Silicate vapor in sub-Neptune atmospheres

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Full paper: Misener & Schlichting (2022), *MNRAS*, in review, arXiv:2201.04299

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Main Takeaways

Motivation

- Substantial silicate vapor is expected at the base of young sub-Neptune atmospheres (Schlichting & Young 2022)
  - **What effect does this SiO vapor have on the atmospheric profile and thermal evolution of sub-Neptunes?**

Mechanism

- Silicate vapor acts as a condensable species
- If molecular weight gradient is steep enough, it can offset thermal buoyancy, inhibiting convection
- Properties of **resulting deep non-convective layer can substantially change atmospheric profile**

Results

- **Inclusion of SiO decreases the overall planet radius** compared to a fully convecting atmosphere with the same base temperature and atmospheric mass
- Consequently, the **atmospheric mass inferred** from observed radii using a model which includes silicate vapor **can be up to five times higher** than if using a model lacking this effect
- Misinterpretation of atmospheric masses is most significant for hotter, younger, and heavier planets with more massive atmospheres
- Differences persist in some sub-Neptunes on gigayear timescales

SiO vapor inhibits convection deep in sub-Neptunes

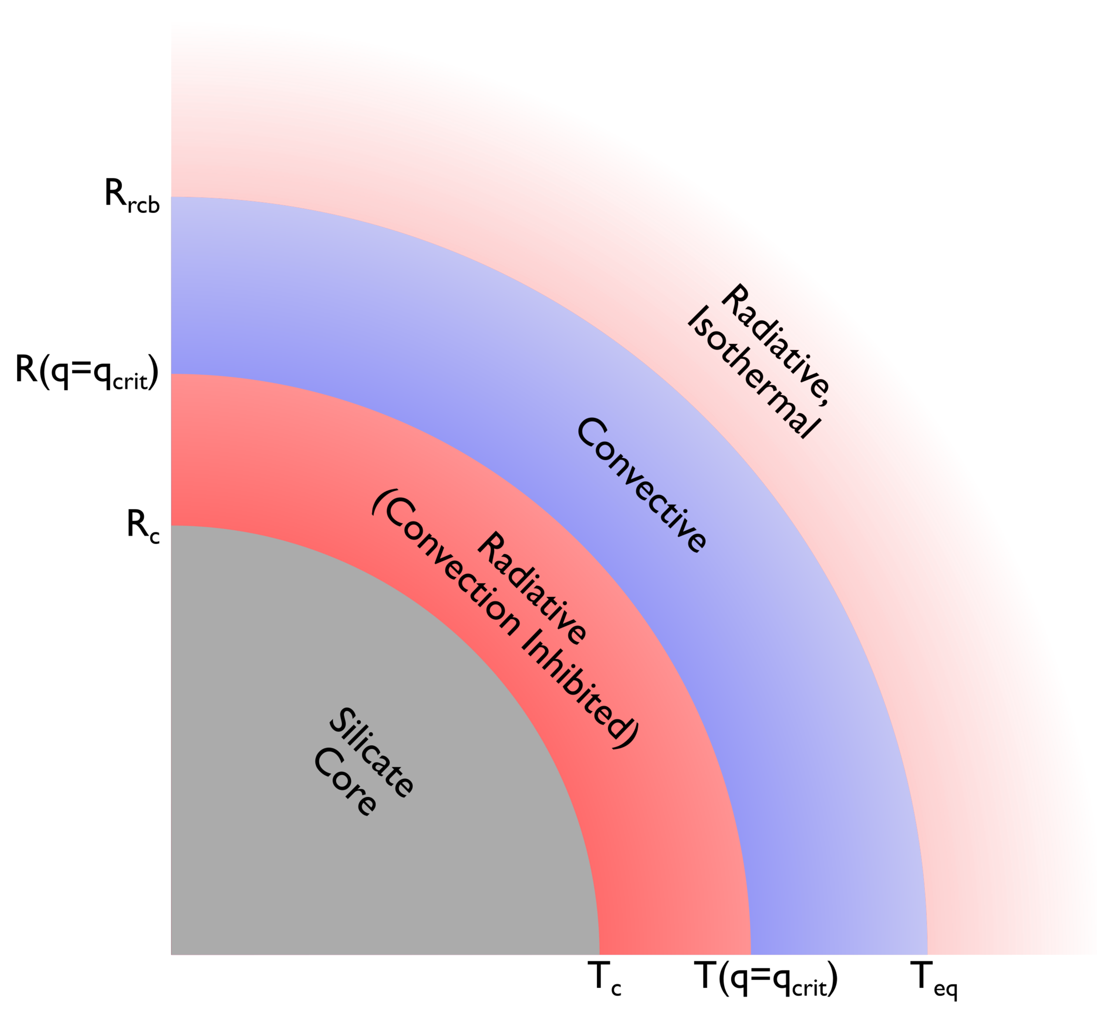

Figure 1: Sub-Neptune structure. The silicate interior (gray) is overlain by a hydrogen-dominated atmosphere, which is divided into non-convective (red) and convective (blue) regions. The inner non-convective region is caused by the silicate vapor.

- Sub-Neptunes form with temperatures at the silicate-atmosphere interface >5000 K (Ginzburg et al. 2016)
- At these temperatures, substantial SiO should be present as vapor in the atmosphere (Schlichting & Young 2022)
- SiO vapor acts as a condensable species, altering the atmospheric *P*-*T* profile and increasing in abundance with depth
- If enough vapor is present, convection is inhibited by the large molecular weight gradient (e.g. Guillot 1995, Leconte et al. 2017, Ormel et al. 2021)
  - Leads to inner non-convective region shown in Fig. 1
  - Inhibition of convection occurs when mass mixing ratio q exceeds a critical value, which depends on the molecular weights μ and the gradient of the vapor pressure P_{svp}:

$$q_{crit} = \frac{1}{\left(1 - \frac{\mu_H}{\mu_{sv}}\right) \frac{\partial \ln P_{svp}}{\partial \ln T}}$$

Deep non-convective regions alter observable radii

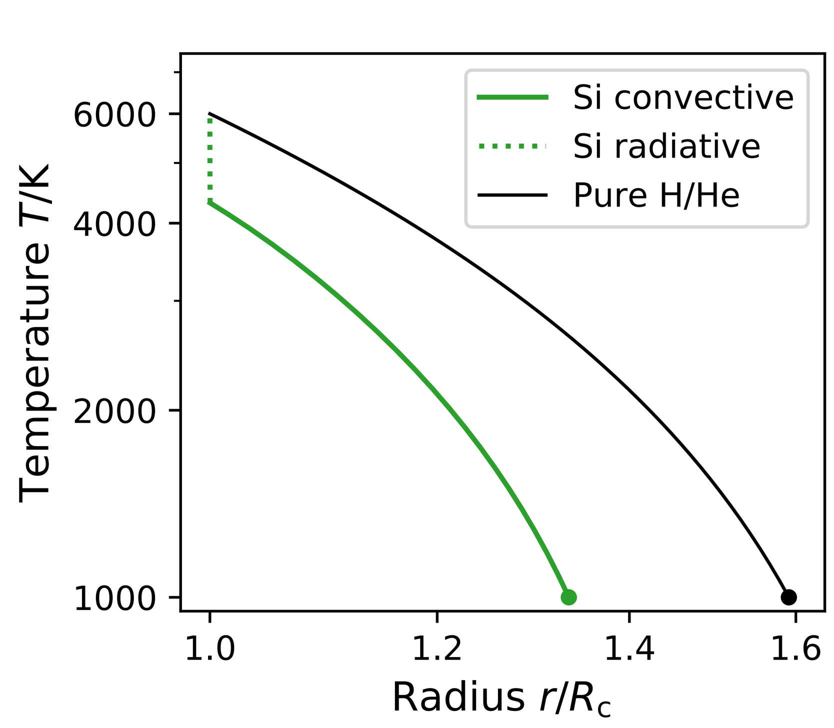

Figure 2: Radial temperature profile in a H-dominated sub-Neptune atmosphere which includes silicate vapor (green), compared to a pure H/He atmosphere (black). Dots represent the outer radiative-convective boundary. Silicate vapor leads to a decrease in a planet's radius.

- For realistic opacities and conductivities (Freedman et al. 2014, McWilliams et al. 2016), the temperature gradient of the inner non-convective region is steep
  - Leads to a narrow radiative region, as in Fig. 2
- Therefore, accounting for this inner radiative region leads to a smaller planet radius than a pure H/He atmosphere of the same mass, equilibrium temperature, and base temperature

Deep non-convective regions affect long-term evolution

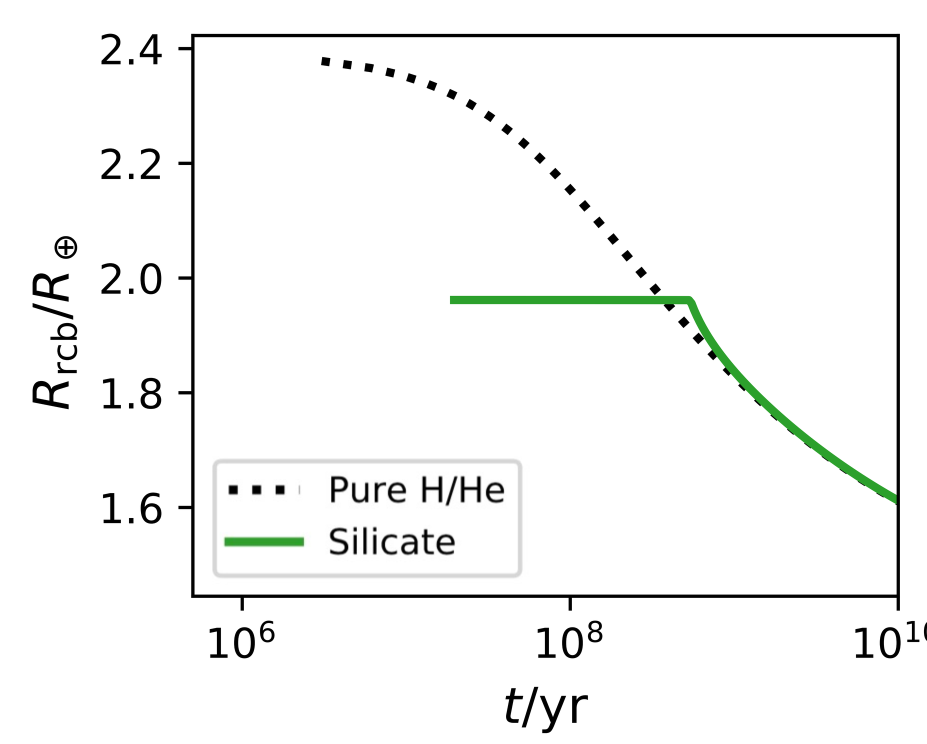

Figure 3: Thermal evolution in time of the planet radius R_{rcb} for a sub-Neptune including silicate vapor (green), compared to a pure H/He atmosphere (black). Both planets begin with the same base temperature at t=0. Silicate vapor leads to changes in a planet's radius evolution.

- Fig. 3 demonstrates that the decrease in radius due to convection inhibition slows cooling and alters sub-Neptune radius evolution on gigayear timescales
- Differences persist until the mass mixing ratio $q<q_{crit}$ at the base of the atmosphere, when convection is no longer inhibited

Misinterpretation of inferred atmospheric masses of sub-Neptunes due to neglecting silicate vapor

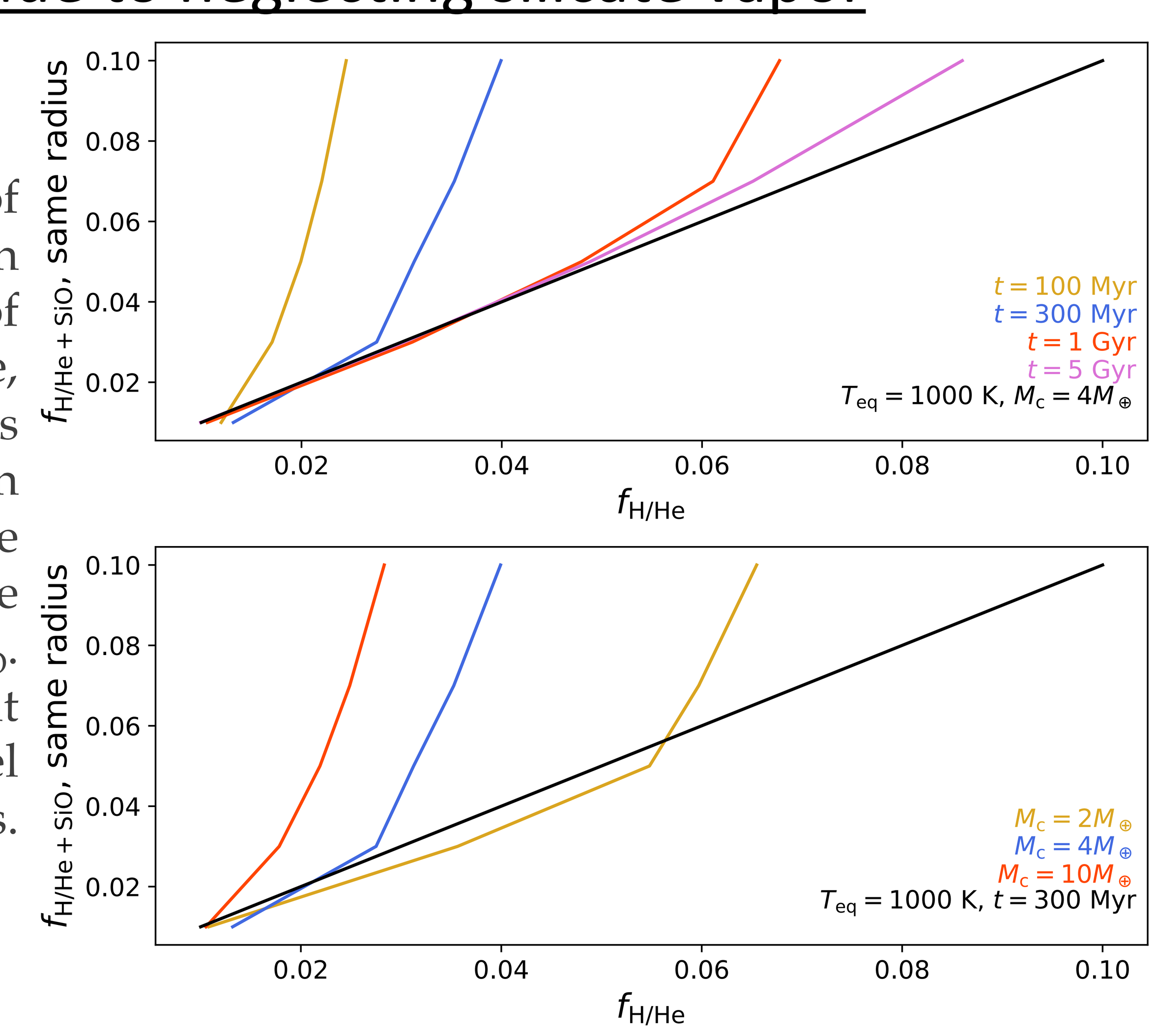

Figure 4: Comparison of atmospheric mass fraction inferred for a sub-Neptune of a given radius if a pure H/He, fully convecting atmosphere is assumed, $f_{H/He}$, to the fraction inferred from the same observed radius once silicate vapor is included, $f_{H/He+SiO}$. Top panel compares planets at four ages, while bottom panel compares three planet masses.

- Accounting for silicate vapor typically increases the atmospheric mass one infers from an observed planet radius compared to a pure H/He model, as shown in Fig. 4
- The largest differences between the models occur for younger planets (top) with larger planet masses (bottom), hotter equilibrium temperatures (see paper), and more massive atmospheres
- Presence of silicate vapor may affect accretion and loss of primordial H/He atmospheres around super-Earths and sub-Neptunes

References

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