DISRUPTION AND REACCUMULATION: FORMING THE TOP-SHAPED ASTEROIDS RYUGU AND BENNU AND EXPLAINING THEIR DIFFERENT LEVELS OF HYDRATION.
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Introduction: Images of Ryugu and Bennu from 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 [1]. Moreover, they have the same bulk density and hydrated minerals, but the depth of the hydration band is much deeper for Bennu than for Ryugu [2,3]. We perform numerical simulations of asteroid disruption and subsequent fragment reaccumulation to investigate the conditions under which the catastrophic disruption of 100 km-diameter asteroid parent bodies can lead to bodies resembling Bennu and Ryugu, including their shapes, their porosity and their hydration level. 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 [4,5,6]. Moreover, aggregates with different levels of porosities and hydration can be formed in a single collision, supporting a possibly common origin for the two bodies.

Asteroid Disruption Process: Asteroids as small as Ryugu and Bennu are likely reaccumulated fragments formed from the disruption of larger bodies. Large asteroid disruptions include both a fragmentation phase during which the asteroid is broken up into small pieces and a gravitational phase during which fragments may reaccumulate due to their mutual gravitational attraction and form rubble piles. Early simulations of these two successive phases successfully reproduced the size distributions of asteroid families [7], showing that all fragments larger than 200 m are likely rubble piles formed by reaccumulation of smaller pieces. Model improvements [8] allowed assessing shapes, with our initial simulations reproducing the shape of the asteroid Itokawa and the presence of boulders on its surface [9]. Moreover, we can also address the level of heat experienced during the disruption by the material forming the different resulting aggregates, and their level of compaction (or porosity) [10].

Numerical Simulations of Asteroid Disruption: We conducted a series of simulations involving the catastrophic disruption of 100 km-diameter microporous asteroids [11]. 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 and the gravitational phase was computed using the N-body code *pkdgrav*. N-body runs used the Soft-Sphere Discrete Element Method (SSDEM) [12], covering a range of friction parameters between the rubble-pile constituents [13]. Once aggregate growth ceased, we computed a best-fitting ellipsoid to each body and a shape model for certain ones of interest. We also tracked the peak temperature experienced by the components of each aggregate in order to determine whether different aggregates formed in a single disruption can have different levels of hydration, as observed between Bennu and Ryugu, while preserving organic materials.

Results: We find that the final shapes of aggregates formed in a disruption cover a wide range of aspect ratios. However, for angles of friction in the range of that of Bennu [4], a concentration of aggregates of various sizes with aspect ratios as high as those of Bennu and Ryugu, which correspond to oblate spheroids, is remarkable (Fig. 1). Moreover, analyzing in more detail the shapes of our simulated aggregates, we find that some are very close to that of top-shape asteroids like Bennu and Ryugu. Our results imply that these bodies could form with their observed shapes as a direct result of reaccumulation. This is in line with observations that the ridge is one of the oldest features of those asteroids, as suggested by the largest undisturbed craters that overlay the equator of both objects.

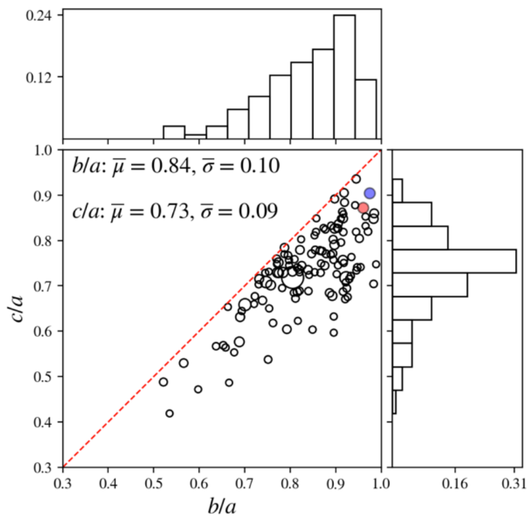

Figure 1: Example of a distribution of axial ratios of aggregated produced from the catastrophic disruption of a 100 km-diameter asteroid, computed with SSDEM. The marginal distributions of the minor-to-major axes (c/a) and the intermediate-to-major (b/a) axes are also presented. The majority of reaccumulated rubble piles are oblate with axial ratios (b/a and c/a) that are both > 0.7, and only a small number of the rubble piles are prolate. Bennu's and Ryugu's shapes are represented with blue and red circles, respectively.

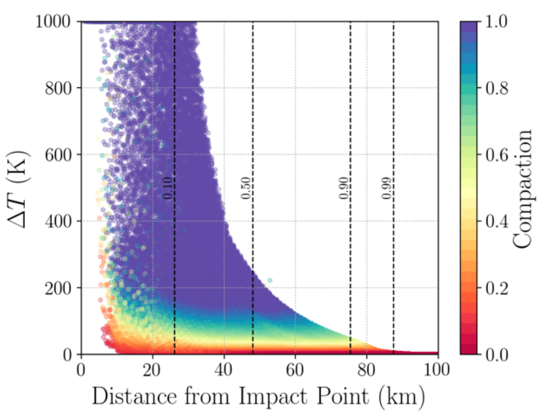

Figure 2: Peak temperature change experienced by the material forming one of the top shapes in our simulation as a function of the distance from the impact point where this material originated in its parent body. The level of compaction is scaled using colors and the vertical dashed lines highlight the fraction of escaping material that originate from within a given distance of the impact point (in this example, 50% of escaping material came from within 50 km of the impact point).

We also find that for a given aggregate shape, the average peak temperature change can cover a wide range (Fig. 2) and is correlated with the distance from the impact point where the material constituting those aggregates originated in the parent body. This average can exceed the threshold temperature at which phyllosilicate minerals may start to dehydroxylate (~400 ˚C for chrysotile). Therefore, we can expect those aggregates to have different levels of hydration. Thus, the different levels of hydration observed for Bennu and Ryugu do not necessarily mean that they come from two different parent bodies with two distinct thermal histories or that they experienced different surface heating histories after formation. It can actually be the natural outcome of the disruption of the same parent body, regardless of its internal heating history [14].

Conclusion: Numerical simulations of catastrophic disruption show that aggregates with a shape corresponding to or close to a top shape can form during such an event, and that these aggregates can show a difference in hydration level. Therefore, the observed hydration level difference between Bennu and Ryugu does not have to be due to a difference in their history once formed, but can be at the heart of their formation by the disruption of a common parent body. Their ridges could also originate from the event that formed them, which would solve the problem of the apparent old ages of these structures.

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