CONSTRAINING THE HABITABLE ZONE BOUNDARIES FOR WATER WORLD EXOPLANETS

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Planets with global water oceans have been the subject of intrigue both in Hollywood and in the exoplanet community. Kuchner (2003) [1] and Leger et al. (2004) [2] first proposed the possibility of water worlds - water-rich (>1% water by mass) super-Ganymede exoplanets that formed from volatile ice-rich material beyond the snow line but that never attained masses sufficient to accrete or retain large amounts of H_2/He nebular gas. This pathway for producing low-mass water-rich planets has played out as a robust prediction of planet formation simulations, leading to planets that could have a comet-like composition, with up to 50% of their mass constituted of astrophysical ices. If located at an appropriate orbital separation from their host star, water worlds may host a global surface water ocean. Habitable (liquid ocean-bearing) water worlds are especially timely because 1) water worlds formed from remnant cores of evaporated mini-Neptunes could be one of the dominant formation mechanisms for volatile-rich habitable zone planets around M dwarf stars [3], and 2) their larger sizes relative to terrestrial planets make them more amenable to observations with current and upcoming telescopes such as Hubble Space Telescope (HST) [4] and James Webb Space Telescope (JWST) [5].

The classical habitable zone does not apply to water worlds with global oceans. Currently, most calculations of the habitable zone consider Earth-like planets, for which the amount of CO_2 in the atmosphere is stabilized by the carbonate-silicate cycle. Water worlds lack exposed landmass for continental silicate weathering feedback. Due the important oceanic mass, the hydrostatic pressure at the oceanic floor may reach the stability field of high pressure polymorphs of water ice (ice phases VI and VII), hindering chemical interactions between the liquid water and the silicates. In the absence of a carbonate-silicate cycle, the solubility of CO_2 in the ocean [6] and the formation of CO_2-rich clathrates [7] determine the concentration of CO_2 in the water world's atmosphere. We use coupled models of planet interiors, clathrate formation, liquid-vapor equilibrium, and atmospheric radiative transfer to constrain the atmospheric abundance of CO_2 and corresponding habitable zone boundaries of water world exoplanets. We focus in particular on planets orbiting M dwarf stars, since these will be prime targets for characterization with JWST.

References:

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