Super-Earth Formation in Nascent Protostellar Disks: Connecting ALMA Observations to Exoplanet Studies

Kosuke Seki[1], *Satoshi Okuzumi[1]

1. Department of Earth and Planetary Sciences, Tokyo Institute of Technology

Super-Earths and sub-Neptunes are the most common types of known exoplanets. How these types of planets form is one of the key questions in planet formation theories. Theories of super-Earth formation have been challenged by recent ALMA disk surveys showing that the mass in solids in ~ 1–5 Myr-old Class II disks objects is barely enough to account for Earth-mass planets (Pascucci et al. 2016; Ansdell et al. 2017; Manara et al. 2018). This is particularly problematic with formation scenarios invoking the so-called pebble accretion (e.g., Bitsch et al. 2019) because sub-Earth-sized planetary embryos can only capture a small fraction (typically ~ 10% or less) of dust particles drifting toward the central star.

Here, we examine the possibility that super-Earths formed in earlier phases of protostellar disk evolution, i.e., in the Class 0/I phases. We construct a simple viscous disk model that reproduces the mean dust mass of Class I/II disks (Tychoniec et al. 2018) and the mean gas disk radius of Class II disks (Ansdell et al. 2018) from recent ALMA disk surveys. We calculate the radial profiles of the gas and dust surface densities, temperature, and the maximum size of dust aggregates (or pebbles) by treating dust growth, opacity, evolution, and viscous accretion simultaneously. Migration and pebble accretion by planetary embryos are calculated using analytic formulae (Ormel & Klahr 2010; Paardekooper et al. 2011).

We demonstrate that planetary embryos can grow into Earth-sized planets via pebble accretion if they form and start accretion earlier than 1 Myr after disk formation. The formation of super-Earths requires sticky dust aggregates that grow large and can be efficiently captured by embryos. Our model treating disk temperature evolution consistently with dust evolution shows that the migration of super-Earths after 3 Myr is inward everywhere, suggesting that some mechanisms are needed to slow down or reverse their migration. Most super-Earths forming in our model contain >10 wt% water, implying that super-Earths are more water-rich than the Earth.

Keywords: Super-Earths, ALMA, Protoplanetary disks

©2020. Japan Geoscience Union. All Right Reserved.