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Dust-Plasma Interactions

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Our theoretical research on dust-plasma interactions has concentrated on three main areas: (A) studies of grain charging and applications; (B) waves and instabilities in weakly correlated dusty plasmas with applications to space and laboratory plasmas; (C) waves in strongly coupled dusty plasmas. We describe our work briefly, with reference to our list of research publications and talks that follow.

(A) Grain charging and applications

We extended our prior studies (Sorasio et al., 2001, *Planet. Space Sci.* **49**, 1257) on the role of thermionic emission in the production of electrons by a micrometeoroid entering the Earth's atmosphere, by considering a range of entry angles and speeds. We considered how the characteristics of electron production via thermionic emission might be a discriminant between two classes of meteoroids characterized by their entry speeds (fast moving and slow moving)[1,12].

We suggested a mechanism to explain the positive charge on dust observed in the tropical mesopause by Gelinas et al., 1998 (*Geophys. Res. Lett.* **25**, 4047). The positive charge was unexpected because the observation was after local astronomical sunset, so that photoemission under solar UV would not be operative. Our suggested mechanism involves positive charging of micrometeoroids due to thermionic emission high up in the mesosphere before they start ablating in the mesopause region [2].

In collaboration with G. Delzanno and G. Lapenta, we considered how thermionic emission from a dust grain can fundamentally affect the shielding potential around the grain. In particular, depending on the physical parameters of the plasma, the shielding potential can acquire a potential well. Using representative laboratory dusty plasma parameters, we found that an attractive well could form under certain conditions, and suggested that this could lead to a type of attractive force between grains of like charge [3,13]. Recently, we also considered whether a potential well could form around a thermionically emitting micrometeoroid in the Earth's atmosphere [4].

In a theoretical note [5], we proposed the possible use of dusty plasmas as substrates for surface enhanced vibrational spectroscopy studies. A primary enhancement mechanism for surface enhanced Raman scattering is thought to involve the excitation of surface plasmons on substrates such as metal colloids or roughened metal surfaces on which analyte molecules are adsorbed. We argued that compared with metal colloids, dust in plasmas have much faster charging times, are immersed in background plasma that is generally transparent to IR, can be composed of a wide variety of materials (including semiconductors that may have surface plasmon resonances in the infrared), are free of solvents, and allow a range of temperatures. We also discussed some possible complications associated with the use of plasmas.

We are currently working on other possible applications using the optical properties of dust grains. One application involves the use of enhanced light absorption (arising from the excitation of surface plasmon resonances) as a diagnostic for the gross features of dust waves in a plasma containing nano-sized dust grains that could be magnetized in the presence of an external magnetic field [6].

In collaboration with other authors, a review on dusty plasma effects at Saturn, including predictions for Cassini observations, was prepared [7].

(B) Waves and instabilities

Motivated by the fact that experimental groups plan to conduct laboratory dusty plasma experiments with large magnetic fields B on the order of a few T (e.g., *Morfill*, 2002, AIP Conf. Proc. **649**, 507), we have begun to investigate the effect of large B on several instabilities important for laboratory dusty plasmas. We considered the case where the ion and electron motion is strongly magnetized, while the dust motion is collisional and non-magnetized. We found that the presence of a strong magnetic field tends to hinder the growth of the ion-dust streaming instability, which has implications for the stability of 'plasma crystals' [8]. We also investigated drift wave instabilities in the dust-acoustic and dust lower-hybrid frequencies [9]. We considered a situation in which negatively charged dust is spatially localized, creating an electron depletion or 'hole' with an electron density gradient at the boundary. We investigated conditions for the excitation of dust wave instabilities driven by electron diamagnetic and $\mathbf{E} \times \mathbf{B}$ drifts for parameters that may be representative of possible laboratory conditions, and found that the critical drifts can be lower than for some other cross-field instabilities.

We have also been working on waves in dusty plasmas in the Earth's ionosphere. For example, artificial gas-dust formations can be generated by the exhaust of space vehicle engines that can inject combustion products into the ionosphere (Platov et al, 2004, *J. Spacecraft Rockets* **41**, 667). We are investigating conditions for the excitation of lower hybrid waves by charged dust particulates streaming perpendicular to the ambient magnetic field in such dusty plasma clouds (Rosenberg and Sorasio, 2004). Such instabilities might affect radar backscatter from these clouds, when the Bragg condition for radar backscatter (i.e., unstable wavelength = half the radar wavelength) is satisfied.

(C) Strongly coupled dusty plasmas

A combined theoretical analysis and numerical simulation study of collective modes in a 2-dimensional Yukawa (screened Coulomb) system in the strongly coupled liquid state, done in collaboration with G. Kalman and others, was published [11]. This system provides a simple model for a 2-dimensional strongly coupled dusty plasma. The theory and simulations showed good agreement, and experimental parameters for observing such waves were suggested.

Together with G. Kalman, we began collaborations with Z. Donko and P. Hartmann (at Research Inst. for Solid State Phys. and Optics of the Hungarian Academy of Sciences) on beam-plasma instabilities and magnetic dipole effects in dusty plasmas.

(D) Talks

Several talks were given at national or international scientific conferences [12-16]. In addition, Dr. M. Rosenberg organized a special session on the physics of dusty plasmas at the 2004 URSI National Radio Science Meeting in Boulder Colorado, Jan. 5-8, 2004.

List of publications and talks

[1]. D. A. Mendis, W.-H. Wong, M. Rosenberg, and G. Sorasio, "Micrometeoroid flight in the upper atmosphere: electron emission and charging," to appear in *J. Atmos. Sol.-Terr. Phys.*, 2004.

[2]. D. A. Mendis, W.-H. Wong, and M. Rosenberg, "On the observation of charged dust in the tropical mesosphere," *Phys. Scripta* **T113**, 141 (2004).

[3]. G. Delzanno, G. Lapenta, and M. Rosenberg, "Attractive potential around a thermionically emitting microparticle," *Phys. Rev. Lett.* **92**, art. no. 035002 (2004).

[4]. G. Delzanno, G. Lapenta, and M. Rosenberg, "Charging of meteoroids: effect of thermionic emission," submitted to *J. Atmos. Sol.-Terr. Phys.*, 2004.

[5]. M. Rosenberg, D. P. Sheehan, and J. R. Petrie, "Use of dusty plasmas for surface enhanced vibrational spectroscopy studies," *J. Phys. Chem. A* **108**, 5573 (2004).

[6]. M. Rosenberg and P. K. Shukla, "A possible method for diagnosing waves in dusty plasmas with magnetized dust, " in preparation, 2004.

[7]. M. Horanyi, T. W. Hartquist, O. Havnes, D.A. Mendis, and G. E. Morfill, "Dusty plasma effects in Saturn's magnetosphere," *Rev. Geophys.* **42**, Art. No. RG4002 (2004).

[8]. M. Rosenberg and P. K. Shukla, "Ion-dust two-stream instability in a collisional magnetized dusty plasma," *J. Plasma Phys.* **70**, 317 (2004).

[9]. M. Rosenberg and P. K. Shukla, "Low-frequency drift wave instabilities in a strongly magnetized collisional dusty plasma," *Plasma Phys. Contr. Fusion* **46**, 1807, 2004.

[10]. M. Rosenberg and G. Sorasio, "Dusty plasma instability in gas-dust clouds in the

ionosphere," in preparation, 2004.

[11]. G. Kalman, P. Hartmann, Z. Donko, and M. Rosenberg, "Two- dimensional Yukawa liquids: correlation and dynamics," *Phys. Rev. Lett.* **92**, art. no. 065001 (2004).

[12]. D. A. Mendis, M. Rosenberg, and W.-H. Wong, "Micrometeoroid flight in the upper atmosphere: electron emission and charging," talk at AGU Fall Meeting, San Francisco, Dec. 2003 (abstract in *Eos. Trans. AGU*, 84 (46), Fall Meet. Suppl. Abstract SA41A-05).

[13]. G. Delzanno, G. Lapenta, and M. Rosenberg, "Charging of meteoroids: effect of thermionic emission," talk at AGU Fall Meeting, San Francisco, Dec. 2003 (abstract in *Eos. Trans. AGU*, 84 (46), Fall Meet. Suppl. Abstract SA41A-06).

[14]. M. Rosenberg, "Drift instabilities in collisional dusty plasmas: applications to space and the laboratory," talk at URSI National Radio Science Meeting, Boulder CO, Jan. 5-8, 2004.

[15]. M. Rosenberg, "Some dusty plasma instabilities with application to near-Earth space," Invited talk at 35th COSPAR Scientific Assembly, Paris, France, July 18-25, 2004.

[16]. D. A. Mendis, W.-H. Wong, M. Rosenberg, and G. Sorasio, "The role of micrometeorites as sources of ionization in the upper atmosphere," Invited talk at 35th COSPAR Scientific Assembly, Paris, France, July 18-25, 2004.