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LETTERS

A New Interpretation of the Bipolar HII Region S106 from HCN $J = 3 - 2$ Mapping Observations *

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Abstract The first mapping observations of the bipolar HII region S106 in HCN $J = 3 - 2$ line were made by KOSMA submillimeter telescope in April, 2004. The results show that there is a bipolar outflow centered on the high-mass star S106 IRS4 and that the flat structure of molecular cloud core is perpendicular to the axis of the outflow. This image roughly corresponds to the optical image where a dark lane bisects the bipolar HII region. Together with the optical, infrared and radio data, we conclude that the central UC HII region and molecular outflow formed before the two lobes of the bipolar HII region, and that a neutral disk is responsible for the bipolar HII region and the outflow.

Key words: ISM: clouds – nebulae: HII region – star: formation – individual: S106

1 INTRODUCTION

Bipolar HII region S106, at a distance of 600 pc (Staude et al. 1982), is powered by an early B or late O star, S106 IRS4, with a few $10^4\,L_\odot$, and an extinction of $A_v \sim 21$ mag (Eiroa et al. 1979; Bally et al. 1998). Many observations at optical, infrared and radio wavelengths (Smith et al. 2001; Bally et al. 1983, 1998; Aspin et al. 1989; Kurtz et al. 1994) suggested: (1) the bipolar lobes are hollow cavities with limb-structure; (2) the strongest optical, infrared and radio emissions come from the limb-brightened edges corresponding to ionization fronts; (3) a dark lane bisects the bipolar lobes and S106 IRS4 is embedded in the dark lane responsible for the bipolar HII region; (4) the lifetime of the expanding UC HII region G76.383–0.621 excited by S106 IRS4 is $10^4 - 10^5$ yr and the dynamical timescale of the bipolar HII region is $10^3 - 10^4$ yr. Bally et al. (1982, 1983) deduced the mass of the lane to be 100 $M_\odot$ from CO observations and suggested a neutral molecular disk with a density $10^6\,\mathrm{cm}^{-3}$ to be responsible for the bipolar

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HII regions. Bieging et al. (1984) identified a molecular disk of 23 $M_\odot$ with a timescale of 10^5 yr from the HCN $J = 1-0$ line. Barsony et al. (1989) argued that the so-called neutral disk originates from the molecular gas which swept up from the ambient cloud core as opposed to a molecular disk.

HCN $J = 3-2$ emission has a high critical density of $\geq 10^6$ cm^{-3} and traces dense molecular clous or their interfaces, which is an ideal tracer of the S106 environment. The dynamics and morphology of S106 is further investigated in this paper. Here, we present the first mapping observations of S106 IRS4 in the HCN $J = 3-2$ line. Based on the dynamical timescale of the bipolar HII region and the lifetime of the central UC HII region embedded in the dark lane as traced by the radio image, as well as data on other wavelengths, we examine the mechansm of star formation in this region.

2 OBSERVATIONS

We made mapping observations in the HCN $J = 3-2$ line of S106 IRS4 ($\alpha(1950) = 20^{\rm h}25^{\rm m}33.8^{\rm s}$, $\delta(1950) = +37°12'50.0''$) using the Köln Observatory for Submillimeter Astronomy (KOSMA)[1] 3m submillimeter telescope at Gornergrat, Switzerland in April 2004 (Kramer et al. 1998; Qin et al. 2004). We used a grid of $1'$. The half-power beamwidth of the telescope at the observing frequency of 226.538 GHz is $120''$. The pointing and tracking accuracy is better than $10''$. A DSB receiver with a noise temperature of 164 K was used. The AOS spectrometer has 1801 channels, with a total bandwidth of 288 MHz and an equivalent velocity resolution of 0.18 km s^{-1}. The beam efficiency at observing frequency is 0.68 and the front spillover efficiency is 0.93. All spectra were observed in beam-switch mode. The data were reduced using the CLASS (Continuum and Line Analysis Single-Disk Software) and GREG (Grenoble Graphic) software.

3 RESULTS AND DISCUSSION

Figure 1 shows the HCN $J = 3-2$ map around S106 IRS4 with $1'$ spacing. The wings are obvious, extending from –8 to –5 km s^{-1} in the blue and from 2 to 5 km s^{-1} in the red (see Fig. 2), which is similar to the CO line wings (Schneider et al. 2002).

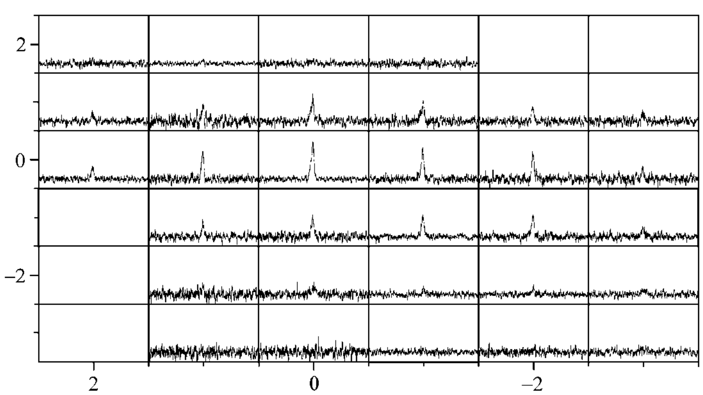

Fig 1 HCN $J = 3-2$ spectra with $1'$ space.

[1] The KOSMA 3m submillimeter telescope is operated by the University of Köln in collaboration with Bonn University.

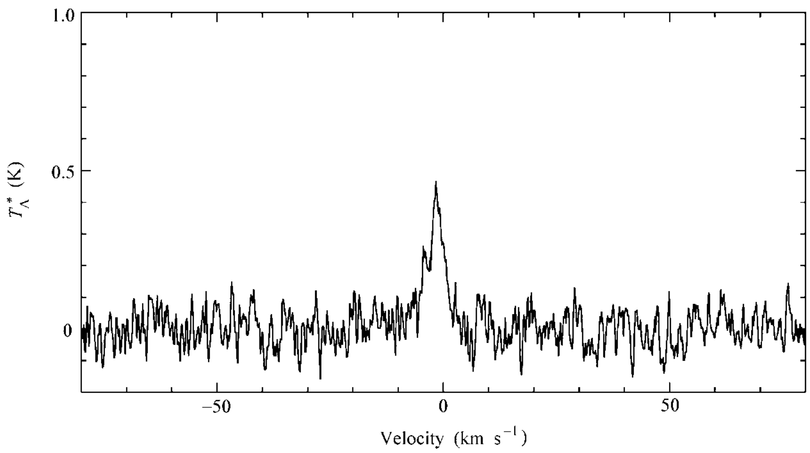

Fig. 2 Spectrum at position (0, –1).

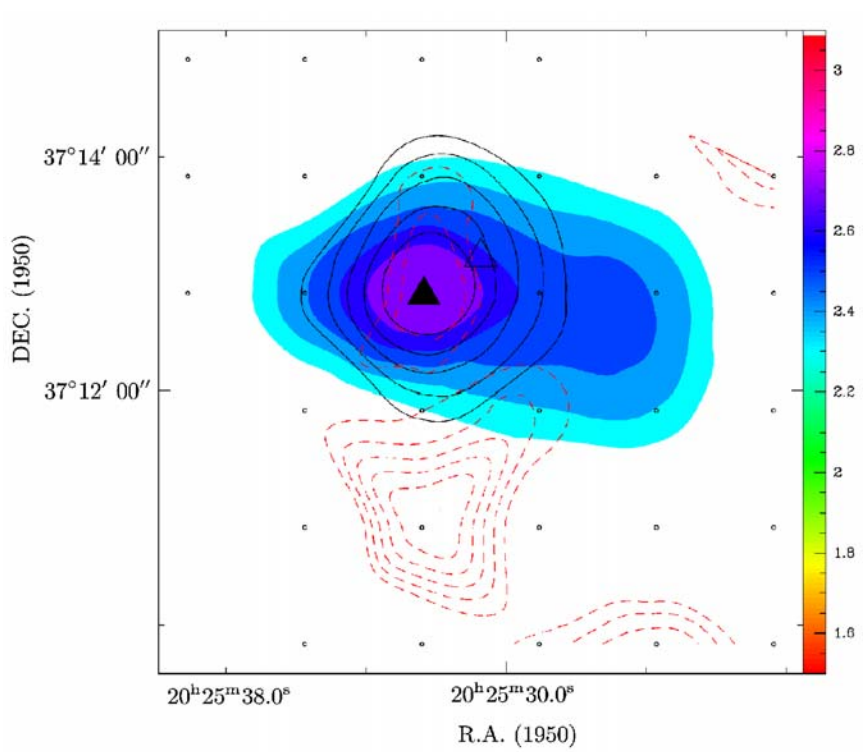

Fig. 3 Outflow and core contours in the HCN $J = 3-2$ line. The blue wing contours (solid line) extend from 0.17 to 0.34 K km s^{-1} with 0.03 K km s^{-1} spacing; the red wing contours (dashed line) extend from 0.066 to 0.13 K km s^{-1} with 0.013 K km s^{-1} spacing. The core contours (grey) extend from 0.9 to 3.0 K km s^{-1} in steps of 0.3 K km s^{-1} (the filled triangle represents S106 IRS4 and the hollow triangle marks S106 IRS2).

We integrate the line wings and core component (from –5 to 2 km s^{-1}), and obtain the contours shown in Fig. 3. The solid and dashed contours represent blue and red lobes of the outflow, and the gray contours indicate molecular cloud core emission. The outflow parameters are estimated, following the method of Garden et al. (1991).

Assuming the HCN emission in the line wings and center to be optically thin, and taking the rotational constant B=44.315976 GHz and permanent dipole moment $\mu = 3$ debye, we find the total column density of HCN is: $N = 1.25 \times 10^{12} \int T_{\rm A}^*/\eta \; dv ({\rm cm}^{-2})$.

If we further assume $X_{\rm HCN} = [{\rm HCN}]/[{\rm H_2}] = 5 \times 10^{-9}$ (Turner et al. 1997) and $T_{\rm ex} = h\nu/K = 12.7$ K, we obtain the outflow parameters as follows: the size R and the characteristic velocity V are 0.26 pc and 2.18 km s^{-1}; the timescale $t_{\rm d} = R/{\rm V}$ is 8.3×10^4 yr and the mass is 6.6 $M_\odot$; the momentum P is 14.4 $M_\odot$ km s^{-1}; the mass loss rate $M_{\rm loss} = P/(t_{\rm d} v_{\rm w})$ is 8.6×10^{-7} $M_\odot$ yr^{-1}, assuming 100 km s^{-1} as the finial wind velocity (Bally et al. 1983). The core radius is 0.3 pc, and mass is 7.5 $M_\odot$.

In Fig.2 we can see that line profile is composed of narrow ($V_{\rm LSR} = -4.3$ km s^{-1}, $\Delta V_{\rm FWHM} = 1.4$ km s^{-1}) and broad ($V_{\rm LSR} = -1.1$ km s^{-1}, $\Delta V_{\rm FWHM}$= 3.8 km s^{-1}) velocity features. According to the HCN observations of some bipolar reflection nebulae by Deguchi et al. (1986) who suggested that the narrow velocity feature indicates a neutral disk around the infrared source and the broad feature indicates outflow motion, we conclude that there is a neutral disk perpendicular to the outflow in this region.

From Fig. 3, the flat molecular cloud core bisects the outflow, and the two lobes that are aligned in opposite direction are in a hollow shell structure. The outflow is perpendicular to the flat core. The morphology of the outflow and the molecular cloud core is roughly consistent with the dark lane and bipolar lobes of optical, infrared, radio images (shell structure) presented by several authors (Smith et al. 2001; Bally et al. 1983, 1998; Aspin et al. 1989). S106 IRS4 is located at the center of the UC HII region G76.383–0.621 associated with 2 cm, 3.6 cm compact radio continuum and identified as excited sources of UC HII regions (Kurtz et al. 1994), that are still deeply embedded in the compact molecular cloud (dark lane). The K-band observation by Hodapp et al. (1991) shows an infrared star cluster with a age of $1 - 2 \times 10^6$ yr centered on S106 IRS 4 that includes 160 stars embedded in the dark lane. They detected eight compact thermal IR sources comprising 106 stars. However, only IRS2 and IRS4 are self-luminous sources (Smith et al. 2001). IRS4 is located at the axes of the HCN outflow while IRS2 departs from the axes. We identify S106 IRS4 as the exciting source of the outflow. The outflow timescale 8.3×10^4 yr is similar to $3 - 5.8 \times 10^4$ yr of the disk shown by Bally et al. (1982, 1998) who acquired the age of the disk by assuming a size of 100 AU, a density of 10^6 cm^{-3} (similar to critical density of HCN), a mass loss rate of 10^{-7} $M_\odot$ yr^{-1} (8.6×10^{-7} $M_\odot$ yr^{-1} in our work), and 10 km s^{-1} for the propagation velocity of ionization-shock fronts. Assuming 10 km s^{-1} for the propagation velocity of ionization-shock fronts, we calculate the dynamical timescale of the bipolar HII regions and find that it is less than 10^4 yr. Thus, there exist two contradictions in the morphology and dynamics of this region: (1) the bipolar HII regions, the hollow infrared and radio shells have a morphology similar to our HCN observations, and they have as common exciting source S106 IRS4; (2) we find it puzzling that the expanding UC HII region G76.383–0.621 and the bipolar HII region S106 have the same origin in S106 IRS4, and the age of the UC HII region G76.383–0.621 is greater than that of the bipolar HII region S106. Combining with the shell structure of the HCN outflow, we propose a straightforward scheme to explain the paradox. First, the high mass star S106 IRS4 forms in the dense molecular cloud core by collapse and accretion and excites the UC HII region G76.383–0.621. Stellar wind from S106 IRS 4 sweeps up the ambient material and forms two dense shells which are constrained to the two streams by a thick accretion disk embedded in the dense molecular cloud core with a timescale of $> 10^4$ yr (Snell et al. 1980). UV photons escaping from the expanding HII region irradiate the outer surfaces of the bipolar shell and form the ionization fronts with a timescale of $< 10^4$ yr that are identified as the bipolar HII region; convergent shock fronts collide at or heat the inner face of the bipolar shells and reradiate in infrared wavelengths; infrared shells coming from the hot dust shells of the bipolar outflow was confirmed by Smith et al. (2001) with their obtaining a constant color temperature 135 ± 10 K inside the shell. According to the disk photo evaporation model of Hollenbach et al. (1994), when the expanding UC HII regions irradiate UV photons, the dense ionized gas around S106 IRS4 is replenished by the material photo-evarated from the neutral disk. In this way, we can detect the UC HII region G76.383–0.621.

4 CONCLUSIONS

Our HCN mapping observations show that a flat molecular core bisects the bipolar outflow. S106 IRS4 is the exciting source of the outflow. The morphology of the outflow roughly corresponds to those of the optical, infrared and radio wavelengths. The high mass star S106 IRS4 deeply embedded in dense dark lane first produces the molecular outflow, the neutral disk and the UCHII region G76.383–0.621. UV photons escaped from the central star irradiate the outer surface of the dense shell of the molecular outflow and produce the ionization fronts shown as a bipolar HII region. Infrared shells arise from the hot bipolar dust shells by the heat of convergent shock fronts.

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References

Aspin C., Mclean L. S., Schwarz H. E. et al., 1989, A&A, 221, 100
Bally J., Scoville N. Z., 1982, ApJ, 255, 497
Bally J., Snell R. L., Predmore R., 1983, ApJ, 272, 154
Bally J., Yu K. C., Rayner J. et al., 1998, AJ, 116, 1868
Barson M., Scoville N. Z., Bally J. et al., 1989, ApJ, 342, 212
Bieging J. H., 1984, ApJ, 286, 591
Deguchi S., Claussen M. J., Goldsmith P. F., 1986, ApJ, 303, 810
Eiroa C., Elsasser H., Lahulla J. F., 1979, A&A, 74, 89
Felli M., Staude H. J., Reddmann T. et al., 1984, A&A, 135, 261
Garden R. P., Hayashi M., Gatley I. et al., 1991, ApJ, 374, 540
Hodapp K. W., Rayner J., 1991, AJ, 102, 1108
Hollenbach D., Johnstone D., Lizano S. et al., 1994, ApJ, 428, 654
Kramer C., Degiacomi C., Graf U. U. et al., 1998, SPIE, Kona/Hawaii
Kurtz S., Churchwell E., Wood D. O. S., 1994, ApJS, 91, 659
Qin Sheng-Li, Wu Yue-Fang, Wang Jun-Jie et al., 2004, Chin. Phys. Lett., 21(8), 1677
Schneider N., Simon R., Kramer C. et al., 2002, A&A, 384, 225
Smith N., Jones T. J., Gehrz R. D. et al., 2001, ApJ, 121, 984
Snell R. L., Loren R. B., Plambeck R., 1980, ApJ, 239, L17
Staude H. J., Lenzen R., Dyck H. M. et al., 1982, ApJ, 255, 95
Turner B. E., Pirogov L., Minh Y. C., 1997, ApJ, 483, 235