Distributions and kinematics of molecular species around T Tau

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Circumstellar material on small ($\lesssim$ 2000 AU) scales around T Tau has been inferred from infrared and submillimeter continuum observations of the dust as well as interferometric CO observations (Weintraub et al. 1989, Beckwith & Sargent 1991). This material, possibly a proto–planetary disk, encompasses both T Tau and its infrared companion, which is separated by 100 AU.

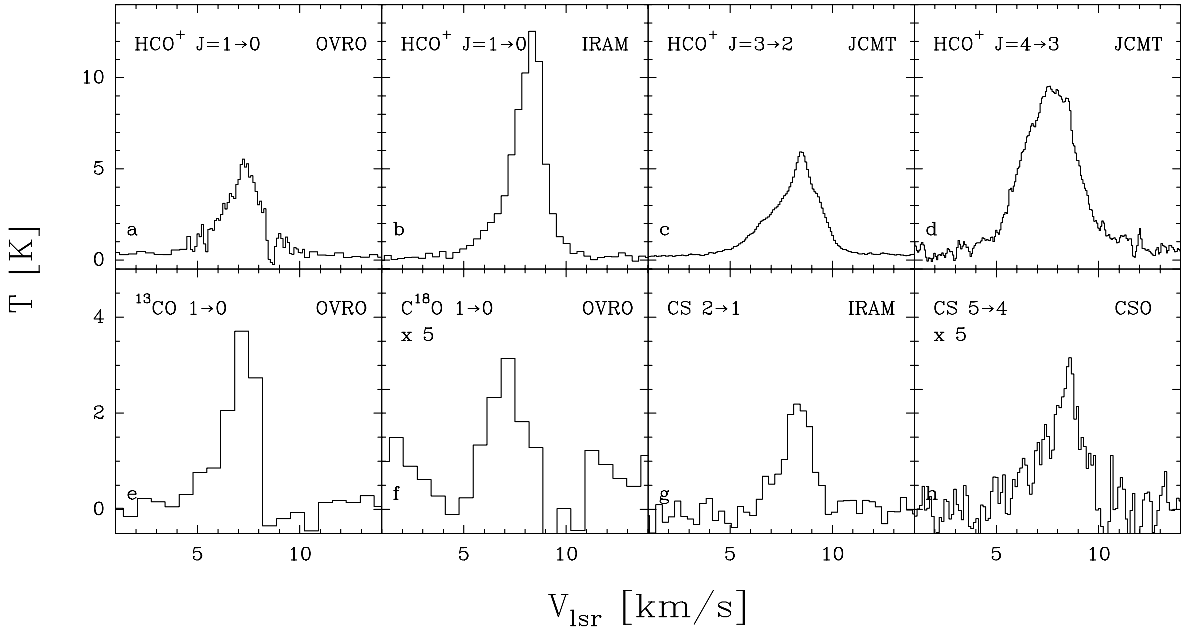
We report single dish and interferometer observations of several molecular species to study the chemical and physical structure of this circumbinary gas. Fig. 1*a* shows the HCO^+ J=1→0 emission in the direction of T Tau, obtained with the OVRO interferometer in a $7'' \times 7''$ beam. For comparison the spectrum of HCO^+ J=1→0 in a $25''$ beam, observed with the IRAM 30m dish, is shown in Fig. 1*b*. It is clear from these spectra that a narrow extended ($\gtrsim$ 6000 AU) component at $\approx$ 8.3 km s^{-1} is resolved out by the interferometer. A compact object remains for which the HCO^+ J=1→0 profile is quite asymmetric and peaks at $\approx$ 7.2 km s^{-1}. The same compact object is also detectable in HCO^+ J=3→2 (Fig. 1*c*) and J=4→3 (Fig. 1*d*) profiles obtained with the JCMT in $19''$ and $14''$ beams respectively. The blue side of these spectra closely resembles the OVRO spectra of the J=1→0 transition. The J=3→2 line still shows some of the narrow emission from the background cloud.

The compact object is identified with a circumbinary disk ($\approx$1000 AU size) or the inner part of an accretion envelope around the young stars. From the maps it appears that the highest velocities arise closest to the position of T Tau, consistent with either interpretation. The higher excitation HCO^+ lines indicate that warm T $\gtrsim$30 K and dense $\gtrsim 10^6$ cm^{-3} material is present.

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

Because the absorption is red–shifted with respect to T Tau this implies that material is falling onto the circumbinary material. The accretion rate is estimated to be $\approx 2 \times 10^{-7}$ $M_\odot yr^{-1}$ or larger. This is the first evidence that some infall from the surrounding envelope is continuing in the later phases of stellar evolution. Accretion through the disk in more evolved young stellar objects is often suggested to explain FU Orionis–type phenomena (Hartmann et al. 1993). In this respect it is interesting to note that a flare was recently observed for T Tau S, the IR companion (Ghez et al. 1991).

The shapes of the ^{13}CO and $C^{18}O$ J=1→0 transitions (Fig. 1*e*, *f*) can be readily understood in this picture by recalling that CO has a very small dipole moment. Thus the



Interferometer and single dish spectra toward T Tau

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 expected, consistent with Fig. 1*f*.

Fig. 1*g* shows the IRAM CS J=2→1 line in the direction of T Tauri. Compared with the HCO^+ we notice that the disk component in this line is weak. This is confirmed by OVRO images in the CS J=2→1 line (not shown), which hardly show any compact emission. Also the higher excitation lines, such as the J=5→4 show little CS in the dense and warm environment close to the stars.

From the $C^{18}O$ J=1→0 interferometer spectrum a H_2 column density can be estimated, which is used to calculate a fractional abundance of HCO^+ of 10^{-9} in the circumbinary material. This is only slightly lower than that found in the surrounding Taurus cloud. In contrast, CS is about 20 times less abundant in the circumbinary material than in the surrounding cloud. A similar result was found for HL Tau, for which Blake et al. (1992) argue that the polar molecule CS is depleted onto grains in the dense circumstellar disk. Indeed, such behavior is not expected for HCO^+, because it is an ion formed rapidly by the reaction of H_3^+ with CO.

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