EPSC Abstracts
Vol. 5, EPSC2010-223, 2010
European Planetary Science Congress 2010

Numerical simulations of catastrophic disruption of porous bodies: application to dark-type asteroids and Kuiper-Belt family formation

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Abstract

Asteroids of dark (e.g. C, D) taxonomic classes as well as objects in the Kuiper Belt and comets are believed to have high porosity, not only in the form of large voids but also in the form of micro-pores. The presence of such microscale porosity introduces additional physics in the impact process. We have recently enhanced our 3D SPH hydrocode—used to simulate the catastrophic breakup of small bodies—with a model of porosity [1] and validated it at small scale by comparison with impact experiments on pumice targets [2]. Our model is now ready to be applied to large range of problems. In particular, accounting for the gravitational phase of an impact event, we can now address the problem of the formation of dark-type asteroid families, such as Veritas, and Kuiper-Belt families, such as Haumea.

1. Introduction

Measured bulk densities of a few C-type asteroids, such as the NEAR spacecraft target Mathilde, whose bulk density is about 1.35 g/cm^3 [3], indicate that dark type bodies contain higher porosity compared to meteorite analogues. The very low bulk densities (< 1 g/cm^3) of cometary bodies also suggest a high fraction of porosity. Two kinds of porosity can be defined: macro-scale porosity is characterized by the presence of large voids between the blocks that compose a small body, while micro-scale porosity is characterized by the presence of small pores whose size is smaller than the thickness of the shock front (and generally than the numerical resolution) during an impact. The presence of micro-pores introduces new phenomena during an impact. In particular, those pores are crushed, which causes an additional dissipation of energy and leads to compaction and heating of the material. Thus, one cannot use a model of fragmentation of non-porous materials to study the impact process of porous bodies by simply reducing the original bulk density of the material to account for porosity. Several models of porosity have been developed and introduced in numerical codes [1], [4], [5], [6]. Recently we used our model, which was validated at small scale by comparison with impact experiments on pumice targets [2] to characterize for the first time the catastrophic impact energy threshold, usually called Q^*_D, as a function of the target's diameter, porosity, material strength and impact speed [7]. We can now apply it for the first time to the formation of dark-type asteroid families and Kuiper-Belt families, from the catastrophic break-up of a large parent body at high impact speeds (> km/s).

2. Formation of the Veritas family

The asteroid family named after the asteroid Veritas is thought to have been formed from the disruption of a 140 km-diameter parent body. Its age is quite young and has been estimated to be about 8 Myr [8]. Therefore, its current properties should still be close to those resulting from the disruption. However, this family is not in a dynamically quiet region of the main belt and alternative scenarios have been considered regarding the attribution of some members to this family. Because it is classified as a C-type family, we have studied its formation using our fragmentation model for both non-porous and porous bodies (coupled with the numerical code pkdgrav to follow the gravitational evolution of the fragments, which contribute to the collisional process at such a scale) and considered different scenarios. Preliminary results provide strong constraints on the original properties of the parent body and on the actual membership to this family, which may require revisions to the definition of this family. The current state of this investigation will be presented.

3. Formation of the Haumea family

The Haumea family is the first family identified in the Kuiper Belt [9]. Haumea is a rapidly rotating elongated dwarf planet (~ 1500 km in diameter), which has two satellites. All members of the Haumea system share a water ice spectral feature that is distinct from all other KBOs. Because the relative speeds between the Haumea family members are rather small, it was suggested that a catastrophic break-up at impact speeds consistent with the dynamical history of the Kuiper Belt (2–3 km/s) could not form this family and that all of the unusual characteristics of the Haumea system can be explained by a graze-and-merge giant impact between two comparably sized bodies [10]. However, such a suggestion was made without accounting for the potential presence of small-scale porosity in the Haumea parent body, which may allow the formation of this family using an impact speed consistent with the dynamical history of the belt. We have started to perform numerical simulations of the catastrophic disruption of the Haumea parent body, represented by a differentiated body containing micro-porosity, and using high impact speeds (3 km/s). Results of our investigation will be presented, indicating whether a scenario consistent with the dynamics of the Kuiper-Belt is found or if the formation of this family must rely on an unexpected event.

6. Summary and Conclusions

Thanks to our model of fragmentation of porous materials, in addition to that of non-porous materials, we can now address the impact process on a wide range of small bodies belonging to different kinds of populations and characterize their impact response and the outcome of their disruptions. After having characterized the catastrophic impact energy threshold Q^*_D as a function of target diameter, porosity, material strength and impact speed, we have started studying the formation of dark-type asteroid families and Kuiper-Belt families, showing that accounting for porosity leads to different outcomes that may better represent the properties of these families and constrain their definition. The parameter space is still large and many interesting families exist that need to be investigated. Therefore, these yet preliminary investigations will continue on the long term and be applied to a large range of cases.

Acknowledgements

PM, MJ and DCR acknowledge financial support from the French Programme National de Planétologie. from NASA PG&G ”Small Bodies and Planetary Collisions" and from NASA under Grant No. NNX08AM39G issued through the Office of Space Science, respectively.

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