Unified simulations of formation and atmospheric evolution of super-Earths

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A large number of super-Earths have been discovered, and most of them are not in mean-motion resonances. Atmospheres of transiting super-Earths have also been observed by transmission spectroscopy. Several observational evidences suggest that most super-Earths do not possess massive H/He atmospheres. The amount of atmospheres is typically up to 10wt%. However, according to the theoretical study of atmospheric accretion, super-Earths accumulate massive H/He atmospheres within the lifetime of protoplanetary disks.

In this work, to address this issue, we consider the following four mechanisms: (i) envelope heating by pebble accretion, (ii) mass loss during giant impacts, (iii) atmospheric loss by stellar XUV photoevaporation, and (iv) disk dispersal due to magnetically driven and photoevaporative winds. We investigate whether these mechanisms influence the amount of the atmospheres that form around super-Earths. We develop a simulation code combining an N-body simulation of planetary formation by pebbles/planetesimals and an atmospheric evolution simulation.

We perform numerical simulations and demonstrate that the observed orbital properties of super-Earths (e.g., non-resonant configuration) are well reproduced by our simulations. Regarding the amount of H/He atmospheres, we find that the first three mechanism (i)-(iii) are not enough to reduce the amount of atmospheres. In contrast, super-Earths can avoid accreting massive H/He atmospheres in disks (iv) that dissipates via magnetically driven and photoevaporative winds. In conclusion, we succeed in reproducing both orbital and atmospheric properties of observed super-Earths using N-body simulations that include atmospheric evolution.

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