Water condensation during formation: the impact on the critical core mass

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Abstract

During the formation of a planet, once the core reaches a lunar mass, it can start to bind some gas from the protoplanetary disk. The planetesimals that are accreted from this stage on, undergo thermal ablation and physical disruption when crossing the atmosphere. Thus, the primordial H-He atmosphere gets enriched in volatiles and silicates from the planetesimals.

This change of composition affects the thermal structure of the atmosphere. In particular, if the planet is located in a region where the temperature and pressure are suited for water condensation to take place, the release of latent heat modifies drastically the adiabatic temperature gradient. We show how this effect reduces the critical core mass and the implications this has for the type of planets that can be formed.

Internal structure code:

Solves the internal structure equations assuming a given luminosity:

$$\frac{\partial P}{\partial r} = -\rho \frac{Gm}{r^2}$$

$$\frac{\partial m}{\partial r} = 4\pi r^2 \rho$$

$$\frac{\partial T}{\partial r} = \frac{T}{P}\frac{\partial P}{\partial r}\nabla$$

$$\nabla_{ad} = \left(\frac{\partial \ln T}{\partial \ln P}\right)_s$$

$$\nabla_{rad} = \frac{3\kappa L P}{64\pi\sigma G m T^4}$$

Schwarzschild criterion: convection if $\nabla_{rad} > \nabla_{ad}$

EOS:

software CEA (Chemical Equilibrium Applications) —>

- Solves chemical equilibrium for arbitrary gaseous mixture
- Ideal gas, but considers dissociation and ionization of compounds.
- Includes condensation of some species, like H_2O in solid and liquid phase.

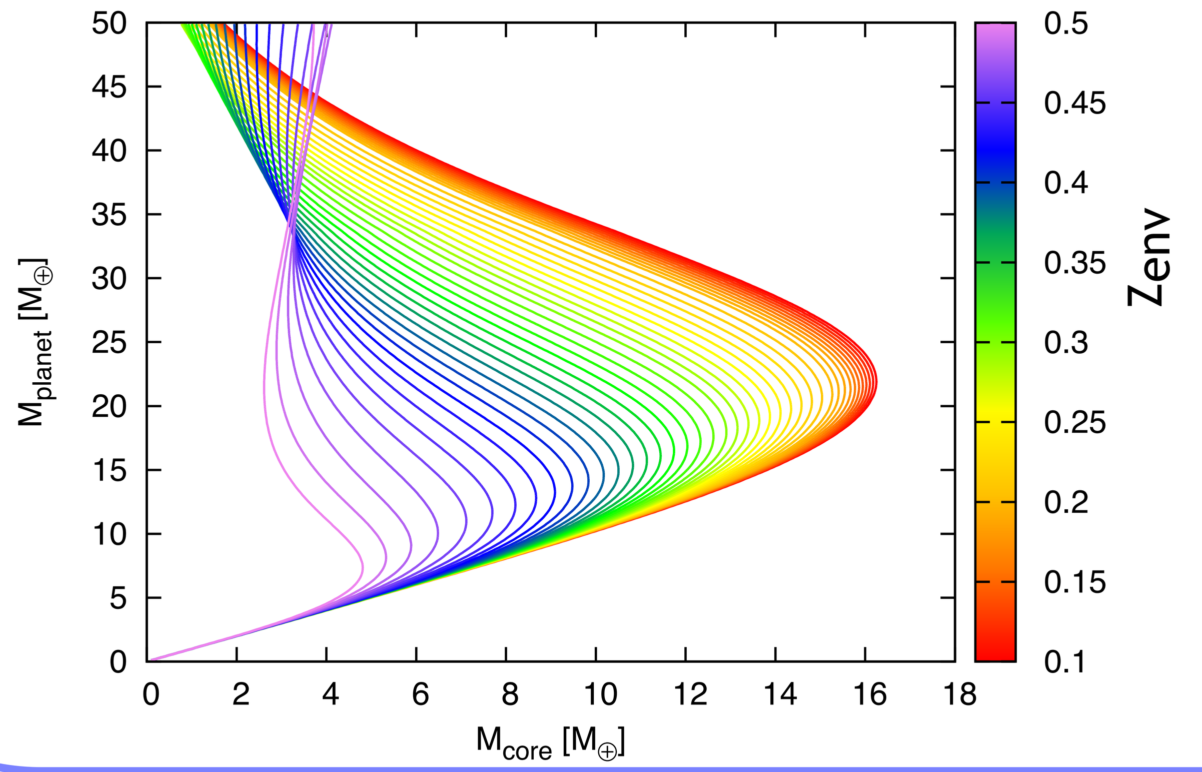
Opacity:

- GAS: Ferguson opacities (Alexander & Ferguson 1994) extended for all ranges of metallicities (solar relative abundances)
- DUST: Semenov et al. (2003)

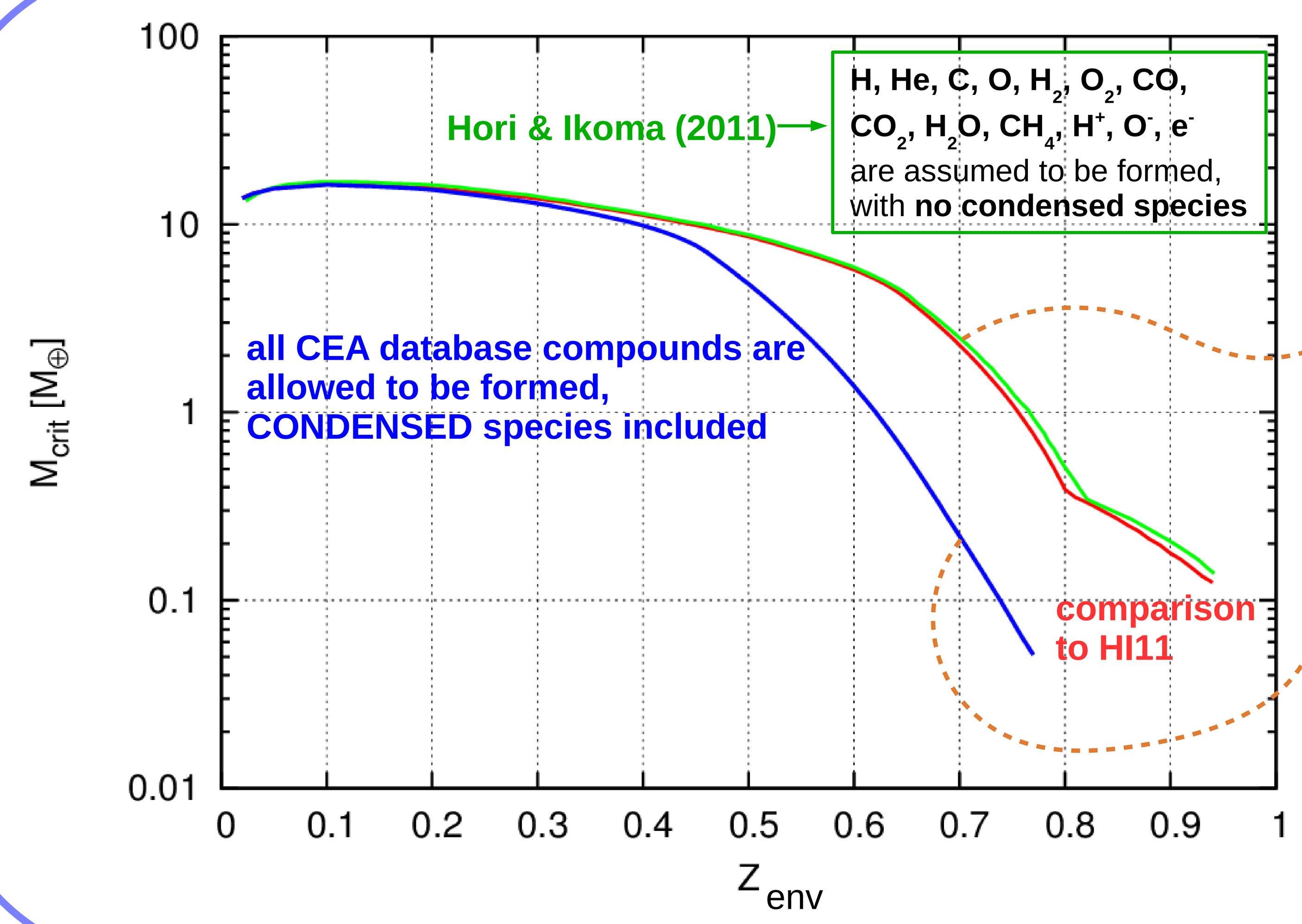
By solving them we compute the **critical core mass (Mcrit)** → maximum mass of the core able to sustain an envelope in hydrostatic equilibrium

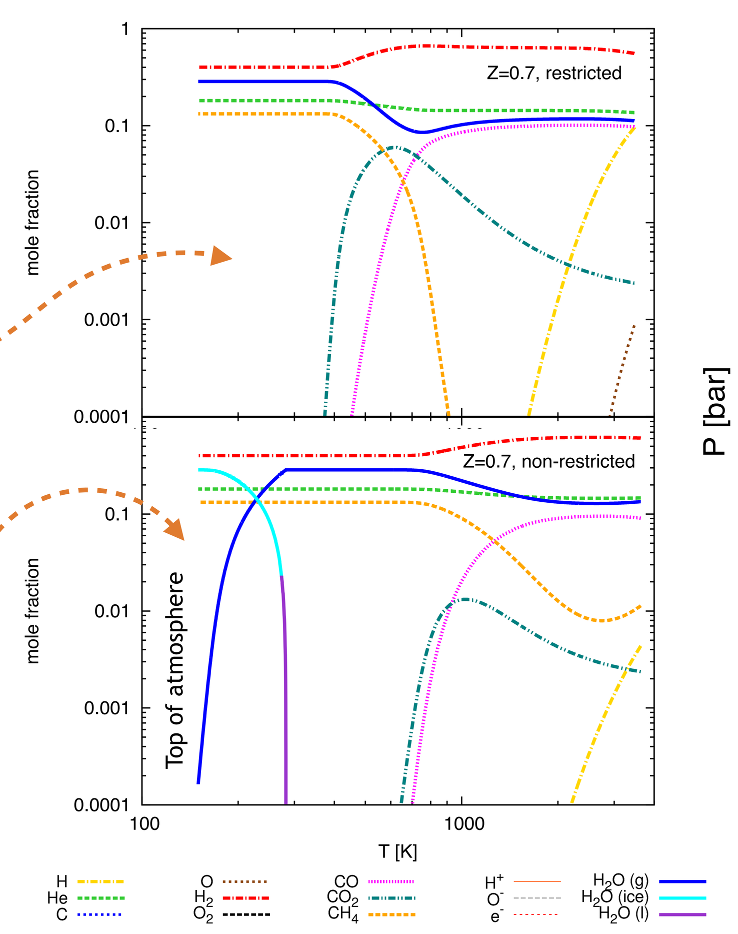
for different **envelope metallicities** → $Z_{env} = \frac{M_{Z,env}}{M_{env}}$

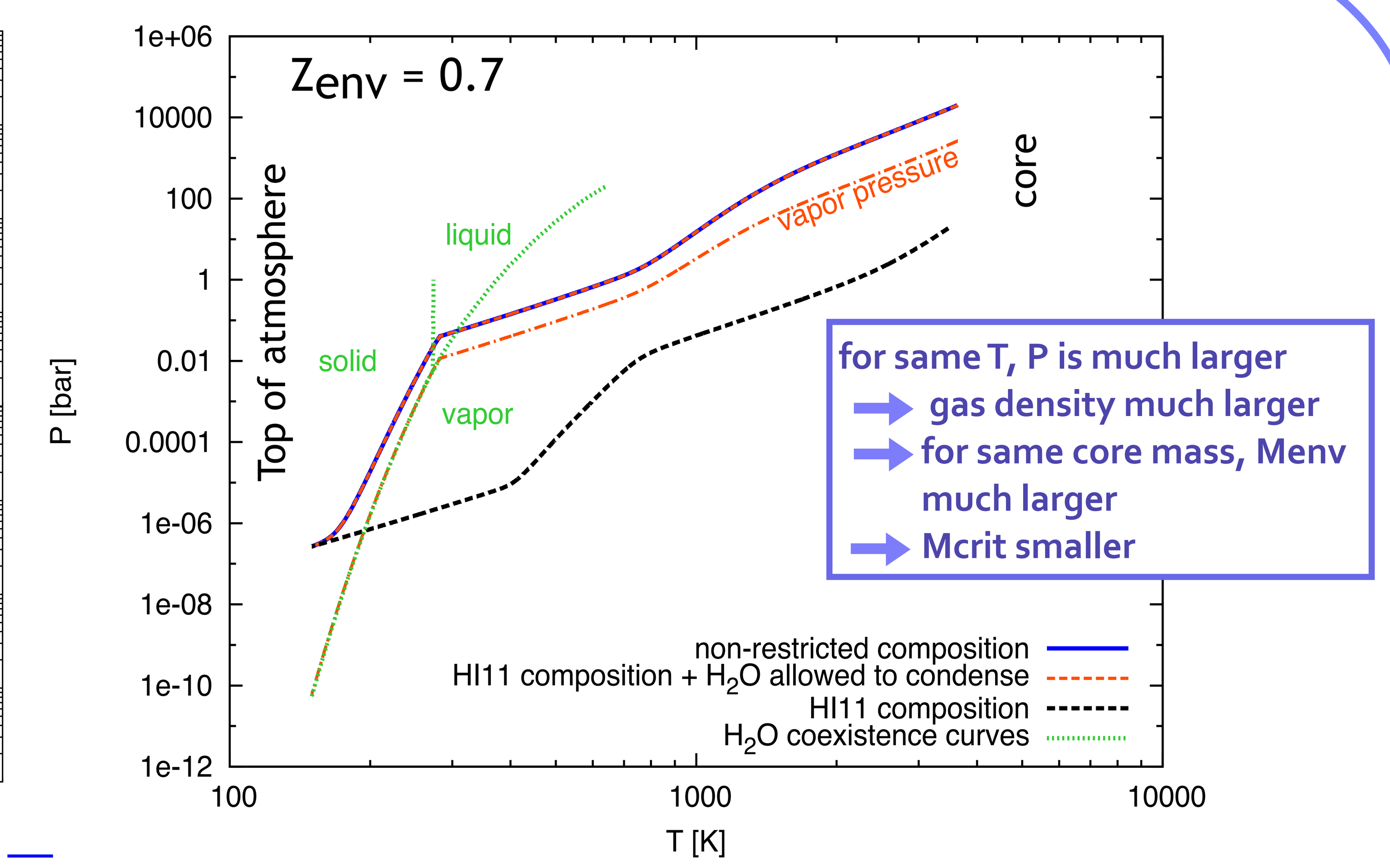
$M_{Z,env}$: mass of elements heavier than H and He in the envelope



- Boundary conditions for
- a = 5.2 AU
- L = 10^{27} erg/s
- core density = 3.2 g/cm^3

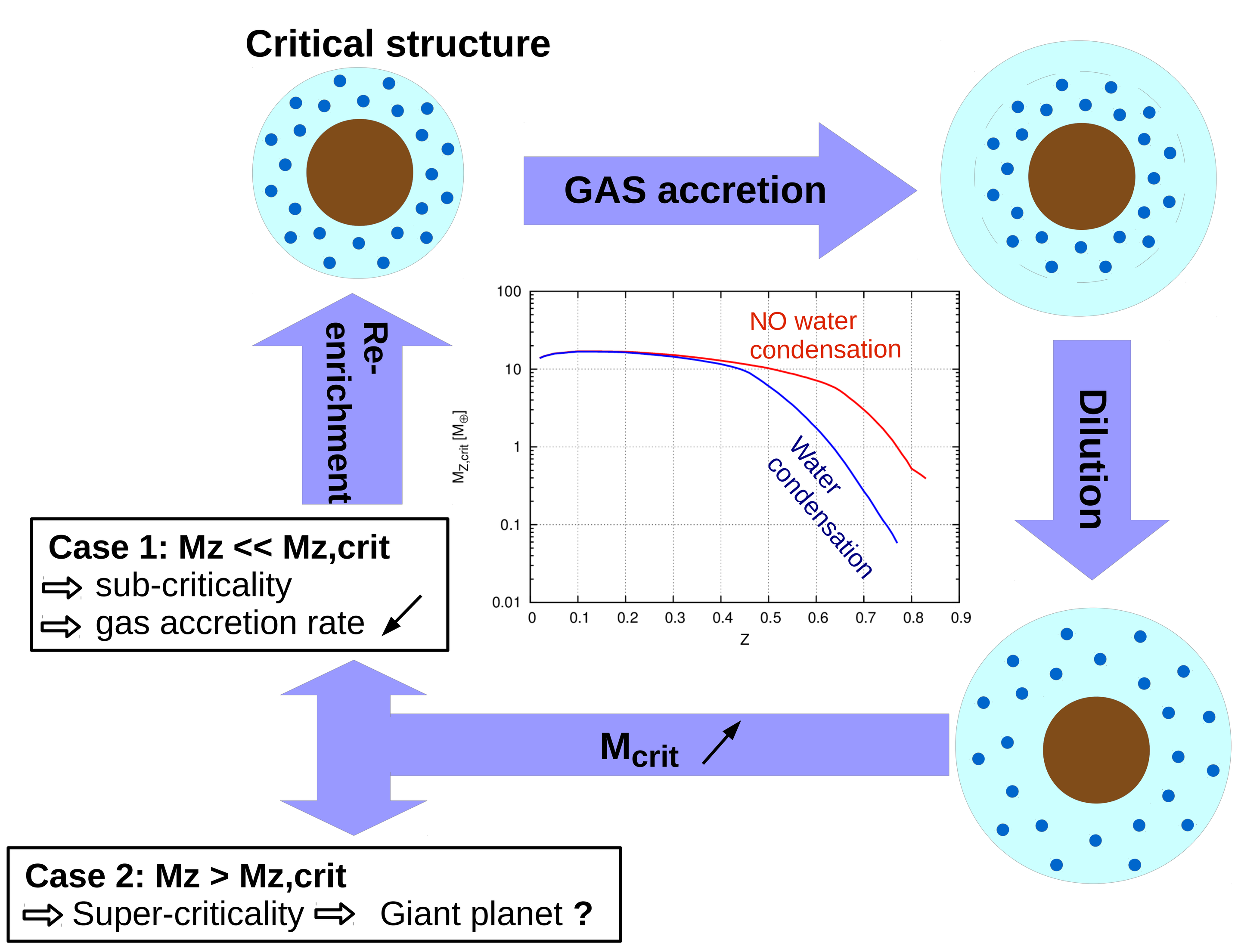






(Venturini et al. 2015, A&A)

Implications for formation?



Conclusions:

- The critical core mass for volatile-rich envelopes was computed, corroborating the reduced values found by HI11.
- When boundary conditions are suitable for H2O condensation to take place, the change from dry to moist adiabat in the P-T profile has a dramatic influence in reducing Mcrit.
- Small critical core masses could lead to the formation of small enriched objects, but this possibility should be tested with quasi-static, self-consistent formation models.