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The effect of cometary dust size and shape on mantle thermophysical properties: a DEM study

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Abstract

Active comets are among the largest objects in the Solar System, and models of them necessarily cover a wide range of spatial and temporal scales. As such, continuum methods are often used to study their thermophysical evolution. However, it is becoming increasingly clear that the properties of comet and asteroid surfaces at the smallest scale can dominate global behaviour and must be included [1]. This is best done with a discrete approach which can model the interactions of individual dust and ice particles. Such an approach is used here to determine the properties of bulk material with a variety of sizes and shapes which can be used as input for further continuum models.

1. The aggregate mantle

There is considerable evidence for the highly inhomogeneous nature of cometary surfaces, on both the microscopic and macroscopic scales. Studies of protoplanetesimal dust agglomeration [2] and light scattering of cometary dust [3] assume complex fractal aggregate shapes, similar to IDPs captured in the upper atmosphere [4]. It is likely that the upper layers of a cometary mantle contain similarly structured grains. Since both forces and heat in granular media are transferred by complex stress networks, which in turn depend on the size and shape of individual particles, the thermophysical behaviour of such “fluffy” aggregates should be understood.

The Discrete Element Method (DEM) [5] is used here to model the interaction of many such aggregates under low gravity conditions, where forces that are negligible under terrestrial gravity play a more dominant role.

1.1 The role of cohesion

The upper layers of a cometary mantle are generally considered to comprise an ice-free granular layer. As such, dust particles are free to move in response to various forces, such as gas drag and gravity. However, little detailed consideration has been given to date to the role of particle-particle adhesion. Such attractions can arise from electrostatic charging, or simply from the ever-present Van der Waals forces. It is known from the terrestrial powder industry that fine powders, in which cohesive forces are equal to or greater than the particle weight, behave differently from larger particles. These powders show clustering into high porosity aggregates and an increasing angle of repose. Moreover, gas flow can be inhibited and subsequently released impulsively through forced channels [6].

Under low gravity, the particle weight is significantly reduced and therefore much larger particles may show cohesive behaviour [7].

1.2 The effect of particle size and shape

Most continuum modelling approaches necessarily assume non-interacting monodisperse spherical particles, or generalisations thereof. However, the size and shape of cometary mantle material undoubtedly play key roles in the thermal and physical behaviour of the mantle.

It is well-known that a bi-disperse granular system subject to vibration (for example due to impacts in the cometary case) undergoes sorting by size (e.g. the “Brazil nut effect” and other phenomena). It is also clear that complex aggregate shapes should result in increased apparent friction due to particle interlocking. The end result of such dynamical processes is a volume of material whose structure depends strongly on its formation history and which can be highly inhomogeneous.

2. DEM modelling of cometary mantles

To address these issues, a Discrete Element Modelling (DEM) approach is used to study the behaviour of a collection of aggregate dust grains. This allows a physically self-consistent determination of the macroscopic quantities needed for continuum modelling (e.g. porosity, thermal conductivity, tensile strength etc.) based on realistic particle shapes and sizes.

Early results will be presented showing the dependence of packing density (~porosity) on the coefficient of friction and adhesive forces for a variety of agglomerate sizes and shapes. Once a dust particle bed with appropriate packing has been achieved, various experiments can be performed, for example vibrating the bed to simulate impact shock wave transmission, and applying heat to one boundary to study the heat conductance.

This last approach is an important one to characterize the dependence of the mantle thermal conductivity on microscopic particle properties. It is planned to use the results of parametric DEM studies as input for conventional continuum modelling to investigate the influence of particle shape, size and inter-particle forces on the larger scale models of cometary evolution.

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