Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)
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PPS020-P21 Room:Convention Hall Time:May 25 10:30-13:00

Effects of MHD-turbulence-generated electric fields on ionization states in protoplanetary disks

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Magnetorotational instability (MRI; Balbus & Hawley 1991) is one of the most important mechanisms for angular momentum transport in protoplanetary disks.

This instability requires a sufficiently high ionization degree, but it is uncertain whether such an ionization degree is maintained in all parts of the disks. In particular, small dust grains can significantly lower the ionization degree and make a large disk region MRI-inactive (Sano et al. 2000).

All previous studies on disk ionization have implicitly assumed that the electric field generated in MRI-driven turbulence is so weak that electric acceleration (heating) of ionized particles is negligible. However, a simple estimate based on numerical simulations imply that this effect is not necessarily negligible (Inutsuka & Sano 2005).

In this study, we have reanalyzed the ionization state of protoplanetary disks taking into account electric heating of ionized particles as well as their adsorption onto dust grains. The results are summarized as follows:

(1) If the electric field E exceeds a critical value E_{crit}, electric heating becomes effective for electrons, leading to the conductivity decreasing with increasing E. This effect could lower the saturation level of MRI turbulence when the initial vertical magnetic field is weak.

(2) If E is so strong that the mean electron energy exceeds 1 eV, runaway ionization occurs through collisions between high-energy electrons and neutral gas particles. This leads to jump of the conductivity by more than eight orders of magnitude. When the initial vertical magnetic field is strong, this effect allows MRI-driven turbulence to be self-sustained.

Keywords: protoplanetary disk, ionization state, dust grains, MHD turbulence, electric heating