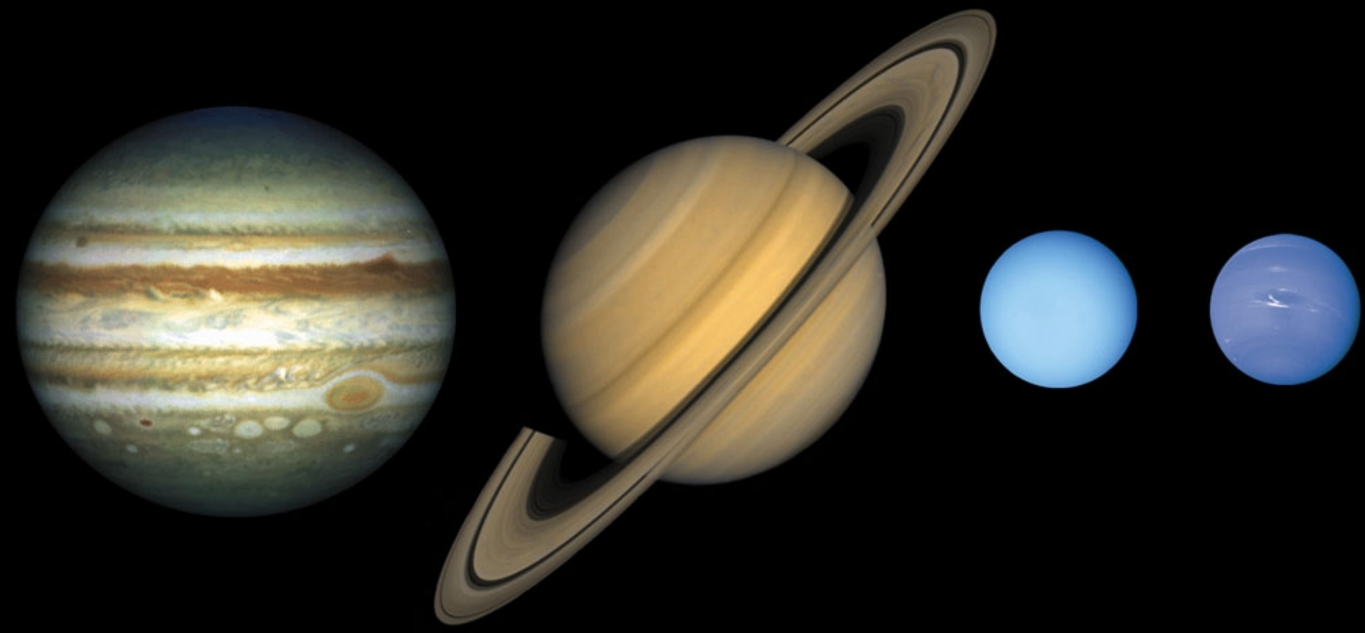
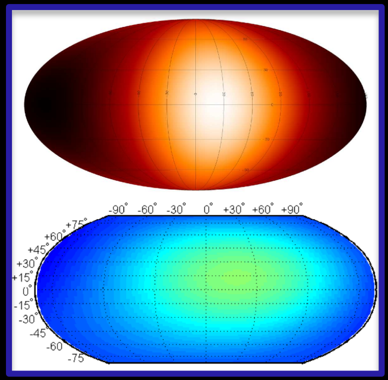


Atmospheres of Giant Planets

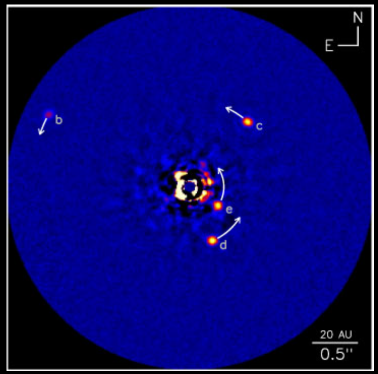


de Wit+12, Majeau+12

Emily Rauscher

Spitzer Postdoctoral Fellow

Princeton (→ U Michigan)



credit: Keck Observatory

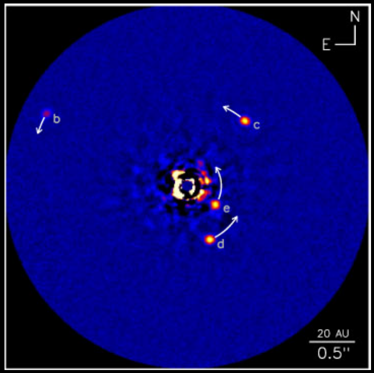
Atmospheres: the next step

Detection:
orbital distance
mass and/or radius
age?
companions?

Characterization:
temperature
composition
spatial structure
chemistry, clouds, etc.
etc., etc., etc.

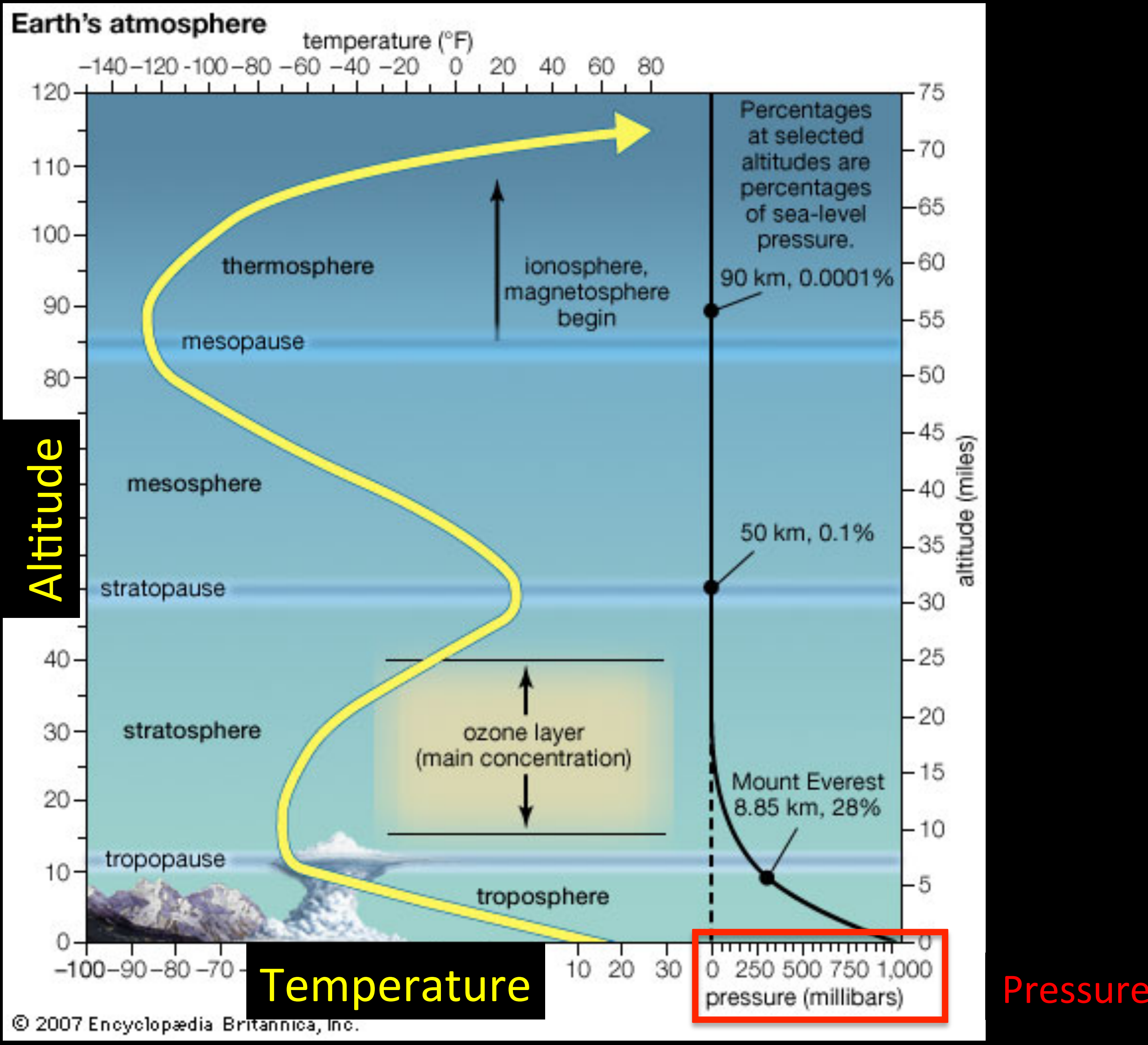
Reviews:

Seager & Deming, "Exoplanet Atmospheres", ARA&A (2010)
Burrows & Orton, "Giant Planet Atmospheres", in *Exoplanets* ed. Seager (2011)
Madhusudhan, Knutson, Fortney, & Barman, "Exoplanetary Atmospheres", PPVI chapter (2014)



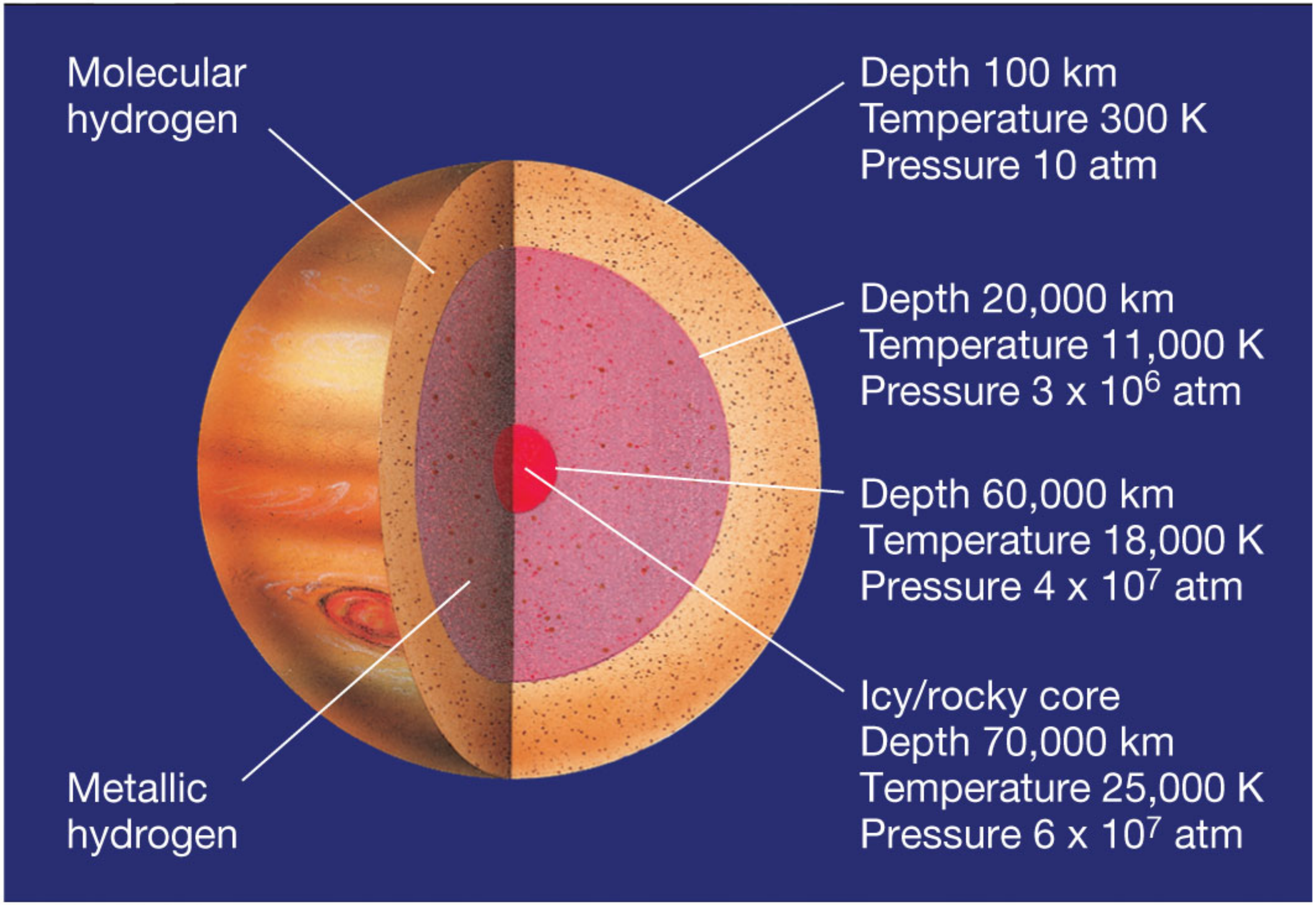
Basic question:

WHAT DEFINES THE ATMOSPHERE?

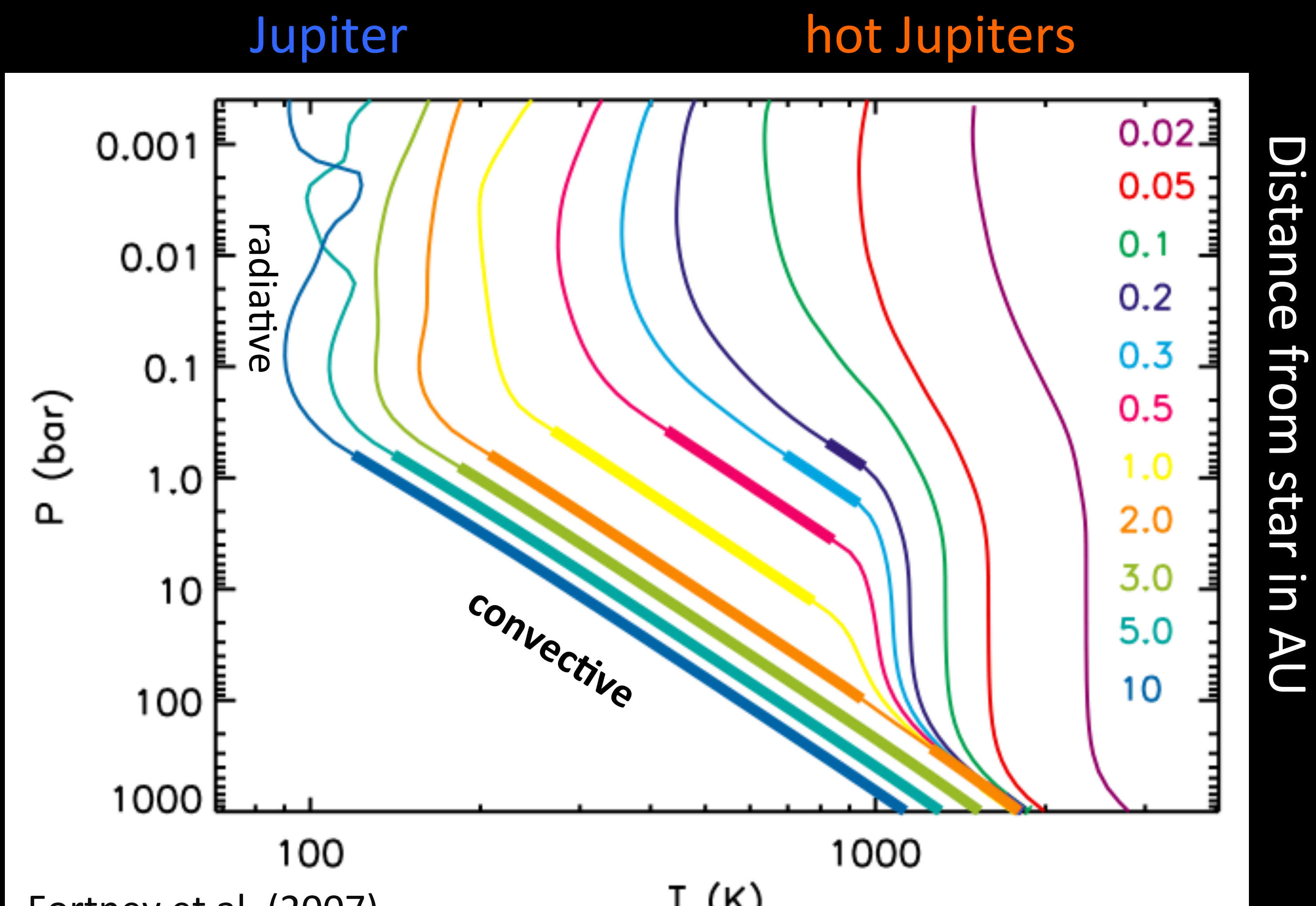


Earth's atmosphere
temperature (°F)
−140 −120 -100 −80 −60 −40 −20 0 20 40 60 80
120
110
100
90
80
40
30
20
10
0
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
altitude (miles)
thermosphere
ionosphere, magnetosphere begin
Percentages at selected altitudes are percentages of sea-level pressure.
90 km, 0.0001%
mesopause
mesosphere
50 km, 0.1%
stratopause
ozone layer (main concentration)
stratosphere
Mount Everest 8.85 km, 28%
tropopause
troposphere
−100 −90 −80 −70
10 20 30
0 250 500 750 1,000
pressure (millibars)
© 2007 Encyclopædia Britannica, Inc.
Altitude
Temperature
Pressure

What if there's no surface?



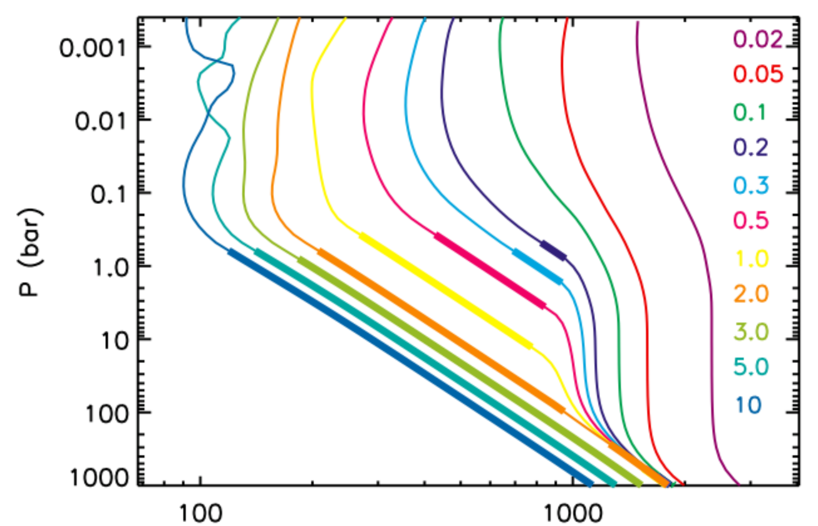
Defining the atmosphere



Fortney et al. (2007)

Defining the atmosphere

Pressure-Temperature (P-T) Profiles



Fortney et al. (2007)

λ-dependent opacities (κ) are a function of temperature, pressure, and *composition*

↓ stellar flux

↓ absorbed

local radiative equilibrium:

$$dF/dP = 0$$

multi-λ radiative transfer:

$$F\,(P, T, \kappa, F_{\uparrow}, F_{\downarrow})$$

assuming hydrostatic equilibrium:

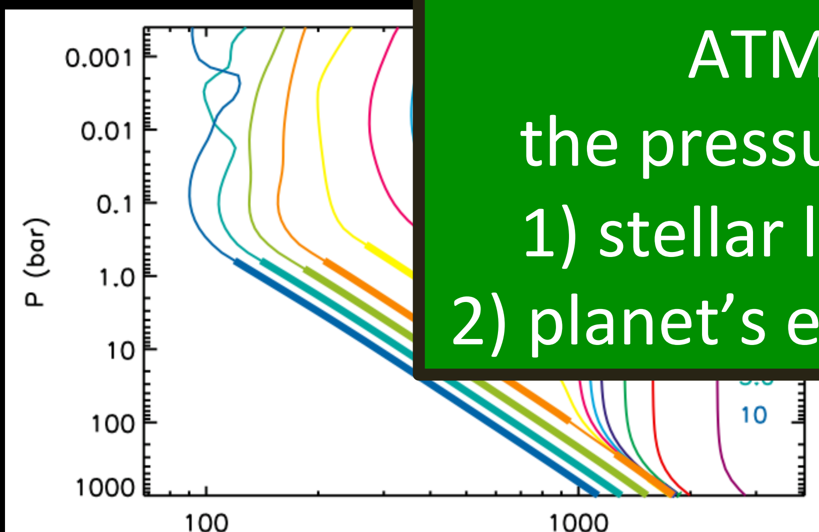
$$\tau = (\kappa/g)\,P$$

adiabatic profile

↑ intrinsic heat

Defining the atmosphere

Pressure-Temperature
(P-T) Profiles



Fortney et al. (2007)

λ-dependent opacities (κ) are a function of temperature, pressure, and *composition*

ATMOSPHERE:
the pressure range where
1) stellar light is absorbed
2) planet's emission originates

↓ stellar flux

↓ absorbed

orium:

= 0

nsfer:

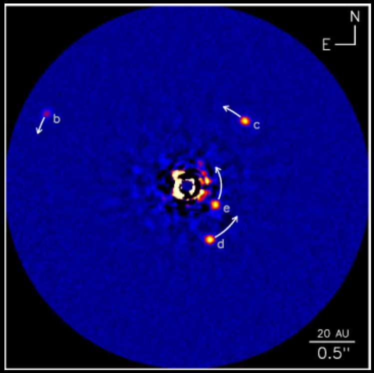
F↑, F↓)

assuming hydrostatic equilibrium:

$\tau = (\kappa/g)\, P$

adiabatic profile

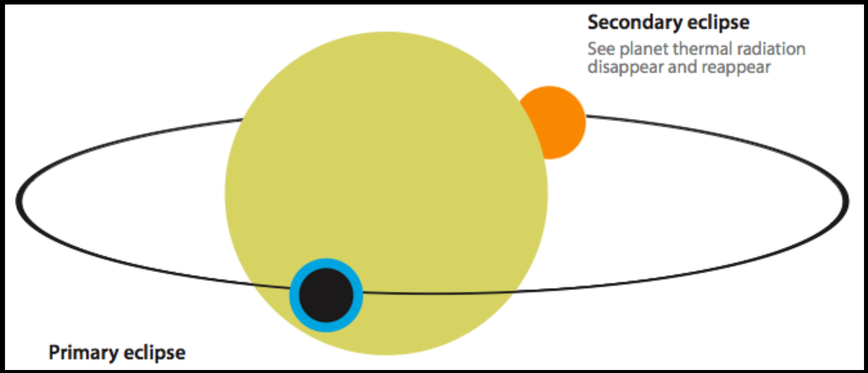
↑ intrinsic heat



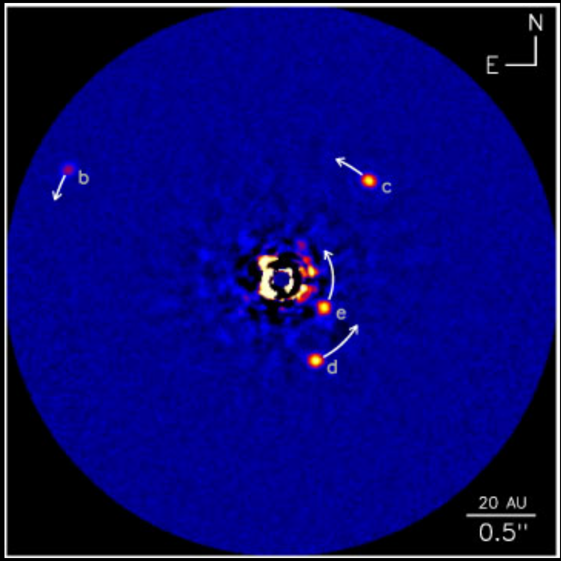
For the observers:

WHAT DO WE MEASURE?

Exoplanet atmospheric measurements



Seager & Deming (2010)



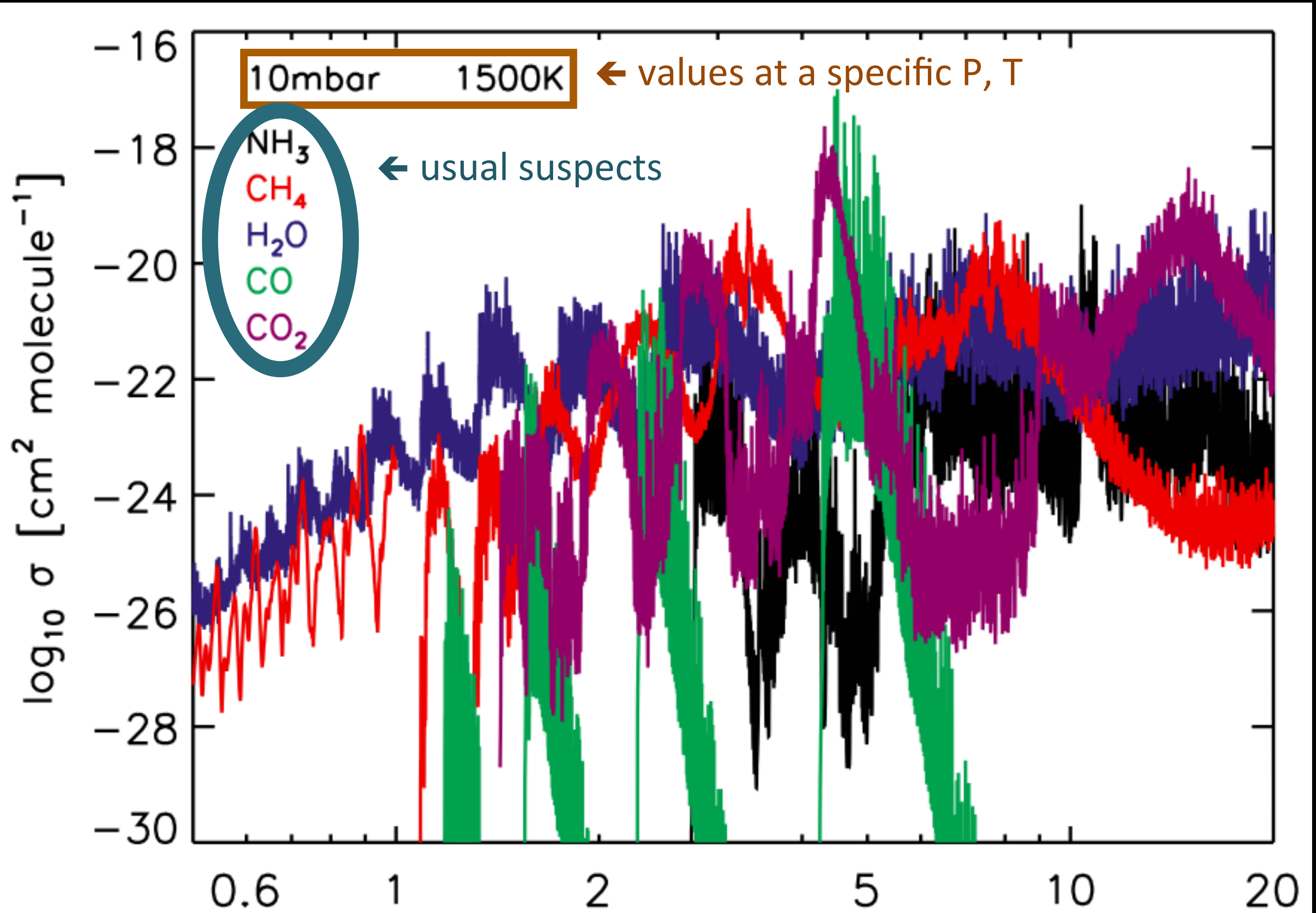
credit: Keck Observatory

Absorption

Emission

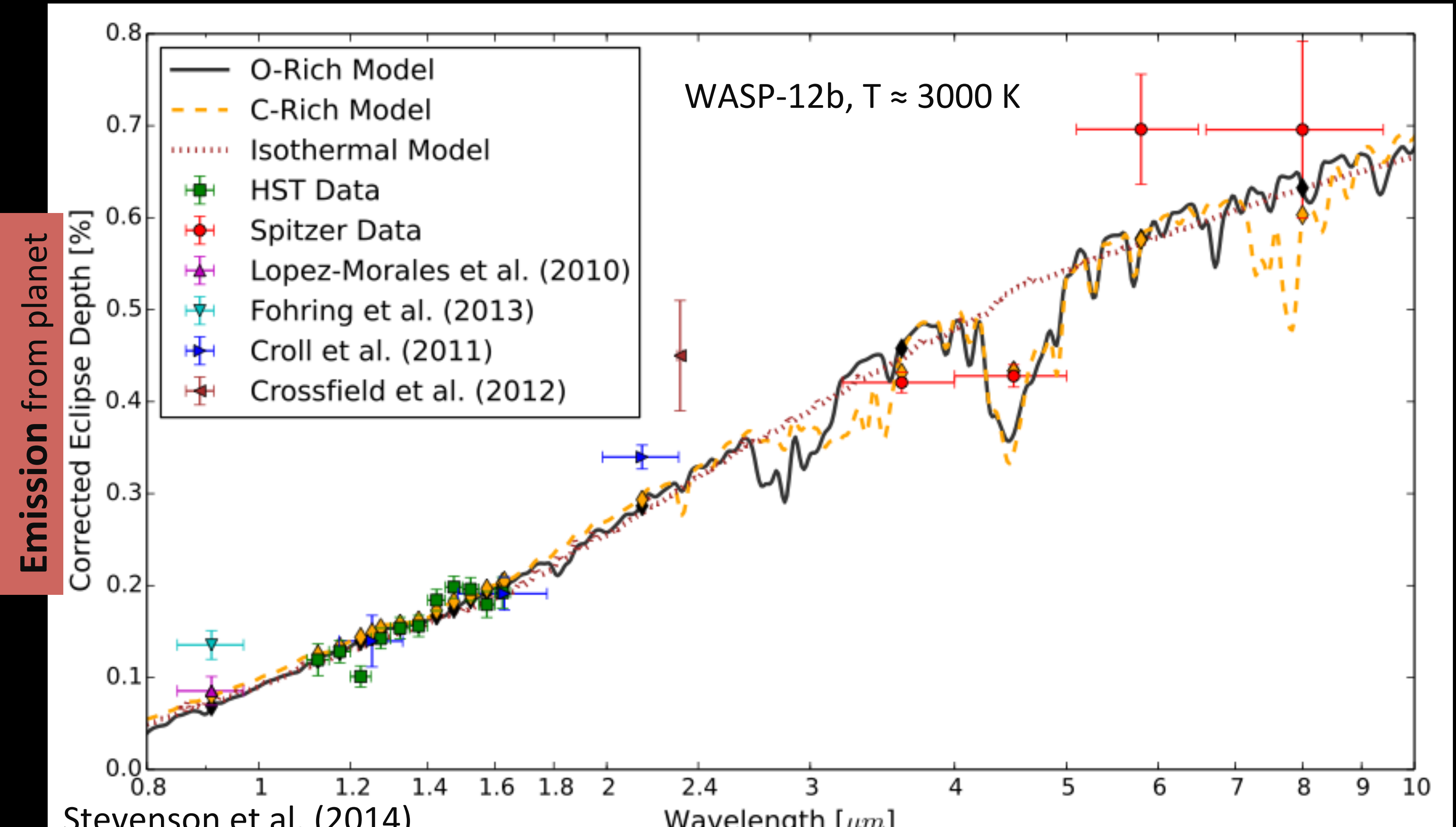
Reflection

Opacities depend on: λ, T, P, abundances



Shabram et al. (2011)

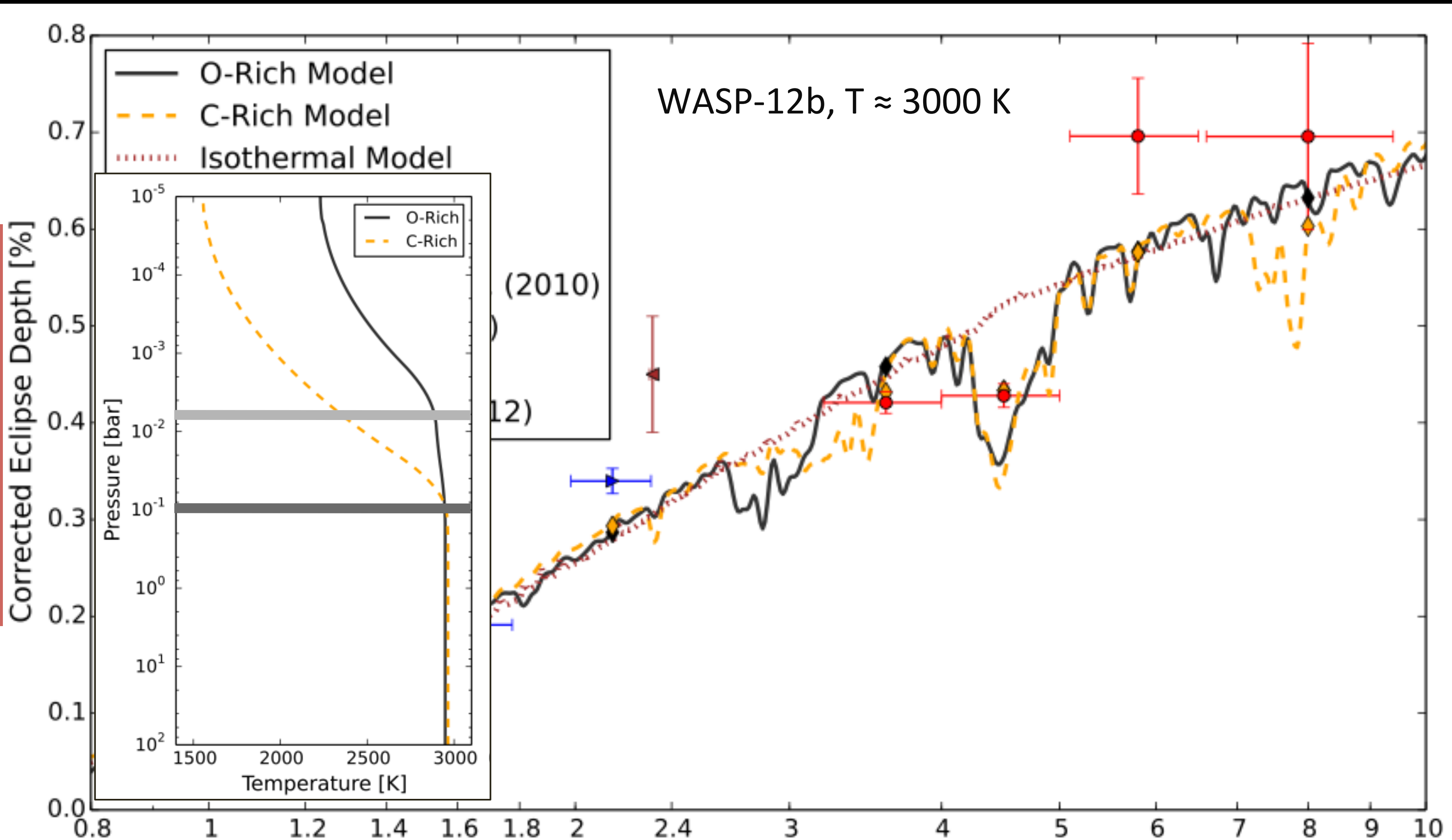
Interpreting data: T(P) and composition



Stevenson et al. (2014)

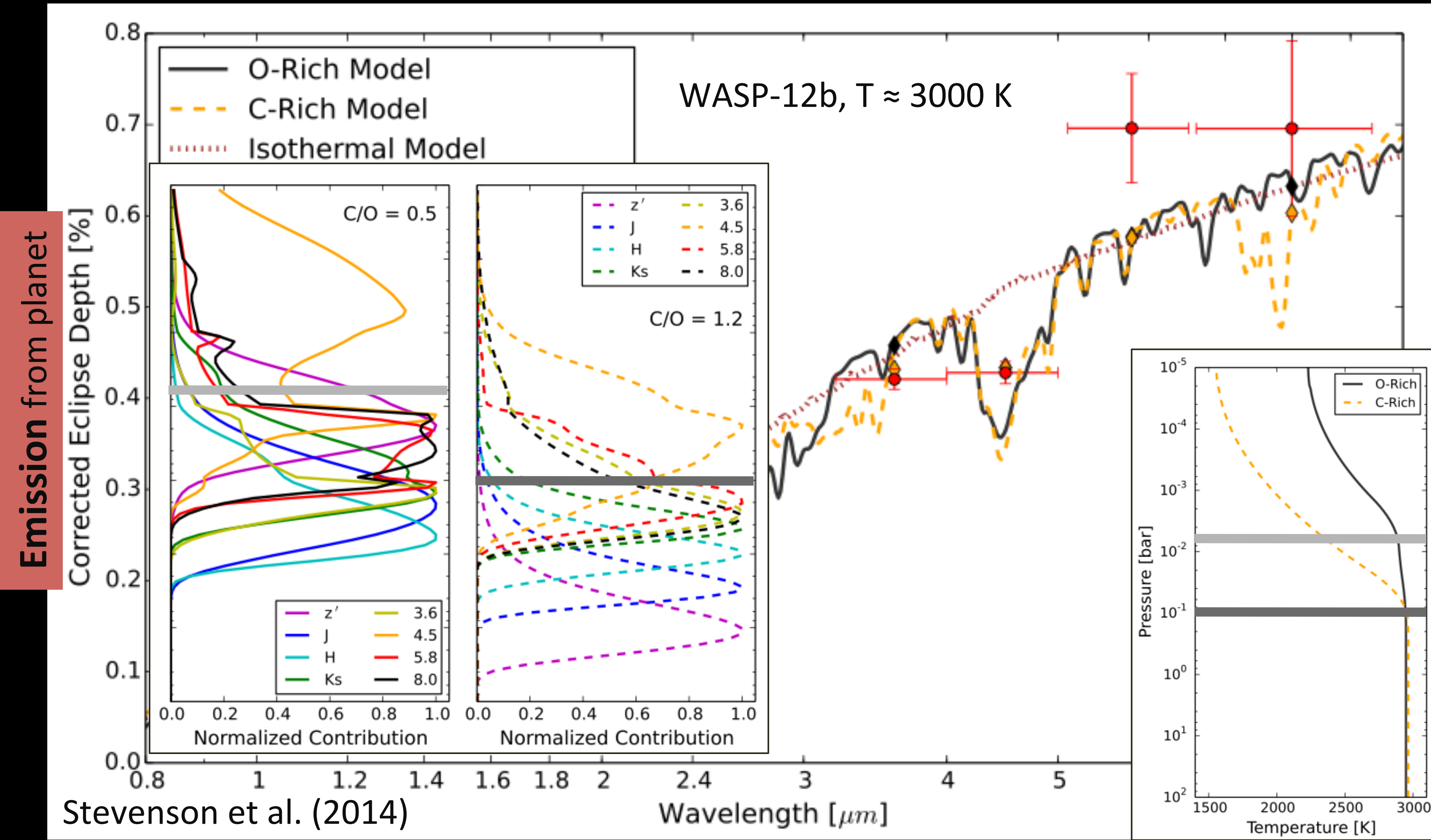
Interpreting data: T(P) and composition

Emission from planet



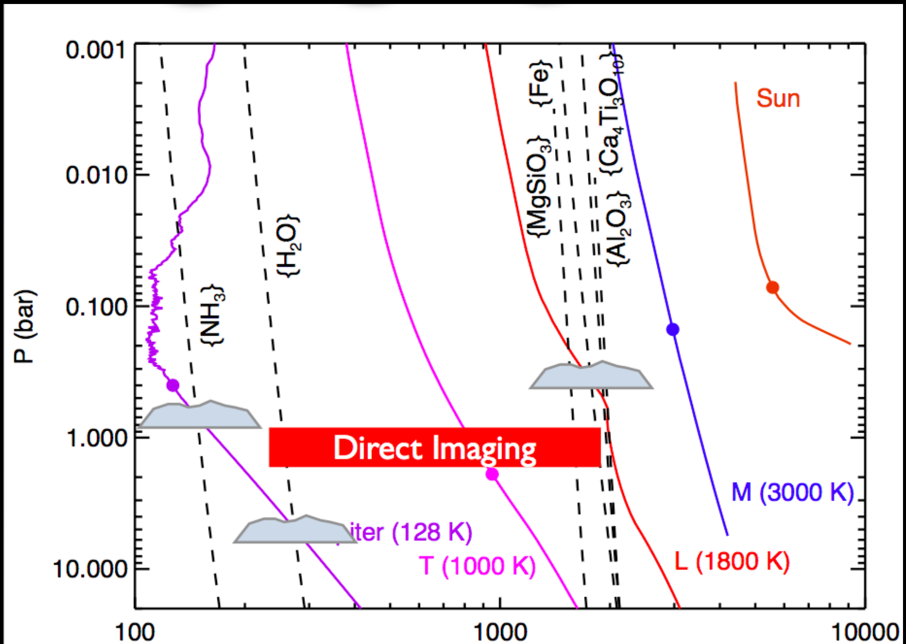
Stevenson et al. (2014)

Interpreting data: T(P) and composition

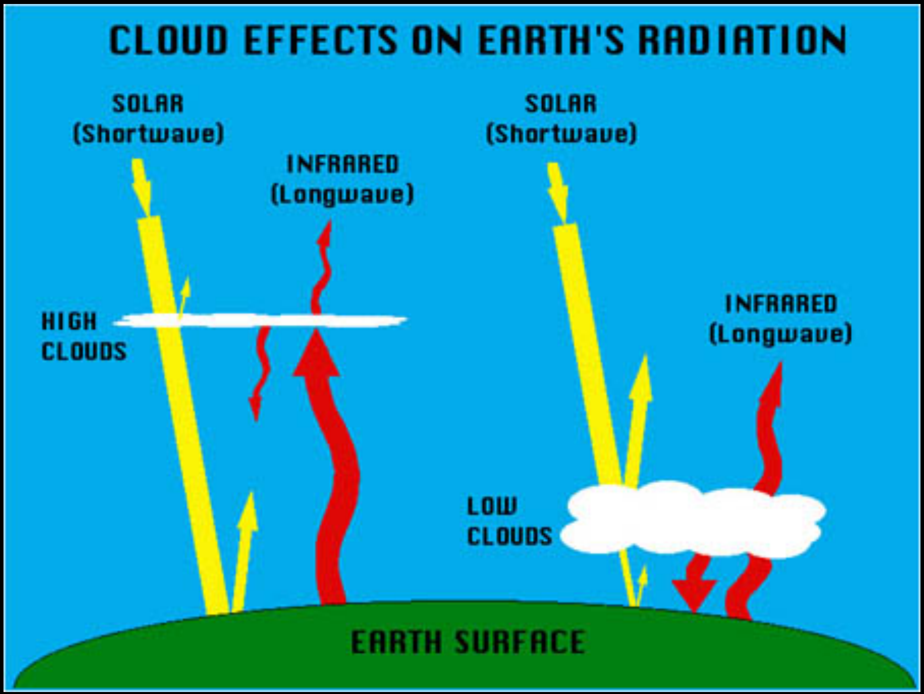


Stevenson et al. (2014)

Unavoidable complication: clouds



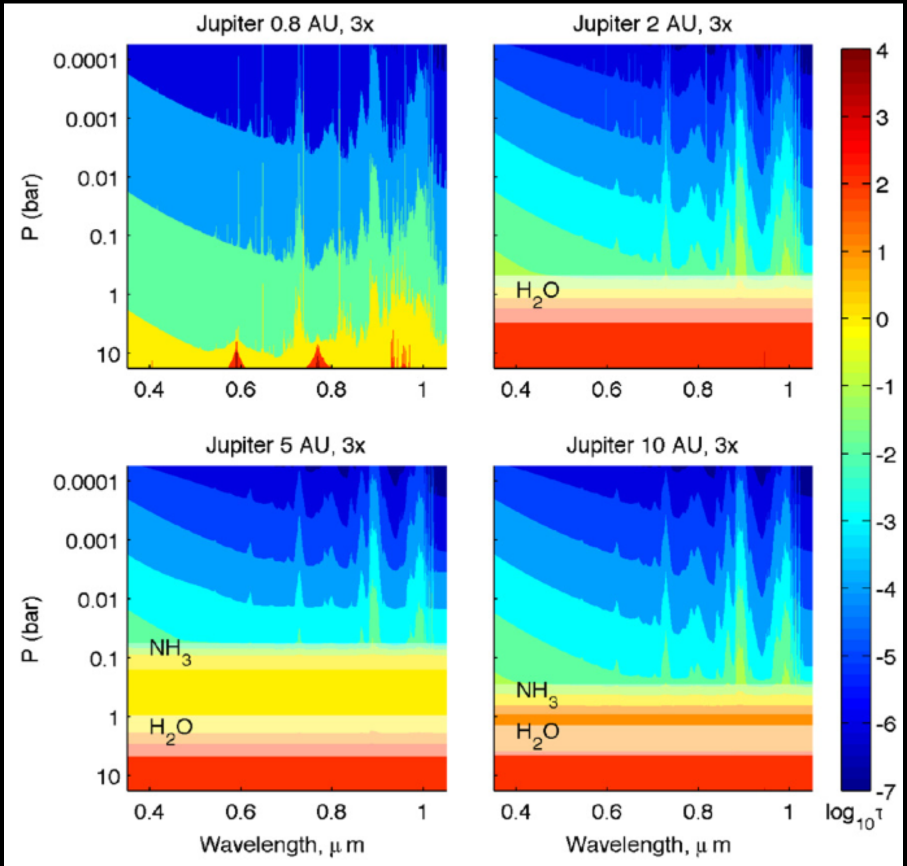
credit: M. Marley

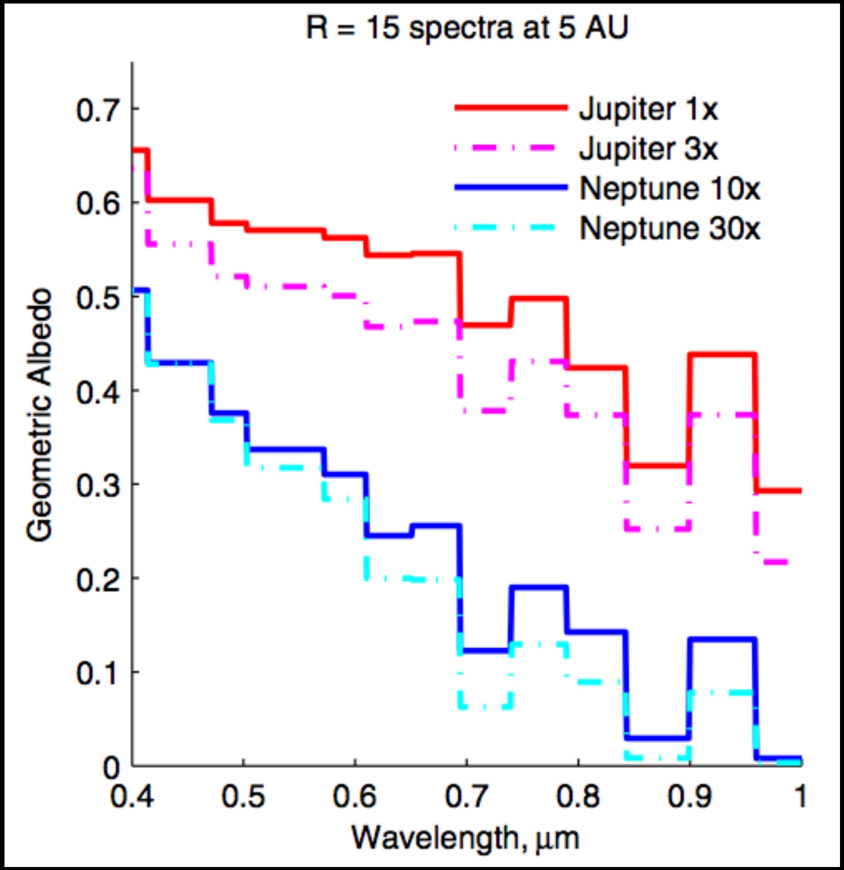


Clouds form where P-T profiles cross condensation curves

Clouds can reflect incoming radiation and absorb or emit thermal radiation

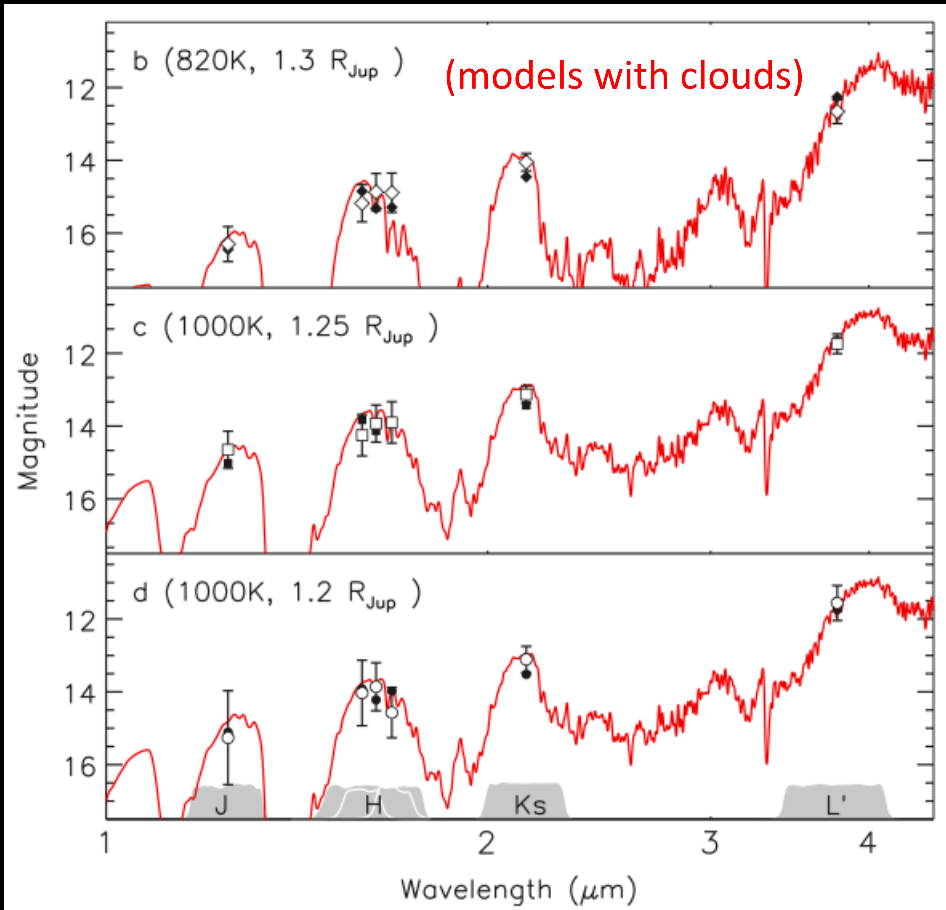
Observational impact: reflection

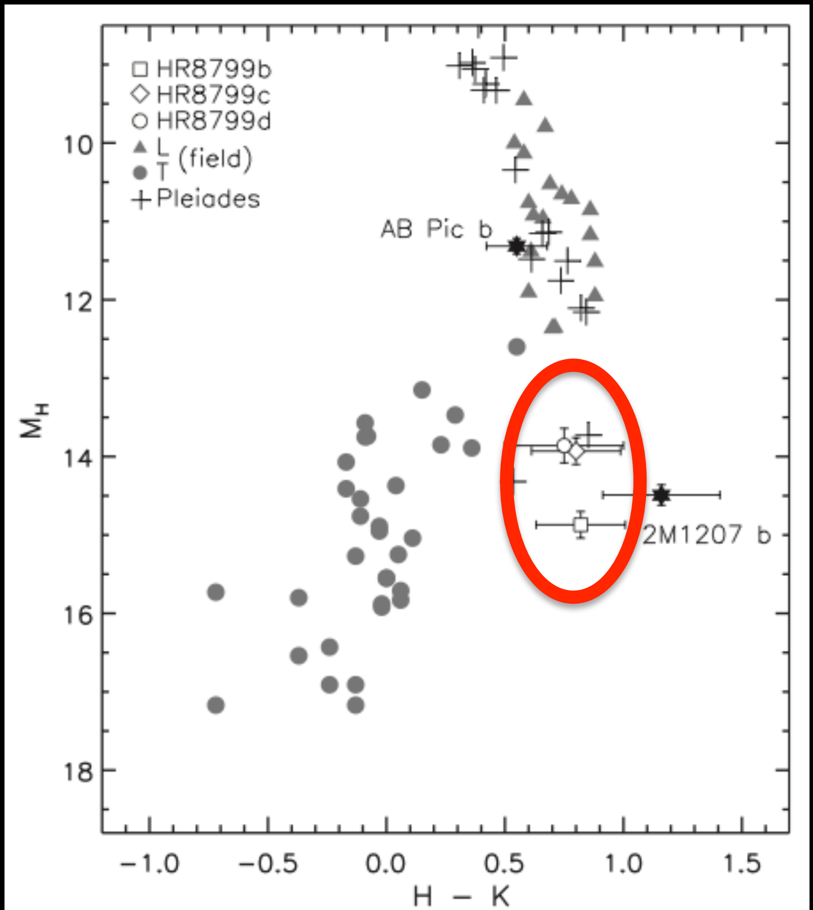




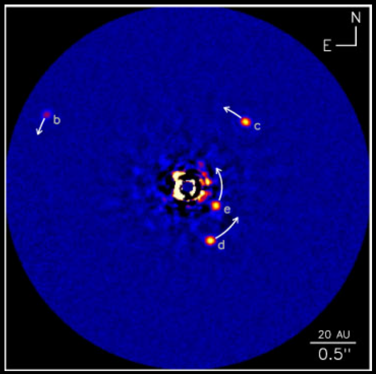
Cahoy et al. (2010)

Observational impact: emission





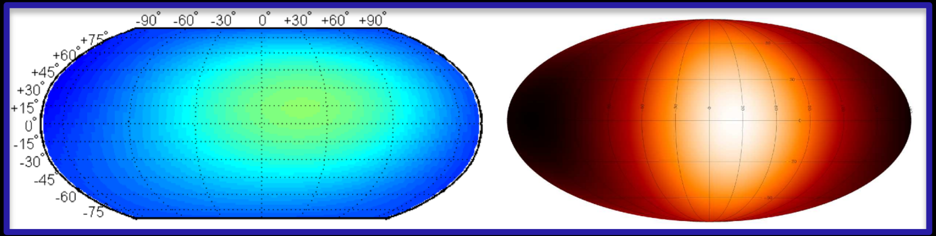
Marois et al. (2008)



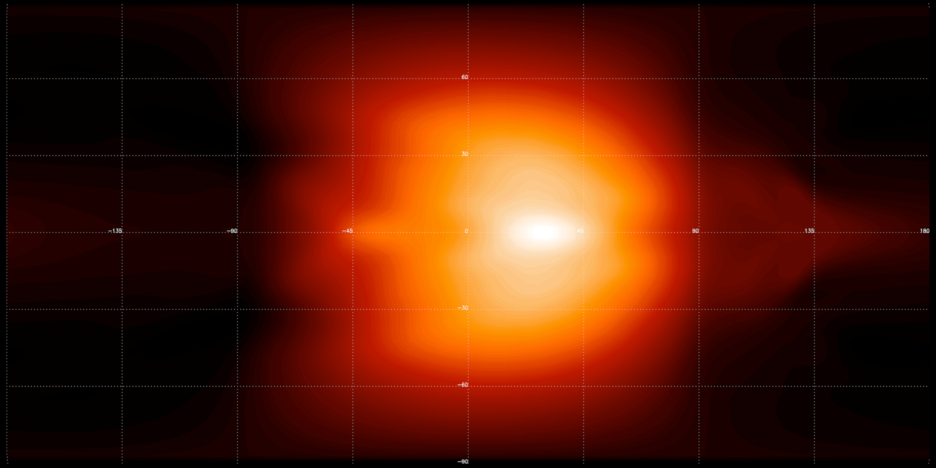
more physics,

MORE COMPLICATIONS

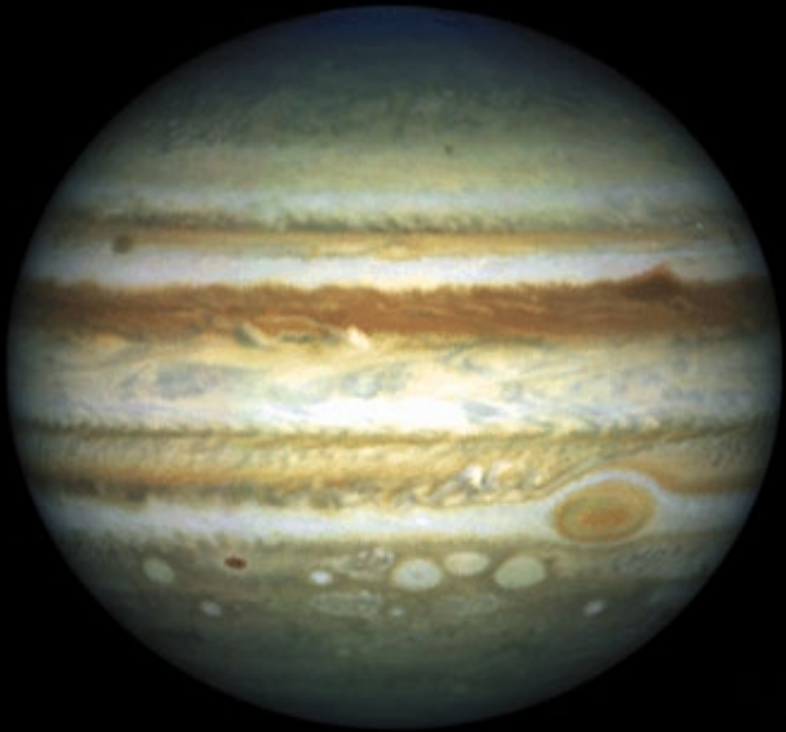
Planets are not 1D



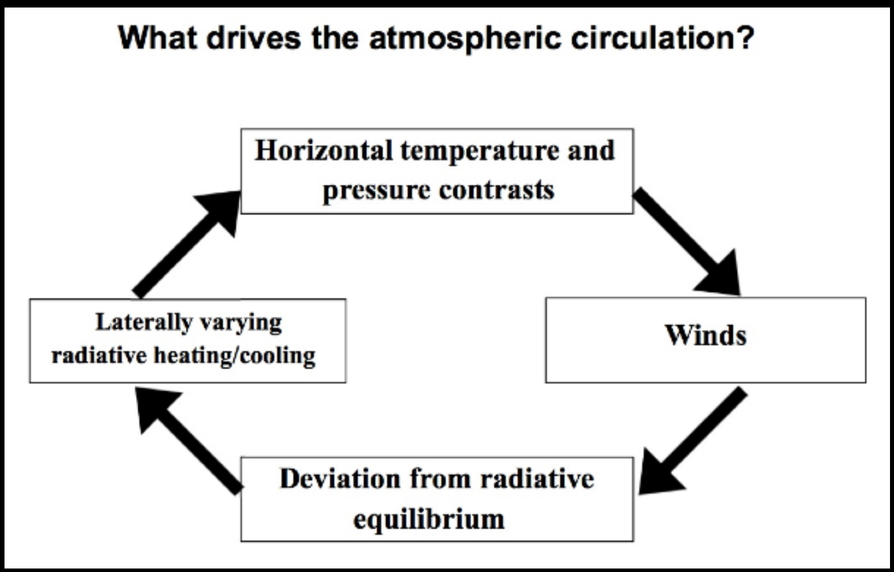
de Wit et al. (2012), Majeau et al. (2012)



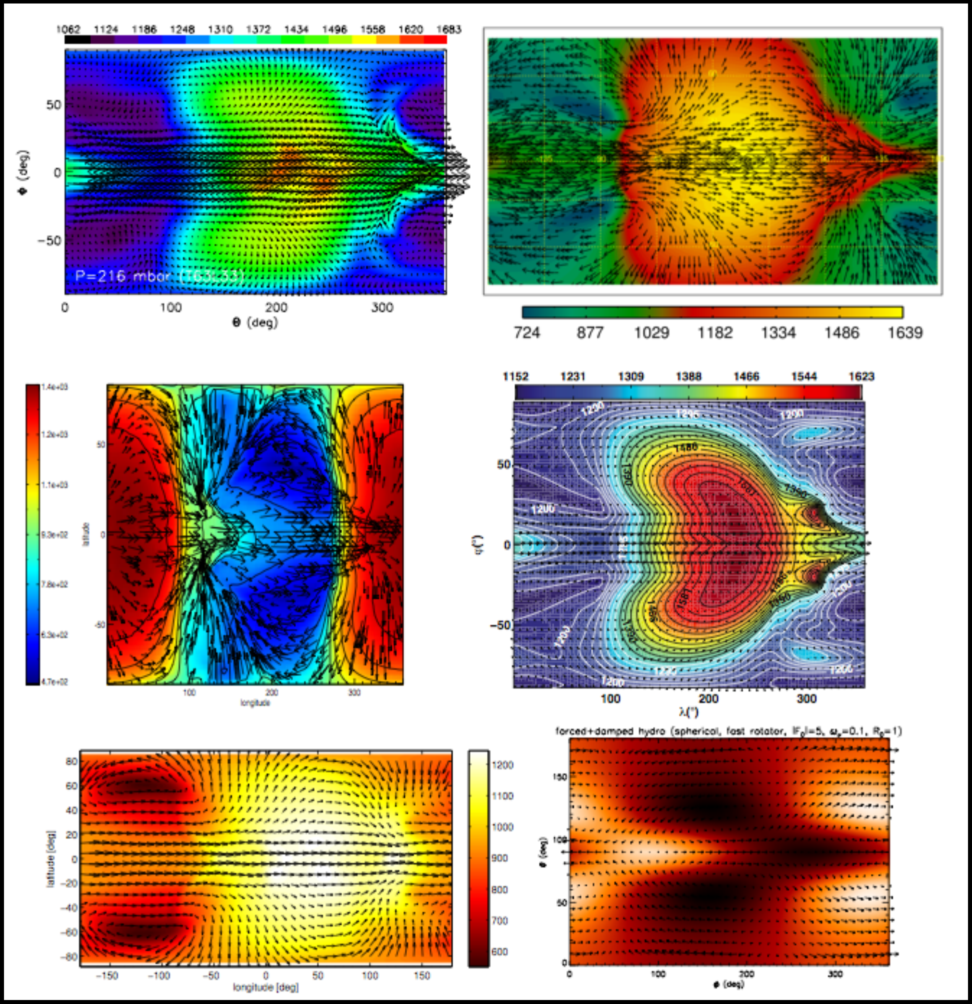
adapted from Rauscher & Menou (2012)



Atmospheric Circulation

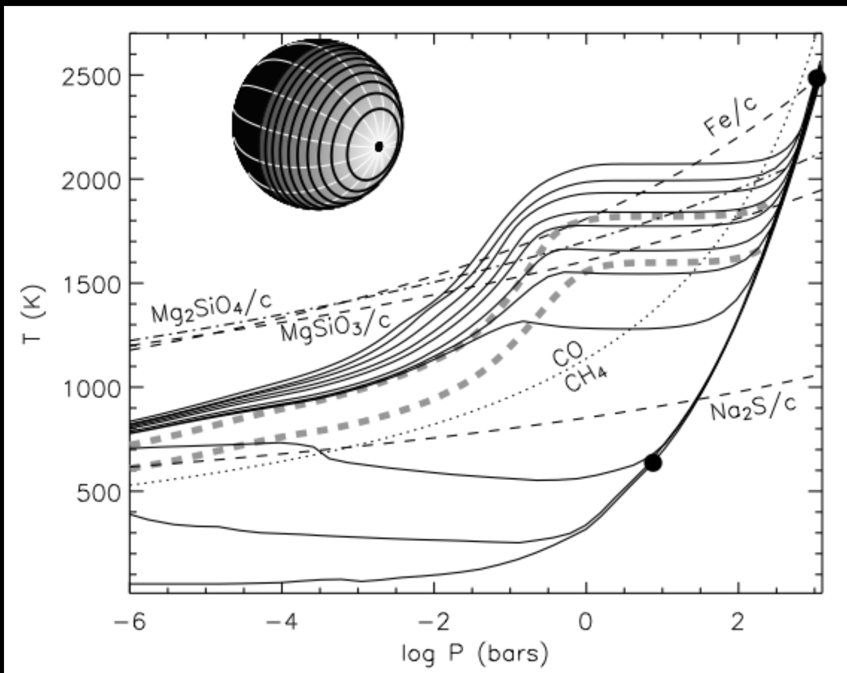


from review by Showman, Cho, & Menou, in *Exoplanets* ed. Seager (2011)

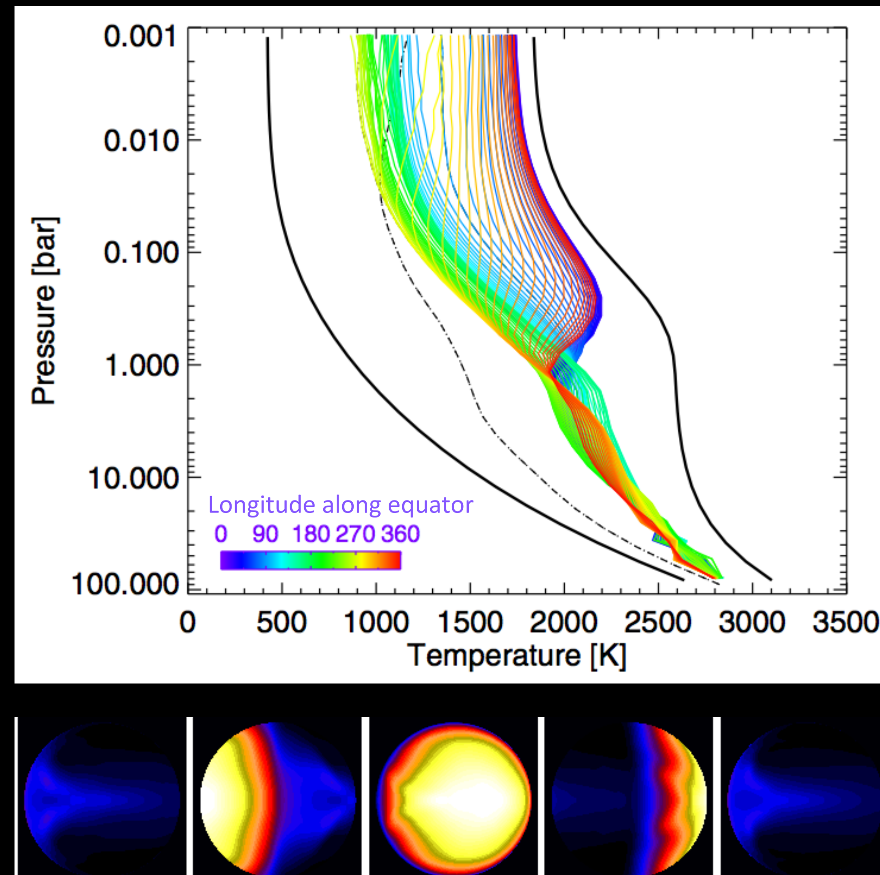


from review by Heng & Showman (2014) for AREPS

P-T profiles are not always spatially uniform



Barman et al. (2005)

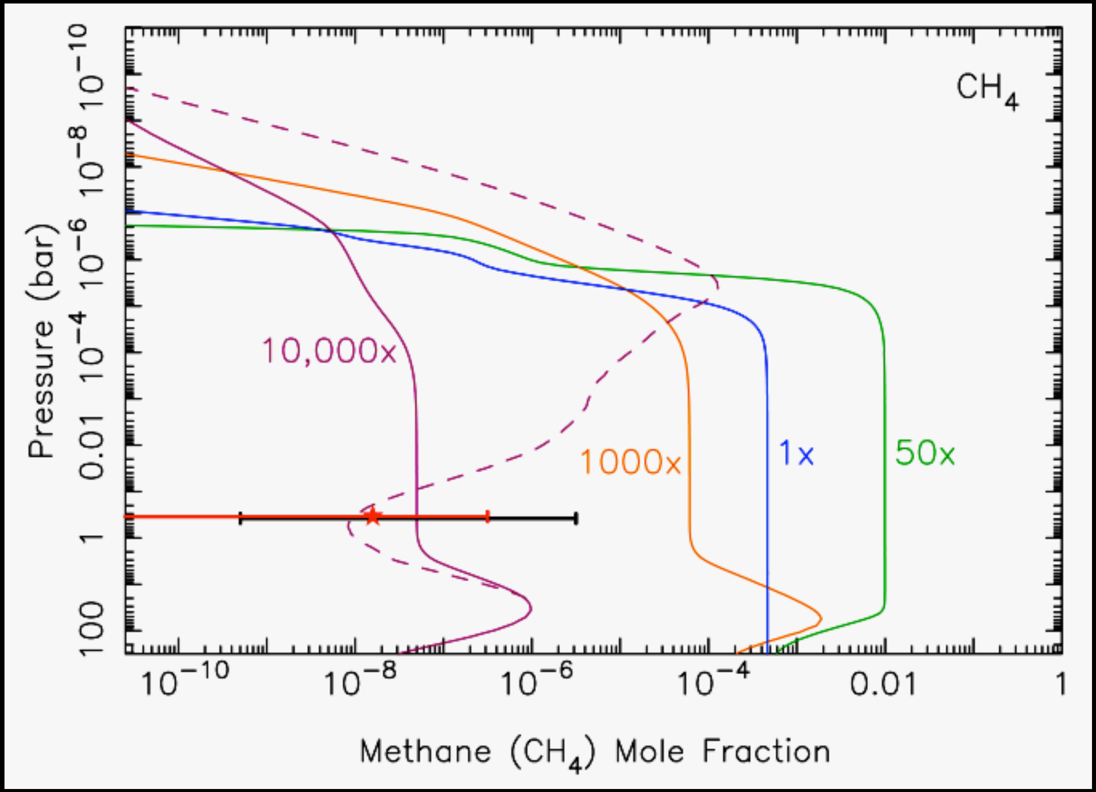


Rauscher & Menou (2012)

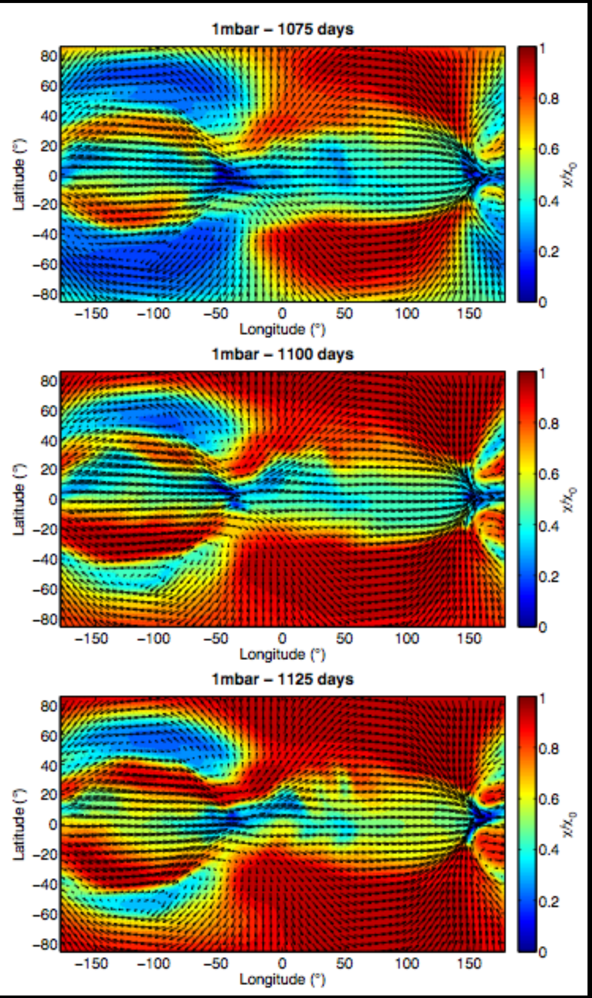
A planet's spectrum may change because of viewing geometry, rotation, or atmospheric variability

see also: Fortney et al. (2006, 2010); Burrows, Rauscher et al. (2010)

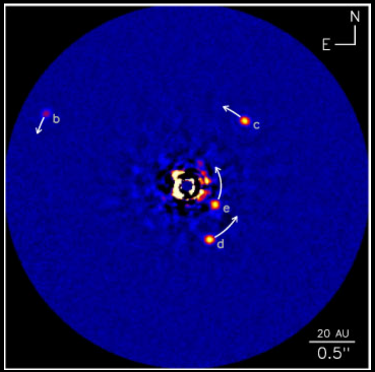
We should expect disequilibrium
(neither LRE, nor chemical equilibrium)



Moses et al. (2013)



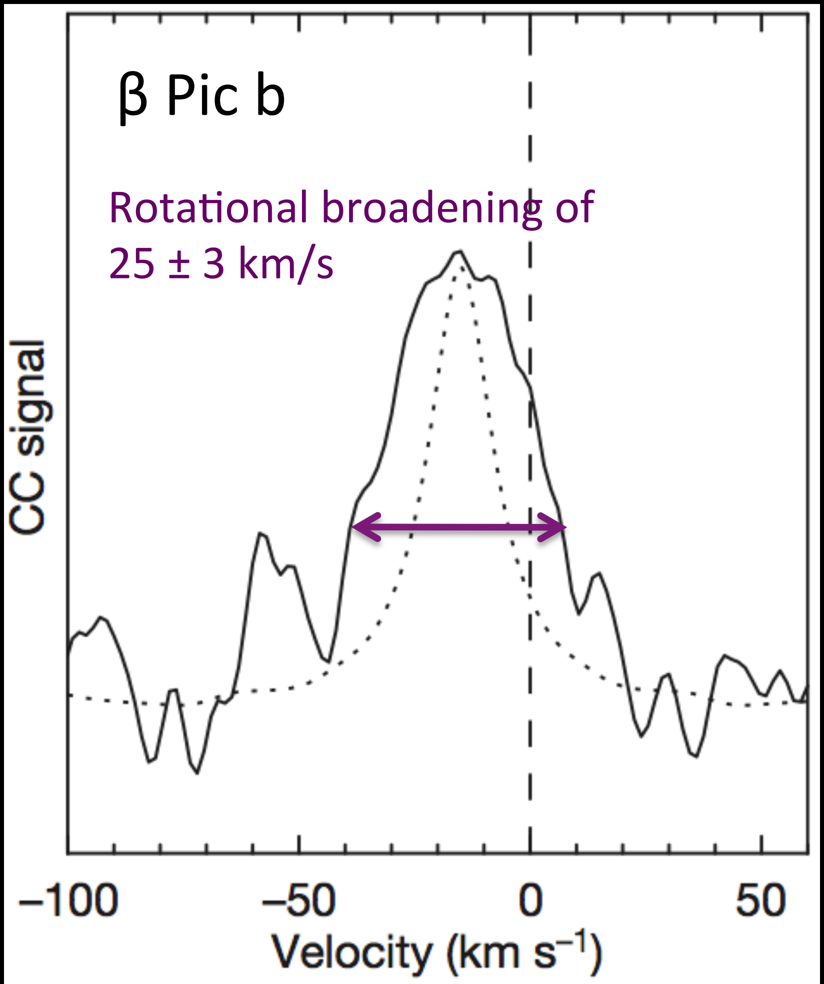
Parmentier et al. (2013)



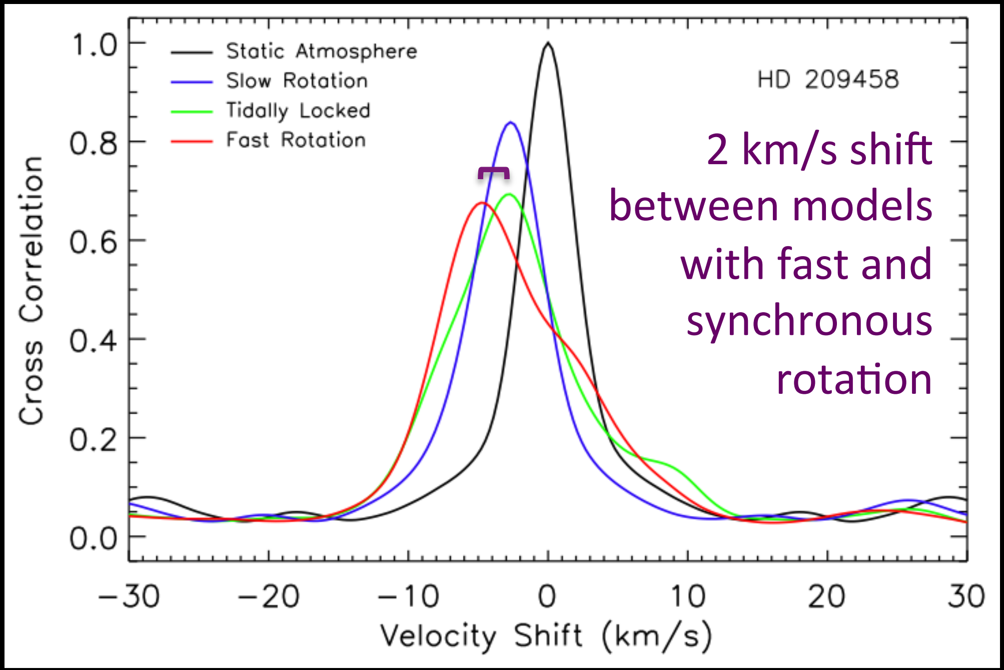
(time permitting)

BONUS MATERIAL

Measuring rotation



Snellen et al. (2014)

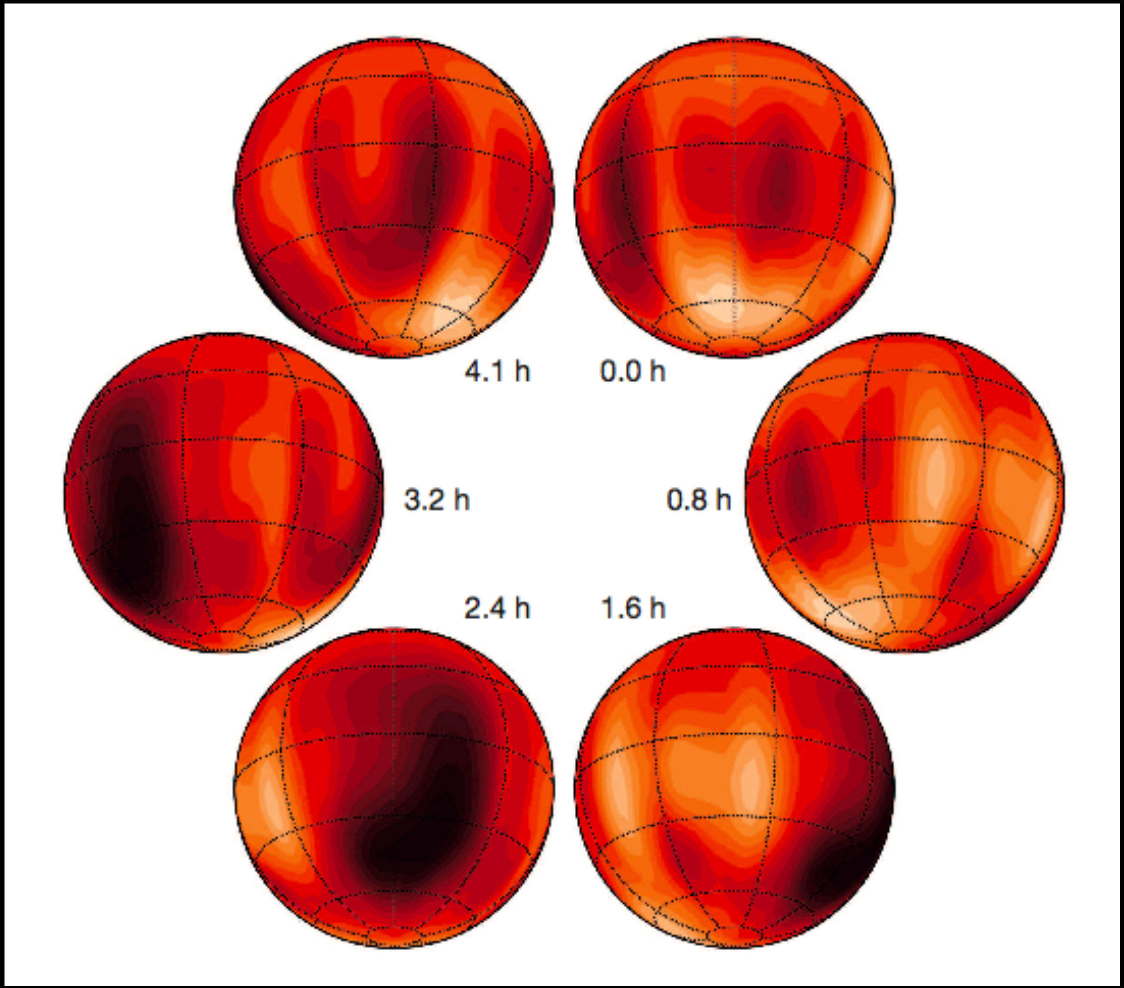


Rauscher & Kempton (2014)

The current & future ability of high-resolution spectroscopy

(related: brown dwarf variability)

Connection to brown dwarf variability

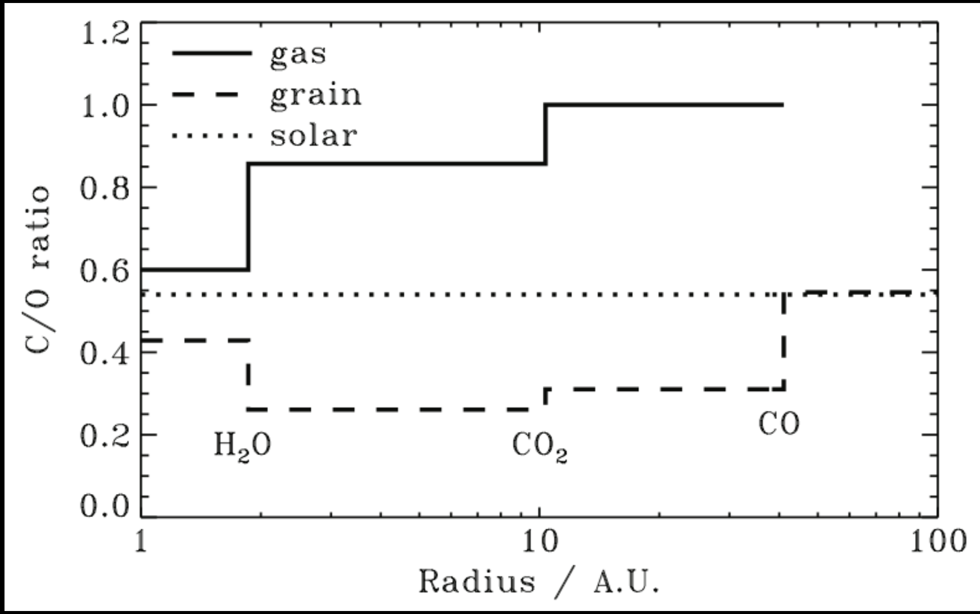


Crossfield et al. (2014)

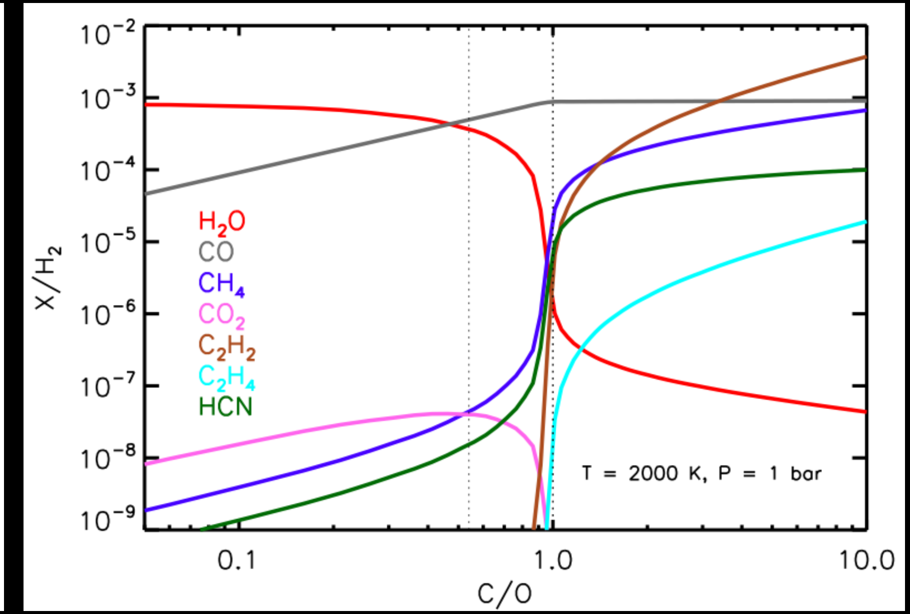
Signature of formation location?

The C/O ratio in protoplanetary disks should vary with radius because of condensation of molecular gases at snowlines

The relative atmospheric abundances of molecules (as a function of T, P) depends on the C/O ratio

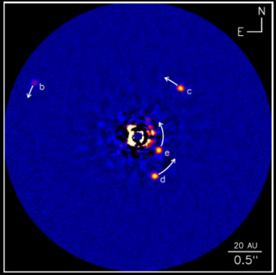


Öberg et al. (2011)



Madhusudhan (2012)

Points to remember



- Atmospheric characterization: beyond detection, measuring physical properties
- Simplest atmosphere: 1D, $F_{\star}$, F_{int}, $\kappa(\lambda)$, T(P)
- Observations: emission & reflection
  Tell us: T(P), composition/abundances, clouds
- More detail: non-uniformity, disequilibrium, variability and rotation, etc.