Characterizing terrestrial exoplanets: The case for a Large Mid-Infrared Interferometry Mission

Sascha P. Quanz (ETH Zurich) - Contact person

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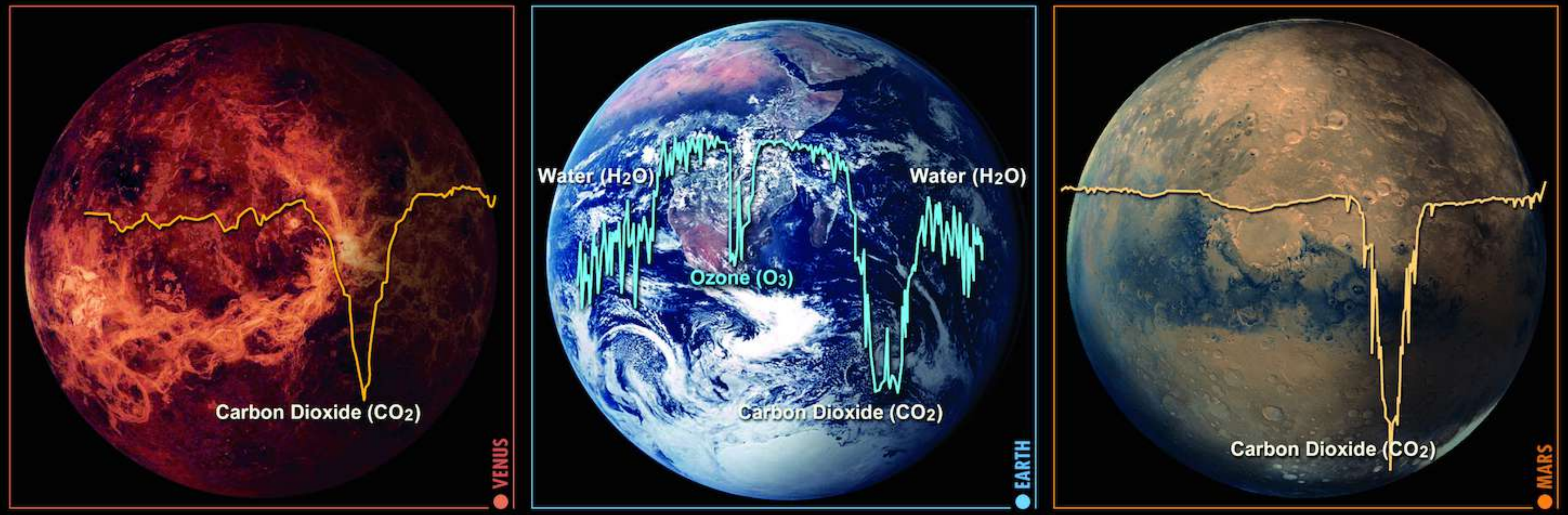
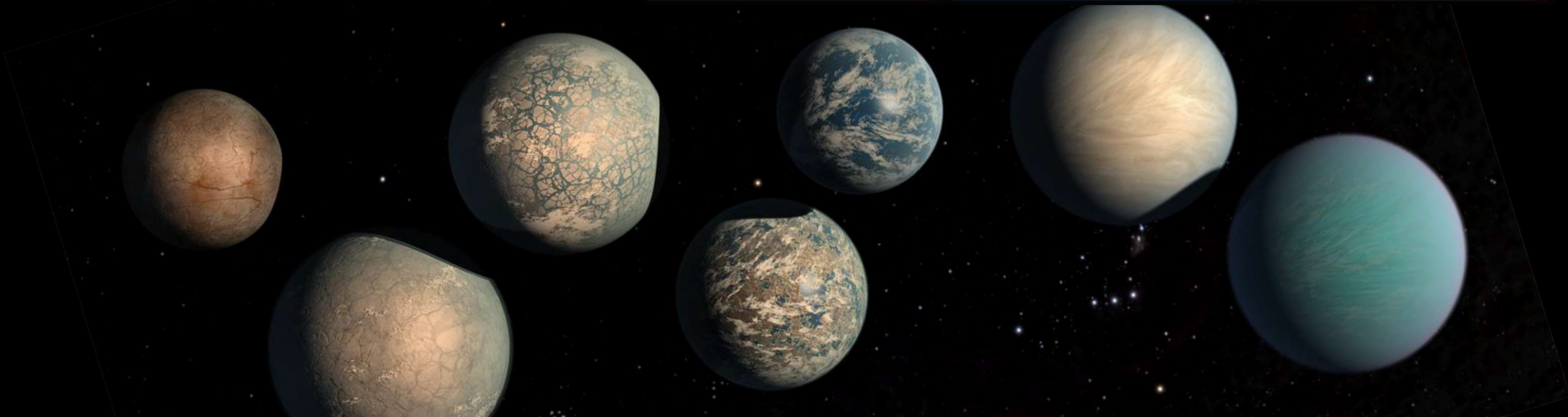
Olivier Absil, Willy Benz, Xavier Bonfils, Jean-Philippe Berger, Denis Defrere, William Danchi, Ewine van Dishoeck, David Ehrenreich, Jonathan Fortney, Scott Gaudi, Adrian Glauser, John Lee Grenfell, Michael Ireland, Markus Janson, Stefan Kraus, Oliver Krause, Lucas Labadie, Sylvestre Lacour, Michael Line, Hendrik Linz, Jerome Loicq, Bertrand Mennesson, Michael Meyer, Yamila Miguel, John Monnier, Enric Palle, Didier Queloz, Heike Rauer, Ignasi Ribas, Sarah Rugheimer, Franck Selsis, Gene Serabyn, Ignas Snellen, Alessandro Sozzetti, Karl Stapelfeldt, Stephane Udry, Mark Wyatt



ESA Voyage 2050 workshop
CSIC, Madrid, Spain, 29-31 October, 2019



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(1) Atmospheric diversity

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Spectroscopy is key and upcoming MIR characterisation missions will focus on hot / warm ***transiting*** exoplanets

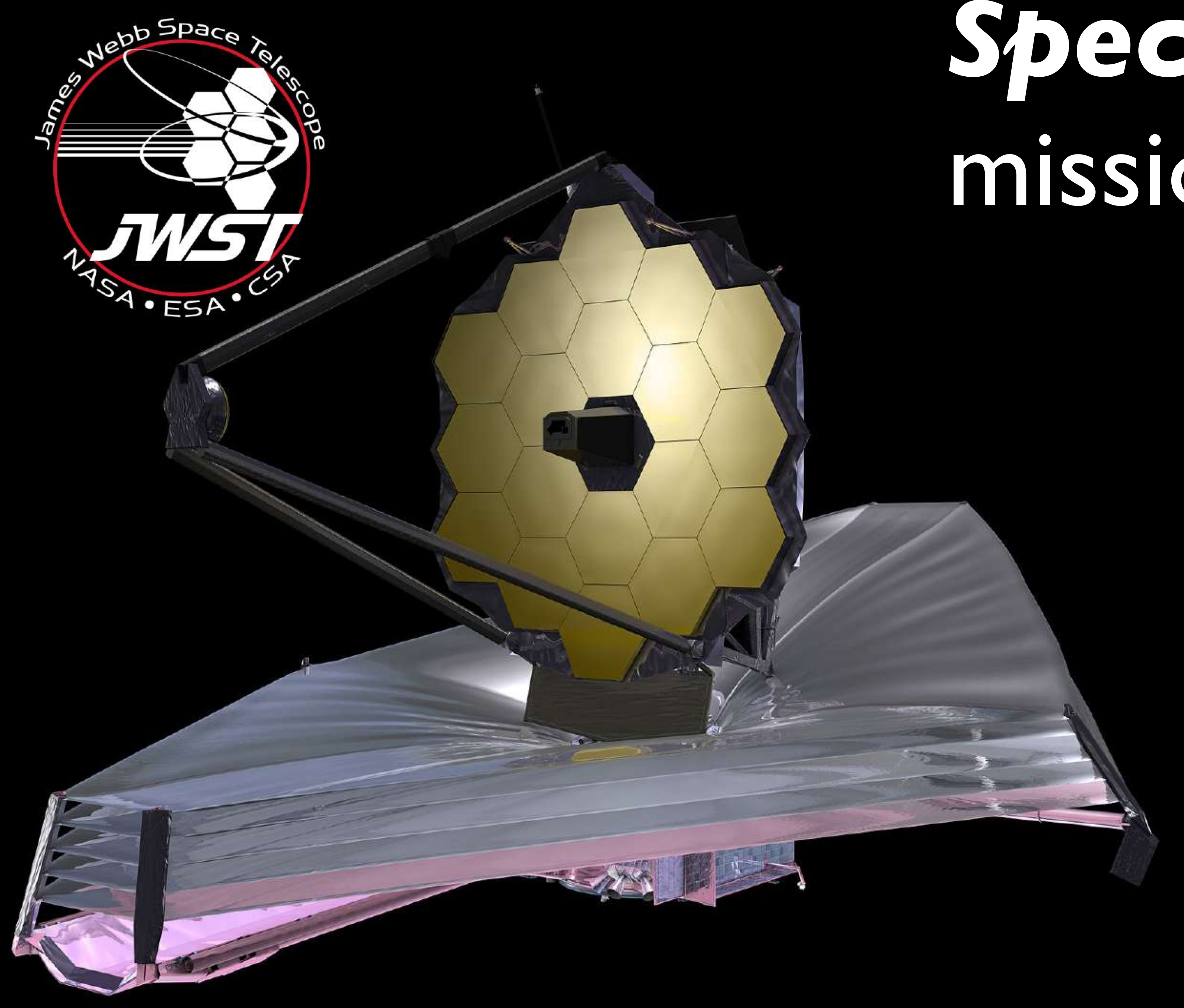

Image credit: NASA; ESA / UCL; NASA Mission Concept Study Report (OST)

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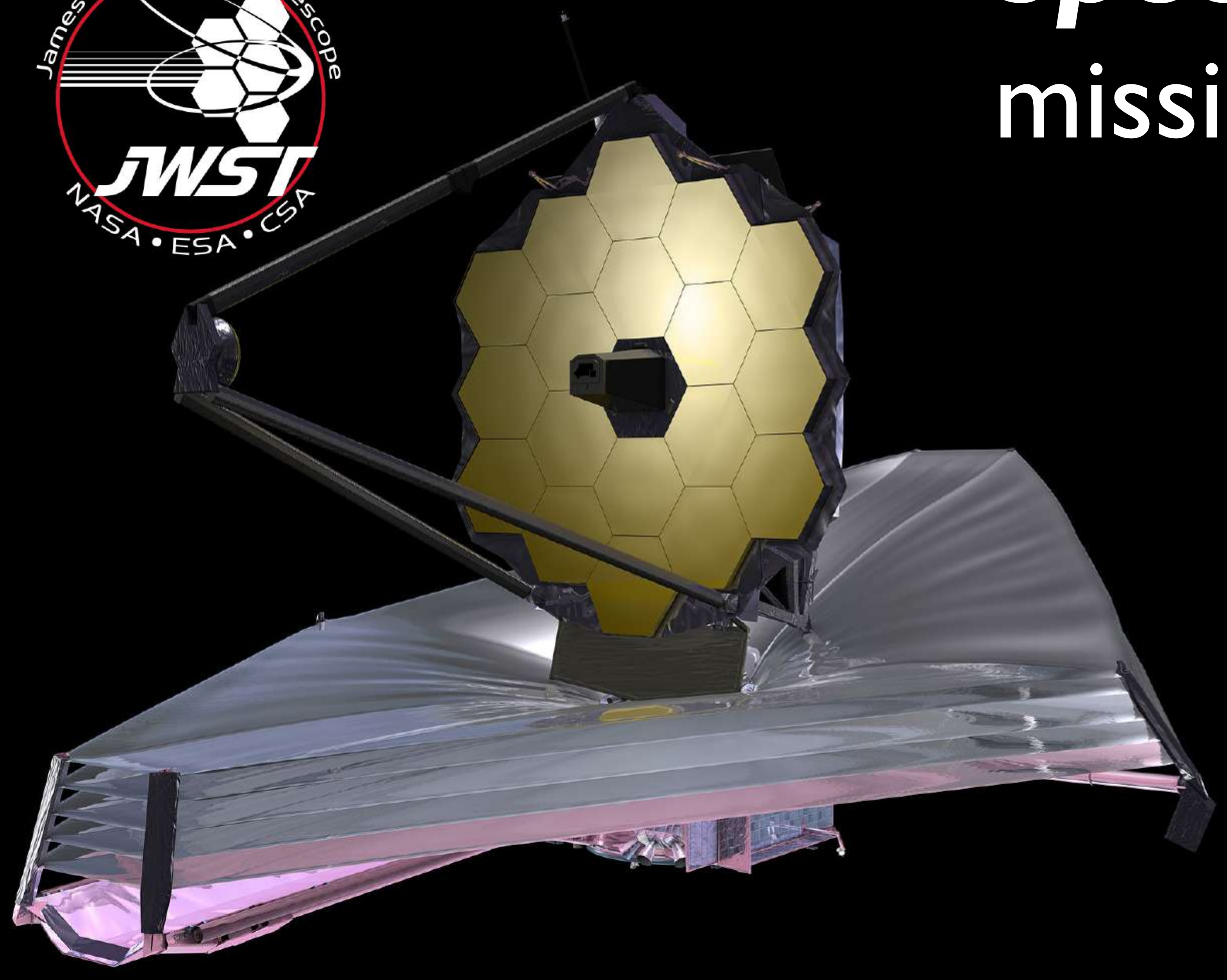


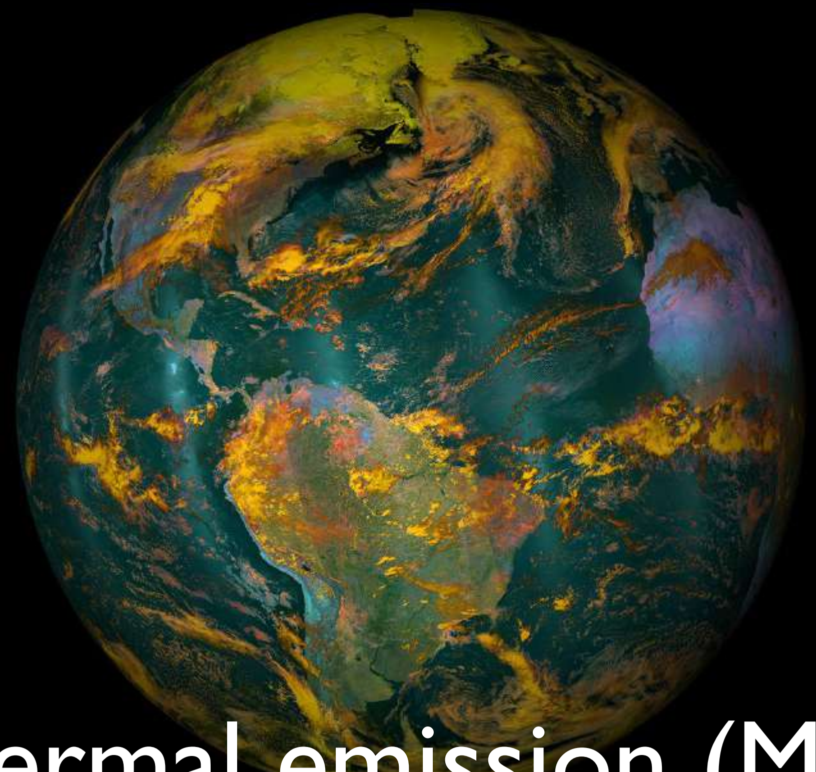
"A long term scientific objective is to characterize the whole range of exoplanets, including, of course, potentially habitable ones. ARIEL would act as a pathfinder for future, even more ambitious campaigns."

ARIEL Assessment Study Report (Yellow Book)

Image credit: NASA; ESA / UCL; NASA Mission Concept Study Report (OST)

The next step: a direct detection / spectroscopy mission

Reflected light (UV - NIR)



Thermal emission (MIR)

Image credit: NASA/NOAA; NASA/NOAA GOES Project; NASA; ESA

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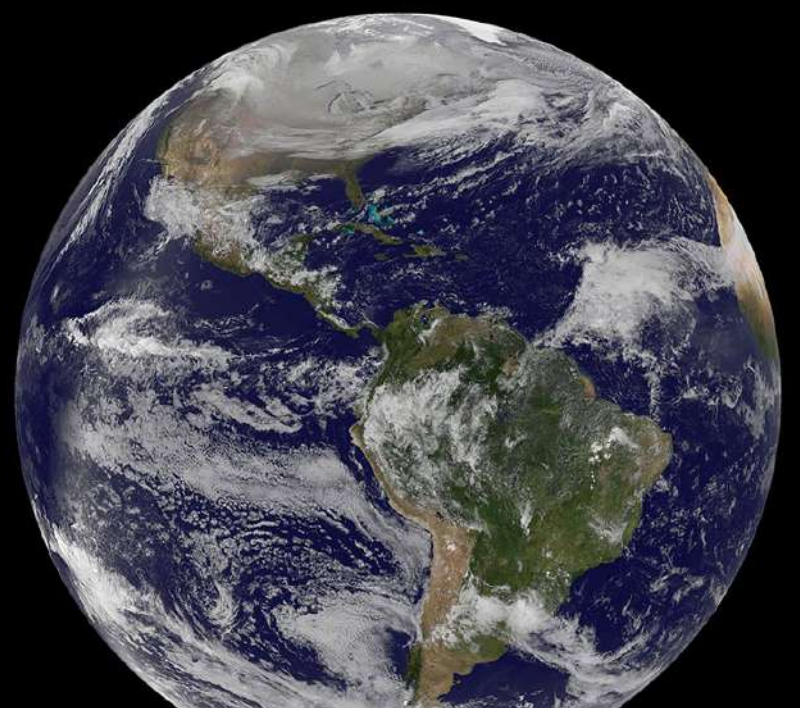

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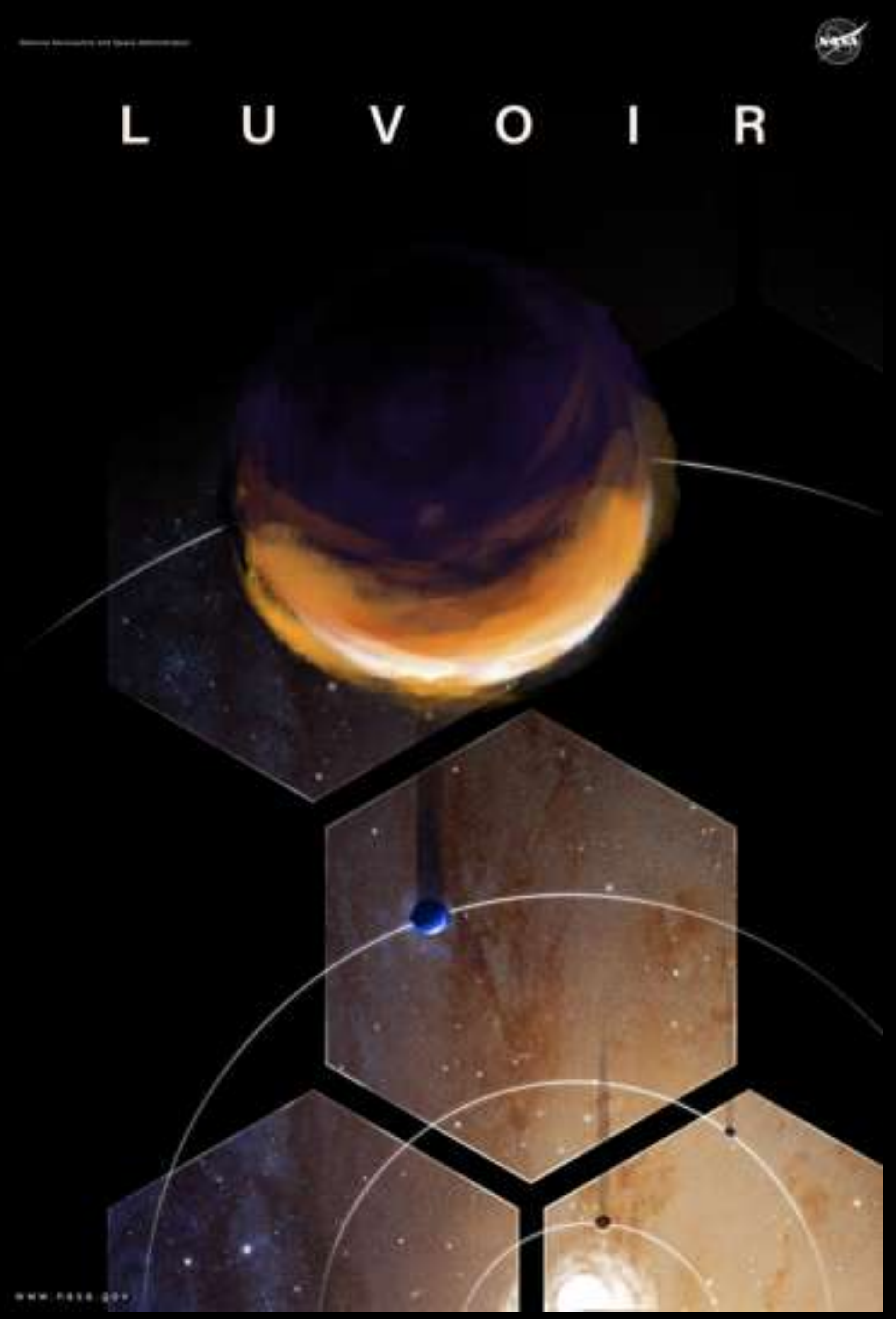

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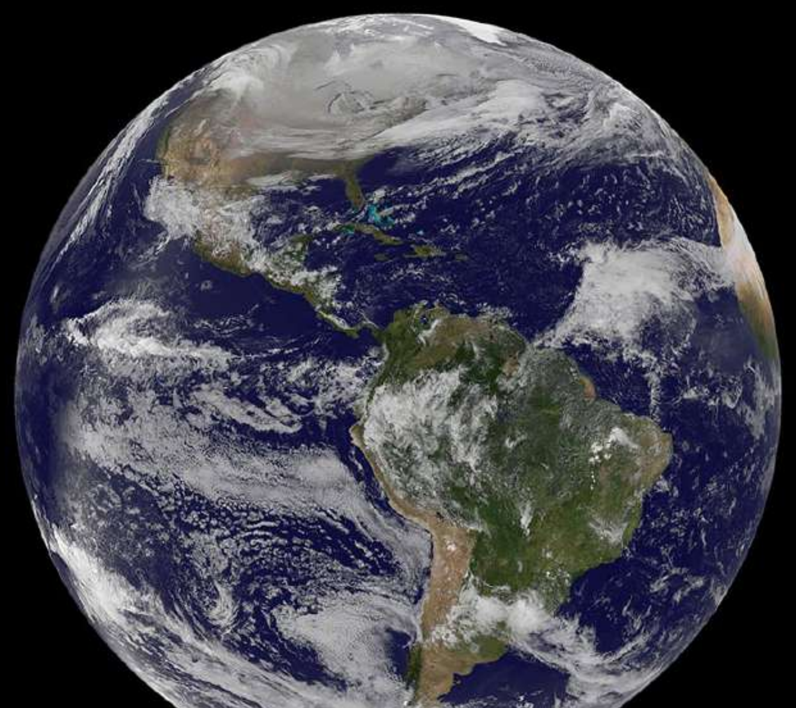

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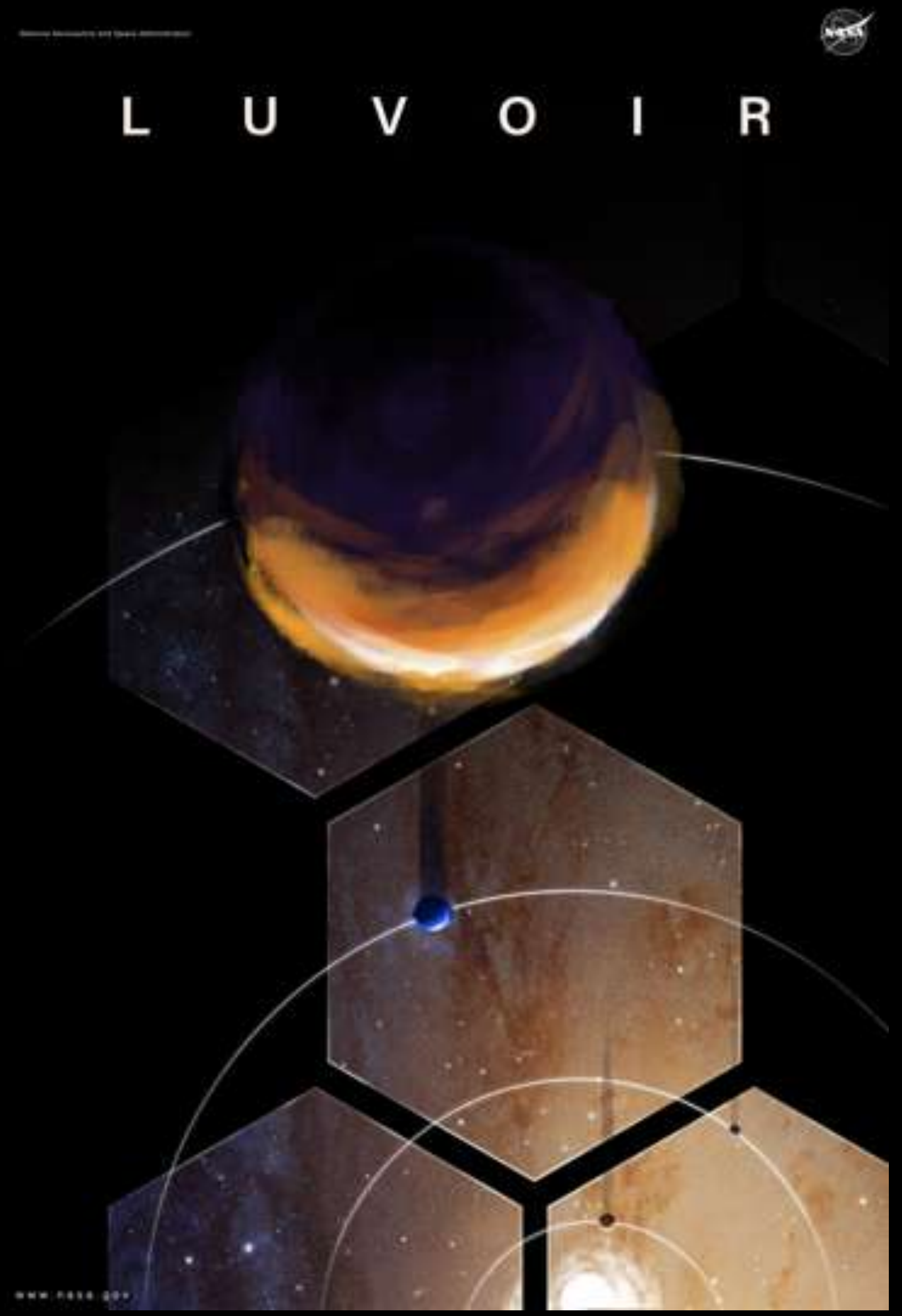

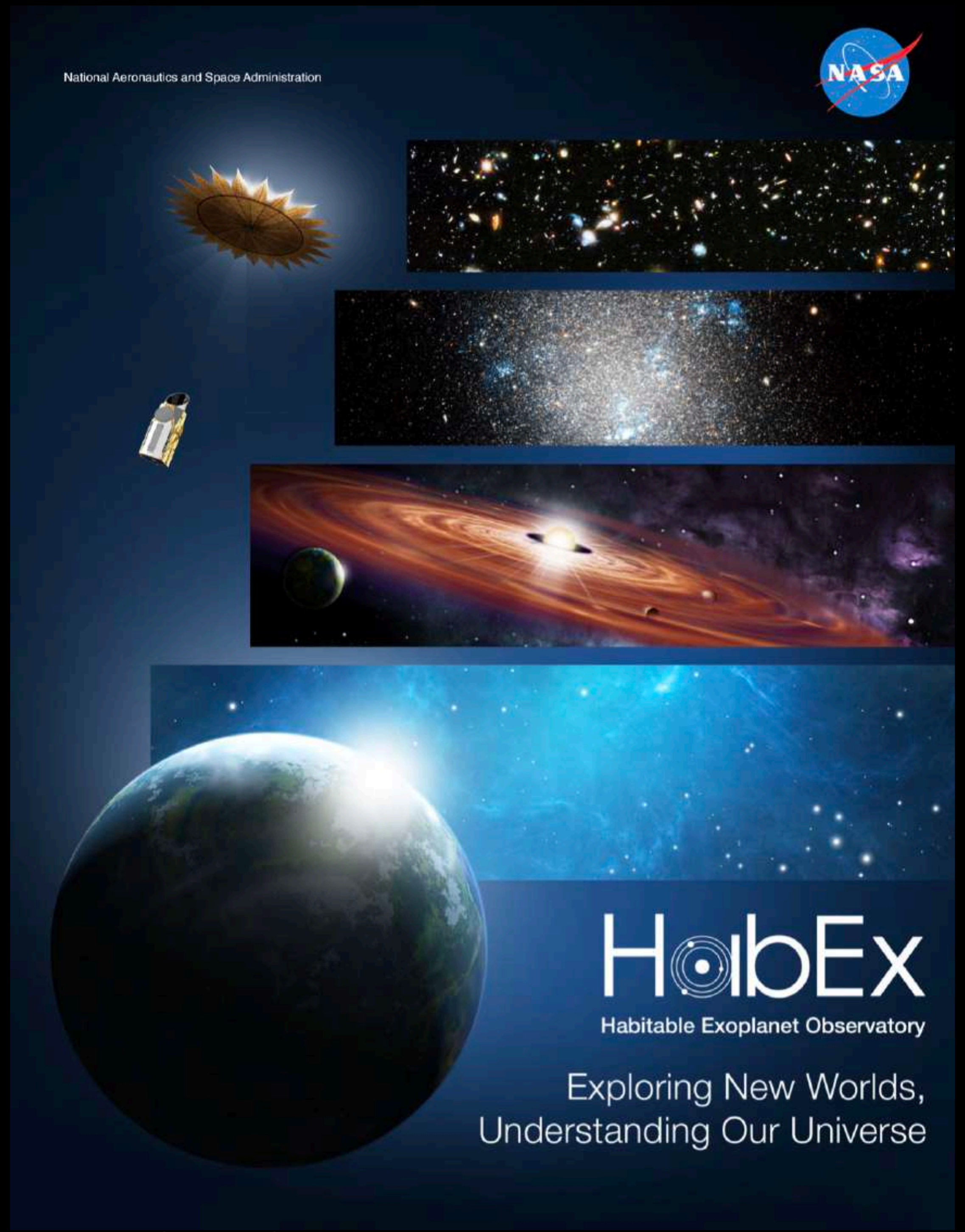

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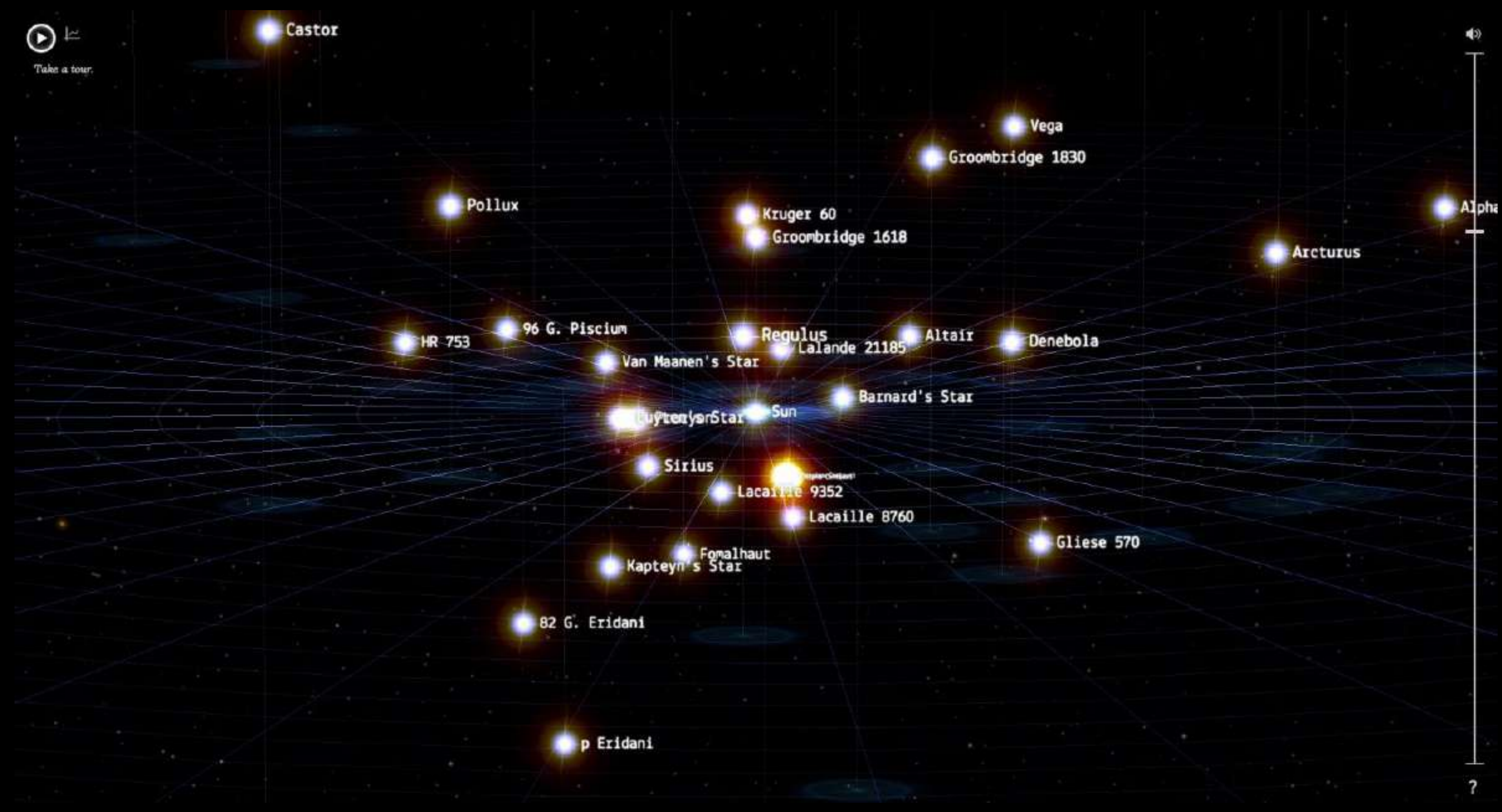
(1) Atmospheric diversity - total planet yield in search phase

cf. Kammerer & Quanz 2018; Quanz et al 2018

(1) Atmospheric diversity - total planet yield in search phase

Stellar sample

318 nearby FGKM main sequence stars within 20 pc
(many more stars exist - target catalog under revision)



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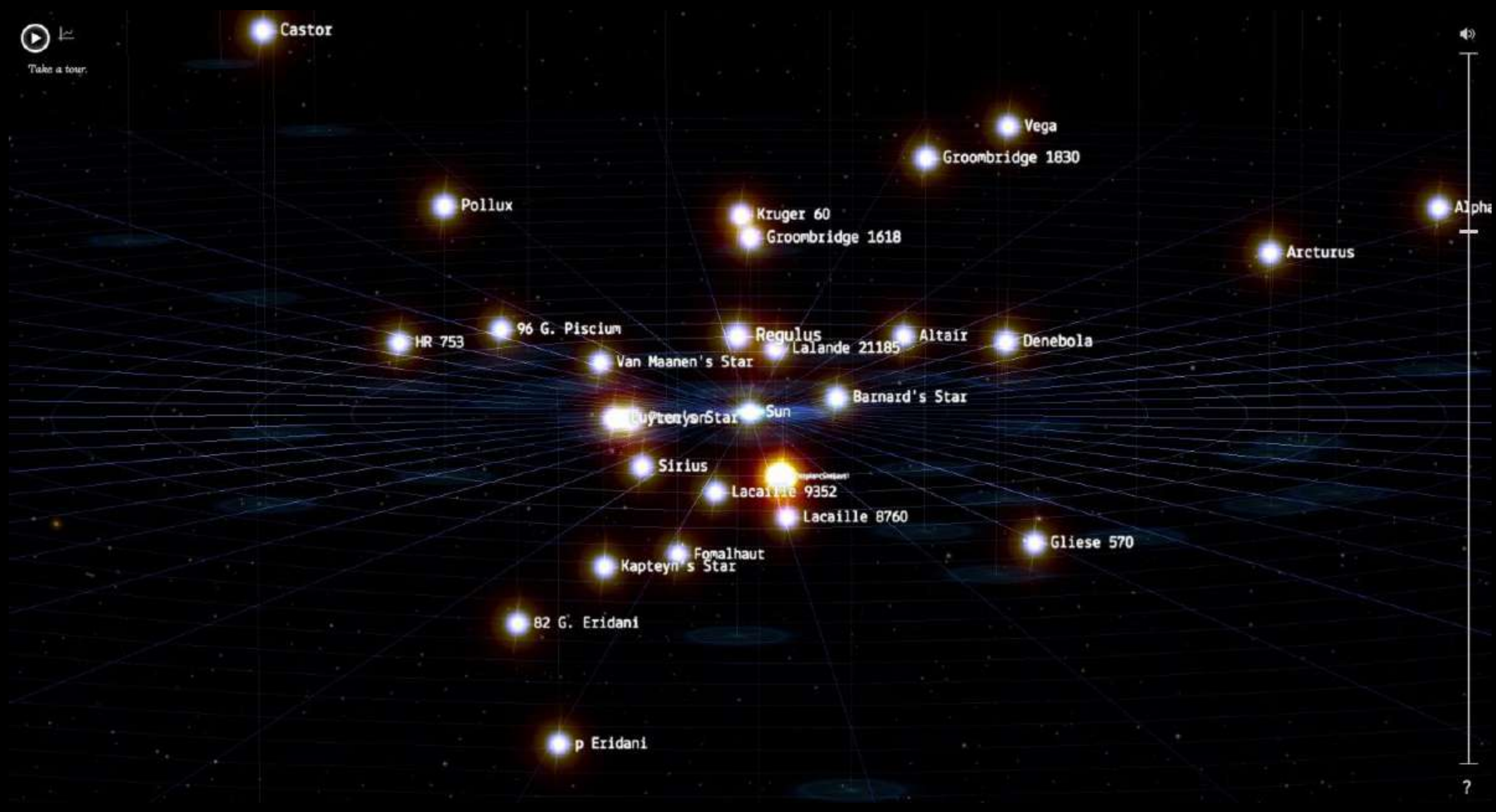

Planet population (Kepler)

Occurrence rates and period and radius distributions:
- NASA's SAG 13 report
- Dressing & Charbonneau 2015

- Radius: 0.5 - 6 R_{Earth}
- Period: 0.5 - 200 / 500 days
- Spectral type dependence
- Random orbits & albedos

cf. Kammerer & Quanz 2018; Quanz et al 2018

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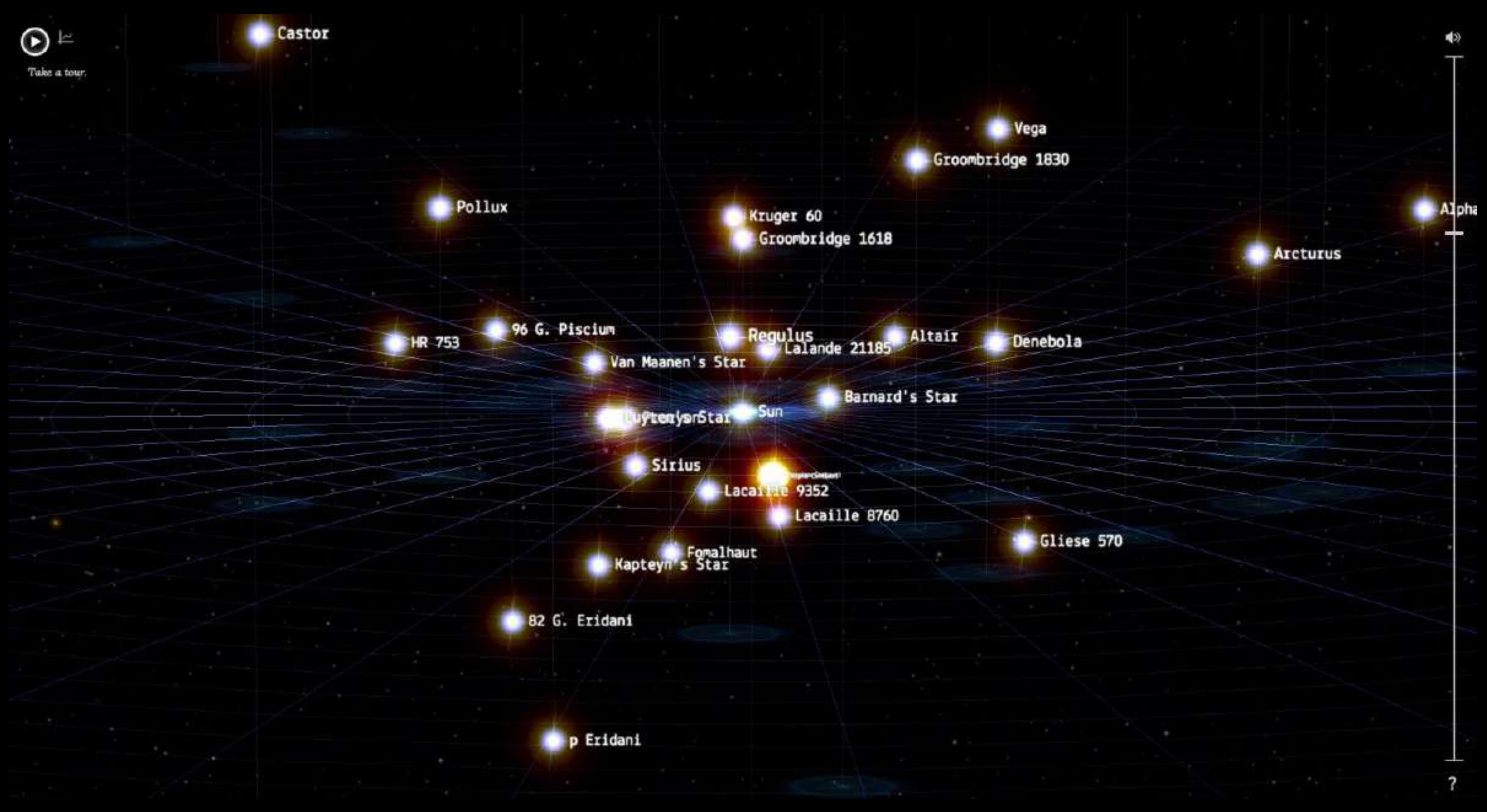

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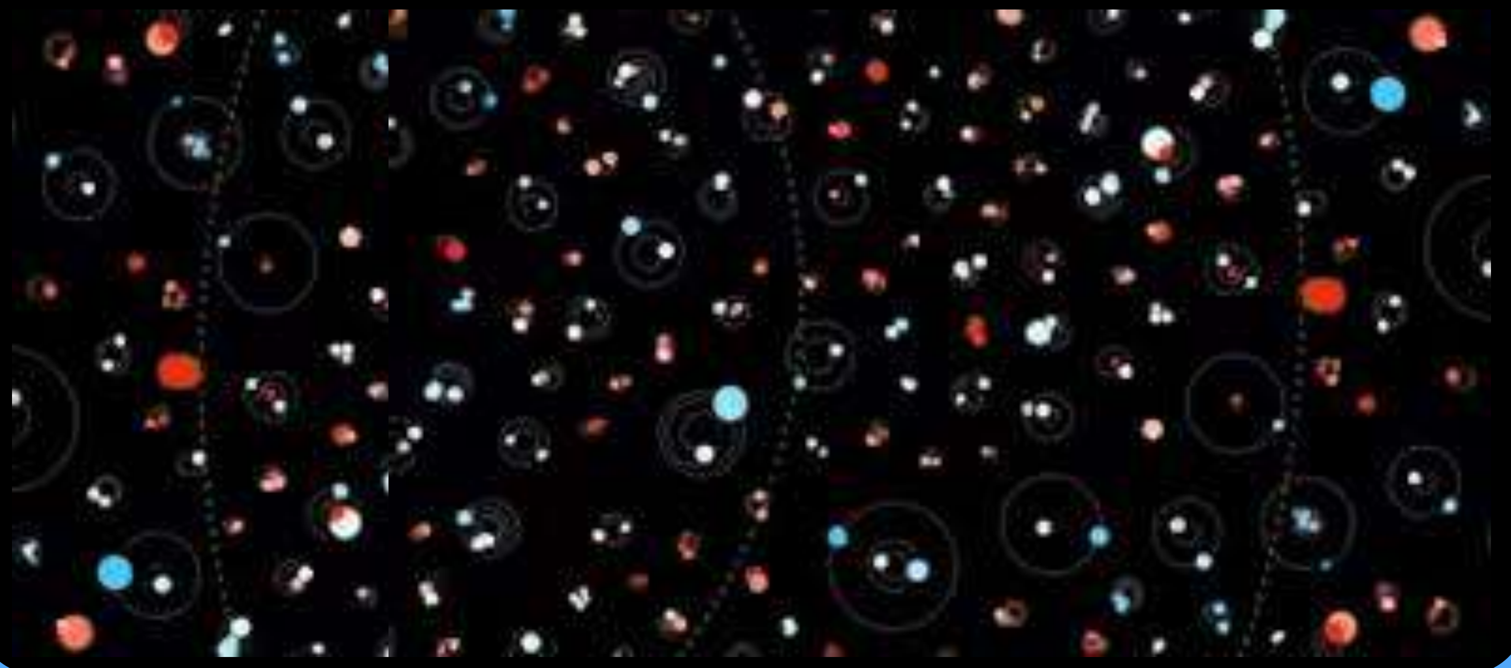


Technical specifications

Spatial resolution: 5 mas at 10 μm
(spacecraft separations ~200 m)

Sensitivity (10σ in 10 hours):
- 0.16 μJy @ 5.6 μm
- 0.54 μJy @ 10 μm
- 1.39 μJy @ 15 μm

3 λ-ranges considered

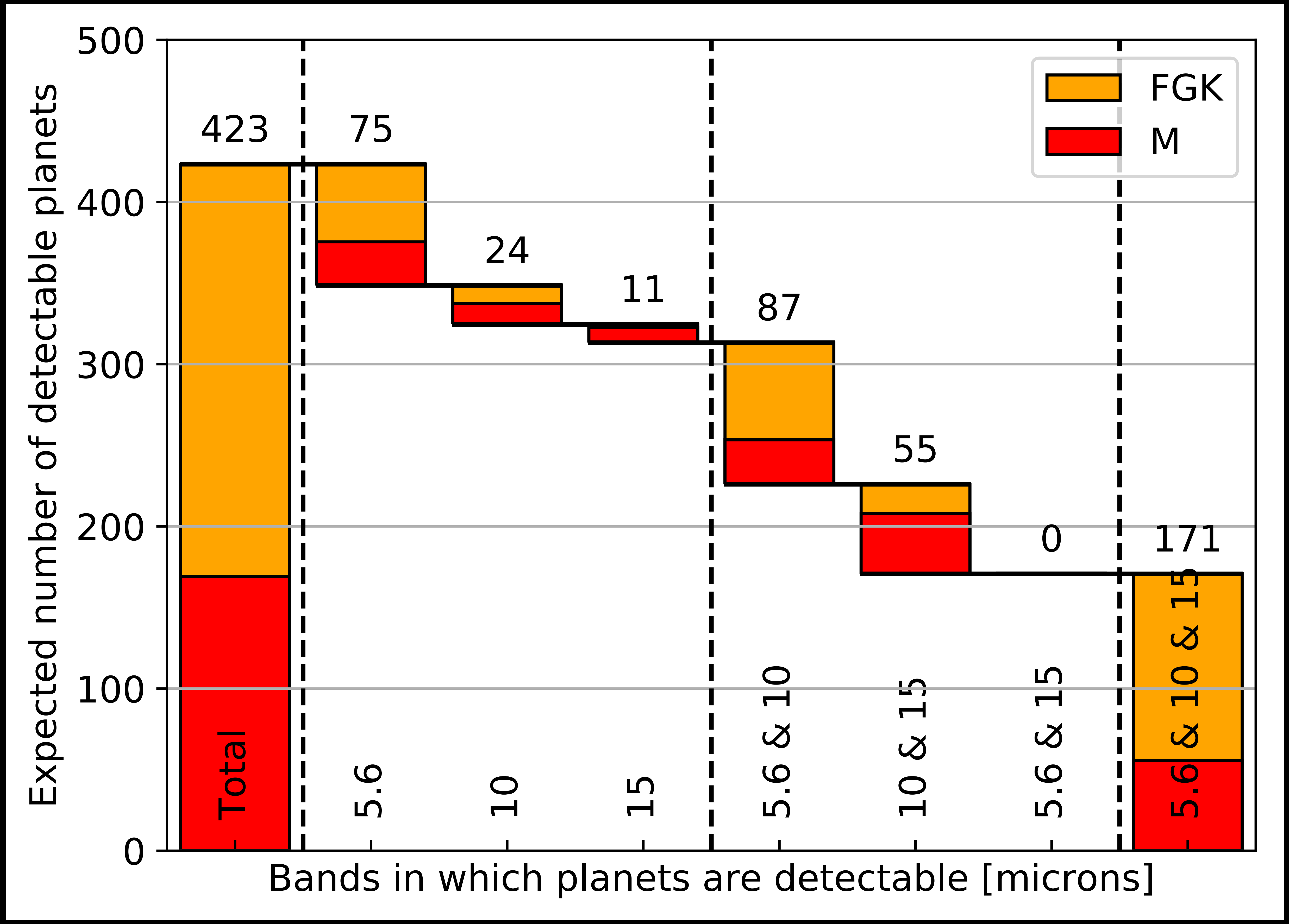
Starlight suppression:
~1e5 - 1e6 (from spacecraft)
~1e8 (after post-processing)

Earth has ~0.4 μJy at 10 μm seen from 10 pc

cf. Kammerer & Quanz 2018; Quanz et al 2018

(1) Atmospheric diversity - total planet yield in search phase

Planets per filter combination



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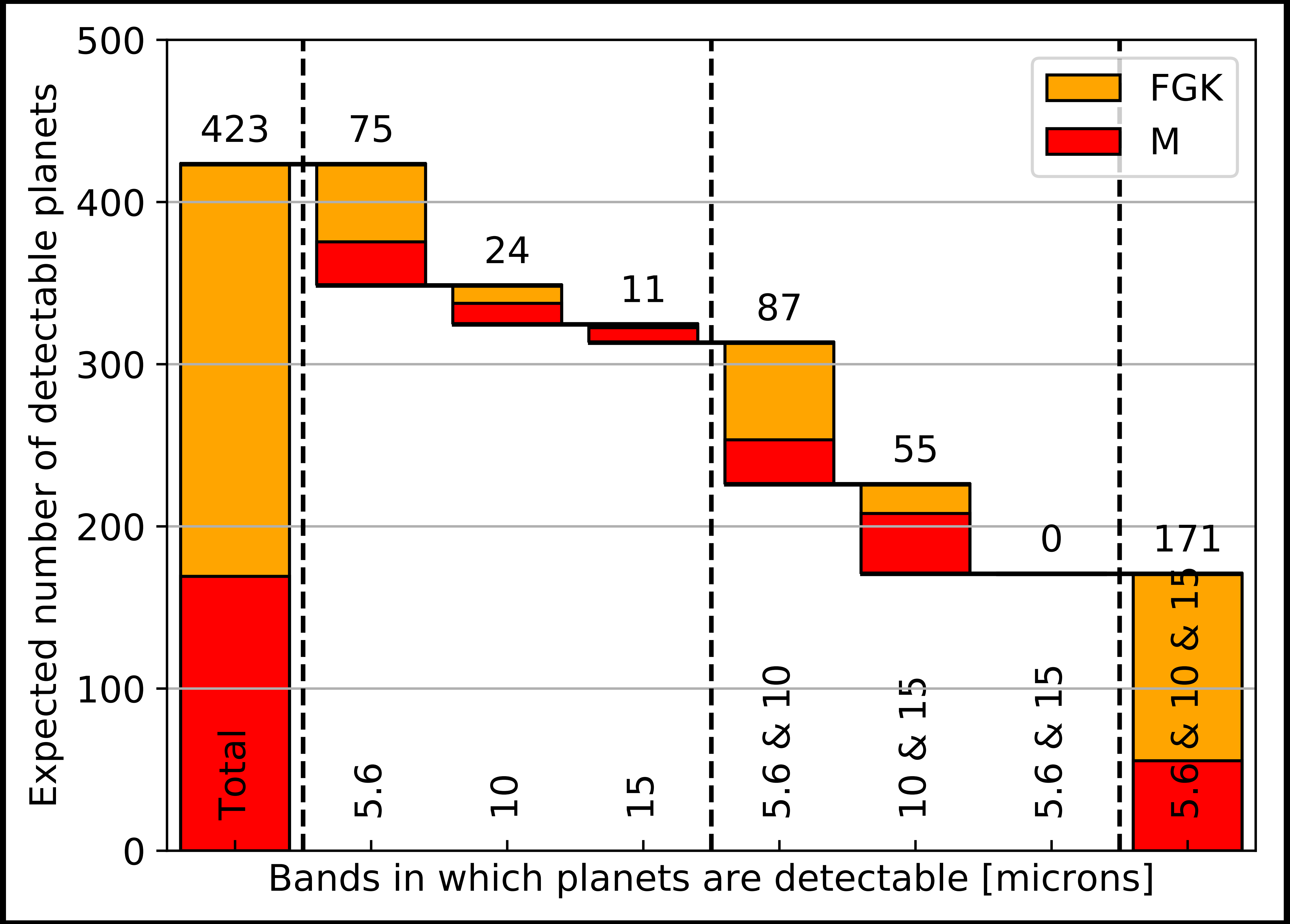
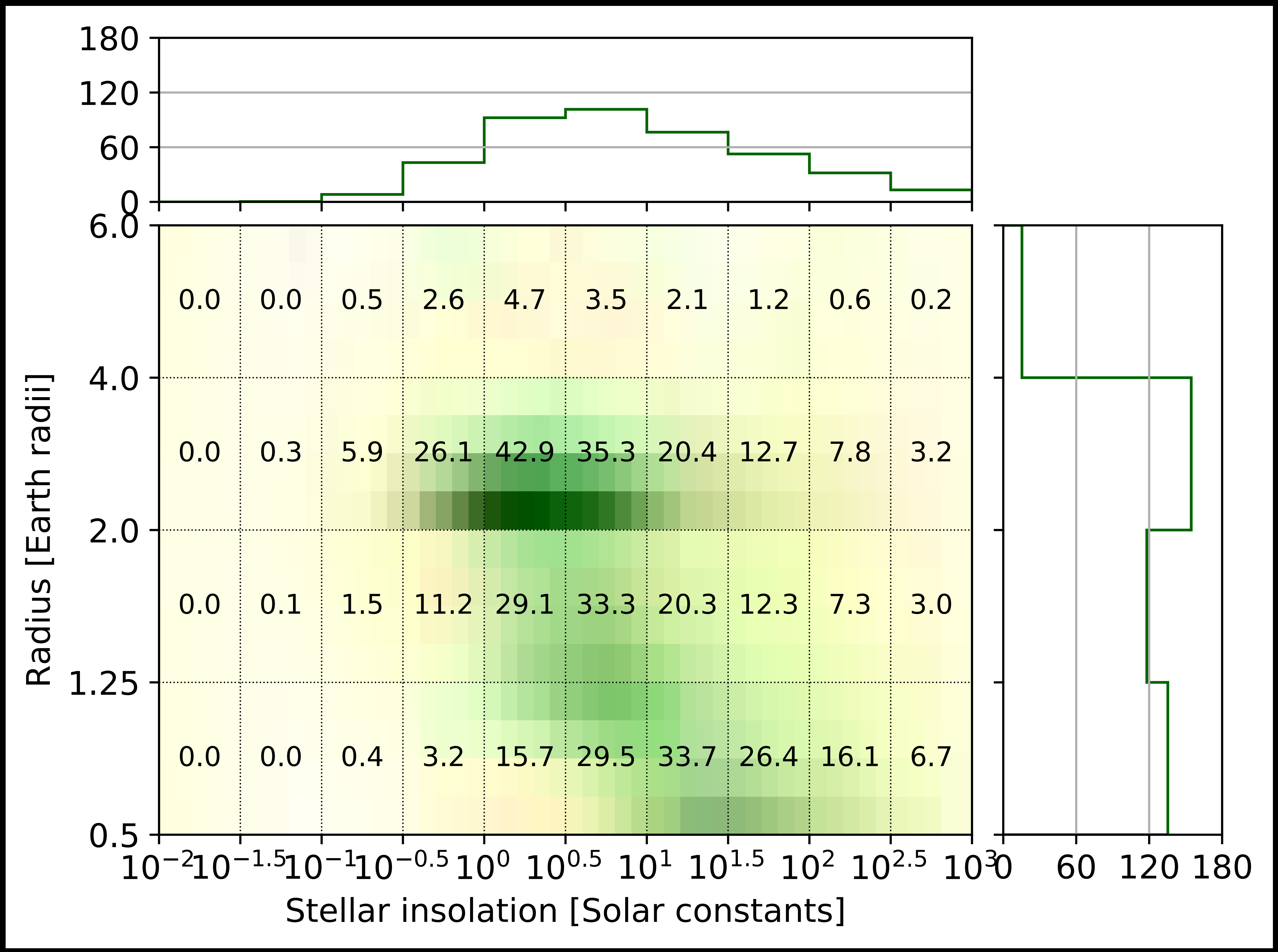


Planets per radius-insolation bin (10 μm)



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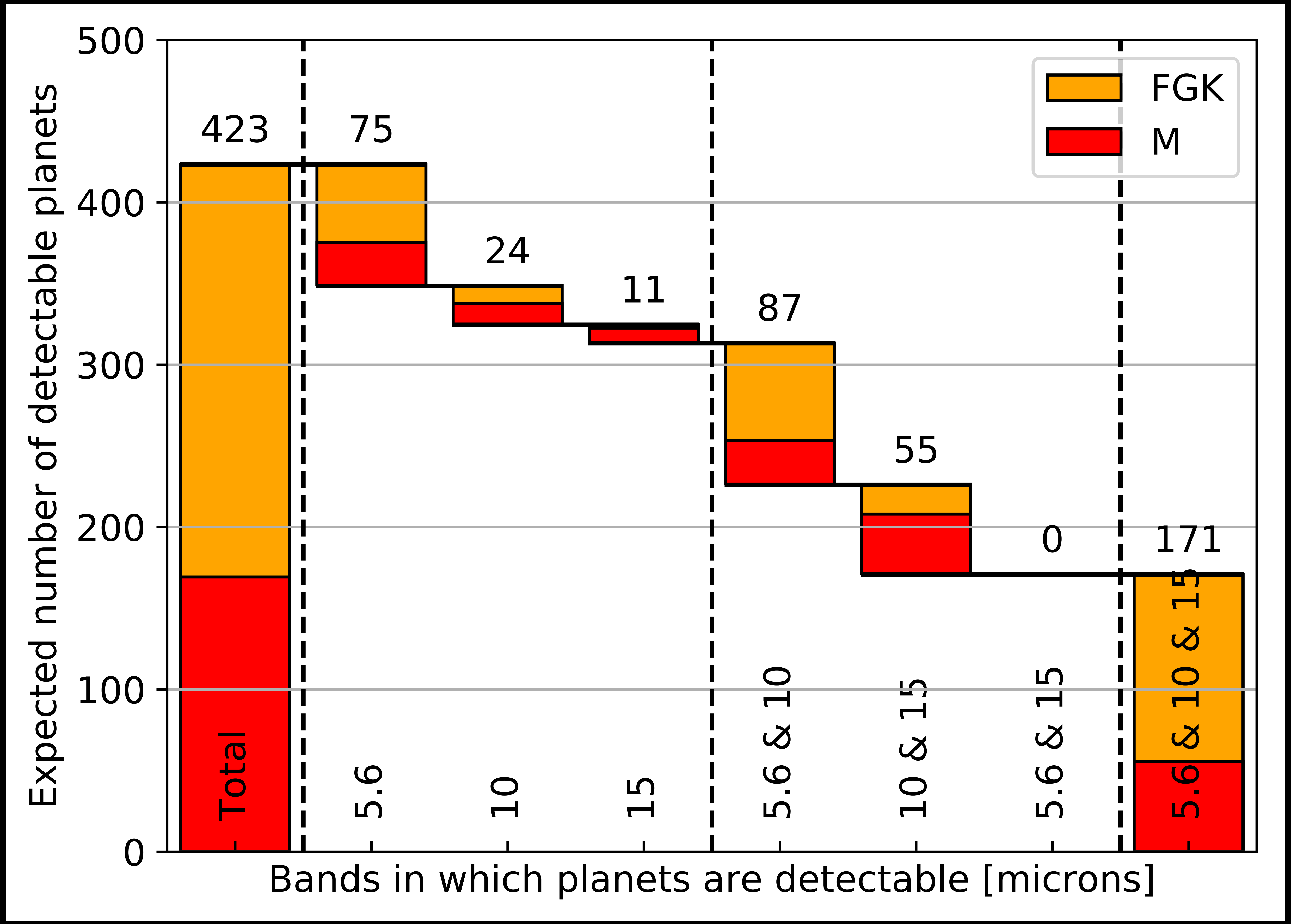

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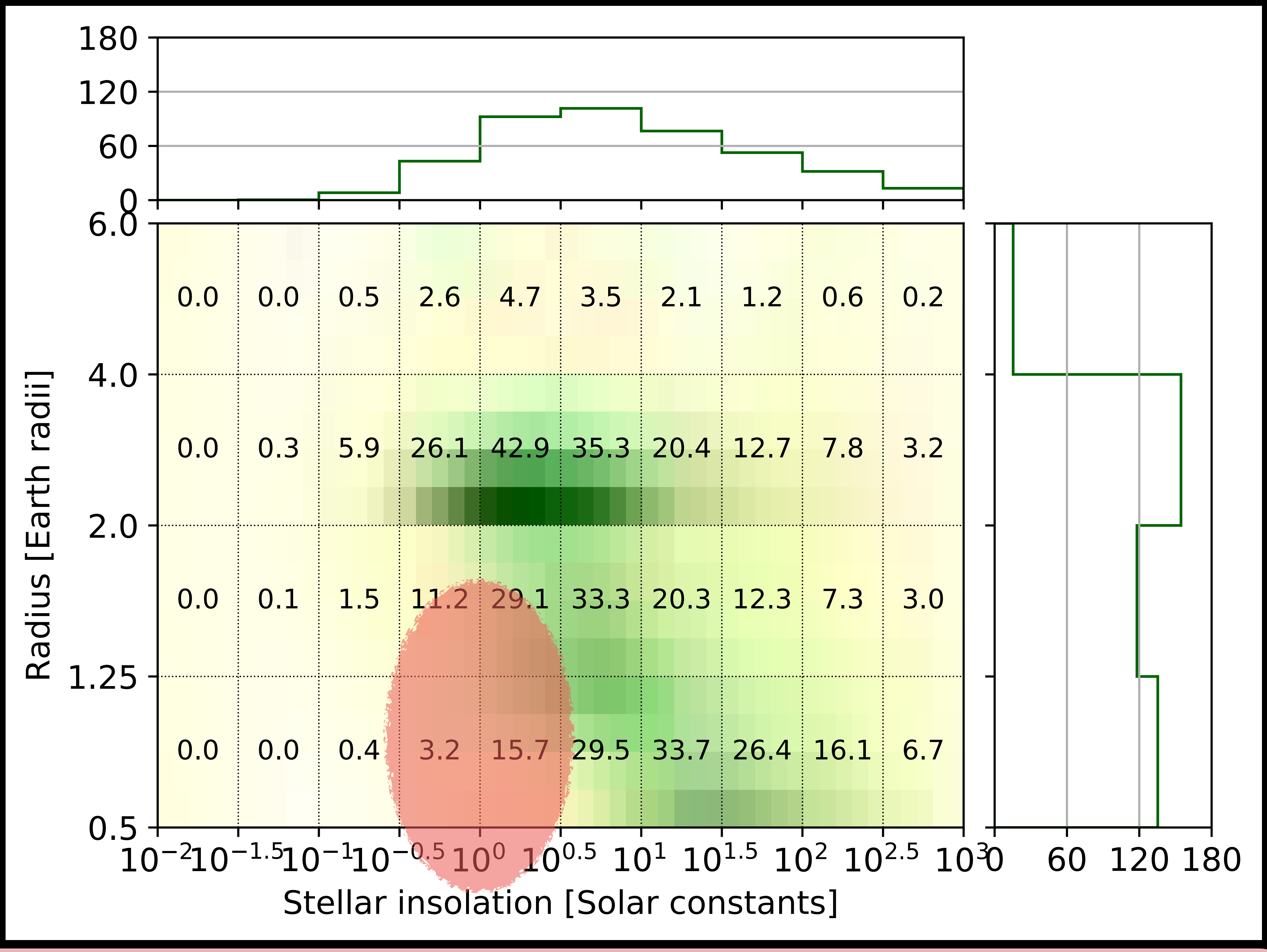

Requirement: 30 planets w/ $0.5\,R_\oplus \leq R_{\mathrm{planet}} \leq 1.5\,R_\oplus \quad 0.35\,S_\oplus \leq S \leq 1.75\,S_\oplus$

cf. Kammerer & Quanz 2018; Quanz et al 2018

(2) Occurrence rate of "habitable" planets

Focus on terrestrial exoplanets (R = 0.5-1.5 $R_\oplus$) in habitable zone (S_0= 0.35 - 1.75 $S_\oplus$)

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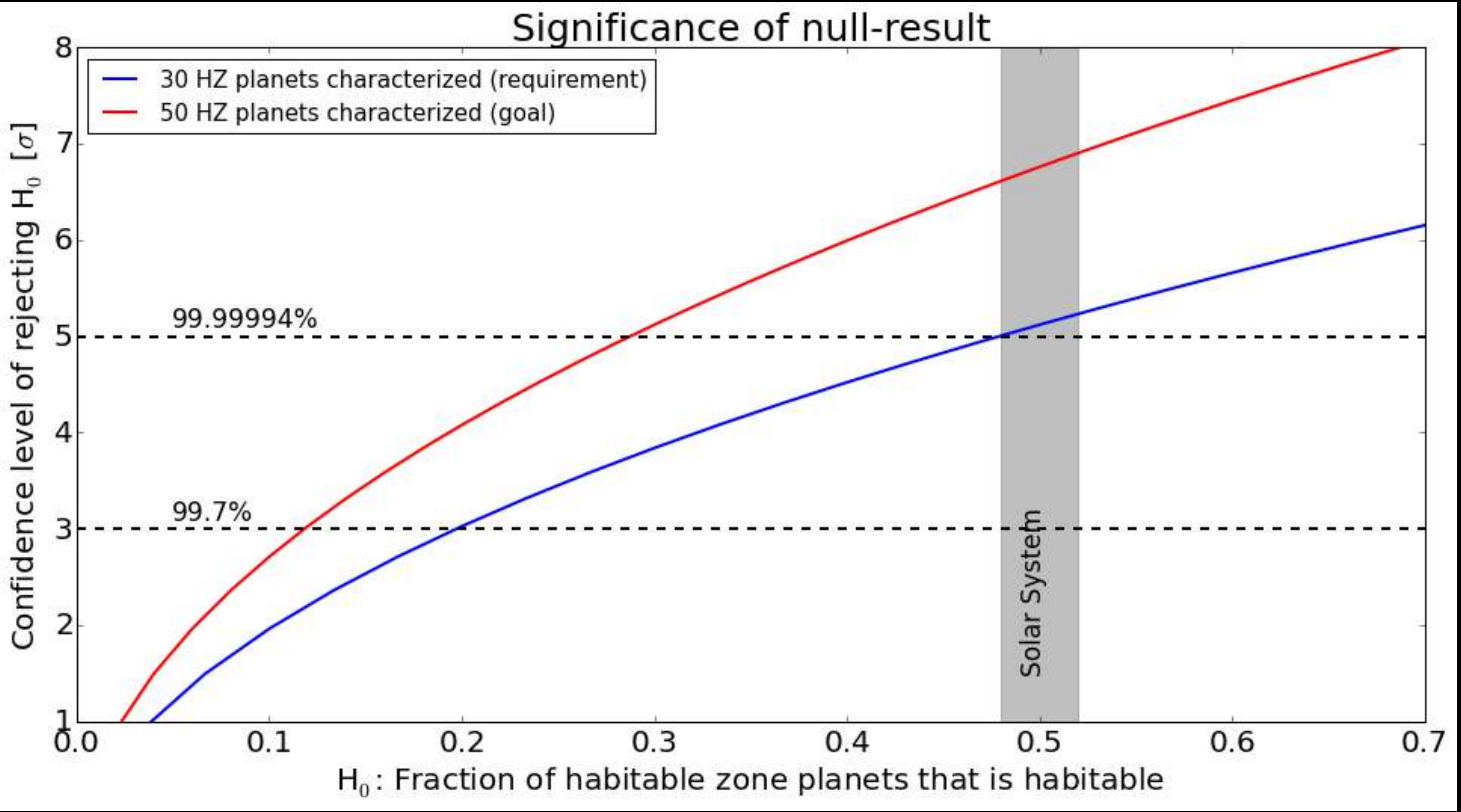
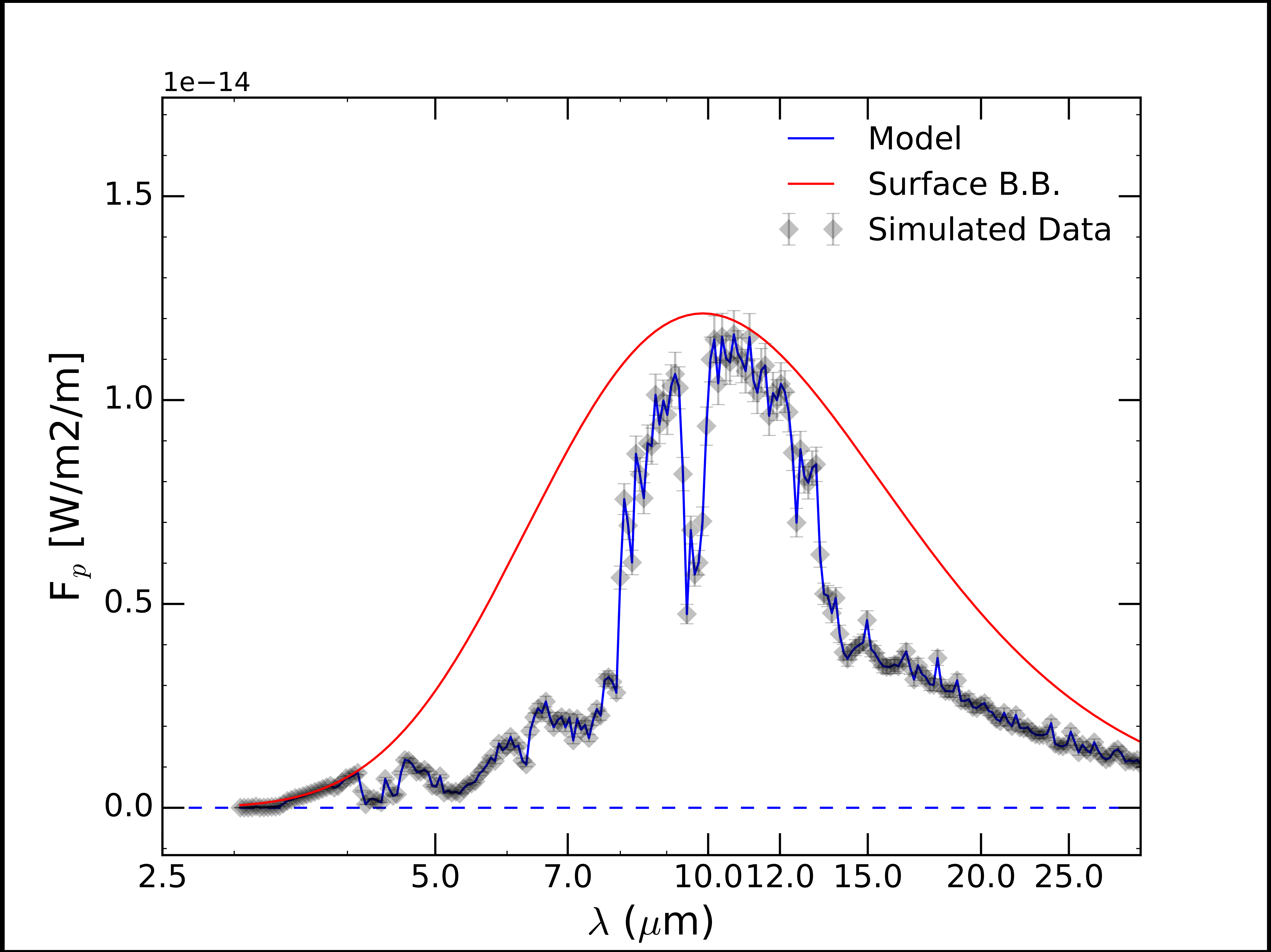


(3) Atmospheric characterization potential and biosignatures

Retrieval study of an Earth-twin



Quanz, Line & Fortney, in prep.

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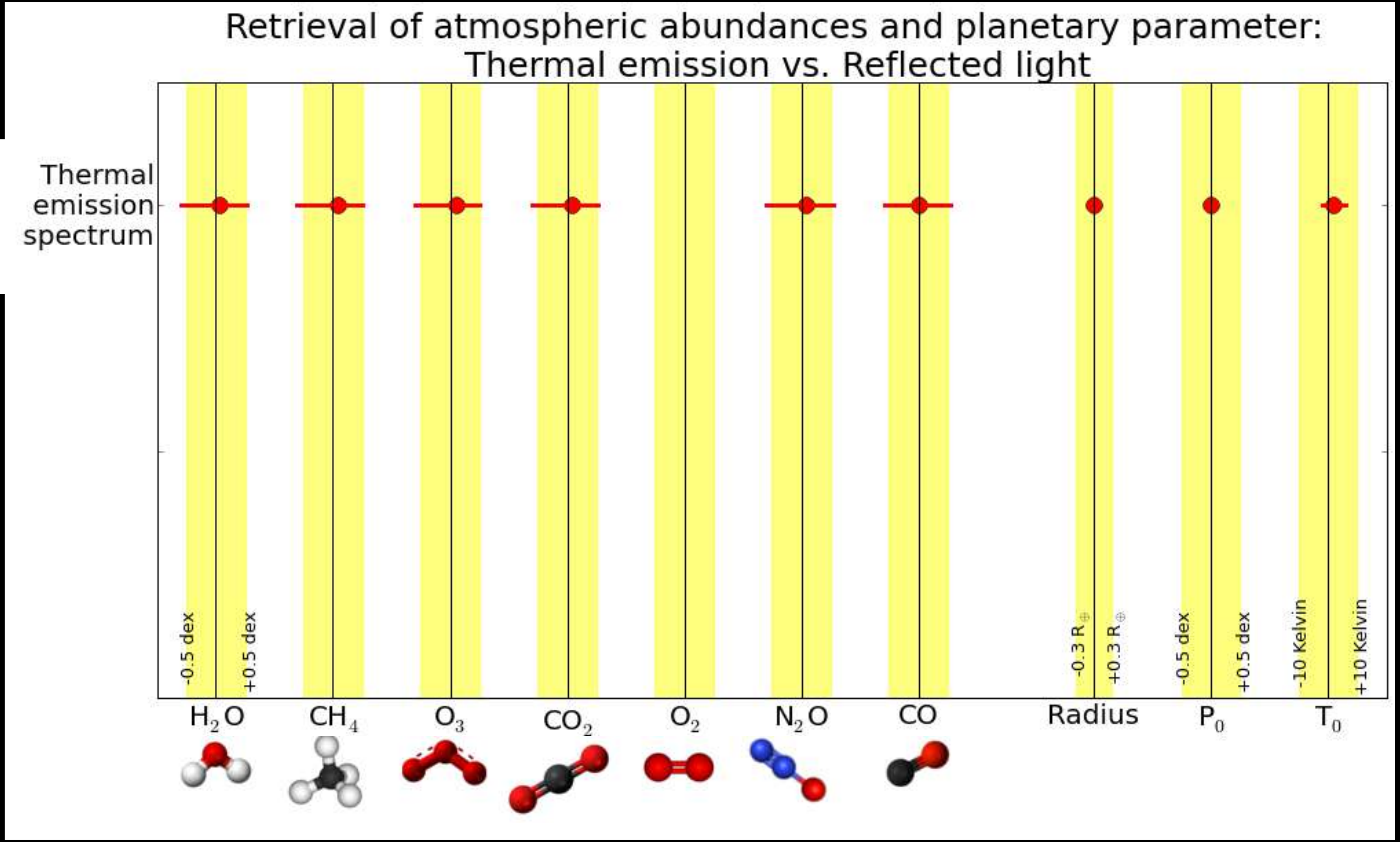
3 - 20 micron
SNR = 20
R = 100



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3 - 20 micron
SNR = 20
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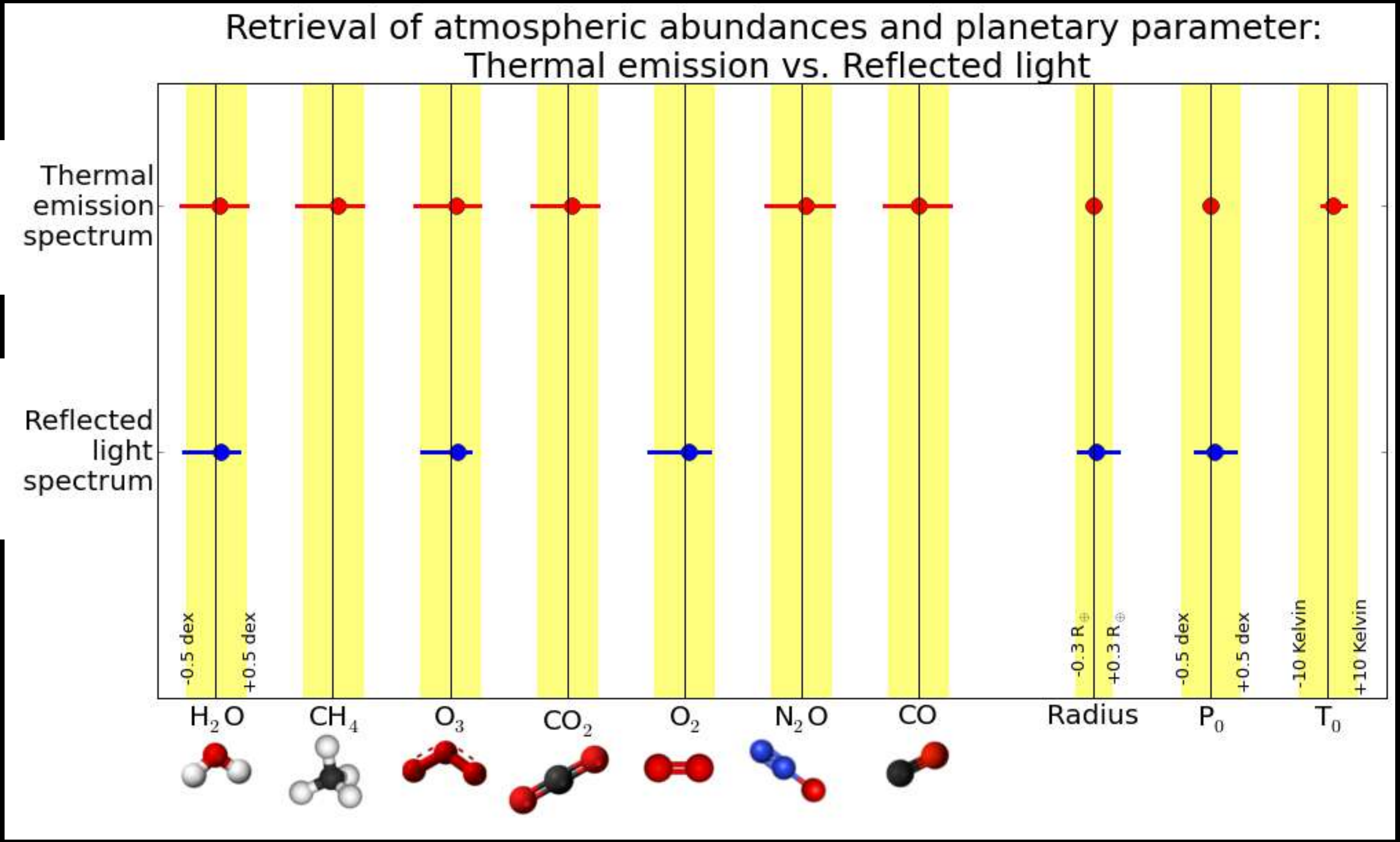
0.4 - 1 micron
SNR = 20
R = 140
(Feng et al. 2018)



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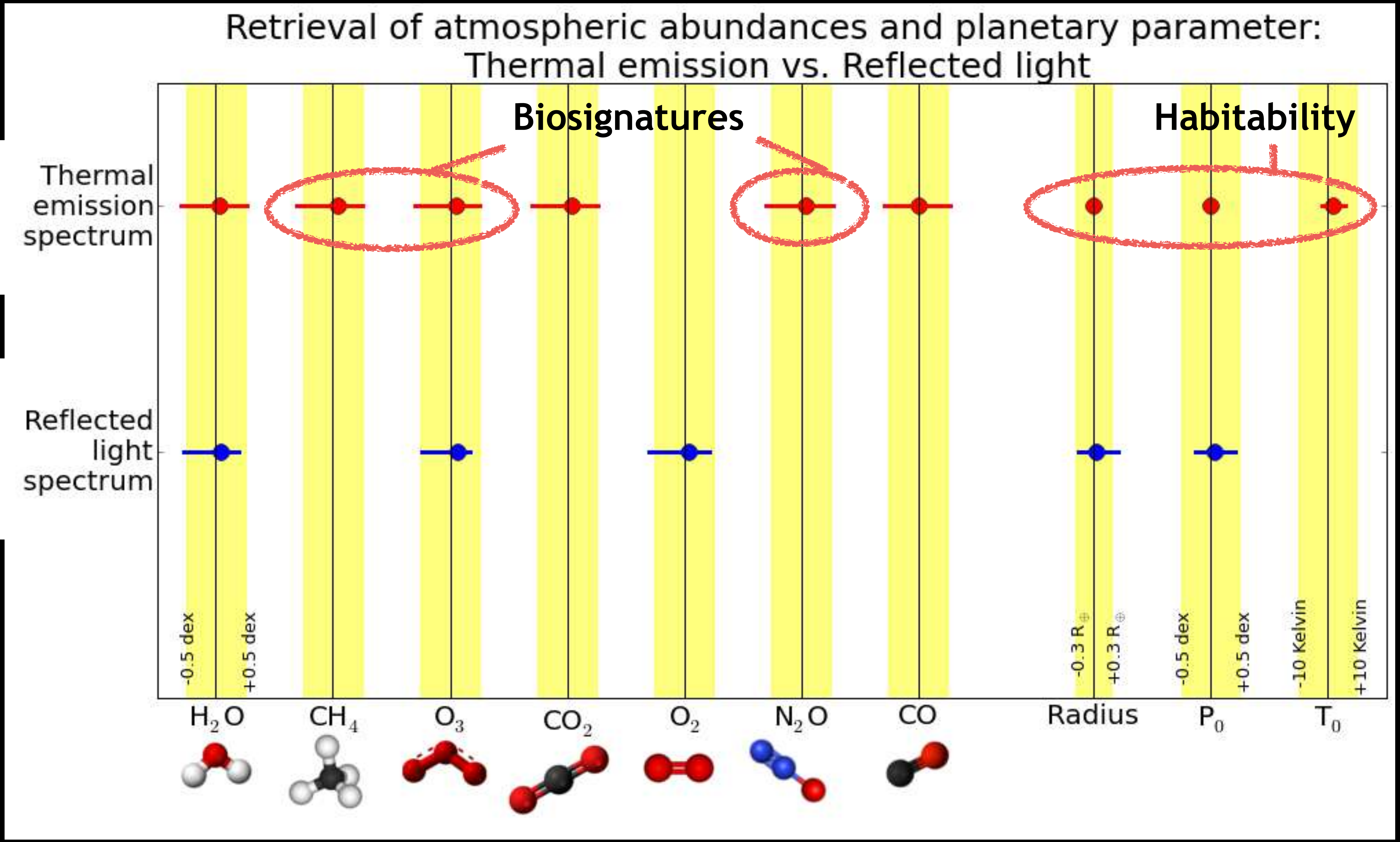

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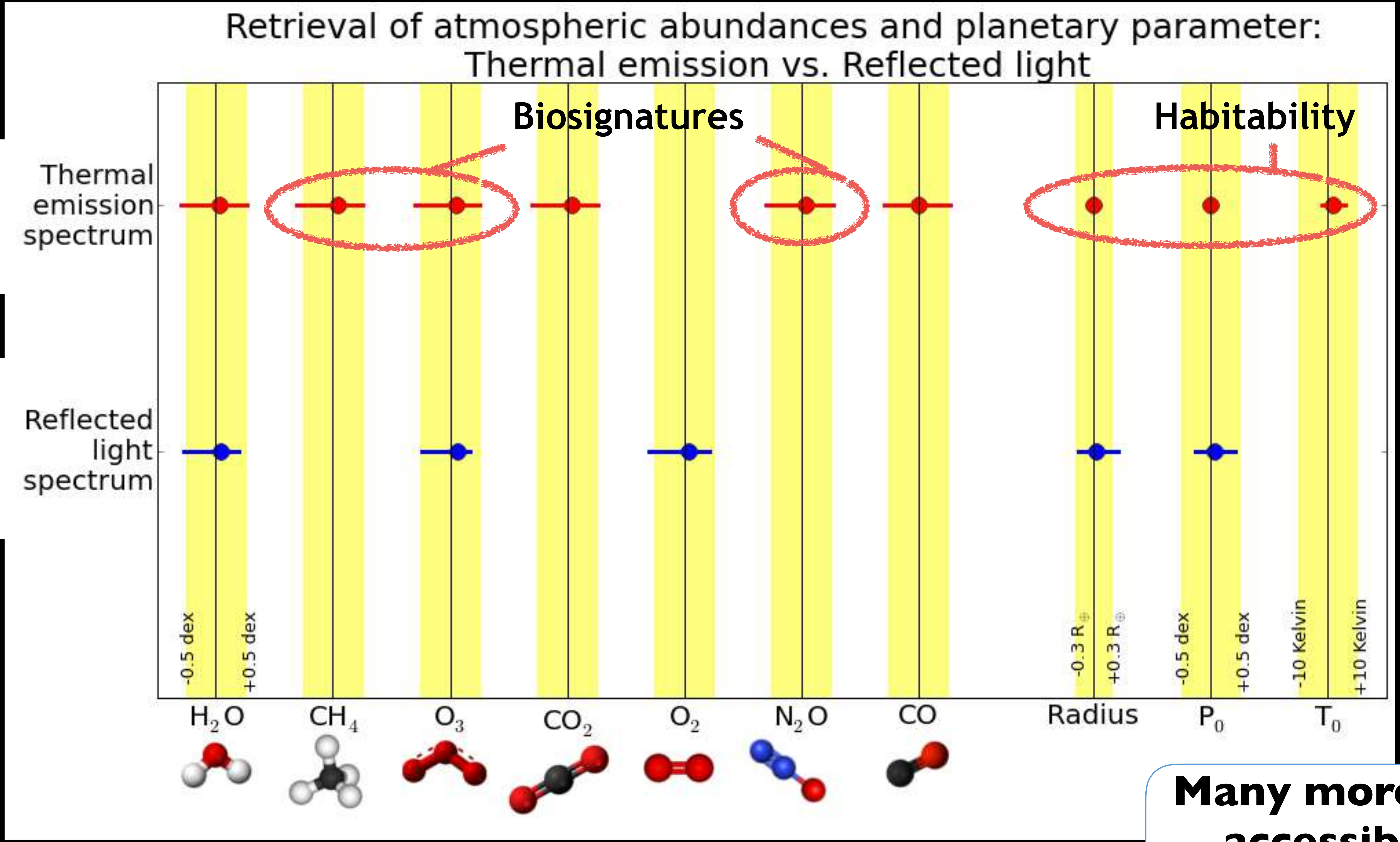


Many more molecules accessible at MIR wavelengths

Quanz, Line & Fortney, in prep.

Advances in key technologies for space-based nulling interferometry

Starlight suppression

The lab testbed at JPL demonstrated the main components of a high performance four-beam nulling interferometer at a **level needed for space** (10 micron, 10% bandwidth, nulls of 8e-6 and starlight suppression of 1e-8 after post-processing; Martin et al. 2012)

Significant progress from ground: VLTI, LBTI, Keck

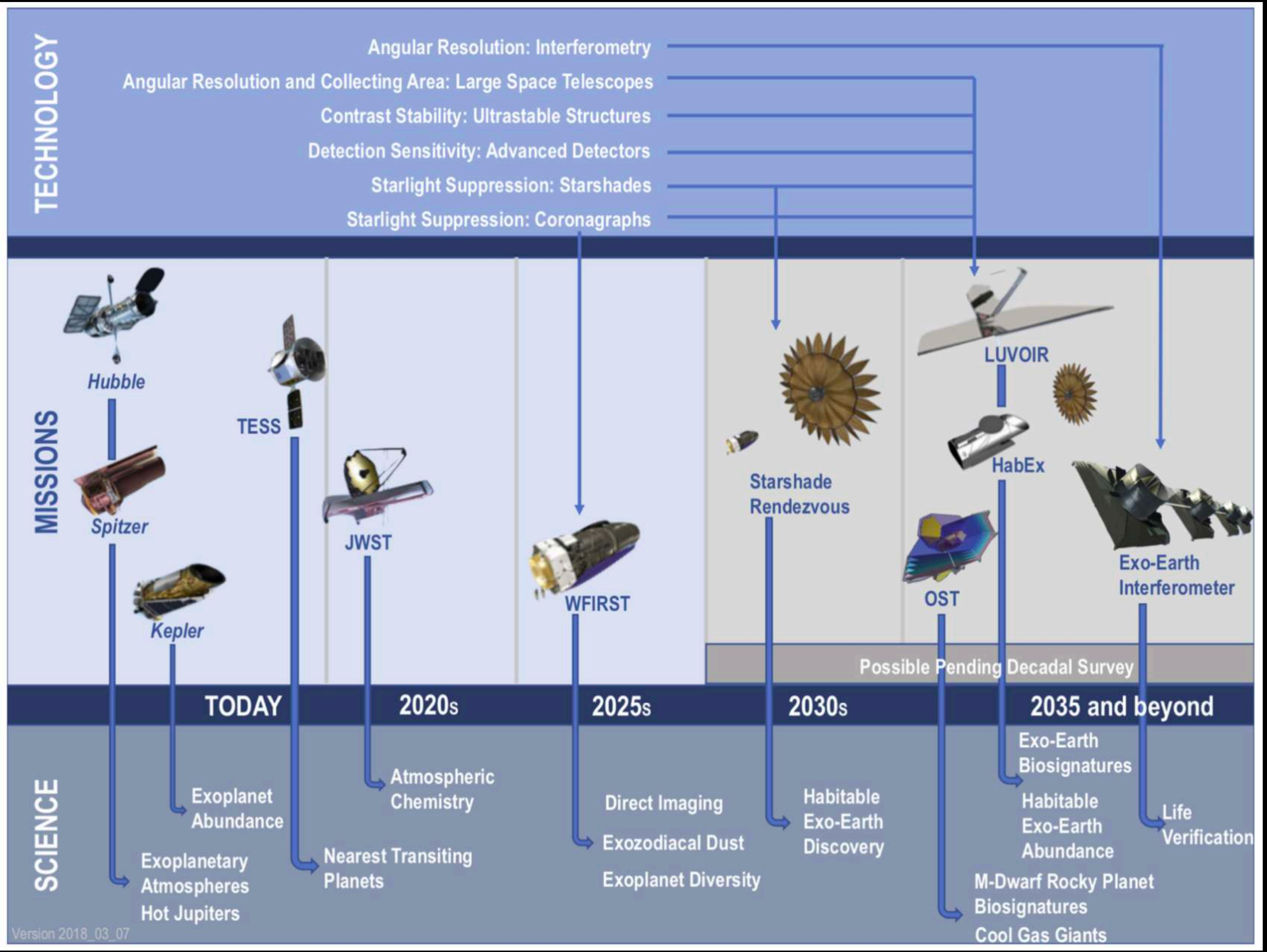
Formation flying

ESA's PROBA-3 (launch planned end of 2020) will maintain formation to millimetre and arc second precision at distances of 150 m or more; the pair will be flying autonomously, without relying on guidance from the ground. **This would exceed requirements for nulling interferometer.**

(cf. results from the PRISMA mission; cm-precision formation flying)

Image credit: ESA

The next step(s) in exoplanet science: possible scenarios



"Technology development support in the next decade for future characterization concepts such as **mid-infrared (MIR) interferometers** [...] will be needed to enable strategic exoplanet missions beyond 2040."

"[…] That said, the common (although often unspoken) belief is that such a **nulling, near-infrared (NIR) interferometer would be a necessary** follow-up to any reflected light direct imaging mission, as detecting the exoplanet in thermal emission is not only required to measure the temperature of the planet, **but is also needed to measure its radius,** and so (with an astrometric or radial velocity detection of [...] the mass of the planet) measure its density and thus determine if it is truly terrestrial."

National Academy of Sciences, "Exoplanet Science Strategy" report (09/2018)

Image credit: NASA/JPL/Caltech; https: // exoplanets. nasa. gov/ exep/ technology/ technology-overview/ (accessed July 4, 2019)

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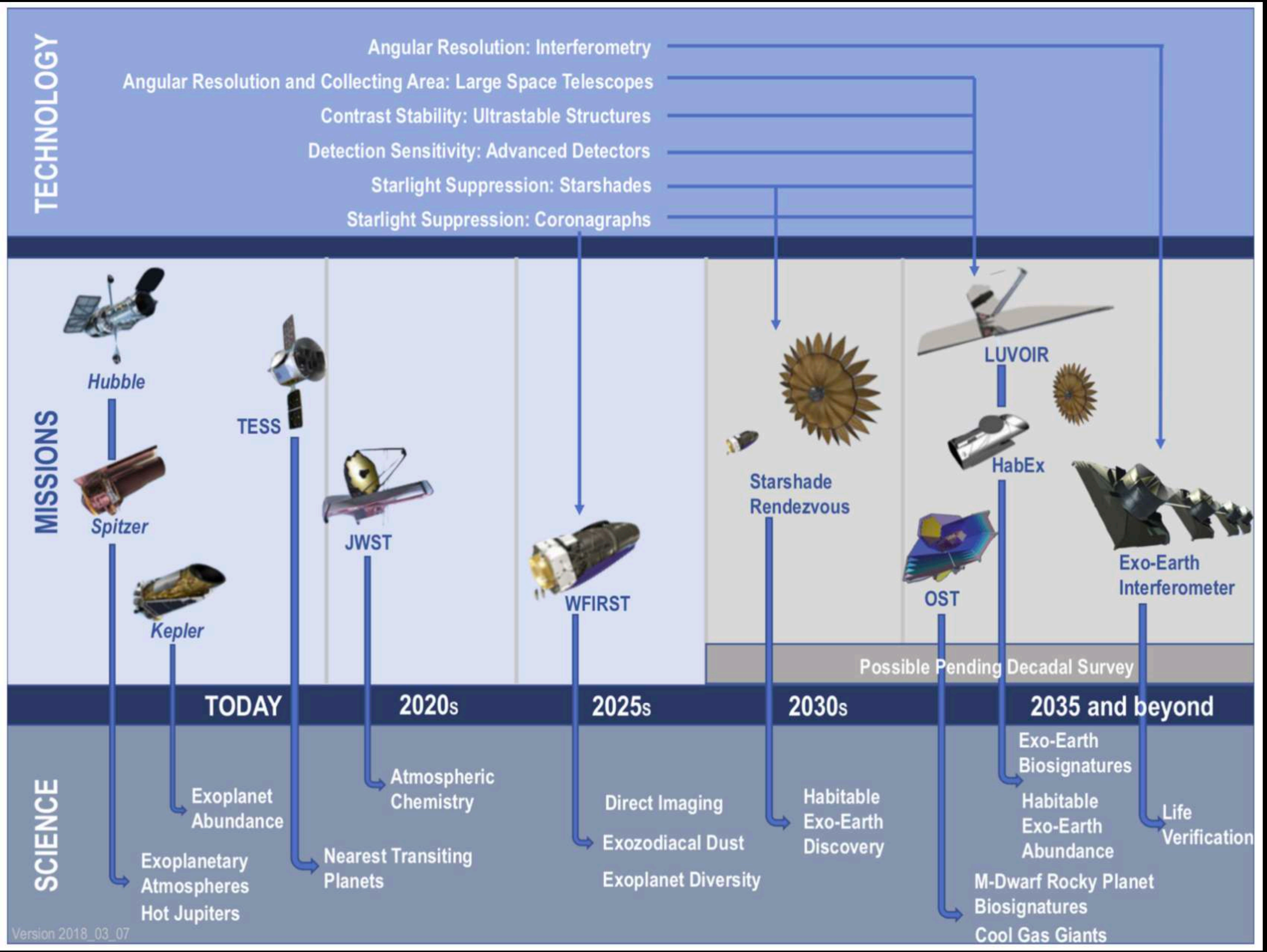

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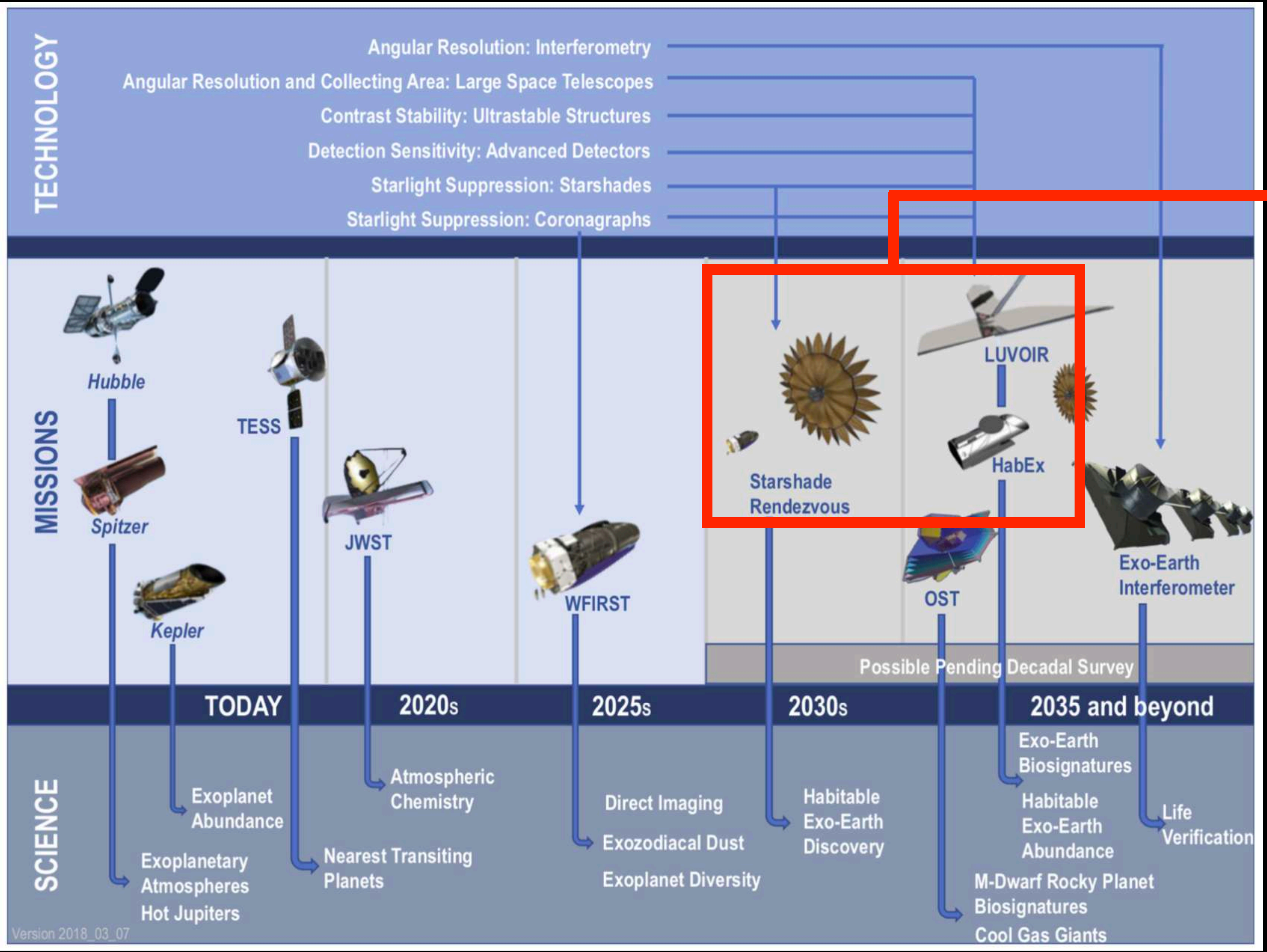

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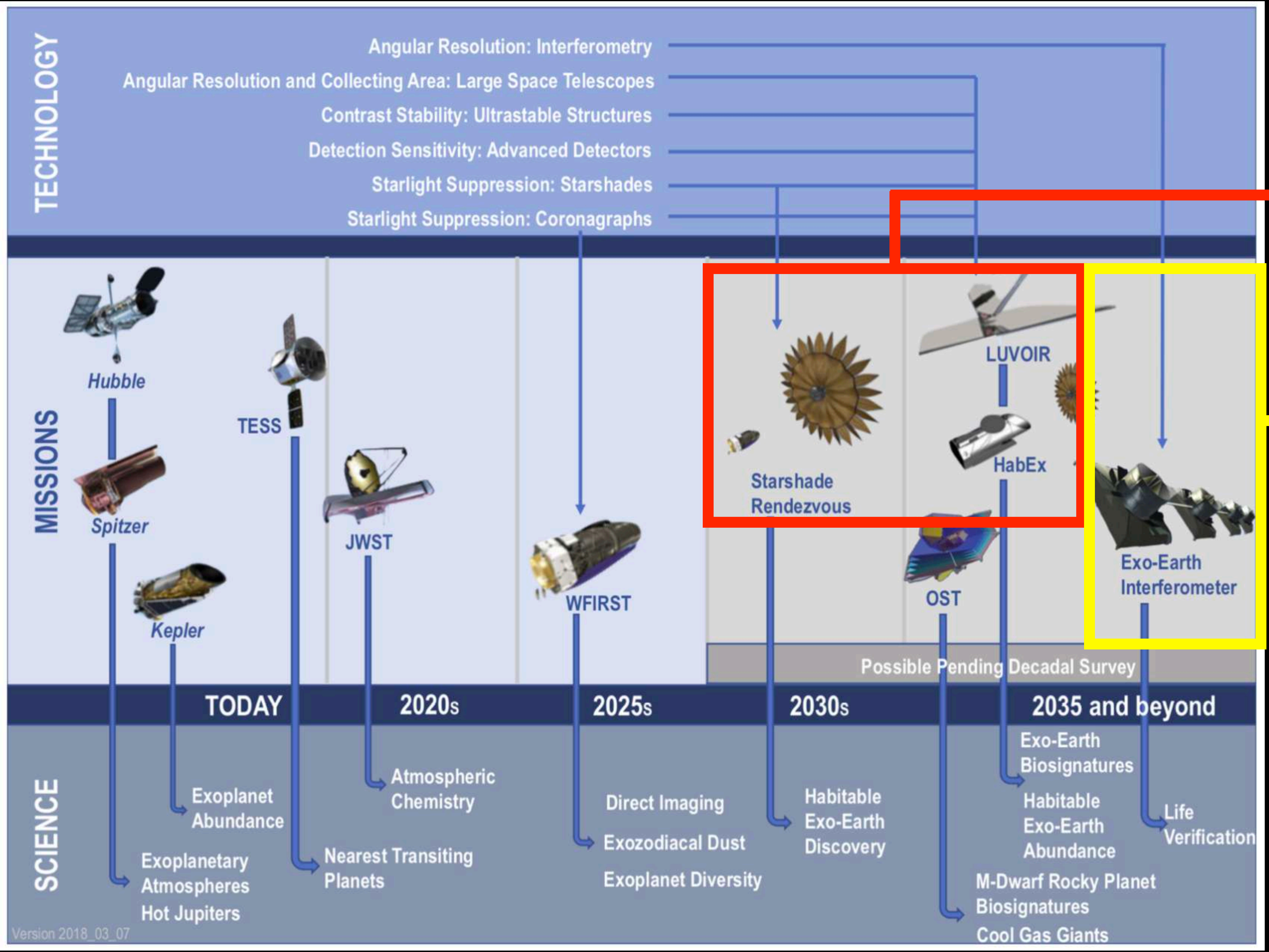

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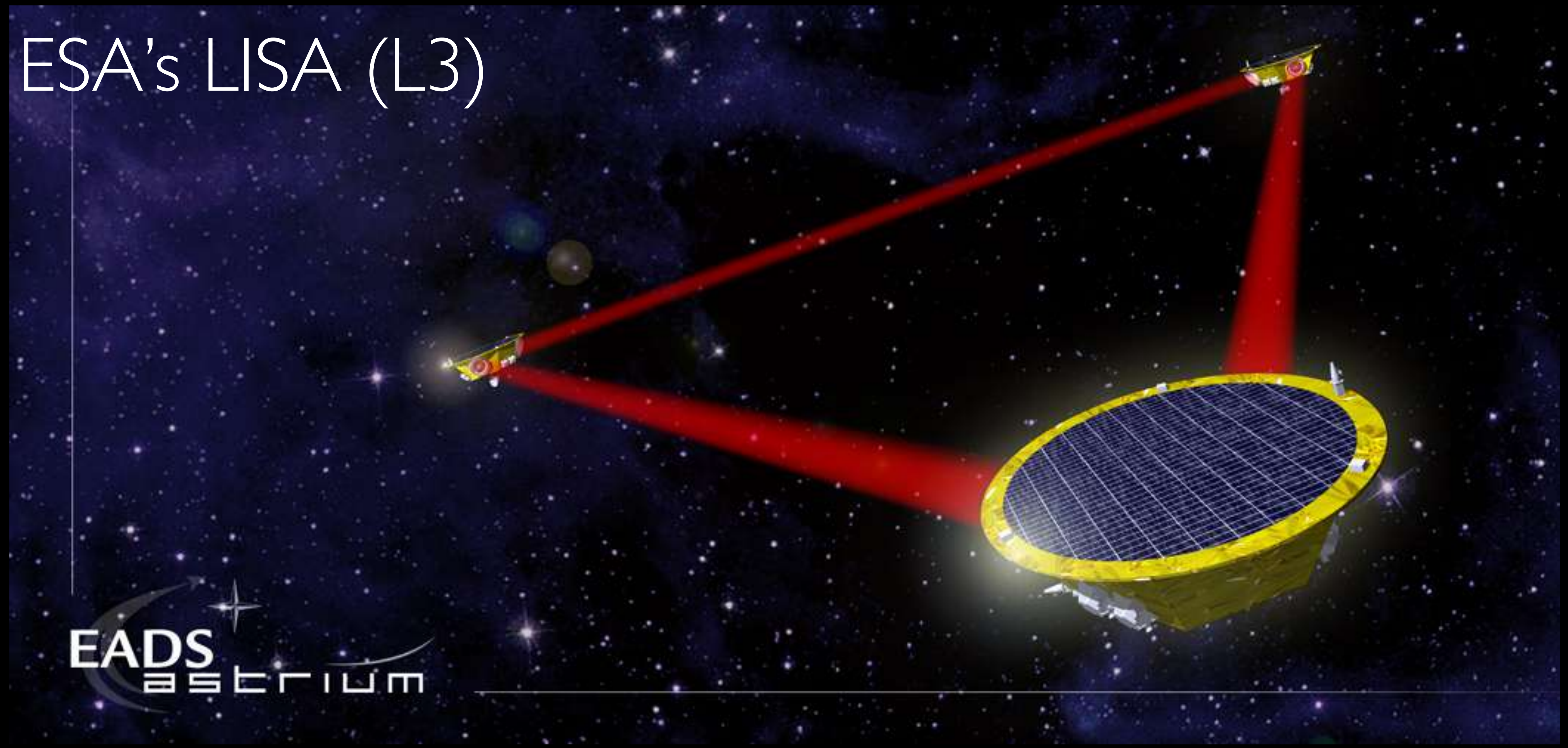
Europe is in a strong position to lead a space-based MIR interferometer…

Formation flying

MIR instruments

MIRI

Space interferometry



Cryogenics

ESA's Herschel

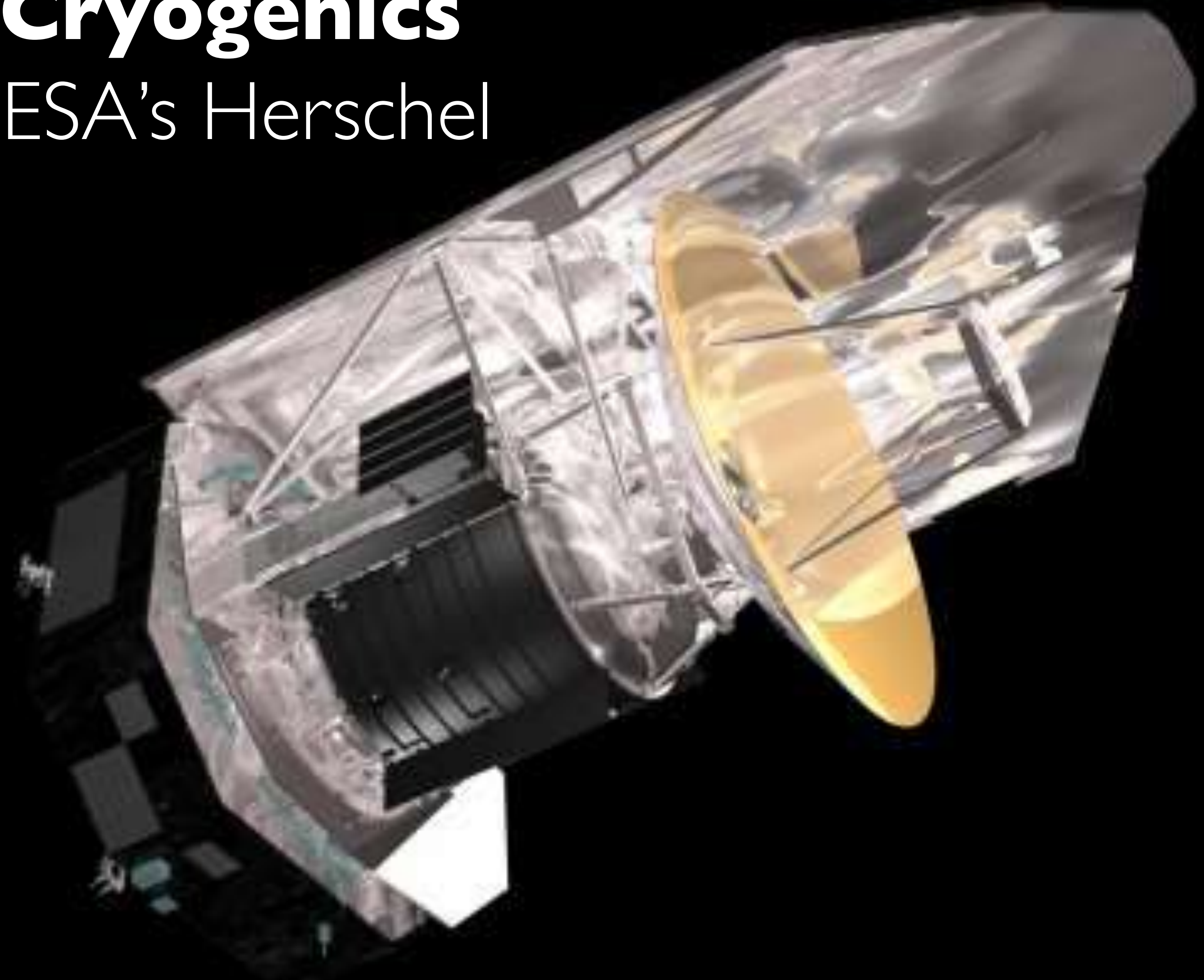
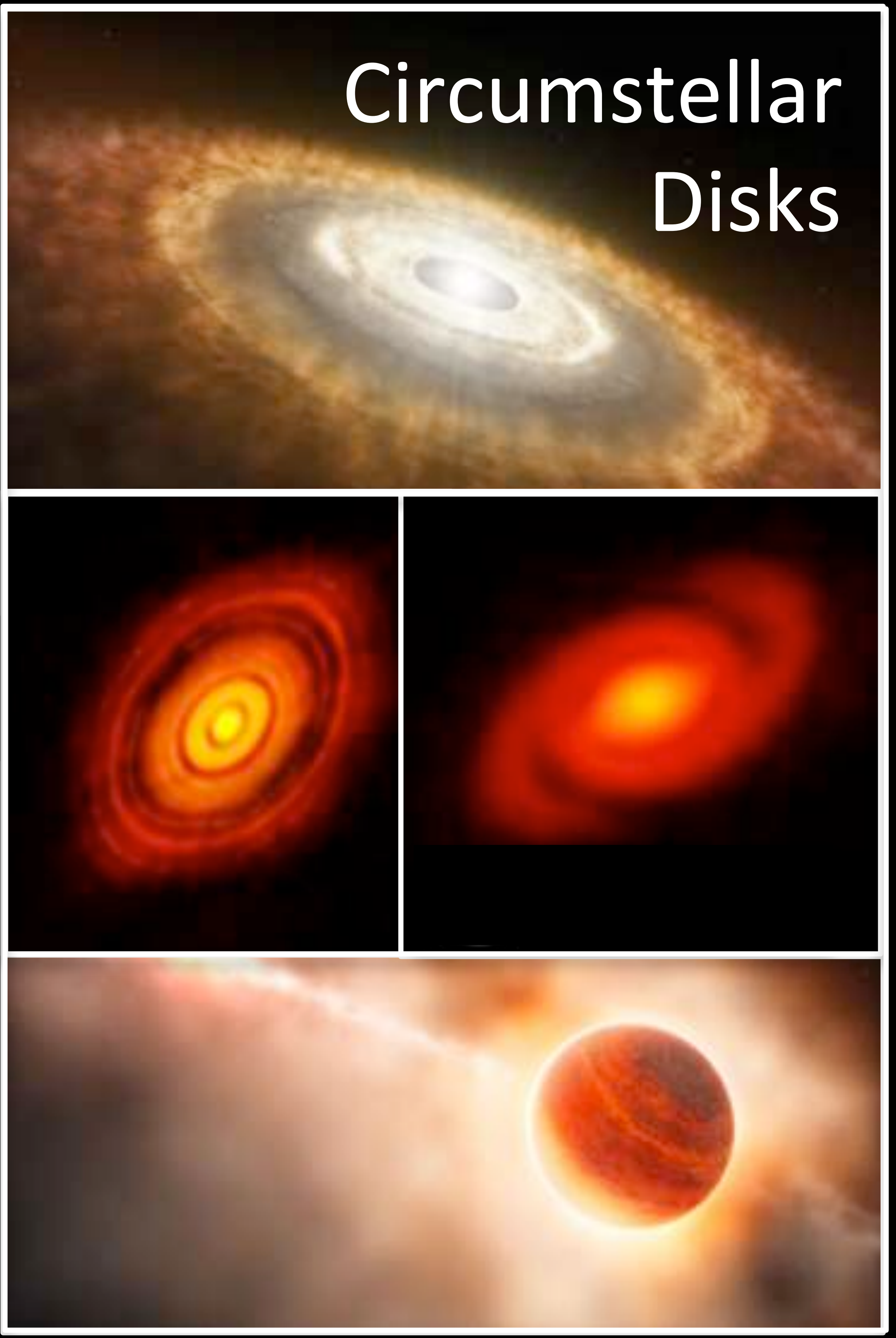
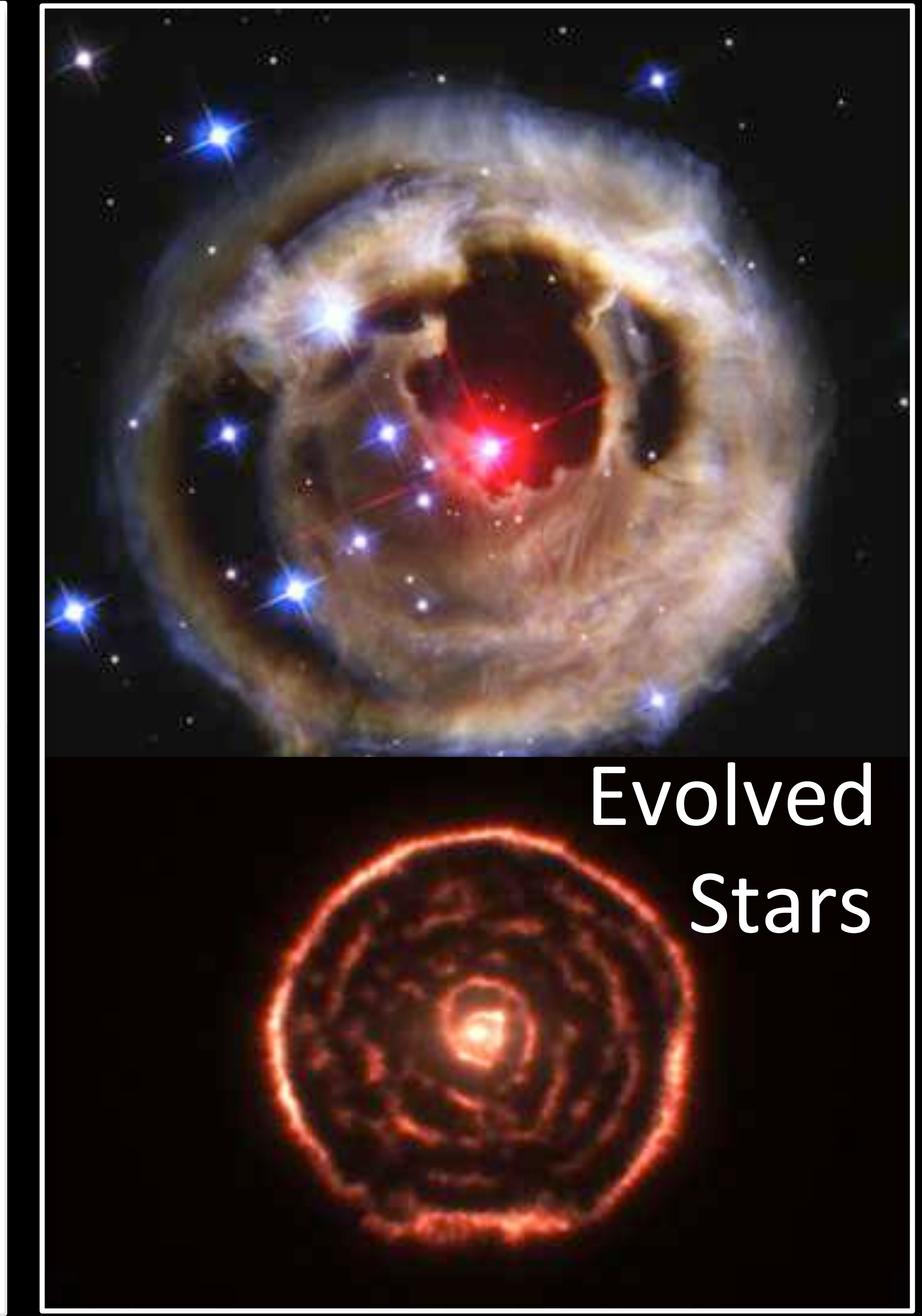


Image credit: ESA - P. Carril; EADS Astrium

…and other communities will appreciate such a mission





Upcoming Lorentz Center workshop

LIFE

Large Interferometer For Exoplanets

www.life-space-mission.com

Lorentz center

Dates

- May 11-15, 2020

Goals

- Get input and engage a wider community
- Re-fine science objectives and requirements
- Assess and discuss recent development in relevant technologies

Summary

Free-flying mid-infrared (nulling) interferometer

Wavelength range: ~3 - 20 μm

Spectral resolution: R ~ 20 - 100

Total mission lifetime (requirement) 5-6 years:
- search phase
- characterization phase
- other science

Lots of heritage exist and significant progress has been made ever since mid-2000s

Europe has chance to maintain leadership in one of the most vibrant fields of 21st century astrophysics

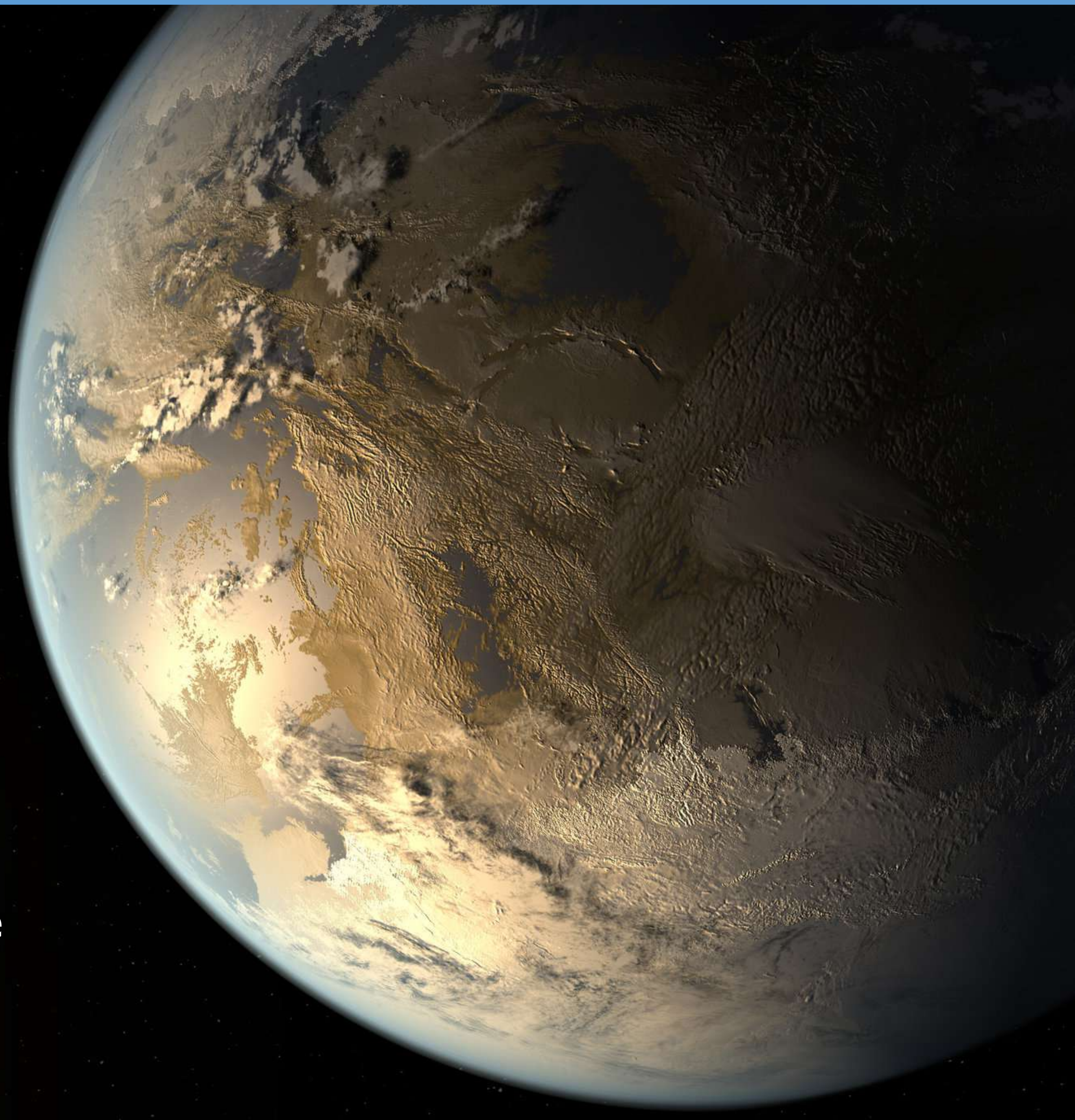


Image credit: NASA Ames/JPL-Caltech/T. Pyle

Thank you

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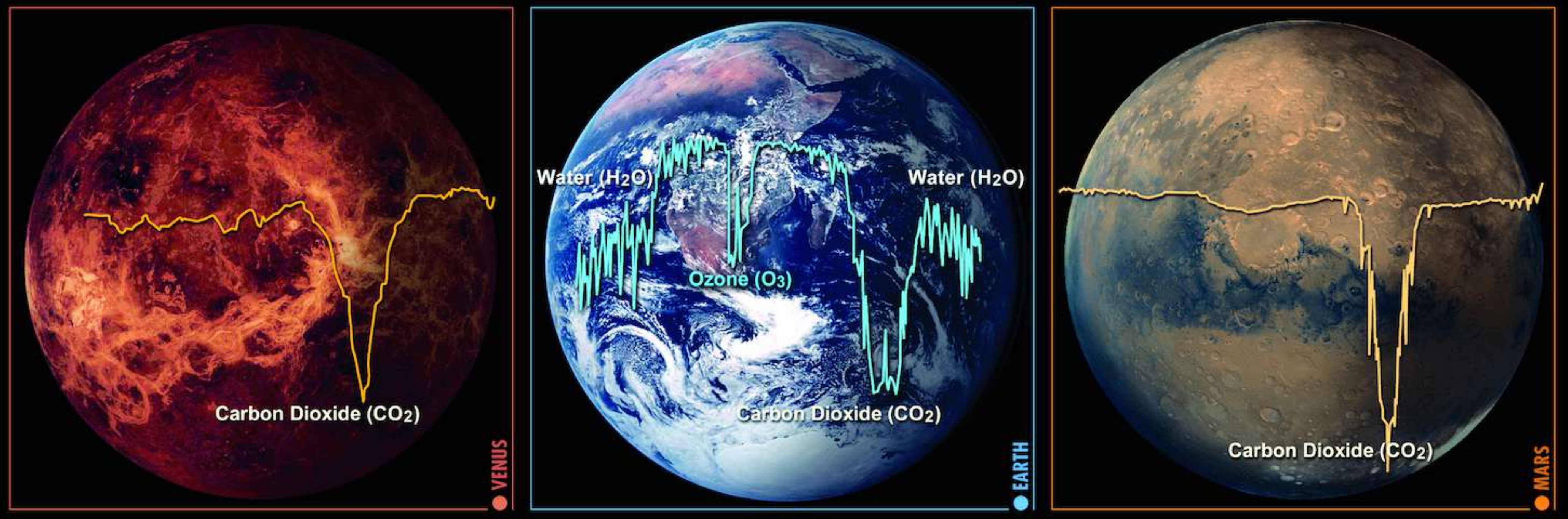

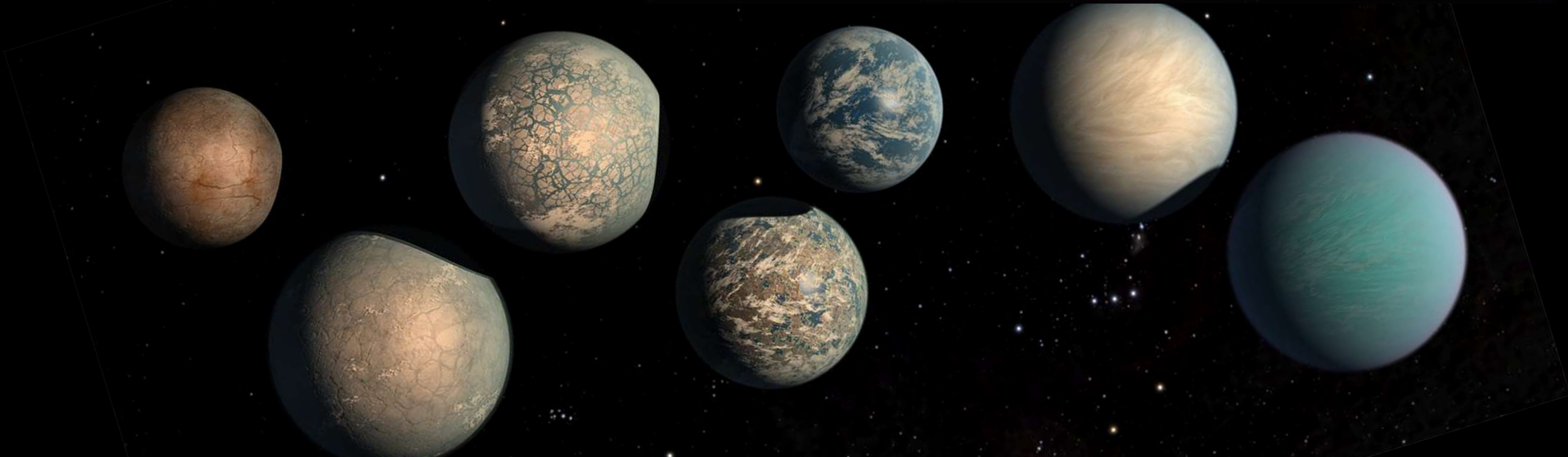

Image credit: NASA/JPL Caltech; ESA Medialab