Exospheric Atmosphere Simulation for Ultraviolet Transit Observation of Exoplanet

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Many exoplanets have been discovered to date, including Earth-like planets located within or near the habitable zone (HZ). It is expected to advance our observational understanding of the habitable planets and the concept of HZ. The runaway greenhouse effect that determines the inner edge of the HZ results in the evaporation of the entire ocean on Earth-like planets. Because of that, an atmosphere enriched in water vapor is formed in a shorter period than the inner edge of the HZ. Thus, around the inner edge of the HZ, planets would have significantly different atmospheric compositions depending on their location. However, there is no knowledge related to the changes in the major atmospheric compositions inside and outside the HZ by observations of terrestrial planets by the James Webb Space Telescope (JWST). Although the TRAPPIST-1 system is the most characterized system which has seven terrestrial planets, observations by the JWST are limited in TRAPPIST-1b and c which have shorter periods than the inner edge of HZ. They suggest the planets have no or thin atmospheres.

Terrestrial planets around low-mass stars such as K- and M-type stars are good candidates for the present and near future observations. Because the majority of low-mass stars have higher activity than that of the sun, planets around low-mass stars receive much more X-ray and extreme ultraviolet (XUV) radiation than that of the present-day Earth. Because TRAPPIST-1d is located near the inner edge of the traditional HZ, the planet would be in a runaway greenhouse state and have a water vapor atmosphere if H2O is still present today. In a previous study [Ehrenreich et al. (2015)], they showed the large transit depth of the hydrogen Ly-α line of GJ436b because orbital motion and stellar gravity formed a tail of hydrogen atomic clouds induced by the atmospheric escape from the hydrogen dominated warm Neptunes. As in the Neptunes, a large transit depth in Ly-α would be observed in the water vapor atmosphere of the TRAPPIST-1d. This is because a strong XUV radiation would result in the escape of atomic hydrogen and oxygen dissociated from the water vapor atmosphere. In addition, the transit depth depends on the distribution of atoms in the exosphere which is related to the atmospheric escape rate. Thus, it provides direct insight into the evolution of planetary atmospheres. This is hard to infer from the observation by the JWST because it mainly observes the lower atmosphere. Therefore, it is necessary to construct an exospheric atmosphere model and investigate the observational feasibility of Ly-α transit of the water vapor atmosphere in the runaway planets.

In this study, to investigate the observational feasibility of the water vapor atmosphere by UV transit observations, we estimated the transit depth of hydrogen Lyα in TRAPPIST-1d, which may have a water vapor atmosphere. To estimate the number density and velocity distribution of hydrogen atoms, we developed an exospheric atmosphere model based on previous studies. The model considers the radiation pressure from the steller Ly-α line, stellar and planetary gravity, centrifugal forces, and planetary orbital motion. The main parameters of the model are the intensity of Ly-α line radiation from the stars and the amount of escape rate from the exobase. In this presentation, we will show the results of the tail structure and the Ly-α transit depth of the TRAPPIST-1d.

Keywords: terrestrial exoplanet, ultraviolet spectroscopy, water vapor atomosphere