Testing magnetic accretion models against ALMA observations of the HL Tau disk

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Atacama Large Millimeter/submillimeter Array (ALMA) has revealed that the dust disk around the young star HL Tau consists of multiple nearly concentric rings and gaps (ALMA Partnership et al. 2015). The well separated rings indicate that the dust disk is geometrically thin, suggesting that the turbulence in the gas disk is weak, at least near the outer edge of the disk. On the other hand, the strong Brgamma emission from this system points to strong gas accretion from the disk to the star, with the accretion rate of ~ 10^{-7} M_{sun} yr^{-1} (Beck et al. 2010). The simplest accretion model where the accretion is assumed to be steady and driven only by turbulence does not explain the strong gas accretion and the significant settling of the millimeter-sized dust particles simultaneously (Pinte et al. 2016).

Here we show that additional gas accretion powered by magnetic disk winds could resolve this paradox. Recent magnetohydrodynamic (MHD) simulations show that the magnetic diffusivity arising from weak ionization suppresses MHD turbulence. Yet accretion takes place as winds launched from the disk surface accelerate via magnetic forces, extracting orbital angular momentum (e.g., Bai & Stone 2013; Simon et al. 2013; Zhu et al. 2015). Based on the results of the recent MHD simulations, we construct a simple, one-dimensional magnetic accretion model where we incorporate the angular momentum transport due to both MHD turbulence and winds as well as the turbulent diffusion of dust particles along the disk's vertical direction. We find that our model simultaneously reproduces three important observational features of the HL Tau disk---the high accretion rate onto the central star, the absence of evidence for gravitational instability, and the geometrically thin subdisk of millimeter-sized dust particles---when the strength of the magnetic field driving the disk wind falls within a certain range. Direct observations of gas outflow from the disk surface and/or surface gas inflow toward the central star will provide further constraints on the mechanism of protoplanetary disk accretion.

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