MASS-LOSS EVOLUTION OF SUPER EARTHS: EFFECTS OF STELLAR TYPES H. Kurokawa[1], L. Kaltenegger[2,3], and T. Nakamoto[3], [1]Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan (kurokawa@nagoya-u.jp), [2]Max Planck Institut fuer Astronomie, [3]Harvard Smithsonian Center for Astrophysics, [4]Tokyo Institute of Technology

Introduction: The search for exoplanets has pushed toward small planets called “super Earths" whose masses are ~1-20 Earth masses. Especially, recent transit observations have revealed a populations of low mass, low density “super Earths", which possibly have large amounts of H/He envelopes. Widespread radii of super Earths indicates the diversity of compositions of super Earths (Fig. 1). These super Earths are ubiquitous around different types of host stars.

The diversity originates possibly from both formation and evolution histories. Formation processes including planetary migration and capture of protoplanetary disk gas contributes the diversity [2][3]. Also, compositions of super Earths are affected by mass-loss evolution due to XUV (X-ray and EUV) driven escape of H/He envelope [4][5][6]. Because XUV luminosities differ among different spectral types of stars by an order of magnitude, the study of mass-loss evolution around different stellar types provides insights to distinguish the effects of formation processes and later evolution.

Model: We calculate the evolution of super Earths having H/He envelopes on rocky cores, considering XUV-driven atmospheric escape and Roche-lobe overflow. The model is based on [7]. The rate of mass loss is calculated with the energy-limited escape formula [8] in which the rate is proportional to incoming XUV flux,

$$\frac{\mathrm{d}M_{\mathrm{planet}}}{\mathrm{d}t} = \frac{\eta \pi F_{\mathrm{XUV}} R_{\mathrm{XUV}}^3}{G M_{\mathrm{planet}} K_{\mathrm{tide}}}, \qquad (1)$$

where M_{planet} is the planetary mass, η is the efficiency, R_{XUV} is the radius where the XUV radiation is absorbed, G is the gravitational constant, and K_{tide} is the tidal correction factor. We assume the efficiency of 0.1 [6]. XUV evolution models are based on X-ray observations for different stellar types [9][10] and a scaling relation between X-ray and EUV luminosities [11]. We use masses and luminosities of Kepler-21, the Sun, HAT-P-26, and GJ1214 as proxies for F-, G-, K-, and M-type stars.

Results: By calculating the mass-loss evolution for different core masses, initial envelope masses, separations from host stars, and different spectral types, we obtain the critical separation to lose H/He envelope in a certain duration (Fig. 2). The critical separation is

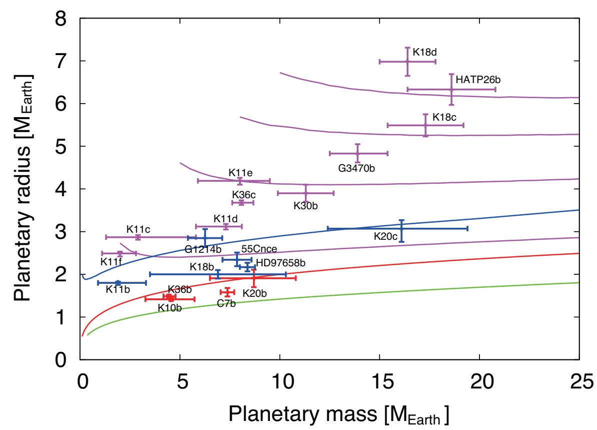

Figure 1: Mass and radius of transiting exoplanets with measured masses, along with theoretical curves for different compositions; iron (green), rock (red), ice (blue), and H/He envelope of 1, 10, 20, 30 wt% on rocky core. Colors of planets indicate possible compositions; rocky (red), icy or having thin H/He envelope (blue), and having thick H/He envelope (magenta). The theoretical curve for an icy composition is provided by Kenji Kurosaki [1].

approximately proportional to an inverse of core mass. The mass loss is determined by an energy balance between gravitational energy of envelope and radiation energy of incoming XUV (Eq. 1). As radius is almost independent on mass for super Earths having H/He envelopes (Fig. 1), the gravitational energy is proportional to M_{core}^2. The incoming XUV flux is proportional to square of the separation a_{planet}^2. Thus these dependences produce the critical separation proportional to an inverse of core mass.

The critical separation to lose H/He envelope is small for super Earths orbiting low mass stars, meaning that super Earths having H/He envelopes are more stable around low mass stars. This is due to the lower incoming XUV flux and the lower equilibrium temperature at the same separation for low mass stars. The lower XUV flux results in a lower rate of mass loss (Eq. 1). The lower equilibrium temperature also reduces the rate of mass loss because the radius in Eq. 1 depends on the equilibrium temperature. As the critical separation is affected by these two effects, the separation can be scaled with the incident XUV flux nor incident bolometric flux.

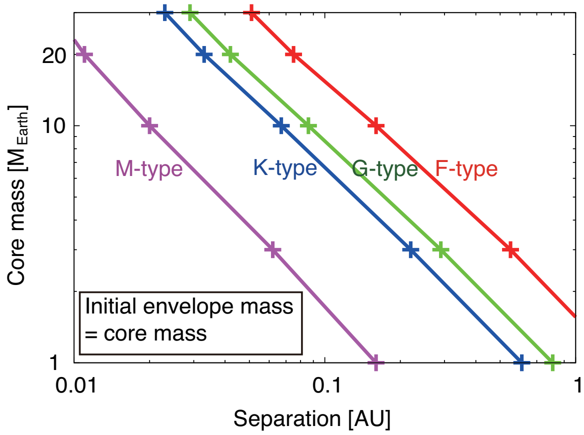

Figure 2: Critical separation where H/He envelope is lost in 10 Gyrs as a function of core mass for different stellar sypes of host stars.

Discussion: Observed super Earths and the comparisons with our theoretical criteria are shown in Fig. 3. Generally, observations show the transition of super Earths with/without envelopes depending on mass and separation, which is similar with the theoretical prediction. The comparisons show that all of super Earths with H/He envelopes have larger separations than the critical separations to lose envelope, except for Kepler-11 c and Kepler-11 f. Mass-Radius relations of super Earths having smaller separation than the criteria is all explained by rocky or icy compositions (Fig. 1) with the two exceptions. If Kepler-11 is exceptionally a XUV-inactive star which results in weak mass-loss for the planetary system, our results indicate that the compositions of super Earths are shaped by mass-loss evolution after their formation stages.

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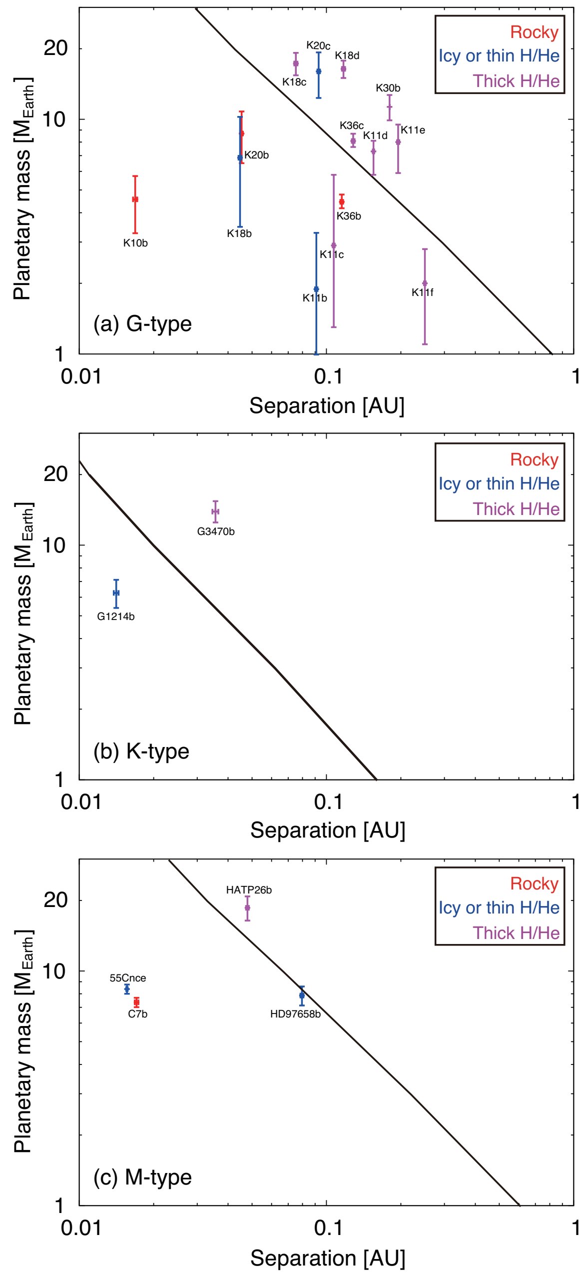

Figure 3: Comparisons of critical separations to lose H/He envelope completely within 10 Gyrs (black lines) with observed super Earths (points) for (a) G-type stars, (b) K-type stars, (c) M-type stars. Colors are the same as Fig. 1.