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Large asteroid families modelled by impact events

P. G. Benavidez (1,2), D. D. Durda (3), B. Enke(3), A. Campo Bagatin (1,2), D. C. Richardson (4), E. Asphaug (5) and W. F. Bottke (3)
(1) Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal, (2) Instituto Universitario de Física Aplicada la Ciencias y la Tecnología, (3) Southwest Research Institute, (4) University of Maryland at College Park, (5) Arizona State University

Abstract

We present a study of large asteroid families modeled by impact events. To extend the work started by [1] and [2], we performed a new set of simulations in the gravity regime for monolithic and rubble-pile targets of 400 km diameter. Here we analyze and discuss if the studied families are best matched by the modeled size-frequency distribution (SFD) resulting from a monolithic or rubble-pile parent body.

1. Introduction

Many authors have used the fragment SFDs produced by impact simulations to glean insights into parent body sizes and disruption conditions for asteroid families (e.g., [1], [2], [3). In particular, several authors have used the results of SPH codes to explore the disruption of $D > 100$ km-diameter parent bodies. Basically, what these studies do is plot to the same scale the modeled SFD and the observed family SFD in a single chart. Modeled impacts assume a particular target size; therefore, the resulting largest remnant and SFD of associated fragments may need to be offset to larger or smaller sizes to match the observed SFD. This offset suggests a larger or smaller parent body for the observed family. However, in some cases, especially when the parent body is actually quite different in size from the particular modeled target (usually 100 km diameter), the methodology used to date could provide results that are not entirely accurate. Specifically, the SFDs of $D >> 100$ km-diameter targets could have significantly different features compared to those for a $D = 100$ km target, i.e., relative mass of the largest fragment and/or the SFD slope of smaller fragments. This is because the effects of gravity in the reaccumulation process of such larger bodies do not simply scale linearly.

On this basis, we extend the systematic investigation of impact outcomes started by [1] and [2] to 400 km-diameter targets using the same range of impact conditions and two internal structures: monolithic and rubble-pile.

2. Modeled families' SFD

The procedure applied to determine families is detailed in [4]. We have considered asteroid families with an alternative estimation of the parent body size. That is, the progenitor size estimation is based on geometric considerations ([3] and [5]). Then, we selected families with large expected parent bodies (of order $D = 400$ km) to compare with our new set of simulations. This procedure ensures the shift is appropriately small, so we have higher confidence when matching the SFDs.

We investigated four asteroid families: Hygiea, Vesta, Themis and Eunomia. To measure a match between our simulation and the observed families we calculate the chi-square statistic (χ^2) to find the best matches for both monolithic and rubble-pile targets.

3. Results and Conclusions

For the Hygiea family, a good match was found that corresponds to a cratering event onto a rubble-pile target involving a projectile of $D = 54.4$ km at 7 km/s and impact angle of 60°. Regarding the monolithic target, all the "best" potential cases have problems fitting the size range from ~25 to ~70 km-diameter. Then, the parent body of the Hygiea family could have a rubble-pile internal structure of 416 km diameter.

For the Eunomia and Vesta families we found fairly good matches. For Eunomia, the best match corresponds to a super-catastrophic breakup onto a monolithic target that was impacted by a projectile of D ~186 km at 6 km/s and impact angle of 45°. The results suggest that the parent body of the Eunomia family could be a monolithic body of 382 km diameter. Regarding impact simulations with a rubble-pile target, we found at least four different impact conditions that match the observed SFD for fragments larger than D ~25 km. However, below this size, the modeled SFD slope became shallower than the observed one. We rule out these cases on this basis. On the other hand, [6] found two subfamilies within Eunomia, which they attribute to separate cratering events. This could suggest that some collisional process happened in this family, modifying its SFD at some level. Then, this could explain why the matches found are fairly acceptable but not perfect. It should be studied carefully in future work.

For the Vesta family, an impact simulation with a monolithic target impacted by a projectile of D ~100 km at 6 km/s and impact angle of 75° is the one that best matches the observed SFD. The agreement is quite good for fragments of $D > 15$ km, but below this size the modeled SFD slope remains very steep, as is usual for such oblique impacts. The parent body size estimated from this impact is $D = 468$ km, in good agreement with the geometrical estimation.

For the Themis family, it was not possible to find a good match. From either monolithic or rubble-pile targets it is possible to match the largest fragment and the SFD slope for $D < 60$ km, however it is hard to reproduce the observed bump around $D = 100$ km. The χ^2 value suggests that the SFDs of rubble-pile cases are closer to the observed one, but there are no really satisfactory matches because the bump is not as bulging as in the Themis SFD. The fact we could not find an acceptable match for this family could be due to several reasons:

a) The modeled internal structures in this work are very simple and the Themis family could have a more complex internal structure.
b) The existence of the Beagle subfamily indicates that the Themis family has undergone some collisional activity over time.
c) It could be possible that the Themis parent body had a size $D \sim 250 - 300$ km or different bulk density than the simulated targets.

We suggest that an extension of impact simulation models to differentiated targets is necessary to build a more complete picture of the impact physics. It would helps to constrain the impact conditions of the Themis family and likely other families.

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