

The Evolution of Extrasolar Sub-Neptunes: The Effects of Atmospheric Escape and Hydrogen Repletion

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Sub-Neptunes, which have the sizes between Earth and Neptune, are the most discovered extrasolar planets. Sub-Neptunes possess thick hydrogen-rich atmospheres, and have low densities compared with planets composed of entirely rock. The orbital periods of the most part of confirmed sub-Neptunes are less than 100 days. Strong stellar XUV irradiation induces intense atmospheric escape from these short-period sub-Neptunes, so that they are expected to lose their entire atmospheres within their ages. Thus, the existence of these planets cannot be explained by current theoretical models.

Previous studies have attempted to explain the atmospheres of sub-Neptunes by considering dissolved hydrogen in magma oceans which replenishes hydrogen in their atmospheres (Chachan & Stevenson 2018), but this effect is not enough to explain the observations (Modirrousta-Galian et al. 2020). On the other hand, in the context of earth's formation, a recent experimental study has shown that hydrogen could be preferentially partitioned into the core compared to the magma ocean by orders of magnitude (Tagawa et al. 2021).

In this study, we focus on the effect of dissolved hydrogen in the metallic core to replenish the escaping atmosphere. We calculated the thermal and mass-loss evolution of sub-Neptunes with the one-dimensional interior-structure model which takes hydrogen-replenishment from the magma ocean and core into account. The results show that, in some cases, the atmospheric lifetimes of sub-Neptunes can be extended ten times or more than those in the conventional model due to the hydrogen replenishment from their metallic cores. In particular, this effect is more significant when the bottom of the magma ocean is molten for a long time. Comparing our models with observed extrasolar sub-Neptunes, we suggest that the existence of short-period sub-Neptunes could be partially explained by hydrogen replenishment from metallic cores.

To verify whether the hydrogen replenishment from the metallic core is actually ongoing on the observed planets, it is necessary to observationally constrain the He/H ratios in their atmospheres. Moreover, the model used in our study depends on several parameters which have not been fully constrained, such as the partitioning coefficient of hydrogen between silicate melt and metallic iron under the conditions expected for sub-Neptune interiors. The lab and/or numerical experiments to constrain such parameters are essential for better understanding the role of hydrogen replenishment from planetary interiors on the evolution of sub-Neptunes.

References:

- Chachan, Y., & Stevenson, D. J. 2018, *ApJ*, 854, 21.
Modirrousta-Galian, D., Locci, D., Tinetti, G., & Micela, G. 2020, *ApJ*, 888, 87
Tagawa, S., Sakamoto, N., Hirose, K., et al. 2021, *Nature Communications*, 12, 2588

Keywords: Exoplanet formation, Exoplanet evolution, Exoplanets atmospheres