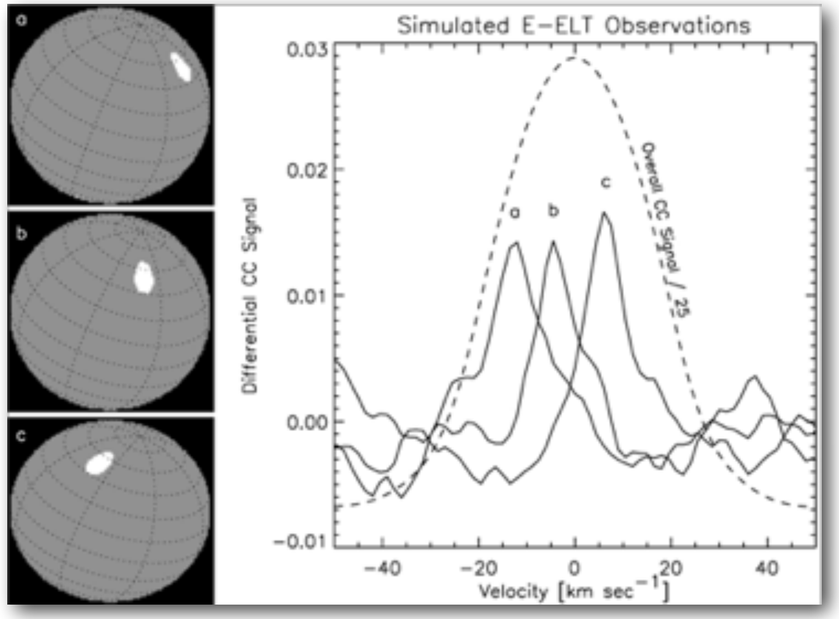
Doppler tomography with high-resolution IFS (R = 100,000)

From brown dwarf cloud maps…



Crossfield et al. 2014

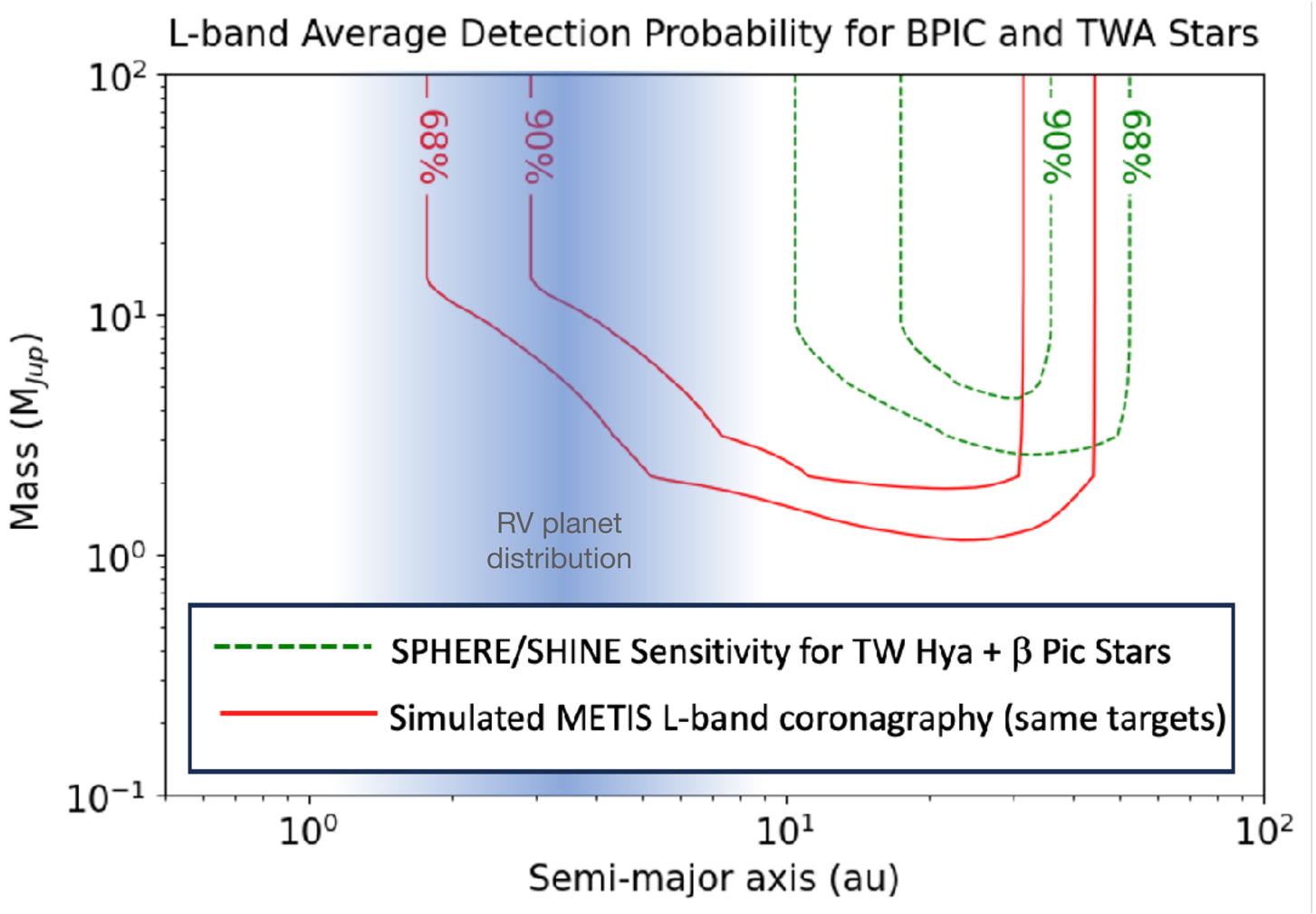
to clouds in giant planets atmospheres!



Snellen et al. 2014

Targeted survey(s): ice-line giant planets

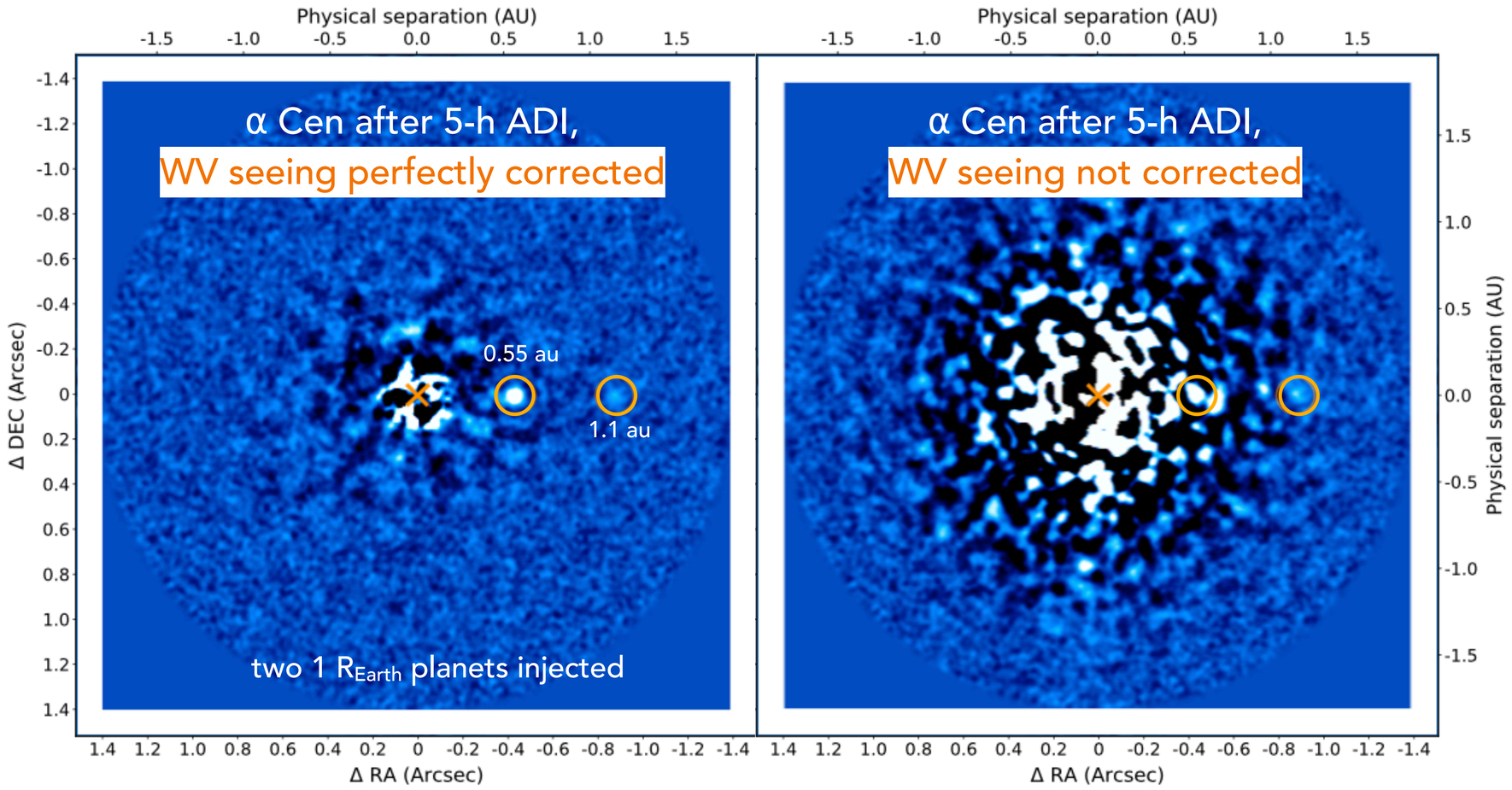
- Goal: constrain the long-period end of RV planet distribution
- METIS can resolve the water ice line up to ~100 pc
  - better sensitivity than NIRCam within 10 au



Courtesy S. Hinkley

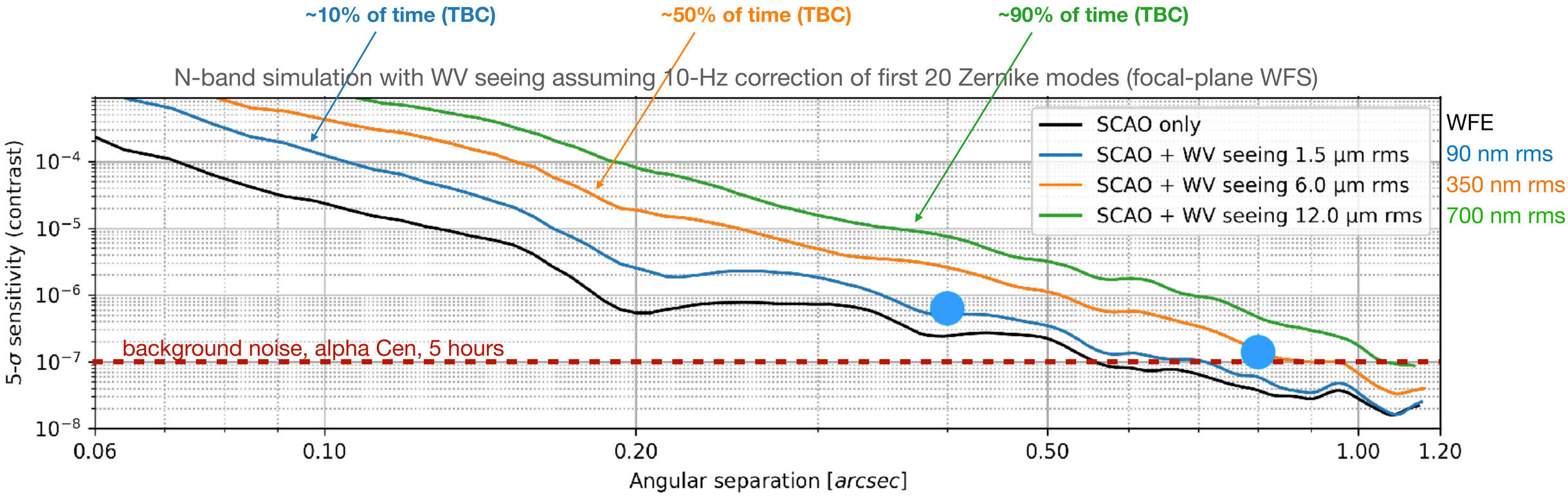
A shot at Earth-like planets?

- Terrestrial regime accessible at **N band** around α Cen, if WV seeing corrected



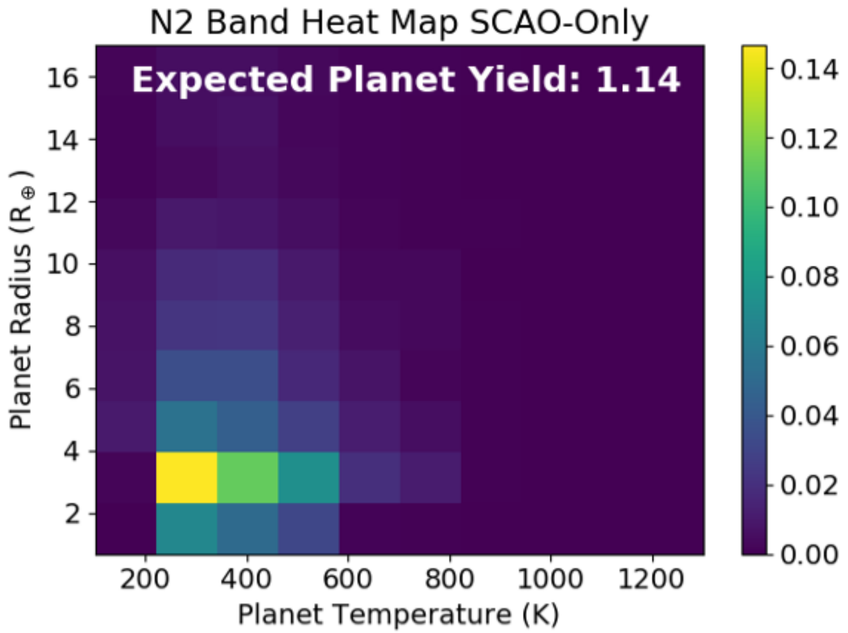
Impact of WV seeing at N band

- Ability to correct for WV seeing in real time will be driving rocky planet yield
  - simulations below assume partial correction of WV seeing for various conditions



Is the detection of a temperate planet likely?

- Using Kepler occurrence rates (Bowens et al., 2021)
  - 50+% chance of finding a low-mass temperate planet around α Cen in two 1h visits
  - 1-night blind survey of six most promising nearby stars yields 1+ temperate mini-Neptune on average



Bowens et al., 2021

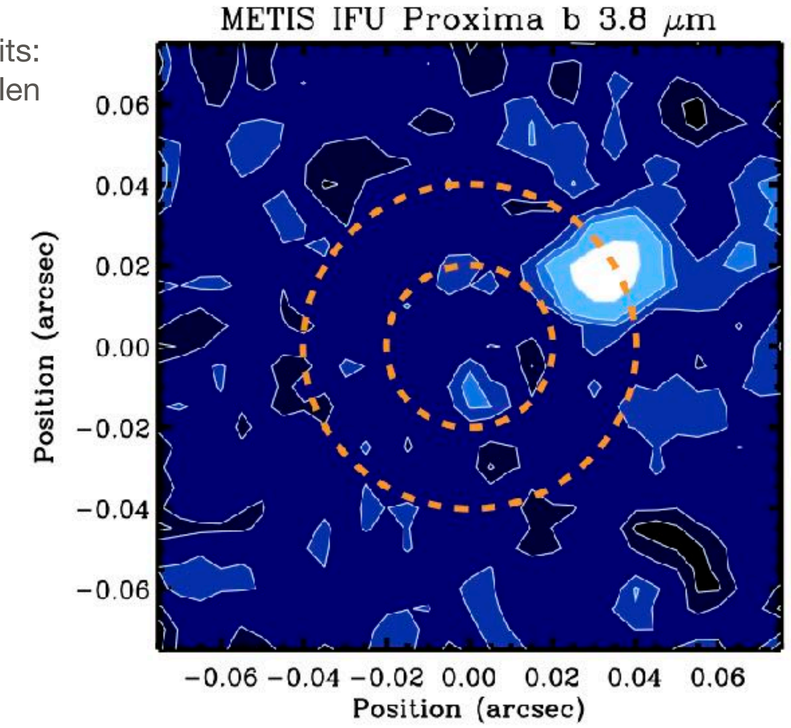
Table 4. Optimized observation plan for the candidate stars in the *N*2 band.

Star	Observation number	Month	Yield increase
α Cen A	1	–	0.477
Sirius	1	–	0.277
α Cen B	1	–	0.263
Sirius	2	3	0.083
Procyon	1	–	0.061
α Cen A	2	3	0.050
α Cen B	2	3	0.045
Altair	1	–	0.043
Sirius	3	6	0.038
α Cen A	3	6	0.027
Procyon	2	2	0.022
α Cen B	3	4	0.020
Sirius	4	11	0.018
α Cen A	4	9	0.018
α Cen B	4	6	0.015
Altair	2	2	0.014
Procyon	3	4	0.010
τ Ceti	1	–	0.008
Altair	3	4	0.006
Procyon	4	6	0.005
Altair	4	6	0.002

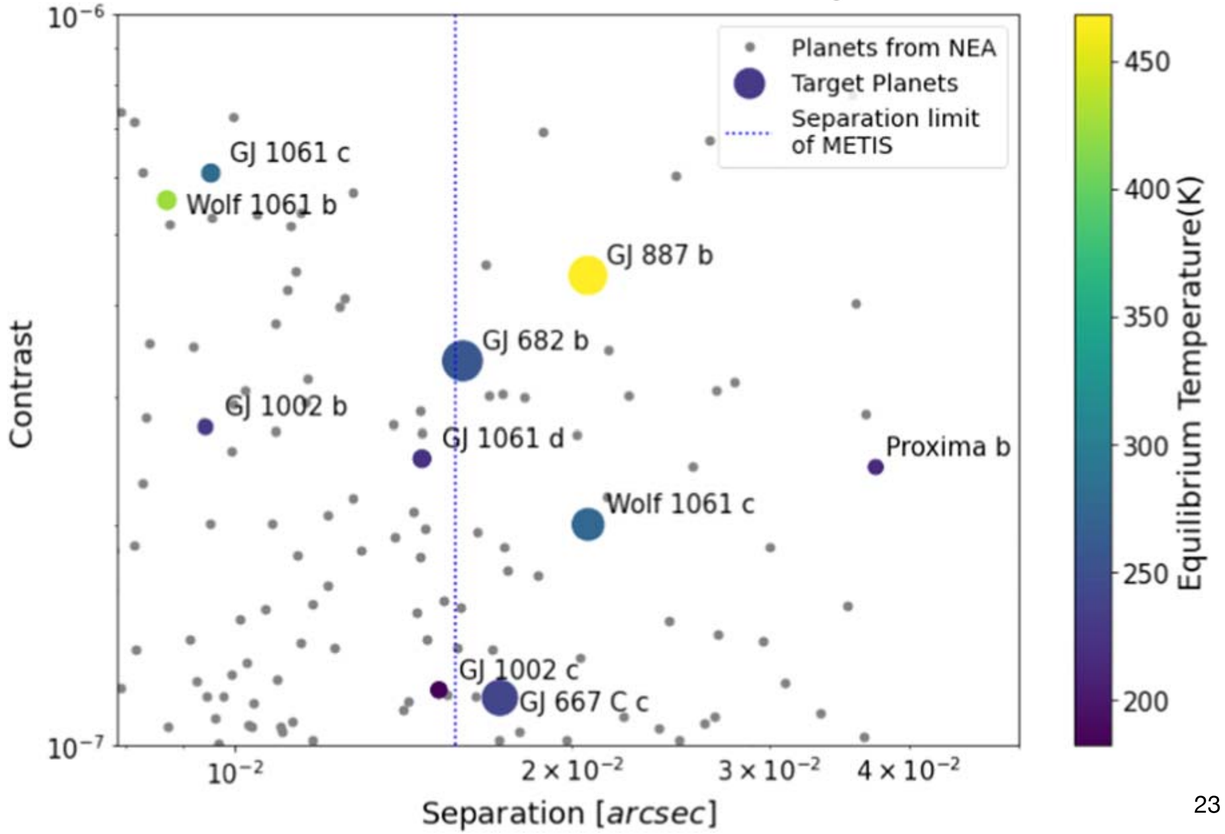
Rocky planet atmospheres with IFS+HCI (L band)

- Proxima b potentially accessible using HCI+CCF at R=100,000 in 10 hours
  - HDO could even be detected if photon-noise limit can be reached (Mollière & Snellen 2019)
- A couple more promising targets

Simulation credits:
I. Snellen

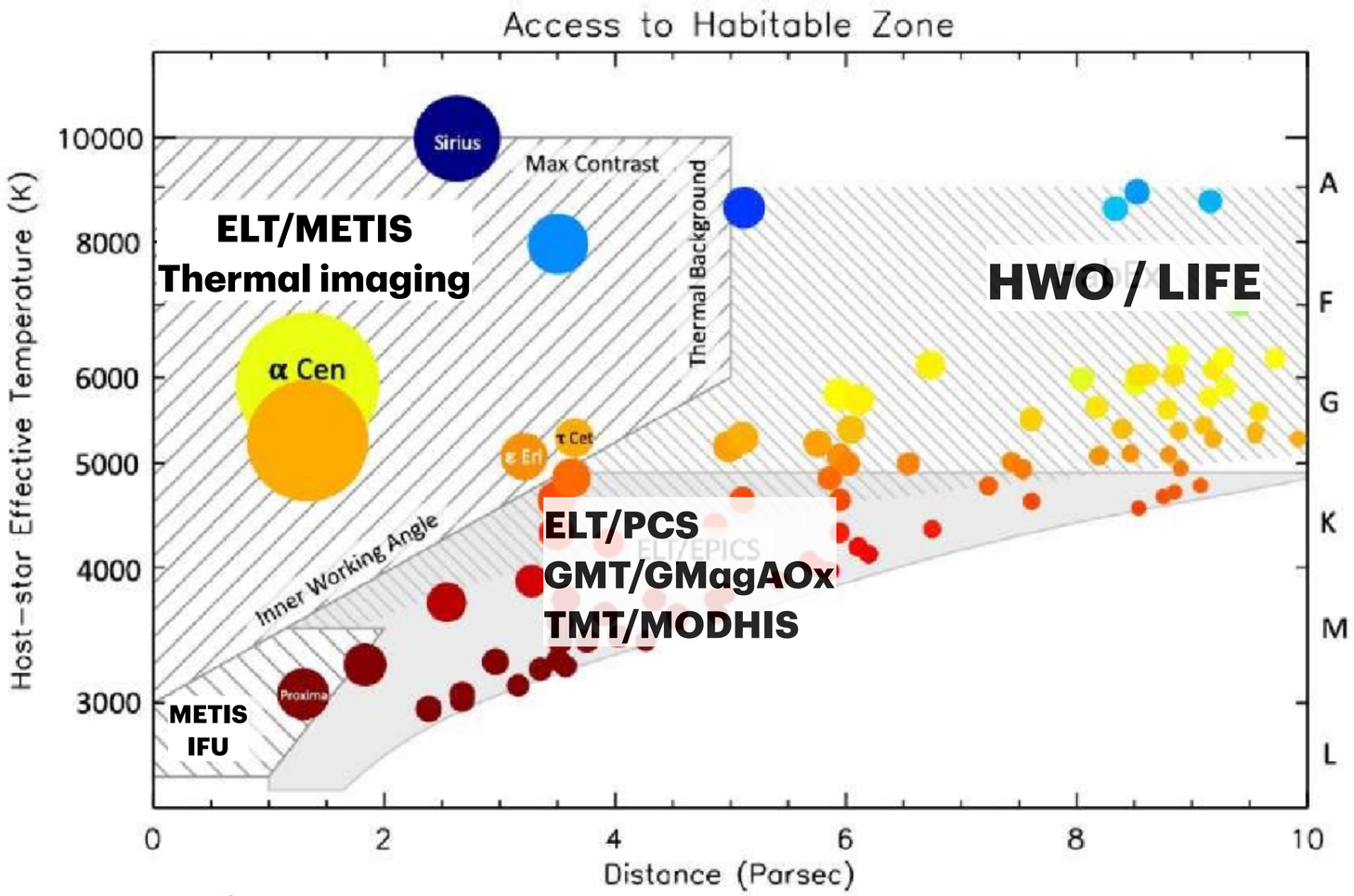


Zhang et al. 2024



Toward Earth-like planets

Ultimate science case



METIS FDR science case

- Thermal Emission
  ELT/METIS + LIFE (space)
- Reflected light
  ELT/PCS + HWO (space)

Just five more years to go !

METIS documentary
produced by ESO

Meet METIS, a multi-tool instrument for the ELT | ELT Updates

4.7K views • 1 year ago

European Southern Observatory (ESO)

Credit: ESO Directed by: Martin Wallner Written by: Rebecca Forsberg and Rory Harris Script Consultants: Jeff Lynn, Bernhard ...

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