The Role of Tiny Grains on the Accretion Process in Protoplanetary Disks

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Tiny grains such as PAHs have been thought to dramatically reduce the coupling between gas and magnetic fields in weakly ionized gas such as in protoplanetary disks (PPDs) because they provide tremendous surface area to recombine free electrons. The presence of tiny grains in PPDs thus raises the question of whether the magnetorotational instability (MRI) is able to drive rapid accretion to be consistent with observations. Charged tiny grains have similar conduction properties as ions, whose presence leads to qualitatively new behaviors in the conductivity tensor, characterized by n_bar/n_e>1, where n_e and n_bar denote the number densities of free electrons and all other charged species respectively. In particular, Ohmic conductivity becomes dominated by charged grains rather than electrons when n_bar/n_e exceeds about 10^3, and Hall and ambipolar diffusion (AD) coefficients are reduced by a factor of (n_bar/n_e)^2 in the AD dominated regime relative to that in the Ohmic regime. Applying the methodology of Bai (2011), we find that in PPDs, when PAHs are sufficiently abundant (>1e-9 per H_2), there exists a transition radius r_trans of about 10-20 AU, beyond which the MRI active layer extends to the disk midplane. At r<r_trans, the optimistically predicted MRI-driven accretion rate M_dot is one to two orders of magnitude smaller than that in the grain-free case, which is too small compared with the observed rates, but is in general no smaller than the predicted M_dot with solar-abundance 0.1 micron grains. At r>r_trans, we find that remarkably, the predicted M_dot exceeds the grain-free case due to a net reduction of AD by charged tiny grains, and reaches a few times 1e-8M_Sun/yr. This is sufficient to account for the observed M_dot in transitional disks. Larger grains (>0.1 micron) are too massive to reach such high abundance as tiny grains and to facilitate the accretion process.

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