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Granular physics in low-gravity enviroments

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Abstract

The granular media are formed by a set of macroscopic objects (named grains) which interact through temporal or permanent contacts. Several processes has been identified which require a full understanding, like: grain blocking, formation of arcs, size segregation, response to shakes and impacts, etc.

These processes has been studied experimentally in the laboratory, and, in the last decades, numerically. The Discrete Element Method (DEM) simulate the mechanical behavior in a media formed by a set of particles which interact through their contact points.

We describe the implementation of DEM for the study of several relevant processes in minor bodies of the Solar System. We present the results of simulations of the process of size segregation in low-gravity environments, the so-called Brazil nut effect, in the cases of Eros and Itokawa. The segregation of particles with different densities is also analyzed, with the application to the case of P/Hartley 2. The surface shaking in these different gravity environments could produce the ejection of particles from the surface at very low relative velocities. The shaking that cause the above processes is due to impacts or explosions like the release of energy by the liberation of internal stresses or the reaccommodation of material. We run simulations of the passage of seismic wave produced at impact through a granular media.

1. Introduction

Granular materials of different sizes are present on the surface of several atmosphereless Solar System bodies. Polarimetric observations, direct images and landing on asteroids and the Moon have shown the presence of very fine particles, the so-called regolith, as well as boulders of m-sizes and bigger on their surfaces.

Furthermore, it has been proposed that several processes typical of granular material can explain some features observed on the surfaces of these bodies; like the size segregation of boulders on Itokawa, the displacement of boulders on Eros, the avalanches, etc..

The phenomena related to granular material has been studied in the framework of the discipline called Granular Physics. The granular media are formed by a set of macroscopic objects (named grains) which interact through temporal or permanent contacts. The range of materials studied by Granular physics is very broad, like: rocks, sands, talc, powders, pills, etc..

These processes has been studied experimentally in the laboratory, and, more recently, numerically. The numerical simulation of the evolution of granular materials has been done with the Discrete Element Method (DEM). DEM is a family of methods for computing the motion of a large number of particles, like molecules or grains, under given physical laws.

The low-gravity space environments are difficult to be reproducible in a ground-based laboratory. Therefore, the numerical simulation is the most promising technique to study the phenomena affecting granular material in vacuum and low-gravity environments.

For the DEM simulations we have used an adapted version of the package ESyS-particle ([1]; *https://launchpad.net/esys-particle*) to our needs. ESyS-particle is an Open Source software for particle-based numerical modeling.

2. Numerical experiments

2.1 Size and density segregation

Consider a recipient with one large ball on the bottom and a number of smaller ones on top of it. All the balls have similar densities. After shaking the recipient for a while, the large ball rises to the top and the small ones sink to the bottom ([2],[3]). This is the so called Brazil nut effect (BNE).

In order to simulate this effect under different gravity conditions, we run simulations of a 3D box with many small particles and one big particle on the bottom, the so called intruder model system ([3]). We run simulations under several gravity conditions: the surface of the Earth, Moon, Ceres, Eros and Itokawa,

For all the different gravity environments, we can find a floor's velocity threshold above which the BNE does occur. We conclude that the BNE is effective in a wide range of gravity environments, expanding 5 order of magnitude on surface gravity.

Other particle-specific properties can affect the segregation process, like the particles' density. We investigate the behavior of a mixture of light and heavy particles under different gravity environments. After repeated shakings, most of the light particles go to the top and most of the heavy ones sinks to the bottom. Due to the strong shakes, the particles suffer large displacements, but, in a statistical sense, the two set of particles are segregated. A density segregation is then observed, although it is not complete.

2.2 Particle lifting and ejection

Let us consider a layer of material that is uniformly shocked from the bottom of the layer. The motivation of this experiment is to consider what would happen if a seismic wave, generated somewhere in a body and propagating through it, reach another region of the body from below.

In the simulations, we observe that the particles are not moving as a compact set, rather, the upper particles are moving faster and the particles separate from each other. The upper particles can reach velocities larger than the floor's velocity.

We conclude that a layer shocked from below would produce the lifting of particles at the surface if the displacement of the bottom exceeds a certain velocity threshold. Particles can acquire vertical velocities comparable to the displacement velocity of the bottom, and in a low-gravity environments, to the surface's escape velocity. The particles could enter in sub-orbital or orbital flights, creating a cloud of gravitational weakly bounded particles around the object.

2.3 Global shaking due to impacts and explosions

In the previous simulations we have shown that several physical processes can occur in a layer of granular media when it is shocked from below. A big quake in a distant point could produce such a shock. The quake could be produced by another small object impacting the body or by the release of some internal stress.

In order to study this process, we run the following set of simulations. We fill a km-size sphere with small spheres of a given size range. On a given point of the surface, we simulate an explosion by giving some kinetic energy to a small group of particles. We note that the a shock front with a spherical shape propagates to the interior from the explosion point. We are interested in the effects of the explosion at large distances from the explosion point. For many of the simulations, a fraction of the near surface particles, far from the explosion point, acquire velocities over the escape one. Therefore, an explosion would induce the ejection of particles from the surface at low velocities. These particles could either enter into orbit around the body or slowly escape from it, producing a cloud of fine particles that may take many days before disappearing. We conclude that explosion events like the one produced in our simulations would be enough to induce the shaking required to produce size and density segregation on the surface of these bodies.

3. Summary and Conclusions

The application of these results to real cases will be the subject of further studies, but we foreseen some situations where the results presented here will be relevant:

- The internal structure of a small asteroid like Itokawa, formed as an agglomerate of m-size particles, and the relevance of the Brazil nut effect produced by repeated impacts.
- The non-uniform distribution of active zones in comets, like P/Hartley 2, and the internal density segregation of icy and rocky boulders produced by shakes caused by explosions and impacts.
- The formation of dust clouds at low escaping velocities after an impact onto a km-size asteroid.

References

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