CONSTRANTS ON H₂O AND H₂ PROPORTIONS IN THE VOLATILE ENVELOPES OF YOUNG, H₂-PRODUCING, SMALL-RADIUS EXOPLANETS

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Small-radius exoplanets with low densities discovered by Kepler could have either accreted volatile envelopes from the nebular disk, or produced them via water-rock interaction.

Volatiles in Kepler extrasolar planets

Kepler and the K2 have discovered nearly 2000 confirmed extrasolar planets (March 2016) through Transit-Timing Variations and Radial Velocities [1]. ~ 300 of these exoplanets are 1.6 < R₂Earth < 2.5 [1]. From calculations of their mass and density we assume that they are rocky Earth-like core compositions under low molecular weight envelopes dominated by H₂ [e.g., 2]. Possibly, the planets do not accrete H₂ from the nebula, but produce it through reactions such as:

\[ \text{Fe}^0 + \text{H}_2 \rightarrow \text{FeO} + \text{H}_2 \] [e.g. 3]

and:

\[ 6\text{Fe}_2\text{SiO}_4 (\text{fayalite}) + 11\text{H}_2\text{O} \rightarrow 3\text{Fe}_2\text{Si}_2\text{O}_5(\text{OH})_4 (\text{serpentinite}) + 2\text{Fe}_2\text{O}_4 (\text{magnetite}) + 5\text{H}_2 \] [e.g. 4]

Before testing the potential to generate a H₂O + H₂ inventory from water-rock reactions, the equilibrium H₂O/H₂ needs to be constrained for plausible F/O₂ conditions during planetary formation, since the upper weight limit of the envelope is ~ 1.7 wt. % for terrestrial-like rocky core compositions, if all Fe⁰ is oxidized to Fe³⁺ [5, 6, 7]:

~ 32 wt% Fe⁰ × (3 e⁻ / 2 e⁻) × (2 amu / 56 amu) ≈ 1.7 wt%

(For cores with Fe contents similar to Solar System rocky planets.)

H₂O/H₂ proportions in envelopes

H₂O/H₂ was calculated using the van Laar gas mixing model [11] and the compensated-Redlich-Kwong (“CORK”) equation of state and CHO software by T. Holland [12]. The effects on H₂O/H₂ are shown with varying temperature and O/F₂ (relative to IW) for 1 kbar (Fig. 2a) and 10 kbar (Fig. 2b).

We assume planet radius scales with mass [e.g. 13]

\[ r_{\text{Earth}} \propto m_{\text{Earth}}^{0.77} \]

Volatil outgassing from the core increases the pressure at the core-envelope interface (Pₑ), as seen in Fig. 3 for planets of different masses (units Earth mass, Mₑ). For 1Mₑ, Pₑ = 1.9 × 10⁸ bar at the 1.7 wt. % outgassing limit.

Hypothesis test:

- Low H₂O/H₂ = low molecular weight — envelope could be achieved by outgassing.
- High H₂O/H₂ = high molecular weight envelope – a “water-world” different from the two-layer (core + envelope) models of e.g., [8, 9]. This envelope cannot be achieved by outgassing.

Conclusions + further work

- We now have H₂O/H₂ constraints for the envelope at a variety of conditions.
- Increased volatile outgassing increases pressure at the core-envelope interface.
- Calculations will be expanded to ~ 6000 K and we will calculate the H₂O + H₂ in the coexisting magma.
- Model results will be compared to volatile abundance constraints of Kepler and K2 planets.

References


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