Final Report:
Interaction of Small Bodies with the Atmosphere

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Research progress during reporting period:

The research during this grant was concerned with two main themes: (1) the study of instabilities in dusty meteor trails, and other dusty plasmas in the ionosphere, and (2) the physics of meteor flight. Spin-offs of the work also included applications to dusty plasma phenomena in the laboratory and in astrophysics. Below we provide a summary of the completed research.

Instabilities in Dusty Meteor Trails and Plasmas

During this project, we have made significant progress in the analysis of several wave instabilities that could be relevant to dusty meteor trails or to polar mesosphere summer echo (PMSE) regions. There are theoretical and observational indications that certain meteor trails may contain dust. It has been shown in theoretical studies by Rosinski and Snow [1961] and Hunten et al. [1980] that when meteors ablate, they can form dust by accretion. Recently, Kelley et al. [1998] have reported on the detection of a meteor contrail and meteoric dust in the Earth's upper mesosphere at about 90-95 km. Further, the phenomenon of PMSE (strong radar backscatter observed from regions of the summer polar mesosphere), is thought to be associated with the presence of dust particles that are composed possibly of ice that condense on meteoric particles [e.g., reviews by Cho and Rottger, 1997; Havnes, 2001].

First, we investigated the effect of dust on the gradient drift instability (also referred to as "type II electrojet instability" [Kelley, 1989]). The gradient drift instability is applicable to the low E-region ionosphere (about 90-130 km) in both equatorial and auroral regions [see Kelley, 1989]. It is driven by electron E × B and diamagnetic drifts, the latter arising due to (vertical) gradients of ionization in the ionosphere. (In equatorial regions, vertical is perpendicular to the magnetic field B, while in auroral regions, there is also a component of density gradient perpendicular to B, since the magnetic field is inclined by about 10^o to the vertical). Typically, vertical plasma density gradients are on the order of several km in the (dust-free) lower ionosphere, and the waves excited by the gradient drift instability have long wavelengths, on the order of hundreds of meters to kms [see e.g. Fejer and Kelley, 1980]. However, due to the presence of charged dust, there may be shorter scale electron density gradients. Recently, observations have been reported of meter-scale vertical variations in the charge density of negatively charged dust in the polar summer mesosphere [Havnes, 1996b] . This implies corresponding gradients in the electron density, due to the requirement of overall charge neutrality. We investigated how such small scale electron density gradients would alter conditions for the gradient-drift instability at altitudes h ~ 90 km in daytime (or polar summer) conditions [Rosenberg and Shukla, 2002] . We found that, if there are perpendicular electron density gradients with scale size ~ several tens of meters, waves with wavelengths ~ a few meters may be driven unstable by small electron E ×B drifts on the order of the ion thermal speed. This may have relevance to PMSE observations at 50 MHz, if the enhanced backscatter is due to scattering from waves. The Bragg condition for radar backscattering at this frequency requires unstable waves with wavelengths of 3 m, which we found could be unstable for the range of parameters considered. A paper on this topic was published [Rosenberg and Shukla, 2002].

Secondly, we extended the above calculation to consider the effect of negatively charged dust on the gradient drift instability in a meteor trail. As background, gradient drift and Farley-Buneman instabilities in dust-free meteor trails have recently been investigated in a series of papers (Oppenheim et al. [2000]; Oppenheim et al. [2002a,b]; Dyrud et al. [2001]). If such instabilities arise in meteor trails, it would have implications for radar scattering from the trails. The latter paper by Dyrud et al. [2001] points out that the altitude range for which the gradient drift instability may be operative in a meteor trail is limited to altitudes h > 95-100 km. This is because, for a cylindrical trail aligned along B, the perpendicular (to B) ambipolar electric field E? would point radially inward at those altitudes since perpendicular diffusion is dominated by ions. As the electron density decreases radially, both the electron diamagnetic and E? × B drifts would have the same direction, which is a condition for the gradient drift instability to occur.

However, we suggest that if negatively charged dust is present in a meteor trail, the dust can generate an electron density depletion or 'hole', with the dust density decreasing and the electron density increasing at the boundaries. In this case, for a trail aligned along B, the electron diamagnetic and E? × B drifts would have the same direction if E? were directed radially outward. Such a radially outward pointing ambipolar electric field could occur at altitudes < 95 km, where perpendicular diffusion is dominated by electrons. Thus, we investigated conditions under which a gradient drift instability could occur in a meteor trail containing negatively charged dust at altitudes < 95 km. Using parameters that are representative of the 90 -95 km altitude daytime ionosphere, we found that an instability may occur if the perpendicular (to B) electron density gradient scalelength ~ 10 m, the dust negative charge density is comparable to the electron density, and the electron E? × B drift is > ~ 0.2 times the ion thermal speed. This work was presented at URSI and COSPAR meetings, and a paper was submitted [Rosenberg and Shukla, 2004b].

Third, we investigated a new type of very low frequency, short wavelength drift instability with application to dusty meteor trails [Rosenberg and Shukla, 2002]. We considered a meteor trail plasma at altitude h > ~ 100 km, composed of electrons, ions, positively charged dust [i.e., due to photoemission by solar UV, see e.g. Havnes et al, 1996a; Rosenberg and Shukla, 2000] and background neutrals. We assume a cylindrical meteor trail is aligned along the magnetic field, while the density of all three charged species decreases in the radial direction. There is a radial ambipolar electric field E? which electrostatically confines both the positive ions and the positively charged dust (in the low E-region, ion diffusion dominates at h > 100 km [Dyrud et al, 2001]). Using a slab model for this configuration and a kinetic theory analysis, we found a new dust-acousticdrift type instability. The instability is driven by electron E? ×B and diamagnetic drifts, has a maximum growth rate larger than the dust acoustic frequency, and a range of unstable perpendicular wavelengths < the ion mean free path. Our results show that, at h ~ 100 km, and for certain dust parameters corresponding to larger meteors (e.g., meteor mass ~ 100 g), unstable waves with wavelengths on the order of 1 m to a few m could be excited, even for small values of electric field on the order of a few mV/m, and large values of perpendicular electron density gradient on the order of 10 m(i.e., later time evolution of trail). A paper on this work was published [Rosenberg and Shukla, 2002].

Fourth, together with a visiting post-doc, Gianfranco Sorasio, we are extending the above calculation to study conditions for exciting a short wavelength dust wave instability in a dusty plasma cloud at higher altitudes, where the ions are also magnetized. This is partially in an attempt to find a mechanism involving Bragg backscatter from waves to explain L-band radar echoes at high altitudes [Brosch et al, 2004]. As background, observations of radar echoes in the L-band at ~ 1 GHz at two different altitudes during Leonid activity have recently been reported [Brosch et al., 2001; Brosch et al., 2004]. One altitude range corresponds to the classical meteor ablation zone at 80-130 km, while the other altitude range is much higher with a peak at ~ 250 km. Brosch et al. [2004] speculated that the L-band echo at the higher altitude might be associated with the presence of charged meteoric dust or 'smoke' particles that could reflect radar emission. The latter paper claims that such an hypothesis could also help explain some observations involving the movement of longer duration tracked radar echoes.

Although the exact mechanism for the reflection of radar emission was not specified in Brosch et al. [2004], we surmise that it has to do with the possible formation and persistence of gradients in the electron density owing to the presence of the negatively charged dust [see Kelley et al., 1998]. For an L-band radar at ~ 1 GHz, the Bragg condition for radar backscatter requires density irregularities (or waves) with scale size ~ 15 cm. The question then arises as to what could generate irregularities of this size. Thus we are investigating the conditions under which a dust-acoustic drift instability with such short wavelengths might occur. We have found certain conditions for instability, and a paper is in preparation [Rosenberg and Sorasio, 2004]. We may also investigate another instability related to the presence of charged dust, namely, an ion-acoustic or lower-hybrid instability that might be driven by a'beam' of falling charged dust. These types of instabilities involving charged dust may also have application to possible dusty plasmas generated in space shuttle exhaust plumes [see Bernhardt et al., 1995], as well as by special modes of rocket engine operation(at h> 150 km) that can inject several kg of material as a dispersed dust cloud into the atmosphere [Platov et al, 2002].

In addition to the research on dust wave instabilities in dusty space plasmas, we also worked on related dust wave instabilities in laboratory dusty plasmas. We [Rosenberg and Shukla, 2003] proposed that a dust-acoustic instability could be a possible mechanism for the excitation of very low frequency waves in an inductive gas discharge experiment reported by Zobnin et al [2002]. Our theoretical results appeared to be consistent with features of the experimental results.

Further, we investigated how a strong external magnetic field would affect dust wave instabilities in collisional dusty plasmas in the laboratory, motivated by upcoming dusty plasma experiments with magnetic fields on order of a few T[e.g., Morfill, 2002]. We considered instabilities in a dusty plasma with magnetized electrons and ions and collisional, unmagnetized dust. We found that magnetic field effects hinder the onset of the ion-dust two-stream instability, which may have implications for the melting conditions of ‘plasma crystals’ [Rosenberg and Shukla, 2004a]. We have also considered very low frequency drift instabilities in such dusty plasmas. For parameters that may be representative of upcoming magnetized dusty plasma lab experiments, we found that drift instabilities could have lower thresholds than Hall current instabilities [Rosenberg and Shukla, 2004c] .

Physics of Meteor Flight

We extended the analysis of Sorasio et al. [2001] on the physics of the heating and ablation of meteoric particles, including the effects of thermionic emission. This involves solving the simultaneous equations for the continuity of charge, mass, momentum, and energy of a meteoroid entering the Earth’s atmosphere, including all sources and sinks of energy, to study its charging (due to both current collection from the background plasma, and thermionic emission), deceleration, mass loss, and heating along its path. In Sorasio et al. [2001], we considered the free molecular regime (corresponding to meteoroids of radius $\lesssim$ 1 cm) in the altitude range of interest (h $\gtrsim$ 80 km), considered only nighttime conditions and used simplified models for the background neutral and plasma parameters. Our results show that, while the same meteoroid can change its charge polarity during flight, meteoroids with widely different material work functions could have opposite polarity at the same altitude. We also found that, while the escaping thermionic electrons do not constitute a significant source of energy loss from the surface, they could be a larger source of meteoric electrons at high altitude, compared to electrons produced by the ablation process, if the work function W of the meteoroid is sufficiently small (i.e. W $<\sim$ 2 eV). Furthermore, we found that the altitude range of meteoric ionization is larger than in the case when the ionization is due only to collisions between the sublimating molecules and the background molecules.

Together with a student, Wai-Ho Wong, we extended the analysis of Sorasio et al. [2001] on the electrical, dynamical and thermal history of of meteoroid in flight. We considered the effects of different initial entry speeds and angles, by considering both fast moving ‘cometary’ and slow moving ‘asteroidal’ micrometeoroids at several discrete entry angles. We also removed several simplifying assumptions from the earlier analysis and introduced a new current (which we call the ablation current) which plays a progressively important role in calculating the grain charge with increasing entry speed. While the main conclusions are qualitatively similar to those of the previous study, the quantitative differences are significant. As before the micrometeoroid can change its charge polarity during flight and the altitude range of meteoric ionization is larger than in the case when ionization is due only to collisions between sublimating molecules and background atmospheric molecules, with the initial angle of entry playing a crucial role. Even more important is the role of the initial entry speed which changes the altitude profile of electron emission not only quantitatively but also qualitatively which may provide a clear discriminant between these two classes of micrometeoroids that are classified by their entry speed. A talk on this study was presented at the Fall 2003 AGU meeting [Mendis et al., 2003], and a paper was submitted [Mendis et al., 2004].

We have developed new functions and capabilities into the plasma kinetic code CELESTE that we use for the simulation of meteoroid flights. The code uses a fully kinetic approach where the meteor is treated self-consistently. The interactions between the meteoroid and the plasma species is treated microscopically: the collisions between the plasma species and the meteoroid surface are accounted for as they happen in reality. The meteoroid charges self-consistently as the plasma species hit the surface of the meteoroid and stick on it. Furthermore thermionic emissions are considered kinetically by injecting new electrons from the meteor surface. The simulation tool has been tested and results have been obtained for typical conditions during meteor flights. Furthermore we have included the effect of collisions through an innovative approach specifically designed for dusty plasmas and meteor flight [Ricci and Lapenta, 2002].

The model described above provides the possibility to investigate for the first time the spatial distribution and the eventual destiny of the electrons generated by thermionic emission.

Our analysis of the physics of meteor flight [Sorasio et al, 2001] treats the various species and processes involved in ablation and thermionic emission without describing the spatial dependence of the plasma properties.

We studied the attractive potential well which can be formed around meteoroids in presence of a sufficient thermionic current. Initially, we have considered parameters which correspond to laboratory experiments, namely a plasma where the electron temperature is of the order of 1 eV. These results have been presented to the 2003 Non-Neutral Plasmas Workshop and are the basis of a paper which has been published on Physical Review Letters [Delzanno et al.,2004].

During the last year, the goal of our current research has been four-fold, with two lines of investigation following from the last year and two arising from new ideas.

First, we have continued the analysis of the effect of collisions on the potential well. This is motivated by the fact that questions have been raised claiming that collisions of the plasma with the background neutrals can fill the well, leading to a monotonic behaviour of the shielding potential. Consequently, our PIC code has been modified in order to consider such effect. Each particle can collide with an atom with a probability given by

where n_g is the background density, $\sim = 5 \cdot 10^{-15}\,cm^2$, v_p is the particle velocity and dt is the time step of the simulation. When a plasma particle collides, its velocity is

$$P = 1 - \exp(-n_g \sim v_p dt) \tag{1}$$

replaced by the sampling of a Maxwellian distribution with temperature of the background gas. The main difficulty that we are facing when collisions are included in the framework of our numerical tool consists in the fact that the method of particle injection from the boundary of the system has to be changed. The particle injection method is a crucial point of the numerical investigation of charging and shielding of objects in a plasma. In fact, the object acts like a sink of plasma particles, and the injection is the source which allows to reach and mantain an equilibrium. However, the injection method relies on the knowledge of the distribution function for the injected particles, which is not any more a Maxwellian with a given plasma temperature when collisions are included (as some of the plasma particles have now velocities proportional to the velocity of the background gas). This study is currently under investigation, as we have implemented a new method to overcome the difficulty outlined above and are now testing it. The investigation is conducted for a range of parameters which correspond to laboratory conditions, namely a gas pressure of the order of mtorr (temperature of the gas of the order of 0.02 eV).

Second, we have extended the study of the charging mechanism to the case of meteoroid parameters, corresponding to the ionosphere. We have considered a range of parameters varying the height between 100 and 200 km (results with parameters at 150 km of altitude are presented in [Delzanno et al., 2004b]). This corresponds to a plasma with ion and electron temperature of the order of 0.1 eV. Furthermore, we have considered different night-time conditions, with plasma densities of the order of 10^{10} m^{-3}, for millimeter to centimeter sized meteoroids. We have found that the potential well can appear also in this case: the bigger is the grain, the deeper is the well, but only up to a saturation level. Moreover, the dependence of the shielding potential from the work function of the grain is crucial: a change of the work function can lead to a different polarity of the charge on the grain and a different behaviour of the potential around the meteoroid. We have found that at lower altitudes, potential well solutions can be obtained only with higher work functions. This result can be understood by considering that the potential well exists only if the balance between plasma currents and the thermionic current is in a certain range. At lower altitudes, the plasma current is reduced and so higher work functions are needed to reduce the thermionic current. Therefore, our investigation suggests that the potential well could form at specific altitudes, which of course would be different for meteoroids of different sizes and materials.

Third, we have extended our study to other cases of electron emission from the grain, namely secondary emission and photoemission. Secondary emission is present in plasmas where energetic particles, colliding with the grain, can extract some electrons from it. At present, there is no complete theory of secondary emission and the common choice is to assume a Maxwellian distribution function for the secondary electrons, with the electron yield for incident electron given by the Sternglass formula [Meyer-Vernet, 1982] . This study is not of direct relevance for the meteor flight but it is of considerable interest for example for rocket experiments in the ionosphere [MacDonald, 2004] or for dust grains at the edge of a tokamak [Krasheninnikov et al., 2004]. Photoemission has to be taken into account when grains are exposed to UV light. For a metallic particle, it can be modeled starting from the Sommerfeld model of a metal exactly as it happens for thermionic emission [Sodha, 1963], [Sodha and Guha, 1971]. However, unlikely thermionic emission, the resulting distribution function of the photoelectrons is not a Maxwellian but a more complicated function. Photoemission must be taken into account for meteoric flights during day time. Moreover, this study is also important for common situations of laboratory and, above all, for astrophysical scenarios. We have modified our numerical PIC code to take into account these two effects and performed a simulation campaign with parameters typical of laboratory experiments. Our results show that even in these cases a potential well can be present.

Fourth, we have developed a new analytical theory describing the (steady state) charging and shielding of an object in a plasma. The motivation for this study arises from the fact that, up to now, there has been no general theory for the charging process. The classical theories of charging contain a certain degree of approximation, an example is given by OML theory [Shukla and Mamum, 2002], which is beyond doubt the most widely used theory of charging. In the framework of the OML theory, the equilibrium potential of the grain is calculated without solving the Poisson equation and it results in gross inaccuracies for larger grain. Furthermore, the theoretical effort so far was mainly devoted to the primary charging case (namely without electron emission from the grain). Therefore, we have developed an analytical, kinetic theory for the steady state potential

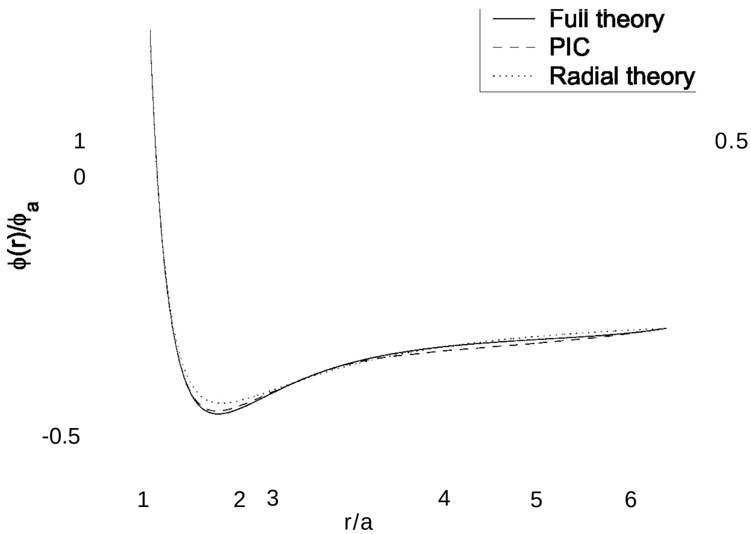

Figure 1: Thermionic emission. Shielding potential obtained by the analytical theory we have developed and by PIC simulation.

surrounding the grain. Our theory relies only on the assumption of positively charged grains. By using the conservation of angular momentum and energy, together with a given distribution function far away from the grain (where the plasma is umperturbed), we have calculated analytically the plasma currents and densities by performing integrals in phase space. The novelty with respect to previous theories is that we also take into account the particles that travel in a non-monotonic effective potential (which is a combination of the shielding potential plus a centrifugal part). Emitted electrons (either due to thermionic, secondary or photoemission) are also treated kinetically, currents and distribution functions given by the models briefly described above. Finally the Poisson equation is solved numerically, imposing the net current to be zero on the grain and the shielding potential to be zero at the outer boundary of the computational domain. Figure 1 shows a comparison of the shielding potential obtained by the analytical theory and by PIC simulation, for the case of thermionic emission. The agreement is remarkable. These results will be presented at the 2004 APS Division of Plasma Physics held in Georgia and at the 2004 AGU meeting in San Francisco.

As already pointed out, one of the main discoveries of the research carried out within the project is the presence of an attractive potential well surrounding the grains.

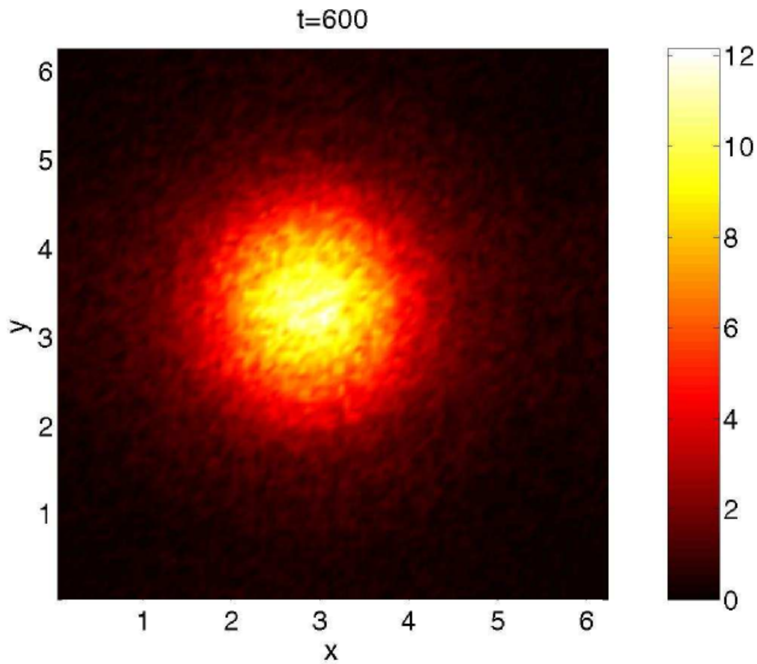

Figure 2: Jeans collapse of a system of emitting dust particles interacting gravitationally and electrostatically (through the attractive potential well).

Such a discovery is of considerable interest as it provides a novel mechanism for the attraction of dust particles in a plasma. This mechanism is certainly relevant for laboratory experiments concerning for example plasma crystals, but is even more important for astrophysical applications, such as the collapse of molecular clouds to form solar systems. We have started preliminary work on this topic as we believe it is very promising. As preliminary headway, we have built a numerical tool to study the collapse of a system of particles. When particles are simply neutral, the system collapses due to self-gravitation (the so-called Jeans instability). If particles are charged, electrostatic repulsion can impede the gravitational collapse. However, if particles are charged but the interaction potential has the form of the attractive potential well that we discovered, the system can collapse again. Figure 2 shows a numerical simulation of the collapse of a system of emitting dust grains that interact through gravitational and electrostatic forces, where the electrostatic interaction is modeled with the attractive potential well.

The collaboration of our group at LANL and the group of Prof. Rosenberg at

UCSD has been very fruitful in the interpretation of the results presented.

These studies will be shown at the Division of Plasma Physics of the American Physical Society in October 2003.

Students Involved

Several students are currently involved in the project.

Gian Luca Delzanno from Politecnico di Torino has visited both the lab PI at IGPP-LANL and the university PI at UCSD, conducting a collaboration with the whole team on the interpretation and theory support for the simulations of the meteor flight he conducted.

Federico Ferrero, Gianluca Zuccaro, Stefano Markidis, Paolo Ricci, Laura Abrardi, Enrico Camporeale from Politecnico di Torino, Italy and Jianwei-Ju from UNM have been involved in the research conducted at IGPP-LANL.

Wai-Ho Wong is an undergraduate student at UCSD who has been working on the physics of meteor flight with Drs. Mendis and Rosenberg at UCSD. Gianfranco Sorasio of the Instituto Superior Tecnico of Portugal visited UCSD.

<u>Research articles:</u>

1. Lapenta, G., “Ion flow induced attractive force in complex plasma crystals”, Physica Scripta, 64, 599, 2001.
2. Ricci P., and Lapenta, G., “Properties of the Lenard-Balescu collision operator: A numerical study”, Phys. Plasmas, 9, 430, 2002.
3. Rosenberg, M. and Shukla, P.K., “Gradient-drift instability in space dusty plasmas,” Planet. Space Sci. 51, 1, 2003.
4. Lapenta, G., “On the Nature of the Force field in Plasma Wakes”, Phys. Rev. Lett., submitted, 2002.
5. Rosenberg, M. and Shukla, P. K., “ Dust-acoustic-drift wave instability in a space dusty space plasma,” J. Geophys. Res. 107, 1492, 2002.

6. Rosenberg, M., and Shukla, P. K., "Some instabilities in collisional dusty plasmas," in Dust Plasma Interaction in Space, (ed., P. K. Shukla), Nova Science Publ., New York, 2002.
7. Rosenberg, M. and Shukla, P. K., "A note on dust-acoustic instability in an inductive gas discharge plasma," Plasma Phys. Control. Fusion 45, L31, 2003.
8. Delzanno, G.L., Lapenta, G., and Rosenberg, M, "Attractive Potential among a Thermionically Emitting Microparticle", Physical Review Letters 92 (3), 035002 (2004).
9. Rosenberg, M. and Shukla, P. K., "Ion-dust two-stream instability in a collisional magnetized dusty plasma," J. Plasma Phys. 70, 317, 2004a.
10. Rosenberg, M. and Shukla, P.K., "A note on gradient drift instability in a dusty meteor trail," Planet. Space Sci. , submitted, 2004b.
11. Rosenberg, M. and Shukla, P. K., "Low-frequency drift instabilities in a strongly magnetized collisional dusty plasma," Plasma Phys. Control. Fusion, to appear, 2004c.
12. Mendis, D.A., Wong, W.-H., Rosenberg, M. and Sorasio, G., "Micrometeoroid flight in the upper atmosphere: Electron emission and charging," J. Atmos. Sol.-Terr. Phys., submitted, 2004.
13. Delzanno, G.L., Lapenta, G. and Rosenberg, M., "Charging of meteoroids: effect of thermionic emission," J. Atmos. Sol.-Terr. Phys., submitted, 2004b.
14. Rosenberg, M. and Sorasio, G., "A dusty plasma instability as a possible mechanism for high altitude radar echoes," in preparation, 2004.

Invited talks, and contributed talks and posters:

1. Rosenberg, M., "Dust wave instabilities in collisional plasmas," poster at DPP-APS meeting, Long Beach, CA, Oct. 29-Nov. 2, 2001.

2. Ricci, P., G. Lapenta, U. de Angelis, V. Tsytovich, "Kinetic Theory of Dusty Plasmas", invited talk at the Second Capri Dusty Plasma Workshop, Capri, Italy, May 9-11, 2001.
3. Lapenta, G., " Aligning Forces in Dusty Plasmas Due to Ion Flows", poster at the 43rd Annual Meeting of the APS Division of Plasma Physics October 29 - November 2, 2001, Long Beach, California, 2001.
4. Rosenberg, M., "Cross-field instabilities in collisional dusty plasmas," invited talk, URSI National Radio Science Meeting, Boulder, CO, Jan. 9-12, 2002.
5. Rosenberg, M., " Waves and instabilities in collisional dusty plasmas,", invited talk, IEEE Int'l Conf. on Plasma Science, Banff, Alberta, Canada, May 26-30, 2002.
6. Rosenberg, M., "Drift and streaming instabilities in collisional dusty plasmas, " invited talk, XXVIIth General Assembly of the International Union of Radio Science, Maastricht , The Netherlands, Aug. 17-Aug.24, 2002.
7. Kalman, G. and Rosenberg, M., "Instabilities in strongly coupled plasmas," poster at International Conf. on Strongly Coupled Coulomb Systems, Santa Fe, NM, Sept. 2-6, 2002.
8. Delzanno, G.L., G. Lapenta, M. Rosenberg, "Interaction of Small Bodies with the Atmosphere", poster at the 44th Annual Meeting of the APS Division of Plasma Physics, November 11-15, Orlando, Florida, 2002.
9. Mendis, D.A., Wong, W.-H., 2003, Rosenberg, M., and Sorasio, G., "Micrometeoroid flight in the upper atmosphere: electron emission and charging," talk presented at Fall AGU Meeting, San Francisco, 2003.
10. Rosenberg, M., 2003, "Effect of a strong magnetic field on dust wave instabilities in a collisional plasma," talk presented at 10th Workshop on the Physics of Dusty Plasmas, St. Thomas, USVI, June, 2003.

11. Delzanno, G.L., G. Lapenta, M. Rosenberg, “Attractive Potential via Thermionic Emission”, poster at the Workshop on Non-Neutral Plasmas 2003, Santa Fe, New Mexico, July 7-11, 2003.
12. Delzanno, G.L., G. Lapenta, M. Rosenberg, “Shielding of emitting dust particles”, poster at the 45th Annual Meeting of the APS Division of Plasma Physics, Albuquerque, New Mexico, October 27-31, 2003.
13. Delzanno, G.L., G. Lapenta, M. Rosenberg, “Charging of meteoroids: effect of thermionic emission”, talk at the meeting of the American Geophysical Union, San Francisco, California, December 8-12, 2003.
14. Rosenberg, M., “Drift instabilities in collisional dusty plasmas: applications to space and the laboratory,” talk presented at the URSI National Radio Science Meeting, Boulder, CO, Jan. 5-8, 2004.
15. Delzanno, G.L., G. Lapenta, M. Rosenberg, “Electrostatic Potential around a Thermionically Emitting Dust Particle”, poster at the IV Italian Conference on Plasma Physics, Arcetri (Fi), Italy, January 12-14, 2004.
16. Delzanno, G.L., G. Lapenta, “Jeans Collapse of a System of Electron Emitting Dust Particles”, talk at the April meeting of the American Physical Society, Denver, Colorado, May 1-4, 2004.
17. Delzanno, G.L., G. Lapenta, M. Rosenberg, “A mechanism for the attraction of Dust Particles in a Plasma”, invited talk at the IV Workshop on Dusty Plasmas, Capri (Na), Italy, June 1-5 2004.
18. G. Lapenta, P. Ricci, U. De Angelis, V. Tsytovich, Simulation of Charging and Shielding of Dust Particles in a Plasma, 2004 Capri Dusty Plasma Workshop, Capri, Italy, June 1–5, 2004.
19. Rosenberg, M. “Some dusty plasma instabilities with application to near-Earth space,” invited talk at 35th COSPAR Scientific Assembly, Paris, July 18-25, 2004.

20. Mendis, D. A., Wong, W.-H., Rosenberg, M. and Sorasio, G., “The role of micrometeorites as sources of electrons in the upper atmosphere,” invited talk at 35th COSPAR Scientific Assembly, Paris, July 18-25, 2004.
21. Delzanno, G.L., “Theory and simulations of the shielding of emitting dust particles”, invited talk at the Oxford Centre for Industrial and Applied Mathematics, Oxford, UK, September 22, 2004.
22. Delzanno, G.L., “Charging and shielding of objects in a plasma”, talk at the’Plasma seminars of the Burning Plasma Research Group’, Politecnico di Torino, Torino, Italy, October 18, 2004.
23. G.L. Delzanno, A. Bruno, G. Lapenta, G. Sorasio, Theory and simulation of the shielding of emitting dust particles, 46th Annual Meeting of the APS Division of Plasma Physics, November 15-19, Savannah, Georgia, USA, 2004.
24. In addition, the university P.I., Dr. Rosenberg, convened a session on Dusty Plasmas at the URSI National Radio Science Meeting at the University of Colorado, Boulder, CO, Jan. 5-8, 2004.
25. G. Lapenta, G.L. Delzanno, 3D Collective behaviour of a System of Emitting Dust Particles, 46th Annual Meeting of the APS Division of Plasma Physics, November 15-19, Savannah, Georgia, USA, 2004.

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Kudeki, E., 1994, Geophys. Res. Lett. 21, 2433. [14] Cho, J.Y.N. and Rottger, J., 1997, J.

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