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Mass-Loss Evolution of Super-Earths: Constraints on Their Compositions and Origins

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Recent progress of he search for exoplanets, for example the transit observations with Kepler space telescope, has pushed toward small planets. Especially, "Super-Earths", that are planets having sizes from Earth to Neptune, are revealed as quite common: ~30% of solar-type stars have super-Earths (Howard et al., 2012). Therefore, an understanding of their compositions, which is related to their origins, is important for planet formation and evolution.

We can speculate the compositions of super-Earths both whose masses and radii are known by using theoretical mass-radius relations for different compositions. Some fraction of super-Earths have low density, which suggests the presence of H/He envelopes formed by protoplanetary-disk gas capture. There exist. on the other hand. high-density super-Earths possibly having rocky- or water-rich compositions. The origin of this dichotomy is one problem that we address in this study, which possibly arises from the difference of the amount of captured disk gas due to different masses and disk temperature in their formation stages, or from XUV (X-ray and EUV)-driven atmospheric escape in later evolution stages (e.g., Lopez et al., 2012). Another problem that we address in this study is "the degeneracy of composition": The compositions of super-Earths can be fitted by various ratios of H/He envelope, rock, and water. Their atmospheric compositions have been speculated by measuring their transmission spectra, but recent observations using Hubble Space Telescope suggested that cloudy atmospheres of super-Earths (Kreidberg et al., 2014; Knutson et al., 2014). If clouds are common in atmospheres of Super-Earths, direct measurements of their compositions are difficult because clouds obscure any features of atmospheric species.

In this study, we show constraints on these problems of compositions and origins of super-Earths by calculating their mass-loss evolution due to XUV-driven atmospheric escape considering the differences of host-stellar types. The ratio of XUV luminosity and bolometric luminosity differs among stellar types, which enables us to distinguish formation origin and mass-loss origin of the dichotomy of super-Earths with or without H/He envelopes. Also, the degeneracy of compositions can be solved by considering stability criteria to lose H/He envelopes.

We calculated the critical orbital radii to lose H/He envelopes for different stellar types, that corresponds to different equilibrium temperature depending on stellar types. The obtained critical separations are consistent with the distribution of the observed super-Earths with or without H/He envelopes, suggesting that the observed dichotomy has a mass-loss origin.In this case, we expect that super-Earths having moderate density and orbiting inside the critical separation are water-rich super-Earths without H/He envelope.

We also evaluated uncertainty caused by mass-loss model and XUV luminosity and discuss the validity of our results.

Keywords: exoplanet, atmospheric escape, composition, super-Earth