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Gravitation re-accumulation as an origin of asteroid shapes

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Abstract

We study the collisional and dynamical evolution of irregularly shaped fragments following an asteroid catastrophic disruption. Our goal is to understand the shapes and internal structure of gravitational aggregates through numerical simulations of the whole process. We concentrate our efforts on the re-accumulation phase after an energetic collision has taken place. Our starting point is the situation corresponding to the time at which part of the fragments have escaped the system and the remaining are beginning to re-accumulate. We study their evolution and interaction under their mutual gravitational forces using a discrete-element *N*-body numerical code (PKDGRAV). Here we show the results concerning final shape of tens of end-state aggregate structures ranging from rounded to elongated and contact binary. In the latter case we show a common formation pattern.

1. Introduction

Most asteroids smaller than some 100 km are believed to be gravitational aggregates formed in collisional processes in the main asteroid belt. Current observational evidence shows that there is a wide diversity of asteroid shapes. However, the reason why some asteroids look roundish while others look elongated is not currently understood, and no overall process responsible for such shapes has been identified to date.

Speculations on the origin of asteroid shapes invoke mechanisms such as collisions and spin-up effects. The case of contact binaries is particularly interesting, that is elongated bodies in which two parts can be clearly identified: a body where most of the mass is, and a head, both resting on each other in a stable configuration.

The fate of asteroid shaping is likely related to their collisional history and internal structure. Asteroids are formed inside the asteroid belt, where relative encounter speeds are distributed about 5.8 km/s and collisions are mostly catastrophic. Unfortunately, no direct measurement of asteroid interiors has been possible yet. Notwithstanding, experimental, theoretical, statistical, and numerical studies have been carried out over the last four decades and may help us to understand the processes that affect such bodies and may influence their structure and shape. This study is part of a wide investigation about the process of fragment re-accumulation that follows high-speed impacts between asteroids. The detailed description of the overall study and quantitative results regarding asteroid density and porosity and their implications are in [1].

2. Methodology

We perform numerical simulations of the collisional and dynamical evolution of irregularly shaped rigid fragments interacting under their mutual gravitational forces after a collision takes place. Each rigid fragment (usually referred to as fragments or components) is modelled as a packing of hundreds of rigid particles whose mutual distance is kept constant. Such fragments cannot deform nor break, so they move under rigid-body mechanical laws and can experience partially inelastic collisions with other fragments. Such simulations were performed using a discrete-element N-body numerical code (PKDGRAV) [2], [3], [4].

3. Results

The final shapes of the end-state aggregate structures are generally irregular due to the fact that the re-accumulation process is mostly stochastic. Different mass distributions, irregular fragment shapes, and different angular momenta drive each system to configurations with no particular link to their initial conditions. Some relation of shapes to the size of the initial cloud of fragment can be envisioned.

We identify a general mechanism for the formation of contact binary objects. Our results are quantitatively in agreement with the different density estimation of the two components of contact binary asteroid Itokawa [5] visited by the Hayabusa space probe (JAXA). Some of the performed simulations of the reaccumulation phase even lead to the formation of a satellite.

4. Summary and Conclusions

The process of gravitational re-accumulation of fragments following asteroid collisions offers a general mechanism to explain asteroid (and possibly comet) morphology, including contact binaries and possibly asteroid pairs and clusters, while it suggests a possible scenario for the formation of asteroid binary systems.

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