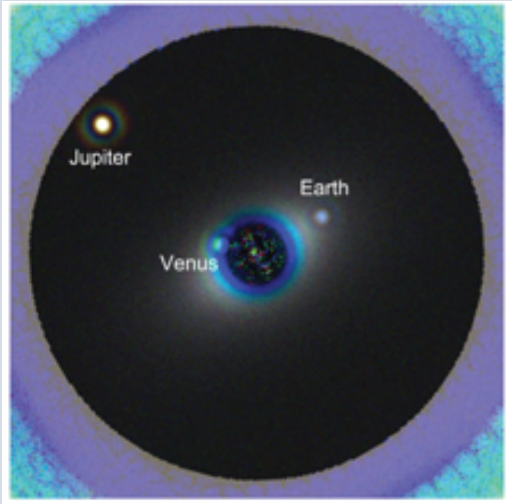
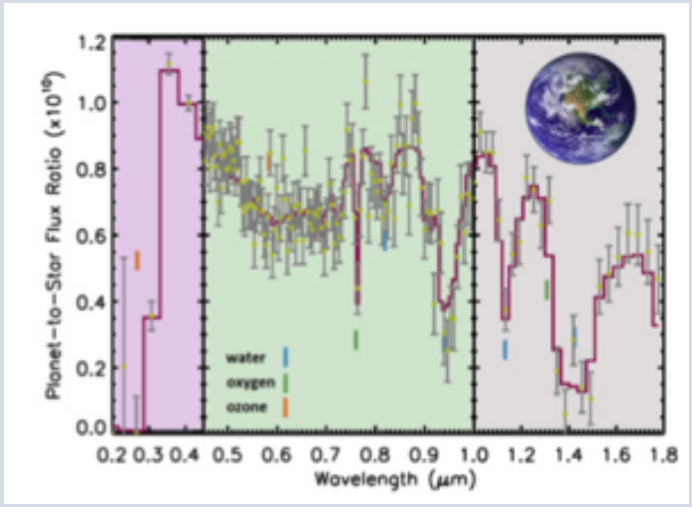
# Characterizing Terrestrial Exoplanets:
## The Case for a Large High-Contrast-Imaging Mission




*LUVOIR, HabEx Reports*

***Contact:*** Ignas Snellen, Leiden Observatory, NL

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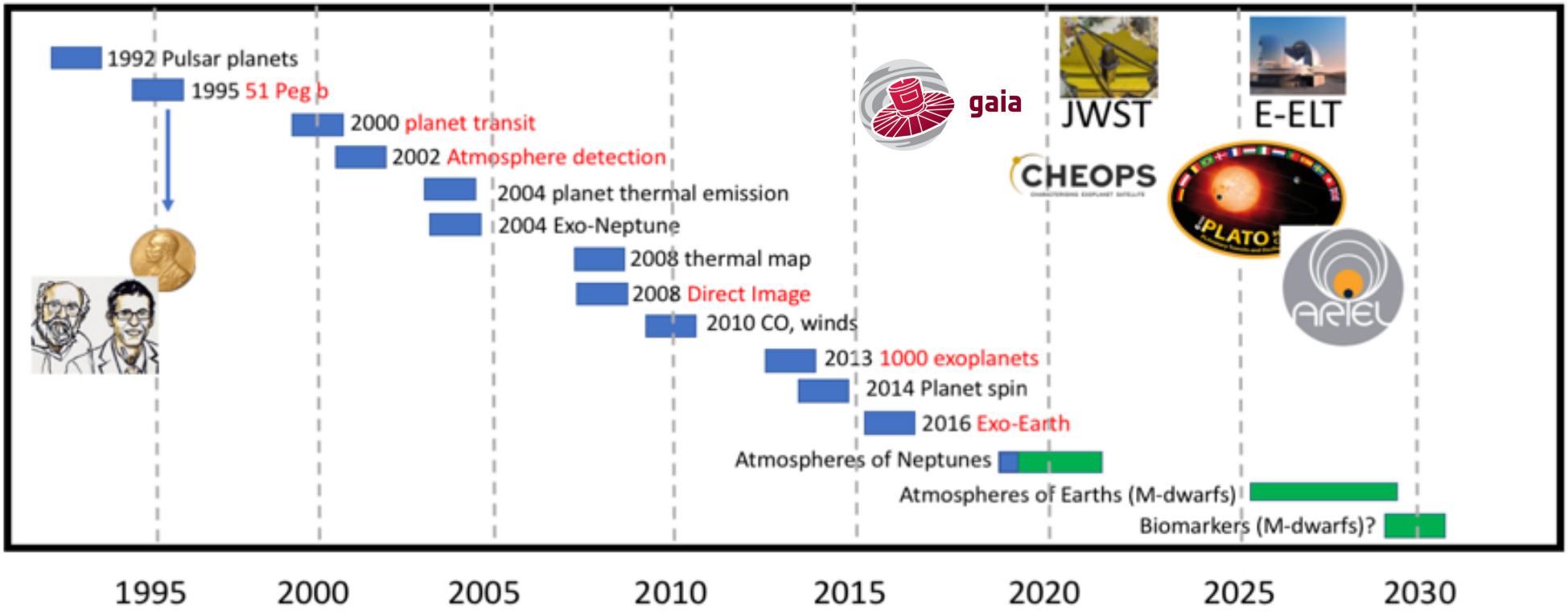
# A Revolution in Exoplanet Research



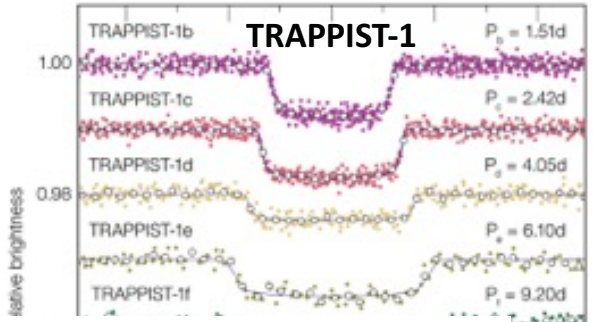

# Current Status of Exoplanet Science

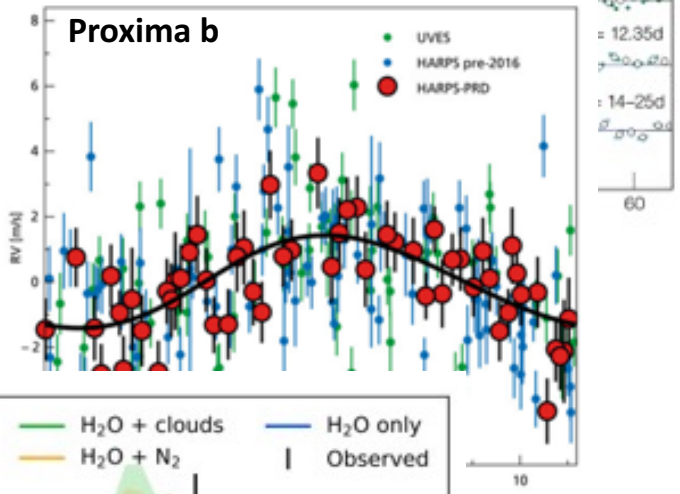
## What we can do now:

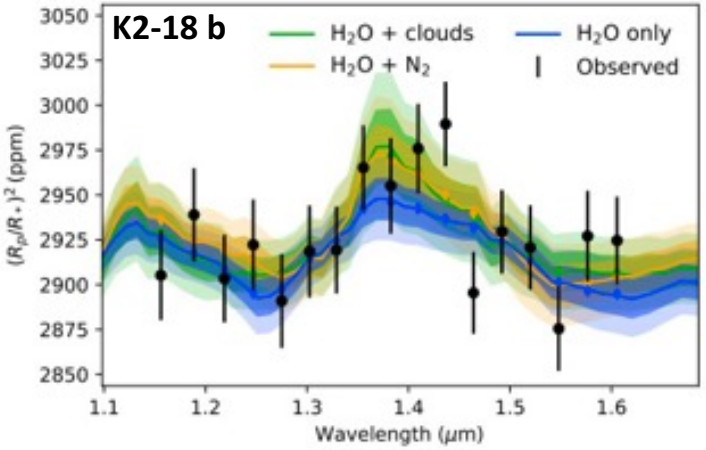
- Find planets down to Earth-size and mass;
  *around small dwarf stars*
- Characterization of gaseous planets;
  *molecules, clouds, climate, circulation, spin*

## Lessons learned so far:

- Planets are very common;
  *10% gas-giants, 25% Neptunes, >50% rocky*
- Planets show a large diversity;
  *Hot Jupiters, super-Earths, mini-Neptunes*



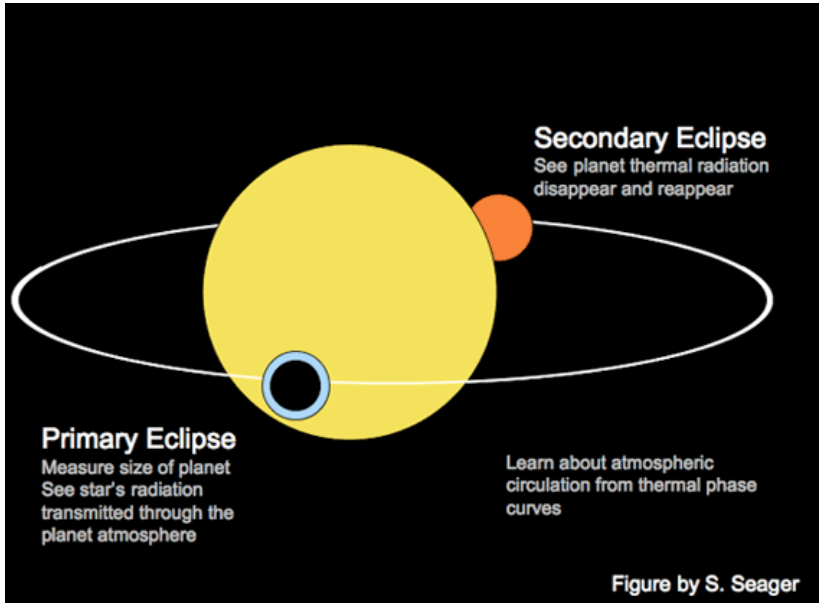



# Atmospheric Characterization Techniques

## Time Differential:

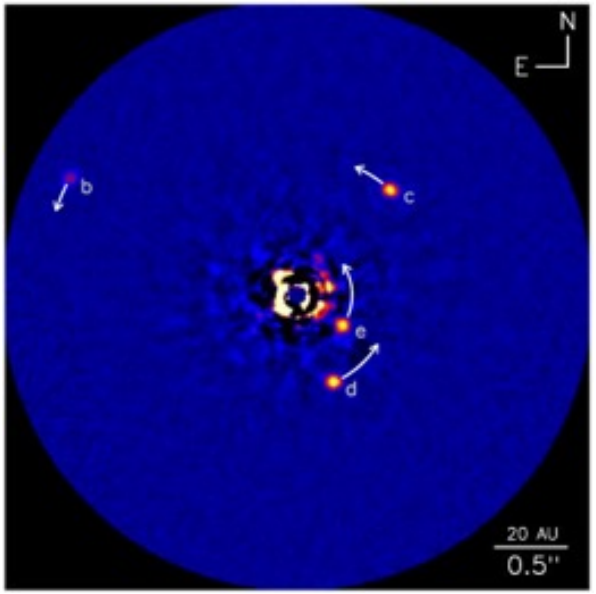
*Transits, eclipses, phase curves*




$S/N \propto D_{tel}$

## Angular Differential:

*High-Contrast Imaging / Interferometry*




$S/N \propto D_{tel}^{2}$

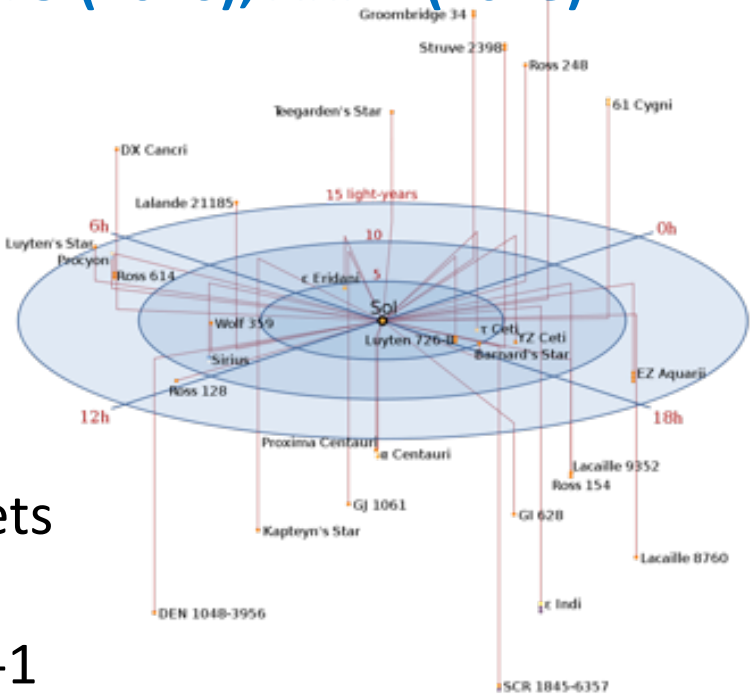
$resolution \propto D_{tel}^{-1}$

# Exoplanets: What to expect 2020 – 2035?

- Great new observatories: JWST (2021) & Extremely Large Telescopes (2026)
- NASA TESS; WFIRST; **ESA Gaia; CHEOPS (2019); PLATO (2026); ARIEL (2028)**

## Likely Status - 2035:

- Nearby transiting planet population unveiled
- Local planet M-dwarf population known
- Twin-Earths around Sun-like stars still challenging




- In-depth statistical data on hot/warm gaseous planets
- First atmospheric studies of few Earths/M-dwarfs
- Atmospheric constituencies of Proxima-b/TRAPPIST-1
- **Atmospheric characterization of twin-Earths around sun-like stars, out of reach**

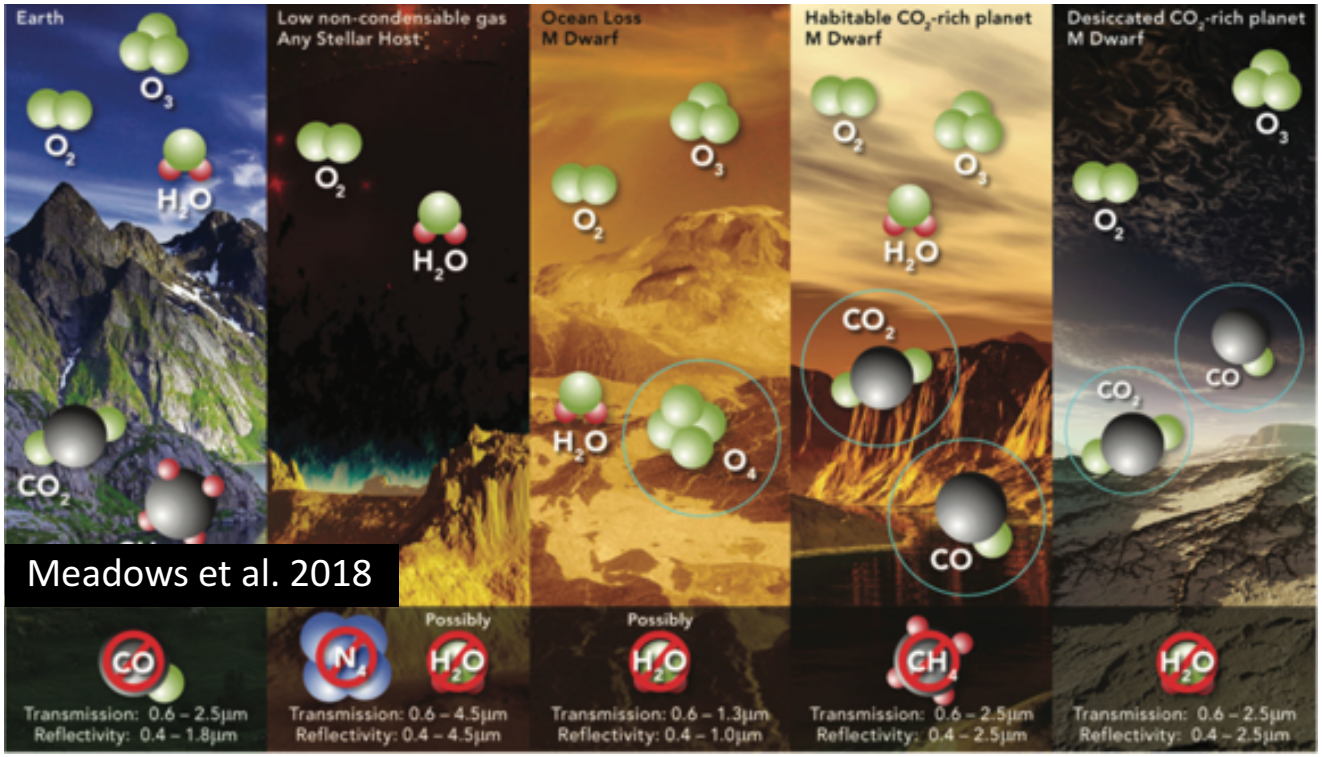
# Exoplanet science drivers in 2035 and beyond

- Planetary architectures around Sun-like stars
- Atmospheres of the wide diversity of planets
- Climates + physical/chemical processes & Geology
- Main constituencies of temperate-rocky-planet:
  - $N_2/CO_2$ dominated atmospheres?
  - $H_2O$ present?
  - $O_2$ – $CH_4$ Biomarker gases present?
  - Biomarker gases due to biotic or abiotic processes?


**Biosignature**: *an effect of biological activity on its environment, detectable at interstellar distances*

**Requirements:** *Surface ocean? geological activity? magnetic field?*

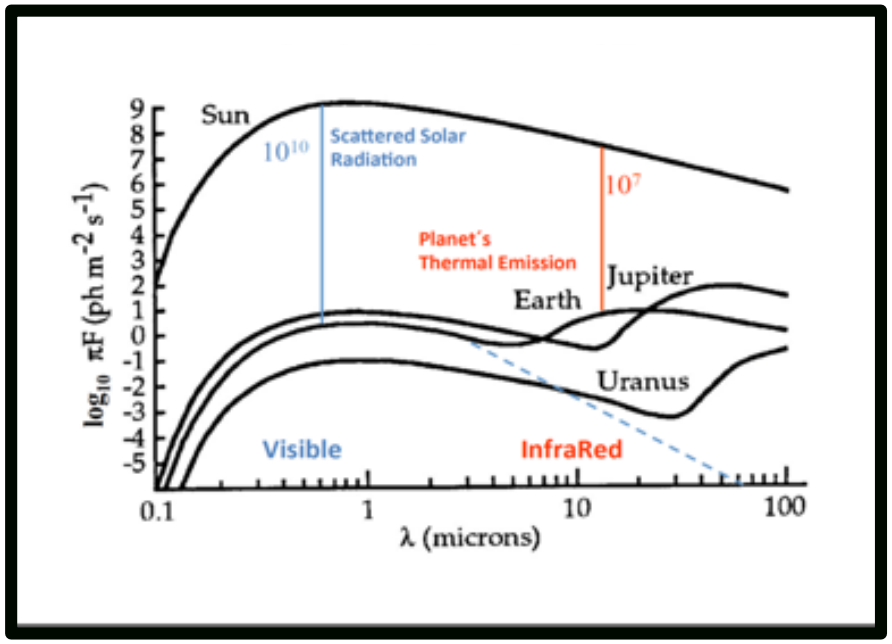
**Life detection will always require understanding of evolutionary and geophysical context of a planet**



Meadows et al. 2018

# Challenges

→Transits too infrequent and signal too small
→Contrast too large for ground-based telescopes




# Solutions

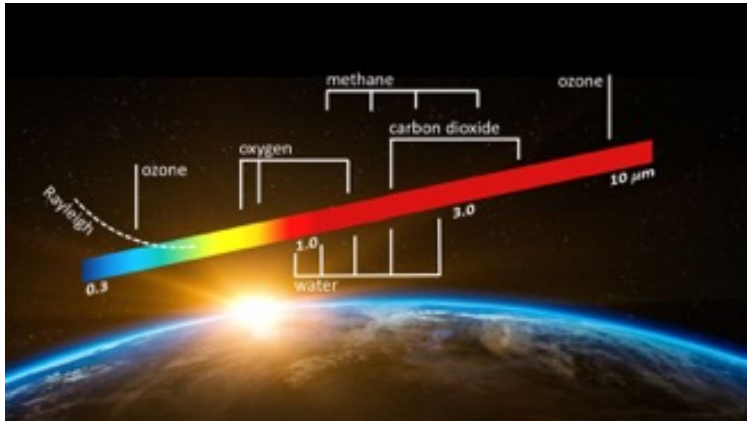
1. **Large High-Contrast-Imaging Telescope** [LUVOIR/HabEx/ESA-alone]
2. IR Space Interferometer (*talk*: Sasha Quanz)
3. Potential others: starshade + ground-based telescopes [*wp*: Janson]

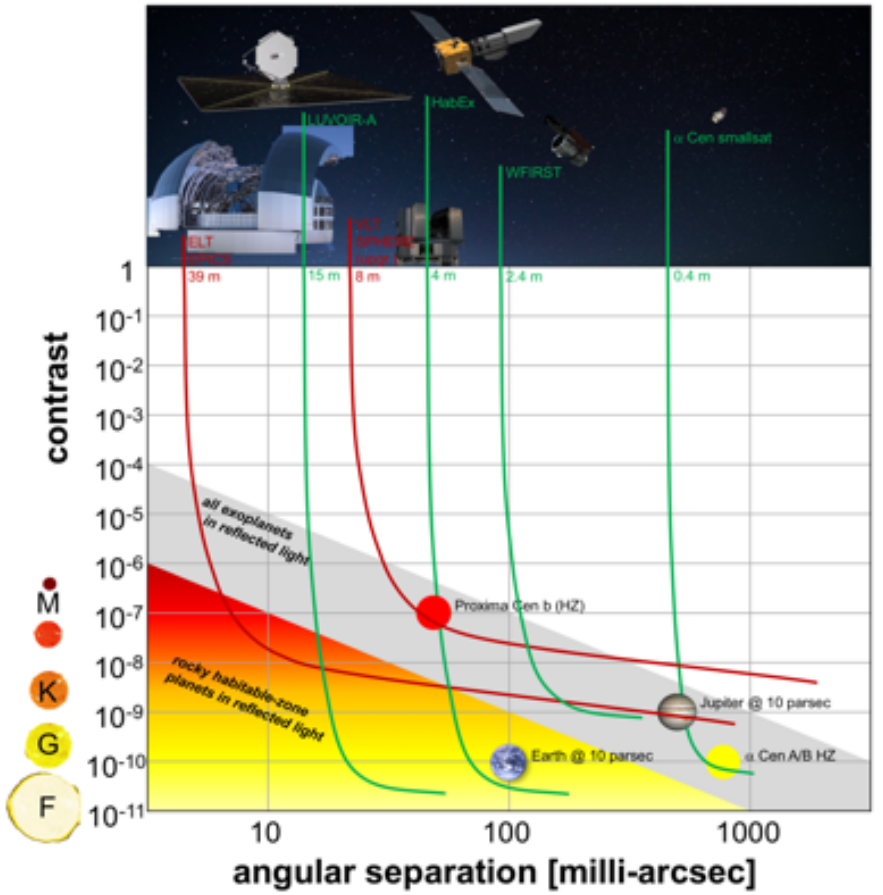
**ESA should be able to make an educated decision in 10 yrs**
**Start a European development program for technology validation now**

# Requirements for a HCI Space Mission

- A contrast of $10^{-10}$ at an IWA of 80 -100 m.a.s.[a]
- Wavelength range covering the optical and NIR
- Sufficient Spectral Resolution for molecular detections
- Light Collecting Power + mission life time = # planetary systems

[a] depends on $\lambda$ / starshade

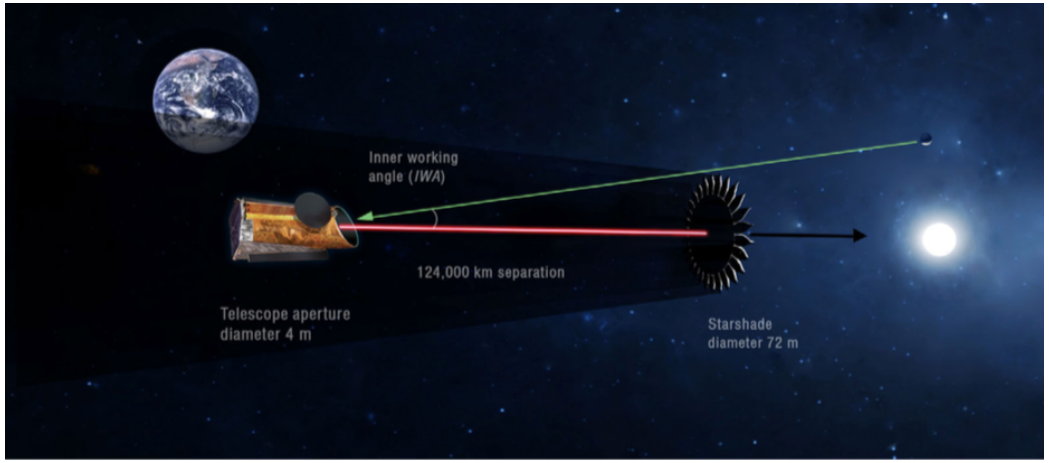


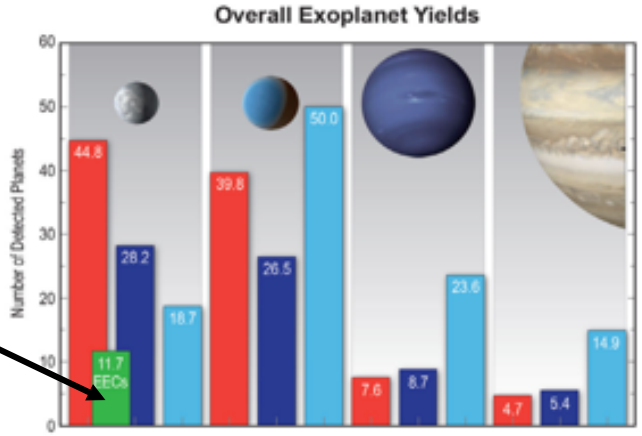



# Current NASA studies

## Habitable Exoplanet Observatory

*4m Telescope + External Occulter*

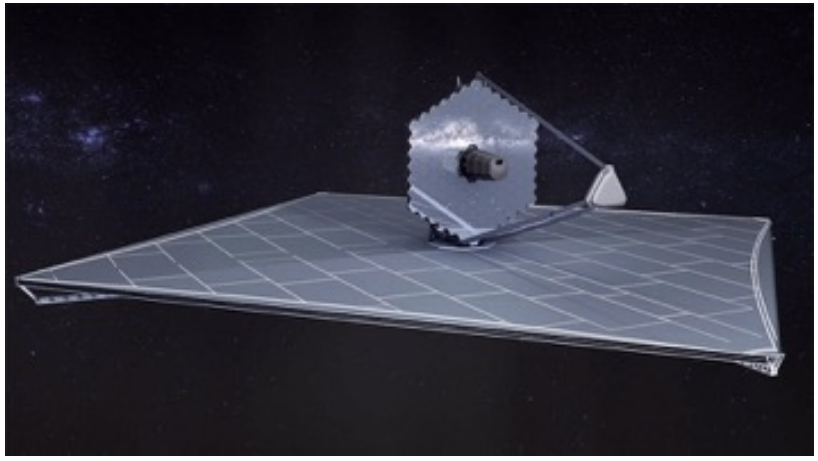



**4-30 EA**

## Large UV/Optical/IR Telescope - LUVOIR

*8m & 16m aperture*



Planet yield:

**[10 – 55] & [20 – 110] Earth Analogs**

General-purpose observatory

# ESA stand-alone mission?

NASA **WFIRST** is the only HCI mission (as tech demonstrator).
Opportunity for **full science+technology demonstrator** mission?

*Bridge the gap between young-Jupiter and Earth-analog science*

**3-meter ESA HCI telescope:**

- Jupiter analogs out to 50 lyr
- Dozen(s) of sub-Neptunes
- Down to rocky planets

# The road ahead – central message & recommendations

**ESA should be able to make an educated decision in 10 yrs**
**Start a European development program for technology validation now**

**A technological and science development path for Europe**

- Testbeds for technology demonstration for HCI in space
- Increase TRL of specific technologies and subsystems
- Possible opportunity for full science+technology demonstrator mission?

**European Expertise areas** [*wp Sect. 5.5*]

*Large space telescopes*
*Adaptive Optics*
*Coronagraphy*
*Wavefront sensing*
*System design*
*Spectroscopy*
*Polarization techniques*
*Detectors*
*Astrophotonics*
*Data-reduction techniques*

# A census of support from the Exoplanet community

**Belgium**
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