論文の内容の要旨

Planetesimal Accretion under a Realistic Accretion Condition
（現実的な合体条件を考慮した微惑星集積）

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Terrestrial planets, ice giants and the cores of gas giants are thought to be formed by the accumulation of planetesimals. There has been no research on accumulation correctly evaluating the merging criteria at the time of planetesimal collision by using *N*-body simulation, while a recent study used the conditions of protoplanet coalescence. In order to properly know the accretion process of planetesimals, it is necessary to clarify the merging criteria of the planetesimal including the rebound.

The rotation of protoplanet in the giant impact stage of planetesimal accretion affects the merging criteria of protoplanets and that becomes the initial condition of the study of terrestrial planet's rotation. The origin of Mars's rotation is revealed by the study of protoplanet's rotation because Mars is the survivor of protoplanets. The study of protoplanet's rotation is limited, in particular, the study using *N*-body simulation as first-principle calculation doesn't exist. The method is useful to know the mass, the velocity and the spatial distribution of planetesimals during the accretion process. Because the evolution of the distributions affects the rotation angular momentum of protoplanets, the study using *N*-body simulation is needed to know the realistic rotation of protoplanets, including Mars. In addition, the rebound of colliding planetesimals affects the rotation of protoplanets. Thus, the simulation needs to include the realistic merging criteria of planetesimals.

In this study, as the first step, we investigate conditions that determine coalescence vs. rebound (merging criteria) by numerically colliding undifferentiated rocky planetesimals, undifferentiated icy planetesimals, and differentiated icy planetesimals using Smoothed Particle Hydrodynamics (SPH). We vary the total mass, mass ratio, collision speed, and collision angle of the colliding planetesimals. We investigate the critical impact velocity distinguishing coalescence from the rebound by a radical change of the largest remnant's mass represented against impact velocity. The critical impact velocity normalized by the escape velocity depends on the mass ratio of planetesimals and the impact angles. The critical impact velocity normalized by the escape velocity decreases with the target mass increasing relative to impactor mass, and decreases with increasing the impact angle whose maximum value shows us a grazing collision. The critical

impact velocity is independent of the total mass of the planetesimals. This condition has a very small dependence on the composition and internal structure of the planetesimals. From the above results, we formulate the critical impact velocity as a variable for the planetesimals' mass ratio and collision angle.

As the second step, we investigate the accretion process of planetesimals to know the formation process and the rotation of protoplanets, including Mars, by using *N*-body simulation code named GPLUM (Global PLanetary system simulation code with Mass-dependent cut-off method). We apply to GPLUM the merging criteria necessary to account for the bounce of planetesimals. We set two hundred thousand rocky 100km-sized planetesimals as a narrow ring around the sun and calculate the orbits of the planetesimals by using *N*-body simulation. We compare the results of imperfect coalescence case and the results of perfect coalescence case, where all colliding planetesimals merge. Protoplanets grow similarly in each case but the time for sweeping surrounding planetesimals elongates in the imperfect coalescence case. The mass distribution is bipolarized since the growth of planetesimals is prevented by the rebound. Then, runaway growth and oligarchic growth becomes more prominent than the perfect coalescence case.

For both cases, the spin angular velocity rapidly increases when the collision with massive planetesimal occur. However, the angular velocity decrease with mass increasing by planetesimals accretion from random directions.
The mean spin angular velocity of planetesimals and protoplanets under the imperfect coalescence case is 70% and 30% smaller than the perfect coalescence case, respectively. The obliquity of protoplanets distribute in a wide range of angle and they have the peak around 90°, which is parallel to the ecliptic plane of the planetary system. The distribution is almost isotropic, which means the obliquity is decided by the stochastic component of angular momentum.