Atmospheric H-C-O ratio for super-Earth/sub-Neptune with rocky core

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Exoplanet hunting efforts have revealed the prevalence of planets with radii between Earth and Neptune. These planets are now called super-Earths and/or sub-Neptunes (hereinafter referred to as super-Earths). Their mass-radius relationship suggests that relatively larger ones should have thick atmospheres, and below the atmosphere may exist silicate cores. The origin of these planets remains as an open question, and new atmospheric spectroscopy with JWST, which has just started, is expected to provide more clues. For example, recent JWST data suggest that the atmospheres of K2-18b and GJ1214b are metal-rich (e.g., Madhusudhan et al. 2023; Kempton et al. 2023). Interpretation of these atmospheric data should be coupled with an understanding of the planetary processes that alter atmospheric compositions. Previous works have argued that if their atmosphere directly connects to the silicate layers, the silicate layers are likely to be molten due to the high temperature in the deep atmosphere. The presence of magma beneath the atmosphere would then have substantial effects on the atmospheric composition through the redox reaction between the atmospheric species and rock, dissolution of atmospheric species into magma, and the vaporization of rocky materials (e.g., Kite et al., 2019; Schlichting and Young 2022; Misener and Schlichting 2022). In a scenario where a silicate core with Earth-like (relatively oxidized) composition reacts with an H2-rich atmosphere, the molten silicate would oxidize the atmosphere, releasing a substantial amount of O into the atmosphere. In addition, efficient dissolution of H-bearing species (namely H2O and H2) mildly increases the ratio of insoluble atmospheric elements to H. (i.e., C/H and N/H). In this presentation, we examine how the characteristic variety of atmospheric elemental compositions can be affected by the redox state of magma and planetary parameter through chemical equilibrium and volatile dissolution calculation of the H-C-O systems between atmosphere and underlying magma. We find that the key planet property for the atmospheric elemental composition in H, C and O is the bounded-oxygen fraction of iron in magma that controls the redox state of magma. For example, in our one nominal planet case (the mass of 6 Earth masses, the radius of 1.9 Earth radii, and the equilibrium temperature of 750 K), O/H increases from ~3 to ~100 and C/O decreases from ~1 to ~0.05 in the unit of Solar value with the bounded-oxygen fraction of iron from 0.01 to 1. As one discussion, we demonstrate how spectra can change considering different atmospheric compositions under the chemical equilibrium assumption. We show that the atmosphere overlying highly reduced rock with a bound-oxygen fraction of iron of 0.01 mainly exhibits features of CH4, H2O, and CO2 in its transmission spectra. Conversely, atmospheres overlying intermediately reduced and oxidized rock with bound-oxygen fractions of iron of 0.1 and 1 predominantly display features of H2O and CO2 in their transmission spectra. While we haven’t conducted the detailed detectability estimation for them, we would like to discuss on it and the caveats of our investigations in this presentation.

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