EPSC Abstracts
Vol. 8, EPSC2013-664, 2013
European Planetary Science Congress 2013

Dust growth in magnetised plasmas

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Abstract

The evolution and character of plasma dust has wide-ranging implications for astrophysics, including plasma chemistry and the evolution of planetary atmospheres. Here we present calculations of dust growth by ion accretion, under the combined influence of an applied magnetic field and the evolving electrostatic field arising from the charged grain. Simulations of ion trajectories through a magnetised plasma sheath will demonstrate the inhomogeneity of mass loading on an isolated grain surface.

Introduction

The presence of ambient free charge from electrical storms or cosmic ray impact can have a significant effect on the mechanisms of dust growth, producing as a consequence an atmospheric feedback loop which has the capacity to alter the atmospheric chemistry. In a plasma (a gas of positive ions, electrons and neutral species) dust acquires a negative electric charge as a result of a preferential absorption of electrons, by virtue of the latter's higher mobility compared to heavier positive ions. Hence dust grains are associated with strongly localised unbalanced charge concentrations: plasmas react by adjusting the ambient charge population to create a region around the grain which shields the rest of the medium from the consequent electric field, keeping the latter strongly localised in a region called sheath next to the grain [1]. Positive ions in the field-free ambient atmosphere are accelerated towards the dust grain if they enter this region; the local electrostatic conditions can influence enormously the ion trajectories, leading to non-uniform deposition and the evolution of non-spherical grains [1]. The presence of a magnetic field further complicates the growth, since it influences the fluxes of both ions and neutrals [2, 3].

The simulation strategy involves calculating the electric potential ϕ around the grain, subject to the boundary condition $\phi = phi_s$ on the grain surface, and $phi = 0$ at distances greater than the sheath length from the surface.

The equation of motion for a particle with mass m, charge q, and velocity $\mathbf{v}$ in electric field $\mathbf{E} = -\nabla\phi$ and magnetic field $\mathbf{B}$ is given by $m\dot{\mathbf{v}} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ in which $\mathbf{v} = \dot{\mathbf{r}}$, $\mathbf{r}$ being the particle's position vector, and $\dot{}$ denoting the time derivative. If a particle moves in uniform electric and magnetic fields, the result motion consists of a uniform circular motion in the plane perpendicular to the magnetic field plus a uniform translational motion in the direction of $\mathbf{E} \times \mathbf{B}$ with speed $v_E = E/B$: the drift velocity. When the electric field is spatially nonuniform, particles experience different fields whilst in motion, and hence the drift velocity and Larmor radius are functions of position. The motion of charged particles then requires a numerical solution, which we performed using Runge-Kutta technique on the equations of motion.

Results and discussion

In order to investigate the effect of the magnitude and orientation of electric and magnetic fields on dust growth patterns, batches of 100 ions are launched from a representative range of different positions toward the grain. The ion's launch velocity $v = 5$ is chosen to give Larmor radius at launch (defined by $R_L = mv_{launch}/(eB)$ comparable to a characteristic grain dimension. Two cases will be considered; the growth of an ellipsoidal grain in the presence of electric and magnetic fields and the growth of a spherical grain in the presence of electric field only. Fig. 1 shows ions deposition locations onto ellipsoidal grain surface in presence of electric and parallel magnetic fields. It can be noticed higher ions accumulation near the grain ends. For a spherical grain in presence of electric field only, ions would be deposited uniformly over the surface of the grain.

The direction of the magnetic field is also critical for dust growth. Two situations will considered: growth of ellipsoidal grain in a presence of a parallel oriented (in respect to the major ($x-$) axis of the grain) magnetic field; and growth of ellipsoidal grain in a presence of a perpendicular magnetic field, in the $z-$ direction. The former case is the one represented in Fig. 1. Notice here that some ions which start far from the grain tend to collide onto grain surface. The situation is different when magnetic field direct perpendicular to grain as shown in Fig. 2. It is clear from this figure that fewer ions hit the grain than the previous case. Most ions starting from further away do not hit. However, thos that do collide tend to collide at grain ends, indicating that the dust is likely to grow more elongated. Hence while the parallel magnetic field may provide faster growth, perpendicular field influences elongation.

Figs. 3 and 4 show frequency plot of the impact energies of ions for the two cases where the magnetic field is parallel and perpendicular to x-axis respectively. From Fig. 3 there are discrete energies bands, whereas Fig.4 shows a continuum energy distribution.

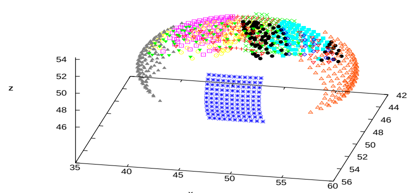

Figure 1: Coloured points represent ion density on grain surface.Every color indicates ions belongs to the same patch. The grain semi-axes a, b, c are of lengthes $10, 5, 5$ respectively. R_L at launch is comparable to the grain's semi-axis b, and magnetic field is parallel to x-axis.

In summary, the calculations presented here show the influence of the magnetic field oriented parallel and perpendicular to the long-axis of the grain on the ion flux to that charged grain. Most ions starting near the grain surface ultimately collide with it, while those starting further away execute orbital motion around the magnetic field lines and drift toward the grain. Moreover, the energy spectrum for impacting ions shows discrete structure in presence of a parallel oriented magnetic field. Finally, we note that the magnetic field influences the spatial deposition pattern of ions, leading to increasing ions fluxes at the grain ends.

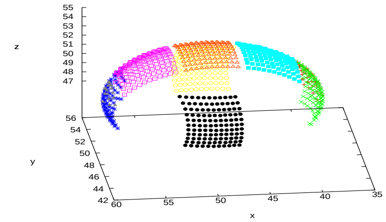

Figure 2: Conditions are as for Fig. 1, but the magnetic field is perpendicular to x-axis.

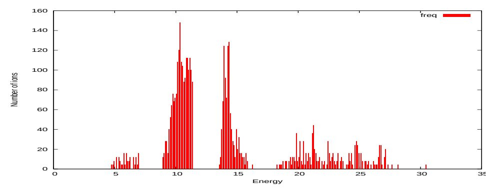

Figure 3: Frequency plot of energies of ions where the magnetic field is parallel to x-axis. The presence of discrete structure is evident.

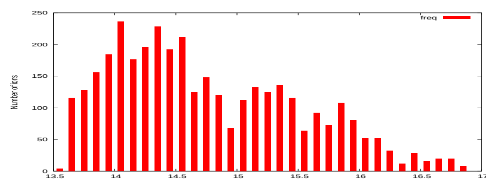

Figure 4: Frequency plot of energies of ions where the magnetic field is perpendicular to x-axis. Figure shows a continuum energy distribution .

References

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