Nebular ingassing of volatiles and conditions for a habitable planet

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The discovery of thousands of exoplanets highlights the need to understand the conditions necessary for a habitable (volatile-rich) planet. We consider the process of nebular ingassing, in which an accreting planet acquires volatiles from a dense, hot, hydrogen-rich atmosphere derived from the stellar nebula. We combine gas transfer scaling laws similar to what are used for ocean uptake of CO_2 with previously published nebular atmosphere models [1,2] to calculate the amount of H and He ingassed to the Earth during its accretion. The important variables include the mean age of the planet surface, planet mass, duration of the solar nebula, and the planet accretion rate. Notably, we include in our calculations the persistence of Earth's nebular atmosphere for several million years after dissipation of the solar nebula.

Our model indicates that, for an Earth-sized (1 M_e) body, the surface pressure of its nebular atmosphere can exceed 0.5 kb and the surface temperature can exceed 3000 K, implying a super-heated global magma ocean. Under these conditions, the magma ocean of an Earth-sized body is predicted to ingass several ocean equivalents of H and orders of magnitude more ^{3}He than present-day mantle concentrations. Later, as the nebular atmosphere dissipates, a portion of the hydrogen acquired during atmosphere growth outgasses, raising the oxidation state of the magma due to H loss.

Because the nebular atmospheric pressure depends on planet mass to the power 3-4, the planetary mass attained while its nebular atmosphere was present becomes a critical parameter for determining later habitability. A 0.5 M_e body will ingas almost no hydrogen for water production from its nebular atmosphere, whereas a 4 M_e body will ingas 10s to 100s of ocean equivalents of hydrogen, leading to a 'water world'. The importance of having exposed land as a driver for nutrient recycling is debated [e.g., 3,4]. However, if nebular ingassing is an important contributor to a planet's volatile inventory, then a near-Earth sized body is a critical condition for a habitabile world.

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