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A BIPOLAR OUTFLOW: L1641-NORTH AND ITS AMBIENT DENSE CLOUD

Y. FUKUI, H. TAKABA, T. IWATA, AND A. MIZUNO
Department of Astrophysics, Nagoya University
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ABSTRACT

We report high angular resolution observations of $J = 1$–0 emission from CO, HCO^+, and HCN in L1641-North, a bipolar outflow newly found during an unbiased CO($J = 1$–0) survey made with the Nagoya 4 m radio telescope. The high-velocity CO wings show a clear bipolar structure and are localized within 0.2 pc of a central infrared source IRAS 05338−0624. The outflow is associated with a dense cloud that is significantly elongated *in the same direction* as the outflow axis, contrary to what is expected for disk collimation of the bipolar outflow. This suggests that large interstellar gas disks are not always necessary for collimation. The collimation in L1641-North is likely made very close to the outflow center, i.e., within ~0.02 pc of the driving source.

Subject headings: interstellar: matter — stars: circumstellar shells — stars: winds

I. INTRODUCTION

The nature of the collimation mechanism is one of the most important issues pertaining to bipolar molecular outflows. For example, it has been suggested that dense interstellar clouds, often called disks, elongated orthogonally to outflow axes focus isotropically expanding outflow winds into two opposite directions (see Table 1 in Rodríguez 1987, and references therein). On the other hand, an opposing view that interstellar clouds are not responsible for the collimation has been presented on the basis of millimeter-wave molecular and far-infrared observations (Takano *et al.* 1984; Kawabe *et al.* 1984; Davidson and Jaffe 1984). This controversy is still not settled.

L1641-North is one of the outflows recently discovered during an unbiased survey made with the Nagoya 4 m radio telescope (Fukui *et al.* 1986). In this *Letter*, we report high-resolution observations of $J = 1$–0 emission from CO, HCN, and HCO^+ in L1641-North. These observations show that there is an elongated dense cloud in the region aligned with the outflow axis. We shall discuss the implications of this distribution on the collimation of the outflow.

II. OBSERVATIONS

Observations were made on three nights in 1986 March and May with the NRO 45 m[1] telescope. The telescope had a beam size of 17″ with a main beam efficiency of 0.45 at 2.6 mm, and a beam size of 22″ with a main beam efficiency of 0.7 at 3.3 mm. We employed two cooled Schottky mixer receivers tuned at 88–90 GHz and 115 GHz, respectively, in order to simultaneously observe the $J = 1$–0 spectra of CO, HCN, and HCO^+. The single sideband system temperatures were typically 800–1000 K, respectively. The telescope beam was divided into two orthogonal polarizations with a polarization splitter installed in the beam-guided optics and fed into the two receivers, respectively. Pointing accuracy was generally better than 5″. The spectral data were obtained with two acousto-optical spectrometers having 40 kHz frequency resolution and 40 MHz band width. The inner 2′ × 2′ region of L1641-North was mapped with a grid spacing of 20″, while the periphery was mapped with a grid spacing of 30″. The absolute intensity scale of CO was established by referring to NGC 2071-North (Fukui *et al.* 1986; Iwata, Fukui, and Ogawa 1988) and is given as T_R*. The intensities of HCO^+ and HCN were corrected for the main beam efficiency, ohmic losses, and the atmospheric extinction. The distance to L1641-North is assumed to be 500 pc.

[1] This work was carried out under the common use observation program at the Nobeyama Radio Observatory (NRO). NRO, a branch of the Tokyo Astronomical Observatory, University of Tokyo, is a cosmic radio observing facility for outside users.

III. RESULTS AND DISCUSSION

a) The CO *Outflow*

The redshifted and blueshifted ^{12}CO emission, shown in Figure 1, represent a compact bipolar outflow with the infrared source IRAS 05338−0624 at its center. The ^{12}CO lobes are distributed within 0.2 pc of the *IRAS* source and have a full velocity extent of 28 km s^{-1} at an intensity level of 0.1 K. We note that the intensities of the red and blue lobes steeply decrease toward the infrared source by factors of more than 3, respectively, showing no overlapping there. The red lobe has two conspicuous peaks separated from each other by about 1′.2, whereas the blue lobe is singly peaked. The dynamical time scale is estimated to be fairly short, 1.4×10^4 yr, from the maximum spatial and velocity extents of the ^{12}CO wings.

^{13}CO wings were observed toward 10 selected positions where ^{12}CO wings are intense, and were then averaged. The averaged ^{13}CO spectrum was compared with the corresponding ^{12}CO spectrum in order to estimate the physical parameters of the high-velocity gas. The calculations were made by assuming LTE with an excitation temperature of 25 K (Takaba *et al.* 1986), and the results are listed in Table 1. Calculations were made following Margulis and Lada (1985) with some modifications described in Iwata, Fukui, and Ogawa (1988). We also determined centroids of the two ^{12}CO lobes by averaging coordinates weighted with the integrated intensity of the ^{12}CO wings, and obtained a position angle of the flow axis of 40° by connecting the two centroids.

b) The Dense Cloud; HCN *and* HCO^+ *Distribution*

In Figure 2 the distributions of the HCN $J = 1$–0, $F = 2$–1 and HCO^+ $J = 1$–0 emission are displayed. Shown are the intensities integrated from $v_{LSR} = 6$–8 km s^{-1}, representing the

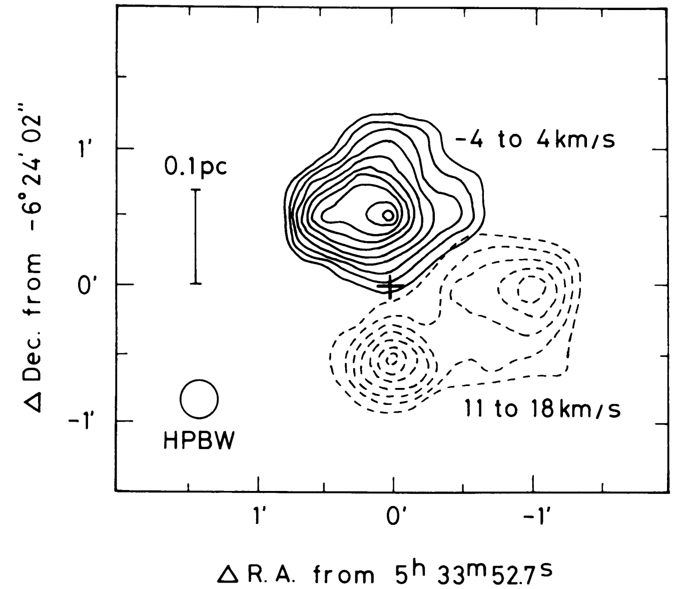

FIG. 1.—Distribution of the high-velocity ^{12}CO $J = 1$–0 emission in L1641-North. The integrated intensity of the blue wing ($v_{LSR} = -4$ km s^{-1} to 4 km s^{-1}) is shown by solid contours and that of the red wing ($v_{LSR} = 11$ km s^{-1} to 18 km s^{-1}) is shown by dashed contours. Contours are every 2.2 K km s^{-1} with the lowest contour at 9 K km s^{-1}. The position of IRAS 05338−0624 is denoted by a cross, which corresponds to R.A.(1950) = $5^h33^m52^s.7$, and decl.(1950) = −6°24′2″.

distribution of the quiescent dense gas peaked at 7 km s^{-1} (Takaba *et al.* 1986). The dense cloud in L1641-North is conspicuously elongated with a position angle of 45°, nearly in the same direction as the outflow. This characteristic of the elongated dense cloud is peculiar among known bipolar outflow sources (for two possible similar elongated clouds, see Torrelles *et al.* 1983).

We have compared the dense gas distribution with the CO lobes in Figure 2. We find that the southwestern part of the dense cloud is elongated toward the intensity minimum of the red ^{12}CO lobe, showing a kind of anticorrelation between the high-velocity ^{12}CO gas and the dense cloud. We interpret this anticorrelation as arising from interaction between the dense cloud and the outflow. Namely, the outflowing gas expanding toward the southwest has been slowed down due to the interaction with the southern part of the dense cloud, forming the two ^{12}CO peaks toward less dense regions surrounding the dense cloud. We also note that the northeastern part of the dense gas is located toward the eastern edge of the blue ^{12}CO lobe which has a steep intensity gradient there. This may also indicate that the morphology of the blue lobe is affected by the interaction with the northeastern part of the dense cloud.

The linewidth of the $F = 2$–1 component of HCN is 1 km s^{-1}, and the hyperfine line ratios are equal to their LTE values, suggesting that the HCN $J = 1$–0 emission is optically thin. The HCO^+ emission, on the other hand, may be somewhat optically thick as suggested by a broader linewidth of 1.5 km s^{-1}. The HCN line therefore is probably a better tracer of the dense gas. The HCN cloud is peaked toward IRAS 05338−0624 and shows a very uniform distribution of peak velocity at 7.0 km s^{-1}. The size of the HCN cloud is ∼1′ (NW–SE) × 2′ (NE–SW) (=0.15 pc × 0.3 pc). Using the virial theorem for a uniform sphere having a radius of 0.1 pc and a velocity width of 1 km s^{-1}, the total mass of the dense cloud is roughly estimated to be ∼20 $M_\odot$. The average density is estimated to be ∼1 × 10^5 cm^{-3}, considerably greater than that of the surrounding ^{13}CO cloud, ∼10^4 cm^{-3} (Takaba *et al.* 1986).

c) The Collimation Mechanism

The CO outflow and dense cloud in L1641-North represent an entirely opposite case from disk collimation, because the dense cloud appears to be elongated in the same direction as the outflow axis. The outflow axis is probably nearly perpendicular to the line of sight as suggested by no overlapping of the two lobes toward IRAS 05338−0624. We interpret that the dense cloud associated with IRAS 05338−0624 is actually distributed in the direction of the outflow lobes from IRAS 05338−0624, as it appears. This is consistent with the dynamical interaction between the outflow and the dense cloud.

The CO outflow carries a considerable amount of kinetic energy, implying that the outflow can dynamically disturb the distribution of the dense gas by transferring momentum via shocks. Such an effect, however, does not seem to be important in L1641-North; the dense cloud has uniform peak velocity, showing no sign of dynamical disturbance. The CO lobes having total momentum of ∼9 $M_\odot$ km s^{-1} (Table 1) could accelerate the dense cloud up to ∼0.5 km s^{-1} if momentum was conserved and completely transferred to the dense cloud. This upper limit for the velocity shift is consistent with the observed uniform velocity distribution. In addition, the crossing time for the dense cloud is more than 10^5 yr, much longer than the dynamical timescale of the outflow of ∼10^4 yr. The dense gas distribution in L1641-North is therefore little affected by the outflow at present and is essentially unchanged from before the onset of the outflow. Consequently, we suggest that the L1641-North bipolar outflow is collimated on a scale much smaller than we have resolved, has expanded toward the

TABLE 1

PHYSICAL PARAMETERS OF THE OUTFLOW

Component	Velocity Range[a] (km s^{-1})	Mass[b] ($M_\odot$)	Momentum[c] ($M_\odot$ km s^{-1})	Kinetic Energy[c] (ergs)	Mechanical Luminosity[c] ($L_\odot$)
Blue	−6.5– 5.5	1.2	6.3	3.4 × 10^{44}	0.08
Red	10.5–21.5	0.4	3.0	2.3 × 10^{44}	0.07
Total	−6.5–21.5	1.6	9.3	5.7 × 10^{44}	0.15

[a] Determined from ^{12}CO($J = 1$–0) spectra at an intensity level of 0.1 K.

[b] Determined for the velocity ranges, 3.5–5.5 km s^{-1} and 10.5–11.5 km s^{-1}, respectively, where ^{13}CO($J = 1$–0) wings are seen.

[c] Geometrical averages of the upper and lower limits (Margulis and Lada 1985; Iwata, Fukui, and Ogawa 1988).

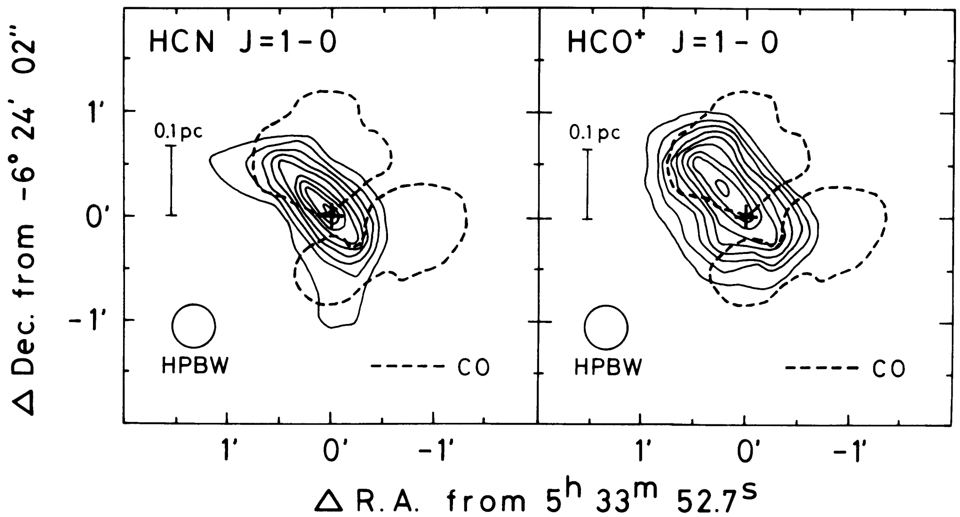

FIG. 2.—(*left*) The integrated intensity map of the HCN (J = 1–0, F = 2–1) emission in L1641-North. The velocity range of integration is from v_{LSR} = 6 to 8 km s^{-1}, and contours are every 0.45 K km s^{-1} from the lowest contour at 3.6 K km s^{-1}. The second lowest CO contour of Fig. 1 is overlaid by the dashed contour. (*right*) The integrated intensity map of the HCO^+ (J = 1–0) emission. The integration range is the same as in (*a*), and contours are every 0.75 K km s^{-1} from the lowest contour at 6 K km s^{-1}.

dense regions on the NE and SW of IRAS 05338−0624 against the pressure gradient due to the ambient molecular gas, and has dynamically interacted with the dense cloud resulting in the present lobe morphology. Thus, we reach a conclusion that *large interstellar gas disks are not always necessary for the collimation of bipolar outflows*, and in this case some other mechanism must be at work.

Recent theoretical models have suggested that outflows might be magnetohydrodynamically accelerated by rapidly rotating circumstellar disks (Uchida and Shibata 1985; Pudritz and Norman 1986; Maruyama and Fujimoto 1987). According to these models, the collimation is a natural consequence of acceleration perpendicular to the disk, and occurs on a scale of $\sim 10^{16}$ cm. The present result seems to support this type of model, instead of those based on interstellar focusing due to pressure gradients in large disks. The present HCN map shows no disklike feature perpendicular to the flow axis larger than about 10″. Thus, we are able to set an upper limit to the collimation radius of ~0.02 pc.

To summarize, we have made a high-resolution study of molecular emission from L1641-North and have found that the dense gas distribution is elongated in the same direction as the CO outflow. We interpret this result as meaning that the collimation of the bipolar CO outflow is made very close to the central source, i.e., within ~0.02 pc, and we suggest that large interstellar gas "disks" are not always necessary for the collimation of molecular outflows. This interpretation is consistent with the results of recent magnetohydrodynamical models for bipolar outflows.

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Y. FUKUI, T. IWATA, A. MIZUNO, and T. TAKABA: Department of Astrophysics, Nagoya University, Chikusa-ku, Nagoya 464, Japan