Modeling High-Porosity Regolith on Low-Gravity Planetary Surfaces  J. V. DeMartini¹ and D. C. Richardson³,
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Introduction: Recent sample-return missions to asteroids (101955) Bennu [1] and (162173) Ryugu [2] have revealed their rough surfaces are strewn with regolith particles ranging from millimeters to tens of meters in diameter with a broad spectrum of shapes [3]. Numerical modelers often simulate these kinds of bodies as rubble piles composed of discrete particles with rock-like material properties. The particles in most models for the past few decades have been independent spheres meant to represent the individual grains that make up the surface and interior of a rubble pile [4, 5]. It has been shown, however, that grain shape has a significant effect on the flow and equilibrium states of particles in granular media [6]. Simulating irregular grain shape is thus imperative for accurately modeling the surfaces and interiors of rubble-pile asteroids.

One of the most challenging aspects of simulations using spherical particles is creating high-porosity media. The densest packing distribution of monodisperse spheres has ~26% porosity; porosities of polydisperse spheres in a randomly packed orientation approach 35-45%. Bennu and Ryugu were each found to have bulk densities on the order of 1.1 g/cc, indicating bulk macroporosities of 50% or larger [1, 2]. Furthermore, the depth to which the arm of the OSIRIS-Rex TAGSAM spacecraft penetrated Nightingale crater showed that it met little resistance from the regolith surface of Bennu [7], which may indicate that the finer-grained parts of regolith surfaces could have porosities larger than the bulk macroporosity. The low bulk densities and high macroporosities of rubble piles that have been visited by spacecraft seem to indicate subsurface structure mainly supported by contact networks between regolith grains strengthened by grain shape and interparticle cohesion from electrostatic and van der Waals forces [8]. These recent results, in combination with historical measurements on the lunar surface [9], show a need to be more methodical in preparing “fluffy” granular beds to accurately reproduce surface structure on low-gravity, airless bodies.

Modeling & Approach For our experiments, we use the parallel N-body gravity tree code PKDGRAV [10]. PKDGRAV uses a soft-sphere discrete element method to model surface grains as individual spheres that feel interparticle and uniform gravity, cohesion, and contact forces. The contact forces from the soft-sphere method allow particles to slightly interpenetrate at the point of contact, using a restoring spring force to model the stiffness (akin to the Young’s modulus) of the material and applying normal and tangential damping and forces like interparticle friction. More recently, we have made improvements to routines handling irregularly shaped “aggregate” particles, made by “gluing” together two or more spheres [11].

Aggregates allow PKDGRAV users to capture geometric effects like bulking, where low-sphericity polyhedra generally occupy larger volumes than spheres when packing, accounting for increased porosity and resistance to flow in granular media. With this in mind, we model the gentle deposition of aggregates under microgravity and lunar gravity to create highly porous (>50% porosity) granular assemblies both with and without cohesion. We use aggregates composed of centimeter-scale spheres and model both symmetric and asymmetric shapes, as well as systems with both aggregates and single spheres. We calculate the porosity of these systems by generating a concave hull around the settled system and calculating the ratio of the total volume in particles interior to the hull to the total hull volume, with interior particle volume modified to account for particle-particle overlaps and particle fractions partially exterior to the hull [12] (Fig. 1).