

Constraining the XUV irradiation and H/He ratios of short-period exoplanets using escaping H and He absorption lines

*Toshi Suganuma¹, Shota Notsu², Hiroyuki Kurokawa³

1. Department of Earth and Planetary Environmental Science, School of Science, The University of Tokyo, 2. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 3. Department of Earth Science and Astronomy, Graduate School of Arts and Sciences, The University of Tokyo

Short-period exoplanets are known to show a gap in the period–size distribution for small planets (the radius valley) and a dearth of Neptune-sized planets (the Neptune desert) (e.g., Fulton et al. 2017; Szabó & Kiss 2011). One of the factors contributing to the formation of such a statistical distribution is atmospheric escape. This mass-loss rate is determined by the incident flux of X-rays and extreme ultraviolet (XUV) into the atmosphere under the energy-limited escape (e.g., Lammer et al. 2003; Lopez & Fortney 2013; Owen & Wu 2013). However, there is observational uncertainty for stellar XUV luminosities since they are subject to extinction by the interstellar medium. Thus, observations of atmospheric escape have been conducted using mainly the hydrogen Ly α and He triplet lines at 10830Å. The former exhibits strong absorption and can be detected even in atmospheres exposed to weak XUV radiation, while the latter requires a high level of XUV irradiation. By using both absorption lines, it is expected to constrain the stellar XUV luminosity. On the other hand, the strength of these absorption lines is also naturally governed by the amount of hydrogen and helium in the atmosphere. If the H/He mass ratio of the envelope is known, it is possible to constrain the evolution of planetary atmospheres. For example, it is thought that lighter hydrogen is preferentially lost from the atmosphere due to escape (Renyu et al. 2015), so that the helium enrichment in atmosphere would strongly suggest that atmospheric escape is a major factor in the formation of the radius valley (Cherubim et al. 2024). Additionally, because atmospheres supplied by outgassing tend to be depleted in noble gases, planets with low helium content may indicate the presence of a secondary atmosphere (e.g., Catling & Kasting 2017). However, there is no established theoretical framework to relate escaping H and He line observations to these unknown parameters. Therefore, we aim to theoretically derive the relations between the incident XUV flux and atmospheric H/He ratio with the strengths of escaping H and He absorption lines.

In this study, we first constructed a standard atmospheric escape model developed by Oklopčić & Hirata (2018) and Lampón et al. (2020), assuming an H/He atmosphere. We evaluated the strength of the hydrogen absorption lines: Ly α and H α , as well as the He triplet absorption line and used equivalent width (EW) as a measure of absorption line strength. The EW of each absorption line was calculated for a XUV flux range of 10^{-2} – 10^4 in $10^{0.25}$ times the value received by GJ436b in logarithmically equal intervals of $10^{0.25}$ and for H/He mass ratio range of 0.0–1.0 in 0.01 steps.

The results show that as XUV flux increases and the relative helium content in the atmosphere grows, the He triplet becomes more abundant and extends to higher altitudes, leading to an increase in EW. Furthermore, the He triplet absorption was found to be much more sensitive to XUV flux and H/He ratio variations compared to others. These findings suggest that observing multiple atomic species with different excitation energies could help to constrain the XUV luminosity of young stars, which are difficult to observe precisely. Additionally, it would become possible to determine the H/He abundance ratio in exoplanetary atmospheres and provide new insights into atmospheric composition changes associated with escape, a process that remains poorly understood from an observational perspective.

Keywords: exoplanet, atmospheric escape, He triplet, XUV

