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Abundance of water oceans on high-density exoplanets from coupled interior-atmosphere modeling

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Liquid water is generally assumed to be the most important factor for the emergence of life, and so a major goal in exoplanet science is the search for planets with water oceans. On terrestrial planets, the silicate mantle is a large source of water, which can be outgassed into the atmosphere via volcanism. Outgassing is subject to a series of feedback processes between atmosphere and interior, which continually shape both atmospheric composition, pressure, and temperature, as well as interior dynamics. For example, water has a high solubility in surface lava, which can strongly limit its outgassing into the atmosphere even at low atmospheric pressures. In contrast, CO_2 can be easily outgassed. This drives up the surface pressure and temperature, potentially preventing further water outgassing [1].

We present the results of an extensive parameter study, where we use a newly developed 1D numerical model to simulate the coupled evolution of the atmosphere and interior of terrestrial exoplanets up to 5 Earth masses around Sun-like stars, with internal structures ranging from Moon- to Mercury-like. The model accounts for the main mechanisms controlling the global-scale, long-term evolution of stagnant-lid rocky planets (i.e. bodies without plate tectonics), and it includes a large number of atmosphere-interior feedback processes, such as a CO_2 weathering cycle, volcanic outgassing based on the pressure-dependent solubility of volatiles in surface lava, a water cycle between ocean and atmosphere, greenhouse heating, as well as the influence of a primordial H_2 atmosphere, which can be lost through escape processes. While many atmosphere-interior feedback processes have been studied before in detail (e.g. [2, 3]), we present here a comprehensive model combining the important planetary processes across a wide range of terrestrial planets.

We find that a significant majority of high-density exoplanets (i.e. Mercury-like planets with large cores) are able to outgas and sustain water on their surface. In contrast, most planets with intermediate, Earth-like densities either transition into a runaway greenhouse regime due to strong CO_2 outgassing, or retain part of their primordial atmosphere, which prevents water from being outgassed. This suggests that high-density planets could be the most promising targets when searching for suitable candidates for hosting liquid water. Furthermore, the degeneracy of the interior structures of high-density planets is limited compared to that of planets with Earth-like density, which further facilitates the characterization of these bodies, and our results predict largely uniform atmospheric compositions across the range of high-density planets, which could be verified by future spectroscopic measurements.

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