DISTRIBUTION AND KINEMATICS OF HCO^+ AROUND T TAURI

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ABSTRACT The circumbinary material around T Tauri is studied on scales of 1000 AU using emission from HCO^+ and CO isotopes. The HCO^+ J=1→0 profile observed with the Owens Valley millimeter interferometer shows red–shifted absorption, which is interpreted as large scale infall from a surrounding envelope. Such infall at relatively evolved stages of the star formation process could lead to the FU Orionis–type outbursts observed for this system.

INTRODUCTION

The T Tauri stage is often identified with the low mass counterpart of the Herbig Ae/Be star phenomenon. In these stages the object is presumably surrounded by a disk–like structure of dust and molecular gas (Shu et al. 1987). In T Tau this material has been inferred from infrared and submillimeter continuum observations of the dust as well as millimeter observations of the CO molecule (Weintraub et al. 1989; Beckwith & Sargent 1991). The molecular gas encompasses both T Tau and its infrared companion, which are separated by 100 AU. An outflow blowing away the surrounding molecular material is also present in this system, but does not show a clear bipolar structure (Levreault 1988) because the system is observed almost pole–on (Herbst et al. 1986). This geometry makes it difficult to disentangle the different components on the basis of their kinematics, but has the advantage that the full disk/envelope area is seen, resulting in larger fluxes.

OBSERVATIONS

Fig. I*a* and I*b* show the HCO^+ J=1→0 emission in the direction of T Tau, obtained with the Owens Valley interferometer (OVRO) in a $7'' \times 7''$ beam. For comparison the spectrum of HCO^+ J=1→0 in a $25''$ beam, observed with the

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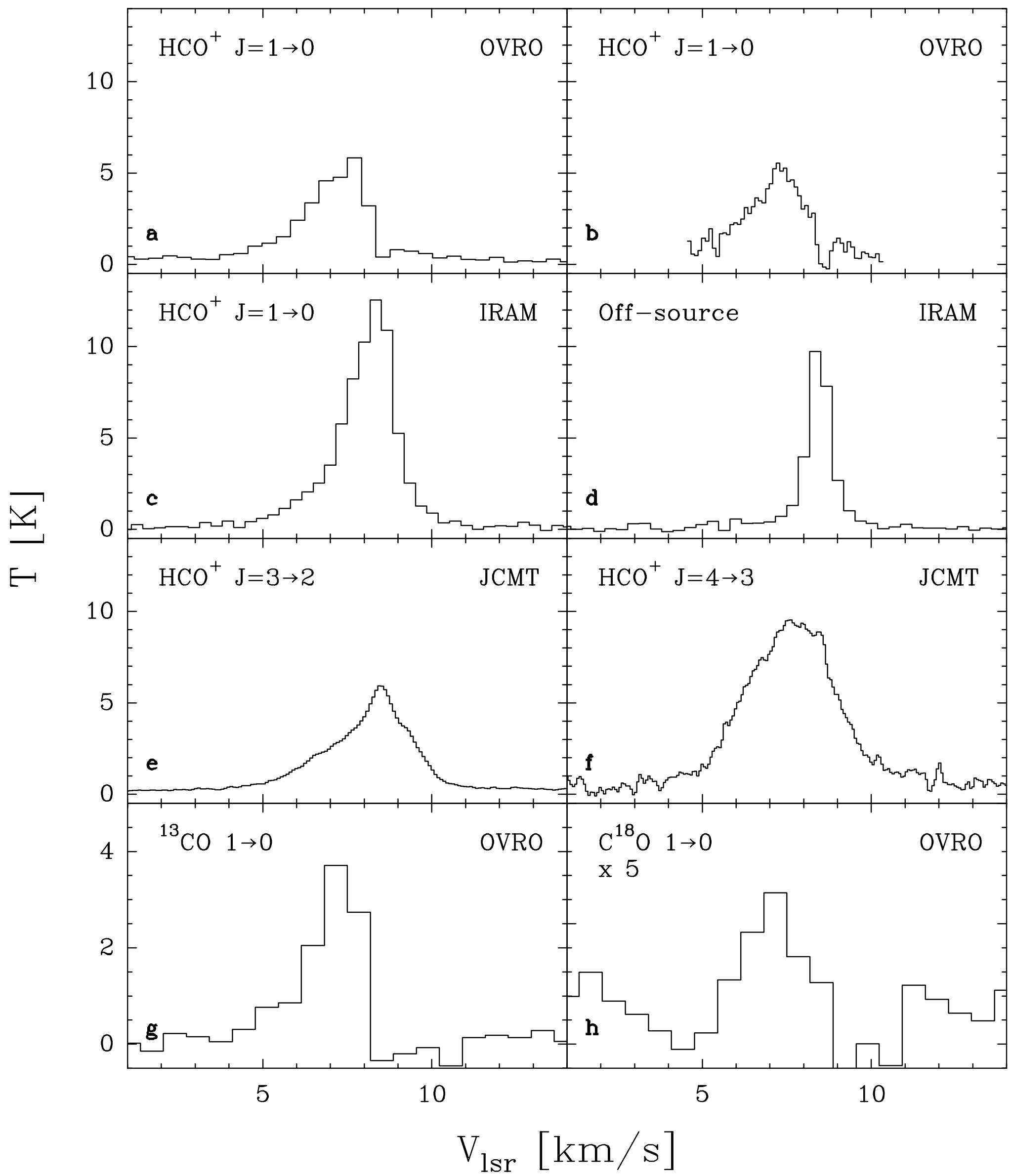

FIGURE I Interferometer and single dish spectra towards T Tau

IRAM 30m dish, is shown in Fig. I*c*. It is clear from these spectra that a narrow component at $\approx$ 8.3 km s^{-1} is resolved out by the interferometer. A compact object with a size of $\approx$1000 AU remains for which the HCO$^+$ J=1$\rightarrow$0 profile is quite asymmetric and peaks at $\approx$ 7.2 km s^{-1}. The smooth component can also be seen at the off–set position (Fig. I*d*); most of this emission comes from a quiescent cloud of $\gtrsim$6000 AU size.

The same compact object is also detectable in the higher excitation HCO$^+$ J=3$\rightarrow$2 (Fig. I*e*) and J=4$\rightarrow$3 (Fig. I*f*) transitions. These profiles were obtained with the JCMT with 19$''$ and 14$''$ beams respectively. The blue side of these spectra closely resembles the OVRO spectra of the J=1$\rightarrow$0 transition. The J=3$\rightarrow$2 line still shows some of the narrow emission from the (mostly background) quiescent cloud. Fig. I*g* shows the ^{13}CO J=1$\rightarrow$0 spectrum, also obtained with OVRO. Clearly, a similar structure as seen in the HCO$^+$ spectrum is observed, although the spectral resolution is not as high. The C^{18}O line (Fig. I*h*) is much weaker with no significant asymmetry.

INTERPRETATION

The slightly resolved compact object is identified either with a circumbinary disk around the young stars, or with the inner part of an accretion envelope (Calvet et al., these proceedings). The HCO$^+$ J=1$\rightarrow$0 channel maps show that the highest velocities arise closest to the position of T Tau, consistent with either interpretation. The higher excitation lines also arise from this same component, indicating that warm $T_{\rm kin}$ > 30 K and dense $n_{\rm H_2} > 10^6$ cm^{-3} material is present.

The most satisfying interpretation for the striking dip at 8.5 km s^{-1} in Fig. I*a* and *b* is absorption by colder foreground HCO$^+$. This explains why the higher excitation lines are more symmetric (Fig. I*e* and *f*), since the excited levels are much less populated in the lower density envelope. The IRAM J=1$\rightarrow$0 profile (Fig. I*c*) does not show the absorption, because it occurs only against the compact object covering only a small fraction of the beam. In addition, emission from the background cloud fills in the absorption in the HCO$^+$ 1$\rightarrow$0 and 3$\rightarrow$2 single–dish profiles.

Because the absorption is red–shifted with respect to T Tau this implies that material is falling onto the binary system. Thus the only difference between the shape of the HCO$^+$ J=4$\rightarrow$3 and compact J=1$\rightarrow$0 emission is foreground absorption. Fig. **??** shows the spectra of the absorption obtained by subtracting a scaled J=4$\rightarrow$3 profile from the J=1$\rightarrow$0 spectra. From the large optical depth of the J=1$\rightarrow$0 absorption and the absence of absorption in the J=4$\rightarrow$3 line, the physical parameters of the absorbing gas are constrained to $T_{\rm kin} < 20$ K, $n_{\rm H_2} < 10^5$cm^{-3} and $N_{\rm HCO^+} \approx (2-4)\times 10^{12}$ cm^{-2}. This yields a lower limit to the accretion rate of $\approx 2\times 10^{-7}$ M$_\odot$yr^{-1} for spherical symmetry. In this calculation we have assumed a fractional abundance of HCO$^+$ of $(6-8)\times 10^{-9}$ (Guélin et al. 1982) or smaller.

The shapes of the ^{13}CO and C^{18}O J=1$\rightarrow$0 transitions can be readily understood in this picture by recalling that CO has a very small dipole moment. Thus the absorption coefficients of CO isotopes are factors of 1000 smaller than that of HCO$^+$. ^{13}CO, however, is 200–1000 times more abundant than HCO$^+$, so that some ^{13}CO absorption likely occurs. However, for C^{18}O negligible absorption is

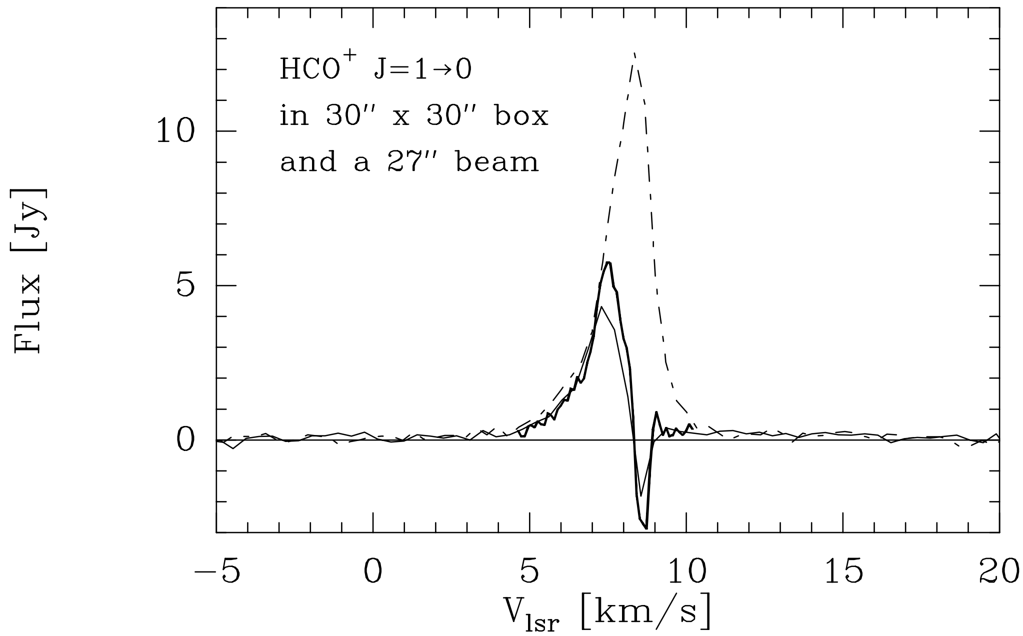

FIGURE II Difference spectrum of OVRO J=1→0 and JCMT J=4→3, showing clearly the absorption in the J=1→0 line.

expected, consistent with Fig. Ih.

Some evidence for large scale accretion has been presented previously by Zhou et al. (1993) for protostellar cores at $\approx 10^5$ yr since the onset of collapse. However, the age of T Tau is significantly larger, about 10^6 yr. The current result is the first indication that some infall from the surrounding envelope is continuing onto the circumbinary material in the later phases of star formation. Accretion through the disk in more evolved young stellar objects has been suggested to explain FU Orionis–type outbursts (Hartmann et al. 1993, Bell, these proceedings). In this respect it is interesting to note that a flare was recently observed for T Tau S, the infrared companion (Ghez et al. 1991). It is estimated that the amount of matter involved in the flare can be accreted in $\lesssim$100 yr, provided that the material is deposited at radii sufficiently close to the star.

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