Jet Propulsion Laboratory
California Institute of Technology

Earths and super-Earths

Science Enabled by Direct Imaging Technology

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California Institute of Technology

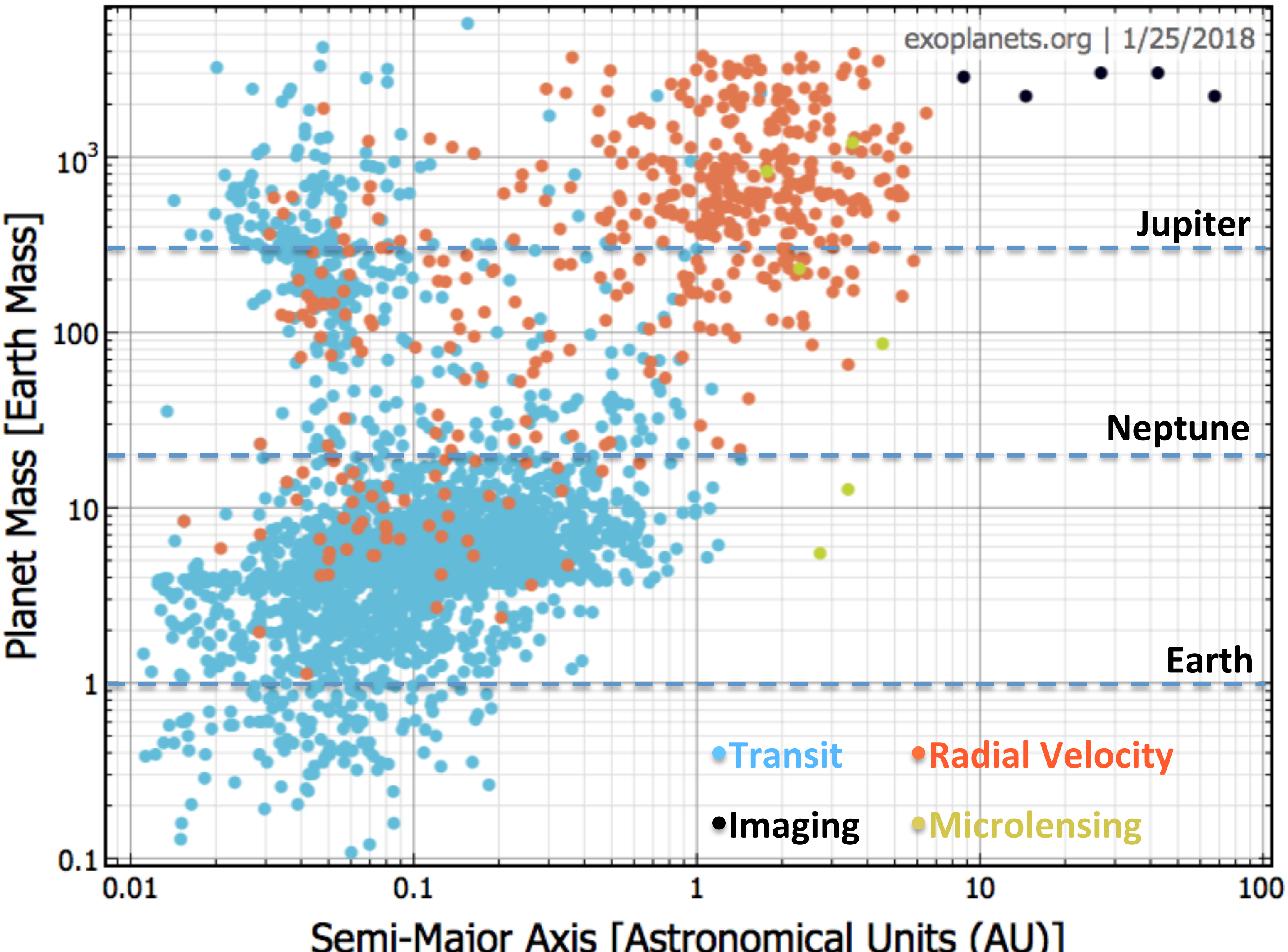
Workshop on Technology for Direct Detection and Characterization of Exoplanets

April 9, 2018

Pasadena CA

Exoplanet Demography

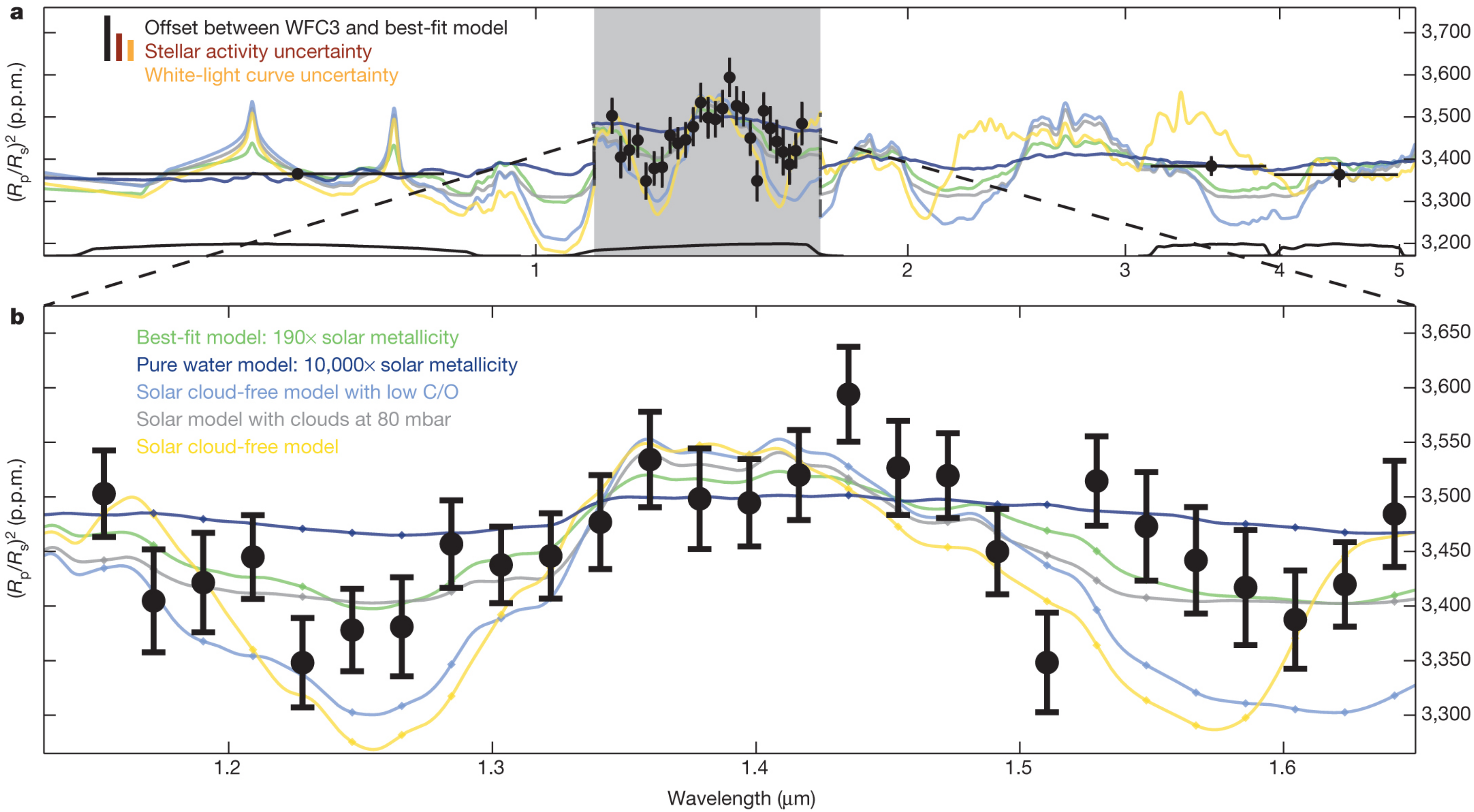
Commonality of Small Planets



Detecting ExoPlanet Atmospheres

In transit

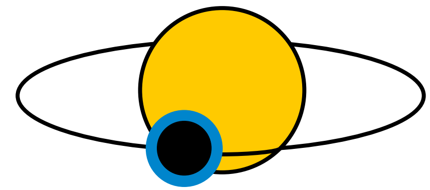
HAT-P-11b, a Neptune-sized planet

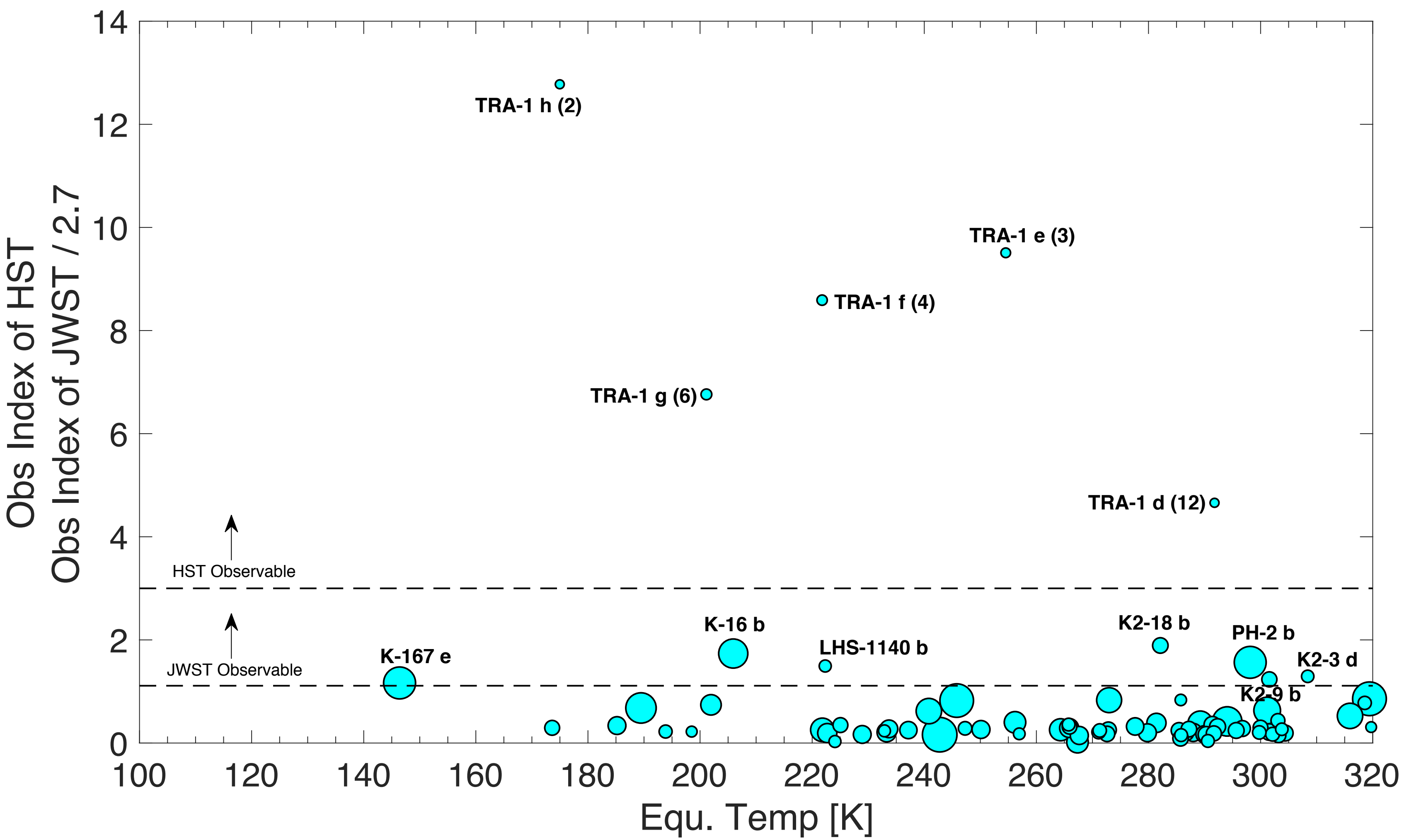


Fraine et al. 2014

H_2 Atmospheres

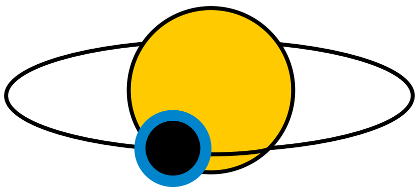
Detectable via transit

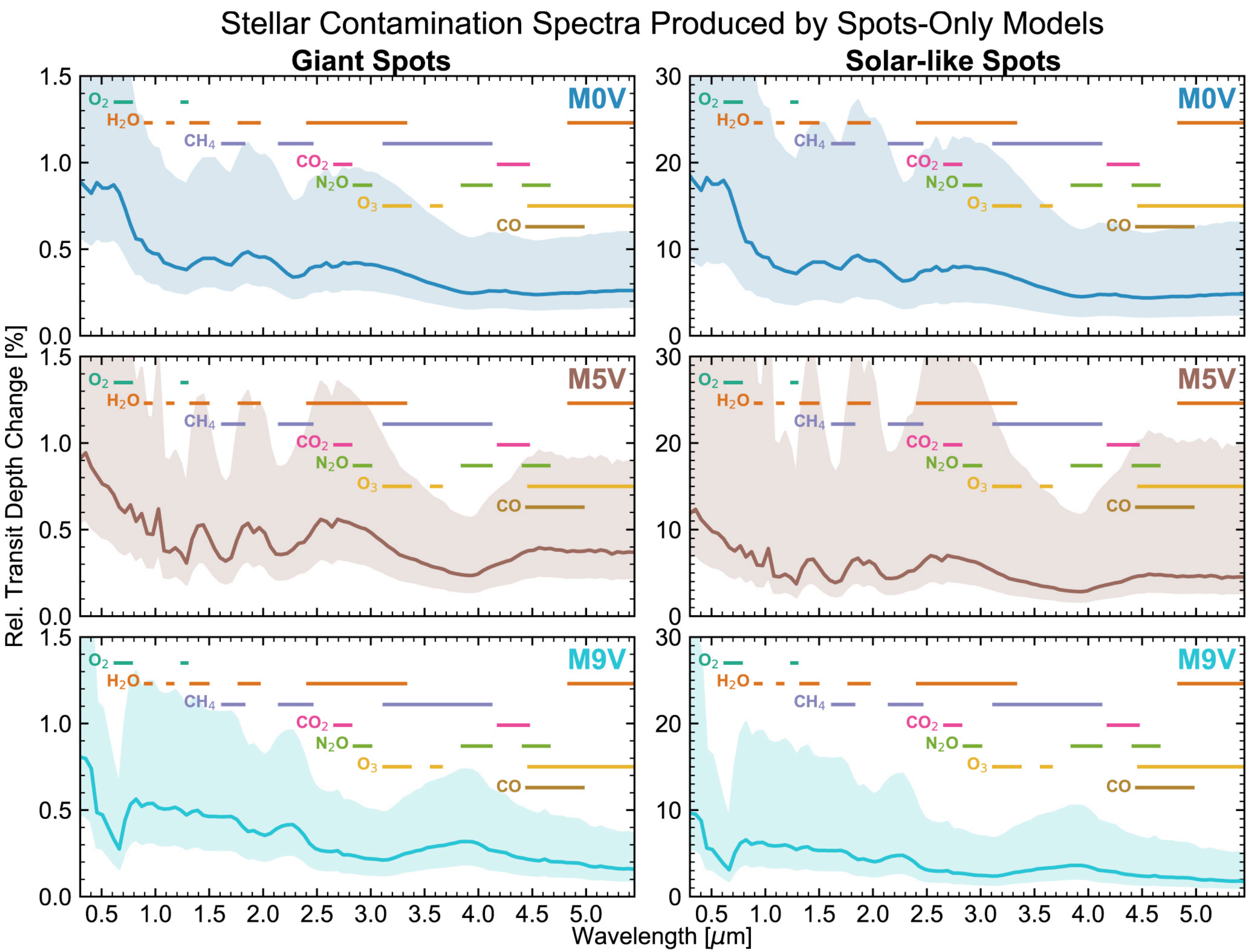




Non-H_2 Atmospheres?

Complication with stellar variability





Transit Feature

- Up to 10% for H_2 atmospheres
- <1% for non-H_2 atmospheres

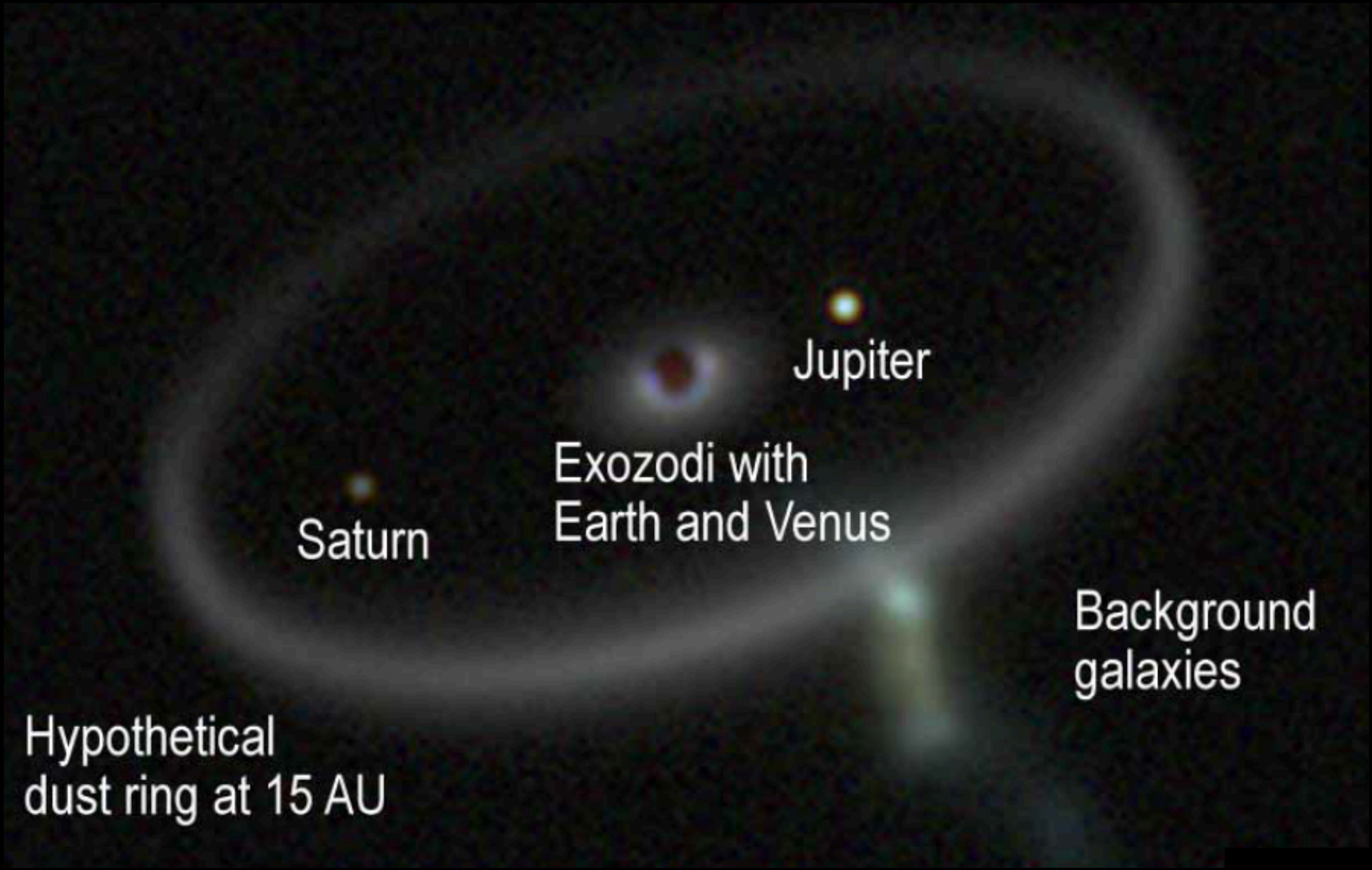
Emission Feature

- 1-2%

Rackham et al. 2018

Direct Detection of a Solar System

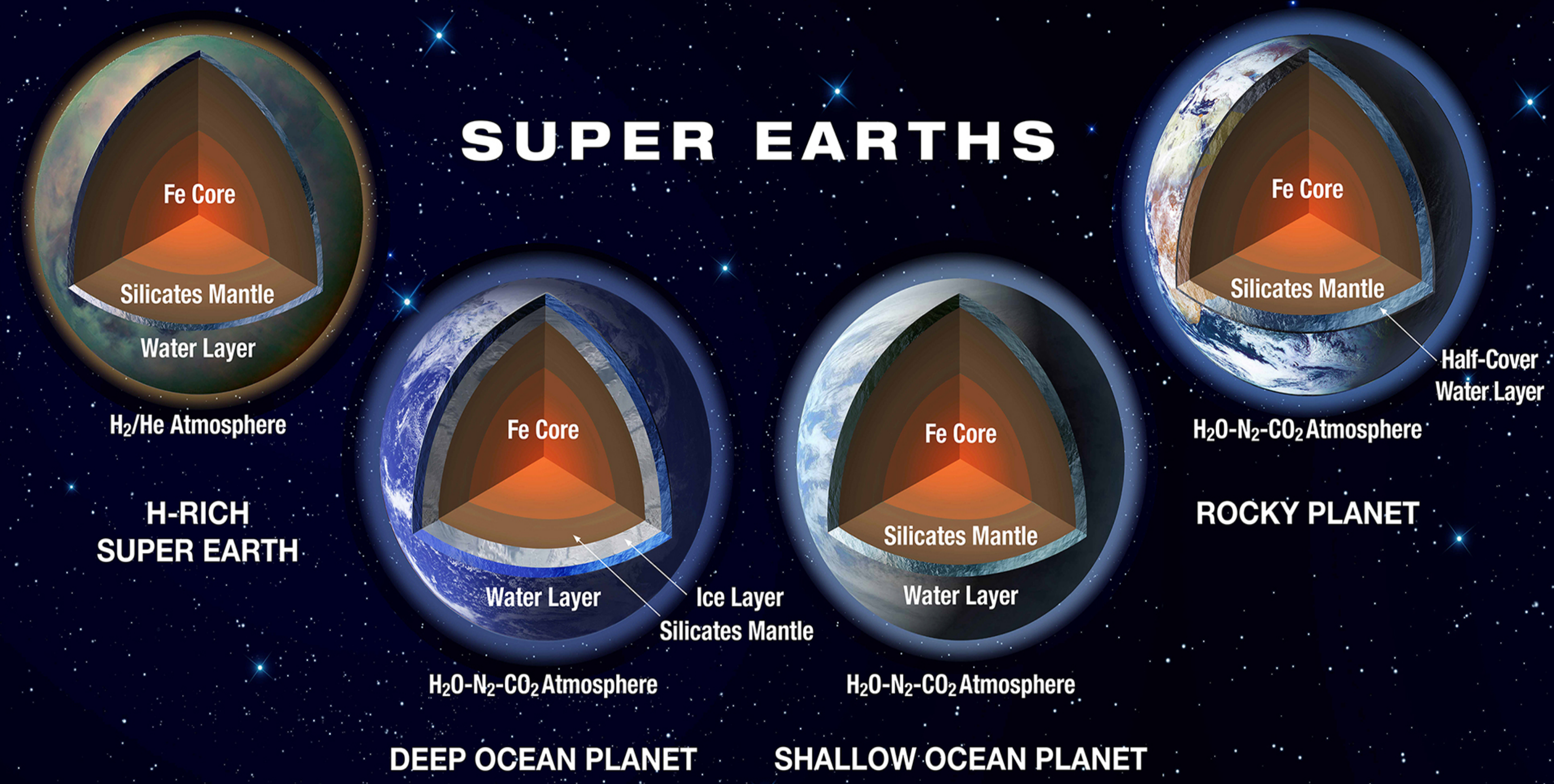
Starshade Rendezvous Mission simulated image of a nearby star



EXO-S Final Report 2015

Detecting Earths


SUPER EARTHS
Fe Core
Silicates Mantle
Water Layer
H2/He Atmosphere
H-RICH
SUPER EARTH
Fe Core
Water Layer
Ice Layer
Silicates Mantle
H2O-N2-CO2 Atmosphere
DEEP OCEAN PLANET
Fe Core
Silicates Mantle
Water Layer
H2O-N2-CO2 Atmosphere
SHALLOW OCEAN PLANET
Fe Core
Silicates Mantle
Half-Cover
Water Layer
H2O-N2-CO2 Atmosphere
ROCKY PLANET



How do we know

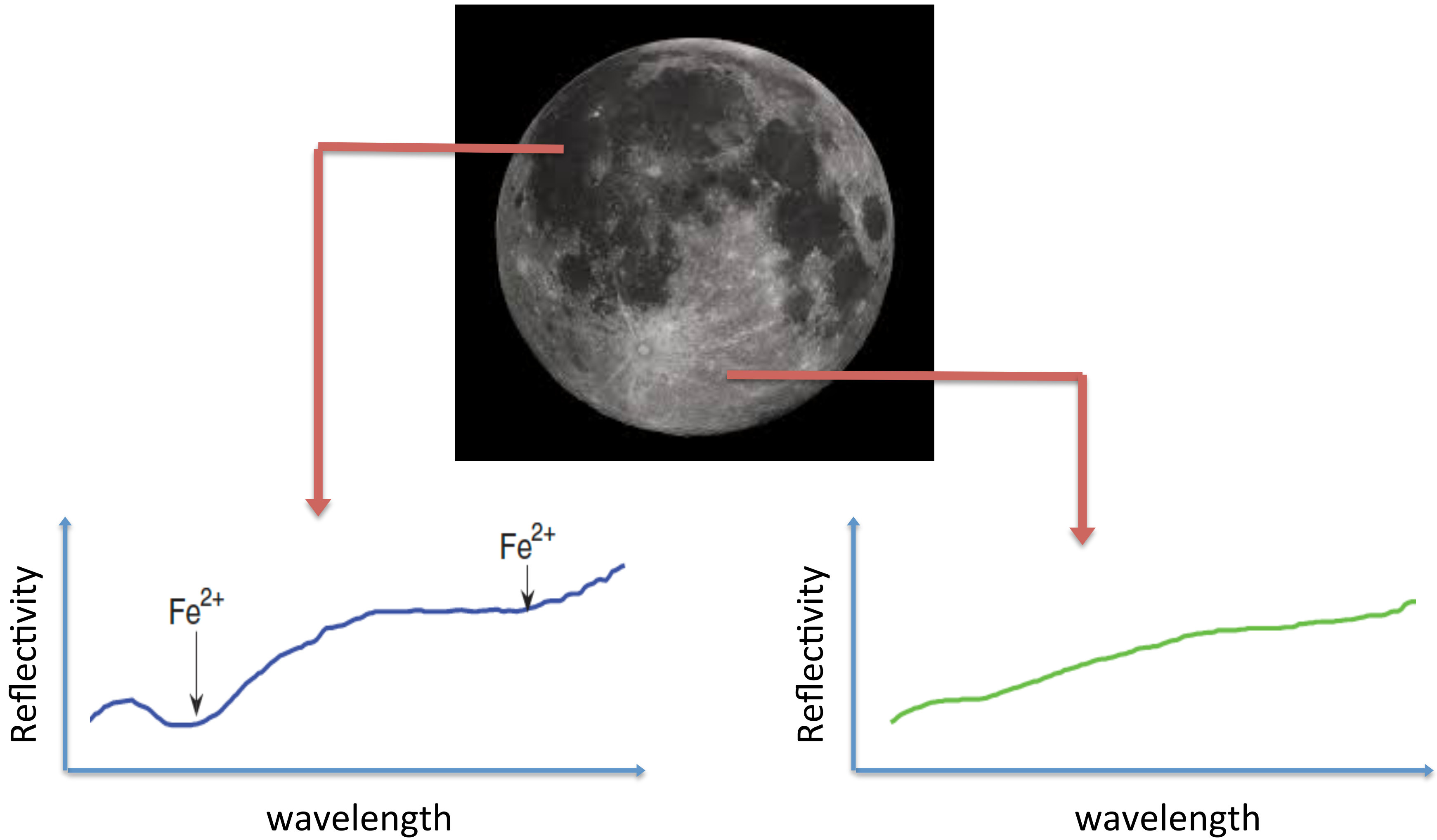
whether an exoplanet has an atmosphere?

whether an exoplanet's atmosphere has evolved?

whether an exoplanet has geological/biological activities?

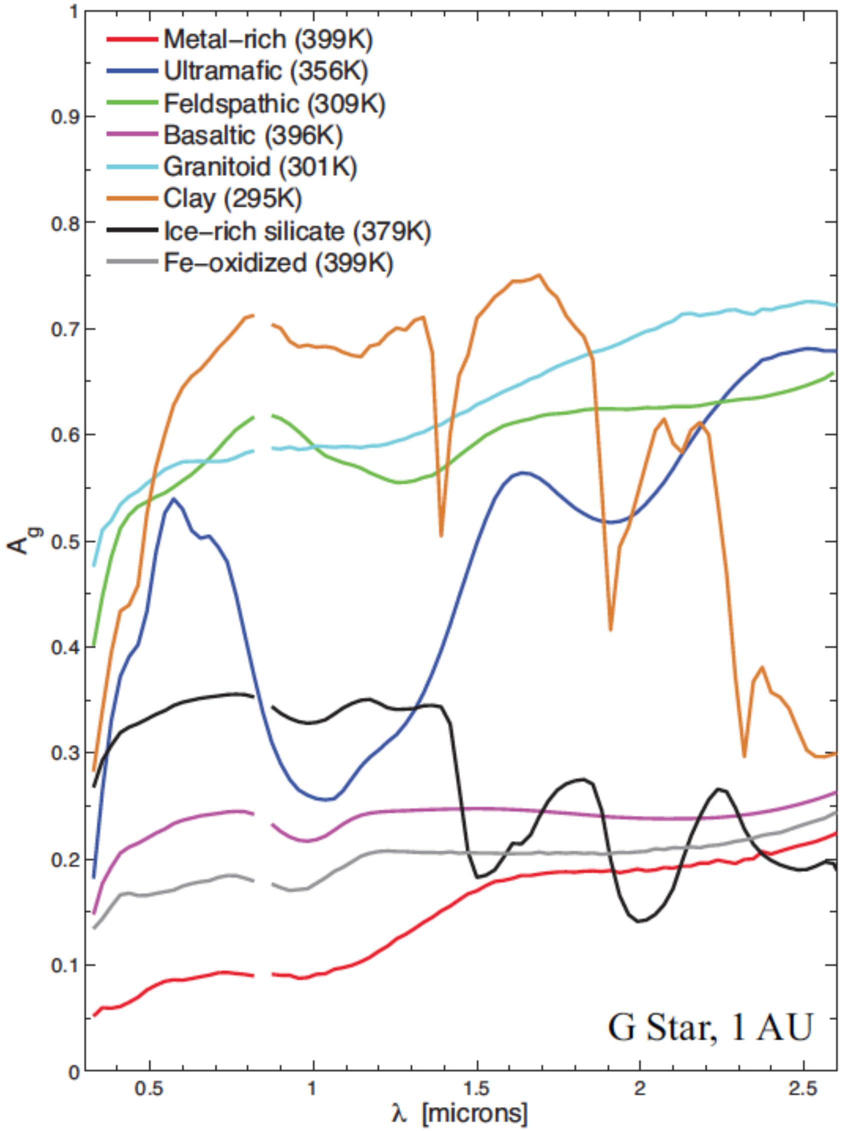
Detect Rocky Exoplanet Surfaces

Spectral features of rocky planetary surfaces



Detect Rocky Exoplanet Surfaces

Direct detection of rocky exoplanets



Metal-rich

Primary crust with mantle ripped off

Ultramafic

Primary crust with mantle overturn or secondary crust from hot lavas

Feldspathic

Primary crust without mantle overturn

Basaltic

Secondary crust

Granitoid

Tertiary crust

Clay

Aqueously altered crust

Ice-rich silicate

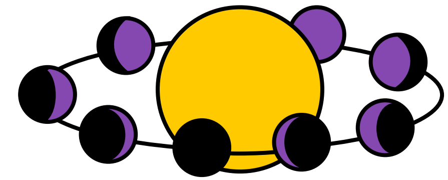
Ice-rich surface

Fe-oxidized

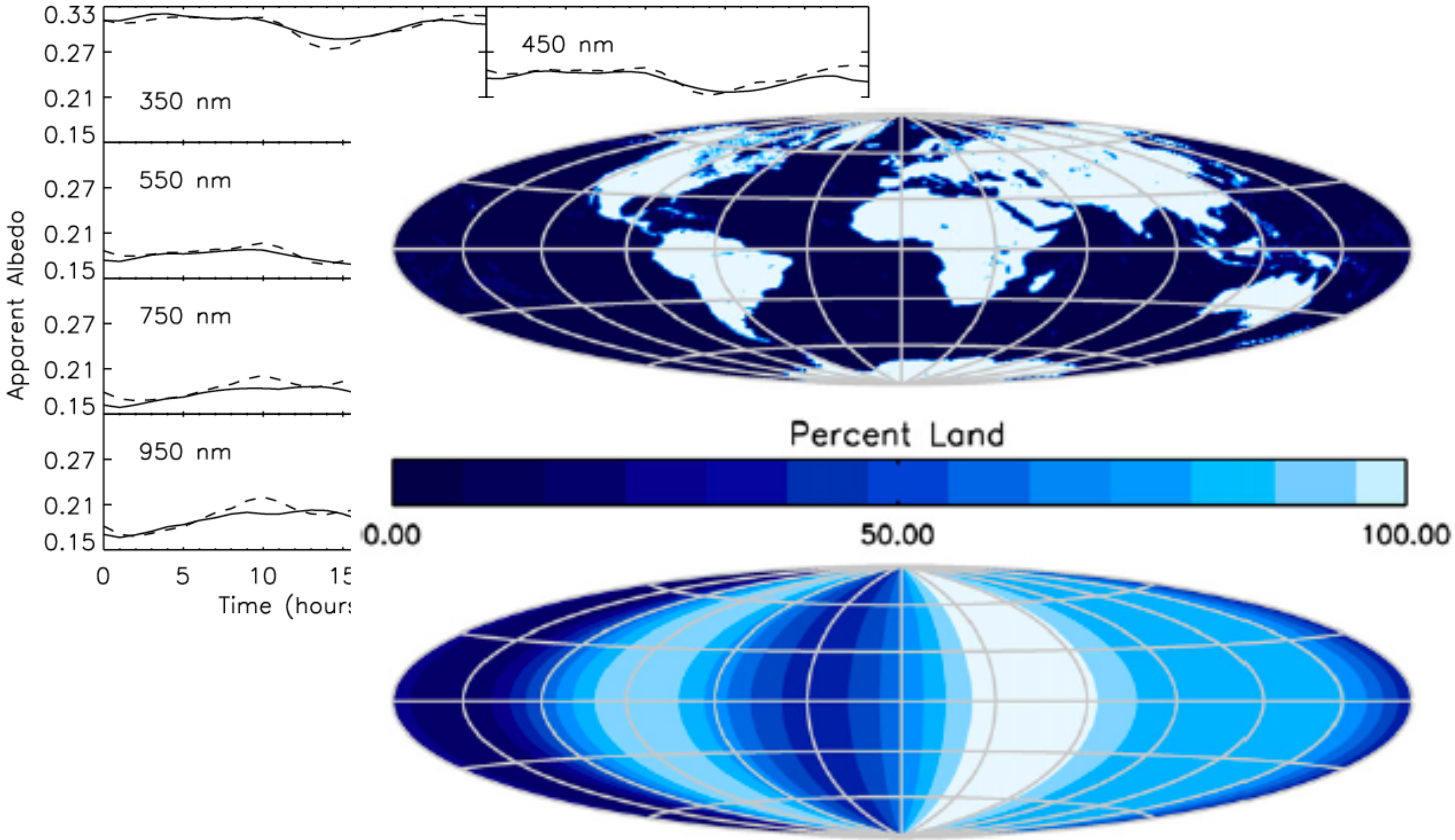
Oxidative weathering

Hu et al. 2012

Delineate Land and Sea



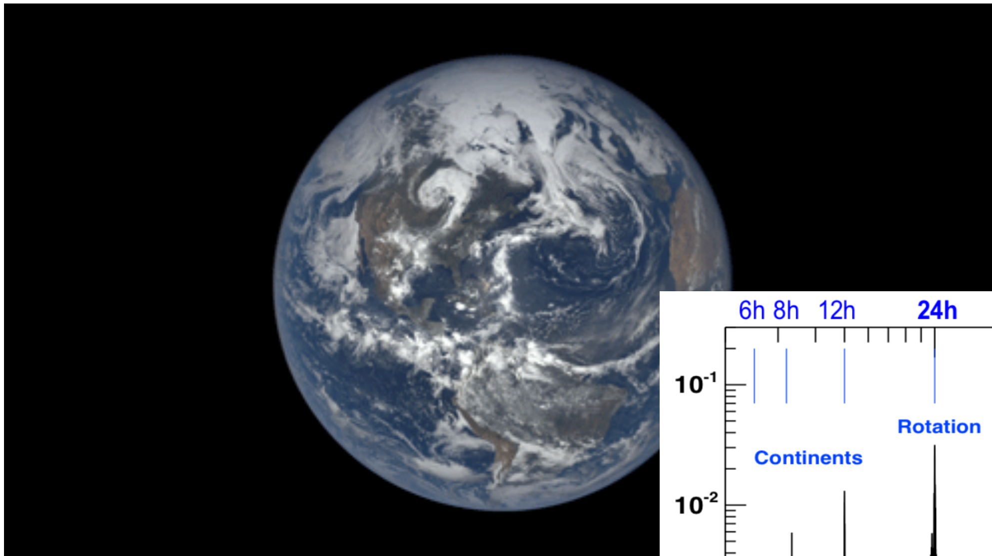
From phase curves of a rocky planet



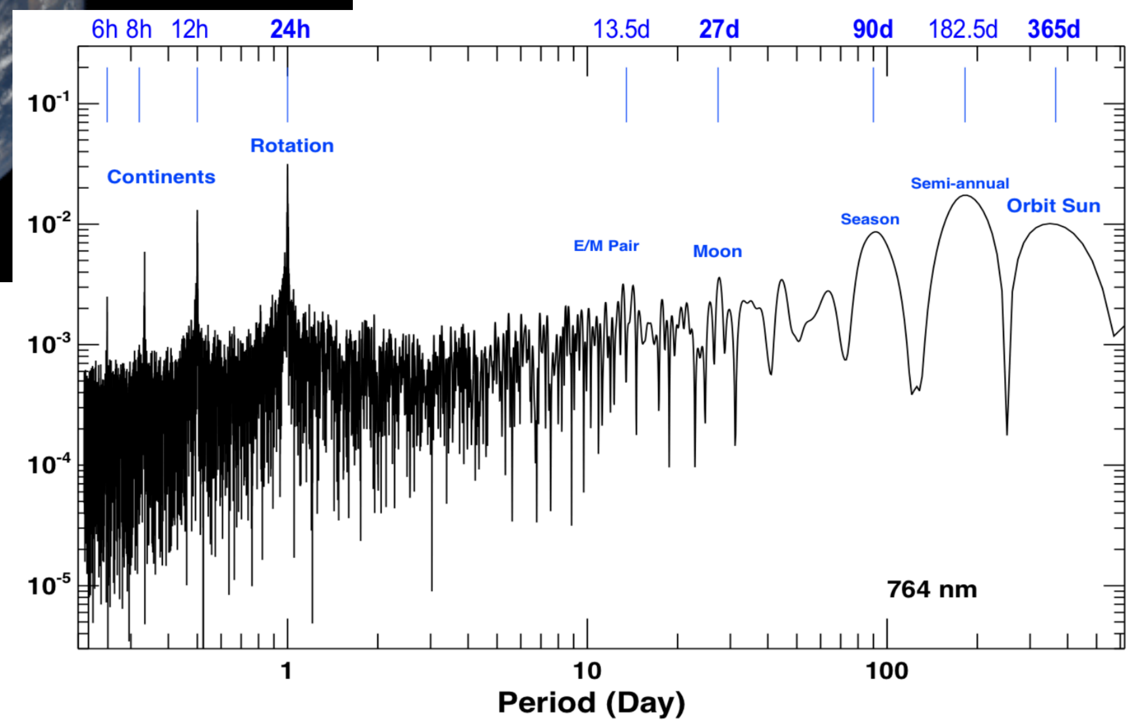
Cowan et al. 2009

Rotation Period and Hydrological Cycle

What we learned from DSCOVR observations of Earth



Minimum sampling rate is 10 hours



Jiang et al. 2018

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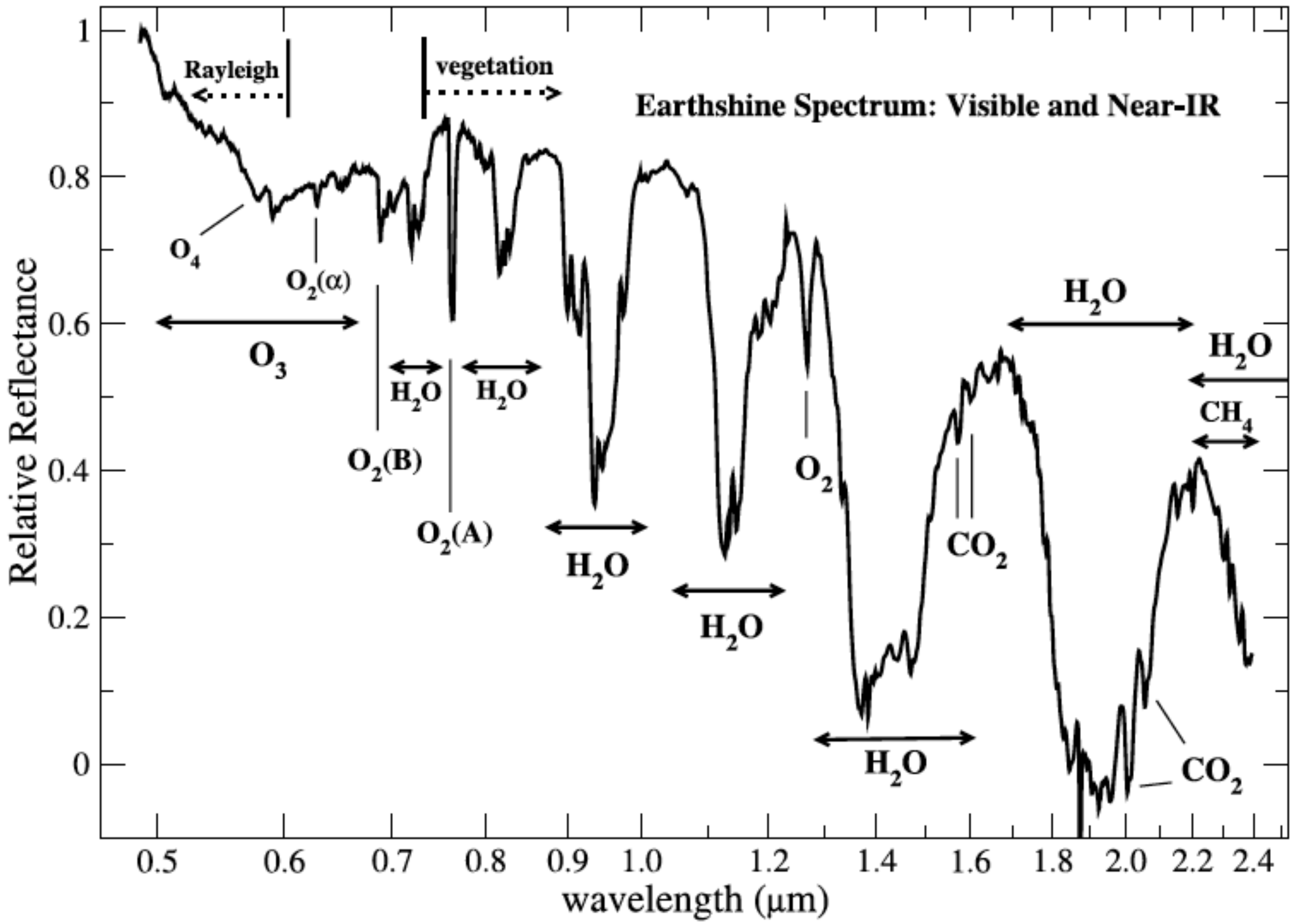
Detecting an Earth-like Atmosphere

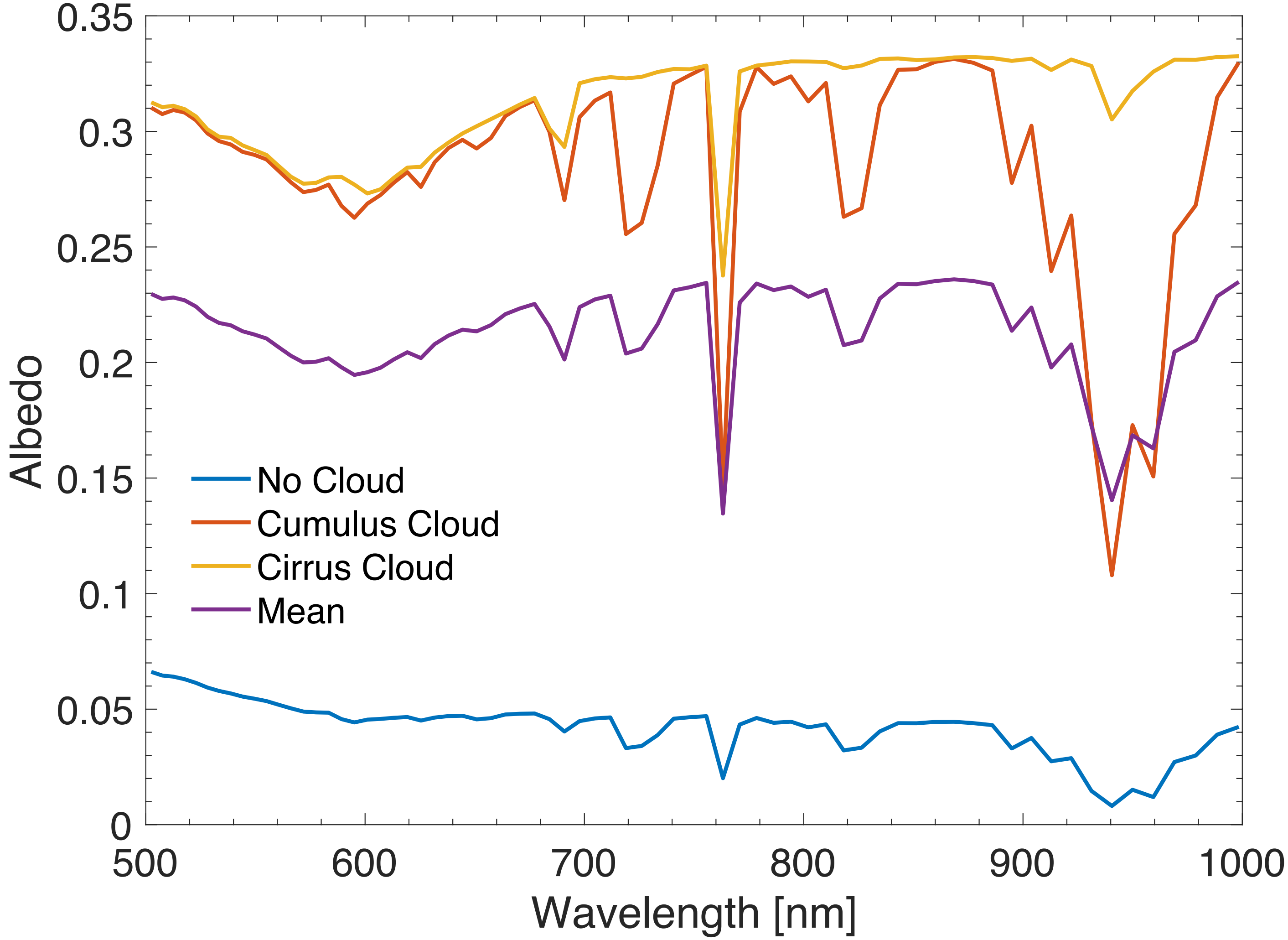
Water, Oxygen, and Carbon Dioxide



Turnbull et al. 2006

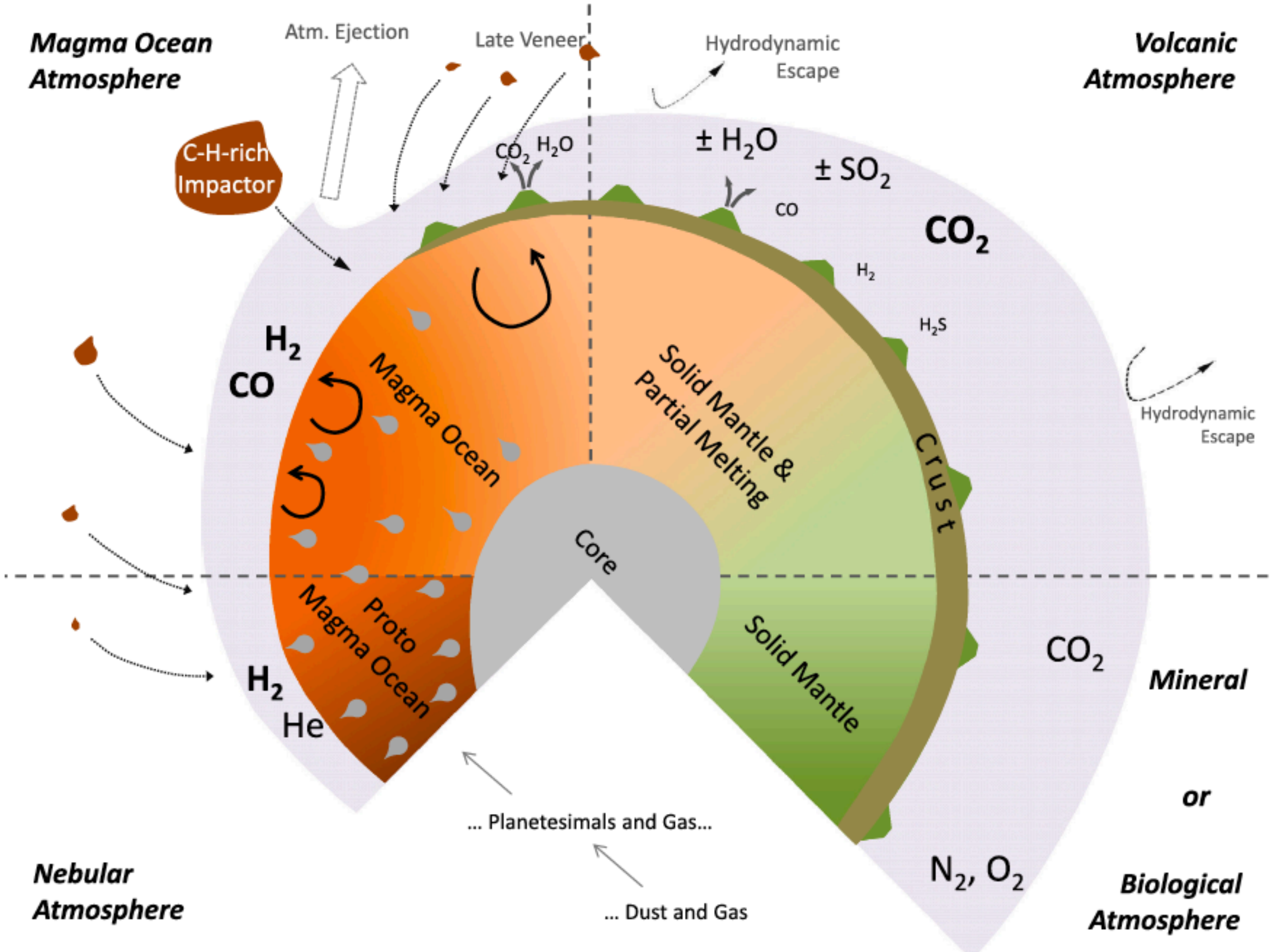
Detecting an Earth-like Atmosphere

Importance of Clouds



Detecting Earths and Super-Earths

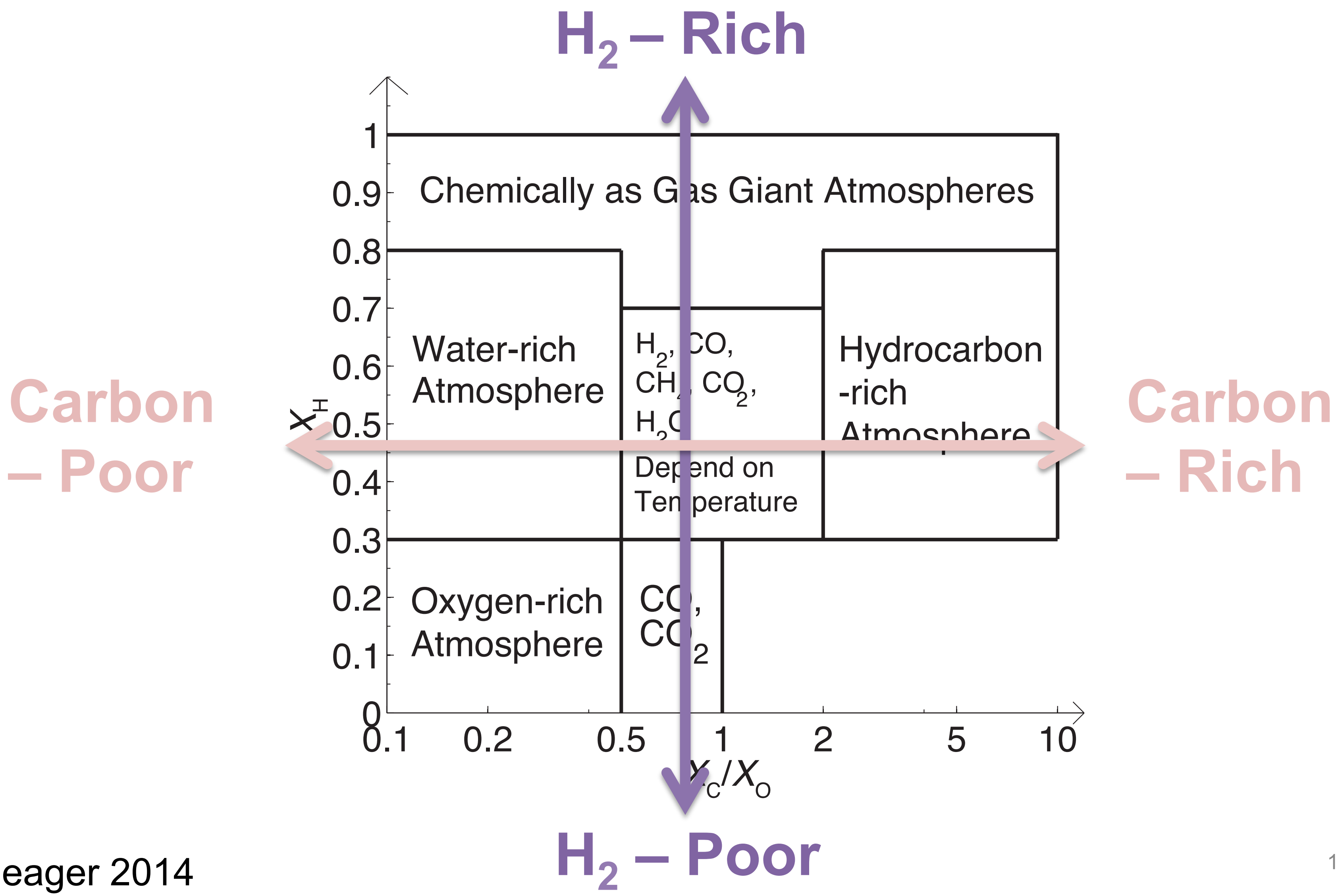
Diverse atmospheric composition of rocky planets



Gaillard & Scaillet 2014

Continuum from Super-Earths to Sub-Neptunes

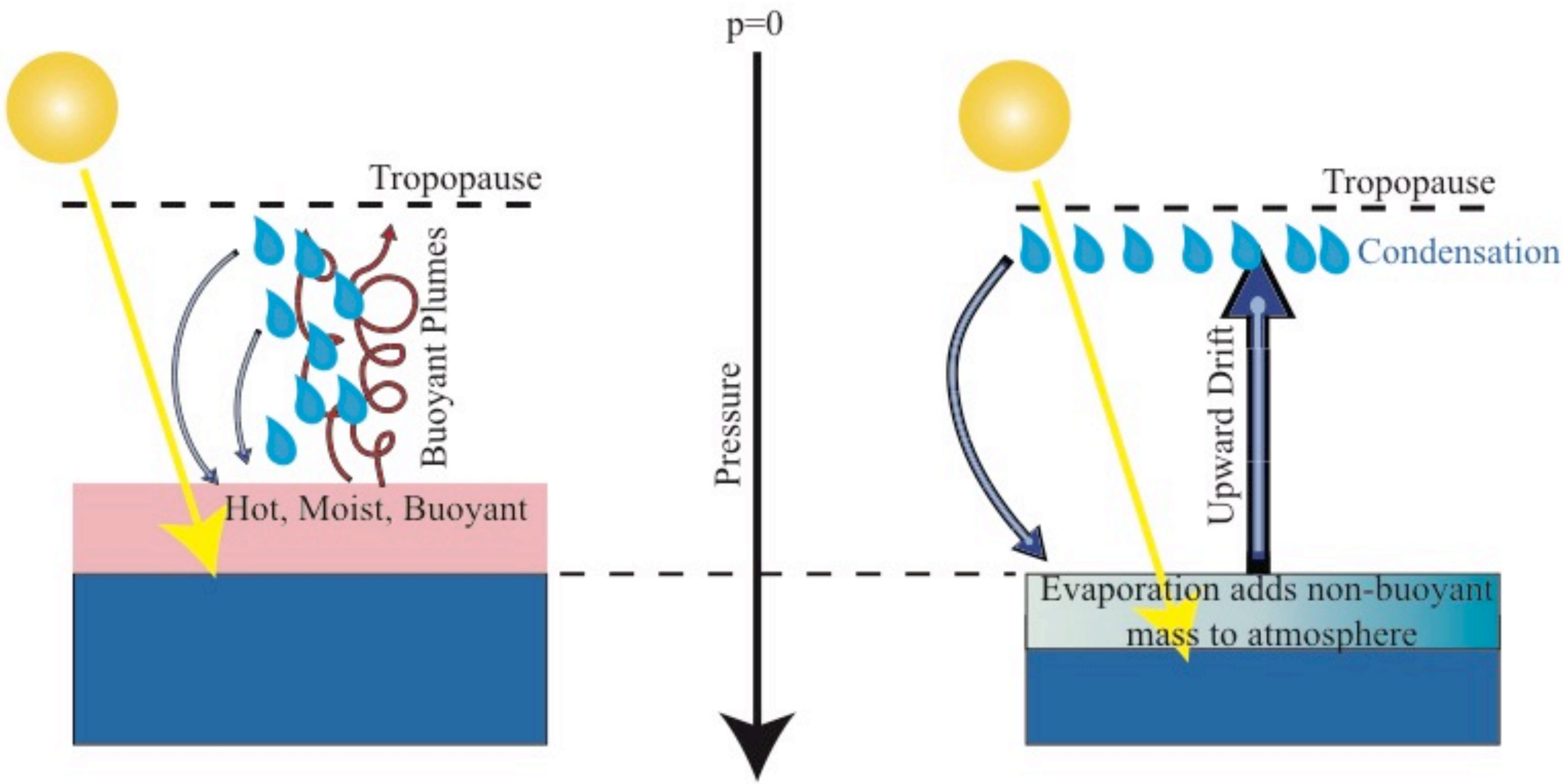
Diversity of Atmospheres



Hu & Seager 2014

A Special Case for Water Worlds

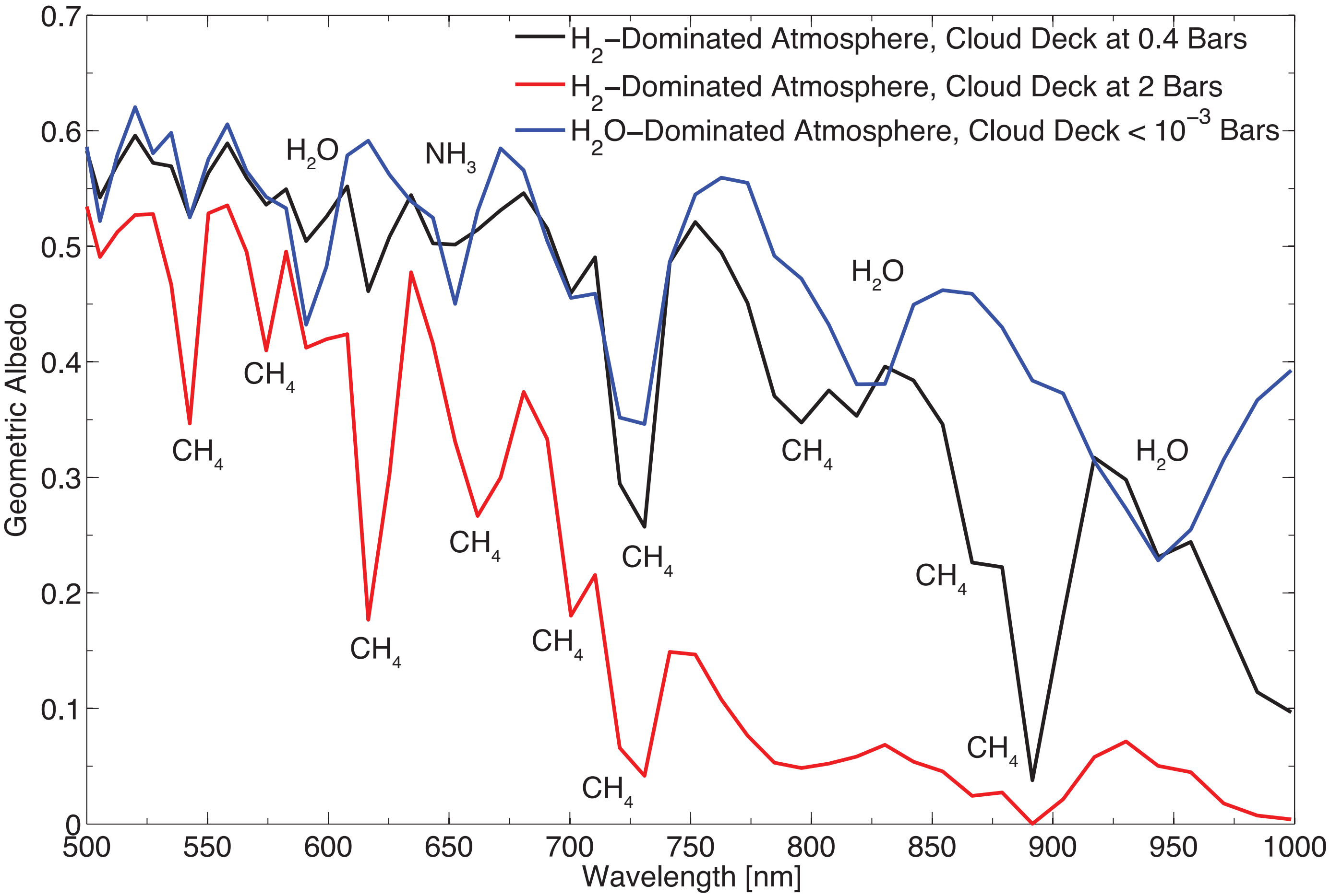
Condensible-Rich Atmospheres



Ding & Pierrehumbert 2016

Distinguish Water Worlds vs. Giant Planets

In reflected light



Interplay between clouds and C, N, O abundances

Haze Production in Photochemical Processes

Neptunes and H_2O-rich Super-Earths

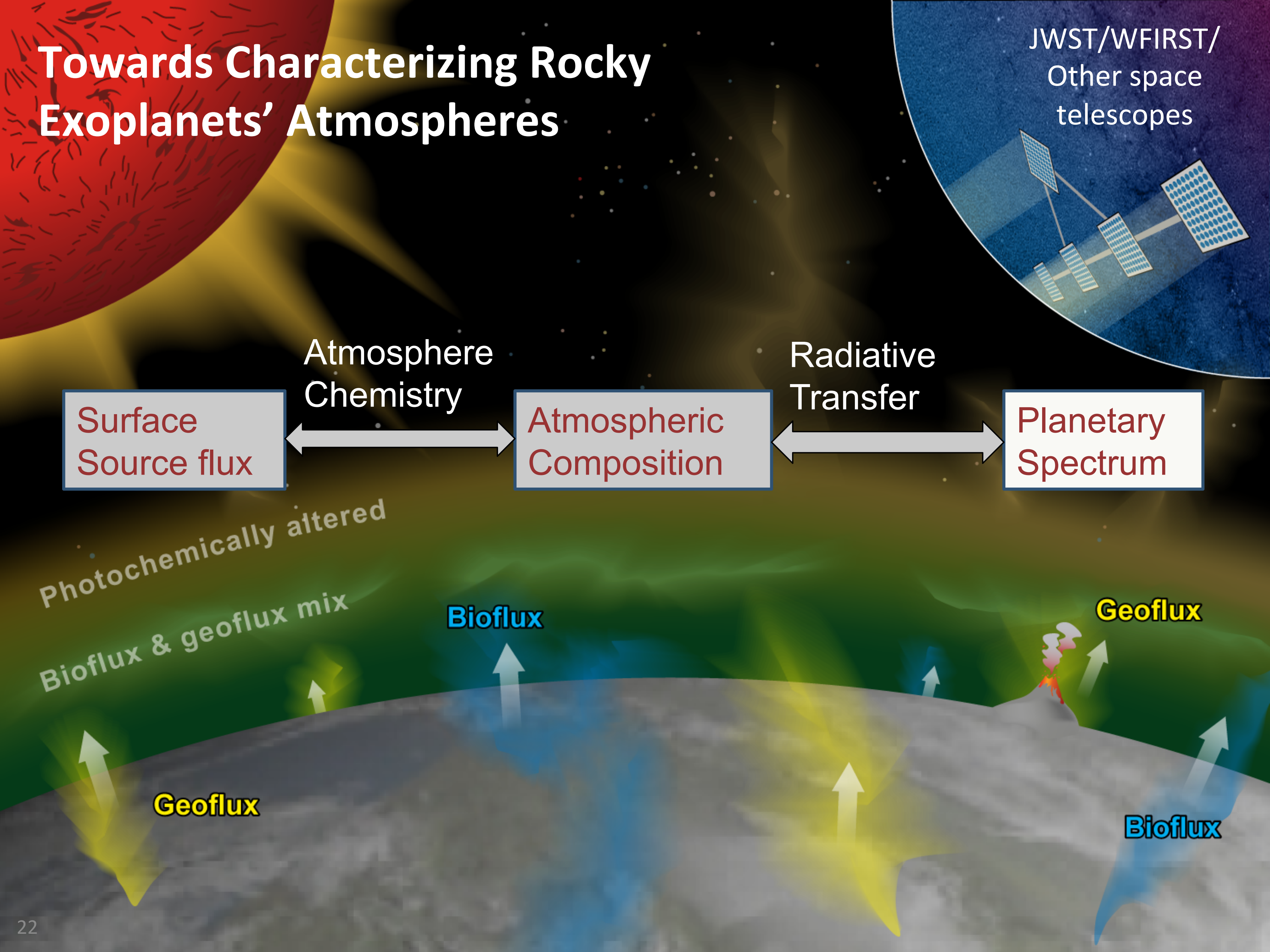
Spectral Degeneracies and Information Content

Hu 2014;
Filippatos & Hu in prep.

How do we know

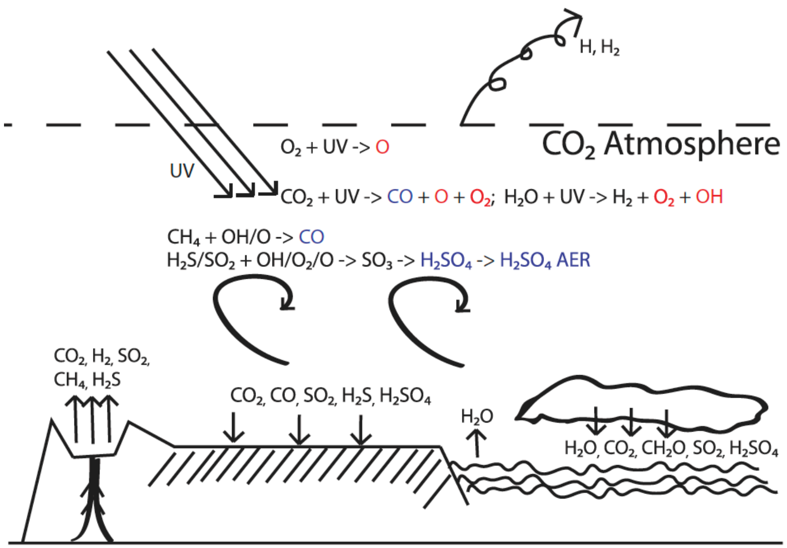
- **whether an exoplanet has an atmosphere?**
- **whether an exoplanet's atmosphere has evolved?**
- **whether an exoplanet has geological/biological activities?**

Towards Characterizing Rocky Exoplanets' Atmospheres

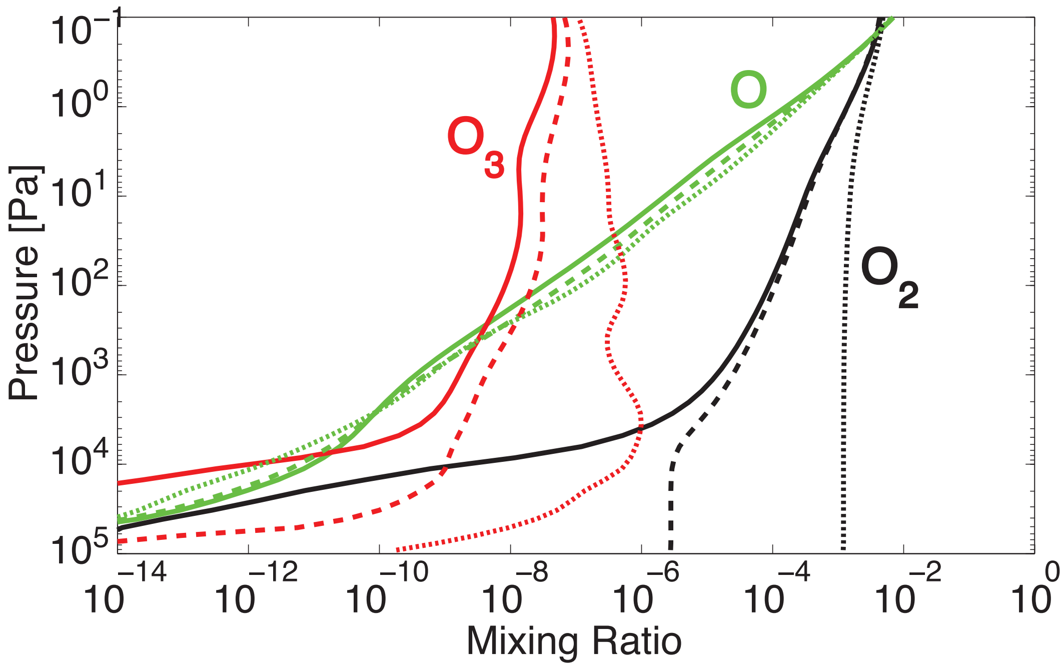


Characterize Rocky Exoplanets' Atmospheres

Volcanic emission controls O_2 buildup in CO_2 atmospheres



Escape of hydrogen is balanced by a net oxidizing flux from the atmosphere to the ocean

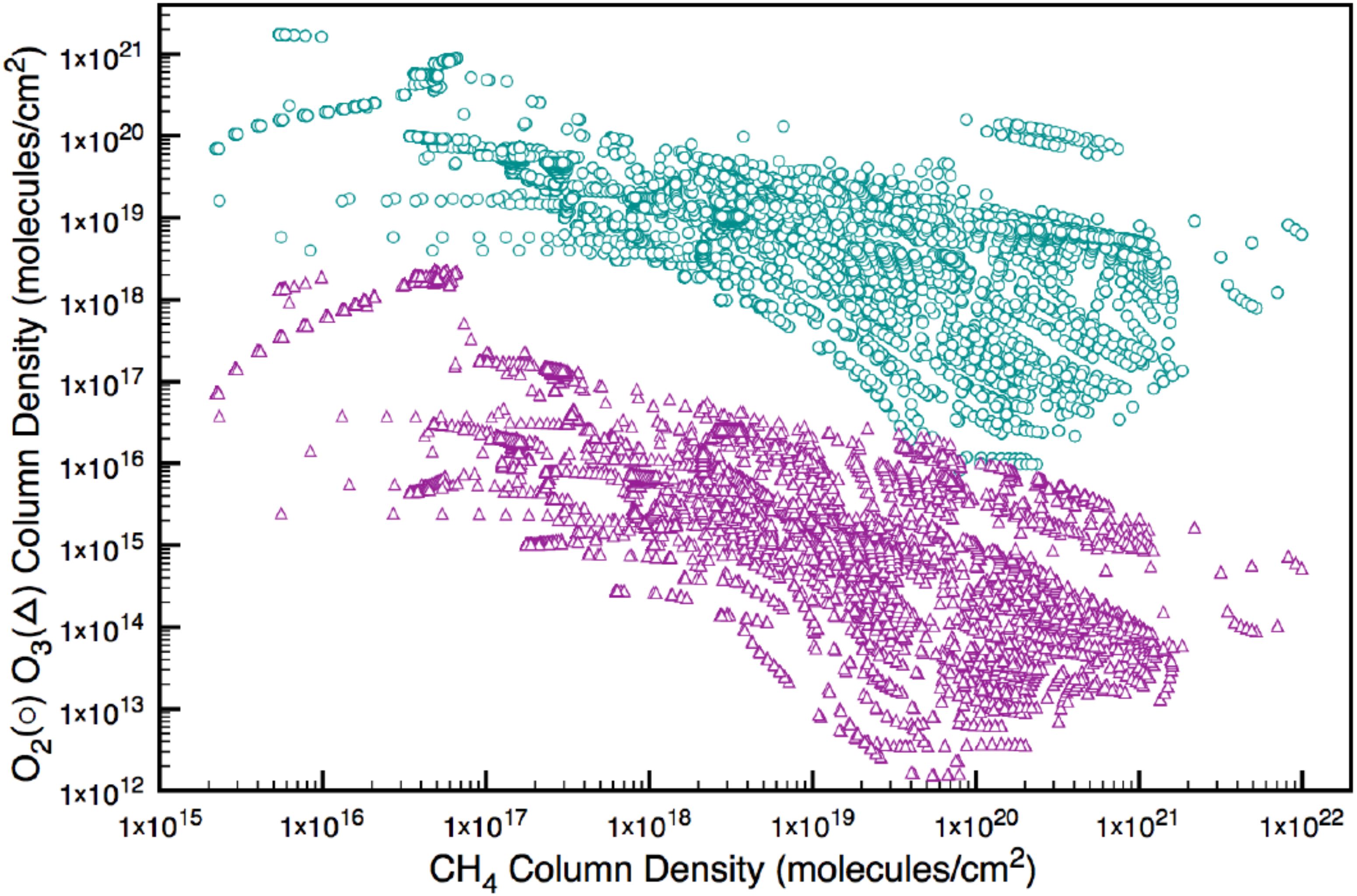


Solid: Earth-like vol. emission
Dashed: Low vol. emission
Dotted: No vol. emission

Hu et al. 2012

Characterize Rocky Exoplanets' Atmospheres

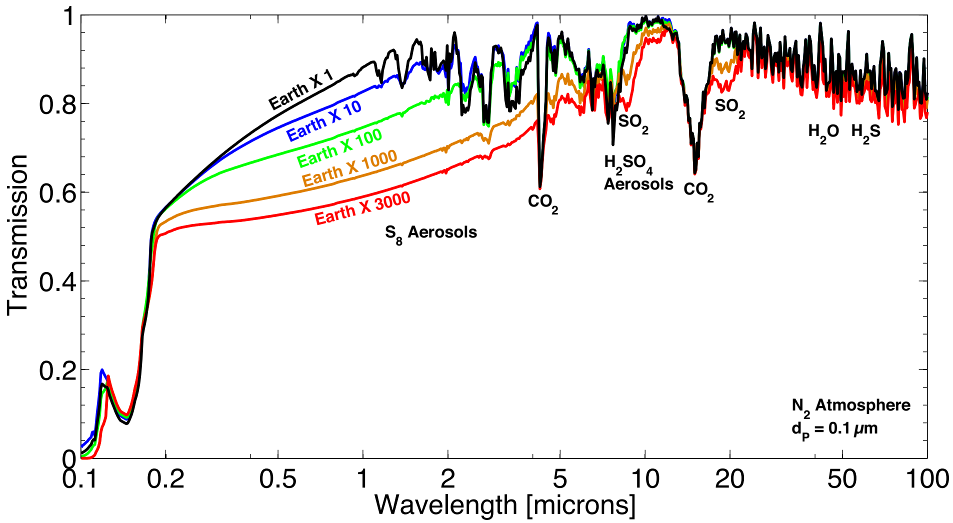
O_2 and CH_4 together as a biosignature

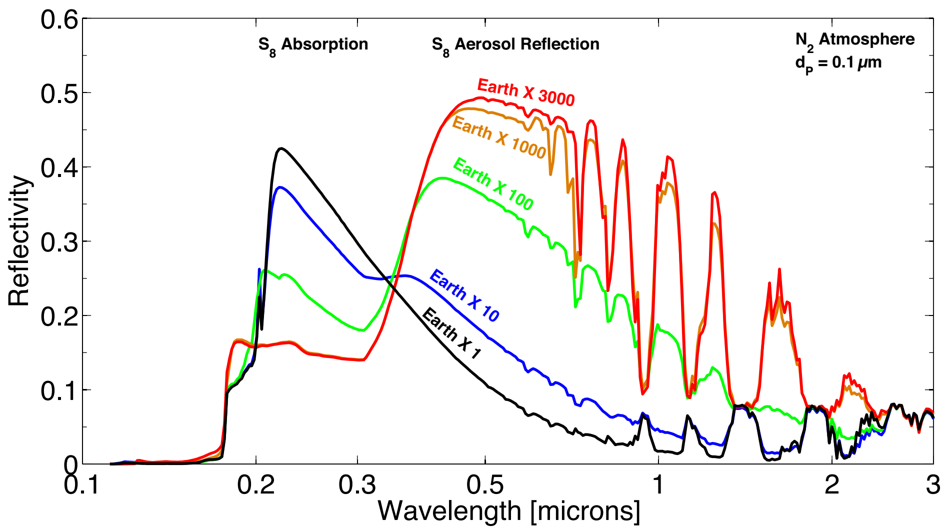


Domagal-Goldman et al. 2014

Characterize Rocky Exoplanets' Atmospheres

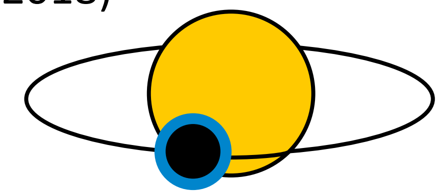
Measuring volcanic outgassing





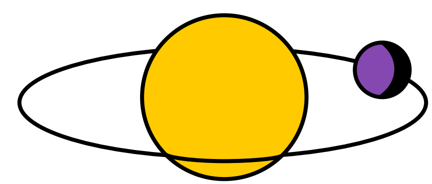
Transit

- Ground-based transit surveys, TESS
- James Webb Space Telescope (JWST, launch 2018)



Direct imaging

- Starshade Rendez-vous with WFIRST
- Flagship concepts for 2020 Astrophysics Decadal Survey (HabEx + LUVOIR)



Hu et al. 2013

Conclusion

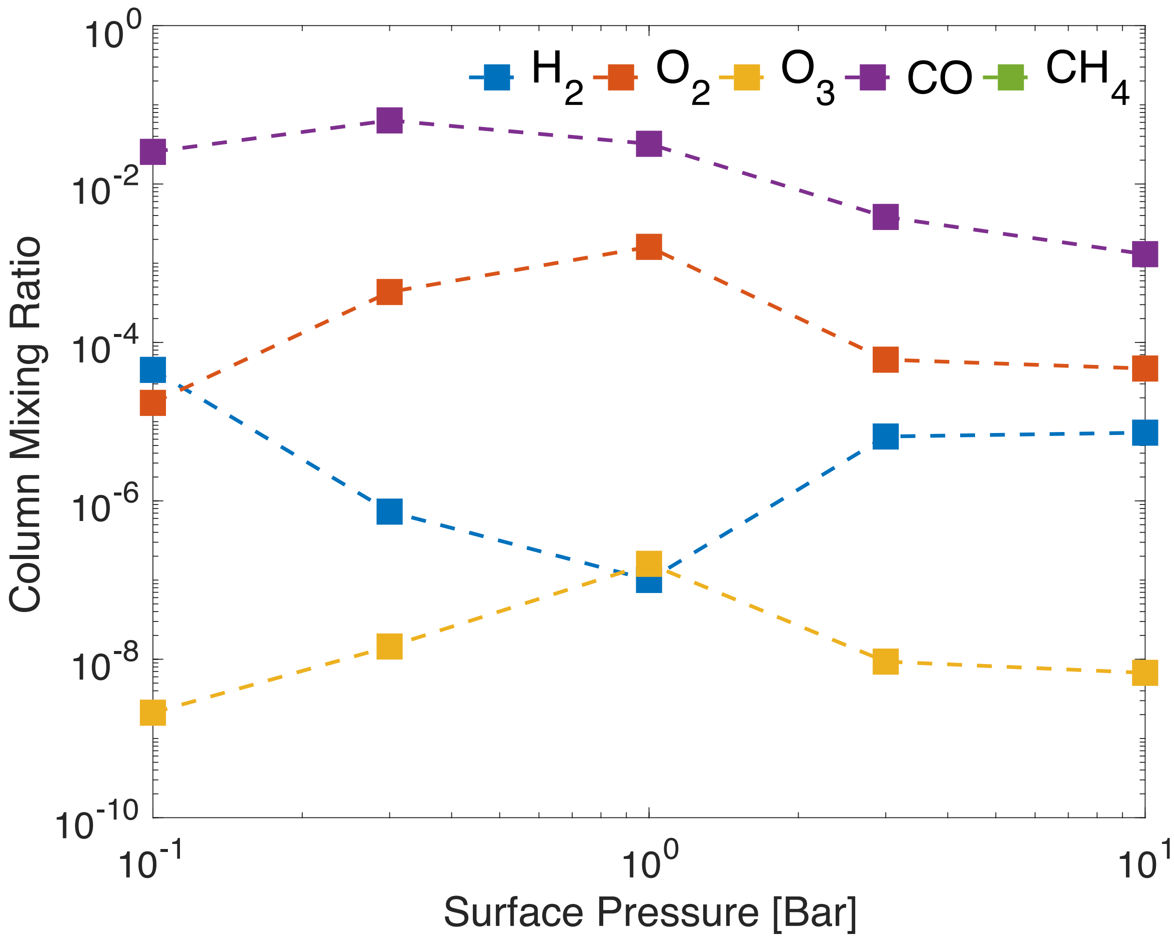
- Direct imaging will enable characterization of Earths and super-Earths
- We may learn about: surface type, atmospheric H_2O, O_2, CO_2, rotation period, variability of clouds
- It may be hard to directly measure: size of planet, mass of atmosphere, liquid water ocean
- Intrinsic widths of spectral features will determine the required resolution, and the need to measure variability will determine the required collection area

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

Carl Sagan, *Contact*, 1985

Characterize Rocky Exoplanets' Atmospheres

Sensitivity to atmospheric surface pressure



How does O_2 buildup depend on surface pressure and irradiation?

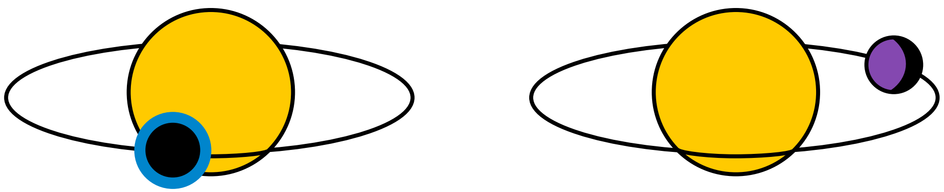
Tre'Shunda James
Intern at JPL

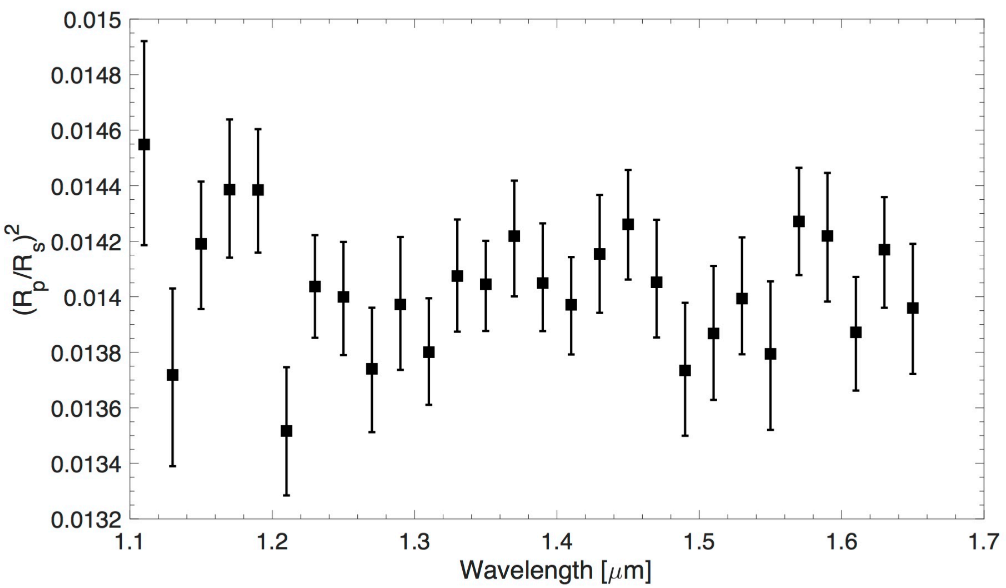
Oxygen buildup peaks at ~1 bar

James & Hu, in prep.

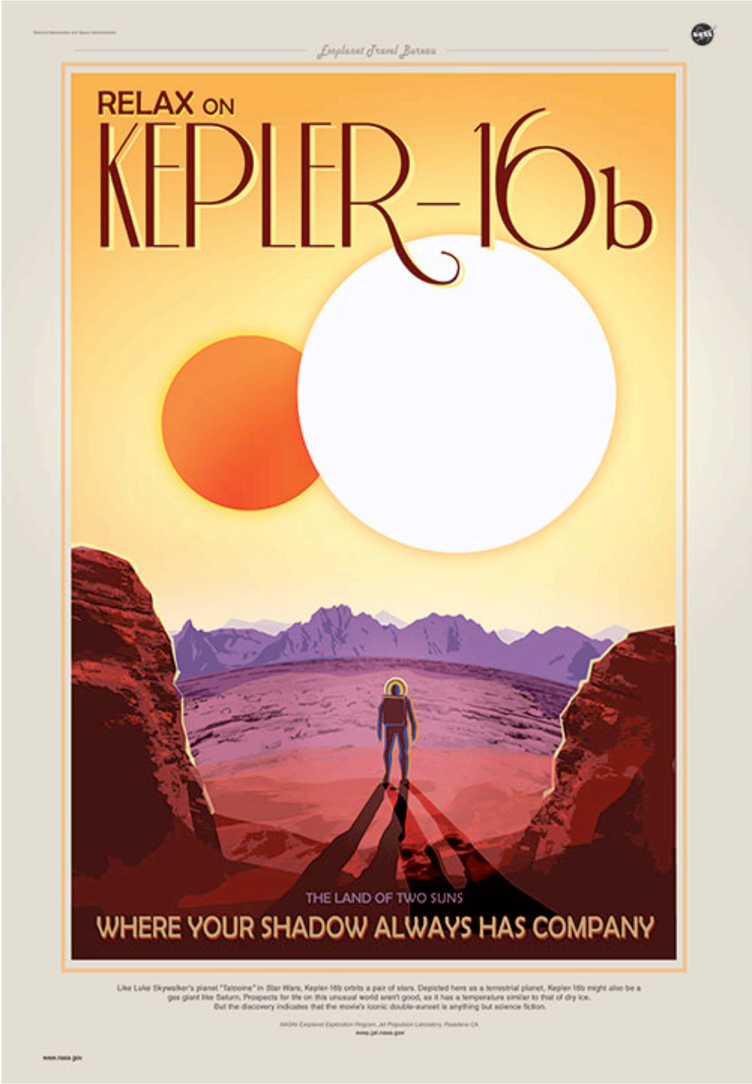
Atmospheres of Wide-Separation Exoplanets

Synergy between transit and direct imaging





Transit spectrum of a 229-day-period exoplanet Kepler 16-b (HST GO 14927, PI Renyu Hu)



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