Millimeter-Wavelength Signatures of Disk Accretion

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ABSTRACT

We present recent results from the Submillimeter Array that use resolved observations of four nearby disk systems (HD 163296, TW Hydrae, GM Aurigae, and MWC 480) to study signatures of disk accretion. Using 1.3 and 0.87 mm continuum and CO J=3-2 data, we show that a simple model motivated by similarity solutions of the time evolution of accretion disks can reconcile the apparent discrepancy between gas and dust outer radii, obtained by commonly-used models described by power laws in surface density and temperature. For two systems, we further investigate accretion processes with new observations designed to probe turbulent linewidths and magnetic field structure, the central aspects of alpha-disk model with MRI turbulence: observations of the CO J=3-2 line in TW Hya at 44 m/s spectral resolution allow us to study disk kinematics at a new level of detail, while spatially resolved 0.87 mm polarimetric observations of the HD 163296 disk allow us to test the first realistic predictions of polarized emission from dust grains aligned by magnetic fields threading the disk.

1. GAS AND DUST EMISSION AT DISK OUTER EDGES AS CLUES TO ACCRETION PROCESS

Recent millimeter-wave observations of protoplanetary disks have revealed an apparent discrepancy between the extent of the disk in thermal continuum and molecular gas emission. Using archival SMA observations of four nearby disk systems, we examine two models of circumstellar disk structure and the effects of their treatment of the disk outer edge. We show that for these disks, models described by power laws in surface density and temperature truncated at an outer radius are incapable of reproducing both the gas and dust emission simultaneously; however, while we cannot rule out the implied disparate radii, we show that a realistic alternative model, grounded in the physics of accretion, provides a consistent picture for the extent of both the gas and dust. For details, see Hughes et al. 2008a, ApJ, 678, 1119.

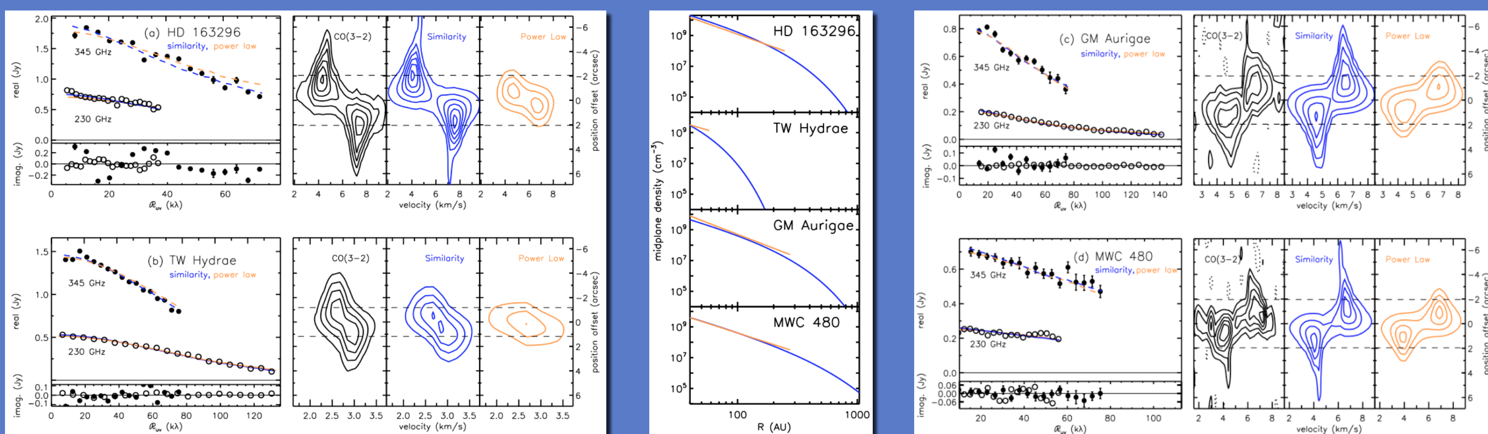


Fig. 1 – Comparison between the data and two types of models (similarity solution from Hartmann et al. 1998, and power law) for the four disks in our sample: (a) HD 163296, (b) TW Hydrae, (c) GM Aurigae, and (d) MWC 480. For each source, the left panel shows the real and imaginary visibilities as a function of deprojected (u,v) distance from the phase center, at 230 (open circles) and 345 GHz (filled circles). Lines represent the best fit to the 345 GHz continuum for the power law (orange) and similarity (blue) models. The right panel shows position-velocity diagrams of the J=3-2 rotational transition of CO along the major axis of the disk for the data (black) and best-fit similarity solution (blue) and power-law (orange) models. The horizontal dashed line across the right panel represents the extent of the outer radius derived for each source through fitting the continuum emission with a power-law model. The contour levels, beam, and velocity resolution for each source are as follows: (a) [2,4,6,8,10,12]x1.1 Jy/beam, 3.0x2.1 arcsec at PA 14.3, and 0.35 km/s; (b) [2,4,6,8]x2.0 Jy/beam 4.0x1.8 arcsec at PA 3.1, and 0.18 km/s; (c) [2,4,8,12,16]x0.5 Juy/beam, 2.3x2.1 arcsec at PA 12.9, and 0.35 km/s; (d) [2,4,6,8,10]x0.5 Jy/beam, 2.5x2.3 arcsec at PA 45.3, and 0.35 km/s. The plot in the center shows the midplane density structure of the best-fit power-law model (orange) and similarity solution (blue).

2. CONSTRAINING MAGNETIC FIELD PROPERTIES WITH POLARIMETRY

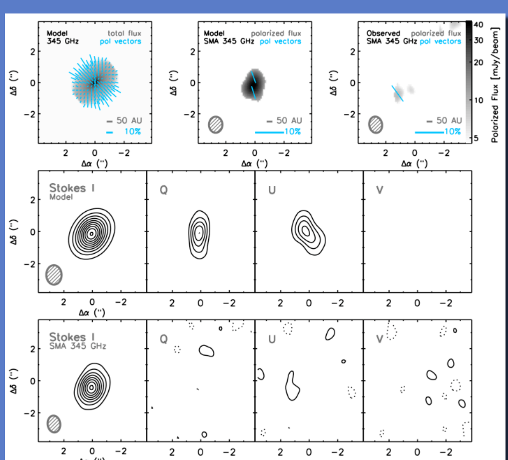
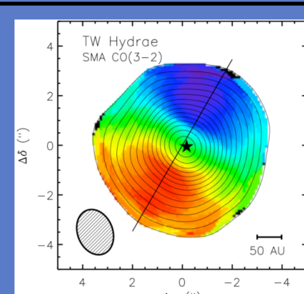


Fig. 2 – Comparison between the Cho & Lazarian model and the SMA 345 GHz data. The top row shows the model at full resolution (left), a simulated observation (center), and the data (right). The grayscale shows the total (left) or polarized flux; blue vectors indicate the percentage and direction at half-beam intervals. The center and bottom rows compare the model prediction (center) with the SMA data (bottom) in the four Stokes parameters. Contour levels: multiples of 10% of the peak flux (0.9 Jy/beam) in Stokes I or increments of 2σ for Q, U, and V, where σ is the rms noise of 2.7 mJy/beam. Beam is indicated in the lower left of each panel.

The magnetorotational instability, thought to generate turbulence in disks, requires the presence of a subthermal magnetic field, which should be observable via polarized emission of dust grains aligned with the field. We are using the SMA polarimeter to test the first realistic predictions of polarized emission from disks, from the models of Cho & Lazarian (2007). These models, which include a realistic disk structure (based on Chiang & Goldreich 2001) threaded by a toroidal magnetic field with grains aligned via the radiative torque mechanism, predict that the polarized flux will be 2-3% of the total millimeter-wave flux from the disk. Observations of the disk around HD 163296 yield an upper limit at least 5x lower than the predicted value (Fig 2), corresponding to a total polarization fraction of less than 0.4%.

3. CONSTRAINING TURBULENCE: RESOLVING NONTHERMAL WIDTH OF MOLECULAR LINES

Turbulence is the most commonly invoked source of the "anomalous" viscosity that drives the viscous transport of material through the disk. The only directly observable quantity associated with turbulence is the nonthermal width of spectral lines. Previous observations at millimeter wavelengths have indicated turbulent linewidths at or just below the spectral resolution of the data. We are using the new high spectral resolution observing mode of the SMA correlator to resolve the turbulent linewidth in both the spectral and spatial domains, in order to determine both its magnitude and variation with radius. Observations of the CO(3-2) emission from the TW Hya disk at a spectral resolution of 44 m/s (Fig 3 & 4) can be reproduced using only thermal and rotational line broadening; a simple model described by radial power laws in temperature and surface density with uniform CO abundance allows us to place an upper limit on the turbulent linewidth of approximately 20 m/s.



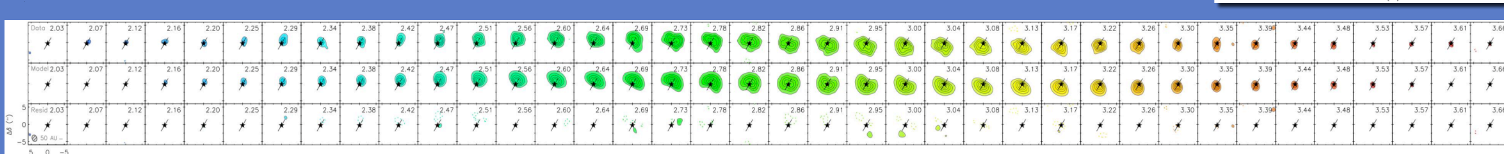


Fig. 3 & 4 – SMA CO J=3-2 observations of the TW Hya disk at a spectral resolution of 44 m/s (top) compared with the best-fit model (center), and residuals (bottom), and a moment map of the full data set (upper right). The star position is marked with a star symbol, and the disk major axis is indicated by a line. The channel rms is 0.9 Jy/beam; contours are [2,4,6,...]σ. LSR velocity is indicated by color and in the upper right of each panel. The synthesized beam and physical scale are indicated in the lower left panel.