Aperture Synthesis Observations of NH_3 and CS in Orion-KL

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ABSTRACT. We have made aperture synthesis maps of Orion-KL in NH_3(1,1),(2,2) and CS(J=1-0) emissions using the Nobeyama Millimeter Array. Both NH_3 and CS maps show new detailed structures that have not been recognized before. Two NH_3 filaments in the size of $\sim$0.45 pc $\times$0.04 pc are found extending to the northwest direction of Orion-KL. These filaments are associated with the HH objects and the finger-like H_2 emissions; they are probably formed through the interaction with high velocity, highly channeled winds from the KL region. The CS maps show, on the other hand, shell structures around IRc2 as well as the well-known rotating disk. These shells coincide with the two lobes of the shock-excited H_2 emission, being interpreted as the shock-compressed shells of ambient molecular gas interacting with the outflow from IRc2.

1. Introduction

Orion-KL is often taken to be a prototype of massive star-forming regions. There are at least three self-luminous sources in the region. IRc2 (L $\sim 10^5$ $L_\odot$), one of the three, is confirmed to be a source of essentially all the luminosity in this region (Downes *et al.* 1981; Wynn-Williams *et al.* 1984).

A massive molecular disk and a bipolar molecular outflow have been found around IRc2. The disk is elongated to the NE-SW direction and is rotating differentially (Plambeck *et al.*1982; Hasegawa *et al.* 1984; Vogel *et al.* 1985). The bipolar molecular outflow has been recognized by high resolution observations. Its axis is parallel to the rotating axis of the disk on the sky (Genzel *et al.* 1981; Erickson *et al.* 1982; Wright *et al.* 1983; Masson *et al.* 1987). The outflow is confined in a small area in spite of its high velocity reaching $\sim$100 km s^{-1}; its dynamical timescale is 10^3 years. This timescale is one or two orders of magnitude less than those of the other outflows (Bally and Lada 1983). Orion-KL deserves detailed studies in order to understand the evolution of molecular outflows and their interaction with ambient material in the early stage of star formation. Here we present higher resolution interferometric maps of NH_3 and CS (J=1-0) around Orion-KL. The high resolution maps show the new structures such as interacting shells around the bipolar outflow and filamentary structures extending out from the KL region as well as the rotating disk along the OMC-1 ridge.

2. Observations

The NH_3 (1,1),(2,2) and CS (J=1-0) lines were observed with the Nobeyama Millimeter Array (NMA; Ishiguro *et al.* 1984). The obtained spatial resolutions for our

NH_3 and CS maps are 16″ and 9″, respectively. The parameters of the observations are summarized in the table below. We used Orion-KL as the phase center for the observation (*R.A.*(1950)= $5^h32^m47^s$, *decl.*(1950)= −5°24′22″). The data reductions have been carried out using the AIPS package installed in FACOM M380 and VP50 at Nobeyama Radio Observatory. No primary beam corrections were made for the maps.

TABLE: OBSERVATIONAL PARAMETERS.

Transitions	NH_3(1,1),(2,2)	CS (J=1-0)
Frequency (GHz)	23.694 and 23.722	48.991
Date	Dec, 1986 ~May, 1987	March ~June, 1988
Mapping Area	$5' \times 6'$	$2' \times 2'$
Frontends	Cooled HEMT Receiver*	SIS Receiver**
T_{sys}(SSB)	200 K	300 K
Backends	Digital spectro-correlator*** (1024 ch., B = 80 MHz)	
Spatial resolution	16″	9″
Velocity resolution	1.0 km s^{-1}	0.5 km s^{-1}
Velocity coverage	1000 km s^{-1}	500 km s^{-1}
Bandpass calibrator	3C84	
Visibility calibrator	0528+134 (S = 2.0 Jy)	0605−085 (S = 3.2 Jy)
Field of view	300″	150″

*Kasuga *et al.* 1986, **Kawabe *et al.* 1989, ***FX; Chikada *et al.* 1987

3. Results and discussion

3.1 NH_3 filaments

Figure 1*a* and 1*b* show the spatial distributions of the NH_3 (1,1) emission in the LSR velocity ranges of 6.9 ~8.9 and 8.9 ~10.9 km s^{-1}, respectively. Three main features are prominent in Figure 1: (*1*) a strong compact source at the center, corresponding to the "hot core", (*2*) the OMC-1 ridge extending to the north at V_{LSR}= 9.9 km s^{-1} (Figure 1*b*) and to the south at V_{LSR}= 7.9 km s^{-1} (Figure 1*a*), and (*3*) two clumpy filaments extending toward the north at 7.9 km s^{-1} (Figure 1*a*), which are newly found in our observations. The length and width of the filaments are 0.45 pc and less than 0.04 pc, respectively. If we assume that the NH_3 clouds are optically thin, the NH_3(1,1-2,2) rotational temperature is 20 ~30 K and the total mass of the filaments is about 10 $M_\odot$, when the fractional abundance of NH_3 is $\sim 10^{-8}$.

These filamentary structures are seen in other observations. The west-side filament (W-filament) also appeared in the NH_3(1,1) map in Batrla *et al.* (1983). The southern part of the east-side filament (E-filament) can be identified in the high resolution CS map (Mundy *et al.* 1988) and was pointed out as the HCO^+ ridge (Olofsson *et al.* 1982).

HH objects and finger-like H_2 emissions (H_2 fingers) have been observed along these filaments as shown in Figure 2 (Axon and Taylor 1984; Taylor *et al.* 1984). The HH objects are located on the NH_3 filaments: HH9 and HH1 are at their southern edges. The H_2 fingers seem to extend from the southern edge of the E-filament. From these positional coincidences, the HH objects and the H_2 fingers may be physically associated with the NH_3 filaments. Similar case of high velocity HH objects associated with low velocity cloudlets has been observed in the HH7-11 region (Rudolph and Welch 1988). These observational results are consistent with the idea that the filamentary NH_3 cloudlets are condensed through the interaction of the high velocity winds with the ambient gas, and that the strong shocks causing the HH objects are created at the

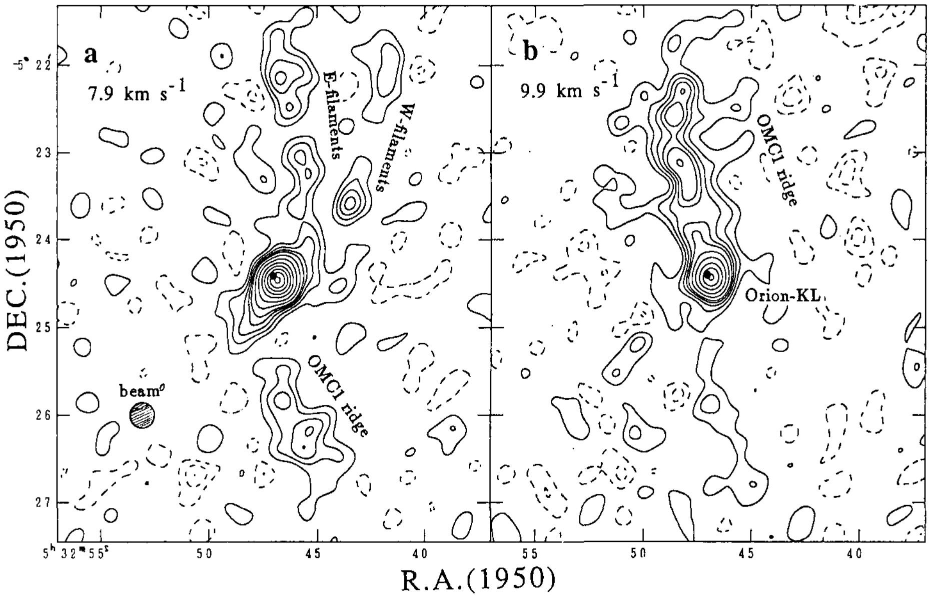

FIGURE 1—a. NH_3 (1,1) map with the V_{LSR}= 6.9 ~8.9 km s^{-1}. The central velocity are shown at the top-left corner. Filled-circle shows the position of IRc2. —b. NH_3 (1,1) map with the V_{LSR}= 8.9 ~10.9 km s^{-1}.

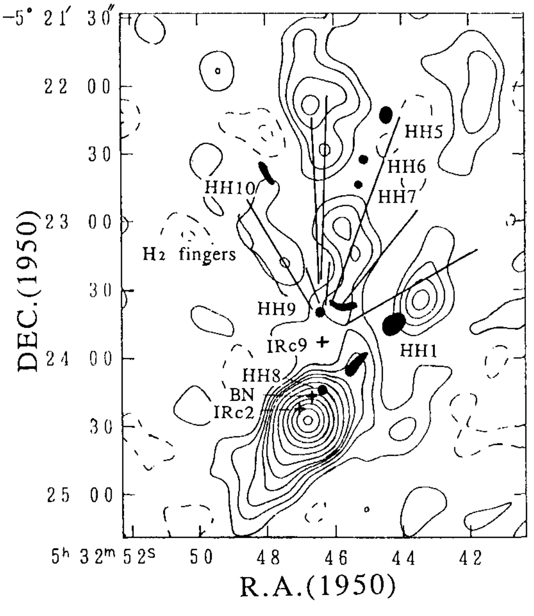

FIGURE 2—NH_3 (1,1) filaments with the HH objects (Axon and Taylor 1984) and H_2 fingers (Taylor *et al.* 1984).

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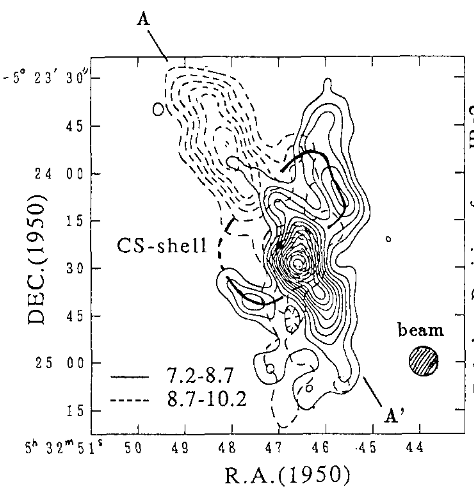
front surfaces of these cloudlets. The tangential velocities of the winds are estimated to be about 200 km s^{-1} from the measurement of proper motions of the HH objects (Jones and Walker 1985), which gives the dynamical timescale of $\sim 10^3$ years consistent with the timescale of the molecular outflow from IRc2. This suggests that the wind originates from the Orion-KL region as is discussed below.

3.2 CS disk

Figure 3 shows the spatial distributions of CS (J=1-0) emission in the LSR velocity ranges of 7.2 $\sim$8.7 and 8.7 $\sim$10.2 km s^{-1}, respectively. Three main features are seen in the CS maps: (*1*) a strong peak located at the south of IRc2, which correspond to the "hot core" showing broad line emissions, (*2*) the CS disk, seen as a ridge structures from SW to NE with P.A. = 30°, and (*3*) the CS shells shown by the thick lines in Figure 3, which has been newly found in our observations.

A thin edge-on disk structure appears in our maps. The thickness and diameter of the disk are 0.03 pc and 0.3 pc, respectively. A position-velocity map of the disk is shown in Figure 4 along the line A – A' in Figure 3. This map shows two features of the disk. One is the broad line (ΔV $\sim$10 km s^{-1}), hot core component at 10″ south of IRc2. This component is considered to be an active part of the inner edge of the disk. The other is the main body of the disk which extends to the north at V_{LSR}= 10 km s^{-1} and to the south at V_{LSR}= 8 km s^{-1}. The rotational velocity at the emission peak (r $\sim$0.07 pc) is $\sim$ 1 km s^{-1}, implying the rotation period of 5 $\times 10^5$ years. The higher contours in Figure 4 indicate that the rotation is not a simple rigid motion, but rather a differential rotation as has been suggested by Vogel *et al.* (1985).



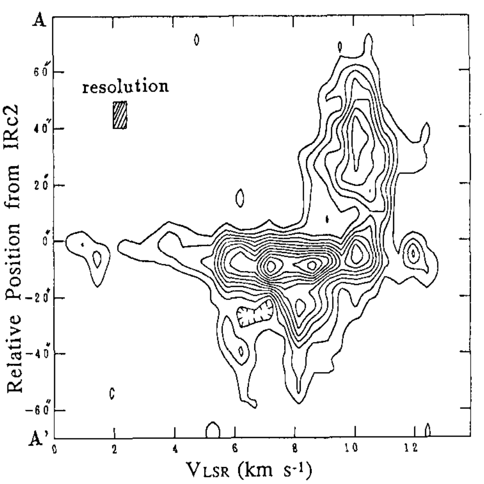


FIGURE 3(*top-left*)— CS (1-0) map with the V_{LSR}= 7.2 $\sim$8.7 km s^{-1}(*thin solid lines*) and with V_{LSR}= 8.7 $\sim$10.2 km s^{-1}(*broken lines*). Thick solid lines show the CS shell structures. Filled-circle shows the position of IRc2.

FIGURE 4(*top-right*)— Position-velocity map along the line A – A' in Figure 3. The spatial and velocity resolutions are shown at the top-left corner.

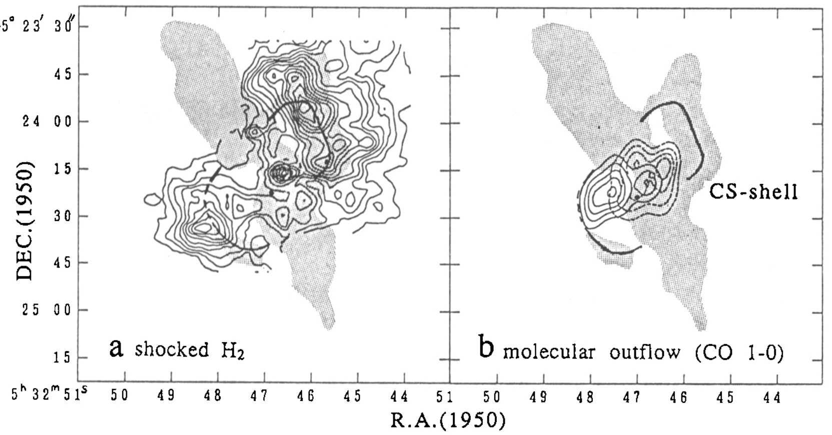


FIGURE 5—**a.** The shocked H_2 emissions (Hasegawa *et al.*1989) and **b.** the high velocity molecular outflow (Masson *et al.*1987) superposed on the CS emission presented in Figure 3. The CS shells are shown with solid lines.

3.3 CS shells

The shell structures are seen in Figure 3 as faint extensions from the disk component, with IRc2 being located at their center. They are elongated perpendicular to the disk with the size of 0.08 pc $\times$0.13 pc. The thickness of the shell have not been resolved yet by our 9″ beam and is less than 0.02 pc. Figure 5*a* and 5*b* shows the comparison of these shell structures with the shock excited H_2 emission (Beckwith *et al.* 1978; Hasegawa *et al.* 1989) and with the high velocity molecular outflow (Erickson *et al.* 1982; Wright *et al.* 1983; Masson *et al.* 1988). There is a good positional coincidence between the CS shells and the two lobes of the shocked H_2 emission. The H_2 emission is weak at the center where the massive disk is located. The molecular outflow is confined inside the shell structures. These results support the hydrodynamical models of molecular outflows that high velocity winds accelerate neutral gas which in turn sweeps up the ambient material to form a shock-compressed shell (Königl 1982, Okuda and Ikeuchi 1986). It seems that the NH_3 filaments are located on the extension of the blue-shifted lobe of the molecular outflow. We can suppose that the high velocity winds expand out through the CS shell toward the directions along which the NH_3 filaments and the HH objects are formed, as discussed before. Although the density of the shocked CS shell cannot be inferred only from our data, detection of the CS emission from the shell implies the gas density higher than 10^4 cm^{-3}, which gives the mass of the shell of $\sim$0.1 $M_\odot$, if we assume the thickness of the shell is 0.02 pc.

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Discussion:

DYSON (Comment): Your model is similar to the one we (Axon, Dyson, Tylor & Hughes) proposed for the Orion HH objects based on their optical spectroscopy. We also invoked channels in the neutral cloud to direct stellar wind onto denser blobs.

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