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Dynamical simulations of cometary dust within the near-nucleus environment

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Abstract

The Rosetta mission to comet 67P/Churyumov-Gerasimenko is providing unique constraints on the physical and dynamical properties of cometary dust (Rotundi et al. 2015, Schultz et al. 2015), and some of the first results are surprising. Examples include:

- Very large dust grains were detected near the nucleus at heliocentric distances greater than 3.5 AU. Grains from about ten to several hundred micron in size have been detected and collected by GIADA and COSIMA, while the OSIRIS camera revealed tracks of particles up to 2 cm in diameter;
- Dust grains from 67P hit the detectors at speeds 1 to 10 m/s, and grain speed is not strongly correlated with size. Optically detected grains move away from the nucleus at around 3.5 m/s;
- The dust grains appear to be weakly bound, fluffy agglomerates with porosities about 50%.

These results have motivated us to reassess the complex dynamics of cometary dust in the relatively unconstrained near-nucleus region. Here we present models of idealised dust particles and simulate their interactions with gravity from the sun and the nucleus, with solar radiation, and with sublimating gas drag. The dust particles are modelled as porous random aggregates constructed using different algorithms: ballistic particle-cluster aggregation (BPCA, or BA for short), ballistic agglomeration with one migration (BAM1), ballistic agglomeration with two migrations (BAM2), hierarchical aggregates of aggregates (AgAg) and ballistic cluster-cluster aggregates (BCCA).

1. Model Details

Following [3], we model dust grains as random aggregates of monomers with a wide range of filling factors, from 0.15 for BA aggregates, where incoming monomers stick to the growing cluster at the first point of contact, to 0.30 for BAM2 aggregates, where incoming monomers are allowed up to two migrations before sticking.

In addition, we consider for the first time hierarchical aggregates (AgAg, see [4]). Hierarchical aggregates have a spatial structure similar to that of the well-known BCCA aggregates, which are also considered in our study.

Radiative forces are calculated following [5], and the optical properties of the particles are calculated using a combination of Mie theory and effective medium theory. Forces due to gas drag account for the non-equilibrium velocity distribution of gas molecules [6]. A mean momentum transfer from a gas molecule to the aggregate is estimated by Monte-Carlo simulations.

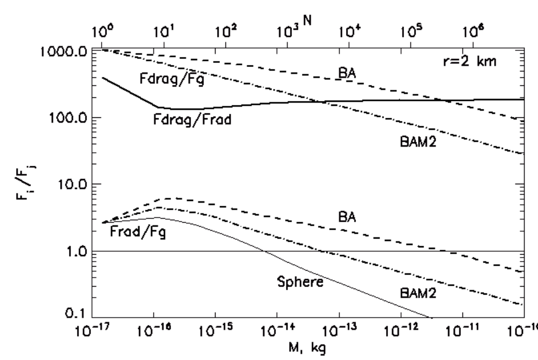

Figure 1: Ratio of different forces acting on grains: F_{drag}/F_{rad}, F_{drag}/F_g, F_{rad}/F_g, as a function of aggregate mass (or number of monomers) at the surface of a homogeneous spherical nucleus. Results for BA and BAM2 aggregates, and solid spheres are shown.

2. Results

Figure 1 compares the different forces acting on a dust grain near the nucleus surface and shows that gas drag is the dominant force. For all tested particle sizes, gas drag is orders of magnitude larger than cometary gravity and solar radiation forces.

We find that there is maximum size of particle that can be lifted by gas drag, irrespective of the type of aggregate considered. This limit is a function of gas production. If the total gas production of a homogeneous spherical nucleus is about 2 kg/s the maximum mass of lifted dust grains ranges from 10^{-4} kg for BAM2 aggregates to 10^{-3} kg for BA aggregates. Due to the rapid reduction in the density of the expanding gas, the region of effective dust acceleration is quite small: particles reach terminal speed at a distance of about ten nucleus radii. A dust grain speed is only a few percent of the speed of gas flow, so the gas drag force is decreased mainly due to a decrease in gas density.

3. Conclusions

We find that none of the grains structures considered is able to explain simultaneously 1) the high grain porosity, 2) the low speeds and 3) the "flat" velocity curve of dust grains measured by Rosetta. To explain the latter, we propose that dust grains must break-up well beyond the gas drag acceleration region, and probably near the spacecraft.

References

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