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Transmission spectrum models of exoplanet atmospheres with haze: Effects of growth and settling of haze particles

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Since the first discovery of an exoplanet in 1995, detection of more than 1500 exoplanets has been reported. Recently, in addition to detection, multi-wavelength transit observations have been done to characterize detected exoplanets. From a decline in apparent stellar brightness due to a planetary transit, we can measure the planetary radius. Also, the observed wavelength-dependent radius (which is often called the transmission spectrum) provides the information of absorption and scattering of stellar light by molecules in the planetary atmosphere. Thus, the composition of the planetary atmosphere can be constrained by comparison between the observational and theoretical transmission spectra. The constraint on atmospheric composition is expected to give an important clue to the origin of the planet.

Until today, transmission spectra of 20 exoplanets have been obtained. Some of the recent observations detected flat or featureless spectra, inferring the existence of particles such as hazes floating in the atmosphere. This means the existence of hazes would obscure the predicted spectral features of molecular absorption, making it difficult to prove its atmospheric composition. Also, the transmission spectra seem to be somewhat diverse. Some contain the Rayleigh-slope feature in the visible, some show molecular and atomic features in the near-IR. These observational facts raise questions such as how common hazy atmospheres are beyond the solar system, how diverse transmission spectra of hazy atmospheres are, and how much information of atmospheric composition one can obtain from hazy atmospheres.

There are a few theoretical studies of transmission spectra of exoplanet atmospheres that consider the effect of haze in the atmosphere (e.g., Howe & Burrows 2012; Morley et al. 2013). However, the models of haze are ad hoc; they treated the size, number density, and vertical distribution of haze particles as parameters. While they found parameter ranges in which the theoretical transmission spectra match the corresponding observations, they did not discuss if the viability of those haze properties is physically supported.

In this study, to derive realistic properties of hazes in the atmospheres of transiting exoplanets, we have developed a new theoretical model that considers the creation, collisional growth, and settling of haze particles. Also, with obtained properties of hazes, we have modeled transmission spectra of the atmospheres, using the numerical code that we developed previously. We have found that the haze particles tend to distribute in a wider region than previously thought and that haze particles of various sizes are formed in the atmosphere, which in general yield flat spectra. Simulating the transmission spectra for wide ranges of parameters concerning haze such as atmospheric composition, temperature, and UV irradiation from the host star, we constrain the parameter ranges that result in observed features in the transmission spectra. We also find the parameter ranges that show features of molecular absorptions in the spectra without being obscured by haze, making it possible to derive the information of the atmospheric composition from the observation of the transmission spectra.

Keywords: exoplanets, transits, transmission spectrum models, atmospheric composition, haze