2024+: Observing Exoplanet Atmospheres with the E-ELT

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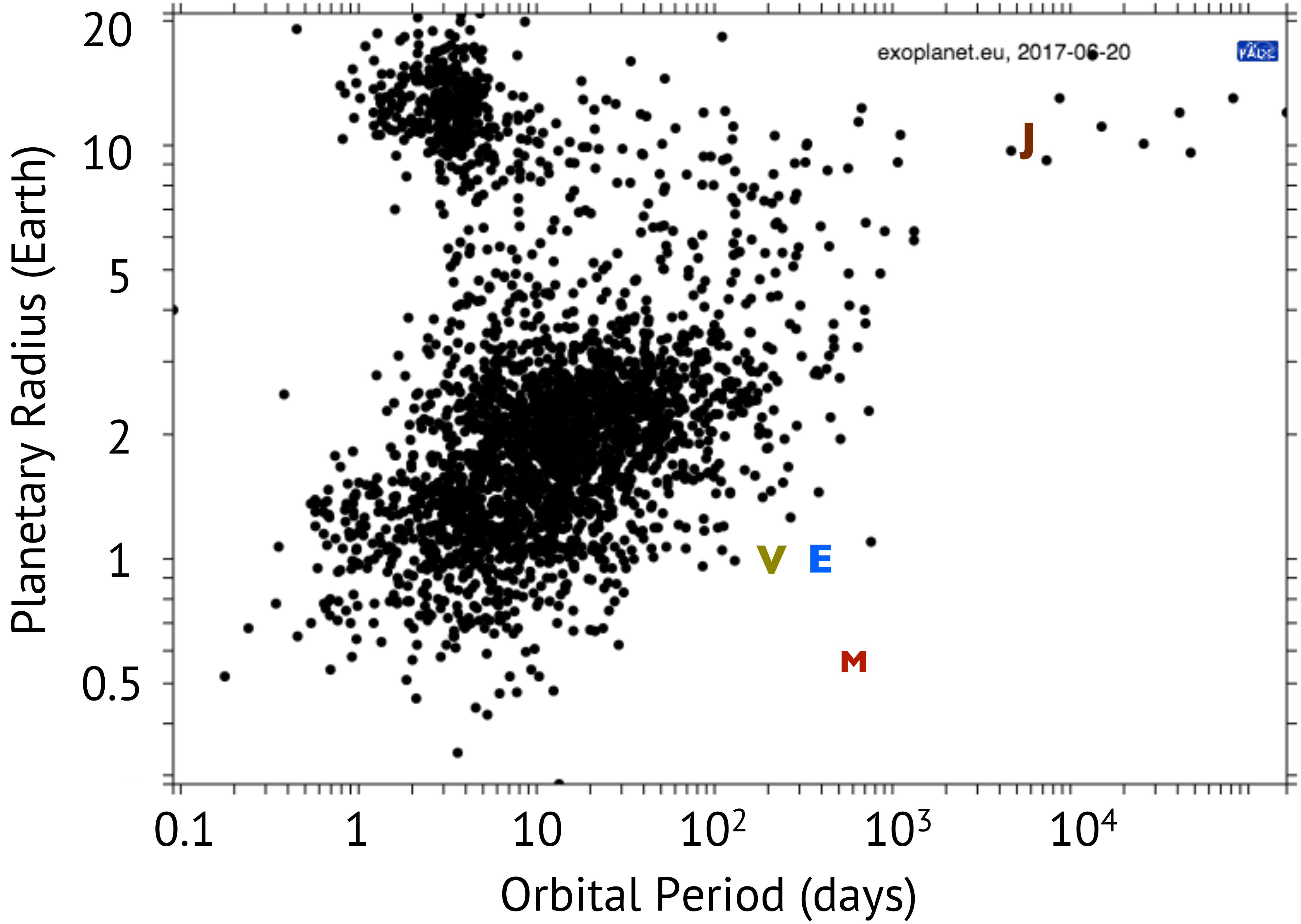
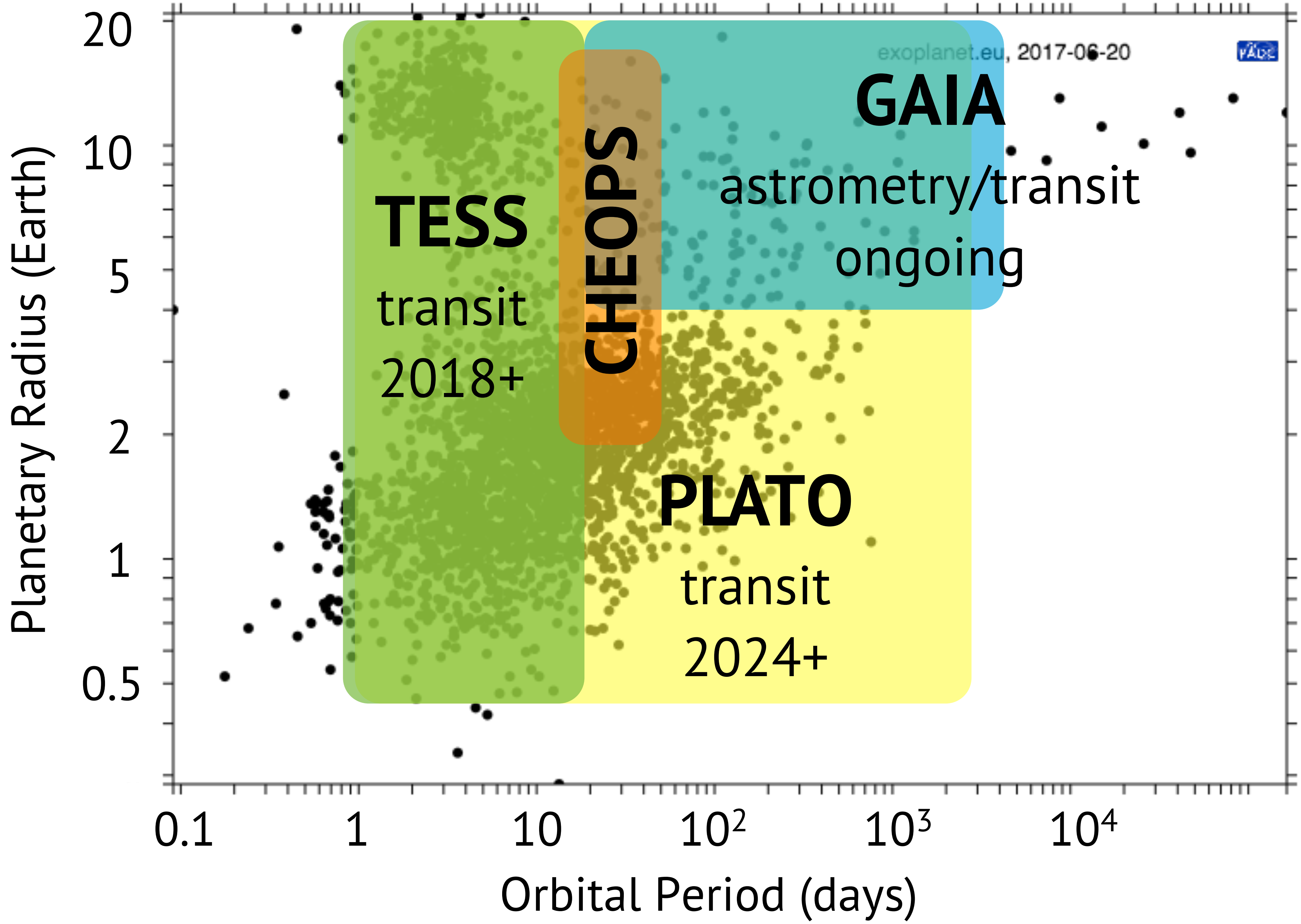
Where do we stand today?



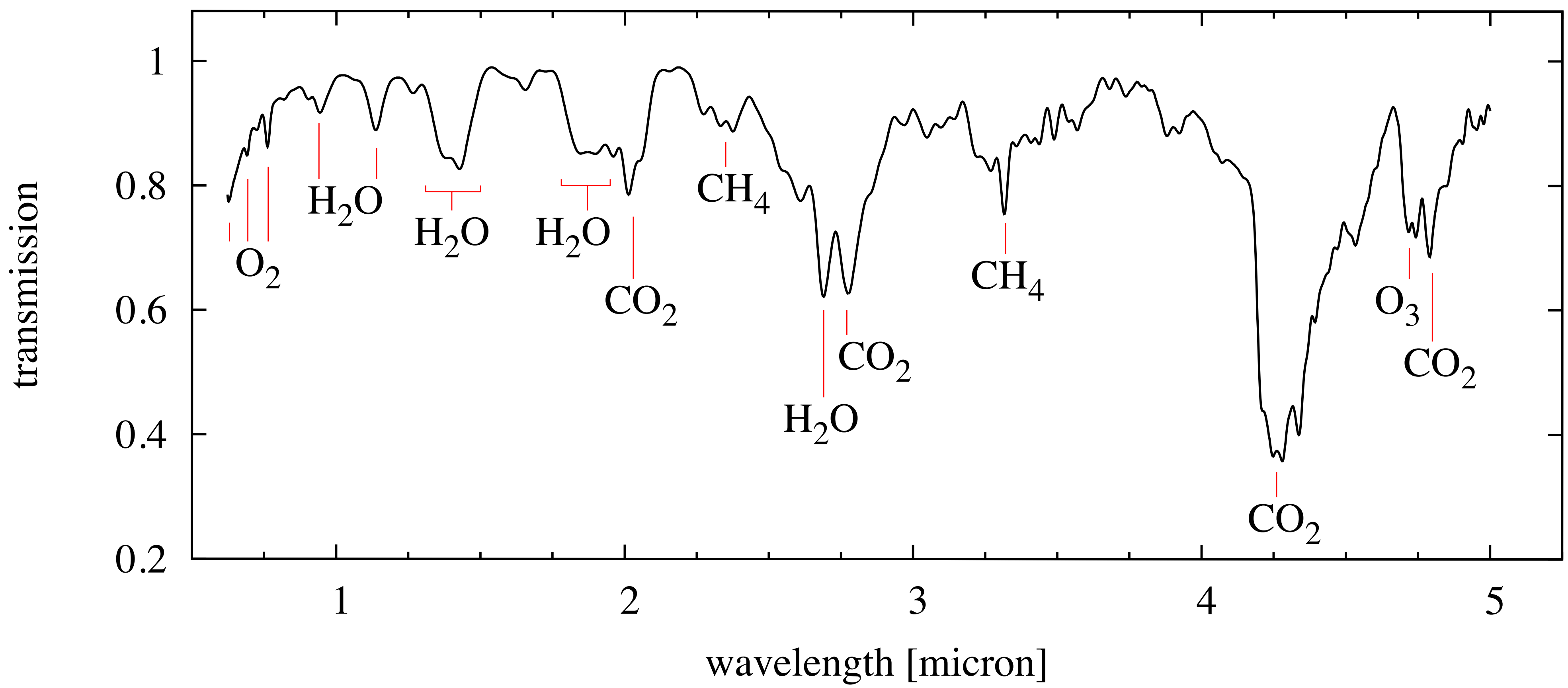
Where will we stand in 2024?



Atmospheres: where will we stand in 2024?

JWST: **transmission spectroscopy in the IR (2019+)**

- ★ mostly atmospheres of hot/warm transiting Neptunes & Jupiters
- ★ very few Earth-sized exoplanets (e.g. Trappist, TESS, …)
- ★ mostly from 2-5 μm
- ★ reveal molecules CO, CO_2, CH_4, H_2O and clouds & haze

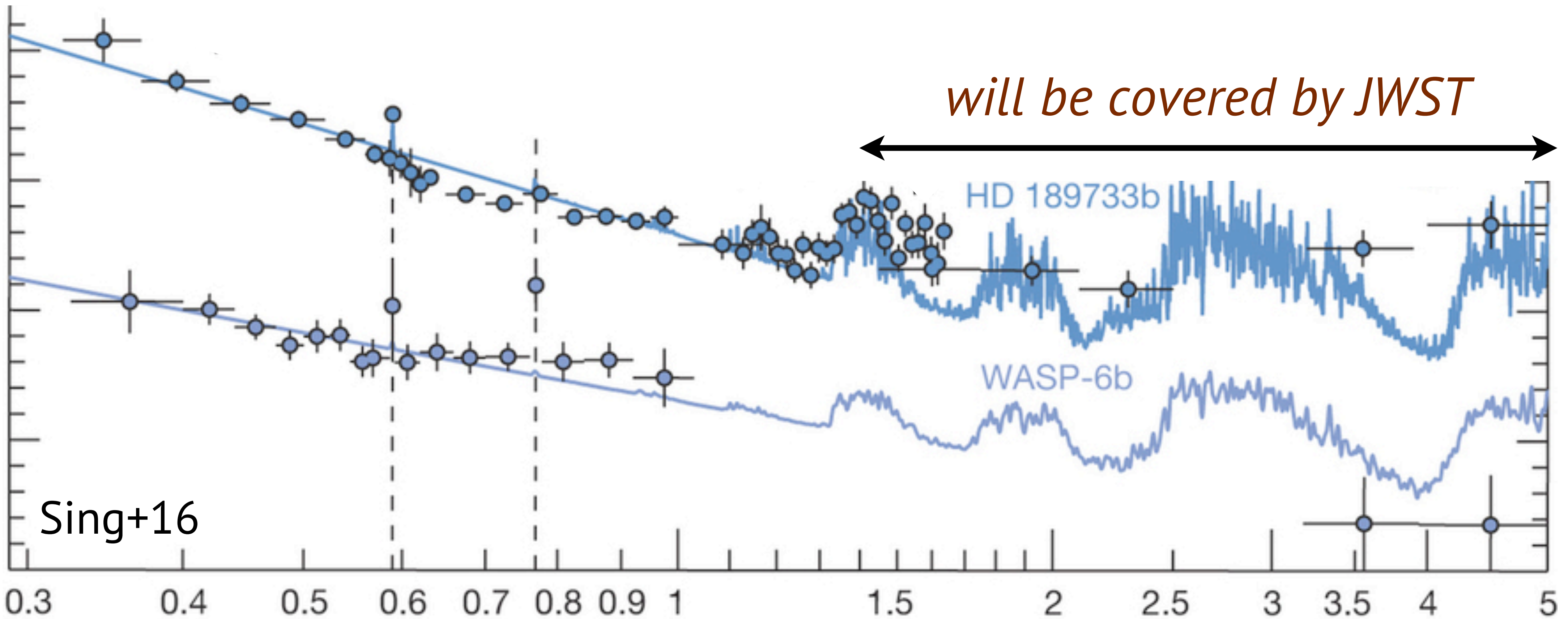


Atmospheres: where will we stand in 2024?

JWST: transmission spectroscopy in the IR (2019+)

HST & Ground-based surveys: transmission spectroscopy in the visual

- ★ atmospheres of hot/warm transiting Neptunes & Jupiters
- ★ in the visual
- ★ reveal Na, K,TiO and Rayleigh scattering slope, clouds & haze



Atmospheres: where will we stand in 2024?

JWST: transmission spectroscopy in the IR (2019+)

HST & Ground-based surveys: transmission spectroscopy in the visual

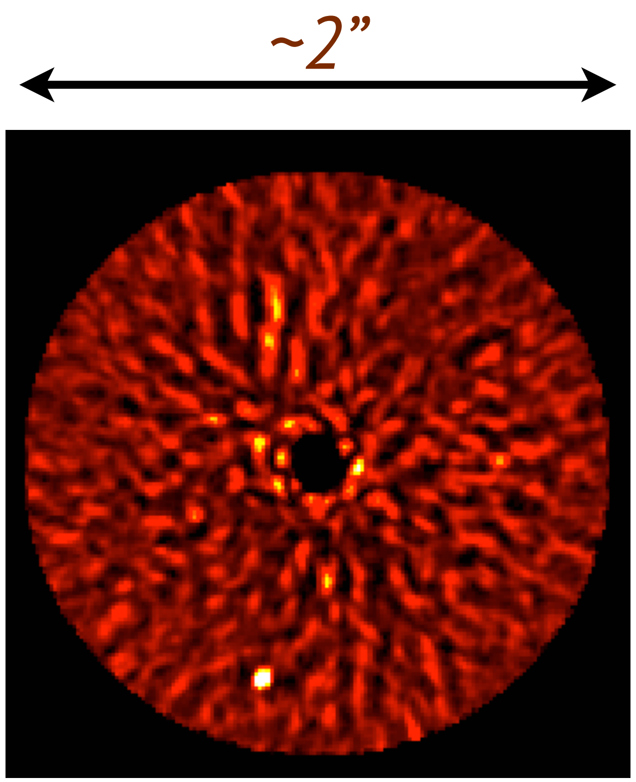
SPHERE, GPI, JWST: direct imaging with coronagraph

- ★ atmospheres of **young** Neptunes & Jupiters in the near-IR
- ★ reveal molecules CO, CO_2, CH_4, H_2O
- ★ SPHERE coupled with hi-res spectrographs (~100k), reach contrast ratios of ~$\mathbf{10^{-8}}$ (cf. visual contrast Earth/Sun = 10^{-10})

Combining direct imaging + hi-res spectroscopy to reach contrast 10^8: SPHERE + ESPRESSO/CRIRES

★ Direct imaging w/coronagraph suppresses the star up to ~**10^5** (e.g. SPHERE/IRDIS in the near-IR)

★ High-res spectroscopy of (hot) Jupiters
- in the near-IR → contrast of **~10^{-3}** *(e.g. Brogi+12, Rodler+12)*



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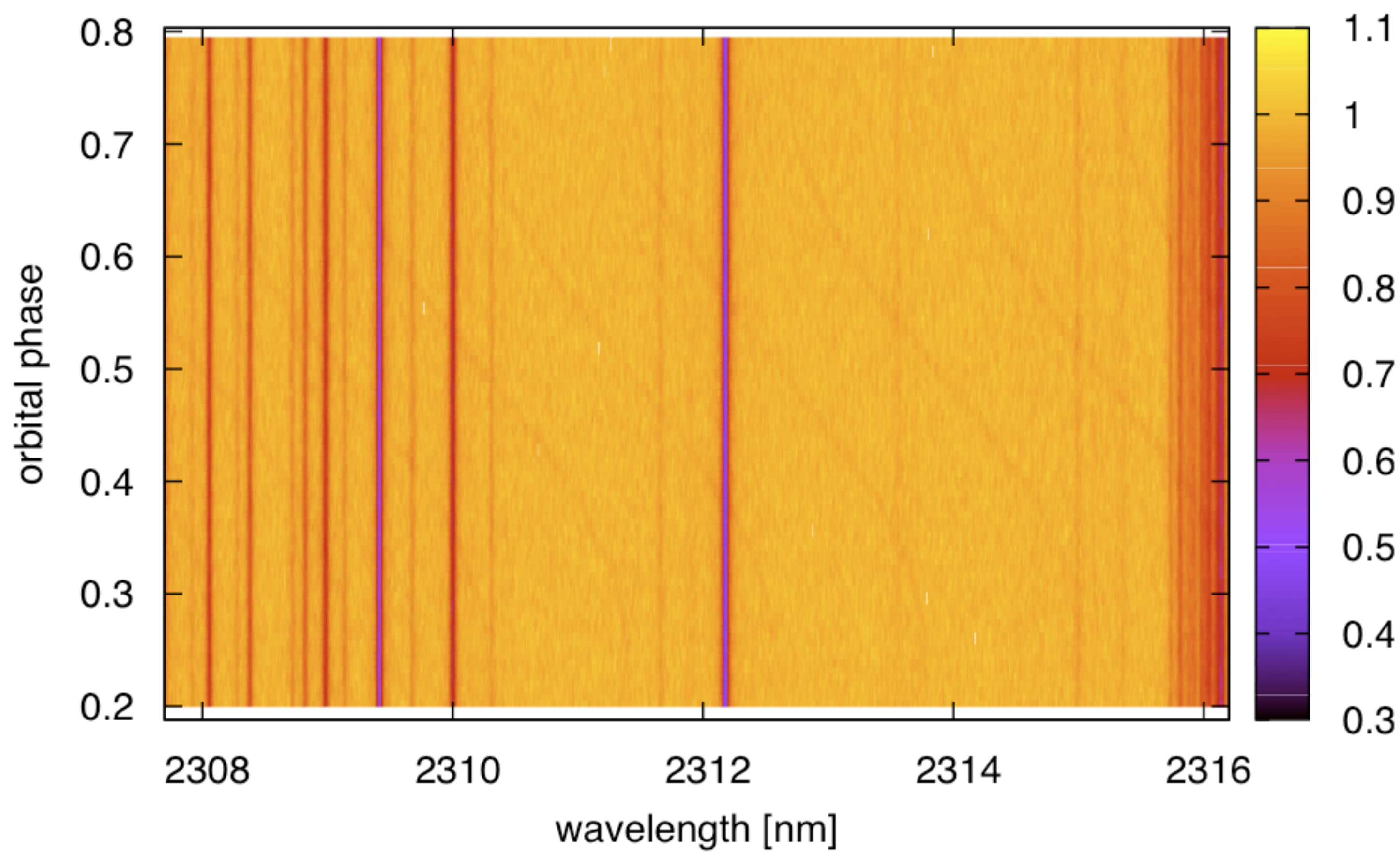

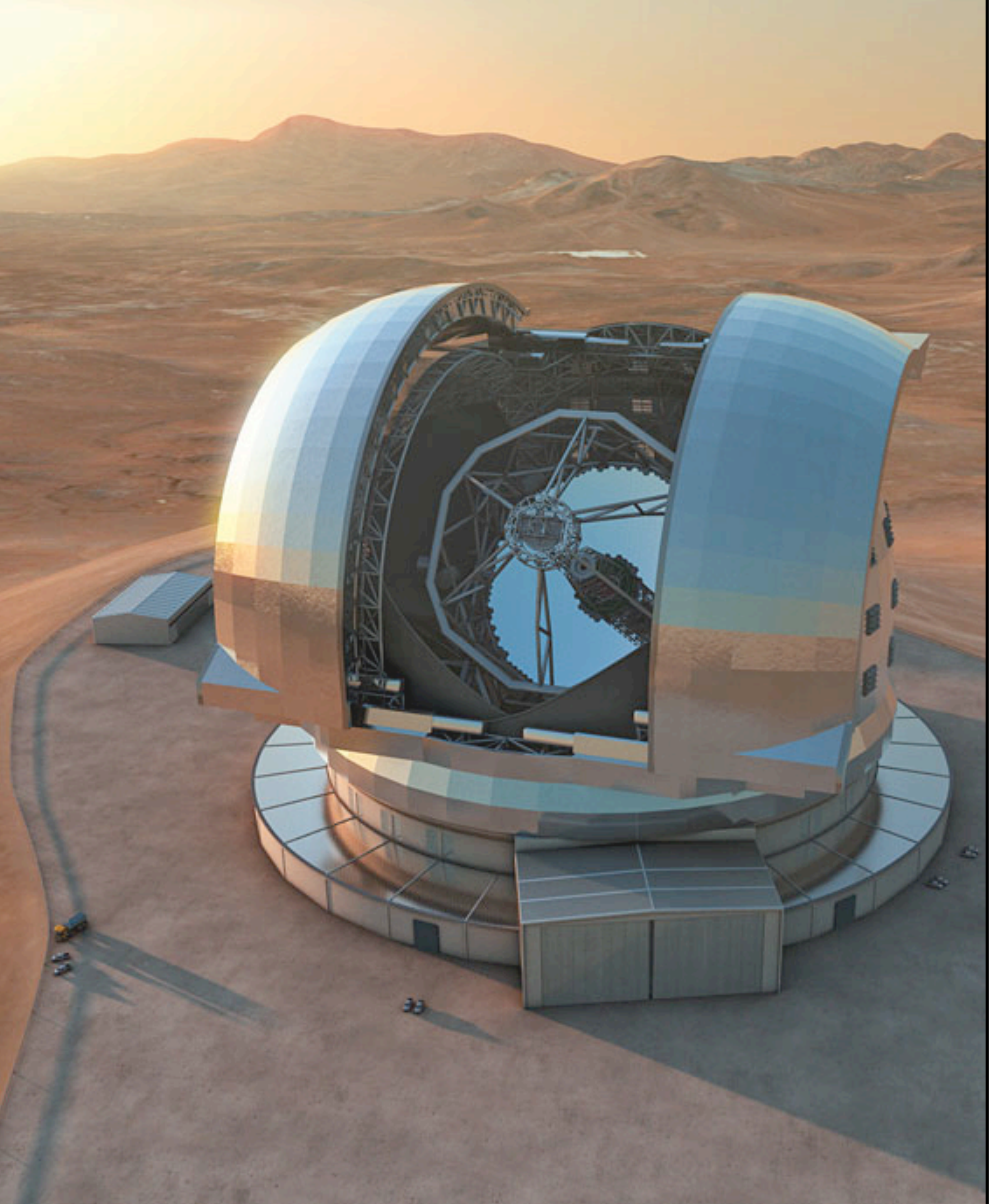

E-ELT

2024: first light

24x larger collecting area than the VLT, 35x larger than JWST

3 first generation instruments

Spatial resolution:
1 µm: ~7 mas
5 µm: 33 mas
10 µm: 66 mas

METIS - Mid-IR ELT Imager and Spectrograph

★ Diffraction limited imaging (Strehl 80%) and coronagraphy from 3 to 14 µm in a 20”x20” FOV

★ High-resolution (R~100k) IFU from 2.9 to 5.3 µm

★ Contrast in L-band (2.9-4 µm) of $\mathbf{10^{-6}}$ for >0.18” (cf. JWST: >0.4”)

★ Contrast in M-band (4.6-5.3 µm) of $\mathbf{10^{-6}}$ for >0.18”

METIS - Mid-IR ELT Imager and Spectrograph

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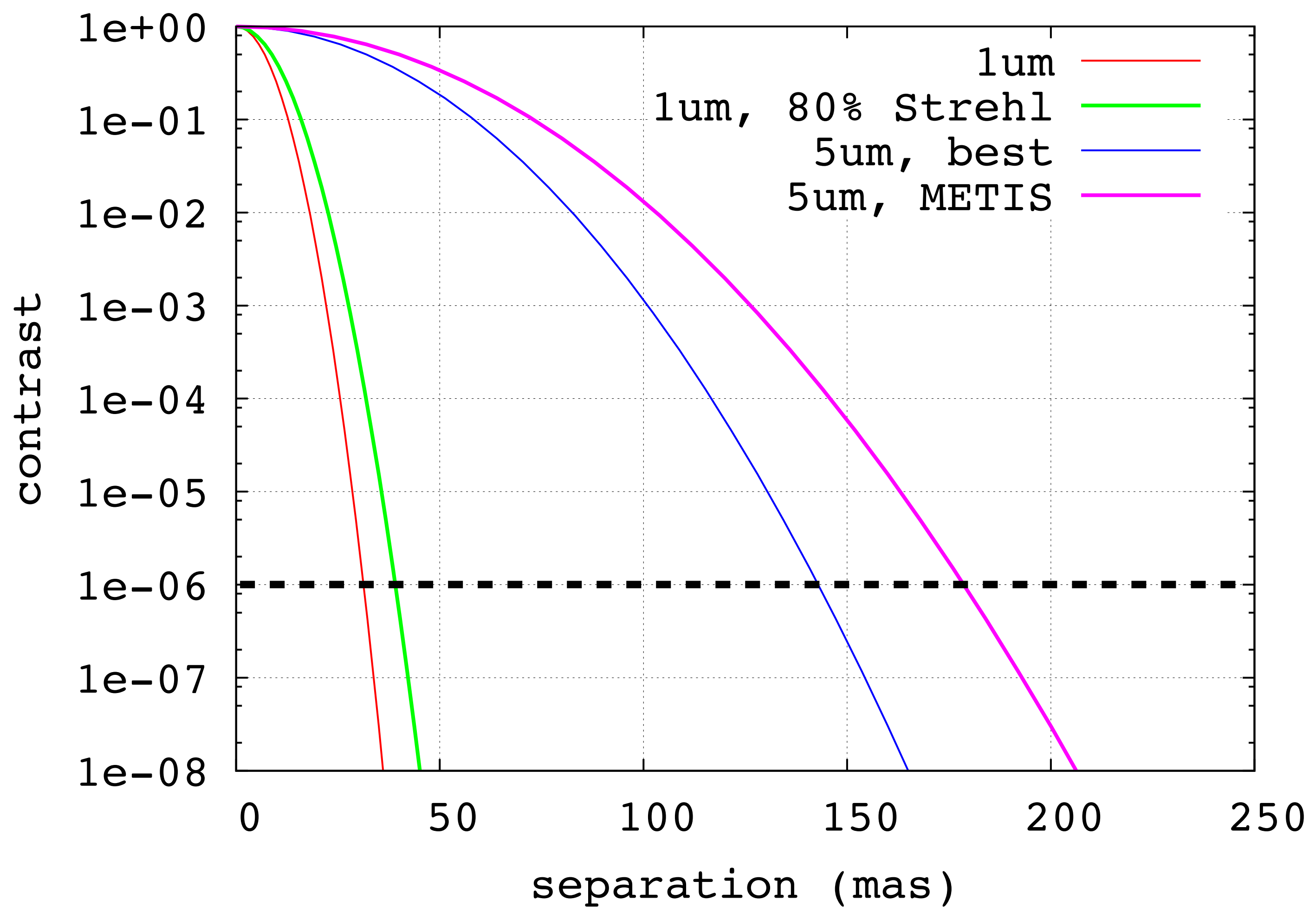

METIS - Mid-IR ELT Imager and Spectrograph

MICADO - near-IR wide field camera/spectrograph

- ★ wavelength range: 0.8 - 2.4 μm with 1’x1’ FOV
- ★ imaging close to the diffraction limit in the J-K bands
- ★ spectroscopy at R=3000
- ★ coronagraphy for exoplanet characterization

METIS - Mid-IR ELT Imager and Spectrograph

MICADO - near-IR wide field camera/spectrograph

HARMONI - visible & near-IR integral field spectrograph

- ★ wavelength range: 0.47 - 2.45 µm with 6”x9” FOV
- ★ integral field spectrograph with R from 500 to 20k.

Phase 1 instrumentation (for Nasmyth A platform):

METIS - Mid-IR ELT Imager and Spectrograph

MICADO - near-IR wide field camera/spectrograph

HARMONI - visible & near-IR integral field spectrograph

Phase 2 instrumentation (for Nasmyth B platform):

HIRES - visible & near-IR spectrograph

★ R~100,000 in V; R~30,000 in J,H; R~60,000 in K

MOSAIC - visible & near-IR multi-object spectrograph

★ R~5,000 & 15,000

★ up to 200 objects in a FOV of 32' diameter

EPICS - SPHERE for the E-ELT (2030+) - *planned*

The E-ELT will be a direct imaging machine!

- ★ Imaging of ⩾ Earth-sized planets in the habitable zone around our neighbor stars
- ★ Imaging of cool ⩾ Neptune-sized planets on wide orbits

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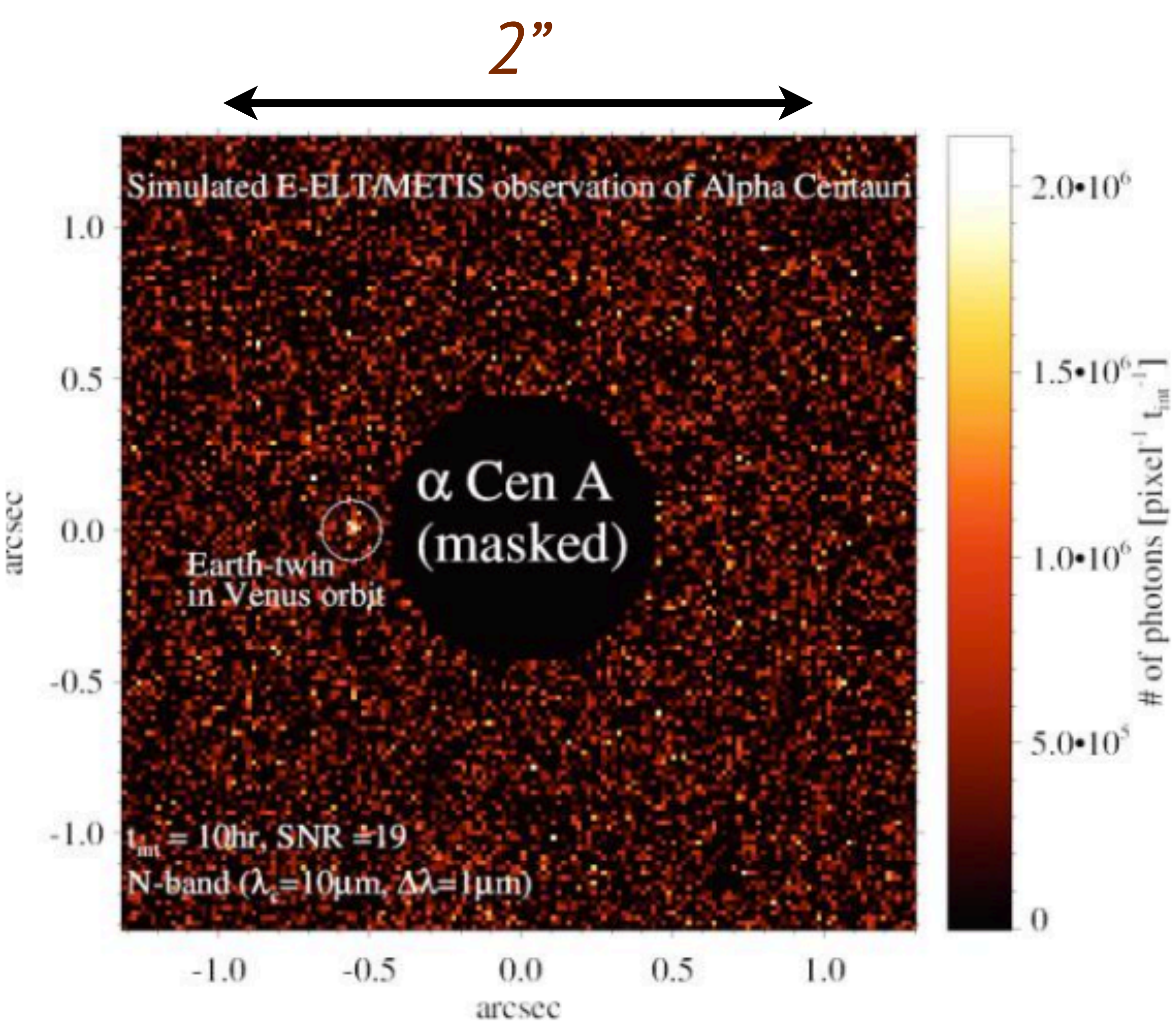
High-Resolution Spectroscopy (R~100k)

- ★ Transmission spectroscopy of transiting ⩾ Super-Earths
- ★ Reflected starlight from / thermal emission of hot ⩾ Super-Earths

Example 1: an Earth around α Cen A in a Venus orbit

★ METIS imaging in the N-band (~10 µm)



★ contrast planet/star: **~10^{-5}**

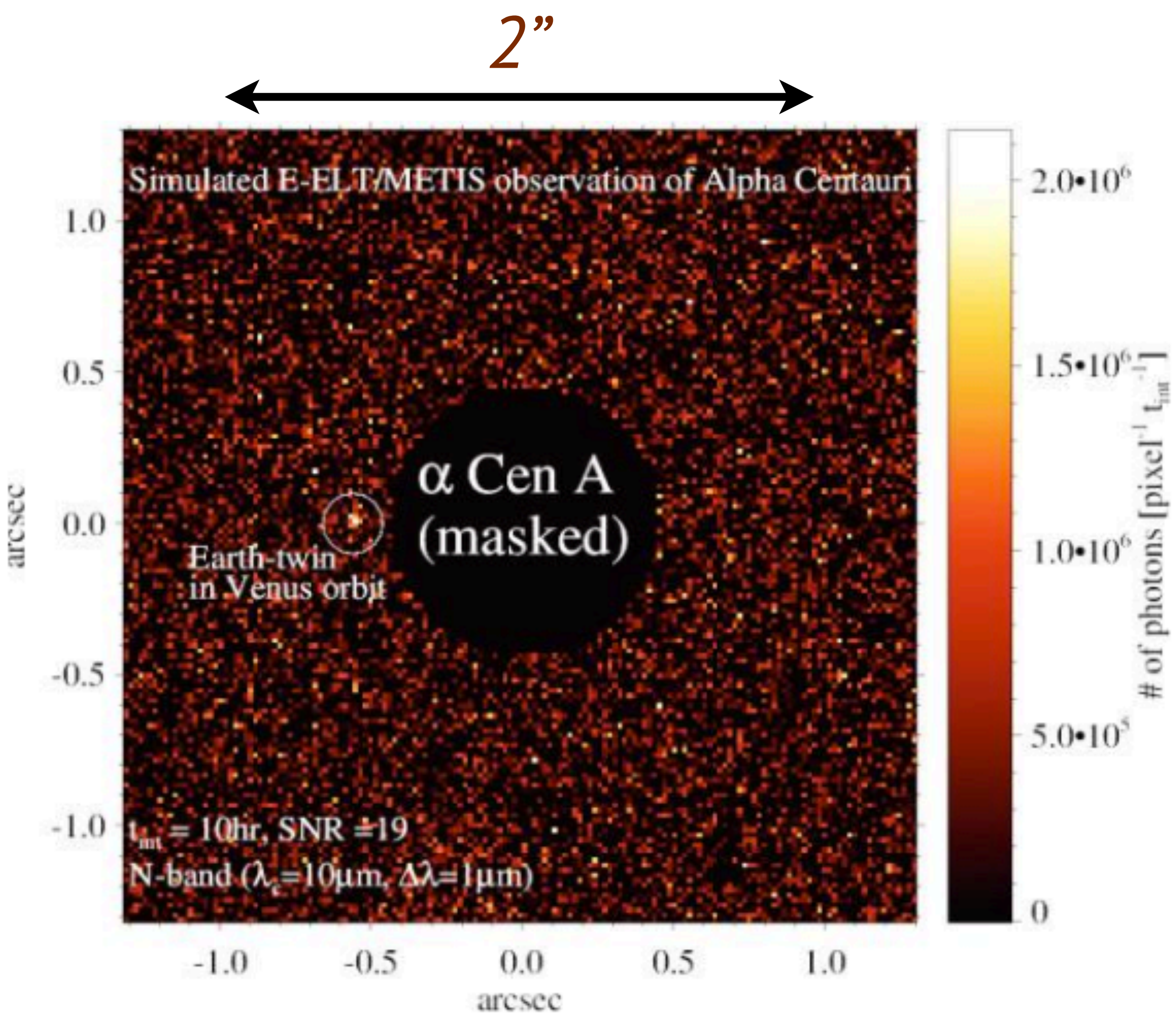
★ METIS coro N-band: **10^{-5}**

★ with 10 hours on target, we could characterize the atmosphere of an Earth-sized planet on a Venus orbit.

★ We would be able to measure O_3

Example 1: an Earth around α Cen A in a Venus orbit

★ METIS combines direct imaging with hi-res spectroscopy (2.9-5.3 μm)



★ contrast planet/star: **~10^{-9}**

★ METIS coro x spec: **10^{-6}** x **10^{-3}** = **10^{-9}**

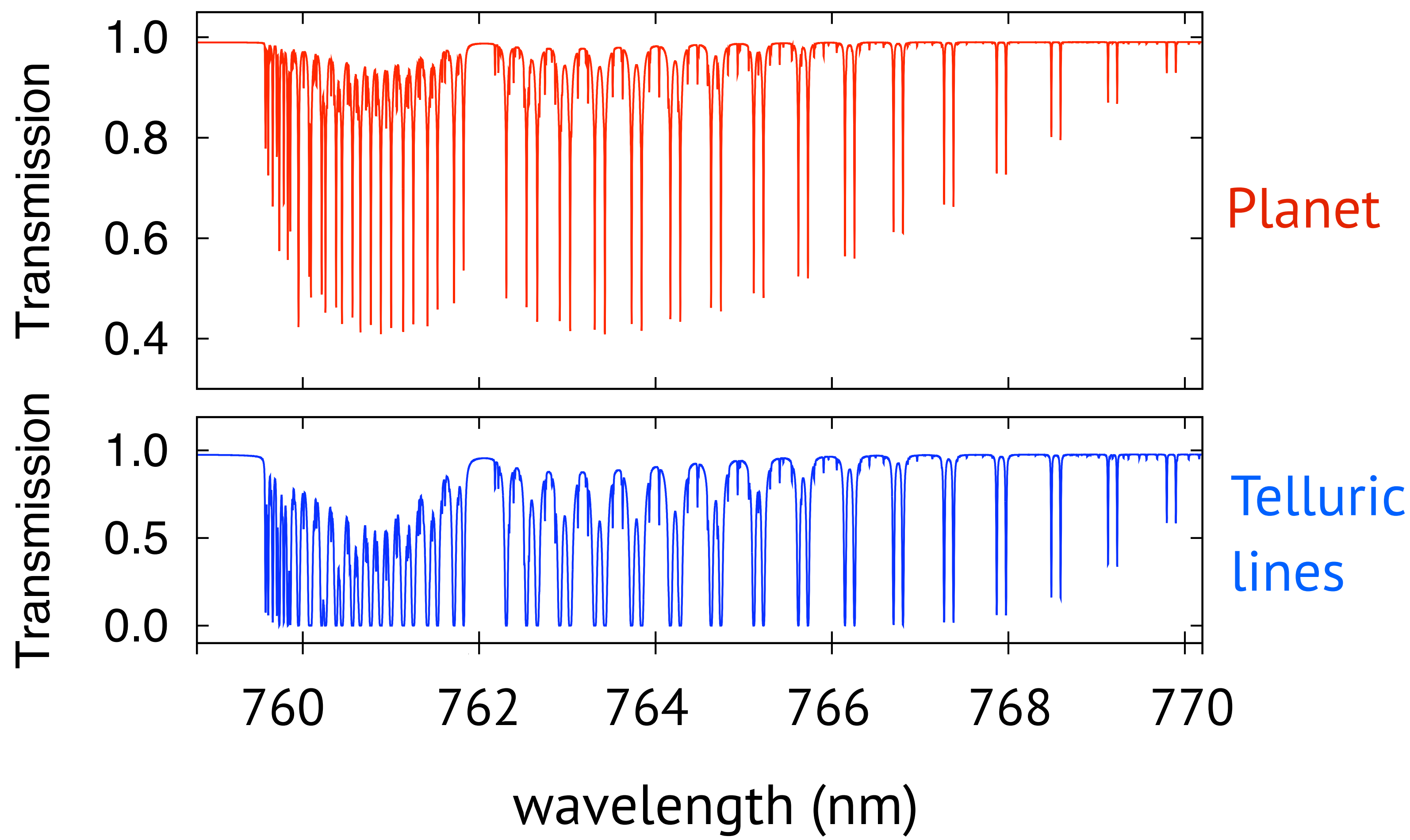
★ with 10 hours on target, we could characterize the atmosphere of an Earth-sized planet on a Venus orbit.

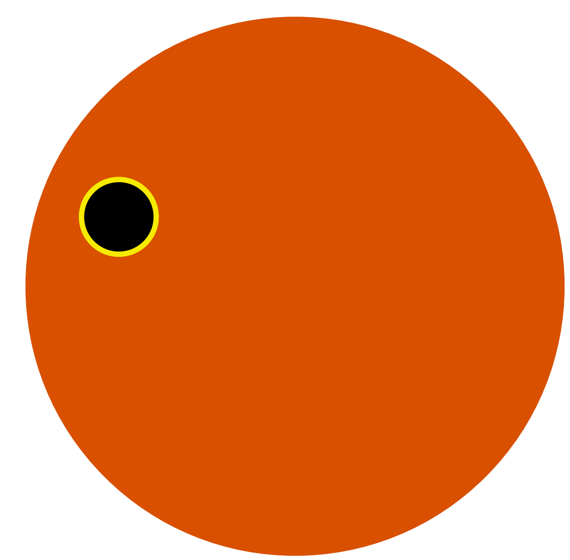
★ We would be able to measure CO_2, CH_4, H_2O

Example 2: O_2 in the atmosphere of a Super-Earth around an M-dwarf

- ★ Hi-res (R~100k) transmission spectroscopy
- ★ R=1.5xEarth, Earth-like atmosphere
- ★ orbiting around an M4-dwarf

★ contrast: ~ **$3x10^{-5}$**





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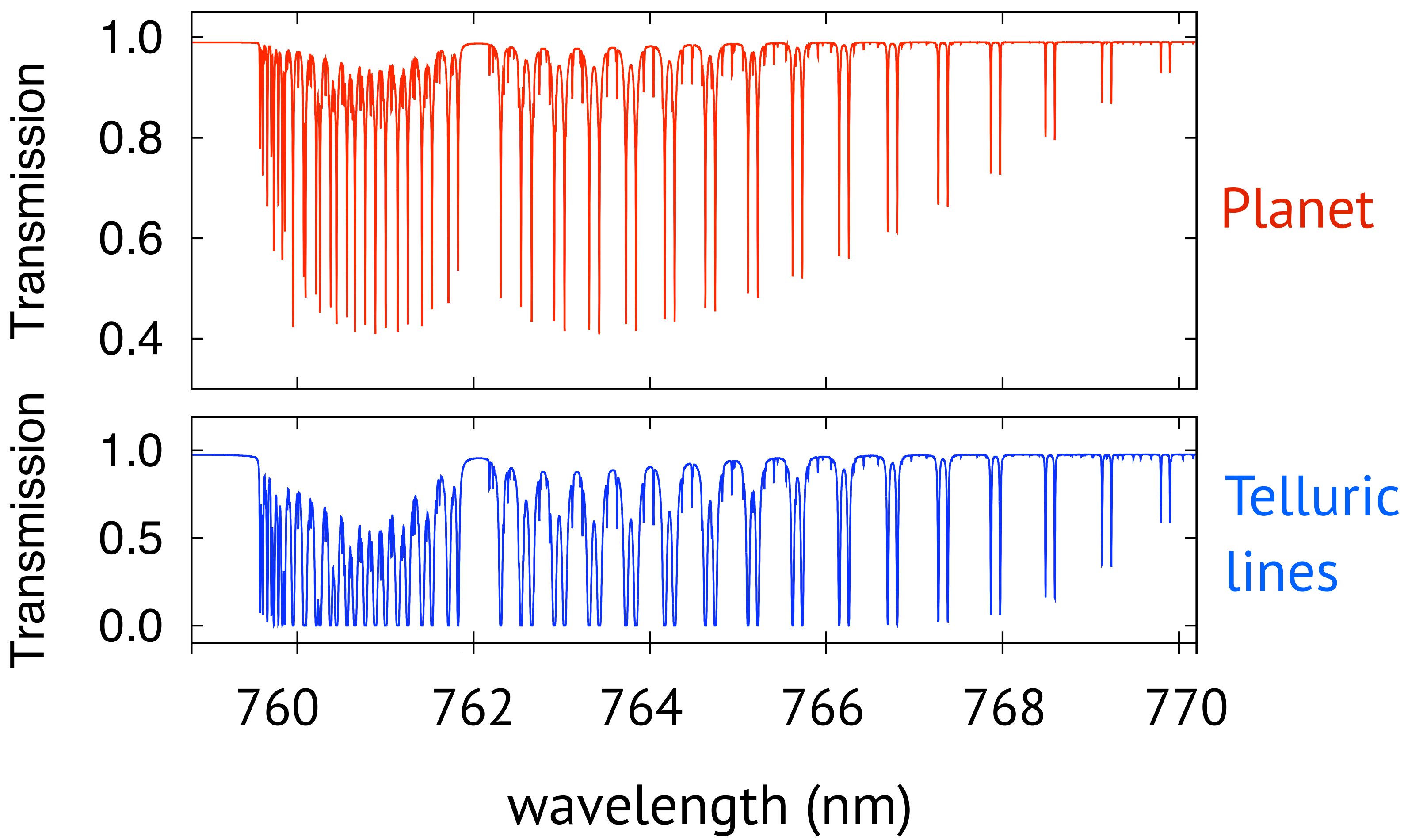
★ contrast: ~ **$3x10^{-5}$**



⇒ with 30 hours:

3σ detection of O_2

(Rodler+14, ApJ)

The E-ELT will be a direct imaging machine!

- ★ The combination of coronagraphy with high-resolution spectroscopy will allow us to reach contrast ratios planet/star beyond ~10^{-9}.
- ★ Spectroscopic characterization of Earth-sized planets around our neighbor stars (reflected starlight and thermal emission)
- ★ Spectroscopic characterization of cool and highly-reflective Neptune-sized planets beyond Mars orbits (reflected starlight)

High-Resolution Spectroscopy (R~100k)

- ★ Transmission spectroscopy of transiting Super-Earths
- ★ Reflected starlight from / thermal emission of hot Super-Earths (transiting and non-transiting)