Capture of planetesimals by gas drag

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Regular satellites of the giant planets in the Solar system are moving on nearly circular and coplanar orbits, thus they are thought to be formed in circumplanetary gas disks. Solid materials in the circumplanetary disk that formed satellites are supplied from the protoplanetary disk. Canup & Wards (2002) assumed that the major building blocks of regular satellites are meter-sized or smaller bodies that are brought to the disk with the gas inflow from the protoplanetary disk. On the other hand, supply of solid bodies to circumplanetary disks has been recently studied in detail using orbital integration (Fujita et al. 2013, Tanigawa et al. 2014). These works showed that bodies that are sufficiently large to be decoupled from the gas flow can contribute to the formation of regular satellites. Influence of captured solid bodies on satellite system formation would vary depending on the timing of capture. When planetesimals are captured by gas drag from the circumplanetary disk in the midst of accretion of regular satellites, part of captured planetesimals would contribute to the growth of satellites, while the rest spirals into the central planet. However, the circumplanetary disk dissipates at some point due to either gap formation in the protoplanetary disk or global dispersal of the protoplanetary disk. Planetesimals captured by such a waning circumplanetary gas disk would survive in the disk for a long period of time, and may become irregular satellites after the dispersal of the disk.
However, capture of planetesimals by weak gas drag from waning circumplanetary disks has not been examined in detail. Cuk & Burns (2004) examined capture of irregular satellites by waning disks in the late stage of planet formation, and discussed the origin of a cluster of prograde irregular satellites of Jupiter. Assuming that the cluster members are collisional fragments derived from a single body, they integrated orbits of the cluster progenitor backward in time until it escaped from the planet's Hill sphere, taking account of weak gas drag from the circumjovian disk. They found that some planetesimals captured into prograde orbits about Jupiter likely experienced a period of temporary capture before permanent capture. However, Cuk & Burns (2004) mainly focused on the capture of prograde irregular satellites and did not examine capture and orbital evolution of retrograde irregular satellites.
In the present work, we examine capture of planetesimals in waning circumplanetary gas disks using three-body orbital integration. In addition to the process of capture, we also examine subsequent orbital evolution of captured planetesimals. We find that some of captured planetesimals can survive in the circumplanetary disk for a long period of time under such weak gas drag. Captured planetesimals have semi-major axes smaller than about one third of the planet's Hill radius. Distributions of their eccentricities and inclinations after disk dispersal depend on the strength of gas drag and the timescale of disk dispersal, and initially strong gas drag and quick disk dispersal facilitates capture and survival of planetesimals. However, in such a case, final orbital eccentricities and inclinations of captured bodies remain rather large. Although our results suggest that some of the present irregular satellites of gas giant planets with small semi-major axes would have been captured by gas drag, other mechanisms are required to fully explain their current orbital characteristics.
Also, gas drag capture was proposed as the origin of the Martian satellites, but has not been examined in detail. Thus, we also examine capture of planetesimals by gas drag form a spherically symmetric atmosphere.

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