CO J=6–5 OBSERVATIONS OF PROTOSTELLAR OUTFLOWS

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1. Introduction

Although the CO J=1–0 transition is the most frequently used tracer of molecular outflows from protostars, CO J=6–5 is a better probe of warm, dense gas in outflows, since the upper state energy of the J=6 level is 110 K above ground in comparison to 5.5 K for J=1. In this short contribution we compare CO J=6–5 to lower J observations of the NGC 2071 outflow, and concentrate the discussion on the outflow structure, overall density and temperature, and the extremely high velocity (EHV) CO features. We present data here for the NGC 2071 outflow, but in an associated journal article we will also present data on several other outflows. The CO J=6–5 data were obtained in December 1994 at the Caltech Submillimeter Observatory (CSO) on Mauna Kea, Hawaii.

2. General Properties of the Outflow

In Figure 1 we show channel maps of the NGC 2071 outflow(s) in both the CO 6–5 and CO 3–2 lines. Generally, the maps of the two transitions look quite similar, except that the 6–5 observations show more detailed structure since the beam size is half that of the 3-2 observations ($11''$ vs $22''$). The average physical conditions in the outflow implied from the line ratio

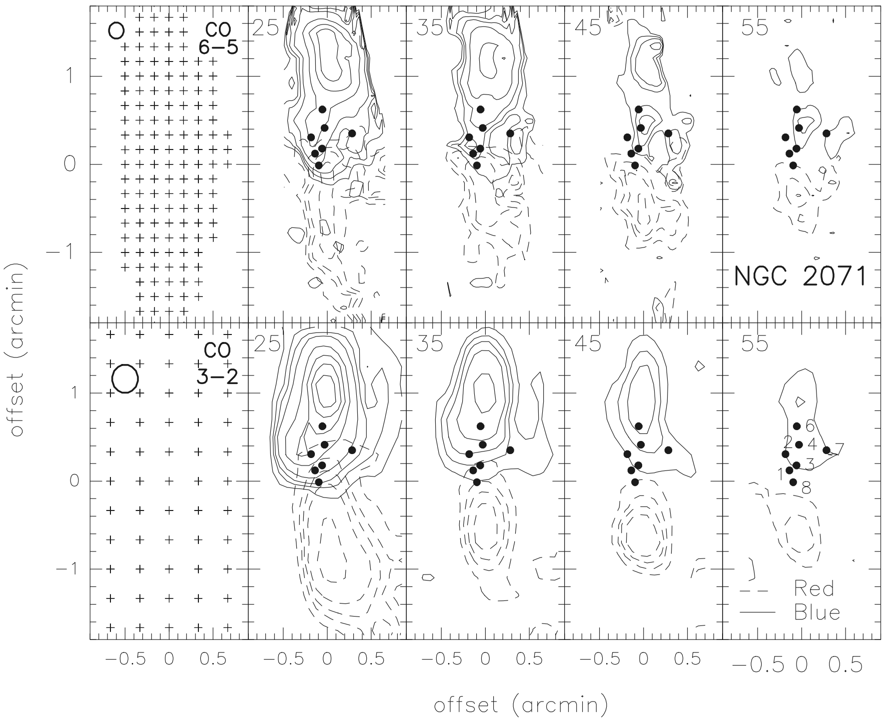

Figure 1. Channel Maps of the CO 6-5 and CO 3-2 emission from the NGC 2071 Outflow. The channel velocity relative to the cloud is shown in the top right corner. The maps have been rotated to lie along PA=36°. The black dots in the center represent the IR sources within the dense core (Walther et al. 1993).

are temperatures of 30–60 K and densities of 10^3-10^4 cm^{-3}. The temperatures are significantly warmer than the ambient cloud, which is 10–15 K, as derived from the optically thick cloud emission profile.

The 25-45 km s^{-1} J=6–5 channel maps show a conical shape for the opening of the blue shifted outflow lobe originating near IRS 8 (−0.1, 0). Similar conical lobe shapes have been seen in recent interferomoter observations of other outflows (cf. Bachiller et al. 1995; Masson, Chernin & Carlstrom, in preparation). The conical shape is most likely produced by the combination of a density gradient in the core, and impulses provided by the jet shocks. We also identify a second, parallel outflow from the IRS 7 source at (0.3, 0.3). Interferometer observations of NGC 2071 are planned to investigate these features in more detail.

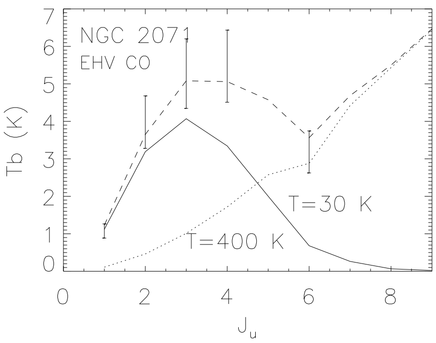

Figure 2. Brightness temperatures of CO transitions at the position and velocity range of the EHV CO feature (cf. Chernin & Welch 1995).

3. Extremely High Velocity CO Features

It has been argued that the EHV features directly trace where the jet is accelerating ambient gas (cf. Chernin & Masson 1992). The EHV CO velocities range from 40–60 km s^{-1}, and therefore the CO is probably re-formed after a dissociative shock (Hollenbach & McKee 1989; Neufeld & Dalgarno 1989a,b). If the pre-shock density is greater than about 10^4 cm^{-3}, the shock models predict a molecule re-formation plateau in the post-shock region which is held at a temperature of a few hundred degrees by the formation heating of H_2.

Figure 2 shows the brightness temperatures derived from BIMA (1–0) and CSO observations, and the expected optically thin emission from collisionally excited 30 and 400 degree gas. From our data in Figure 2, and given the error bars on the individual measurements, it is not clear whether we detect a ≈ 400 K plateau, but this will be more tightly constrained with J=7–6 and J=8–7 observations, which will soon be possible with further improvements in submillimeter receivers.

The CSO is supported by the National Science Foundation under grant AST 93-13929.

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