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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words）

It is generally accepted that the large satellites around gas planets formed out of the gas disks, the circumplanetary disks (CPDs), which accompanied the planets' formation. Previous works showed that if enough satellitesimals (km-sized bodies) exist in the disk, satellites with the current satellites' mass can form by two-body collisions. A problem with this scenario, however, is the formation of satellitesimals. Unless CPDs features pressure reversals, the progenitor dust grains will not have had the time to conglomerate, because of the strong radial drift. Moreover, gas gap structures formed by the planets must prevent the dust from flowing into CPDs. An alternative idea to get the material of satellites is planetesimal-capture. However, the growing planets and the gas gaps push out the planetesimals from the feeding-zones and the capture rates decrease. Therefore, how to get the material is a big issue in satellite formation research. Another problem is difficulty in reproducing the characteristics of the satellites simultaneously and consistently. In the case of the Galilean (Jovian) satellites, there are a lot of studies about the characteristics but they can only explain a part of them and contradict each other in part.

First, we investigated the possibility that satellitesimals form in-situ in CPDs. We calculated the radial distribution of the surface density and representative size of dust particles. They grow by mutual collisions and drift toward the planet in with a continuous supply of gas and dust from the parent PPD. In order for the particles to form satellitesimals, the growth must take place faster than they fall onto the planet. We found that this radial drift barrier is overcome if the particles can grow larger than the size which their Stokes number (stooping time normalized by the Kepler-time) is greater than unity. This condition is the same with that of planetesimal formation in PPDs. We also found that the satellitesimals can form (i.e. the above condition is achieved) if the ratio of the dust to gas accretion rates into CPDs is larger than unity. The dust-to-gas ratio must be lower than unity in general, our results suggest that the in-situ satellitesimal formation via particle sticking is viable only under an extreme condition. However, satellitesimals may form episodically or locally in special conditions, for example, the dust vertical diffusion is weak and the gas surface density is low, predicted in some recent hydrodynamical simulations.

We then constructed a new alternative scenario for the origin of the Galilean satellites which can form the satellites even in the material scarcity. In our new scenario, two kinds of small amount of solid material are supplied to the CPD; mm-sized dust particles and km-sized planetesimals. The captured planetesimals accrete the particles drifting toward Jupiter (i.e. pebbles) so effectively that the planetesimals can grow to satellites before the disk disappears thanks to strong gravitational focusing and aerodynamic drag. However, the growth timescale is longer than that of classical formation scenarios, we invoked an inner disk truncation radius to halt their migration. Other parameters were tuned for the model to match physical, dynamical, compositional, and structural constraints of the Galilean satellites. In contrast to the previous scenarios, our new ``slow-pebble-accretion'' scenario then reproduced most of the important characteristics simultaneously and consistently; (1) the mass of all the Galilean satellites, (2) the orbits of Io, Europa, and Ganymede captured in mutual 2:1 mean motion resonances, (3) the ice mass fractions of all the Galilean satellites, and (4) the unique ice-rock undifferentiated Callisto and the other three differentiated satellites. However, only Callisto's orbit could not be reproduced but it was also captured in resonance with Ganymede's one.

We found that the in-situ satellitesimal formation in CPDs is very difficult. Therefore, we built a new formation scenario especially for the Galilean satellites, using drifting pebbles instead of satellitesimals. However, our simulations are simplified and, in reality, satellitesimals originated from special conditions may contribute to satellite formation. Therefore, we should investigate satellite formation processes including both satellitesimals and pebbles as a next step. Future measurements of the D/H ratio in H2O ice of the Galilean satellites by JUICE mission may be able to find out which accretion mechanism was actually dominant. We are now also working on 2-D orbital simulations of the satellites to investigate the resonance capture to solve the problem of Callisto's orbit because we have only carried out simple 1-D simulations. The origin of the large Saturnian satellites should also be investigated. Our discussion about satellitesimal formation can be applied to the Saturnian system. However, more explanations for the long orbital periods of the satellites will be needed for applying the new Galilean satellite formation scenario to the Saturnian system. General satellite formation will be an attractive research area in future. In particular, satellite formation associated with the evolution of the planets' envelope will be important. Finally, observations of exomoons will open the way to statistical general satellite formation studies.