Highly Evolved Exoplanet Atmospheres

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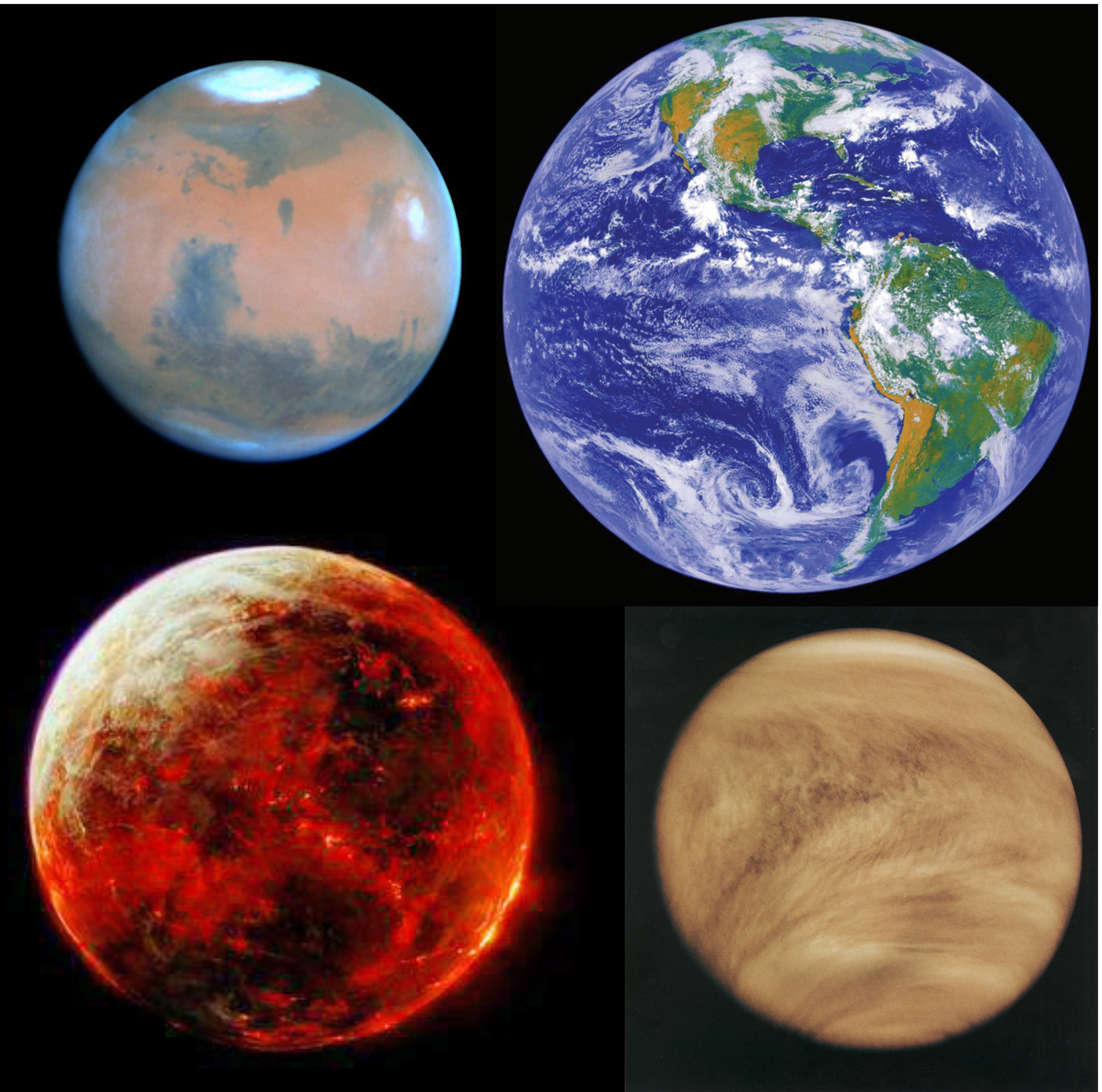
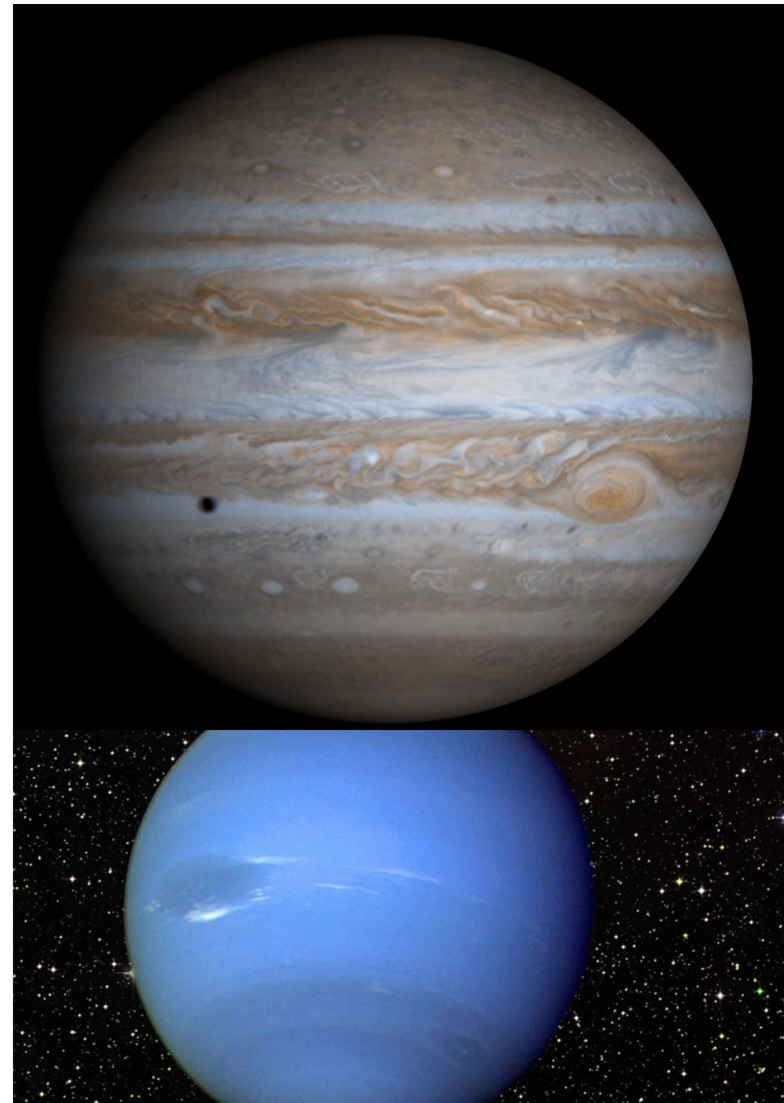
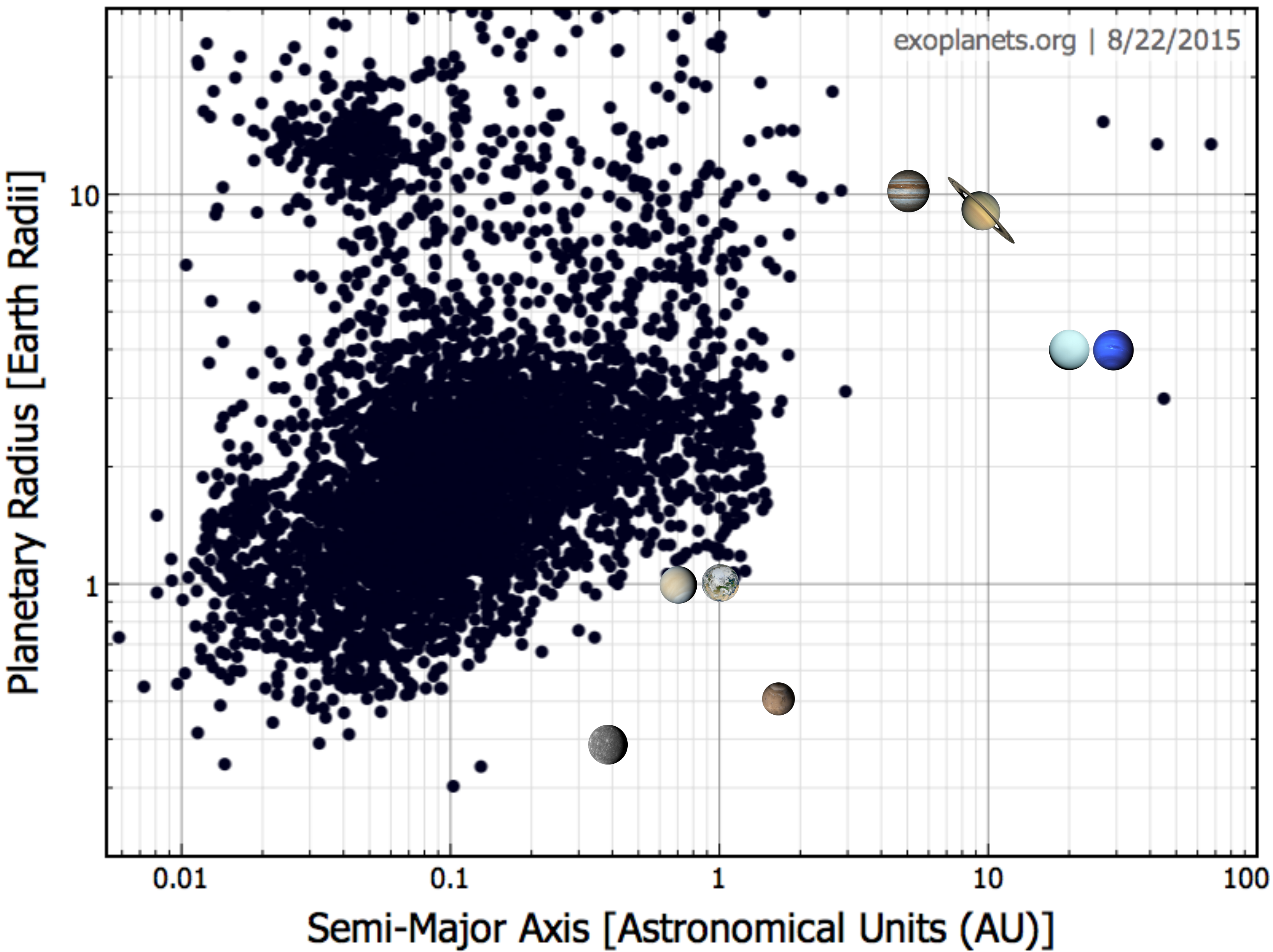
Diverse Atmospheres on Terrestrial Planets

H_2+He Atmospheres on Gas Planets

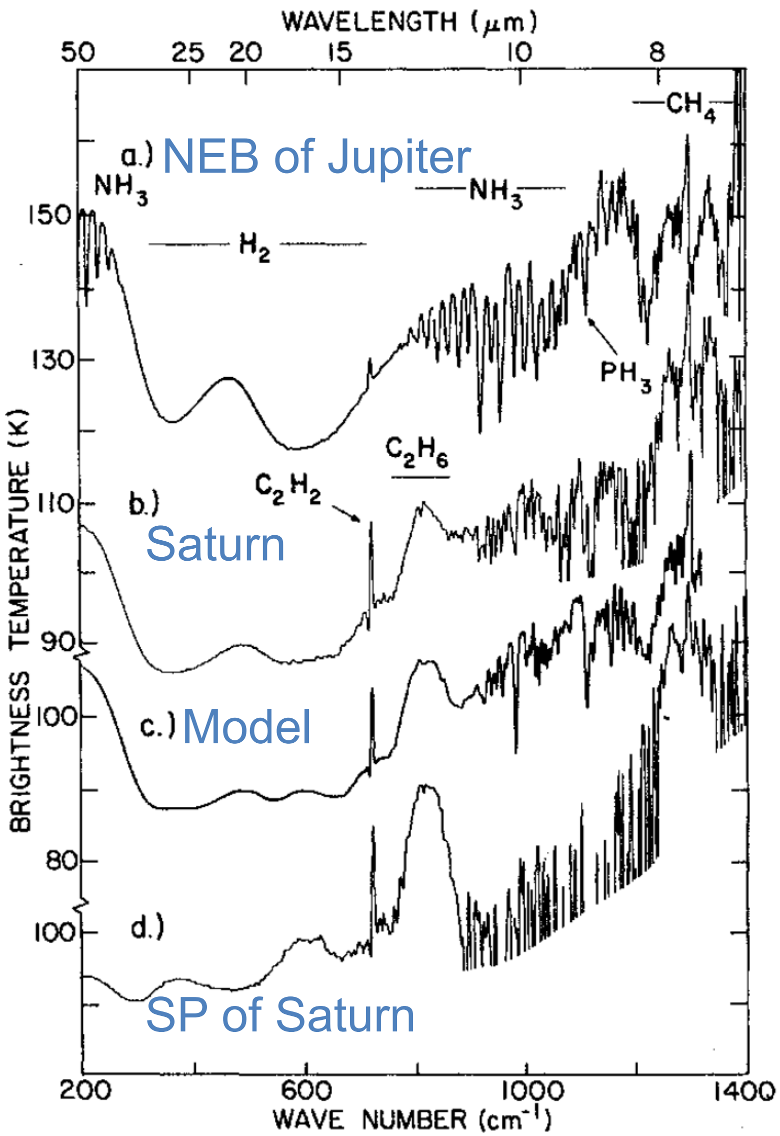


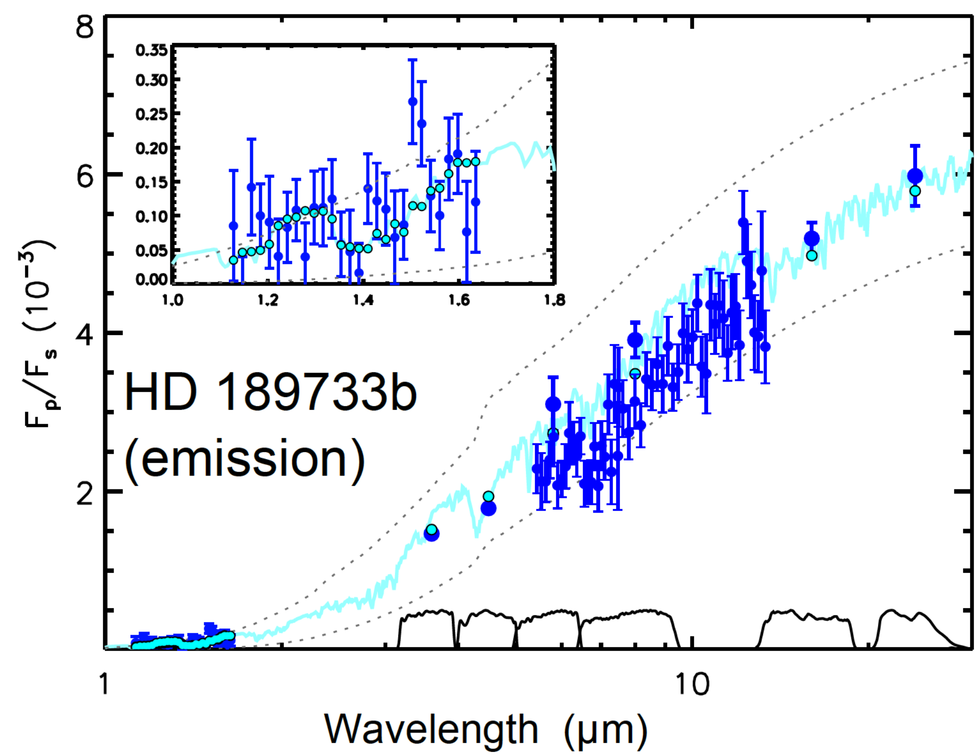


Diversity in Planet Population



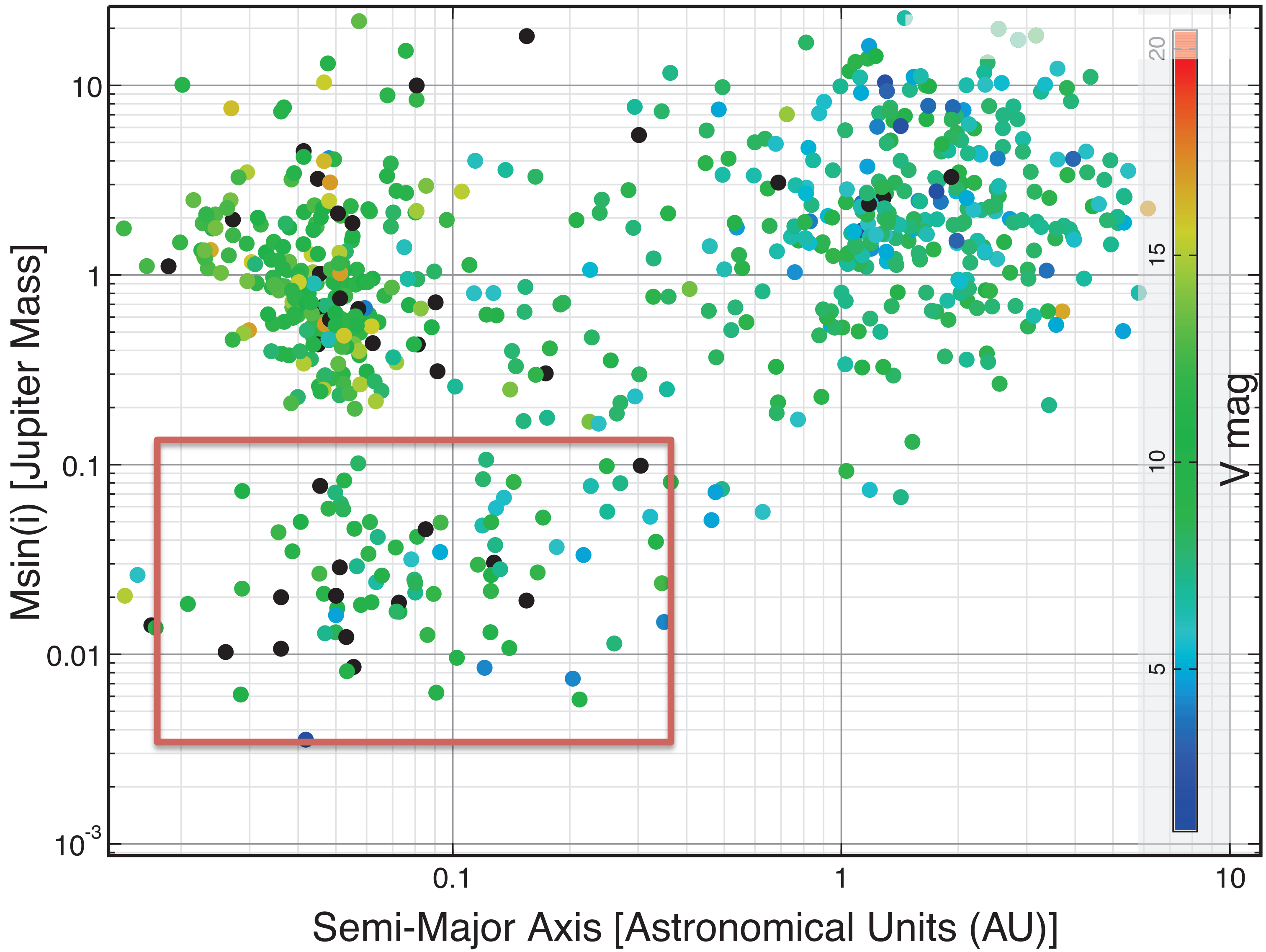
Detecting (Exo)Planet Atmospheres





Hanel et al. 1981; Crossfield et al. 2015

Warm (Sub) Neptunes

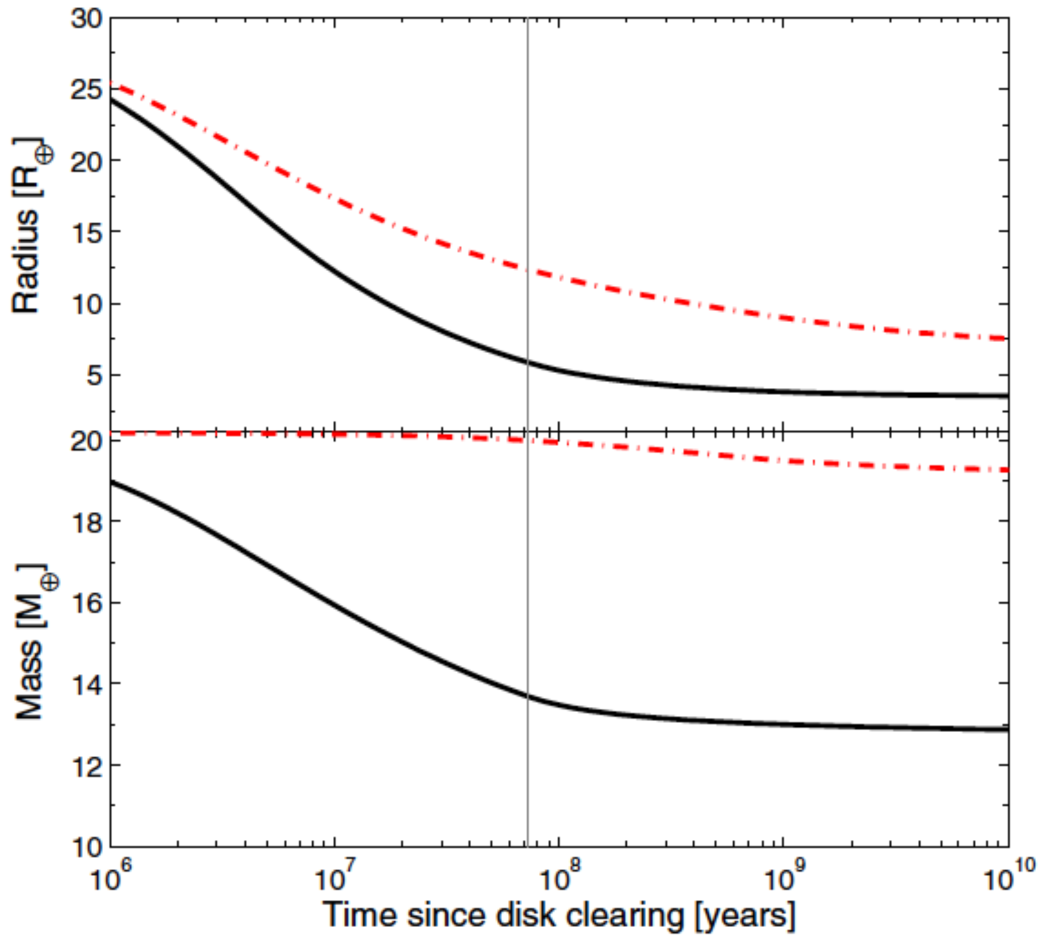


Exoplanets.org, 8/20/2015

What could happen to the H/He envelopes of super Earths/mini Neptunes?

Photoevaporation

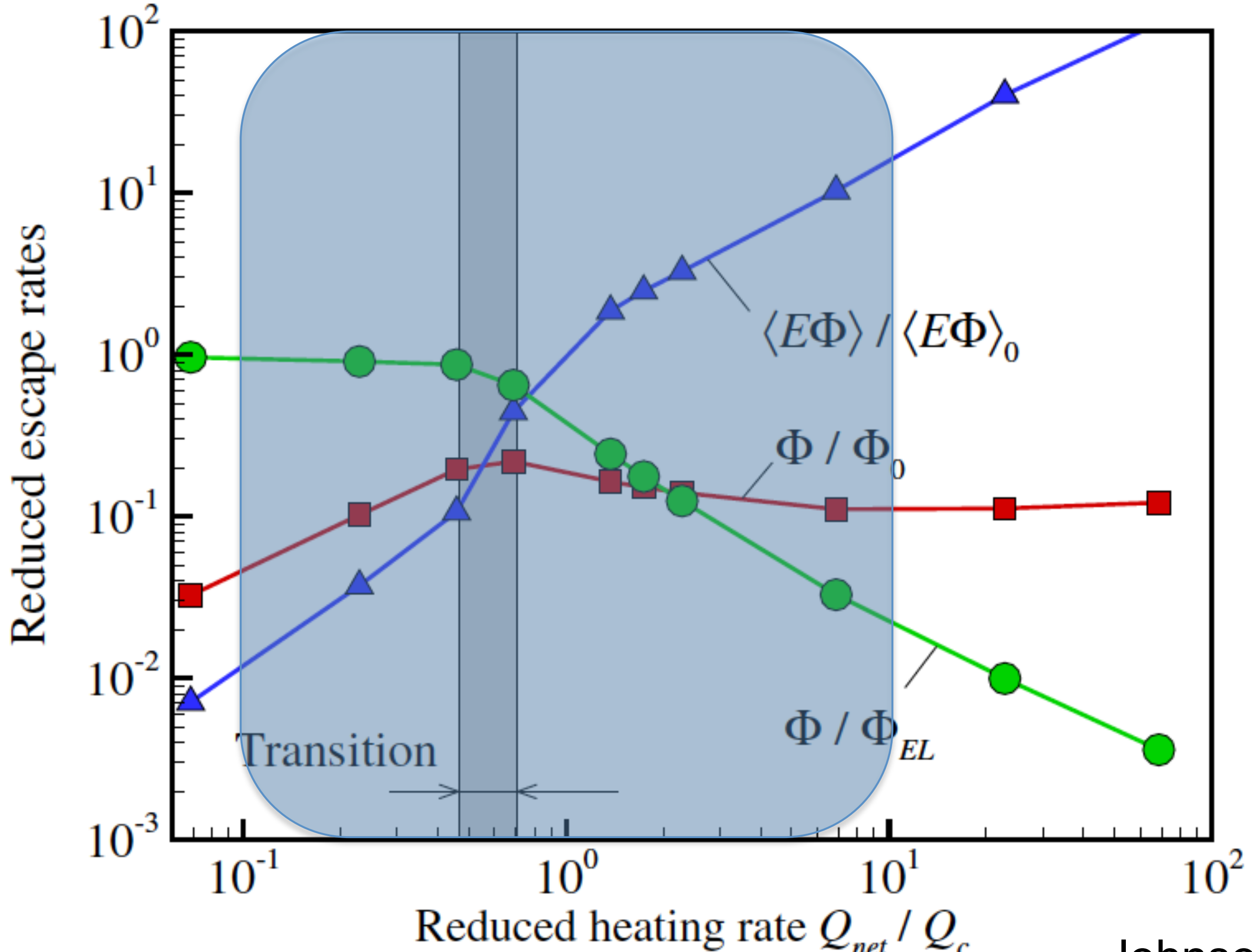
EUV and perhaps X-ray radiation of a planet's host star drives evaporation of its atmosphere



Lopez et al. 2012; Owen & Wu 2013

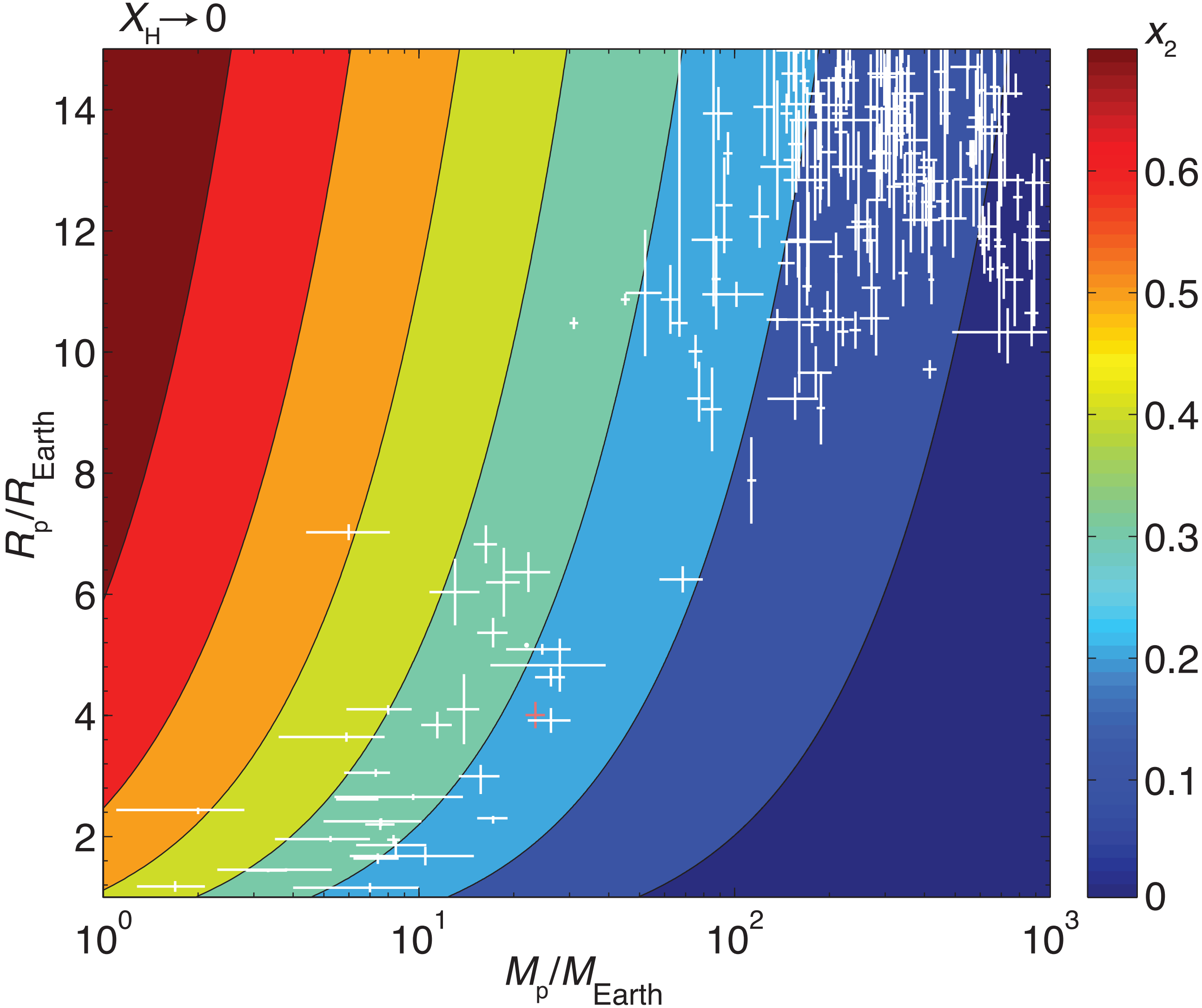
Transonic Hydrodynamic Escape

The escape rate does not increase with the heating rate in the transonic regime



Johnson et al. 2013

He vs. H in Hydrodynamic Escape



$$x_2 = \frac{\phi_{He} / \phi_H}{X_{He} / X_H}$$

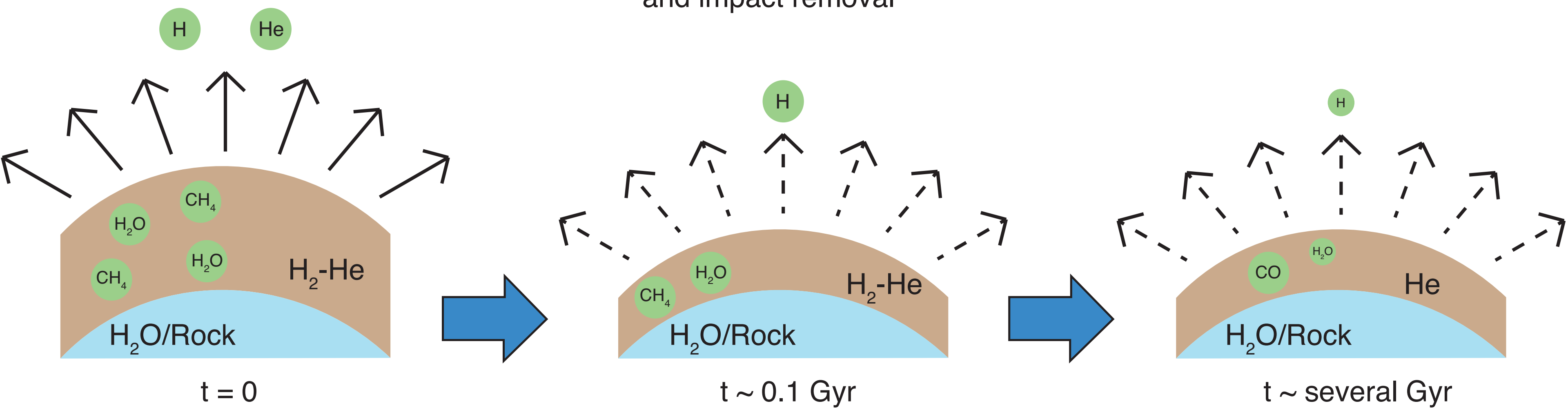
$x_2 = 1$: No Fractionation

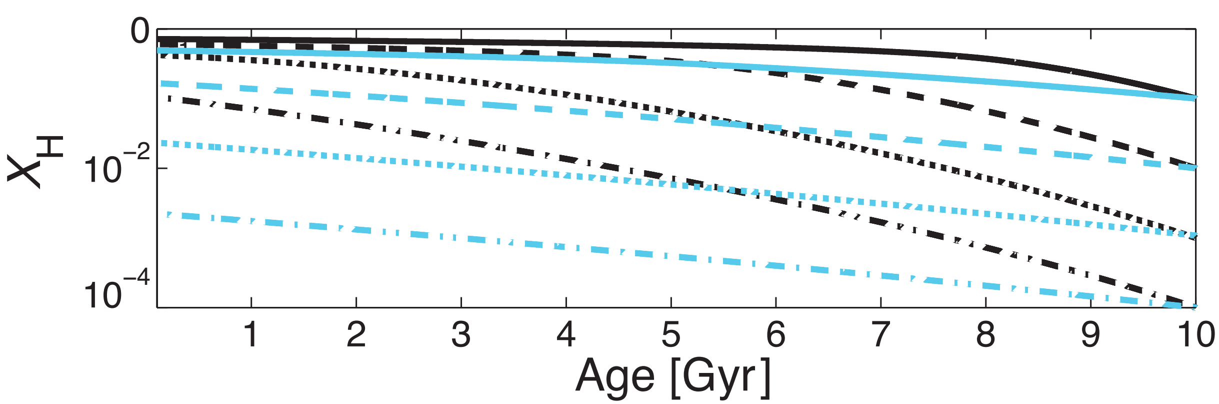
$x_2 < 1$: Fractionation in Escape

$x_2 = 0$: Diffusion-Limited Escape

Hu et al. 2015

Formation of a Helium Atmosphere





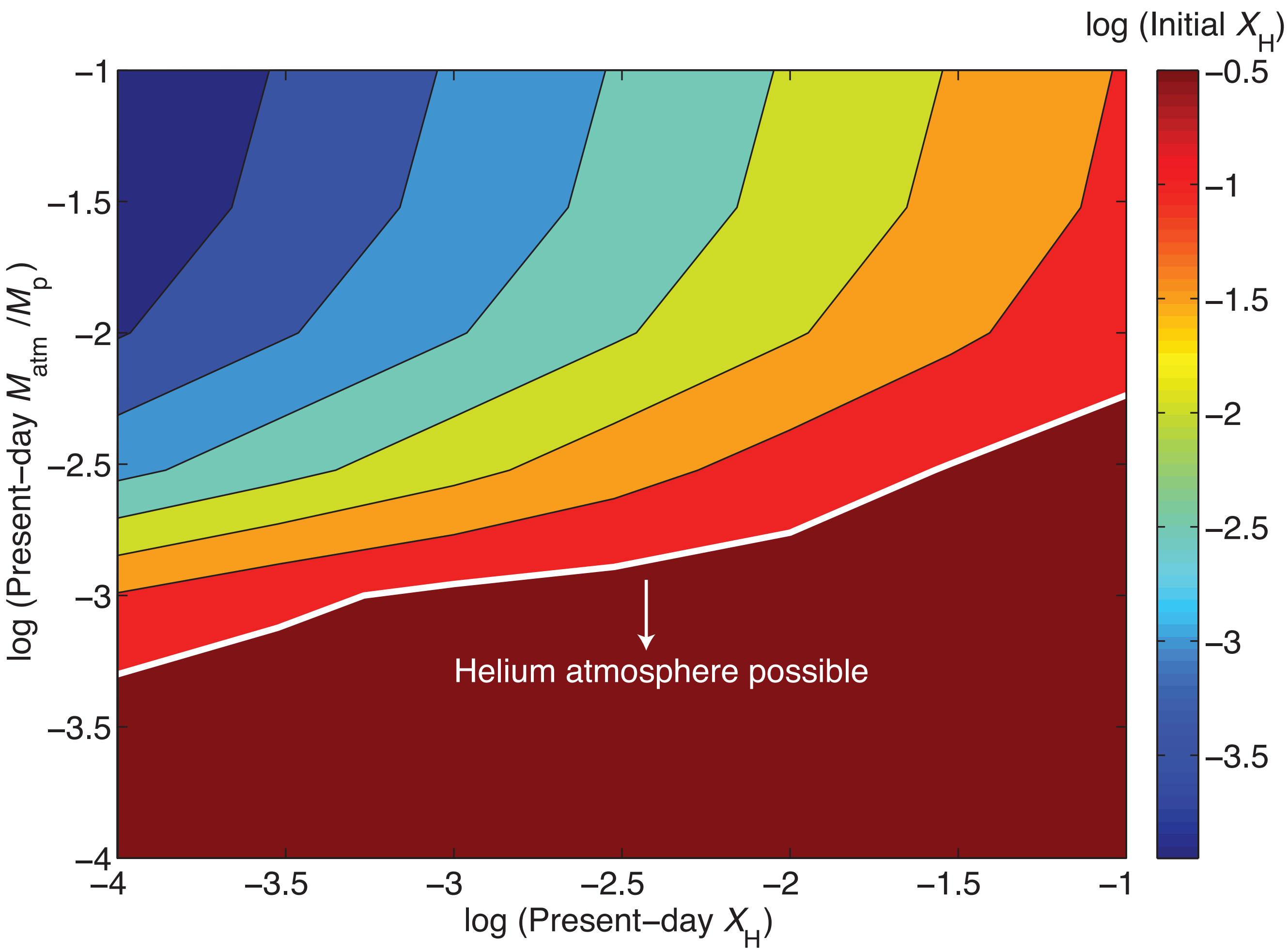
For GJ 436 b

Black: Initial Mass ~ 0.2 % Planetary Mass

Blue: Initial Mass ~ 0.4 % Planetary Mass

Hu et al. 2015

Formation of a Helium Atmosphere

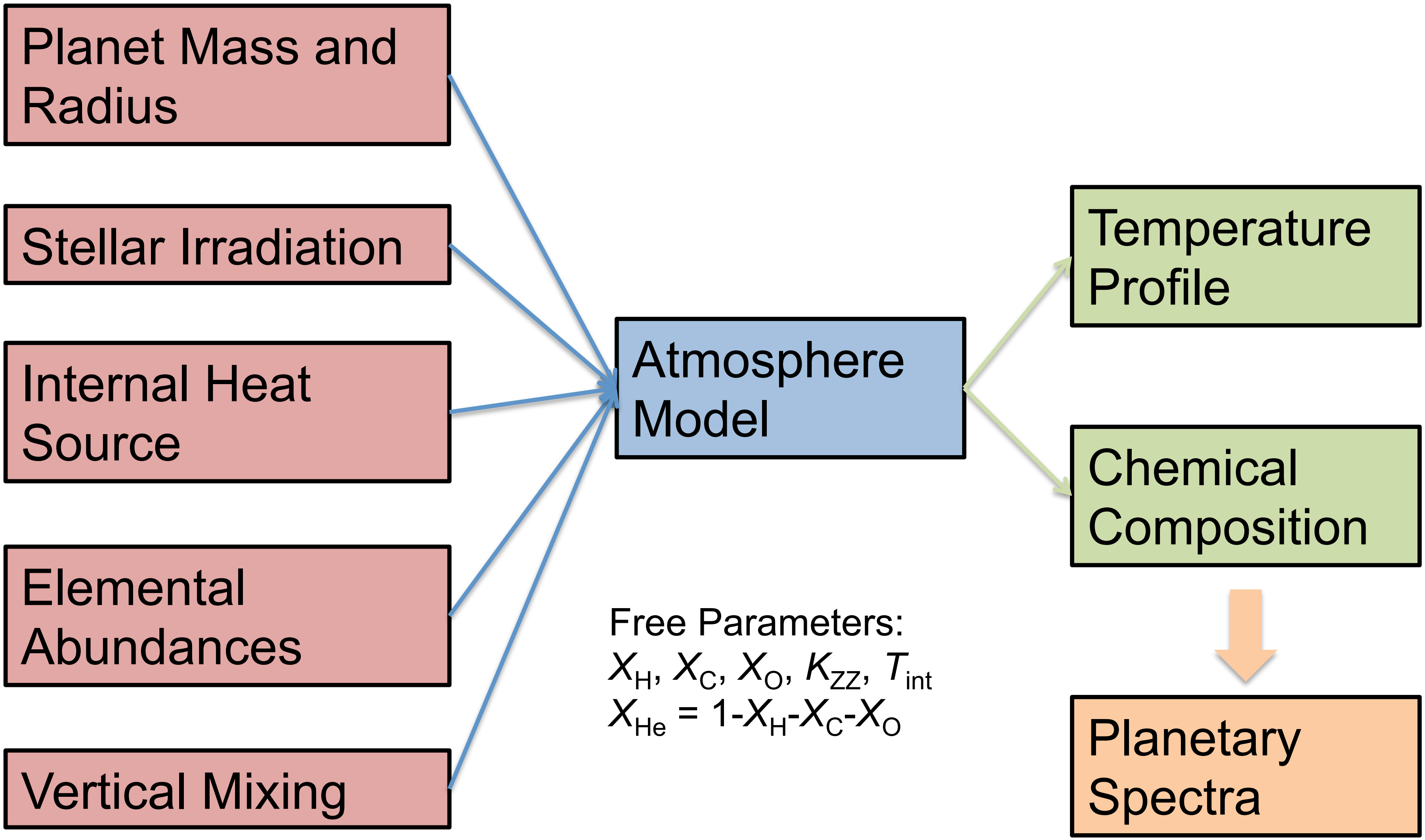


If the mass of the atmosphere is a fraction of 1% planetary mass, hydrodynamic escape can reduce the hydrogen abundance in the atmosphere by several orders of magnitude in ~10 billion years

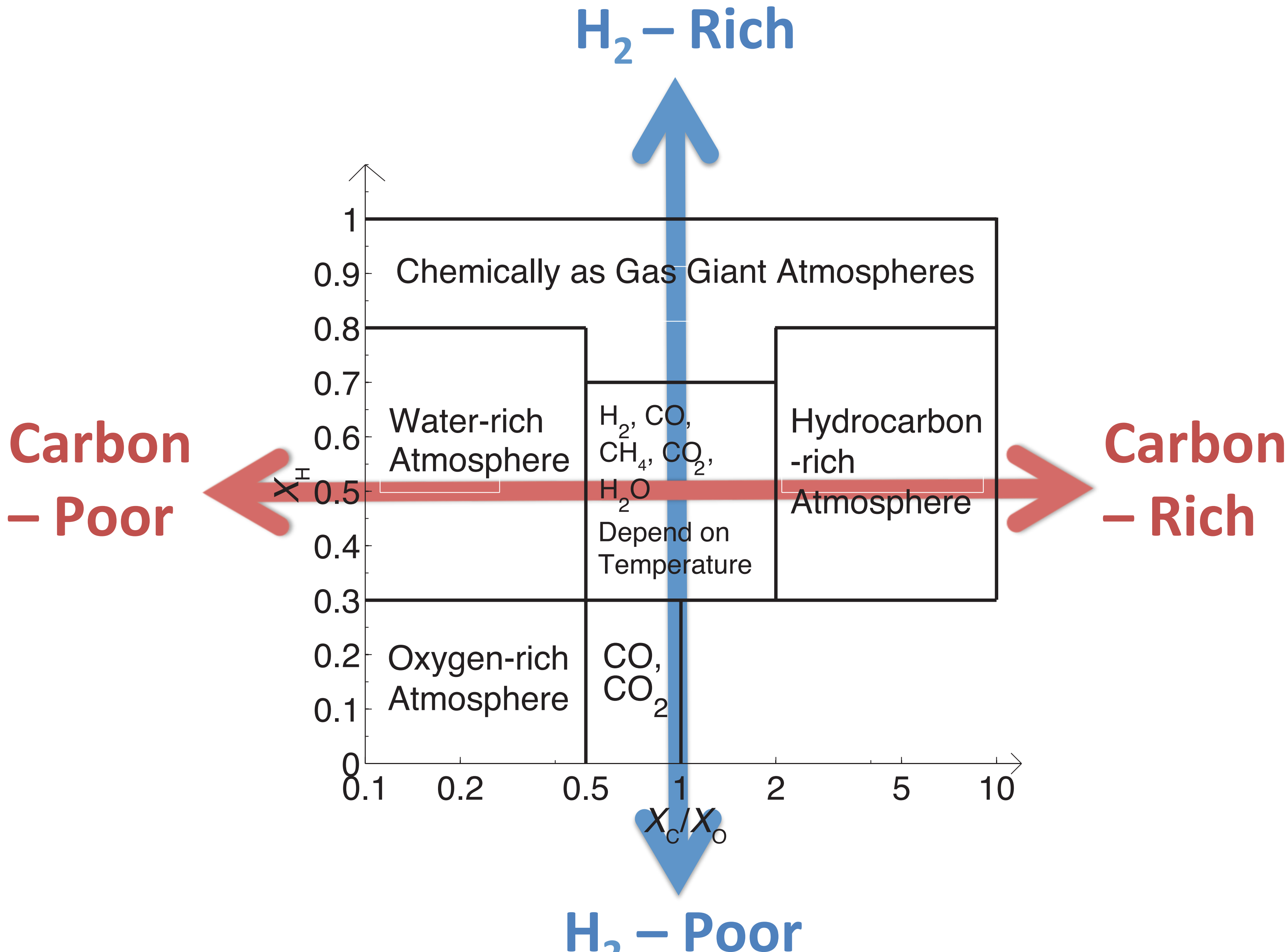
Hu et al. 2015

What are the atmospheres of evolved super Earths/mini Neptunes made of?

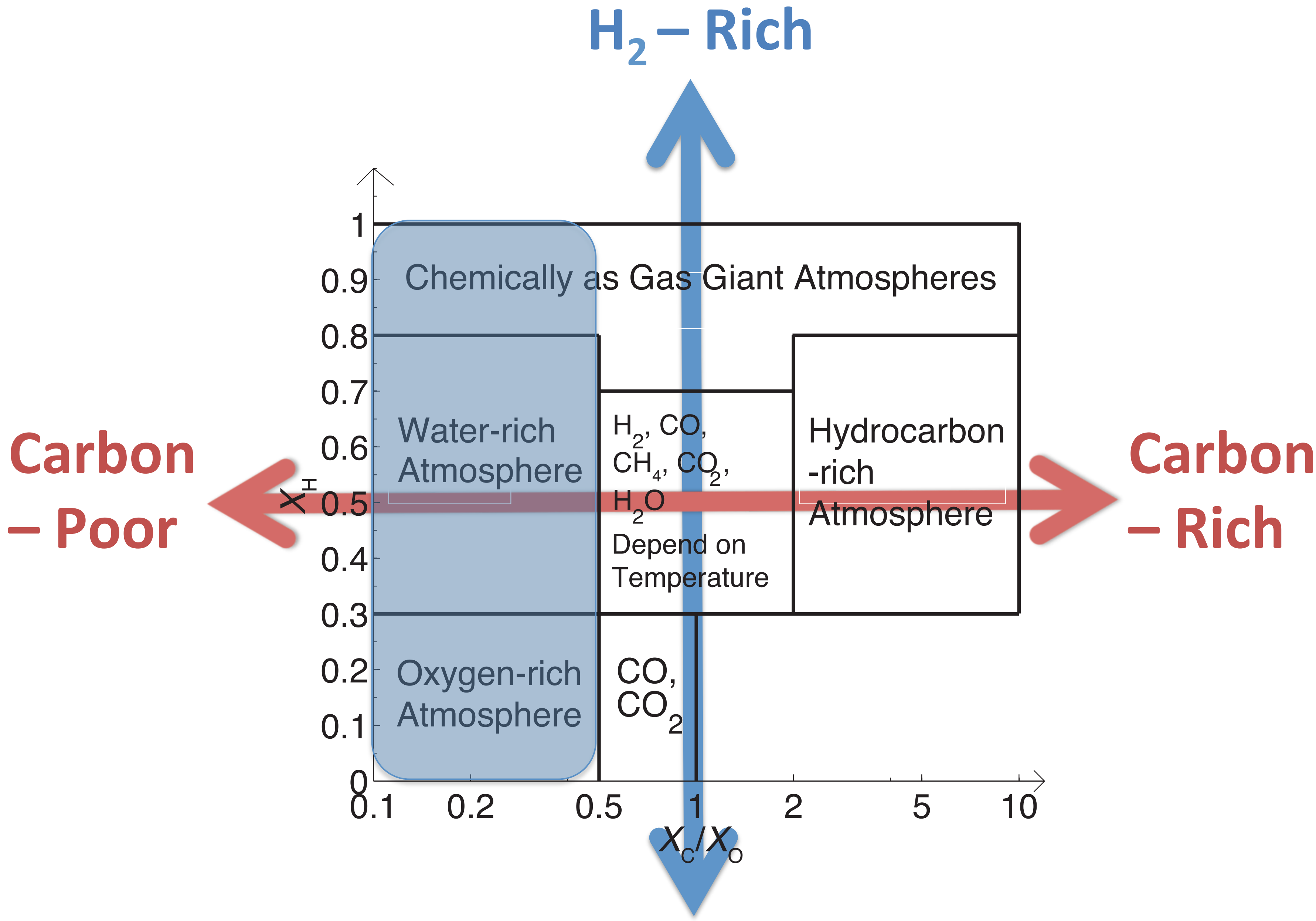
Photochemistry-Thermochemistry Model



Hu et al. 2012, 2013; Hu & Seager 2014



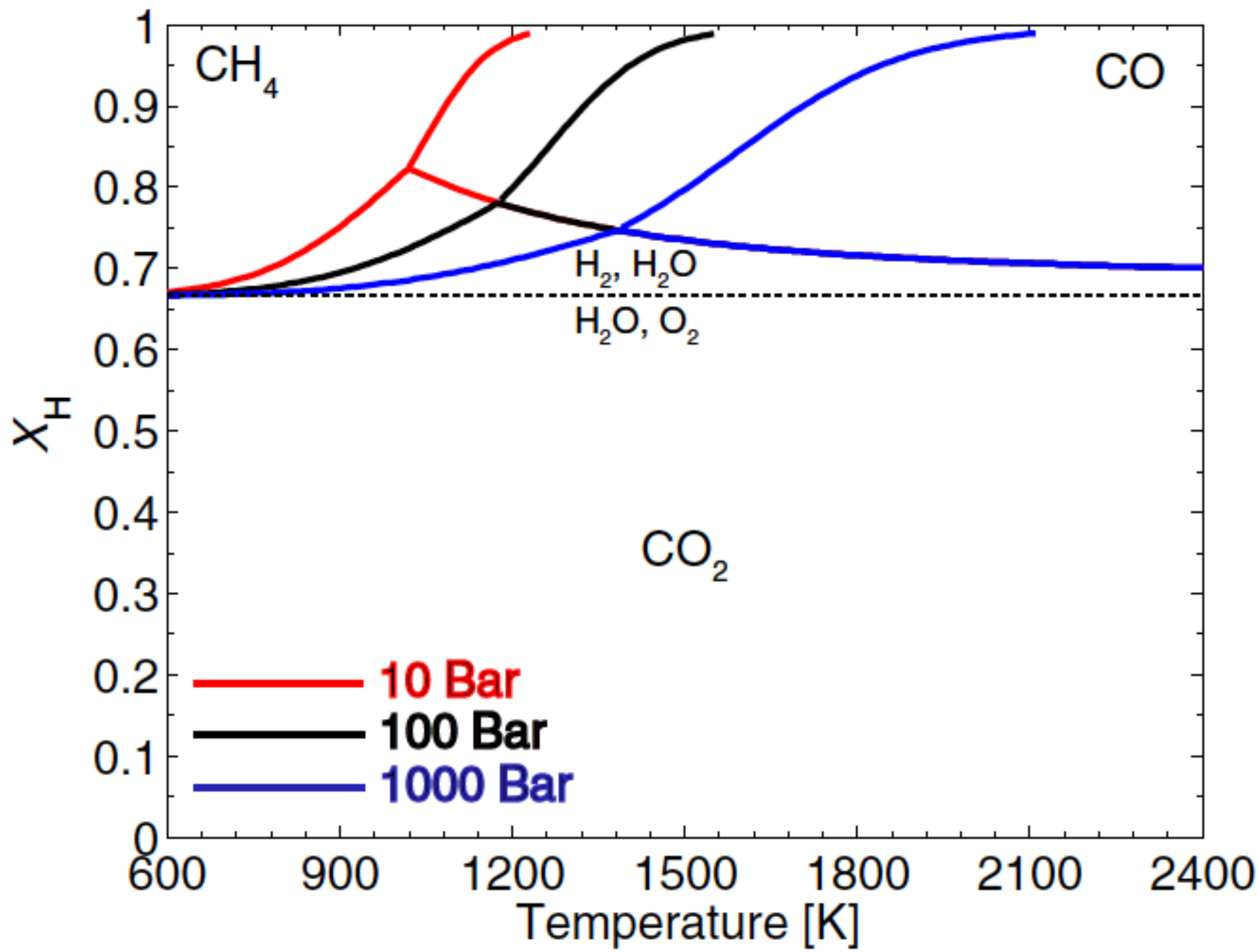
Hu & Seager 2014



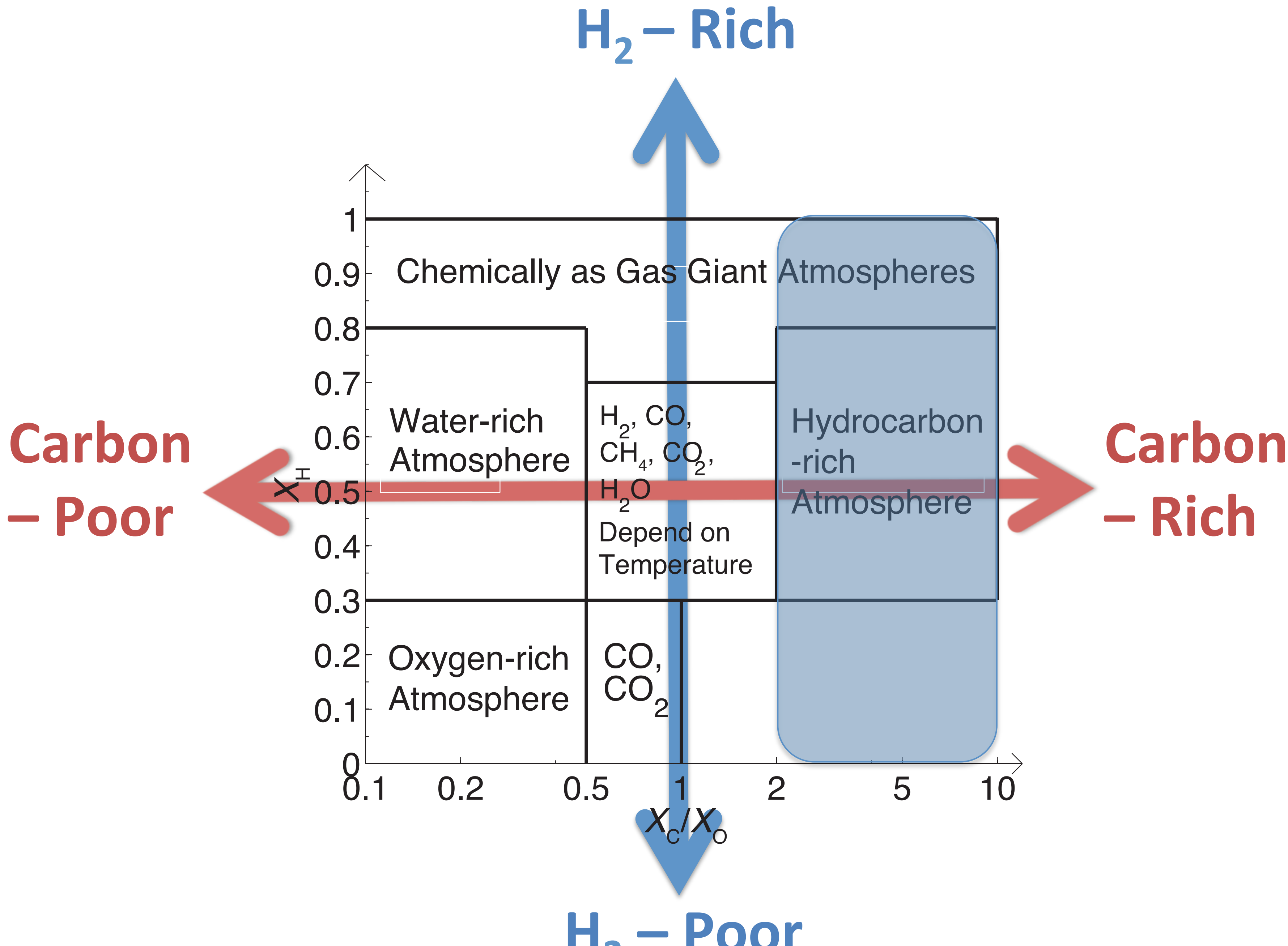
Hu & Seager 2014

Stability Diagram of O-Rich Atmosphere

Hydrogen content and temperature dominate the speciation of carbon



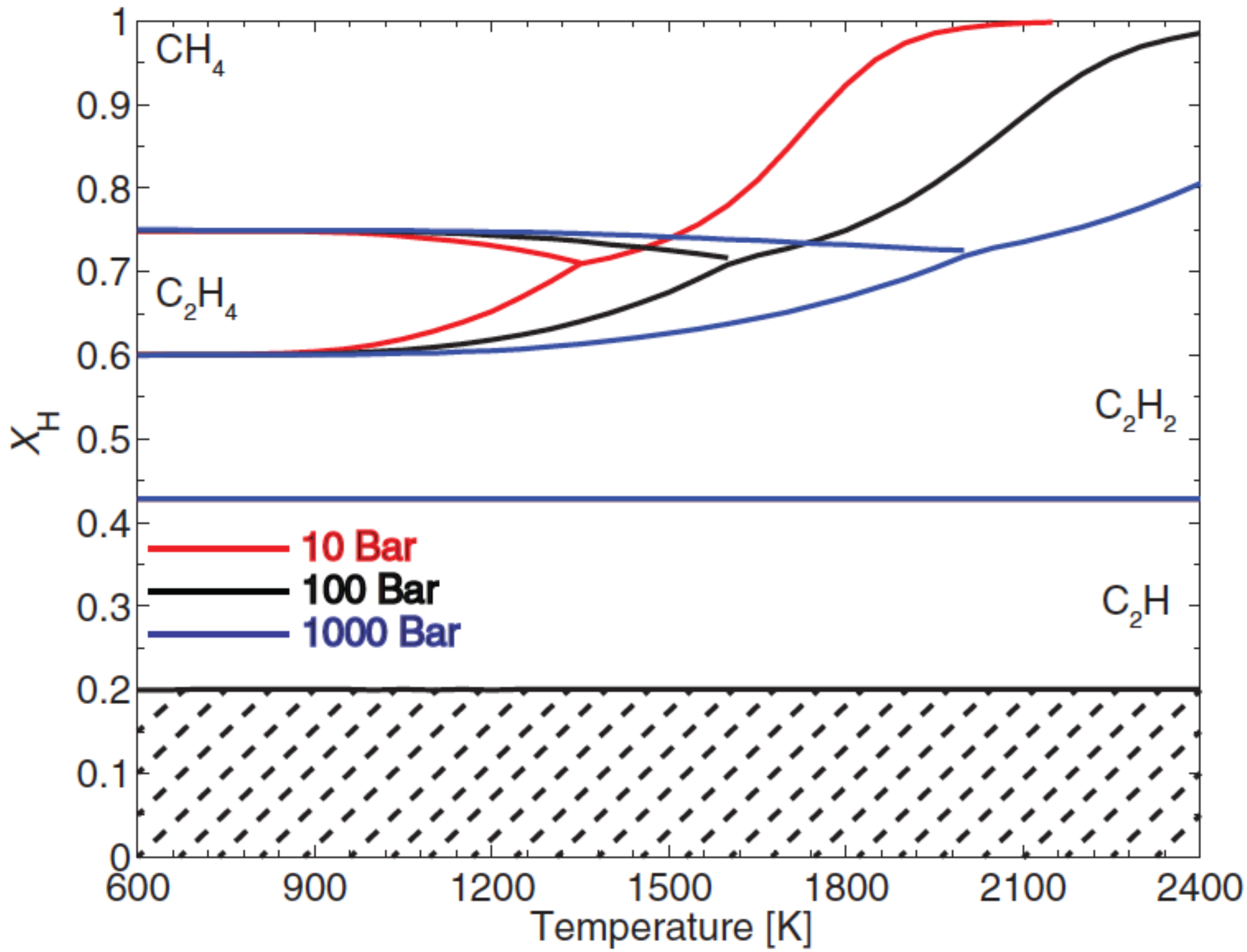
Hu & Seager 2014



Hu & Seager 2014

Stability Diagram of C-Rich Atmosphere

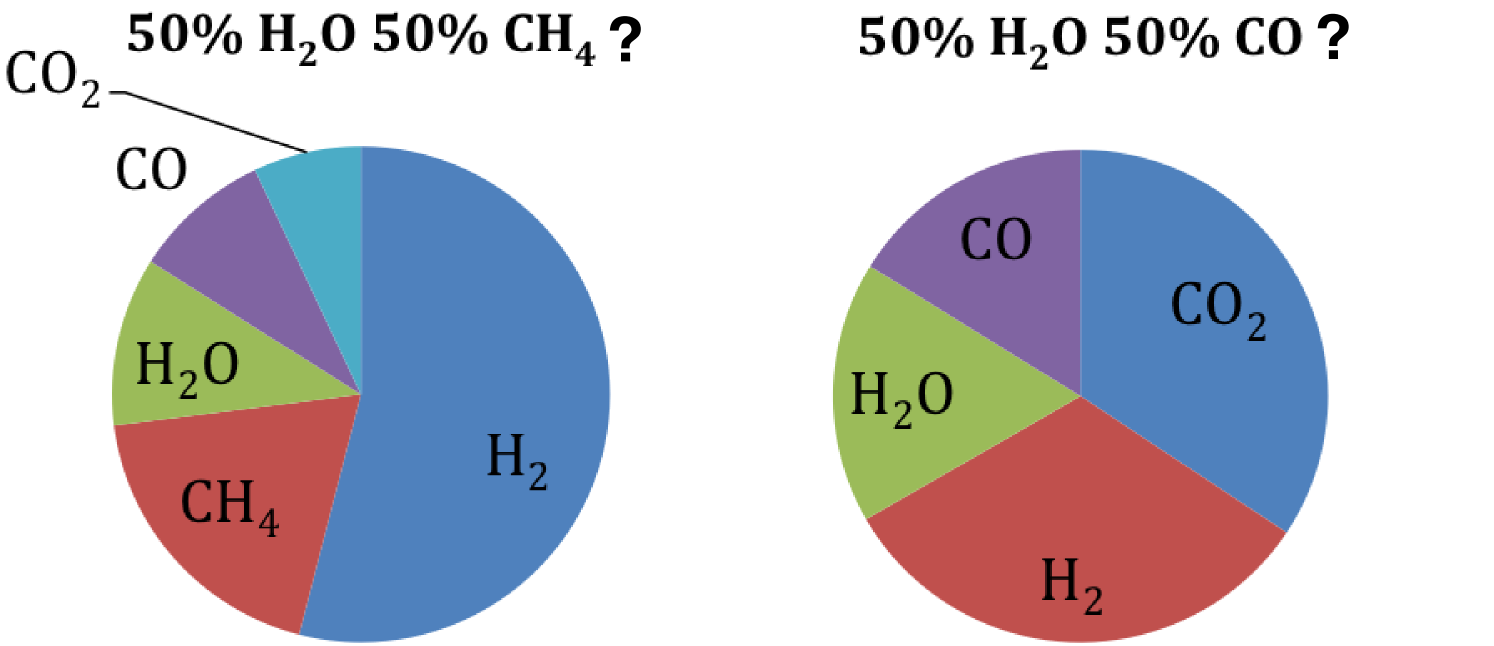
High-order hydrocarbons form as a result of hydrogen loss



Hu & Seager 2014

Compatibility of Atmospheric Gases on Super Earths

- H_2 is compatible with all common gases of C, H, O elements, including CO_2
- H_2O is not compatible with significant amounts of CH_4 or CO
- CH_4 is not compatible with CO_2

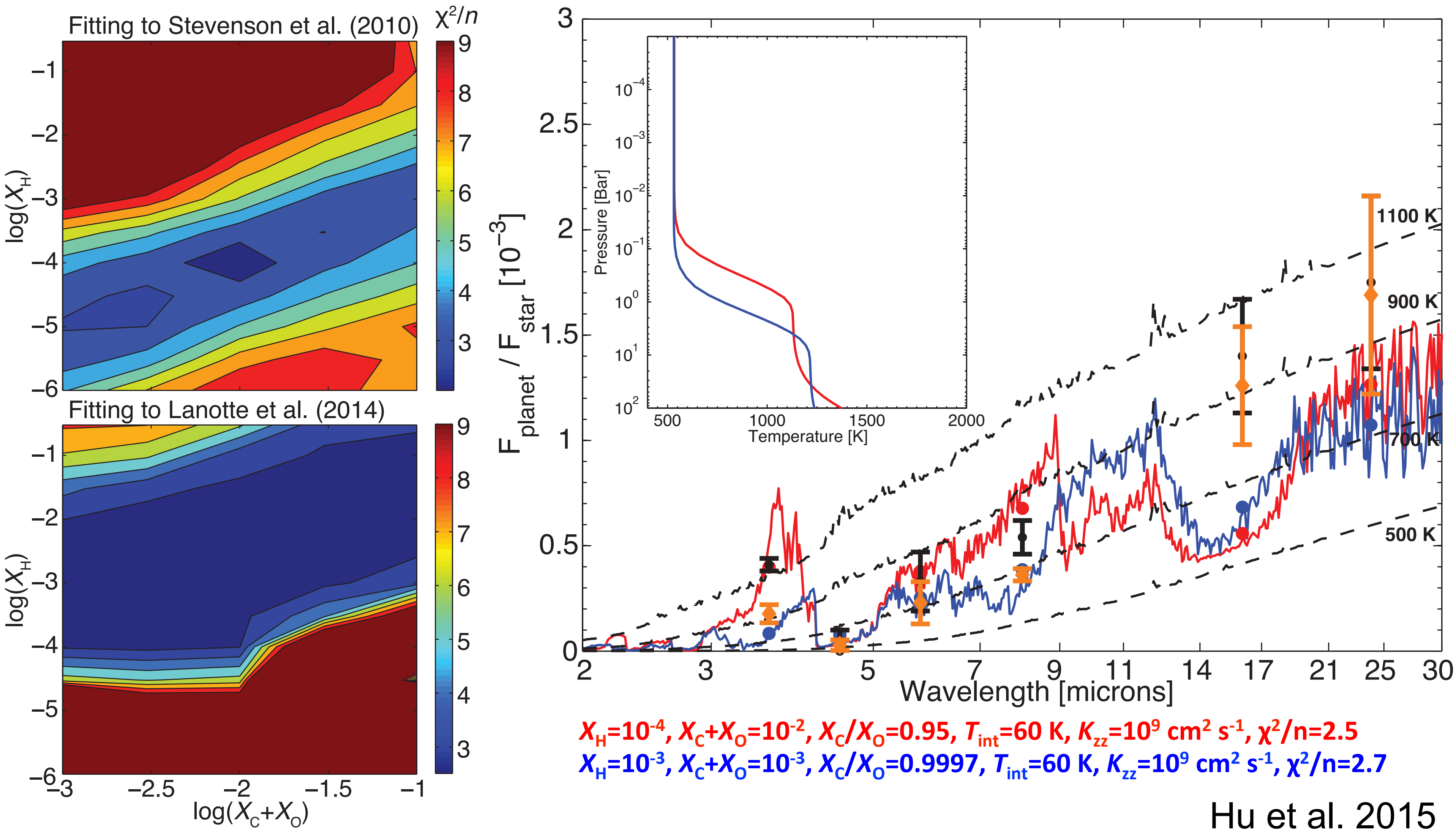


Hu & Seager 2014

How to detect highly evolved exoplanet atmospheres?

- via thermal emission

Thermal Emission of GJ 436 b Fitted by a Helium Atmosphere



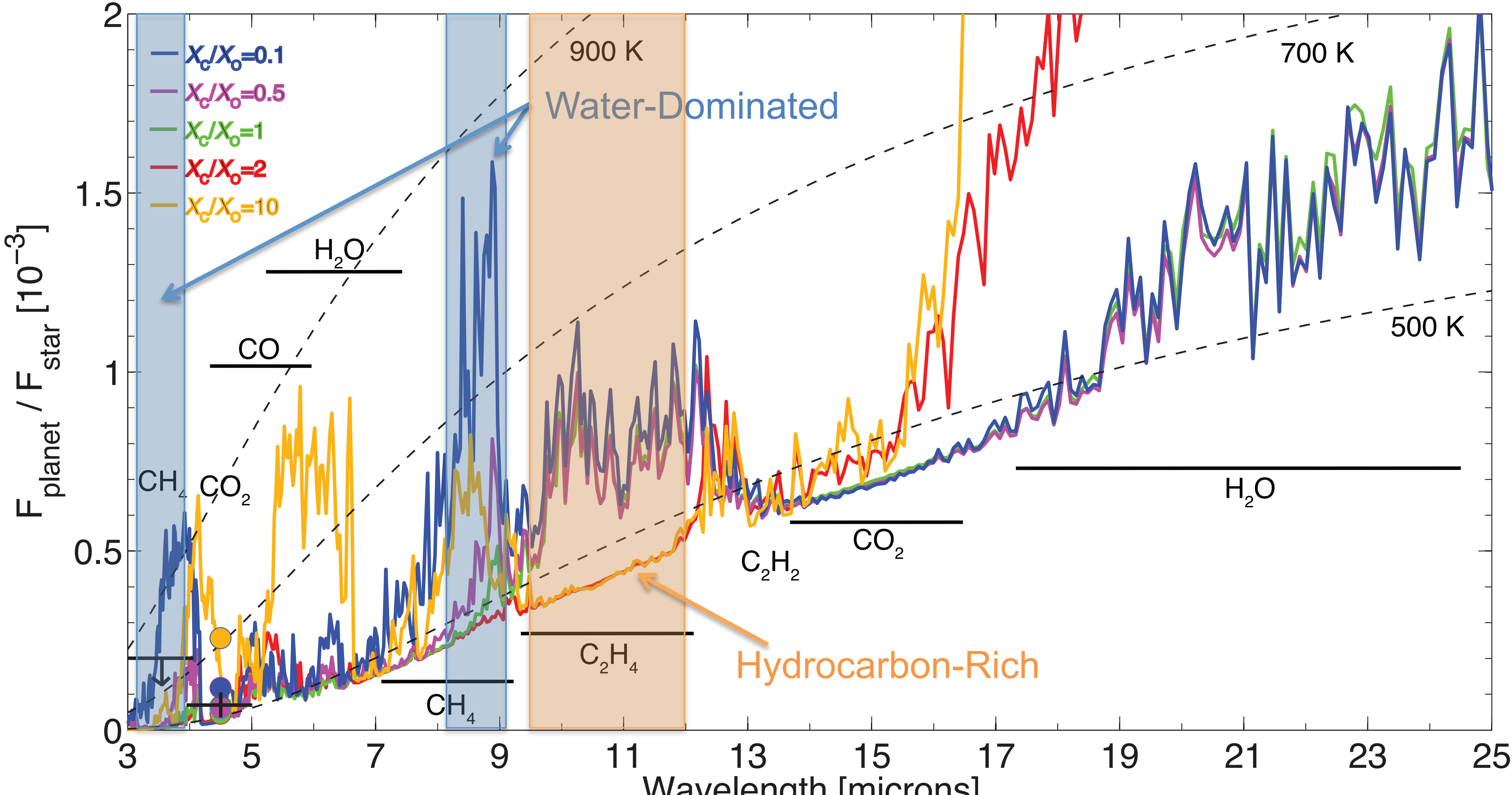
$X_H=10^{-4}$, $X_C+X_O=10^{-2}$, $X_C/X_O=0.95$, $T_{int}=60$ K, $K_{zz}=10^9$ cm^2 s^{-1}, $\chi^2/n=2.5$

$X_H=10^{-3}$, $X_C+X_O=10^{-3}$, $X_C/X_O=0.9997$, $T_{int}=60$ K, $K_{zz}=10^9$ cm^2 s^{-1}, $\chi^2/n=2.7$

Hu et al. 2015

Thinking about JWST

Observing a planet in thermal emission can distinguish atmosphere scenarios



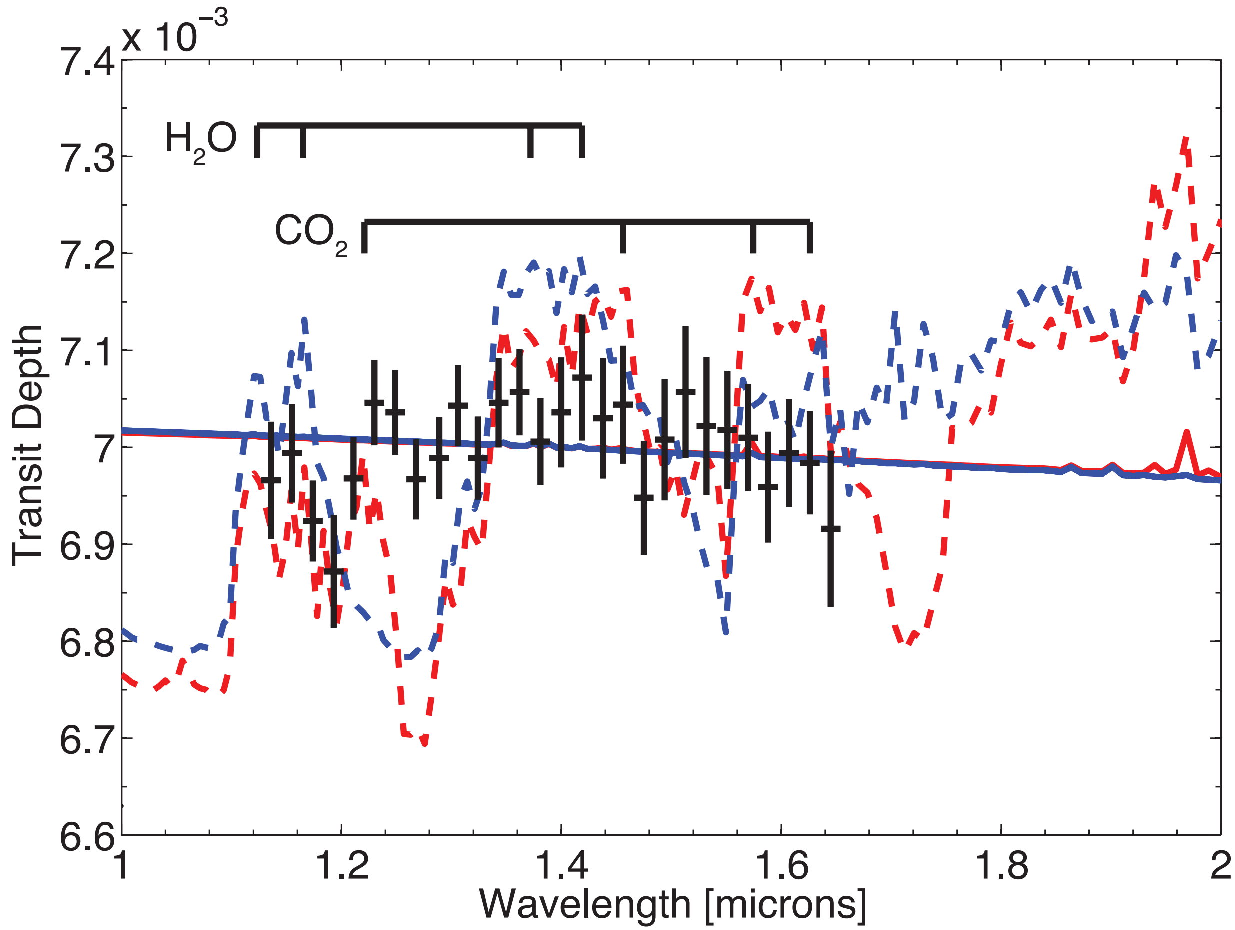
Hu & Seager 2014

How to detect highly evolved exoplanet atmospheres?

- via transmission

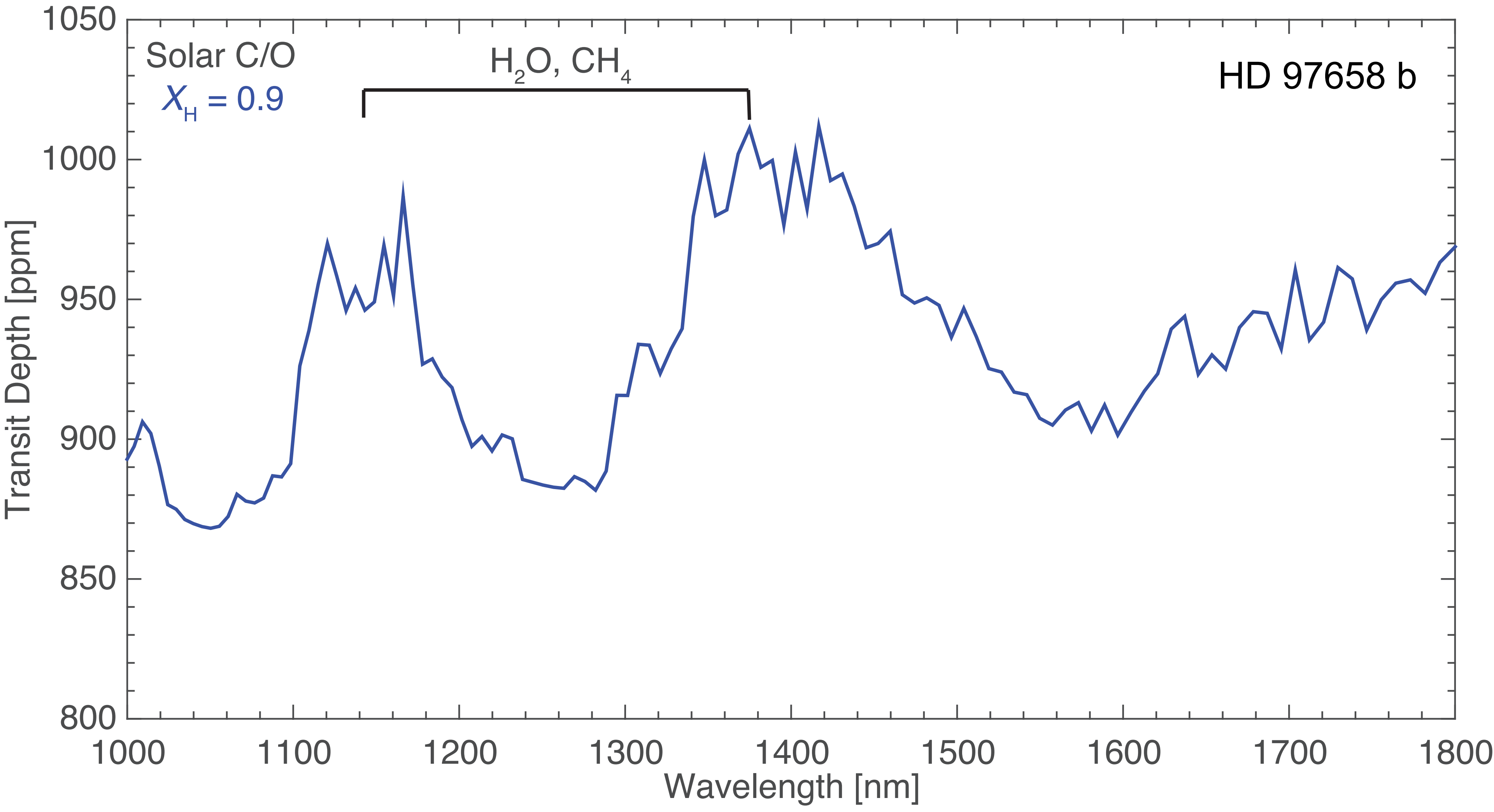
Transmission of GJ 436 b Fitted by a Helium Atmosphere

- A helium atmosphere on GJ 436 b must have an aerosol layer at the pressure of 1 – 100 mbar to be consistent with the transmission spectrum
- Without the aerosol layer, H_2O and CO_2 features dominate the transmission spectrum



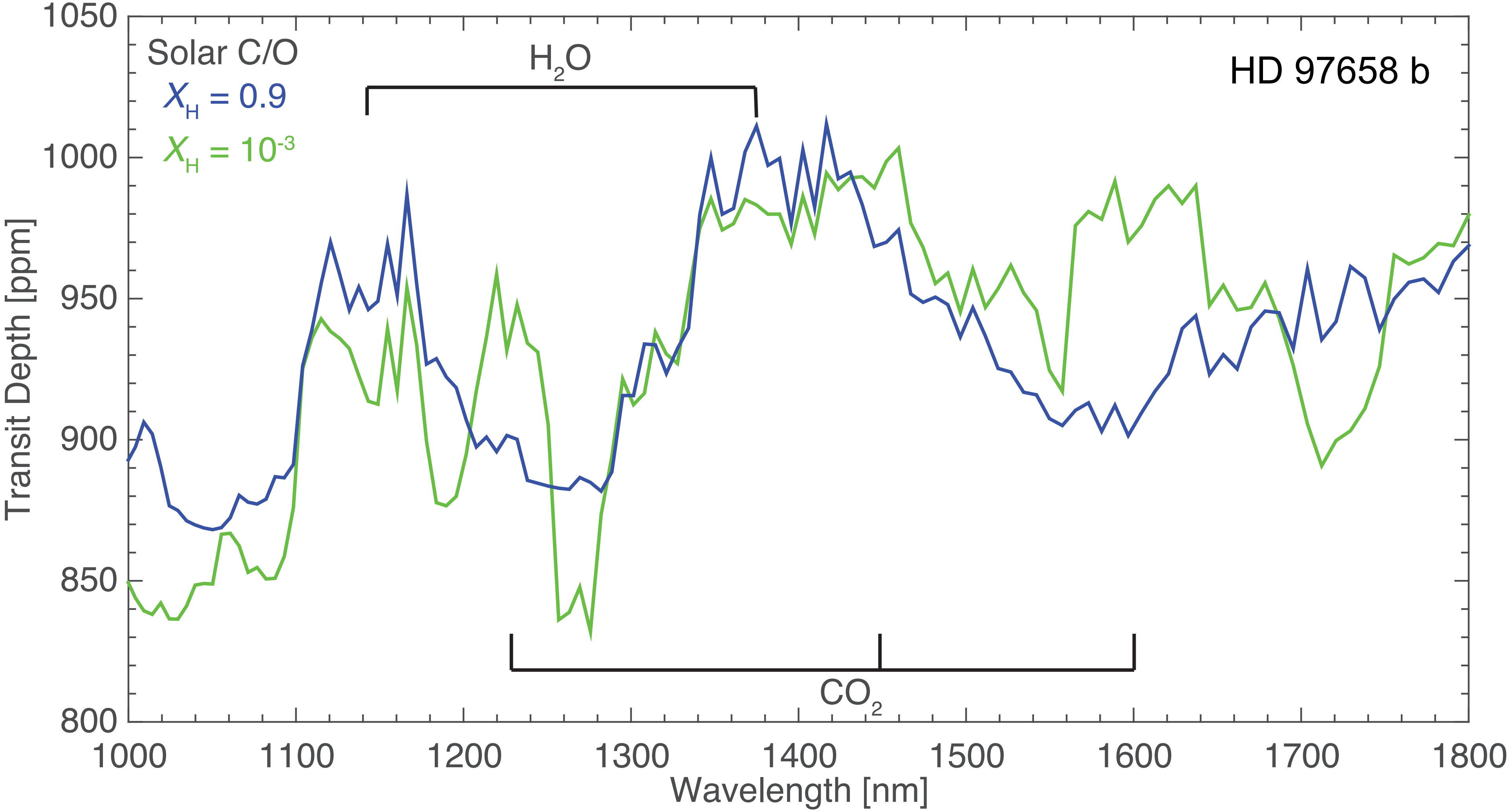
Knutson et al. 2014; Hu et al. 2015

Evolution of Transmission Spectrum



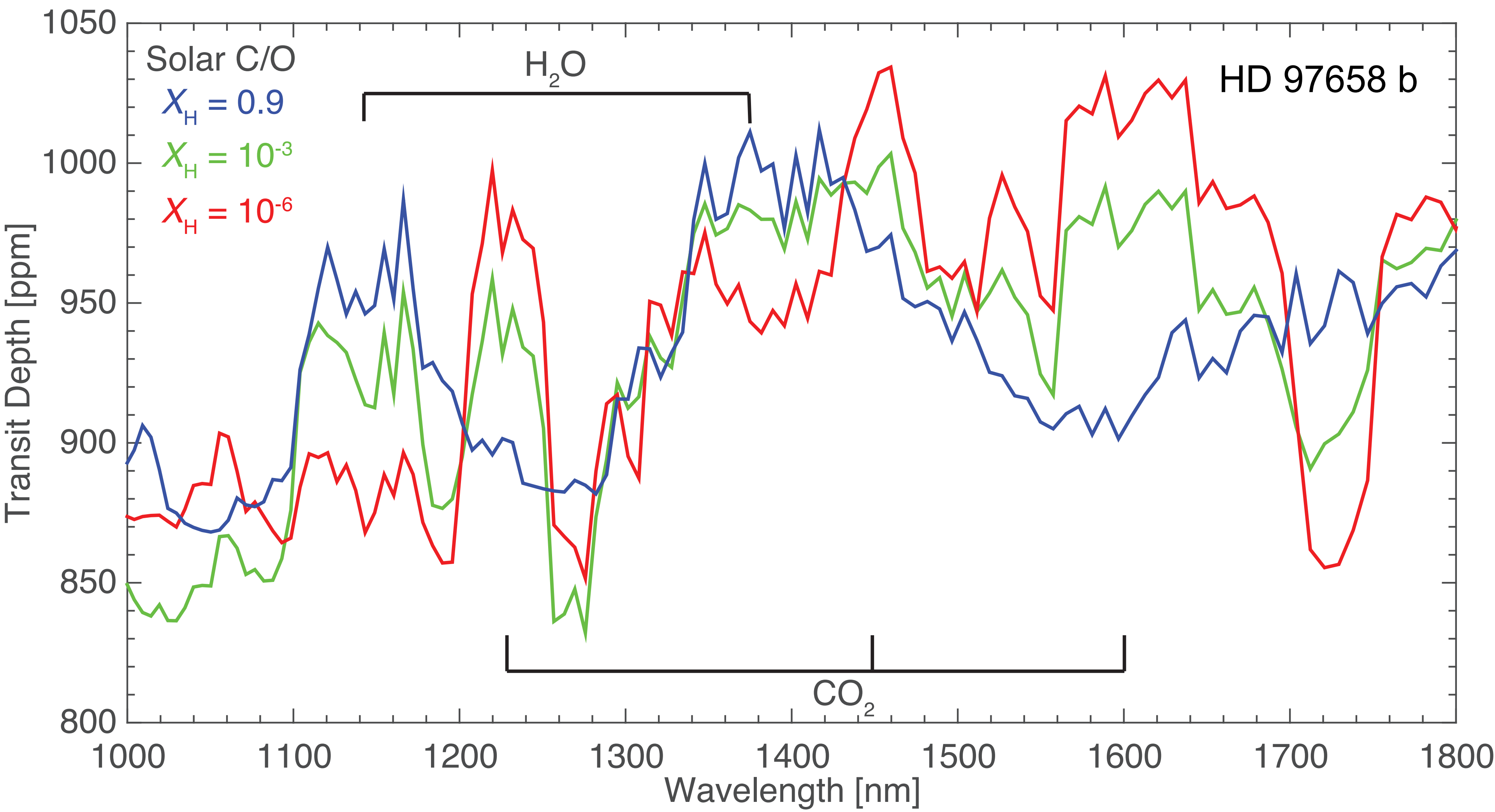
Hu 2015, in prep.

Evolution of Transmission Spectrum



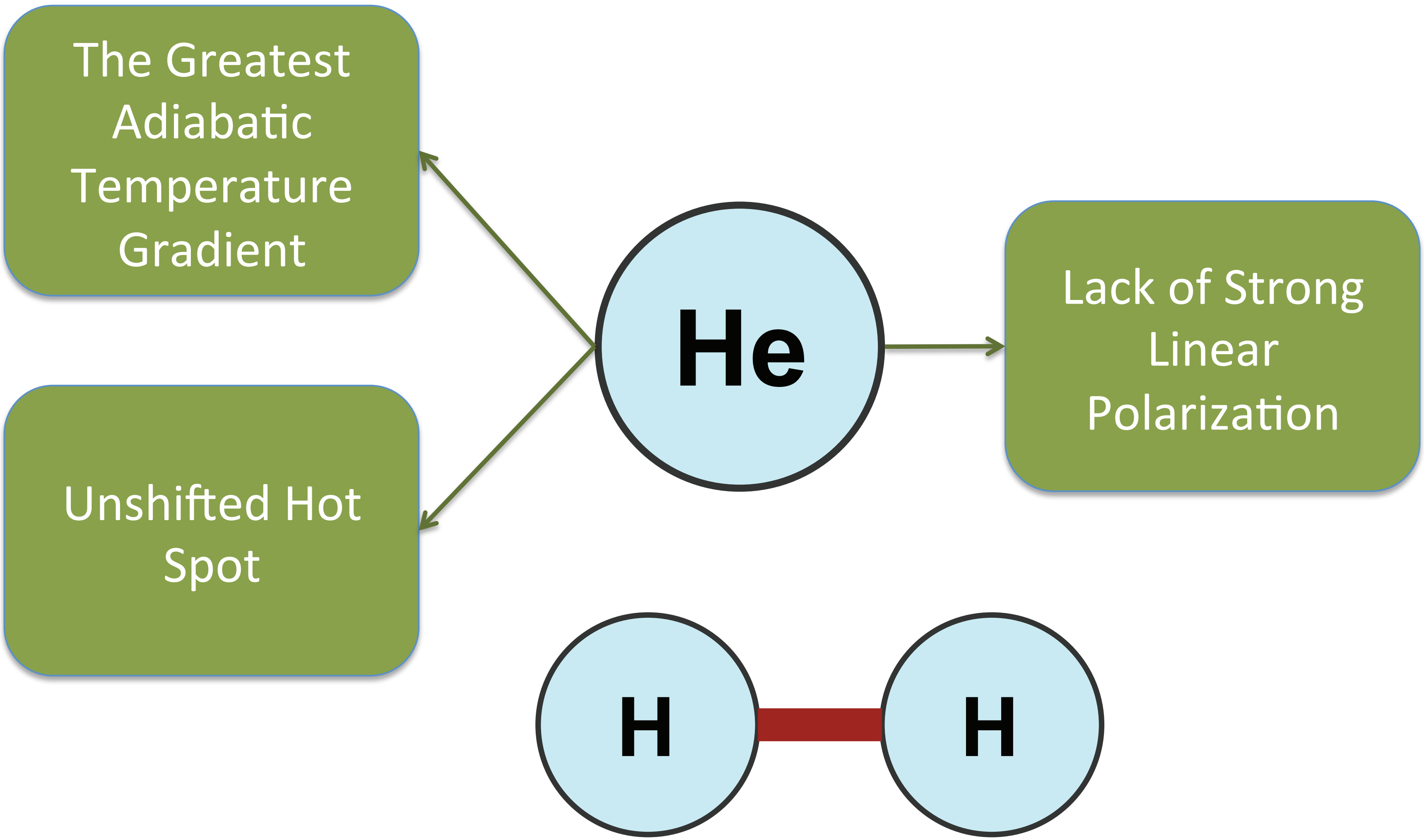
Hu 2015, in prep.

Evolution of Transmission Spectrum



Hu 2015, in prep.

Characteristics of Helium Atmosphere



Hu et al. 2015

Conclusions

- Neptune- and sub-Neptune-sized exoplanets may have highly evolved atmospheres depleted in hydrogen but abundant in helium
- A helium atmosphere can fit the emission features of GJ 436 b
- Evolution of short-period exoplanets leads to distinctive atmospheric characteristics, testable by current transit observations