Formation of Various Asteroidal Shapes Through Collisions Between Equal-Mass Planetesimals and Its Application

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Recent in-situ observations by spacecraft and light curve observations by telescopes reveal shapes of about 1,000 asteroids, which lead to statistical discussion of past solar system using shapes of asteroids. About 60 percent of asteroids have the ratio between minor and major axis length less than 0.6, and thus significant fraction of asteroids have irregular shapes such as asteroid Itokawa. Irregular shapes of asteroids are supposed to be formed through collisional destruction and coalescence of planetesimals. Therefore, clarifying the relationship between impact conditions (e.g., impact angle or velocity) and shapes of collisional outcomes leads to constrain collisional environment or epoch that forms asteroidal shapes.

For relatively small objects like planetesimals, the material strength or friction is also important in addition to the self-gravity. To investigate resultant shapes of planetesimals formed through collisional destruction and reaccumulation, we developed the numerical simulation code of Smoothed Particle Elastic Dynamics (Sugiura and Inutsuka 2016, 2017) with the fracture model (Benz and Asphaug 1995) and friction model (Jutzi 2015) to describe property of rocky material. Owing to the friction model, we can reproduce irregular shape formation of rubble piles through reaccumulation of fragments.

We reproduced collisions between basaltic planetesimals with the radius of 50 km (i.e., equal-mass impacts), and varied the impact velocity from 50 m/s to 400 m/s with the increment of 25 m/s and the impact angle from 5 degree to 45 degree with the increment of 5 degree. We totally conducted 135 simulations. After each impact simulation, shape of the largest remnant is measured. As a result, we found that shapes of the largest remnants are classified to following 5 shapes depending on the impact velocity and angle: bilobed shapes, spherical shapes, flat shapes, elongated shapes, and hemispherical shapes. We also found that equal-mass impacts form extremely irregular shapes, such as extremely flat shapes with the ratio between minor and major axis length less than 0.4 or extremely elongated shapes with the ratio between intermediate and major axis length of about 0.2.
Extremely flat asteroids such as (471) Papagena or (1633) Chimay exist in the asteroid belt. However, average impact velocity in the present asteroid belt is about 4 km/s, which is much larger than ~100 m/s. Equal-mass impacts with such high impact velocity lead to catastrophic destruction, and our preliminary high-resolution simulation showed that catastrophic destruction does not form flat shapes. Impacts with small impactors compared to targets do not lead to catastrophic destruction, but such impacts also do not form flat shapes because impacts with high-mass ratio tend to merely form craters. Therefore, our simulations imply that extremely flat asteroids in the asteroid belt are formed through nearly equal-mass impacts in primordial environment before the formation of Jupiter.

Keywords: asteroid geometry, planetesimal collision, SPH method

