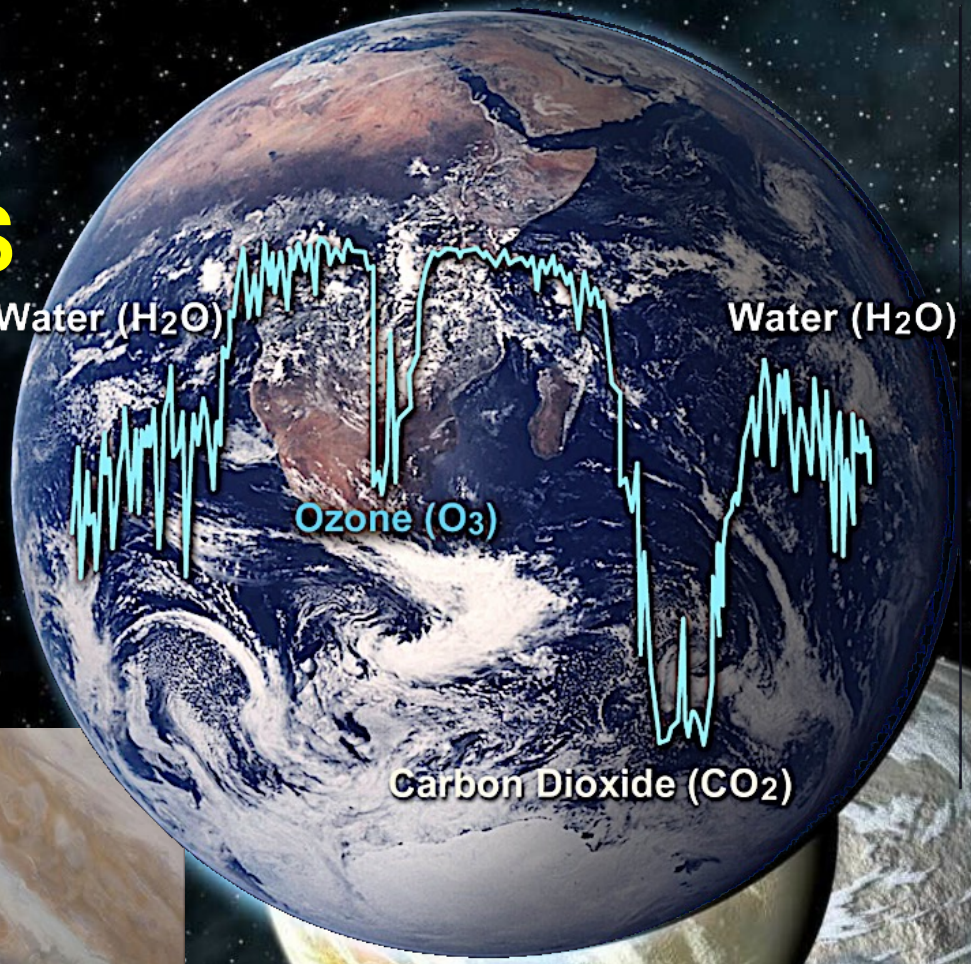
# The Demographics of Life

Panel Discussion

Sagan Summer Workshop

Thursday, July 24, 2025

# The Drake Equation --- Greenbank Observatory (1961)

$$N = R_* f_p n_e f_\ell f_i f_c L$$

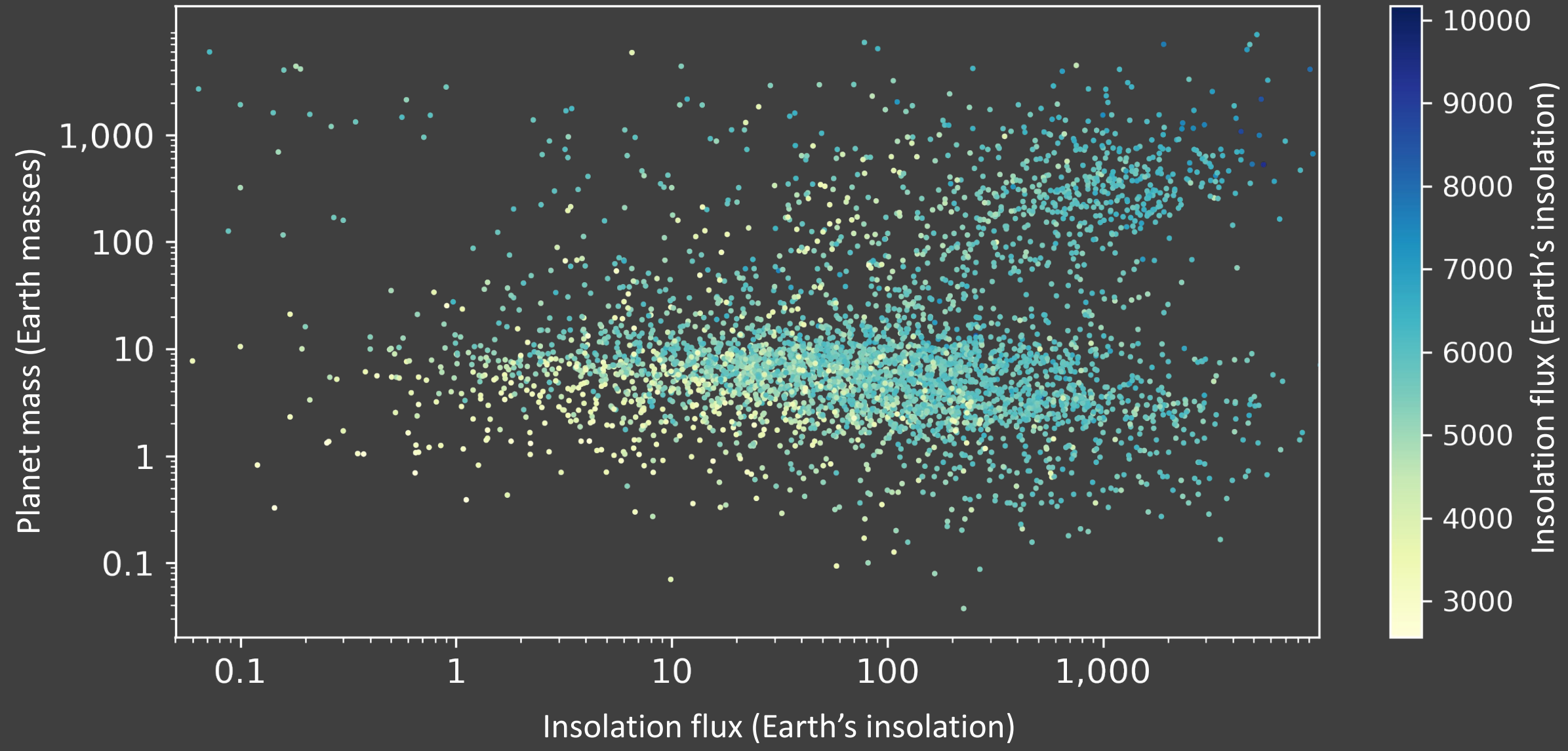
Jessie Christiansen (NExScI) Demographics of Planets

Laurie Barge (JPL) Development of Life and Solar System Searches

Lisa Kaltenegger (Cornell) Finding Habitable Worlds and Identifying Life

Jason Wright (Penn State) Demographics of Communi-cative Life

# Demographics of ‘abodes’ of life



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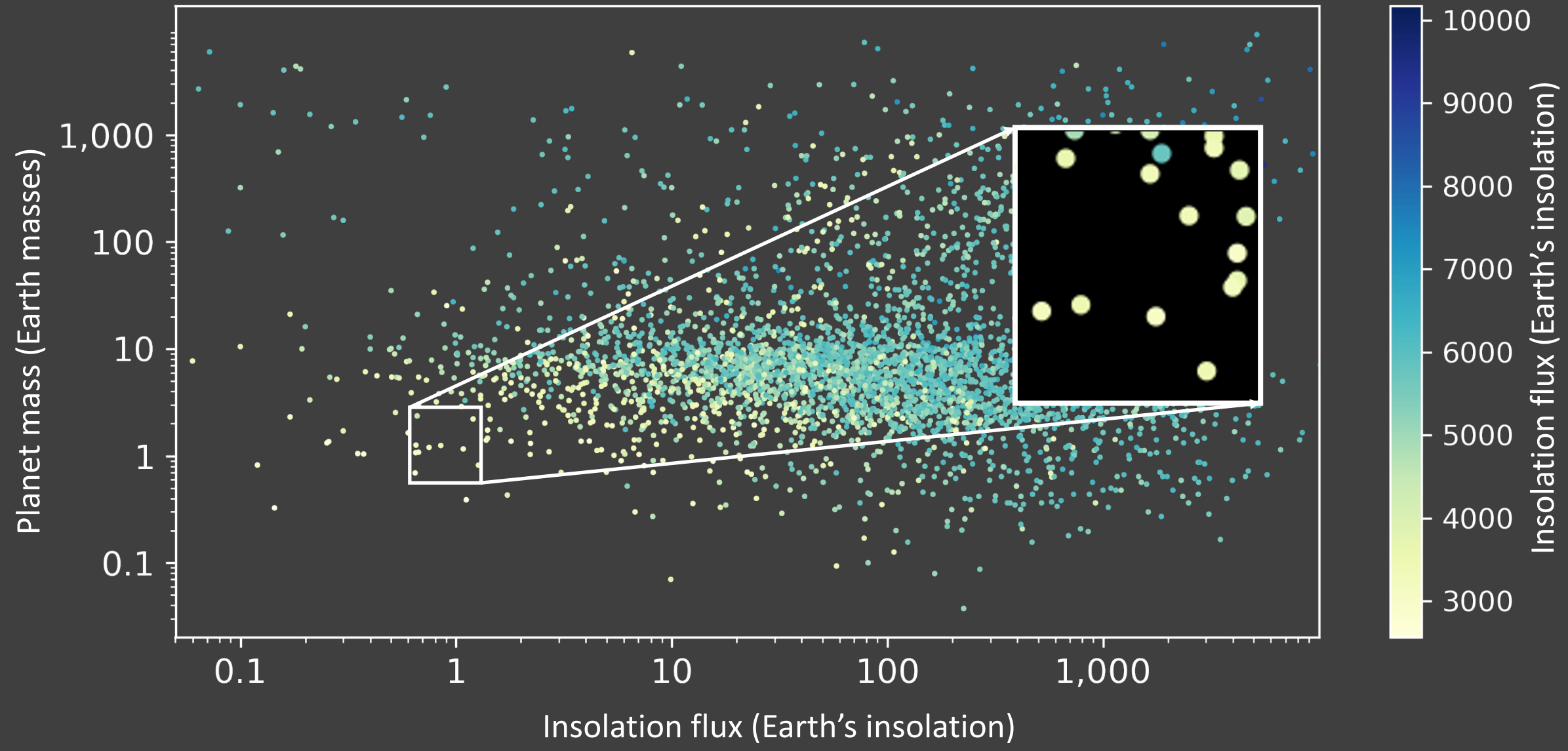
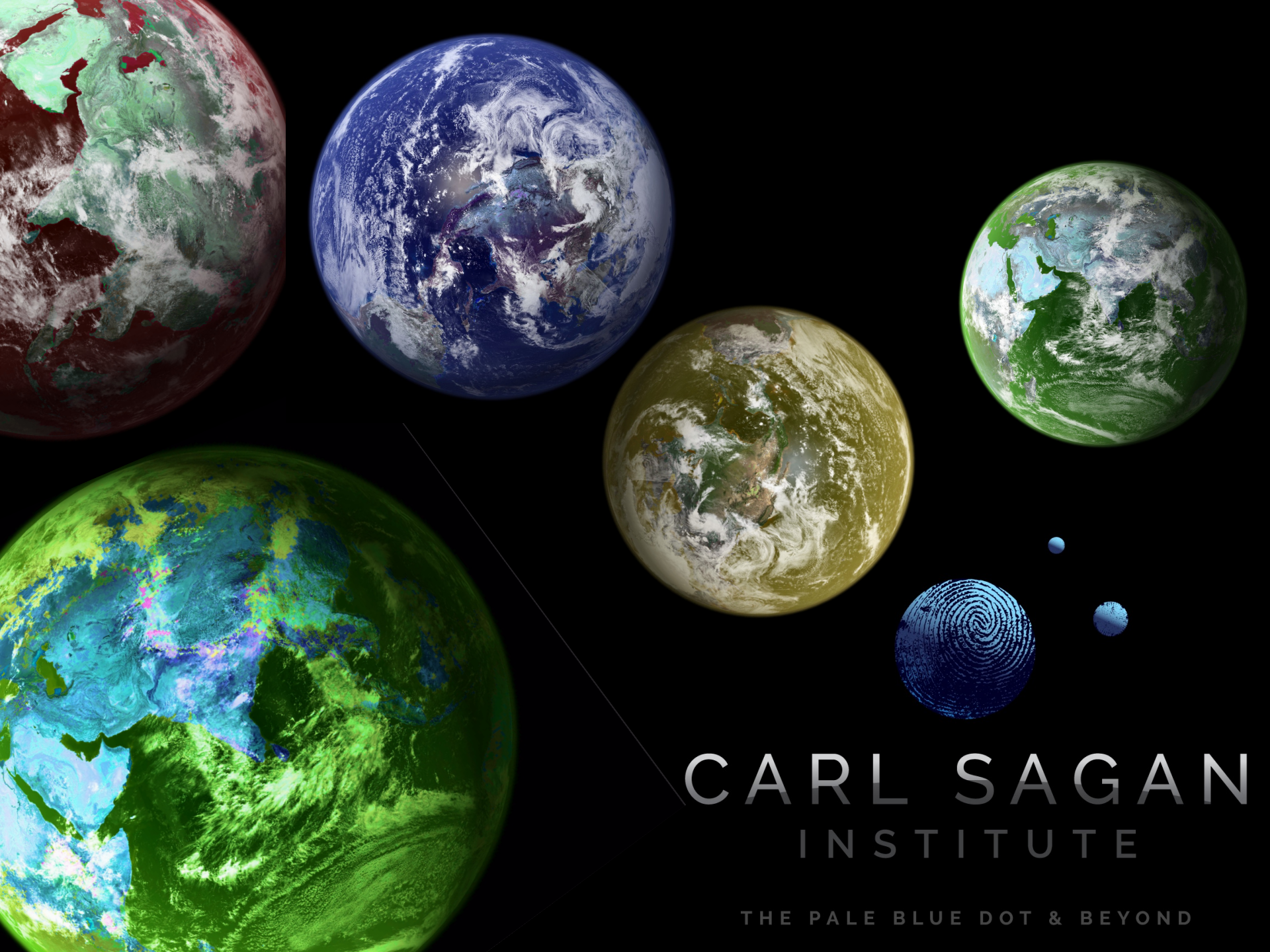
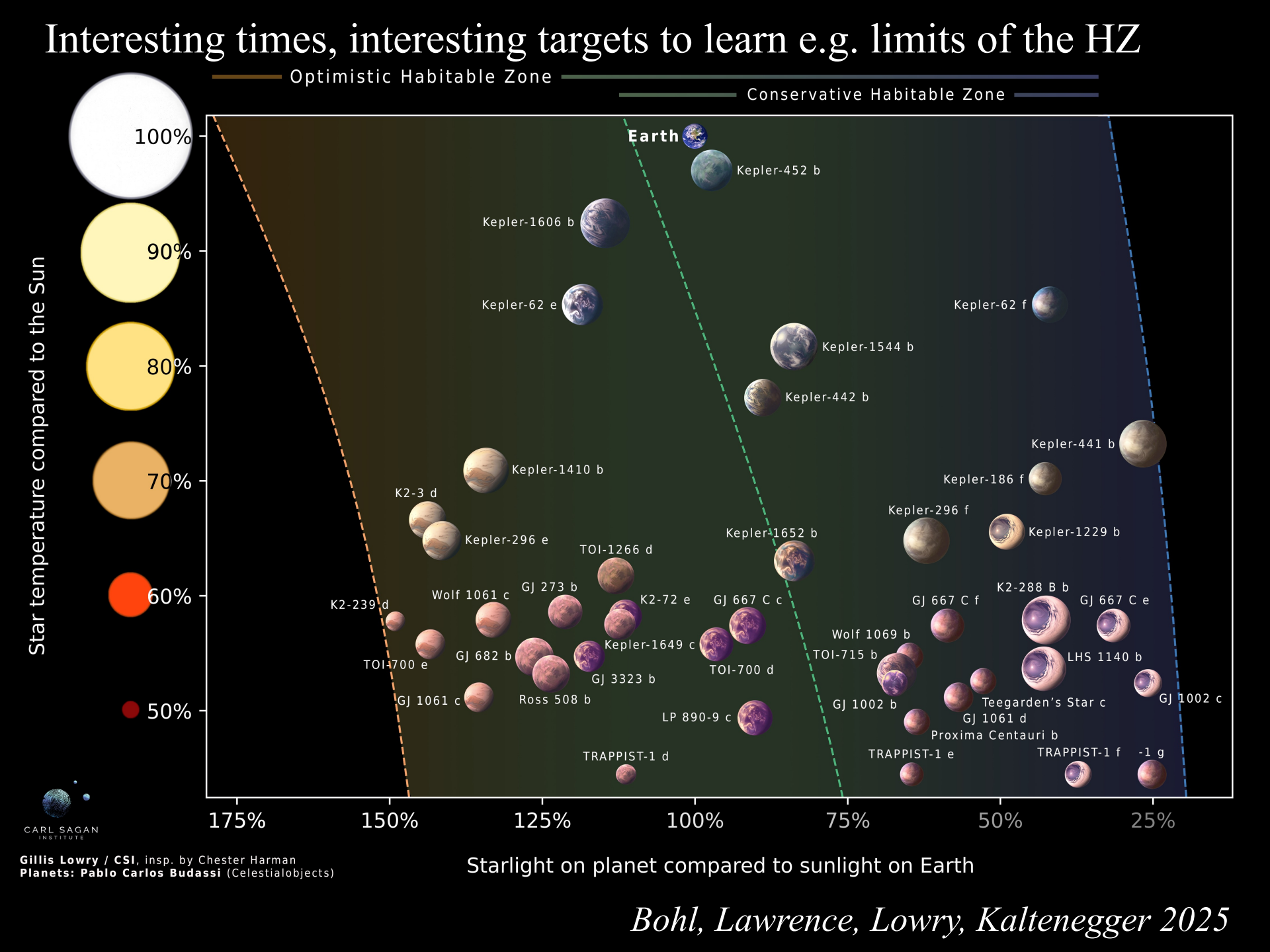



CARL SAGAN
INSTITUTE
THE PALE BLUE DOT & BEYOND

# Interesting times, interesting targets to learn e.g. limits of the HZ

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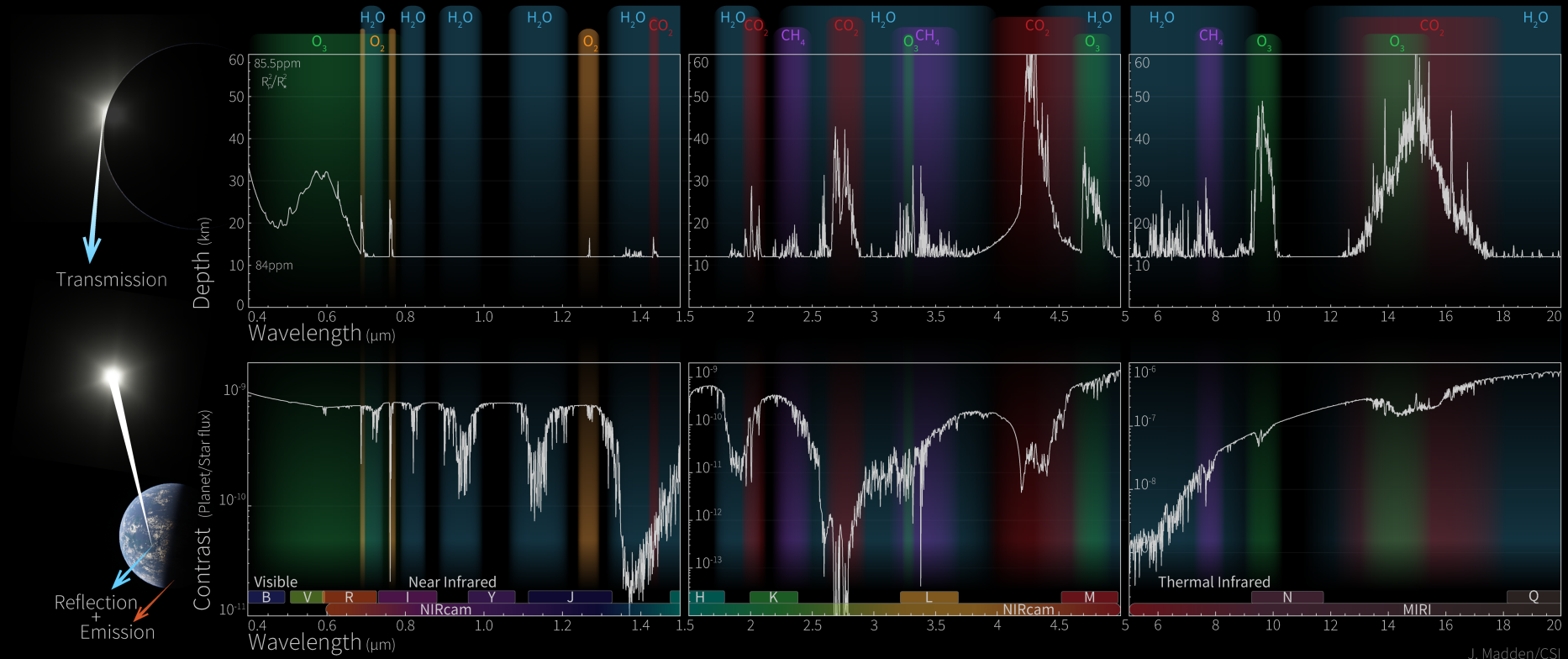
**Gillis Lowry / CSI**, insp. by Chester Harman
**Planets: Pablo Carlos Budassi** (Celestialobjects)

*Bohl, Lawrence, Lowry, Kaltenegger 2025*

# Atmospheric Signatures of an Exo-Earth




WIDE wavelength range to identify chemicals

Biosignature pairs: best so far: $O_2/O_3$ **with** reducing gas (star)

Changes i) with stellar type ii) through geological time

$O_2$ & $CH_4$: about 2 billion years for Earth

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*Kaltenegger et al 2007, 2023*

*ONLINE SPECTRA DATA BASE (on zenodo) and will be interface autumn 2025*

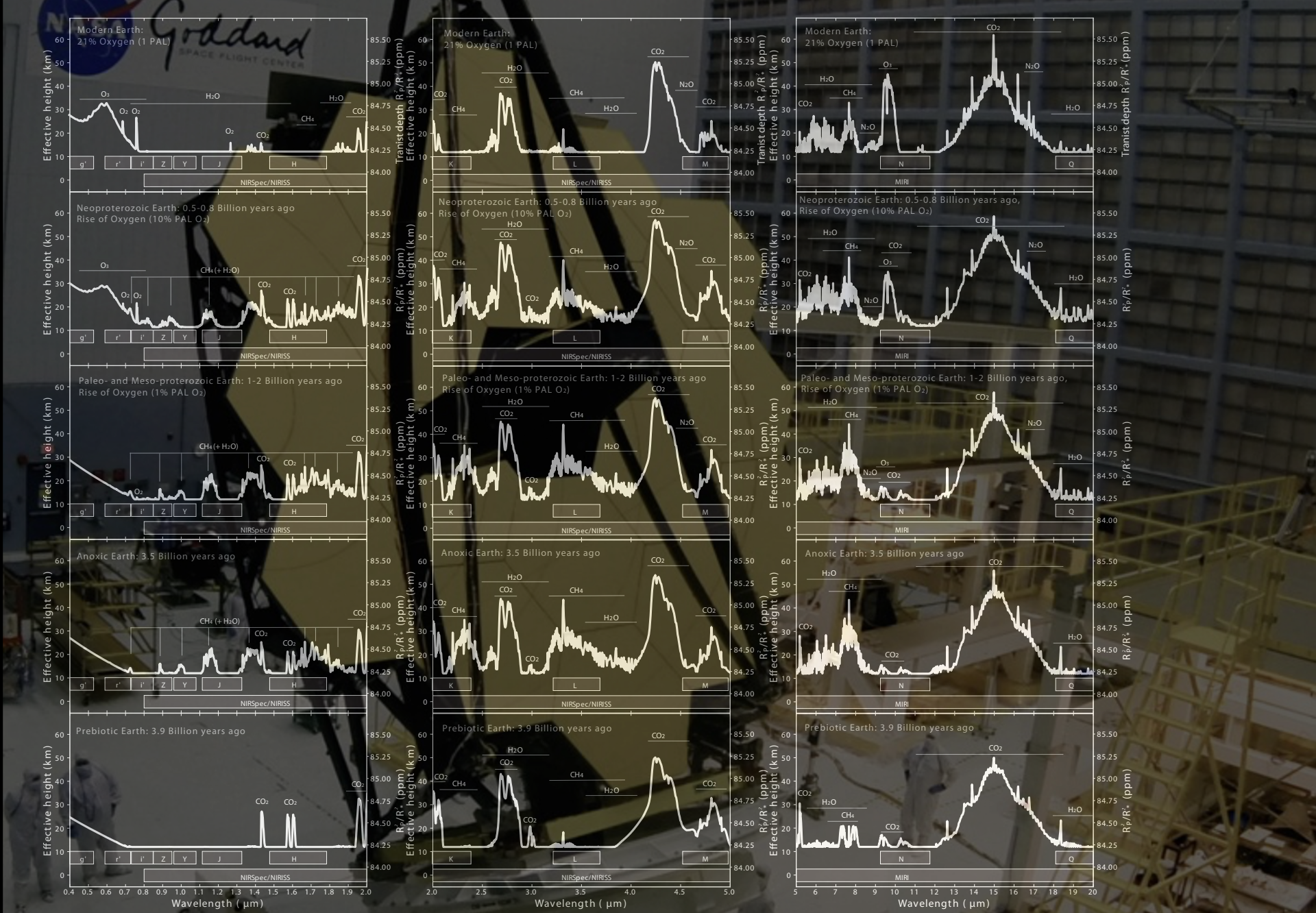
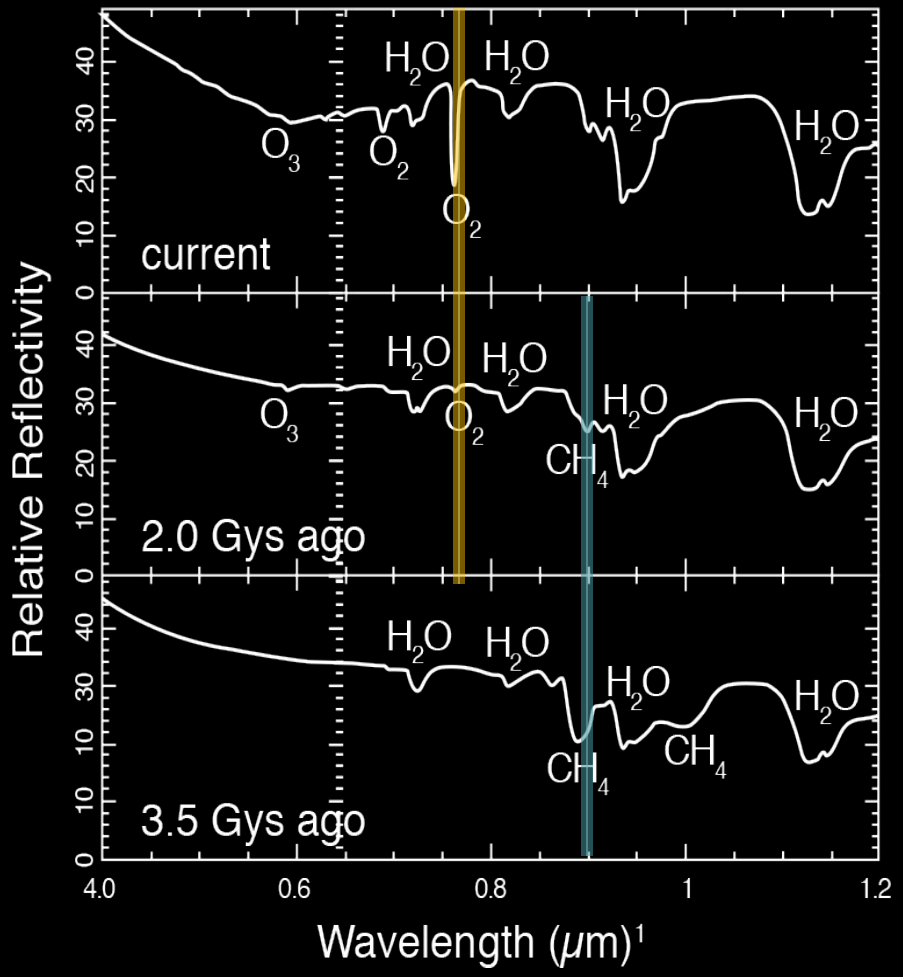
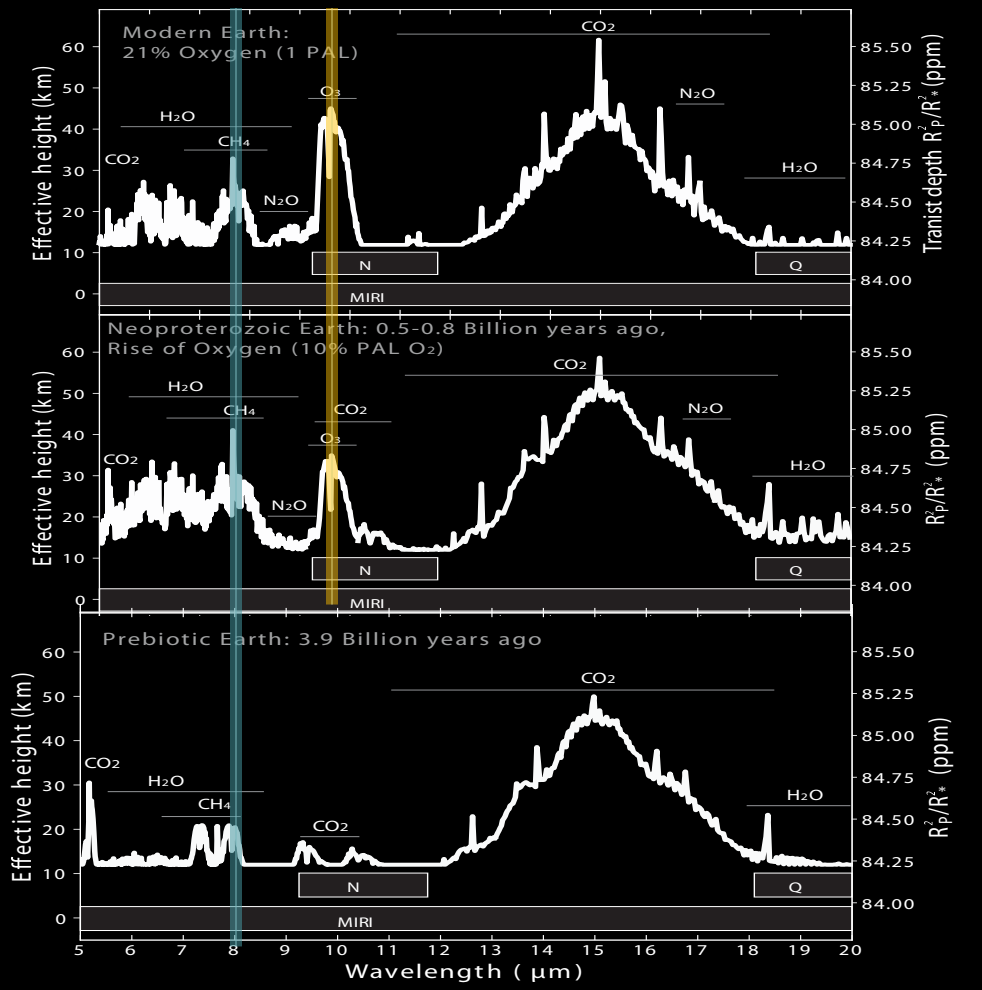



Figure: Model Spectra for Earth through geological time from 0.4 to 20 μm

*Kaltenegger et al 2007, Rugheimer & Kaltenegger 2018, Kaltenegger et al 2020*




SPECTRAL EVOLUTION OF AN EARTH-LIKE PLANET

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Harvard Smithsonian Center for Astrophysics, Cambridge, MA; lkaltenegger@cfa.harvard.edu

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Jet Propulsion Laboratory, Pasadena, CA; Harvard Smithsonian Center for Astrophysics, Cambridge, MA

and

Kenneth W. Jucks
Harvard Smithsonian Center for Astrophysics, Cambridge, MA

*Received 2006 April 13; accepted 2006 November 8*

ApJ 2007

**High-resolution Transmission Spectra of Earth Through Geological Time**

Lisa Kaltenegger[1,2], Zifan Lin[1,2], and Jack Madden[1,2]
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[2] Carl Sagan Institute, Space Science Building 311, Ithaca, NY 14850, USA

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MNRAS 2022, MNRAS 2023

ANNUAL REVIEWS

*Annual Review of Astronomy and Astrophysics*

# How to Characterize Habitable Worlds and Signs of Life

Lisa Kaltenegger

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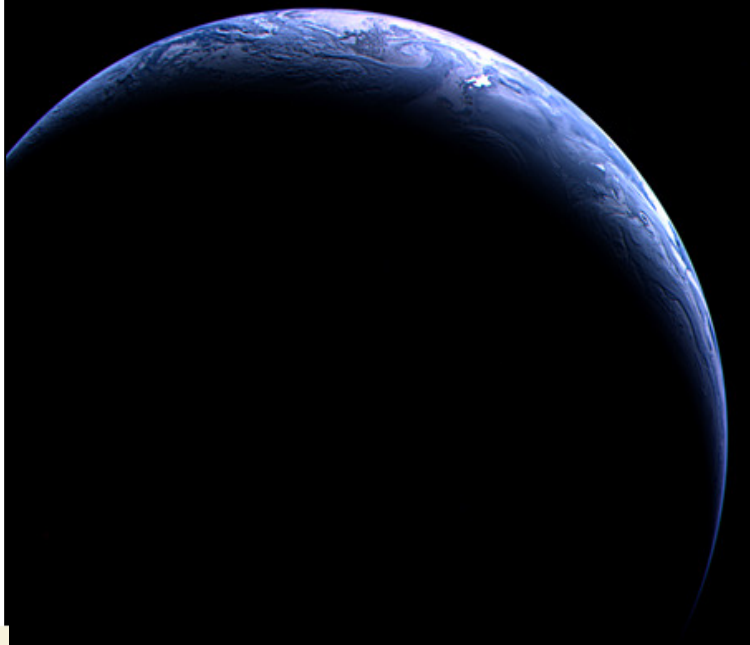
## Keywords

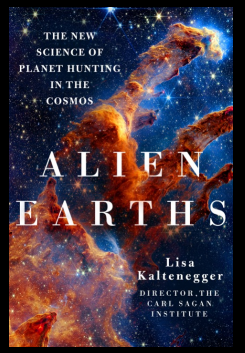
Earth, exoplanets, habitability, habitable zone, search for life

## Abstract

The detection of exoplanets orbiting other stars has revolutionized our view of the cosmos. First results suggest that it is teeming with a fascinating diversity of rocky planets, including those in the habitable zone. Even our closest star, Proxima Centauri, harbors a small planet in its habitable zone, Proxima b. With the next generation of telescopes, we will be able to peer into the atmospheres of rocky planets and get a glimpse into other worlds. Using our own planet and its wide range of biota as a Rosetta stone, we explore how we could detect habitability and signs of life on exoplanets over interstellar distances. Current telescopes are not yet powerful enough to characterize habitable exoplanets, but the next generation of telescopes that is already being built will have the capabilities to characterize close-by habitable worlds. The discussion on what makes a planet a habitat and how to detect signs of life is lively. This review will show the latest results, the challenges of how to identify and characterize such habitable worlds, and how near-future telescopes will revolutionize the field. For the first time in human history, we have developed the technology to detect potential habitable worlds. Finding thousands of exoplanets has taken the field of comparative planetology beyond the Solar System.

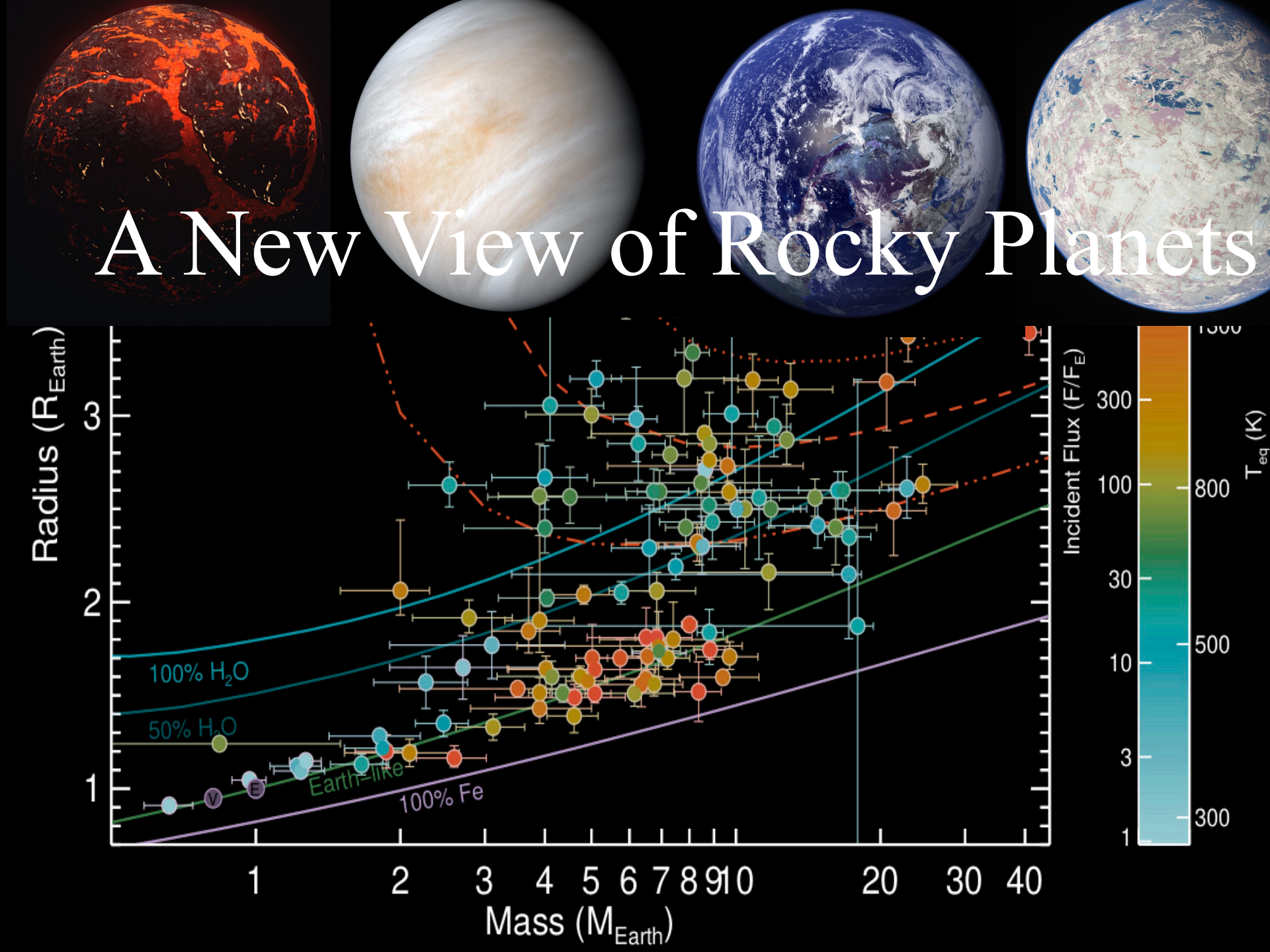


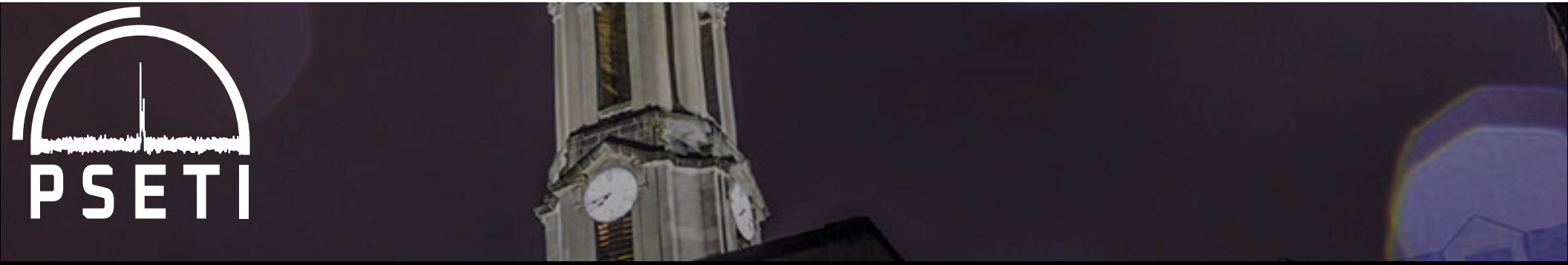





*Kaltenegger 2017, Grenfell 2017, Fuji et al 2018, Schwieterman el al 2018*

# A New View of Rocky Planets






# Technosignatures

Jason T Wright
July 24, 2025
Sagan Summer Workshop

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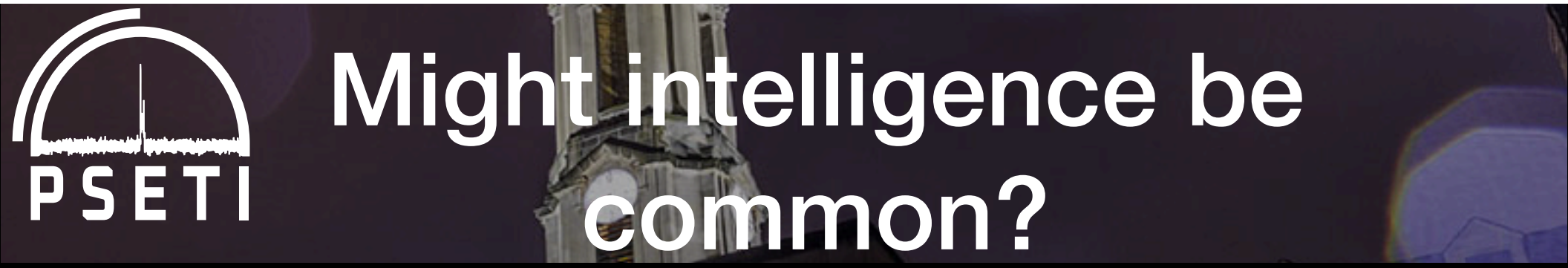
- Intelligence on Earth has unambiguously emerged *many* times



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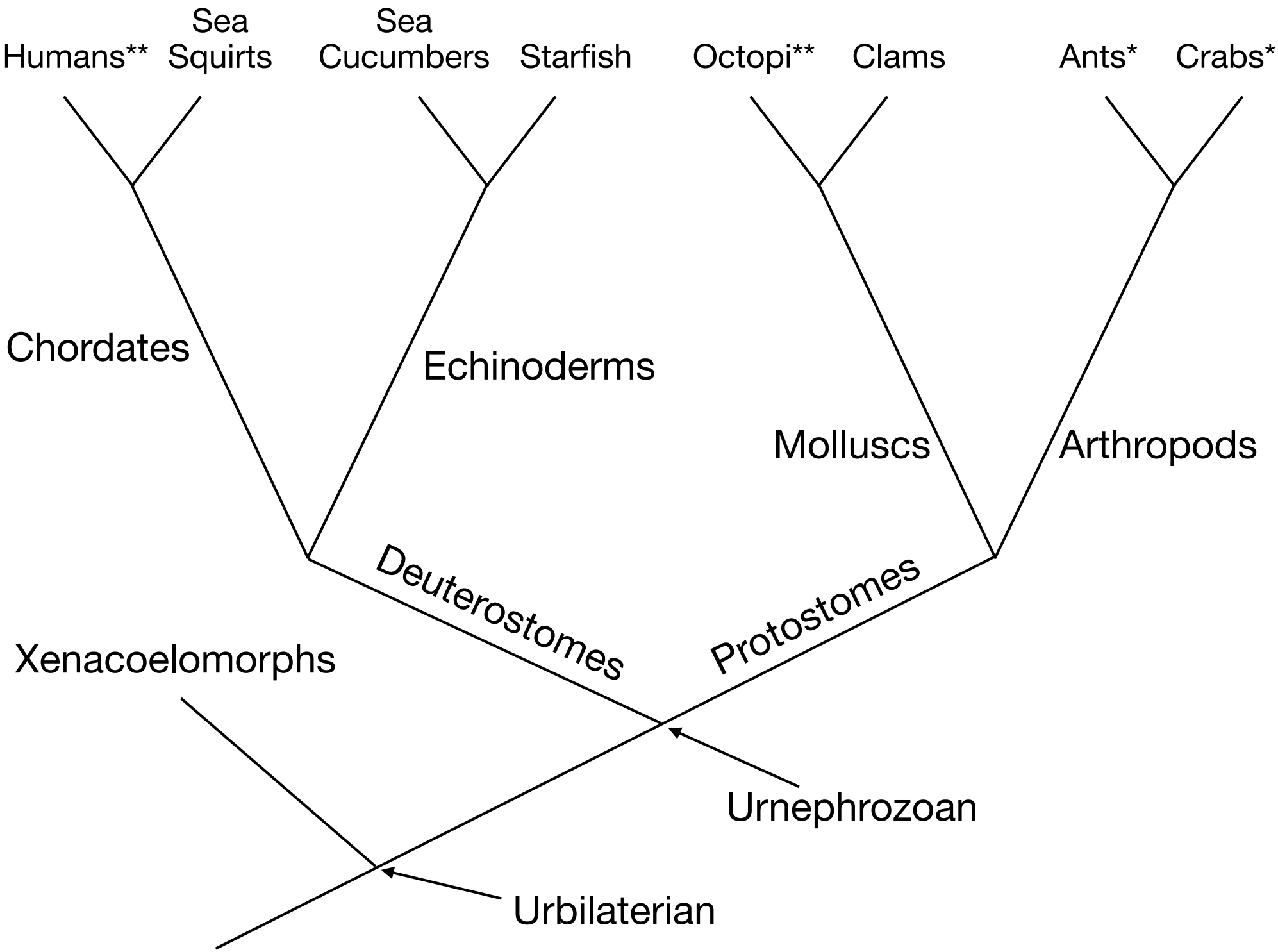
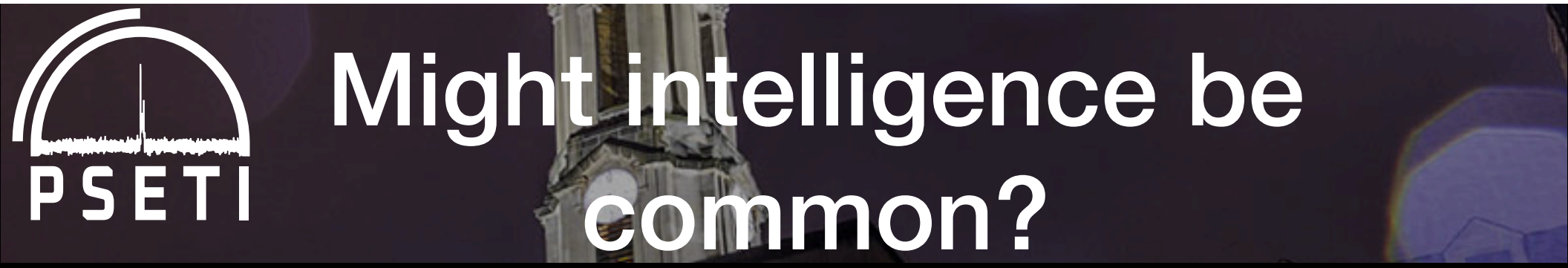

Humans**
Sea Squirts
Sea Cucumbers
Starfish
Octopi**
Clams
Ants*
Crabs*
Chordates
Echinoderms
Molluscs
Arthropods
Deuterostomes
Protostomes
Xenacoelomorphs
Urnephrozoan
Urbilaterian



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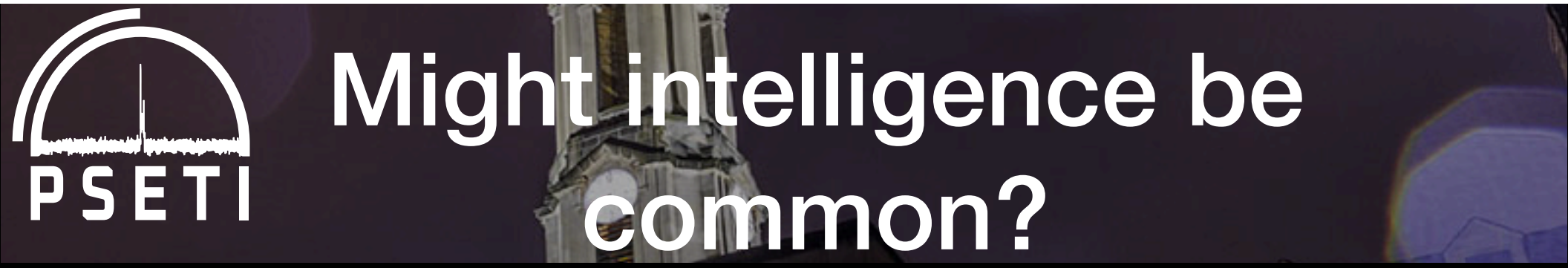


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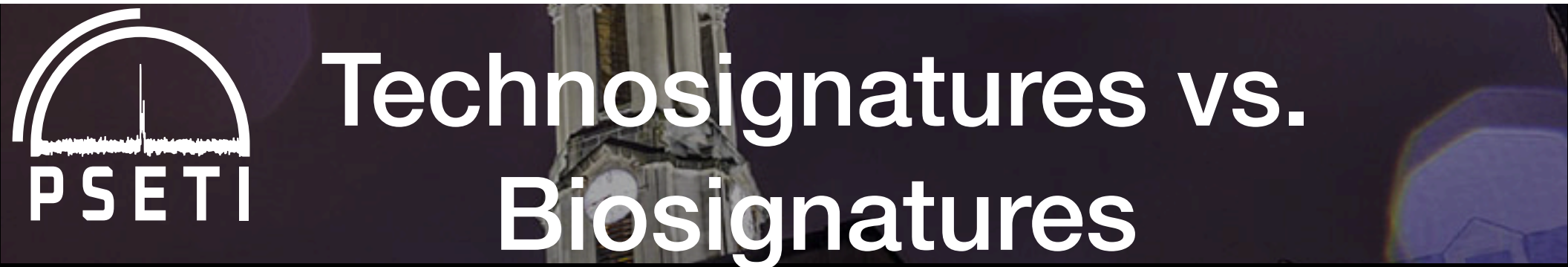
- We cannot even be sure we are the first technological species on Earth!



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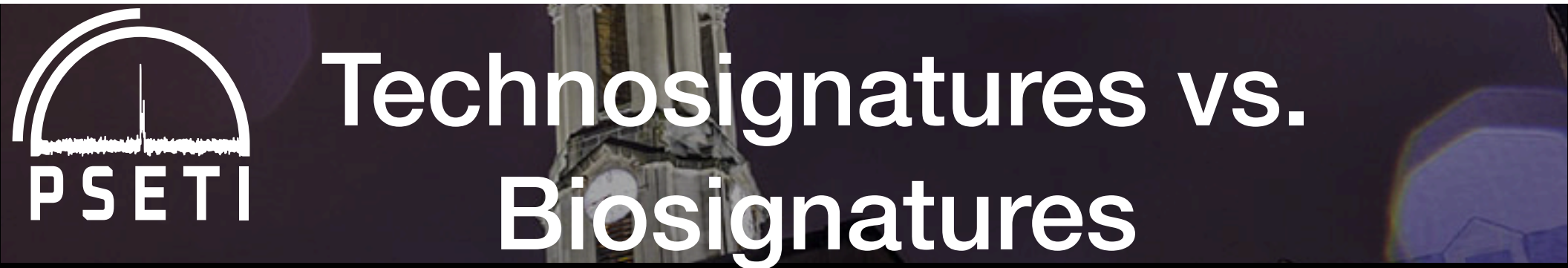

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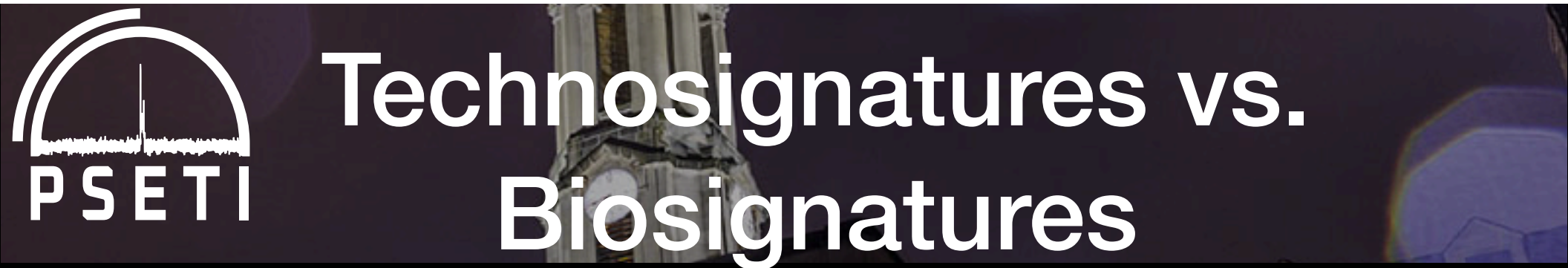

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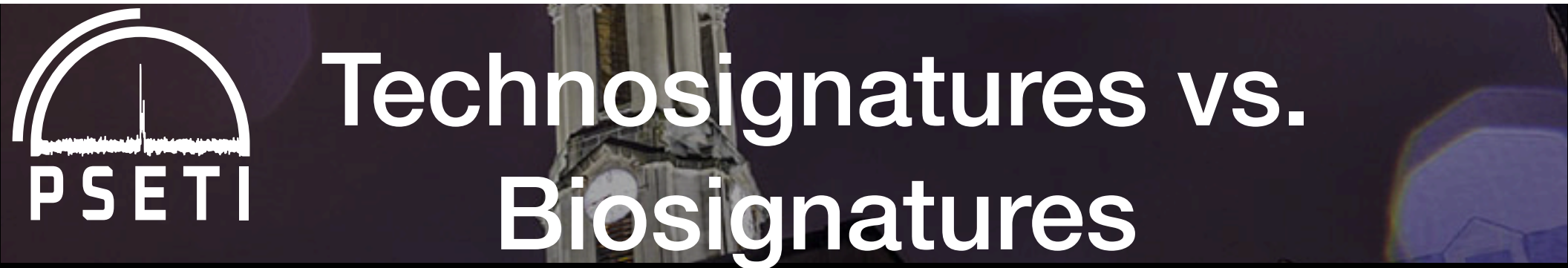

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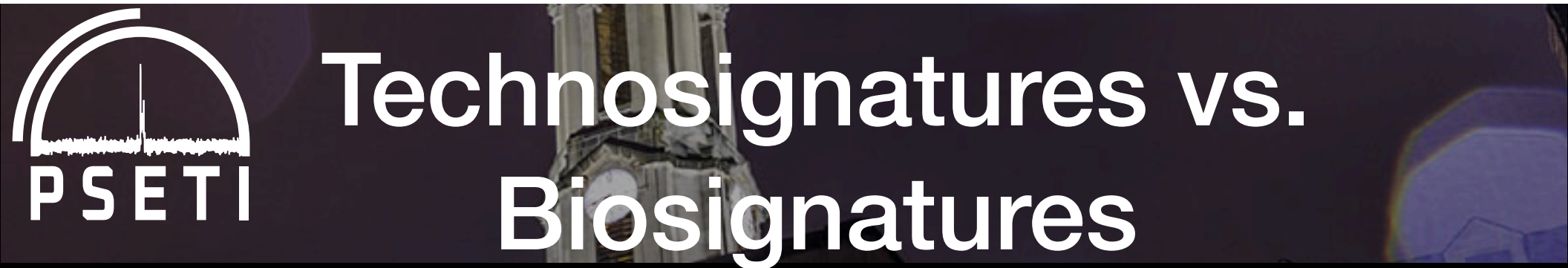

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  - Longer-lived: Technology has the capacity to far outlast biospheres