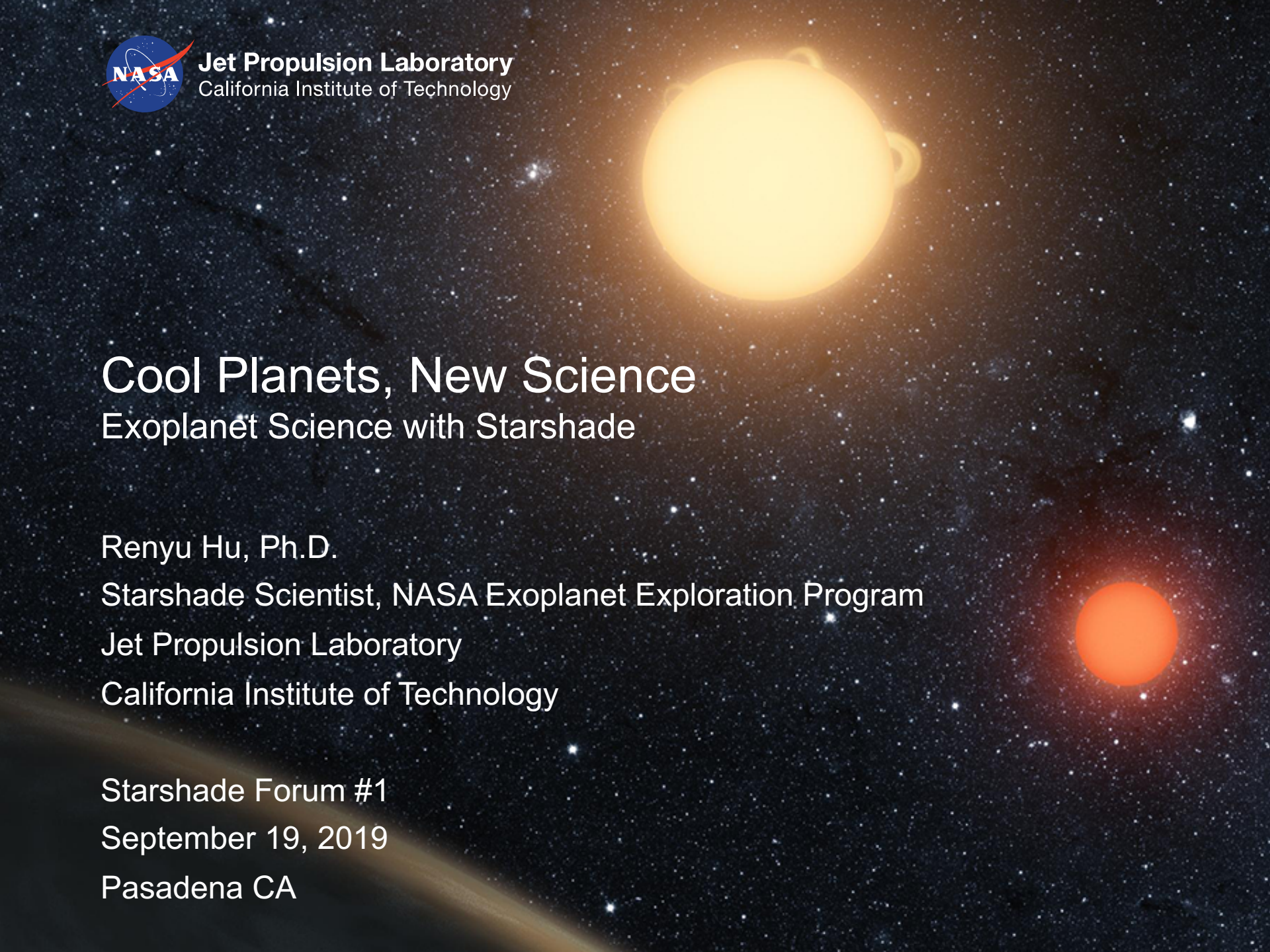


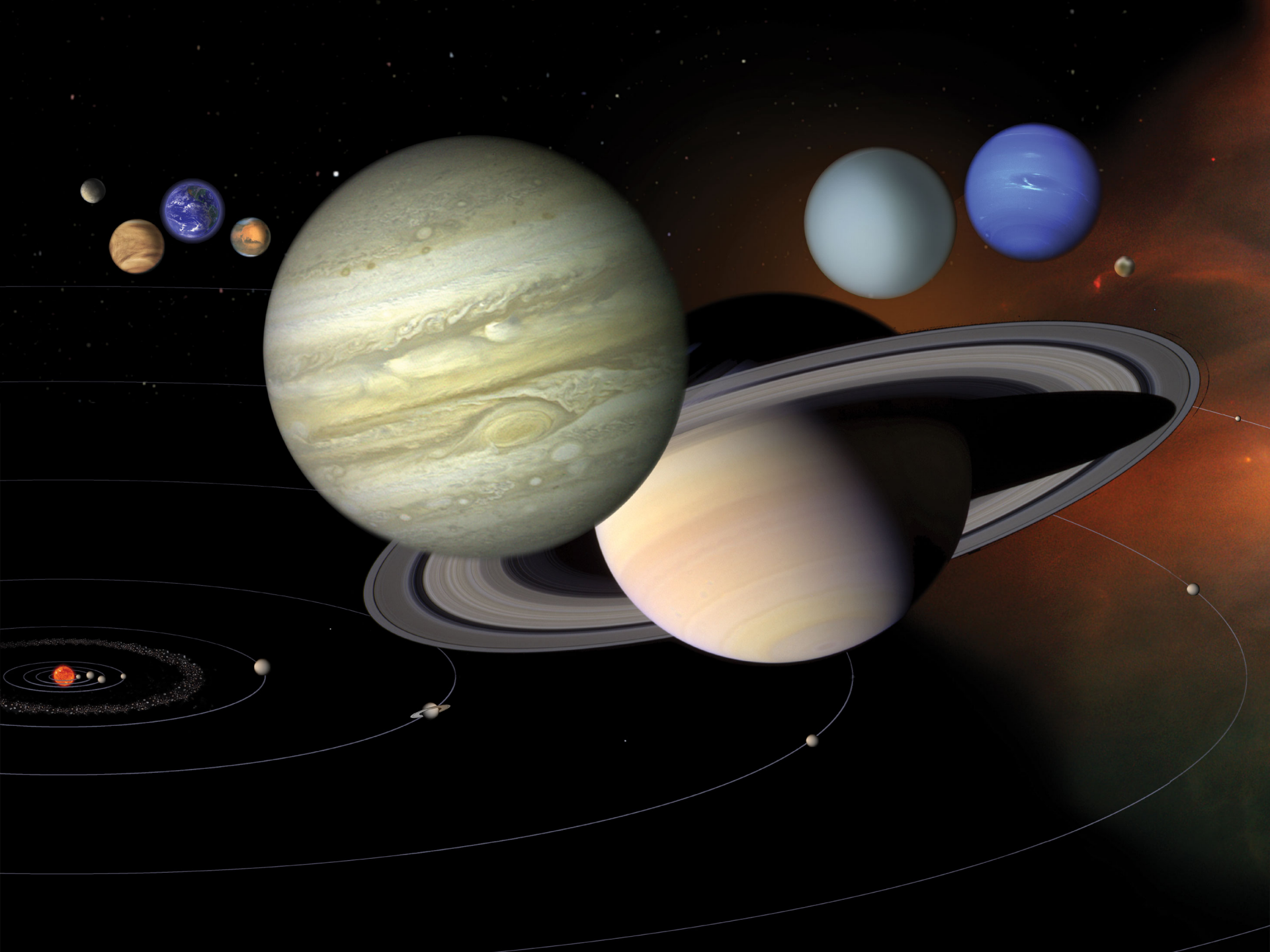
Jet Propulsion Laboratory
California Institute of Technology

# Cool Planets, New Science

## Exoplanet Science with Starshade

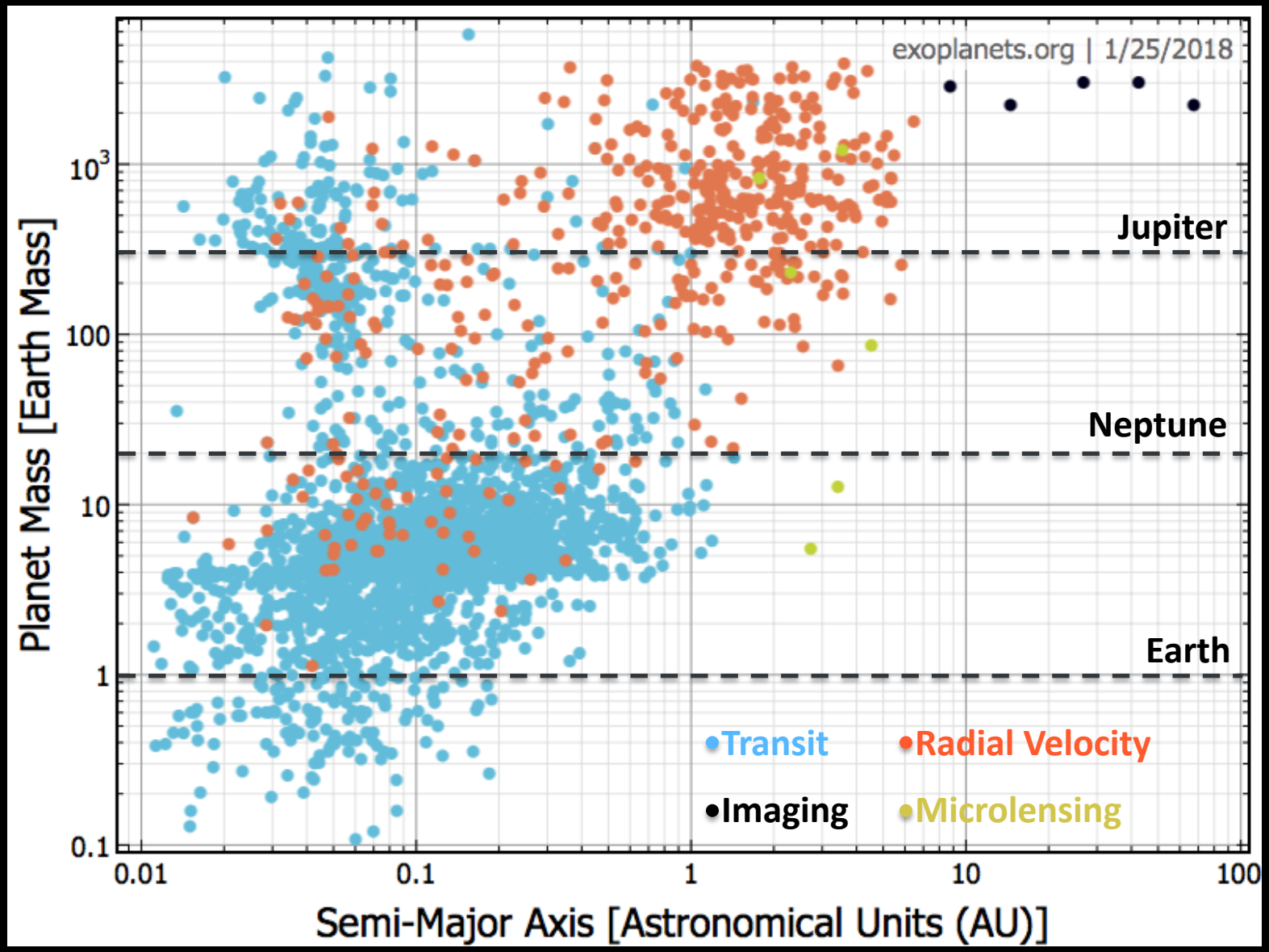
Renyu Hu, Ph.D.
Starshade Scientist, NASA Exoplanet Exploration Program
Jet Propulsion Laboratory
California Institute of Technology

Starshade Forum #1
September 19, 2019
Pasadena CA



# Exoplanet Demography

>25% nearby stars have Earth-sized planets in their habitable zone

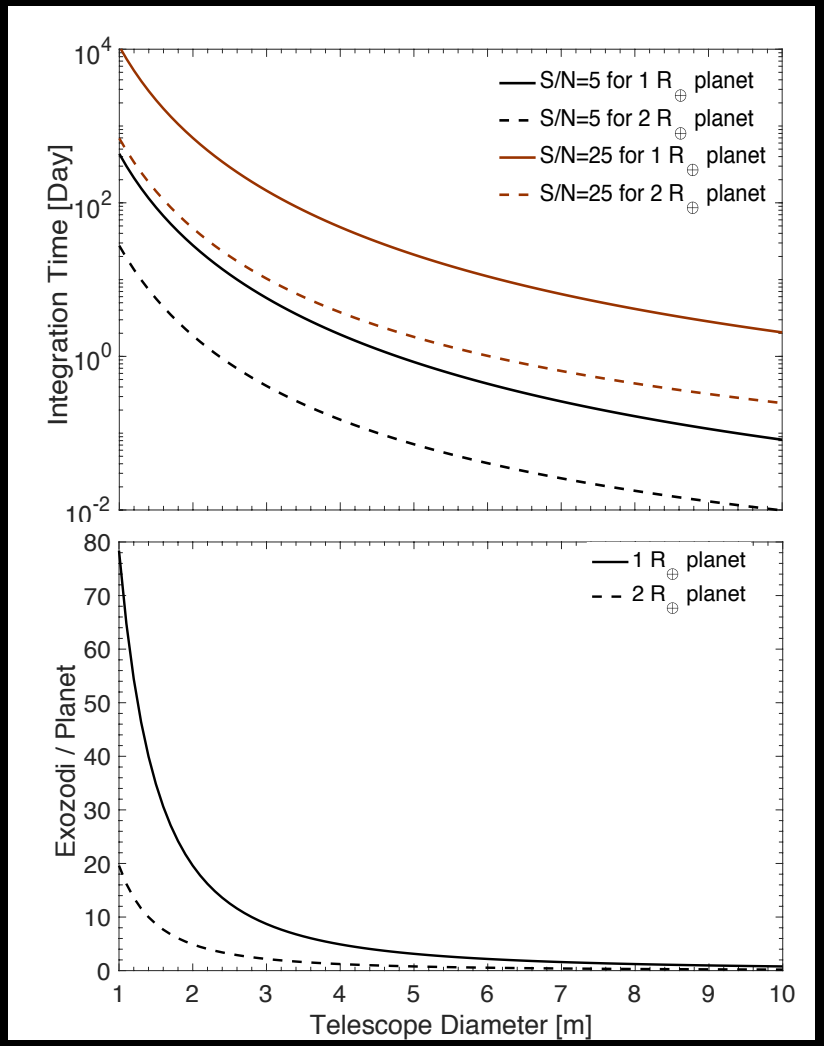


# Exoplanet Detection with Starshade

From the instrument contrast to planetary S/N

$$\text{S/N} = \frac{N_P}{\sqrt{N_p + 2\left(N_S C + N_E + N_Z\right)}}$$

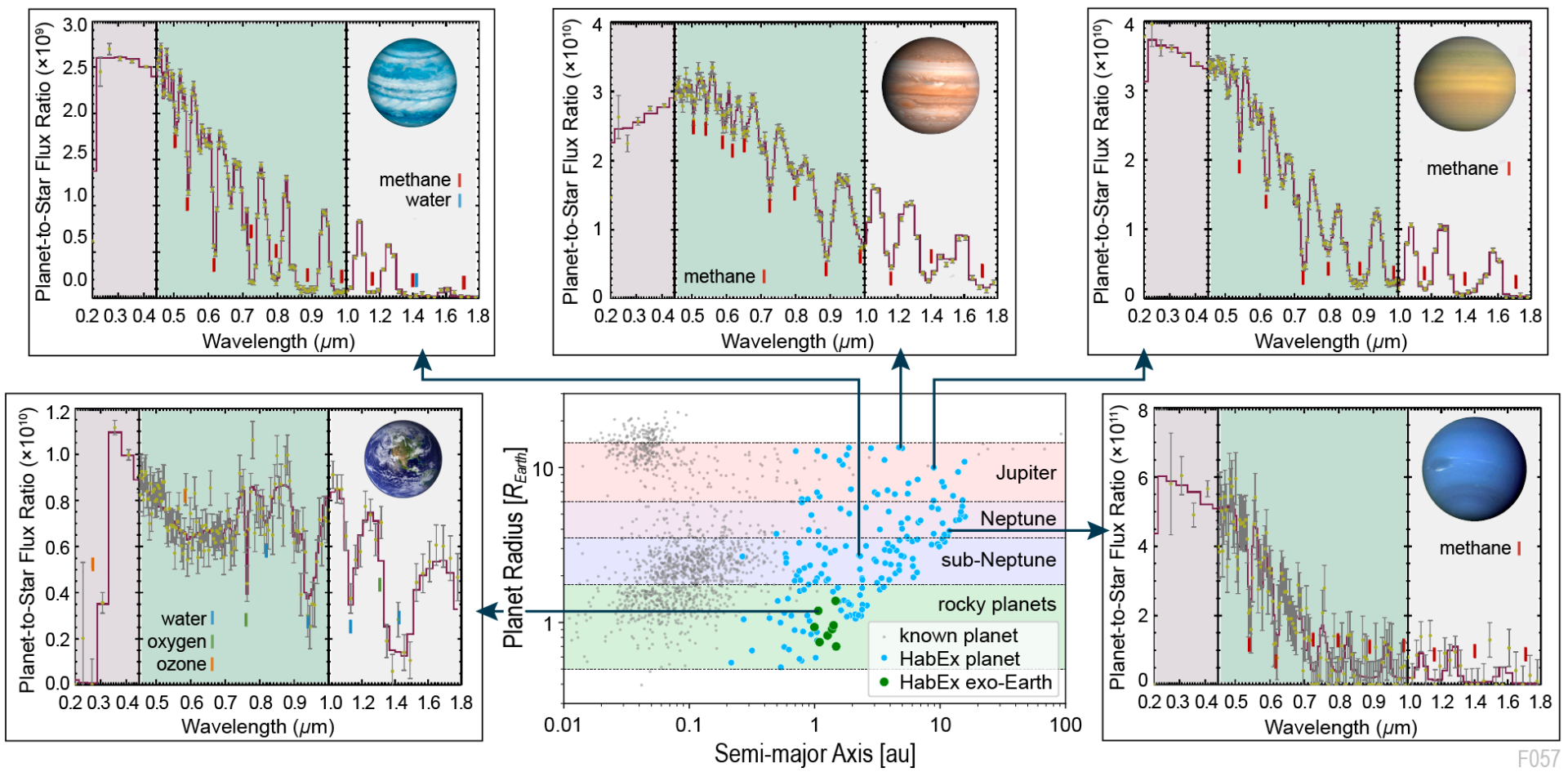
- "Speckles" from starshade << exozodiacal light for <4-m telescope
- To detect the spectral features, for a reasonable integration of ~20 days, a 1-$R_\oplus$ planet requires a 5.2-m telescope, and a 2-$R_\oplus$ planet only requires a 2.6-m telescope




Hu et al. 2019, White Paper of the Astro2020 Decadal Survey

# Family Portraits of Nearby Planetary Systems

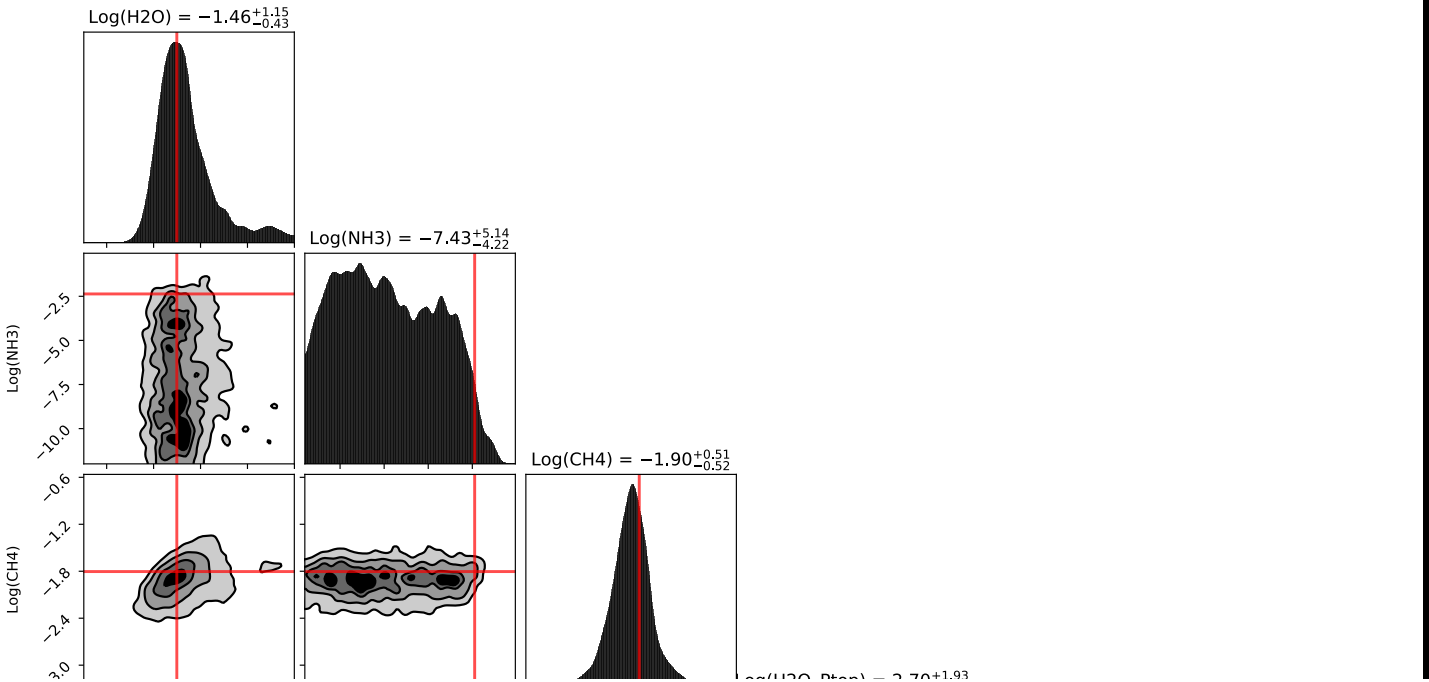
## Planetary characterization enabled by starshade spectroscopy

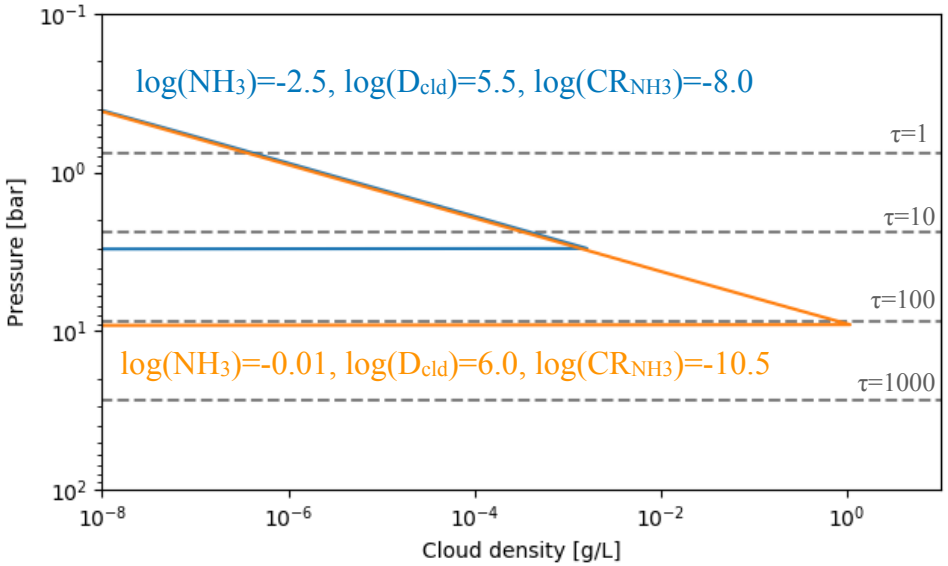


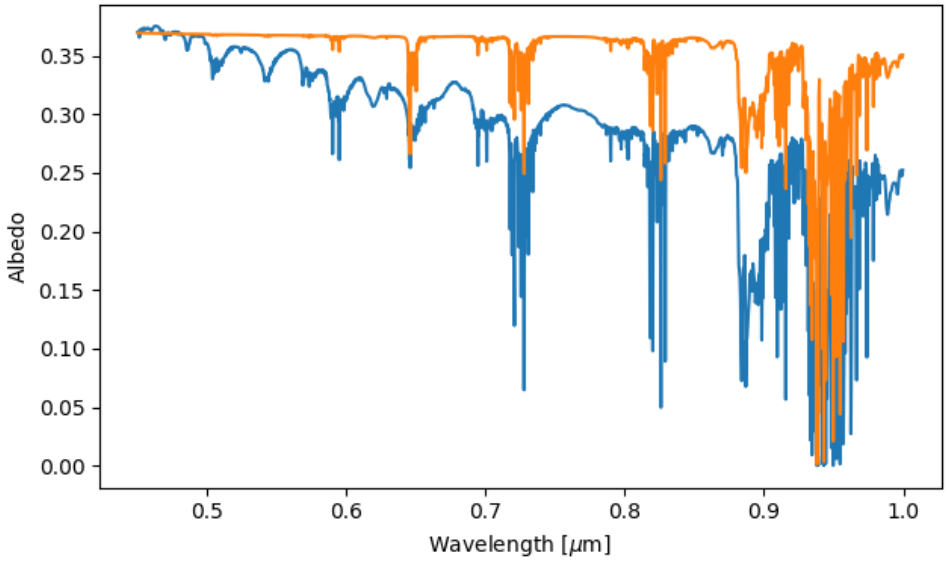

HabEx Final Report, 2019

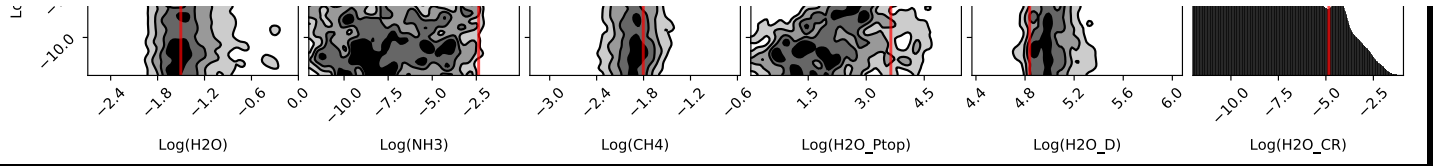
# Chara

Cloud a



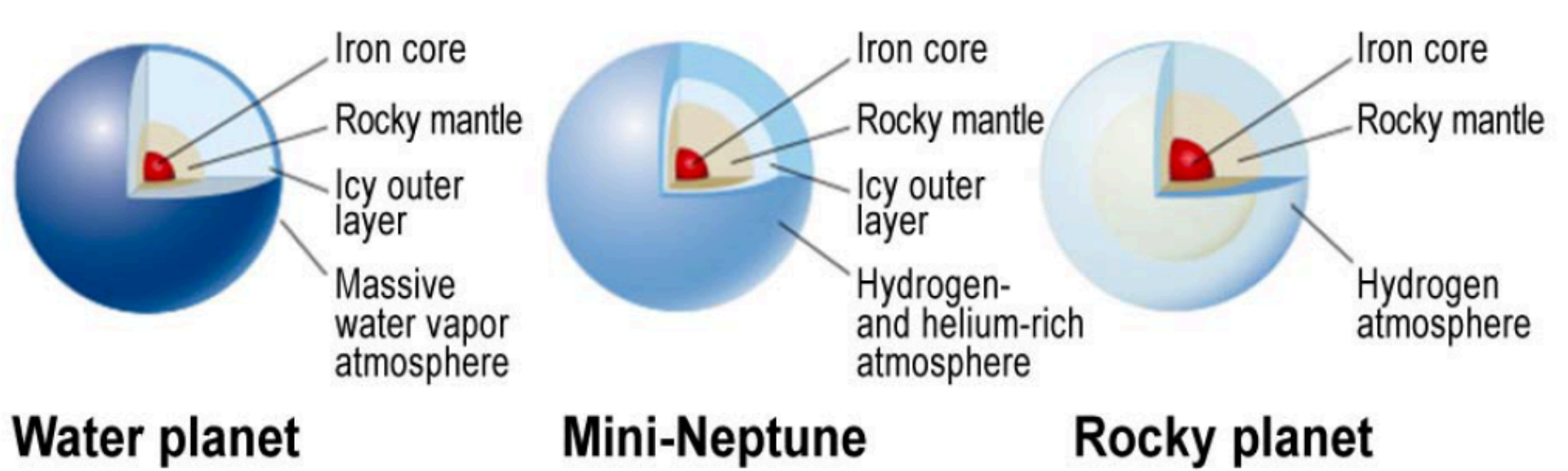




Damiano & H

# Characterizing Sub-Neptunes and Super Earths

- Is there a surface?
  - Cloud, liquid, or solid
- What is the composition of the atmosphere?
  - $H_2$-dominated or non-$H_2$-dominated
- What are the formation and evolution pathways?

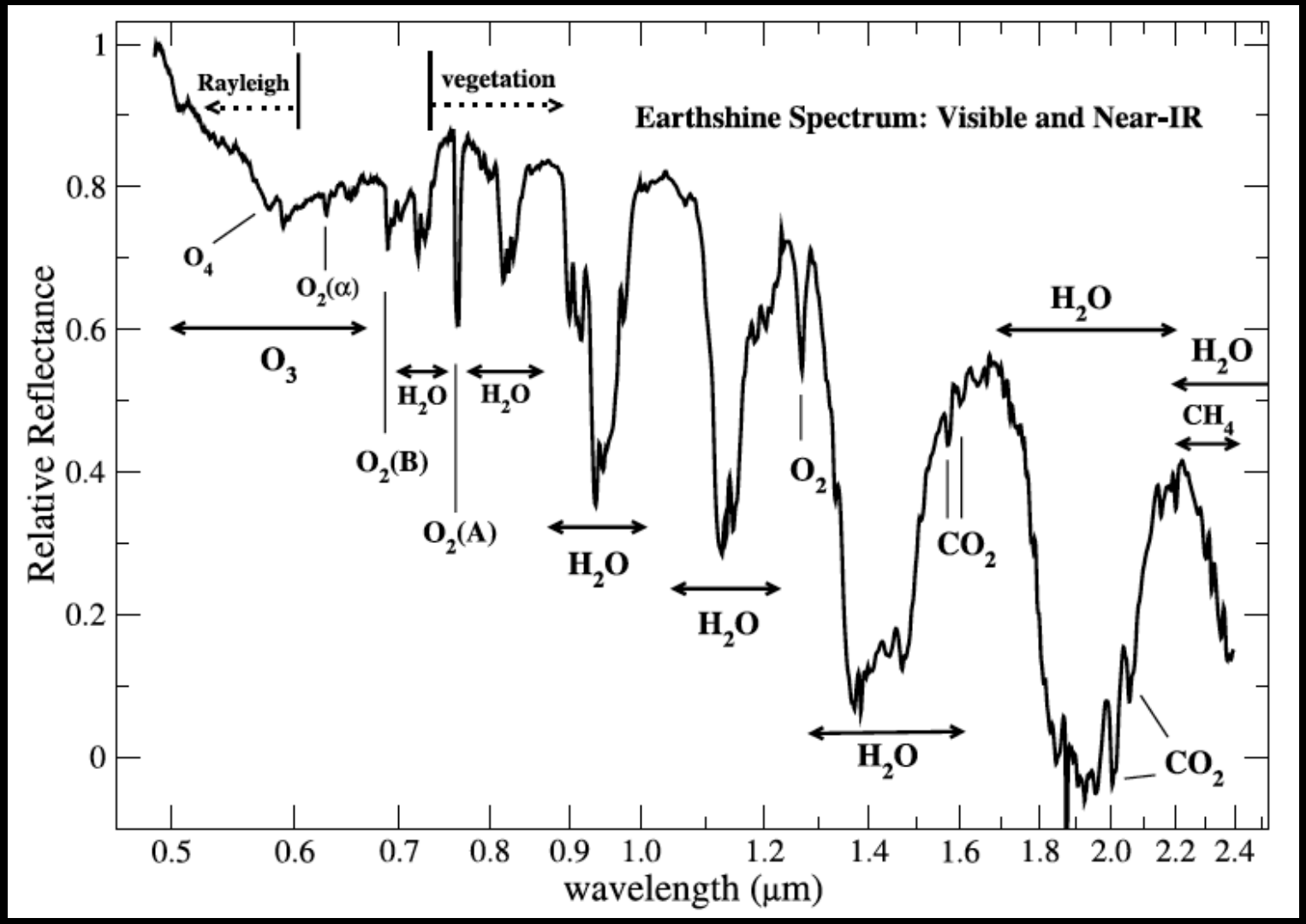



Seager et al. 2015

# Detecting Earths

# Detecting an Earth-like Atmosphere

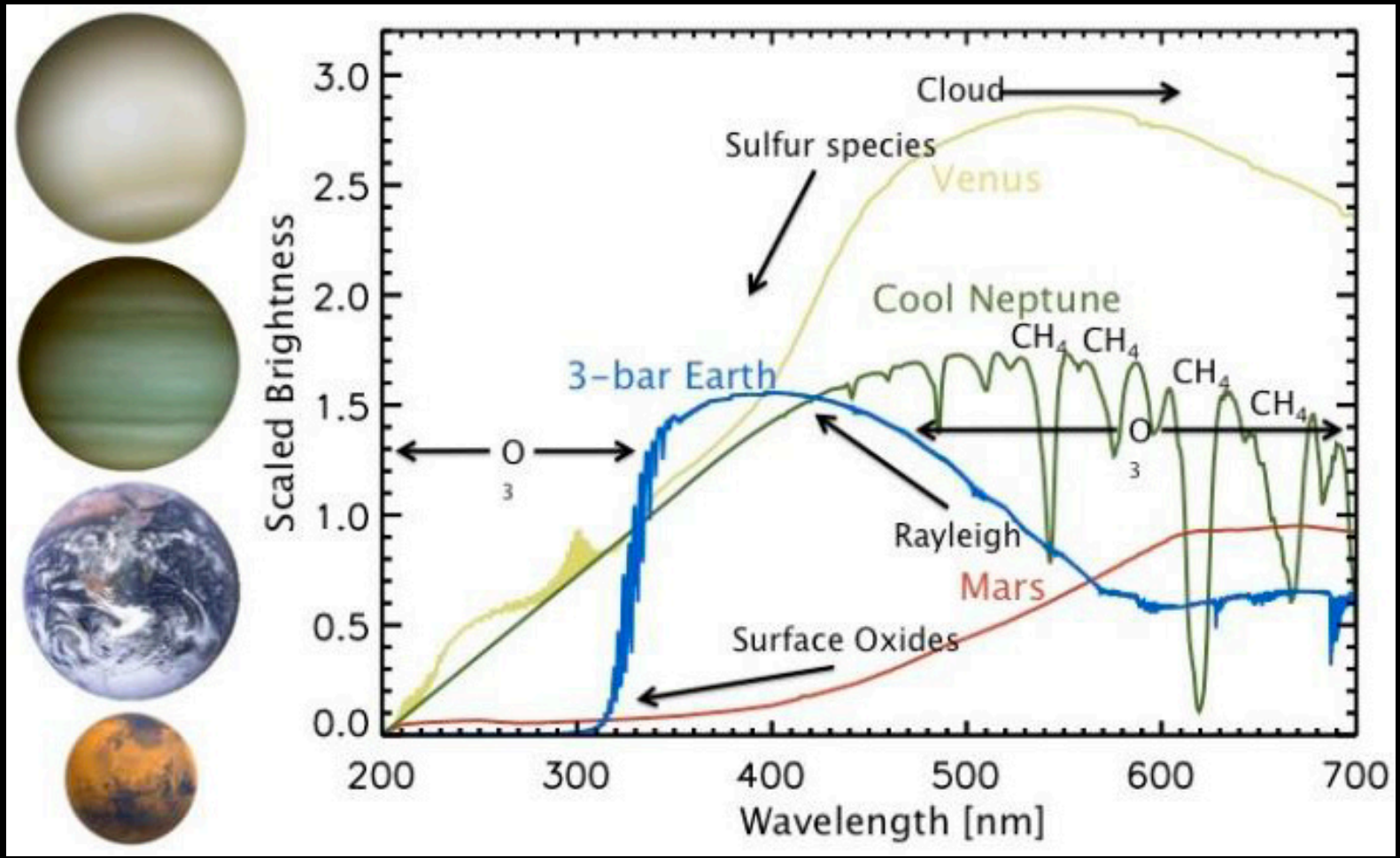
Water, Oxygen, and Carbon Dioxide




Turnbull et al. 2006

# From Earths to super-Earths

Diversity in the spectral appearance of rocky planets



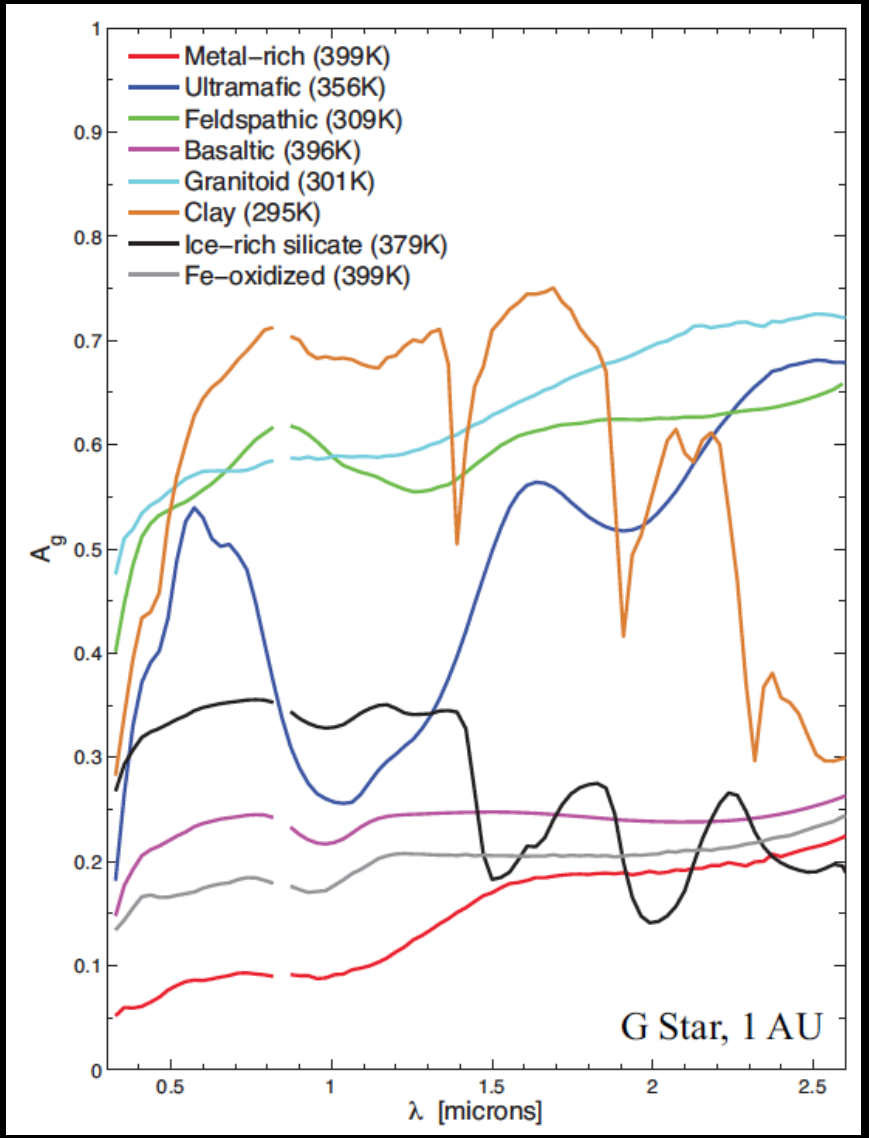

HabEx Final Report, 2019

# Detecting Earths

Bare-Rock Exoplanets

- Rocky exoplanets without atmospheres have spectral features in reflection

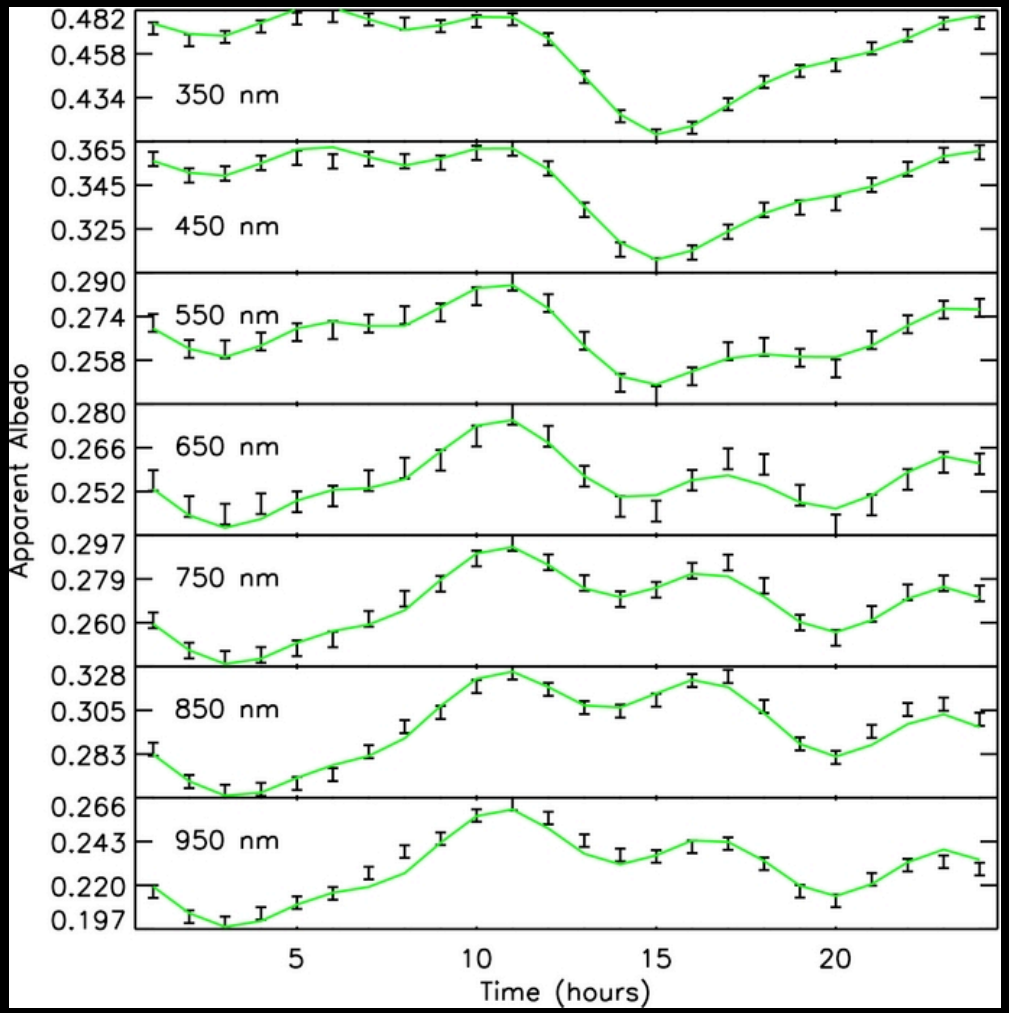
- Signature absorption features in 1-2 μm are characteristic of water ice and hydrated minerals

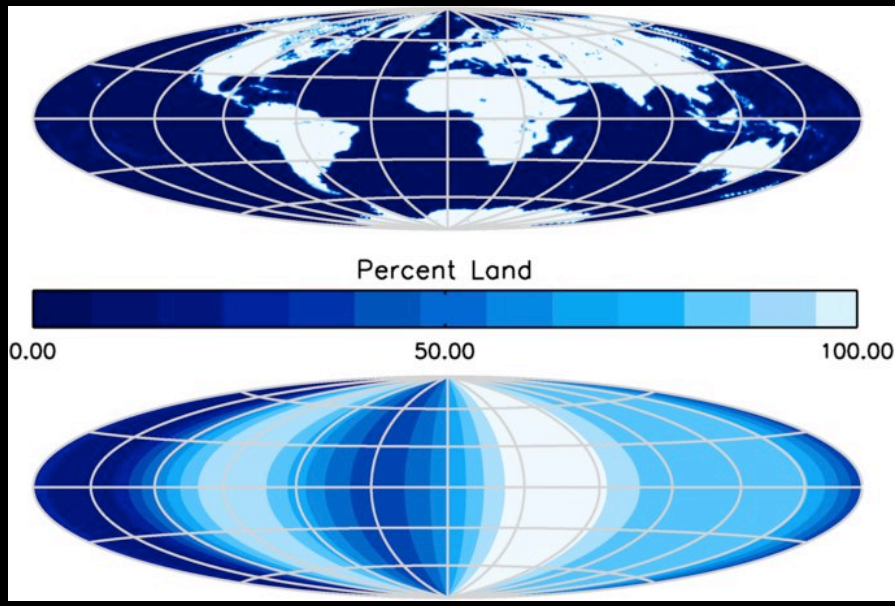



Hu et al. 2012

# Detecting Earths

## Land and Sea

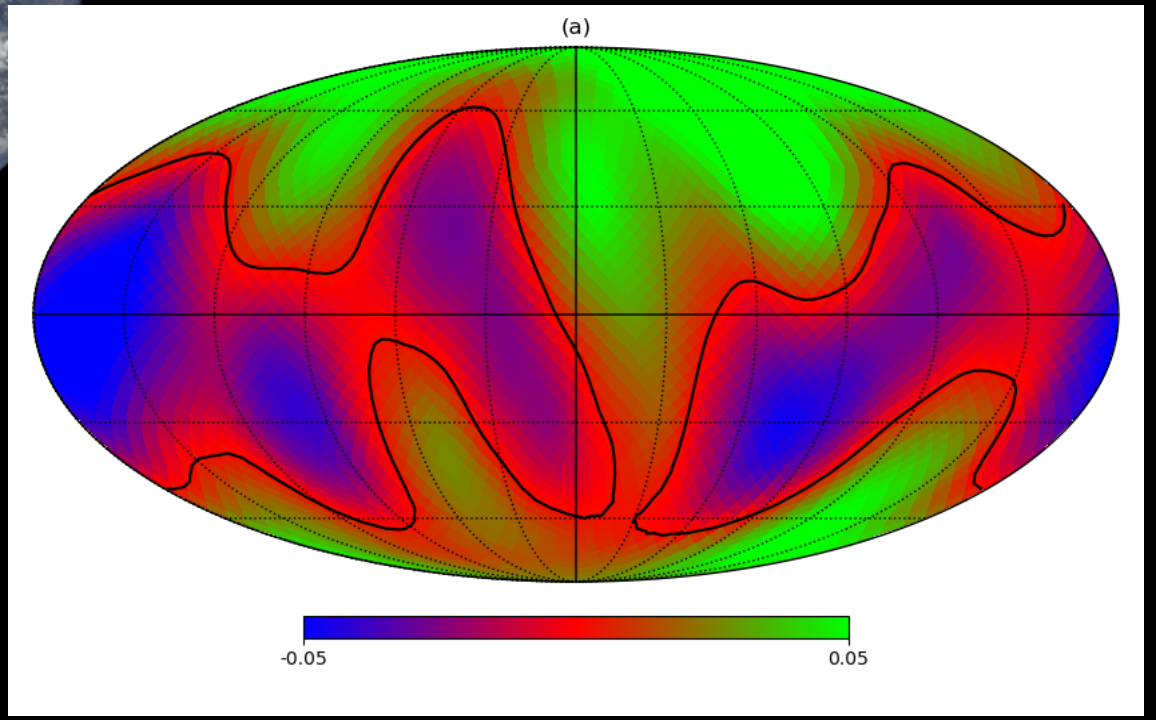



Cowan et al. 2009

# Rotation Period and Hydrological Cycle

What we learned from DSCOVR observations of Earth

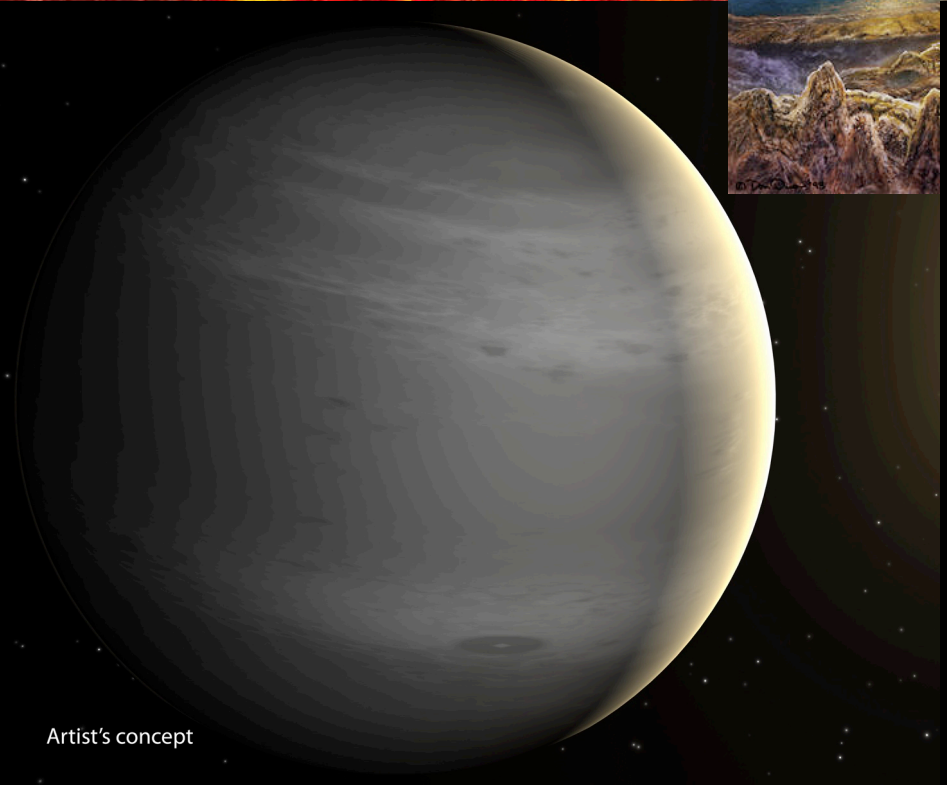



Jiang et al. 2018, Fan et al. 2019

JPL

We could not guess how different from us they (extraterrestrials) might be.

Carl Sagan, *Contact*, 1985



Artist's concept



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