UNIFORM INFALL TOWARD THE COMETARY H\textsc{ii} REGION IN THE G34.26 + 0.15 COMPLEX?

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ABSTRACT

Gas accretion is a key process in star formation. However, gas infall detections in high-mass, star-forming regions with high spatial resolution observations are rare. Here, we report the detection of gas infall toward a cometary ultracompact H\textsc{ii} region (“C”) in the G34.26+0.15 complex. The observations were made with the IRAM 30 m, the James Clerk Maxwell Telescope 15 m telescope, and the Submillimeter Array (SMA). The hot core associated with “C” has a mass of \( \sim 76 \pm 11 \, M_\odot \) and a volume density of \( (1.1 \pm 0.2) \times 10^5 \, \text{cm}^{-3} \). The HCN (3–2) and HCO\(^+\) (1–0) lines observed by single dishes and the CN (2–1) lines observed by the SMA show redshifted absorption features, indicating gas infall. We found a linear relationship between the line width and optical depth of the CN (2–1) lines. Those transitions with larger optical depths and line widths have larger absorption areas. However, the infall velocities measured from different lines seem to be constant, indicating that the gas infall is uniform. We also investigated the evolution of gas infall in high-mass, star-forming regions. A tight relationship was found between the infall velocity and the total dust/gas mass. At stages prior to the hot core phase, the typical infall velocity and mass infall rate are \( \sim 1 \, \text{km} \, \text{s}^{-1} \) and \( \sim 10^{-4} \, M_\odot \, \text{yr}^{-1} \), respectively. While in more evolved regions, the infall velocity and mass infall rates can reach as high as several \( \text{km} \, \text{s}^{-1} \) and \( \sim 10^{-3}–10^{-2} \, M_\odot \, \text{yr}^{-1} \), respectively. Accelerated infall has been detected toward some hypercompact H\textsc{ii} and ultracompact H\textsc{ii} regions. However, the acceleration phenomenon is not seen in more evolved ultracompact H\textsc{ii} regions (e.g., G34.26+0.15).

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

Online-only material: color figures

1. INTRODUCTION

Our understanding of high-mass star formation is still uncertain due to difficulties caused by large distances, large extinctions, and cluster formation behavior, as well as the strong interactions between the forming young stars and their surroundings (Zinnecker & Yorke 2007). Is high-mass star formation merely a scaled-up version of low-mass star formation with higher accretion rates, or is high-mass star formation characterized by particular properties that are dramatically different from low-mass star formation? There are two promising models that account for high-mass stars (\( M > 8 \, M_\odot \)). One model is called the “monolithic collapse and disk accretion” model (York & Sonnhalter 2002; McKee & Tan 2003) and the other is called the “competitive accretion” model (Bonnell et al. 2002, 2004). The former suggests that high-mass stars form directly from isolated massive gas clumps, as do low-mass stars, but with a much larger accretion rate. The latter claims that high-mass stars form in the center of a cluster by competing for cloud gas with the other protostars. To distinguish the different models, detailed observations of gas accretion in high-mass, star-forming regions are needed.

Several surveys of gas infall have been carried out with single dishes and gas infall has been found to be common in high-mass, star-forming regions (Fuller et al. 2005; Wu & Evans 2003; Wu et al. 2007). However, due to poor spatial resolution, single-dish observations cannot resolve individual cores or protostars. Thus, it is hard to investigate the accretion mode of high-mass star formation with single-dish observations. In recent years, high-spatial resolution observations of infall in high-mass, star-forming regions with interferometers have been made (Sollins & Ho 2005; Qin et al. 2008; Zapata et al. 2008; Wu et al. 2009; Girart et al. 2009; Shi et al. 2010; Liu et al. 2011a, 2011b; Zhu et al. 2011; Qiu et al. 2011, 2012). Infall was detected in high-mass, star-forming regions at various evolutionary stages. Optically thick lines toward regions in early evolutionary phases (prior to the hot core phase) often show a blue profile plus an inverse P-Cygni profile with a small infall velocity (\( \sim 1 \, \text{km} \, \text{s}^{-1} \)) and a shallow absorption dip (Zhu et al. 2011; Liu et al. 2011b). However, toward more evolved regions with bright continuum emission, where the protostars have gained more mass and the ultraviolet (UV) radiation has become strong enough to resist gravity, inverse P-Cygni profiles are often detected in lines (Qin et al. 2008; Zapata et al. 2008; Wu et al. 2009; Girart et al. 2009; Shi et al. 2010; Liu et al. 2011a; Qiu et al. 2011, 2012). The infall velocities (several \( \text{km} \, \text{s}^{-1} \)) and mass infall rates (\( \sim 10^{-3}–10^{-2} \, M_\odot \, \text{yr}^{-1} \)) in these regions are high and the core may collapse faster on the inside than the outside (Wu et al. 2009; Qiu et al. 2011). However, such high-spatial resolution studies are still rare. More samples are needed to constrain the properties of gas infall in high-mass, star-forming regions.

In this paper, we report the results of a high-spatial resolution study with the Submillimeter Array (SMA), the IRAM 30 m, and the James Clerk Maxwell Telescope (JCMT) 15 m telescopes toward a cometary ultracompact H\textsc{ii} region G34.26+0.15. Located at a distance of 3.7 kpc (Kuchar & Bania 1994), G34.26+0.15 is a high-mass, star-forming complex. Previous centimeter observations (Reid & Ho 1985) have detected a shell-like H\textsc{ii} region (“D”), a cometary ultracompact H\textsc{ii} region (“C”), and two hypercompact H\textsc{ii} regions (“A” and “B”) in the G34.26+0.15 complex. A hot core with a kinetic temperature of 160 ± 30 K was also detected toward the cometary ultracompact H\textsc{ii} region “C” (Mookerjea et al. 2007). In this work, we report uniform infall detections toward the cometary ultracompact H\textsc{ii} region (“C”) by analyzing HCN (3–2), HCO\(^+\) (1–0), and CN (2–1) lines.

2. OBSERVATIONS AND DATA

The observations of G34.26+0.15 with the IRAM 30 m telescope at Pico Veleta, Spain were carried out in 2005 August.
Details of the observations can be found in Wu et al. (2007). In this paper, the C\(^{34}\)S(5–4), C\(^{17}\)O (1–0), and HCO\(^+\) (1–0) lines were used.

The single-pointing observations of HCN (3–2) were carried out in 2005 April with the JCMT telescope in Hawaii. The JCMT beam size for HCN (3–2) was 18′3 (FWMH) and the main beam efficiency was 0.69. During the observations, the weather was good with \(\tau = 0.045\). The system temperature was 271 K and the noise level of the line was about 0.15 K.

The SMA data were obtained from the SMA raw data archive. The observations of G34.26+0.15 were carried out with the SMA in 2011 April in its compact configuration. The phase reference center was R.A.(J2000) = 18h53m18s \(\pm\) 01″, decl.(J2000) = 01°14′58″. The one receiver 4 GHz mode with a uniform spectral resolution of \(\approx 0.8125\) MHz (128 channels per chunk) was adopted. The 230 GHz receivers were tuned to 227.5 GHz for the lower sideband and 239.5 GHz for the upper sideband.

In the observations, Saturn and quasi-stellar object (QSO) S573 and deconvolved size of the core are 11.4 Jy and 1″, respectively, the free–free contribution at 1.3 cm and 2.8 mm are as high as 5 Jy and 6.7 Jy, respectively, the free–free contribution of “B,” which was not marked in Figure 3. The emission peak of the 1.3 mm continuum from SCUBA/JCMT is shown as red solid contours. The contour levels are from 10% to 90% in steps of 10% of the peak emission. The long white dashed lines represent the possible jets/outflow directions.

(A color version of this figure is available in the online journal.)

3. RESULTS

3.1. Overall Picture of the G34.26+0.15 Complex

G34.26+0.15 is a star-forming complex composed of four \(\text{H}\ II\) regions (“A,” “B,” “C,” and “D”) at different evolutionary stages (Reid & Ho 1985). As shown in Figure 1, the polycyclic aromatic hydrocarbon (PAH) emission (pink contours) revealed by the \textit{Spitzer}/IRAC 8 \(\mu\)m band forms a shell-like structure, which shows the boundary of the expanding \(\text{H}\ II\) region “D.”

The sequential star formation in this region seems to be induced by the expansion of the \(\text{H}\ II\) region “D.”

The strong, extended emission in the 4.5 \(\mu\)m band of \textit{Spitzer}/IRAC is usually thought to be dominated by shock-excited molecular \(\text{H}_2\) and CO in protostellar outflows (Noriega-Crespo et al. 2004; Reach et al. 2006; Smith et al. 2006; Davis et al. 2007; Takami et al. 2010). To reduce the contamination from the stellar emission, we present the IRAC [4.5]/[3.6] flux ratio image in color in Figure 1. The flux ratio is comparable to or higher than \(\sim 1.5\) in the jets, in contrast with the stars (flux ratio \(< 1.5\); Takami et al. 2010). As depicted by the long white dashed lines, one can identify several elongated structures (jets?) from the ratio image, especially to the northwest and the southwest of the dust core. If the large [4.5]/[3.6] ratio traces the distribution of shocked gas, there seem to exist multiple jets generated from the G34.26+0.15 complex. As shown in Figure 2, one can identify broad line wings in the HCN (3–2) line. The terminal velocity of the red wing even reaches as high as 40 km s\(^{-1}\), indicating energetic outflow motions.

3.2. 1.3 mm Dust Emission Obtained from the SMA Observations

As shown in grayscale in Figure 3, the 1.3 mm continuum emission from the SMA observations reveals a dense core. The positions of two hypercompact \(\text{H}\ II\) regions (“A” and “B”) and one ultracompact \(\text{H}\ II\) region (“C”) are marked with stars. The expanding shell–like \(\text{H}\ II\) region “D” is located to the southeast of “B,” which was not marked in Figure 3. The emission peak of the 1.3 mm continuum emission coincides with the cometary ultracompact \(\text{H}\ II\) region “C.” The peak flux of the 1.3 mm emission is 8.31 \(\pm\) 0.38 Jy beam\(^{-1}\). The total integrated flux and deconvolved size of the core are 11.4 Jy and 1′74 × 1′29 (P.A. = −50.5), respectively. Since the integrated flux densities at 1.3 cm and 2.8 mm are as high as 5 Jy and 6.7 \(\pm\) 0.4 Jy (Mookerjea et al. 2007), respectively, the free–free contribution

Figure 2. Single-dish spectra at the dust emission peak of G34.26+0.15. (A color version of this figure is available in the online journal.)
The emission at 1.3 mm is 7.8 ± 0.8 Jy beam−1 observed by the SMA. The contour level for each transition is 3.3. Gas Infall Toward the Dust Core

To the 1.3 mm emission cannot be ignored. Adopting a spectral index of 0.2 (Mookerjea et al. 2007), the expected free–free emission at 1.3 mm is 7.8 ± 0.5 Jy. Therefore, the dust contribution at 1.3 mm is 3.6 ± 0.5 Jy.

Assuming that the dust emission is optically thin and that the dust temperature equals the kinetic temperature 160 K (Mookerjea et al. 2007), the total gas mass of the dust core can be obtained with the formula $M = S_ν D^2/κ ν B ν(T_d)$, where $S_ν$ is the flux of the dust emission at 1.3 mm, $D$ is the distance, and $B ν(T_d)$ is the Planck function. The dust opacity at 1.3 mm is $κ ν = 0.009$ cm2 g−1. Here, the ratio of gas to dust is taken to be 100. Thus, the mass and volume density of the envelope within the inner ∼0.01 pc radius are 76 ± 11 $M_☉$ and (1.1 ± 0.2) × 108 cm−3, respectively.

3.3. Gas Infall Toward the Dust Core

As shown in Figure 2, both of the optically thin C34S (5–4) and C17O (1–0) lines at the dust core are single peaked. From Gaussian fits, the peak velocities of the C34S (5–4) and C17O (1–0) lines are 57.9 and 58.2 km s−1, respectively. Here, we take the average value of 58.05 km s−1 as the systemic velocity of the dust core. In contrast, both the HCN (3–2) and HCO+ (1–0) lines show a redshifted absorption dip around 61 km s−1.

Table 1

Parameters of CN Absorption Lines

| Transition          | Frequency (GHz) | $\log_{10}(A_J)$ (log10 (s−1)) | $E_A$ (K) | $n_{\text{crit}}$ ($10^3$ cm−3) | $V_{\text{obs}}$ (km s−1) | $V_{\text{in}}$ (km s−1) | $ΔV$ (km s−1) | $τ$     |
|---------------------|-----------------|---------------------------------|-----------|---------------------------------|--------------------------|--------------------------|--------------|--------|
| $N = 2–1, J = 3/2–3/2, F = 3/2–3/2$ | 226.315         | −5.00                           | 16.31     | 1.62                            | 61.22 (0.08)             | 3.17 (0.08)               | 3.51 (0.19)  | 0.20 (0.05) |
| $N = 2–1, J = 3/2–3/2, F = 3/2–5/2$ | 226.333         | −5.34                           | 16.31     | 0.74                            | 61.54 (0.11)             | 3.49 (0.11)               | 2.59 (0.25)  | 0.13 (0.05) |
| $N = 2–1, J = 3/2–3/2, F = 5/2–5/2$ | 226.360         | −4.79                           | 16.31     | 2.63                            | 61.39 (0.03)             | 3.34 (0.03)               | 4.13 (0.08)  | 0.68 (0.09) |
| $N = 2–1, J = 3/2–1/2, F = 1/2–3/2$ | 226.617         | −9.47                           | 16.31     | 1.55                            | 61.47 (0.18)             | 3.42 (0.18)               | 3.10 (0.42)  | 0.08 (0.05) |
| $N = 2–1, J = 3/2–1/2, F = 3/2–3/2$ | 226.632         | −4.37                           | 16.31     | 6.15                            | 61.20 (0.03)             | 3.15 (0.03)               | 3.86 (0.06)  | 0.85 (0.10) |
| $N = 2–1, J = 3/2–1/2, F = 5/2–3/2$ | 226.660         | −4.02                           | 16.31     | 13.66                           | 61.12 (0.04)             | 3.07 (0.04)               | 5.22 (0.09)  | 1.68 (0.24) |
| $N = 2–1, J = 3/2–1/2, F = 3/2–1/2$ | 226.679         | −4.28                           | 16.31     | 7.60                            | 61.13 (0.03)             | 3.08 (0.03)               | 4.36 (0.06)  | 1.00 (0.12) |

Figure 3. CN (2–1) absorption contours overlaid on the 1.3 mm continuum emission observed by the SMA. The contour level for each transition is 0.8 Jy beam−1 km s−1. The stars mark the positions of two hypercompact H II regions and one ultracompact H II region. (A color version of this figure is available in the online journal.)

Figure 4. CN (2–1) absorption lines (green) at the 1.3 mm continuum emission peak of G34.26+0.15. The red lines are Gaussian fits. The systemic velocity (58 km s−1) of G34.26+0.15 is marked by blue dashed lines. (A color version of this figure is available in the online journal.)

All of the spectra of the CN (2–1) transitions from the SMA observations show redshifted absorption features. Figure 4 presents the spectra of four CN (2–1) transitions, all of which show redshifted absorption. The parameters of the unblended CN (2–1) lines are summarized in Table 1.

The redshifted absorption of the lines (inverse P-Cygni profile) is regarded as evidence of a cold infalling layer in front of a bright continuum background (Wu et al. 2009; Wyrowski et al. 2012). The redshifted absorption feature of the HCN (3–2), HCO+ (1–0), and CN (2–1) lines indicates that gas is still falling down to the dense inner part of the cometary H II region “C.”

4. DISCUSSION

4.1. Uniform Infall Toward the Cometary H II Region “C”

Infall motion has been identified toward the hyper-ultra compact H II regions (Wu et al. 2009; Qiu et al. 2011). The dust/gas cores associated with these H II regions always collapse faster on the inside than on the outside (Wu et al. 2009; Qiu et al. 2011). Toward the cometary H II region “C” in the G34.26+0.15 complex, the HCN (3–2) and HCO+ (1–0) lines from single-dish observations and the CN (2–1) lines from the SMA observations all show a redshifted absorption dip around 61 km s−1, which is ∼3 km s−1 away from the systemic velocity. Additionally, the 893 GHz HDO line observed by APEX, the NH3 (32+–22) line observed by SOFIA, and the NH3 (2,2) line observed by the Very Large Array also show redshifted absorption dips.
around 61 km s$^{-1}$ (Gómez et al. 2000; Wyrowski et al. 2012; Liu et al. 2013a). Since HCN, HCO$^+$, CN, HDO, and NH$_3$ sample different spatial scales and have the same 3 km s$^{-1}$ absorption, infall motion may be uniform toward the cometary H II region “C.”

The critical densities $n_{\text{crit}}$ of different transitions of CN (2–1) lines can be calculated as

$$n_{\text{crit}} = \frac{A_{ij}}{K_{ij}},$$  \hspace{1cm} (1)

where $A_{ij}$ and $K_{ij}$ are the Einstein coefficient and collisional rate coefficients, respectively. We adopted the collisional rate coefficients at 100 K from LAMDA$^2$ in these calculations. The calculated critical densities are listed in the fifth column of Table 1. The critical densities of the CN (2–1) lines vary from $7.4 \times 10^3$ to $1.4 \times 10^7$ cm$^{-3}$, indicating that various transitions of CN (2–1) can be used to trace different parts of the gas core. In Figure 3, we plot the contours of the absorption of various CN (2–1) transitions. One sees that various transitions of CN (2–1) do trace different parts of the gas core. The optical depth of each CN (2–1) line can be estimated from

$$\tau_L = -\ln \left( \frac{I_L}{I_C} \right) = -\ln \left( 1 + \frac{\Delta I_L}{I_C} \right),$$  \hspace{1cm} (2)

where $\Delta I_L = I_L - I_C$ is the observed line intensity at the continuum peak and $I_C$ is the observed peak continuum intensity. The optical depth is listed in the last column of Table 1. From Figure 3, we see that the transitions of CN (2–1) with larger optical depths also have larger absorption areas.

The line widths of various CN (2–1) transitions are listed in the eighth column of Table 1. We found that the transitions with smaller line widths also have smaller absorption areas in Figure 3. This phenomenon is quite similar to the “Larson relationship” found in molecular clouds (Larson 1981). It seems that the non-thermal motion in the outer part of the core is more active than that in the inner part. As shown in Figure 5, there exists a linear relationship between the line width and optical depth of CN (2–1) lines. The infall velocities were measured from various CN (2–1) transitions with $V_{in} = V_{\text{obs}} - V_{\text{sys}}$. The absorption velocity $V_{\text{obs}}$ of each line was obtained from a Gaussian fit and is listed in the sixth column of Table 1, while the infall velocities are listed in the seventh column. As shown in Figure 5, the infall velocity seems to be constant for various optical depths and line widths, indicating that the infall motion is uniform in this region. The average infall velocity measured from the CN (2–1) lines is $3.25$ km s$^{-1}$.

4.2. The Evolution of Gas Infall in High-mass, Star-Forming Regions

In Table 2, we summarize the parameters of 11 high-mass, star-forming regions with infall detections from (sub)millimeter interferometer observations. The infall velocities were measured with $V_{in} = V_{\text{obs}} - V_{\text{sys}}$. The mass accretion rates, $M_{in}$, can be estimated using the simple expression

$$\dot{M}_{in} = 4\pi r_{in}^2 \mu m_H n V_{in},$$  \hspace{1cm} (3)

where $\mu$ is the mean molecular weight and $m_H$ is the mass of hydrogen. Assuming that the infall speeds $V_{in}$ arise from the velocity gain of gas free-falling from rest at $r = 0$ to $r_{in}$, $r_{in}$ can be calculated as

$$r_{in} = \frac{2GM}{V_{in}^2}.$$  \hspace{1cm} (4)

The mean volume density $n$ within $R_{in}$ is estimated as

$$n = \frac{M}{4/3 \pi r_{in}^3 \mu m_H}.$$  \hspace{1cm} (5)

The calculated mass accretion rates are listed the fifth column of Table 2. We also summarized the parameters of two low-mass, star-forming regions for comparison. From Table 2, one can find that the infall velocities and mass accretion rates in high-mass star-forming regions are much larger than those in low-mass, star-forming regions. The typical infall velocities and mass accretion rates in low-mass, star-forming regions are $\sim 0.5$ km s$^{-1}$ and $\sim 10^{-5} M_\odot$ yr$^{-1}$, respectively. In high-mass, star-forming regions, the infall velocities and mass accretion rates can reach as high as several km s$^{-1}$ and $\sim 10^{-3} M_\odot$ yr$^{-1}$, respectively.

However, the infall velocities and mass accretion rates change with time in high-mass, star-forming regions. At evolutionary stages earlier than the hot core phase (e.g., W3SE-SMA1 and JCMT 18354-0649S), a typical infall velocity and mass accretion rate are $\sim 1$ km s$^{-1}$ and $\sim 10^{-4} M_\odot$ yr$^{-1}$, respectively. In the hot core phase (including hypercompact and early phases of ultracompact H II regions), the infall velocities and mass infall rates can reach as high as several km s$^{-1}$ and $\sim 10^{-3} - 10^{-2} M_\odot$ yr$^{-1}$, respectively. However, what is even more surprising is that during this stage accelerated gas infall is often revealed (e.g., NGC 7538 IRS 1, G10.6–0.4, and G19.61–0.23; Wu et al. 2009; Qiu et al. 2011). In other words, with different molecular tracers, the infall velocities inferred in the inner part are larger than the infall velocities in the outer part. However, this infall acceleration phenomenon is not seen in more evolved ultracompact H II regions (e.g., G34.26+0.15 “C”).

In Figure 6, we show a tight relationship between the infall velocity and the total dust/gas mass. The relationship can be fit with a power law. If we take the low-mass, star-forming regions into account, the power-law index is 0.34. However, the
Table 2
Parameters of High-mass, Star-forming Regions with Infall Detections from (Sub)Millimeter Interferometers

| Name                  | Distance (kpc) | \( M_\text{V} \) (\( M_\odot \)) | \( \dot{M}_\text{in} \) (k m s\(^{-1}\)) | \( \dot{M}_\text{in} \) (10\(^{-3}\) \( M_\odot \) yr\(^{-1}\)) | Lines                        | Stages | Refs. |
|-----------------------|----------------|----------------------------------|------------------------------------------|-------------------------------------------------|--------------------------------|--------|-------|
| Low-mass, star-forming regions |
| IRAS 16293−2422B      | 0.12           | 2                               | 0.49                                     | 0.04                                             | CH\(_3\)OCHO-E (174,13−164,12) | Class 0 | 1     |
|                       |                |                                 |                                          |                                                 | CH\(_3\)OCHO-A (174,13−164,12)                   | Class 0 | 1     |
|                       |                |                                 |                                          |                                                 | H\(_2\)CCO (111,11−101,10)                       | Class 0 | 1     |
|                       |                |                                 |                                          |                                                 | CH\(_3\)OH (9\(_{6,6}−8_{-7,7}\))                | Class 0 | 2     |
| NGC 1333 IRAS 4A      | 0.35           | 1.1                             | 0.68                                     | 0.11                                             | H\(_2\)CO (3\(_{1,2}−2_{1,1}\))                  | Class 0 | 3     |
| NGC 1333 IRAS 4B      | 0.35           | 0.48                            | 0.47                                     | 0.04                                             | H\(_2\)CO (3\(_{1,2}−2_{1,1}\))                  | Class 0 | 3     |
| High-mass, star-forming regions |
| W3SE-SMA1             | 2              | 32                              | 0.9                                      | 0.26                                             | HCN (3−2)                                    | HMPO\(^{2d}\) | 4     |
| JCMT 18354-0649S      | 5.7            | 42                              | 1.3                                      | 0.78                                             | HCN (3−2)                                    | HMPO      | 5     |
| W51e2-E               | 5.1            | 140                             | 2.5                                      | 5.57                                             | HCN (4−3)                                    | HMC?      | 6     |
| G31.41+0.31           | 7.0            | 577                             | 3.1                                      | 10.62                                            | C\(^{34}\)S (7−6)                             | HMC\(^{4}\) | 7     |
| W51 IRS2              | 7              | 90                              | 4                                        | 22.81                                            | CN (2−1)                                     | HMC       | 8     |
| IRAS 18360−0537 MM1    | 6.3            | 13                              | 1.5                                      | 1.20                                             | CN (2−1)                                     | HMC       | 9     |
| NGC 7538 IRS 1        | 2.65           | 20.1                            | 2                                        | 2.85                                             | C\(^{12}\)O (2−1)                             | HCN H\(_{\text{II}}\) | 10    |
|                       |                |                                 |                                          |                                                 | SO (5\(_{6}−4_{5}\))                           |           |       |
|                       |                |                                 |                                          |                                                 | CH\(_3\)OH (8_{1,8}−7_{0,7})                    |           |       |
|                       |                |                                 |                                          |                                                 | HNCO (10\(_{6,9}−9_{0,0}\))                    |           |       |
|                       |                |                                 |                                          |                                                 | G10.6−0.4                                    | HC H\(_{\text{II}}\) | 11    |
|                       |                |                                 |                                          |                                                 | G9.62+0.19 E                                 | HC H\(_{\text{II}}\) | 12    |
|                       |                |                                 |                                          |                                                 | G19.61−0.23                                  | UC H\(_{\text{II}}\) | 14    |
|                       |                |                                 |                                          |                                                 | G34.26+0.15                                  | Cometary UC H\(_{\text{II}}\) | 15    |

Notes.

a The infall velocities were measured with \( V_{\text{in}} = V_{\text{obs}} − V_{\text{sys}} \), which may slightly differ from values in the literature.

b Only the infall velocities inferred from those molecular lines with absorption areas comparable with the continuum emission are used in the calculations.

c (1) Pineda et al. 2012; (2) Zapata et al. 2013; (3) Di Francesco et al. 2001; (4) Zhu et al. 2011; (5) Liu et al. 2011b; (6) Shi et al. 2010; (7) Girart et al. 2009; (8) Zapata et al. 2008; (9) Qiu et al. 2012; (10) Qiu et al. 2011; (11) Liu et al. 2011a; (12) Sollins & Ho 2005; (13) Liu et al. 2011a; (14) Wu et al. 2009; (15) This work.

d High mass protostellar objects.

e Hot molecular core.

Figure 6. Relationship between infall velocity and the total dust/gas mass. The red dashed line represents the power-law fit to both the high-mass and low-mass data points, while the pink solid line shows the power-law fit to only the high-mass data points. We assume a 50% error in the measurements of both infall velocity and mass.

(A color version of this figure is available in the online journal.)

Whether or not the core collapses depends on the balance of gravity, thermal and turbulent support, and magnetic fields. As the protostars in the cores evolve, the internal heating and UV illumination may also play an important role in resisting gravity. More detailed observations and numerical simulations are needed to address how these factors function in the gas accretion as the protostars evolve.

5. SUMMARY

Here, we report the detection of gas infall toward the cometary ultracompact H\(_{\text{II}}\) region “C” in the G34.26+0.15 complex. From the 1.3 mm continuum emission, we estimated that the total dust/gas of the hot core associated with the cometary ultracompact H\(_{\text{II}}\) region “C” is about 76 ± 11 \( M_\odot \). Both the HCN (3−2) line observed by JCMT and the HCO\(^+\) (1−0) line observed by IRAM show a redshifted absorption dip around 61 km s\(^{-1}\), indicating gas infall in this region. We also detected absorption lines of multiple CN (2−1) transitions from the SMA observations. We found a linear relationship between the line width and optical depth of the CN (2−1) lines. Those transitions with larger optical depths and line widths have larger absorption areas. However, the infall velocities measured from different lines to be constant, indicating that the gas infall is uniform. The uniform infall may be due to the expansion of the cometary H\(_{\text{II}}\) region and the feedback from the central protostars in the form of UV radiation and stellar winds.
We also investigated the evolution of gas infall in high-mass, star-forming regions using data collected from the literature. We found that the infall velocity and mass infall rate in high-mass, star-forming regions are much higher than those in low-mass, star-forming regions. However, the infall also evolves with time. At stages prior to the hot core phase, a typical infall velocity and mass infall rate are \( \sim 1 \text{ km s}^{-1} \) and \( \sim 10^{-4} M_\odot \text{ yr}^{-1} \), respectively. While in more evolved regions, the infall velocities and mass infall rates can reach as high as several km s\(^{-1}\) and \( \sim 10^{-3} - 10^{-2} M_\odot \text{ yr}^{-1} \), respectively. Accelerated infall has been detected toward several hypercompact H\(\text{\textsc{ii}}\) and ultracompact H\(\text{\textsc{ii}}\) regions. However, the acceleration phenomenon is not seen in more evolved ultracompact H\(\text{\textsc{ii}}\) regions (e.g., G34.26+0.15).

As the protostars in the cores evolve, internal heating and UV illumination may play an important role in resisting gravity. Thus, gas infall in more evolved H\(\text{\textsc{ii}}\) regions may be decelerated or even eventually halted.

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