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Magnetorotational Instability Driven Accretion in Protoplanetary Disks

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The gas dynamics in protoplanetary disks (PPDs) is strongly affected by non-ideal MHD effects. Using a complex chemical reaction network with standard prescriptions for X-ray and cosmic-ray ionizations, as well as the most up-to-date results from numerical simulations, we study the non-ideal MHD effects on the magnetorotational instability (MRI) and angular momentum transport in PPDs. We first show that no matter grains are included or not, the recombination time is always shorter than the orbital time in the bulk of PPDs, justifying the validity of local ionization equilibrium. The full conductivity tensor at different disk radii and heights is evaluated, with the MRI active region determined by requiring that (1) the Ohmic Elsasser number be greater than 1; (2) the ratio of gas to magnetic pressure beta be greater than beta_min(Am) as identified by Bai & Stone (2011), where Am is the Elsasser number for ambipolar diffusion. With full flexibility as to the magnetic field strength, we provide a general framework for estimating the MRI-driven accretion rate M_dot and the magnetic field strength in the MRI-active layer. We find that the MRI-active layer always exists at any disk radii as long as the magnetic field in PPDs is sufficiently weak. However, the optimistically predicted M_dot in the inner disk (r=1-10 AU) appears insufficient to account for the observed range of accretion rate in PPDs (around 1e-8M_Sun/yr) even in the grain-free calculation, and the presence of solar abundance sub-micron grains further reduces M_dot by one to two orders of magnitude. Our results suggest that stronger sources of ionization, and/or additional mechanisms such as magnetized wind are needed to explain the observed accretion rates in PPDs. In contrast, our predicted M_dot is on the order of 1e-9M_Sun/yr in the outer disk, consistent with the observed accretion rates in transitional disks. (Abridged)

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