

**Composition and fate of short-period super-Earths: The case of CoRoT-7b.** D. Valencia<sup>1\*</sup>, M. Ikoma<sup>1,2</sup>, T. Guillot<sup>1</sup>, and N. Nettelmann<sup>3</sup>, <sup>1</sup>Observatoire de la Côte d'Azur, BP 4229, 06300 Nice, France, \*[valencia@oca.eu](mailto:valencia@oca.eu), <sup>2</sup>Tokyo Institute of Technology, Ookayama, Tokyo, Japan, <sup>3</sup>Universitat Rostock, D-1851, Rostock, Germany

**Introduction:** The first transiting super-Earth was detected last year: CoRoT-7b. This is the smallest planet with a measured radius  $R = 1.68 \pm 0.09 R_E$  [1] and mass  $M = 4.8 \pm 0.8 M_E$  [2]. It is also the most irradiated planet with a period of only 0.85 days around a sunlike star (semi-major axis of 0.017 AU). Two important questions about CoRoT-7b arise naturally: What is its composition and possible origin? With knowledge of hot Jupiters, mass loss estimates, and internal structure and evolution models, we investigate its composition and origin. The framework we present is applicable to any transiting short-period super-Earth.

**Limits to the mass loss:** Close in-planets are vulnerable to evaporation because of intense irradiation from their star. Tian et al 2008 [3] have simulated the escape of Earth's atmosphere and demonstrate that for EUV irradiation fluxes above  $\sim 10$  times the solar value, the atmosphere is in the hydrodynamic regime. Given the high irradiation, this is the appropriate regime for CoRoT-7b. We calculate an escape rate for CoRoT-7b of  $\sim 10^{11}$  g/s, similar to that for HD 209458b and most importantly, rather independent of composition. Furthermore, we predict that mass loss will occur even if the planet is rocky. This is because the silicate atmosphere that would form is thick enough to capture UV photons that power the escape (nanobars of atmosphere are enough).

**Structure Models:** To calculate the possible structure and evolution of rocky planets up to ice and gas giants, we combine two models. For the solid interior with use that of Valencia et al (2008) [4], and for the vapour/gaseous envelope we use that of Guillot & Morel (1995) [5]. The models are tied at the interface by using the pressure of the envelope as a boundary condition to the solid interior.

### Results Structure:

**Rocky CoRoT-7b.** We calculate the M-R relations for five different compositions: a super-Moon (with little/no iron, or Mg-silicate mantle planet), an Earth-like composition (differentiated planet with 33% iron core, and 67% mantle by mass and 10% iron molar content), an undifferentiated planet with the same Fe/Si ratio as Earth (76% iron molar content), a super-Mercury planet and a pure iron planet. The first and latter are highly unlikely compositions because Mg, Si and Fe have similar condensation temperatures. Any M-R combination above the super-Moon relation re-

quires the presence of volatiles. We infer that CoRoT-7b if rocky is depleted in iron with respect to the Earth. (Fig 1)

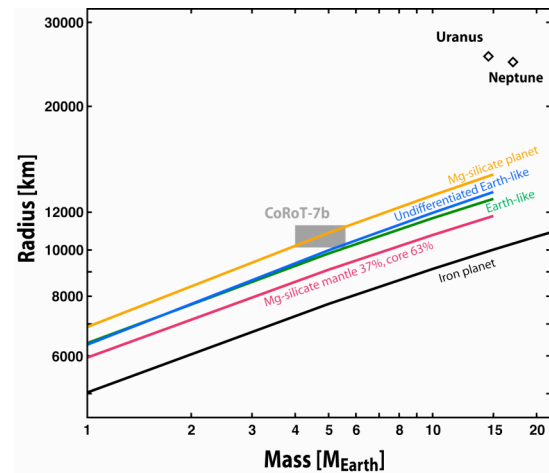


Fig.1 Mass-radius relations for five different compositions: pure iron, super-Mercury, Earth-like, undifferentiated with same Fe/Si to Earth's, super-Moon (Mg-silicate planet). Compositions with progressive amounts of Fe lie below the Mg-silicate planet relation. CoRoT-7b is depleted in iron relative to the Earth.

**Vapor CoRoT-7b.** Fig. 2 shows the mass-radius relations for different amounts of  $H_2O$  (and other "ices") in vapor form above an Earth-like composition, after 2Ga of evolution. The best fit scenario for the M and R is 3% vapor, with an upper limit of  $\sim 10\%$  for a one-sigma level uncertainty.

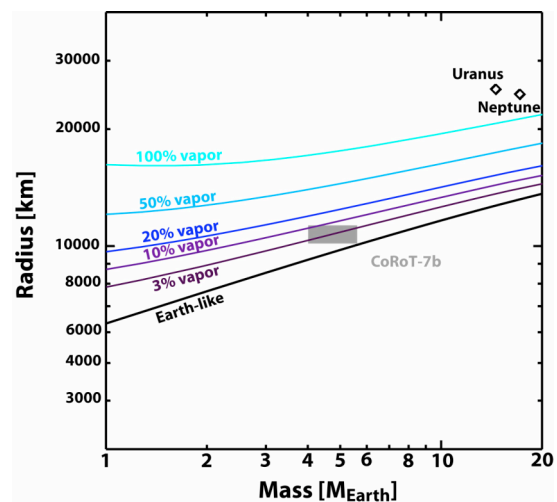


Fig.2 Mass-radius relations for a planet made of iron, rocks and progressive amounts of vapor.  $H_2O$  and other "ices" in vapor form are considered above an Earth-like rocky nucleus. Models with vapor have been evolved for 1 Ga and radii correspond to the 10 bar level.

*Limits to Hydrogen and Helium.* We find that the maximum amount of H-He is 0.01% by mass. This would evaporate in only 1 My, and thus we estimate that CoRoT-7b cannot possess a H-He atmosphere.

**Results Origin:** The combined mass and thermal evolution including mass loss is calculated by noting that for each planetary mass and central specific entropy corresponds a given planetary radius, and therefore a given mass loss, and that central entropy should be conserved during mass loss. Because evaporation is highly dependent on the planetary density, the choice of initial conditions affects the outcome significantly.

*Gaseous or Vapor-like in origin.* We highlight possible origins and considered either that the planet formed in situ or migrated after a first phase of contraction. Vapor planets tend to be relatively compact and suffer significant but limited mass loss, while H-He planets tend to be very tenuous and loosely bound to the rocky nucleus. The inverse dependence of mass loss on mean planetary density produces rapid evaporation during the early stages when the planets have a considerable envelope and thus are light.

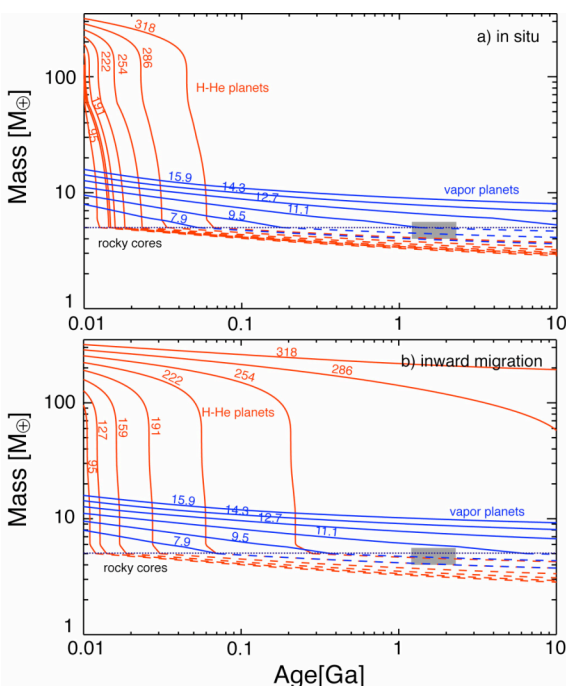


Fig.3 Mass evolution of hypothetical CoRoT-7b precursors as a function of time. Red: gas-giants, Blue: vapor planets. Top panel: planets that formed in situ. Lower panel: Planets that migrated to 0.017 AU before an initial compaction phase of 10 My. Labels indicate initial masses in earth-masses. All cases assume an inner rocky Earth-like nucleus of  $5 M_E$ .

Gas giants that formed in situ filling their Roche-lobe, suffer faster evaporation than contraction and

always lead to the complete loss of the envelope. Our different choices show that CoRoT-7b's origin could be either gaseous or vapor-like. (Fig 3)

*Rocky origin.* It could have also formed as a rocky planet. For it to be now an Earth-like planet (densest rocky scenario that fits the data), or a super-Moon planet (lightest), the precursor should have formed with a larger mantle which eroded. Hence, if it formed rocky, CoRoT-7b must have formed with a lower bulk elemental Fe/Si ratio than Earth's.

We note that so far we have not considered undifferentiated vapor/gas planets due to lack of relevant equations of state and opacities. A mixed scenario would require high temperatures to be maintained. Thus, our limits on the amount of volatiles could be larger if they are hidden within the solid structure.

**Conclusions:** The inferred M and R of CoRoT-7b are consistent with a rocky planet that would be depleted in iron relative to Earth. However, a one sigma increase in mass ( $5.6 M_E$ ) and one sigma decrease in size ( $1.59 R_E$ ) would make the planet compatible with an Earth-like composition (33% iron, 67% silicates). Alternatively, it is possible that CoRoT-7b contains a significant amount of volatiles. An equally good fit to the data is found for a mass of the vapor envelope above a solid Earth-like nucleus equal to 3% (and up to 10% at most). We can rule out the presence of H-He envelope. However, the CoRoT-7b's origin cannot be inferred from the present observations. A significant mass loss  $\sim 10^{11}$  g/s, independent of composition is to be expected. With high enough sensitivity, spectroscopic transit observations of CoRoT-7 should constrain the composition of the evaporating flow and thus allow distinguishing between a rocky and a volatile-rich vapor planet.

**References:** [1] Leger et al. 2009. A&A, 506: 287; [2] Didier et al. 2009. A&A, 506: 303; [3] Tian et al. 2008. JGR, 113, 5008; [4] Valencia et al. 2006. Icarus, 181: 545, [5] Guillot T and Morel P. 1995 A&A, 109, 109.