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Ionization and charging in dusty atmospheres

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Abstract

The role of electrostatic fields (possibly transient) in atmospheric ionization and charging can influence not only gas chemistry via non-equilibrium, electron-moderated reactions but also the overall energetics of processes such as lightning and sprites.

1. Introduction

Particles gain energy by accelerating in electric fields, but often it is not clear how such electric fields are created in an astrophysical or planetary context. However, the intrinsic collective nature of plasmas is such that often electric fields can spontaneously arise sufficient to propel charged particles to extraordinary energies from relatively modest disturbances. The key here is that extreme energies are produced by non-equilibrium events in which only a minority of the candidate particles reach extreme energies: the energy distribution function (edf) of accelerated particles shows rapid evolution, producing a high-energy tail with the requisite properties (for example, [1]). Such events can arise in plasmas in which a macroscopic disturbance produces a non-linear response in the spatial distribution of charged-particles, leading to a (generally spatially localised) amplification of the original electrical disturbance. The context can most clearly be expressed in a series of project-relevant examples. **Alfvén ionization** results from a strong neutral fluid-flow impinging on a magnetised plasma, producing pockets of energised electrons that quickly reach (within nanoseconds) the threshold energies required to ionize the neutral flow if the flow is strong enough [2]. **Dust** fragments in an electron-ion plasma become charged, and develop a sheath-field structure that insulates the ambient plasma from the local field around the grain, but produces biased and irreversible growth by attracting an enhanced ion flux through the sheath from the surrounding medium. This is most significant in the interstellar and planetary medium, where charged dust-grains, particularly if evolving in a magnetic field, can grow anisotropically [3], with localised inhomogeneous electric fields playing a significant role in non-thermal atmospheric processing [4, 1], grain dynamics [5] and the production of energetic particle beams [6]. **Ionization fronts** are triggered by small accumulations of free electrons that are sufficiently energetic (that is, above the ionization threshold) to create an irreversible avalanche of free charge, with accompanying self-field that ensures propagation. Although such behaviour is ubiquitous in astrophysics, the context of particular interest here lies in fluid flows: gas-plasma interactions in solar and planetary contexts involve the relative streaming of (neutral) gas and (ionized) plasma, leading to ionization fronts via Alfvén ionization [7] relevant to planetary atmosphere composition.

In this article we shall address (via theory and simulation) the role of transient electrostatics in several contexts, ranging from ionization fronts produced by large-scale flows (see Fig. 1 in partially ionized magnetospheres to the role of charged dust in enhancing above-cloud discharges [8] (Figs. 2, 3).

References

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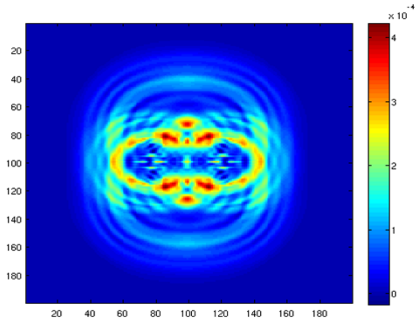

Figure 1: Simulation of the residual ionization fraction from Alfvén ionization caused by relative gas-plasma flow in a magnetized atmosphere: the magnetic field is aligned horizontally, and the gas disturbance arises from a spherical density wave propagating outwards from the centre.

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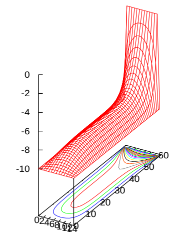

Figure 2: Plot of the simulated electrostatic environment in the vicinity of a hypothetical recent sprite event. The long edges represent the charge sheet caused by dust grains that have acquired electrons from the sprite discharge. Note the significant electric field at the end of the charge sheets, caused by field fringing.

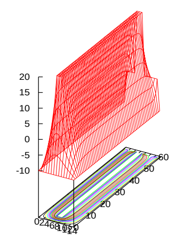

Figure 3: As Fig 2, but this time including the positive ions left by the electron avalanche.