A Snowball in Hell: The Potential Steam Atmosphere of TOI-1266c

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Introduction: The recent discovery of two planets orbiting TOI-1266 (Stefánsson et al., 2020) offers a rare opportunity to begin observing the simultaneous impacts of both a planet and host star evolving through time. While both planets' masses are poorly constrained at present, planet c could ultimately fall into one of several categories, including that of a super-Venus or a warm sub-Neptune. This latter scenario would mean that TOI-1266c could still have a substantial water inventory if it originally formed beyond the ice line and migrated to its present location. If so, then planet c would be a long-lived analogue of Venus during its runaway greenhouse state, which is thought to have lasted millions of years (e.g., Zahnle & Kasting, 1986).

Modeling and Results: We simulate the evolution and present state of TOI-1266c using parameterized atmospheric escape estimates (Owen & Alvarez, 2016), 1-D photochemical and radiative-convective climate models (Arney et al., 2017; Kopparapu et al., 2013), and the Planetary Spectrum Generator (PSG; Villanueva et al., 2018). We find that if planet c starts off with more than a few percent by mass water (H_2O) and even trace amounts of hydrogen (H_2), its atmospheric composition is relatively stable over its lifetime. This is because H_2 is expected to both be lost preferentially and react with any oxygen remaining from water photolysis and subsequent hydrogen escape, which together prevent the accumulation of oxygen. With a smaller initial volatile inventory, however, oxygen and/or carbon dioxide can become major constituents (or even the dominant species) in the atmosphere. These terminal scenarios are potentially differentiable using the James Webb Space Telescope (*JWST*), particularly if focused on detecting the strong 4.3-micron CO_2 feature. Confirming the presence of oxygen could be challenging, however, since its spectral features are relatively narrow in the ultraviolet, visible, and near-infrared.

Connections to Rocky Planets: The potential to observe a Venus analogue, particularly if it remains in a steam-dominated runaway greenhouse at present, offers an unparalleled window into the history and evolution of a unique terrestrial planet as well as one of the first few steam atmospheres accessible with *JWST*. Data about water-dominated atmospheres are also relevant to the bounds of habitability for terrestrial planets, particularly those that form around low-mass host stars (Luger & Barnes, 2015) and orbit older stars (e.g., Rushby et al., 2013; Lehmer et al., 2020). Lastly, observations of exoplanets that may have accumulated oxygen derived from water loss are important to establishing a baseline for larger planet sample size analyses, particularly in the context of biosignatures (e.g., Bixel & Apai, 2020).

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