THE ASTROPHYSICAL JOURNAL, **282**:L73–L75, 1984 July 15

HIGH ANGULAR RESOLUTION CS OBSERVATIONS OF THE CO BIPOLAR FLOW SOURCE GL 490 WITH THE 45 METER TELESCOPE

R. KAWABE, H. OGAWA, Y. FUKUI, T. TAKANO, H. TAKABA, Y. FUJIMOTO, K. SUGITANI, AND M. FUJIMOTO
Department of Astrophysics, Nagoya University
Received 1984 February 21; accepted 1984 March 30

ABSTRACT

By using the 45 m millimeter-wave telescope, we have observed the CO bipolar flow source associated with an infrared source, GL 490, in the $J = 1\text{–}0$ line of carbon monosulfide. The high angular resolution of the telescope, 30″, has allowed us to find a compact CS cloud about 0.3 pc × 0.13 pc in extent around GL 490, which is elongated orthogonally to the direction of the CO bipolar flow. Part of the cloud shows signs of expansion at velocities of $\lesssim 4$ km s^{-1}, although the total outgoing momentum of the CS cloud is smaller than that of the CO flow by an order of magnitude. This implies that the CS compact cloud has not been responsible for collimating the bipolar flow in this object.

Subject headings: infrared: sources — interstellar: molecules — stars: formation

I. INTRODUCTION

GL 490 is an infrared compact source with a total luminosity of about 1.4×10^3 $L_\odot$, equivalent to a B3 star in the zero-age main sequence (Harvey *et al.* 1979). High-velocity wings in the $J = 1\text{–}0$ ^{12}CO and ^{13}CO spectra were detected toward GL 490 and were interpreted as an energetic mass outlfow of a bipolar geometry from GL 490 (Lada and Harvey 1981). The presence of dense molecular gas was shown by the detection of HCN ($J = 1\text{–}0$) and CS ($J = 2\text{–}1$) spectra at the millimeter wavelength (Morris *et al.* 1974). But, so far, no further observations of dense molecular gas associated with GL 490 have been reported.

In this *Letter*, we report observations of the $J = 1\text{–}0$ CS emission made with a 30″ beam of the 45 m millimeter-wave telescope. The data show the presence of a compact and dense cloud which is elongated orthogonally to the CO bipolar flow as well as expanding, less dense gas over a velocity range of approximately 7 km s^{-1}.

II. OBSERVATIONS

Observations were made in 1983 January and February using the new 45 m millimeter-wave telescope at Nobeyama.[1] The half-power beamwidth and the beam efficiency of the telescope were measured to be about 30″ and 0″.65, respectively, at 6 mm wavelength. The pointing was accurate within 3″ in rms, as known by observing SiO maser sources.

The receiver was the same as the one described in a separate paper on NGC 2071 (Takano *et al.* 1984), and we do not describe it here. Backends were acousto-optic spectrometers. A spectrometer gave a velocity resolution of 0.24 km s^{-1}, and a velocity coverage of 240 km s^{-1}. The $J = 1\text{–}0$ lines of C^{32}S and C^{34}S were observed simultaneously by employing two spectrometers.

We mapped a region centered at the infrared source (R.A. = $3^h23^m38^s.8$, decl. = 58°36′39″, 1950.0; Joyce *et al.* 1977). Positions are given hereafter as the offsets from this point. Observations were made by position switching with a reference point separated from the observed position by (−3′, −20′) in (R.A., decl.). The 3 σ upper limit for the CS emission at the reference point was 0.3 K.

III. RESULTS

The C^{32}S spectrum toward GL 490 is shown in Figure 1. We find that the spectrum has a peak at $v \sim -12.5$ km s^{-1} and blueshifted and redshifted wings over a velocity range of about 7 km s^{-1}. In Figure 2 we show maps of the CS integrated intensity at four velocity sections. At $v \sim -13.5$ km s^{-1} (Fig. 2*b*), we see an elongated CS cloud which is localized around the infrared source. The size of this cloud is about 60″ × 30″ (= 0.3 pc × 0.13 pc if we take the distance of 900 pc). A more extended cloud which is not fully covered in the present observations is dominant at $v \approx -11.5$ km s^{-1} (Fig. 2*c*). The distribution of the line wings is shown in Figures 2*a* and 2*d*. We find that the line wings are also localized near GL 490; we note that in Figure 2*d* the component peaked at (30″, −30″) is not part of the red line wing but is part of the extended cloud seen in Figure 2*c* because the component does not look like a line wing.

Figure 3 shows superposition of the CS distribution on the map of the CO high-velocity wings. The figure shows that the three components of CS, i.e., the −13.5 km s^{-1} cloud, and the red and blue wings, are closely associated with the infrared source as well as with the CO high-velocity wings. The elongations of the three components are similar and are nearly orthogonal to the direction of the CO high-velocity lobes. It is noteworthy that the line wings are located symmetrically with respect to the infrared source, but their symmetry in velocity is *in the sense opposite* to that of the CO line wings.

IV. DISCUSSION

a) *Mass of the CS Cloud*

The CS data can be used to estimate the hydrogen density in the CS cloud. The CS line intensity has been calculated as a

[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, is a cosmic radio observing facility open for outside users.

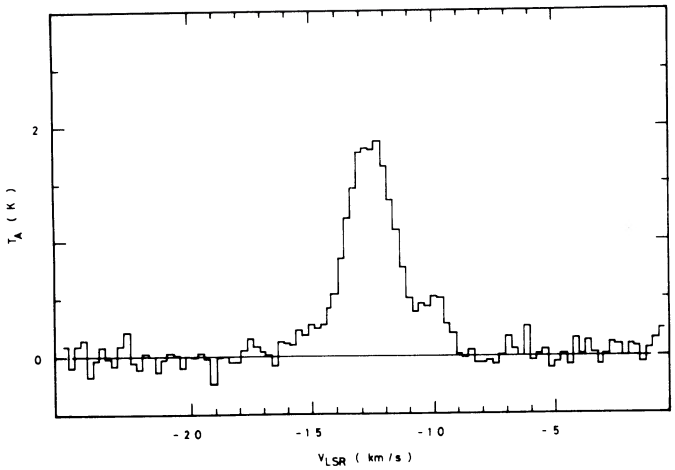

FIG. 1.—A $C^{32}S$ (J = 1–0) spectrum toward GL 490

function of hydrogen density and CS fractional abundance by using the large velocity gradient approximation. In the calculation, the kinetic temperature was assumed to be 20 K (Plambeck *et al.* 1982). Comparison with the CS data indicates that the hydrogen density toward GL 490 is in the range 3×10^4—3×10^5 cm^{-3} for the CS fractional abundance of 3×10^{-10}—3×10^{-11} km^{-1} s^{-1} pc^{-1} derived for dense cores of the interstellar molecular clouds (Linke and Goldsmith 1980). The density gives a total mass of the CS compact cloud of 10–100 $M_\odot$ (the size was taken to be 0.13 pc × 0.27 pc from the map in Fig. 2, and the size along the line of sight was assumed to be 0.27 pc). Similarly, the mass of each line wing has been estimated to be 2–10 $M_\odot$. An independent mass estimate comes from the ^{12}CO and ^{13}CO data; if we take the H_2 column density of 3×10^{22} cm^{-2} (Lada and Harvey 1980) derived from CO data obtained with a 1′ beam, the total mass of the compact cloud is estimated to be 20 $M_\odot$. Because the ^{13}CO spectrum has the same velocity range as the CS wings, approximately 7 km s^{-1}, this total should include the mass of the CS wings. Thus we infer that the total mass of the CS compact cloud is close to the lower end of the mass derived above, i.e., a few tens of $M_\odot$. Further, the −13.5 km s^{-1} component of 3 km s^{-1} velocity width implies a dynamical mass of 50 $M_\odot$, which should include the stellar mass of 10 $M_\odot$. In the following, we use 50 $M_\odot$ as an upper limit for the gas total mass of the compact CS cloud.

As a consequence of the mass estimate, we find that the CS line wings cannot be bound by gravitation, but that they indicate expanding gas from the central infrared source.

b) *Can the Compact CS Cloud Collimate the Flow?*

It has been suggested that disks around the central sources may be responsible for focusing for other objects (e.g., Snell, Loren, and Plambeck 1980; Bally 1982). This, however, is not

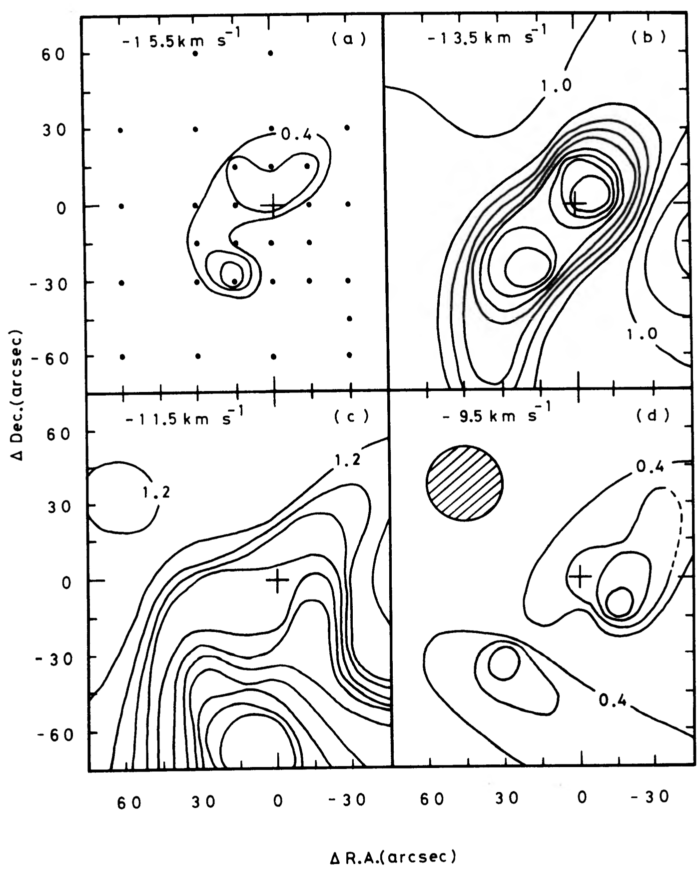

FIG. 2.—Integrated intensity maps for four velocity sections: (a) −16.5 to −14.5 km s^{-1}; (b) −14.5 to −12.5 km s^{-1}; (c) −12.5 to −10.5 km s^{-1}; and (d) −10.5 to −8.5 km s^{-1}. Contour unit is 0.2 K km s^{-1}. The beam size is shown in (c). The position of the infrared source is shown by a plus sign in each panel.

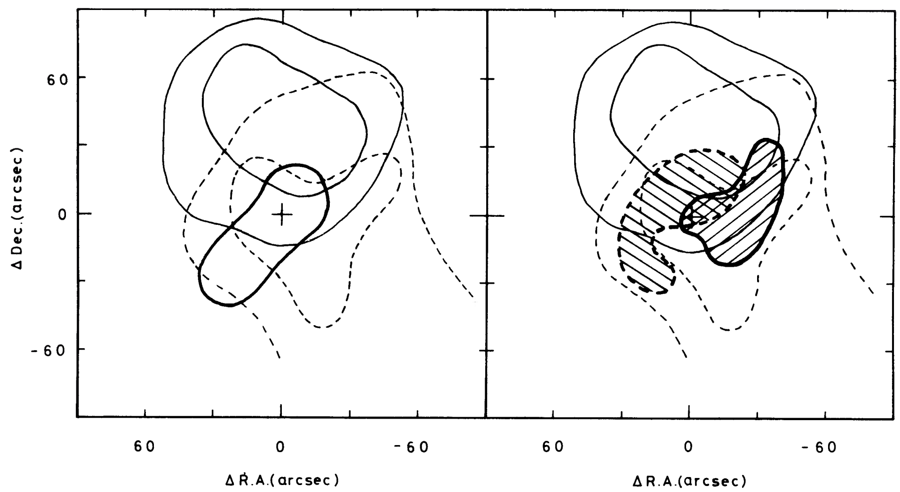

FIG. 3.—Overlay of the CO high-velocity wings and the CS compact components. The contour of the CO integrated intensity is taken from Lada and Harvey (1981). (*Left*) The dark solid contour is the -13.5 km s^{-1} CS cloud; (*right*) the dark solid contour with hatchmarks is the distribution of the CS red wing, and the dark dashed contour with hatchmarks is that of the CS blue wing.

likely the case in the GL 490 compact cloud. In the following, we argue that collimation of the flow is taking place at a radius much smaller than that of the compact CS cloud. The total outward momentum of the CO bipolar flow can be estimated to be approximately 750 $M_\odot$ km s^{-1}, which comes from the total mass of the CO flow of roughly 30 $M_\odot$ and the ^{12}CO expansion velocity of about 25 km s^{-1} (Lada and Harvey 1981). On the other hand, the sum of the possible expanding momentum of the CS compact cloud including the wings is only about 80 $M_\odot$ km s^{-1} and actually is probably much less. If the CS compact cloud has been focusing the flow, the cloud should show more significant expansion because of the momentum which should have been transferred from the outflowing gas. This suggests that the CS cloud approximately 10^{17} cm in extent has not been focusing the flow and implies that the bipolar flow has already been well collimated at a radius much smaller than 10^{17} cm which is not resolved with the 30″ beam. Near-infrared polarization measurements (Kobayashi *et al.* 1978) show a strong polarization orthogonal to the axis of the CO bipolar flow. This may suggest the existence of a circumstellar disk which is actually focusing the high-velocity gas.

c) A Model

It is interesting to study the geometry of the CS cloud and the line wings. The elongated shape of the CS cloud suggests that the cloud may be a disk around GL 490 which is oriented orthogonally to the direction of the CO bipolar flow. A similar disk which shows a clear sign of rotation is reported for NGC 2071 (Takano *et al.* 1984). Because of severe blending with the extended cloud at -11.5 km s^{-1}, the present data do not clearly indicate whether or not the GL 490 CS cloud is rotating.

It is noteworthy that the wings show symmetry in the sense opposite to that of the CO bipolar flow. A possible model for them is that they are expanding gas in the disk which is tilted to the line of sight. Because the expansion should be due to acceleration by the high-velocity flow, the wings may originate from the surface layer of the thin disk. The opposite velocity symmetry of the wings can be well explained by this model.

A similar model has been presented for the Orion SO cloud by Plambeck *et al.* (1982). The overall geometry of the Orion cloud seems similar to that of the GL 490 cloud. A major difference is that the size of the GL 490 cloud is about one order of magnitude larger than that of the Orion SO cloud.

The observations were assisted by the staff of the Nobeyama Radio Observatory, a branch of the Tokyo Astronomical Observatory. One of the authors (T. T.) was in part financially supported by the Japanese Society for the Promotion of Sciences. This work was in part supported by the Grant-in-Aid for Scientific Research of the Ministry of Education, Science, and Culture (58420004).

REFERENCES

Bally, J. 1982, *Ap. J.*, **261**, 558.
Harvey, P. M., Cambell, M. F., Hoffmann, W. F., Thronson, H. A., and Gatley, I. 1979, *Ap. J.*, **229**, 990.
Joyce, R. R., Capps, R. W., Gillet, F. D., Grasdalen, G., Kleinmann, S. G., and Sargent, D. G. 1977, *Ap. J.* (*Letters*), **213**, L125.
Kobayashi, Y., Kawara, K., Maihara, K., Okuda, H., Sato, S., and Noguchi, K. 1978, *Pub. Astr. Soc. Japan*, **30**, 377.
Lada, C. J., and Harvey, P. M. 1981, *Ap. J.*, **245**, 58.
Linke, R., and Goldsmith, P. 1980, *Ap. J.*, **235**, 437.
Morris, M., Palmer, P., Turner, B., and Zuckerman, B. 1974, *Ap. J.*, **191**, 349.
Plambeck, R. L., Wright, M. C. H., Welch, W. J., Beiging, J. H., Baud, B., Ho, P. T. P., and Vogel, S. N. 1982, *Ap. J.*, **259**, 617.
Snell, R. L., Loren, R. B., and Plambeck, R. L. 1980, *Ap. J.* (*Letters*), **239**, L17.
Takano, T., Fukui, Y., Ogawa, H., Takaba, H., Kawabe, R., Fujimoto, Y., Sugitani, K., and Fujimoto, M. 1984, *Ap. J.* (*Letters*), in press.

M. FUJIMOTO, Y. FUJIMOTO, Y. FUKUI, R. KAWABE, H. OGAWA, K. SUGITANI, H. TAKABA, and T. TAKANO,: Department of Physics, Nagoya University, Chikusa-ku, Nagoya, Japan