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OBSERVATIONS OF CO $J = 2 \rightarrow 1$ AND $3 \rightarrow 2$ LINES TOWARD EXTREMELY HIGH VELOCITY OUTFLOWS

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ABSTRACT

We observed CO $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$ lines toward several star formation regions with extremely high velocity (EHV) outflows: W3 IRS5, W28 A2, GL2591, S140, and Cepheus A. The full width of the wings are 90–235 km s^{-1}. Some wings show clear break of slope in the line profile implying that the nature of the EHV outflow is different from that of the high velocity outflow. We suggest that the EHV CO wing emission is tracing CO molecules in the stellar wind or jet which drives the high velocity outflow.

Key Words : interstellar matter, star formation

I. INTRODUCTION

Molecular outflows are common in star formation regions and considered as an important part of protostellar collapse, transporting excess mass and angular momentum away from the central object. However, the nature of the driving mechanism for the outflows is not yet clearly understood. Extremely high velocity (EHV) outflows ($V > 20$ km/s) were first discovered in late 80s (Lizano et al. 1988; Koo 1989, 1990; Margulis & Snell 1989), and about 15 EHV outflows are known. While high velocity (HV) outflows ($5 < V < 20$ km/s) are probably ambient gas swept-up or entrained by the neutral wind from the newly formed star, the nature of EHV outflows is not yet clear.

In our previous study of EHV outflows (Choi et al. 1993), we observed CO $J = 3 \rightarrow 2$ EHV wings with full width of 70–140 km/s. We tested the hypothesis that the EHV gas traces the stellar wind by comparing the driving forces between EHV and HV outflows. We found that the ratio of driving force of the EHV gas to the HV gas anti-correlates with the Lyman-continuum photon production rate. The ratio is close to unity for low-mass star formation regions, but very small (0.07–0.3) for high-mass star formation regions. Possible explanations for the force deficit are: (1) A major part of carbon is not in the form of CO (see Choi et al. 1994). (2) EHV CO wings could be much more extended than our observations indicate. (3) EHV emission arises from ambient gas and does not trace the driver of the HV outflow.

In this paper, we present CO $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$ observations significantly more sensitive than those presented in Choi et al. (1993).

II. OBSERVATIONS

We observed W3 IRS5, W28 A2, GL2591, S140, and Cepheus A using the 10.4 m telescope of the Caltech Submillimeter Observatory (CSO) with CO $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$. The data were obtained using the 230 GHz and the 345 GHz SIS receiver in double-sideband mode. For CO $J = 2 \rightarrow 1$ line, which was observed in 1996 May, we used both 500 MHz and 1.5 GHz AOS spectrometers. For CO $J = 3 \rightarrow 2$ line, which was observed in 1995 June, September, and December, we used a 500 MHz AOS spectrometer only. We used chopping secondary mirror for position switching. Typically, the chopping frequency was 0.511 Hz and the off-position was 300″ away along the azimuth.

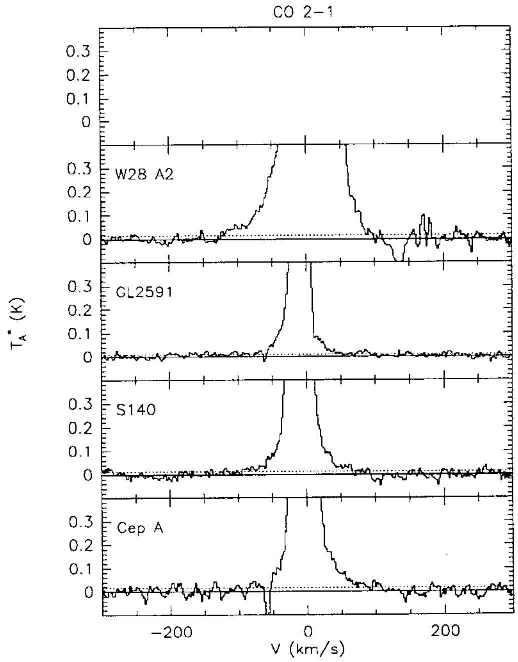

Fig. 1.— The CO $J = 2 \rightarrow 1$ spectra shown in blown-up vertical scale in order to show the EHV wings. The velocity resolution is 2.05 km s^{-1}. The baselines were taken from velocity intervals of (-300, -200) and (200, 300) km s^{-1}. Dotted lines show the noise level (1σ).

III. RESULTS

Our observation reveals CO line wings wider than previously observed. Full width of the wing ranges from

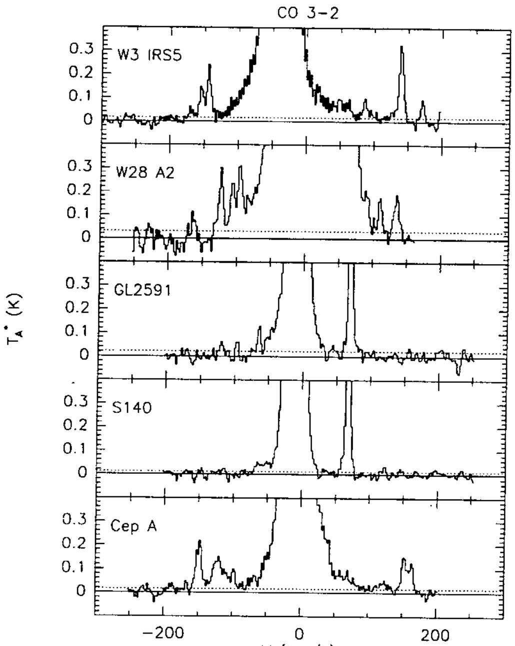

Fig. 2.— The same as Fig. 1 for the CO $J = 3 \rightarrow 2$ spectra. The velocity resolution is 2.0 km s^{-1}.

90 to 235 km s^{-1}. Since most of the CO $J = 2 \rightarrow 1$ wings in our observations smoothly disappear below noise level (Fig. 1), longer integration time might reveal even wider wings. Determination of the CO $J = 3 \rightarrow 2$ line width is rather limited by the presence of other molecular lines overlapping with the CO EHV wings (Fig. 2).

Since we observed only the central position of each source, we cannot estimate the total momentum in the EHV outflow. ¿From the line width, we expect that the momentum in the EHV outflow may be ~2 times larger than given in Table 5 of Choi et al. (1993). This increase in the momentum estimate is not large enough to explain the force deficit described in Choi et al. (1993). However, more sensitive observations could reveal much wider wing and larger momentum in the EHV outflows.

With the extremely high velocities seen in our observations, it is unlikely that the source of EHV emission is swept-up ambient molecular gas. First, theoretical prediction on the velocity of swept-up gas is typically only a few tens of km s^{-1} (Shu et al. 1991). Second, it is hard to accelerate molecular gas to such high velocities (~80 km s^{-1}) without dissociation. Once dissociated by a fast shock, molecules can reform only when the column density of the shocked material is larger than 10^{20} cm^{-2} (Neufeld & Dalgarno 1989; Hollenbach & McKee 1989). For most sources in this paper, the column density is much less. Third, some EHV wings show clear break of slope in the middle of the wing. These breaks may imply a change of the nature of the emission source. Therefore, we suggest that the EHV CO wing emission is tracing CO molecules in the stellar wind or jet which drives the high velocity outflow.

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