Collisional Growth From Dust to Planets in a Protoplanetary Disk

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Planets are considered to be formed in a protoplanetary disk composed of gases and solids. In the standard scenario, kilometer-sized or larger planetesimals are generated from dust grains and collisional coagulation of the planetesimals forms planetary embryos. Once planetary embryos are as large as 10 Earth masses, the embryos start rapid gas accretion, which results in gas giant planets (Mizuno 1980; Ikoma et al. 2000; Hori & Ikoma 2010).

Dust particles grow to meter-sized pebbles via collisions in a protoplanetary disk. Pebbles lose substantial angular momentum due to gas drag because of the sub-Keplerian rotational velocity of gas and spiral onto the central star. If pebbles are compact, then radial drift is too rapid to grow to planetesimals (Weidenschilling 1977). However, successive collisions of dust produce highly porous aggregates (Suyama et al. 2008, 2012). Icy porous aggregates that consist of a number of spherical submicron particles do not suffer from catastrophic disruption unless the impact velocities exceed 60–90 m/s (Wada et al. 2009, 2013). Okuzumi et al. (2012) investigated the collisional evolution of the mass and porosity of icy dust aggregates, whereby icy fluffy dust aggregates were determined to grow into planetesimals faster than they drift. The filling factor of the aggregates becomes as low as 10-5 when radial drift is most effective. Since the compaction of aggregates by ram pressure and self-gravity is effective with the growth of aggregates, the filling factor of kilometer-sized or larger planetesimals increases up to ~ 0.1 (Kataoka et al. 2013).

Because the mechanisms for planetesimal formation was unclear, planet formation was usually investigated from planetesimals. However, we can consider planet formation from dust grains because fluffy dust aggregates overcome the drift barrier. We investigate the collisional evolution of dust grains in protoplanetary disks. Planets are formed only via collisional growth in inner disks ($< 10\,\mathrm{AU}$) if turbulence is weak. However, growing dust aggregates drift inward without planet formation. Drifting dust from the outer disk contributes the growth of planets in the inner disk, if planets can grow as large as the Earth.