EPSC Abstracts
Vol. 10, EPSC2015-767, 2015
European Planetary Science Congress 2015

NanoRocks: Studying Planet Formation and Planetary Rings on the International Space Station

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Abstract

We report on the initial results of the NanoRocks experiment on the ISS, which simulates collisions in protoplanetary disks and planetary ring systems. The objective of the NanoRocks experiment is to study low-energy collisions inside systems of multiple mm-sized particles of different shapes and materials. In September 2014, NanoRocks reached ISS as part of the NanoRacks platform. First video data from the experiment operations on ISS allows for the measurement of energy damping inside multi-particle systems and the observation of the formation of clusters.

1. Scientific Background

We report on the initial results of the NanoRocks experiment on the International Space Station (ISS), which simulates collisions that occur in protoplanetary disks and planetary ring systems. The standard model of planet formation proceeds from the gravitational collapse of an interstellar cloud of gas and dust through collisional accretion of solids into planetesimals and eventual runaway growth to form the terrestrial and giant planets [4]. A critical stage of that process is the growth of solid bodies from mm-sized chondrules and aggregates to km-sized planetesimals where gravity becomes an important force for further growth. Theories on this dust growth phase include gravitational instability ([3], [6]) and direct binary accretion of particles [5]. To characterize the collision behavior of dust in protoplanetary conditions, experimental data is required, working hand in hand with models and numerical simulations.

In addition, the collisional evolution of planetary rings takes place in the same collisional regime. Particles in Saturn's main rings collide at speeds on the order of 1 cm/s. The viscous evolution of the ring depends on the amount of energy dissipated in these low energy collisions. With the age and origin of Saturn's rings remaining a major unknown in our understanding of the solar system, there is a critical need for fundamental data on the collisional interactions between particles in an environment like that of the rings (microgravity, with a regolith coating on larger particles). Clumping of particles in Saturn's rings has been observed by Cassini, illustrating that even in an environment where tidal forces inhibit gravitational aggregation, some accretion does occur in the form of self-gravity wakes [2].

2. The NanoRocks Experiment

The objective of the NanoRocks experiment is to study low-energy collisions of mm-sized particles of different shapes and materials. The low relative velocities required for these collisions can only be obtained under long-term microgravity conditions. The main component of this experiment is an aluminum tray (~8x8x2cm), which is divided into eight sample cells each holding different types and combinations of particles (i.e., glass, acrylic, copper, and rock). This tray is mounted on three springs to allow for its 3-dimensional shaking. During an experiment run, a magnet hits the bottom of the tray at regular time intervals to agitate the particle samples. The low-energy collisions generated by this shaking are recorded autonomously with a high-speed camera commanded by on-board electronics (Figure 1). Each experiment run consists of a 60 minute recording of the samples while they are being shaken once every minute.

In September 2014, NanoRocks reached ISS as part of the NanoRacks platform. Since its arrival, the experiment has been performing nominally, recording low-velocity collisions inside of the sample cells. About 10 experiment runs have been performed and 5 video files were downloaded from Station.

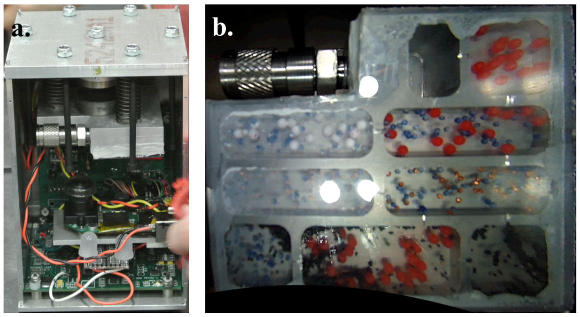

Figure 1: The NanoRocks experiment: a. Experiment hardware before closing: the camera and electronics can be seen at the bottom of the picture, while the tray and its springs and magnet are at the top. b. Recorded image of the experiment tray containing the eight particle samples during an experiment run on ISS.

3. First Data Results

First data analysis clearly shows the damping of the particle system "temperature" by inter-particle collisions that are not perfectly inelastic (Figure 2). The mean velocity evolution in the NanoRocks trays after each shaking event indicates a stochastic distribution of the coefficient of restitution [1]. The temporal evolution of the kinetic energy in the different many-particle systems can be measured.

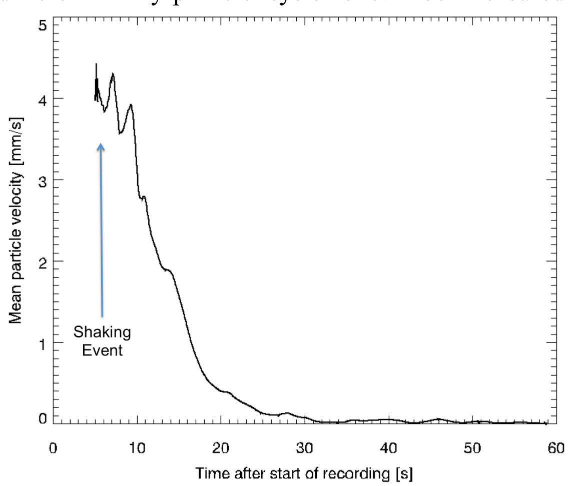

Figure 2: Mean particle velocity during and after a shaking event in one of the NanoRocks experiment cells. The damping of the system's energy through inter-particle collisions can clearly be recognized.

In addition, very low energy collisions in the NanoRocks many particle systems lead to the systematic formation of structures and clusters after a relaxation time following shaking events (Figure 3).

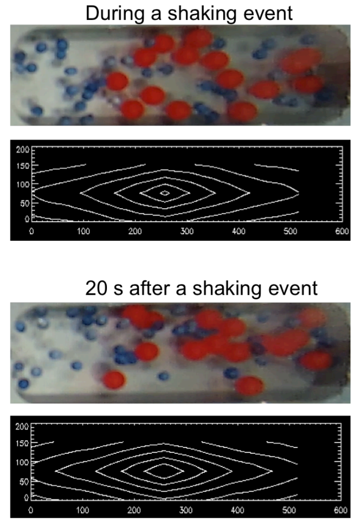

Figure 3: Particle clumping in one of the NanoRocks trays, during and 20 s after a shaking event. The contour levels of the auto-correlated images are shown under the originals (same contour levels) and indicate the mean clump size in the tray.

Acknowledgements

We would like to thank Space Florida for funding this work and the NanoRacks team for their support in operating the payload on Station and retrieving the scientific data.

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