Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.26200

Applying a fully coupled atmosphere-interior evolution model to explore habitability of ancient Venus and exo-Venus analogs

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While observations of rocky planets in the solar system and beyond provide snapshots in time, evolutionary models are needed to understand and anticipate long-term habitability prospects. Solar system planets provide an invaluable opportunity to ground truth such models, and Venus is a prime candidate for such analysis. The history of Venus remains poorly understood, and although Earth and Venus are assumed to have formed similarly the two planets are now extremely different. This dichotomy requires further exploration to determine if Venus could have ever been habitable. Additionally, the evolution of Venus is potentially representative of a large population of exoplanets, exo-Venus analogs, which are closer to their host stars and receive more stellar radiation than Earth. Here, we present the results of exploring Venus's past with a new magma ocean, redox, atmospheric escape, and climate evolution model for terrestrial planets that self-consistently accounts for thermochemical equilibrium and volatile partitioning. This innovative geochemical model can self-consistently accommodate arbitrary atmospheric compositions, and thereby capture the transition from H2-rich nebula atmospheres to high mean molecular weight secondary atmospheres. We find that early Venus could have possessed a wide range of early atmospheres that are much more diverse than the oxidized, H2O+CO2 dominated, post-accretion secondary atmospheres that are typically assumed for magma ocean models. Specifically, comparatively dry, CO-CO2 atmospheres are a common endpoint of our magma ocean evolution. Since CO is a poorer greenhouse gas than CO2, we also explore the habitability implications for such atmospheres in the context of early Venus. Missions to Venus within the next decade will provide better constraints for models such as this to accurately understand the history of Venus, motivating this type of exploration of possible histories of Venus. Furthermore, the importance of characterizing Venus's interior and atmospheric evolution extends beyond the scope of a singular planet, as there are many exoplanets which may be best understood, especially with respect to habitability, through this evolutionary modeling approach.