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Asteroid Shapes Formed Through Collisions and Constraint on Collisional History of Large Asteroids

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Abstract

Asteroids in the solar system are remnants of planetesimals existed in the planet formation era. Collisional lifetimes of asteroids larger than 100 km are much longer than the age of the solar system, and thus their shapes may be formed through impacts in the primordial solar system. We investigate shapes of asteroids formed through non-destructive impacts (mainly occur in the planet formation era) and destructive impacts (mainly occur in the present solar system) through numerical simulations. As a result, we find that similar-mass and non-destructive impacts produce various shapes including extremely flat shapes, while destructive impacts mainly produce spherical and bilobed shapes. These results suggest that flat asteroids with diameters larger than 100 km were probably formed through non-destructive impacts in the primordial environment and remain the same until today.

1. Introduction

Asteroids in the solar system are remnants of planetesimals existed in the planet formation era. Collisional lifetimes of asteroids larger than 100 km are much longer than the age of the solar system [6], and thus they may record information of the planet formation era. As we notice from the elongated shape of the asteroid Itokawa, asteroids have not only spherical shapes but also irregular shapes. Irregular shapes of large asteroids are mainly formed through collisions with asteroids. Because of the lack of large protoplanets, impact velocities in the planet formation era are smaller than several 100 m/s, which is comparable to the escape velocity from 100 km asteroids ~ 100 m/s. In contrast, impact velocities in the present solar system are about 5 km/s. Thus impacts in the primordial environment mainly result in non-destructive ones, while those in the present environment mainly result in destructive ones. Therefore, if we find the difference between shapes of asteroids formed through non-destructive impacts and those formed through destructive impacts, we can constrain the formation era of asteroids using those shapes.

2. Method

To investigate asteroid shapes formed through collisions, we conduct numerical simulations with Smoothed Particle Hydrodynamics (SPH) method for elastic dynamics [5]. We include the self-gravity, a model of fracture for brittle solid [1] and friction between completely damaged rock [4] to treat collisional destruction and shape formation through reaccumulation of fragments. For fast calculation of impact simulations, we parallelize our simulation code using Framework for Developing Particle Simulator (FDPS) [2,3].

3. Results

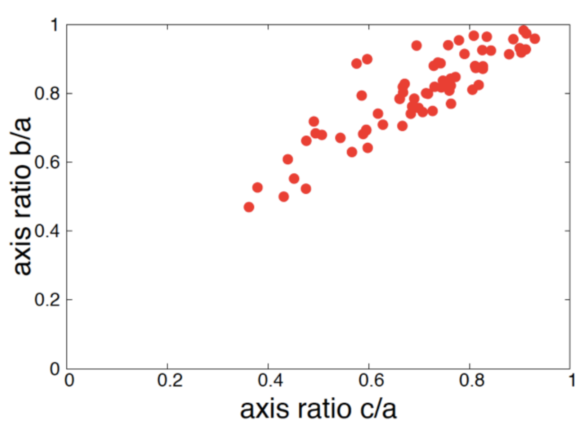

Figure 1: The axis ratio of remnants produced through a destructive impact and resolved by more than 5,000 SPH particles. The vertical axis shows the ratio of the minor to major axis lengths, and the horizontal axis shows the ratio of the intermediate to major axis lengths.

Figure 1 shows the axis ratios of remnants produced through the simulation of a destructive impacts with the impact velocity of 350 m/s, the impact angle of 15 degrees, and the diameters of impacting two bodies of 100 km. From Fig. 1, we find that spherical shapes and elongated (or bilobed) shapes are mainly formed through the impact, but flat shapes with the ratio of the minor to major axis lengths smaller than 0.6 are not formed. We also conduct the simulations of several destructive impacts with the impact velocity of 500 m/s – 2 km/s, and we find that any impacts do not produce flat remnants.

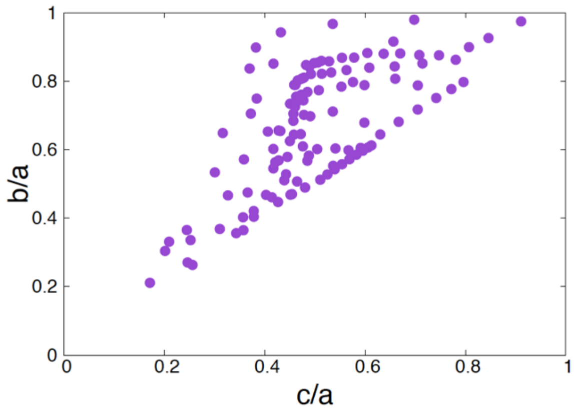

Figure 2: The axis ratios of the largest remnants produced through equal-mass and non-destructive impacts.

Figure 2 shows the axis ratios of the largest remnants produced through 135 simulations for equal-mass and non-destructive impacts. Diameters of impacting two bodies are 100 km, and we vary the impact velocity from 50 m/s to 400 m/s and the impact angle from 5 degrees to 45 degrees. From Fig. 2, we find that equal-mass and non-destructive impacts produce various irregular shapes including extremely flat shapes with the ratio of the minor to major axis lengths of about 0.4.

4. Discussion and Conclusion

Asteroid impacts in the present solar system mainly result in destructive ones, and thus Fig. 1 suggests that flat asteroids are difficult to be formed in the present environment. In contrast, impacts in the planet formation era mainly result in non-destructive impacts, and Fig. 2 shows that equal-mass and non-destructive impacts can produce flat asteroids. Thus we suggest that flat asteroids may be formed through low-velocity impacts in the planet formation era.

We investigate shapes of asteroids with diameters larger than 100 km. All the 8 asteroids that are included in asteroid families, which means they experience recent destructive impacts, have spherical shapes with the ratio of the minor to major axis lengths larger than 0.6. This is consistent with the result of our simulations of the destructive impacts. In contrast, the asteroids that do not belong to any asteroid families include several extremely flat asteroids with the ratio of the minor to major axis lengths of about 0.4, which is also consistent with the results of our simulations of the equal-mass and non-destructive impacts. Therefore, we conclude that the flat asteroids with diameters larger than 100 km in the solar system were probably formed in the planet formation era and remain the same until today.

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