Characterizing exoplanetary atmospheres with a mid-infrared nulling spectrograph

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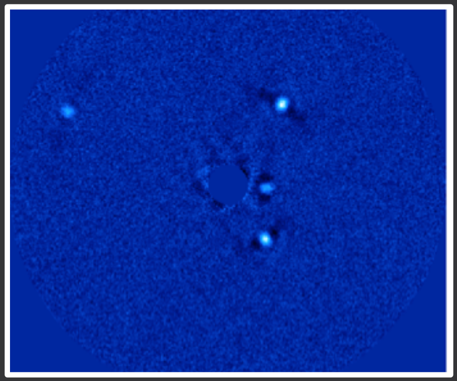
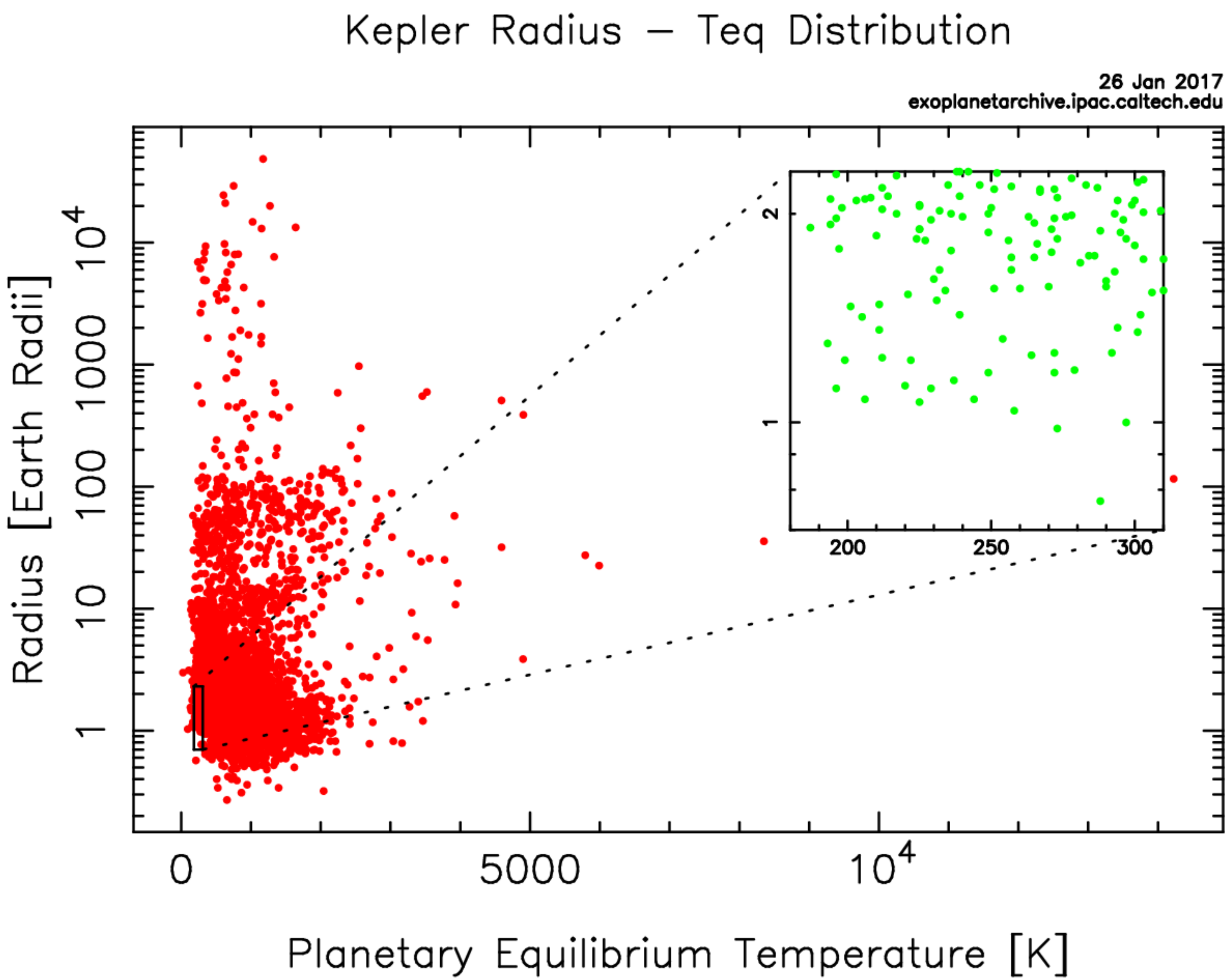


June 27th 2017
EWASS – Prague

HZ rocky planets are ubiquitous



Prevalence of HZ rocky exoplanets

- HZ limits are debated (see table)
- Rocky planets: $R < 1.6\ R_{Earth}$ (Rogers et al. 2015)
- Prevalence of HZ rocky exoplanets:
- See also latest results from Exopag: https://exoplanets.nasa.gov/exep/events/191/

Winn et al. 2015

Type of star	Type of planet	Approximate HZ boundaries[a] $[S/S_\oplus]$[b]	Occurrence rate [%]	Reference
M	1–10 $M_\oplus$	0.75–2.0	41^{+54}_{-13}	Bonfils et al. (2013)
FGK	0.8–2.0 $R_\oplus$	0.3–1.8	$2.8^{+1.9}_{-0.9}$	Catanzarite & Shao (2011)
FGK	0.5–2.0 $R_\oplus$	0.8–1.8	34 ± 14	Traub (2012)
M	0.5–1.4 $R_\oplus$	0.46–1.0	15^{+13}_{-6}	Dressing & Charbonneau (2013)
M	0.5–1.4 $R_\oplus$	0.22–0.80	48^{+12}_{-24}	Kopparapu (2013)
GK	1–2 $R_\oplus$	0.25–4.0	11 ± 4	Petigura et al. (2013)
FGK	1–2 $R_\oplus$	0.25–4.0[c]	~0.01[c]	Schlaufman (2014)
FGK	1–4 $R_\oplus$	0.35–1.0	$6.4^{+3.4}_{-1.1}$	Silburt et al. (2015)
G	0.6–1.7 $R_\oplus$	0.51–1.95	$1.7^{+1.8}_{-0.9}$	Foreman-Mackey et al. (2014)

Next steps

1. Detecting nearby small planets

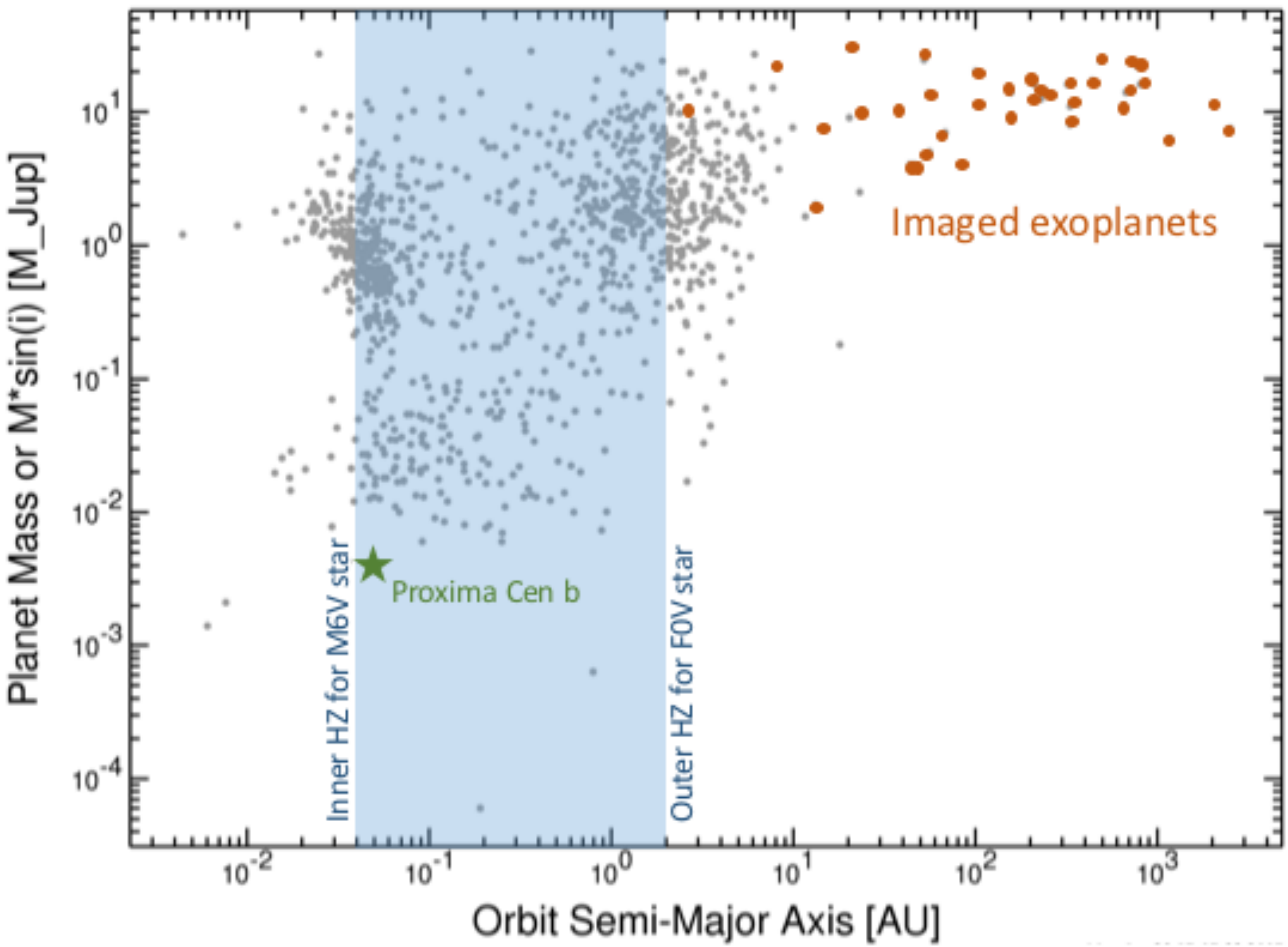
2. Atmospheric characterization:

- Atmospheric studies require the detection of planetary photons, which is extremely difficult.

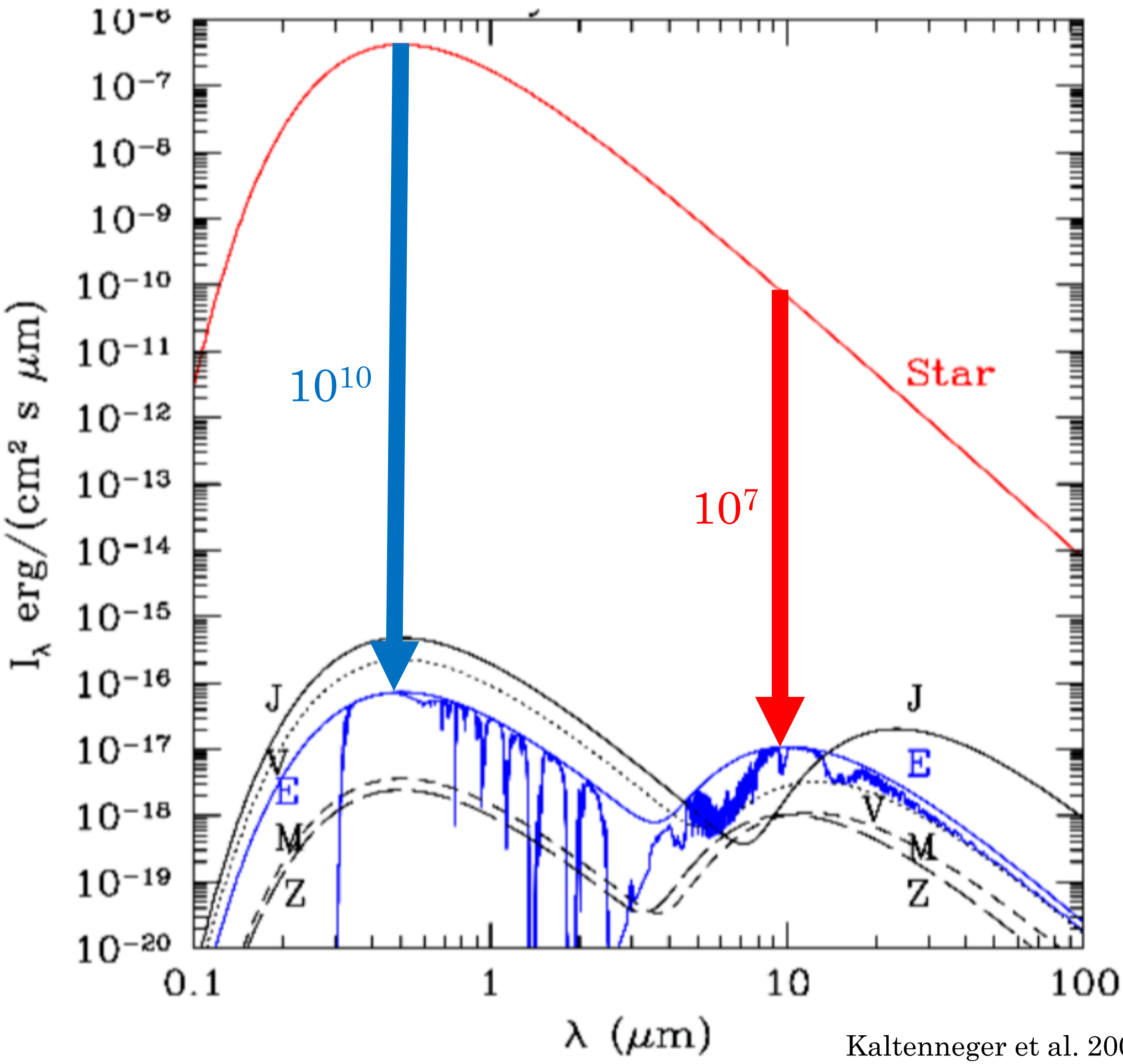
- So far, (almost) only done on giant exoplanets
  - Atmospheres from ~600 to 3000K;
  - Atmosphere evaporation and wind from Lyman-α line (e.g., Vidal-Majar et al. 2003);
  - Planet maps from phase light curve (e.g., Crossfield et al. 2010);
  - Atmospheric atoms/molecules clearly identified: Na, K, H_2O, CO.

- But first spectrum of “near” HZ rocky planets (TRAPPIST 1b&c, de Wit et al. 2016)

Direct imaging



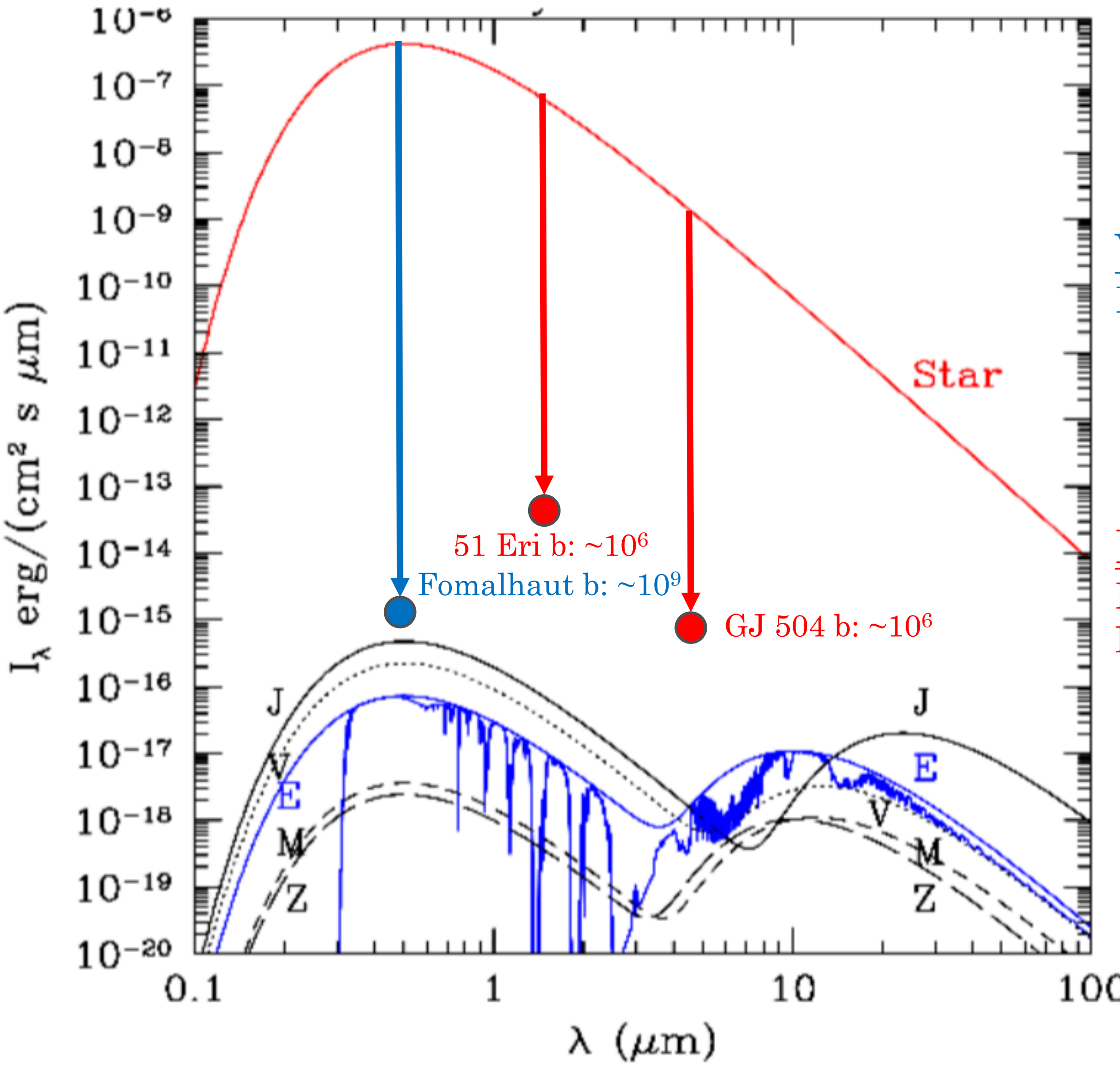
The observing challenge



Kaltenneger et al. 2009

1. Contrast
   - Visible: 10^{-10} fainter
   - IR: 10^{-7} fainter

The observing challenge



<u>Visible</u>: ~10^9

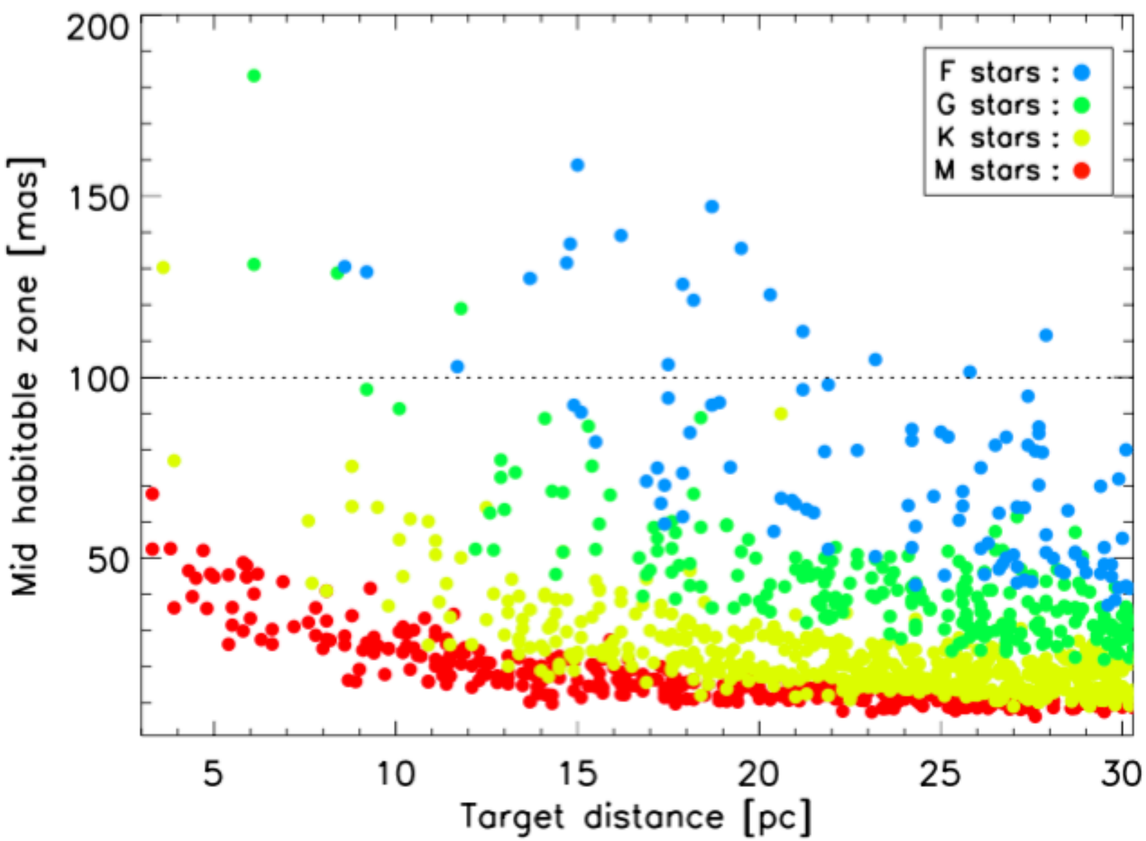
Fomalhaut b but 150x sep

<u>Infrared</u>: ~10^6

H band: 51 Eri b but 13x sep

L band: GJ 504b but 40x sep

The observing challenge



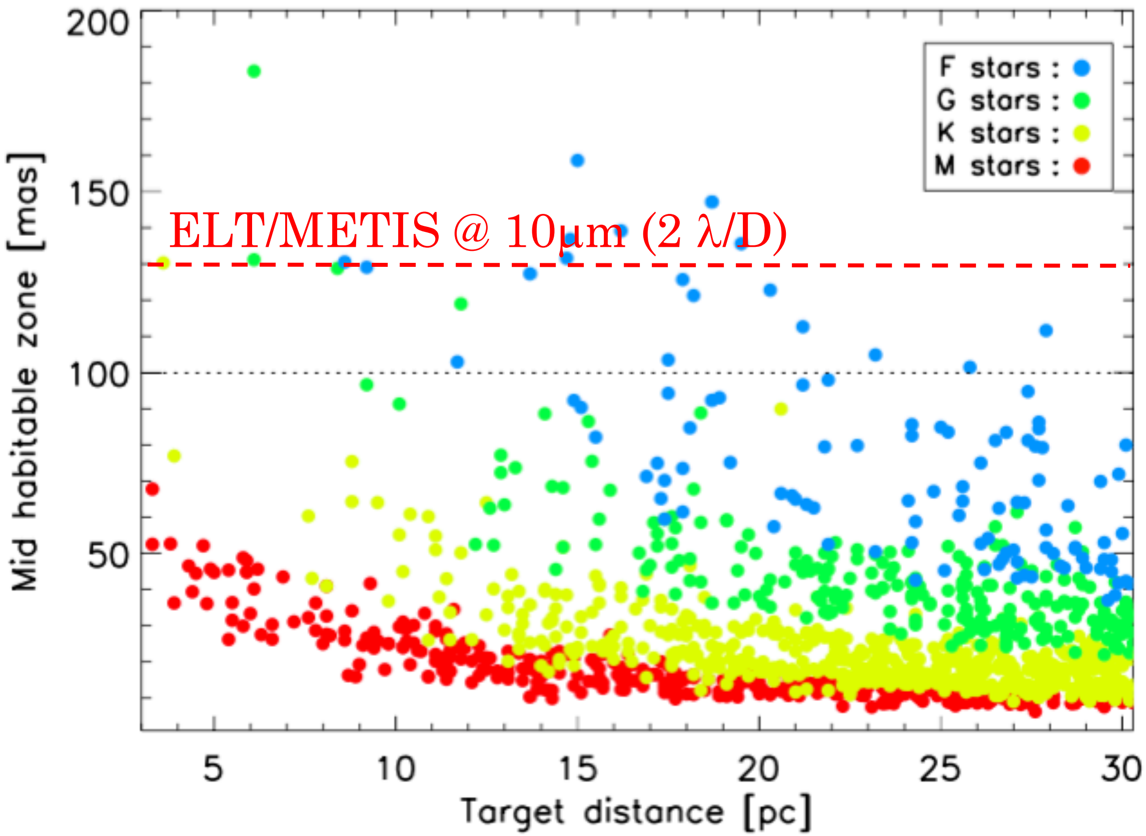
2. Angular sep.:
~10 to 150 mas

<u>Diffraction limit</u>

8m aperture
- 16 mas in visible
- 320 mas in IR

39m aperture
- 3.5 mas in visible
- 65 mas in IR

The observing challenge



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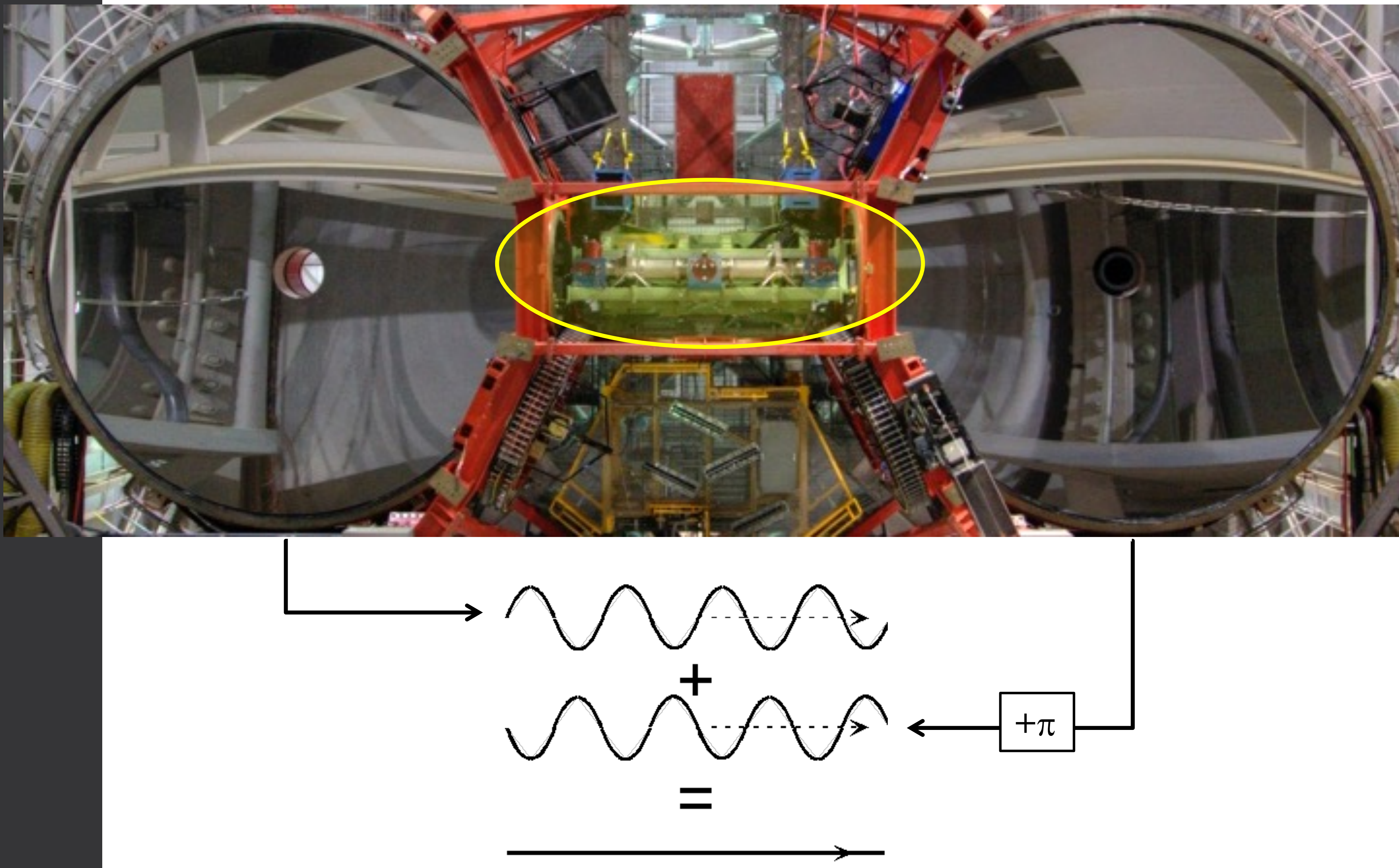
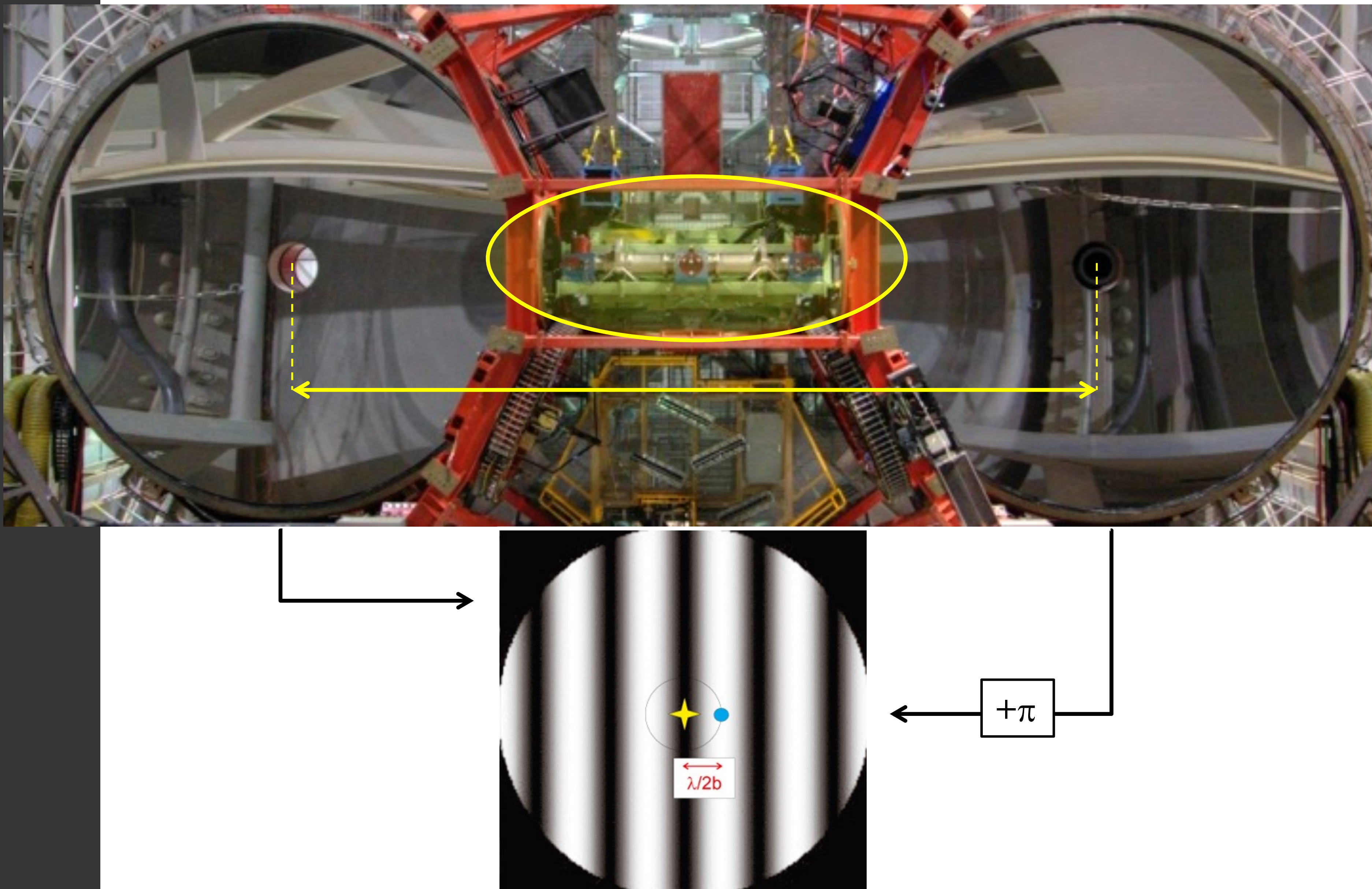
Nulling interferometry



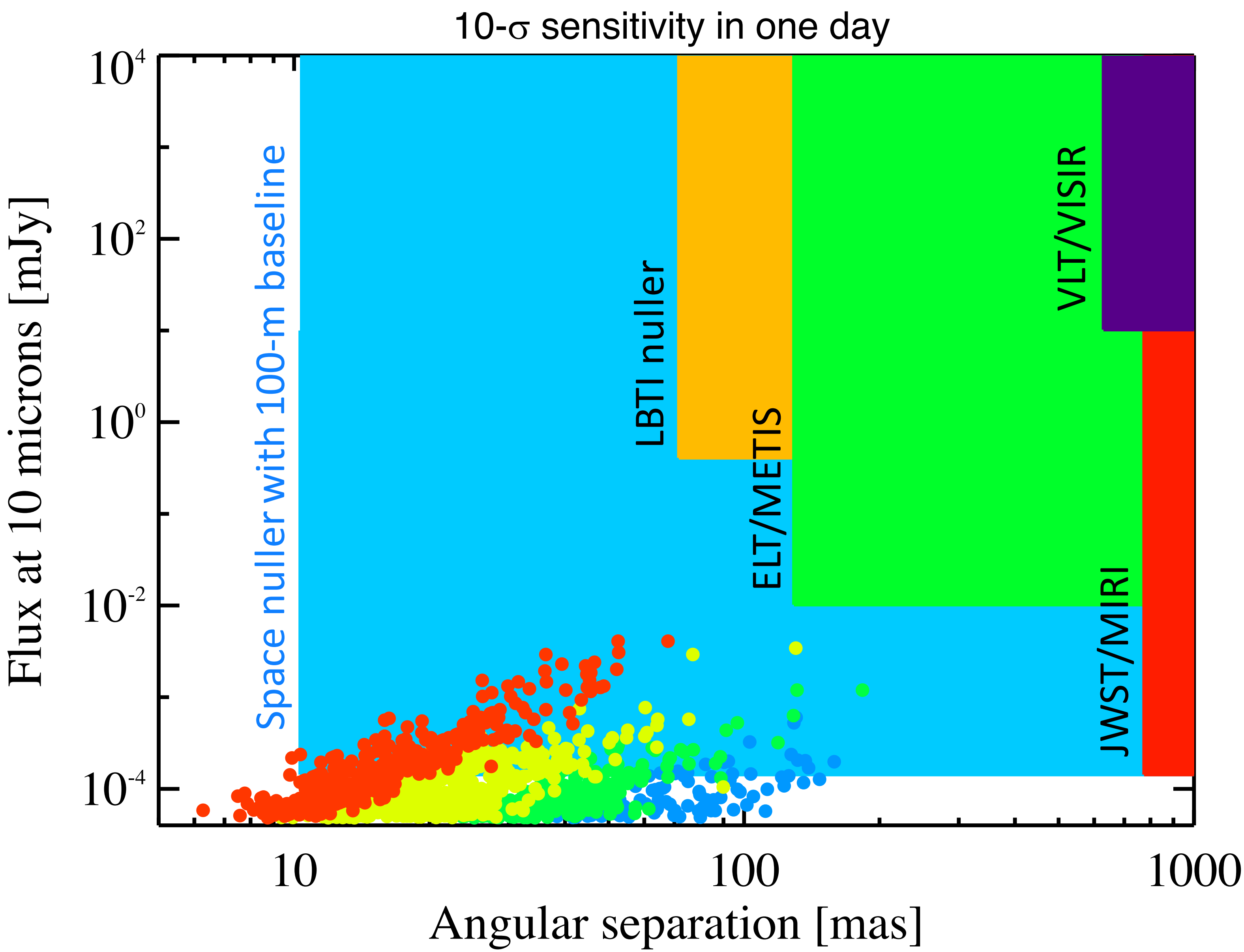
Nulling interferometry



Nulling interferometry

- Key advantages:
    - Interferometry provides the required **angular resolution**
    - Nulling provides the required **contrast**
- Must be space-based to get **reasonable integration times**

Nulling interferometry



Space-based interferometry

- Mid-IR space-based nulling interferometer (6 to 20 μm)
- Observe the habitable zone of nearby main sequence stars

Detection of about 200 Earth-like planets with possible follow-up (CO_2,O_3,$H_2$0) spectroscopy for about 20

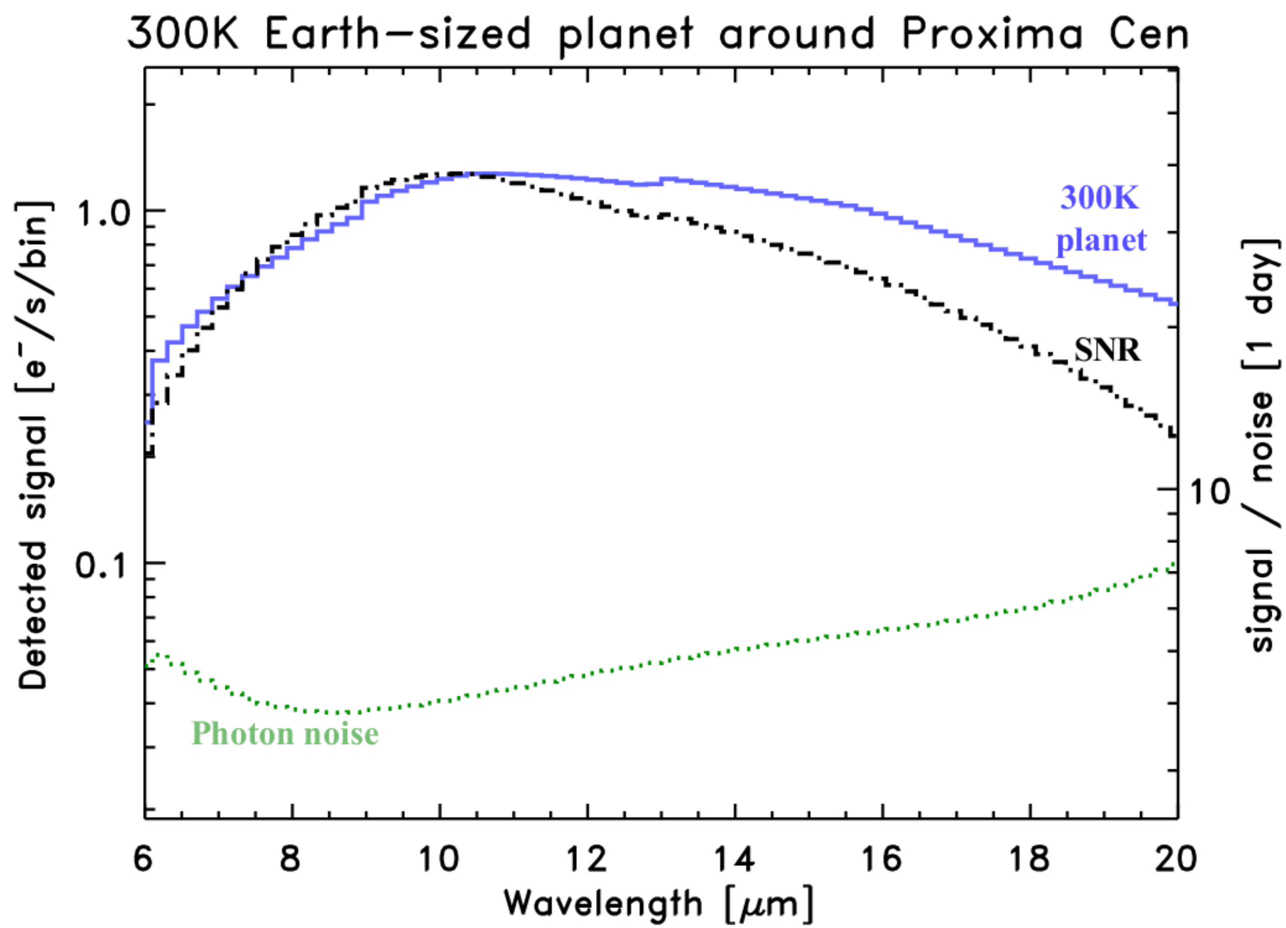
Yield in a 5-year mission

Diameter	1m	2m	4m
Detection	58	189	497
# F	3	10	35
# G	11	43	136
# K	14	61	183
# M	30	75	143
CO_2,O_3,H_2O	11	21	60
# F	0	1	2
# G	0	4	11
# K	2	5	18
# M	9	11	39

Defrère et al. 2010

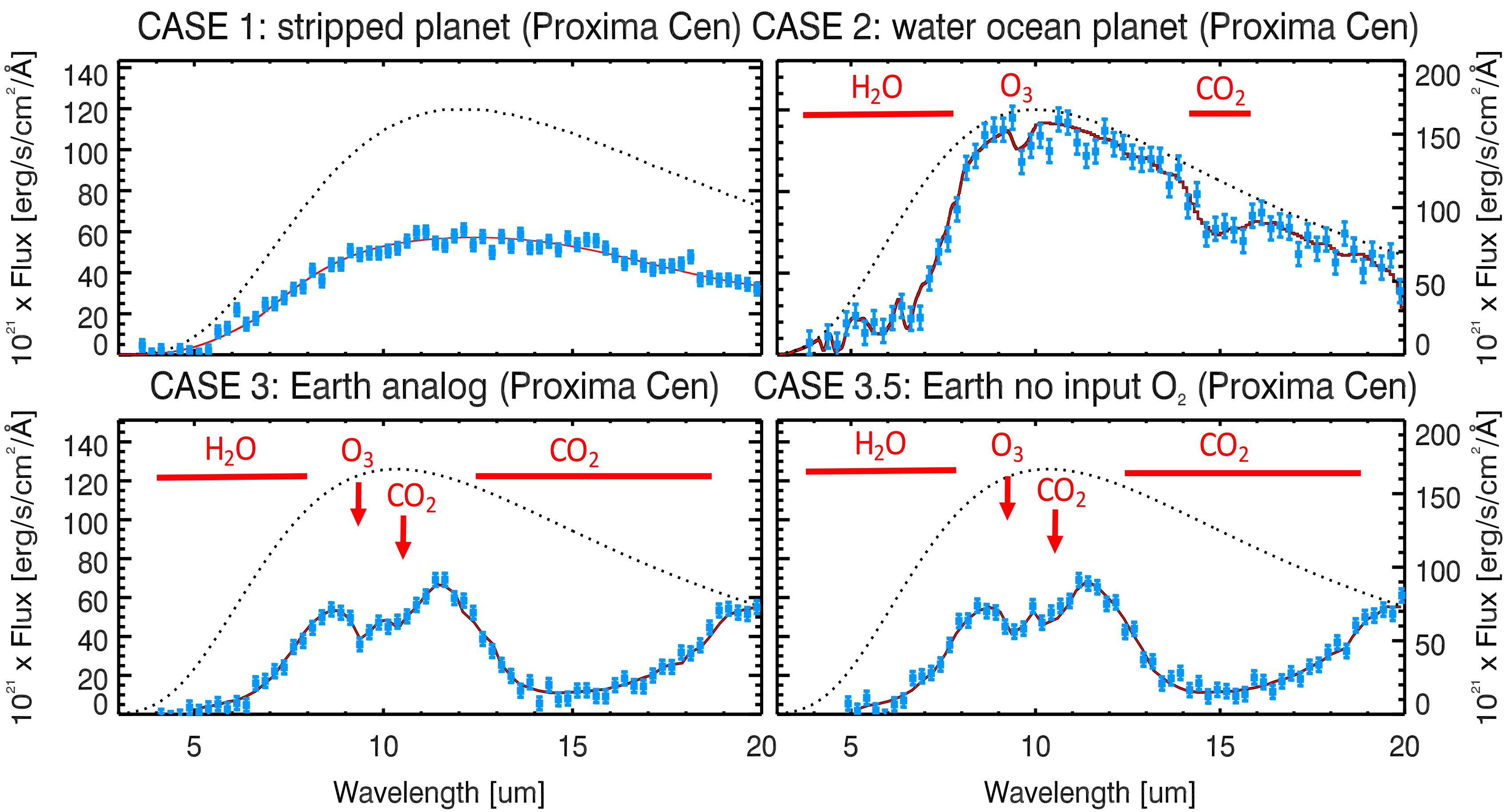
The case of Proxima Cen b

- Ideal target for mid-infrared interferometer.
- SNR in 1 day of integration with four 75-cm aperture and R = 40



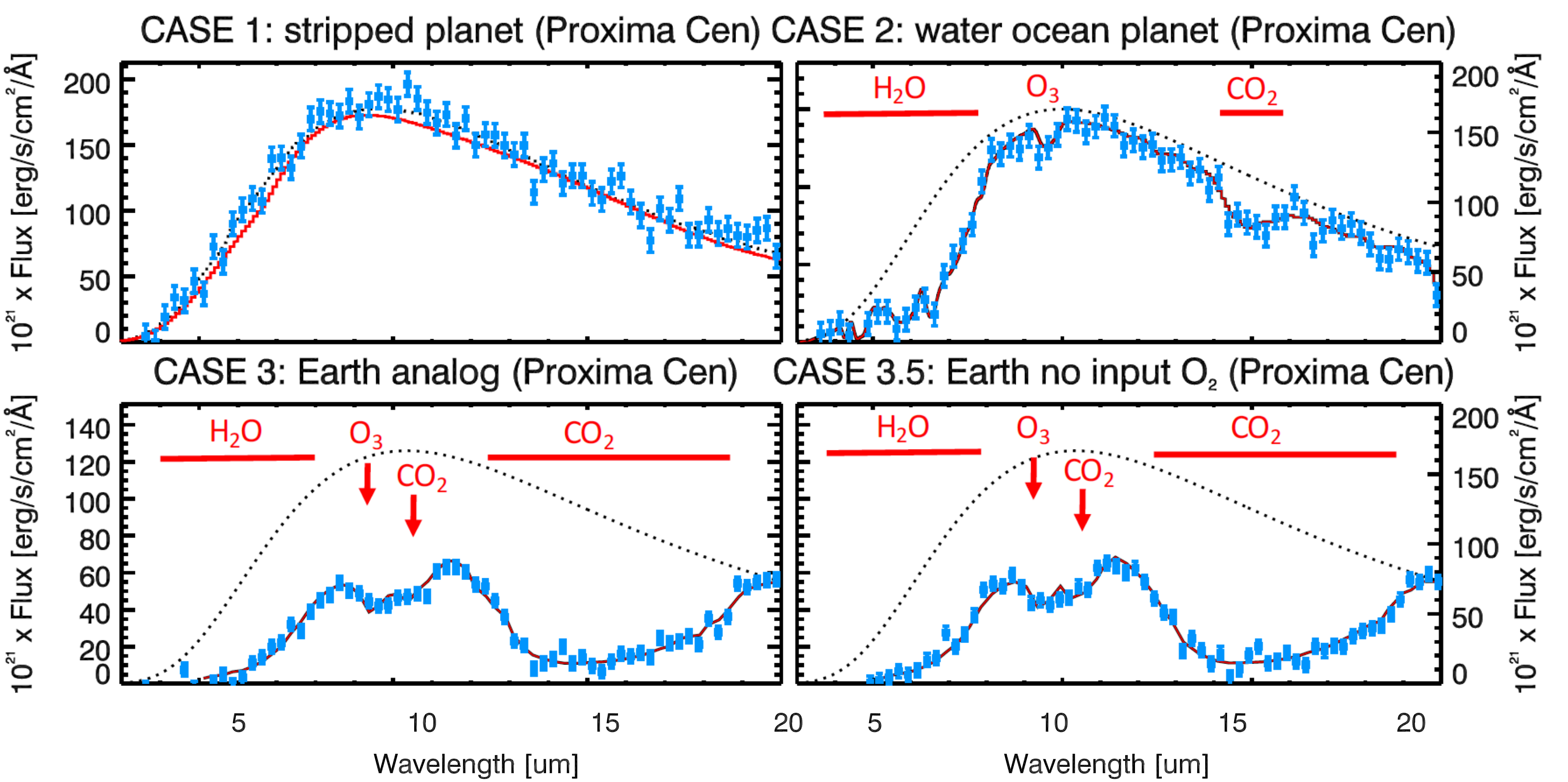
The case of Proxima Cen b

- Simulated observations (R=40, blue points) imposing a S/N of 20 on continuum detection at 10 μm).
- All spectral features detected in a single visit (besides O_3):



The case of Proxima Cen b

- What is the required SNR and spectral resolution required to distinguish these scenarios?

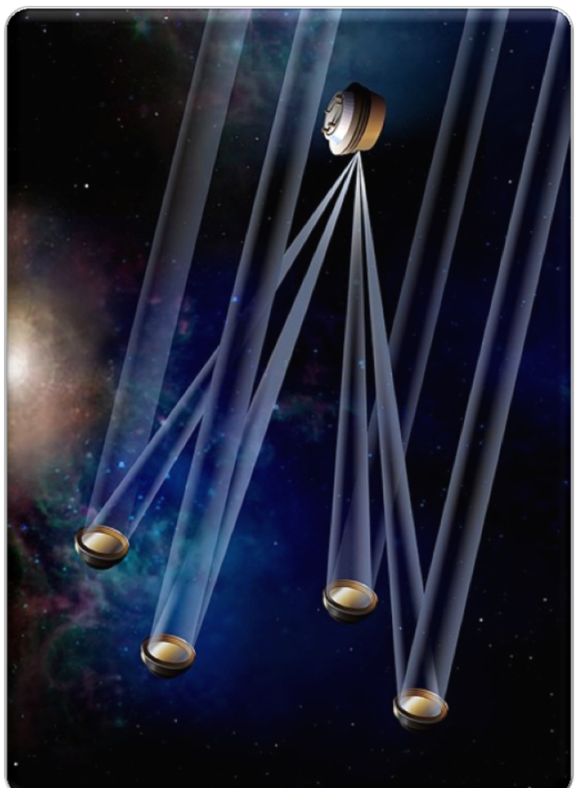


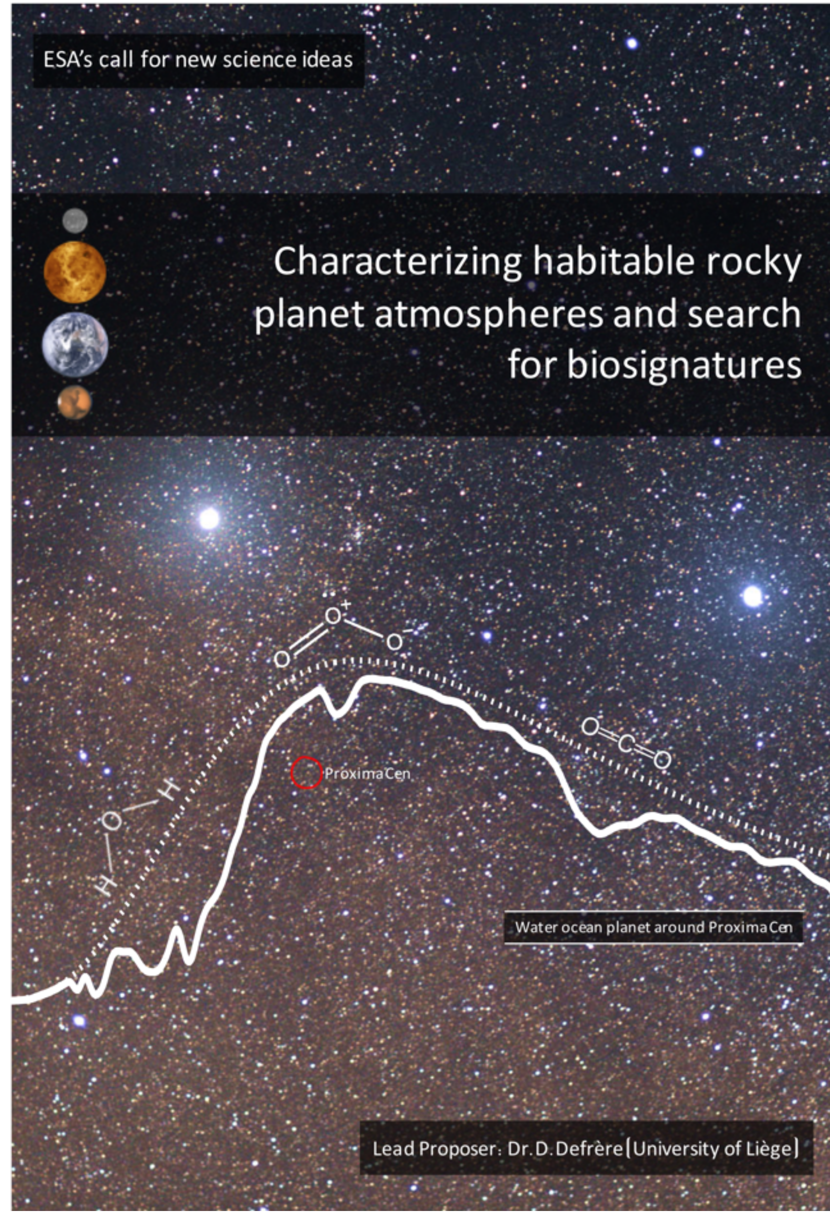
History

- Several industrial studies in Europe mid 2000s (Alcatel and Astrium)
- Extensively studied by NASA/JPL until 2007
- Proposed to ESA as L mission in 2007 (Cosmic Vision)
- Most technologies now at least TRL5
    - ❖ Free-flying demonstrated by the PRISMA mission
    - ❖ Beam combination demonstrated at JPL (at room temperature)

Technology developments are required!

- Technology developments are required.
- Proposed to ESA in September in the context of the call for new science ideas.





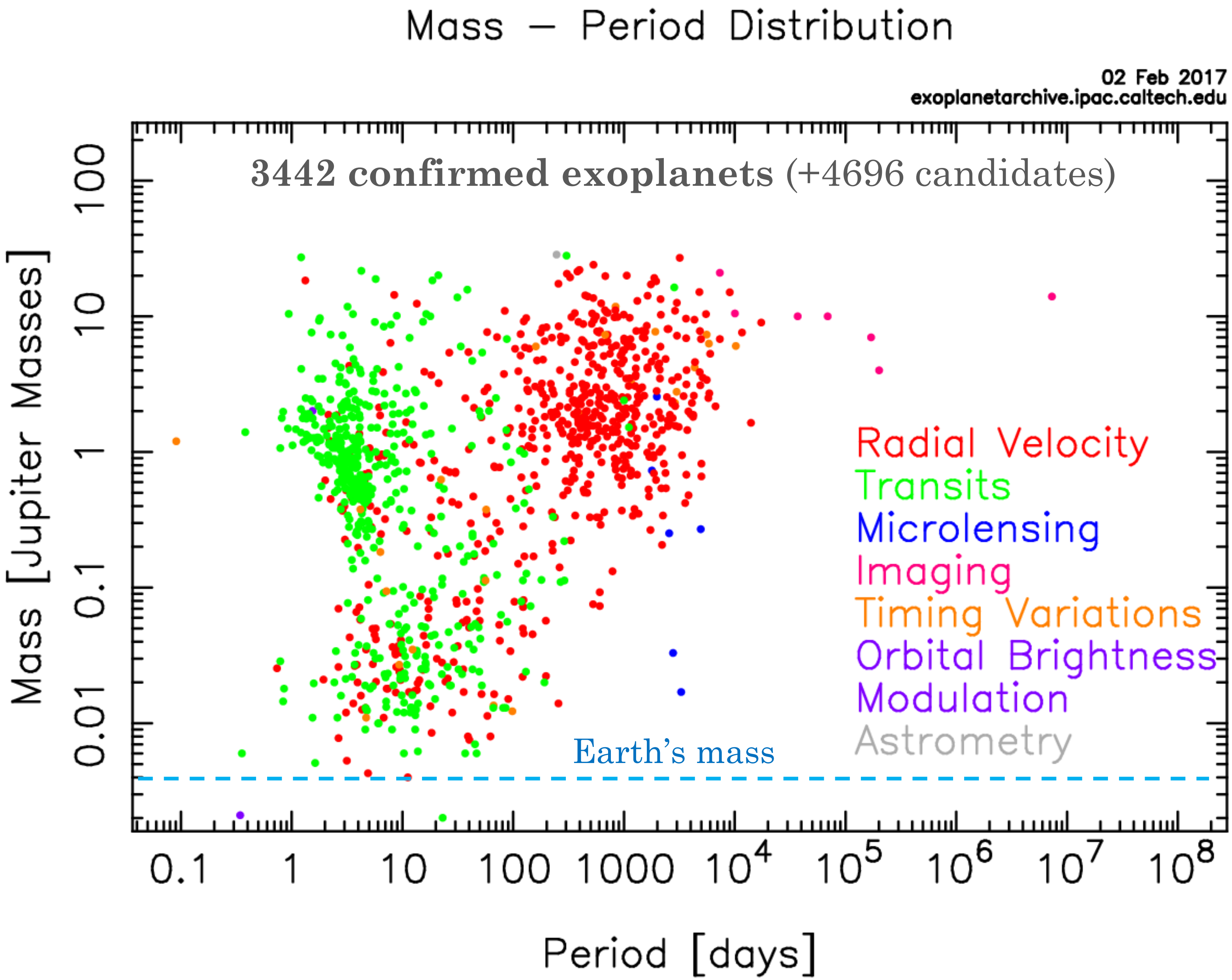
Summary

- A flagship mid-infrared nulling interferometer could:
  - Perform a survey to detect nearby rocky planets
  - Characterize any nearby planets;
  - Provide spectroscopic observations (R=40) of ~20 Earth-sized planets.

- A small mid-infrared nulling interferometer is well suited to characterize Proxima b

Backup slides

Exoplanet zoo



Exoplanet zoo (2/2)