Simulations of impacts on rubble-pile asteroids

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Rubble-pile asteroids can contain a high level of macroporosity. For some asteroids, porosities of 40 % or even more have been measured [1]. While little is known about the exact distribution of the voids inside rubble-pile asteroids, assumptions have to be made for the modeling of impact events on these bodies. Most hydrocodes do not distinguish between micro- and macroporosity, instead describing brittle material by a constitutive model as homogeneous.

We developed a method to model rubble-pile structures in hypervelocity impact events explicitly. The formation of the asteroid is modelled as a gravitational aggregation of spherical 'pebbles', that form the building blocks of our target. This aggregate is then converted into a high-resolution Smoothed Particle Hydrodynamics (SPH) model, which also accounts for macroporosity inside the pebbles.

We present results of a study that quantifies the influence of our model parameters on the outcome of a typical impact event of two small main-belt asteroids. The existence of void space in our model increases the resistance against collisional disruption, a behavior observed before [2]. We show that for our model no a priori knowledge of the rubble-pile constituents in the asteroid is needed, as the choice of the corresponding parameters does not directly correlate with the impact outcome.

The size distribution of the pebbles used as building blocks in the formation of an asteroid is only poorly constrained. As a starting point, we use a power law $N(>r) \propto r^{\alpha}$ to describe the distribution of radii of the pebbles. Reasonable values for the slope α range around $\alpha = -2.5$, as found in the size distribution of main-belt objects [3,4]. The cut-off values for pebbles, $r_{\min}$ and $r_{\max}$ are given by practical considerations: In the SPH formalism, properties are represented by weighted averages of particles within their smoothing length h, preventing the resolution of structures below that scale. Using spheres with radius in the range of h results in a practically monolithic body, as well as using spheres of a radius similar to the asteroid itself. We quantify the sensitivity of impact outcomes to the choice of parameters.

Propagation of the shock front inside the asteroid depends on the pebble size distribution. While larger pebbles transmit the shock wave further into the structure, resulting in a steeper crater, small pebbles result in a more evenly distributed shock front and a wider crater. Because the shock wave is transmitted only at the small contact area of the pebbles, the shock wave is focused at the contact points and material can be compressed or damaged even at a distance to the impact zone. We create maps of the displacement of pebbles at the surface of the asteroid on the opposing site of the impact event. This can possibly be used to relate surface features on asteroids like Šteins or Itokawa to specific impact events.

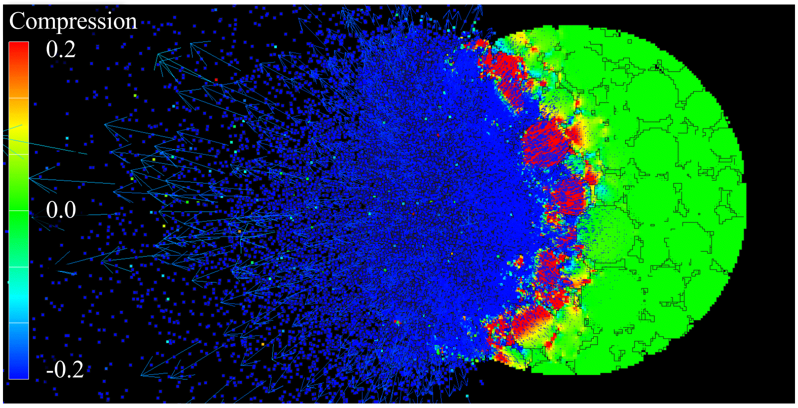

Figure: Compression inside an impacted asteroid of $r_{\text{ast}} = 164\,\text{m}$ by an impactor of $r_{\text{imp}} = 4\,\text{m}$ at $v_{\text{imp}} = 5.5\,\text{km}\,\text{s}^{-1}$. The asteroid model was created using a gravitational aggregate formed by spherical pebbles that follow a power law with slope $\alpha = -2.5$, limiting minimal radius $r_{\min} = 6.86\,\text{m}$ and limiting maximal radius $r_{\max} = 32\,\text{m}$.

References: [1] Britt, D. et al. Asteroids III, pp. 485–500, 2003. [2] Holsapple, K. A., PSS, 2009, Vol 57, No. 2, p.127–141. [3] Davis, D. et al. Asteroids III, pp. 545–558, 2002. [4] Gladman, B., et al., Icarus, Vol. 202, pp. 104–118, 2009.