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EXTREMELY HIGH VELOCITY OUTFLOWS

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RESUMEN

Se observan alas de extremadamente alta velocidad en las líneas de CO $J = 3 \to 2$ hacia W3 IRS 5, GL 490, NGC 2071, W28 A2, GL 2591, S140 y Cepheus A. El resultado de nuestra inspección sugiere que las alas de velocidad extremadamente altas son comunes alrededor de fuentes infrarrojas de luminosidad moderada a alta en regiones densas. Si las fuerzas que empujan los flujos de extremadamente alta velocidad y los de alta velocidad son iguales, la fracción de carbono requerida en formas adicionales al CO aumenta con la luminosidad de la fuente y con la tasa de producción de fotones ionizantes.

ABSTRACT

Extremely high velocity wings are seen on the CO $J = 3 \to 2$ lines toward W3 IRS 5, GL 490, NGC 2071, W28 A2, GL 2591, S140, and Cepheus A. The results of our survey suggest that extremely high velocity wings are common around infrared sources of moderate to high luminosity in dense regions. If the driving forces of extremely high velocity and high velocity outflows are equal, the fraction of carbon required to be in a form other than CO increases with source luminosity and with the production rate of ionizing photons.

Key words: **ISM: JETS AND OUTFLOWS — STARS: MASS LOSS — STARS: PRE-MAIN SEQUENCE**

Molecular outflows are common in regions of star formation (Lada 1985; Bachiller & Gómez-González 1992). High velocity (HV) molecular flows most likely consist of ambient cloud material swept up by a faster stellar wind (Snell, Loren, & Plambeck 1980), which is probably neutral (Natta et al. 1988). The idea of a neutral wind gained support from the discovery of very wide wings on the H I spectra (Lizano et al. 1988; Giovanardi et al. 1992) toward several young stars. Lizano et al. (1988), Koo (1989, 1990), and Margulis & Snell (1989) also found extremely high velocity (EHV) wings on CO lines toward a few sources, suggesting that there might be CO in the stellar wind itself. In recent years, there have been additional observations of EHV CO outflows (see references in the caption of Figure 2). Some authors have suggested, however, a close relationship between EHV CO and jets rather than stellar winds (Masson & Chernin 1993; Stahler 1993).

Most previous detections of EHV wings have been toward sources of low to moderate luminosity ($L <$ 1000 $L_\odot$); this work extends the phenomenon to higher luminosity sources. EHV wings, with full-widths of 72 to 140 km s^{-1}, are seen on the CO $J = 3 \to 2$ lines toward several star-forming regions. The full line width of EHV wings of each source are listed in Table 1. Figure 1 shows the CO $J = 3 \to 2$ spectra of two of the sources. Observations of ^{12}CO and ^{13}CO $J = 3 \to 2$ and $J = 2 \to 1$ lines indicate that optical depth generally decreases with increasing velocity separation from the ambient cloud velocity ($|V - V_0|$). Maps of the EHV ($|V - V_0| \gtrsim$ 20 km s^{-1}) and the HV ($5 \lesssim |V - V_0| \lesssim 20$ km s^{-1}) CO emission components show that the morphology of the two components is similar in W3 IRS 5 and W28 A2 but may be different in GL 2591, S140, and Cepheus A.

The results of our survey suggest that EHV wings are common around infrared sources of moderate to high luminosity ($500 - 4 \times 10^5 L_\odot$) in dense regions. Line ratios imply that the EHV gas is usually optically thin and warm. Characteristic velocities range from 20 km s^{-1} to 40 km s^{-1}, yielding time scales of 1600 – 4200 yr. Since most sources in this study are producing some ionizing photons, these short timescales suggest that neutral winds co-exist with ionizing photons.

Table 1

Full Width of CO $J = 3 \rightarrow 2$ Wings

Source	ΔV_{HV}	ΔV_{EHV}
W3 IRS 5	42 km s^{-1}	72 km s^{-1}
GL 490	54	112
NGC 2071	38	118
W28 A2	52	140
GL 2591	36	74
S140	36	86
Cepheus A	36	132

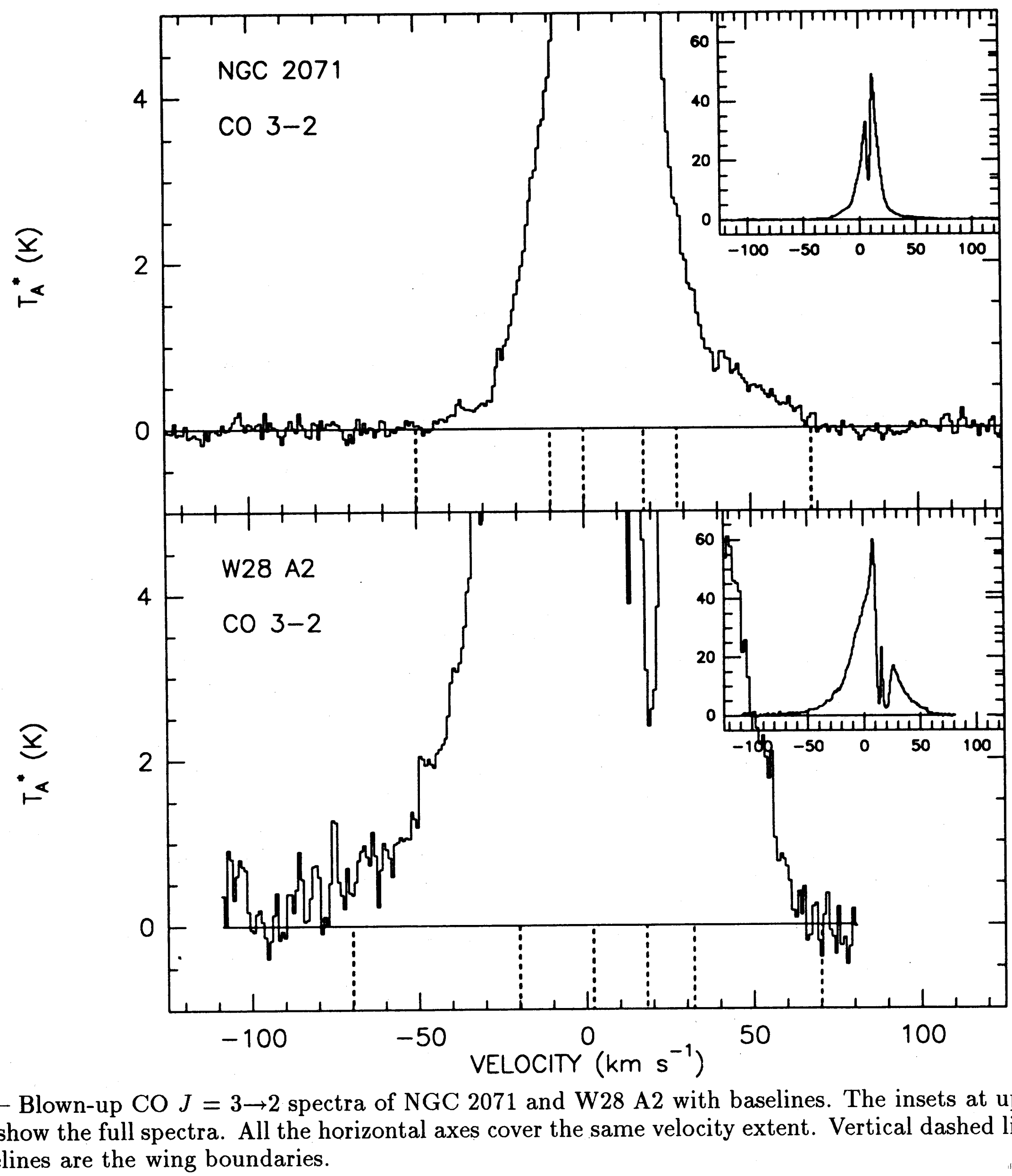

Fig. 1.— Blown-up CO $J = 3 \rightarrow 2$ spectra of NGC 2071 and W28 A2 with baselines. The insets at upper right corners show the full spectra. All the horizontal axes cover the same velocity extent. Vertical dashed lines below the baselines are the wing boundaries.

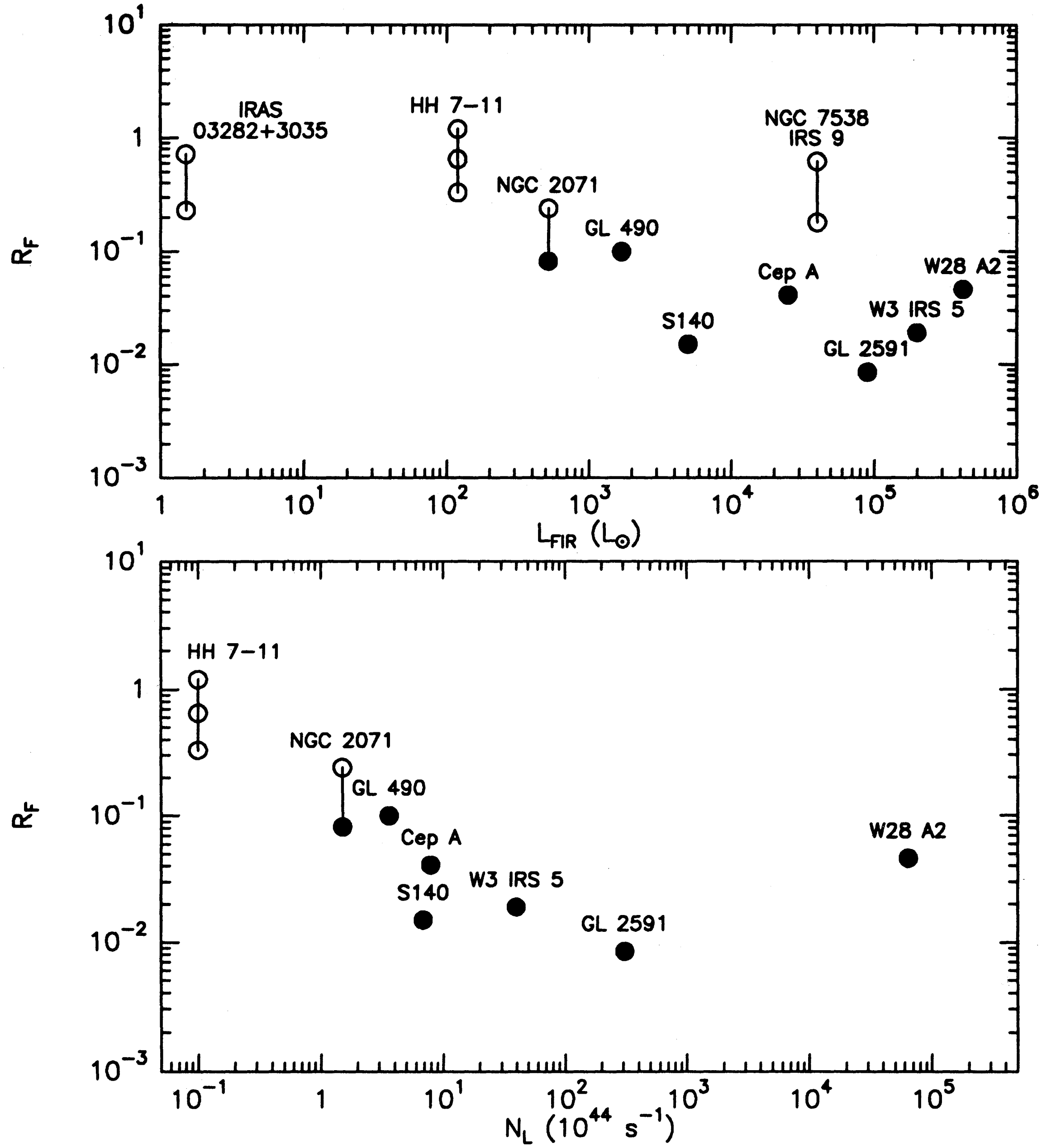

Fig. 2.— The ratio of EHV to HV driving force versus luminosity (upper panel) and the rate of production of Lyman-continuum photons (lower panel). We assumed that the EHV gas is the stellar wind ([C]/[CO] = 1) and that the HV outflow is swept-up molecular gas ([C]/[CO] = 8). Filled pointers are from this paper and open pointers are from other references (Bachiller & Cernicharo 1990; Koo 1990; Bachiller, Martín-Pintado, & Planesas 1991; Mitchell & Hasegawa 1991; Chernin & Masson 1992). If there are multiple references for one source, corresponding pointers are connected by vertical lines.

We examined two possible sources for the EHV CO emission: a neutral stellar wind; and swept-up or entrained molecular gas. Neither can be ruled out. The ratios of driving forces ($R_F = F_{EHV}/F_{HV}$) calculated from CO emission are plotted versus the source luminosity, L_{FIR}, and the production rate of ionized photons, N_L, in Figure 2. If the EHV CO line is emitted from the neutral wind which drives the HV outflow, the EHV and HV forces should be equal. Then the fact that R_F is decreasing with L_{FIR} and N_L implies that the fraction of carbon required to be in a form other than CO increases with L_{FIR} and N_L. This trend is natural in the stellar wind hypothesis, but models of winds around such luminous objects are needed.

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REFERENCES

Bachiller, R., & Cernicharo, J. 1990, A&A, 239, 276
Bachiller, R., & Gómez-González, J. 1992, A&A Rev., 3, 257
Bachiller, R., Martín-Pintado, J., & Planesas, P. 1991, A&A, 251, 639
Chernin, L. M., & Masson, C. R. 1992, ApJ, 396, L35
Giovanardi, C., Lizano, S., Natta, A., Evans, N. J., II, & Heiles, C. 1992, ApJ, 397, 214
Koo, B.-C. 1989, ApJ, 337, 318
Koo, B.-C. 1990, ApJ, 361, 145
Lada, C. J. 1985, ARA&A, 23, 267
Lizano, S., Heiles, C., Rodríguez, L. F., Koo, B.-C., Shu, F. H., Hasegawa, T., Hayashi, S., & Mirabel, I. F. 1988, ApJ, 328, 763
Margulis, M., & Snell, R. L. 1989, ApJ, 343, 779
Masson, C. R., & Chernin, L. M. 1993, ApJ, in press
Mitchell, G. F., & Hasegawa, T. I. 1991, ApJ, 371, L33
Natta, A., Giovanardi, C., Palla, F., & Evans, N. J., II 1988, ApJ, 327, 817
Snell, R. L., Loren, R. B., & Plambeck, R. L. 1980, ApJ, 239, L17
Stahler, S. W. 1993, in *Astrophysical Jets*, ed. M. Livio, C. O'Dea, & D. Burgarella (Cambridge: Cambridge U. Press), in press

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