The Habitat Segregation of Planets: The Origin of the Diversity of Planetary Systems

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We investigate the dependence of the habitat segregation of planets on the mass and the mass distribution of a protoplanetary disk. In the solar system, there are terrestrial (rocky) planets, jovian (gaseous) planets, and uranian (icy) planets from inside to outside. We explain this habitat segregation of the planets using the oligarchic growth model of protoplanets and the condition of jovian planet formation.

In the standard model of a protoplanetary disk, the surface density of the dust component is proportional to the -3/2 power of the heliocentric distance. For this model, the oligarchic growth model gives that the mass and the growth time scale of protoplanets increase with the 3/4 and the 59/20 powers of the heliocentric distance, respectively. In order for a protoplanet to be a jovian planet, the protoplanet must satisfy the two conditions: (1) the contraction time scale of the gas onto the protoplanet from the gas disk is shorter than the lifetime of the gas disk, and (2) the growth time of the protoplanet is shorter than the lifetime of the gas disk. The contraction time scale decreases with the mass of protoplanets, while the growth time of protoplanets increases with the mass of protoplanets. For the standard disk model, conditions (1) and (2) determine the inner and the outer boundaries of the jovian planet region where jovian planets can form, respectively. In the inner and the outer regions outside the jovian region, terrestrial and uranian planets form, respectively.

In the present paper, we quantitatively explain the habitat segregation of planets and show the dependence of the segregation pattern on the initial disk mass and distribution.