Chin. J. Astron. Astrophys. Vol. 3 (2003), No. 1, 69–74
(http://www.chjaa.org or http://chjaa.bao.ac.cn)

Chinese Journal of Astronomy and Astrophysics

A Study of Star Formation in BRC18 *

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Received 2001 October 29; accepted 2002 November 29

Abstract Using the 13.7 m radio telescope at Delingha, the millimeter-wave radio observatory of Purple Mountain Observatory, we made mapping observations in ^{12}CO $J = 1 - 0$ line towards IRAS 05417+0907, located in the bright-rimmed cloud (BRC) BRC18. We used a 7×7 grid with $1'$ spacing, a finer and larger grid than the one used by Myers et al. Our results show that there is a bipolar outflow near IRAS 05417+0907. Combining with the observations at other wave bands, we find that the star formation process in this region is triggered by radiation-driven implosion. The significant difference between the masses of BRC18 and the cores and the relatively large ratio of associated source bolometric luminosity to the mass show that the star formation in BRC18 may be taking place in a sequence.

Key words: ISM: clouds – star: formation– individual: IRAS 05417+0907

1 INTRODUCTION

BRC18 is a small, bright-rimmed molecular cloud (BRC) at the edge of the large HII region S264 excited by early-type stars in the λ Ori clusters (Lada et al. 1976, 1981; Sugitani et al. 1989). It extends 0.37 pc by 1.40 pc at a distance of 500 pc, and harbors the infrared source IRAS 05417+0907 ($\alpha(1950) = 05^{\rm h}41^{\rm m}45.3^{\rm s}$, $\delta(1950) = 09°07'40.0''$). Its $NH_3(1,1)$ map shows a core structure around ($\alpha(1950) = 05^{\rm h}41^{\rm m}52.4^{\rm s}$, $\delta(1950) = 09°09'00.0''$) (Jijina et al. 1999). A 3×3 map in the ^{12}CO $J = 1-0$ line with grid spacing $2'$ was made by Myers et al. (1988). They found an outflow near IRAS 05417+0907. Hodapp et al. (1994) found a localized nebulosity at ($\alpha(1950) = 05^{\rm h}41^{\rm m}45.3^{\rm s}$, $\delta(1950) = 09°07'40.0''$) from a K'-band imaging survey.

IRAS sources associated with BRCs have cold color indices, suggesting that they are young stars or protostars. BRCs are found in/around relatively old ($\tau > 10^6$ yr) HII regions (Sugitani et al. 1989). The lifetimes of IRAS sources associated with outflows are $\sim 10^3 - 10^5$ yr (Sugitani et al. 1991). Previous studies (Sugitani et al. 1989) have shown that both the luminosities and luminosity-to-cloud mass ratios of the IRAS sources with BRCs are significantly higher than those embedded in either isolated globules or in dense cores of dark cloud complexes. The

* Supported by the National Natural Science Foundation of China.

physical conditions in such nebulae match well the implosion model of star formation (Sugitani et al. 1991).

All the observations show that BRC18 is an active star formation region. Sugitani et al. (1991) pointed out that the process of star-formation is different in BRCs and in dense clouds. The star formation process in this region and its triggering mechanism need to be investigated.

Recently, we made a mapping of IRAS 05417+0907 and its associated cloud BRC18 using a 7×7 grid with $1'$ spacing in the ^{12}CO $J = 1-0$ line. We have calculated the parameters of the outflow and associated infrared source. Relevant parameters of BRC18 are also obtained. Combining these data, we shall discuss the process of star formation in BRC18.

2 OBSERVATIONS

Our observations of IRAS 05417+0907 were made in May 2001 with the 13.7 m radio telescope at Delingha, the millimeter-wave radio observatory of Purple Mountain Observatory. The half-power beamwidth of the telescope at the observing frequency of 115.271 GHz is $54''$. The pointing and tracking accuracy is better than $10''$. A cooled mixer receiver with a typical temperature 250 K (single sideband) is used. The AOS spectrometer has 1024 channels, with a total bandwidth of 170 MHz and an equivalent velocity resolution of 0.43 km s^{-1}. Its typical rms noise is 0.20 K. The radiation temperature can be calculated according to $T_{\rm R} = T_{\rm A}^*/\eta_{\rm C}\eta_{\rm fss}$ (Kutner et al. 1981; Mao et al. 1997). The spectral line intensity $T_{\rm A}^*$ was calibrated with the ambient temperature and corrected for atmospheric absorption. Here $\eta_{\rm C}$ is the coupling efficiency between the telescope and the source, and $\eta_{\rm C} = 1$ for our source. The forward spillover and scattering efficiency $\eta_{\rm fss}$ is 0.50 during our observing period. All spectra were taken in the absolute-position-switching mode. The 7×7 map was centered at $\alpha(1950) = 05^{\rm h}41^{\rm m}52.4^{\rm s}$, $\delta(1950) = 09°07'40.0''$. The grid spacing was $1'$, and the integration time was 2 minutes for each position. The data were reduced with the Drawspec software package.

3 RESULTS

The ^{12}CO $J = 1-0$ spectra at IRAS 05417+0907 and the peak of NH_3 core positions are shown in Fig. 1(a) and (b), respectively. The red and blue wings are obvious in Fig. 1. With line center radial velocity at $V_{\rm LSR}$ of 11.7 km s^{-1}, the line wings are integrated from 6.7–10.5 km s^{-1} (blue wing), and from 13.5–17.3 km s^{-1} (red wing). Contours of the line wing emission are shown in Fig. 2(a), and the integrated contours of the core in Fig. 2(b).

The bipolar structure of the spatial distribution of the high velocity gas emission in Fig. 2(a) shows that the supersonic motions originate in outflow motions rather than in rotation, turbulence or collapse (Lada 1985; Myers et al. 1988; Wu et al. 1999). If due to rotation, we must have the relation: $M \geq V^2 r/2G$, where V is the flow velocity, r is its extent, and G is the gravitational constant, and our calculation does not agree with this. Also, both turbulence and collapse seem to be unlikely kinematic candidates for explaining the bipolar structure (Lada 1985).

The outflow parameters are estimated, following the method used by Goldsmith et al. (1984). Under the assumption of LTE and the wing being optical thin, the total column density of CO molecules is

$$N_{\rm CO} = \frac{4.2 \times 10^{13}}{\exp(-5.5/T_{\rm ex})} T_{\rm ex} \int T_{\rm R}(v) {\rm d}v ({\rm cm}^{-2}) \,. \quad (1)$$

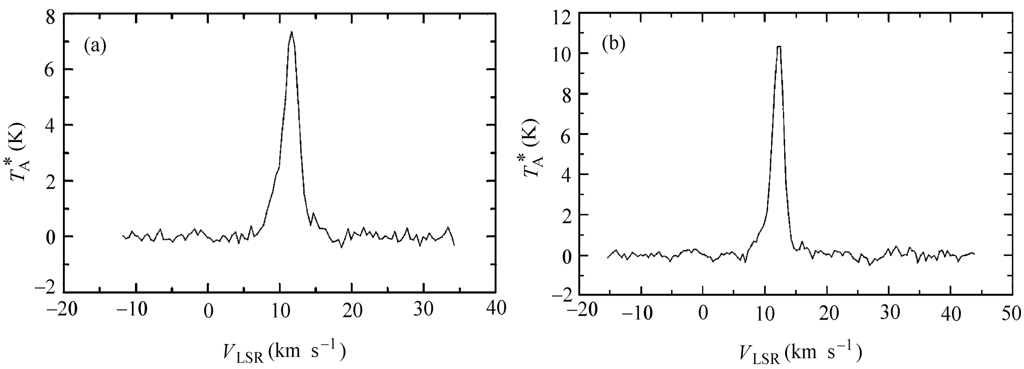

Fig. 1 (a) The $^{12}CO\ J = 1 - 0$ spectra at IRAS 05417+0907 and (b) the peak of NH_3 core positions.

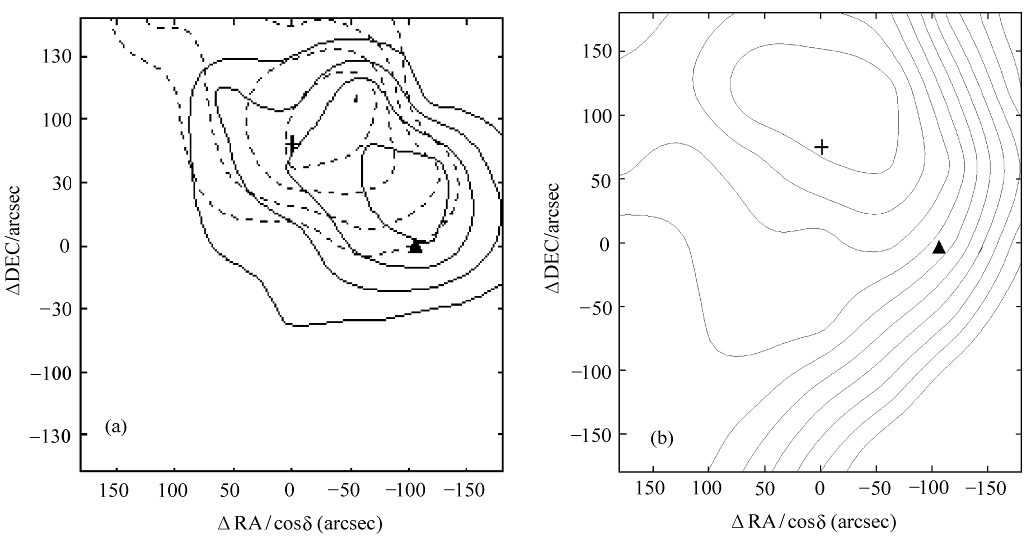

Fig. 2 (a) Contour map of $^{12}CO\ J = 1 - 0$ line wing integrated intensity in IRAS 05417+0907. The blue wing contours (solid lines) are from 16 to 28 $K\,km\,s^{-1}$ at $4\,K\,km\,s^{-1}$ spacing; the red wing contours (dashed lines) are from 8 to 16 $K\,km\,s^{-1}$ at $2\,K\,km\,s^{-1}$ spacing. (b) Contour map of $^{12}CO\ J = 1 - 0$ core integrated intensity. The contours are from 30 to 75 $K\,km\,s^{-1}$ at $5\,K\,km\,s^{-1}$ spacing. (The triangle and plus signs mark the IRAS source and the peak of NH_3 core, respectively.)

If we further assume a CO abundance $X_{CO} = [CO]/[H2] = 10^{-4}$ and $T_{ex} = 20\,K$, where T_{ex} is the excitation temperature, the column density of the HV gas is $N = N_{CO}/X_{CO}$. We have neglected the emission of the HV gas in the core region of the line, and take the CO line wing emission as optically thin ($\tau \ll 1$) approximately (Goldsmith et al. 1984). The outflow parameters are listed in Table 1.

The morphology of the outflow in this work is similar to that of Myers et al. (1988) and the peaks of red and blue wing emission are accordant with theirs. There are some difference between us and them in the parameters of the outflow. The reasons may be (1) they took the excitation temperature to be 10 K, whereas we take it to be 20 K, which is close to the kinetic temperature, obtained by Wu et al. (1989) (19 K) and in this work (22 K); (2) they used a grid spacing of $2'$, and we use one of $1'$.

Table 1 Outflow Parameters

	size (pc)	M ($M_\odot$)	P ($M_\odot$ km s^{-1})	E (erg)
this work	0.3	0.36	1.7	3.4×10^{43}
Myers et al.	0.4	0.86	2.0	6.4×10^{43}
V (km s^{-1})	t (yr)	F ($M_\odot$ km s^{-1} yr^{-1})	$L_{\rm mech}$ ($L_\odot$)	$M_{\rm loss}$ ($M_\odot$ yr^{-1})
4.36	6.7×10^4	2.5×10^{-5}	0.04	2.5×10^{-7}
2.4	18×10^4	1.1×10^{-5}	0.03	1.1×10^{-7}

4 DISCUSSION

In Fig. 2(b), the outflow contours extend from north-east to south-west. It is obvious that the core emission peak is closely associated with the $NH_3(1,1)$ core. IRAS 05417+0907 is associated with a near infrared nebulosity (Hodapp et al. 1994). The detected emission peak (69 mJy) in the 2 mm continuum observation of this region coincides with the position of IRAS 05417+0907 (Sugitain et al. 2000). In Fig. 2 (a), (b), we can see that IRAS 05417+0907 is near the blue-shifted emission and core emission peak. According to PSC of IRAS, there are no other IRAS sources in this region. Lada & Wilking (1980) failed to find any evidence for 2μ sources in a sensitive 2μm infrared survey. All these suggest that IRAS 05417+0907 is the driving source of the outflow.

The infrared flux densities of IRAS 05417+0907 at 12, 25, 60 and 100 μm are 0.28, 2.92, 25.60 and 74.47 Jy (PSC), respectively. The colour indices, $\log(f_{25}/f_{12})$ and $\log(f_{60}/f_{12})$, are 1.02 and 1.96. Using the formula of Casoli et al. (1986), the bolometric luminosity of IRAS 05417+0907 is $21.4\,L_\odot$. This is a low mass star formation region. From Table 1, we can see that the outflow has a significantly lower mass and mass loss rate than those of massive YSOs (Churchwell 1999; Wu et al. 1996).

Under the assumption of $n = 3 \times 10^4$ H_2 by Sugitain et al. (1991), we estimate the mass of BRC18 by $M_{\rm BRC} = 4/3\pi R^3 \mu n = 54.8\,M_\odot$. Here R is the radius of BRC18, $R = l/2$, $l = 0.37$ pc (Sugitani et al. 1991), μ is the hydrogen molecular weight. We have calculated IRAS luminosities per unit cloud mass, $L_{\rm bol}/M_{\rm BRC} = 0.39\,L_\odot/M_\odot$, following the method of Sugitani et al. (1989). If we adopt a relationship between stellar luminosity and mass of $L = kM^{3.5}$, the mass of the core is $2.4\,M_\odot$. The radius of extensive HII region S264 and BRC18 are 55.3 pc (Sugitani et al. 1991) and 0.185 pc. If we adopt 10 km s^{-1} for both the accretion shock velocity in the BRC and expansion velocity of HII region (Sugitani et al. 1991), we obtain an implosion time scale of $< 10^4$ yr and an age of 5.9×10^6 yr for the HII region.

The implosion time scale is $< 10^4$ yr, while the age of the associated HII region is $> 10^6$ yr. Hence, the IRAS source is probably formed after the HII region, under the influence of the HII region. When ionization fronts form under the irradiation of type OB stars, the associated cloud is compressed to much higher densities, i.e., star formation takes place in the short time scale for the collapse of convergent shock fronts according to Sugitain et al. (1991). Hence, we infer that the star formation in BRC18 is triggered by radiation-driven implosion.

The IRAS sources are divided into two types as in Beichman et al. (1983). IRAS 05417+0907 is a type I source, which is considered to have a newly formed or still-forming star embedded in its parental cloud. The mass of the BRC18 is $54.8\,M_\odot$, while that of the young star is $2.4\,M_\odot$. The significant difference between the BRC18 and the core masses may imply multiple stars formation in this region. The typical values of $L_{\rm bol}/M_{\rm BRCs}$ for the isolated dark cloud and dense cores are in the range of $0.03 \sim 0.1\,L_\odot/M_\odot$ (Sugitani et al. 1989; Myers et al. 1983), while the value of BRC18 is $0.39\,L_\odot/M_\odot$. $L_{\rm bol}/M_{\rm BRCs}$ is related to the star formation efficiency (Sugitani et al. 1989). This reveals that star formation efficiency in this region is greater than in the isolated dark cloud and dense cores. High star formation efficiency and probably multiple star formation show that star formation in BRC18 may be taking place in sequence (Sugitani et al. 1995; Wang 2002).

5 CONCLUSIONS

Our 7×7 grid mapping with $1'$ spacing in $^{12}{\rm CO}\,J = 1-0$ shows a bipolar outflow near IRAS 05417+0907. The parameters of the outflow are obtained. The outflow has a significantly lower mass and mass loss rate than those of massive YSOs. IRAS 05417+0907 lies in BRC18 and associates with the HII region S264. From an analysis of the dynamical time of the HII region S264, the outflow and the implosion indicate that the star formation in this region is trigged by a radiation-driven implosion. The value of $L_{\rm bol}/M_{\rm BRC}$ is greater than those of the isolated dark clouds and dense cores, and the mass of BRC18 is greater than that of the young star. A comparison of the ratio of bolometric luminosity to the mass of BRC18 and the significant difference between the masses of BRC18 and core show that star formation in BRC18 may be taking place in a sequence.

Acknowledgements We wish to thank all the staff at Delingha, the millimeter-wave radio observatory of Purple Mountain Observatory for their assistance with our observations. This project was supported by G1999075405 of NKBRSF, 10128306 and 10133020 of NSFC.

References

Beichaman C. A., 1983, In: F. P. Israel, ed., Light on dark matter, Dordrecht: Reidel, p.279
Casoli F., Combes F., Dupraz C. et al., 1986, A&A, 169, 281
Churchwell E., 1999, In: C. J. Lada, N. D. Kylafis, eds., ASP Conf. Ser., The Origin of Stars and Planetary Systems., Kluwer Academic: ASP, p.515
Goldsmith P. F., Snell R. L., Hemeon-Heyer M., 1984, ApJ, 286, 599
Hodapp K. W., 1994, ApJS, 94, 615
Jijina J., Myers P. C., Adams F. C., 1999, ApJS, 125, 161
Kutner M. L., Ulich B. L., 1981, ApJ, 250, 341
Lada C. J., Black J. H., 1976, ApJ, 203, L75
Lada C. J., Wilking B. A., 1980, ApJ, 242, 1056
Lada C. J., Thronson H. A., Smith H. A. et al., 1981, ApJ, 251, L91
Lada C. J., 1985, ARA&A, 23, 267
Mao R. Q., Zeng Q., 1997, Publications of Purple Mountain Observatory, 16, 69

Myers P. C., Linke R. A., Benson P. J., 1983, ApJ, 264, 517
Myers P. C., Snell R. L., Goldsmith P. F. et al., 1988, ApJ, 324, 907
Sugitani K., Fukui Y., Mizuno A. et al., 1989, ApJ, 342, L87
Sugitani K., Fukui Y., Ogura K., 1991, ApJS, 77, 59
Sugitani K., Tamura M., Ogura K., 1995, ApJ, 455, L39
Sugitani K., Matsuo H., Nakano M. et al., 2000, ApJ, 119, 323
Wang J.-J., 2002, Chin. J. Astron. Astrophys. (ChJAA), 2, 260
Wu Y., Evans N. J. II., 1989, ApJ, 340, 307
Wu Y., Huang M., He J., 1996, A&AS, 115, 283
Wu Y., Yang C., Li Y., 1999, Science in China, 42, 732