INTERFEROMETRIC IMAGES OF ^{13}CO EMISSION TOWARD HL TAU

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ABSTRACT. Millimeter wave interferometric images of HL Tau show a clear disk morphology with a nearly keplerian velocity curve. A few a few tenths of a solar mass are in orbit around the star.

With the angular resolution provided by millimeter wave radio interferometers, one can directly image the gas in the circumstellar regions near young stars. HL Tau and R Mon are two pre-main sequence stars that appear to be surrounded by disks of gas and dust (Cohen 1983; Beckwith et al. 1984). We recently observed CO emission toward these stars and found it to be spatially (< 5") and spectrally (< 3 km/s) unresolved in both cases (Beckwith, Sargent et al. 1986); the gas probably resides in the disks. Uncertainties about the amount and distribution of the gas motivated further observations with better sensitivity and spectral resolution, a logical choice being the isotope 13CO. This talk is a brief synopsis of the 13CO observations of HL Tau.

We observed the J=1-0 13CO line (110 GHz) with the Owens Valley Millimeter Interferometer in 1985. Five interferometer configurations produced a synthesized beam of about 6" x 10" (R.A. x Dec) in each of thirty two spectral channels (0.13 km/s resolution) and a broad continuum channel. A description of the instrument and the observing procedures is given in our previous paper.

Figure 1 shows maps of the velocity integrated 13CO emission (1a) and the continuum emission (1b). A cross marks the stellar position in each figure. The continuum emission is completely unresolved and coincident with the star; its distribution reproduces the synthesized beam almost exactly. Most of the 13CO intensity comes from a bright core at the stellar position with the more extended emission looking very much like an edge on disk. The disk is oriented along position angle 147 degrees similar to the angle of 146 degress of the polarized light near HL Tau (Hodapp 1984) and nearly orthogonal to the nearby jet (Mundt and Fried 1983), and the outflow directions from several other nearby stars: L1551 IRS 5 (Snell, Loren, and Plambeck 1980), DG Tau and HH 30 (Mundt and Fried 1983).

Figure 2 show maps of the 13CO emission versus velocity. The

I. Appenzeller and C. Jordan (eds.), Circumstellar Matter, 81–83.

https://doi.org/10.1017/S0074180900156013 Published online by Cambridge University Press

rotation curve derived from positions of maxima is consistent with keplerian velocities. The gas at the stellar velocity (2c, 6.60 km/s) peaks up at the stellar position, gas which is at low red (2b, 7.12 km/s) and blueshifted (2d, 6.08 km/s) velocities peaks at about 10" from the star on opposite sides, and the highest red (2a, 7.64 km/s) and blueshifted (5.9 km/s, not shown) velocities are seen once again close to the star. This general pattern is characteristic of velocities in a central potential.

Assuming the distance to HL Tau is 160 pc and it is a 1 solar mass star, the shift of +/-0.5 km/s at positions +/-10" from the star corresponds to the orbital velocity for material at 1600 A.U. radius. Uncertainties in the stellar mass and peak position make it impossible to show this gas is in precise keplerian motion, but the distribution and magnitude of the velocities are persuasive evidence that the gas is bound to the star, and stellar gravity dominates the potential.

In the central pixel, the 13CO has almost the same brightness temperature as the CO - T(13CO) = 5.2 K and T(CO) = 5.4 K - yielding an optical depth of about 3 for 13CO. Using a previous estimate for the gas excitation temperature of 50 K (Beckwith, Sargent et al 1986), the unknown filling factor reconciling the excitation and brightness temperatures, the total gas hydrogen mass in the central beam is 0.3 solar masses. While the result is uncertain (factor of three, say), it is clear that the disk contains a substantial fraction of a stellar mass.

The continuum radiation is thermal emission from solid particles in the disk. Following the arguments in our earlier paper and using an emissivity coefficient falling as frequency squared (e.g. Hildebrand 1983), the equivalent molecular hydrogen mass implied by the continuum radiation is 0.3 solar masses, in good agreement with that implied by the CO emission.

The disk structure and large mass indicated by the 13CO observations guarantee the stability of the gas against disruption by stellar winds or radiation pressure (Beckwith et al. 1984). It certainly contains enough mass to form a planets similar to those around the sun. With nearly as much mass in the disk as in the star, it is even possible the disk is self-gravitating and influences further accretion of cloud material. It should be possible to directly map the gas distribution in the outer parts of the disk with millimeter wave interferometers, and we expect future observations to play a role in deciding how these disks form and evolve. A more detailed analysis of these data will be presented in a longer article this year (Sargent and Beckwith 1986).

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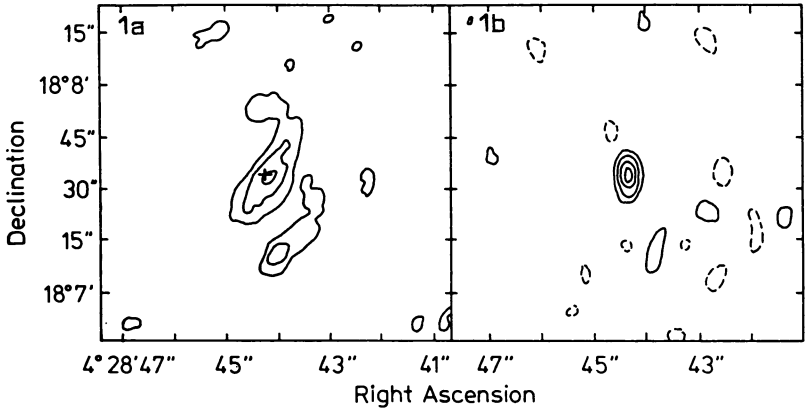

Figure 1: Maps of integrated 13CO (1a) and continuum emission (1b) towa HL Tau. The continuum emission is unresolved and maps the beam.

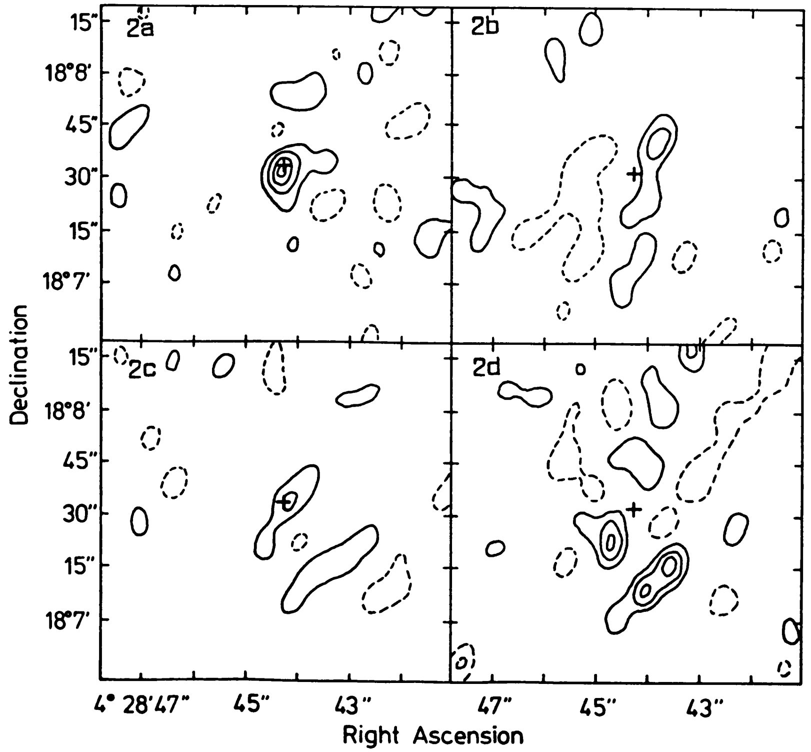

Figure 2: Maps of 13CO emission in different velocity channels. 2a - 7.64 km/s; 2b - 7.12 km/s; 2c - 6.60 km/s; 2d - 6.08 km/s.

https://doi.org/10.1017/S0074180900156013 Published online by Cambridge University Press