Internal structures of asteroids and comets: Beyond spherical cows

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The internal structure of asteroids and comets is fundamentally unknown due to difficulties in sounding their interiors. The measurements carried out by space probes and the observations of binary asteroids (optical and radar) have provided good estimates of the masses of a few asteroids. From their sizes and shape models, estimates of their bulk densities are derived. Such bulk densities are usually smaller than the values corresponding to typical densities of meteorites with compositions matching surface spectroscopical observations of those asteroids, raising doubts about the actual composition of their interiors [1]. Similar arguments — but with much larger uncertainties — hold for comets.

One interpretation of such low bulk densities is that part of the volume is occupied by voids in between the coherent components forming their global structures, qualifying them as gravitational aggregates (also, ”rubble piles”). The origin of such bodies is likely to be related to former catastrophic disruptions or to the original planetesimal accumulation process. Moreover, numerical simulations of the collisional evolution of the asteroid belt predict that most of the bodies between some hundreds of meters and about 100 km should be gravitational aggregates [2]. The situation is a little fuzzier in the case of comets.

In this research, we try to reproduce the internal structure of some of the asteroids with best known physical characteristics (mass, size, rotation state) going beyond the simulation of components by just spheres. We perform numerical simulations that produce irregularly shaped (roughly 3-axial) asteroid components. Simulations are performed using the code PKDGRAV [3,4] with the new soft-sphere implementation [5] that manages the N-body gravitational problem and accounts for collisions between components and for friction between them. In order to mimic non-spherical shapes, groups of spherical particles — the basic elements of the PKDGRAV code — are forced to keep their mutual distances constant so they can be handled and behave like rigid bodies. Both size-ratio distributions for the shapes of the components and their mass spectra are extracted from the results of high-speed impact experiments carried out on basalt targets at NASA AVGR (Ames Vertical Gun Range) in July 2013 [6]. The total mass of the synthetic components is scaled to the mass of some of the best known asteroid masses, assuming a given material density. They are then distributed randomly in space allowing for their self-collapse by mutual gravitational interactions. The total volume of the gravitational aggregate finally formed is then calculated along with its bulk density. Eventually the results are compared with the bulk densities of actual asteroids. If there is no agreement, the mass spectrum of the components is changed so as to fit the observationally estimated values. In addition, the density of the synthetic components can be changed to fit the observed values. When an agreement is finally found, the asteroid structure is plausibly determined for the assumed component shape and mass distribution, and the density of the monolithic components of the observed asteroids is directly given by the density of the synthetic components. The comparison of such densities with known meteoritic analogues allows us to constrain the mineralogical composition of the investigated asteroid.

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