AN INNER HOLE IN THE DISK AROUND TW HYDRAE RESOLVED IN 7 mm DUST EMISSION

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ABSTRACT

We present Very Large Array observations at 7 mm wavelength that resolve the dust emission structure in the disk around the young star TW Hydrae at the scale of the ~4 AU (0.16") radius inner hole inferred from spectral energy distribution modeling. These high-resolution data directly confirm the presence of an inner hole in the dust disk and reveal a high-brightness ring that we associate with the directly illuminated inner edge of the disk. The clearing of the inner disk plausibly results from the dynamical effects of a giant planet in formation. In an appendix, we develop an analytical framework for the interpretation of visibility curves from power-law disk models with inner holes.

Subject headings: circumstellar matter — planetary systems: protoplanetary disks — stars: individual (TW Hydrae)

1. INTRODUCTION

The TW Hya system is thought to be a close analog of the early solar nebula. At a distance of 51 ± 4 pc (Mamajek 2005), it is the closest known classical T Tauri star, and a suite of observational studies have shown that TW Hya harbors a massive disk of gas and dust. Scattered light observations at optical and near-infrared wavelengths reveal a surface brightness profile consistent with a nearly face-on, optically thick flared disk extending to ~200 AU in radius (Roberge et al. 2005; Weinberger et al. 2002; Krist et al. 2000; Trilling et al. 2001). Observations at millimeter wavelengths have detected thermal dust emission and a variety of molecular species, including 13CO, 12CO, CN, HCN, HCO+, and DCO+ (Weintraub et al. 1989; Zuckerman et al. 1995; Kastner et al. 1997; van Dishoeck et al. 2003; Wilner et al. 2003; Qi et al. 2004). The dust also displays signatures of grain growth up to centimeter scales (Wilner et al. 2005), and perhaps substantially larger sizes.

Detailed models of the TW Hya spectral energy distribution (SED) provide constraints on many aspects of the disk structure (Calvet et al. 2002), including the radial dependence of outer disk surface density and temperature, and a clearing of the inner disk within ~4 AU radius. Resolved interferometric observations of millimeter and submillimeter dust emission are in good agreement with the structure inferred from the irradiated accretion disks models that match the SED (Qi et al. 2004; Wilner et al. 2000), although the resolution and sensitivity at these wavelengths have not been sufficient to address the presence of the inner hole.

The inner hole is indicated by two features of the SED (Calvet et al. 2002): (1) a flux deficit from ~2–20 μm, indicative of low (dust) surface density in the inner disk, and (2) a flux excess at ~20–60 μm, thought to originate from the truncated inner edge of the disk, directly illuminated by the star. Similar spectral features have been recognized in other T Tauri star SEDs (e.g., GM Aurigae and DM Tauri; see Calvet et al. 2005) and may signify an important phase in the evolution of circumstellar disks.

One exciting possibility is that a discontinuity in the inner disk is a consequence of the perturbative gravity field of a giant planet. Theories of planet-disk interaction predict the opening of gaps in a disk as a result of the formation of massive planets (e.g., Lin & Papaloizou 1986; Bryden et al. 1999). However, Boss & Yorke (1993, 1996) show that the interpretation of infrared flux deficits as central clearings is not unique and reproduce SEDs of accreting disks around low-mass, pre-main-sequence stars with a combination of opacity and geometry effects in the unresolved system. Spatially resolved observations of disk structure are required to confirm the inference from spectral deficits of inner disk clearing.

To probe the disk morphology on size scales commensurate with the 4 AU transitional radius of Calvet et al. (2002), we have used the Very Large Array to observe thermal dust emission from TW Hya at a wavelength of 7 mm. These observations clearly show a deficit of dust emission in the inner disk consistent with the predicted hole.

2. OBSERVATIONS

We used the Very Large Array to observe TW Hya at 7 mm in the most extended (A) configuration. The observations used 23 VLA antennas (several were unavailable due to eVLA upgrades) that gave baseline lengths from 130 to 5200 k. The observations were conducted for four hours per night on 2006 February 10 and 11 and 2006 March 7, from 7 to 11 UT (0 to 4 MST), during the late night, when atmospheric phases on long baselines are most likely to be stable. Both circular polarizations and two 50 MHz wide bands were used to obtain maximum continuum sensitivity. The calibrator J1037–295 was used to calibrate the complex gains, using an 80 s fast switching cycle with TW Hya. The calibrator J1103–328, closer to TW Hya in the sky, was also included in a few minutes of fast switching each hour to test the effectiveness of the phase transfer from J1037–295. The phase stability was good during the observations of February 11, worse on February 10, and much worse on March 7. Using the AIPS task SMOGL, we pruned the data with phase jumps of more than 70° between phase calibrator scans. This procedure passed about 80% of the data from the night of February 11, but substantially less from the other nights. Therefore, in the subsequent analysis, we have used data only.

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