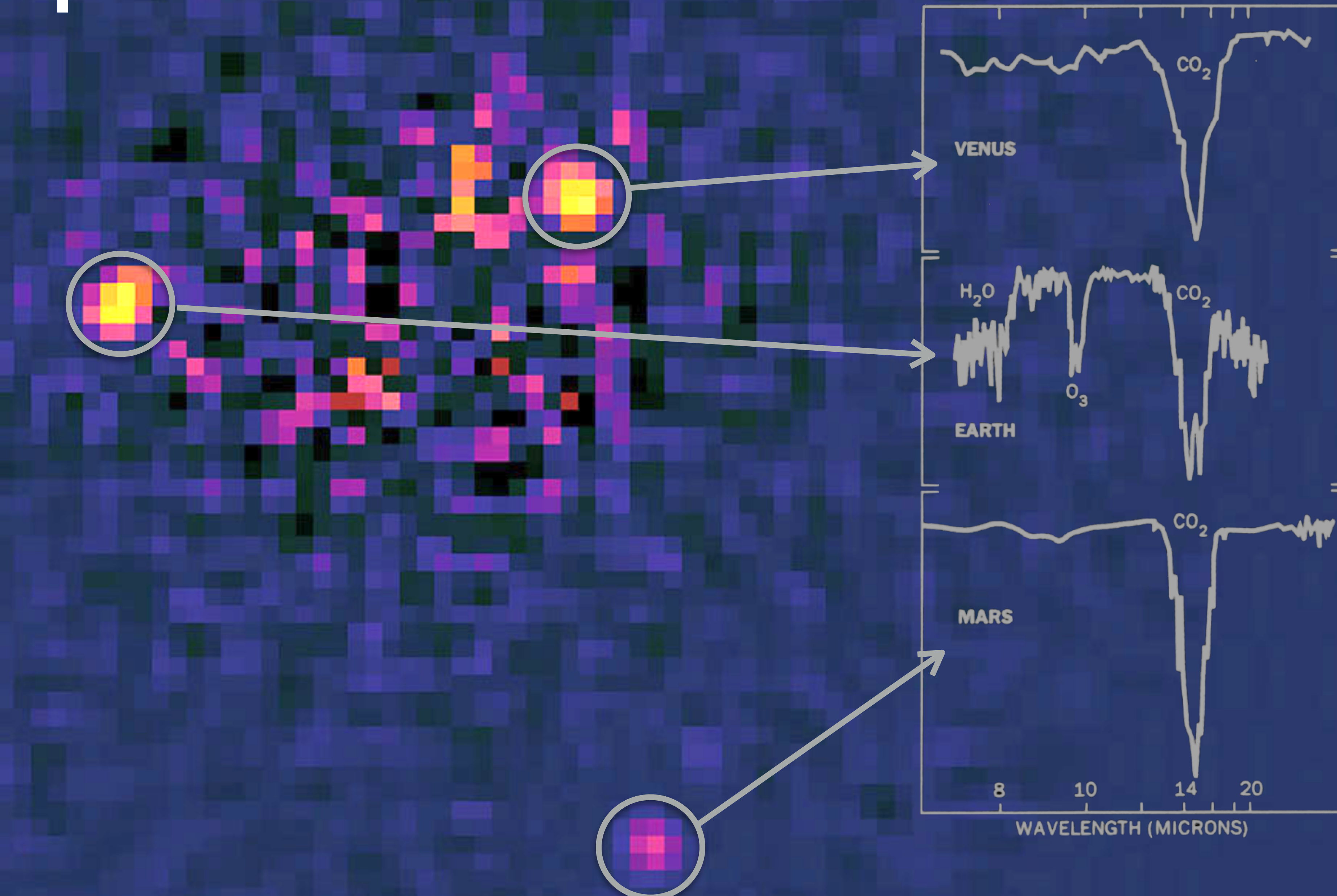
Prospects for mid-infrared imaging of rocky exoplanets



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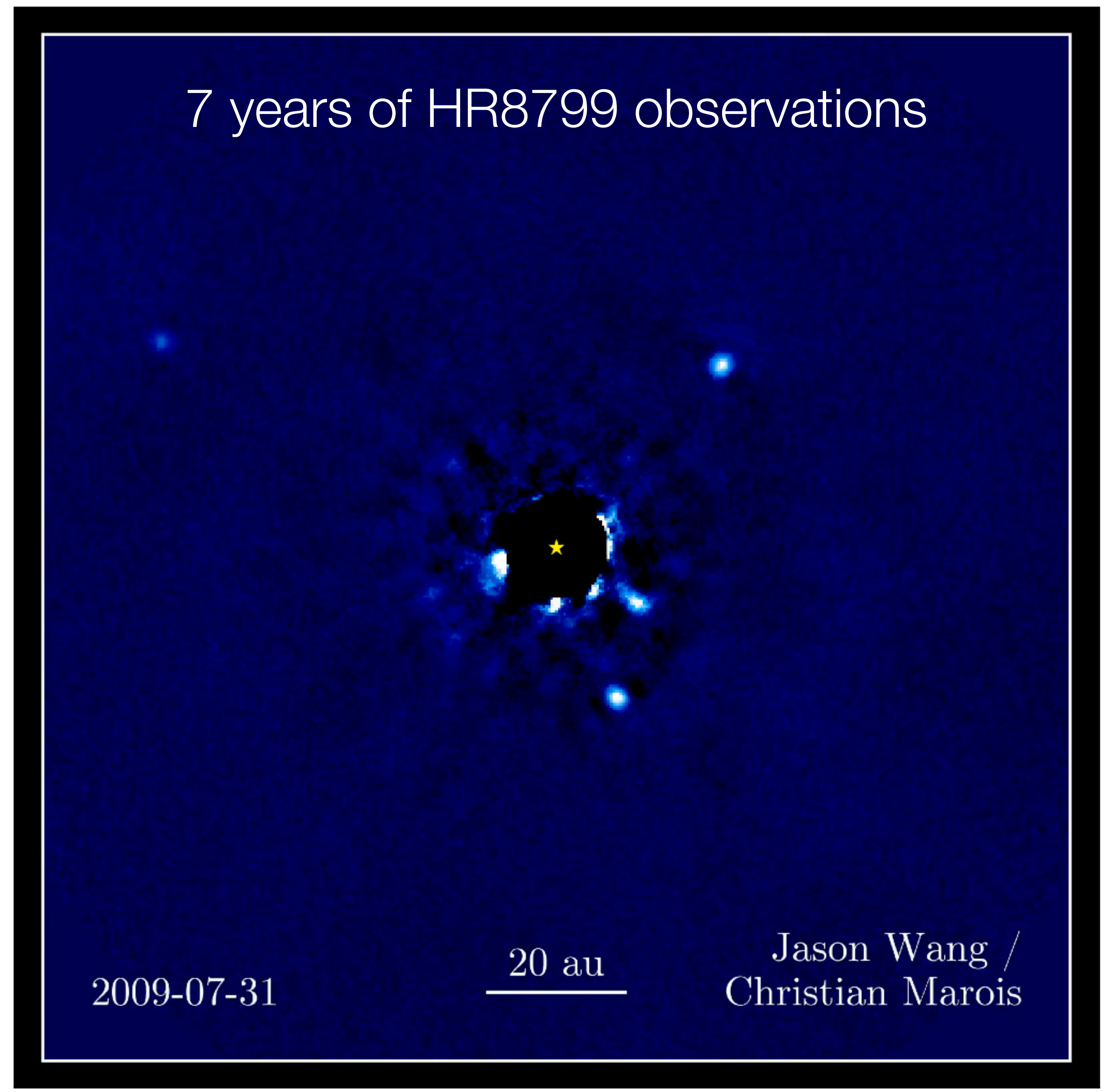
FNRS astrobiology contact group, 17 Dec 2021

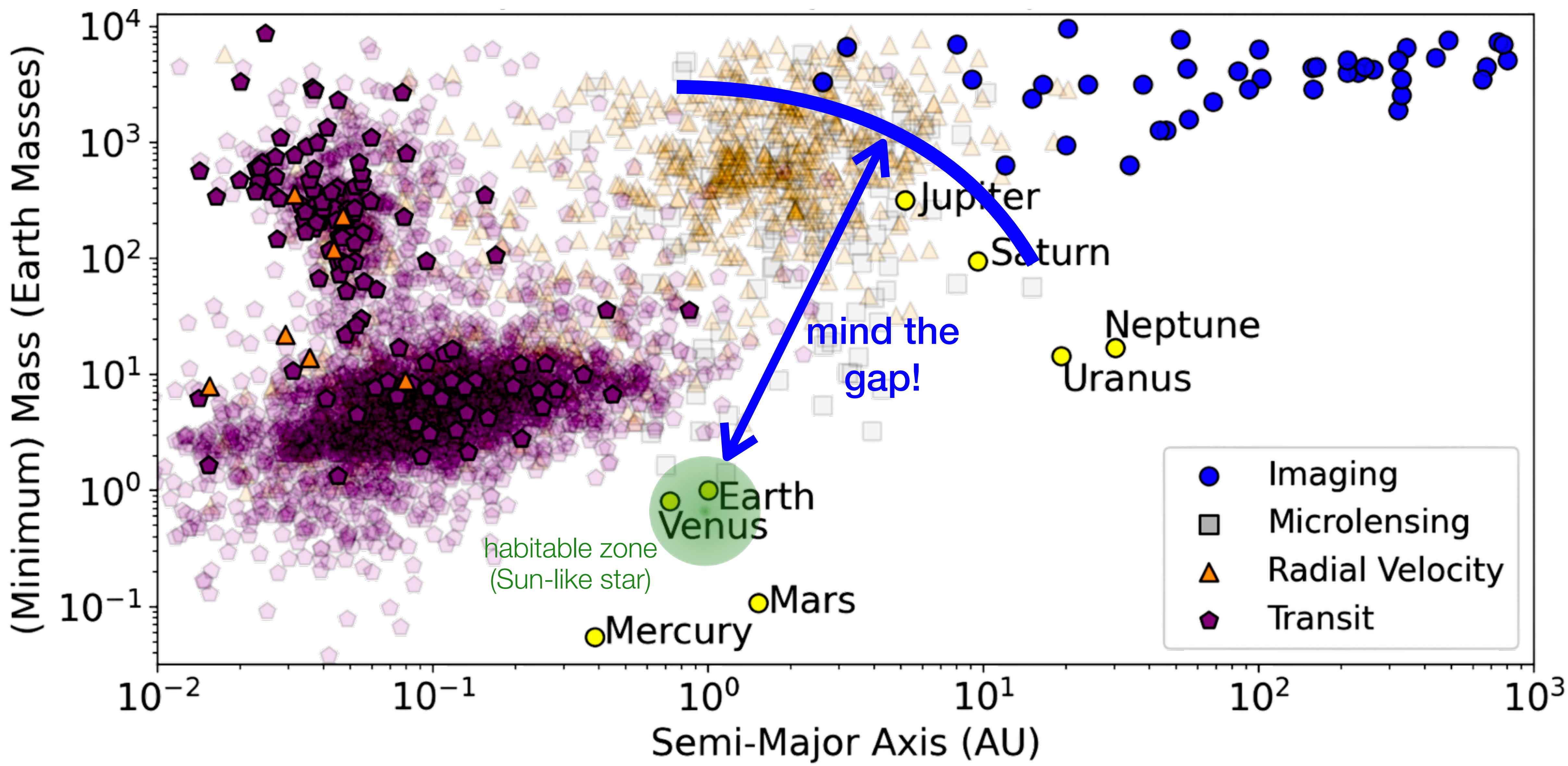
Why high-contrast imaging of exoplanets?

- Separated photons —> spectroscopy!
- Works in principle for any type of star and planetary system



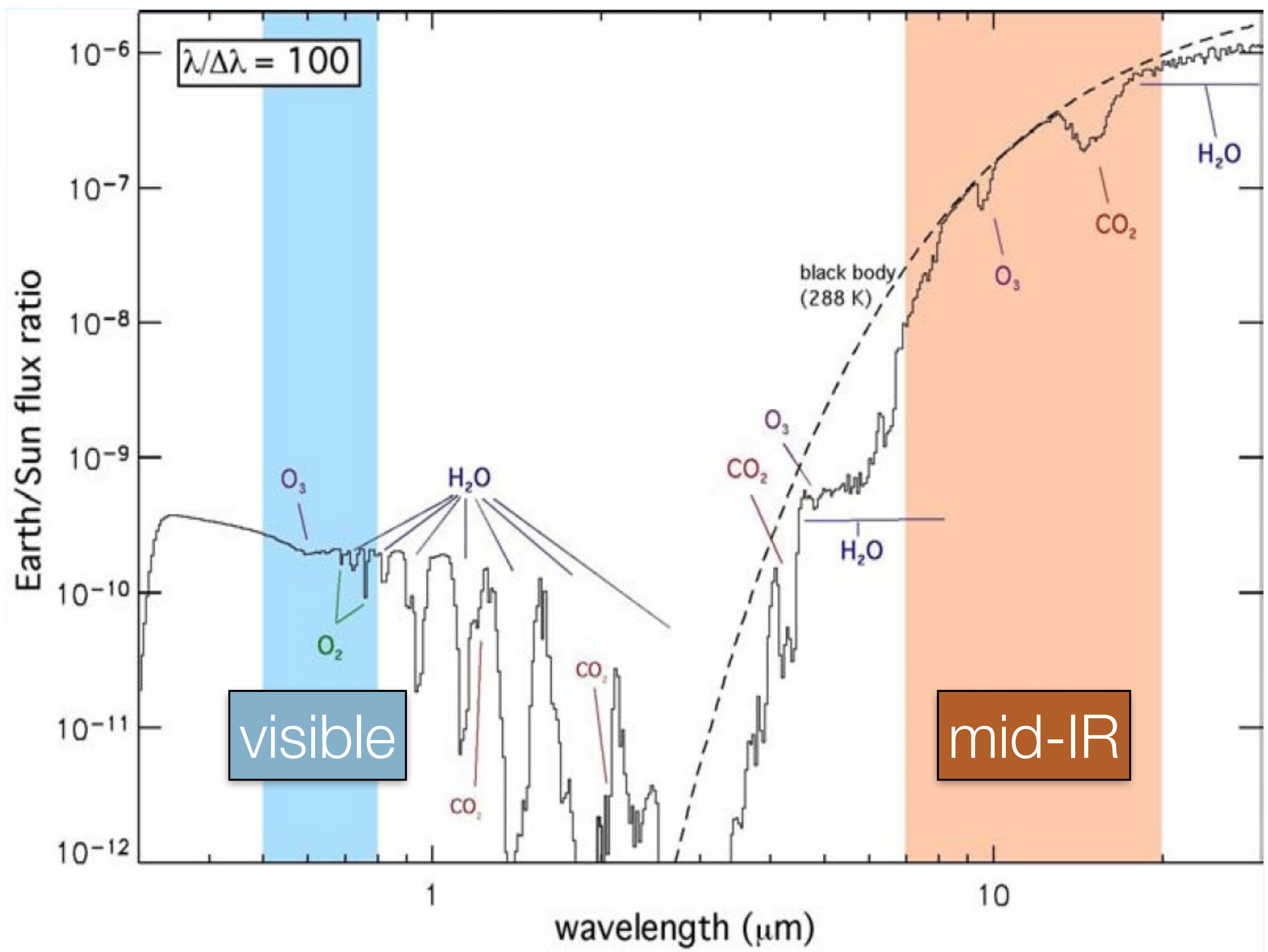
High-contrast imaging today

- Current near-infrared HCI instruments: massive, young planets, far away from their stars



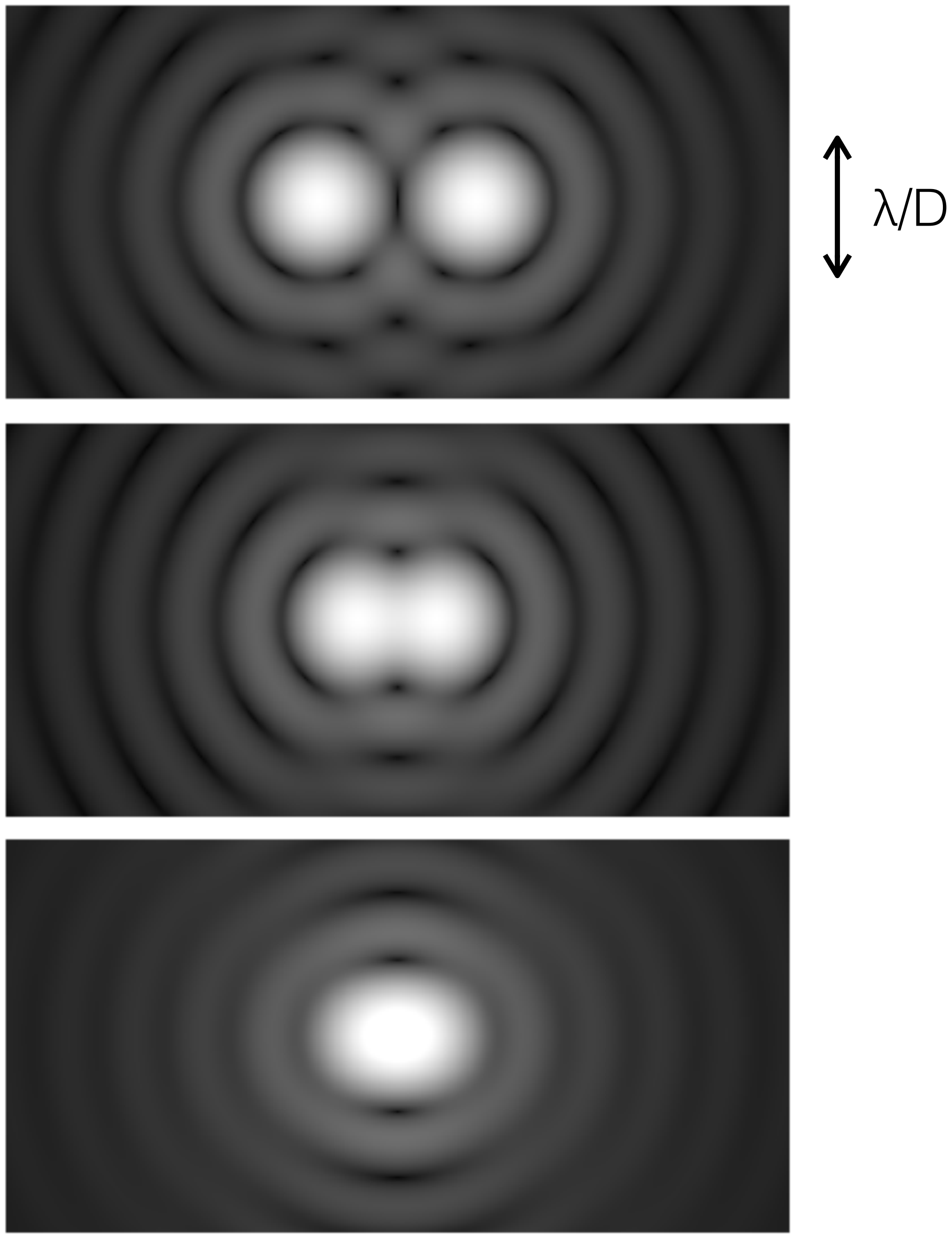
Why the mid-infrared?

- Lower contrast
- Many molecular signatures
- (lower turbulence on ground)

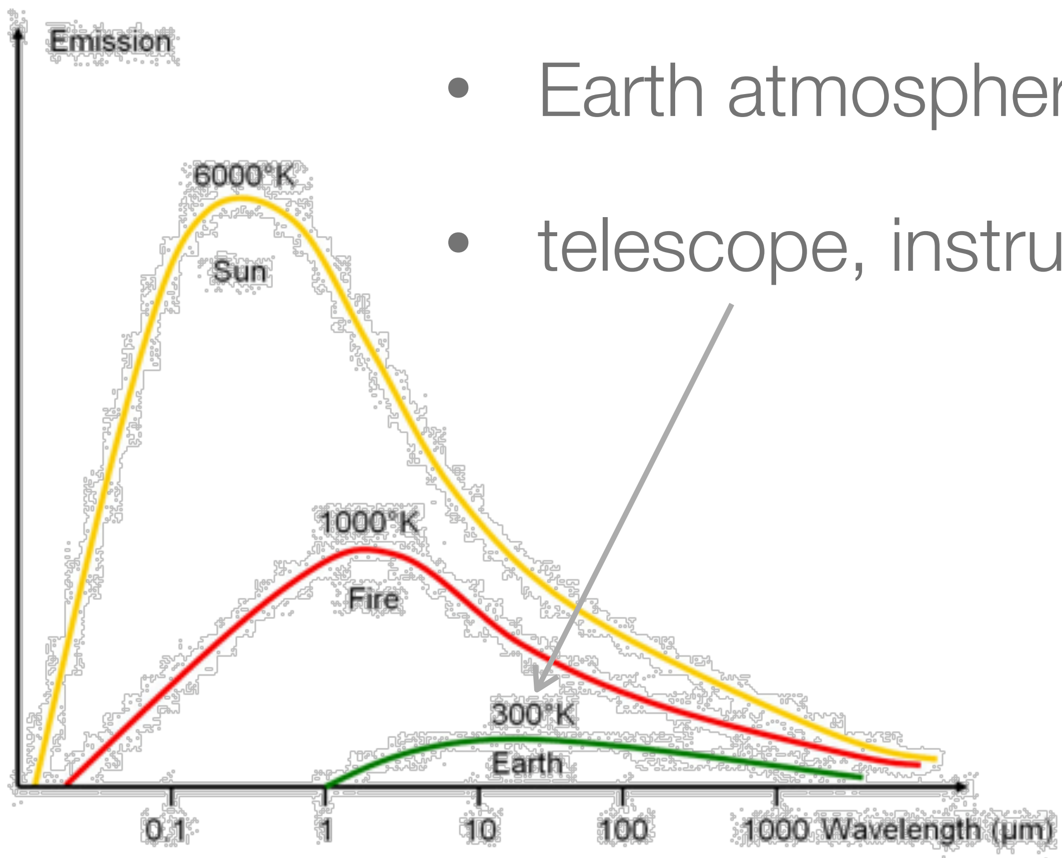


Challenges of mid-infrared high-contrast imaging

- Angular resolution
  - $\lambda/D \sim 0.3''$ for D = 8 m, λ = 10 µm
  - Sun-Earth @ 10 pc —> 0.1” separation



- Thermal background
  - Earth atmosphere
  - telescope, instrument



The EU mid-infrared exoplanet imaging roadmap

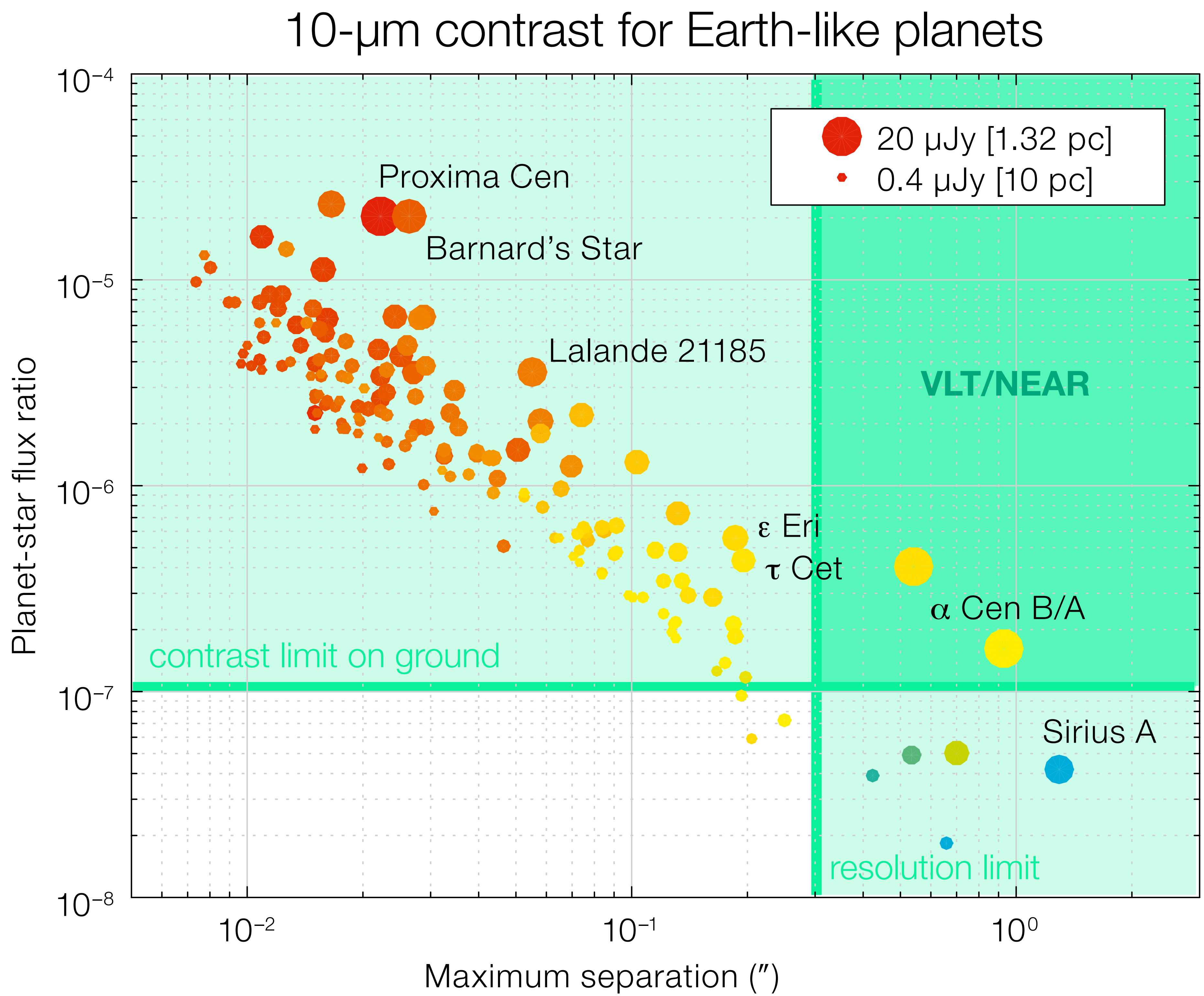
- VLT/NEAR (2019): first test on 8-m telescope
- ELT/METIS (2029): getting serious on a 38-m telescope
- LIFE (2040?): space-borne rocky exoplanet machine

VLT/NEAR

8-m ground based telescope

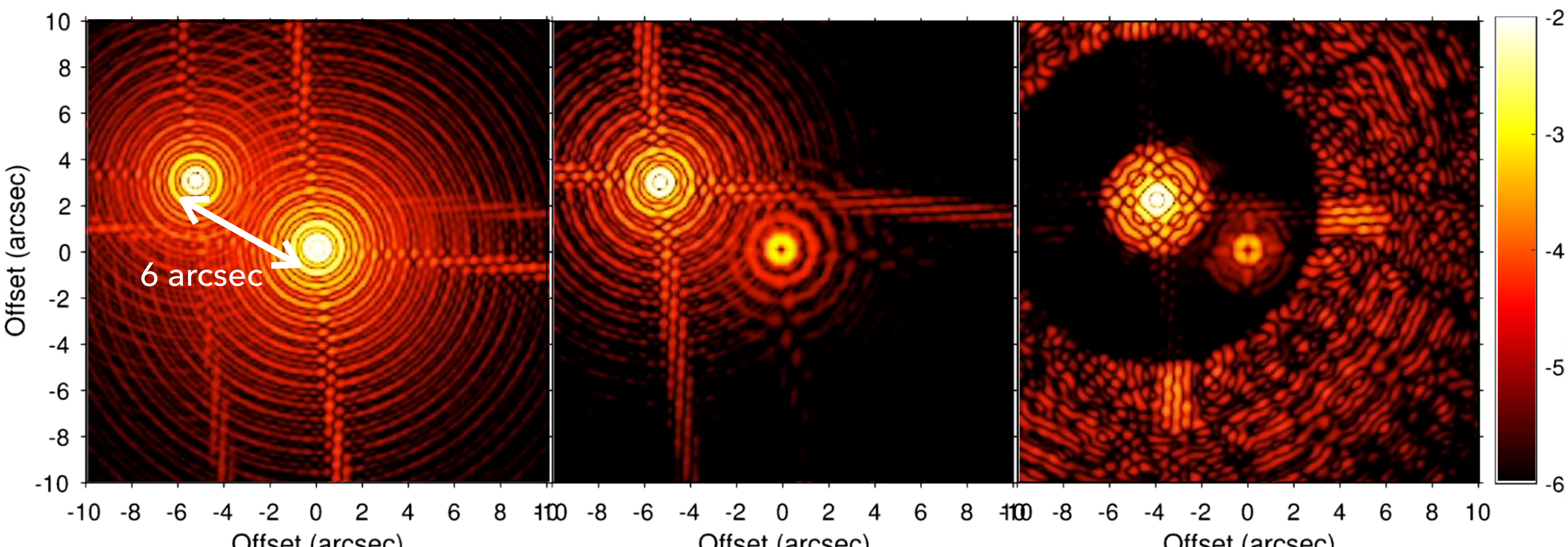
Kasper et al. 2017

Rationale for the NEAR project



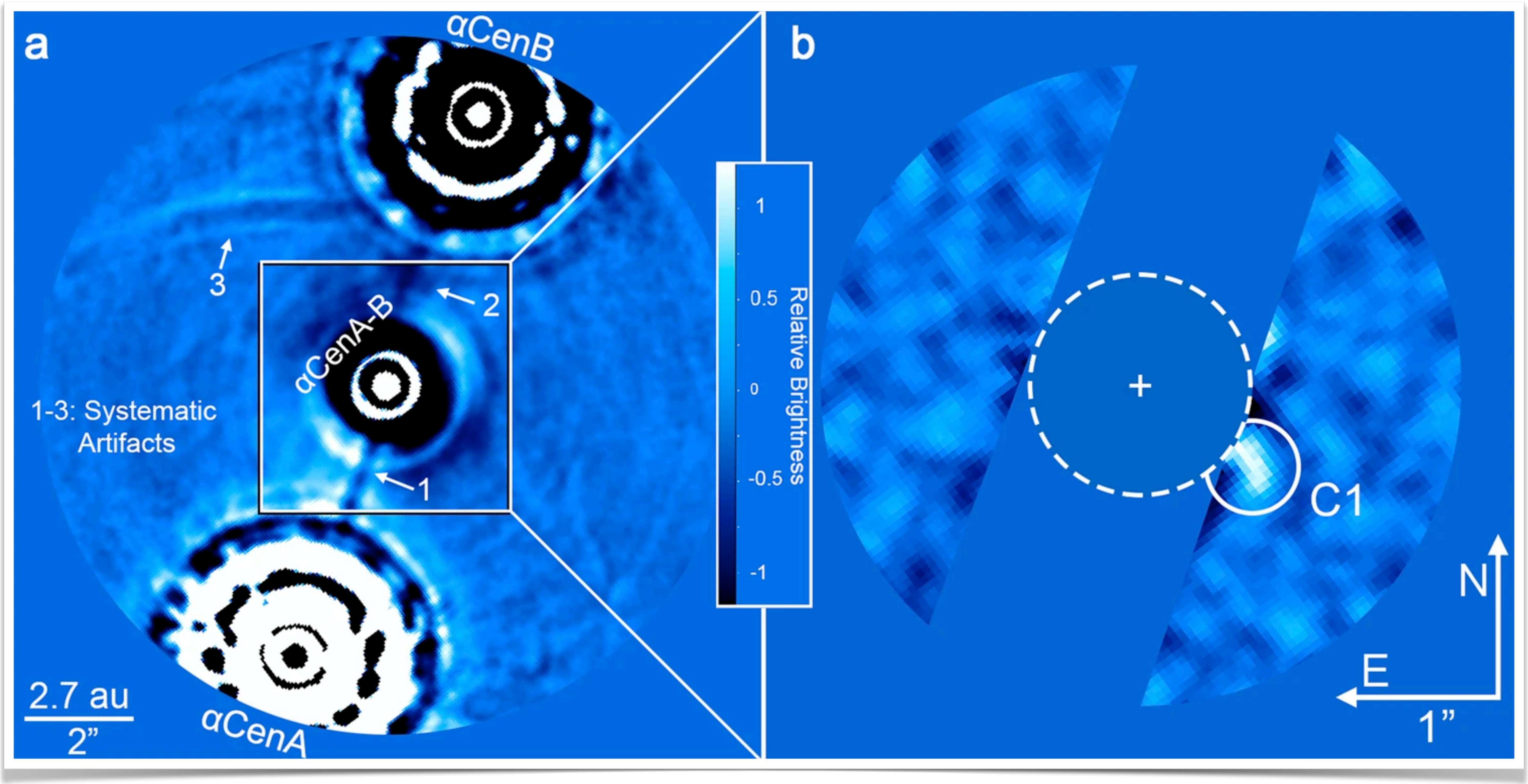
The NEAR concept

- Retrofit an ‘old’ mid-IR camera (VISIR) with adaptive optics and a new vortex coronagraph
- Optimize the coronagraph for the alpha Centauri binary star



A 100-hr observing campaign on alpha Centauri!

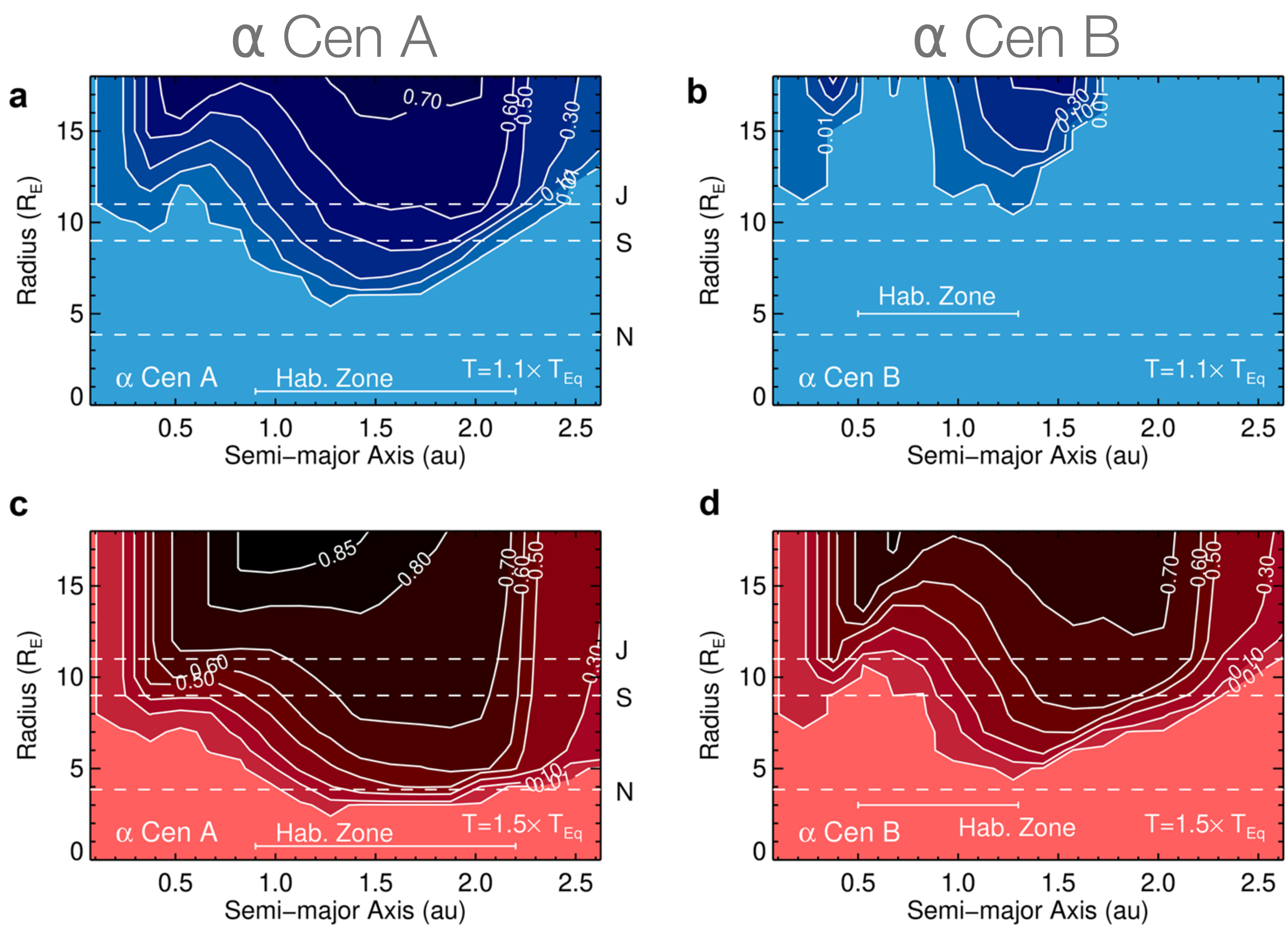
- Candidate companion C1 would have Neptune- to Saturn-mass range, and be temperate (~ 1 au)

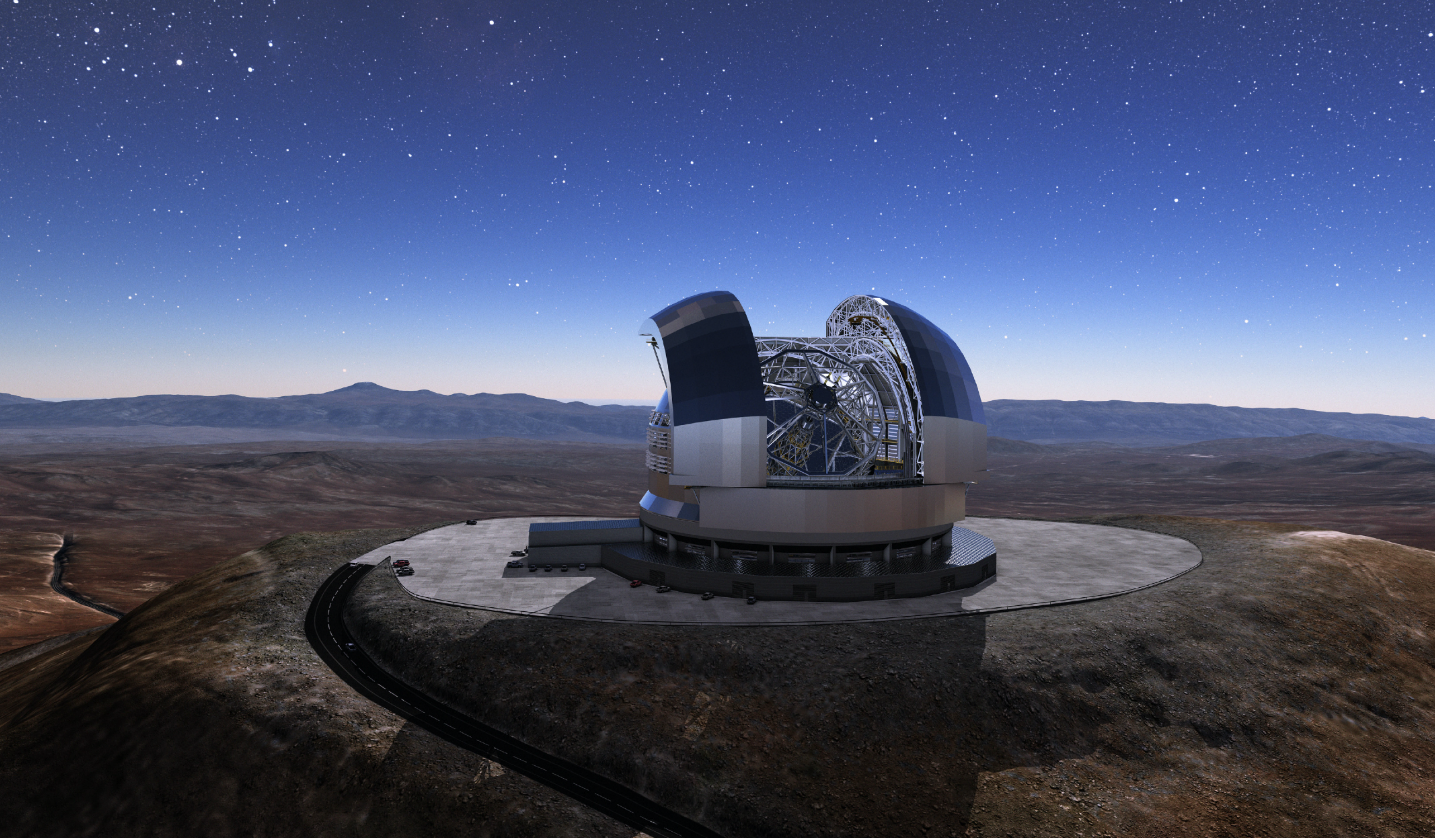


NEAR sensitivity limits

Cold models

Warm models





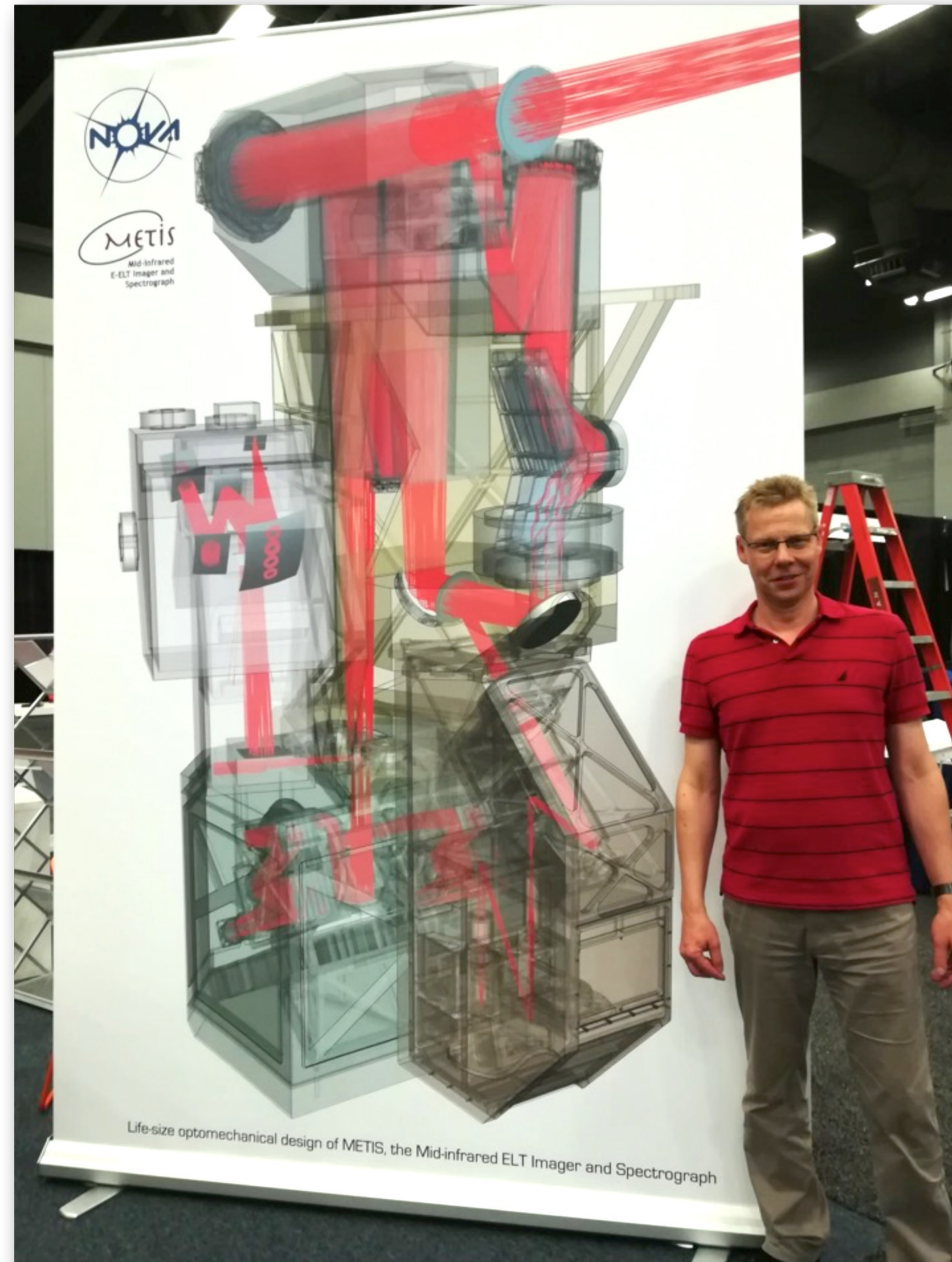
Mid-infrared
E-ELT Imager and
Spectrograph

ELT/METIS

38-m ground-based telescope

METIS in a nutshell

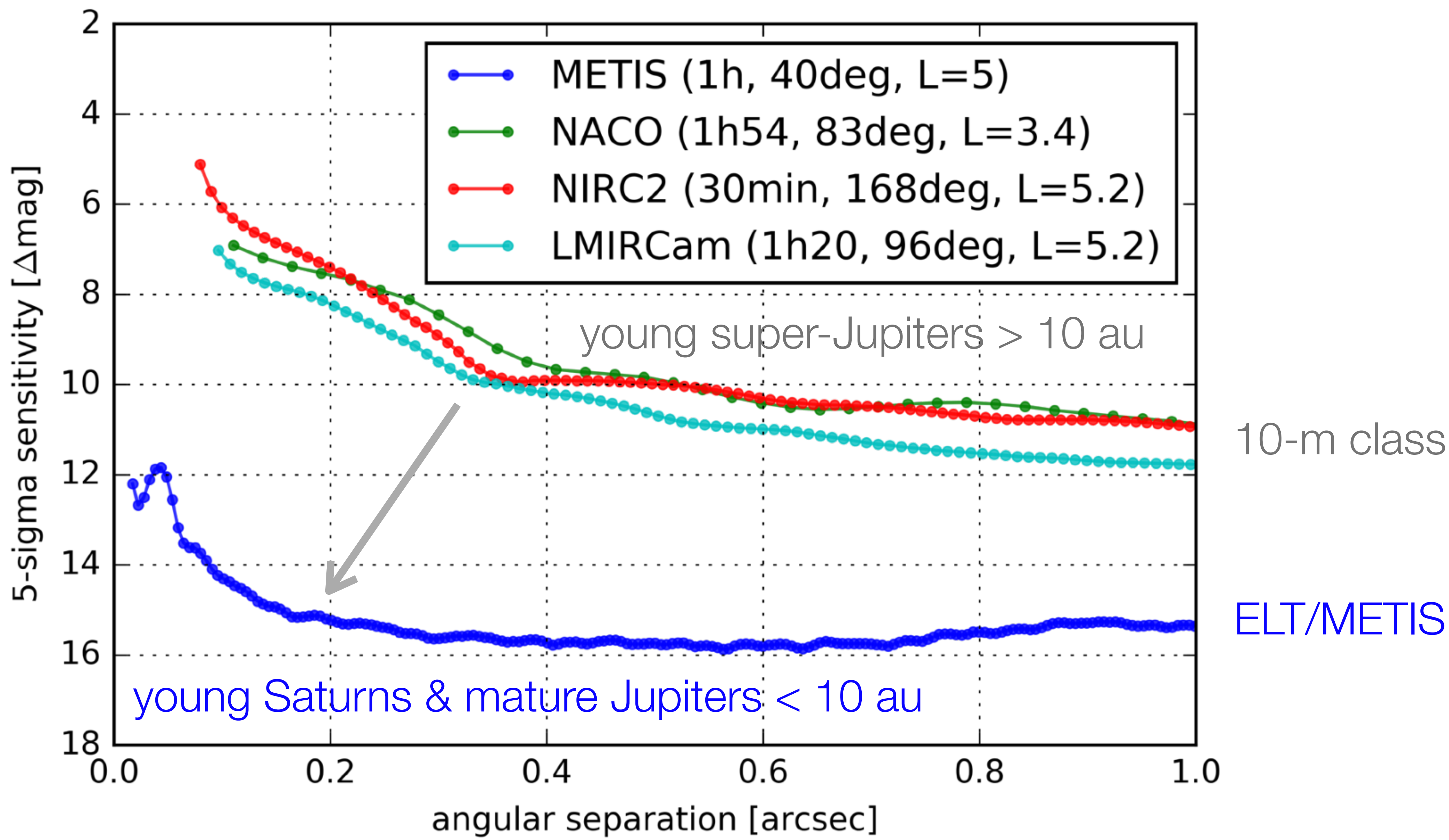
- One of three first-generation instruments for ELT (~2029)
- Imaging at 3 – 19 μm
  - including high-contrast modes
- High resolution (R ~ 100,000) integral field spectroscopy at 3 – 5 μm
  - also combined with high-contrast
- All observing modes work at the diffraction limit of the 38-m ELT with an adaptive optics system



1:1 scale model

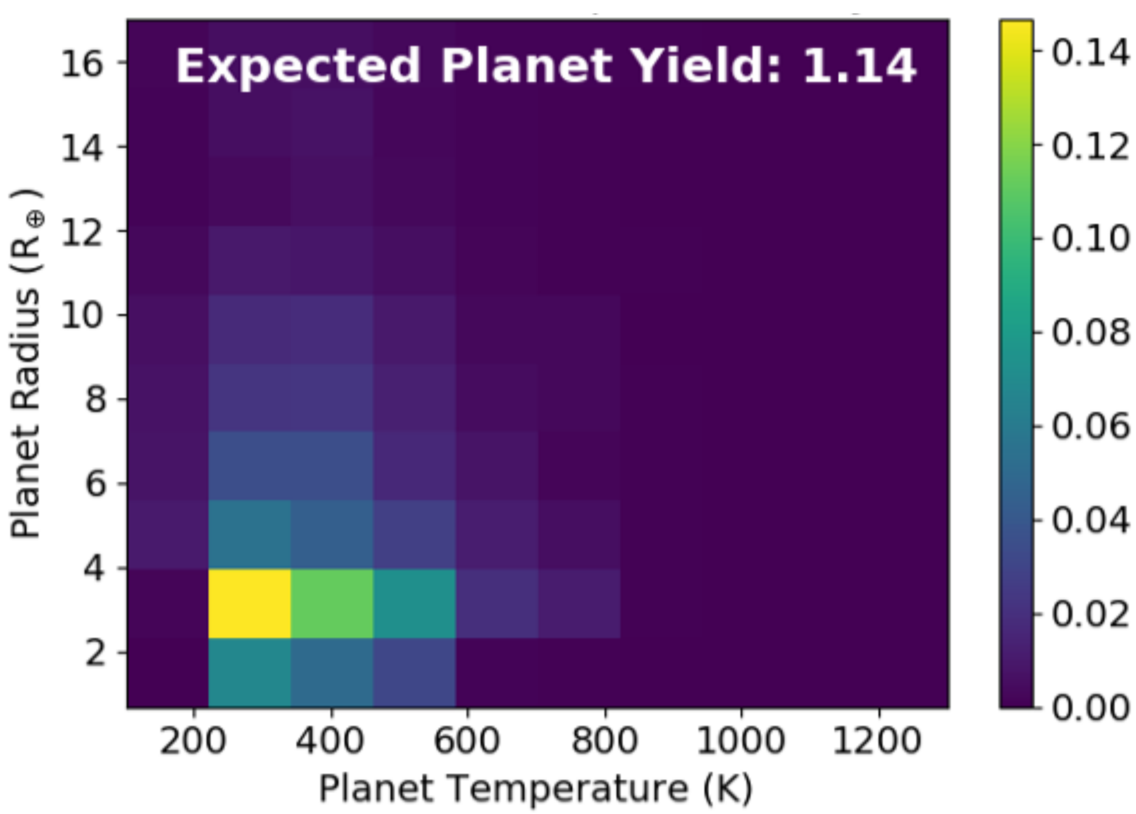
Expected performance at **λ = 4 μm**

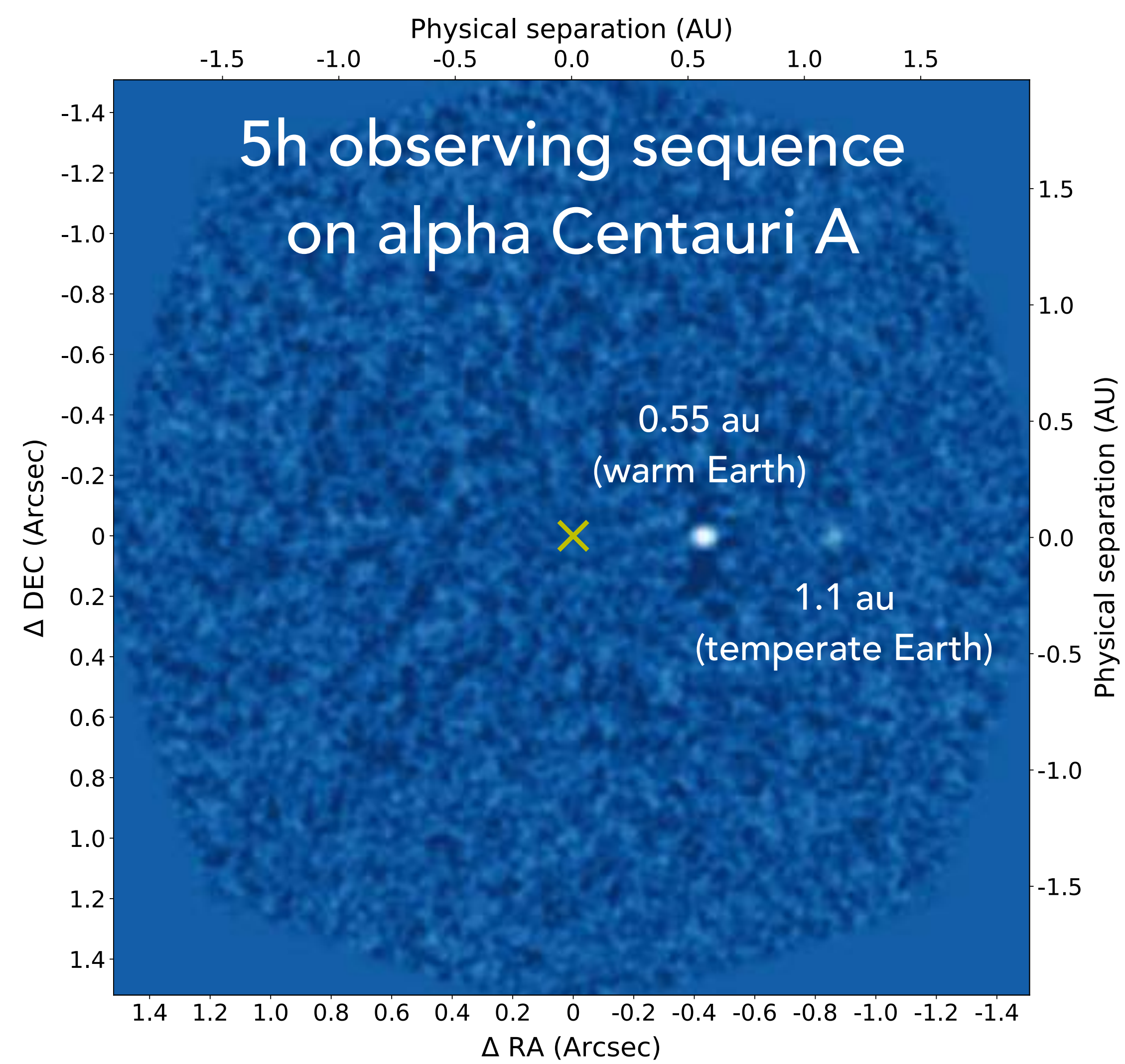
- Based on end-to-end model of full instrument + pipeline



Expected performance at **λ = 11 μm**

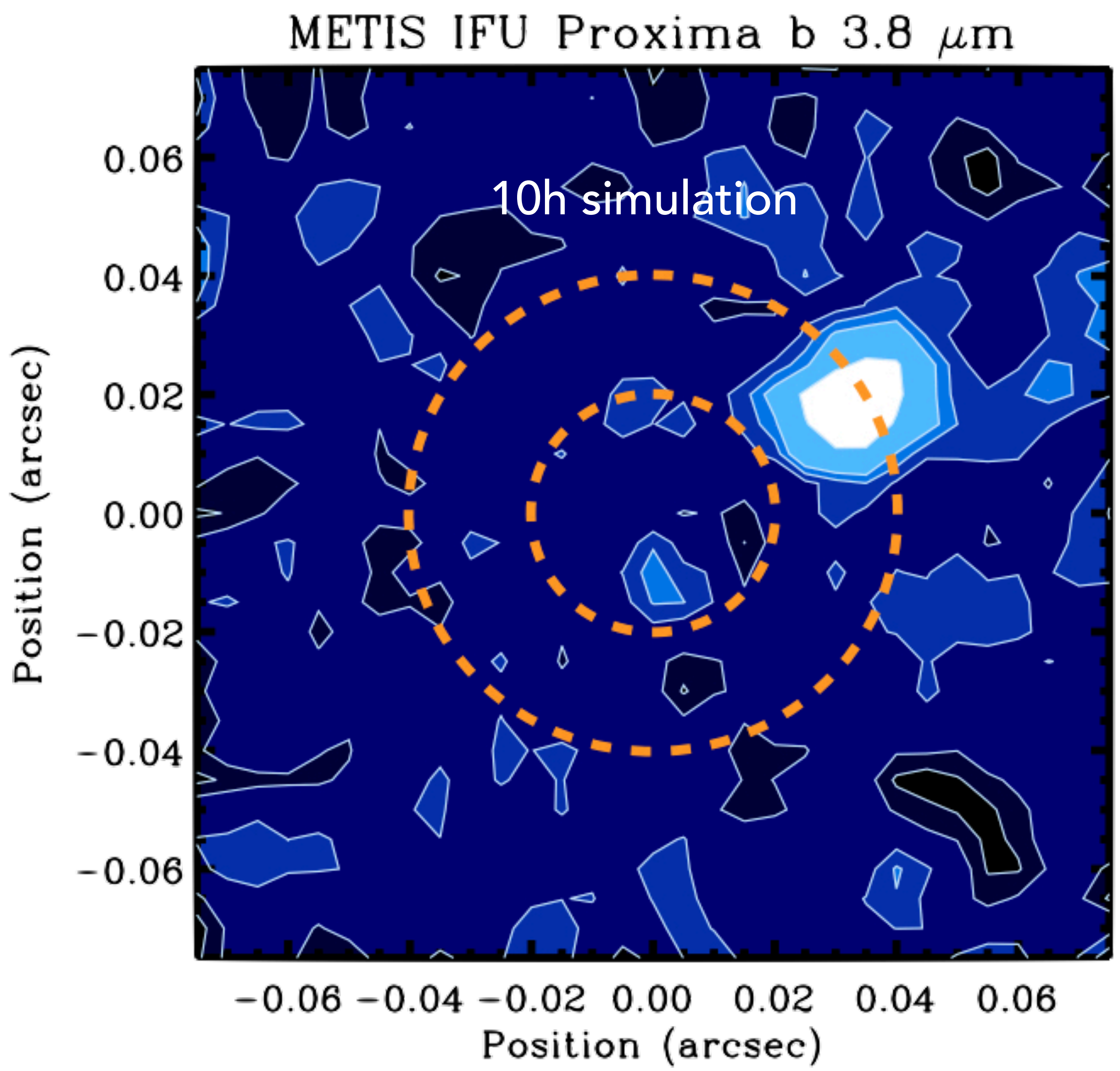
- Earth-like planet around alpha Centauri within reach in 5 hours!
- Expected yield of one 'small' planet for six closest Sun-like stars, taking into account planet occurrence rate

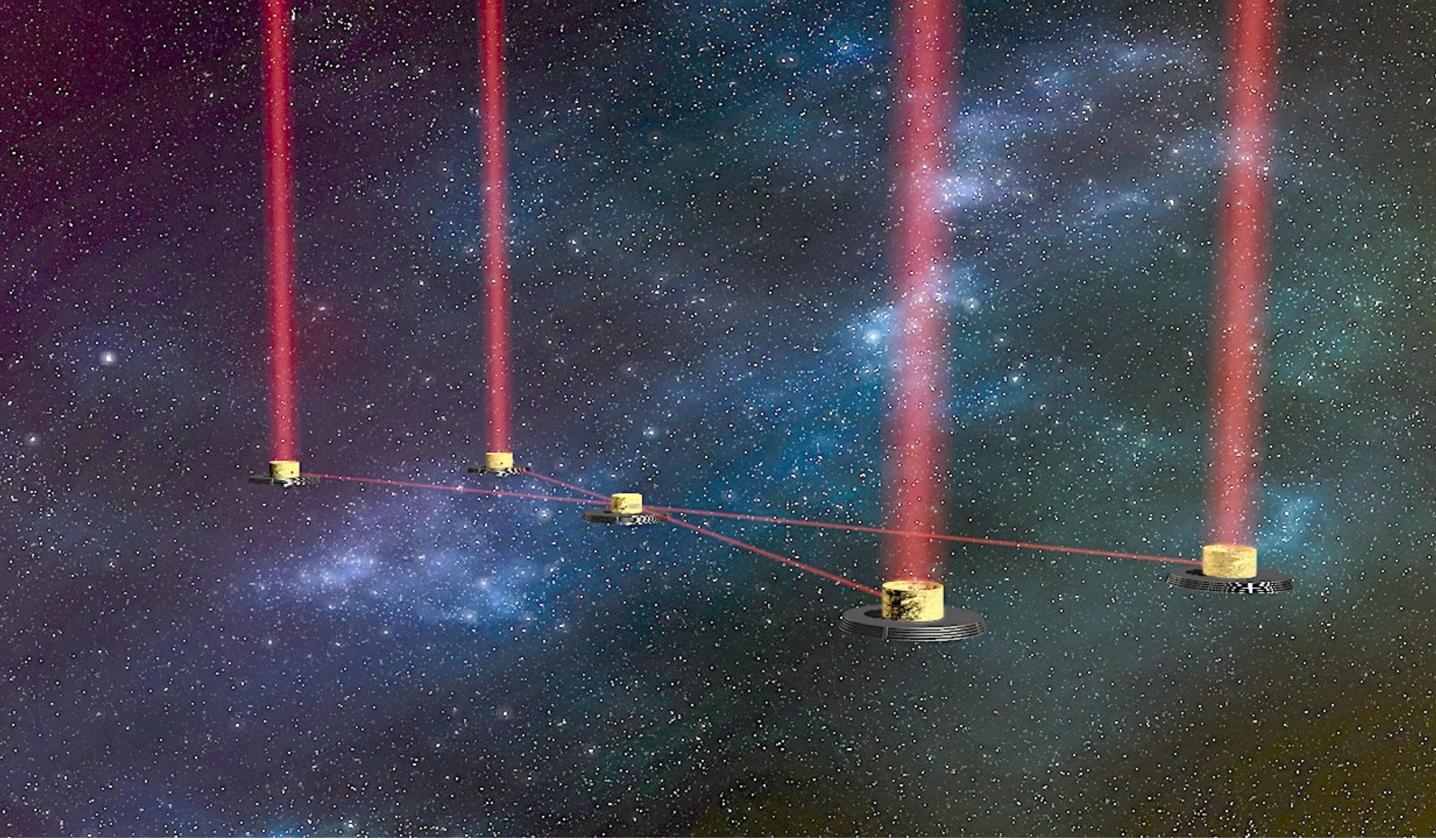




Leveraging the power of high-resolution IFS

- Proxima Centauri b in reflected light
  - 1.1 R_{Earth}, 0.3 albedo, 50% illumination, Earth-like atmosphere
- High-contrast IFS at 3.8 μm
  - λ/D = 20 mas, just enough for Proxima habitable zone
  - 10^{-7} contrast is challenging
- Based on planet's molecular lines —> direct constraints on atmospheric composition





LIFE
Large Interferometer For Exoplanets

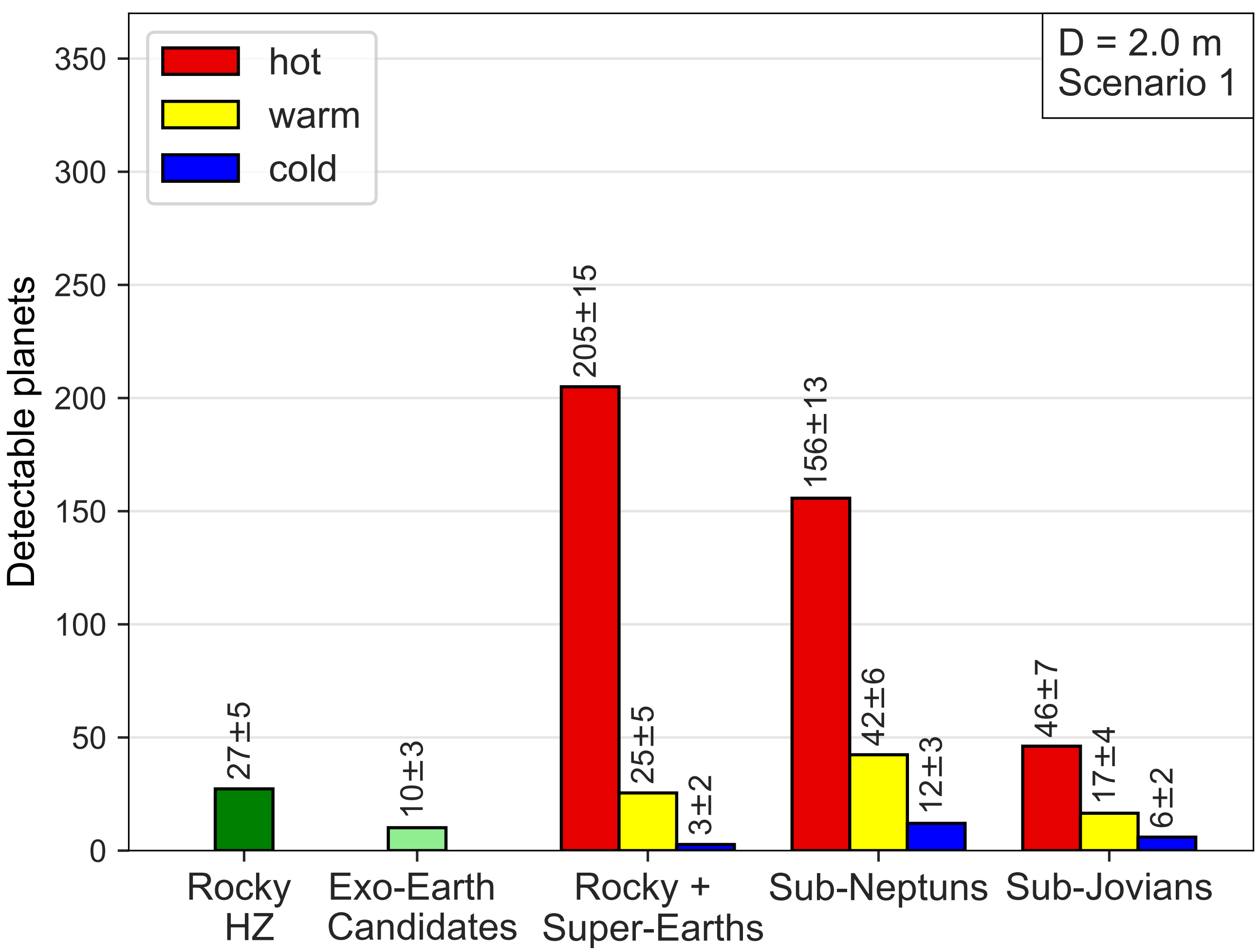
LIFE | large space-based interferometer

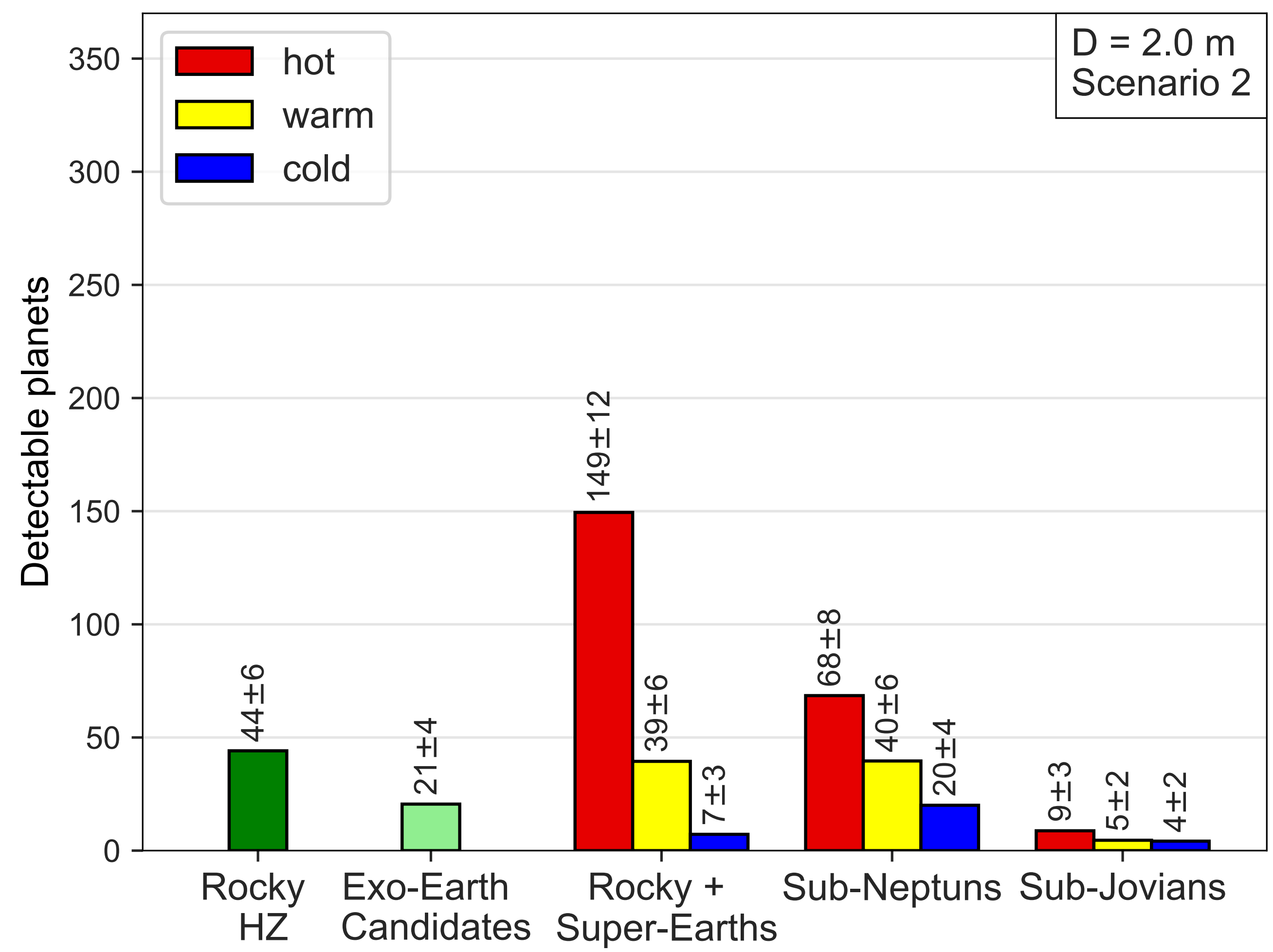
LIFE concept

- Space provides low background & no turbulence
- 30-m telescope in space not possible —> interferometry
  - formation-flying telescopes —> adjustable angular resolution
  - destructive interferences can be used to block starlight
- Mission concept: 2-yr search, 3-yr characterization
- LIFE selected as one of three main themes for L-class missions in ESA Voyage 2050 program

LIFE expected yield

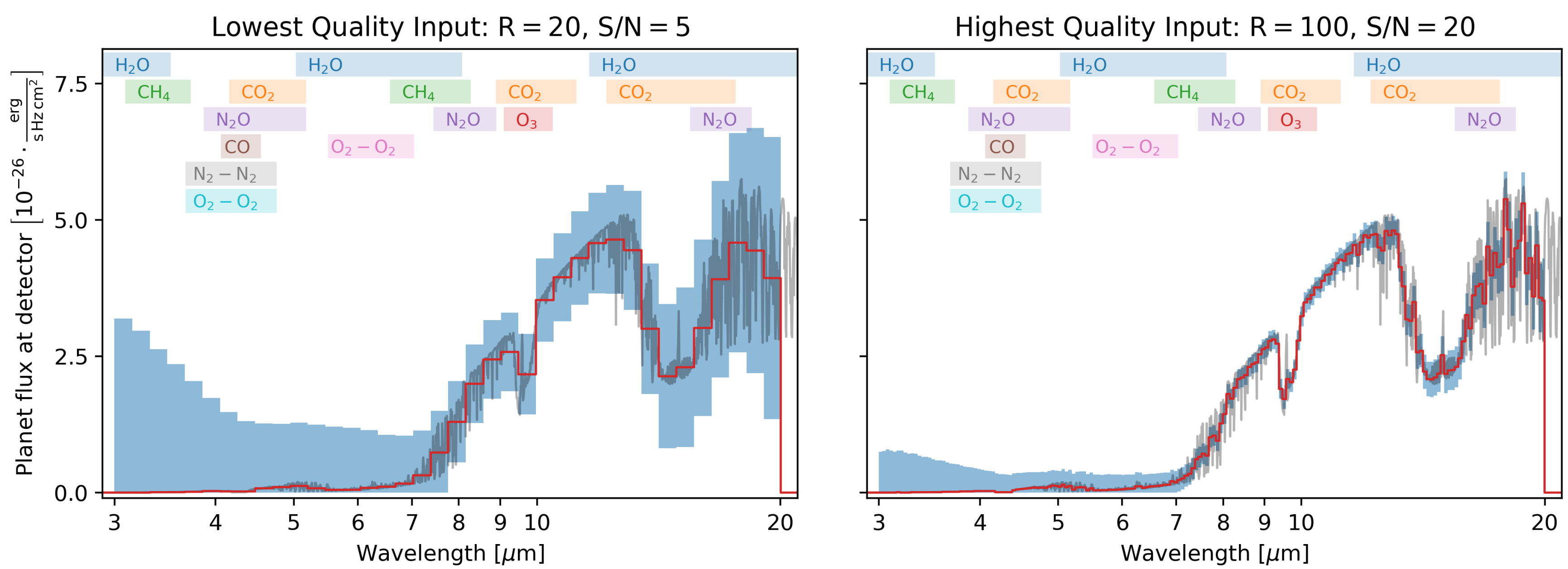
- About 20 to 50 rocky habitable zone exoplanets (mostly around low-mass stars)
- Hundreds of super-Earths / Neptunes

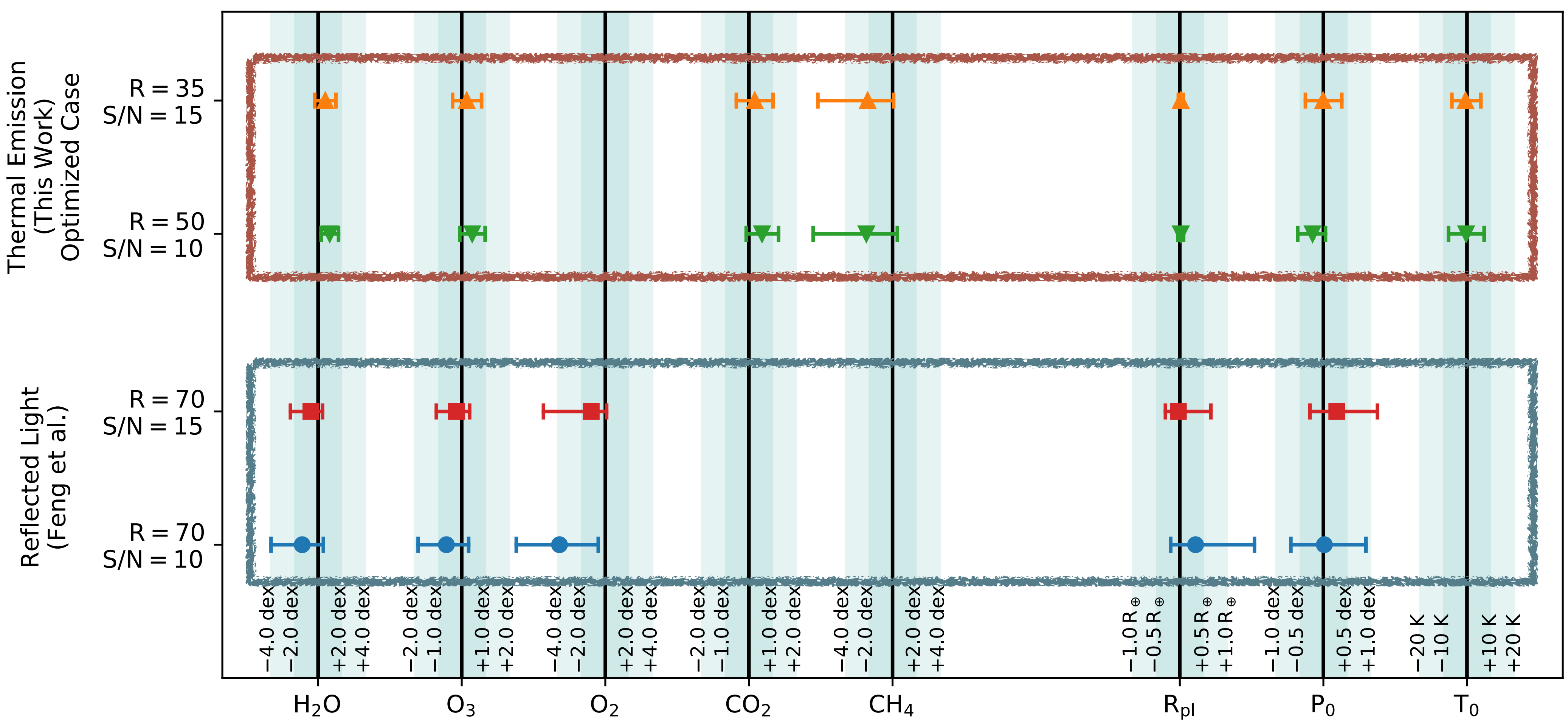




Planet characterization potential

retrieval





LIFE

LUVOIR/HabEx (visible / near-IR)

The future is bright … in the mid-IR!