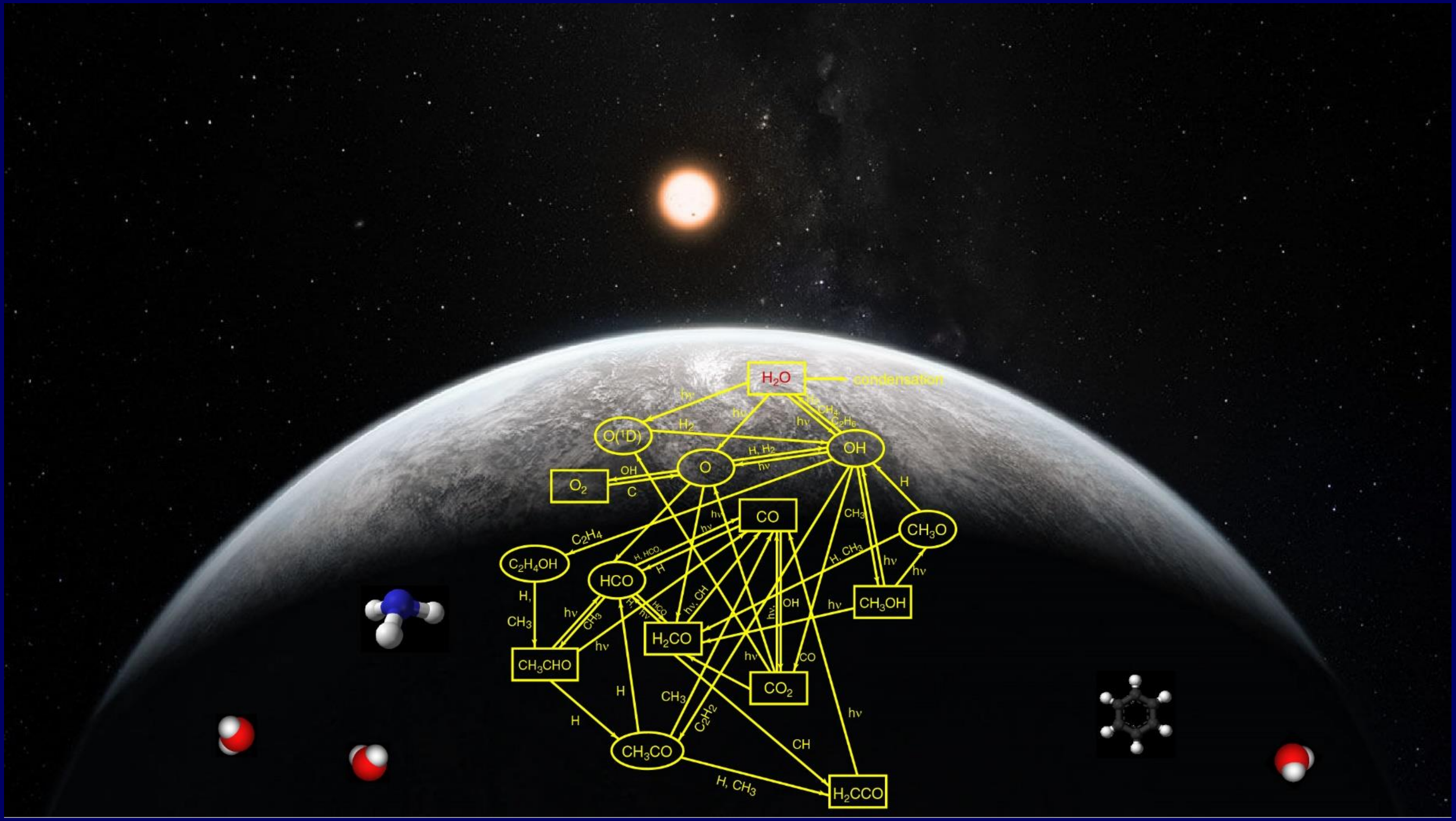
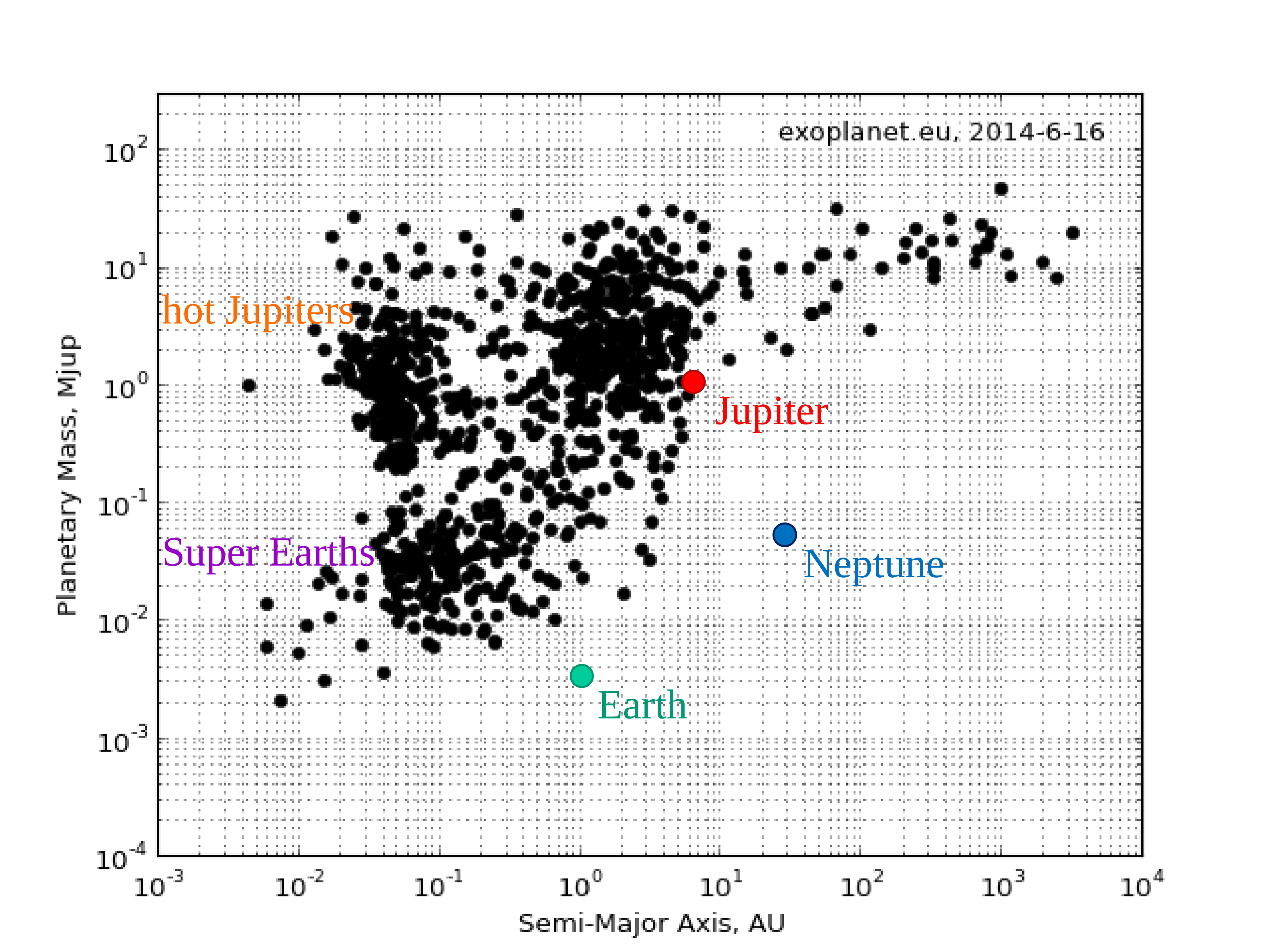
Characterizing the Atmospheres of Extrasolar Planets

Julianne I. Moses (Space Science Institute)

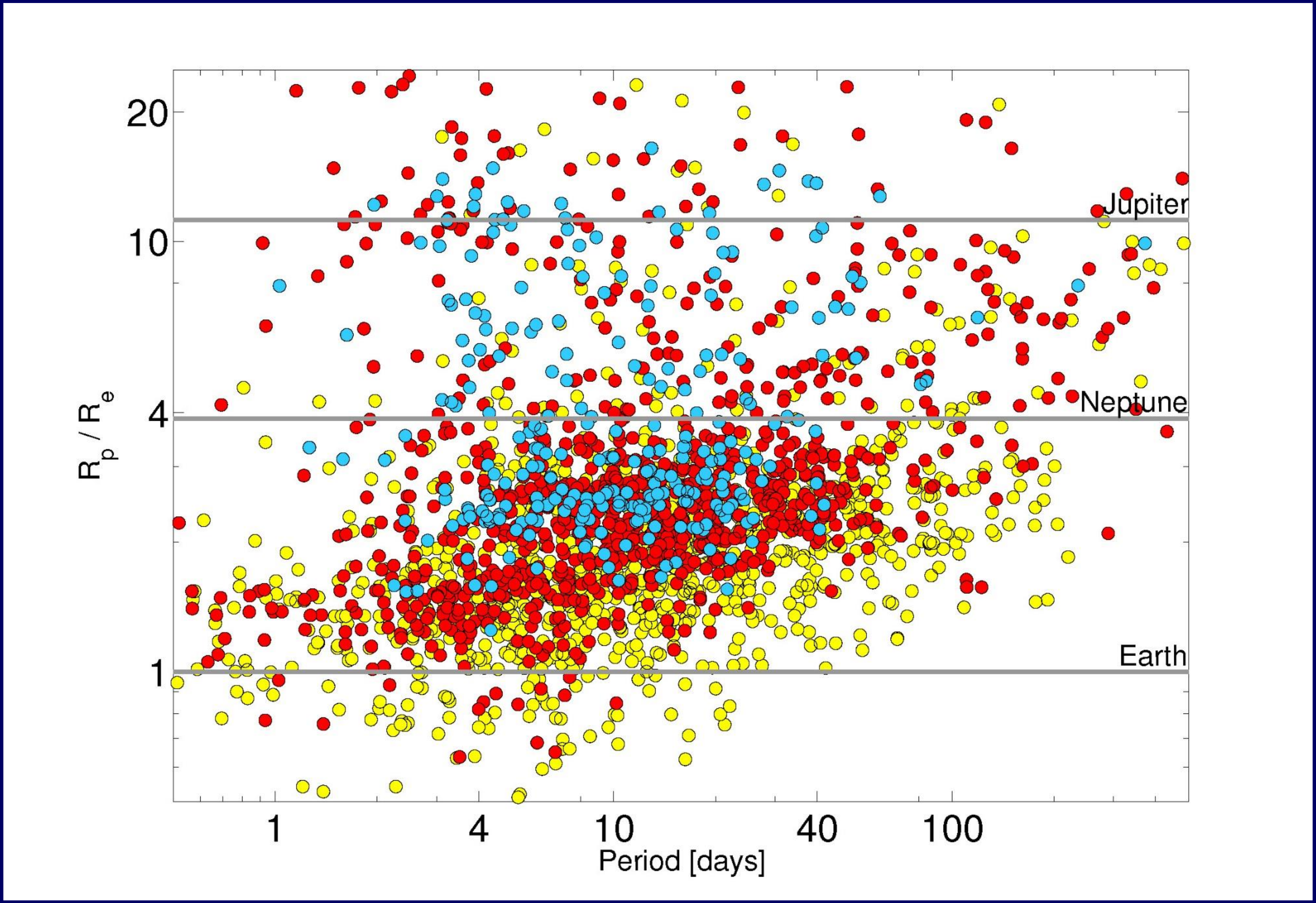


Intern Brown Bag, 18 June 2014

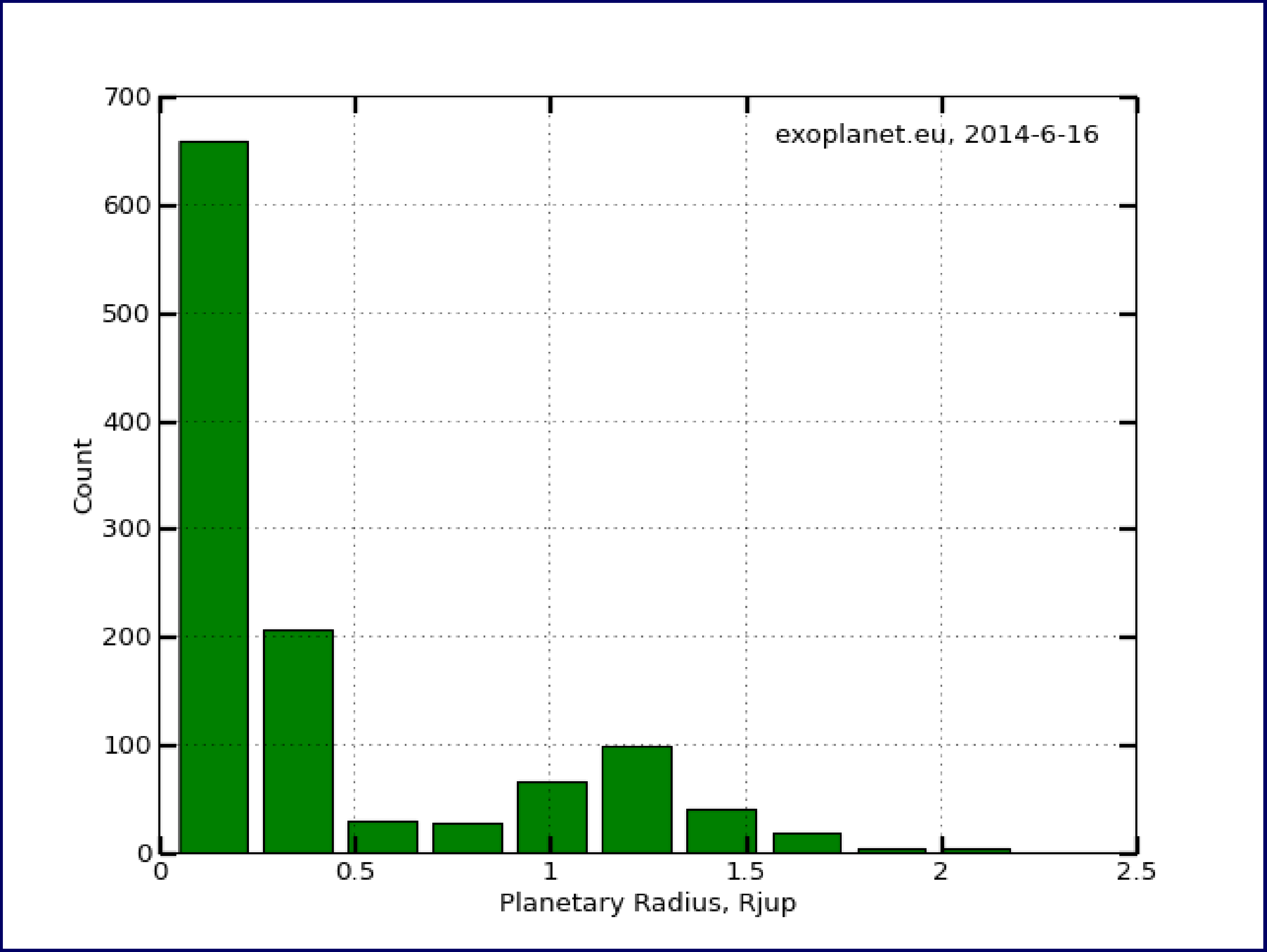
1795 Confirmed Exoplanets as of 16 June 2014



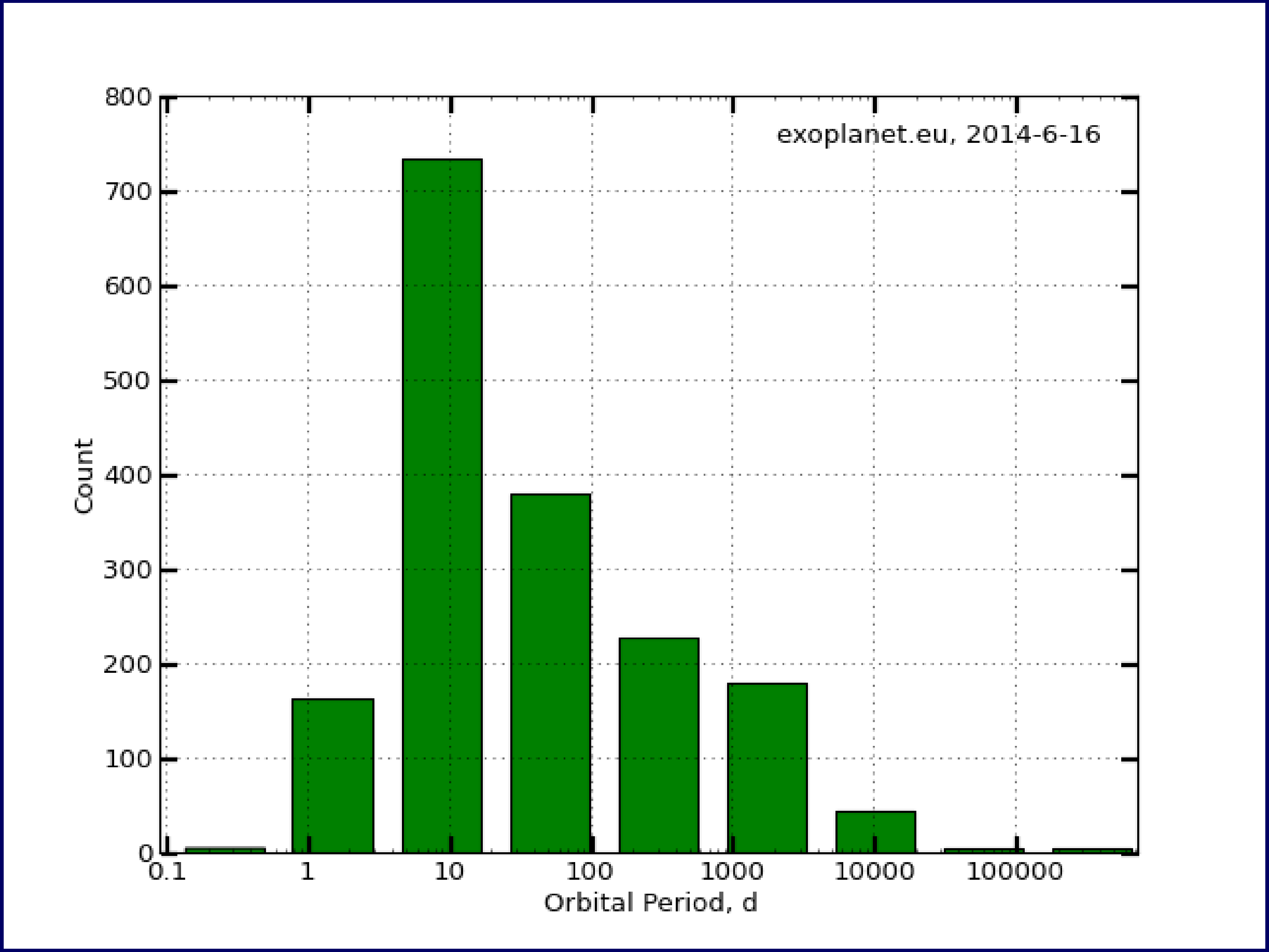
Kepler first 16 months: Batalha et al. (2013)



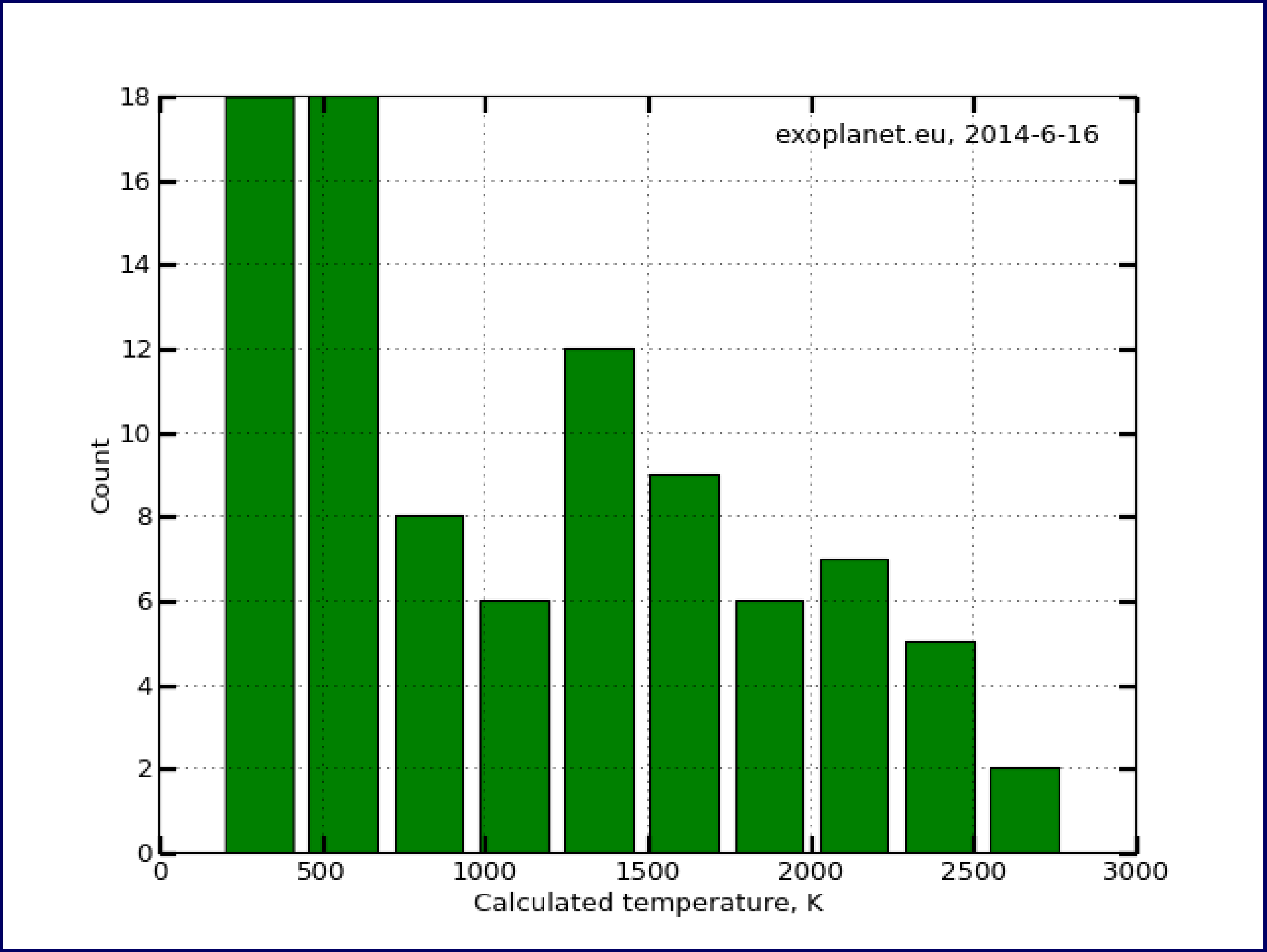
Most known planets have sizes between Earth and Jupiter



Most known planets are close to their host stars

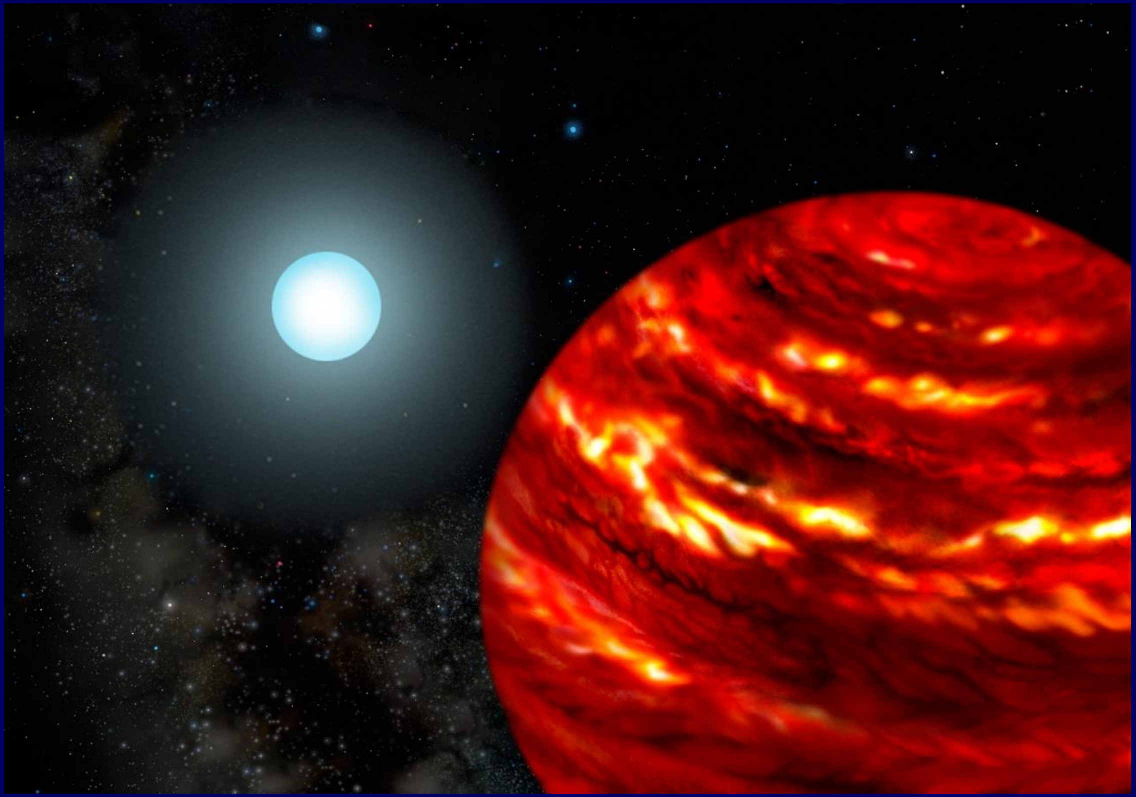


Most known planets are hotter than Earth



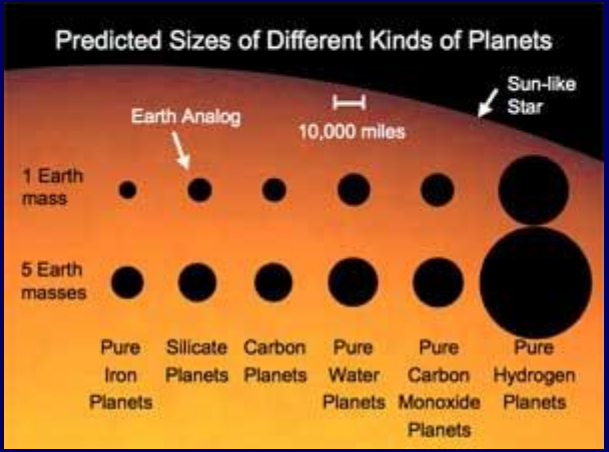
So…. based on our Solar System experience, most known exoplanets should have hot, thick atmospheres

But what do we really know about these atmospheres, and how do we know it?

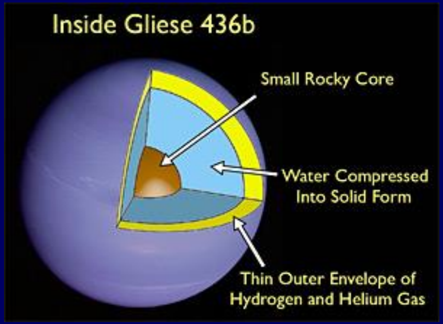


Characterizing Exoplanet Atmospheres

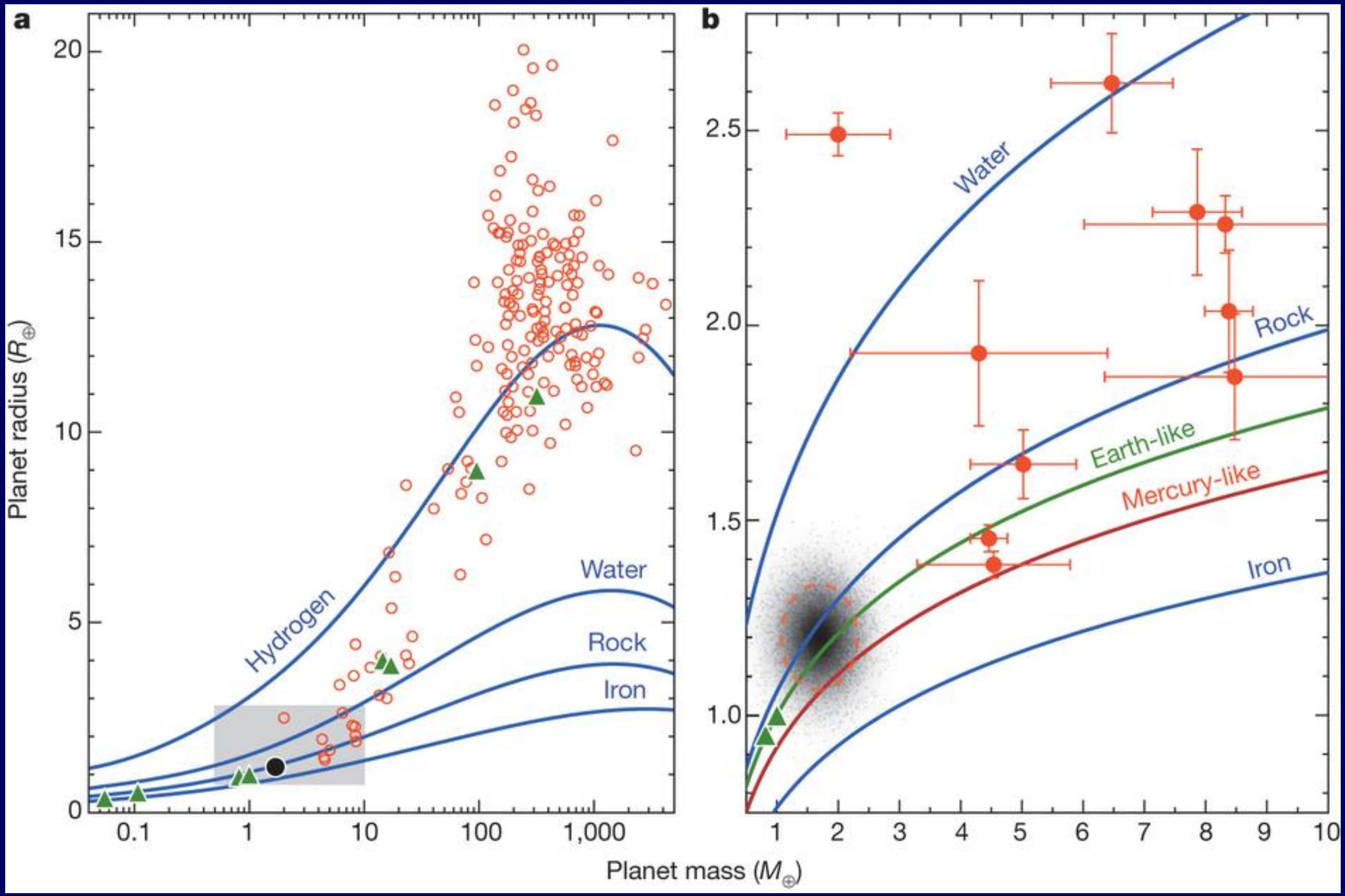
- Planetary bulk density tells you something about volatile content
- Transit and eclipse photometry and spectra can provide information on atmospheric composition, clouds, atmospheric temperatures, longitudinal variations
- Spectroscopy of directly imaged planets can provide information on atmospheric composition, clouds, temperatures



Mass versus radius relation provides some clues to bulk composition and mass fraction of volatiles, but there are degeneracies

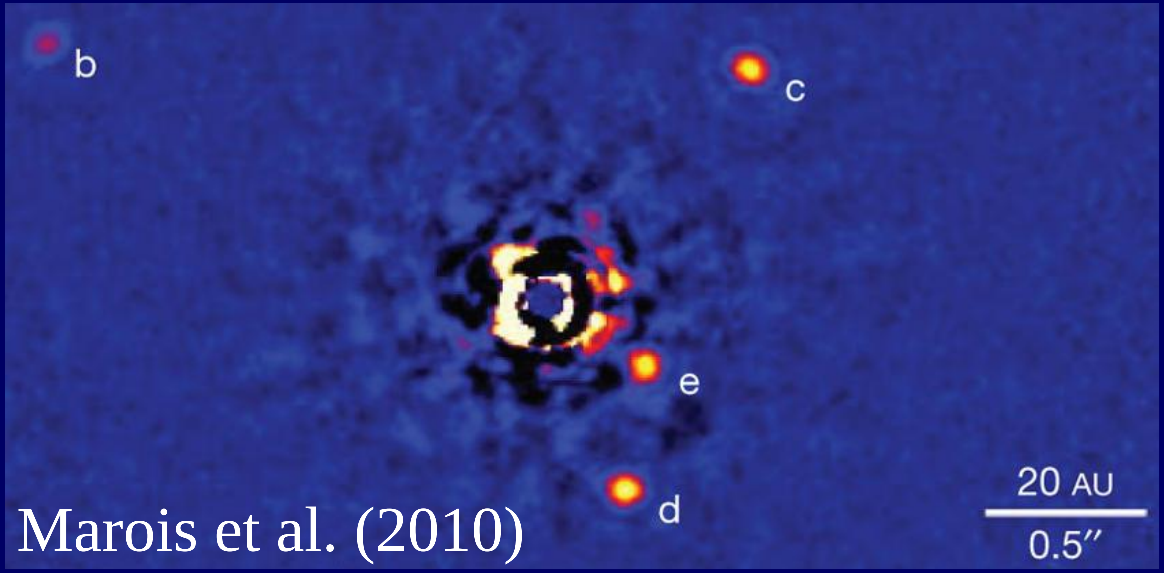


Jason Wright/ UC Berkeley



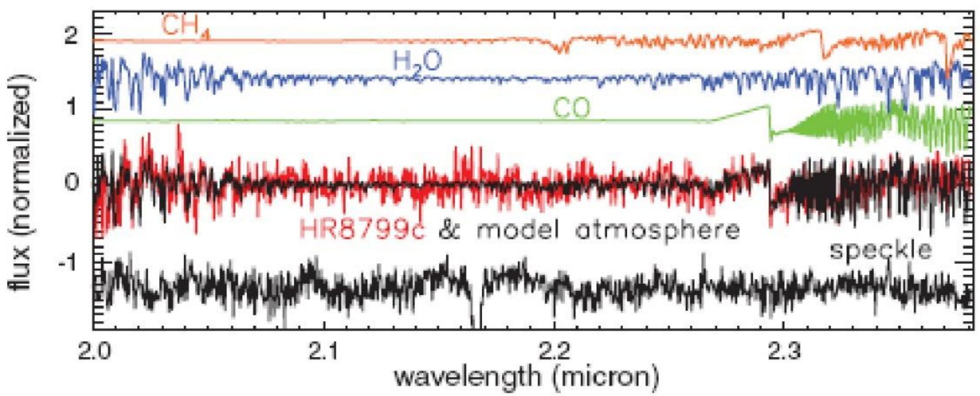
[left] from Howard et al. (2013)

Spectroscopy of Directly Imaged Planets

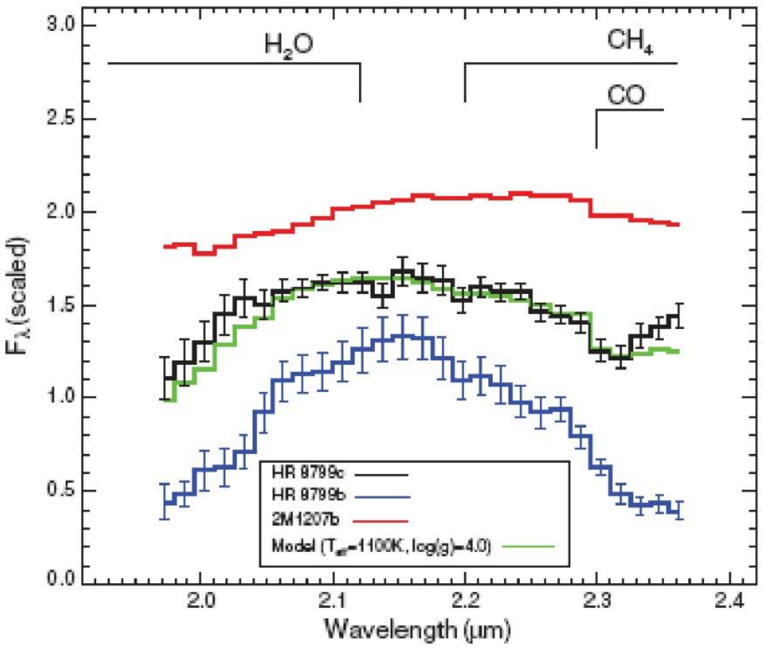


Directly imaged planets tend to be young, hot, large planets far from their host stars

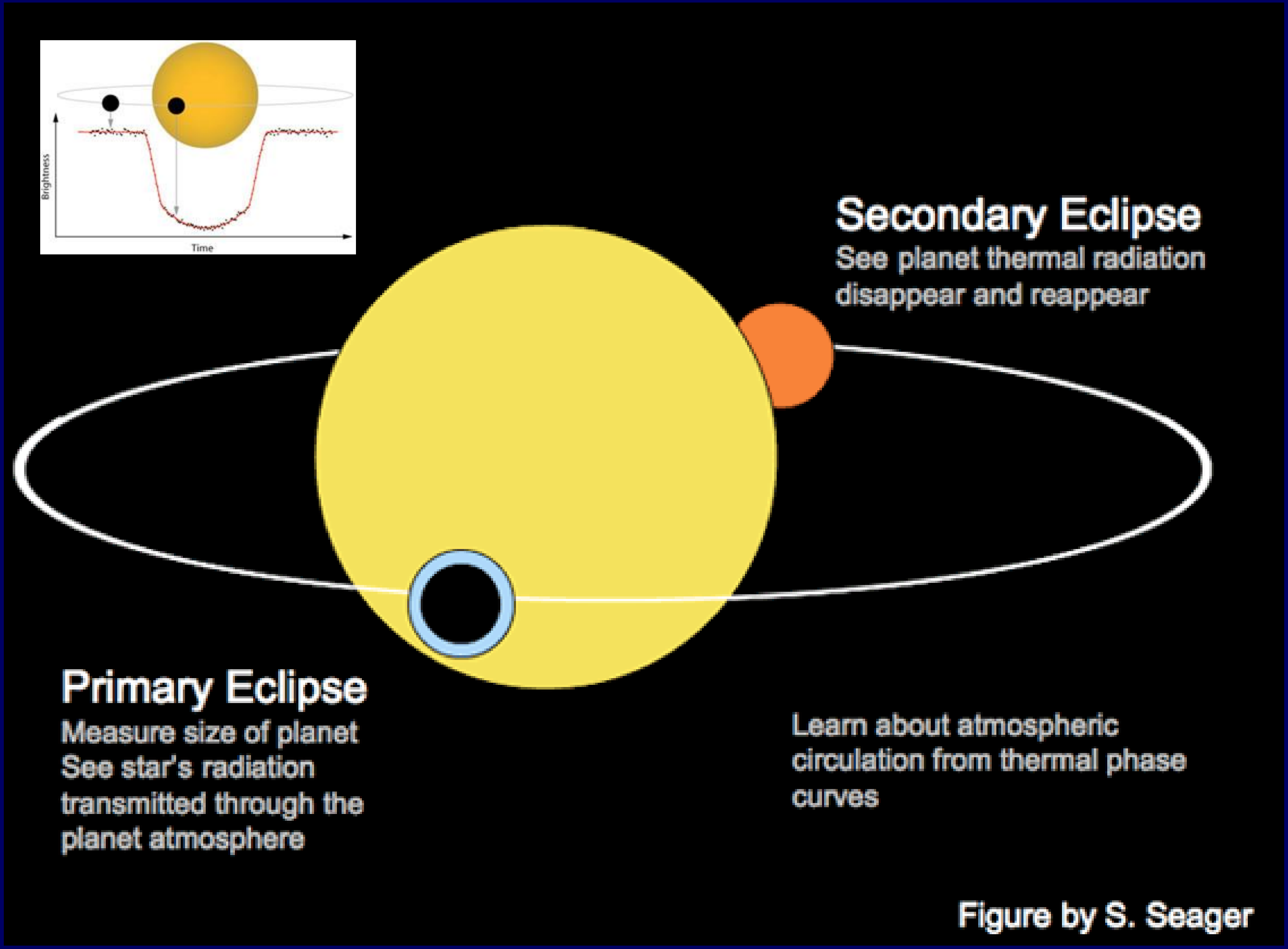
HR 8799c



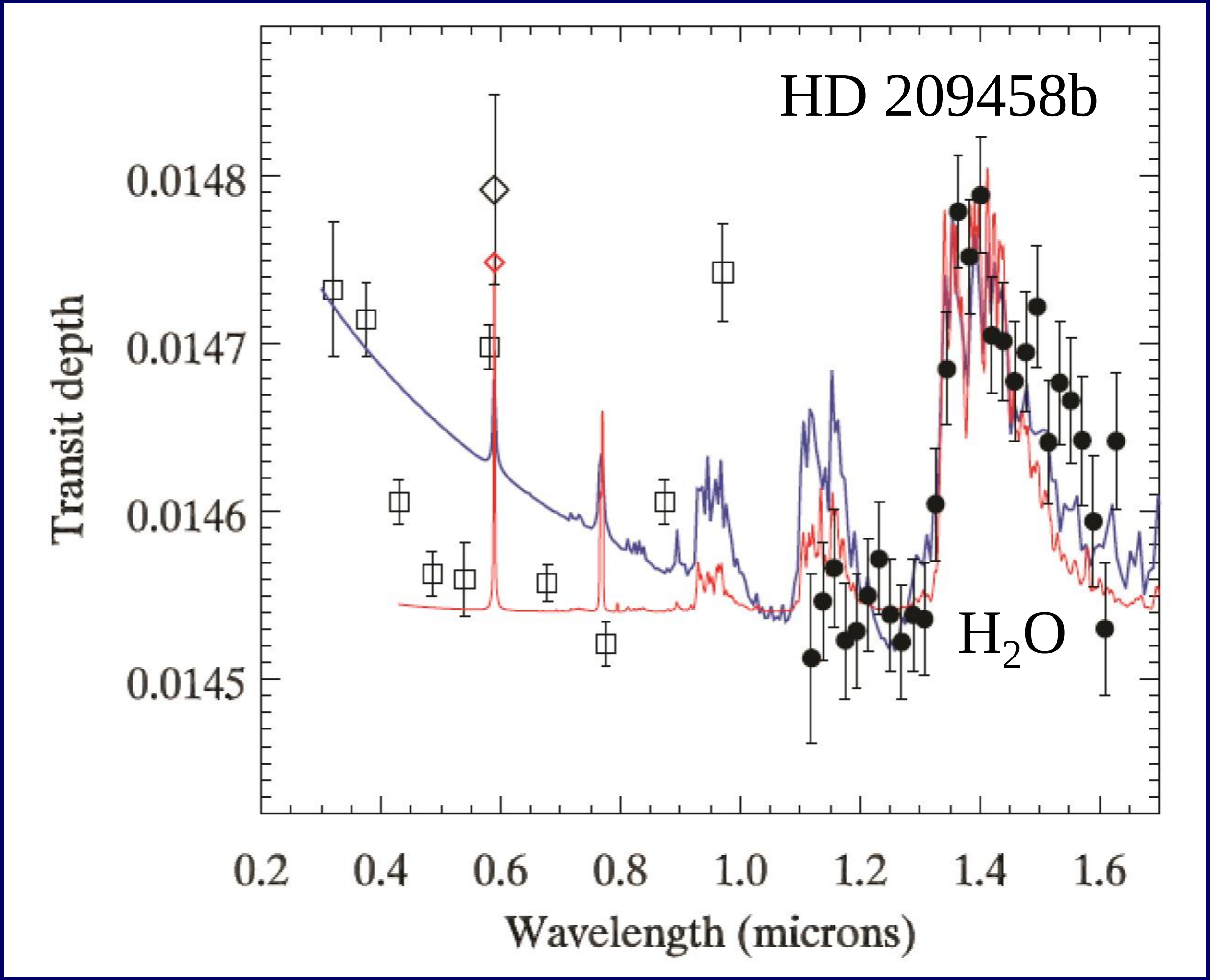
from Konopacky et al. (2013)



Characterizing Exoplanet Atmospheres Through Transits and Eclipses

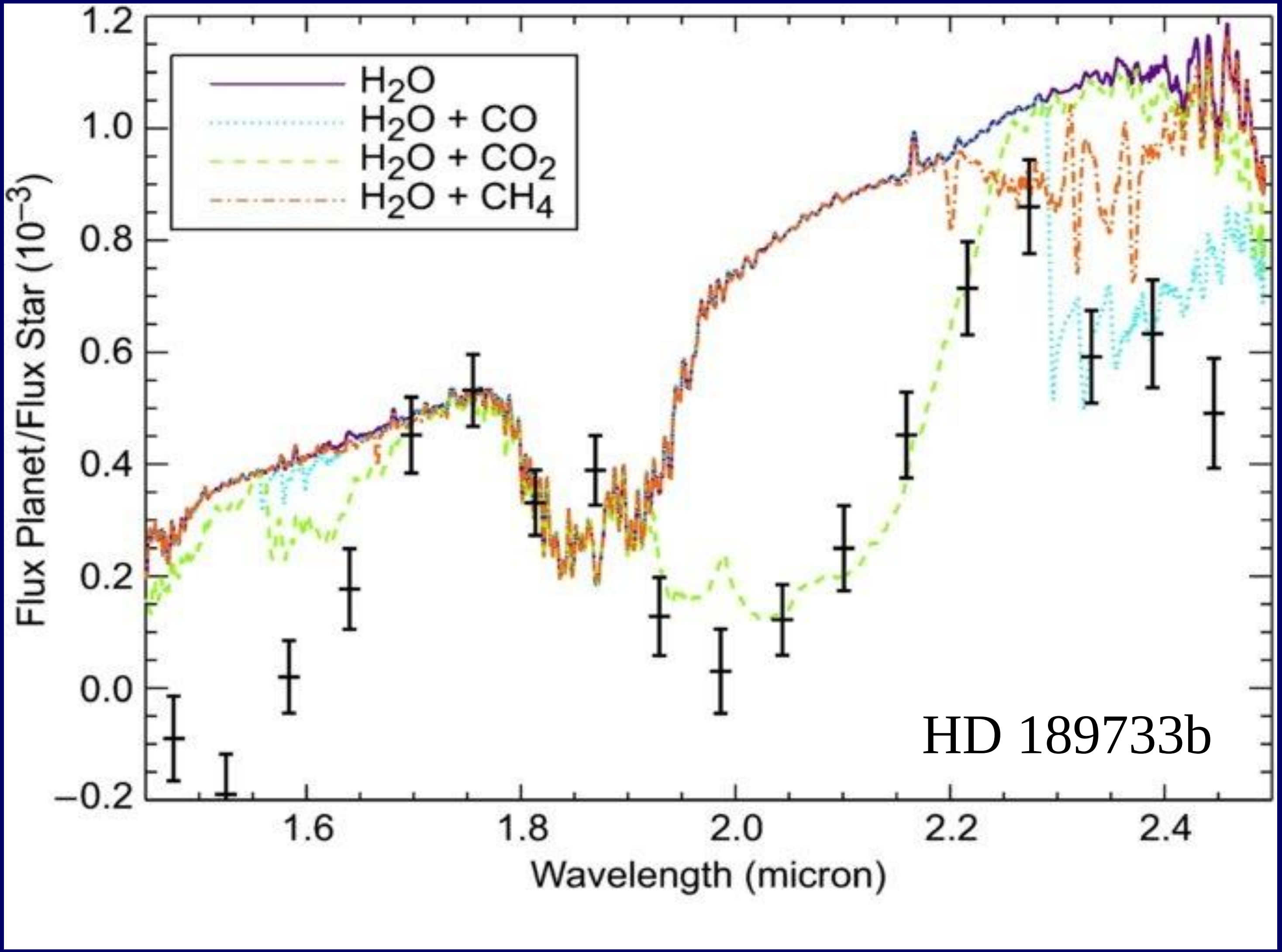


Atmospheric Absorption During Transit



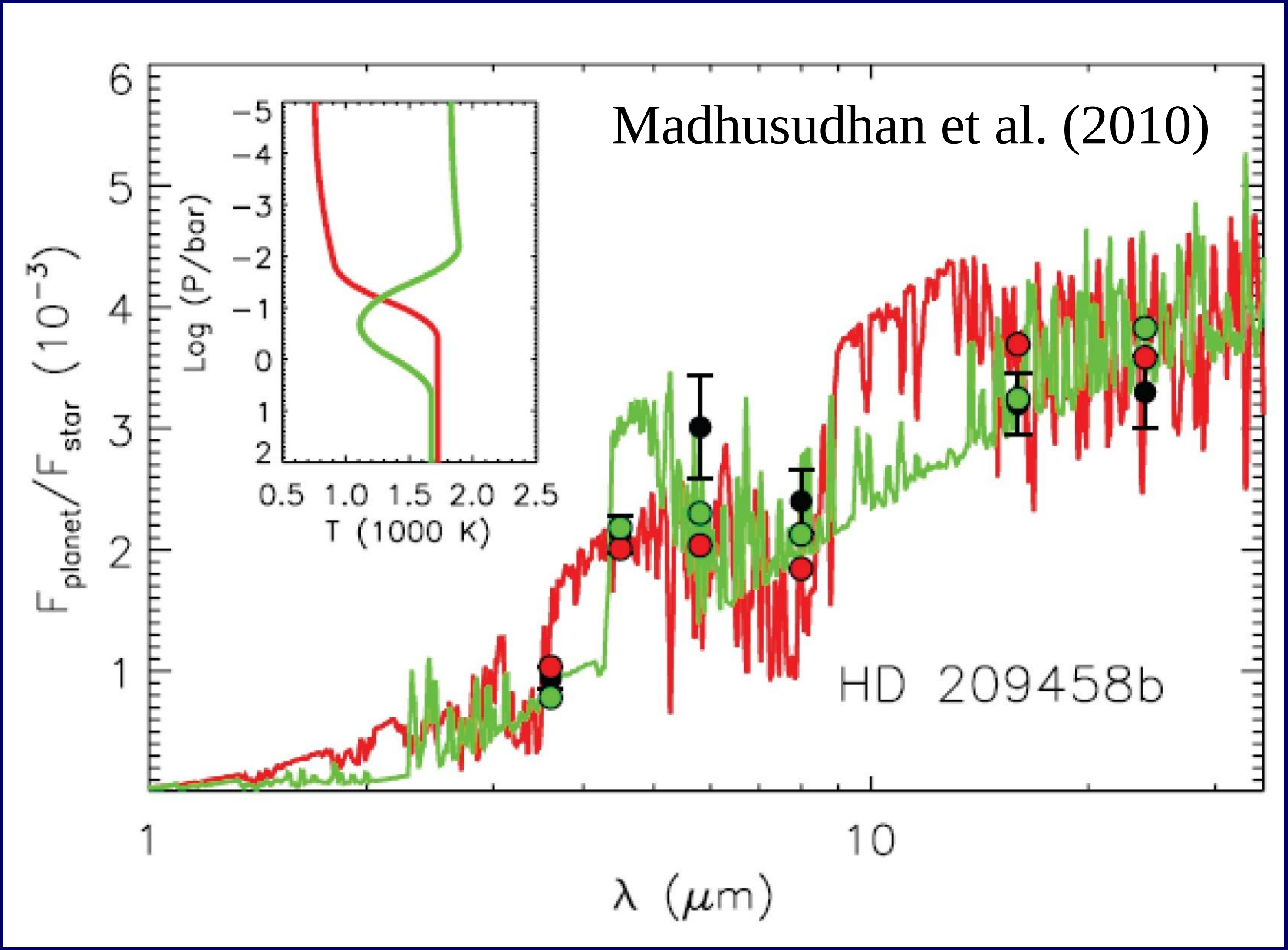
from Deming et al. (2013)

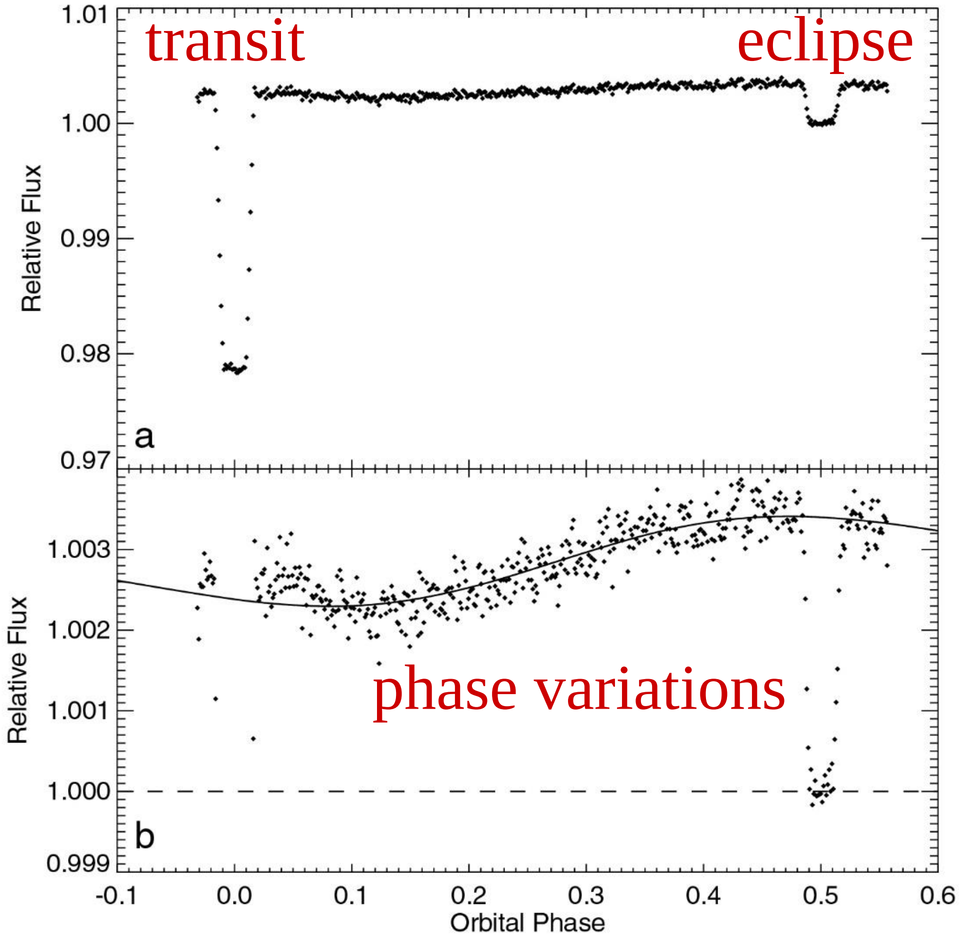
Atmospheric Absorption During Eclipse



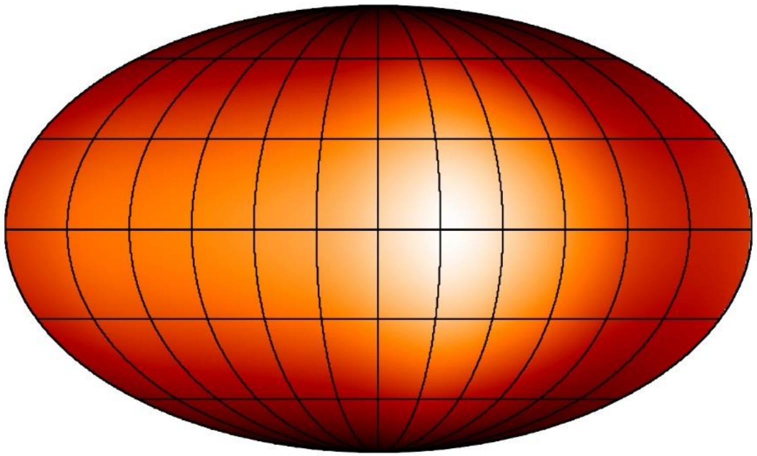
from Swain et al. (2009)

Vertical temperature profile from eclipse photometry and spectra



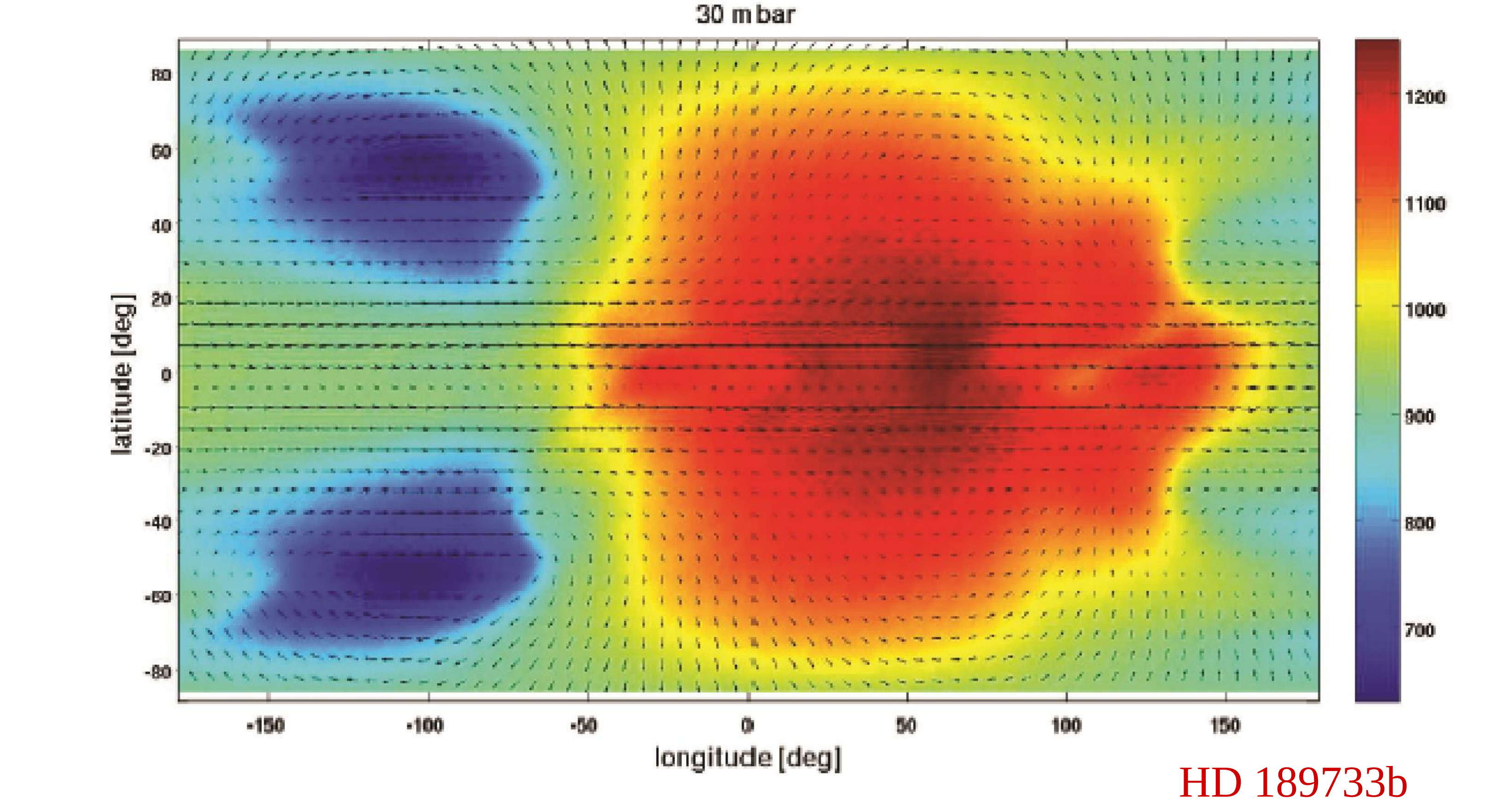


Knutson et al. (2007)
HD 189733b



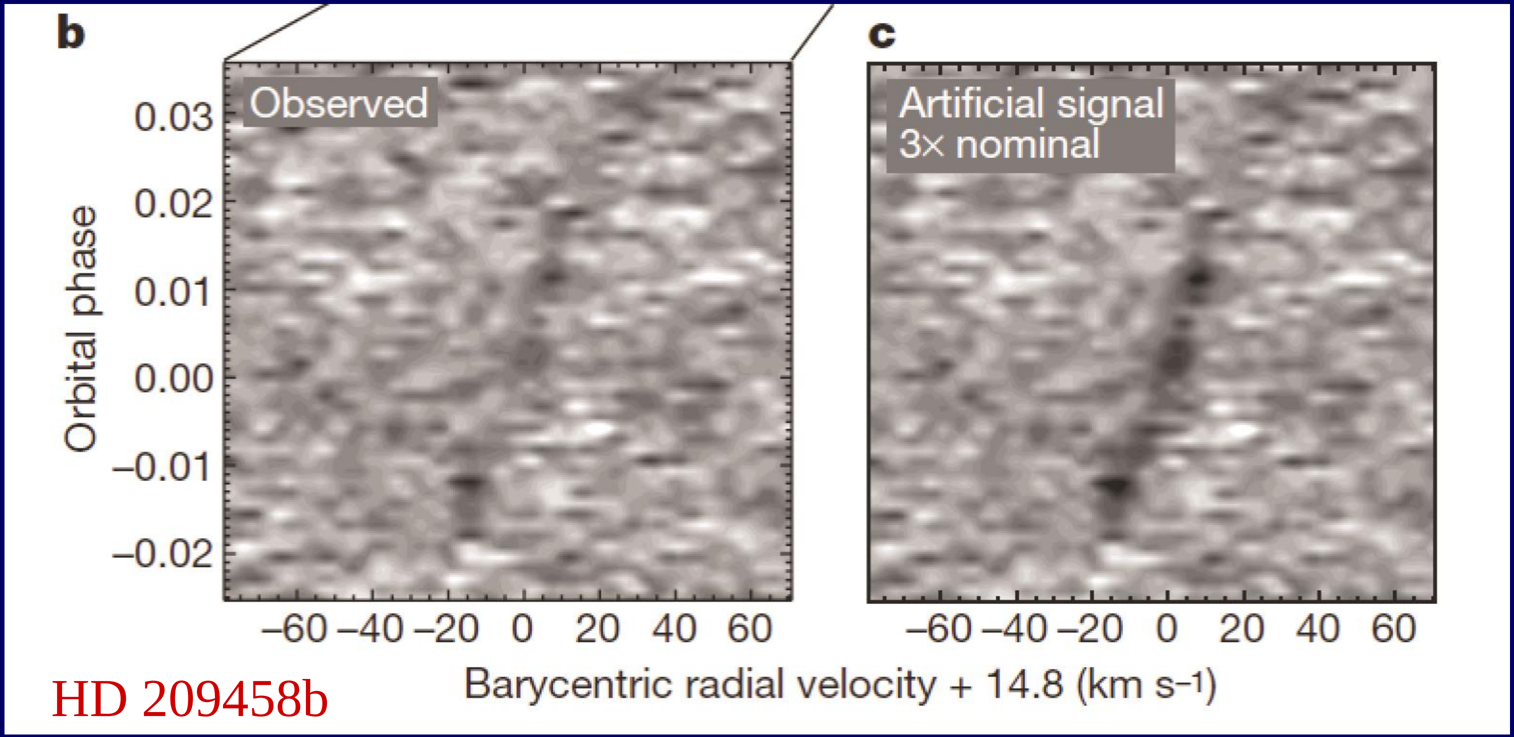
Phase variations give you info on longitudinal T variations →

3D General Circulation Models of Exoplanets



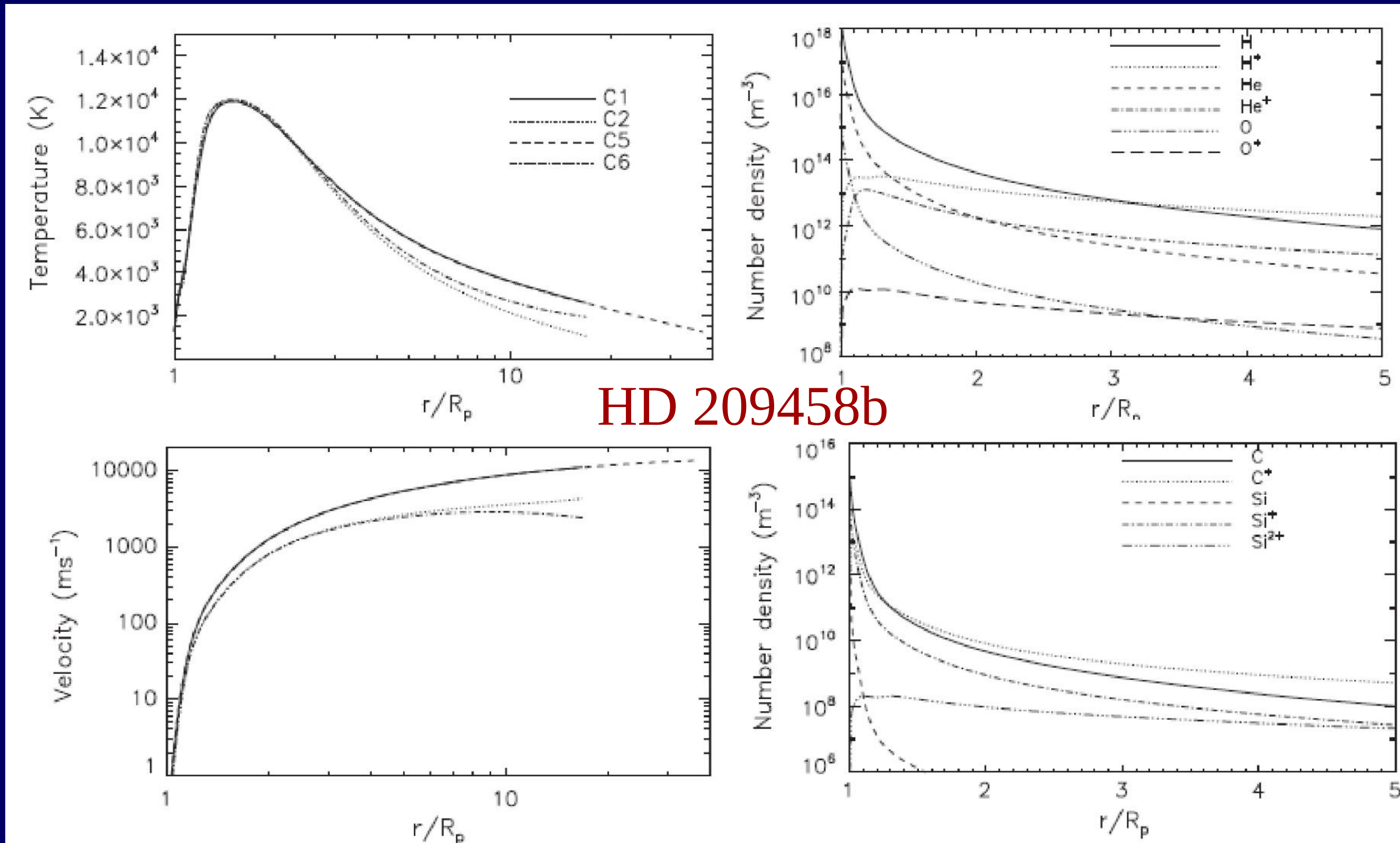
from Showman et al. (2009)

High Spectral Resolution Observations



From Snellen et al. (2010). Cross correlation study identifies CO from the planet → can even determine high-altitude winds!

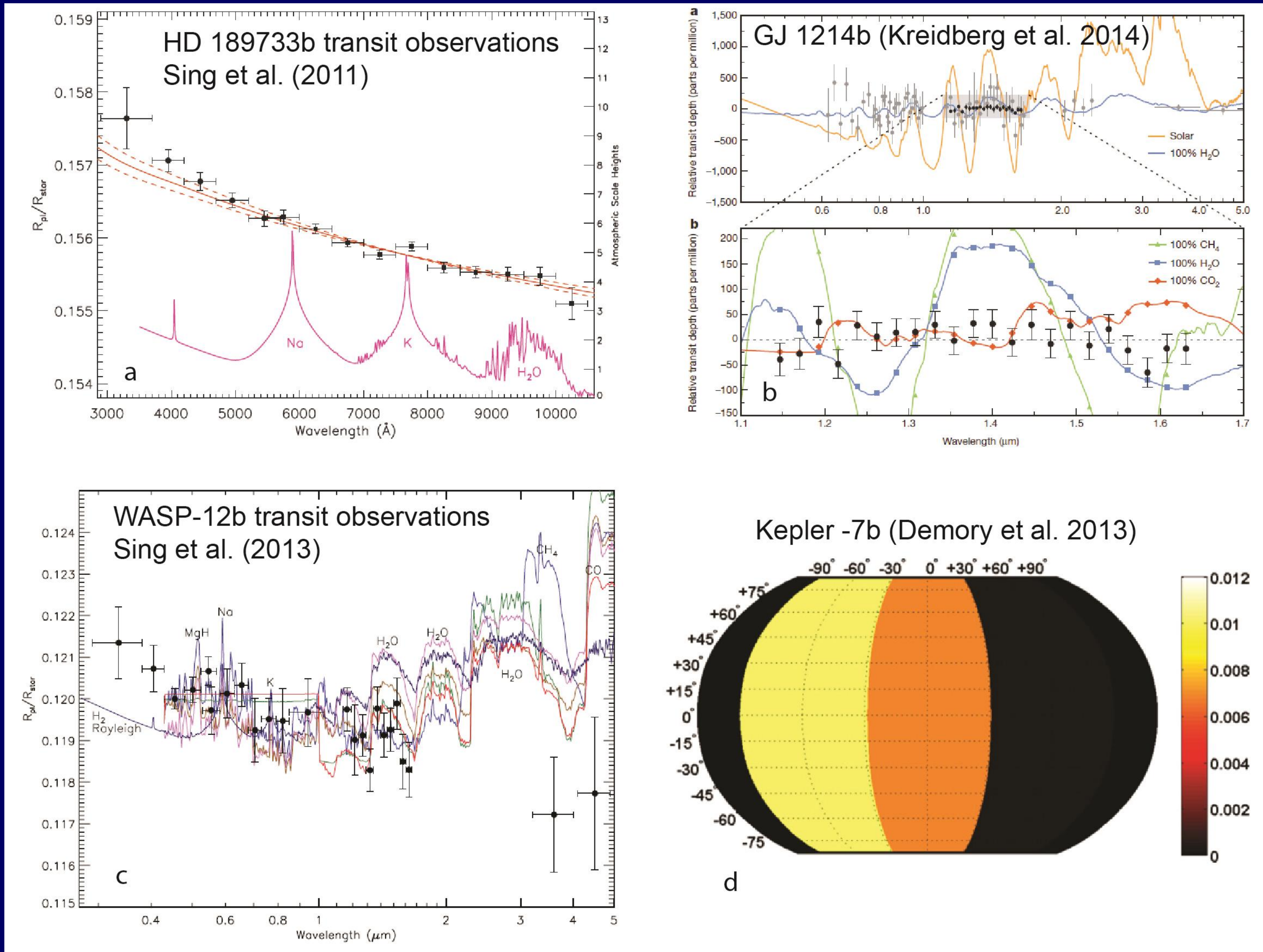
Thermospheric Photochemistry on Exoplanets



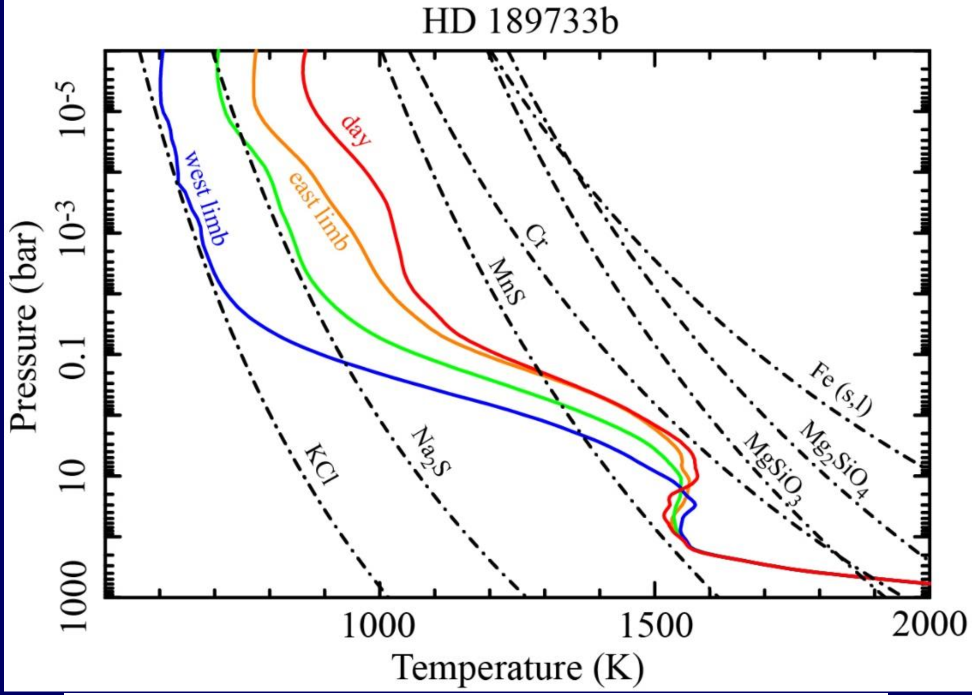
from Koskinen et al. (2013); see also García-Muñoz (2007); Yelle (2004)

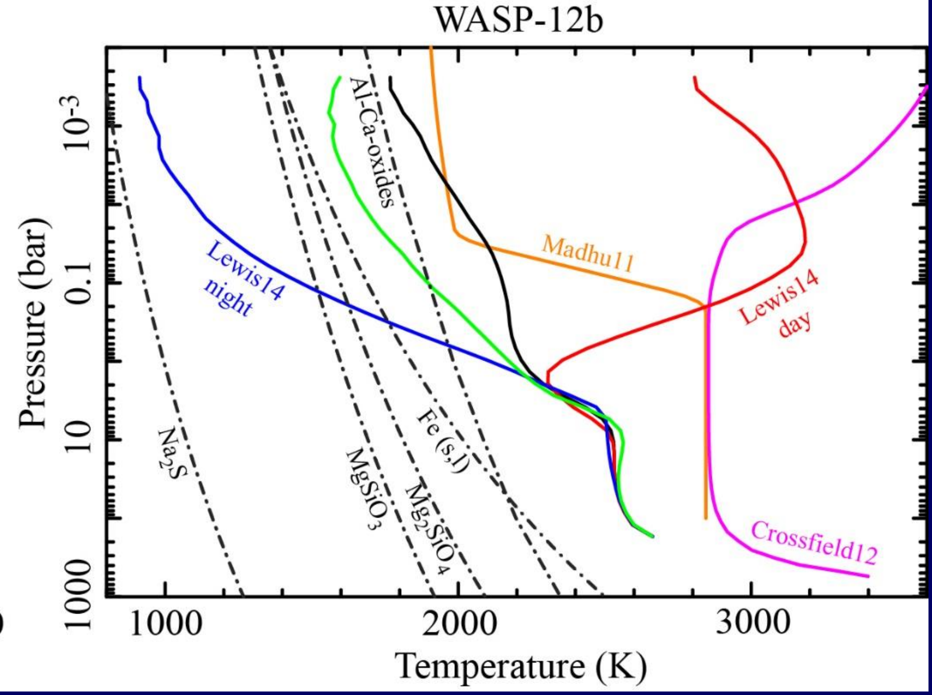
Hot, expanded thermosphere undergoing hydrodynamic escape can have heavy species dragged along with the escaping hydrogen

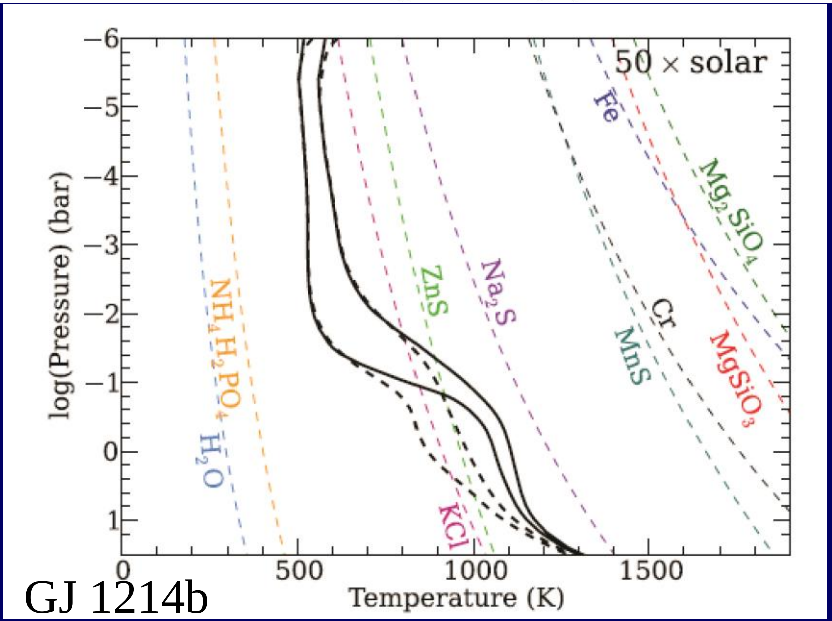
Evidence for Clouds/Hazes



What are these clouds? Need help from theory

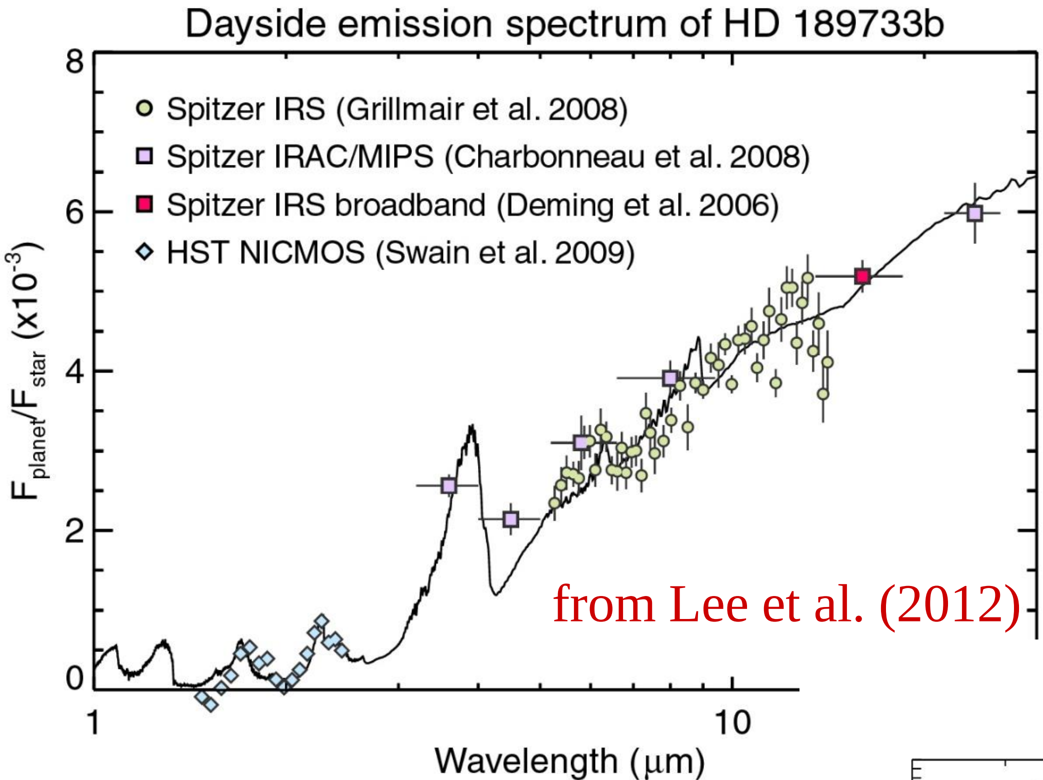






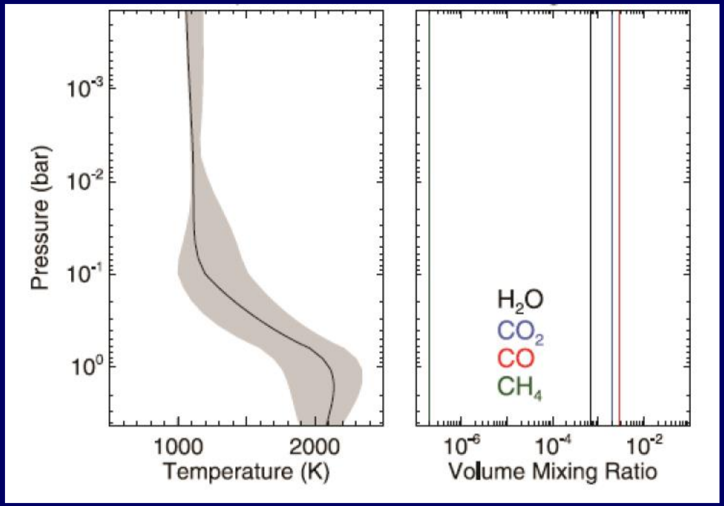
[top] from my 2014 proposal

[left] from Morley et al. (2013)

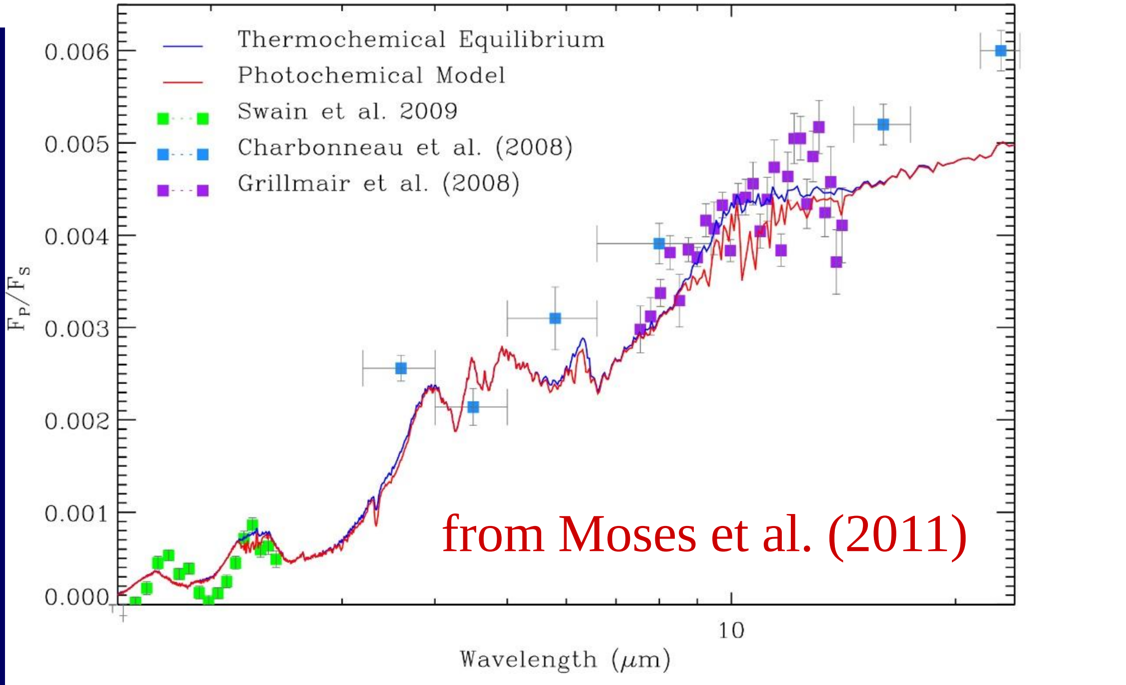


from Lee et al. (2012)

← Model fit via retrievals

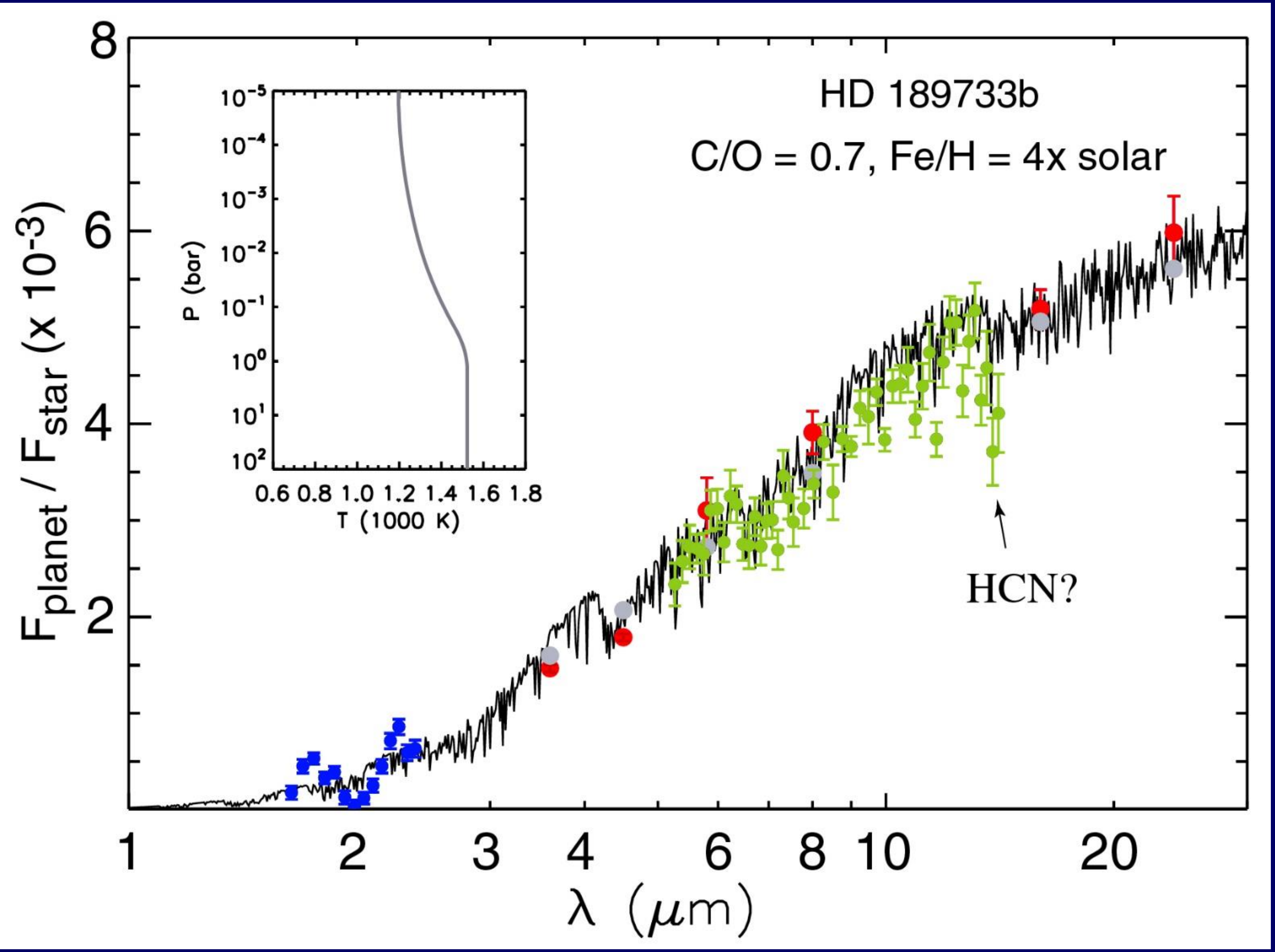


Model fit via
"first principles" →
Spectral modeling
from Caitlin Griffith



from Moses et al. (2011)

Models from a temperature retrieval but realistic chemistry

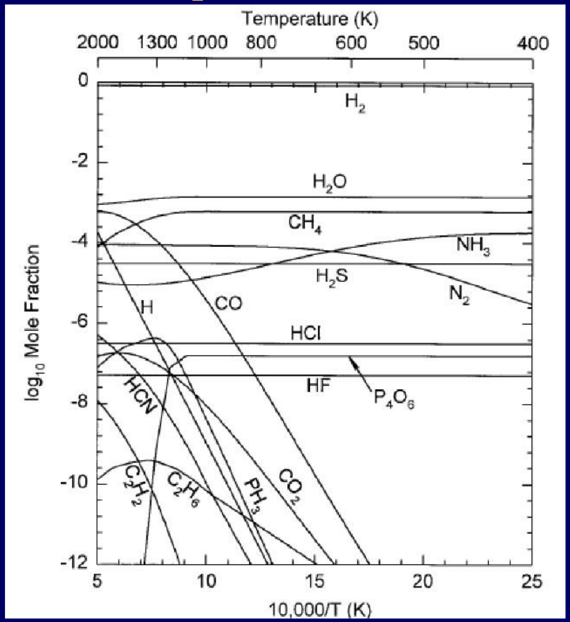


from Moses (2014)

Reliable error bars matter!

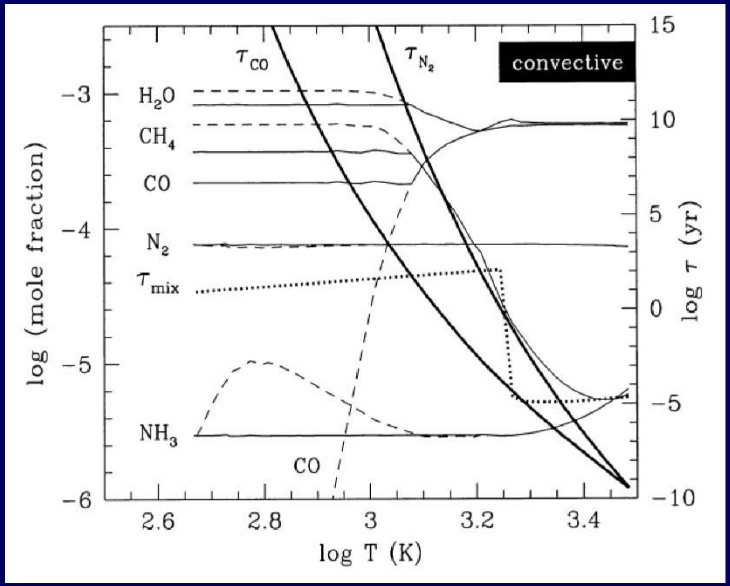
Given observational challenges and limited spectral data at this stage, theoretical modeling is crucial to advancing our understanding of exoplanet atmospheres

equilibrium



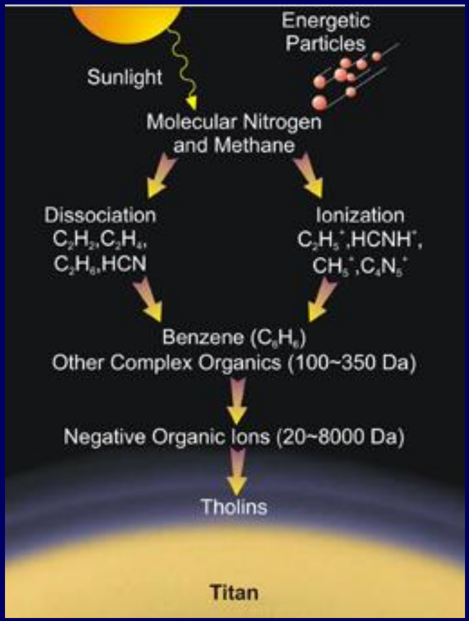
Fegley & Lodders (1996)

quenching



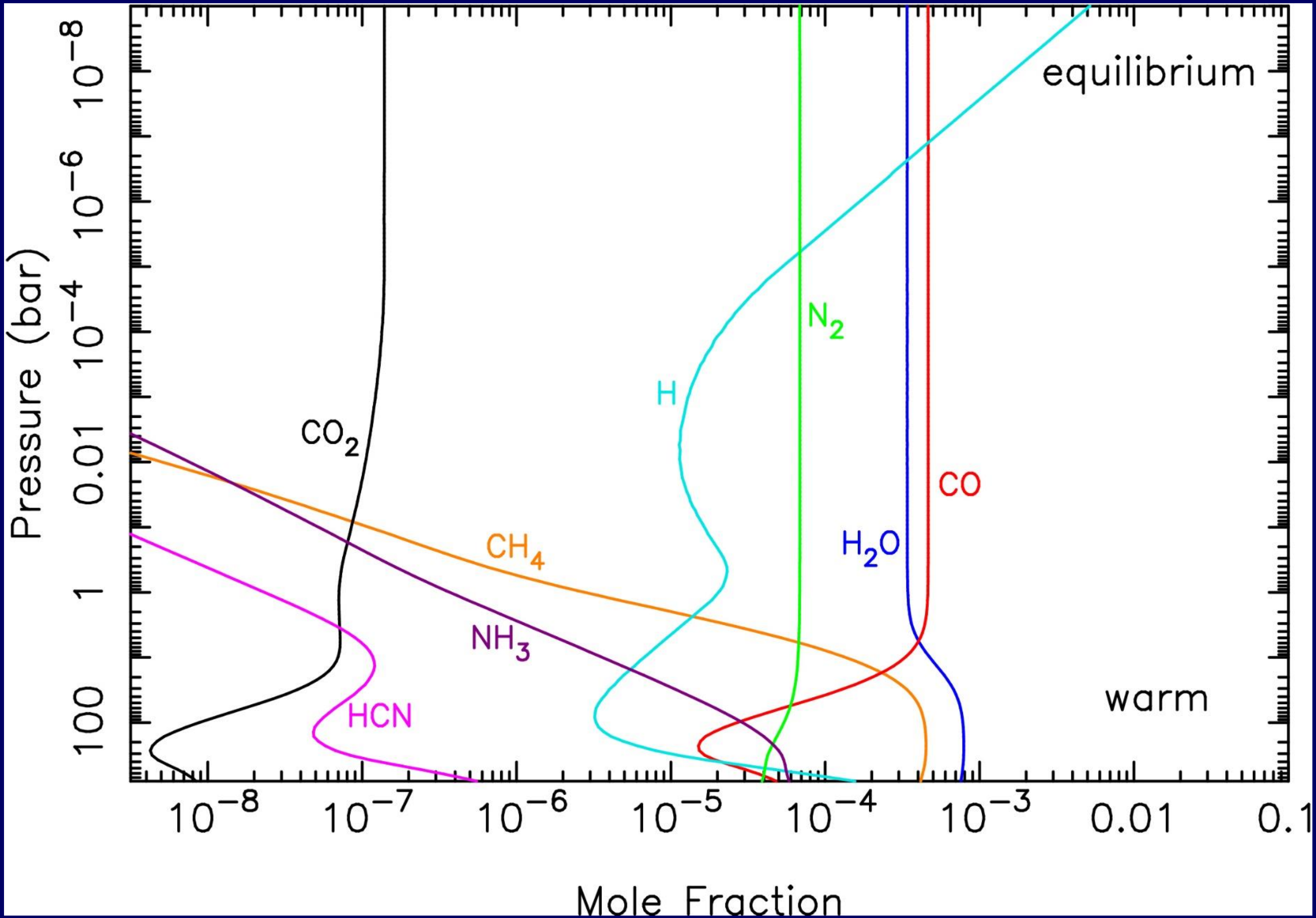
Saumon et al. (2003)

photochemistry

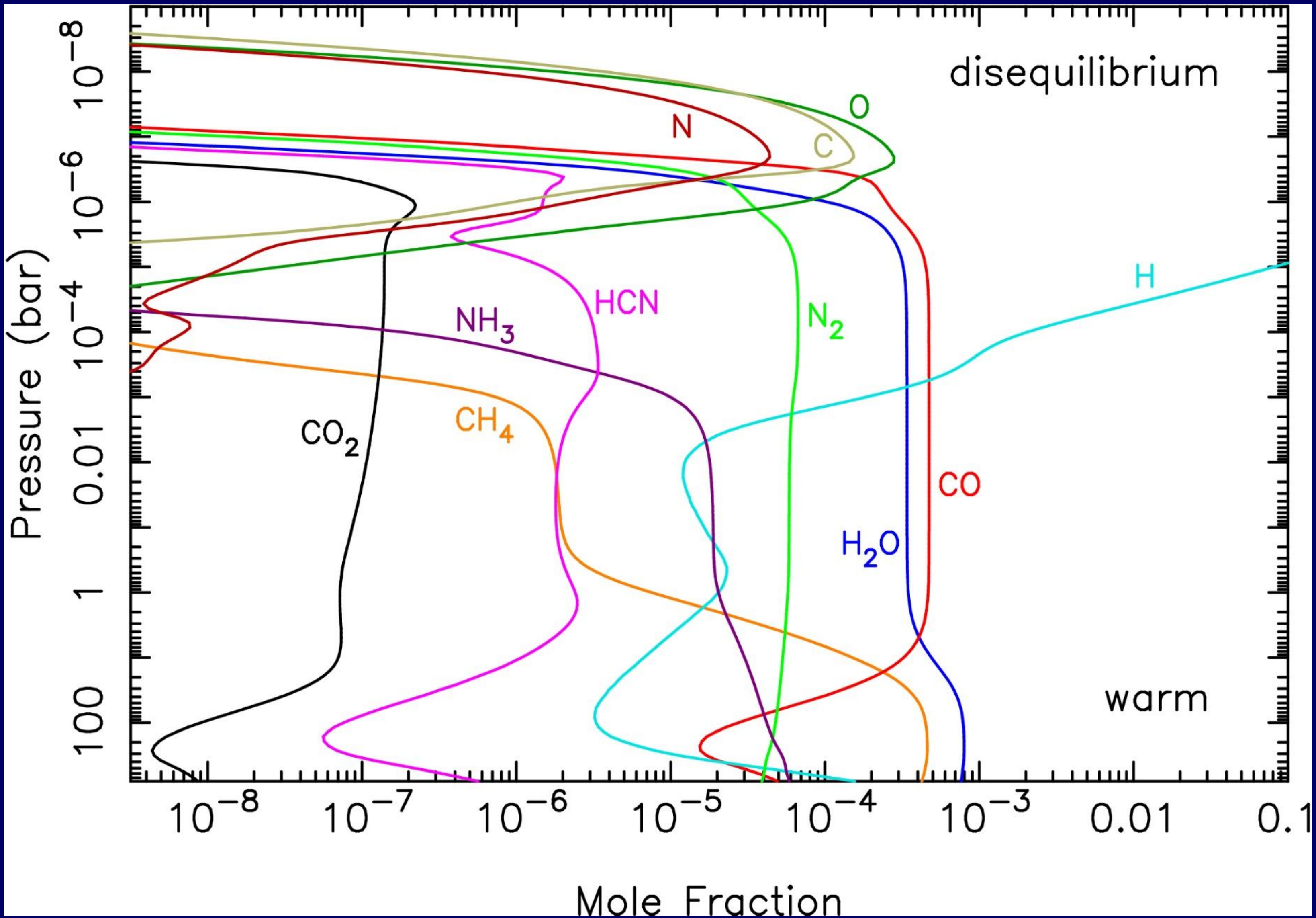


Waite et al. (2007)

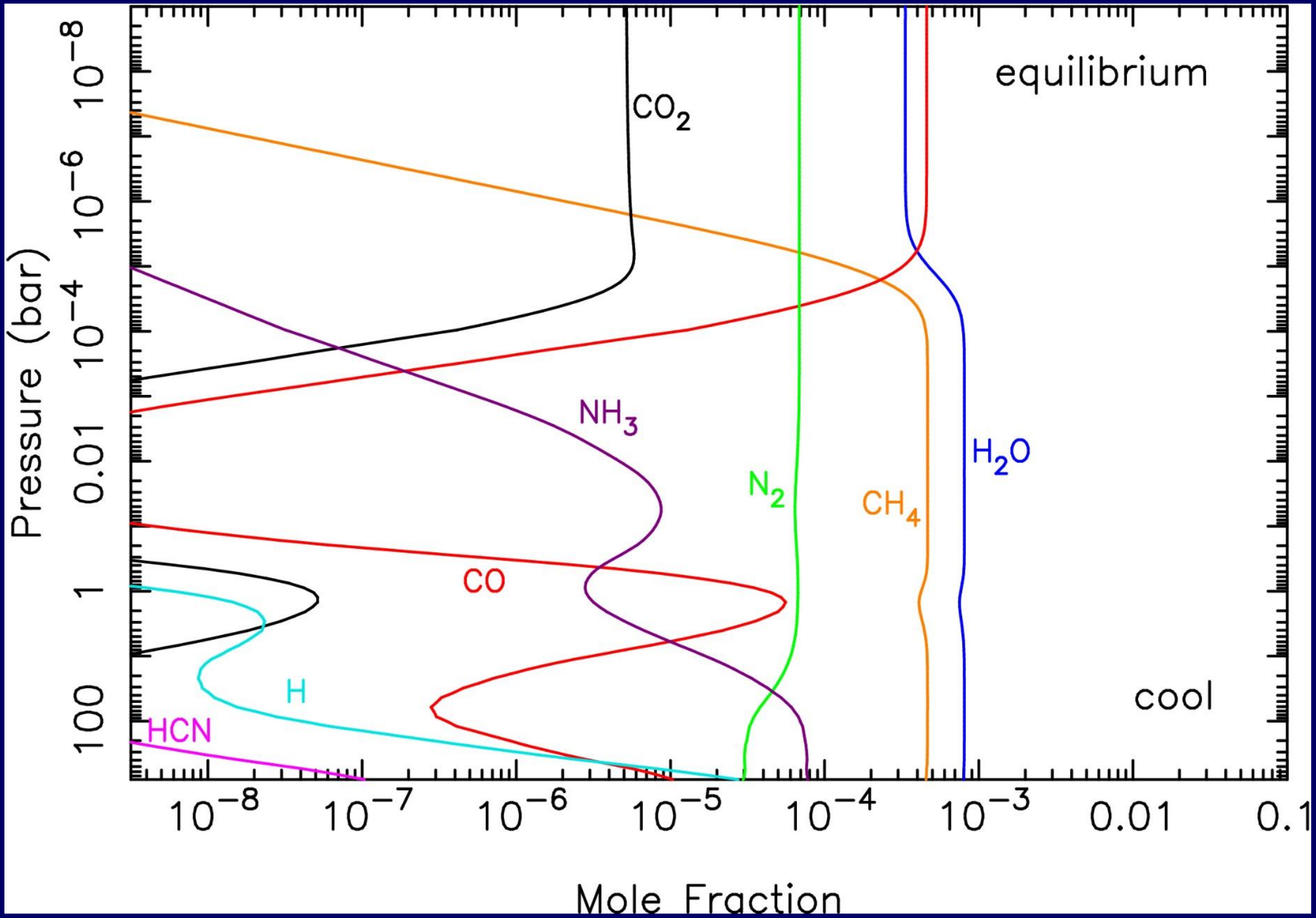
Equilibrium Chemistry: "Warm" Giant Exoplanet



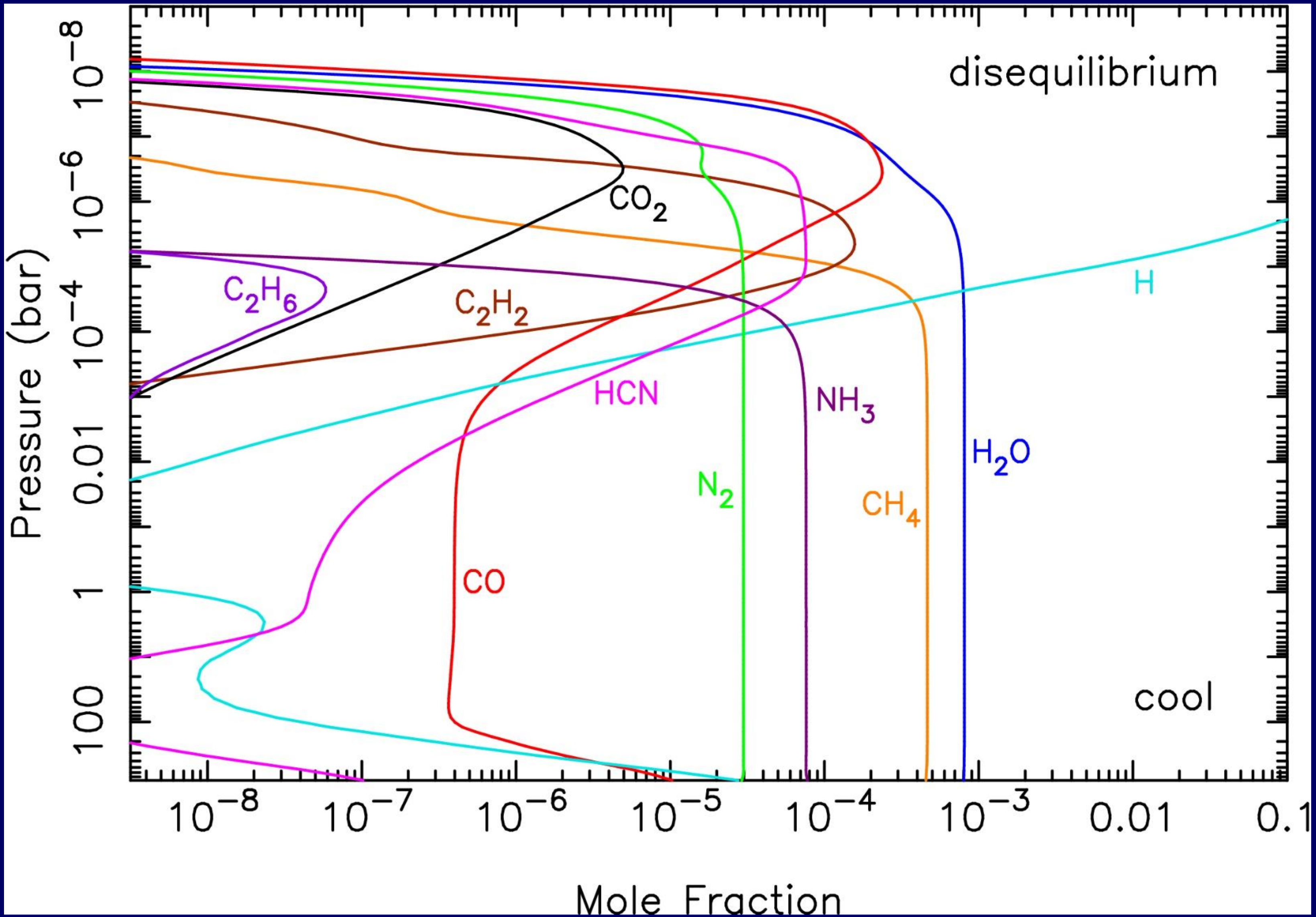
Photochemistry/Quenching: "Warm" Giant Exoplanet



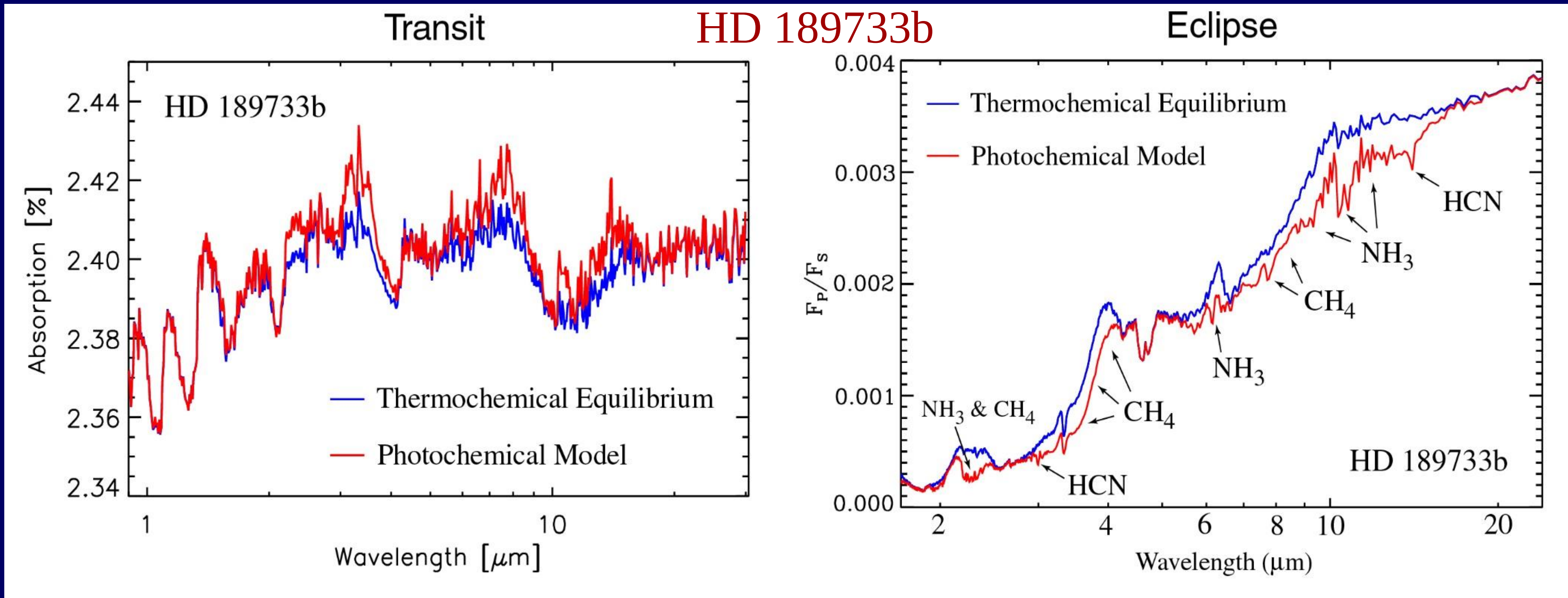
Equilibrium Chemistry: "Cool" Giant Exoplanet

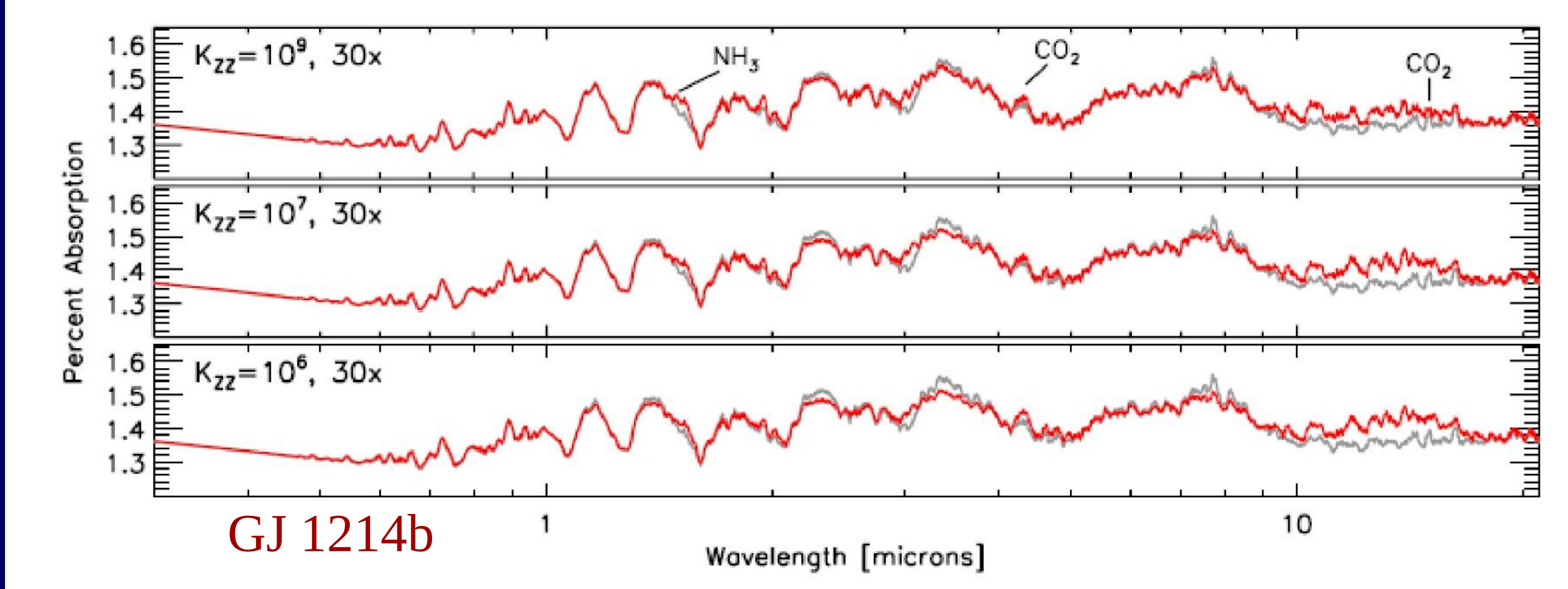


Photochemistry/Quenching: “Cool” Giant Exoplanet



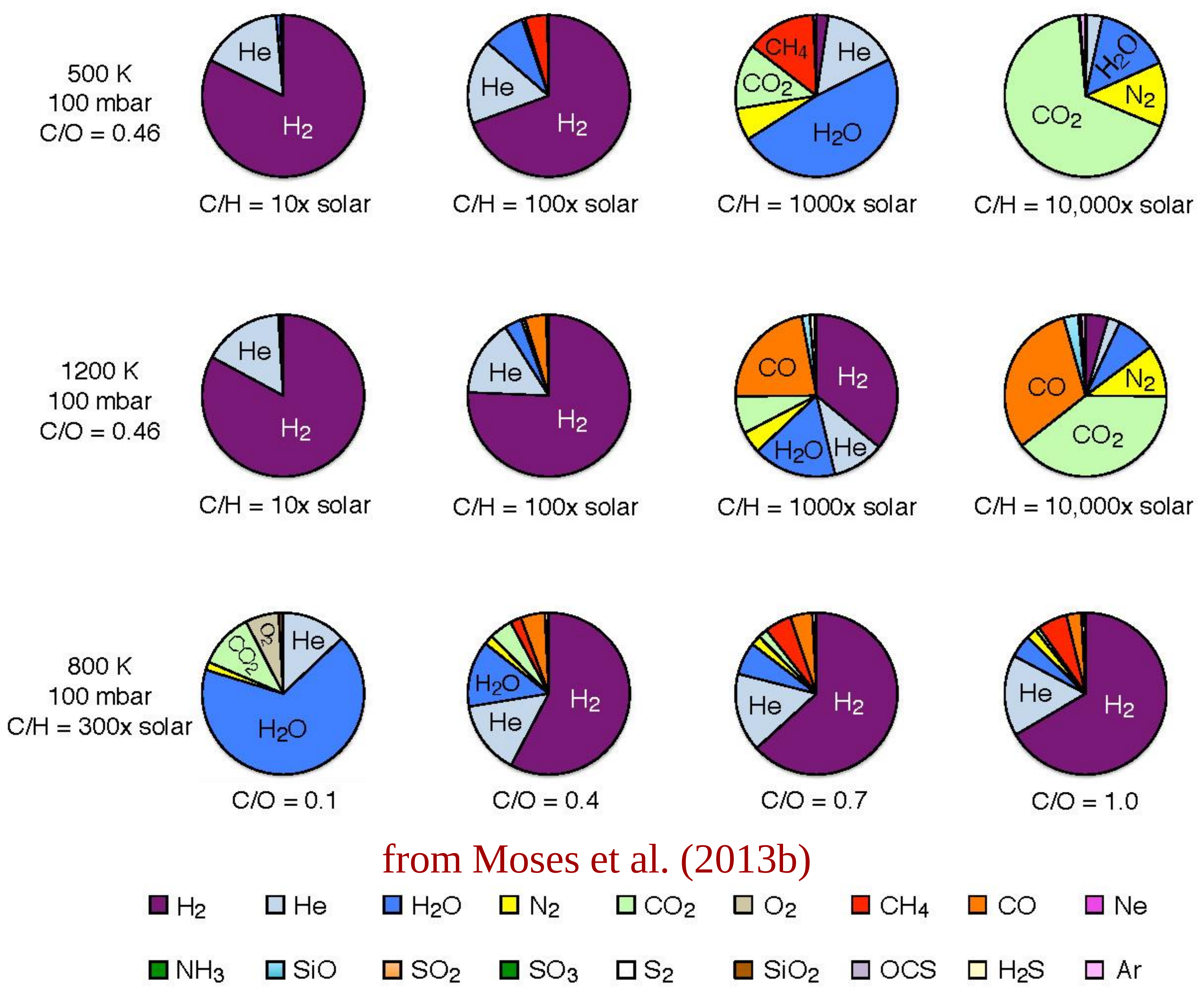
Observational Consequences of Disequilibrium Chemistry





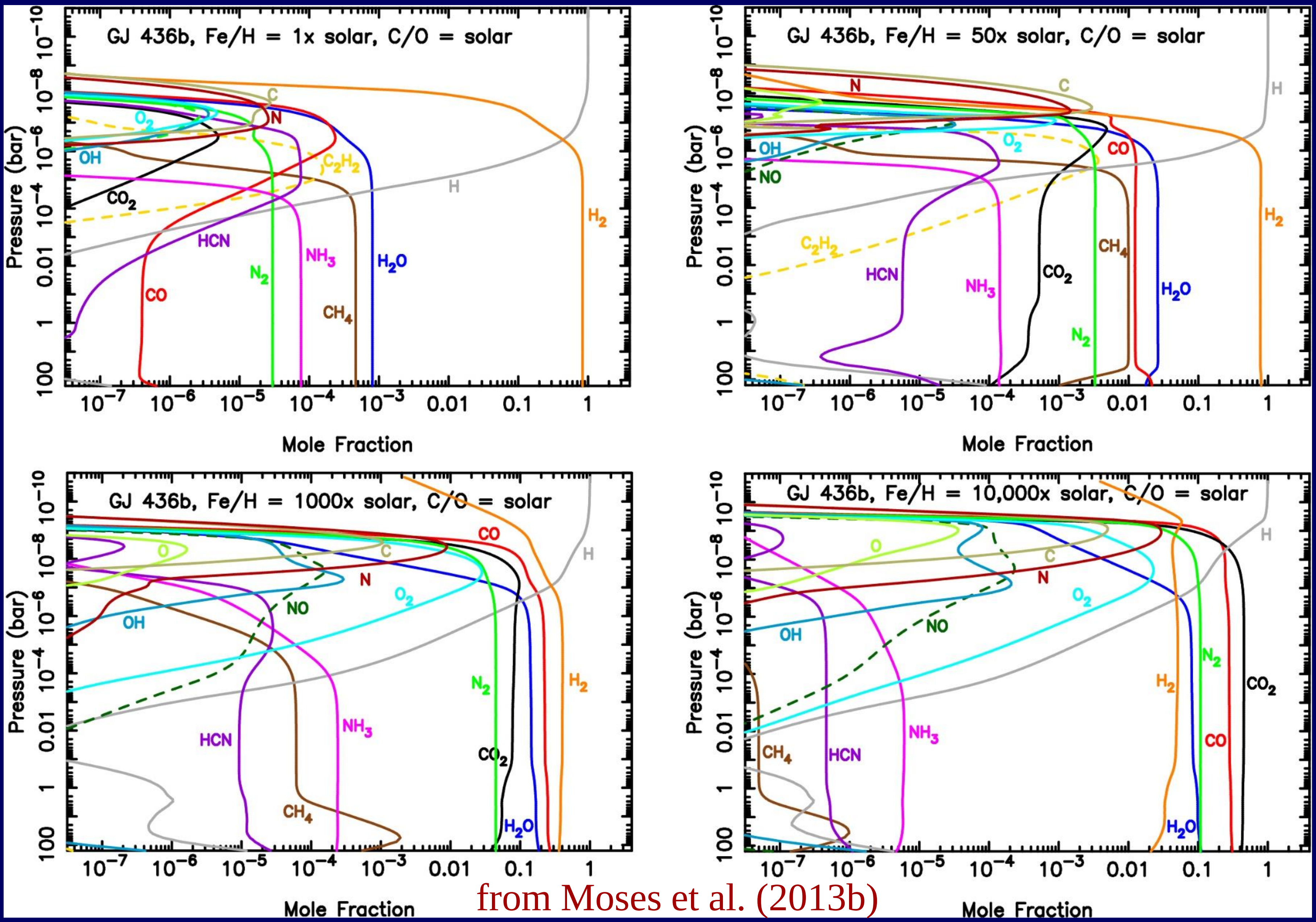
Top: Moses (2014); Bottom: Miller-Ricci Kempton et al. (2012)

Thermochemical Equil. vs Metallicity, Elemental Ratios



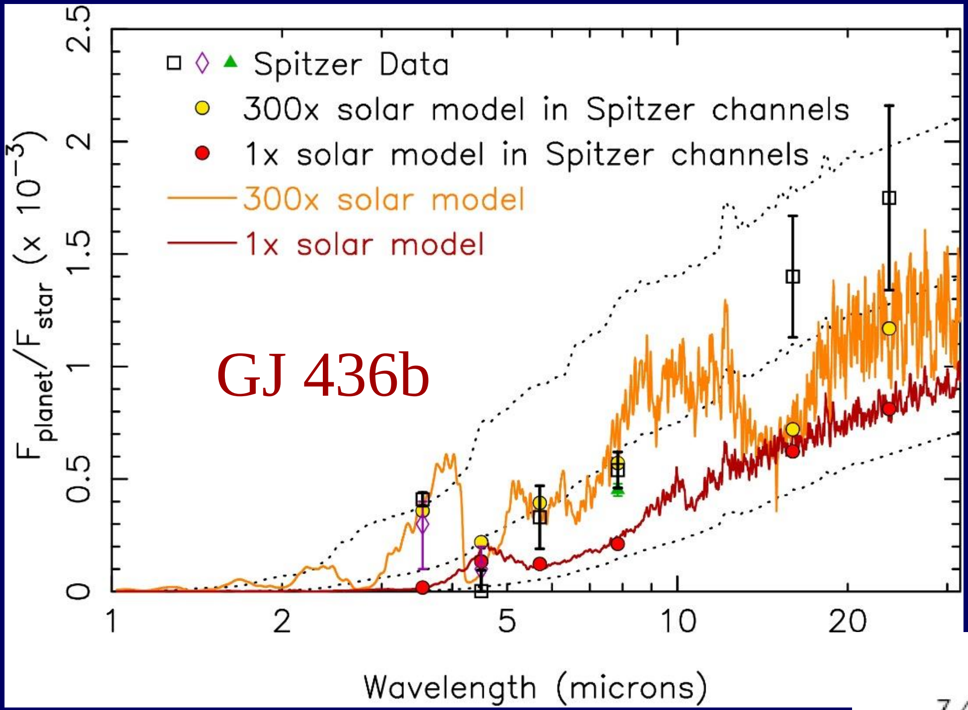
from Moses et al. (2013b)

Super Earth/Mini Neptunes: Fct. of Metallicity



from Moses et al. (2013b)

Observational Consequences of Metallicity & Clouds

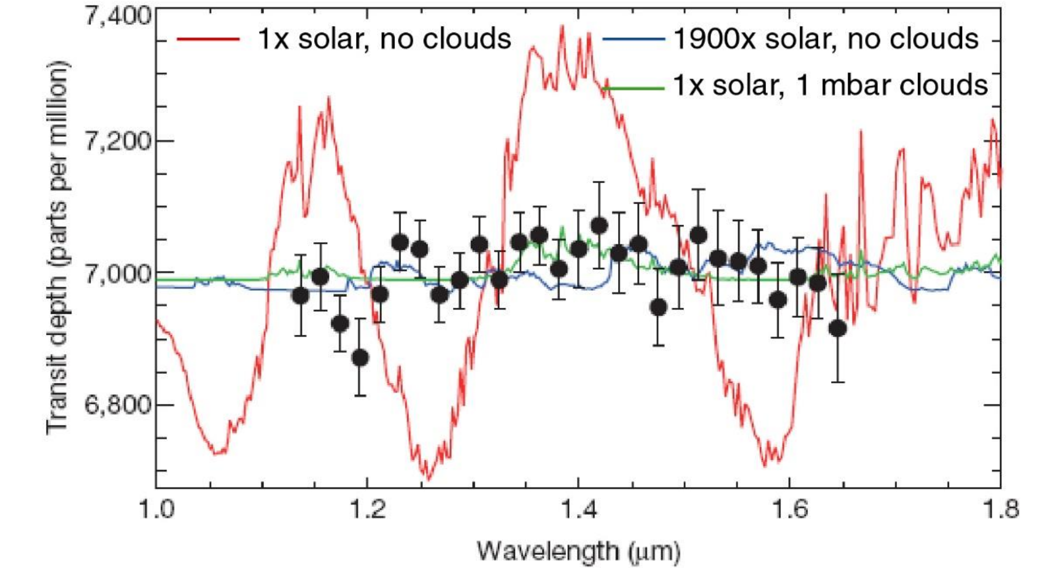


Optically thick clouds cause transit spectra (below) to look flat and emission spectra (left) to resemble blackbody emission

Bottom: from Knutson et al. (2014)

Top: from Moses et al. (2013)

High metallicity causes transit spectra (right) to look flat and causes different molecular features to appear in emission spectra (top)



Conclusions

- Increasingly sophisticated observations and data-analysis procedures are helping to define atmospheric composition, thermal structure, cloud properties on exoplanets
- Determining atmospheric composition from transits may be difficult for small exoplanets, due to high mean molecular weight atmos. and potential high clouds; acquiring good eclipse spectra will be key
- Need something like EChO, FINESSE 2.0, JWST to get eclipse **spectra**
- Need good theoretical models to define missions, predict what we can observe, interpret observations