INFEAL AND OUTFLOW DETECTIONS IN A MASSIVE CORE JCMT 18354–0649S

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ABSTRACT

We present a high-resolution study of a massive dense core JCMT 18354–0649S with the Submillimeter Array. The core is mapped with continuum emission at 1.3 mm and molecular lines including CH3OH (523–413) and HCN (3–2). The dust core detected in the compact configuration has a mass of 47 $M_\odot$ and a diameter of 2″ (0.06 pc), which is further resolved into three condensations with a total mass of 42 $M_\odot$ under higher spatial resolution. The HCN (3–2) line exhibits an asymmetric profile consistent with infall signature. The infall rate is estimated to be $2.0 \times 10^{-3} \ M_\odot \ yr^{-1}$. The high-velocity HCN (3–2) line wings present an outflow with three lobes. Their total mass is 12 $M_\odot$ and the total momentum is 121 $M_\odot$ km s$^{-1}$. Analysis shows that the N-bearing molecules especially HCN can trace both inflow and outflow.

Key words: ISM: jets and outflows – ISM: kinematics and dynamics – ISM: molecules – stars: formation – stars: massive – stars: protostars

1. INTRODUCTION

Studies of high-mass star formation have received much attention during recent years. One of the main questions is whether massive stars form through an accretion-disk-outflow process, similar to low-mass counterparts (Shu et al. 1987), or via collision–coalescence (Wolff & Cassinelli 1987; Bonnell et al. 1998). Studying the characteristics of massive cores at the early stages is critical for understanding their formation process.

High-mass protostellar objects (HMPOs) are precursors of UC HII regions, and represent an essential phase in high-mass star formation (Churchwell 2002). HMPOs often have strong dust emission and high bolometric luminosity. But their radio emission is weak or non-detectable at a level of approximately 1 mJy (Molinari et al. 1996, 2000; Sridharan et al. 2002; Beuther et al. 2002; Wu et al. 2006). Their natal clouds have not been significantly affected by the star-forming process. Thus, they present the information about the early kinematic processes of high-mass star formation.

The dense core JCMT 18354–0649S was first detected in an ammonia survey of high-mass star-forming regions with the Max-Planck-Institut für Radioastronomie (MPIfR) 100 m telescope at Effelsberg (Wu et al. 2006), and was later confirmed by the observation with the Submillimeter Common-User Bolometric Array (SCUBA) of the James Clerk Maxwell telescope (JCMT; Wu et al. 2005). Another SCUBA core which harbors a UC HII region, G35.4 NW, is located about 1° north of JCMT 18354–0649S. The kinetic distance of the two SCUBA cores is 5.7 or 9.6 kpc (Wu et al. 2005), and 5.7 kpc was adopted in this paper. Core JCMT 18354–0649S has no counterpart in the radio continuum. Multiple lines toward this core including HCN (3–2), H13CO+ (3–2), and C17O (2–1) reveal the typical “blue profile” (Wu et al. 2005), indicating that the core is undergoing gravitational collapse (Keto et al. 1988; Zhou et al. 1993; Zhang et al. 1998; Wu & Evans 2003; Wu et al. 2005, 2007; Fuller et al. 2005; Wyrowski 2006; Birkmann et al. 2007; Klaassen & Wilson 2007; Sun & Gao 2008; Velusamy et al. 2008). The core is also associated with a near-infrared (near-IR) point source, corresponding to a star of 6–11 $M_\odot$ (Zhu et al. 2011). Carolan et al. (2009) observed 16 different molecular line transitions including CO, HCN, HCO+ and their isotopes in this region, and modeled the source with a chemically depleted rotating envelope collapsing onto a central protostellar source which has evolved sufficiently to generate a molecular outflow. All the evidence suggests that JCMT 18354–0649S is forming HMPO(s). However, single-dish observations with a resolution of 15″~40″ cannot reveal detailed kinematics in the core at a distance as large as 5.7 kpc. In this paper, we report the results of a high-resolution study with the Submillimeter Array (SMA) in order to probe the details of the core and its kinematic features. The observation and initial results are presented in Sections 2 and 3. Properties of inflow and outflow motions are discussed further in Section 4, and a brief summary is given in Section 5.

2. OBSERVATIONS

The observations of JCMT 18354–0649S were carried out with the SMA in 2005 July with seven antennas in its compact configuration and in 2005 September with six antennas in its extended configuration. The 345 GHz receivers were tuned to 265 GHz for the lower sideband (LSB) and 275 GHz for the upper sideband (USB). The frequency spacing across the spectral band is 0.8125 MHz or ~ 1 km s$^{-1}$ for both configurations. The phase reference center of both observations was R.A.(J2000) = 18h38m08s10 and decl. (J2000) = +38°30′08″10 and decl. (J2000) = −6°46′52″17.

In the observations with the compact configuration, Jupiter, Uranus, and QSO 3c454.3 were observed for antenna-based bandpass correction. An amplitude offset was found on some baselines and the baseline-based errors in bandpass were further corrected using the point source QSO 3c454.3. QSOs 1741–038 and 1908–201 were employed for antenna-based gain correction. Uranus was observed for flux-density calibration. The synthesized beam size is 3.76 × 2.72 (P.A. = −54°).
Figure 1. 1.3 mm continuum emission toward JCMT 18354−0649S. The left one is obtained with the compact configuration. The rms level is 3 mJy beam$^{-1}$ (1σ). The contours are at −6σ, 3σ, 6σ, 12σ, 21σ, 33σ, 48σ, 66σ, and 87σ. The right panel gives the contours of the continuum emission combined from both configurations. The rms level is 2.5 mJy beam$^{-1}$ (1σ) and the contours are at −6σ, 3σ, 6σ, 12σ, 21σ, 33σ, and 48σ. The three near-IR sources are marked with crosses.

For the extended configuration, QSO 3c454.3 was used as a bandpass calibrator, QSOs 1741−038 and 1908−201 were used as gain calibrators, and Uranus was used as a flux calibrator. The total dust and gas mass can be obtained with the formula $M = B_s D^2/κ ν B_ν$, where $B_s$ is the flux at 1.3 mm, $D$ is the distance, and $B_ν(T_d)$ is the Planck function. We adopt a dust opacity index $κ_{130} = 1.4 \times 10^{-2}$ cm$^2$ g$^{-1}$ at 1.3 mm calculated from Ossenkopf & Henning (1994) with a dust opacity index $β = 2$. Here, the ratio of gas to dust is taken as 100. The molecular line CH$_3$OH (523−413) is detected, and its emission peak coincides with the dust core very well (see Section 3.2). The upper energy band (CH$_3$OH bands, respectively. Their positions are marked with crosses in Figure 1. IRS1a (18$^h$38$^m$08$^s$135, $−6'6'46'51'57$) lies about 1'6 northeast of MM1. IRS1b (18$^h$38$^m$08$^s$026, $−6'6'46'56'24$) and IRS1c (18$^h$38$^m$07$^s$929, $−6'6'46'55'34$) are about 3' southwest from MM1 and are much fainter.

3. RESULTS

3.1. Dust Core

The 1.3 mm continuum images are shown in Figure 1. The left panel is obtained in the compact array and the right panel from the combined data of the compact and extended configurations. An elongated core is revealed with the 1.3 mm continuum emission observed with the compact array, and is further resolved into three condensations by the continuum emission using the combined data from both configurations. The three condensations are named as MM1, MM2, and MM3. The peak position of MM1 is R.A.(J2000) = 18$^h$38$^m$08$^s$1, decl.(J2000) = −6$'6'46'52'98$, MM2 peaks at R.A.(J2000) = 18$^h$38$^m$07$^s$9, decl.(J2000) = −6$'6'46'51'36$, and MM3 peaks at R.A.(J2000) = 18$^h$38$^m$08$^s$05, decl.(J2000) = −6$'6'46'51'36$. From the fit of an elliptical Gaussian, the core revealed by the compact array is found to be elongated from southeast to northwest. It has an average FWHM diameter of 0.06 pc (~2") at a distance of 5.7 kpc, smaller than the beam size of the compact configuration. The total integrated flux is 0.47 Jy. The total dust and gas mass can be obtained with the formula $M = B_s D^2/κ ν B_ν$. $κ_{130} = 1.4 \times 10^{-2}$ cm$^2$ g$^{-1}$ at 1.3 mm calculated from Ossenkopf & Henning (1994) with a dust opacity index $β = 2$. Here, the ratio of gas to dust is taken as 100. The molecular line CH$_3$OH (523−413) is detected, and its emission peak coincides with the dust core very well (see Section 3.2). The upper energy level of the CH$_3$OH (523−413) line is 57 K above the ground, indicating relatively warm conditions. Assuming $T_d = 57$ K, a total dust and gas mass of 47 $M_⊙$ is derived. A beam-average gas/dust density amounts to $2.0 \times 10^6$ cm$^{-3}$, which is larger than the 1.1 $× 10^6$ cm$^{-3}$ obtained from a single-dish telescope (Wu et al. 2005).

The three condensations (MM1, MM2, and MM3) have the total integrated flux of 0.42 Jy, leading to a total mass of 42 $M_⊙$ (assuming $T_d = 57$ K as above). MM1 has a diameter of 0.02 pc and a mass of 30 $M_⊙$. MM1 is centrally concentrated and compact, while MM2 and MM3 are much more diffuse and extended.

With UKIRT (United Kingdom Infrared Telescope), Zhu et al. (2011) detected three near-IR sources IRS1a, IRS1b, and IRS1c in H, K, and L bands, respectively. Their positions are marked with crosses in Figure 1. IRS1a (18$^h$38$^m$08$^s$135, $−6'6'46'51'57$) lies about 1'6 northeast of MM1. IRS1b (18$^h$38$^m$08$^s$026, $−6'6'46'56'24$) and IRS1c (18$^h$38$^m$07$^s$929, $−6'6'46'55'34$) are about 3' southwest from MM1 and are much fainter.

3.2. Gas Core

The molecular line CH$_3$OH (523−413) is detected in the compact configuration. Figure 2 presents its spectrum at three positions and the integrated emission overlaid on the 1.3 mm continuum image. The central velocity of the CH$_3$OH (523−413)
The central velocity of CH$_3$OH (5$_{23}$–4$_{13}$) (R.A.(J2000) = 18h38m08s092, decl.(J2000) = $-6^\circ46'55''.318$) coincides with MM1 very well, while there are no CH$_3$OH components corresponding to MM2 and MM3. The deconvolved size of the gas core revealed by CH$_3$OH (5$_{23}$–4$_{13}$) is 3".78 $\times$ 2".76 (P.A. = $-29^\circ$), comparable to the synthesized beam size of the compact array.

The HCN (3–2) (265.886 GHz) spectra obtained from the SMA compact configuration and from the data combined from both compact and extended configurations are presented in the left panel of Figure 4. Both of the two spectra are averaged over a region of 5" $\times$ 5", which shows a redshifted absorption dip and broad wings. The line profiles observed with the SMA and JCMT, as well as a combination of the two, are presented in the right panel of Figure 4. All the spectra in the right panel of Figure 4 are convolved with the JCMT beam (18''.3) for comparison. One can see that the SMA compact array observations recover less than 10% of the JCMT flux around the systematic velocity, but recover more than 30% flux at the wings. The combination of the SMA and JCMT data recovers more than 70% of the JCMT flux at all the velocity channels.

3.3. Kinematic Signatures of Lines

3.3.1. Infall Motion

The left panel of Figure 4 shows the most prominent feature (blue profile) of the HCN (3–2) line at the core. The absorption gap is more than 8 km s$^{-1}$ wide, ranging from 93 to 101 km s$^{-1}$. Figure 5 presents the channel maps of the HCN (3–2) emission from 80 to 109 km s$^{-1}$ constructed from the combined data, which is convolved with the beam of the SMA compact configuration. The absorption is obvious in the velocity range (95, 99) km s$^{-1}$. The absorption dip is also clearly seen in the $P$–$V$ diagrams (see Figure 6), which is much deeper than that revealed by the single-dish observation (Wu et al. 2005).

From the left panel of Figure 4, it is clearly seen that the central velocity of the absorption dip (98 km s$^{-1}$) is redshifted
Figure 4. HCN (3–2) spectra. Left: the solid black line exhibits the spectrum constructed from the SMA compact array and the dashed line shows the spectrum obtained from combining the compact and extended data together. Both of the two spectra are integrated over a region of 5′ × 5′. Right: the solid black line shows the spectrum constructed from the combined SMA and JCMT data, which is convolved with the JCMT beam (18.3″); the dashed line shows the spectrum from JCMT only; the dash-dotted gray line shows the spectrum obtained with the SMA compact array and convolved with the JCMT beam. The vertical dashed lines in both panels mark the position of the systematic velocity (96.7 km s$^{-1}$).

Figure 5. Combined JCMT and SMA HCN (3–2) channel maps from 80 to 109 km s$^{-1}$, which is convolved with the beam of the SMA compact configuration (3.′76 × 2.72, P.A. = -54°). The contours are in steps of 0.5 Jy beam$^{-1}$ (3σ) from 0.5 Jy beam$^{-1}$ (3σ). The velocity of each channel is plotted in the upper left of each panel, and the beam size in the lower right. The positions of MM1, MM2, and MM3 are marked with crosses.

from the systematic velocity (96.7 km s$^{-1}$) by 1.3 km s$^{-1}$. Such a blue asymmetric line profile where the blue emission peak is at a higher intensity than the red one is a collapse signature of molecular cores (Zhou et al. 1993). The spectra constructed from JCMT data and the combined data (the right panel of Figure 4) also show significant “blue profile,” confirming the existence of infall motions.

3.3.2. Molecular Outflow

Besides the absorption dip, the HCN (3–2) line exhibits remarkable broad wings extending more than 40 km s$^{-1}$. A high-velocity gas can also be easily identified in $P-V$ diagrams of the HCN (3–2) emission along the direction of P.A. = 15° and P.A. = 90° as shown in Figure 6. The HCN (3–2) emission obtained from the SMA compact configuration is integrated from 80 to 87 km s$^{-1}$ for the blue lobe and from 103 to 109 km s$^{-1}$ for the red lobe, respectively. The contour map of the integrated flux is shown in Figure 7. As in the channel maps (Figure 5), we can see several clumps in each lobe in the integrated map. The integrated HCN (3–2) emission seems to comprise an S-shaped structure from northeast to south. Another jet-like structure extended more than 10″ is also seen at the west
and 7.16 Jy beam$^{-1}$ difficult to confine due to the contamination of the outflow. than the compact configuration beam, the infall region is still
except that the driving source through Clump 2 is close to IRS1b
direction of the outflow and likely to be outward gas knots.

3" and "Clump 4." These clumps are distributed along the
lobe (NE-lobe), two clumps are also found and named "Clump
1c" and "Clump 1." IR S1a seems to be the driving
emission. The peak is 8.55 Jy beam$^{-1}$ (dashed contours), with contours from 30% in steps of 10% of the peak
emission and 1.3 mm continuum emission combined from both configurations,
ellipses in the lower right corner represent the synthesized beams of HCN (3–2)
lobes (solid contours) and from 103 to 109 km s$^{-1}$ in both panels. The peak is 1.84 Jy beam$^{-1}$ in the left panel and
1.92 Jy beam$^{-1}$ in the right panel. The four clumps are labeled by solid lines with arrows. The clumps are distinguish by the thick dashed lines.
The southern redshifted lobe (S-lobe) comprises two clumps
named “Clump 1” and “Clump 2.” In the northeast blueshifted lobe (NE-lobe), two clumps are also found and named “Clump 3” and “Clump 4.” These clumps are distributed along the direction of the outflow and likely to be outward gas knots. They are probably not physically related to other stellar sources except that the driving source through Clump 2 is close to IRS1b and IRS1c.

4. DISCUSSION
4.1. Infall Motion

Although the HCN emission is extended over a region larger than the compact configuration beam, the infall region is still difficult to confine due to the contamination of the outflow. Since the size of the gas core traced by CH$_3$OH (5$_{21}$−4$_{13}$) is comparable to the compact configuration beam size, the beam size of the compact configuration was taken as the radius ($R_m$) of the infall region (Wu et al. 2009). The kinematic mass infall rate can be calculated using $dM/dt = 4\pi n\mu c_R H_{2} R_{m}^{2} V_{in}$, where $V_{in}$, $\mu$, and $n$ are the mean molecular weight, the H$_2$ mass, and the beam-average gas/dust density, respectively. The infall velocity $V_{in}$ is 1.3 km s$^{-1}$ by comparing the systemic velocity (96.7 km s$^{-1}$) and the velocity of the redshifted absorbing dip (98 km s$^{-1}$) in the HCN (3–2) spectrum (Welch et al. 1987), leading to a kinematic mass infall rate of $2.0 \times 10^{-3} M_\odot$ yr$^{-1}$. In core G10.6–0.4, the redshifted NH$_3$ indicates a large infall velocity 5.0 $\pm$ 1.7 km s$^{-1}$ at about 0.05 pc, and a mass infall rate as high as $5 \times 10^{-3} M_\odot$ yr$^{-1}$ (Keto et al. 1987). Also, with NH$_3$ inverse lines, Zhang & Ho (1997) obtained an high infall velocity $\sim$3.5 km s$^{-1}$ within a region smaller than 0.02 pc toward core W51e2. Large infall velocities ($> 1.5$ km s$^{-1}$) and mass infall rates ($> 1 \times 10^{-3} M_\odot$ yr$^{-1}$) were also detected toward G10.47 and G34.26 with the HCO$^+$ (4–3) line (Klaassen & Wilson 2007). In core G19.61+0.23, an infall velocity of 2.5 km s$^{-1}$ and a mass infall rate as high as $6.1 \times 10^{-3} M_\odot$ yr$^{-1}$ were derived (Wu et al. 2009). It seems that a high-mass infall rate is required by high-mass star formation. The results of the core JCMT 18354–0649S are comparable with those of the above sources. For comparison, the $V_{in}$ from pure free-infall assumption is also derived by the formula $V_{in}^2 = 2G M/R_m$. The pure free-infall velocity inferred is 2.9 km s$^{-1}$, which is larger than the infall velocity obtained from the spectrum.

Wu et al. (2005) obtained a small infall velocity ($\sim 0.3$ km s$^{-1}$) at a radius of 4$''$. The absorption dip of the HCN (3–2) line seen by the SMA is much deeper and broader than that observed by JCMT. However, the kinematic mass infall rate $M_{in} (2.0 \times 10^{-3} M_\odot$ yr$^{-1}$) obtained here coincides well with that obtained with JCMT (Wu et al. 2005), $3.4 \times 10^{-3} M_\odot$ yr$^{-1}$. 4.2. Properties of the HCN (3–2) Outflow

The column density of HCN at each velocity channel in each outflow lobe can be obtained through (Garden et al. 1991)

$$N_{HCN}(v) = \frac{3k}{8\pi^3 B_{\mu^2}} \frac{\exp[hB(J + 1)/kT_{ex}]}{(J + 1)} \times \frac{T_{ex} + hB/3k}{1 - \exp(-h\nu/kT_{ex})} \int \tau_v dv,$$

Figure 6. $P$–$V$ diagrams of HCN (3–2) outflow observed by the SMA along a P.A. of 15$^\circ$ (left panel) and 90$^\circ$ (right panel). The image is smoothed to 2 km s$^{-1}$ velocity resolution. The contour levels are from 15% to 90% in steps of 15% of the peak intensity in both panels. The peak is 1.84 Jy beam$^{-1}$ in the left panel and 1.92 Jy beam$^{-1}$ in the right panel. The four clumps are labeled by solid lines with arrows. The clumps are distinguish by the thick dashed lines.

Figure 7. High-velocity HCN (3–2) intensity contours overlaid on the 1.3 mm continuum image, integrated from 80 to 87 km s$^{-1}$ for the blueshifted lobes (solid contours) and from 103 to 109 km s$^{-1}$ for the redshifted lobe (dashed contours), with contours from 30% in steps of 10% of the peak emission. The peak is 8.55 Jy beam$^{-1}$ km s$^{-1}$ for the blueshifted lobes and 7.16 Jy beam$^{-1}$ km s$^{-1}$ for the redshifted lobe. The empty and solid ellipses in the lower right corner represent the synthesized beams of HCN (3–2) emission and 1.3 mm continuum emission combined from both configurations, respectively. (A color version of this figure is available in the online journal.)

of the continuum emission center. IRS1a seems to be the driving source of the outflow.

4. DISCUSSION
4.1. Infall Motion

Although the HCN emission is extended over a region larger than the compact configuration beam, the infall region is still difficult to confine due to the contamination of the outflow,
where $v$ is the central velocity of the channel relative to the systemic velocity, the rotational constant $B = 44.315976$ GHz, and permanent dipole moment $\mu = 3$ D for HCN; the velocity channel width is smoothed to be 1 km s$^{-1}$. Assuming HCN emission in the line wings to be optically thin and the excitation temperature of $T_{\text{ex}} = 30$ K (Wu et al. 2004), the optical depth $\tau_v$ can be derived by the equation

$$\tau_v = \frac{k T_v(v)}{h v} \left( \frac{1}{\exp(hv/kT_{\text{ex}})} - 1 \right)^{-1} \frac{1}{\exp(hv/kT_{\text{bg}})} - 1,$$

(2)

where $T_v(v)$ is the excess brightness temperature of HCN(3–2) emission at $v$. Adopting $X_{\text{HCN}} = [\text{HCN}]/[\text{H}_2] = 1 \times 10^{-10}$ (Carolan et al. 2009), the mass of each lobe at $v$ can be calculated with

$$M(v) = X_{\text{HCN}}^{-1} \mu_G m_{\text{H}_2} D^2 \int N_{\text{HCN}}(v) d\Omega,$$

(3)

where $D$ and $\Omega$ are the cloud distance and the solid angle, respectively. Thus, the total mass of each lobe is given by $M = \sum M(v)$, the total momentum by $P = \sum P(v)$, and the energy by $E = \frac{1}{2} \sum P(v) v^2$. The dynamical timescale $\tau_{\text{dyn}}$ is estimated as $R/V_{\text{max}}$, where $R$ is the outflow extent, and $V_{\text{max}}$ is the maximum velocity of the outflow lobe. The mechanical luminosity $L$ and the mass-loss rate $\dot{M}$ are calculated as $L = E/t$ and $\dot{M} = P/(t V_{\text{w}})$, where the wind velocity $V_{\text{w}}$ is assumed to be 500 km s$^{-1}$ (Lamers et al. 1995). The derived parameters are listed in Table 1. The total mass, momentum, and energy of the three lobes are 12 $M_\odot$, 121 $M_\odot$ km s$^{-1}$, and 1.3 \times 10^{46}$ erg, respectively. The average dynamical timescale is about $1.6 \times 10^4$ yr, and the total mass-loss rate is $1.6 \times 10^{-5}$ $M_\odot$ yr$^{-1}$. The outflow is massive with parameters similar to that of IRAS 05274+3345E and the other outflows detected toward five massive star formation regions (Bachiller et al. 1997; Choi 2001; Su et al. 2007; Zhang et al. 2007a). HCN outflow of the core JCMT 18454−0649S. The core observed with the compact configuration has a mass of 47 $M_\odot$ and an average density of 2.0 \times 10^6$ cm$^{-3}$. With the combination of the compact and extended configurations, the core is resolved to three condensations with a total mass of 42 $M_\odot$.

5. SUMMARY

Both dust continuum at 1.3 mm and CH$_3$OH emission detected with the SMA reveal a compact core in JCMT 18354−0649S. The core observed with the compact configuration has a mass of 47 $M_\odot$ and an average density of 2.0 \times 10^6$ cm$^{-3}$. With the combination of the compact and extended configurations, the core is resolved to three condensations with a total mass of 42 $M_\odot$.

HCN (3–2) spectra exhibit an infall signature in this region. The redshifted absorption seen in the SMA observation is deeper and broader than that in the JCMT observation. The infall

| Outflow       | $V_{\text{max}}$ (km s$^{-1}$) | $\dot{M}$ (10$^4$ yr$^{-1}$) | Mass ($M_\odot$) | Momentum ($M_\odot$ km s$^{-1}$) | Energy (10$^{45}$ erg) | $L$ ($L_\odot$) | $M_{\text{out}}$ (10$^{-6}$ $M_\odot$ yr$^{-1}$) |
|---------------|-------------------------------|-------------------------------|-----------------|---------------------------------|------------------------|---------------|-------------------------------------|
| Southern lobe | 11.7                          | 1.4                           | 3.3             | 29                              | 3.0                    | 1.8           | 4.0                                  |
| Northeastern lobe | 15.3                  | 1.0                           | 4.2             | 42                              | 4.5                    | 3.6           | 8.0                                  |
| Western lobe  | 15.3                          | 2.3                           | 4.6             | 50                              | 5.5                    | 2.1           | 4.0                                  |

Table 1

HCN—Tracer of Both Inflow and Outflow Motions

HCN is among the most abundant molecular species with a high critical density larger than 10$^6$ cm$^{-3}$, for HCN (1–0) (Carolan et al. 2009), and is believed to trace dense molecular cores. HCN is detected in both low-mass Class 0 and 1 sources (Park et al. 1999; Yun et al. 1999), and high-mass hot cores (Boonman et al. 2001).

HCN is thought as a good tracer of inflow motions (Wu & Evans 2003). The infall asymmetry in the HCN spectra is found to be more prevalent and more prominent than in any other previously used infall tracers such as CS (2−1), DCO$^+$ (2−1), and N$_2$H$^+$ (1−0) during a survey toward 85 starless cores (Sohn et al. 2007). Among the small group of pre- and protostellar objects in L1251B, infall signature was also detected in the HCN emission (Lee et al. 2007). HCN also traces inflow motions very well in massive star formation regions. Wu & Evans (2003) found 12 sources showing “blue profile” in the HCN lines during a spectroscopic survey of 28 massive cores with water masers. Besides HCN, other nitrogen-bearing molecules such as N$_2$H$^+$ are also tracers of inflow motions (Tsamis et al. 2008; Schnee et al. 2007; Crapsi et al. 2005). Recently, the inverse P Cygni profile of the CN line in hot cores was found (Zapata et al. 2008; Wu et al. 2009). These results suggest that nitrogen-bearing molecular species are good tracers of inflowing motions in star formation regions.

Outflows traced by HCN are often detected not only in low-mass star formation regions but also in massive star formation regions (Bachiller et al. 1997; Choi 2001; Su et al. 2007; Zhang et al. 2007a). HCN outflow of the core JCMT 18454−0649S is another good sample. Additionally, Zhu et al. (2011) and Cyganowski (2008) found excess emission at 4.5 $\mu$m at the position of source IRS1a, which is close to the center of the NE-lobe and S-lobe. Such excess emission at the 4.5 $\mu$m band could be shock-excited. In IRAS 20126+4104, HCN emission is also found to be closely related to the shock-excited near-IR H$_2$ knots and was identified to be associated with shock wings (Su et al. 2007). The inner clumps (Clump 1 in the S-lobe and Clump 3 in the NE-lobe) of the core JCMT 18354−0649S should also be coincident with shocks. In fact, models have already demonstrated a dramatic increase of HCN molecules during the intense interaction between outflow and ambient gas, or slow shock front (Mitchell 1984; Nejad et al. 1990). In this process, sulfur and nitrogen react with hydrocarbons to produce various compounds, wherein HCN abundance becomes higher than the rest of the products (Najad et al. 1990). Thus, HCN may trace the outflow even better than sulfur-containing molecules.
rate is $2.0 \times 10^{-3} \ M_\odot \ yr^{-1}$. A high-velocity gas is detected in HCN (3–2) emission. The outflow has three lobes, and their total mass is $12 \ M_\odot$ and momentum $121 \ M_\odot \ km \ s^{-1}$. The average dynamical timescale and the total mass-loss rate are about $1.6 \times 10^4 \ yr$ and $1.6 \times 10^{-5} \ M_\odot \ yr^{-1}$, respectively. All the findings indicate that a high-mass protostar is forming via rapid accretion. Our results suggest that nitrogen-bearing molecules, especially HCN, are good for probing both infall and outflows.

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