Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PEM31-01 Room:503 Time:May 1 15:15-15:40

Physics of weakly ionized dusty plasmas in planet formation

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Planets form in gas disks around young stars. These protoplanetary disks are a typical example of weakly ionized plasmas in space: they are cool ($\sim$10-1000 K) but are nonthermally ionized by galactic cosmic rays and stellar X-rays. The disks can also viewed as dusty plasmas as they contain micron-size dust particles from which planets form.

In this talk, we highlight interesting aspects of protoplanetary disks as weakly ionized dusty plasmas, and discuss their importance in planet formation as well as the MHD of the disks themselves. In particular, we focus on the interplay between charged dust particles and disk's MHD turbulence. Ionized accretion disks are prone to become turbulent because of the magnetorotational instability (MRI; Balbus & Hawley 1991). In protoplanetary disks, the activity of MRI strongly depends on how much dust has grown to larger solid bodies, as small dust particles determine the ionization degree of the disk gas. Meanwhile, turbulence, if present, drives the relative velocity of solid particles, which in turn affects how far the particles can grow by collisions. We briefly review recent developments in the numerical study of MRI-driven turbulence, and then discuss possible coevolution of MRI turbulence and dust particles as predicted by our latest self-consistent simulation (Okuzumi & Hirose 2012).

We will also highlight the importance of plasma heating by turbulent electric fields. A simple order-of-magnitude estimate shows that electric fields in MRI turbulence can significantly heat up electrons in the gas. This implies that Ohm's law can become *nonlinear* in the field strength. To study the nonlinearity of Ohm's law, we construct a gas-dust charge reaction model that takes into account the heating of ionized gas particles as well as impact ionization by hot electrons (Okuzumi & Inutsuka, in prep.). We find that the heating gives rise to negative differential resistivity at a high electric field strength. This occurs because heated electrons more frequently adsorb onto dust particles. The reduced conductivity will lead to suppressed MHD turbulence. Our ionization balance calculations predict that this effect become important in realistic protoplanetary disks (Mori & Okuzumi, in prep.).

Keywords: weakly ionized plasma, dust, planet formation, MHD, turbulence

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Ionospheric disturbances studied by high-resolution GPS total electron content observations

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The Global Positioning System (GPS) is a worldwide precise radio-navigation system formed from a constellation of at least 24 satellites at 20,200 km altitude, 4.2 R_E from the center of the Earth. GPS orbit configuration ensures that 5-10 satellites are visible from any single point on the Earth. The dual-frequency signals from the GPS satellites pass through the ionosphere to reach ground-based GPS stations. The phase and group velocities of radio waves vary in the ionosphere depending on the integrated electron density, that is total electron content (TEC), along the ray path and on the frequency of the radio waves. Using these characteristics, the TEC integrated along the ray path between a GPS satellite and a receiver can be accurately measured using two GPS signals in different frequencies. The TEC strongly reflects variations in the ionosphere at an altitude of about 300 km, where is the peak height of ionospheric electron density.

We have developed high-resolution TEC maps using dense GPS receiver networks. We have been collecting all the available GNSS receiver data in the world to expand the TEC observation area. These GNSS data are provided by IGS, UNAVCO, SOPAC, and other regional data centers. Currently, we are providing global and regional maps of absolute TEC, detrended TEC, and rate of TEC change index (ROTI). These data and quick-look maps are archived and available in DRAWING-TEC website (http://seg-web.nict.go.jp/GPS/DRAWING-TEC/).

These high-resolution GPS-TEC maps have been applied to studies of various ionospheric disturbances. Sudden increase in TEC caused by solar flares were studied using global TEC observations. Regional TEC observations have revealed new characteristics of large- and medium-scale traveling ionospheric disturbances (LSTIDs and MSTIDs). Recently, clear concentric waves and short-period oscillations were observed after huge earthquakes/tsunamis and massive tornadoes, indicating that acoustic and/or gravity waves propagate upward from the lower atmosphere and reach the ionosphere.

In this presentation, we will introduce recent studies of ionospheric disturbances using high-resolution GPS-TEC observations.

Keywords: ionosphere, GPS, TEC, thermosphere

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PEM31-03 Room:503 Time:May 1 16:15-16:30

Observation of Lightning in Protoplanetary Disks by Ion Lines

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Lightning in protoplanetary disks is an important elementary process in protoplanetary disk science. It has been studied as a candidate mechanism for chondrule formation, and it provides unique window to probe the electromagnetic state of the protoplanetary disks. As a consequence, multiple lightning models has proposed for protoplanetary disks, and it is important for protoplanetary disk astrophysics to observationally distinguish which model is correct. Here we study the possibility of observationally distinguishing lightning models in protoplanetary disks.

Lightning on Earth is discharge phenomenon in the air, and the gas discharge physics in air has been studied for centuries and is well understood process. But it has been observed that lightning takes place under electric field amplitude well below the dielectric strength of the air, the fact that has been a long standing mystery. Here, dielectric strength of an insulating material is the maximum amplitude of the electric field the subject material does not cause the electric breakdown. It is physical property of central importance for discharge physics.

In attempt to solve the mystery, traditional Townsend breakdown model has been challenged by new discharge models such as Druyversteyn-Penning breakdown model and runaway breakdown model. The values of the dielectric strength according to the latter two model are much smaller than it by Townsend breakdown model.

We can distinguish the breakdown models by their dielectric strength. Dielectric strength is the point where the electrons accelerated by the electric field reaches certain ionization energy. The electric field also accelerates the positively-charged ion species to the energy comparable to the electrons. Because the ionization energy is a universal constant, the accelerated ion energies are also constant. Observationally, this means that we will observe ion velocities much faster than the thermal velocity, and the observed velocities will be independent of the local density nor temperature among the lightning regions. This will be unique observational feature to detect and distinguish breakdown models in protoplanetary disks. For example, under disk gas that consists of 92% H_2 and 8% He, the characteristic ion speed of HCO^+ is 7.1km/s, 2.9km/s and 0.49km/s, respectively, for Townsend breakdown model, Druyversteyn-Penning breakdown model, and runaway breakdown model.

We have calculated the velocity distribution of the three ion species HCO^+, DCO^+ and N_2H^+, taking the lightning models into consideration. We have simulated the line profile and two-dimensional position-velocity images. We found lightning features of 10-100mJy appear in line profile. Recent ALMA observations e.g. by Mathews et al. (2013) and Qi et al. (2013) achives ~10mJy sensitivity. Therefore we can reject some of the lightning models based on ALMA archive data, and distinguish lightning models by future ALMA observations.

Keywords: Protoplanetary disks, Discharge phenomena, Lightning, Weakly-ionized plasma, astrophysical plasma

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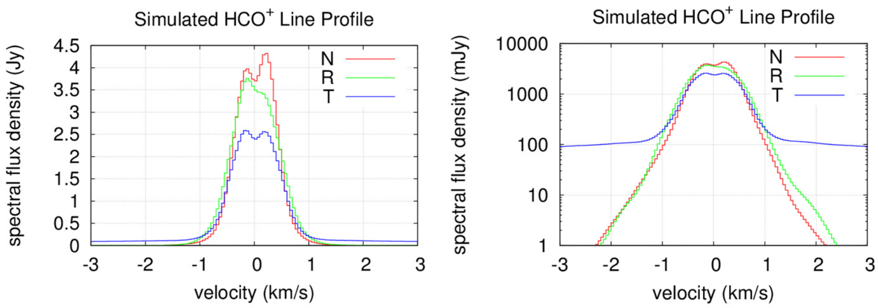

Simulated HCO⁺ line profile of an MMSN disk located at distance *d*=56pc, inclination *i* = 7(deg). The three curves indicate disk without lightning (N), disk with runaway breakdown model (R), and with Townsend breakdown model (T), respectively.

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PEM31-04 Room:503 Time:May 1 16:30-16:45

Investigation of attractive forces associated with overlapping Debye spheres using N-body simulations

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Dust grains are quite common in space. They are thought to exist in, e.g., molecular clouds, protoplanetary disks, Earth's magnetosphere, and planetary rings. In addition, also in laboratories, the lattice formation of dust grains is the well-known phenomena and called Coulomb crystallization. Dust grains immersed in plasmas usually acquire large amount of charges due to several charging processes such as collisions with plasma partilcles and photoemission. Then the charged grains and the ambient plasma are strongly coupled with each other, and such plasmas are called dusty plasmas or complex plasmas. Since in situ observations in the solar system or Ikezi's prediction of Coulomb crystallization, dusty plasmas have been studied for not only astrophysical applications but also industrial applications.

When collisions between dust grains and plasma particles dominate charging processes, the dust grains are nagatively charged because generally the flux of electrons is larger than that of ions. Thus we expect that they repel each other. However, in realty, the force on dust grains is quite complex due to the interaction with the ambient plasma and several types of forces have been proposed (e.g., Shukla and Eliasson [2009]). Interestingly, some attractive forces may also exist and play important roles in aggregation or crystallization of dusty plsamas.

One of proposed attractive forces is that of due to the overlapping of Debye spheres (ODS). Resendes et al. [1998] showed that the potential between two dust grains is similar to Lennard-Jones potentials, which is repulsive at short distance and weakly attractive at longer distance. Moreover, Hou et al. [2009] showed that this type of attractive interaction has, if indeed it exists, the drastic aggregation and crystallization effect in dusty plasmas. On the other hand, it was suggested that the ODS attractive force does not exist when particles electrically trapped by grains are negligible ,i.e., the orbital motion limited (OML) theory is valid (Lampe et al. [2000]), and it has not been confirmed experimentally.

The aim of our study is to investigate the possibility of the ODS potential, by using direct N-body simulations, which allow us to investigate the electrostatic potential structure around the dust grains with minimun assumptions. By using a newly developed N-body simulation code implementing Ewald's sum algorithm, in which the short-range part of the potential is calculated in real space and the long-range part is calculated in wavenumber space, we have shown that in plasmas with a low plasma parameter there does not exist the ODS attractive force. In this study, we introduce the mesh and extend the code to implement the PM (particle-mesh) or PPPM (particle-particle particle-mesh) method allowing us to perform simulations with a much more particles to attempt the investigation of plasmas with the large plasma palameter.

PEM31-05 Room:503 Time:May 1 16:45-17:00

Test-particle simulation of electron-H2O elastic collision along the magnetic field line around Enceladus

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Saturn's inner magnetosphere is dominated by water group neutrals originated from Enceladus' water plume [e.g., Shemansky et al., 1993; Richardson et al., 1998; Esposito et al., 2005]. The neutrals in the inner magnetosphere contribute to one of the important loss processes of plasma through plasma-neutral collisions. However, little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions. In this paper, we will focus on the collisional loss process with neutrals.

We examine the variation of equatorial electron pitch angle distribution and loss rate of precipitated electrons into Saturn's atmosphere through pitch angle scattering due to elastic collisions with neutral H_2O along Saturn's magnetic field line around Enceladus. We focus on 1 keV electrons as a typical energy in the present study. To examine the variation of those, we perform one-dimensional test-particle simulation when the co-rotating electron flux tube passes the dense H_2O region in the vicinity of Enceladus (~6.4 minutes). Results show that the equatorial electron pitch angle distribution near the loss cone ($<$20 degrees and $>$160 degrees) decreases with time through pitch angle scattering due to elastic collisions. It is found that the electrons of ~19 % to the total number of equatorial electrons at the initial condition are lost in ~380 seconds. The calculated loss time is twice faster than the loss time under the strong diffusion.

Keywords: plasma-neutral collision, Saturn, Enceladus, elastic collision, pitch angle scattering

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PEM31-06 Room:503 Time:May 1 17:00-17:15

MHD wave-driven mass loss from gas giants and effects on atmospheric structure

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Recently a number of exoplanets have been found, and some of them are close-in gaseous planets. Such planets are called hot Jupiters, and their surface temperatures are ~1000K due to strong irradiation from central stars.

Information of radius and orbital period of exoplanet can be observed by transit method which is the one of method to detect exoplanets. Additionally, atmospheric composition can be estimated by variation of spectrum between transiting and non-transiting, and atmospheric structure can be estimated by multi-wavelength transit observation. From these observations, inflated hydrogen atmosphere of hot Jupiters and atmospheric escape are suggested. It is observed that escaping atmospheric flow is very fast, and mass loss rate is also estimated. However, detailed mechanism of mass loss from hot Jupiters are still unknown.

We propose a new mechanism of mass loss, which is mass loss driven by magneto-hydrodynamic wave, same as solar wind. Atmosphere is weakly ionized because surface temperatures of hot Jupiters are about 1000K, but it is good to treat as ideal MHD at upper atmosphere. If gas giant have magnetic field and turbulence exist on the surface of planet, magneto-hydrodynamic wave will be generated. The wave propagates upward and dissipates in upper atmosphere, then gas flow is accelerated. In this work, we apply numerical calculation of solar wind to mass loss from hot Jupiters. In consequence, mass loss by this magnetically driven wind is comparable to observed mass loss rate, therefore magnetically driven wind can be important role in mass loss from hot Jupiters.

We also derive an analytical solution for radius and mass dependence of mass loss rate, and it shows a good agreement with numerical results. Dissipation of MHD wave in the atmosphere also affects on atmospheric structure. The gas flow is accelerated to supersonic at upper atmosphere, and temperature become several tens of thousand kelvin. In this talk, we will discuss the possibility of mass loss from general gaseous planet and effects on atmospheric structure.

Keywords: exoplanet, atmospheric escape

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Group motion of heteromorphic fine particles in HF discharge plasma

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Related with complex systems, fine-particle plasmas have much attention to scientists and engineers [1, 2]. Hence, we are trying to make fine-particle plasmas with heteromorphic particle distributions by using a high-frequency (HF) Ar plasma. And the motions of charged particles are observed. In a stainless steel chamber (150 mm in diam, 150 mmh), 100 mm in diam disk electrodes and a 80 mm in diam metal ring are set. In this experiment, HF argon discharge is produced at 10˜13 Pa by applying HF voltage of about 270˜290 V_{rms} to the lower disk-electrode with respect to the upper grounded disk-electrode. And a ring is added on the lower electrode to confine fine-particles. The particles used are silicon carbide, which has diameter of about 8 um, or silicon-nitride (about 8 um), or short hemp (about 25 um diam. 10 ? 1500 um long). They are injected from a dust dropper. A digital microscope camera (SELMIC LWD100) and a CCD video camera are used to investigate the particle behaviors. Under a condition of discharge voltage V_d= 280 V_{rms}, discharge current I_d= 0.2 A_{rms} and pressure p(Ar)= 13 Pa, a disk-shaped cloud is generated as shown in Fig. 1. Each particle motion and the particle-group motion are recorded by the cameras. We could observe planet-like motions like Fig. 2 (track of a SiC particle). In case of the short hemp, there are spin motions and planet-like motions. We conjecture that these motions are activated by the dust-acoustic perturbation.

[1] Y. Hayashi, K. Tachibana, J. Vac. Sci. Technol. A 14 (2) (1996) 506.
[2] H. Thomas, G.E. Morfill, V. Demmel, Phys. Rev. Lett. 73 (1994) 652.

Keywords: fine particle plasma, heteromorphic particles, self organization, planetary motion, spin, dust plasma

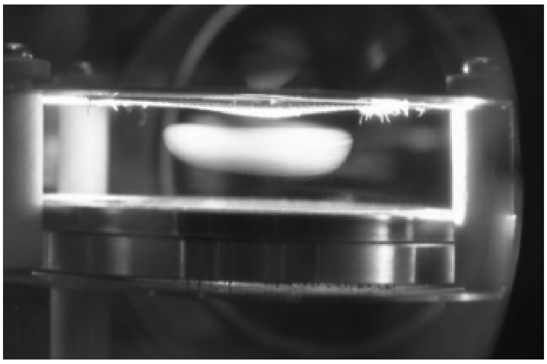

Fig. 1 Fine particles in the HF plasma.

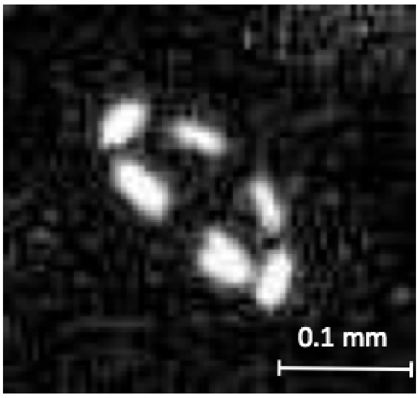

Fig. 2 Planet-like motion of a particle.