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Planetary Evolution Driven by Atmospheric Escape: Sub-Neptune to Super-Earth Transition over a Range of Stellar Types

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Abstract

Recent analyses of the Kepler data [1] show that close-in low-mass planets are divided into a group of Sub-Neptunes (mean density: 1-2 g/cm^3) and Super-Earths (mean density: 3-6 g/cm^3). These groups are separated by a valley or gap. These set of observations can be explained by loss of the primordial H/He envelope of Super-Earths [2]. Analytically, assuming energy-limited atmospheric escape occuring in the upper atmospheric envelope, it can be shown that complete loss occurs if the time integrated XUV irradiation absorbed by the planet is larger than the binding energy of the H/He envelope in the gravitational potential of the core.

Model

We run 10 numerical grids for a population of thermodynamically-evolving (i.e. cooling and contracting) planets subject to energy-limited upper atmospheric escape throughout their lifetime. The 10 grids approximate the evolution of planets around a range of stellar masses $M_* = 0.1, 0.5, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.5\, M_\odot$. The densities are then evaluated by way of their mass and radii against stellar irradiation flux, orbital period, and most interestingly the energy column density arriving at the H/He envelope of the planet. This column can be understood as the time integrated XUV flux absorbed into the planetary envelope integrated over the lifetime of the stellar system.

Results

We find that for a given orbital period, planets around more XUV-luminous, high-mass stars are unable to keep their H/He envelopes as efficiently around less XUV-luminous, low-mass stars. The critical radius below which a H/He envelope cannot be sustained for a given orbital period is referred to as the bare radius, corresponding to a maximum mass for a Super-Earth. The bare radius is therefore the lower boundary of the evaporation valley above which the apparent transition from Sub-Neptunes to Super-Earths is occurring.

To gain an intuition, at a 3-day orbit, the bare radius of a Super-Earth increases by $\sim\ 0.25 R_\oplus$ when the stellar mass increases by $\sim 1 M_\odot$ (Figure 1). Moving up from red (low mass) to blue (high mass) stars shows a roughly linear trend. Considering that the gradient is indeed linear up to higher mass populations, the stellar mass would need to quadruple before the bare radius increases by $\sim 0.25 R_\oplus$.

While the stellar luminosity can significantly alter the fate of a H/He envelope, the locus of the evaporation valley remains the same for different stellar masses, only when the *XUV-energy* arriving at the planet is normalized by distance. On a planetary population level this implies a minimum energy column density is required to trigger evaporation of a Sub-Neptune to a super-Earth.

Summary/Conclusions

As a first step into coupling planetary evolution with stellar evolution towards a global understanding of planetary populations across a broad range of stellar types, our simulations indicate that H/He evaporation is fundamentally driven by the time-integrated XUV flux. The derived energy density is a consequence of the conservation of energy. To first order this conservation law appears to be what drives gas escape from planetary bodies. Future observations confirming this dependency, regardless of stellar type, would put trust into analytical frameworks describing the transition from Sub-Neptunes to Super-Earths.

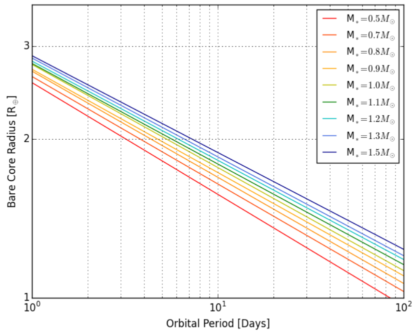

Figure 1: **Planetary evolution based on stellar mass dependence.** The minimum “bare" core radius is shown to decrease as a function of period, where smaller cores can keep their H/He envelopes as the incident stellar insolation decreases. Stellar mass is depicted as going from red (low mass; M dwarf) to blue (high mass; A-type). The stellar mass and luminosities are indicated in the figure legend.

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References

[1] Fulton, B.J., Petigura, E. A., Howard, A.W. et al., The California-Kepler Survey. III. A Gap in the Radius Distribution of Small Planets, AJ, 154, 2017.

[2] Jin, S., Mordasini, C., Parmentier, V., et al.: Planetary Population Synthesis Coupled with Atmospheric Escape: A statistical view of Evaporation, ApJ, 795, 2014.