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Dead zones by electric heating in protoplanetary disks

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Turbulence driven by magnetorotational instability (MRI) is a viable mechanism of angular momentum transport in accretion disks. In protoplanetary disks, however, there is a region where the ionization degree is too low for MRI to be active (e.g., Gammie 1996; Sano et al. 2000). Whether turbulence is present or not strongly affects the growth of dust particles to planetesimals. Therefore, a good knowledge of the size of dead zones is essential to understanding planet formation.

In this study, we focus on the heating of electrons by turbulent electric fields and its effect on the ionization state of protoplanetary disks. Previous studies have assumed that electrons in the disks have the same temperature as the neutral gas. However, this is not necessarily the case in MRI-driven turbulence, in which turbulent electric fields can significantly heat up electrons (Inutsuka & Sano 2005). Heated electrons efficiently adsorb onto dust grains, and therefore electron heating leads to a reduction of the ionization degree (Okuzumi & Inutsuka, in prep.). This could effectively increase the dead zone size by reducing the saturation level of MRI turbulence outside the conventional dead zone.

The aim of this study is to show where in protoplanetary disks the effect mentioned above becomes important. We calculate the ionization degree of disks assuming that MRI operates outside the dead zone. For a minimum-mass solar nebula with the dust grain radius of 0.1um and dust-to-gas mass ratio of 0.01, we find that the effect becomes significant in a region extending from the outer edge of the dead zone (at ~20 AU from the central star) out to 70 AU. Furthermore, our analytic estimate suggests that the saturation level of turbulence in this region is significantly low.

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