Applications of granular-dynamics numerical simulations to asteroid surfaces

D. C. Richardson[1], P. Michel[2], S. R. Schwartz[2], Y. Yu[3], R.-L. Ballouz[1], and S. Matsumura[4]

[1]Department of Astronomy, University of Maryland, College Park, MD, USA 20742
[2]Lagrange Laboratory, University of Nice-Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur, France
[3]School of Aerospace, Tsinghua University, Beijing 100084 Republic of China
[4]School of Engineering, Physics, and Mathematics, University of Dundee, Scotland DD1 4HN

Spacecraft images and indirect observations including thermal inertia measurements indicate most small bodies have surface regolith. Evidence of granular flow is also apparent in the images. This material motion occurs in very low gravity, therefore in a totally different gravitational environment than on the Earth. Upcoming sample-return missions to small bodies, and possible future manned missions, will involve interaction with the surface regolith, so it is important to develop tools to predict the surface response. We have added new capabilities to the N-body gravity tree code pkdgrav [1,2] that permit the simulation of granular dynamics, including multi-contact physics and friction forces, using the soft-sphere discrete-element method [3]. The numerical approach has been validated through comparison with laboratory experiments (e.g., [3,4]).

(1) We carried out impacts into granular materials using different projectile shapes under Earth's gravity [5] and compared the results to laboratory experiments [6] in support of JAXA's Hayabusa 2 asteroid sample-return mission. We tested different projectile shapes and confirmed that the 90-degree cone was the most efficient at excavating mass when impacting 5-mm-diameter glass beads. Results are sensitive to the normal coefficient of restitution and the coefficient of static friction. Preliminary experiments in micro-gravity for similar impact conditions show both the amount of ejected mass and the timescale of the impact process increase, as expected.

(2) It has been found (e.g., [7,8]) that "fresh" (unreddened) Q-class asteroids have a high probability of recent planetary encounters ($\sim$1 Myr; also see [9]), suggesting that surface refreshening may have occurred due to tidal effects. As an application of the potential effect of tidal interactions, we carried out simulations of Apophis' predicted 2029 encounter with the Earth to see whether regolith motion might occur, using a range of plausible material parameters [10]. We confirm that global shape modification of the asteroid will be negligible [11] and focus on the external perturbations affecting sand piles at various surface locations. We predict that no major landslides will occur, but slight disturbances resulting in regolith motion may take place, depending on the details of the sand-pile structure.

(3) The OSIRIS-REx asteroid sample-return mission will use a sampling device designed to penetrate the surface regolith and collect up to 60 g of material by propelling it into the device using compressed nitrogen gas. We conducted numerical experiments for the expected encounter conditions, including the spacecraft touchdown speed and mechanical properties, that show the surface compliance is a strong function of material parameters, even in the micro-gravity environment.

(4) A large intruder in a container filled with smaller particles will rise to the top when the container is shaken vigorously, a phenomenon known as the Brazil-nut effect. This effect has been invoked as a possible explanation for the origin of exposed boulders on small-asteroid surfaces [12]. We studied the effect over a wide range of parameters and compared against experiments [13]. We find the Brazil-nut effect is not sensitive to coefficients of restitution but is sensitive to friction constants and the oscillation frequency. We find the rise speed of the intruder is proportional to the square root of the ambient gravitational acceleration. The critical oscillation speeds for the effect to take place are comparable to expected seismic events from non-destructive impacts on small bodies.

Acknowledgements: DCR acknowledges support from NASA (grants NNX08AM39G, NNX10AQ01G, and NNX12AG29G) and NSF (AST1009579). PM acknowledges support from the French space agency CNES. SM acknowledges support from the Center for Theory and Computation at U Maryland and the Dundee Fellowship at U Dundee. Most simulations were performed using the YORP cluster in the Department of Astronomy at U Maryland and on the Deepthought High-Performance Computing Cluster at U Maryland.

References: [1] Richardson, D.C. et al. 2000, Icarus 143, 45. [2] Stadel, J. 2001, Ph.D. Thesis, U Washington. [3] Schwartz, S.R. et al. 2012, Gran Matt 14, 363. [4] Schwartz, S.R. et al. 2013, Icarus 226, 67. [5] Schwartz, S.R. et al. 2014, P&SS, submitted. [6] Makabe, T., Yano, H. 2008, Proc. 26th Intl. Conf. Space Tech. & Sci. 2008-k-08. [7] Binzel, R.P. et al. 2010, Nature 463, 331. [8] Nesvorny, D. et al. 2010, Icarus 209, 510. [9] DeMeo, F.E. et al. 2014, Icarus 227, 112. [10] Yu, Y. et al. 2014, Icarus, submitted. [11] Scheeres, D.J. 2005, Icarus 178, 281. [12] Tancredi, G. et al. 2012, MNRAS 420, 3368. [13] Matsumura, S. et al. 2014, MNRAS, submitted.