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Numerical simulations of dusty plasma in the Saturn's ring system

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Abstract

Dusty plasmas have been the focus of intense research in the past decade. Dusty plasma is normal plasma, consisting of ions and free electron, which contain micron sized particles. The dust grains become electrically charged due to interaction with the background plasma. Here, in this paper described about the rings of Saturn, the numerical simulations of the interaction between a charged dust cloud and magnetised plasma in the Saturn's ring system.

Keywords : Charged dust, Magnetized plasma and solar system.

1. Introduction

When dust grains are introduced into a plasma, they become charged and from a dusty plasma. Up to 99% of the observable material in the universe consists of plasma. The universe contains also grains in regions ranging from planetary dusts, meteorites, planetary rings and comets to interstellar dusts as in nebulas. The dust and plasma create a mixture of charged dust and plasma called dusty plasma whose physical behaviour must be studied to be able to understand crucial processes in the universe, in a wide range of scales from phenomena in the mesosphere to creation of solar systems and stars. The electromagnetic fields, together with gravitational fields in the universe will then determine the trajectories of the dust grains resulting in a complicated many- body problem.

The gravitationally bound dust clouds in the universe interact with the co rotating plasma in a complicated way. This interaction is widespread in the universe and is important to understand in space physics. A relative nearby example of such interaction is the observed spokes in the Saturnian's ring system. Other examples are the processes in the creation of the solar system, the dust structures at the birthplaces of stars in the nebulas and in the upper atmosphere visible as noctilucent clouds and the meteorite produced dust. The nature of spokes has been discussed for a long time. A plausible theory must explain not only the rapid growth of the spokes but also their correlations with the period of Saturn's magnetic field.

2. Observations

2.1 Radial spokes of Saturn's Rings

Planetary rings are composed of dust particles; the ring of Saturn, of course, is the best example. One of the most interesting features of the rings some by the voyager space craft was the radial spokes in the B-ring (Goertz, 1989).

The spokes appear bright in forward scattered light, suggesting they are micron (or smaller) grains. To be levitated against gravity, however, requires the grains acquire a modest amount of charge, which in turn implies rather dense plasma in the ring. This plasma can be produced by meteor impacts on the ring. The

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plasma clouds, and associated levitated grains, propagate radially dense to an E × B drift, with the azimuthal electric field arising from current closure in the ionosphere. The calculated radial velocities ~ 20 – 40 kms^{-1}, are constant with the observed optical depth of the spokes (Goertz & Morfill, 1983).

Observations from pioneer II, Voyager I and II have revealed that Saturn and Jovian rings consists of micron or submicron size dust. For instance in Saturn no density for F-ring is 30cm^{-3} while for spokes no density 1cm^{-3}.

2.2 Braided rings of Saturn :

The observations from Voyager polarimetre show images of several strands of F-ring which are braided. The rings also contain bright clumps, knots and Kinks in showed a few pictures of braids in F-ring. To explain the braids as due to gravitation of influence of herding satellites (1980 S26, 1980 S27) have largely been unsuccessful. As due to the equilibrium of observed ring current $\sim 10^7$A carried by charged grains of the F-ring. Due to peculiar charging nature of the grains the plasma potential V becomes a function of n.

Thus $E = -\nabla.V = -$ acts like effective pressure, which tries to expel grains along radial direction. This effective pressure is balanced by the Lorentz pinch giving rise to a Bennet pinch like equilibrium. It has been shown that this equilibrium is governed by

$$V^2A_z = v_0Q_{n0}\sin\text{ﬁ}$$

Where v_0 is the velocity of grains in the co-rotating frame and A_z is the $\acute{z}$ component of vector potential. This equation is shown to produce braided and filamented solutions under very general conditions pertaining to F-ring.

3. Theoretical issues :

3.1. Numerical simulations of the interaction between a dust cloud and magnetized plasma

Numerical studies of the growth, introductions were used to explain several peculiar features in the Saturn ring system. The numerical model calculations the dynamics of charged dust to high resolution images of Saturn's moons and ring revealing the Saturn's ring system.

A model for the formation of spokes has been proposed (Goertz and Morfill, 1983). Here a meteor impact on the ring system creates a plasma column in the ring system. The enhancement of plasma, charge the dust particles. The relative motion between the co- rotating plasma and the heavy keplerian orbit bound dust particles then creates a polarization electric field which together with the magnetic field give a radial EXB drift of the dense plasma cloud. An attempt to qualitatively describe this model has been made by Nils Brenning at Royal Institute of Technology (Brenning, 2001). Nils compare the model with observations of a rocket borne experiment Crit I where heavy ions are injected in the ionosphere. The Crit I experiment was followed by another experiment, Crit II which confirmed the results from Crit I (Bolin, *et. al.*, 1996). The experiments were followed by particle simulations (Bolin and Brenning, 1993). Several effects observed on $\hat{z}$ these experiments was later identified the simulations as boundary effects due to the sharp density gradients of the clouds.

The model of the spokes is an idealized model with dust particles uniform in size and the dust cloud with uniform density. The dynamics of a cylinder formed dust cloud is investigated. The cloud has an initial uniform velocity across an external magnetic field. The external field will then create a field within the cloud. The interaction with the external field and the following momentum exchange depend on a dimensionless parameter.

The plasma parameter namely plasma density and electron temperature are measured at the centre of the density plasma device in hot cathode filament discharge technique and its effect on dust charging is studied for hydrogen and argon plasma. A full line cusp magnetic field cage is used for plasma confinement. An advanced cylindrical Langmuir probe is used to measure the plasma parameters for different discharge conditions.

3.2. Magnetized Plasma

Consider the radiation consideration instability in dusty plasma embedded in an external magnetic field $\hat{z}B_0$, where $\hat{z}$ is the unit vector along the z axis and B0 the strength of the magnetic field (Shukla and Mamun, 2002).

Here, Equation =

It hold as long as $/\omega/ << v_e << \omega_{ce}$, expect that $D_e\Delta^2$ is replaced by $D_{\| \|} \Delta_{\| \|}{}^2 + D_\perp \Delta_\perp{}^2$, where ω_{ce} is the electron gyro frequency, $D_{\| \|} = D_e$, $D_\perp = 4.7\ \rho_e{}^2 \upsilon_e$, $\rho_e = V_{Te} / \omega_{ce}$ and the subscript $\| \|$ and $\perp$ denote the components parallel and perpendicular to $\hat{z}$.

The dust number density perturbation, given by (Shukla, *et. al.,* 1999), (Mamun and Shukla, 2000), the equation is

$\approx$

remains valid in a magneto plasma if the wave frequency is much longer than the dust gyro frequency.

Where md is the dust mass,

V_d is the dust neutral collision frequency,

V_{Td} is the dust thermal speed,

$W_J = (4\pi G\rho_d)^{1/2}$ is the Jeans frequency, (Jeans, 1929)

G is the gravitational constant and

$\rho_d = n_{d0}m_d$ is the dust mass density.

4. Result and Discussion

Dusty plasma research has been driven by concerns in space and here on earth. Dusty plasmas occur frequently in space, and are thought to play and important role in star and planet formation. Most research in space plasmas has focused on Saturn's rings, and in the tails of comets. In these two regions, there is a high density of dust, and dusty plasma interaction may be responsible for much of the structure observed by space craft missions. The industrial community has also encouraged the study of dusty plasma.

The code used, is a 2- dimensional version of the code used at the simulations of the Crit experiments. Some very preliminary results have already been obtained and will be followed by simulations on longer time scales where the trajectories of the dust clouds can be followed long enough to estimate the result of the interaction between the cloud and the plasma and make a complement to the theory. The simulation will also investigate the effect of nonsharp edges of the cloud and clouds with particles of different sizes. Computer simulations are needed to take in account the effects such as fringing electric fields, deviations from the simple assumed cylindrical geometry, in homogeneities in dust density and spread in dust size.

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