Structure and evolution of planets with EChO

Tristan Guillot
Observatoire de la Côte d'Azur, Nice

1999

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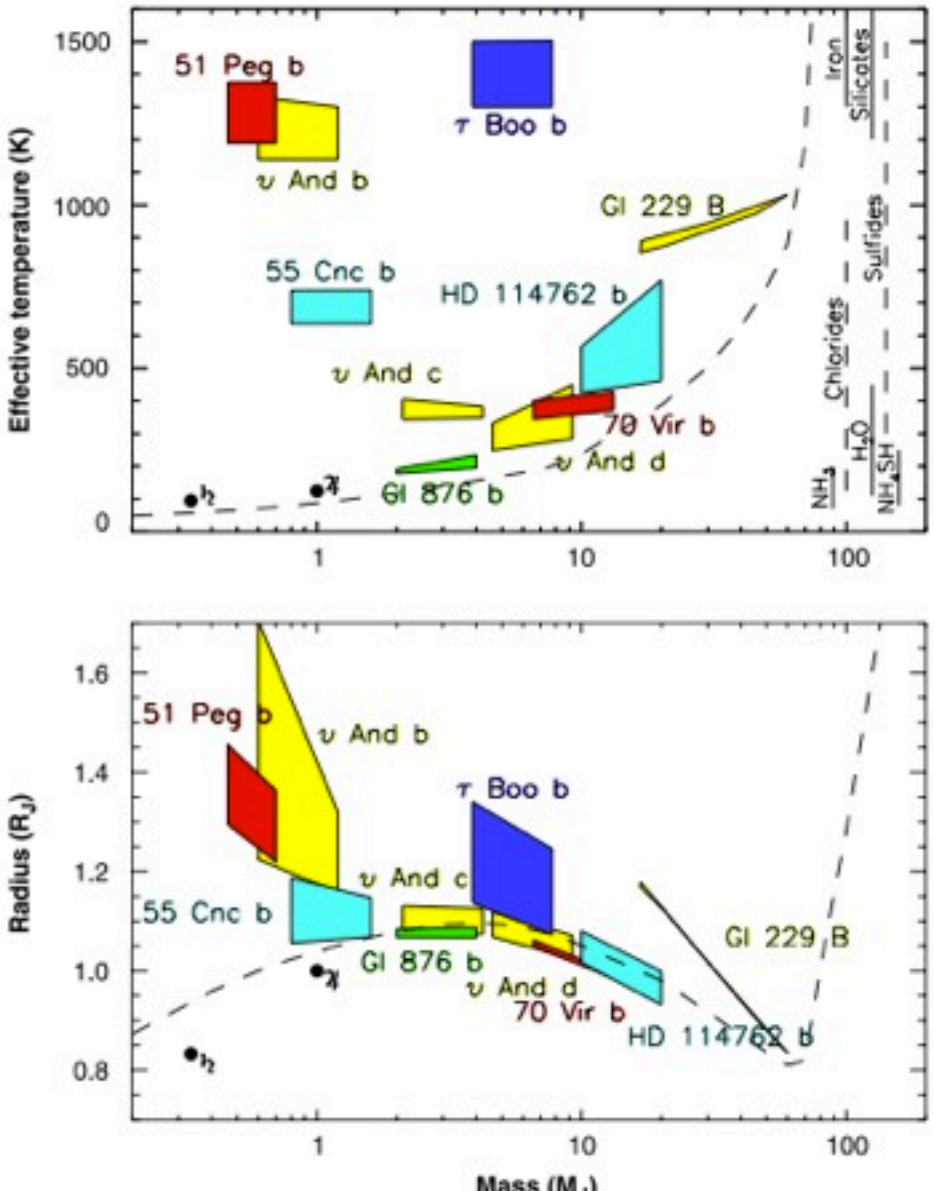
Fig. 3. Predicted effective temperatures and radii (in R_J, ~70,000 km) of some extrasolar planets and brown dwarfs, including reasonable uncertainties for their mass, albedo, and age (see text) and assuming solar composition. Actual radii could be significantly smaller if the planets contain large proportions of heavy elements. The dashed line is for isolated H-He (Y = 0.25) objects after 10 gigayears of evolution. The upper panel also shows potentially important chemical species expected to condense near the photosphere in the indicated range of effective temperatures.



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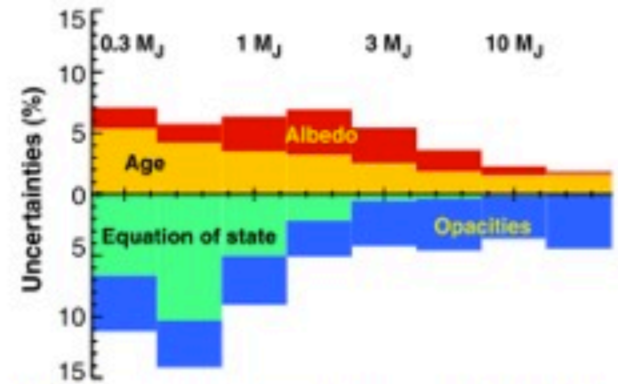

Fig. 4. Fractional uncertainty in radii of extrasolar giant planets (at 0.05 astronomical units from solar-type stars) due to uncertainties in physical parameters (**top**) and input physics (**bottom**), as a function of mass. The corresponding absolute uncertainty about the fraction of the planetary mass that is due to heavy elements is directly proportional to the radii uncertainty [a 10% uncertainty in model radii corresponds to a ~9% uncertainty about the mass of heavy elements; that is, in that case and for a 1-M_J (318 $M_\oplus$) planet, the mass of heavy elements would be known with an accuracy of ~30 $M_\oplus$]. The albedo was assumed to lie between 0.1 and 0.5; the age between 3 and 7 gigayears.

1999

atmospheres & clouds

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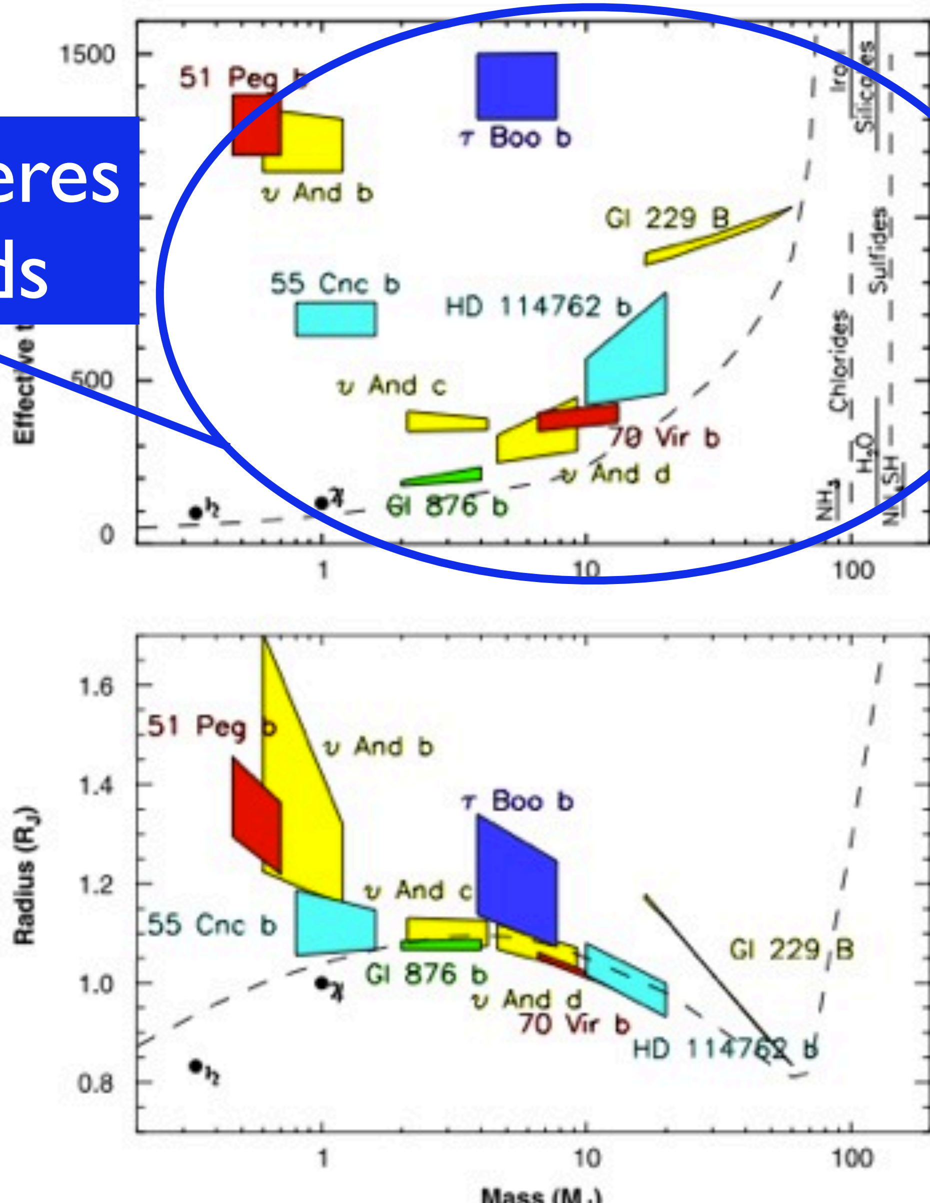

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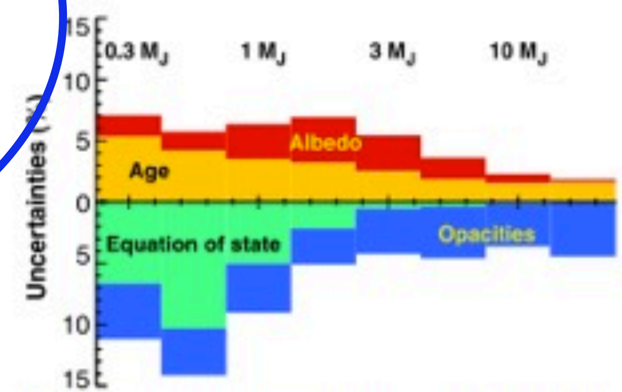

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radii & compositions

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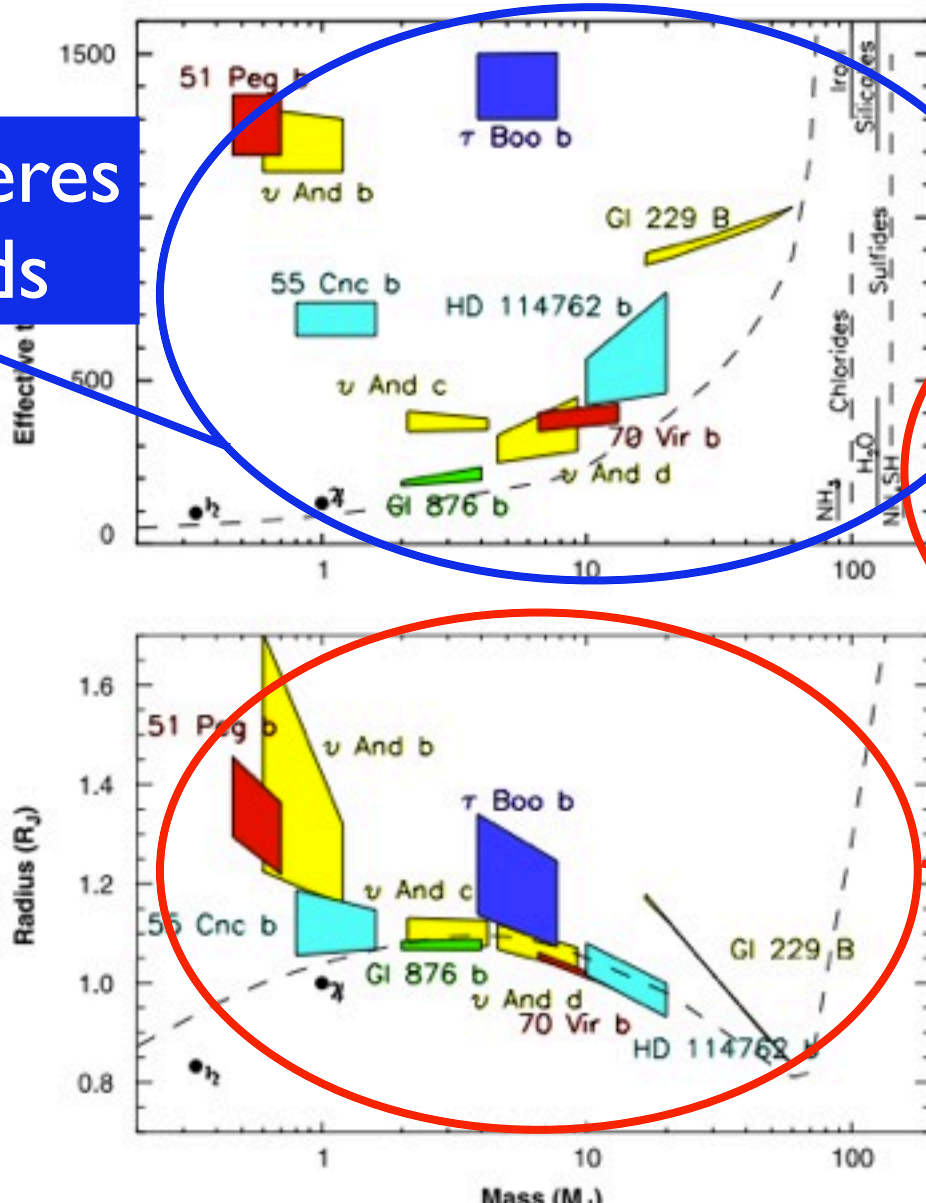

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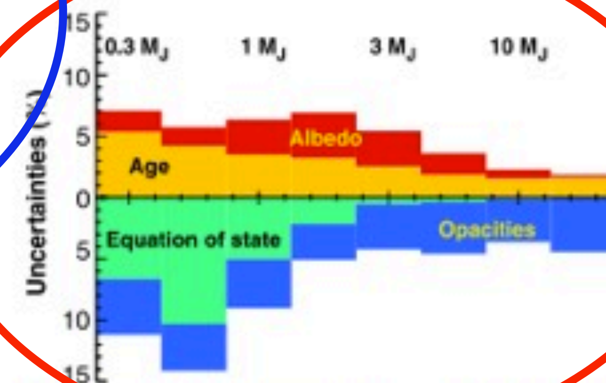

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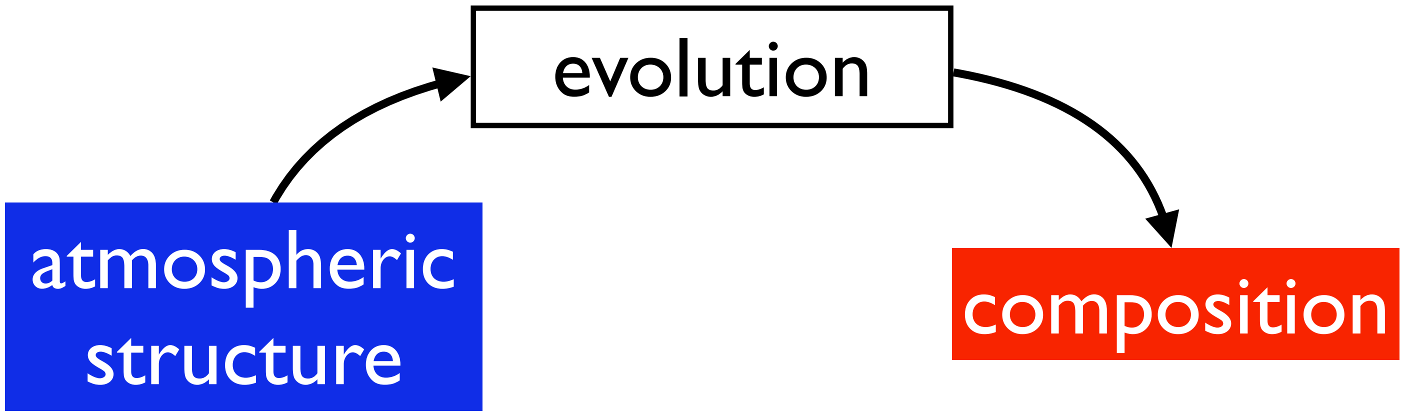
Overarching goals

atmospheric structure

composition

Overarching goals



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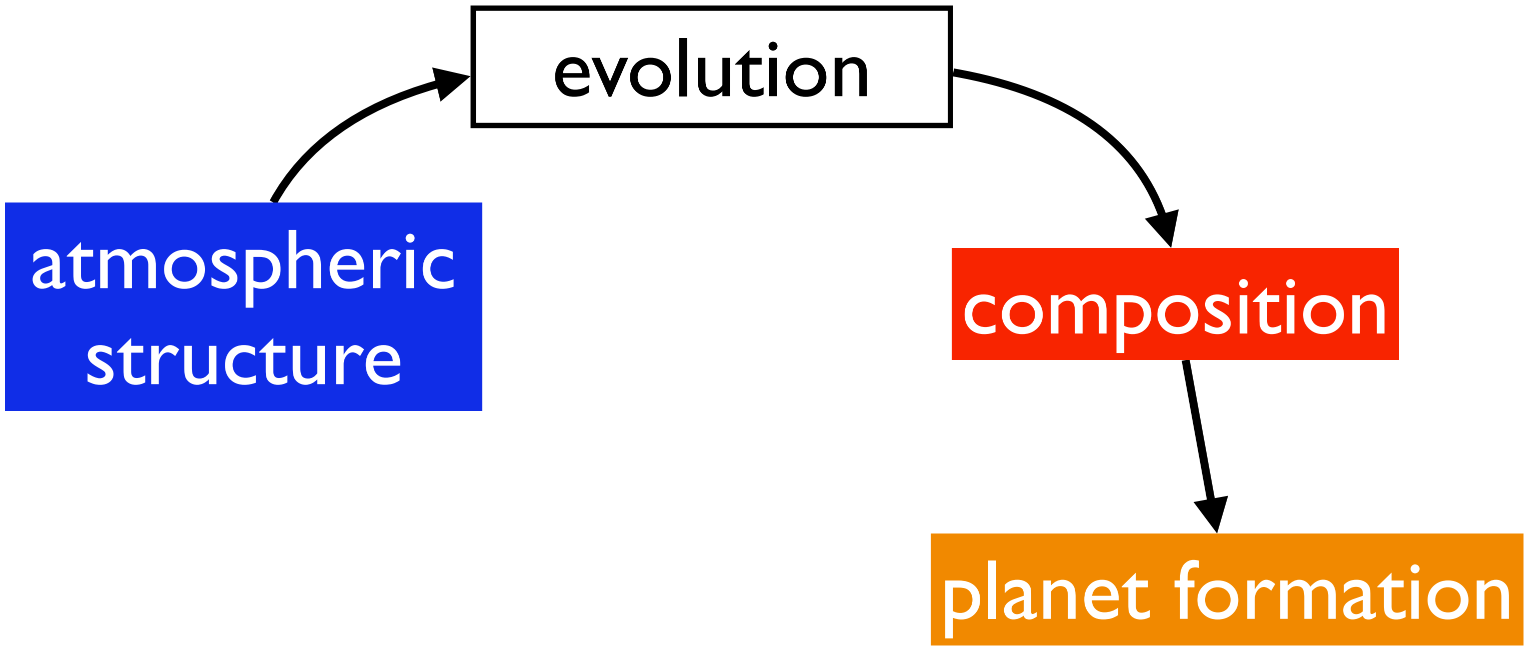

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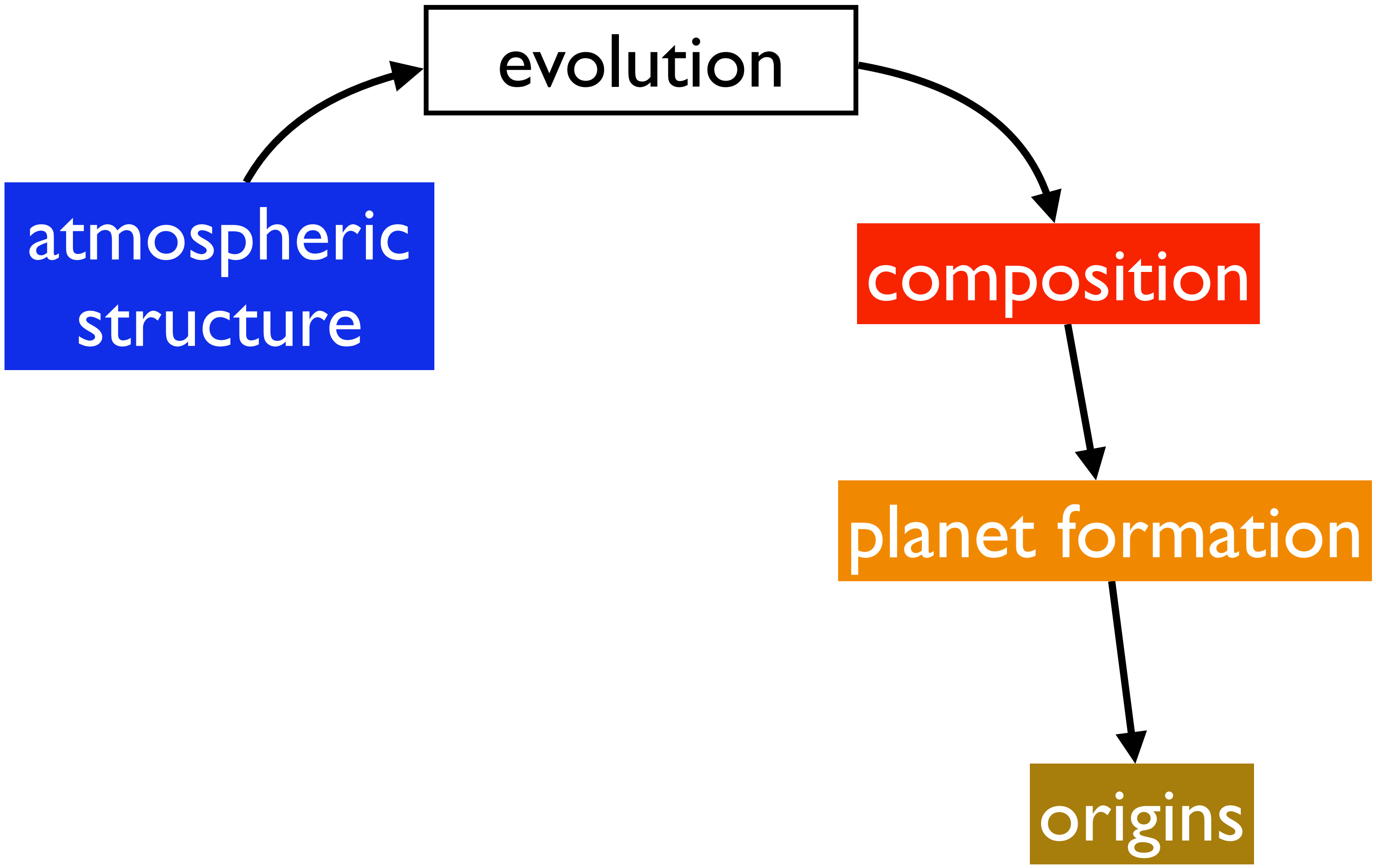

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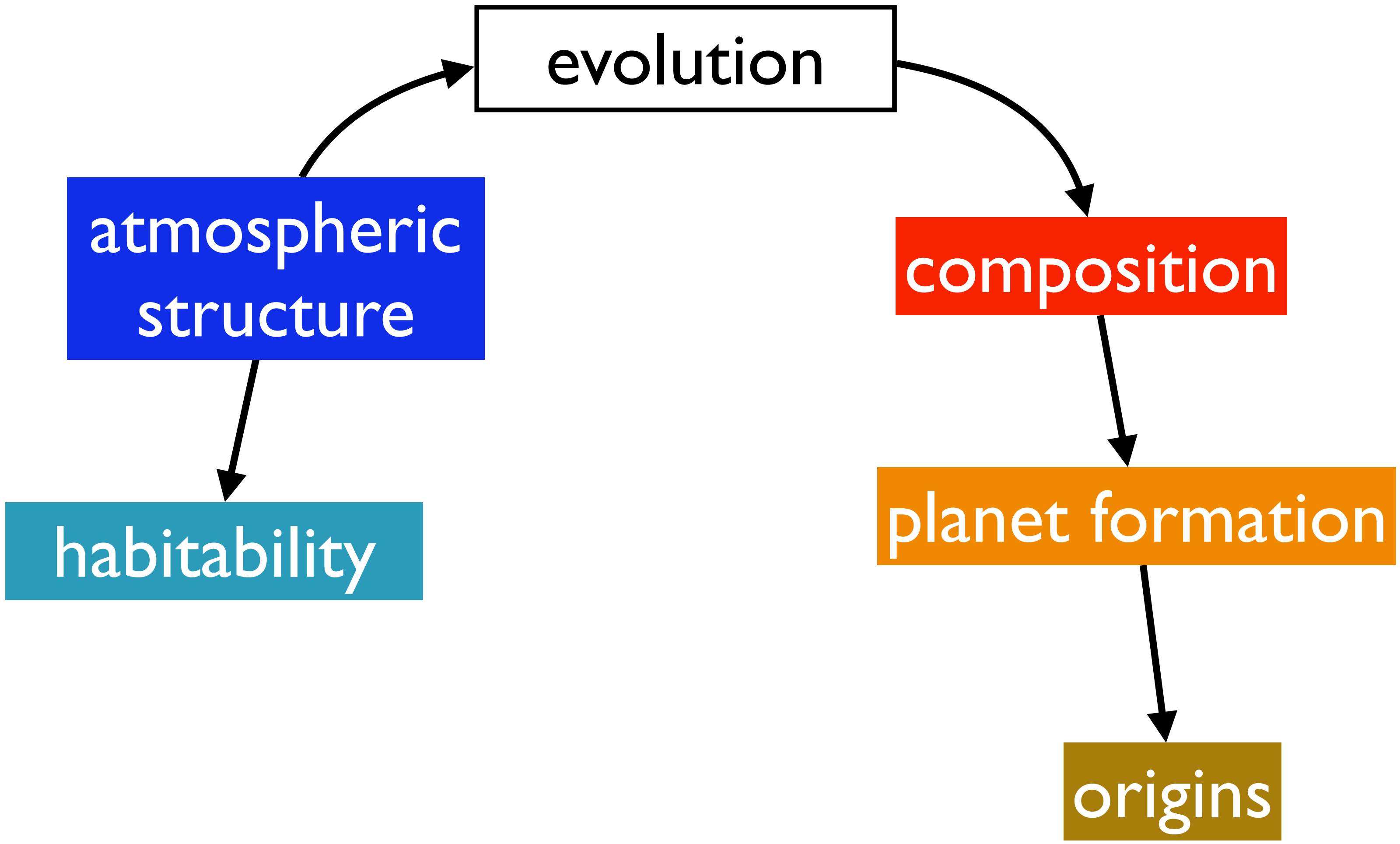

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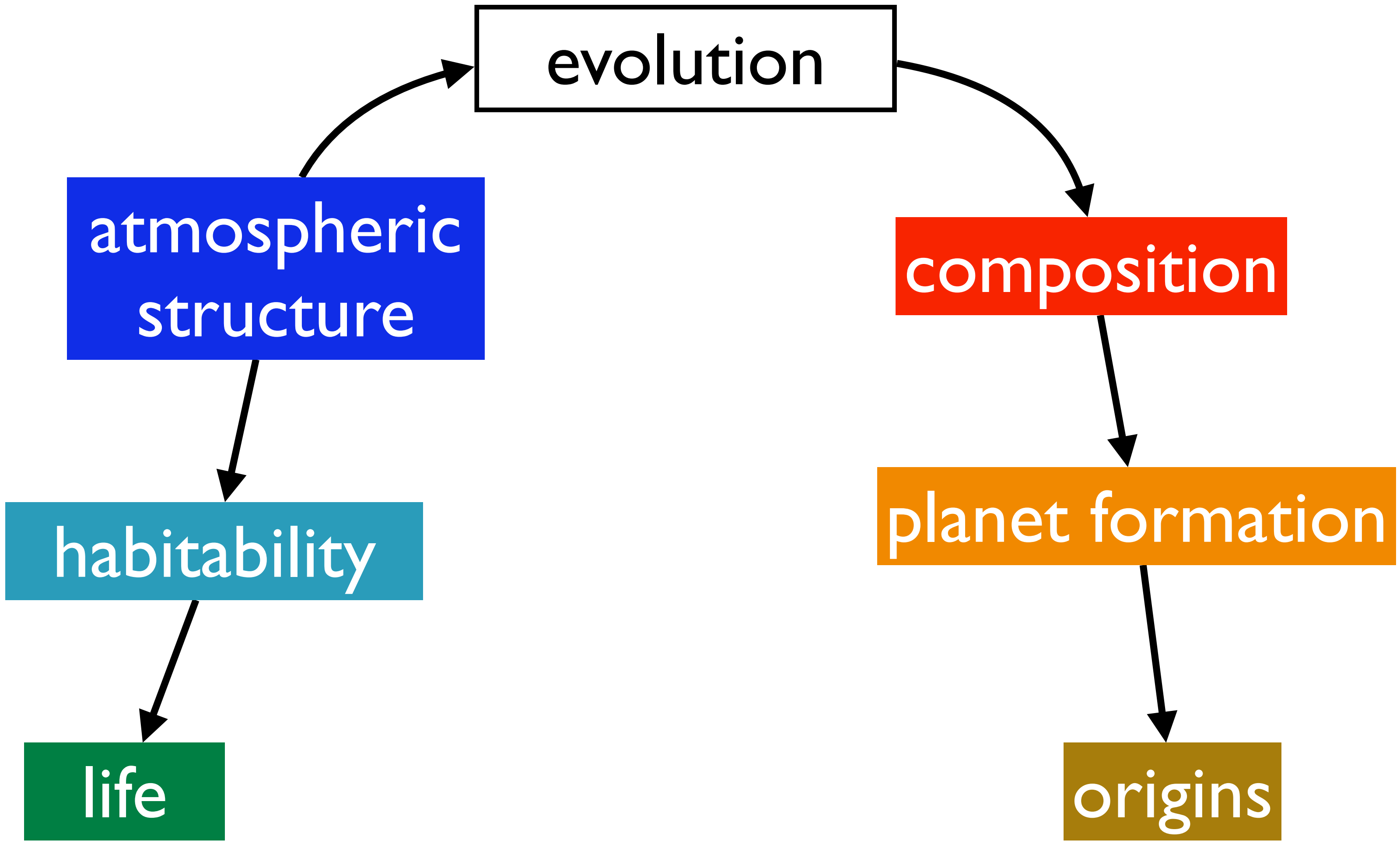
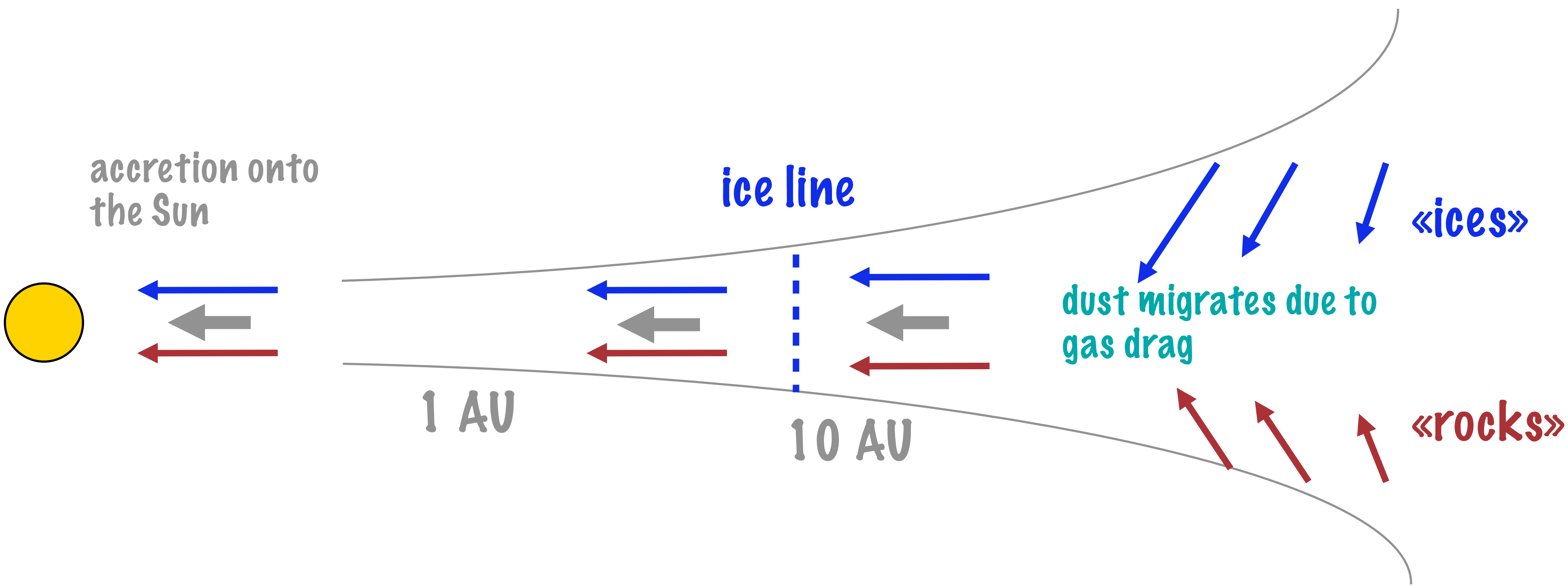


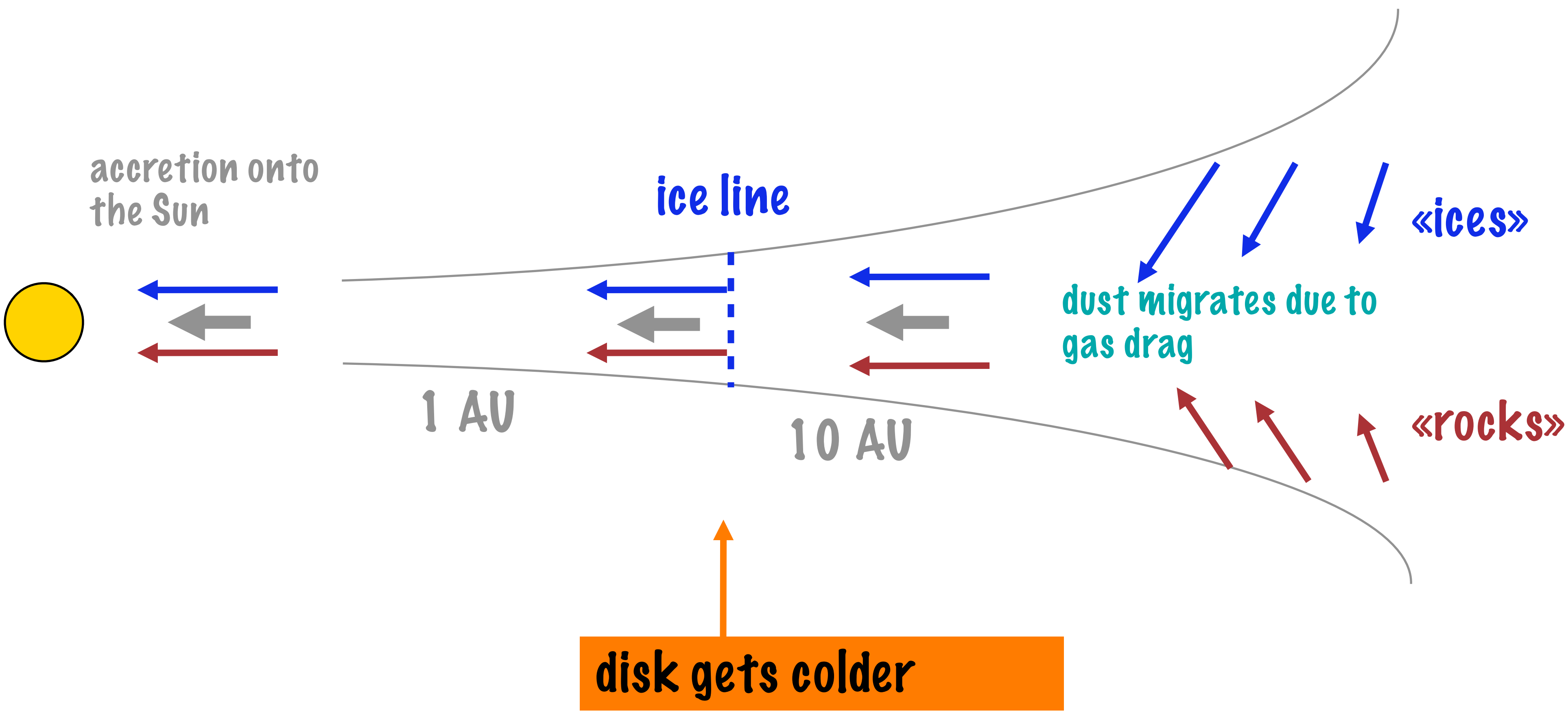
Linking compositions & formation scenario

Evolution of the dust and gas



Guillot & Ida, in preparation

Evolution of the dust and gas



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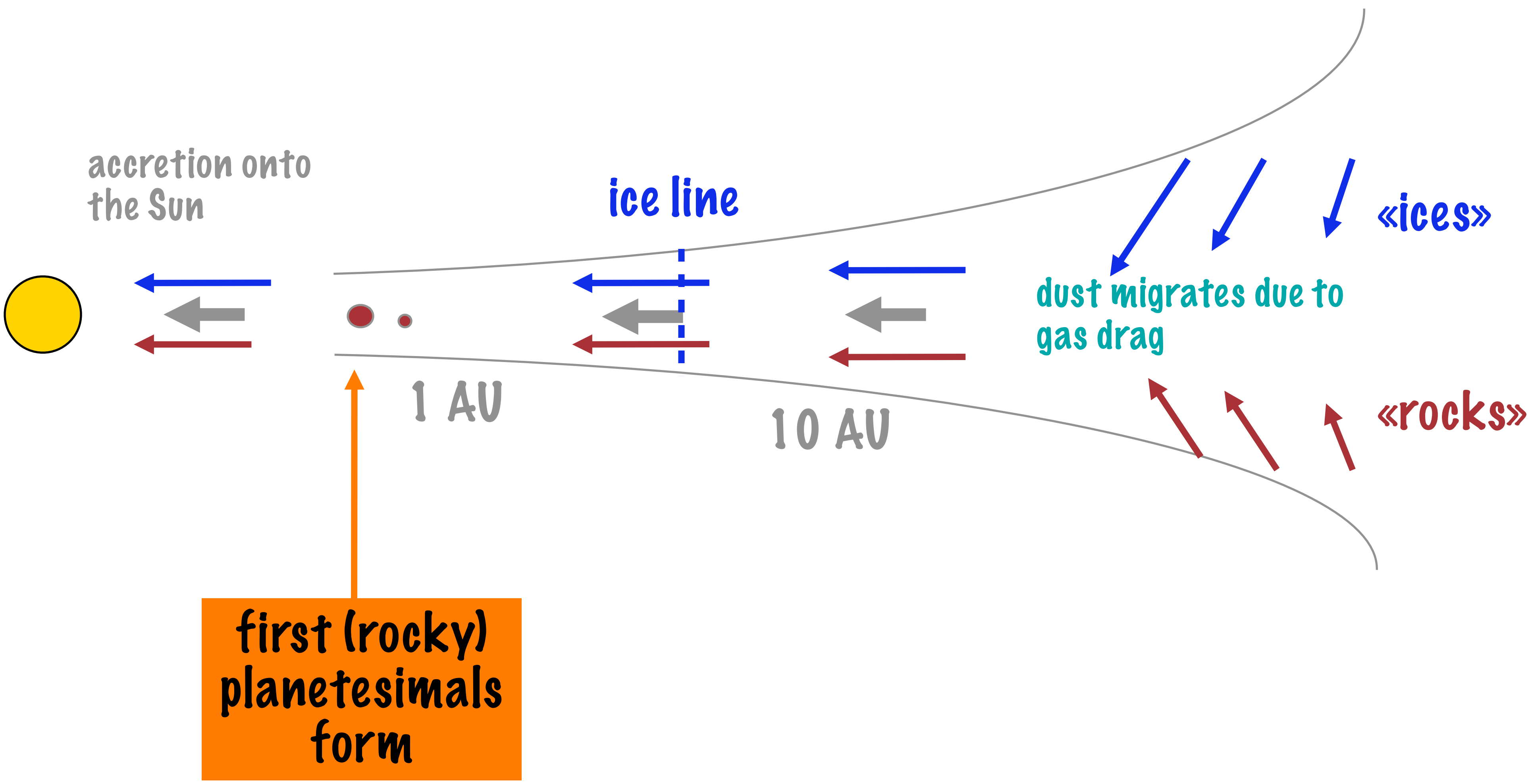

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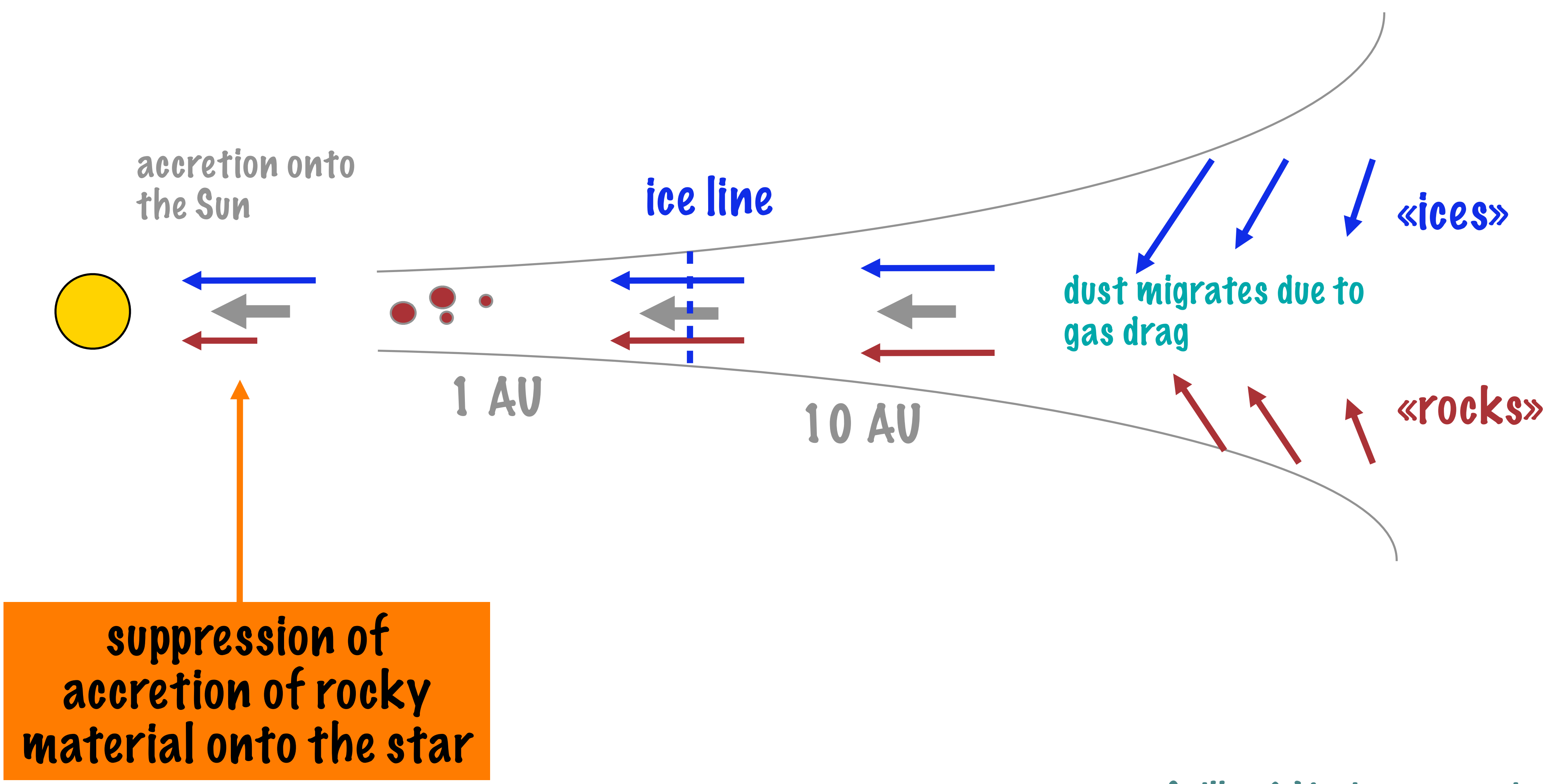

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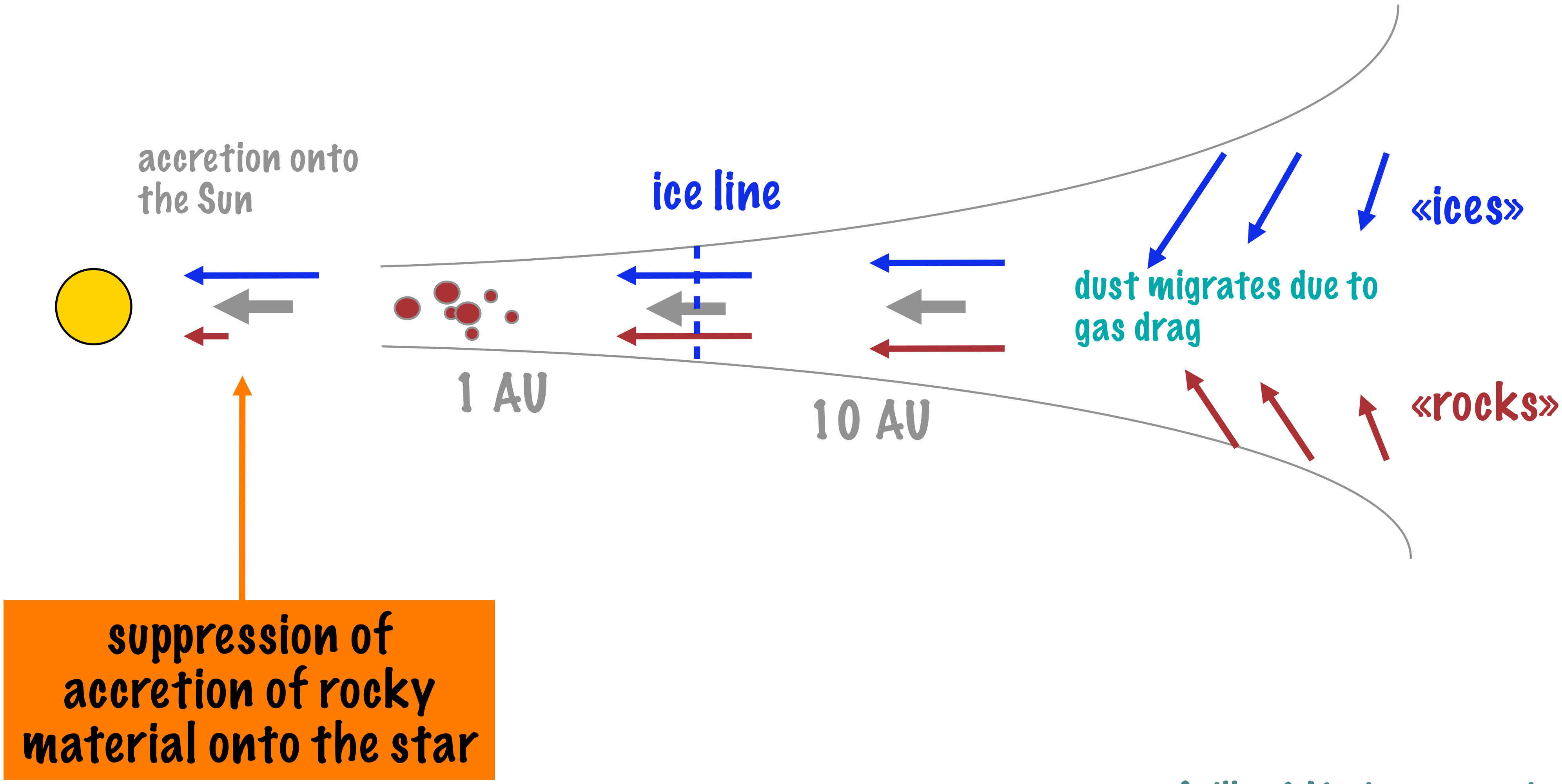

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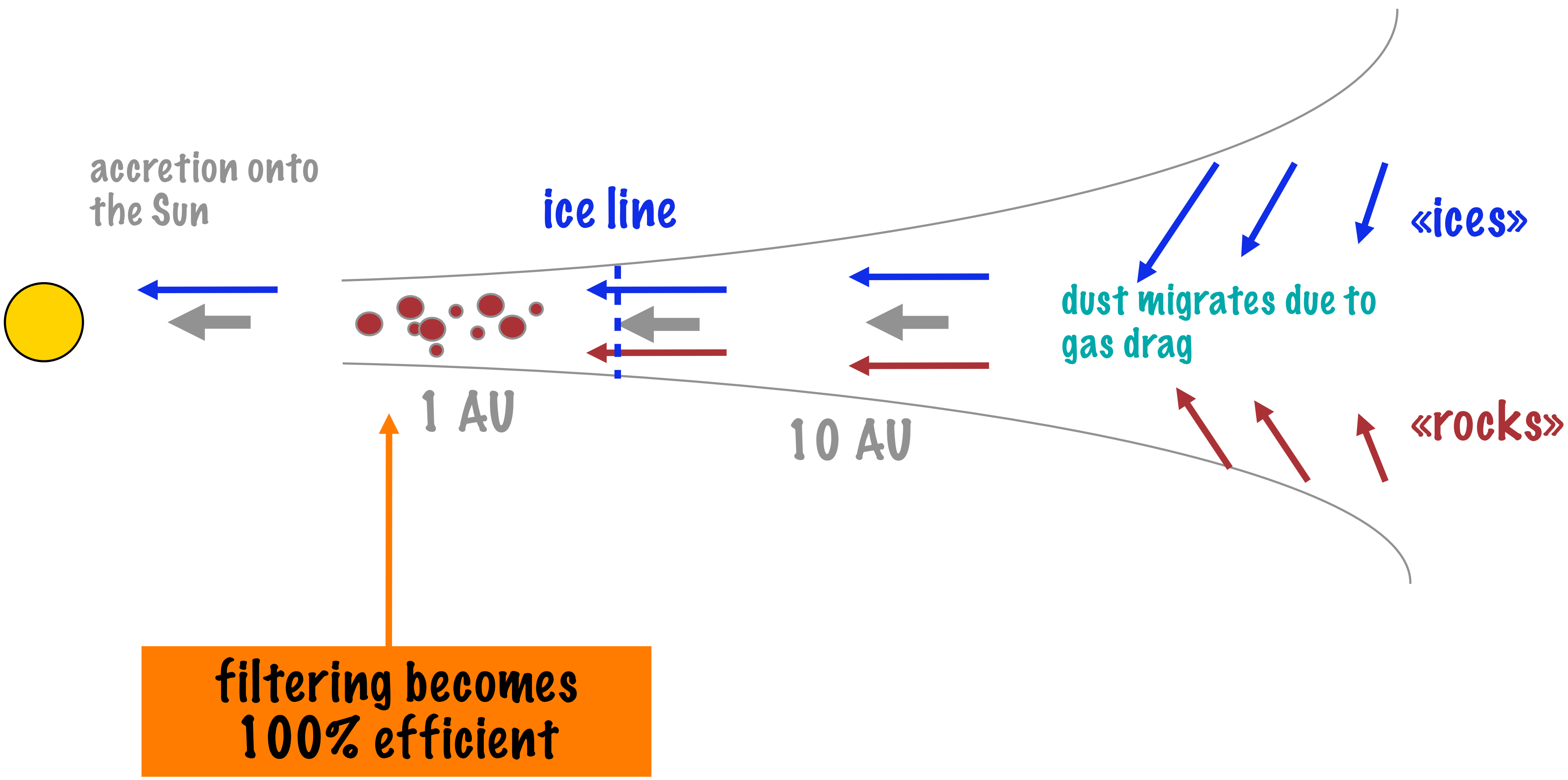

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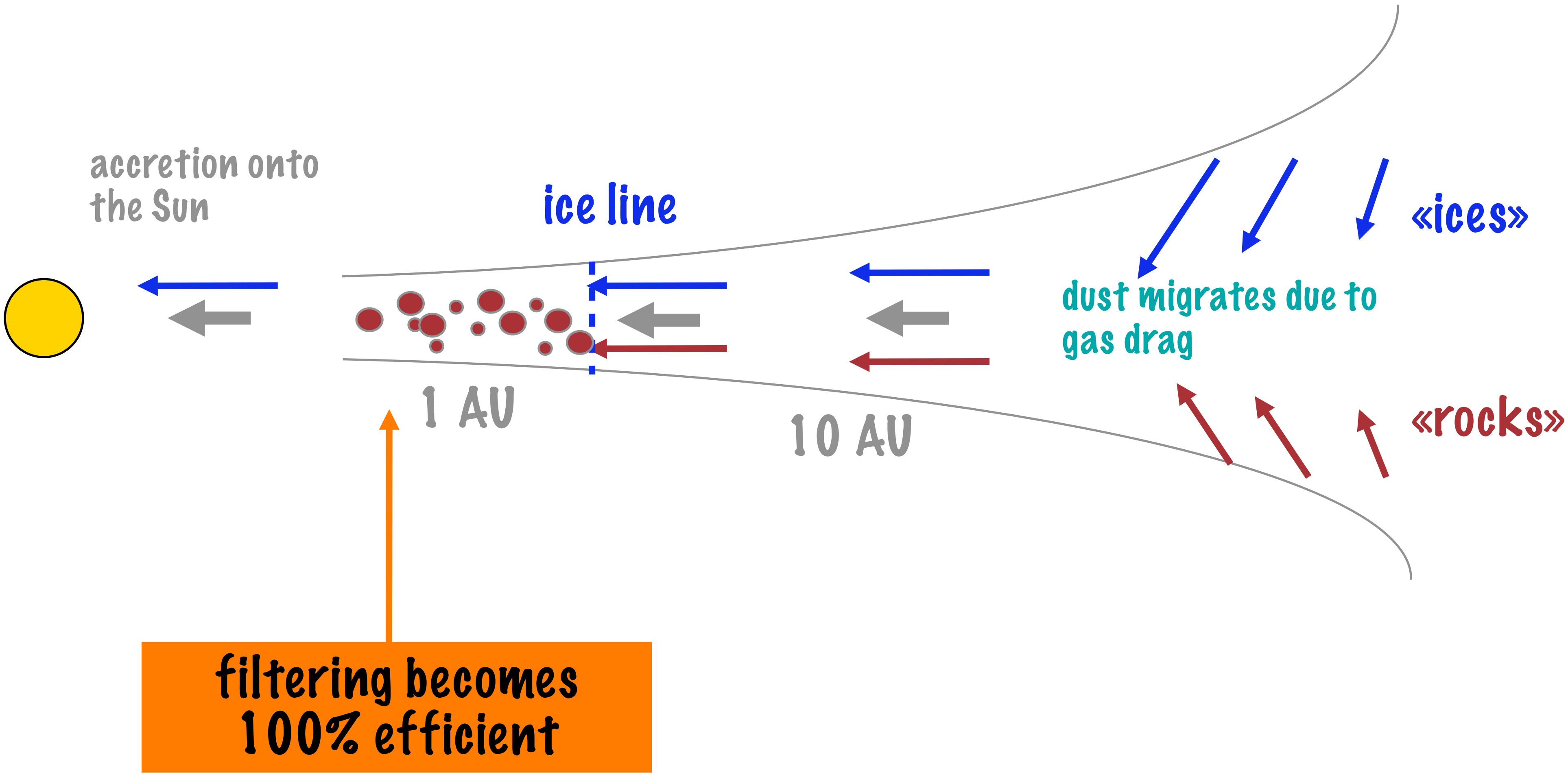

Guillot & Ida, in preparation

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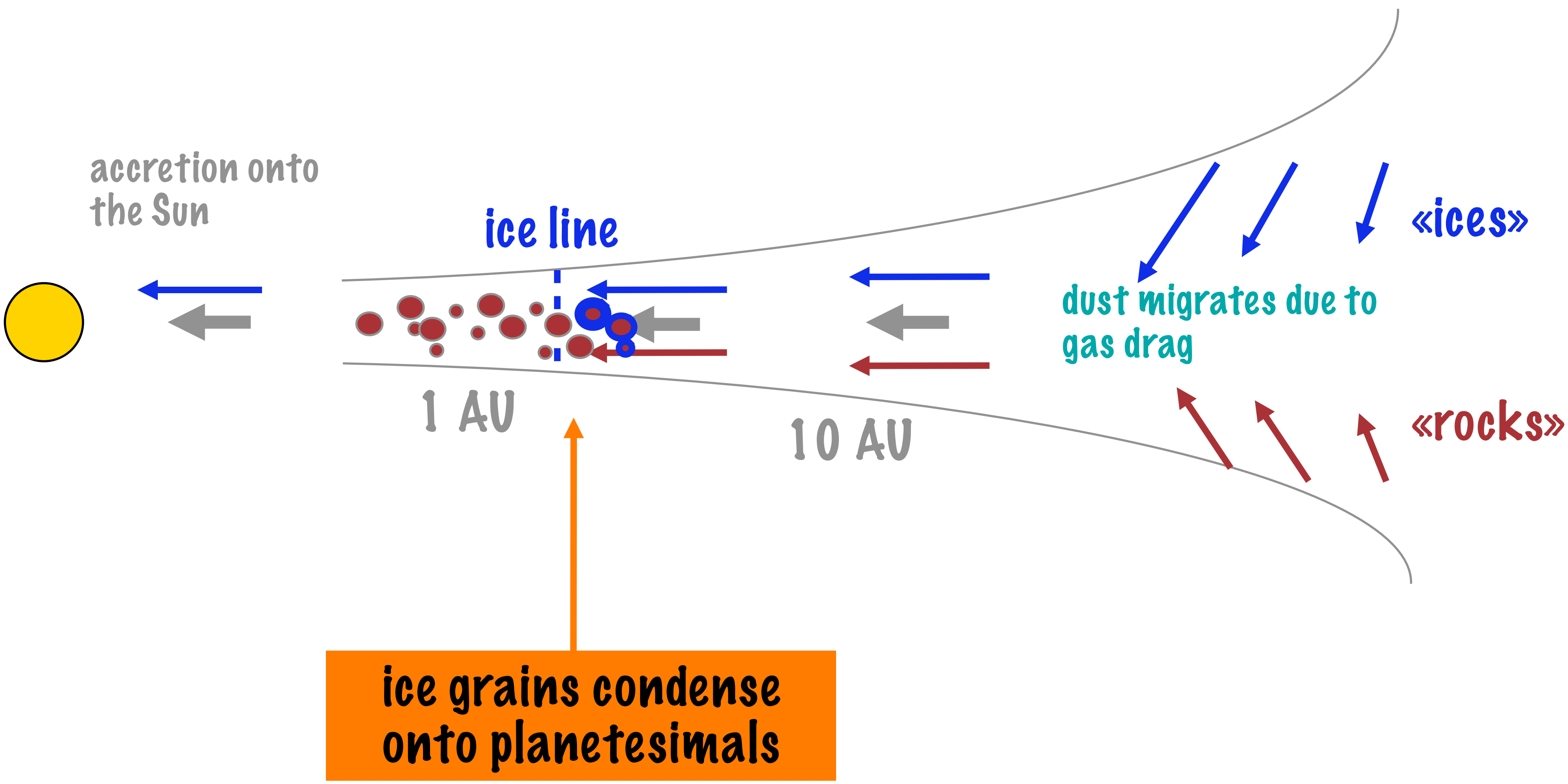

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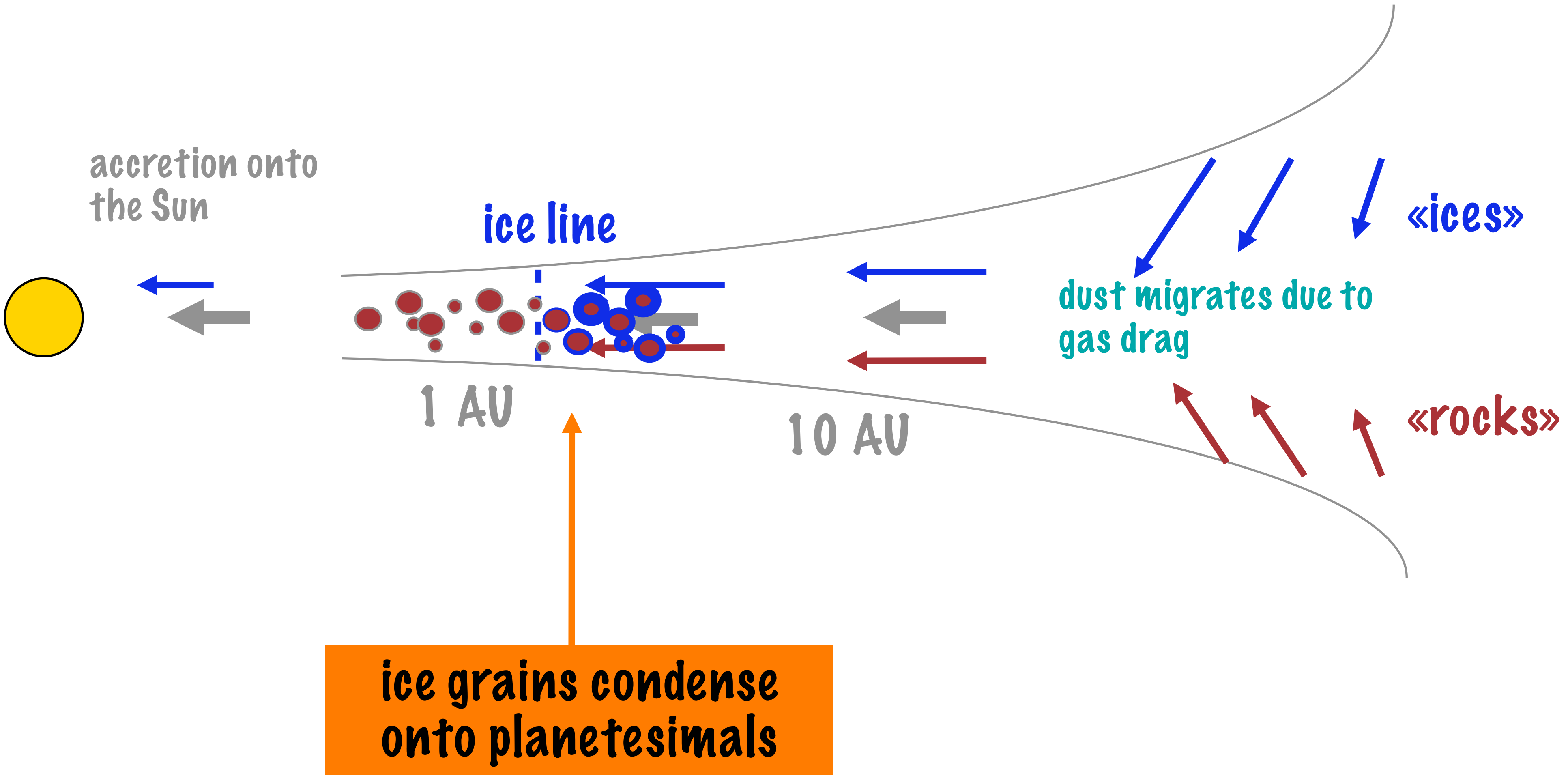

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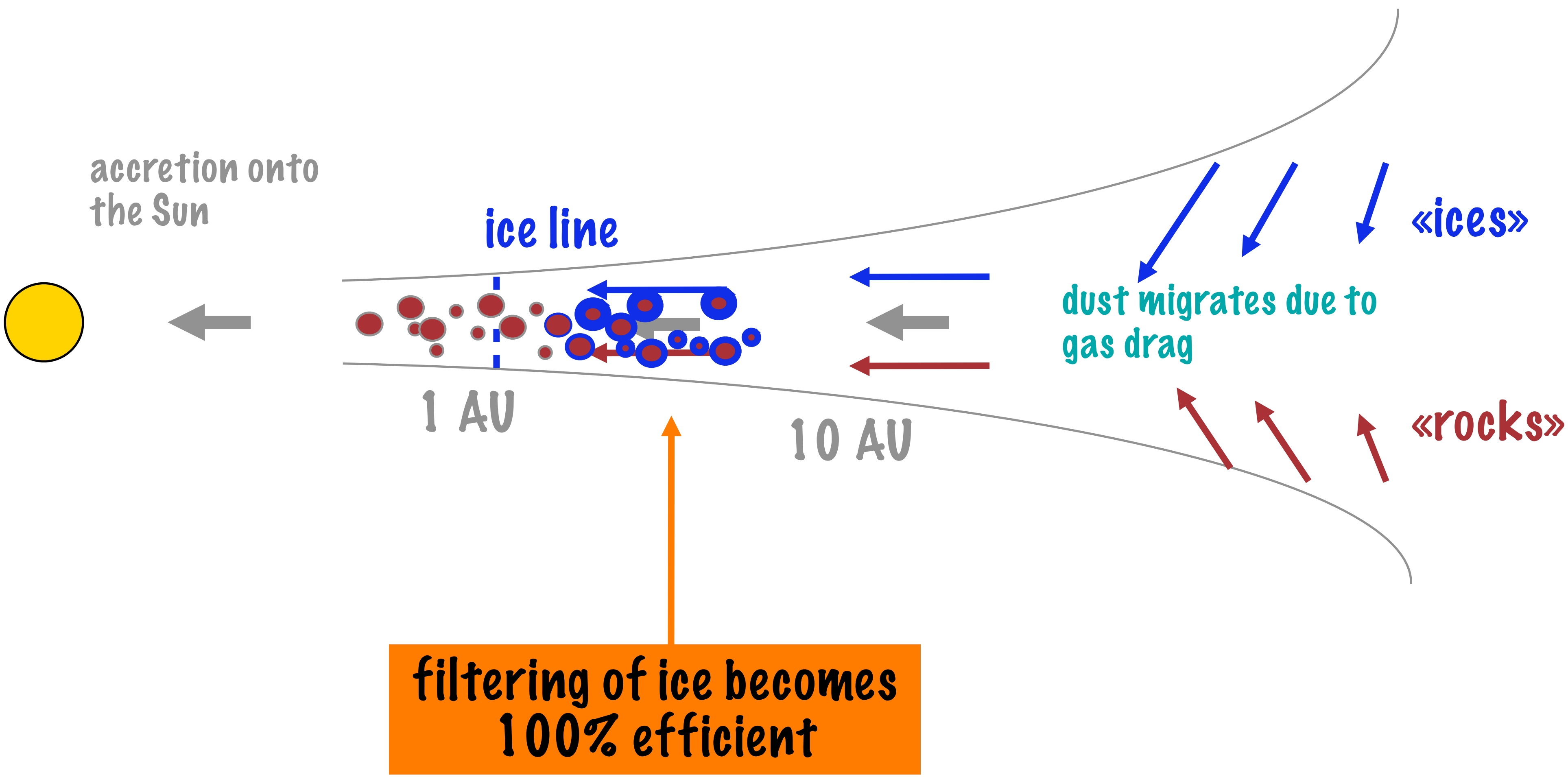

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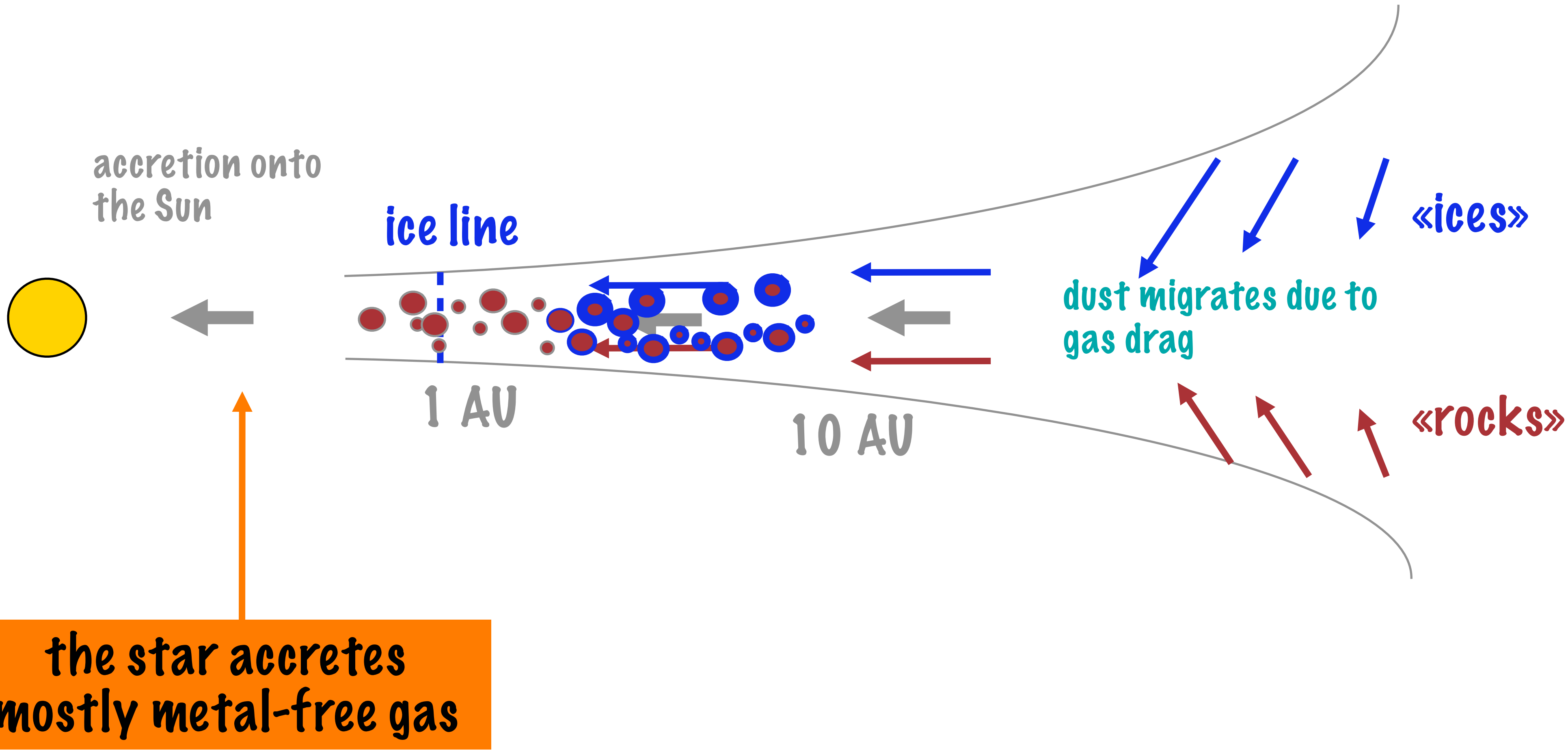
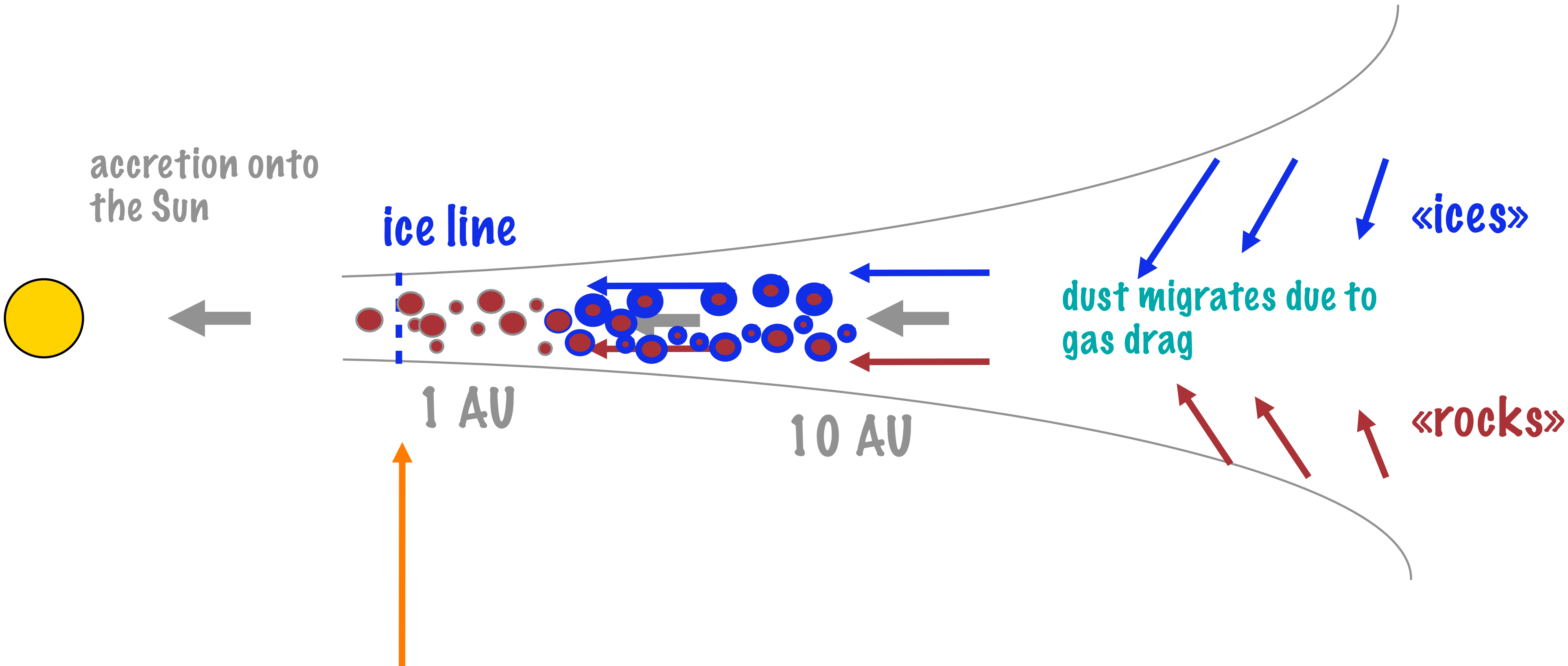


Guillot & Ida, in preparation

Evolution of the dust and gas

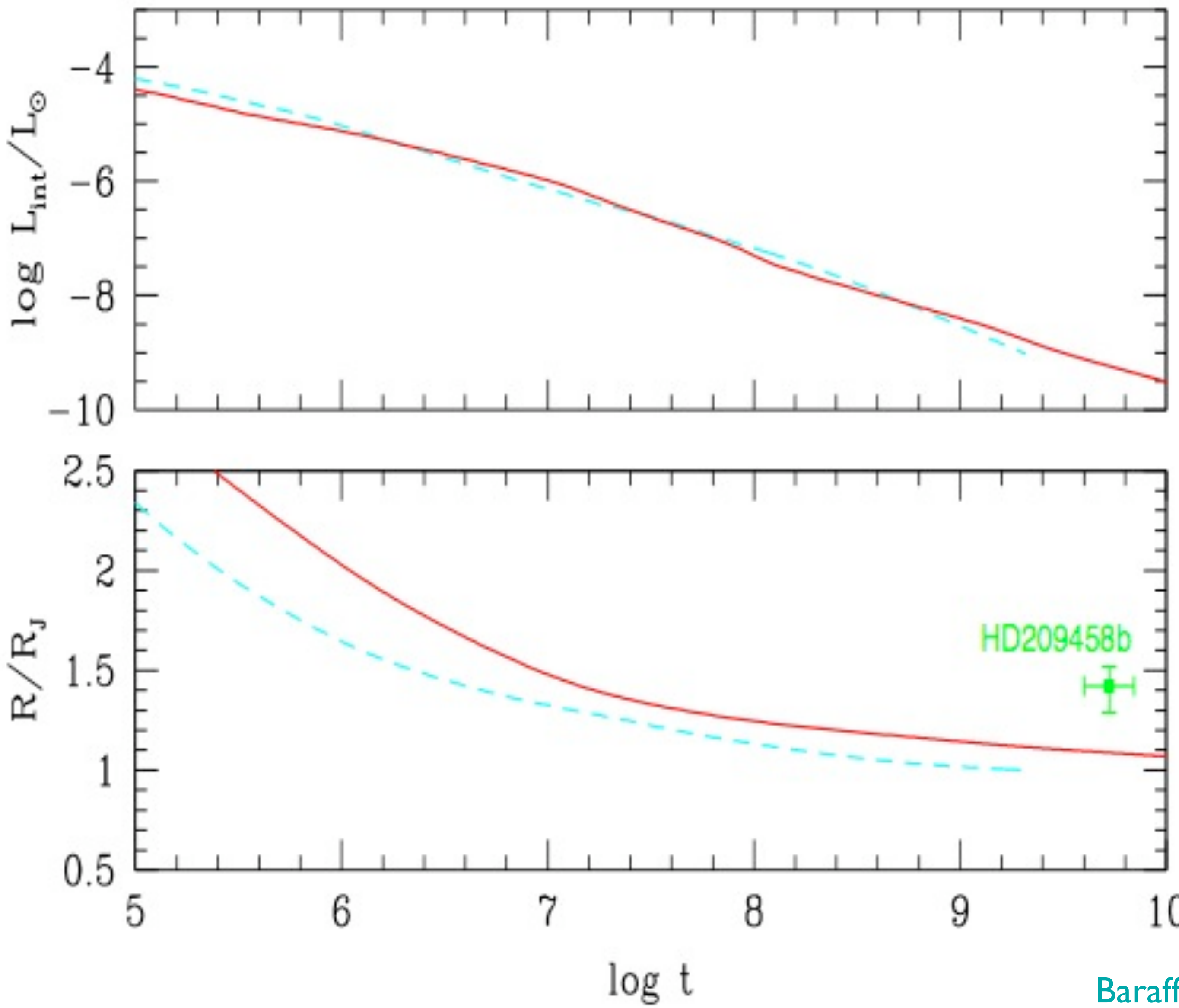


the ice line has moved beyond 1 AU but planetesimals there contain no water

Guillot & Ida, in preparation

Getting the compositions of transiting gaseous planets

The radius anomaly problem



Baraffe et al. (2003)
see also: Bodenheimer et al. (2001)
Guillot & Showman (2002)
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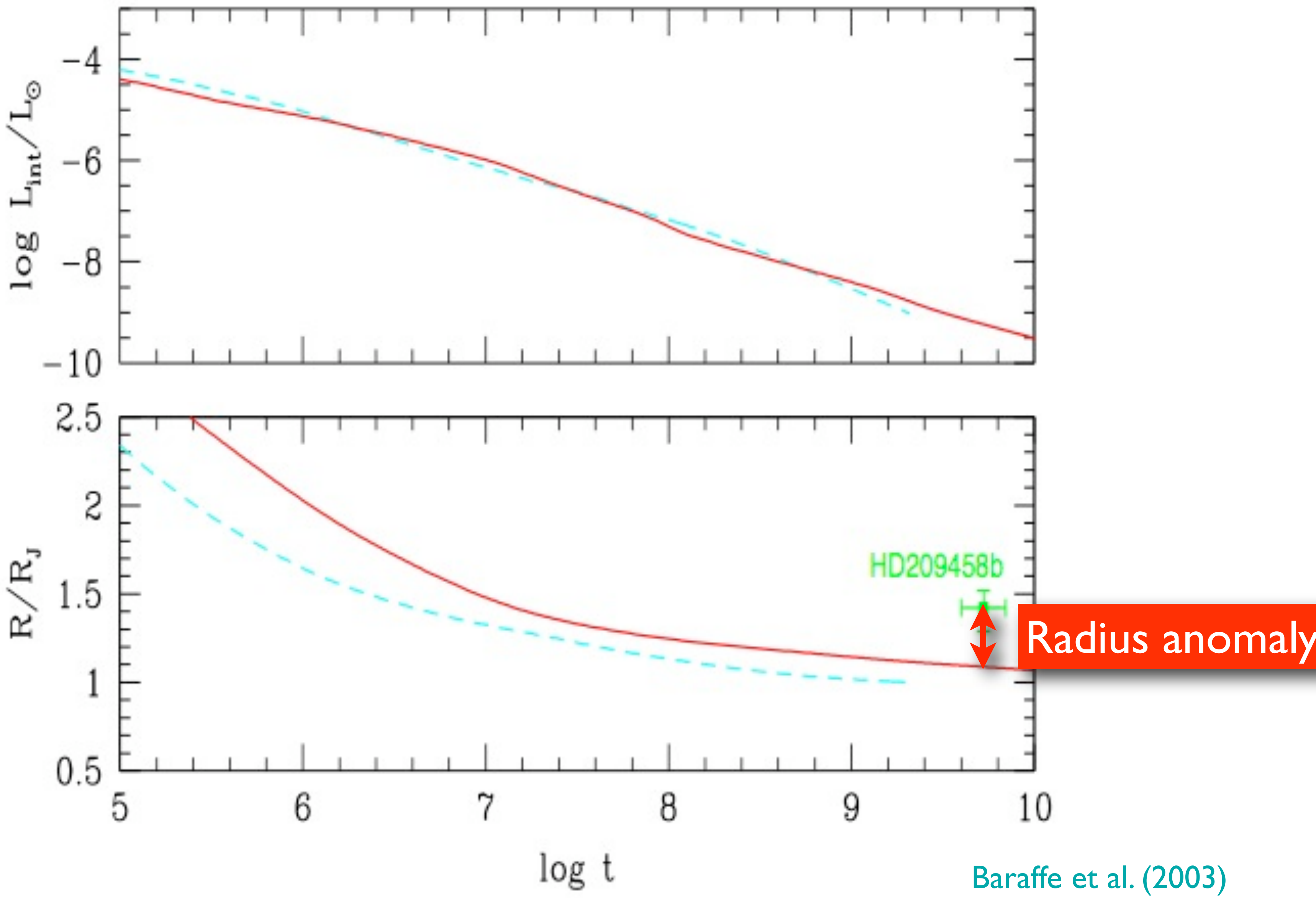
The radius anomaly problem



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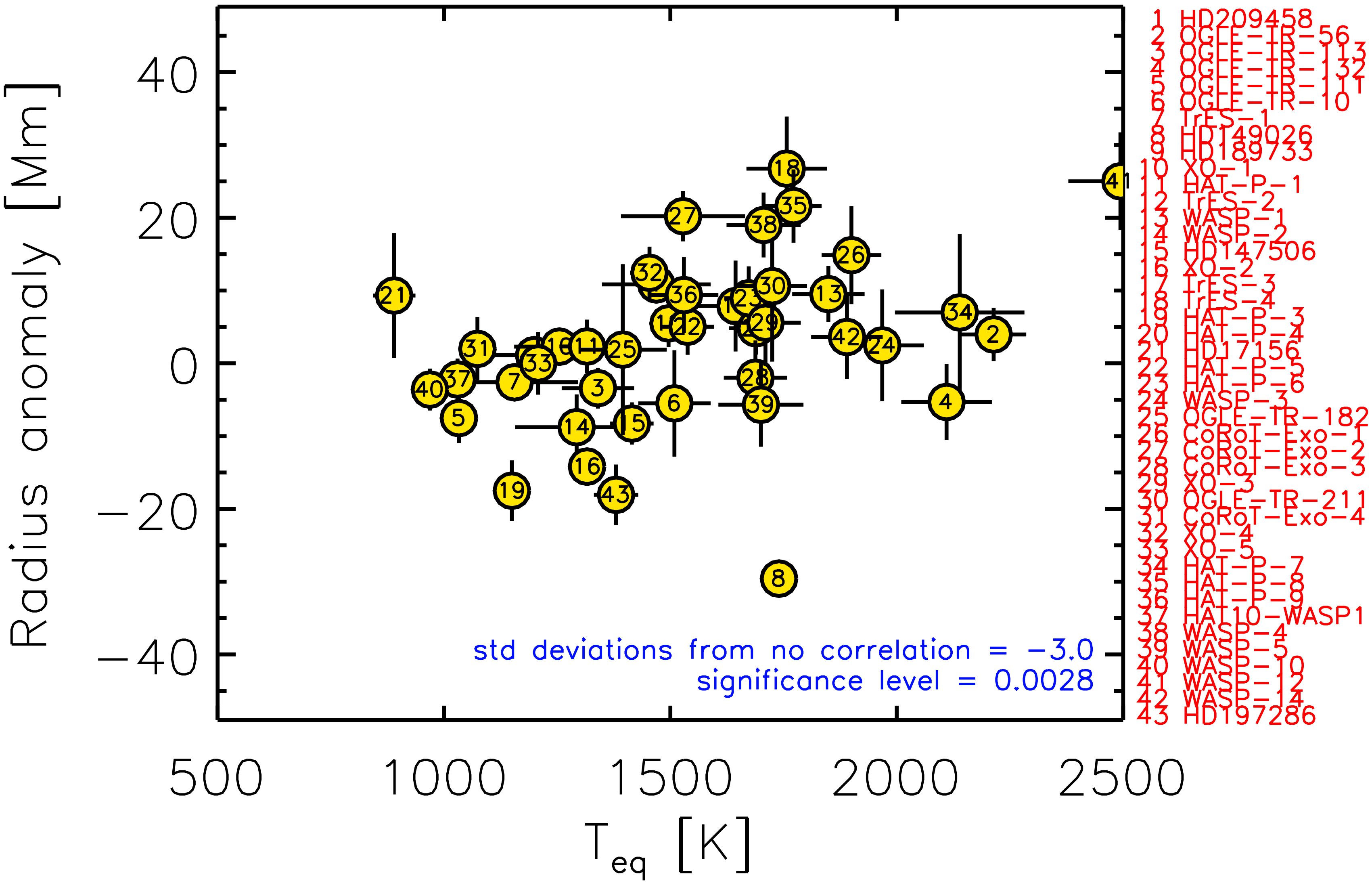

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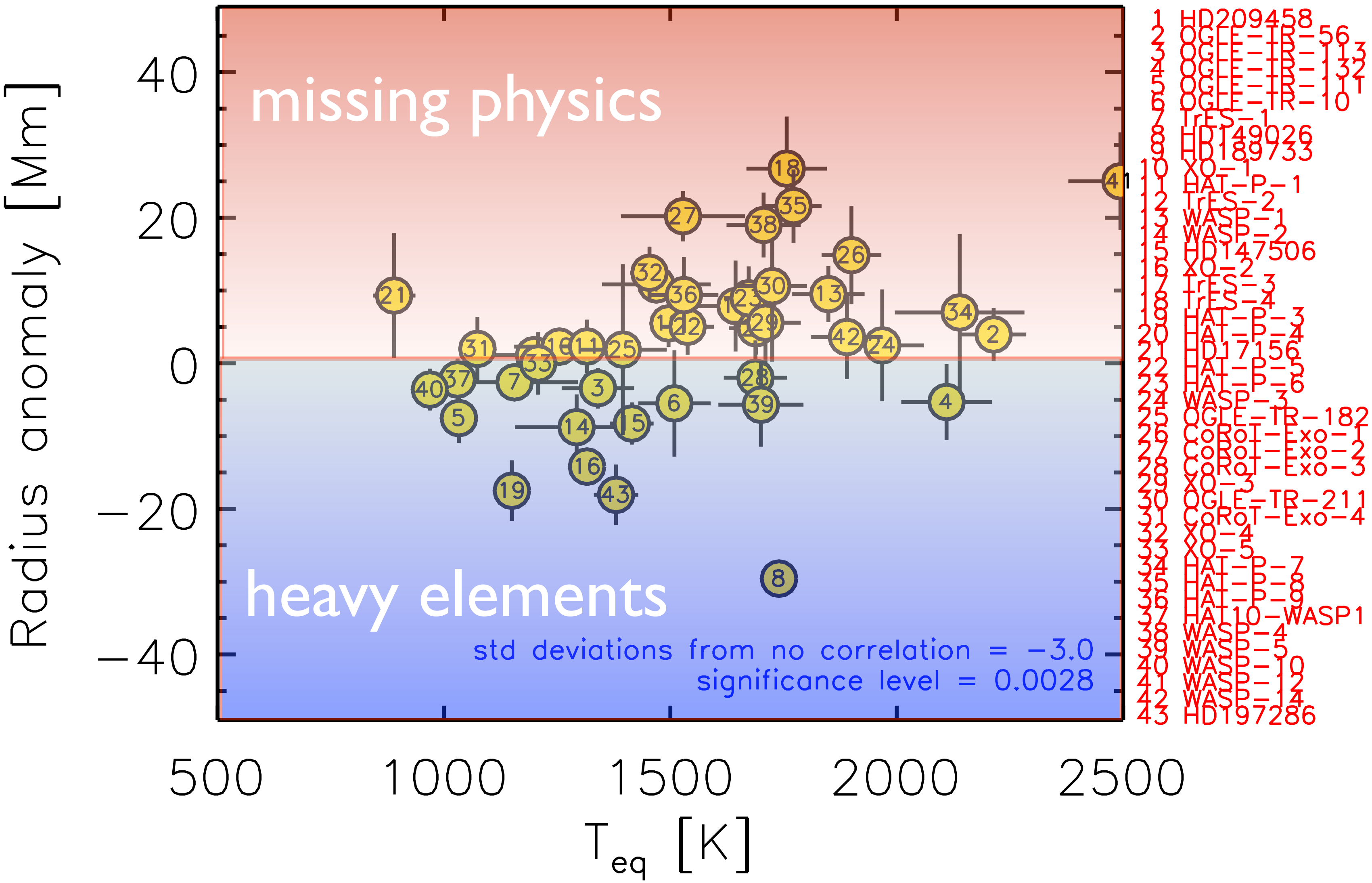

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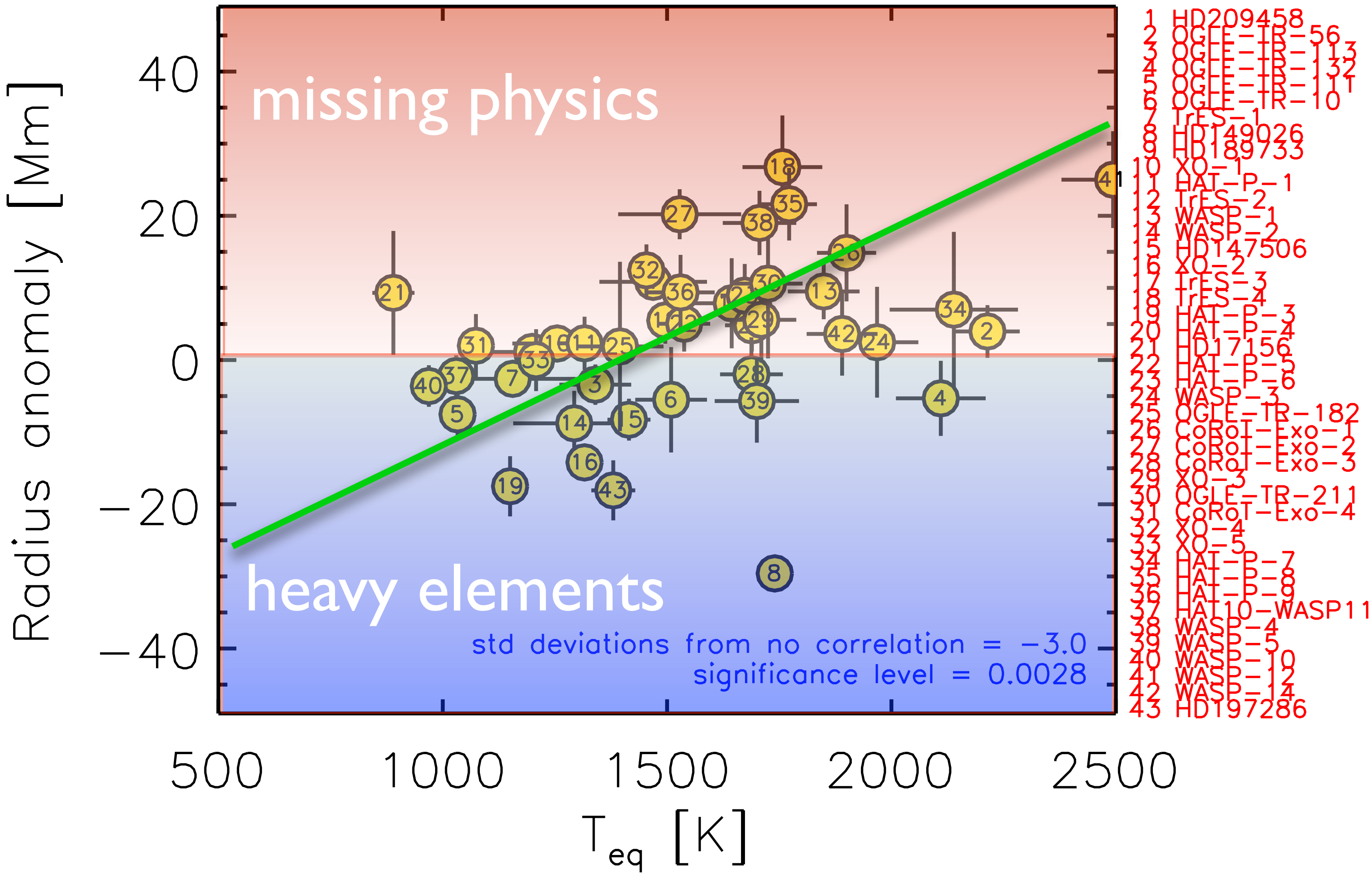
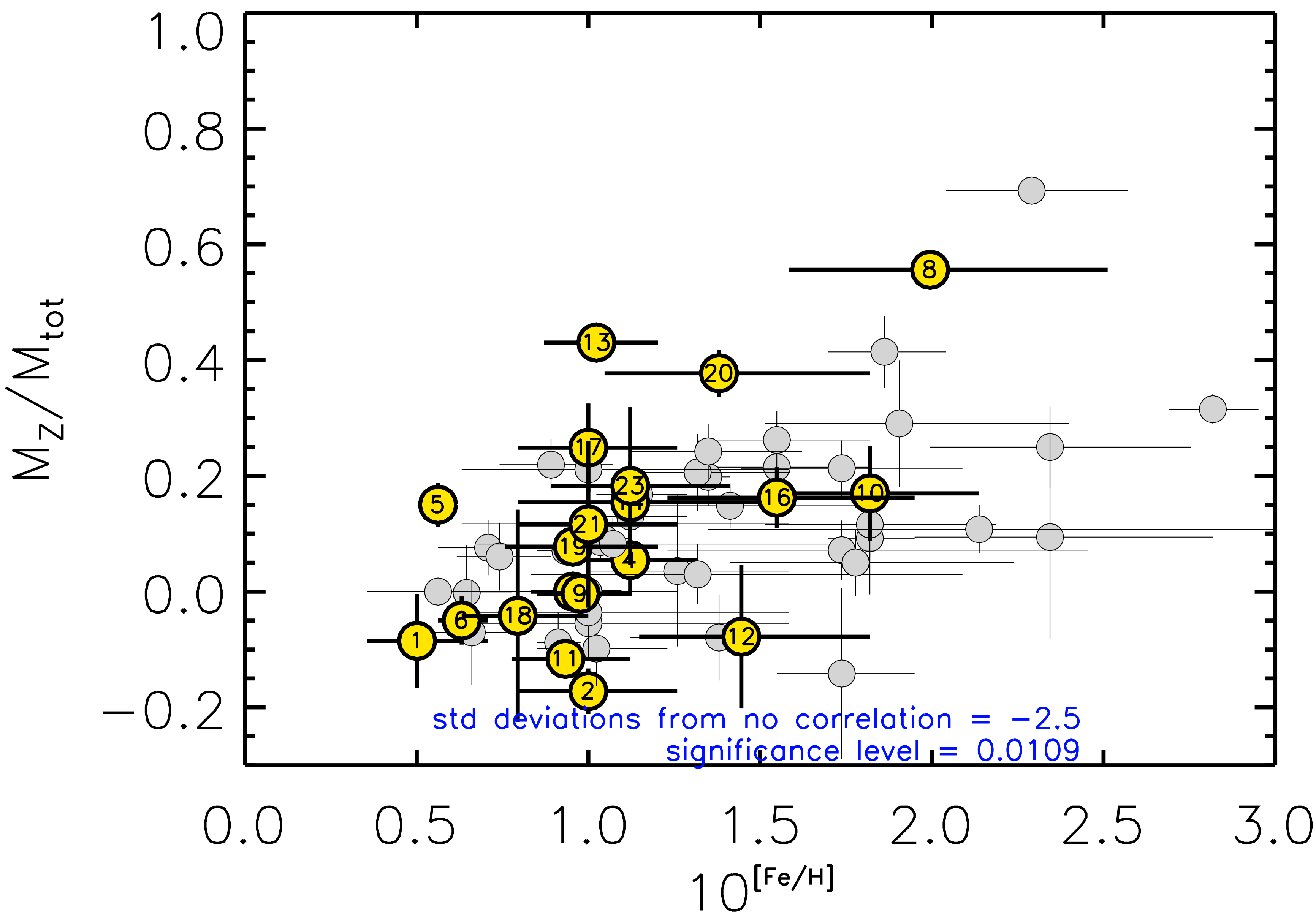


The radius anomaly problem

	magnitude	frequency	a dependence	[Fe/H] dependence	age dependence	Refs
interior/ atmosphere opacities	√	√	~	yes	weak	Guillot et al. (2006), Burrows et al. (2007), Guillot(2008)
Semi-convection	√	?	X	yes	weak	Chabrier & Baraffe (2007)
K.E. model	√	√	√	no	no	Guillot & Showman (2002), Burkert et al. (2005), Guillot et al. (2006, 2008)
Ohmic dissipation	√	√	√	yes	no/yes	Laine et al. (2009), Batygin & Stevenson (2010)
Thermal tides	√	√	√	no	no	Arras & Socrates (2009), Goodman (2009)
Obliquity tides	?	X	√	no	weak	Winn & Holman (2005), Levrard et al. (2006), Fabrycky et al. (2006)
Eccentricity tides	√	?	√	no	strong	Bodenheimer et al. (2001), Gu et al. (2003), Jackson et al. (2008a,b), Ibgui & Burrows (2009), Miller et al. (2009)

Compositions of giant planets



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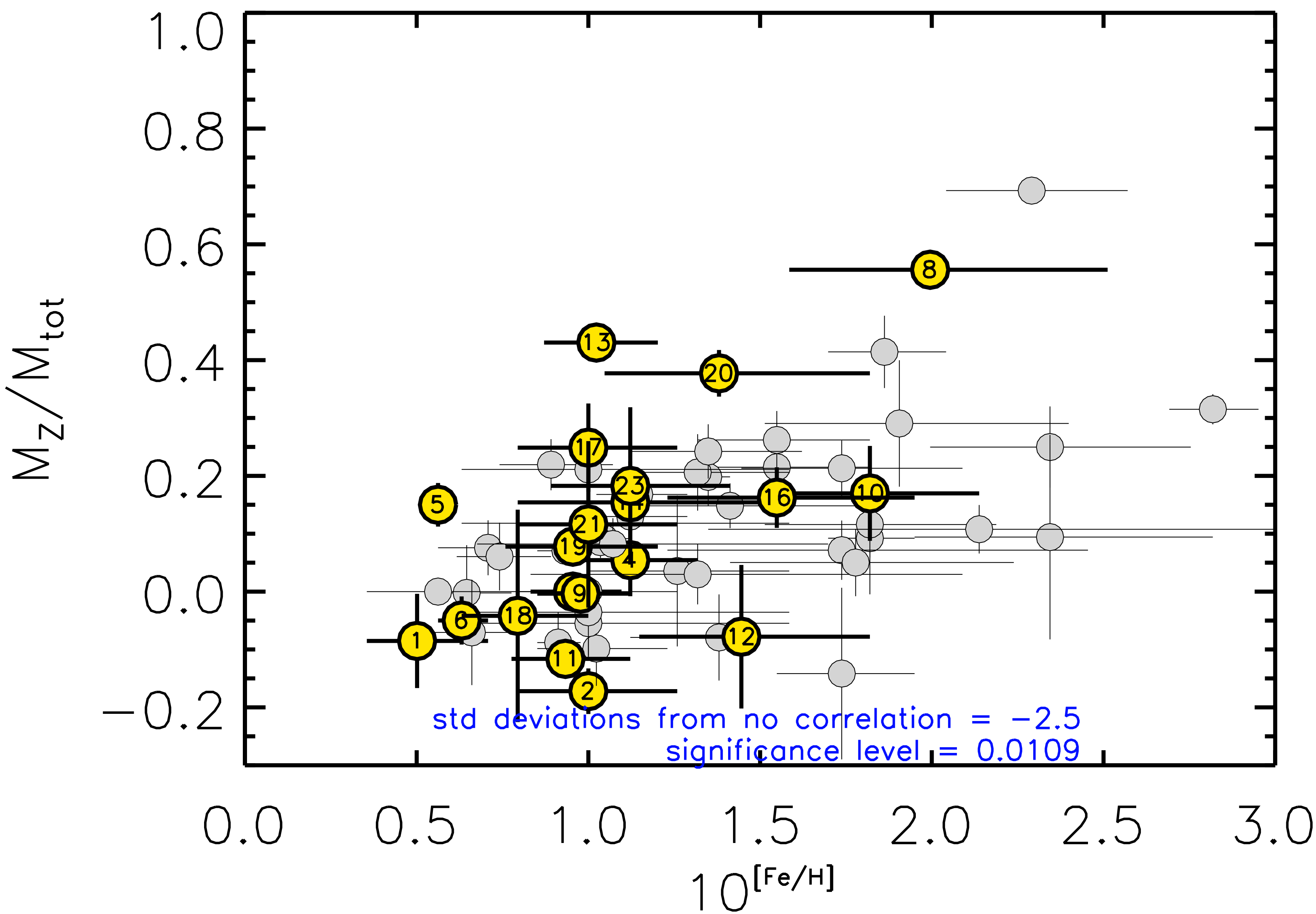
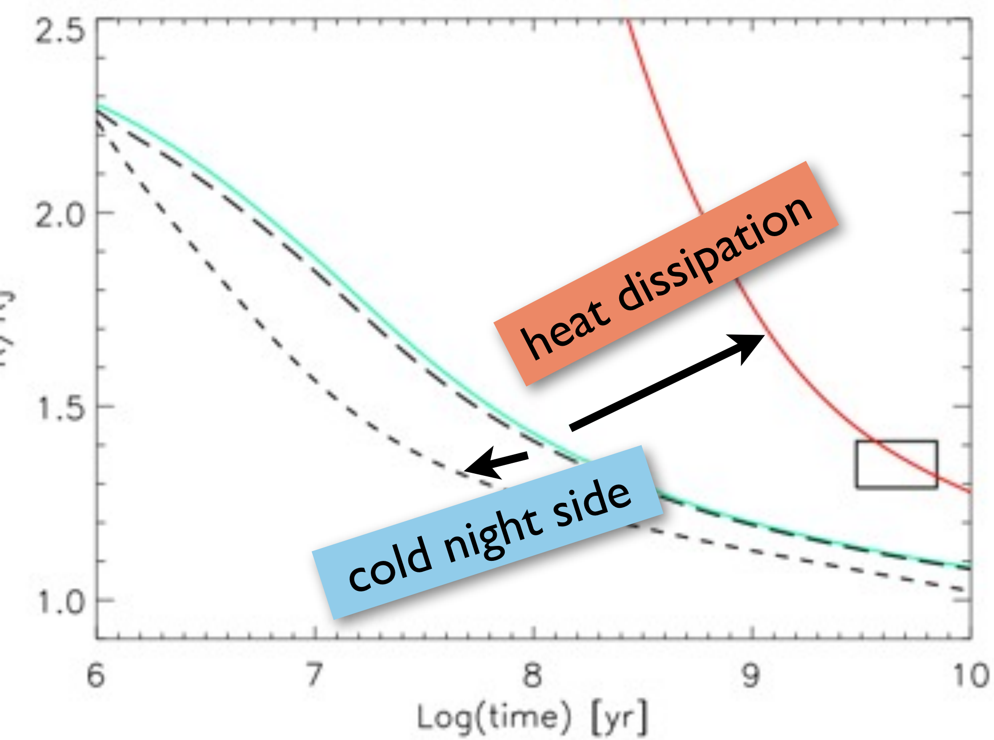
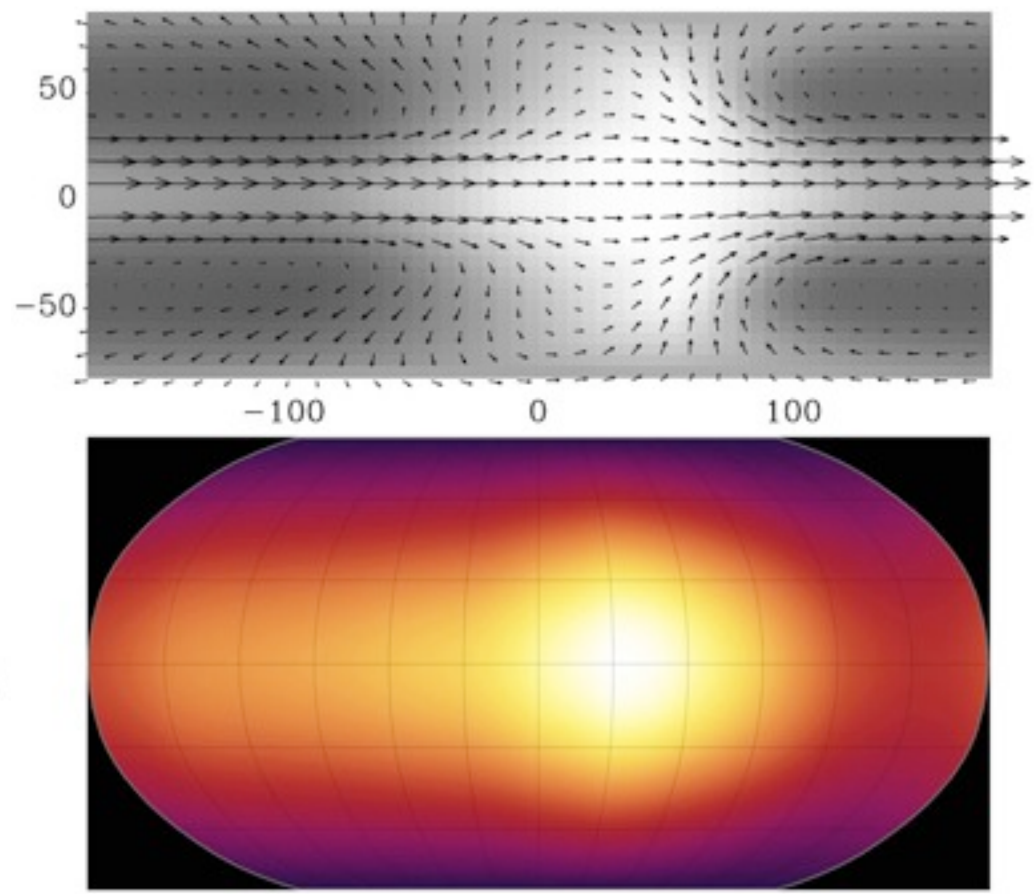


Guillot et al. (2006), Burrows et al. (2007), Guillot (2008), Miller & Fortney (2011), Moutou et al. (2013)

The importance of the atmosphere





Knutson et al. 2007

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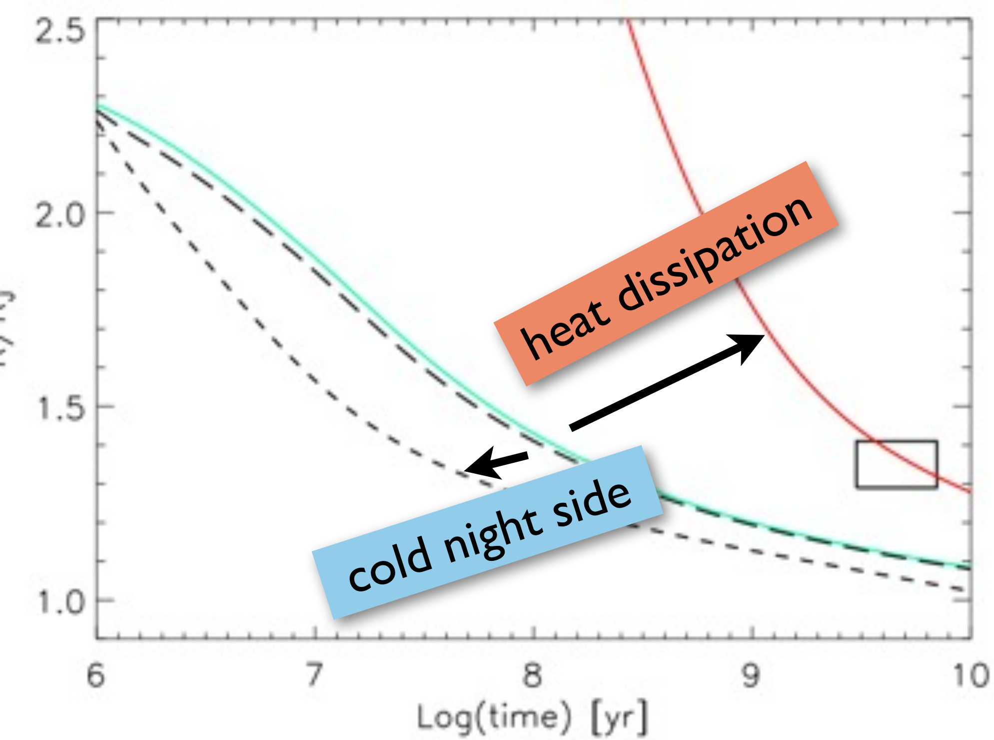
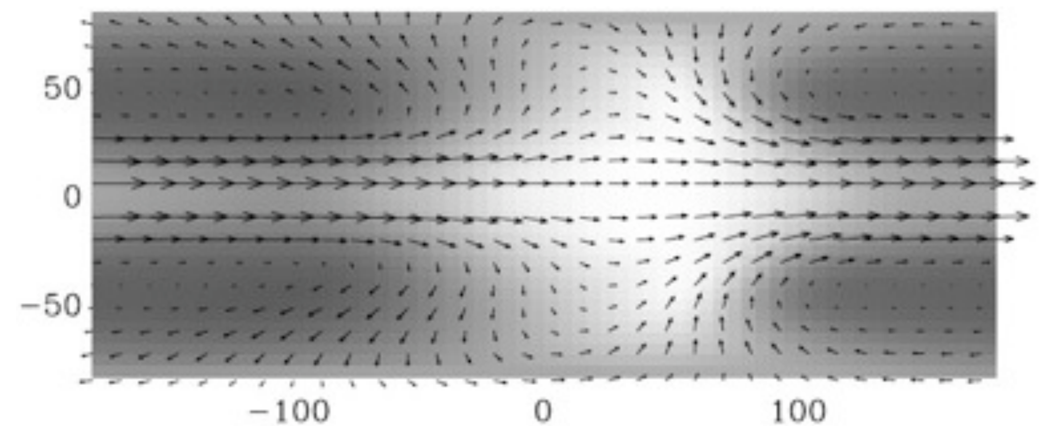
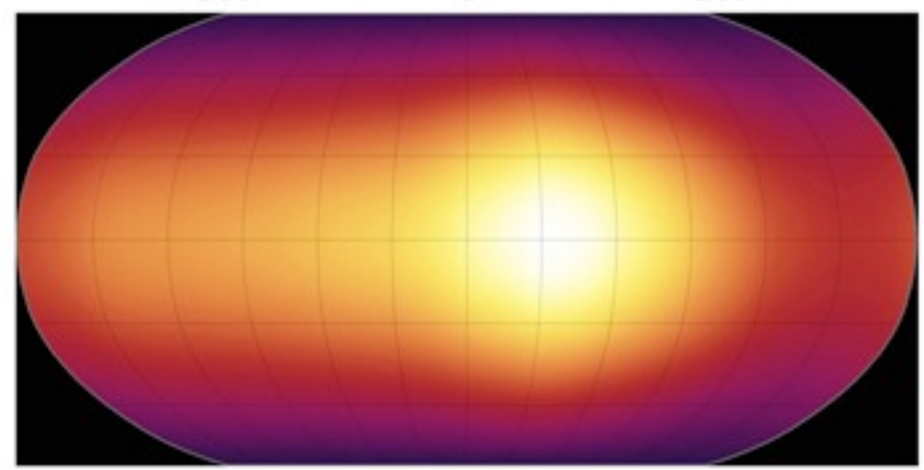


Guillot & Showman (2002);
see also Spiegel & Burrows (2013)

Showman & Guillot (2002)

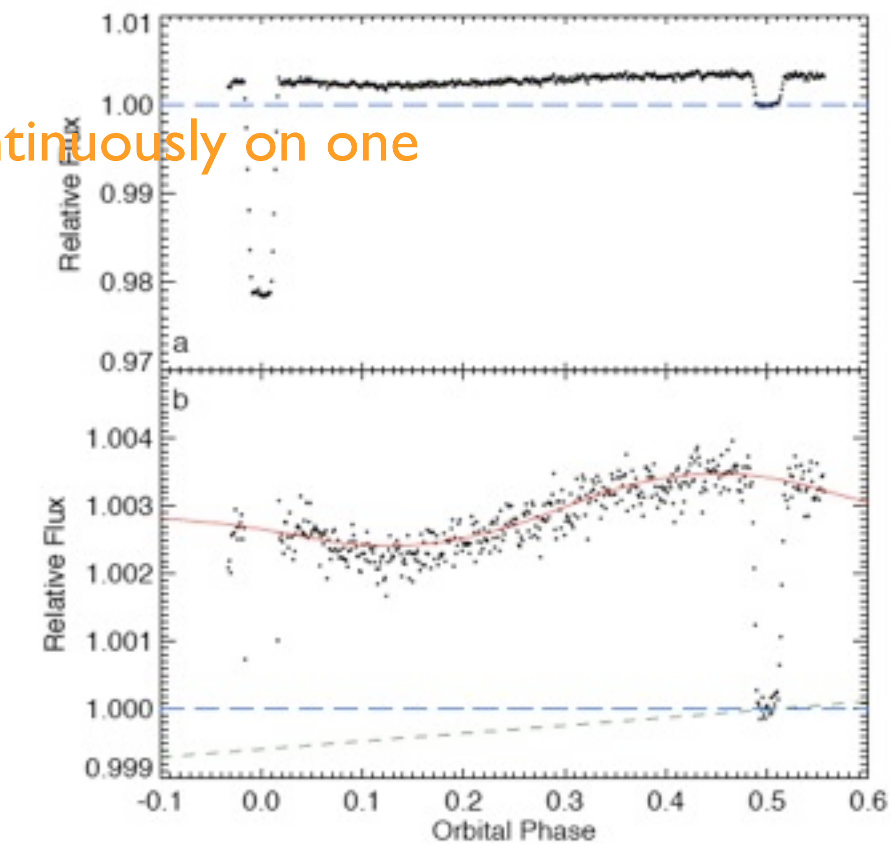




Knutson et al. 2007

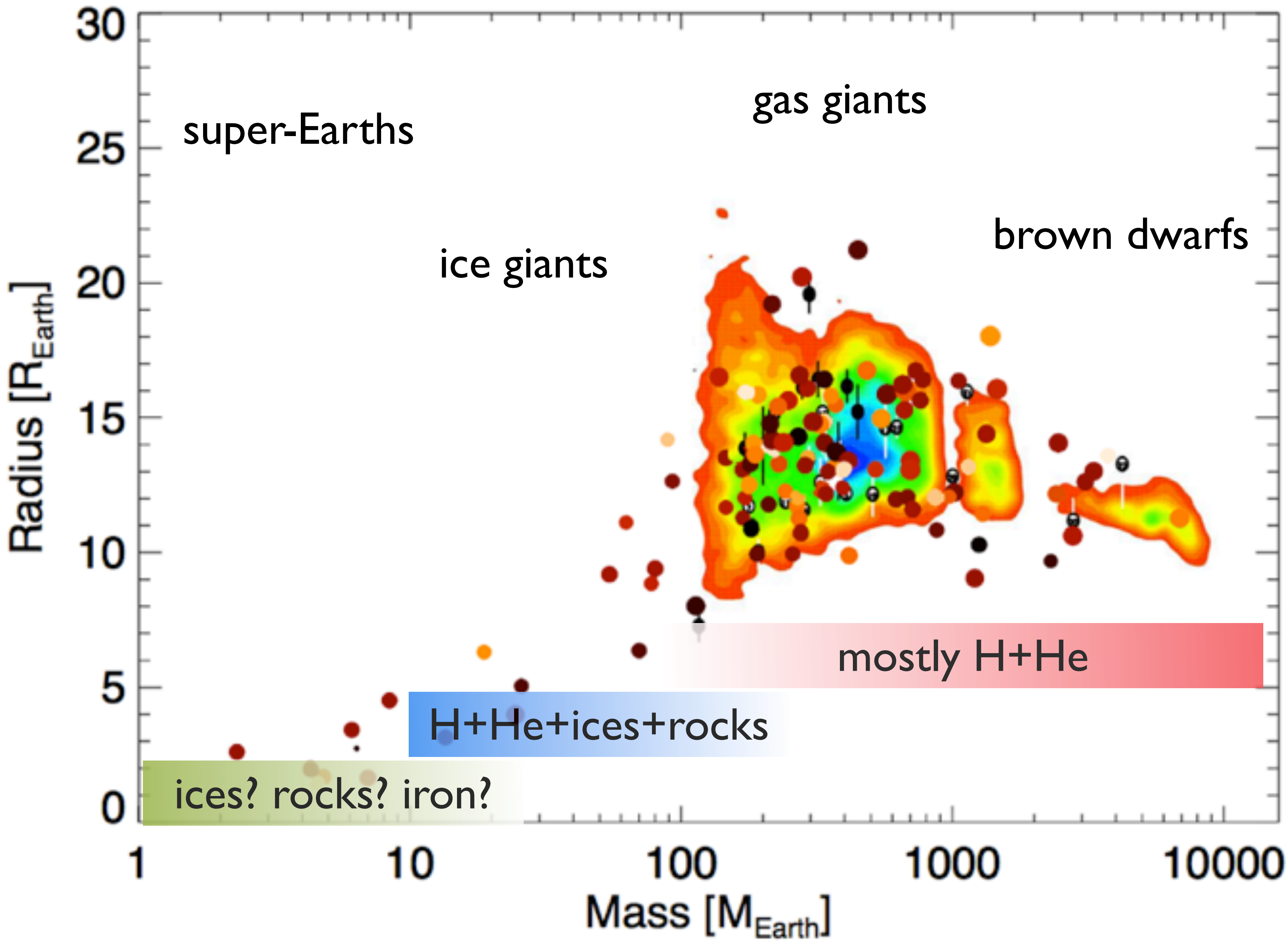
EChO's contribution

- The radius anomaly problem should be (mostly) solved before EChO's launch
- However, in order to obtain global compositions accurately, the main limitation will be the atmospheric structure
  - EChO should observe hot Jupiters continuously on one orbit in order to measure
    - albedo
    - day-night temperature contrast
    - atmospheric composition & structure
    - location in longitude of hottest point
    - ...

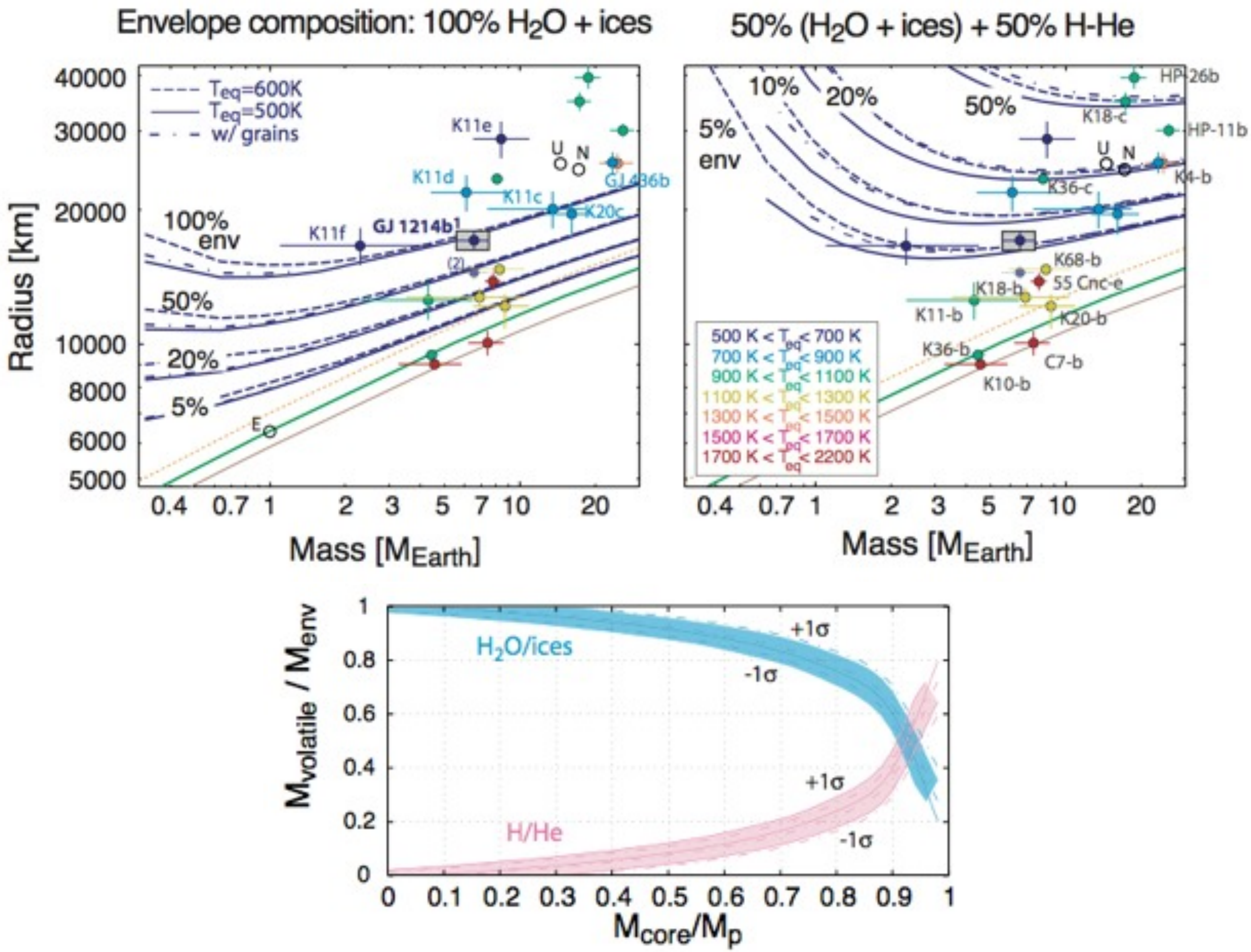


To smaller planets

Compositions & masses



The case of GJ 1214b



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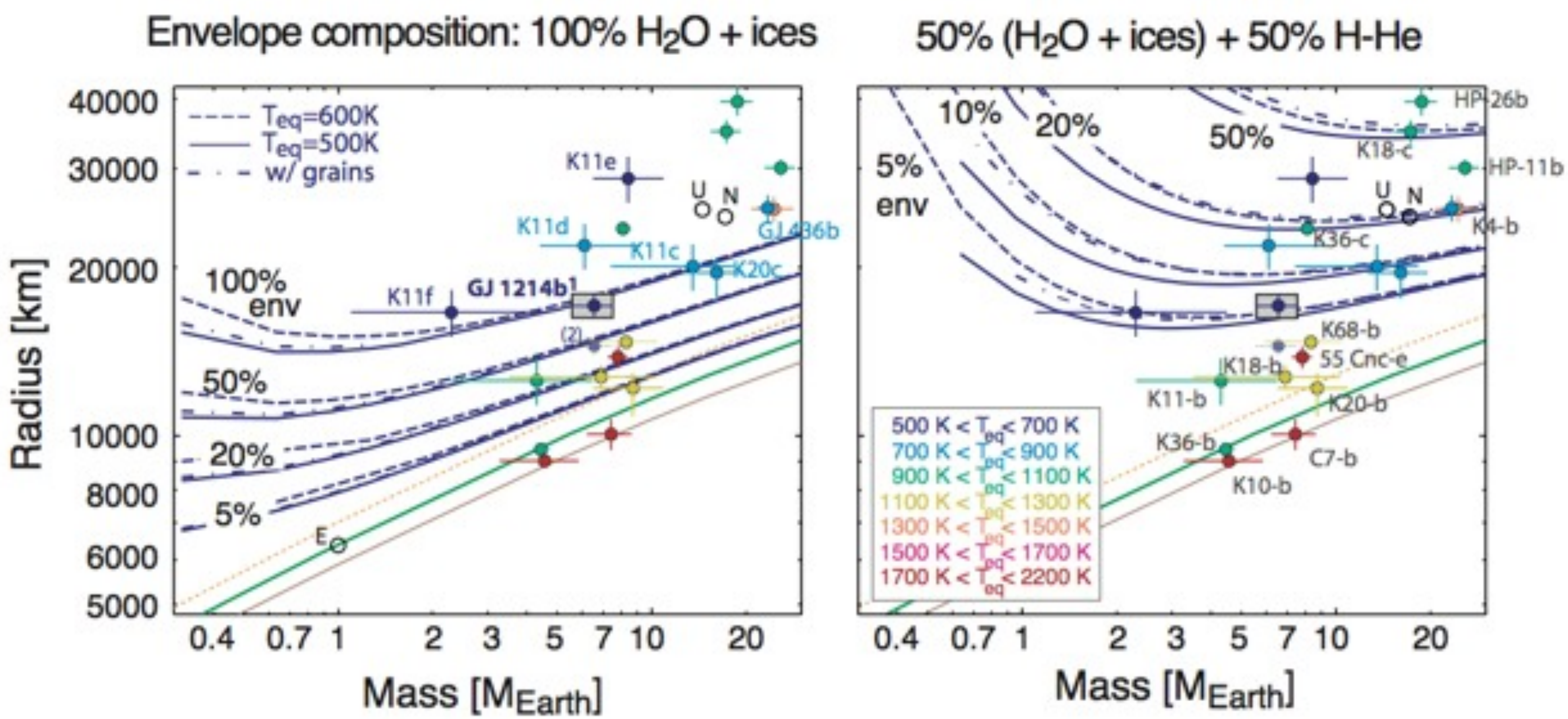
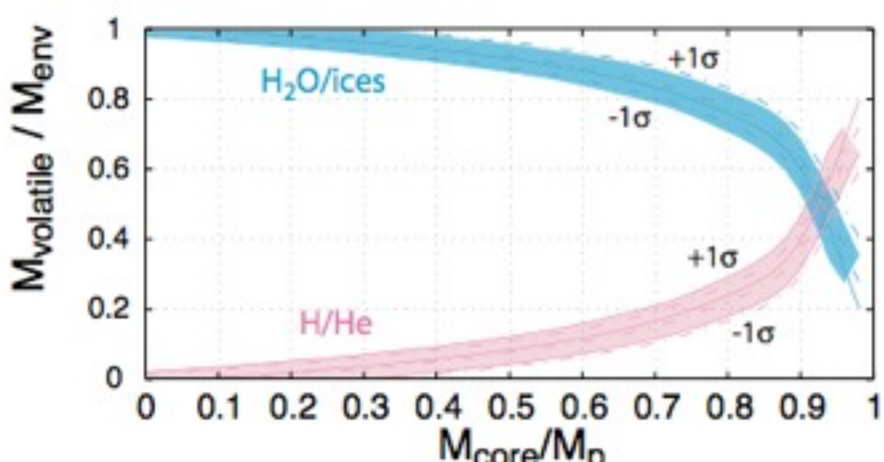
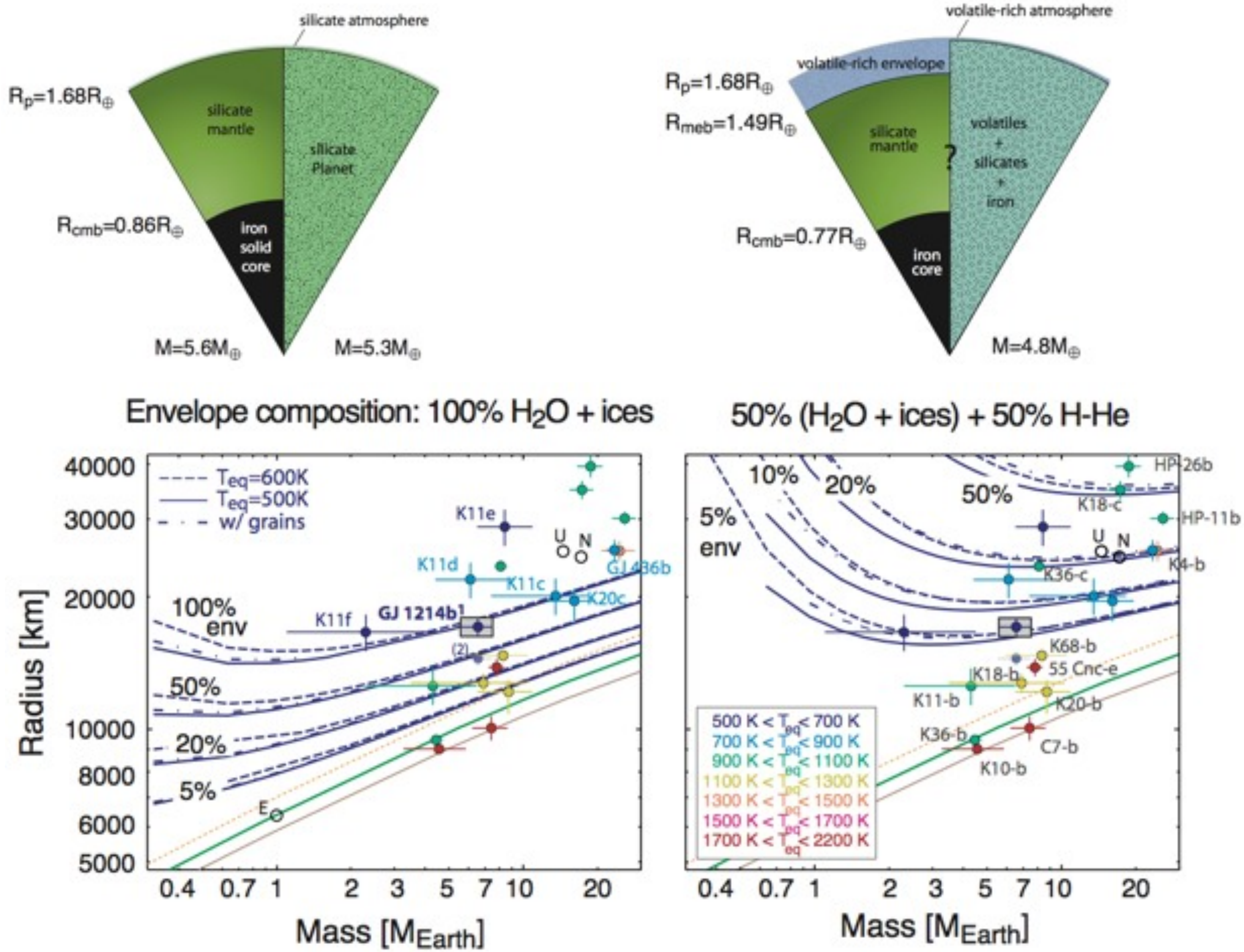




Valencia, Guillot, Parmentier & Freedman (2013)

Compositions of super-Earths



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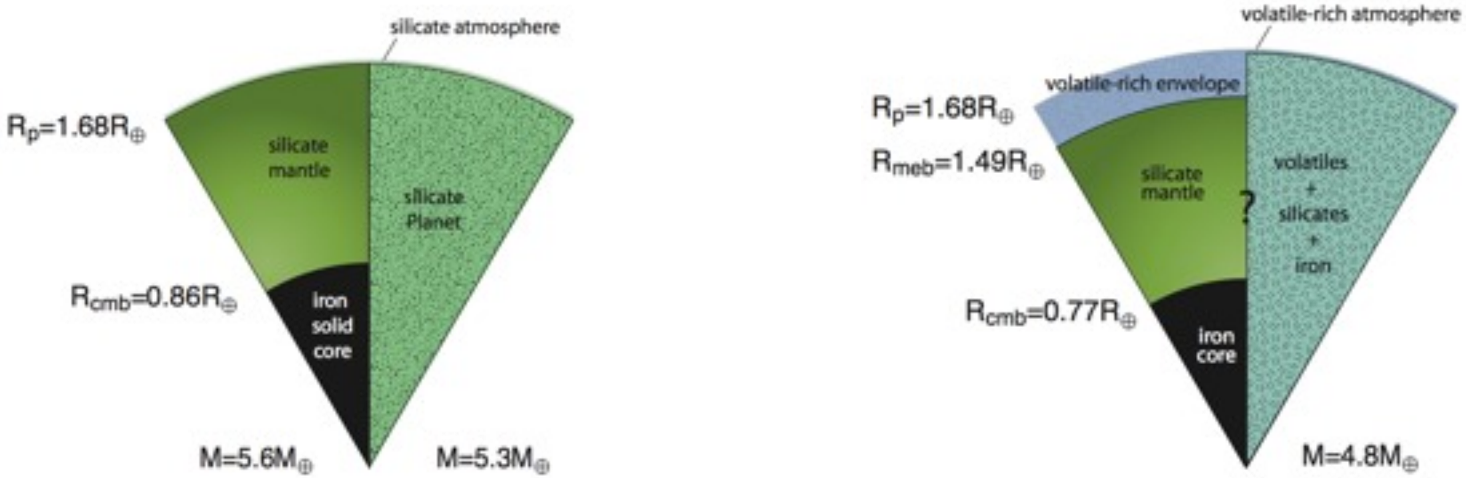
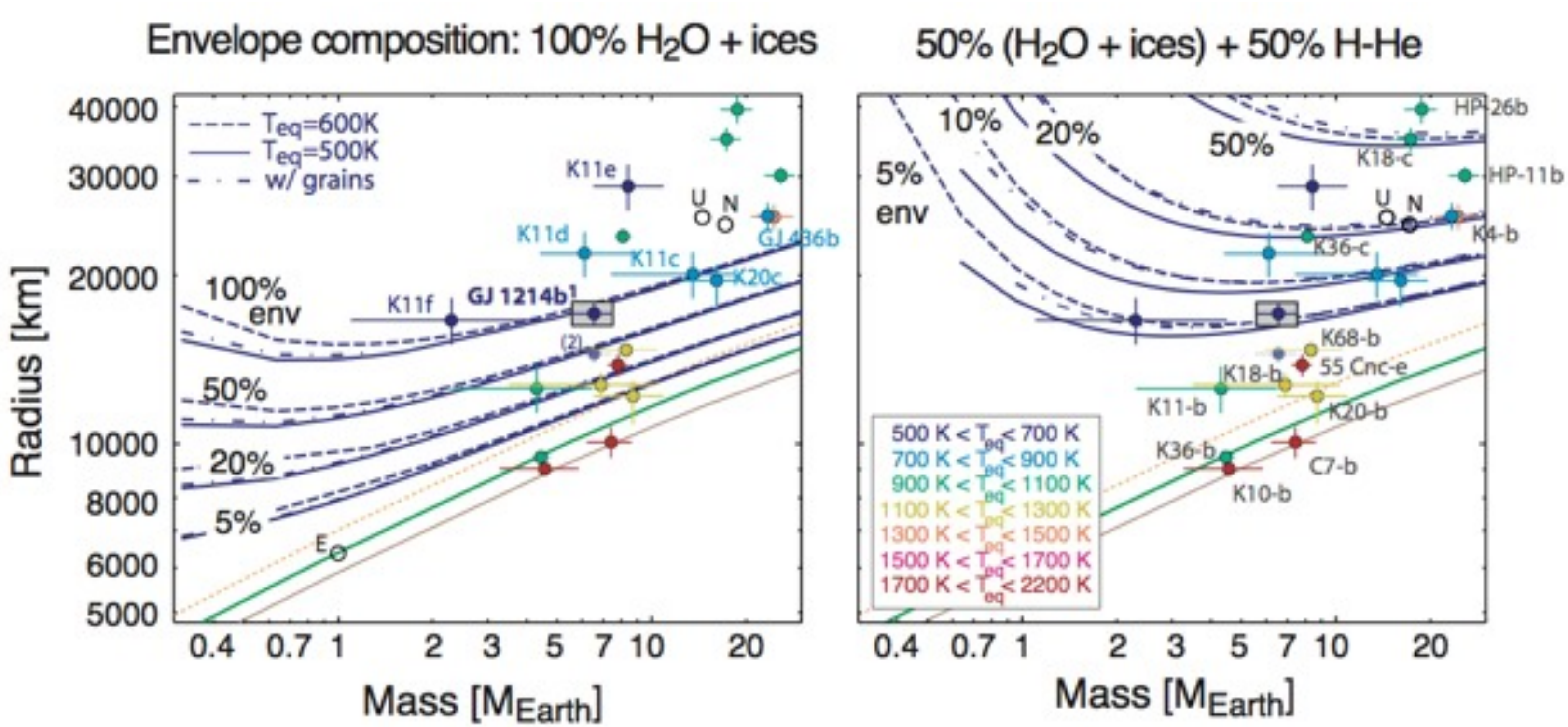


Valencia, Ikoma, Guillot & Nettelmann (2010)



Valencia, Guillot, Parmentier & Freedman (2013)

- The presence of hydrogen and water in close-in planets is a major piece in the planet formation puzzle
  - Indicative of migration?
  - Direct delivery of water to the inner planetary systems?
- Detailed determinations of the abundances of the parent stars will be highly desirable
  - See papers by Ramirez et al. (2009, 2010)

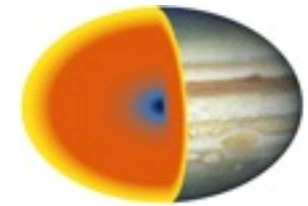
EChO's contribution

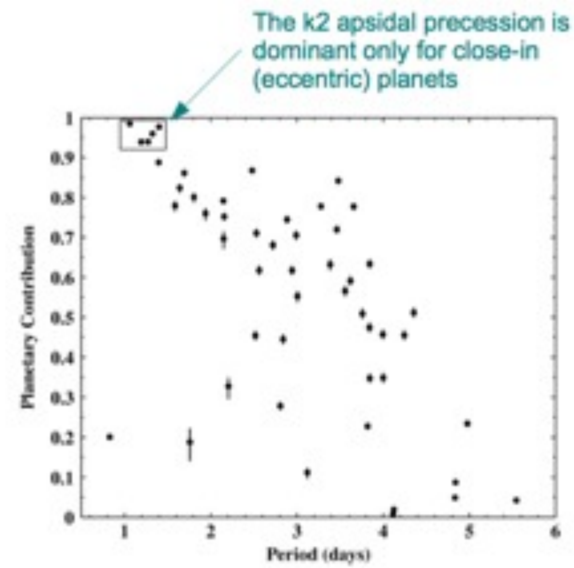
- Measuring spectra of small Neptune-like planets and super-Earths will be essential to determine the composition of the atmosphere
  - differentiate between hydrogen-dominated and water-vapor dominated atmospheres
  - determine the presence of clouds
    - Requires mostly measurements at primary or secondary eclipse
    - Of course, getting a full lightcurve for some of these targets would be a big plus to understand atmospheric dynamics.
- This will be essential to determine the global planet composition and its evolution history.

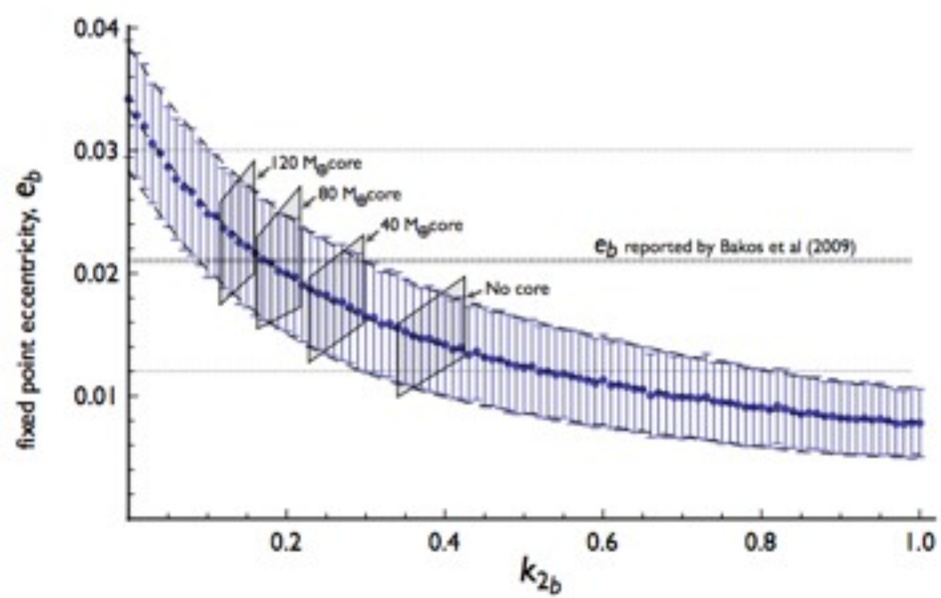
Probing the interior structure

Probing interior structures with k2

- The k2 love number may be thought as a measure of the level of the central condensation. Its measurement can inform us on the presence of a central core.
- Seager & Hui (2002) proposed to determine it from the planet shape during transit ingress & egress. This is probably too difficult (Barnes & Fortney 2003). However it can be measured from the planet's apsidal precession (Ragozzine & Wolf 2009) or from its fixed-point eccentricity (Mardling 2008, Batygin et al. 2009)
- This requires the discovery of short period, (slightly) eccentric planets, the possibility to determine accurately primary & secondary transits and a long time-base, or discovery of a slightly eccentric close-in planet perturbed by an eccentric massive companion.







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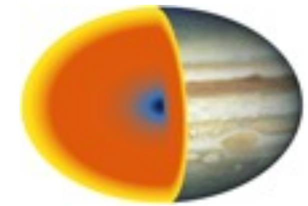
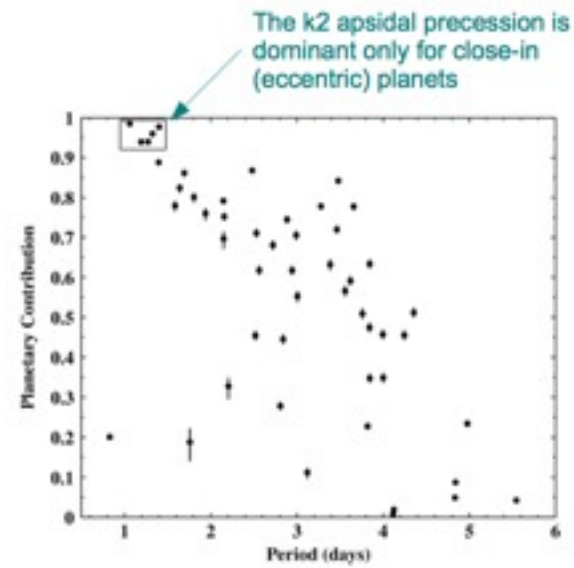
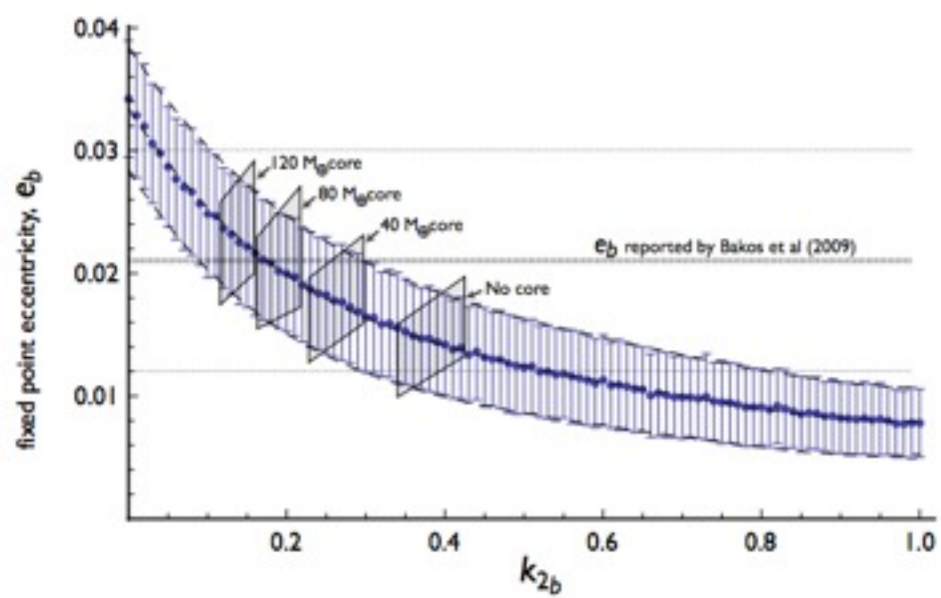




Ragozzine & Wolf (2009)



Batygin et al. (2009)

EChO's contribution

- The determination of k2 would require:
  - discovering (before EChO) a transiting planet with a massive eccentric companion
  - measure the phase of its secondary eclipse with EChO
  - possibly determine precession from an evolution of this phase (not needed in the case of the fixed-point eccentricity).
- This is probably a rare event.

conclusion

Conclusion: Science with EChO

- Interior structure & evolution
  - Fully characterize atmospheres -key to constrain composition-
  - Understand the transition between hydrogen-rich, water-rich and rocky planets
    - 5-50 M_E planets are key targets
    - Evaporation is an important factor for close-in planets
  - Constrain interior structure from k_2
    - Only for rare case with a close-in nearly circular planet perturbed by a distant, eccentric companion
- Atmospheric composition
  - Secondary eclipses
    - Atmospheric temperature
    - Constrain the eccentricity
  - Full light-curve
    - Possibility to compare visible vs. infrared lightcurves
  - Chemical composition
- Formation
  - Why do close-in planets appear to contain hydrogen/water?