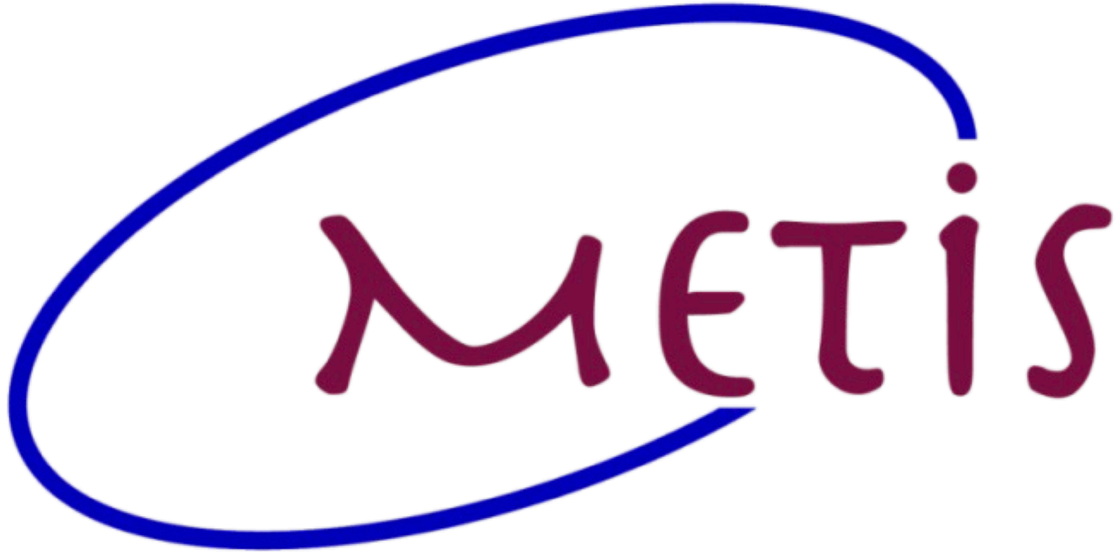




# Towards new breakthroughs in exoplanet science with ELT/METIS

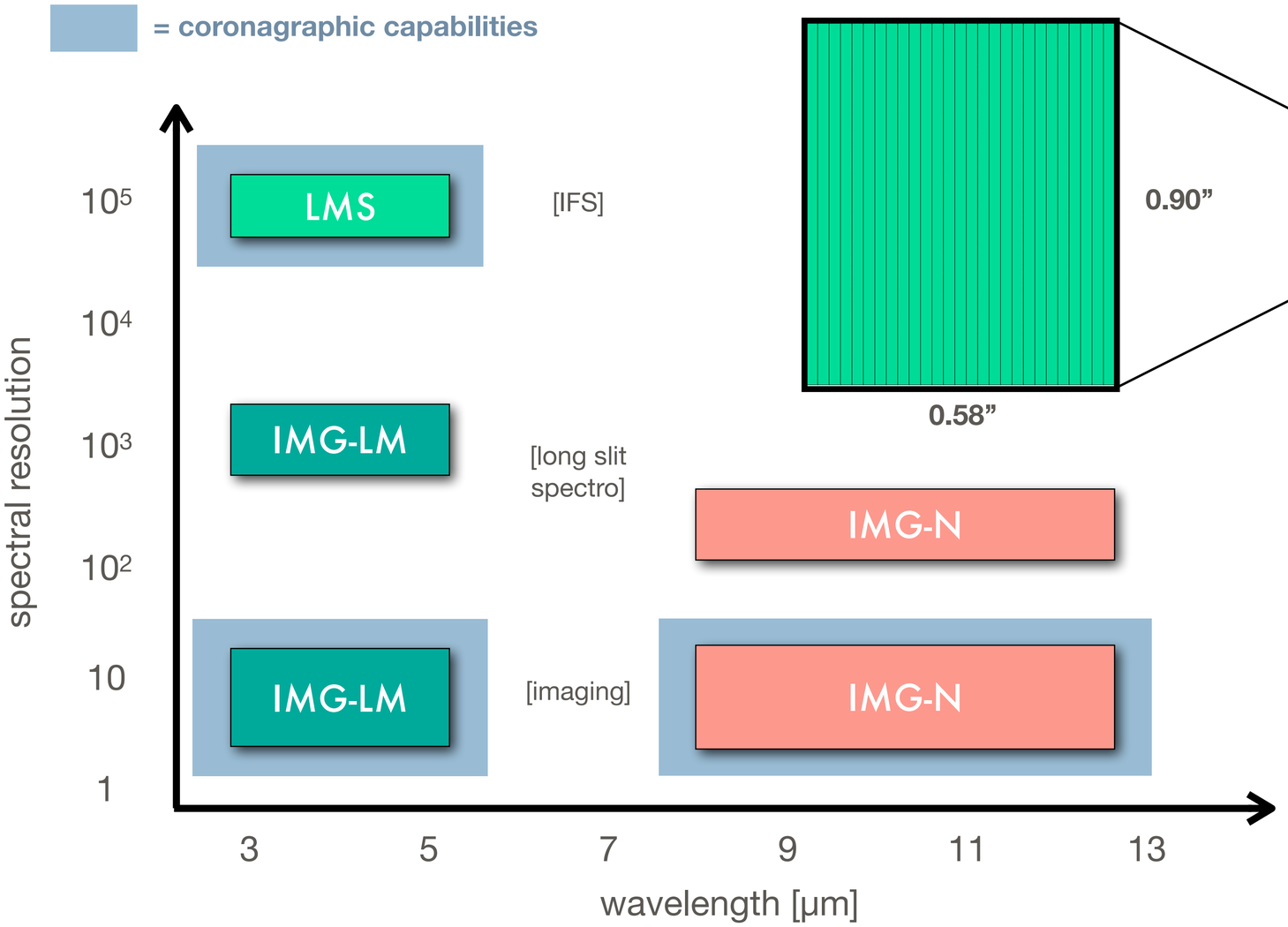
Olivier Absil & the METIS consortium

centra
center for astrophysics and gravitation

Science and Technology Facilities Council
UK Astronomy Technology Centre

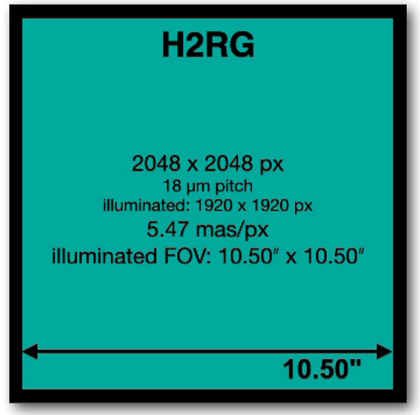
# METIS instrument baseline

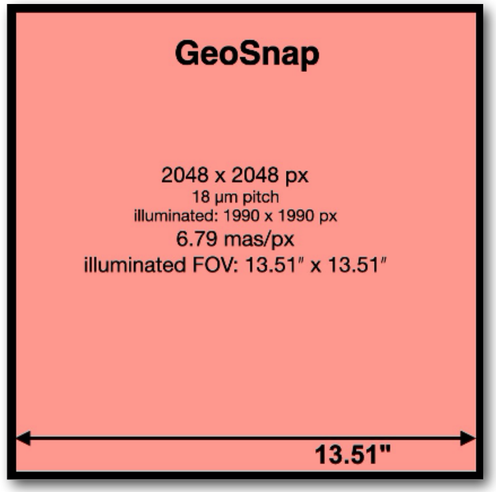
ALL MODES WORKING AT ELT'S DIFFRACTION LIMIT USING SCAO







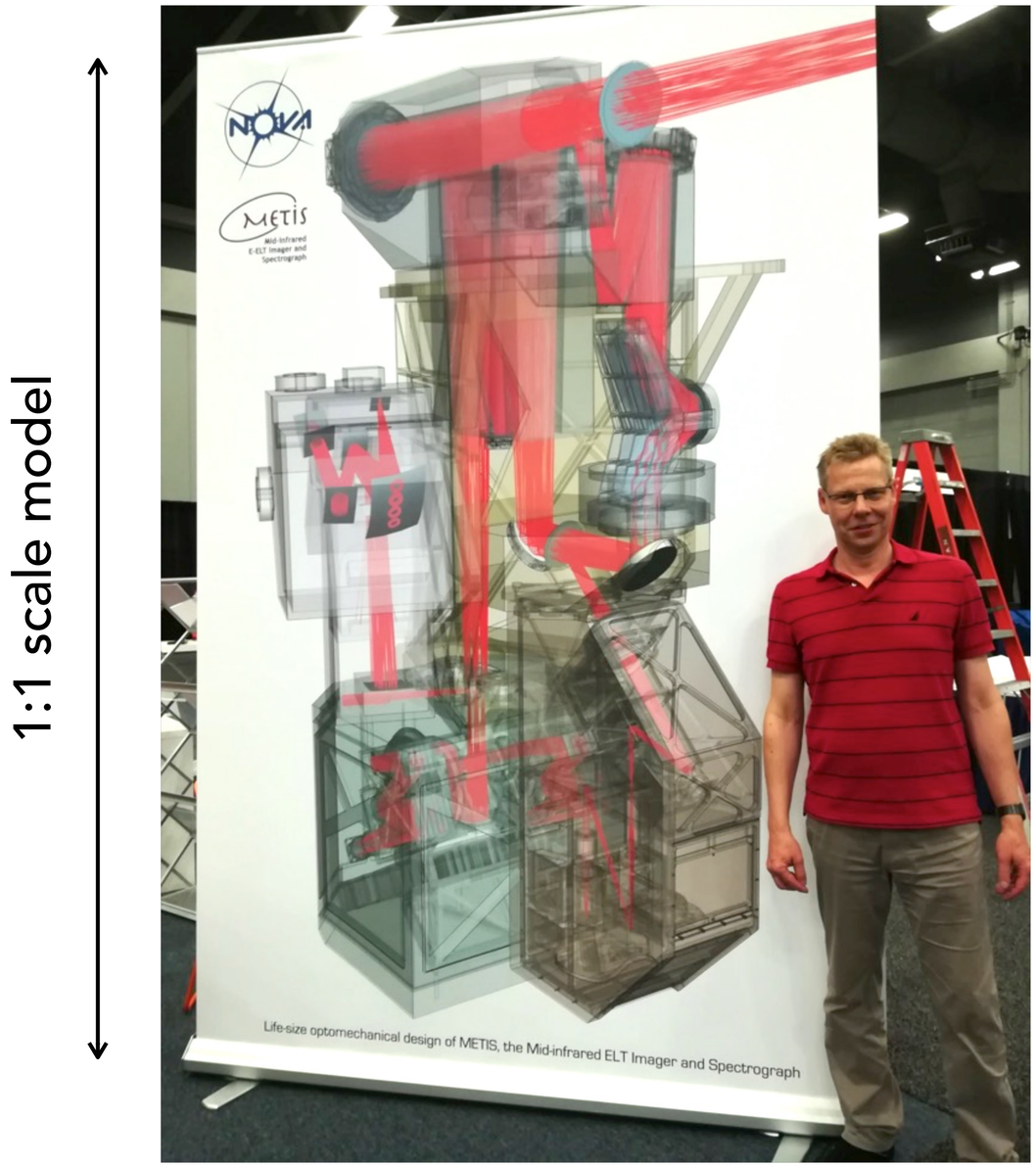


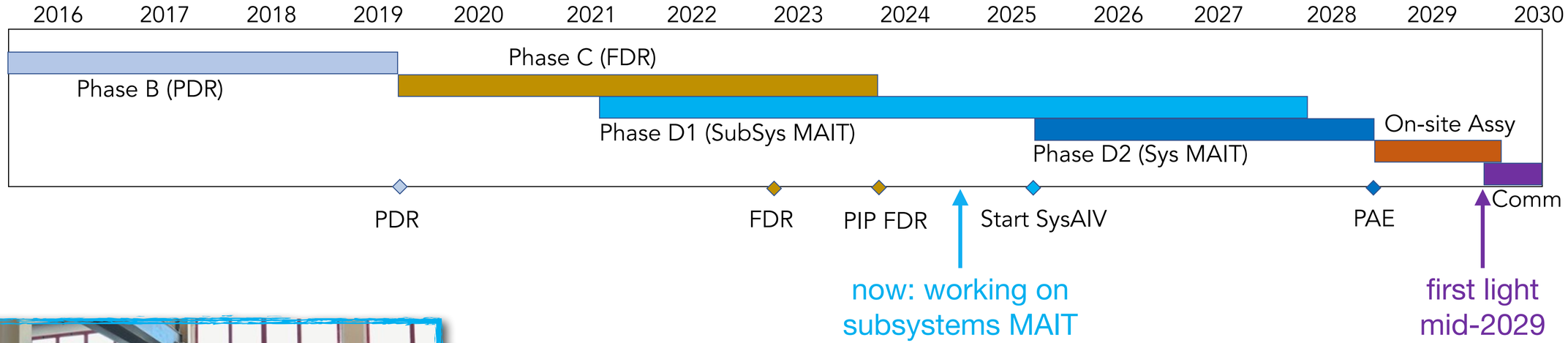

Detectors & fields-of-view

# Extremely large … instrument!

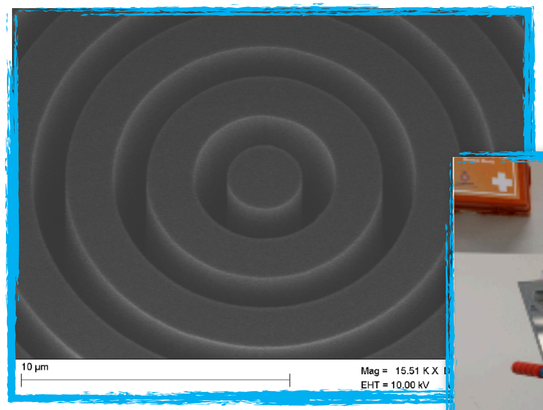
- ~ 700 FTE
- ~ 25 M€ hardware budget
- 14 yrs development



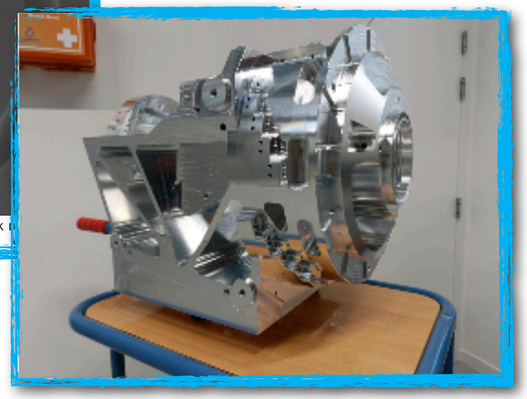
# METIS timeline




Cryostat @ Zürich




Vortex phase mask @ Liège

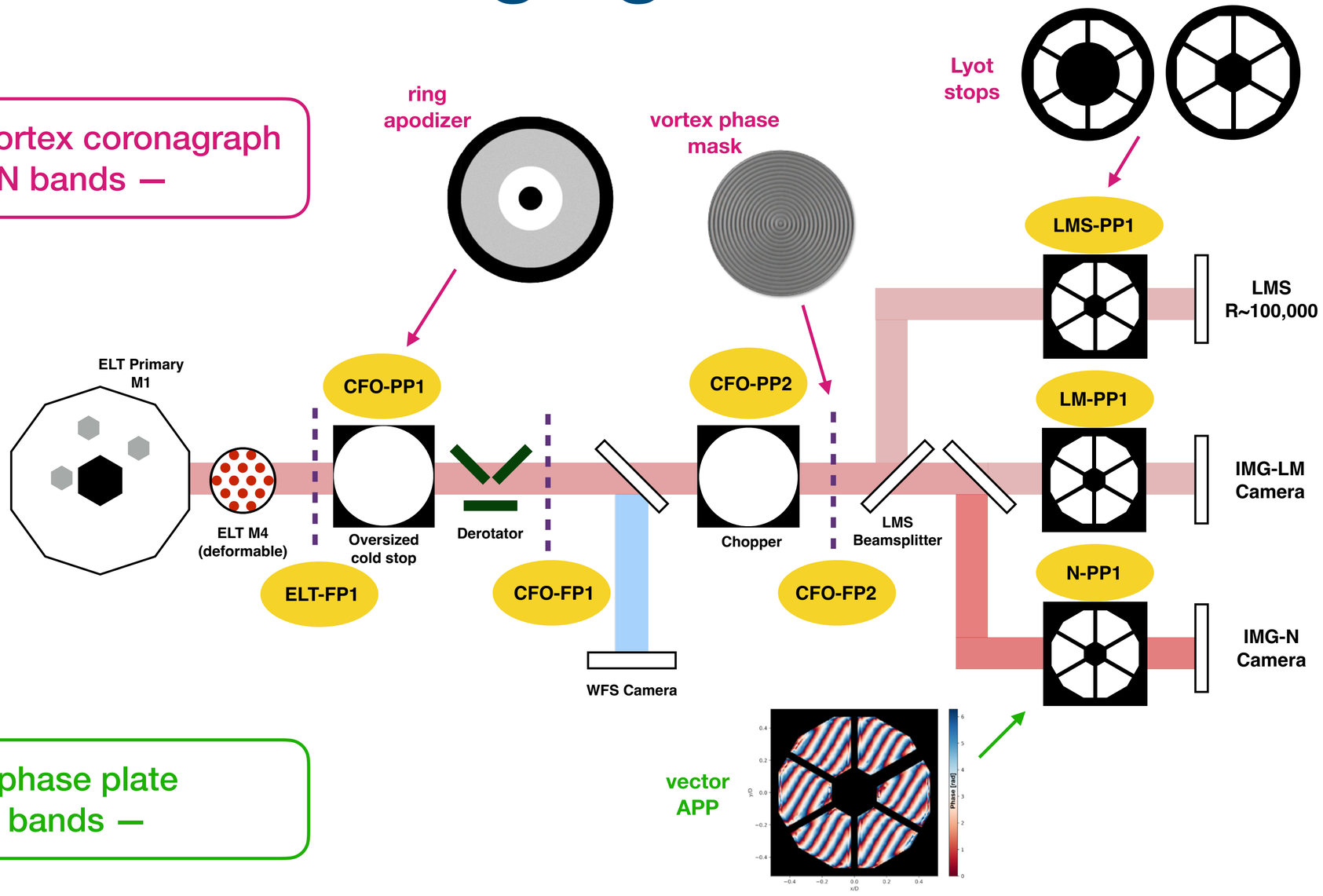


Derotator @ Dwingeloo

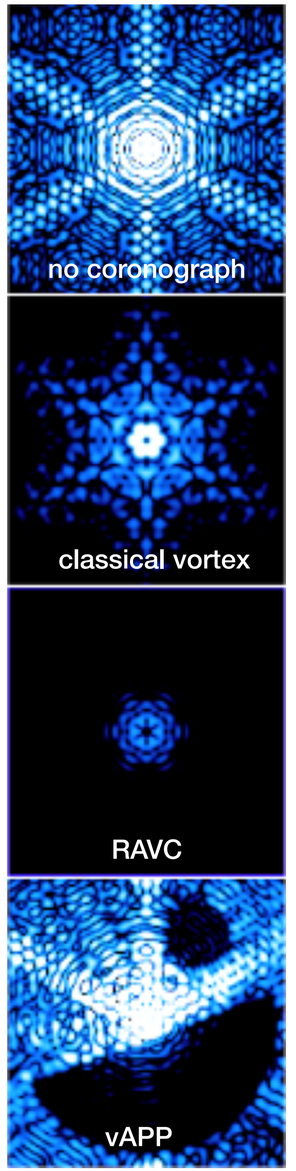
Integration hall getting ready @ Leiden

# High-contrast imaging modes

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

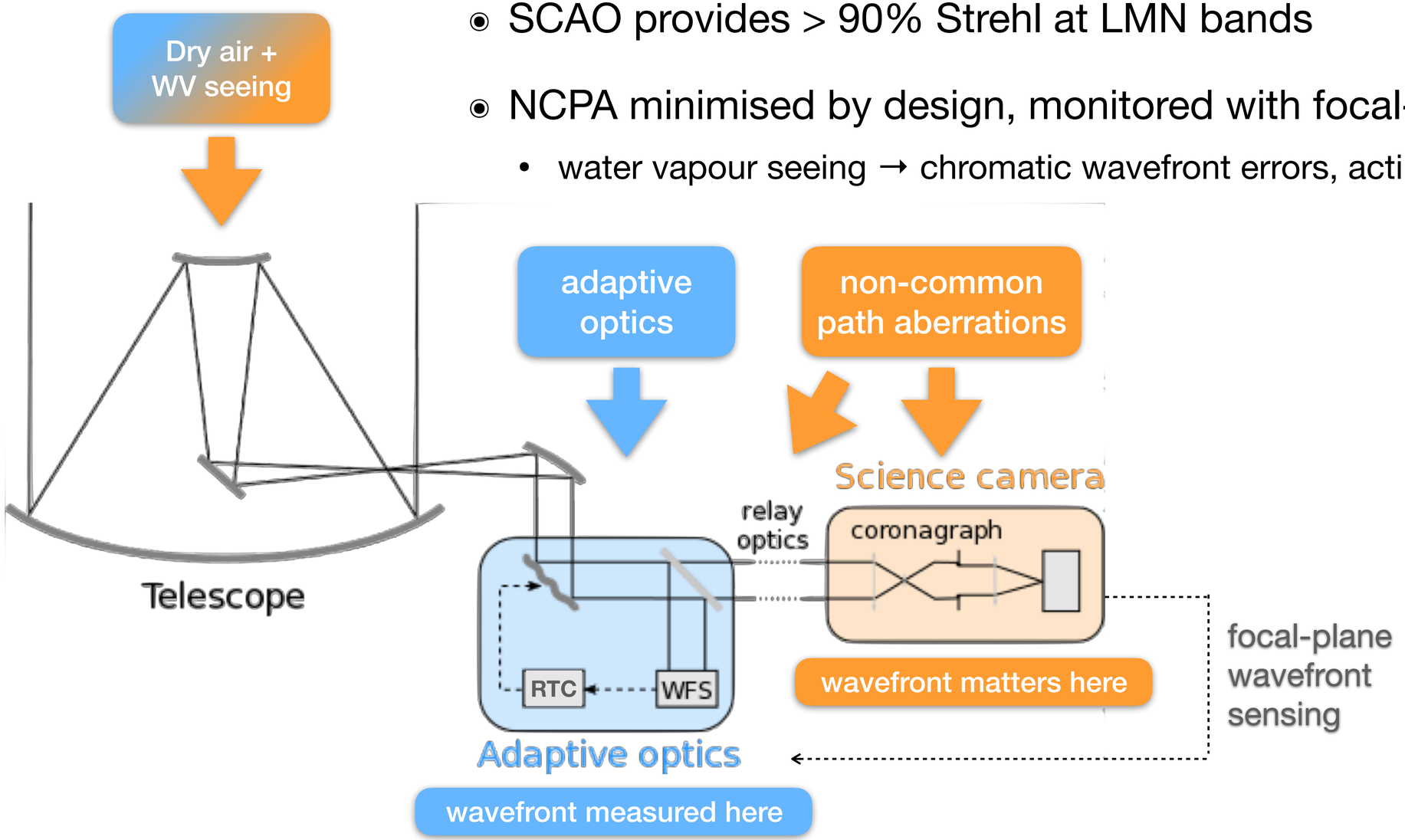



apodizing phase plate
— L & M bands —



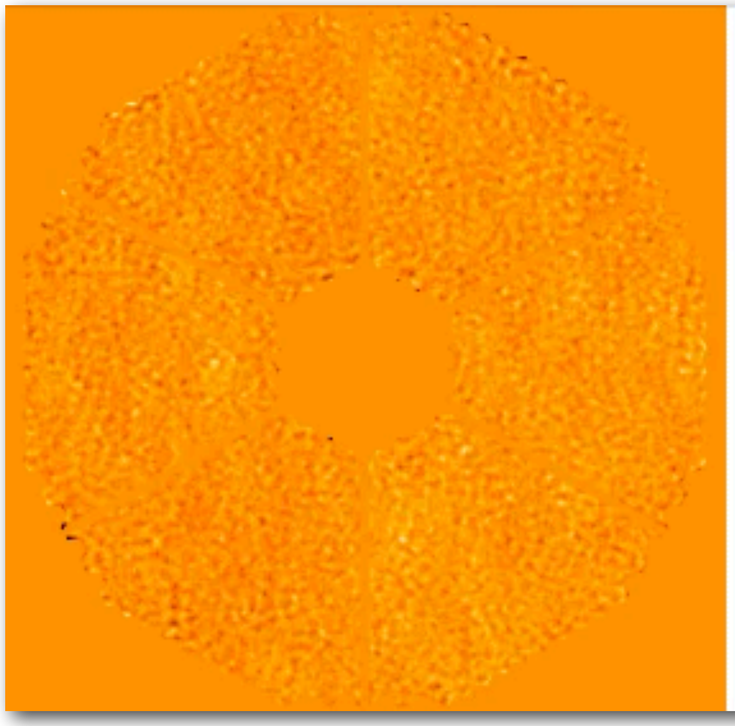
# Wavefront control strategy

- SCAO provides > 90% Strehl at LMN bands
- NCPA minimised by design, monitored with focal-plane WFS
  - water vapour seeing → chromatic wavefront errors, acting like NCPA



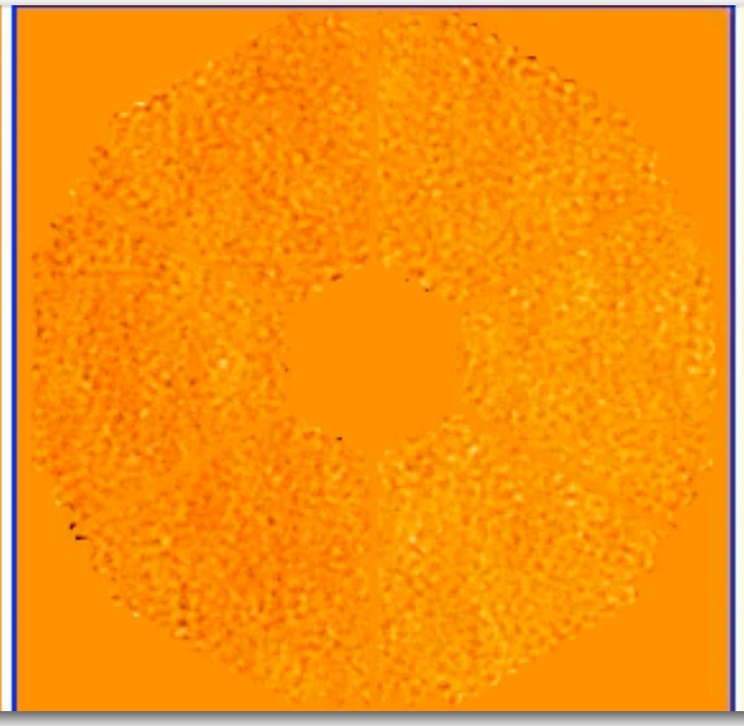
# WV seeing adding to AO residuals

AO only



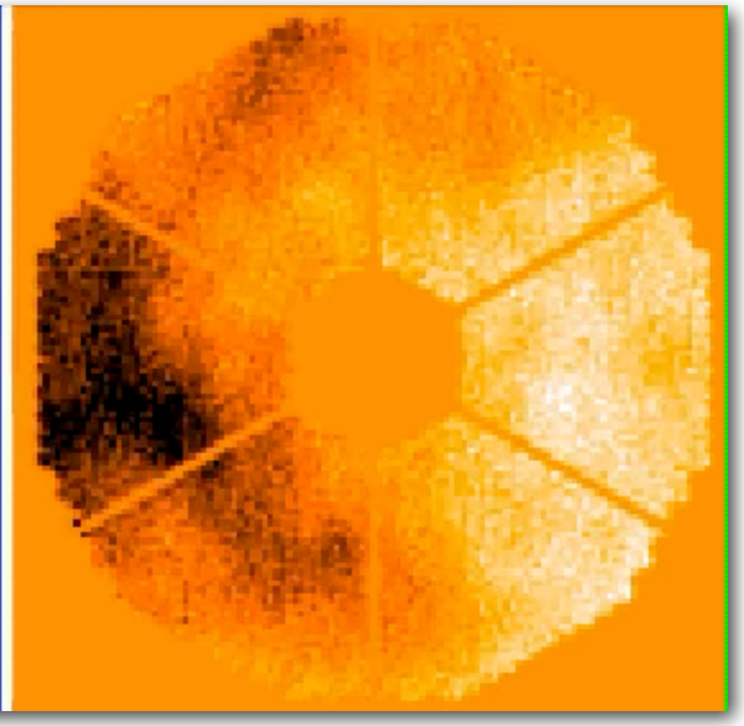
~140 nm RMS WFE

AO + WV (L band)



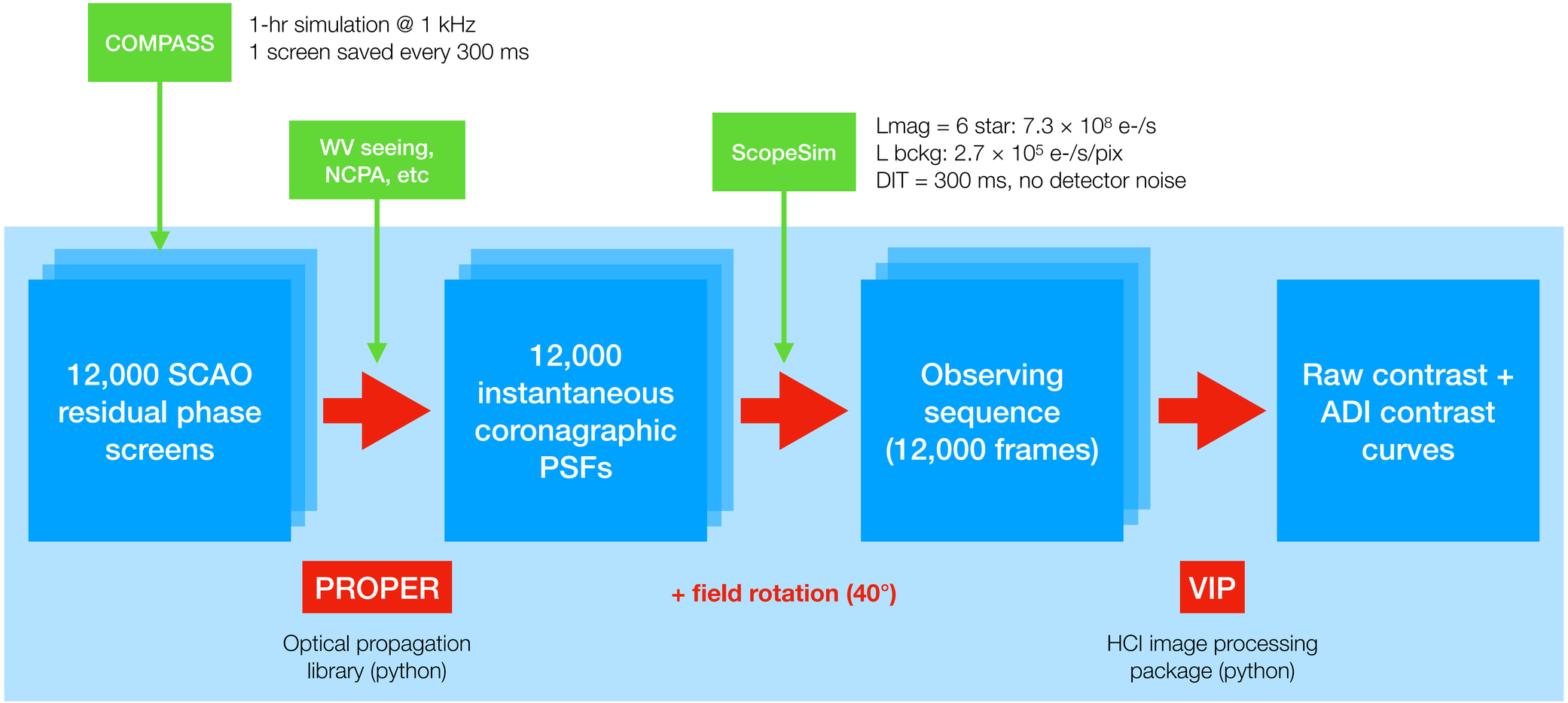
~25 nm RMS additional WFE

AO + WV (N band)



~300 nm RMS additional WFE

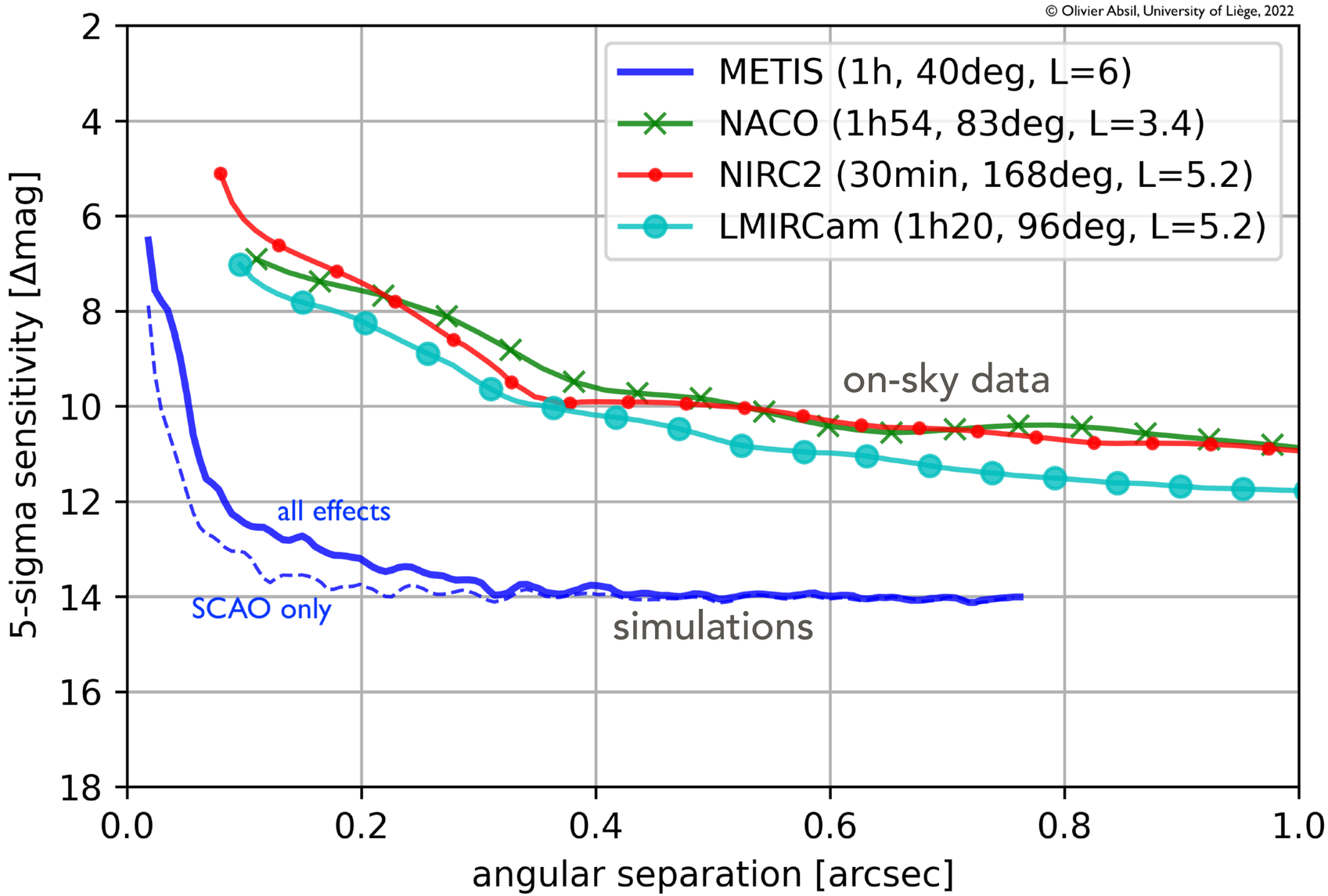
# End-to-end HCI simulations




## HEEPS

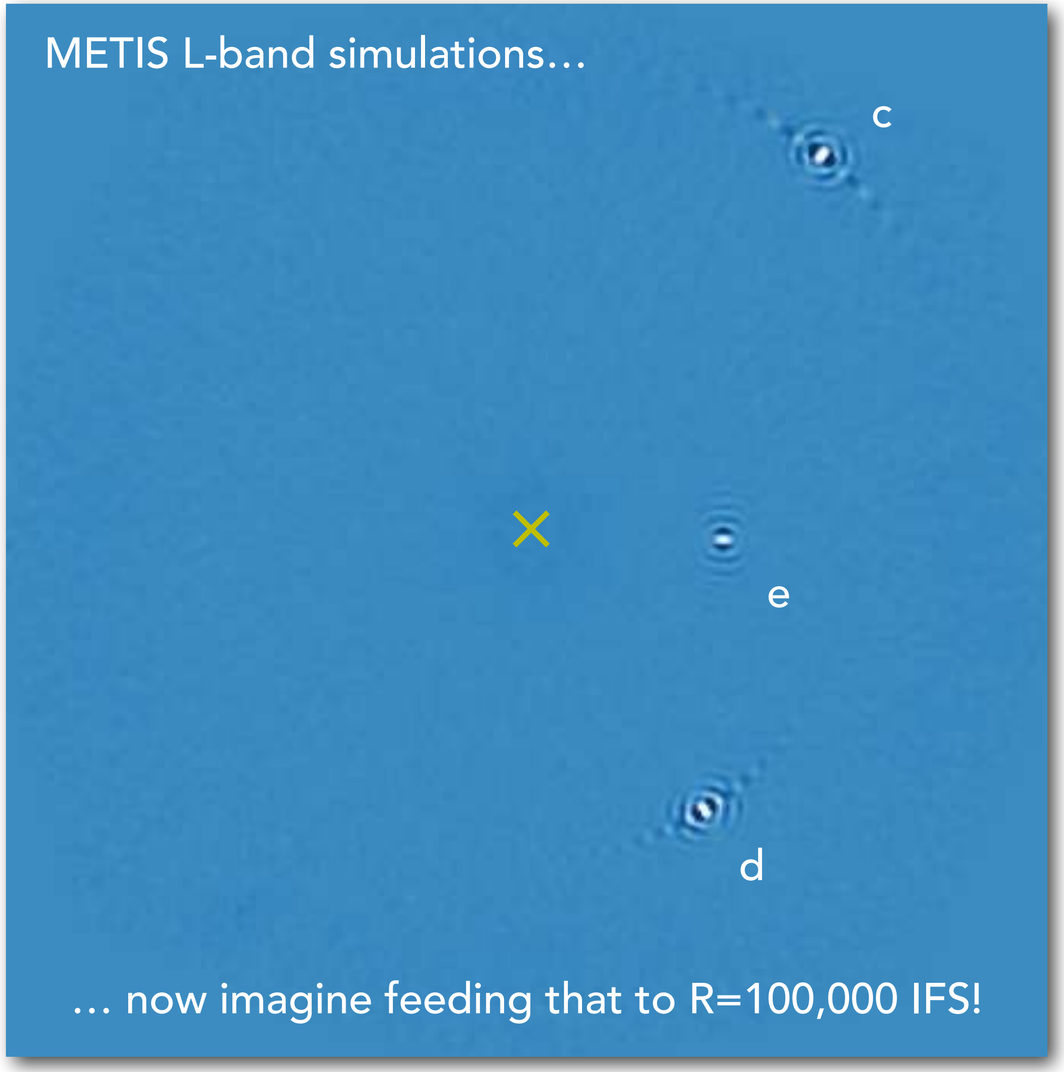
(https://github.com/vortex-exoplanet/HEEPS)

# METIS vs 10-m class telescopes @ L band



# Famous systems, revisited…

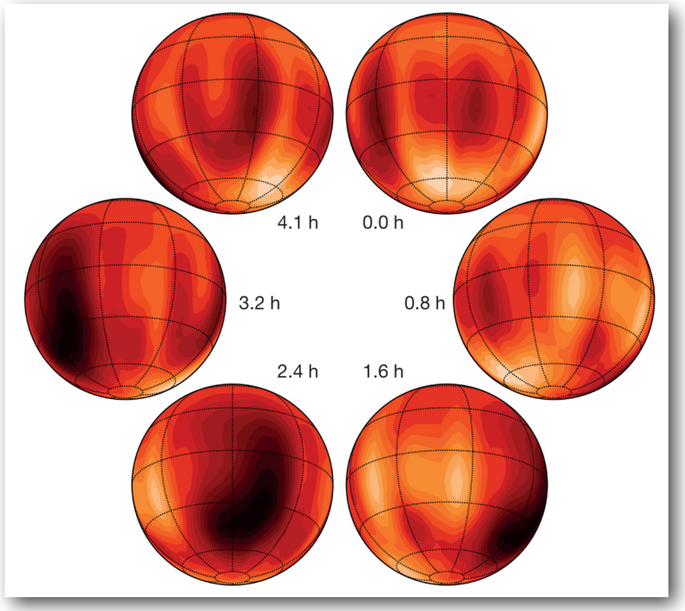
- Characterise planets with dynamical mass measurements
  (cf Lacour & Franson's talks)
  - follow-up of Gaia and RV planets
  - METIS will detect a handful of each kind (Quanz+2015, Wallace+2021)
  - tidally heated super-eccentric planets also look promising (Dong+2013)
- Follow-up directly imaged planets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



# 2D maps of exoplanet atmospheres

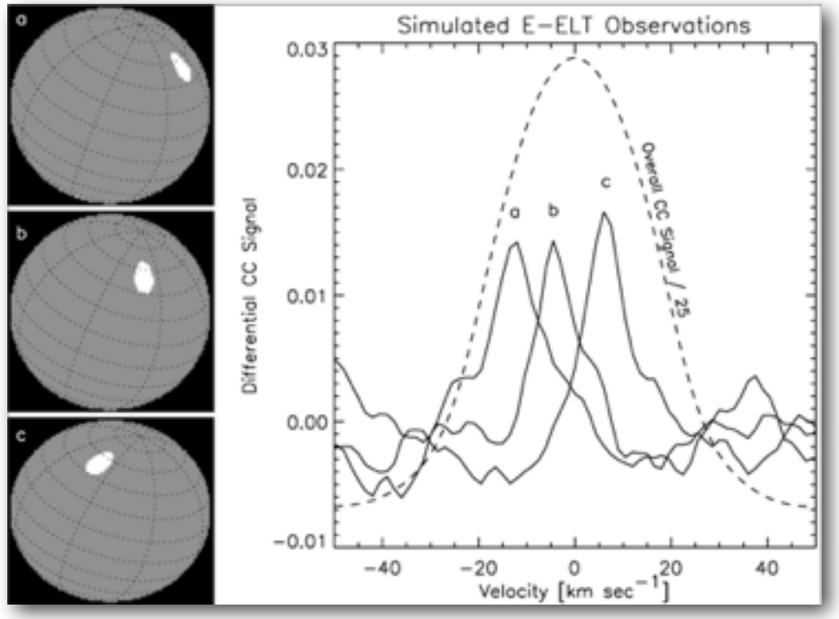
## Doppler tomography with high-resolution IFS (R = 100,000)

From brown dwarf cloud maps…




Crossfield+2014

to clouds in giant planets atmospheres!

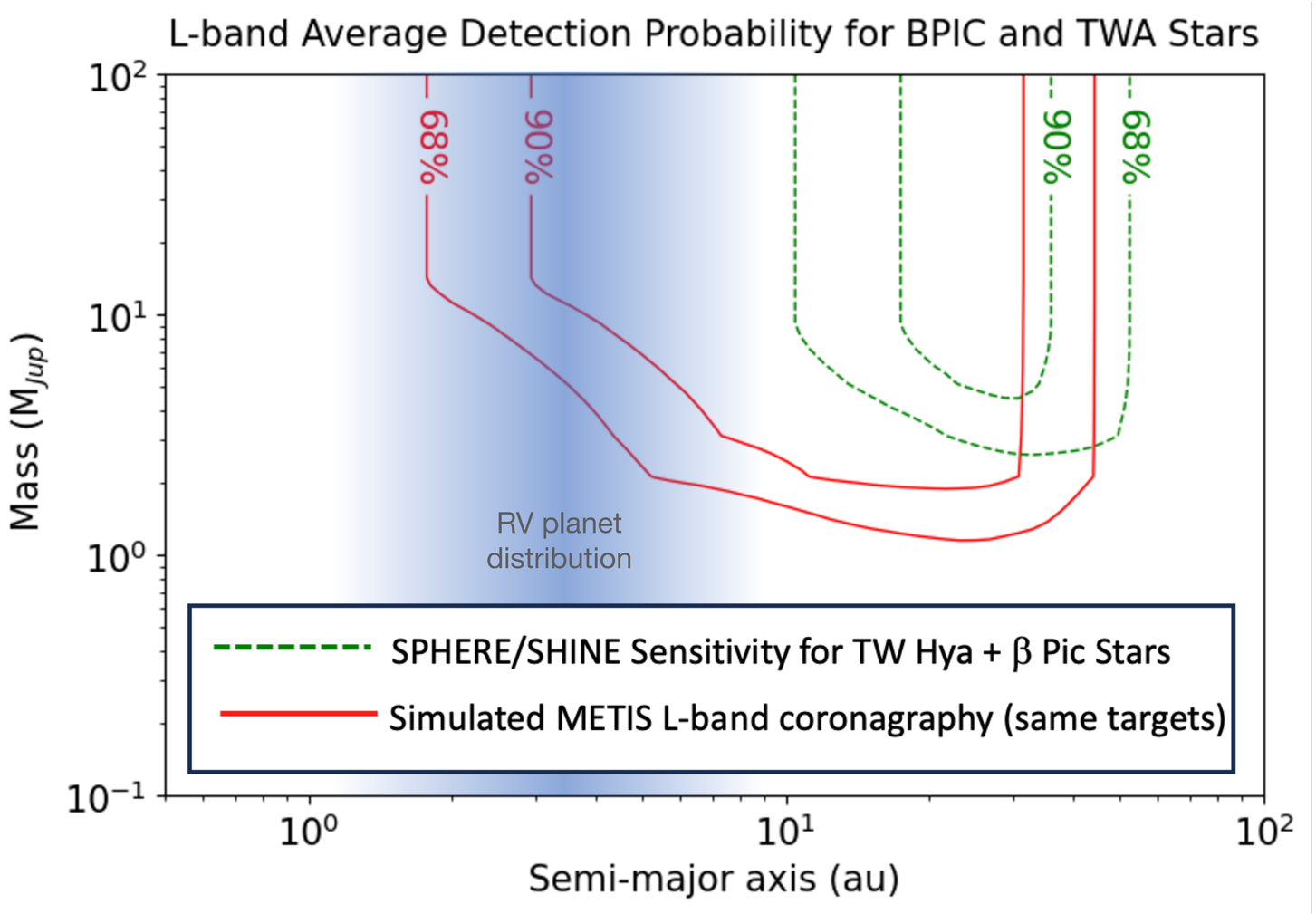



Snellen+2014

Your weather forecast on beta Pic b, starting 2029, and much more
(cf Xuan's talk)

# Targeted survey(s): ice-line giant planets

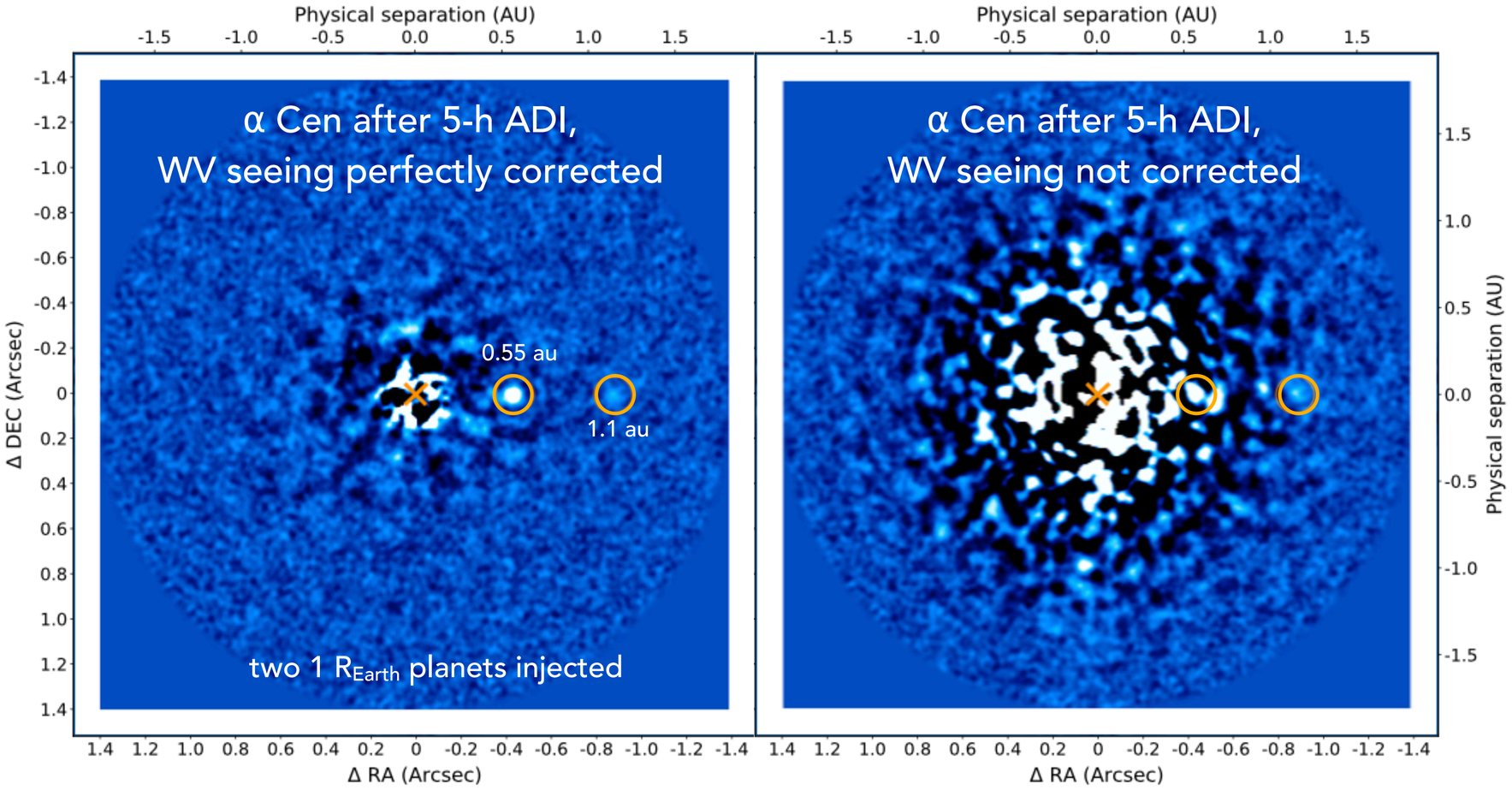
- Goal: constrain the long-period end of RV planet distribution
- METIS can resolve the water ice line up to ~100 pc
  - better sensitivity than NIRCam within 10 au
- Two kinds of mini-surveys
  - nearby moving groups: targeted search, sensitive to beta Pic c and HD 206893 c analogs
  - Sco-Cen: star-hopping RDI strategy on a larger population




Courtesy S. Hinkley

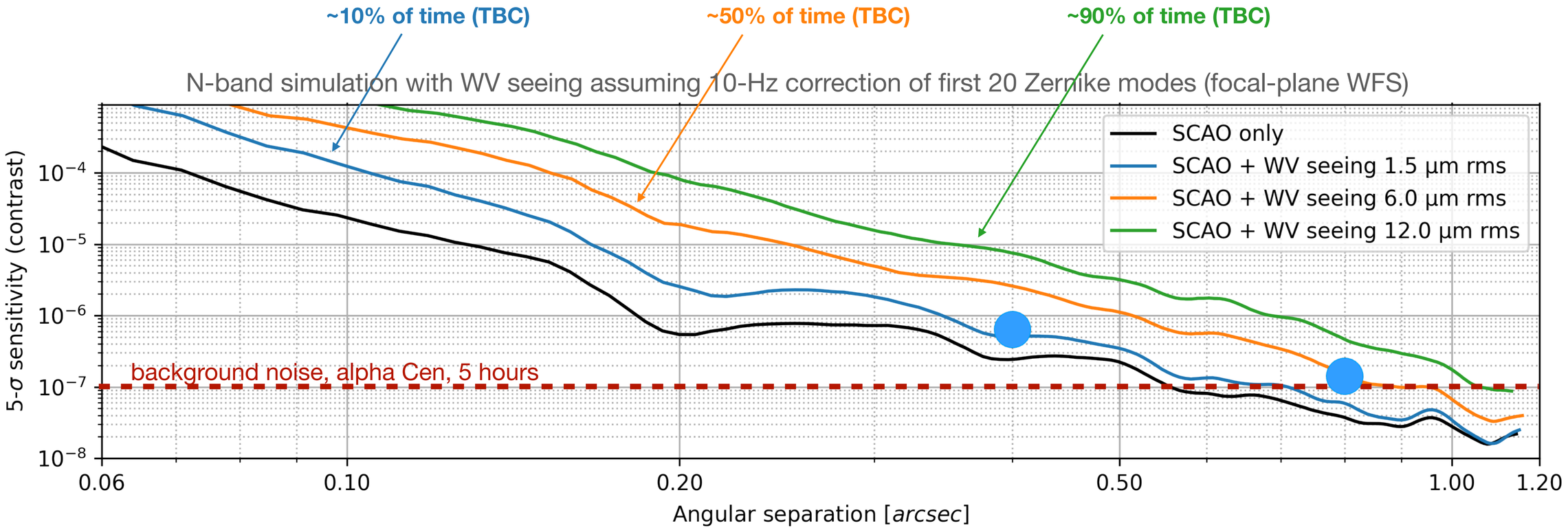
# A shot at Earth-like planets?

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



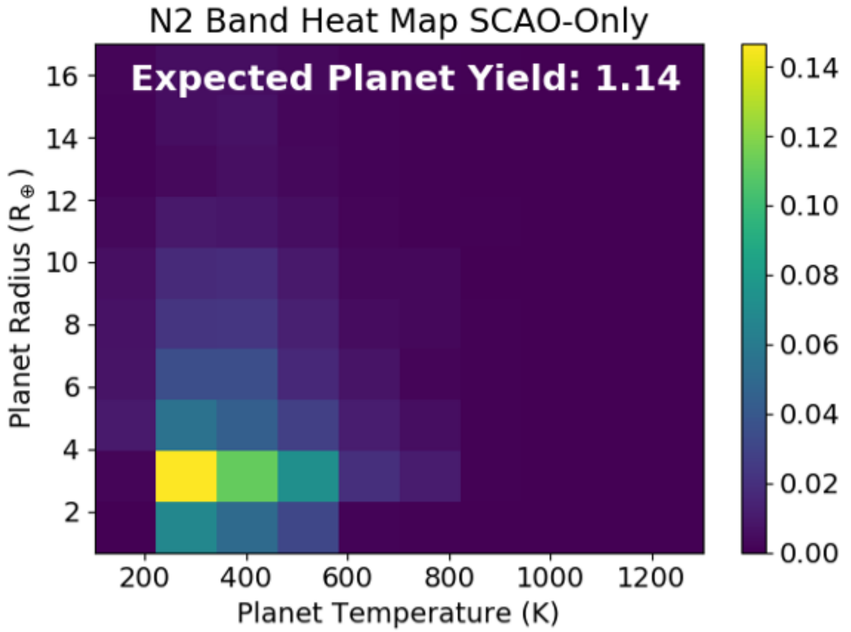
# Impact of WV seeing at N band

- 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+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+2021

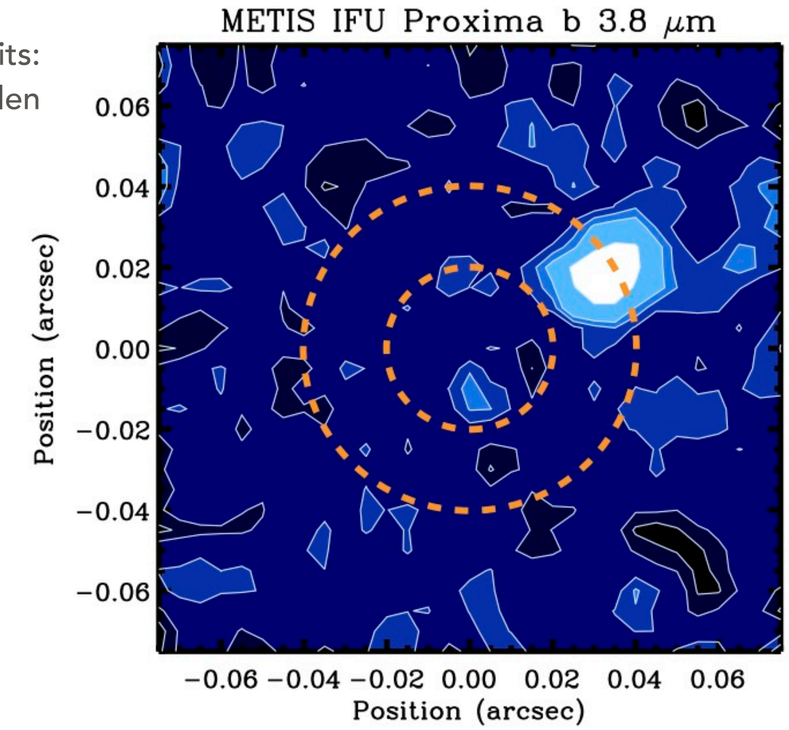
**Table 4.** Optimized observation plan for the candidate stars in the *N*2 band.

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

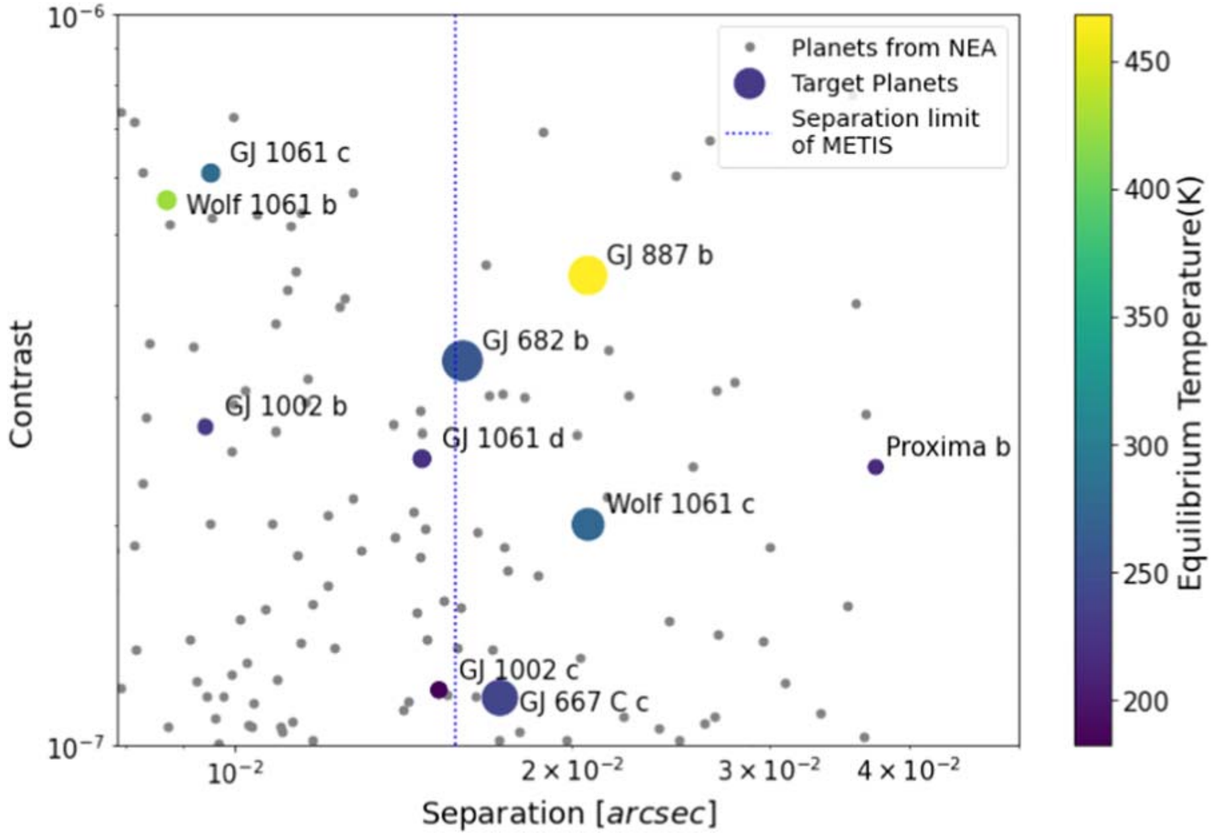
# Rocky planet atmospheres with IFS+HCI (L band)

- 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



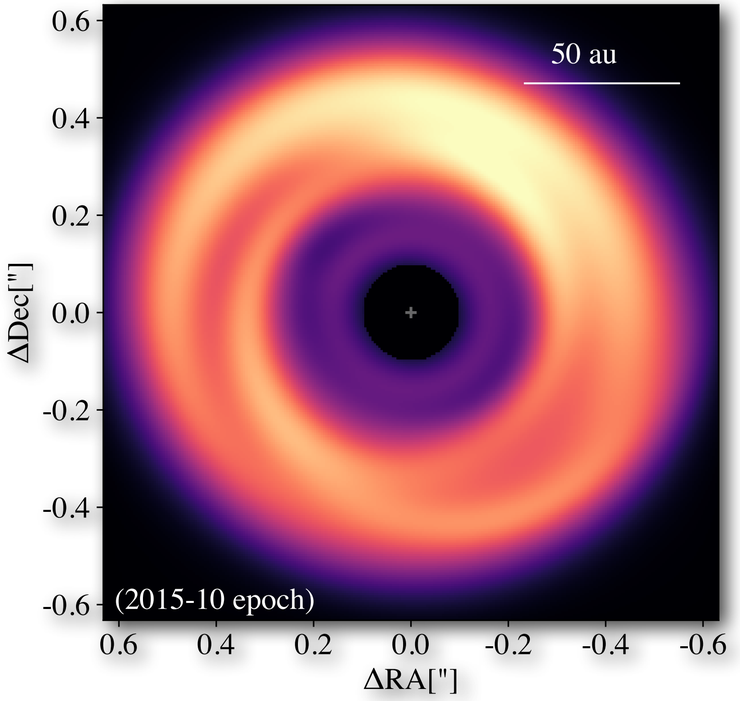

Zhang et al. 2024



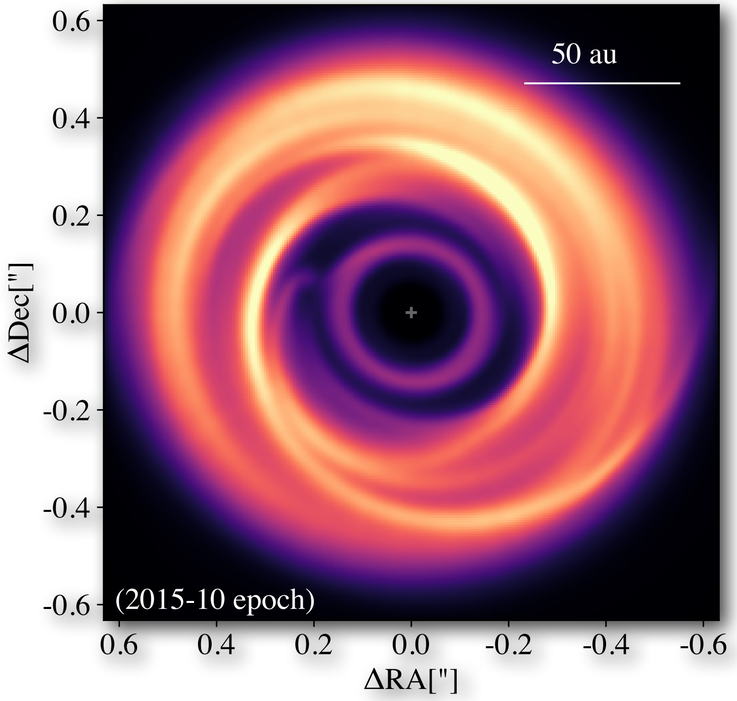
# Protoplanetary disks

- One of the prime science cases of METIS
- Probe details of disk structures
  - monitor their movement
  - connect with presence of protoplanets

MWC758 with NIRC2 (simulation)




MWC758 with METIS (simulation)

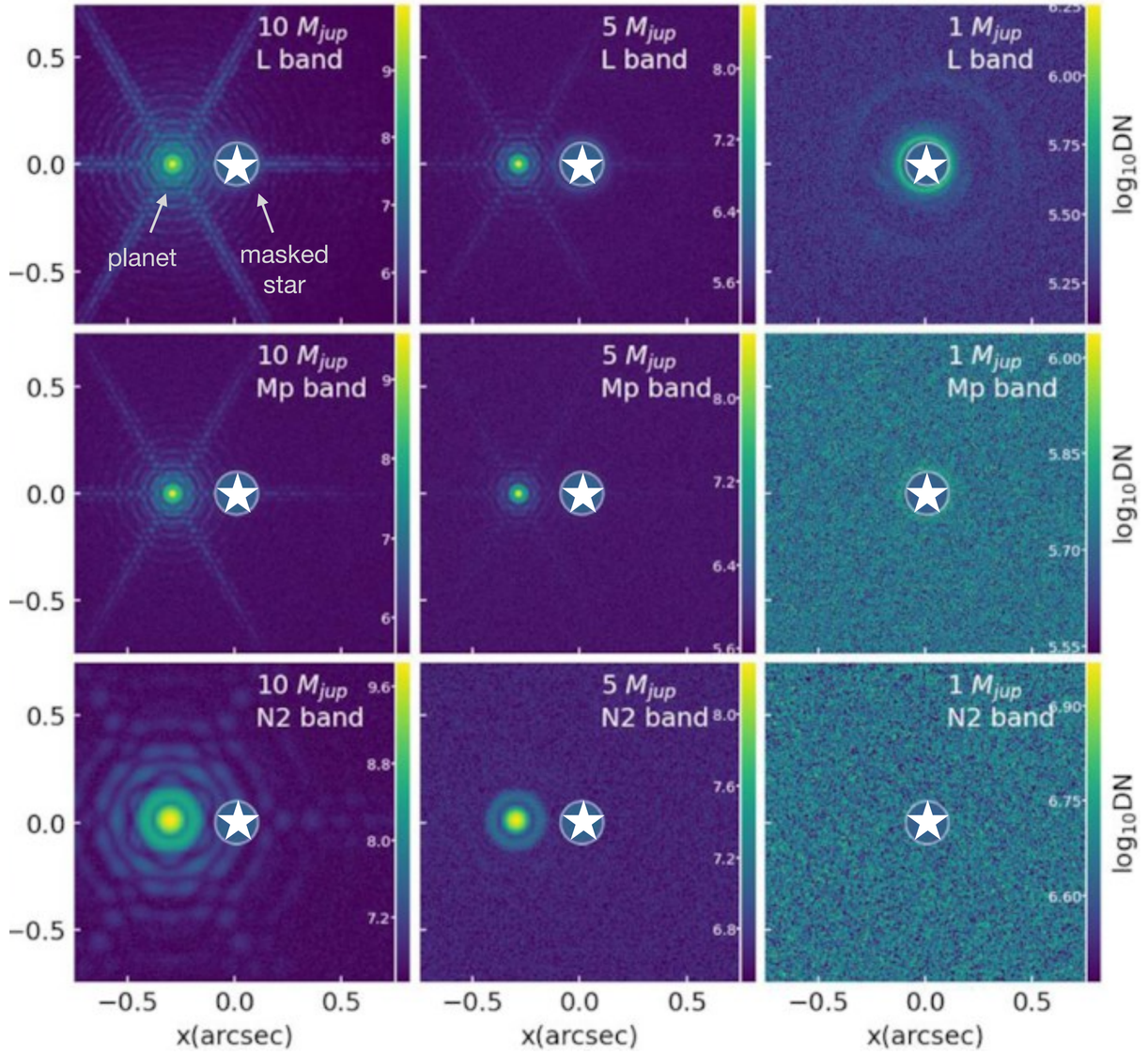



Simulation credits: C. Baruteau + V. Christiaens

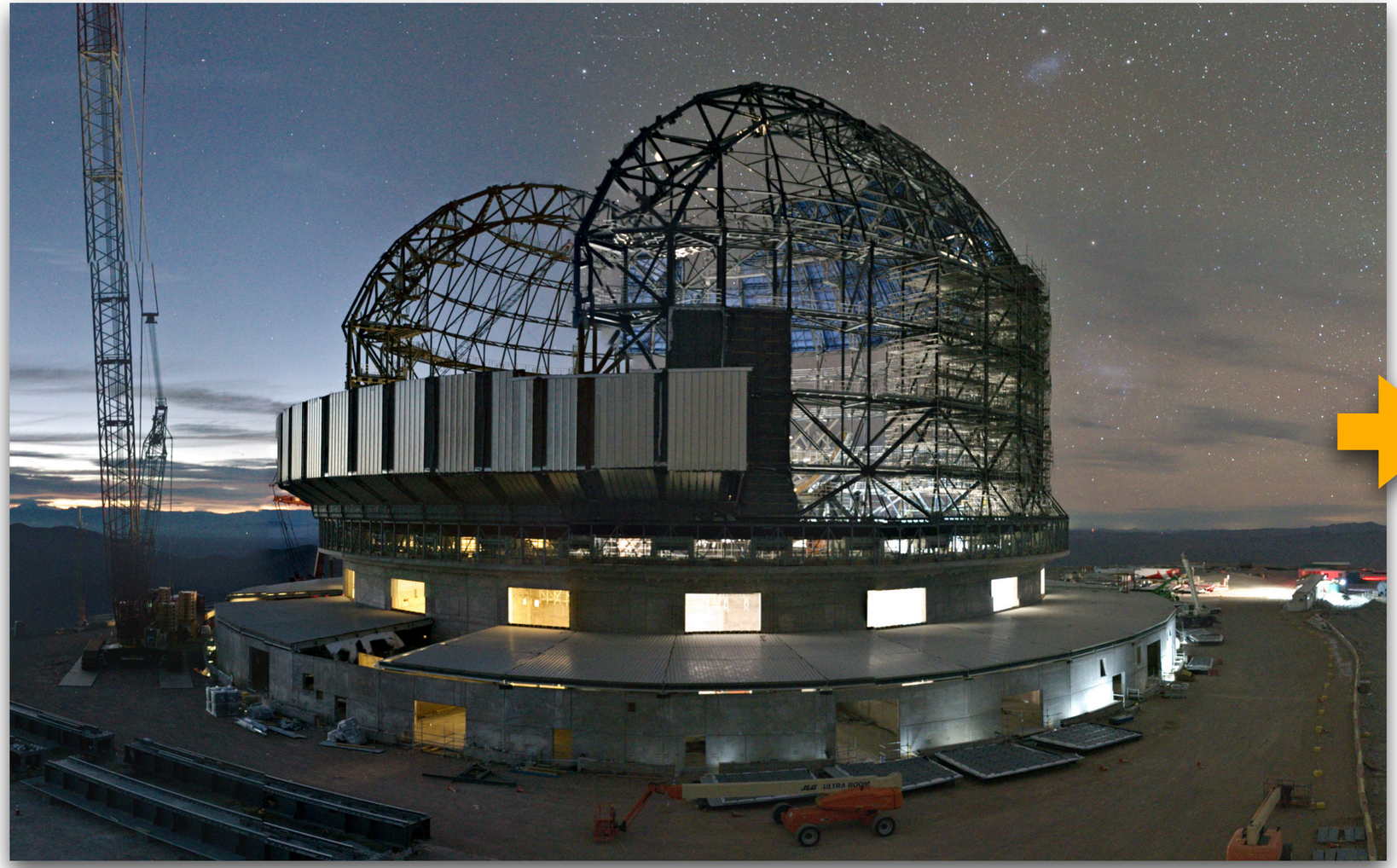
# Forming planets & CPDs

- Simulations of CPD detection at 100 pc (Chen & Szulágyi 2022)
  - 30 au protoplanet illustrated here
  - looks promising for super-Jupiters
- CO gas line from CPD also detectable at R=100,000 (Oberg+2023)
- Next frontier: magma oceans on forming rocky planets in nearby young associations (Bonati+2019)

Chen & Szulágyi 2024



# Expect the unexpected!



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