Simulator for Formation of Rubble-Pile Asteroids Using Open-Source Physics Simulation

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There are various shapes of rubble-pile asteroids. Ryugu and Bennu have a nearly rotationally symmetric top shape, while Itokawa has an elongated shape. Ground-based telescope observations also suggest that there is much diversity in the shape of the rubble-pile asteroids. Even though many factors contribute observed wide variety of rubble-pile asteroids, it is guessed that the size-frequency distribution of fragments of the parent body and their accumulation conditions strongly control them.
The purpose of this research is to investigate the relationship between the conditions for rubble-pile accumulation, including the size-frequency distribution of fragments, and the final shape of the asteroid. This investigation is carried out by simulating the accumulation process of rubble-pile asteroids. In the simulation, the fragments are treated as a rigid body, and basic physical interactions such as contact, friction, rotation, and gravity between fragments need to be reproduced. In this research, we implement these physical processes using open-source physics engine Chrono (https://projectchrono.org/). Chrono can handle physical interactions between objects of various shapes. In addition, while most physics engines used in games and other applications perform single-precision operations, Chrono is capable of double-precision operations. Ferrari et al. (2017, 2020) were early examples attempting to simulate rubble-pile asteroid formation using Chrono, but they were not discussed well the final shapes of rubble-pile asteroids.
This research aims to implement a simulator using Chrono, following previous research, and to simulate with different parameters such as size-frequency distribution, shape, total number, dynamic friction, static friction, rebound, and rolling resistance coefficient of the fragments.
In our test simulation, fragments with a same polyhedron shape with a triaxial ratio of $2:2^{1/2}:1$ (the average triaxial ratio of rocks in space) are attempted to accumulate to form a rubble-pile asteroid. Two cases of the size-frequency distributions of fragments are tested: a monopolistic case with one largest fragment and an oligopolistic case with four largest fragments. Ten runs have been performed for these two cases, and the final shape of the rubble-piles were examined. It was approximated as an ellipsoid and the triaxial ratio was calculated. As the result, all rubble-piles have larger triaxial ratios than that of the single fragment ($2:2^{1/2}:1$). No difference in the triaxial ratio distribution is found between monopolistic and oligopolistic cases. Order of accumulation may affect the final shape: In a case when one of the largest fragments or the second large fragment accumulates later, the rubble-pile shows an elongated shape. This presentation will explain the detailed parameters and accumulation conditions of the fragments in the simulation and discuss the results.

Keywords: rubble-pile asteroid, rigid body simulation, size-frequency distribution

