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The Interplay Between a Planet's Atmosphere and its Global Evolution

what I'm not going to talk about:

- planet interior
- Solar System planets
- C/O ratio

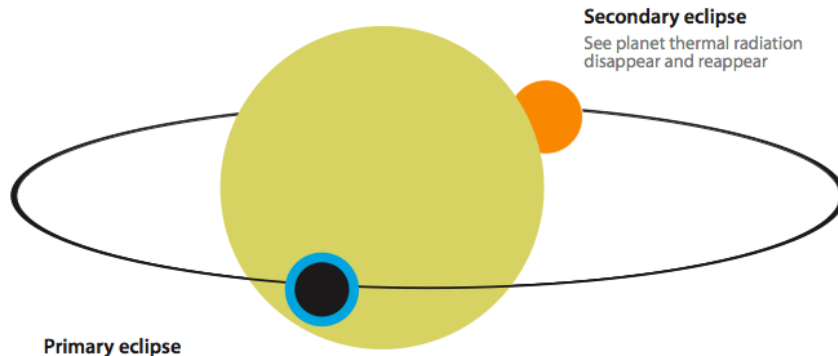
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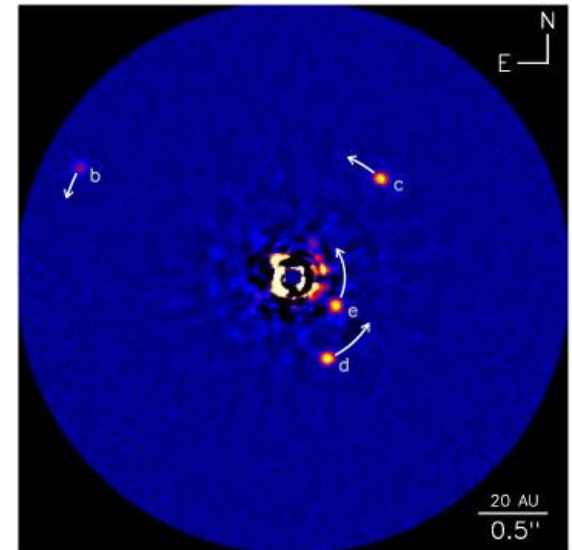
The Interplay Between a Planet's Atmosphere and its Global Evolution

Questions

- How does the **atmosphere** influence the **evolution**?
- How does the **evolution** influence the **atmosphere**?
- What are the **observables**?

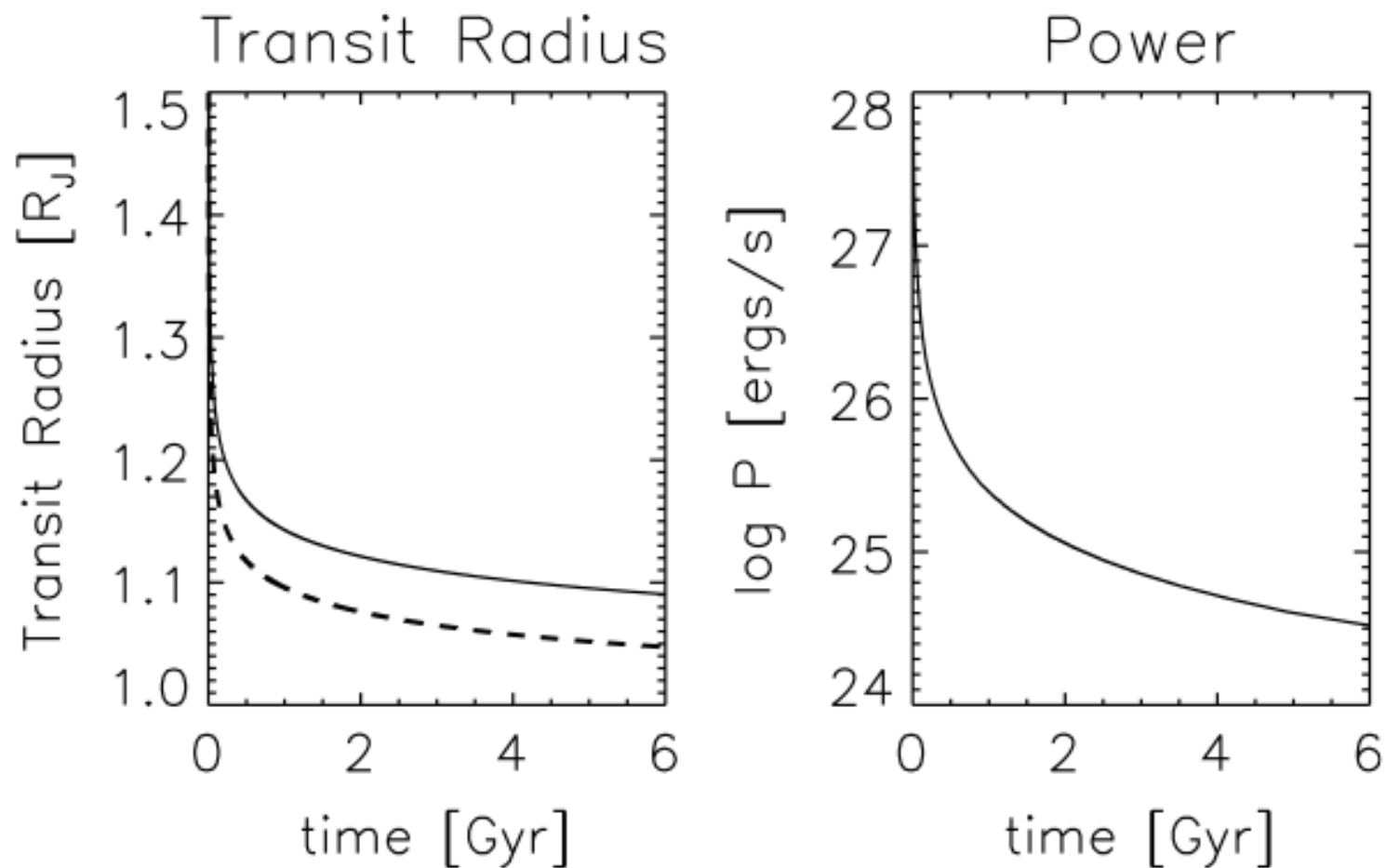


Seager & Deming (2010)



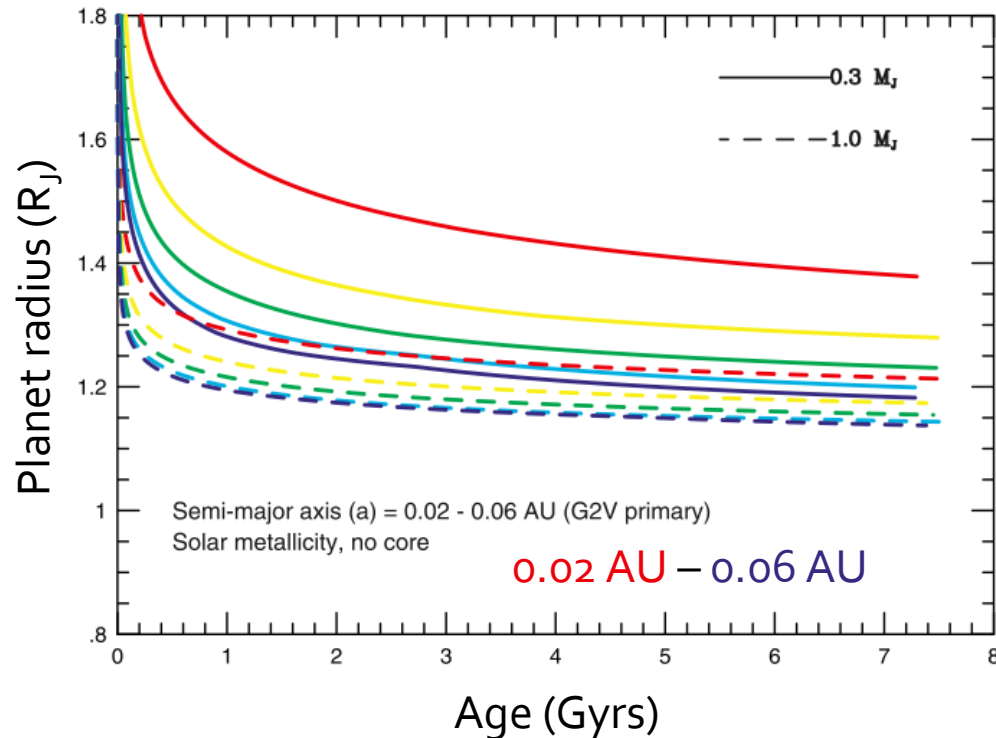
credit: Keck Observatory

Evolution: cooling & shrinking



The atmosphere is a boundary condition

A hot atmosphere slows cooling ↓

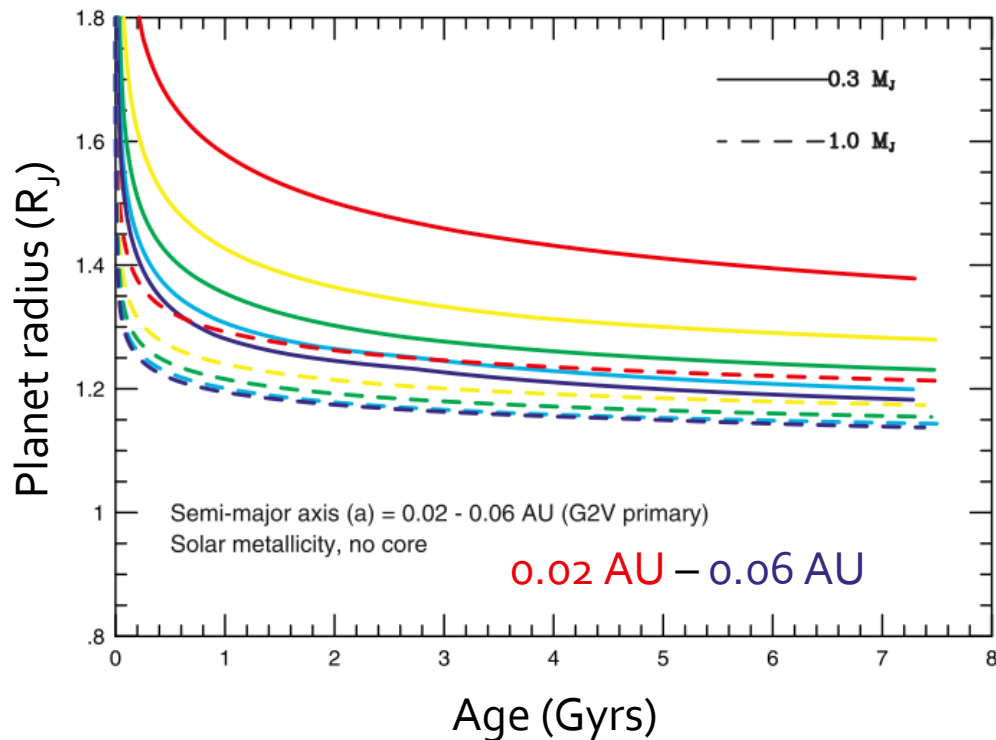


How does the atmosphere influence the evolution?

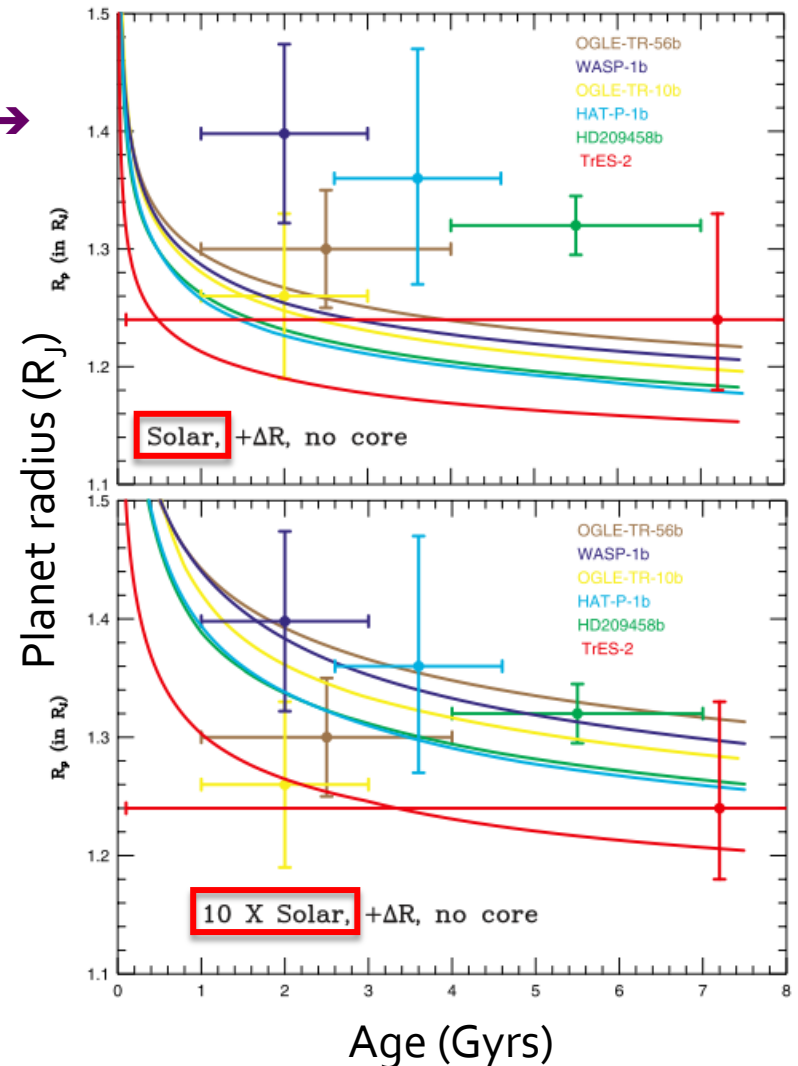
The atmosphere is a boundary condition

A hot atmosphere slows cooling ↓

A higher atmospheric opacity slows cooling →



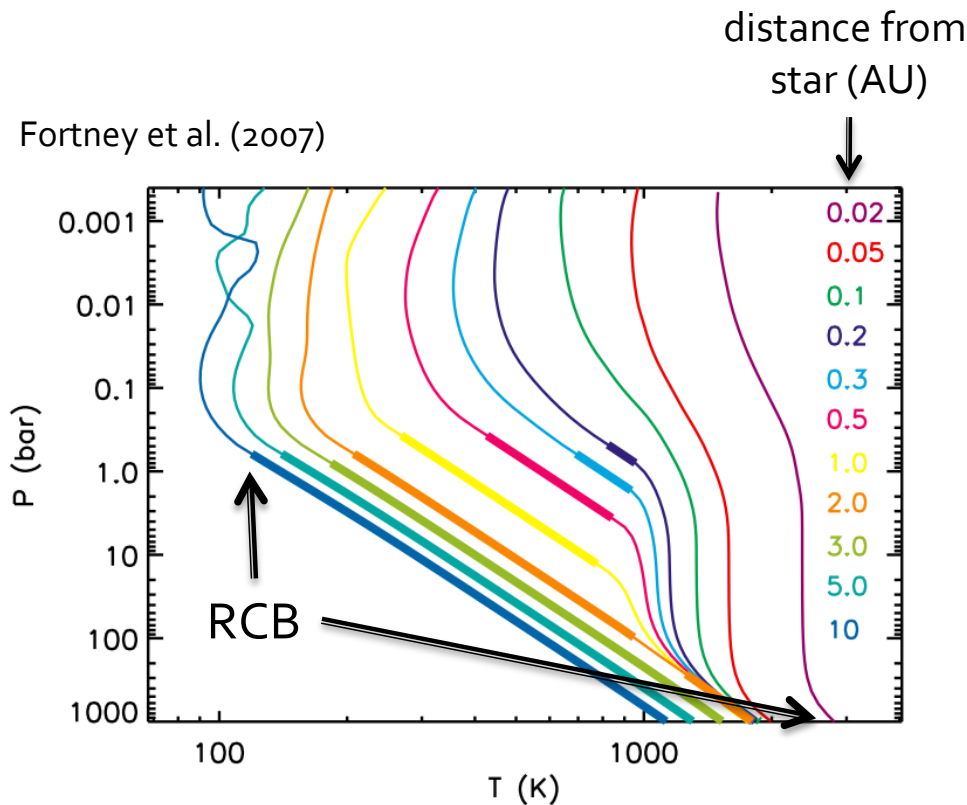
Burrows et al. (2007)



The radiative-convective boundary (RCB) is a bottleneck

How does the atmosphere influence the evolution?

The radiative-convective boundary (RCB) is a bottleneck

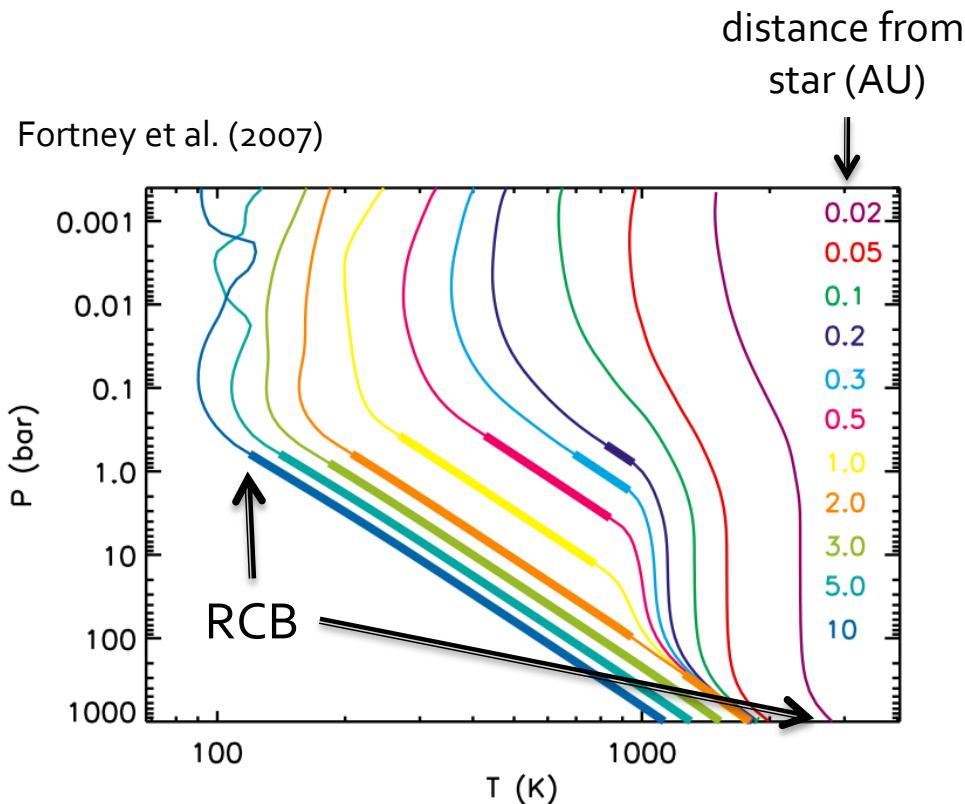


For a RCB at higher pressure:

higher opacity
slower cooling

How does the atmosphere influence the evolution?

The radiative-convective boundary (RCB) is a bottleneck

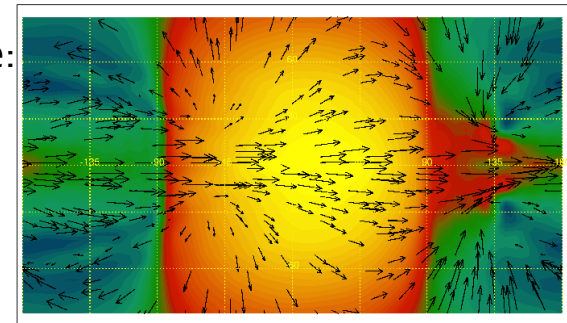


For a RCB at higher pressure:
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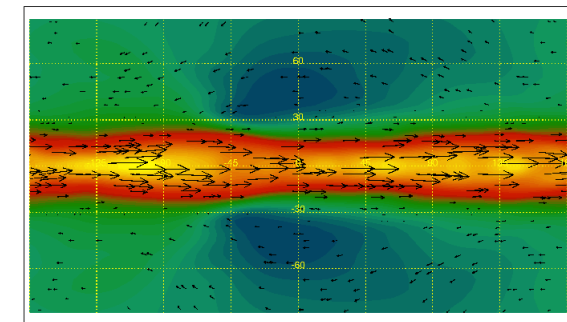
Strong day-night difference in heating, but not seen at depth

temperature:

at low P

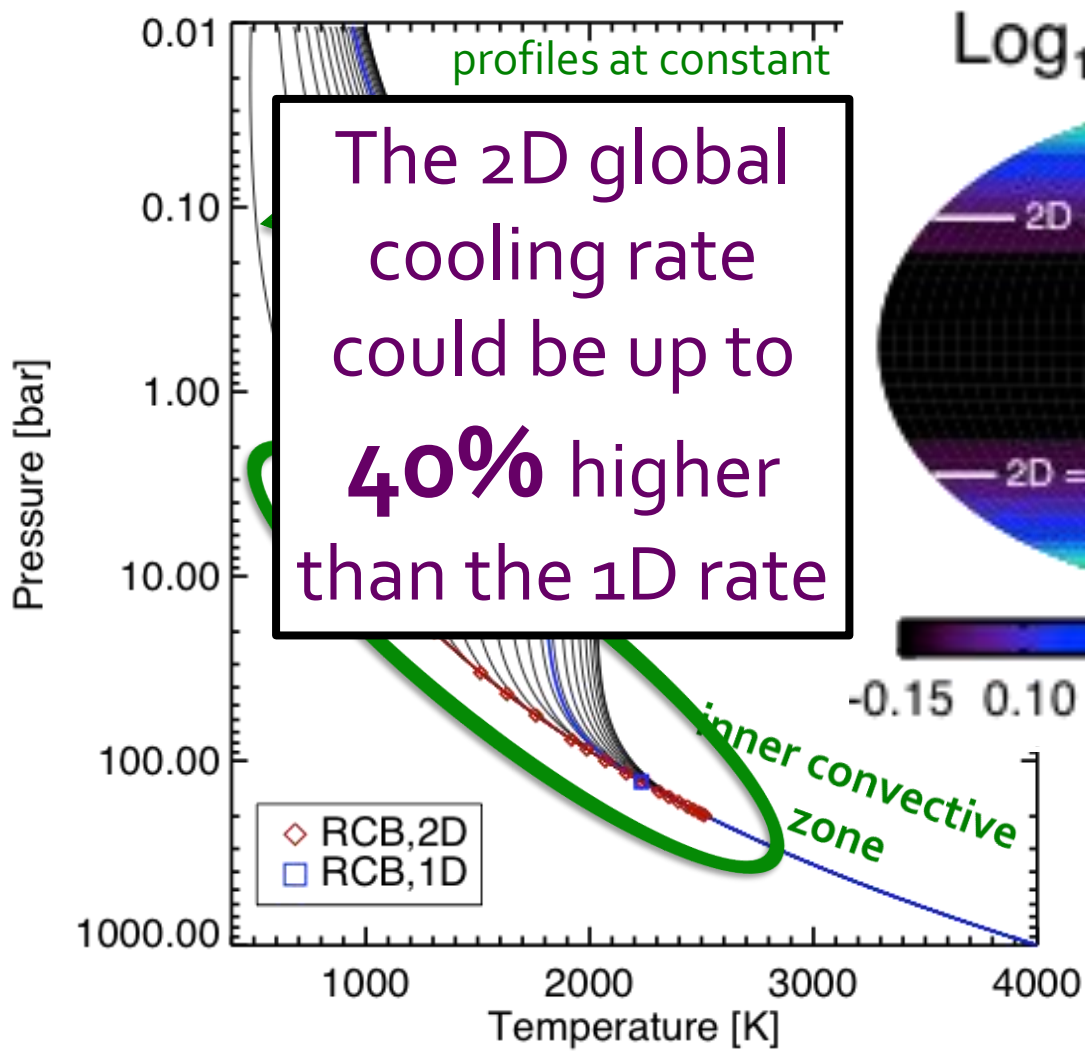


at high P

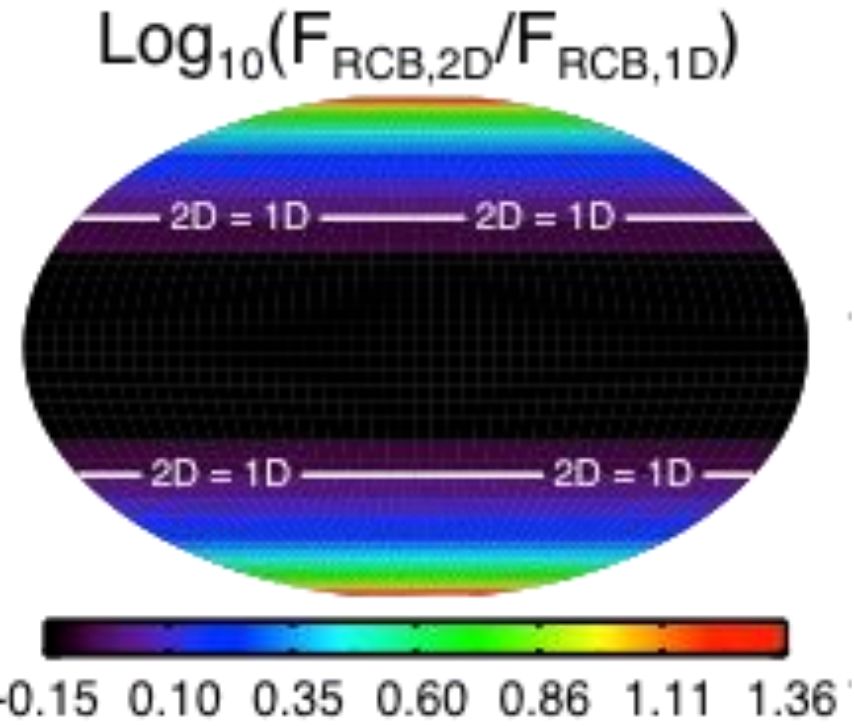


Rauscher & Menou (2012)

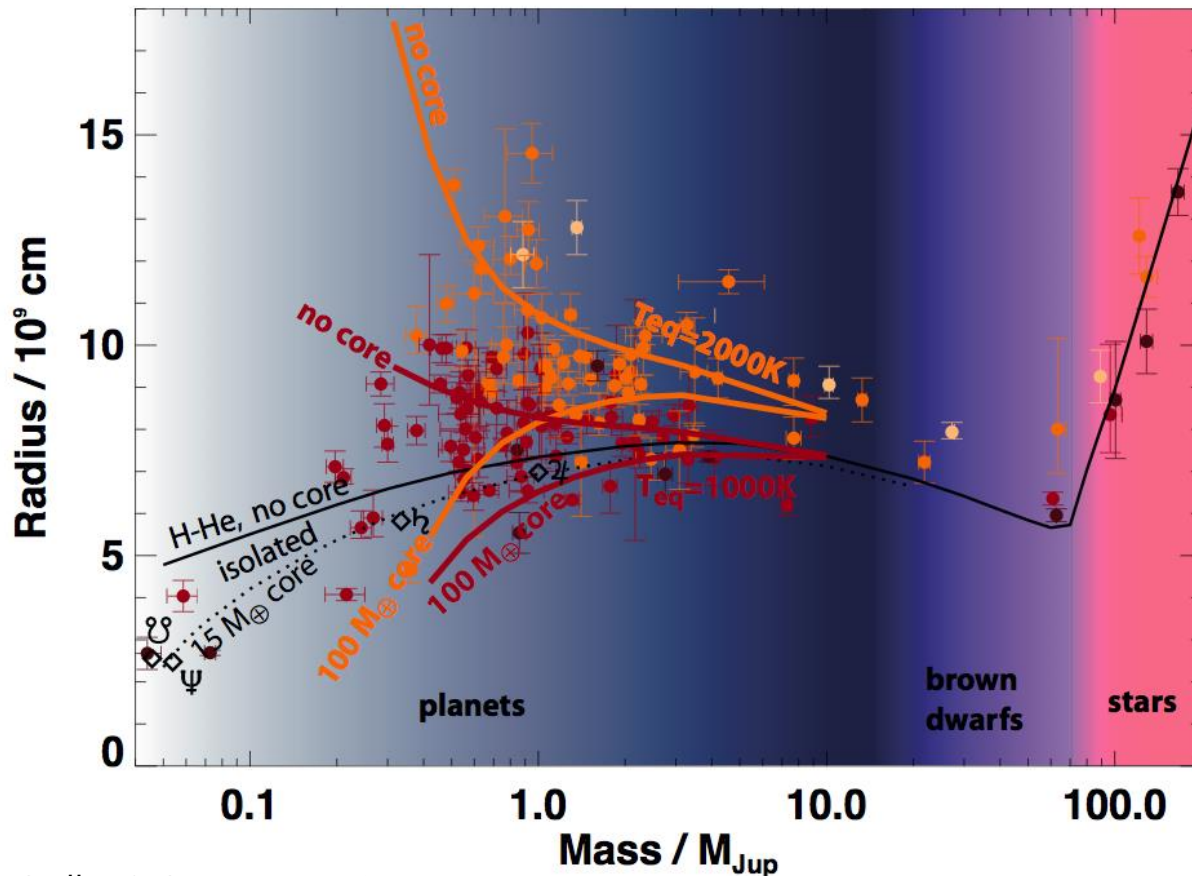
The radiative-convective boundary (RCB) is a bottleneck



The 2D global cooling rate could be up to **40%** higher than the 1D rate



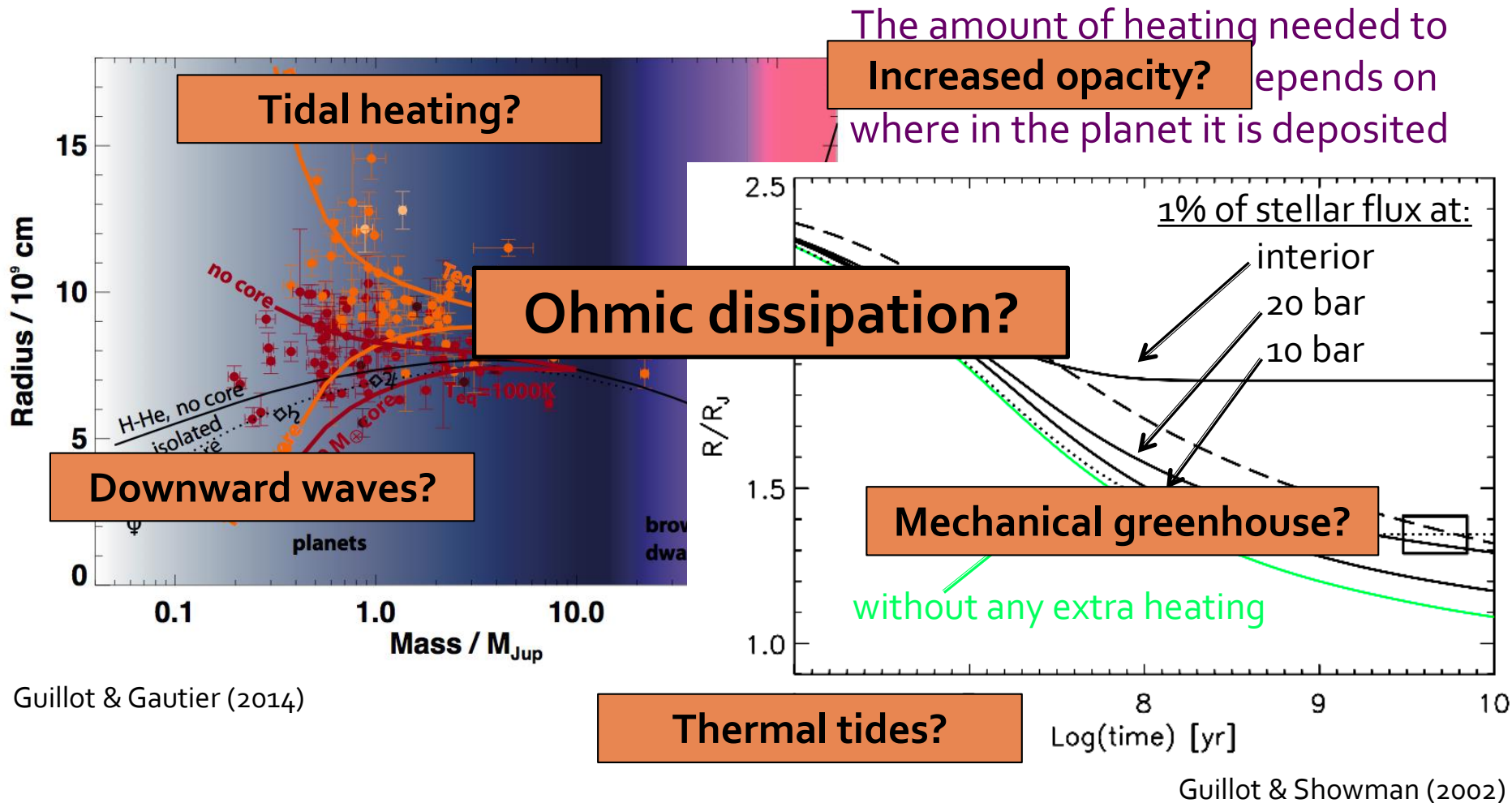
Hot Jupiters with Surprisingly Large Radii



Guillot & Gautier (2014)

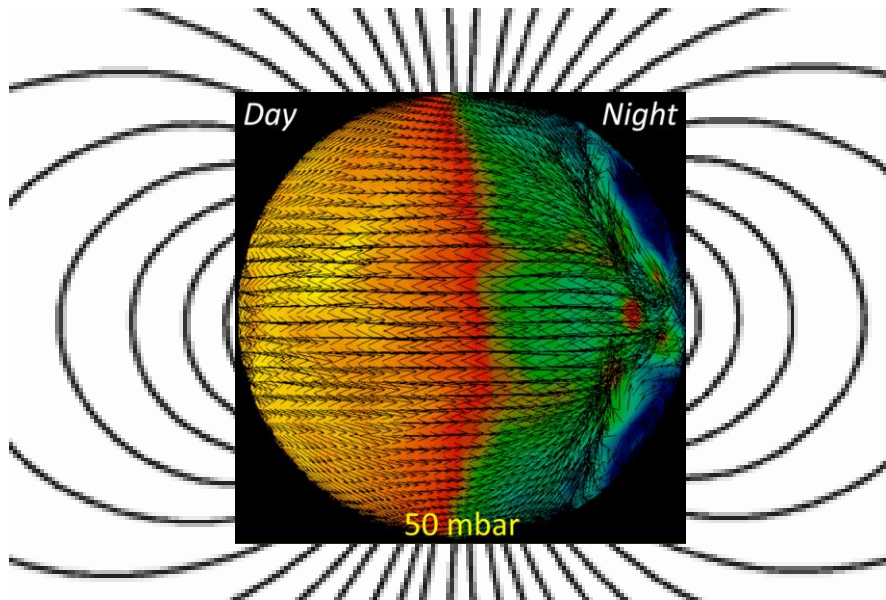
How does the atmosphere influence the evolution?

Hot Jupiters with Surprisingly Large Radii



How does the **atmosphere** influence the **evolution**?

Ohmic dissipation as a possible heating source



The Basic Idea:

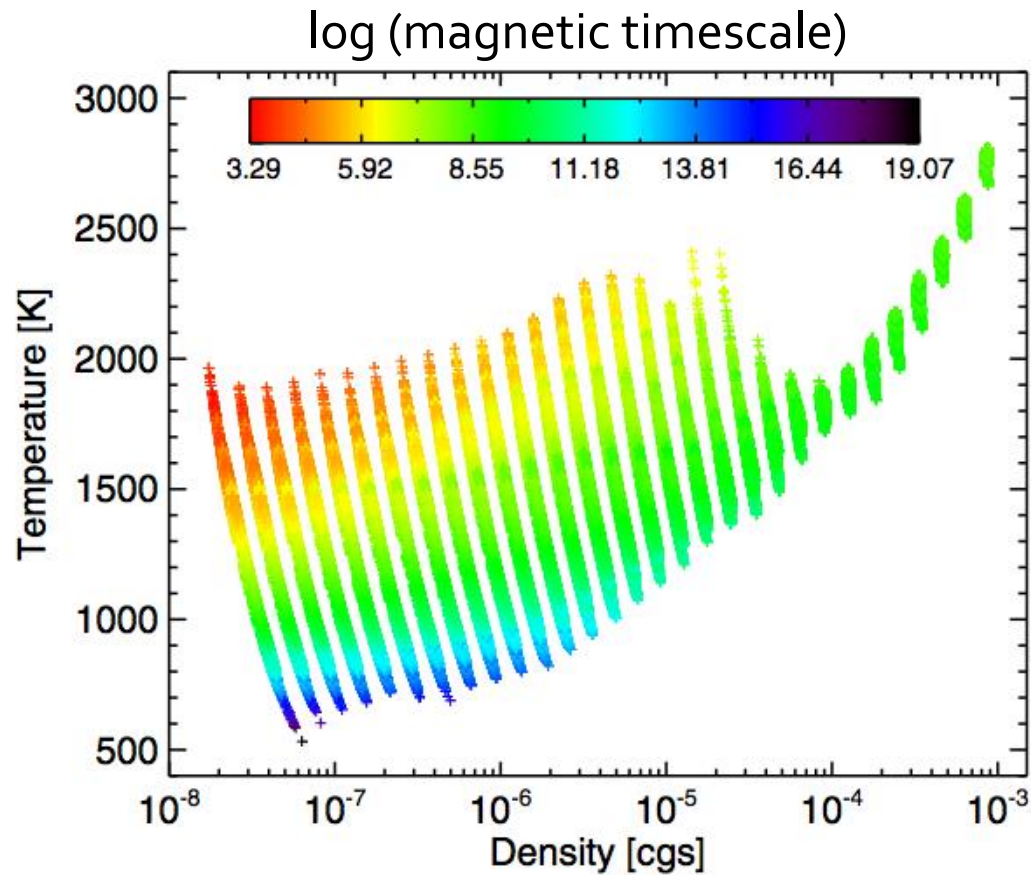
Thermal ionization
 +
 km/s winds
 +
 planetary B field
 =
 currents,
 which experience
ohmic dissipation

→ heating

first set of references: Batygin & Stevenson (2010);
 Perna, Menou, & Rauscher (2010b); Batygin et al. (2011);
 Wu & Lithwick (2012); Huang & Cumming (2012)

How does the atmosphere influence the evolution?

Ohmic dissipation as a possible heating source

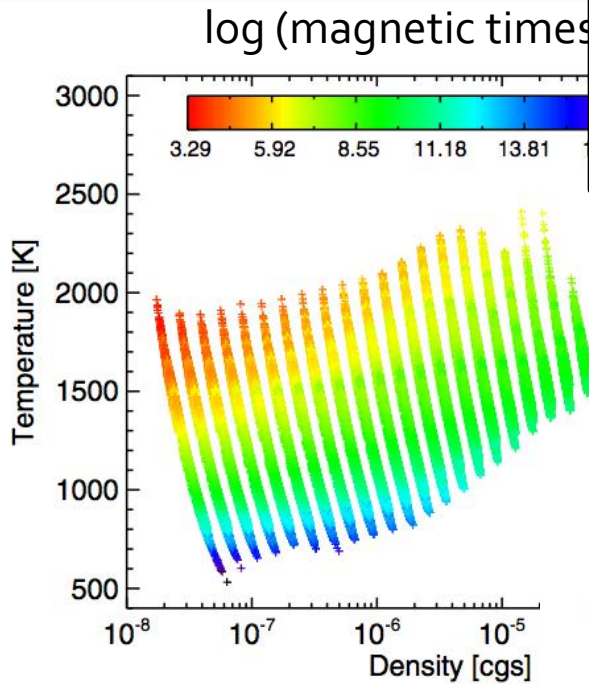


Rauscher & Menou (2013)

How does the atmosphere influence the evolution?

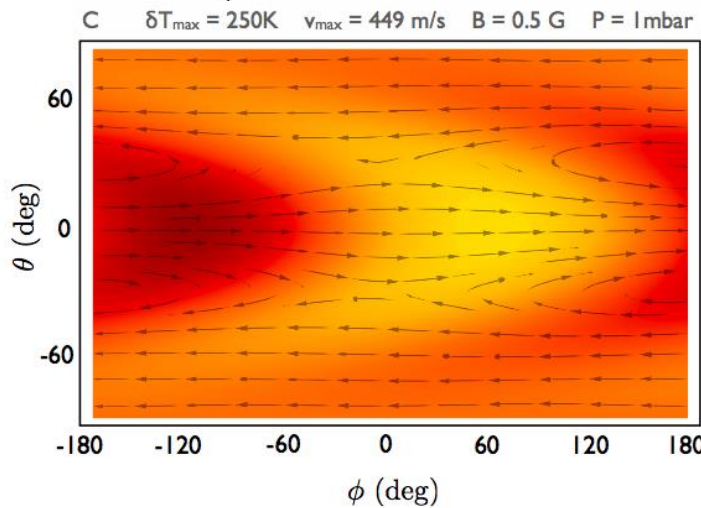
Ohmic dissipation as a possible heating source

Requires including a 3D effect, with feedback, in a 1D model

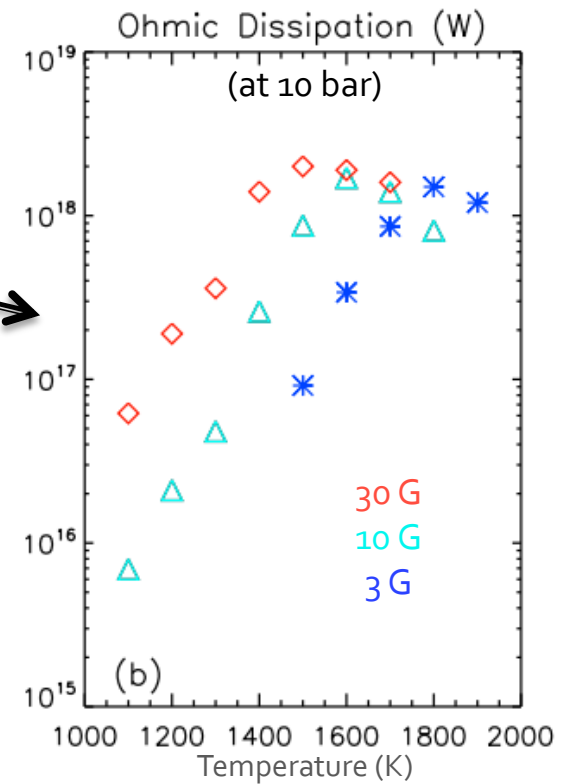


Rauscher & Menou (2013)

non-ideal MHD simulations



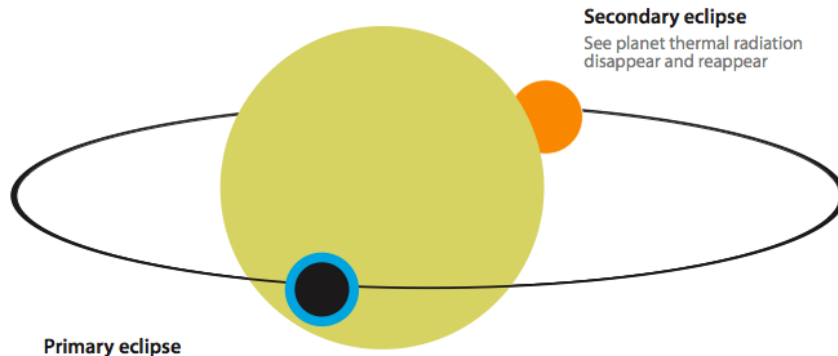
Batygin et al. (2013)



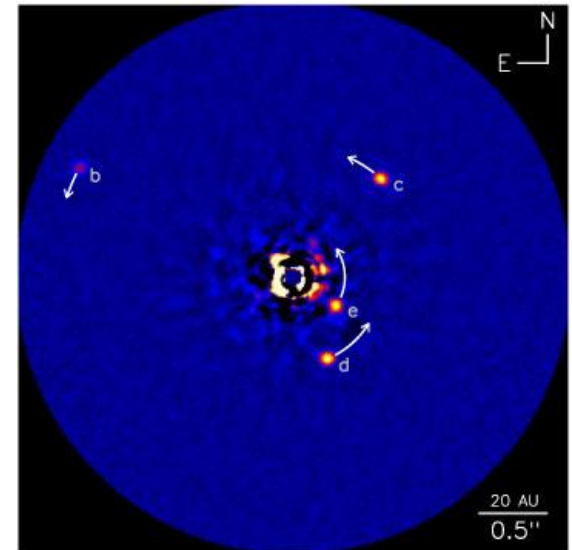
Rogers & Komacek (2014)

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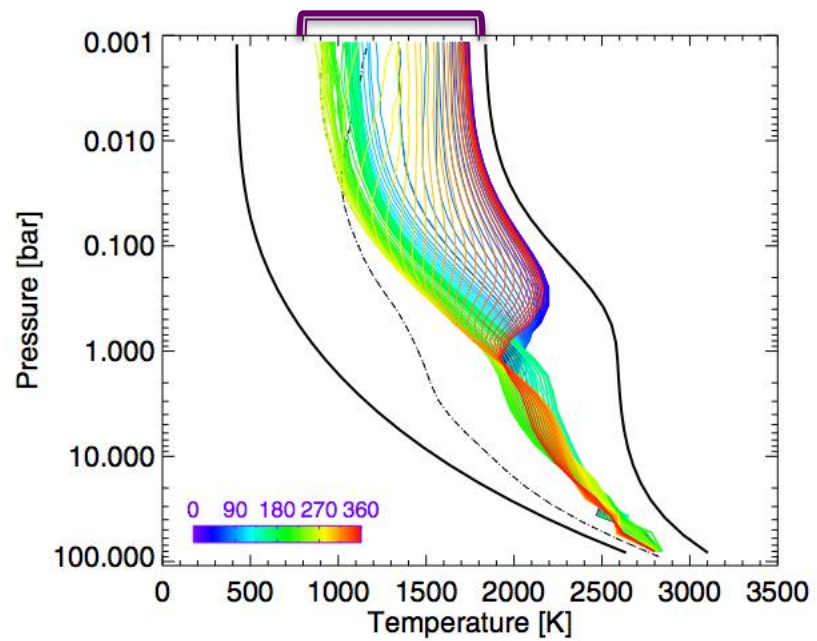
Seager & Deming (2010)



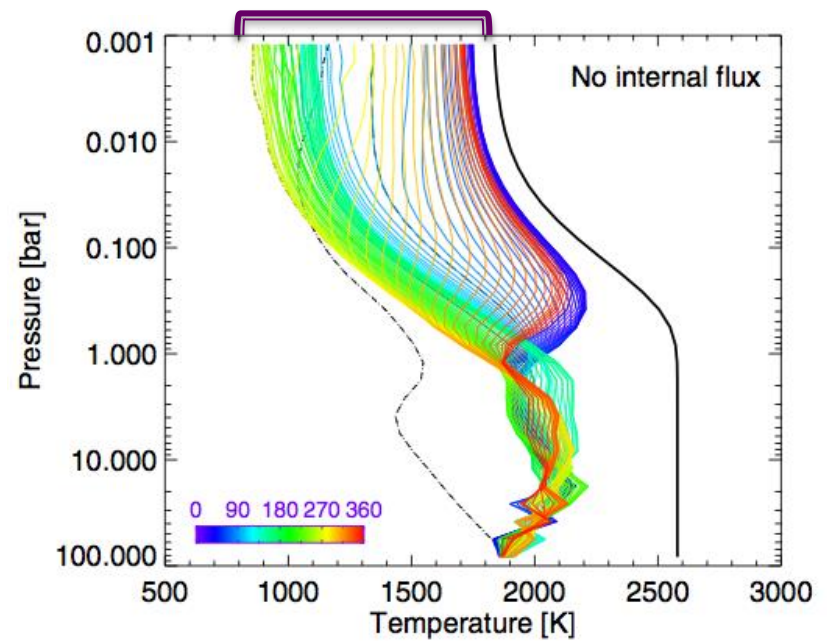
credit: Keck Observatory

“Age” of interior is unimportant (for hot Jupiters)

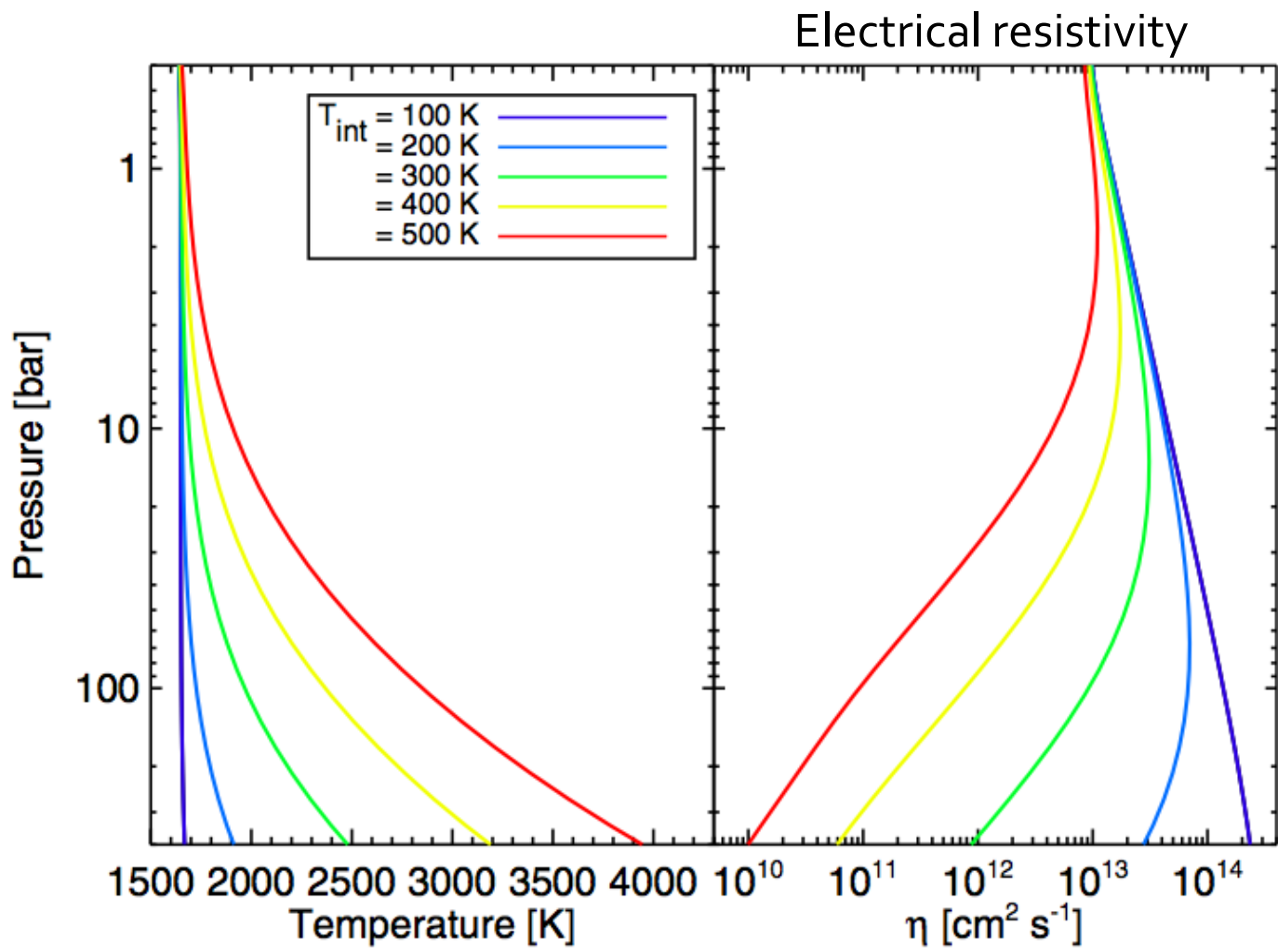
High entropy interior
($T_{\text{int}} = 500 \text{ K}$)



Low entropy interior
($T_{\text{int}} = 0 \text{ K}$)

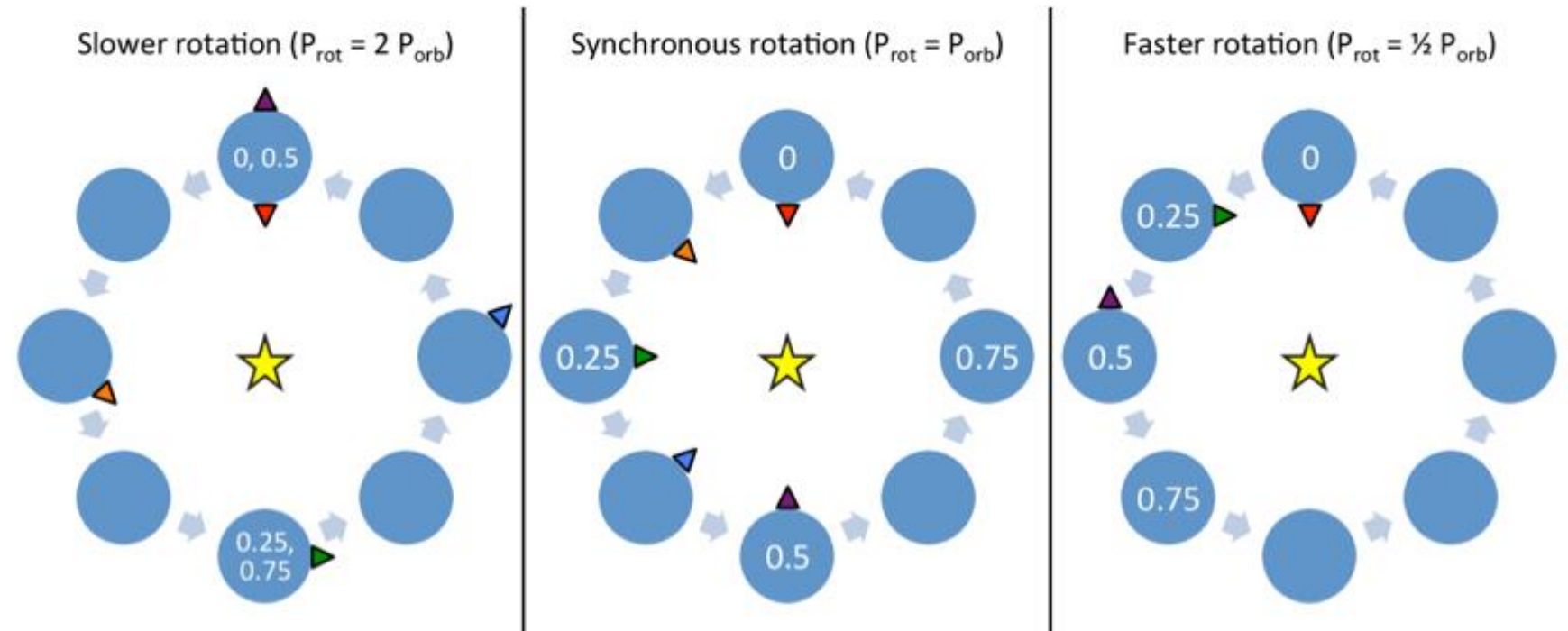


“Age” of interior is unimportant (for hot Jupiters) ... except for when it comes to magnetic effects



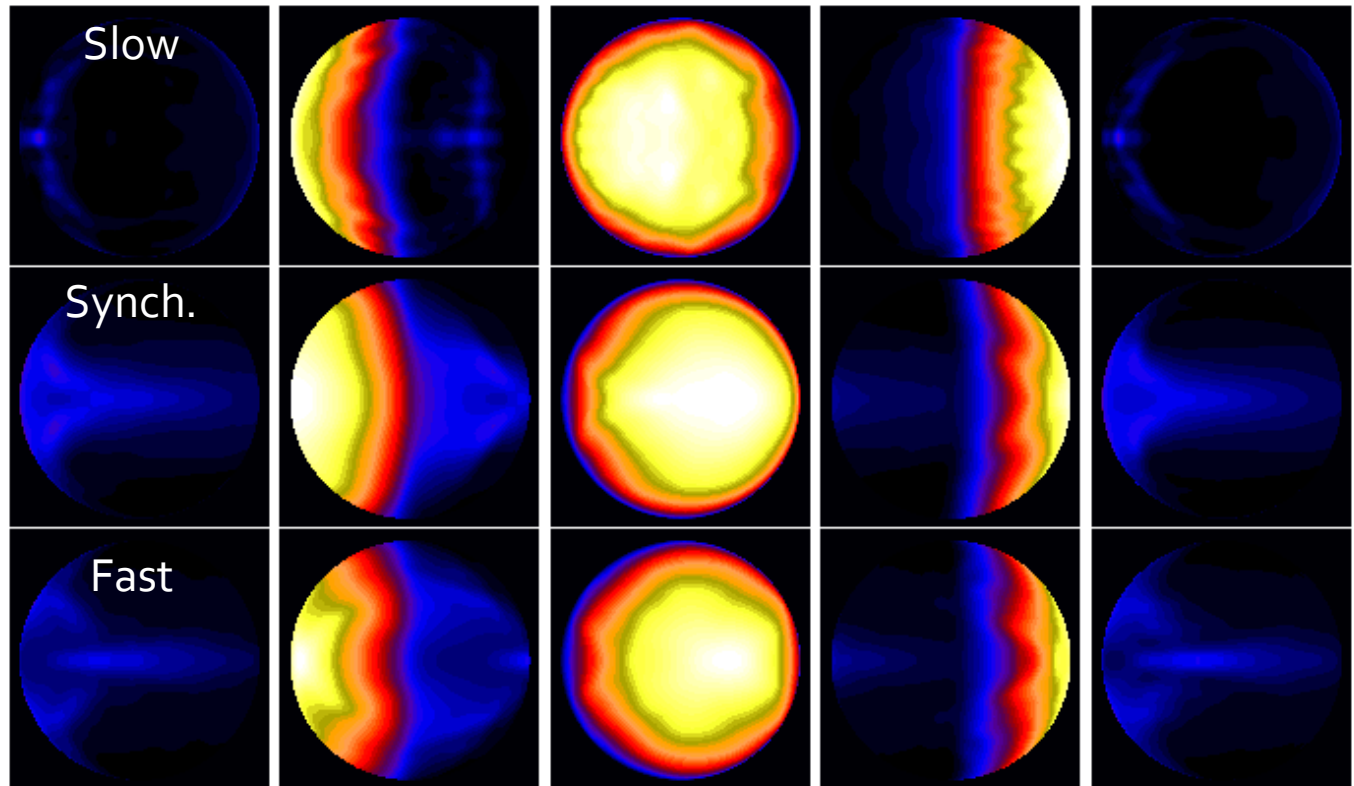
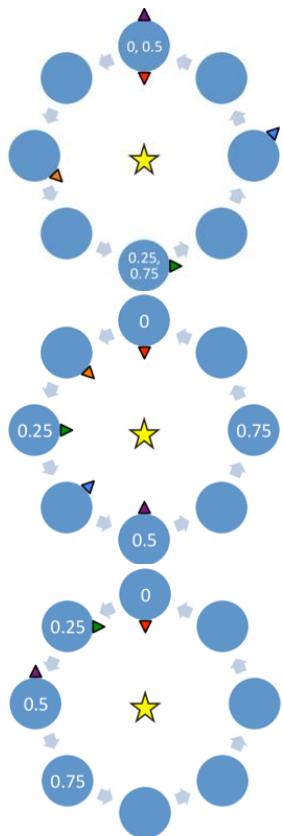
Evolution of a different type: rotation rate

Hot Jupiters are expected to have synchronous rotation
... but what do we know?

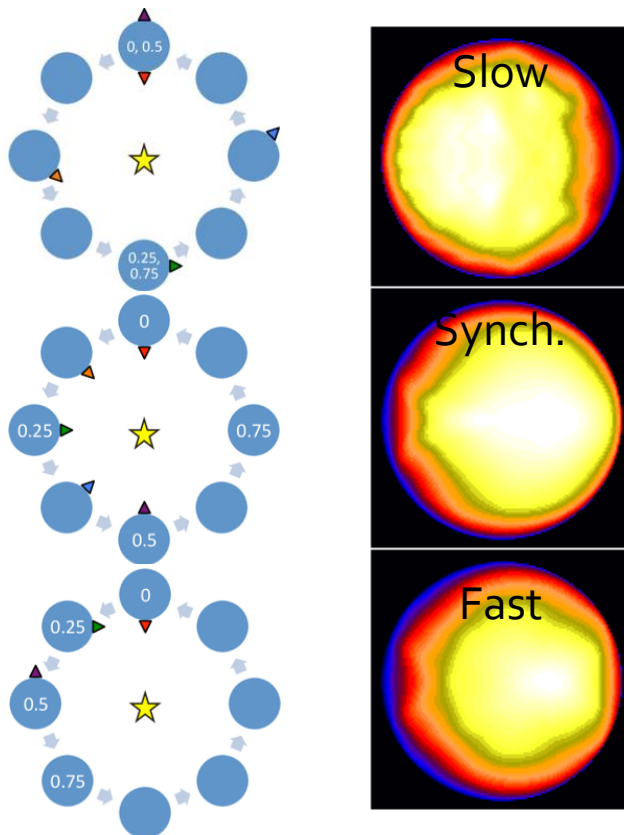


Evolution of a different type: rotation rate

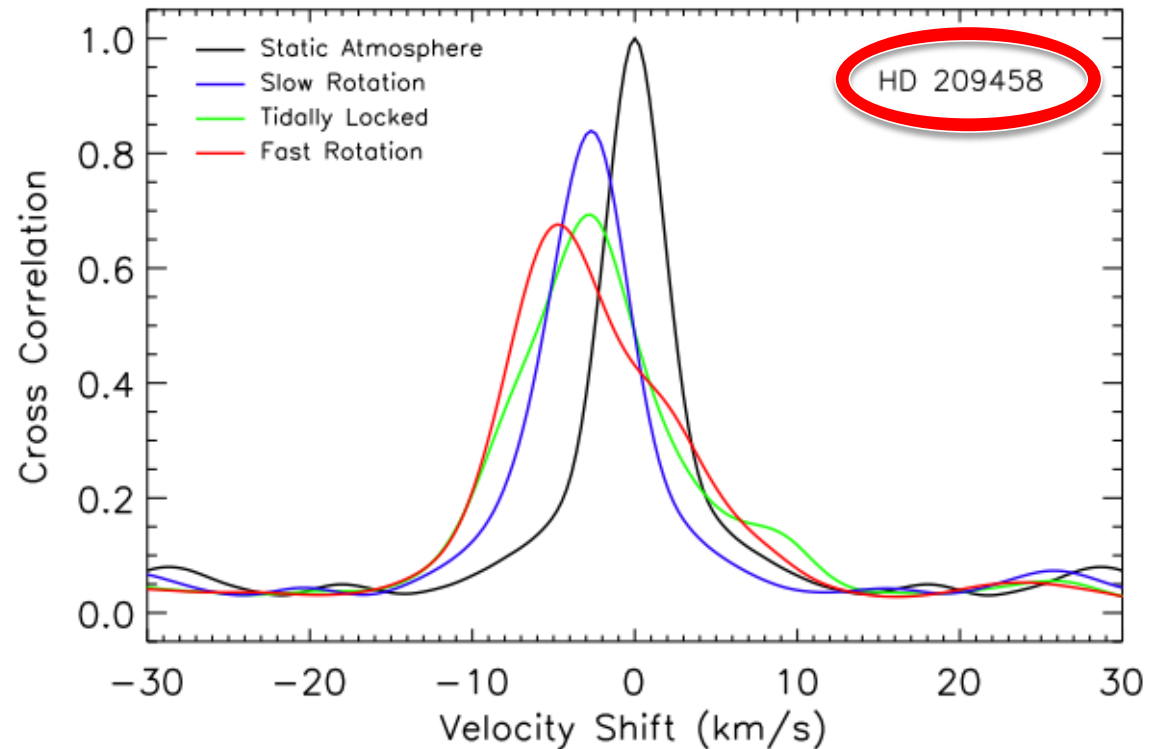
Emitted light, as seen throughout one orbit



Evolution of a different type: rotation rate

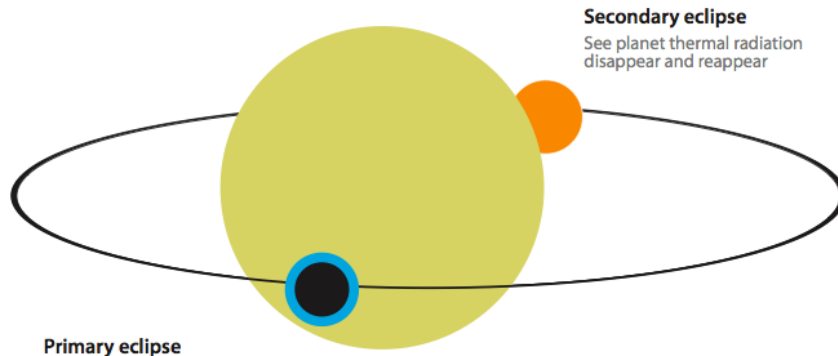


Atmospheric Doppler shift, due to winds & rotation

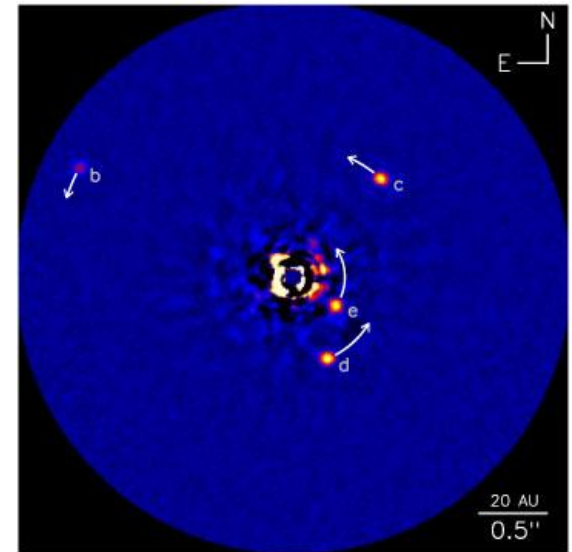


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Seager & Deming (2010)



credit: Keck Observatory

What do we actually measure? (for transiting planets)

- easy**
 - Radius (R_p/R_\star), mass (M_p/M_\star), age (?)
 - Stellar flux (F_\star)
 - Temperature of dayside (F_p/F_\star during secondary eclipse)
 - Composition of the atmosphere (absorption lines during transit)
- moderate**
 - Circulation of the atmosphere (orbital phase curves: ΔF day-night, shifted hot spot)
- wishful**
 - Magnetic effects? (compare: radius, circulation, evaporation, star-planet interaction)
 - Wind speed & rotation rate? (Doppler-shifted atmospheric lines)

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atmosphere

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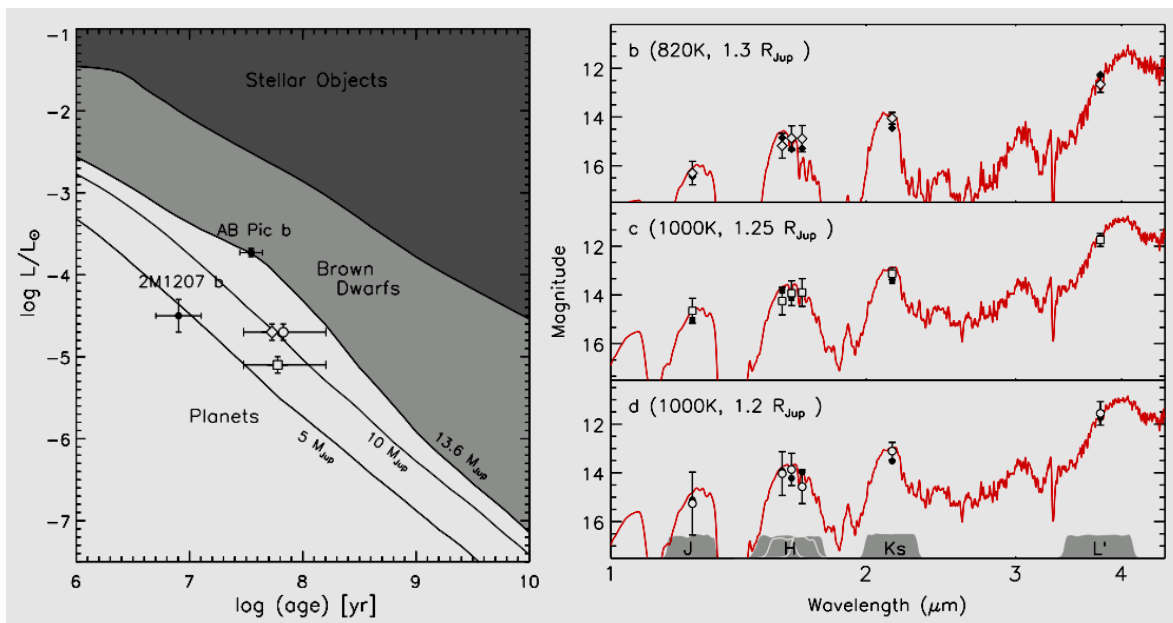
atmosphere

evolution

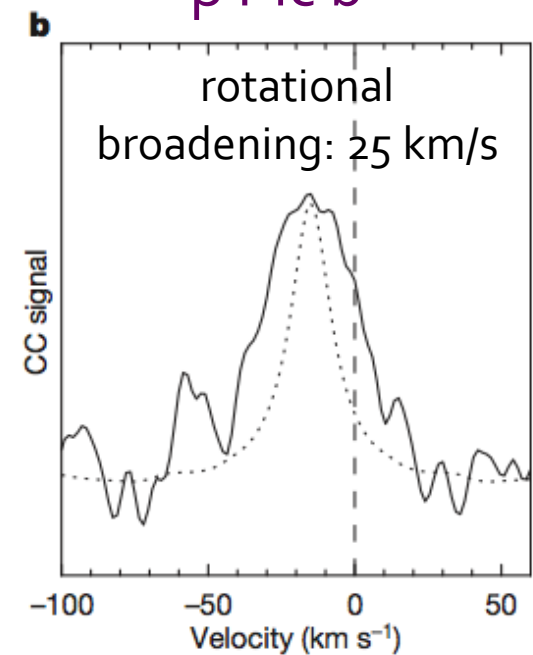
Directly imaged planets

The physical properties of directly imaged planets are “measured” by comparison to evolutionary and atmospheric models

First measured rotation of a planet:
 β Pic b



Marois et al. (2008)



Snellen et al. (2014)

Questions

- How does the **atmosphere** influence the **evolution**?
a lot, in many ways
- How does the **evolution** influence the **atmosphere**?
not obvious
- What are the **observables**?
multiple, and growing