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Disruption and reaccumulation: Forming the top shaped asteroids Ryugu and Bennu

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Abstract

Images of Ryugu and Bennu by the Hayabusa2 (JAXA) and OSIRIS-REx (NASA) missions show that both asteroids have top shapes, which are usually considered to be formed by YORP spin-up. We perform numerical simulations of asteroid disruption and subsequent fragment reaccumulation to investigate the conditions under which the catastrophic disruption of asteroid parent bodies can lead to such shapes. Considering a range of impact energies, we find that oblate spheroids are commonly formed during the reaccumulation phase following the disruption. In some cases, a ridge can also form directly at the equator of reaccumulated bodies. Such a scenario can explain the old age of the ridges of Ryugu and Bennu based on the presence of large craters covering them.

1. Introduction

Images of Ryugu and Bennu show that these two small, low-albedo asteroids have top shapes: oblate spheroids with a more or less pronounced equatorial ridge [1], [2]. The YORP thermal effect and its consequent spin-up has been invoked as the preferred origin of top shapes [e.g., 3]. However, large craters are found to cover the ridges of both asteroids, which implies that these ridges are old [e.g., 1] and which calls into question their late formation by YORP spin-up. Here, we investigate the disruption and reaccumulation process as the possible immediate origin of top shapes.

2. Disruption and reaccumulation

Asteroids as small as Ryugu and Bennu are likely fragments formed from the disruption of larger bodies. Numerical simulations of asteroid disruptions include both the fragmentation phase during which the asteroid is broken up into small pieces and the gravitational phase during which fragments may reaccumulate due to their mutual attractions and form rubble piles. Early simulations successfully reproduced the size distributions of asteroid families [4], showing that all fragments larger than 200 m are likely rubble piles formed by reaccumulation of smaller pieces. Model improvements [5] now allow us to assess shapes, with our initial simulations reproducing the shape of the asteroid Itokawa, as well as the presence of boulders on its surface [6].

We conducted a series of simulations involving the catastrophic disruption of large microporous asteroids (diameters between 600 m and 100 km). We tracked the subsequent gravitational phase where the fragments re-accumulate to form rubble piles. The fragmentation phase was simulated using a Smoothed Particle Hydrodynamics (SPH) hydrocode [7], and the gravitational phase was computed using the N-body code *pkdgrav*. N-body runs used either (i) the Hard-Sphere Discrete Element Method (HSDEM) to govern the contact physics and a model of rigid aggregation [8] or (ii) the Soft-Sphere Discrete Element Method (SSDEM) [9], assuming a range of friction parameters between the rubble-pile constituents [10]. In some cases, we increased the resolution at the time of re-accumulation to more thoroughly investigate the final shape. Once aggregate growth ceases, we computed a best-fitting ellipsoid to each body and a shape model for certain ones of interest. Figure 1 shows examples of results with both HSDEM and SSDEM.

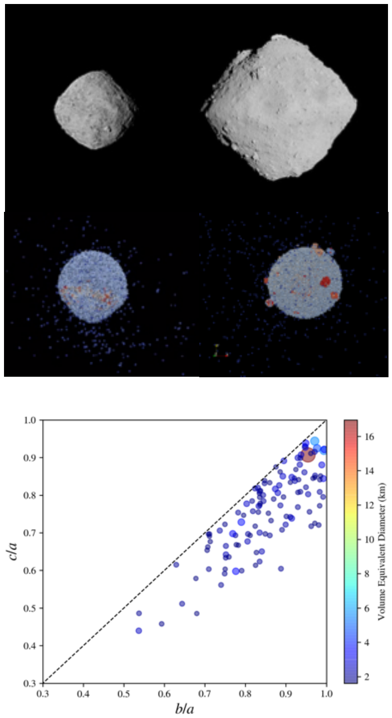

Figure 1: Top: Bennu (left) and Ryugu (right) images by OSIRIS-REx and Hayabusa2, respectively, with two examples of spheroidal aggregates from HSDEM simulations of reaccumulation shown beneath. The different colors on the surface correspond to different smaller boulder aggregates that reaccumulate late [6], which can explain the abundant presence of boulders on both asteroids. Bottom: Example of a distribution of axial ratios of the reaccumulated fragments following the catastrophic disruption of a 100-km asteroid, computed with SSDEM. The majority of reaccumulated rubble piles are oblate with axial ratios (b/a and c/a) that are both greater than 0.7, and only a small number of the rubble piles are prolates.

3. Conclusions

Oblate spheroids are a common product of large asteroid disruptions, and in some circumstances the formation of an equatorial ridge may be possible. We are currently assessing these circumstances. Forming top shapes by this process would provide an explanation to the apparent old age of the ridges of Ryugu and Bennu.

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