DISRUPTION AND REACCUMULATION AS THE POSSIBLE ORIGIN OF RYUGU AND BENNU TOP SHAPES

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Introduction: Images sent by the two sample-return space missions Hayabusa2 (JAXA) and OSIRIS-REx (NASA) show that asteroids Ryugu and Bennu are top shapes: oblate spheroids with a more or less pronounced equatorial bulge, also referred to as diamonds or bi-cones. Radar models of other asteroids, including binary primaries, as well as images by the ESA mission Rosetta of the asteroid Šteins, suggest that such shapes are common, which implies a systematic mechanism that favors their formation. The thermal effect called YORP [1] and its consequent spin-up has been invoked as the origin of top shapes [e.g., 2], but other processes may also lead to such a shape, or at least contribute to it. Here, we investigate the disruption and reaccumulation process and its role in the formation of top shapes.

Disruption and reaccumulation: Asteroids as small as Ryugu and Bennu are likely fragments formed from a larger body that was disrupted. Numerical simulations of asteroid disruptions—including 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—were first conducted in the early 2000s and successfully reproduced asteroid families [3]. These simulations showed that most asteroids with diameters greater than 200 m and formed by the disruption of a larger body are rubble piles produced by the reaccumulation of smaller fragments during the disruption. Early simulations concentrated on the size distribution and ejection speeds of the final bodies, to be compared to those of asteroid families, and not on the actual shapes of reaccumulated bodies. Improvements in the modeling [4] allowed assessing shapes, and the first resulting simulations reproduced successfully the shape of the asteroid Itokawa, as well as the presence of boulders on its surface [5].

Approach: To assess the role of the disruption/reaccumulation process in the formation of top shapes, we conducted a series of numerical simulations of catastrophic disruption of large microporous asteroids (diameters between 600 m and 100 km) and the subsequent gravitational phase when fragments reaccumulate to form rubble piles. The fragmentation phase was simulated using a Smoothed Particle Hydrodynamics (SPH) hydrocode and the gravitational phase was computed using the *N*-body code *pkdgrav*, including the Hard-Sphere Discrete Element Method (HSDEM). Once aggregate growth ceased, to measure the shape, we computed a best-fitting ellipsoid for each aggregate.

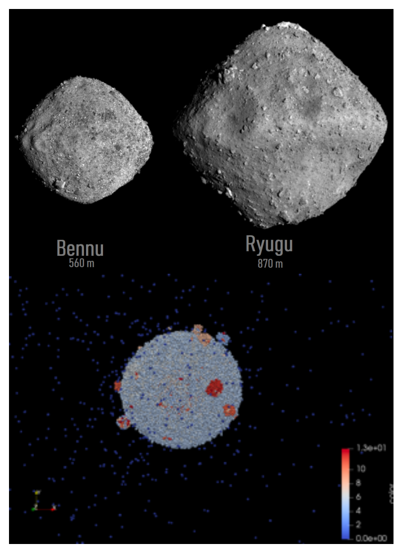

Fig. 1. Top: images of Ryugu (right) and Bennu (left) respectively taken by Hayabusa2 and OSIRIS-REx, to scale (credit: JAXA, U. Tokyo and collaborators; NASA/OSIRIS-REx). Bottom: spheroidal aggregate and surface boulders formed as a result of disruption and reaccumulation (colors permit identification of different boulders composing the aggregate; the color scale is irrelevant).

Results: In the investigated range of impact energies (close to the impact-energy threshold for disruption leading to a largest remnant with a mass about 50% that of the parent body), rapid formation of an aggregate can occur with sufficient mass concentration and low relative speed between particles in the ejecta field. This is followed by reaccumulation of smaller pieces over a longer timescale (Fig. 1). We found that many of the aggregates have aspect ratios that overlap existing top-shape asteroids, such as Ryugu and Bennu, and very few are elongated cigar-like asteroids such as Eros and Itokawa (Fig. 2). The disruption/reaccumulation outcome can thus explain the spheroidal shape of Ryugu and Bennu, as well as the abundance of boulders and other features, and the possible early origin of the ridge on Ryugu and Bennu based on the presence of big craters overlaying it. In some instances, with sufficient angular momentum in the local system, a reaccumulation disk can form that may lead to an equatorial ridge (Fig. 3), but more simulations on longer timescales are needed to confirm that this happens often and leads to top shapes.

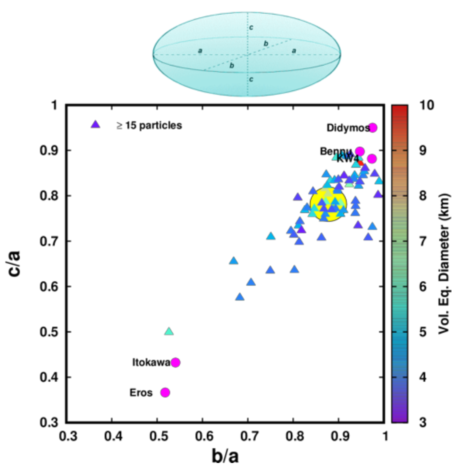

Fig. 2. Aggregates (triangles) formed in a simulation of catastrophic disruption starting with a 100-km diameter, 50% microporous body impacted at 4 km/s at an angle of 15°. Pink circles show real shapes of a few asteroids, including Bennu (Ryugu lies close to it), where most aggregates are concentrated.

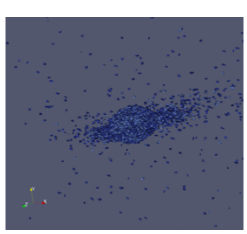

Fig. 3. Example of a forming aggregate surrounded by an equatorial disk of smaller reaccumulating debris.

Conclusions: Our first series of simulations of catastrophic disruption dedicated to the formation of Ryugu and Bennu show that aggregates with similar aspect ratios as Ryugu and Bennu easily form during the disruption process. Such a shape is a pre-requisite to form a top shape by YORP spin-up. Moreover, we also found that in some cases, for which the frequency of occurrence needs to be assessed, a debris disk can also form during reaccumulation that may lead to an equatorial ridge. In this case, the top shape is the immediate result of the catastrophic disruption process, without the need of a subsequent YORP spin-up process.

Perspectives: The current simulations of the gravitational phase were performed using HSDEM. The next step is to do them using the Soft-Sphere Discrete Element Method (SSDEM), which is more computationally expensive but also more realistic, as all contact forces are solved when fragments that reaccumulate are in contact. We will also simulate the formation of actual asteroid families, which are potential sources of Ryugu and Bennu, and check the occurrence of spheroidal/top-shape rubble piles in these specific cases. Then, we will check the consequence of parent-body compositional heterogeneity on that of reaccumulated bodies by tracking the regions within the parent body from which the reaccumulated fragments originate [6].

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