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Experimental study on organic aerosol formation in super-Earths' atmosphere: Implications for transit observations

KOBAYASHI, Jumpei[1*] ; SEKINE, Yasuhito[2] ; HONG, Peng[2]

[1]Dept. Earth & Planet. Sci., Univ. Tokyo, [2]Dept. Complexity Sci. & Engr., Univ. Tokyo

A super-Earth is an extrasolar planet with a mass greater than Earth and below Neptune. Although there is no super-Earth in our solar system, astronomical observations demonstrate that it is one of the major categories of planets beyond the solar system. Recent transit observations of super-Earths, including GJ 1214b, indicate that their atmospheres contain opaque clouds or haze at high altitudes. One candidate for the opaque materials is metallic or salt dusts, such as KCl and ZnS, which would condense in the upper atmospheres of super-Earths. Another candidate is organic haze, such as those observed in the atmosphere of Saturn's moon Titan, which would be composed of high-molecular-weight hydrocarbon aerosols produced through photochemical reactions involving CH_4. Given the proposed formation mechanisms of nearby super-Earths, e.g., planetary migration, they would have a wide variety in chemical composition of atmosphere. However, previous laboratory experiments have mainly focused on organic aerosol formation in Titan's and early Earth's atmospheres. Thus, both the formation rate and optical property of organic haze for various atmospheric compositions have been poorly constrained by laboratory experiments.

In this study, we investigate the formation rate and optical property of organic aerosols formed by laboratory experiments simulating super-Earths' atmospheres with a wide variety in chemical composition. We used initial gas mixtures of H_2 and CH_4 or CO_2 and CH_4, and varied the H_2/CH_4 or CO_2/CH_4 ratios. The experiments were conducted at a total pressure of 1 Torr in a flow system. Cold plasma irradiation was used to initiate aerosol formation. We measured the aerosol formation rate, chemical compositions of intermediate gas molecules, and optical property of aerosol using a spectroscopic ellipsometer, a quadrupole mass spectrometer, and a UV/VIS spectrometer, respectively.

Our experimental results show that the aerosol formation rate decreases with increasing the H_2/CH_4 ratio, suggesting that recycling of high-molecular-weight hydrocarbons to CH_4 occurs through reactions with H and H_2 under H_2-rich conditions. We also show that organic aerosols are produced less efficiently at higher CO_2/CH_4 ratios. The results of gas analyses also show that formation of high-molecular-weight hydrocarbons are inhibited at higher CO_2/CH_4 ratios. These results indicate that oxygen-bearing molecules and radicals formed by CO_2 dissociation oxidizes hydrocarbons produced from CH_4, which results in a lower aerosol formation rate at higher CO_2/CH_4 ratios. Optical constant of the aerosols formed under the conditions simulating super-Earths' atmospheres is significantly lower than those of Titan aerosol analogs.

Based on the experimental results, we discuss the chemical composition and formation process of transiting super-Earths, such as GJ 1214b, by comparing the observed transmittance spectra with the model spectrum. We suggest that organic aerosol production in a H_2-rich or CO_2-rich atmosphere is inefficient so that organic haze would not be capable of explaining the observed transit spectra of super-Earths, even if they contains gaseous CH_4 in the atmospheres.

Keywords: exoplanet, super-Earth, organic aerosol, haze, atmospheric composition