THE ASTROPHYSICAL JOURNAL, 219:95–104, 1978 January 1

CO OBSERVATIONS OF A MOLECULAR CLOUD COMPLEX ASSOCIATED WITH THE BRIGHT RIM NEAR VY CANIS MAJORIS

CHARLES J. LADA AND MARK J. REID
Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory
Received 1977 May 18; accepted 1977 June 17

ABSTRACT

We present extensive CO observations of a large molecular cloud complex ($\sim$15 pc) associated with a bright rim near the peculiar star VY CMa. CO emission peaks in a region along and adjacent to the bright rim which forms the western border of the cloud complex. This emission abruptly decreases across the bright rim, which suggests a physical association of the rim with the cloud. The molecular complex is found to consist of two clouds which have different radial velocities and physical properties. The possibility that these two clouds may be in near-collision is discussed.

The physical association of the bright rim with the cloud complex indicates that the clouds are at the same distance, 1.5 kpc, as the stars which excite the rim. Since VY CMa appears to be located at the tip of the bright rim and has a velocity similar to that of the molecular cloud complex and the stars of the cluster NGC 2362, we conclude that VY CMa is also at the same distance. The resulting luminosity of VY CMa ($5 \times 10^5 L_\odot$) indicates that the star is very massive and places constraints on interpretation of its evolutionary state.

Subject headings: infrared: sources — interstellar: molecules — nebulae: general — stars: individual — stars: massive — stars: variables

I. INTRODUCTION

The large ($\sim$5° diameter) H II region S310 is associated with a number of very young objects. Near the center of S310 are the O stars τ CMa and UW CMa (which are the probable sources of excitation) and the well-studied cluster NGC 2362. Around the edge of this H II region are a number of isolated dark clouds and one conspicuous arrow-shaped bright rim. The overall structure of this region is very similar to that of S264, the H II region excited by λ Ori and also surrounded by a number of bright rims and dark nebulae (see Barnard 1927). Studies of the bright-rimmed clouds B35 and B30 (Lada and Black 1976; Lada 1978) at the edge of S264 suggested that bright rims may significantly enhance the density and temperature of their adjacent neutral clouds.

The bright-rimmed cloud at the edge of S310 is considerably larger in extent than typical bright-rimmed clouds. It contains a number of Hα emission objects (Herbig 1972) and is of particular interest, because the peculiar star VY CMa, a bright infrared emitter and strong microwave maser source, is projected onto the tip of this rim.

We have made extensive CO observations of the bright-rimmed molecular cloud at the edge of S310 to determine the extent to which the physical conditions are similar to those in other bright-rimmed clouds and to ascertain the possible relationship of the cloud to VY CMa. In § III we present observations of spatial and kinematic structure of CO emission in the cloud complex. In § IV we discuss the dynamical nature of the cloud complex, and in § V its association with VY CMa. The distance, luminosity, and evolutionary state of VY CMa are strongly constrained by these findings.

II. EQUIPMENT

Observations of the $J = 1$–0 transition of ^{12}CO and ^{13}CO toward the bright-rimmed cloud near VY CMa were made in 1976 February and April with the 16 ft (5 m) antenna of the University of Texas Millimeter Wave Observatory located on Mount Locke near Fort Davis, Texas.[1] A 40-channel filter bank spectrometer provided spectral coverage of 10 MHz (26 km s^{-1}), with 250 kHz resolution (0.65 km s^{-1}). Spectra were obtained by operating a crystal-mixer receiver in a frequency-switched mode, with the signal band tuned 10 MHz above the comparison band. The system noise temperature was determined to be 1600 K at the ^{12}CO observing frequency and 1800 K at the ^{13}CO frequency. Antenna temperatures for each of the 40 channels were calibrated with a rotating absorber at ambient temperature. The ^{12}CO line temperatures were corrected for atmospheric and instrumental effects by using the method of Davis and Vanden Bout (1973). All observations were taken with the source above 20° elevation.

[1] The Millimeter Wave Observatory is operated by the Electrical Engineering Research Laboratory, University of Texas at Austin, with support from the National Science Foundation, McDonald Observatory, and the National Aeronautics and Space Administration.

III. OBSERVATIONS

a) *Morphology*

Figure 1 is a map of peak ^{12}CO emission in the velocity range between 12 and 38 km s^{-1}, superposed on a deep red photograph of the VY CMa region provided by Dr. G. Herbig. This map was constructed from 175 spectra observed at either 3.′0 or 1.′5 intervals throughout the bright-rimmed cloud. We have coarsely sampled regions outside the 6 K contour and find that the cloud does not appear to extend significantly beyond the contours we have drawn. No CO emission was detected 15′ west of VY CMa.

The general properties of this region are similar to those observed toward other bright-rimmed clouds (cf. Lada and Black 1976). First, there is an abrupt decrease of CO emission and a striking increase in the number density of background stars across the edge of the molecular cloud, which is bordered by the optically visible bright rim. This probably indicates destruction of molecular material at the interface between the ionized rim and the neutral cloud, and it implies a physical association between the optical rim and the western edge of the molecular cloud. That optical emission overlaps parts of the cloud in the north suggests that the source of ionization is in the foreground of at least this part of the cloud. Second, the ^{12}CO emission appears generally brighter along the edge of the cloud adjacent to the bright rim, which probably indicates enhanced heating of the molecular cloud near the cloud-rim interface. Possible reasons for enhanced heating near bright rims have been discussed previously (Lada and Black 1976; Elmegreen and Lada 1977; Elmegreen, Dickinson, and Lada 1977).

The angular extent of the CO emission is roughly 30′ in each direction, which, at the adopted distance of 1.5 kpc (see § IV*a*), corresponds to a linear size of about 15 pc. Thus this cloud is an order of magnitude larger than typical bright-rimmed molecular clouds.

b) *Kinematics*

Figure 2 presents ^{12}CO emission as a function of velocity and declination at the right ascension of strongest CO emission ($\alpha_{1950} = 07^h22^m01^s.6$). The CO emission along the bright rim originates in two clouds which appear to be separated in both velocity and angle (declination). The separation in velocity is quite distinct: The northern cloud has a velocity of 24 km s^{-1}, while the southern cloud has a velocity of about 18 km s^{-1}. There is a sharp separation in declination of the strongest emission (i.e., $T \gtrsim 10$ K) from both clouds. However, the clouds do appear to overlap in two places at the 6 K level. We have made higher-sensitivity (i.e., longer-integration) measurements of CO emission between the declinations of $-25°43'$ and $-25°55'$ in 1977 February. At a level of about 4 K, 24 km s^{-1} CO emission extends continuously from the brightest part of the northern cloud to at least $\delta_{1950} = -25°55'$, which indicates that (at the 4 K emission level) the two clouds overlap in declination. It is important to point out that, at declinations where emission from both clouds is observed, the emission features are clearly separated in velocity.

There appears to be a slight north-south gradient in the 18 km s^{-1} cloud of about 0.2 km s^{-1} arcmin^{-1}, or 0.4 km s^{-1} pc^{-1}, while no such motion is evident in the 24 km s^{-1} cloud.

Spatial contour maps at eight velocities are shown in Figure 3 in order of increasing velocity. Emission from the 18 km s^{-1} cloud is confined to a relatively compact region (about 12′ in diameter) in the southwest section of the field covered by our maps. The slight north-south velocity gradient found for the 18 km s^{-1} cloud in Figure 2 is also apparent on the first three maps of Figure 3. Emission from the 24 km s^{-1} cloud is distributed over a much greater area than that from the 18 km s^{-1} cloud. Comparison of the last five maps in Figure 3 shows that emission in the eastern region of the 24 km s^{-1} cloud is at a lower velocity than emission in the western region along the bright rim; this suggests a slight east-west velocity gradient. This is perpendicular to the sense of the velocity gradient in the 18 km s^{-1} cloud.

c) *Physical Parameters*

We observed ^{13}CO emission at a number of locations in order to estimate the mass and density of each cloud. Spectra of ^{12}CO and ^{13}CO from the regions of peak intensity in each cloud are shown in Figure 4. The ^{13}CO emission in the 18 km s^{-1} cloud is about a factor of 2 stronger than that in the 24 km s^{-1} cloud. This indicates a higher column density of CO in the 18 km s^{-1} cloud. The ^{13}CO column densities are listed in Table 1 for each point where a ^{13}CO line was measured. In addition, Table 1 gives hydrogen column densities estimated from the equation N (all H) $= 3 \times 10^6\, N(^{13}\mathrm{CO})$, which assumes a terrestrial-isotope abundance of carbon, 10% of all carbon in the form of CO, and a solar C to H ratio. The average column densities, masses, and number densities for each cloud within the boundary of the 10 K contour are also given. Besides differing in velocity and spatial location, the 24 km s^{-1} cloud can also be differentiated from the 18 km s^{-1} cloud by its physical properties.

IV. DISCUSSION

a) *Distance to the Molecular Clouds*

In this section we estimate the distance to the molecular cloud complex. Because of the presence of the bright rim at the edge of the cloud complex, we assume that the distance to the clouds is approximately that of the stars, which ionize the rim. There are three candidates for the sources of ionization in this region: τ CMa (HD 57061), an O9 I star (Conti and Alschuler 1971); UW CMa (HD 57060), an O7f star (Conti and Alschuler 1971); and HD 58011, a B1p star (Buscombe 1969).

Tau Canis Majoris is believed to be a member of

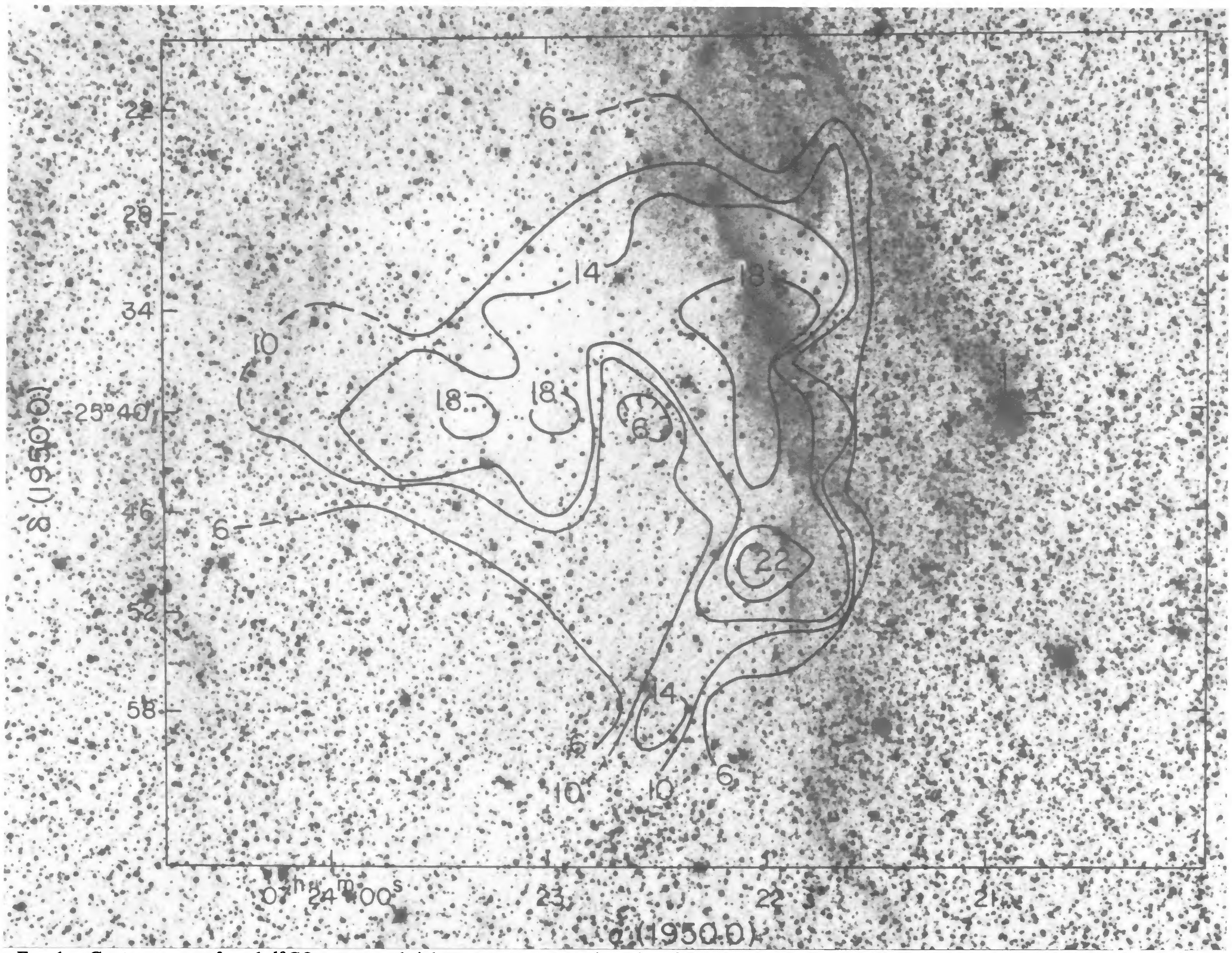

FIG. 1.—Contour map of peak ^{12}CO apparent brightness temperature, in units of K, superposed on a deep red photograph of the region of sky near VY CMa. The photograph is a composite of five negatives taken with the 20 inch (51 cm) Uppsala Schmidt telescope at Mount Stromlo Observatory by C. Roslund and B. Karlsson. The composite was assembled and printed by R. Wilson at Lick Observatory. The position of VY CMa ($\alpha_{1950} = 07^h20^m54^s.6$, $\delta_{1950} = -25°40'11''.9$) is indicated. The overlaid coordinate scales are accurate to about 10″.

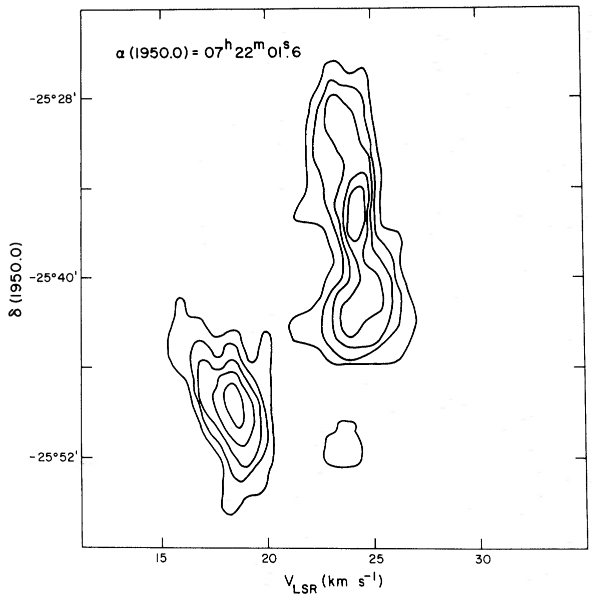

FIG. 2.—Map of ^{12}CO emission (K) as a function of declination and velocity at the right ascension of strongest ^{12}CO emission. The lowest temperature contour is 6 K, and the interval between successive contours is 4 K.

the well-studied cluster NGC 2362, which has a distance, determined from the color-magnitude diagram, of about 1.5 kpc (e.g., Johnson *et al.* 1961; Alter, Ruprecht, and Vanysek 1968; Herbig 1972). This distance estimate is probably accurate to at least 30%. Neither UW CMa nor HD 58011 belong to recognized clusters. However, rough estimates of their distances can be made from their published *UBV* colors and their spectral classification. Using *UBV* data from Kennedy and Buscombe (1974) and Klare and Neckel (1977) and the absolute-magnitude–spectral-type calibration from Blaauw (1963), we find, after correcting for interstellar absorption, the following distance moduli: 10.3 mag (1.1 kpc) for HD 58011 (assuming a B1 V classification) and 10.2 mag (1.1 kpc) for UW CMa (after correcting for the presence of a bright O–B companion which Seyfert 1941 has found to be 2.5 times less bright than the O7f primary of this binary system). The same analysis results in a distance modulus of 10.2 mag (1.1 kpc) for τ CMa. These results imply that all the possible sources of cloud ionization are at the same distance from the Sun; consequently, there should be no ambiguity in assigning a distance to the molecular cloud complex. Since the cluster method of distance determination is probably more accurate than the individual star determinations, we adopt 1.5 ± 0.5 kpc as the distance to the exciting stars, the bright rim, and the molecular cloud complex.

The average local standard of rest (LSR) radial velocity of the stars in NGC 2362 (excluding τ CMa) is about 15 km s^{-1}, while the velocity of τ CMa is 24 km s^{-1}. That these values are close to those of the clouds (18 km s^{-1} and 24 km s^{-1}) again implies a similar distance.[2] The relevant velocity and distance measurements are summarized in Table 2.

TABLE 1

CO Column Densities and Cloud Masses

Offsets*	$N(^{13}CO)$
18 km s^{-1} Cloud	
18′ E 9′ S	8.6×10^{15}
15′ E 6′ S	1.3×10^{16}
15′ E 9′ S	1.9×10^{16}
15′ E 12′ S	5.4×10^{16}
12′ E 9′ S	1.5×10^{16}
$\langle N(^{13}CO)\rangle = 1.2 \times 10^{16}$ cm^{-2}	
$\langle N(\text{all H})\rangle = 3.6 \times 10^{22}$ cm^{-2}	
$\langle n(H_2)\rangle = 4 \times 10^{3}$ cm^{-3} (for 3 pc depth)	
Mass $= 8 \times 10^{3} M_\odot$	
24 km s^{-1} Cloud	
27′ E 0′ N	1.1×10^{16}
18′ E 3′ N	$\lesssim 1.9 \times 10^{15}$
18′ E 0′ N	9.9×10^{15}
15′ E 9′ N	4.8×10^{15}
15′ E 6′ N	6.4×10^{15}
15′ E 3′ N	4.0×10^{15}
15′ E 0′ N	8.3×10^{15}
15′ E 3′ S	5.7×10^{15}
12′ E 0′ N	2.5×10^{15}
$\langle N(^{13}CO)\rangle = 6.1 \times 10^{15}$ cm^{-2}	
$\langle N(\text{all H})\rangle = 1.8 \times 10^{22}$ cm^{-2}	
$\langle n(H_2)\rangle = 1 \times 10^{3}$ cm^{-3} (for 6 pc depth)	
Mass $= 2 \times 10^{4} M_\odot$	

* Offsets with respect to the position of VY CMa: $\alpha_{1950} = 07^h20^m54^s.6$, $\delta_{1950} = -25°40'11''.9$.

b) The Nature of the Molecular Cloud Complex

The molecular cloud complex that we have observed near VY CMa in many ways appears similar to other clouds associated with ionization fronts. However, the identification of two discrete clouds at different velocities and in close angular proximity is unusual. The 6 km s^{-1} separation of the center velocities of the two clouds is large compared with the 3 km s^{-1} internal line widths (full width at half-maximum [FWHM]). Consequently, determination of the spatial boundaries of each cloud (Fig. 3) is not confused by line-of-sight absorption effects at positions where the two clouds appear to overlap. Figure 5 simultaneously displays the maps of 18.2 km s^{-1} and 24.0 km s^{-1} emission. The northern boundary of the 18 km s^{-1} cloud at a 6 K level corresponds remarkably well to the southern boundary of the 24 km s^{-1} cloud. At

[2] The measured optical velocities of UW CMa and HD 58011 are considerably different. However, the true systemic velocities of these stars may not yet be known. UW CMa is a binary whose measured velocity has not been constant (Abt and Biggs 1972), and HD 58011 is a peculiar star characterized by two different velocity systems, one determined from emission lines and the other from absorption lines. The mean of the emission and absorption velocities is close to that of NGC 2362 (Buscombe and Kennedy 1965).

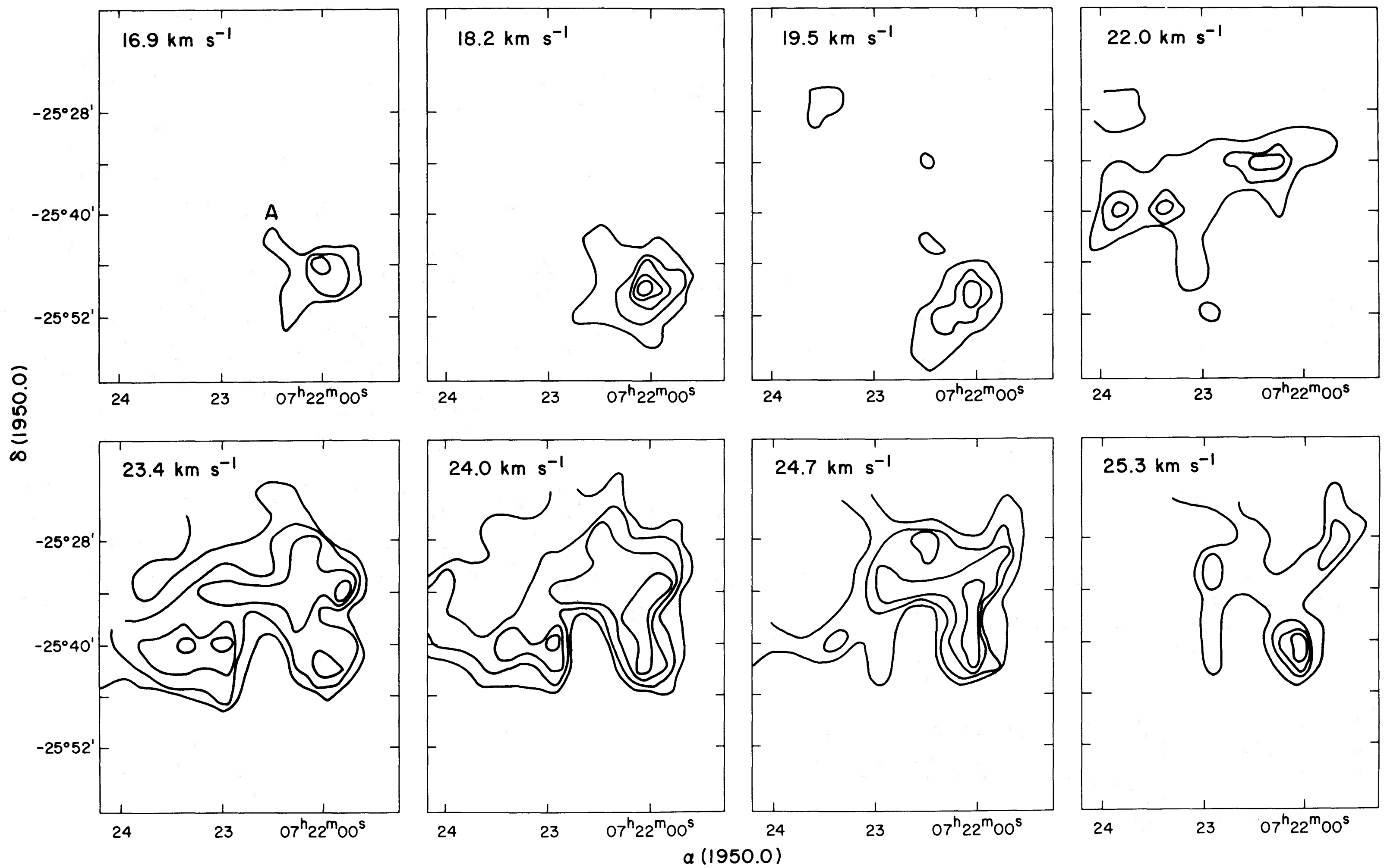

FIG. 3.—Spatial contour maps of ^{12}CO emission at eight different velocities. The range of velocity covered in each map is 0.65 km s^{-1} centered around the value indicated. In each map, the lowest temperature contour has a value of 6 K and the interval between successive contours is 4 K.

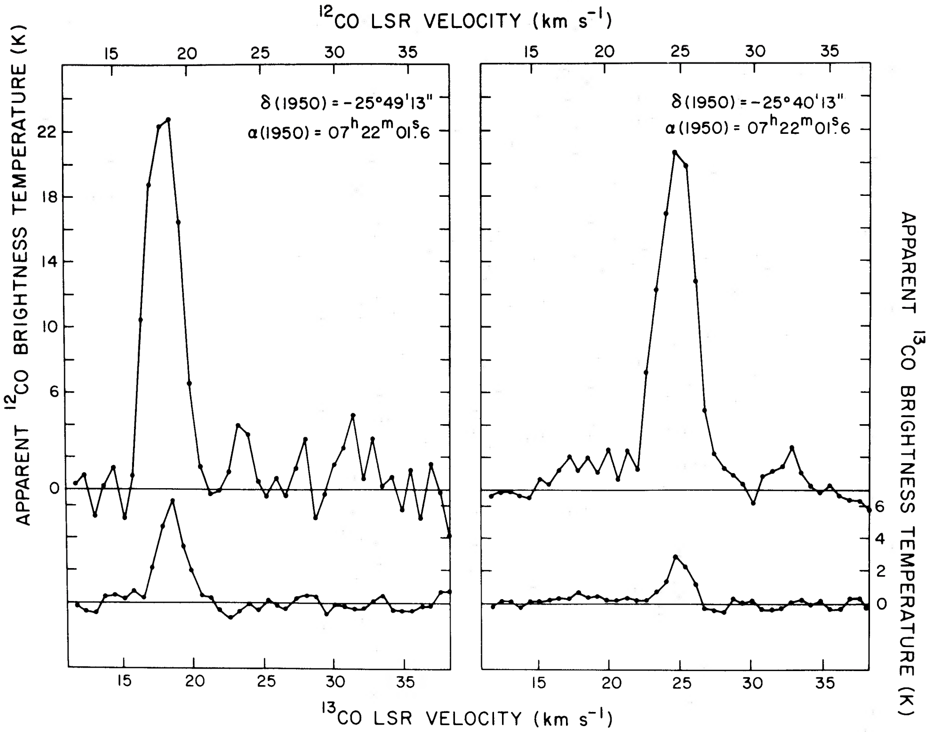

FIG. 4.—Spectra of ^{12}CO and ^{13}CO emission from positions near the regions of maximum ^{12}CO emission in the two clouds discussed in the text.

this apparent interface, sharp gradients of CO emission are seen in each cloud. This, together with their apparent association with the bright rim, suggests that the clouds are also in close physical proximity.

If the clouds were colliding, one would expect both objects to have nearly the same velocity at the collision interface. This is clearly not observed. The possibility that the two clouds could be in orbit around one another is unlikely. The approximate escape velocity for either cloud from the system is

$$V_{esc} = [2G(M_{total})/d]^{1/2} \approx 6 \text{ km s}^{-1}, \quad (1)$$

where M_{total} is the total mass of the two clouds and where d, the separation of the centers of mass, is taken to be 7 pc. Our cloud masses are not seriously *under*estimated, so the true escape velocity is probably no greater than 6 km s^{-1}. The estimated escape velocity is very close to the relative line-of-sight velocity of the two clouds. Thus the clouds are probably not gravitationally bound.

TABLE 2

MEASURED VELOCITIES AND DISTANCE MODULI*

Objects	LSR Velocity (km s^{-1})	Distance Modulus (mag)
NGC 2362............	15	10.9
τ CMa................	24	10.2
UW CMa.............	(see text)	10.2
HD 58011.............	(see text)	10.3
Molecular clouds.......	18, 24	...
VY CMa..............	18	...

* See text for references.

If most of the relative motion of the two objects is in the line of sight, then the two clouds could be experiencing a grazing collision. Since both clouds are of approximately the same size and density, we would expect neither one to be completely disrupted by tidal interactions in such an encounter. However, some tidal interaction might be expected, and one could speculate that the structure in the 18 km s^{-1} cloud seen in Figures 3 and 5 may be due to such disruption. The tongue of emission labeled A in Figure 3 appears only at the lowest velocities and may be tidally distorted material approaching the 24 km s^{-1} cloud. The observed north-south gradient might also be due to such gravitational interaction. However, no corresponding effects are obvious in the 24 km s^{-1} cloud.

Currently available evidence appears to favor the speculation that the clouds are in close spatial proximity and are either experiencing a grazing collision or very close to a direct collision. Observations of cloud-cloud collisions are potentially important, since one promising mechanism for the formation of large molecular clouds involves inelastic cloud collisions (Oort 1954; Field and Saslaw 1965; Taff and Savedoff 1972). Loren (1976) has interpreted CO observations toward NGC 1333 as evidence for a collision between

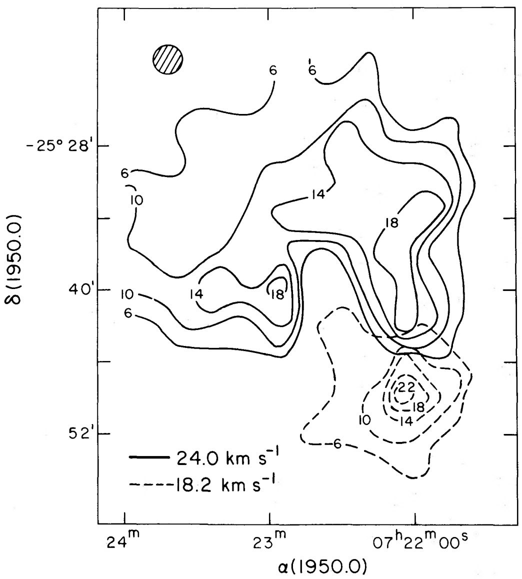

FIG. 5.—Maps of ^{12}CO emission at 18.2 and 24.0 km s^{-1}, plotted together.

two massive clouds. Additionally, two giant clouds (10^{4-5} $M_\odot$) have been observed to be in very close proximity in Orion (Kutner *et al.* 1977). Future studies of the distribution and mutual association of molecular clouds in the Galaxy are essential to understand this problem.

c) *The Nature of VY Canis Majoris*

Combining previously published observations with our data provides interesting information concerning the nature of VY CMa. VY CMa is an irregularly variable M-type star, which is projected on the tip of the bright rim in Figure 1. A very strong infrared emitter, it is one of the brightest known sources at 20 μm (Hyland *et al.* 1969; Low *et al.* 1970). VY CMa is also a very strong OH, H_2O, and SiO maser emitter. Herbig (1970*a*, *b*, 1972) has found that the optical, infrared, and radio spectral properties of this star can best be interpreted by a model which consists of an M-type supergiant star surrounded by an expanding disk of cool gas and dust. Recent observations and interpretations of the ground-vibrational-state SiO (86.8 GHz) emission are consistent with such an expanding model (Buhl *et al.* 1975; Reid and Dickinson 1976). The evolutionary status of VY CMa is a subject of considerable interest and debate. This is due in part to the fact that, until recently, there was no direct way to measure the distance to this star. Herbig argues that, because of its apparent association with the bright rim, VY CMa is a member of the young association containing NGC 2362, τ CMa, and the H II region S310. Thus VY CMa is at the same distance as the cluster NGC 2362 (1.5 kpc). At this distance, VY CMa would have an unusually large luminosity. Hyland *et al.* (1969) favor a closer distance of 400 pc, so that the luminosity of VY CMa would be 4×10^4 $L_\odot$ and consistent with that of an evolved M star of luminosity class Ib.

Determination of the distance to VY CMa is critical to understanding its nature. Recently, observations of the ground-vibrational-state SiO emission (Buhl *et al.* 1975) have yielded the first accurate velocity determination of VY CMa. Reid and Dickinson (1976) find this velocity to be 18 ± 2 km s^{-1}. We interpret this result to indicate that VY CMa is at the same distance as the molecular clouds and NGC 2362, which confirms Herbig's original contention that the distance to VY CMa is 1.5 kpc.

At 1.5 kpc, VY CMa has a total luminosity of 5.6×10^5 $L_\odot$. With an effective temperature of about 3000 K, VY CMa occupies a position in the upper right-hand corner of the H-R diagram. Its position on the H-R diagram indicates that VY CMa is either a very massive pre–main-sequence star or an exceedingly luminous evolved star. The high luminosity places constraints on its possible evolutionary status.

That the microwave maser lines found in VY CMa are typical of those found almost exclusively in the circumstellar envelopes around evolved late-type stars implies that VY CMa may be an evolved star. Because of its high luminosity, one would expect that VY CMa might be very massive. Indeed, red supergiants for which masses can be determined all have masses in excess of 10 $M_\odot$ (Allen 1973). Examination of theoretical evolutionary tracts on the H-R diagram enables us to estimate the mass of VY CMa. Even though such theoretical calculations rarely include supergiants with such a cool surface temperature as VY CMa, it seems evident that only stars with masses in excess of 15–20 solar masses ever reach luminosities which exceed 10^5 $L_\odot$ (Iben 1967; Lamb, Iben, and Howard 1976; Stothers and Chin 1977). Thus, if VY CMa were an evolved star, it would have been an O star while on the main sequence. As such, it should have had a considerable effect on its surroundings. An H II region would have been created, and its parental molecular cloud destroyed. We note that τ CMa and UW CMa have ionized and destroyed surrounding material out to distances of 40 pc or more. Today, VY CMa has a projected distance from the molecular clouds of about 5 pc. Since VY CMa almost certainly formed from the same molecular cloud complex as did τ CMa and UW CMa, we would have expected similar large-scale destruction of molecular material by VY CMa when it was on the main sequence. Apparently, this has not occurred. The observed disruption of the molecular clouds near VY CMa could be due to the effects of τ CMa and UW CMa alone. This argues that VY CMa is not an evolved star.

Because of its association with the bright rim and NGC 2362, Herbig (1970*a*) contends that VY CMa is a pre–main-sequence star. Theoretical tracks for pre–main-sequence evolution of stars of high luminosity are horizontal from right to left across the H-R diagram and indicate a mass for VY CMa also in excess of 15 solar masses.

If VY CMa is a pre–main-sequence star, its microwave maser spectrum is a puzzle. With the possible exception of Orion, this type of maser spectrum (i.e., SiO maser line, double-peaked 1612 MHz OH emission) has been observed only toward evolved M giants. Because of this, we hesitate to conclude firmly that VY CMa is a pre– rather than a post–main-sequence star.

Despite our new observations, the question of the evolutionary status of VY CMa remains open. However, its distance seems to be now firmly established at 1.5 kpc. The resulting high luminosity strongly suggests that, whatever the evolutionary phase, VY CMa is very massive (greater than $\sim 15\,M_\odot$). An interesting consequence of this fact is that the evolutionary time scale of the current phase of VY CMa is probably relatively brief. Theoretical calculations and observations of clusters indicate that stars as massive as VY CMa spend very little time (less than 10^5 years) as red supergiants after evolution off the main sequence (Lamb *et al.*). Similarly, the contraction time for massive pre–main-sequence stars is also very short (certainly much less than 10^5 years). Thus, in observing VY CMa, we are witnessing a rare event.

d) *VY Canis Majoris and the Nature of the Bright Rim*

In most bright-rimmed clouds, the shapes of the rims are oriented so that they point toward the source of ionization. However, the bright rim associated with VY CMa appears to point toward VY CMa and in a direction between the possible ionizing sources. This raises the question of the possible dynamical influence of VY CMa on the shape of the rim. Below, we consider the possibility that mass loss from VY CMa has a significant dynamical influence on the structure of the bright rim. We can estimate at what distance the dynamical pressure due to a mass loss (ρv^2) from VY CMa is equal to the pressure in the ionized gas of the bright rim ($2.1\, n_e k T_{\rm II}$):

$$R({\rm pc}) = \left(\frac{\dot{M} V_{\rm ex}}{8.4\pi n_e k T_{\rm II}}\right)^{1/2}, \qquad (2)$$

where $V_{\rm ex}$ is the expansion velocity, $\dot{M}$ the mass-loss rate, $T_{\rm II}$ the temperature in the H II region, and n_e the electron density. With the mass-loss rate of $3 \times 10^{-4}\, M_\odot\,{\rm year}^{-1}$ and an expansion velocity of $20\ {\rm km\ s^{-1}}$ (Herbig 1972), we have

$$R({\rm pc}) = 10.8 n_e^{-1/2}\,.$$

Thus, for electron densities smaller than $10\ {\rm cm^{-3}}$ in the bright rim, VY CMa could significantly influence the dynamics of the rim. However, to affect a region 3 pc distant from itself, VY CMa must have been losing mass for at least $(3\ {\rm pc})/V_{\rm ex}$, or 1.5×10^5 years. During this time it would have expelled around $50\ M_\odot$ of material in order to have a significant pressure influence. Even though this is approximately the mass of the ionized gas in the bright rim, it seems unlikely that any type of star could lose such a large amount of material.

V. SUMMARY AND CONCLUSIONS

A large molecular cloud complex has been found associated with the bright rim near VY CMa. This molecular complex consists of two clouds which are distinct in radial velocity (18 and $24\ {\rm km\ s^{-1}}$) and in position. As in other molecular clouds associated with bright rims, CO emission peaks along, and abruptly decreases across, the rim which forms one boundary of the cloud complex. Observations of ^{13}CO indicate that the $18\ {\rm km\ s^{-1}}$ cloud has twice the CO column density and about 4 times the total density of the $24\ {\rm km\ s^{-1}}$ cloud. From their association with the bright rim and the close correspondence of the cloud boundaries where they overlap, we infer that the clouds are in close spatial proximity. This suggests that the clouds may eventually collide.

The physical association of the cloud complex with the bright rim implies that the cloud complex is at the same distance as the stars which excite the rim. This is strongly supported by the observation that the radial velocities of the young cluster NGC 2362, the O star τ CMa, and the CO clouds are all near $20\ {\rm km\ s^{-1}}$. The distance to all of these objects is about 1.5 kpc. Since the recently determined velocity of VY CMa is similar to that of these objects, we conclude that VY CMa is also at 1.5 kpc. The resulting luminosity of VY CMa ($5 \times 10^5\, L_\odot$) indicates that it is very massive (greater than $15\ M_\odot$) and places constraints on interpretations of its evolutionary state. Although the microwave maser spectra of VY CMa are typical of those associated with evolved stars, the high mass of VY CMa and the lack of large-scale destruction of molecular cloud material around VY CMa suggests that it has not yet reached the main sequence.

We are grateful to Drs. L. Hartmann and B. Elmegreen for helpful discussions and Dr. G. Herbig for kindly providing us with the optical photograph of the VY CMa region.

REFERENCES

Abt, H. A., and Biggs, E. S. 1972, *Bibliography of Stellar Radial Velocities* (New York: Latham Process).
Allen, C. W. 1973, *Astrophysical Quantities* (3d ed.; London: Athlone).
Alter, G., Ruprecht, J., and Vanysek, V. 1968, *Catalogue of Star Clusters and Associations* (Prague: Czechoslovak Academy of Sciences).
Barnard, E. E. 1927, *Photographic Atlas of Selected Regions of the Milky Way*, ed. E. B. Frost and M. R. Calvert (Washington: Carnegie Institution of Washington).
Blaauw, A. 1963, in *Basic Astronomical Data*, ed. K. Aa. Strand (Chicago: University of Chicago Press), p. 383.
Buhl, D., Snyder, L. E., Lovas, F. J., and Johnson, D. R. 1975, *Ap. J.* (*Letters*), **201**, L29.
Buscombe, W. 1969, *M.N.R.A.S.*, **144**, 31.
Buscombe, W., and Kennedy, P. M. 1965, *M.N.R.A.S.*, **130**, 281.
Conti, P. S., and Alschuler, W. R. 1971, *Ap. J.*, **170**, 325.
Davis, J., and Vanden Bout, P. 1973, *Ap. Letters*, **15**, 43.
Elmegreen, B. G., Dickinson, D. F., and Lada, C. J. 1977, preprint.
Elmegreen, B. G., and Lada, C. J. 1977, *Ap. J.*, **214**, 725.
Field, G. B., and Saslaw, W. C. 1965, *Ap. J.*, **142**, 568.
Herbig, G. H. 1970*a*, *Mém. Soc. Roy. Sci. Liège*, **19**, 13.

Herbig, G. H. 1970*b*, *Ap. J.*, **162**, 557.
———. 1972, *Ap. J.*, **172**, 375.
Hyland, A. R., Becklin, E. E., Neugebauer, G., and Wallerstein, G. 1969, *Ap. J.*, **158**, 619.
Iben, I. 1967, *Ann. Rev. Astr. Ap.*, **5**, 585.
Johnson, H. L., Hoag, A. A., Iriarte, B., Mitchell, R. I., and Hallan, K. L. 1961, *Lowell Obs. Bull.*, **5**, 133.
Kennedy, P. M., and Buscombe, W., comp. 1974, *MK Spectral Classifications Published since Jaschek's La Plata Catalogue* (Evanston: Northwestern University Press).
Klare, G., and Neckel, Th. 1977, *Astr. Ap. Suppl.*, **27**, 215.
Kutner, M. L., Tucker, K. D., Chin, G., and Thaddeus, P. 1977, *Ap. J.*, **215**, 521.
Lada, C. J. 1978, in preparation.
Lada, C. J., and Black, J. H. 1976, *Ap. J.* (*Letters*), **203**, L75.
Lamb, S. A., Iben, I., and Howard, W. M. 1976, *Ap. J.*, **207**, 209.
Loren, R. B. 1976, *Ap. J.*, **209**, 466.
Low, F. J., Johnson, H. L., Kleinmann, D. E., Latham, A. S., and Geisel, S. L. 1970, *Ap. J.*, **160**, 531.
Oort, J. H. 1954, *Bull. Astr. Inst. Netherlands*, **12**, 177.
Reid, M. J., and Dickinson, D. F. 1976, *Ap. J.*, **209**, 505.
Seyfert, C. K. 1941, *Ap. J.*, **93**, 442.
Stothers, R., and Chin, C. 1977, *Ap. J.*, **211**, 189.
Taff, L. G., and Savedoff, M. P. 1972, *M.N.R.A.S.*, **160**, 89.

CHARLES J. LADA: Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

MARK J. REID: National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22901