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Velocity scaling of granular convection and its application to timescale of regolith migration

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On the basis of accurate surface observation of asteroid Itokawa, it has been thought that regolith migration and sorting could occur [1]. Besides, Nagao et al. revealed that cosmic-ray exposure age of Itokawa's surface grains is less than 8 Myr [2]. As a possible explanation for such active and young surface of Itokawa, regolith convection caused by impact-induced seismic shaking has been considered [1]. Indeed, granular convection can be readily observed in the laboratory experiment of vertically vibrated granular matter (e.g. [3]). However, the quantitative feasibility of granular convection under the microgravity environment has not been studied well so far. Although the direct control of gravity is quite difficult, we instead employ the scaling approach to figure out the gravity dependence of granular convective velocity. Specifically, we measure the granular convective velocity under various experimental conditions. Then, using the systematically obtained data, we find a scaling relation among the convective velocity, gravitational acceleration, and other control parameters such as vibration frequency, grain size, and so on. We also estimate the timescale of regolith migration due to the granular convection by using the obtained scaling.

The grains used in this experiment are glass beads of diameter d = 0.4, 0.8, or 2 mm (AS-ONE corp. BZ04, BZ08, BZ2). The experimental setup consists of a cylinder made by plexiglass of its height 150 mm and inner radius R = 16.5, 37.5, or 75 mm. The cylindrical cell is filled by glass beads to make a granular bed of the height H = 20, 50, 80, or 110 mm. The system is mounted on an electromechanical vibrator (EMIC 513-B/A) and shaken vertically. The vibration frequency f is varied from 100 to 300 Hz and the maximum dimensionless acceleration is varied from 2 to 6. Motions of glass beads on the sidewall of the container are captured by a high-speed camera (Photoron SA-5) with a macro lens. PIV (Particle imaging velocimetry) method is used to compute the vertical component of the convective velocity, v_z. The maximum value of the velocity is nondimensionalized as $v_{zmax}/(gd)^{1/2}$, where g is the gravitational acceleration. Using the obtained experimental data, we scale $v_{zmax}/(gd)^{1/2}$ by the shaking parameter S [4] and the dimensionless system size L. S represents the energy balance between vibration and gravity, $S=(2\pi Af)^2/gd$, where A is shaking amplitude. L is the scaled system size defined by $L=(RH)^{1/2}/d$.

As a result of systematic dimensional analysis, we obtain a scaling form, $v_{zmax}/(gd)^{1/2} \sim S^{0.47}L^{0.82}$. From this scaling form, we find that the granular convective velocity v_{zmax} depends on the gravitational acceleration g as $v_{zmax} \propto g^{0.97}$ when the maximum dimensionless acceleration is fixed. This means that the granular convective velocity is almost proportional to the gravitational acceleration. We also find that the timescale of regolith migration due to the granular convection is almost independent of its roll size, by assuming that L is the dimensionless convective roll size. In the presentation, we are going to discuss the consistency between the regolith migration timescale and cosmic-ray exposure age of Itokawa's surface grains.

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[2]K. Nagao *et al.*, Science **333**, 1128-1131 (2011)
[3]A. Garcimartín *et al.*, Physical Review E **65**, 031303 (2002).
[4]P. Eshuis *et al.*, Physics of Fluids **19**, 123301-1 (2007)

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