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ATOMS: ALMA three-millimeter observations of massive star-forming regions – VII. A catalogue of SiO clumps from ACA observations

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ABSTRACT

To understand the nature of SiO emission, we conducted ACA observations of the SiO (2-1) lines toward 146 massive star-forming regions, as part of the ALMA Three-millimeter Observations of Massive Star-forming regions (ATOMS) survey. We detected SiO emission in 128 (87.7 per cent) sources and identified 171 SiO clumps, 105 of which are spatially separated from 3 mm continuum emission. A large amount of the SiO line profiles (60 per cent) are non-Gaussian. The velocity dispersion of the SiO lines ranges from 0.3 to 5.43 km s⁻¹. In 63 sources the SiO clumps are associated with HII regions characterized by H40 α emission. We find that 68 per cent (116) of the SiO clumps are associated with strong outflows. The median velocity dispersion of the SiO line for outflow sources and non-outflow sources is 1.91 km s⁻¹ and 0.99 km s⁻¹, respectively. These results indicate that outflow activities could be connected to strongly shocked gas. The velocity dispersion and [SiO]/[H¹³CO⁺] intensity ratio do not show any correlation with the dust temperature and particle number density of clumps. We find a positive correlation between the SiO line luminosity and the bolometric luminosity, implying stronger shock activities are associated with more luminous protoclusters. The SiO clumps in associations with HII regions were found to show a steeper feature in $L_{\text{SiO}}/L_{\text{bol}}$. The SiO line luminosity and the fraction of shocked gas have no apparent evidence of correlation with the evolutionary stages traced by luminosity to mass ratio (L_{bol}/M).

Key words: ISM: clouds – ISM: jets and outflows – ISM: molecules – stars: formation – stars: massive – radio lines: ISM.

1 INTRODUCTION

As the main contributors of heavy elements and UV-photon radiation, massive stars play an important role in the evolution of interstellar medium (ISM). In the past decades, studies of massive star formation through multiwavelengths and high-resolution observations have made great achievements, but there are still difficulties in understanding the formation process because of large distances, short time-scales, high extinction, and clustered environments (Zinnecker & Yorke 2007; Motte, Bontemps & Louvet 2018). The process of massive star formation itself can also provide strong feedback to the parent clouds and ISM by energetic jets and induced outflows. The jets and outflows interacting with the surrounding medium are ubiquitous at different evolutionary stages in high-mass star formation, such as infrared quiet, infrared bright, and Ultra-Compact (UC) HII stage (Churchwell 2002; Bally 2016; Li et al. 2019a). Thus

studies of such shock activities can help us deepen understanding of the massive star formation processes.

A deep understanding of the properties of jets and outflows is crucial in answering the problems in massive star formation (Motte et al. 2018). Molecular lines are powerful tools to study the physical and chemical conditions and the feedback within massive star-forming regions (SFRs). Various molecular emissions trace different layers in the internal structure of massive clumps embedding high-mass stars (Csengeri et al. 2016). Rotational transitions of different molecules provide us temperatures, densities, UV fields, chemical abundances, and gas kinematics of the massive clumps. Molecules such as CO, SiO, SO, HCO⁺, and CS are good tracers of jets and outflows (Bally 2016). In particular, due to little contamination from the quiescent gas, SiO emissions have been widely used to study shock activities induced by outflows.

Shocks are a universal phenomenon in SFRs. High velocity shocks ($v_s \geq 20$ km s⁻¹) are caused by powerful outflows and jets from massive young protostars (Qiu et al. 2007; Duarte-Cabral et al. 2014; Li et al. 2019b, 2020), while low velocity shocks ($v_s < 10$ km s⁻¹) could be associated with less powerful outflows (Lefloch et al. 1998), cloud–cloud collisions (Louvet et al. 2016) or large-scale gas inflows

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(Jiménez-Serra et al. 2010). SiO is an excellent tracer of shocks. In the shocked regions, grain material is destructed via sputtering or vaporization, leading the Si atoms and Si-bearing molecules to be injected into the gas phase and subsequently oxidized to SiO (Schilke et al. 1997; Gusdorf et al. 2008b). In active star-forming regions, SiO abundance is enhanced by up to six orders of magnitudes compared to quiescent regions (Martin-Pintado, Bachiller & Fuente 1992; Codella, Bachiller & Reipurth 1999). Observations of the SiO emission lines toward different sources exhibit a variety of profiles. Previous studies reported that the spectra of SiO usually shows two Gaussian components both corresponding to similar central velocities but different line widths, namely, the broad component and the narrow one (Martin-Pintado et al. 1992; Lefloch et al. 1998). These two SiO components trace different emission regions and may have different origins (Schilke et al. 1997). The broad components are thought to be related to high-velocity shocks from protostellar outflows, and the narrow components are attributed to low-velocity shocks linked to low-velocity motions (see above).

Based on studies targeting the variation of SiO emission toward different evolutionary stages of star formation, several studies found the brighter SiO emission are associated with higher luminosity sources (Codella et al. 1999; Liu et al. 2020c), which would be consistent with the trend that the SiO abundance in warmer sources is higher than the one in infrared-quiet sources (Gerner et al. 2014; Miettinen 2014). Motte et al. (2007) and Sakai et al. (2010) found that younger sources show brighter SiO emission than mid-infrared bright sources. The studies of Miettinen et al. (2006), López-Sepulcre et al. (2011), and Sánchez-Monge et al. (2013) are consistent with a decrease in SiO abundance in more evolved sources. The results that the SiO abundance have no trend among different evolutionary stages also have been reported by Sanhueza et al. (2012), Leurini et al. (2014), Csengeri et al. (2016), and Li et al. (2019a). Recently, Liu et al. (2021c) reported an increasing trend of the SiO line luminosity with bolometric luminosity, but they do not see the relation between the SiO line luminosity and the bolometric luminosity-to-mass ratio. So far, there is no consensus on SiO abundance variation in different evolutionary stages.

During the past decades, a large number of SiO studies toward massive star-forming regions have been conducted. The SiO abundance and excitation variations have been studied by searching for evolutionary trends in different samples (Codella et al. 1999; Miettinen et al. 2006; Motte et al. 2007; Sakai et al. 2010; Gerner et al. 2014; Csengeri et al. 2016; Li et al. 2019a; Liu et al. 2020c). Moreover, Jiménez-Serra et al. (2010), Duarte-Cabral et al. (2014), Louvet et al. (2016), and Cosentino et al. (2020) investigated the mechanisms responsible for the broad and narrow line profile of SiO. However, previous studies have been focused on either individual sources through interferometer arrays or large samples with single-dish observations. The origin of the SiO emission is still an enigma for astronomers without a high resolution survey of SiO emission toward a large sample of sources with interferometers.

The ALMA Three-millimeter Observations of Massive Star-forming regions (ATOMS) survey employed the Band 3 and covered eight spectral windows (two wide spectral windows in upper side band and six spectral windows in lower side band) toward 146 massive star-forming sources (Liu et al. 2020a). The survey provides us larger samples and high resolution to systematically study various molecular gas involved in star formation. In this paper, we statistically analyse SiO emission of 146 sources using the Atacama Compact 7 m Array observations (ACA) to better understand shocked gas under different conditions and in different evolutionary trends. We establish a catalogue of the SiO clumps for future studies. We present the level

of shock activities and estimate the fraction of the shocked gas in the clumps. The paper is organized as follows: the sample selection and observations are presented in Section 2. Section 3 gives our results. We put discussion in Section 4 and summary in Section 5.

2 OBSERVATIONS

2.1 Sample

A sample of 146 massive SFRs from the ATOMS survey were investigated in this paper. The sample sources were selected from the CS $J = 2-1$ line survey of UC HII regions in the Galactic Plane (Bronfman, Nyman & May 1996). The sample sources are complete for protoclusters characterized by bright CS $J = 2-1$ emission ($T_b > 2$ K), implying reasonably dense gas. The basic parameters of the sample were taken from Liu et al. (2020a,b, 2021b; paper I, paper II, and paper III of the series). The distance of the sample sources ranges from 0.4 kpc to 13.0 kpc with a mean value of 4.5 kpc. The clump mass ranges from 5.6 to $2.5 \times 10^5 M_\odot$, with a median value of $1.4 \times 10^3 M_\odot$. The bolometric luminosity ranges from 16 to $8.1 \times 10^6 L_\odot$, with a median value of $5.7 \times 10^4 L_\odot$. The radii ranges from 0.06 to 4.26 pc, with a median value of 0.86 pc. The dust temperature ranges from 18 to 46 K, with a median value of 29 K.

2.2 ALMA Observations

The present study is based on the ATOMS survey data (Project ID: 2019.1.00685.S; PI: Tie Liu). The survey has collected both 12m-array and ACA data. We focus the latter in this work with an aim at compiling a complete catalogue of SiO emission clumps owing to the benefit from the large field of view of the ACA observations. The Atacama Compact 7 m Array (ACA) observations were conducted from 2019 September to mid-November. The typical ACA observing time is ~ 8 min. The angular resolution of ACA observations is $\sim 13.1-13.8$ arcsec and the maximum recovered angular scale is $\sim 53.8-76.2$ arcsec. The SiO $J = 2-1$, HCO⁺ $J = 1-0$, H¹³CO⁺ $J = 1-0$ lines are included in SPWs 1 \sim 6 at the lower side band with the spectral resolutions of 0.21, 0.11, and 0.21 km s⁻¹, respectively (Liu et al. 2021b,a). The H40 α and CS $J = 2-1$ lines are included in SPWs 7 at the upper side band with the spectral resolutions of 1.49 km s⁻¹. The ACA data were calibrated and imaged by CASA software package version 5.6 (McMullin et al. 2007), and more details about data reduction can be found in Paper I.

3 RESULTS

For the identification of SiO clumps, we firstly generate the integrated intensity (Moment 0) maps of SiO emission using channels with signals higher than 3σ . The rms level σ for each source are listed in Tables A1 and A2. In Moment-0 maps, we have identified 171 SiO clumps in 128 sources by eye. We identified SiO clumps by eye because there are not so many SiO clumps within individual sources and the emission peaks of most SiO clumps are clearly separated from each other in these low-resolution ACA images. Therefore, we did not apply any algorithm in clump identification in order to avoid fake detection close to the edges of images where the signal-to-noise levels are low. Then we used the two-dimensional fitting tools (*imfit*) in CASA to fit these SiO clumps one by one. We get deconvolved sizes (the full width at half maximum, FWHM, and position angle, PA), center positions and integrated intensity for these SiO clumps. SiO clumps in the marginal region are excluded. These results are shown

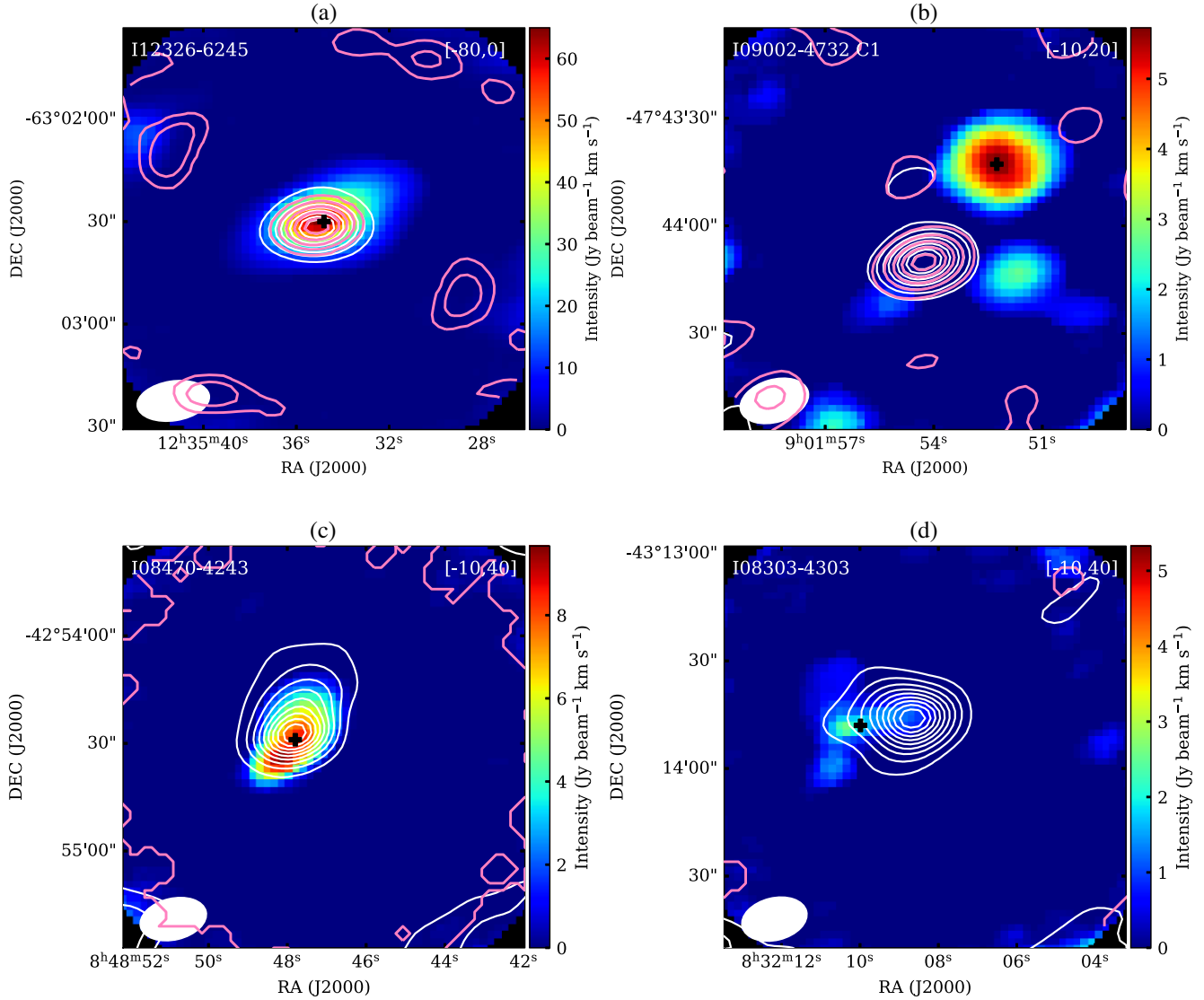


Figure 1. Example sources. The background is SiO (2-1) integrated intensity maps. The white contours are 3 mm continuum emission, and contours are from 10 per cent to 100 per cent in the step of 10 per cent of peak values. The pink contours represent H40 α emission, contours from 10 per cent to 100 per cent in the step of 20 per cent of peak values. The source name is shown on the upper left. The black cross is the central position extracted spectra and the beam size is presented at the lower left corner. The integration ranges are shown in the upper right corner. (A) Panel presents source associated with 3 mm emission and coincided with H40 α emission. (B) Panel shows source separated with 3 mm emission and coincided with H40 α emission. (C) Panel presents source associated with 3mm emission undetected H40 α emission. (D) Panel shows source separated with 3mm emission undetected H40 α emission. All images have a field of view of $2'2''$.

in Tables A1 and A2. Next we extract the spectra of SiO lines toward the peak positions of SiO clumps in all detected sources. The spectra were extracted over the aperture of clumps size or beam size (clumps smaller than the beam size). Examples of the Moment-0 maps and spectra are shown in Appendix A1.

Fig. 1 shows four examples of detected sources. A Moment-0 map of SiO emission overlaid by contours of 3 mm continuum emission and H40 α emission is shown. We classify the sources into four groups based on their different conditions in line emission. The classification criteria are as follows:

(A) 27 SiO clumps in sources containing HII regions: SiO emission associated with both H40 α emission and 3 mm continuum emission.

(B) 59 SiO clumps in sources containing HII regions: SiO emission separated from both H40 α emission and 3 mm continuum emission.

(C) 39 SiO clumps in sources containing non-HII regions: SiO emission associated with 3mm continuum emission.

(D) 46 SiO clumps in sources containing non-HII regions: SiO emission partly separated from 3mm continuum emission.

Fig. 2 present the SiO (2-1), HCO $^+$ (1-0), and CS (2-1) spectra extracted toward four exemplar SiO clumps. We smooth the spectral resolution of SiO and HCO $^+$ to the spectral resolution of CS (1.49 km s $^{-1}$) for comparison. In I12326-6245, I08470-4243, and I08303-4303, the spectra of SiO show high-velocity wings, and we can see two distinct components: a narrow component and a broad component. The broad SiO components especially with red- and/or blue-shifted line wings are likely related to molecular outflows. In I12326-6245, I08470-4243, and I08303-4303, the spectra of HCO $^+$ and CS also show high-velocity wings. In I09002-4732 C1, there

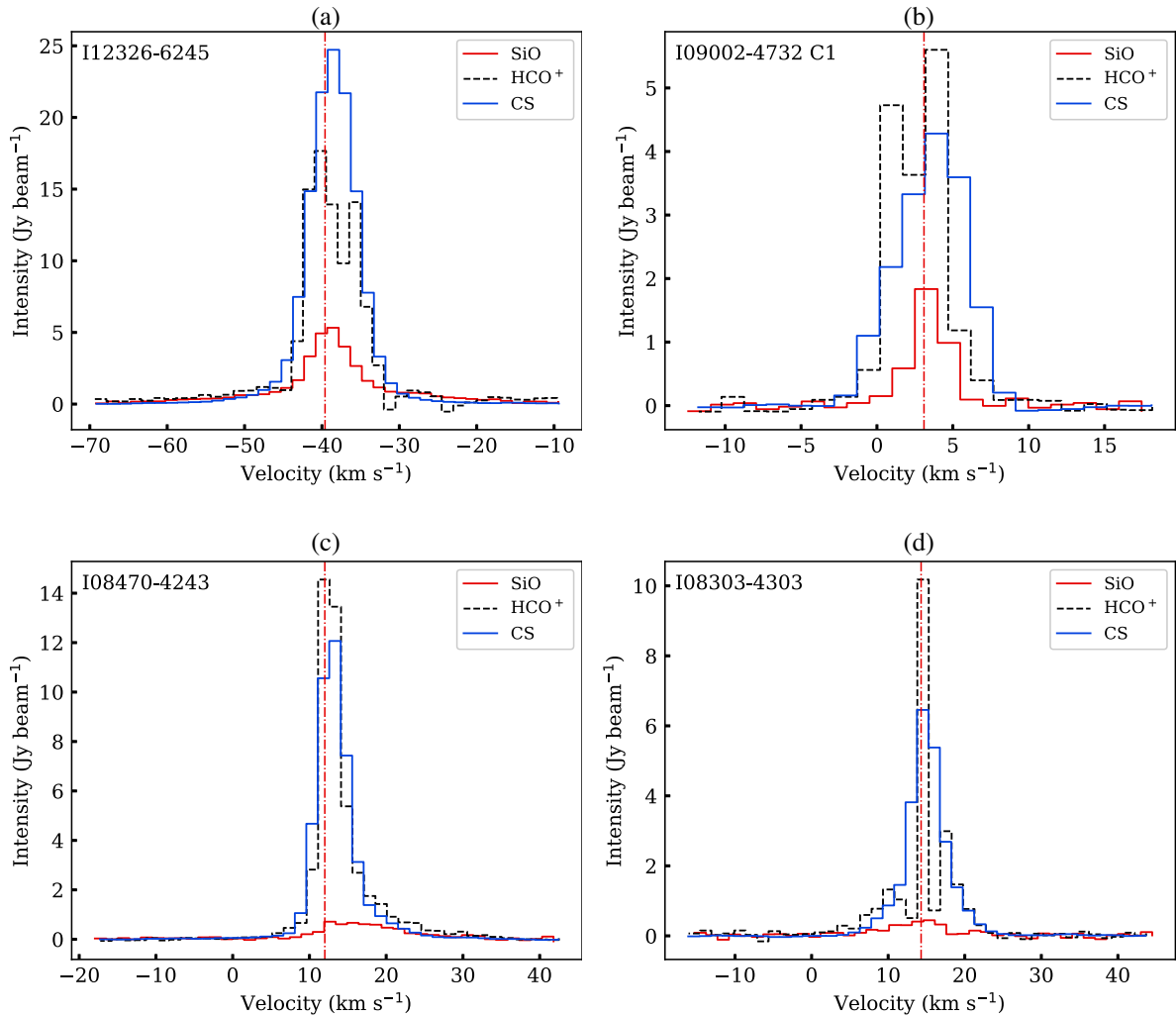


Figure 2. Examples of sources. The red spectrum represents the SiO average spectral extracted over the aperture of SiO clumps or beam. The HCO⁺ and CS spectra are presented as black dashed and blue solid lines. The dash–dotted line indicates the systemic velocity of the source.

is no high-velocity wing emission in all lines, indicating that this source does not have outflows. The spectra of other SiO clumps are shown in Appendix A1.

In most detected SiO clumps, we can see the peak velocity of the narrow components is similar to the systemic velocity (marked by the red dash–dotted line). We thus consider these components coincided with the ambient cloud. In very rare cases such as I08076-3556 (Appendix A1), however, the SiO velocity (~ 40 km s⁻¹) deviated clearly from the systemic velocity (5.9 km s⁻¹) and SiO line emission mainly comes from red-shifted line wings.

3.1 Detection rates of SiO emission

Toward the 146 sources, SiO (2-1) emission was detected in 128 (87.7 per cent) sources, indicating that the presence of shocks is very common in high-mass star-forming regions. In particular, when we inspect the spectra of the sources that do not show strong SiO emission in their Moment-0 maps, we find additional 18 SiO clumps showing weak SiO emission, with peak intensity close to 2σ . We list these weak SiO clumps in Table A2.

Because of the complicated and non-Gaussian SiO line profiles, we instead use their Moment-0 maps, the intensity-weighted velocity

(Moment 1) maps, and the intensity-weighted velocity dispersion (Moment 2) maps to derive their velocity (v), and velocity dispersion (σ_v). The derived parameters of SiO clumps are summarized in Table A1. Notably, the velocity dispersion of SiO emission is mostly larger than the velocity resolution (0.21 km s⁻¹). For the 18 weaker clumps, we use one component Gaussian fit of their averaged spectra to get the line parameters (Intensity, velocity, and velocity dispersion). The derived line parameters are shown in Table A2.

3.2 The velocity dispersion of SiO and the line wings of SiO, HCO⁺, and CS

The velocity dispersions of the detected SiO lines are listed in Tables A1 and A2. For the SiO lines, the range of the velocity dispersion values is 0.3–5.43 km s⁻¹. The mean values is 1.77 km s⁻¹, and the median values is 1.59 km s⁻¹. The histogram of the velocity dispersion is presented in Fig. 3.

To identify strong outflows in these sources, we searched the line wings in SiO, HCO⁺, and CS emission lines. These results are listed in Table A3. Because of relatively high abundance, HCO⁺ emission is a very good tracer of outflows (Myers et al. 1996). Therefore, in outflow regions, HCO⁺ emission is detectable even if SiO emission

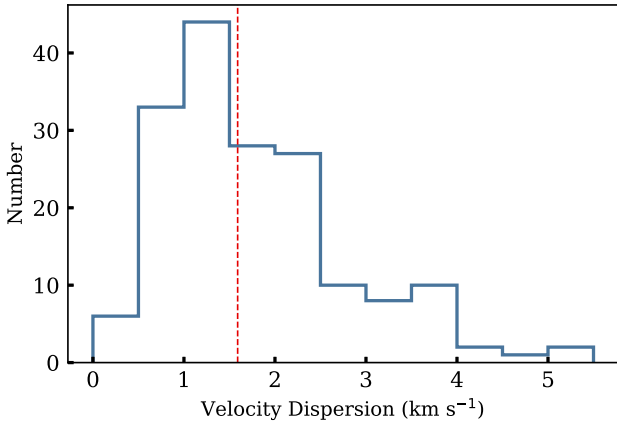


Figure 3. Histogram of the velocity dispersion of the SiO (2-1) lines. The vertical red dashed line represents the median velocity dispersion.

is not detected. However, in some sources the line profile of HCO^+ emission is self-absorbed. We inspect the spectra of CS and find its spectra to be less self-absorbed. As a consequence, we use the line wings of SiO, HCO^+ , and CS together to identify strong outflows. The spectra of SiO, HCO^+ , and CS are shown in Appendix A1. According to the high-velocity line wings, the SiO clumps are divided

into two groups: clumps with strong outflows and without strong outflows. We find 116 clumps are associated with outflows showing wing emission in at least one of the three lines and 50 clumps are not associated with outflows. However, we cannot exclude these clumps without outflows that are not associated with weak outflows. We exclude I17441-2822 spectra in further analysis because this source is close to the Galactic center and shows very complicated line profiles.

3.3 SiO clumps properties

Using the Moment-0 maps of SiO emission, we have identified 171 SiO clumps. We calculated the geometric mean of the major axis FWHM and the minor axis FWHM and got the SiO clumps linear radius. The histogram of the SiO clump radii is presented in Fig. 4. The range of the SiO clump radii is 0.03~0.99 pc. The mean value is 0.3 pc, and the median value is 0.23 pc. In addition, we failed to fit 116 clumps because the shape of SiO clumps is irregular and the size of these SiO clumps is smaller than or close to the beam size. Instead, we give the beam size as these clump sizes, and we marked these clumps in Table A1. The velocities of SiO clumps are approximately consistent with the systemic velocities of the clumps, except for I08076-3556 (Section 3).

In Moment-0 maps, we found that 105 SiO clumps are not spatially coincided with the peak of 3 mm continuum emission with separation

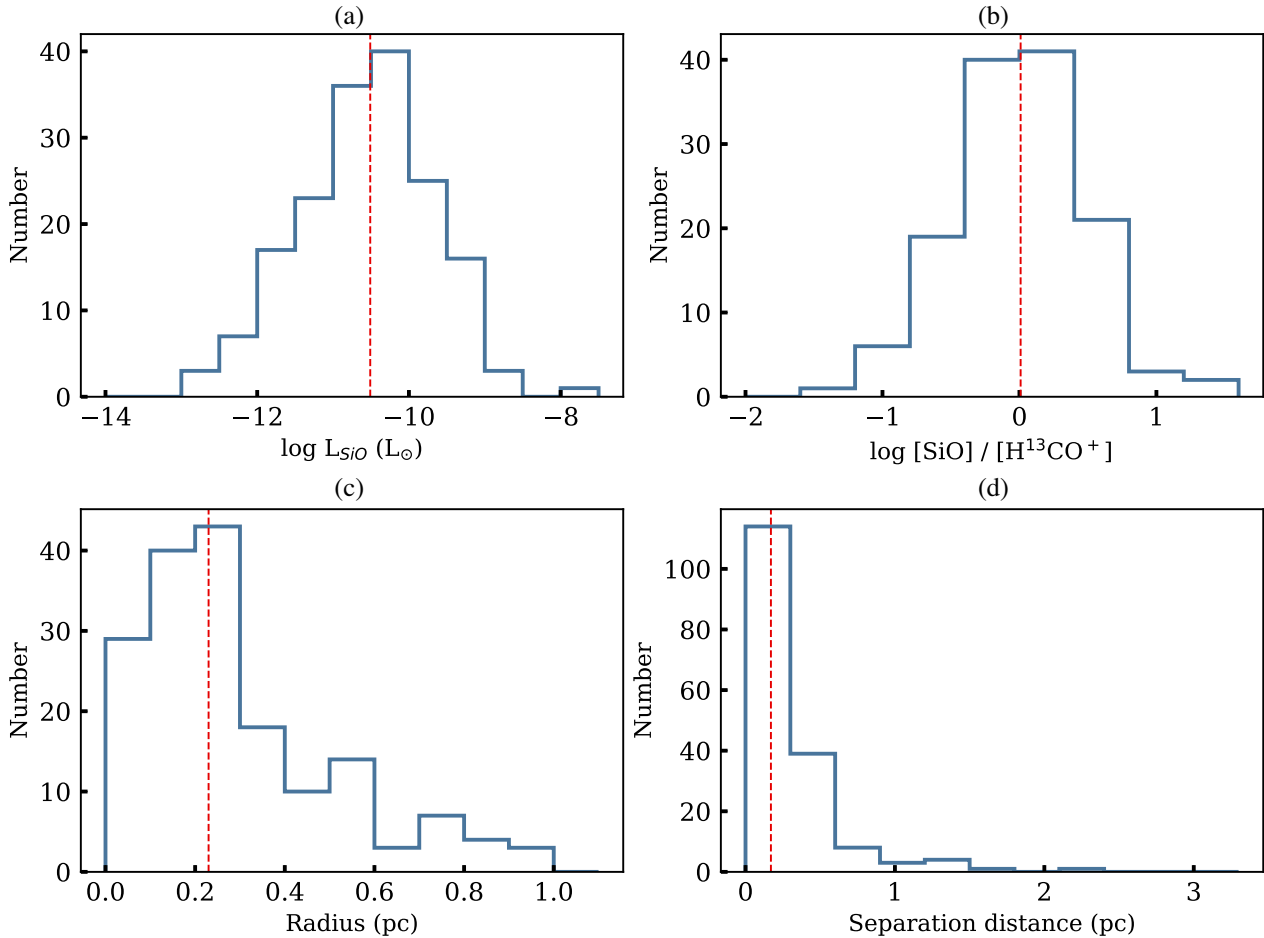


Figure 4. (a) Histogram of the SiO luminosity. (b) Histogram of the $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ ratio. (c) Histogram of separation distance. (d) Histogram of the SiO clump radius. The vertical red dashed line represents the median values of the parameter.

larger than half of beam size. There are 66 SiO clumps associated with 3 mm continuum emission. We derived the distances between the central positions of SiO clumps and the peak positions of the 3 mm continuum emission. These results are listed in Table A3. The histogram of the separation distance is presented in Fig. 4. The range of the separation is 0~3.35 pc. The mean value is 0.3 pc, and the median value is 0.17 pc. An evident tail is presented in the separation histogram which represents these SiO clumps away from the 3 mm continuum emission may not be caused by outflows. This separation between the thermal dust and SiO molecular gas is similar to the results of López-Sepulcre et al. (2016) and Li et al. (2020).

For the 128 sources with SiO emission, 63 sources have H40 α emission above 3σ . The H40 α emission shows a compact structure and is coincident with the 3 mm continuum emission, indicating the existence of compact HII regions. For some of these sources, we find that SiO clumps are surrounding the H40 α emission, indicating the possible existence of shocks induced by interaction between HII regions and their surrounding molecular clouds (Cosentino et al. 2020; Liu et al. 2020a). We will investigate the properties of shocked gas caused by HII regions using the high resolution 12-m array data in a forthcoming work.

We calculate the SiO (2-1) luminosity (L_{SiO}) of the SiO clumps using the integrated intensity and the source distance. L_{SiO} can be derived from the formula:

$$L_{\text{SiO}} = 4\pi \times d^2 \times \int F_{\nu} d\nu, \quad (1)$$

where d is the distance to the source and ν represents the velocity. $\int F_{\nu} d\nu$ is the integrated intensity of the SiO clump.

L_{SiO} from 1.74×10^{-13} to $1.07 \times 10^{-8} L_{\odot}$. The mean value is $2.69 \times 10^{-11} L_{\odot}$, and the median value is $3.1 \times 10^{-11} L_{\odot}$. Fig. 4 (a) shows the number distribution of the SiO luminosity. We used the sum L_{SiO} in one source for statistic analysis. More details on L_{SiO} will be discussed in Section 4.2.

3.4 The fraction of shocked gas

The H¹³CO⁺ emission is a good tracer of relatively quiescent gas. The H¹³CO⁺ abundance does not vary substantially with time (Nomura & Millar 2004). Therefore, column density of H¹³CO⁺ could reflect the dense gas of the clump. Sakai et al. (2010) used SiO column density against H¹³CO⁺ column density to represent the fraction of shocked gas in a dense clump. Assuming both SiO and H¹³CO⁺ emission are optically thin and have constant excitation temperatures, the integrated intensity ratios of SiO emission and H¹³CO⁺ emission can approximately reflect the relative fraction of the shocked gas in the clump, and later we use $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ to represent this ratio. The derived ratios are shown in Table A3. We inspected H¹³CO⁺ spectra and found that 12 sources have absorption features in their spectra. As a result, in the latter analysis, we ignore these 12 sources. For sources containing multiple SiO clumps, we calculate an average $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ ratio. The range of $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ is 0.04~42.79. The mean values is 2.41, and the median values is 1.02. The histogram of $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ of all sources is presented in Fig. 4 (b).

4 DISCUSSION

4.1 The line broadening of SiO emission

The broad components of SiO emission in our sample are likely caused by the high-velocity gas driven by energetic outflows. The high detection rate of the velocity wings of SiO emission (60 per cent) suggests the presence of outflows. Our finding divides

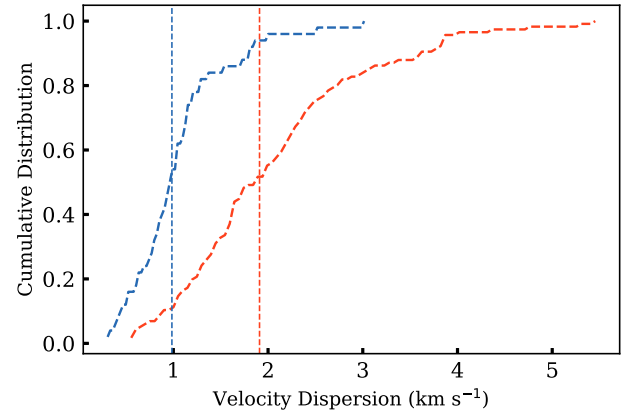


Figure 5. The velocity dispersion distributions for SiO clumps with outflows and without outflows (the red and blue lines). The vertical dashed lines represent the median velocity dispersion of SiO clumps in the two groups: 1.91 km s⁻¹ (red line) and 0.99 km s⁻¹ (blue line) for clumps with and without strong outflows, respectively.

the SiO clumps into two groups (Section 3.2). In the group with outflows, the median velocity dispersion of the SiO emission is as large as 1.91 km s⁻¹. In the other group without outflows, the narrow components of SiO emission are common and the median velocity dispersion of the SiO emission is 0.99 km s⁻¹. This narrow SiO emission could be created by unresolved low mass outflows, cloud–cloud collision, or gas inflows.

We plot the cumulative distribution of the SiO velocity dispersion for these two groups in Fig. 5. The SiO clumps with outflows are presented as red curve, while the clumps without outflows are shown as blue curve. For the SiO clumps with strong outflows, the velocity dispersion values range from 0.58 to 5.43 km s⁻¹ with a mean value of 2.08 km s⁻¹ and a standard deviation of 1.00 km s⁻¹. In contrast, for the SiO clumps without strong outflows, the velocity dispersion values are from 0.32 to 3 km s⁻¹, with a mean value of 1.06 km s⁻¹ and a standard deviation of 0.53 km s⁻¹. In addition, we use the Kolmogorov–Smirnov (KS) test to compare these distributions. The P-value returned by the KS test is the probability that the two samples were drawn from the same distributions. If the P-value is smaller than 5 per cent, we conclude that the two samples were drawn from different distributions. The KS test gives a P-value of about 10⁻¹², indicating that the velocity dispersion distribution of these two groups is very different. The clumps associated with outflows show significantly larger velocity dispersion in SiO emission on average.

In shocked gas, the SiO velocity dispersion is attributed to non-thermal broadening. Gusdorf et al. (2008a) found that the SiO intensity and line width as the shock dissipates. In Fig. 6, we plot the velocity dispersion of the four groups (Section 3) against dust temperature (T_{d}), the particle number density (n) of the clumps, the SiO luminosity (L_{SiO}), and the bolometric luminosity to mass ratio (L_{bol}/M) of clumps from Liu et al. (2020a), respectively. The particle number density can be derived as

$$n = \frac{3M_{\text{gas}}}{4\pi R^3 m_{\text{H}} \mu}, \quad (2)$$

M and R the clump mass and effective radii compiled in Liu et al. (2020a). n is the particle number density. m_{H} is the mass of a hydrogen atom. $\mu = 2.37$ is the mean molecular weight per ‘free particle’. T_{d} and L_{bol}/M are potential evolutionary tracers for high-mass protostars and their natal clumps (Molinari et al. 2008; Elia et al. 2021). More evolved sources show higher T_{d} and L_{bol}/M .

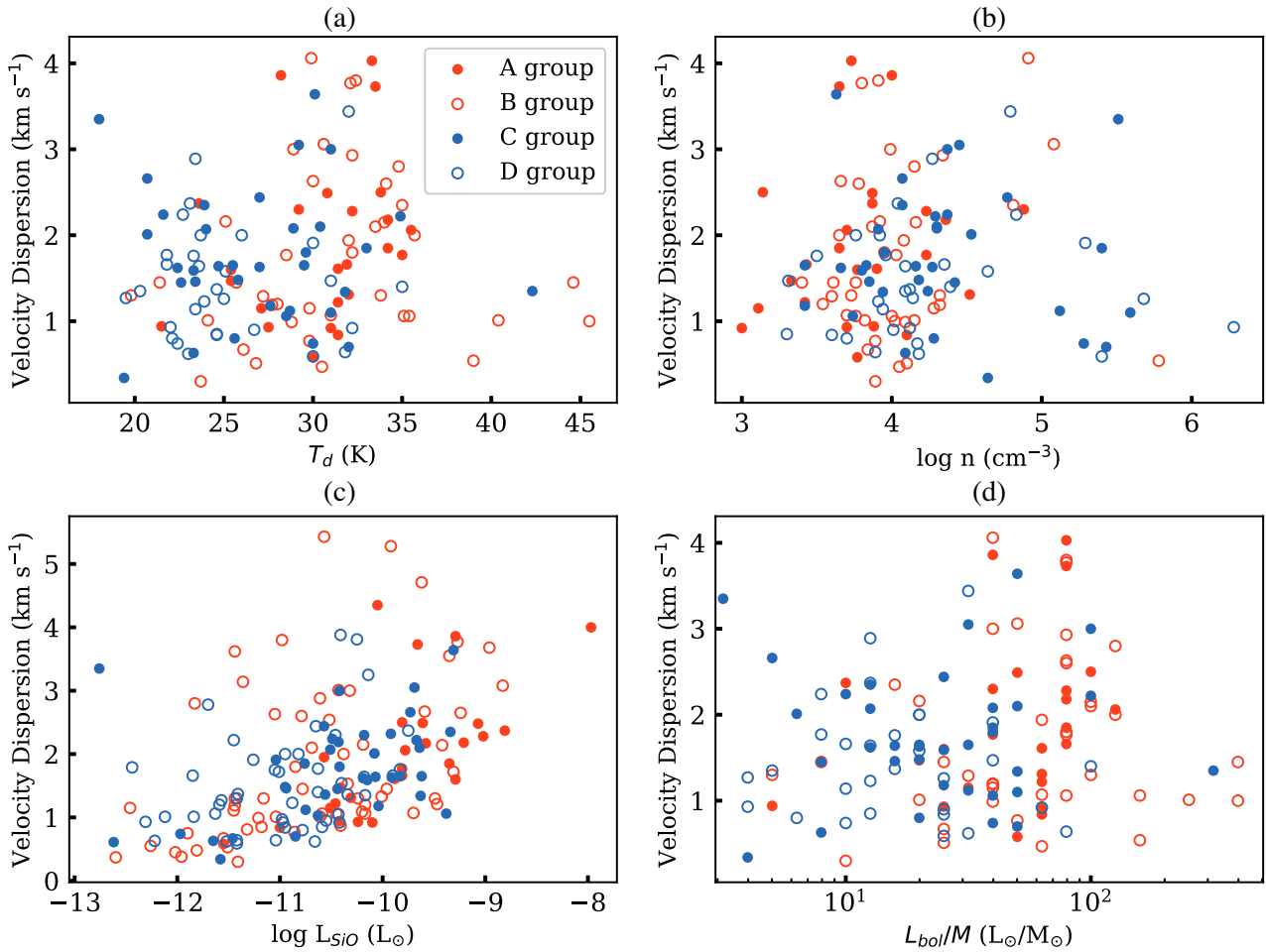


Figure 6. (a) The velocity dispersion of SiO emission against dust temperature (T_d). (b) The velocity dispersion of SiO emission versus the particle density (n) of the clumps. (c) The velocity dispersion of SiO emission against the SiO clump radius. (d) The velocity dispersion of SiO emission versus the bolometric luminosity to mass ratio (L_{bol}/M). The filled red circles (A group) represent the SiO clumps containing HII regions are associated with 3 mm continuum emission. The empty red circles (B group) represent the SiO clumps containing HII regions are separated with 3 mm continuum emission. The filled blue circles (C group) represent the SiO clumps containing non-HII regions are associated with 3 mm continuum emission. The empty blue circles (D group) represent the SiO clumps containing non-HII regions are separated with 3 mm continuum emission.

As shown in Fig. 6, there is no obvious trend between the velocity dispersion of all groups SiO emission and either T_d or n . There is also no statistically significant correlation between the velocity dispersion of all groups and L_{bol}/M . We use the Spearman-rank correlation test between those quantities, and the correlation coefficient is 0.15, 0.06, and 0.13, respectively. In our samples, we found no obvious variations in the velocity dispersion of the SiO emission against T_d , n , and L_{bol}/M , which indicates that the strengths of shocks are not so different under different physical conditions or at various evolutionary stages. Our results are consistent with the results of Csengeri et al. (2016) and Li et al. (2019a), who also found the line width of SiO emission is nearly constant at different evolutionary stages of clumps. In A, B, C groups, the L_{SiO} has a positive correlation with the velocity dispersion of SiO emission, with a correlation coefficient of 0.72, 0.55, and 0.44, respectively. These results suggest that the more intense SiO sources are associated with more active outflows. Whereas in the D group, the L_{SiO} does not correlate with the velocity dispersion of SiO emission. It means its presence of relatively strong SiO emission sources has smaller velocity dispersion. One would expect these SiO clumps may be due

to the aging of outflows as it moves away from its driving source. An alternative explanation is to consider some of these SiO sources caused by unresolved lower mass protostars, cloud–cloud collision, or gas inflows. We will investigate these scenarios in the following work with high resolution 12-m array data.

4.2 The excitation condition for SiO emission

We examine the relationship between the bolometric luminosity and SiO emission-line luminosity in all groups. Fig. 7 shows the SiO line luminosity versus the bolometric luminosity in the upper panel. We exclude two low-mass star-forming sources (I08076-3556 and I11590-6452; Liu et al. 2020a). We can see an increasing trend between these two quantities in all groups. But in the A and B groups (with HII regions), the increasing trend is much steeper. Thus we get two linear fits. In the groups with HII regions, a linear fit is $f(x) = (1.06 \pm 0.12)x - 15.77$ and in the groups without HII regions, another linear fit is $f(x) = (0.54 \pm 0.11)x - 12.84$. The Spearman rank correlation coefficient (ρ) is 0.7 and 0.58, respectively. This implies that higher luminosity sources could have brighter SiO emission,

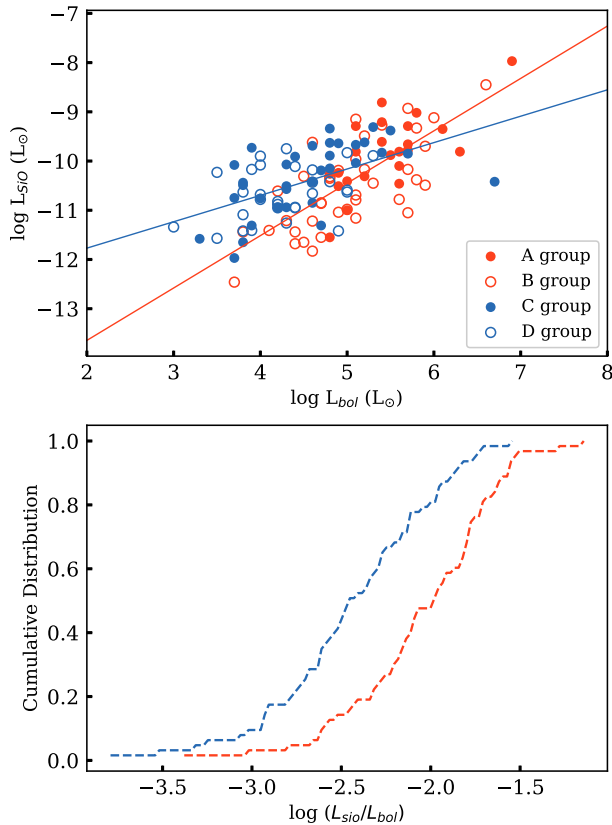


Figure 7. Upper panel: SiO (2-1) line luminosity L_{SiO} versus bolometric luminosity L_{bol} . The red line shows a linear fit of $f(x) = (1.06 \pm 0.12)x - 15.77$ and the blue line a linear fit of $f(x) = (0.54 \pm 0.11)x - 12.84$. The symbols are the same with Fig. 6. Lower panel: The $L_{\text{SiO}}/L_{\text{bol}}$ distributions for SiO clumps with HII regions and without HII regions (the red and blue lines).

indicating stronger shock activity in more luminous proto-clusters. These results are consistent with the results of Codella et al. (1999) and Liu et al. (2021c), who both found a trend of brighter SiO emission in higher luminosity sources. As for the different slope of $L_{\text{SiO}}/L_{\text{bol}}$, this could be due to the different evolutionary stages of these sources. Next, we plot the cumulative distribution of the

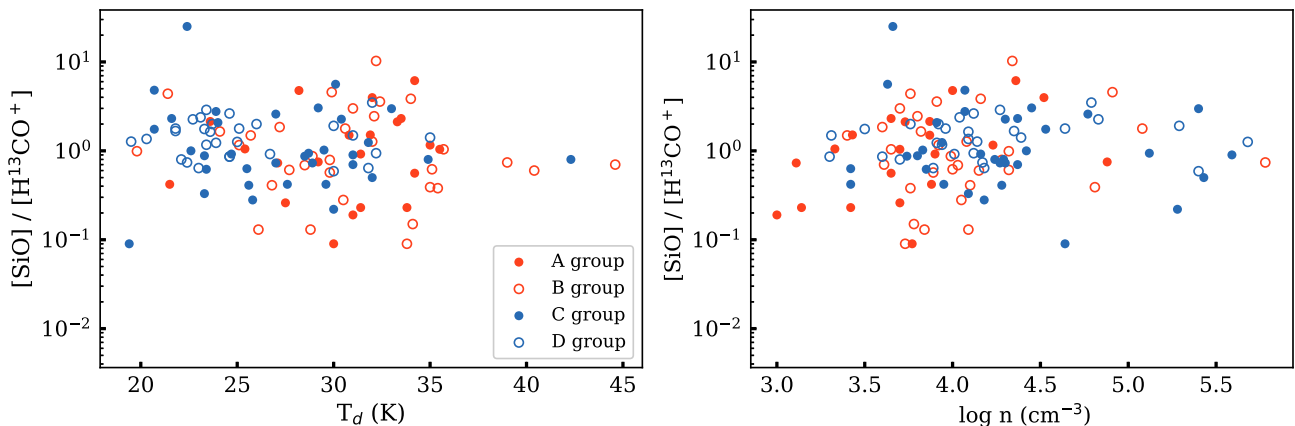


Figure 8. Left: $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ against dust temperature (T_{d}). Right: $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ versus particle number density (n). The symbols are the same as in Fig. 6.

$L_{\text{SiO}}/L_{\text{bol}}$ for the SiO clumps with HII regions and without HII regions in the lower panel. The KS test reveals that the p-value is 10^{-5} , indicating the $L_{\text{SiO}}/L_{\text{bol}}$ for these two groups is from different distributions. Sources containing HII regions show relatively lower $L_{\text{SiO}}/L_{\text{bol}}$ ratios, indicating that HII regions may have negative feedback on surrounding gas and may suppress further star formation, leading to less energetic outflows and thus weaker shocks.

Fig. 8 shows $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ intensity ratio as a function of T_{d} and n in all groups ($p = -0.13, 0.12$, respectively). However, we find the fraction of shocked gas increase as the n increase in A group ($p = 0.5$). Summarizing, in a large fraction of sources (except for the A group), the fraction of shocked gas shows no essential dependence on the T_{d} and n . This indicates that SiO emission is not affected by thermal condition but is more likely affected by shock activities. However, H^{13}CO^+ abundance may not be constant with time (Sanhueza et al. 2012), which may affect the interpretation of $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ ratios.

The bolometric luminosity of a molecular clump will increase as the high mass star evolves, while its mass will decrease. Thus the bolometric luminosity to mass ratio (L_{bol}/M) can be a good tracer of the evolutionary stage of star formation (Molinari et al. 2008, 2016; Elia et al. 2021). L_{bol}/M values can distinguish between the young and evolved sources, and its low values are related to young sources. In the left-hand panel of Fig. 9, we plot the SiO luminosity (L_{SiO}) against L_{bol}/M in all groups ($p = 0.3, -0.04, 0.32, \text{ and } -0.12$, respectively). The L_{SiO} does not vary with L_{bol}/M , suggesting that SiO luminosity has no relationship with evolutionary stages, which is similar to the results of Liu et al. (2021c). The right-hand panel shows $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ versus L_{bol}/M . There is also no correlation between $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ and L_{bol}/M . This implies that the fraction of shocked gas in high-mass star-forming clumps does not change obviously in dense gas at various evolutionary stages. This is consistent with the results reported by Csengeri et al. (2016) and Li et al. (2019a).

5 SUMMARY

In this work, we used ALMA ACA observational data for a statistical study of shocked gas toward 146 massive star-forming regions. We analyse the variation of SiO emission under different physical conditions and evolutionary stages. The main results are summarized as follows:

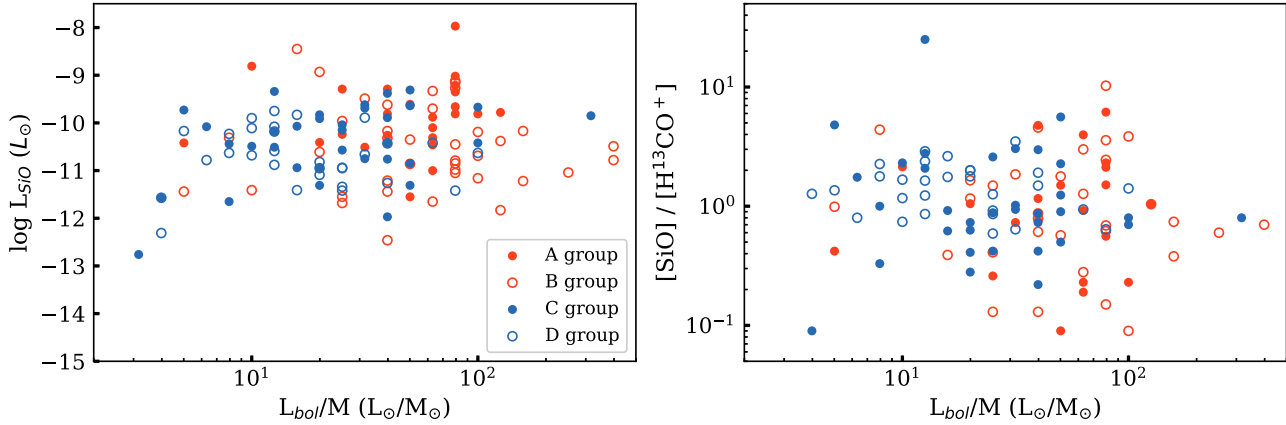


Figure 9. Left: The SiO line luminosity versus L_{bol}/M in the clumps. Right: $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ versus L_{bol}/M . The symbols are the same with Fig. 6.

(1) Among the entire sample, we have detected SiO emission in 128 sources, which contain 171 SiO clumps. SiO (2-1) emission has a high detection rate of 87.7 per cent, above 3σ .

(2) The velocity dispersion of SiO line emission ranges from 0.3 to 5.43 km s^{-1} , with a median velocity dispersion of 1.59 km s^{-1} . Based on the high-velocity emission wings in SiO, HCO^+ , and CS lines, we divided the clumps into two groups. There are 116 SiO clumps associated with strong outflows, which show high-velocity wing emission in at least one line, while the other 50 SiO clumps show no wing emission in the three lines and seem to be not associated with energetic outflows. The two groups have an obvious difference in the velocity dispersion of SiO emission. The median velocity dispersion of outflow sources is 1.91 km s^{-1} , which is significantly larger than that (0.99 km s^{-1}) of the non-outflow sources, indicating that outflow activities have a great influence on the strongly shocked gas. In particular, SiO emission clumps with small velocity dispersion could be formed by low-velocity shocks that are induced by either HII regions or other large-scale compression flows (e.g. cloud–cloud collision), which will be investigated thoroughly in forthcoming works with higher resolution ALMA 12-m array data.

(3) We find a positive correlation between the SiO line luminosity and the bolometric luminosity, implying stronger shock activities associated with more luminous proto-clusters. We also find the SiO clumps with HII regions show a lower $L_{\text{SiO}}/L_{\text{bol}}$ ratio than the SiO clumps without HII regions. In most sources, the velocity dispersion of SiO emission and $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ show no obvious correlations with dust temperature (T_d) and particle number density (n). These results indicated that the SiO emission is not likely affected by thermal conditions but is more likely affected by shock activities. In addition, we do not see clear correlations between the SiO line luminosity and L_{bol}/M . There is also no robust trend in the $[\text{SiO}]/[\text{H}^{13}\text{CO}^+]$ and L_{bol}/M relation. This implies that the fraction of shocked gas in dense gas does not change obviously at various evolutionary stages.

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DATA AVAILABILITY

The data underlying this article are available in the article and in ALMA archive.

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SUPPORTING INFORMATION

Supplementary data are available at [MNRAS](https://academic.oup.com/mnras) online.

Figure A1. All detected sources. Left: The background is SiO (2-1) integrated intensity maps.

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APPENDIX A:

Fig. A1 present the moment maps and spectra for some exemplar sources. The images for all sources are available as on-line supplementary material. Tables A1, A2, and A3 show the derived parameters for SiO clumps.

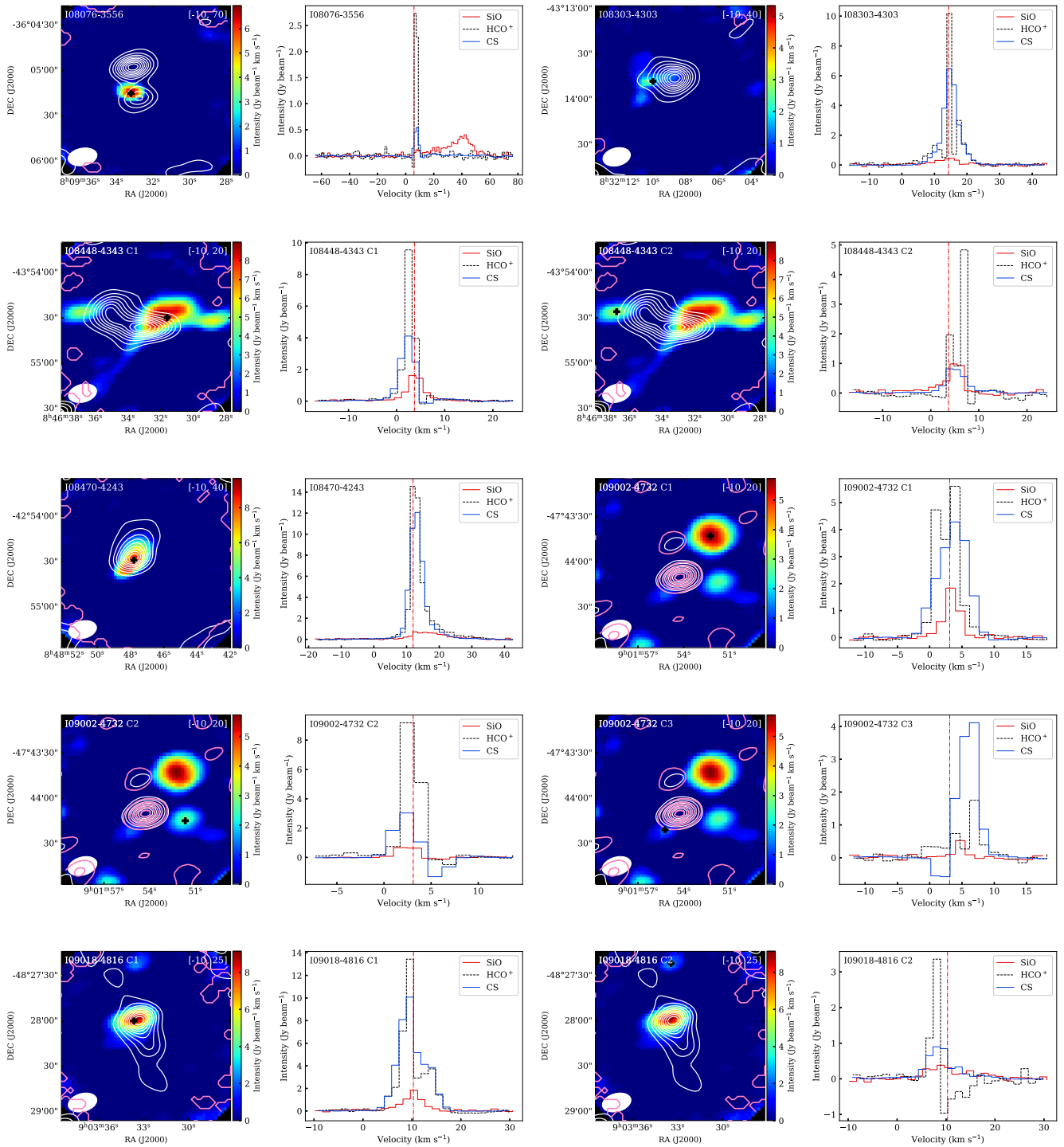


Figure A1. Examples of sources. Left: The background is SiO (2-1) integrated intensity maps. The white contours are 3mm continuum emission, and contours are from 10 per cent to 100 per cent in the step of 10 per cent of peak values. The pink contours represent H40 α emission, and contours are from 10 per cent to 100 per cent in the step of 20 per cent of peak values. The black cross is the position extracted spectra. The source name is shown on the upper left. The integration velocity ranges are shown in the upper right corner. Right: The clump averaged SiO, HCO⁺ and CS spectra are shown in red, black dashed, and blue lines, respectively. The vertical dash-dotted line indicates the systemic velocity of the source. The full images are available as supplementary material.

Table A1. SiO (2-1) line parameters and clump properties in the region with clear detections.

| IRAS | RA (J2000) | DEC (J2000) | R_a (pc) | $\int F_\nu d\nu$ (Jy km s ⁻¹) | v (km s ⁻¹) | σ_v (km s ⁻¹) | | | | | $\log L_{\text{SiO}}$ (L_\odot) | σ (Jy beam ⁻¹) |
|----------------|---------------|----------------|-------------------|---|------------------------------|-------------------------------------|------------------|-------------------|---------------------|------------------|--|--------------------------------------|
| | | | | | | D_{min} | D_{max} | D_{mean} | D_{median} | D_{std} | | |
| I08076-3556 | 08:09:33.21 | -36:05:14.2 | 0.03 ^a | 3.47 ± 0.26 | 39.4 ± 2.47 | 0.96 | 8.6 | 3.71 | 3.35 | 3.26 | -12.76 ± 0.031 | 0.099 |
| I08303-4303 | 08:32:10.05 | -43:13:47.71 | 0.05 ± 0.066 | 2.3 ± 0.61 | 14.61 ± 0.23 | 0.17 | 1.69 | 0.67 | 0.59 | 0.17 | -11.42 ± 0.102 | 0.123 |
| I08448-4343 C1 | 08:46:31.64 | -43:54:29.1 | 0.07 ± 0.016 | 24.7 ± 4.5 | 3.6 ± 1.94 | 0.35 | 2.6 | 1.29 | 1.3 | 0.29 | -11.42 ± 0.073 | 0.124 |
| C2 | 08:46:36.78 | -43:54:26.2 | 0.05 ^a | 4.96 ± 0.36 | 4.11 ± 0.92 | 0.32 | 2.07 | 1.08 | 1.01 | 0.22 | -12.12 ± 0.03 | 0.124 |
| I08470-4243 | 08:48:47.86 | -42:54:28.9 | 0.15 ^a | 12.4 ± 1.2 | 14.66 ± 4.17 | 0.32 | 5.16 | 2.21 | 1.85 | 1.65 | -10.76 ± 0.04 | 0.121 |
| I09002-4732 C1 | 09:01:52.18 | -47:43:42.7 | 0.06 ± 0.019 | 10.46 ± 0.84 | 2.78 ± 0.08 | 0.29 | 1.27 | 0.8 | 0.81 | 0.05 | -11.32 ± 0.034 | 0.128 |
| C2 | 09:01:51.71 | -47:44:14.1 | 0.09 ^a | 2.41 ± 0.3 | 1.86 ± 0.02 | 0.17 | 0.56 | 0.38 | 0.38 | 0.01 | -11.96 ± 0.051 | 0.128 |
| C3 | 09:01:55.28 | -47:44:21.7 | 0.09 ^a | 0.55 ± 0.05 | 4.08 ± 0.06 | 0.17 | 0.59 | 0.36 | 0.37 | 0.02 | -12.6 ± 0.038 | 0.128 |
| I09018-4816 C1 | 09:03:33.61 | -48:27:59.3 | 0.09 ± 0.047 | 11.11 ± 0.9 | 9.64 ± 0.31 | 0.3 | 1.9 | 1.04 | 1.03 | 0.21 | -10.63 ± 0.034 | 0.115 |
| C2 | 09:03:33.4 | -48:27:21.6 | 0.19 ^a | 1.21 ± 0.16 | 7.92 ± 0.95 | 0.39 | 5.24 | 1.49 | 1.2 | 0.71 | -11.59 ± 0.054 | 0.115 |
| I09094-4803 | 09:11:08.42 | -48:15:43.0 | 0.71 ^a | 0.76 ± 0.07 | 74.19 ± 0.04 | 0.17 | 0.8 | 0.54 | 0.62 | 0.04 | -10.66 ± 0.038 | 0.128 |
| I10365-5803 | 10:38:33.17 | -58:19:14.4 | 0.19 ^a | 3.02 ± 0.34 | -22.24 ± 6.94 | 0.36 | 2.53 | 1.73 | 1.91 | 0.38 | -11.26 ± 0.046 | 0.093 |
| I11298-6155 | 11:32:05.36 | -62:12:26.3 | 0.78 ^a | 1.55 ± 0.1 | 33.13 ± 0.32 | 0.72 | 1.87 | 1.36 | 1.31 | 0.14 | -10.31 ± 0.027 | 0.124 |
| I11332-6258 | 11:35:32.00 | -63:14:45.1 | 0.15 ^a | 0.95 ± 0.04 | -15.68 ± 0.43 | 0.17 | 1.16 | 0.79 | 0.74 | 0.04 | -11.97 ± 0.018 | 0.125 |
| I11590-6452 | 12:01:39.09 | -65:09:03.7 | 0.03 ^a | 9.82 ± 0.96 | 1.68 ± 0.36 | 0.17 | 2.37 | 0.87 | 0.93 | 0.12 | -12.31 ± 0.041 | 0.123 |
| I12320-6122 | 12:34:52.43 | -61:39:52.0 | 0.14 | 4.48 ± 0.71 | -43.35 ± 1.25 | 0.29 | 3.32 | 1.42 | 1.45 | 0.58 | -10.78 ± 0.064 | 0.130 |
| I12326-6245 | 12:35:34.85 | -63:02:29.4 | 0.23 ± 0.039 | 92.9 ± 4.5 | -39.9 ± 2.41 | 0.53 | 6.8 | 2.5 | 2.18 | 2.35 | -9.21 ± 0.021 | 0.123 |
| I12572-6316 | 13:00:24.41 | -63:32:31.8 | 0.91 ^a | 0.91 ± 0.01 | 29.85 ± 0.21 | 0.17 | 1.18 | 0.82 | 0.94 | 0.09 | -10.42 ± 0.005 | 0.131 |
| I13079-6218 | 13:11:14.11 | -62:34:45.4 | 0.12 ± 0.026 | 114.3 ± 3 | -40.24 ± 1.13 | 0.75 | 7.14 | 3.86 | 3.86 | 3.59 | -9.29 ± 0.011 | 0.138 |
| I13111-6228 | 13:14:26.50 | -62:44:26.9 | 0.3 ^a | 0.62 ± 0.06 | -38.83 ± 0.48 | 0.32 | 0.93 | 0.59 | 0.58 | 0.02 | -11.55 ± 0.04 | 0.123 |
| I13134-6242 | 13:16:43.88 | -62:58:32.5 | 0.3 ^a | 45 ± 2.3 | -31.78 ± 2.66 | 0.59 | 5.2 | 2.97 | 3.05 | 1.78 | -9.69 ± 0.022 | 0.125 |
| I13140-6226 | 13:17:15.68 | -62:42:27.1 | 0.3 ^a | 7.94 ± 0.56 | -34.56 ± 0.65 | 0.17 | 2.86 | 1.48 | 1.45 | 0.6 | -10.44 ± 0.03 | 0.138 |
| I13291-6249 | 13:32:32.05 | -63:05:08.3 | 0.61 ^a | 17.7 ± 2.9 | -32.62 ± 2.78 | 0.29 | 7.84 | 2.16 | 1.3 | 3.14 | -9.49 ± 0.066 | 0.137 |
| I13295-6152 | 13:32:52.90 | -62:07:49.2 | 0.31 ^a | 0.55 ± 0.06 | -45.08 ± 0.03 | 0.17 | 0.45 | 0.32 | 0.34 | 0.0 | -11.58 ± 0.045 | 0.129 |
| I13471-6120 | 13:50:44.03 | -61:35:07.5 | 0.44 ^a | 3.82 ± 0.47 | -59.11 ± 1.01 | 0.23 | 2.22 | 1.15 | 1.06 | 0.31 | -10.45 ± 0.05 | 0.119 |
| I13484-6100 | 13:51:58.44 | -61:15:36.5 | 0.24 ± 0.086 | 25.6 ± 2.6 | -54.99 ± 0.26 | 0.47 | 4.14 | 1.52 | 1.34 | 0.62 | -9.63 ± 0.042 | 0.127 |
| I14013-6105 | 14:04:54.67 | -61:20:07.6 | 0.33 ^a | 1.88 ± 0.19 | -55.31 ± 0.11 | 0.42 | 1.0 | 0.81 | 0.84 | 0.03 | -11 ± 0.042 | 0.126 |
| I14164-6028 | 14:20:08.47 | -40:42:01.6 | 0.26 ^a | 5.58 ± 0.27 | -46.94 ± 0.05 | 0.35 | 2.01 | 1.15 | 1.12 | 0.23 | -10.75 ± 0.021 | 0.120 |
| I14212-6131 | 14:25:04.65 | -61:44:55.8 | 0.24 ± 0.045 | 33.7 ± 3.1 | -49.99 ± 1.08 | 0.49 | 2.96 | 1.72 | 1.66 | 0.44 | -9.9 ± 0.038 | 0.127 |
| I14453-5912 | 14:49:06.37 | -59:24:36.3 | 0.13 | 9.8 ± 1.4 | -40.79 ± 0.26 | 0.23 | 1.58 | 0.94 | 1.01 | 0.12 | -10.61 ± 0.058 | 0.148 |
| I14498-5856 C1 | 14:53:43.74 | -59:08:54.0 | 0.23 ^a | 2.88 ± 0.34 | -50.6 ± 0.12 | 0.21 | 1.37 | 0.79 | 0.64 | 0.15 | -11.04 ± 0.048 | 0.141 |
| C2 | 14:53:44.58 | -59:09:29.6 | 0.23 ^a | 0.75 ± 0.04 | -51.97 ± 0.66 | 0.22 | 1.79 | 1.11 | 1.06 | 0.26 | -11.63 ± 0.023 | 0.141 |
| I15290-5546 | 15:32:52.77 | -55:56:04.3 | 0.47 ^a | 15.36 ± 0.97 | -85.76 ± 2.44 | 0.23 | 6.24 | 3.73 | 3.73 | 3.21 | -9.66 ± 0.027 | 0.148 |
| I15394-5358 | 15:43:16.66 | -54:07:14.7 | 0.2 ± 0.023 | 80.5 ± 6.3 | -41.15 ± 8.28 | 0.41 | 3.51 | 1.96 | 2.01 | 0.71 | -10.08 ± 0.033 | 0.158 |
| I15408-5356 | 15:44:43.32 | -54:05:20.8 | 0.2 ± 0.037 | 62.5 ± 7.9 | -36.54 ± 1.28 | 0.55 | 4.54 | 2.27 | 2.15 | 0.82 | -10.19 ± 0.052 | 0.149 |
| I15411-5352 C1 | 15:44:59.27 | -54:02:25.5 | 0.13 ^a | 1.22 ± 0.1 | -43.09 ± 0.05 | 0.21 | 1.77 | 0.79 | 0.75 | 0.14 | -11.9 ± 0.034 | 0.148 |
| C2 | 15:45:00.13 | -54:01:39.4 | 0.13 ^a | 0.91 ± 0.12 | -43.25 ± 2.08 | 0.17 | 1.76 | 0.48 | 0.45 | 0.07 | -12.02 ± 0.054 | 0.148 |
| I15439-5449 C1 | 15:47:46.18 | -54:58:16.6 | 0.24 ^a | 0.46 ± 0.05 | -55.71 ± 0.45 | 0.32 | 0.9 | 0.54 | 0.48 | 0.02 | -11.81 ± 0.045 | 0.148 |
| C2 | 15:47:48.78 | -54:58:10.2 | 0.24 ^a | 0.16 ± 0.08 | -54.44 ± 0.14 | 0.3 | 0.92 | 0.55 | 0.55 | 0.03 | -12.26 ± 0.176 | 0.148 |
| I15520-5234 C1 | 15:55:50.17 | -52:43:13.8 | 0.24 ± 0.027 | 202 ± 16 | -41.66 ± 2.55 | 0.58 | 5.73 | 3.26 | 3.55 | 1.52 | -9.35 ± 0.033 | 0.156 |
| C2 | 15:55:48.04 | -52:43:09.4 | 0.2 ± 0.042 | 118 ± 11 | -45.68 ± 0.66 | 0.91 | 2.85 | 2.1 | 2.17 | 0.27 | -9.58 ± 0.039 | 0.156 |
| I15522-5411 | 15:56:07.13 | -54:20:02.6 | 0.2 ^a | 0.95 ± 0.1 | -47.44 ± 0.07 | 0.3 | 1.17 | 0.66 | 0.63 | 0.06 | -11.65 ± 0.043 | 0.157 |
| I15557-5215 | 15:59:40.96 | -52:23:27.6 | 0.3 ^a | 36.8 ± 2.6 | -68.02 ± 13.86 | 0.3 | 6.58 | 2.74 | 2.66 | 2.23 | -9.73 ± 0.03 | 0.149 |
| I15567-5236 | 16:00:33.56 | -52:44:39.1 | 0.44 ^a | 5.98 ± 0.74 | -107.71 ± 1.59 | 0.17 | 5.39 | 1.75 | 1.06 | 2.44 | -10.17 ± 0.051 | 0.155 |
| I15584-5247 | 16:02:20.54 | -52:55:13.0 | 0.32 ^a | 2.15 ± 0.16 | -77.13 ± 1.35 | 0.3 | 2.22 | 1.08 | 1.23 | 0.24 | -10.88 ± 0.031 | 0.158 |
| I15596-5301 | 16:03:32.55 | -53:09:29.8 | 0.74 ^a | 13.1 ± 1.2 | -73.1 ± 0.88 | 0.3 | 1.66 | 1.04 | 1.06 | 0.11 | -9.38 ± 0.038 | 0.159 |
| I16026-5035 | 16:06:24.78 | -50:43:06.2 | 0.33 ^a | 0.59 ± 0.03 | -79.97 ± 0.05 | 0.24 | 0.82 | 0.61 | 0.64 | 0.03 | -11.42 ± 0.022 | 0.166 |
| I16037-5223 | 16:07:38.08 | -52:31:00.9 | 0.72 ^a | 1.152 ± 0.07 | -80.1 ± 0.91 | 0.41 | 1.76 | 1.17 | 1.22 | 0.16 | -10.46 ± 0.026 | 0.156 |
| I16060-5146 | 16:09:52.40 | -51:54:56.2 | 0.49 ± 0.067 | 109 ± 8.9 | -90.96 ± 3.62 | 0.61 | 4.37 | 2.37 | 2.28 | 1.18 | -9.02 ± 0.034 | 0.160 |
| I16065-5158 | 16:10:20.09 | -52:06:11.0 | 0.14 | 49.6 ± 3 | -64.04 ± 0.5 | 0.46 | 5.72 | 2.67 | 2.49 | 1.67 | -9.61 ± 0.026 | 0.155 |
| I16071-5142 | 16:10:59.84 | -51:50:21.2 | 0.18 ± 0.031 | 51.4 ± 1.7 | -86.48 ± 0.47 | 0.3 | 5.01 | 2.56 | 2.35 | 1.66 | -9.34 ± 0.014 | 0.153 |
| I16076-5134 | 16:11:26.66 | -51:41:56.3 | 0.39 ^a | 56.1 ± 1.6 | -86.74 ± 0.41 | 0.69 | 6.67 | 3.66 | 3.64 | 2.98 | -9.31 ± 0.012 | 0.158 |
| I16119-5048 | 16:15:45.35 | -50:55:52.5 | 0.23 ^a | 10.17 ± 0.58 | -51.19 ± 0.54 | 0.55 | 4.18 | 2.32 | 2.07 | 0.89 | -10.51 ± 0.024 | 0.158 |
| I16164-5046 | 16:20:11.30 | -50:53:16.7 | 0.09 | 33.2 ± 1.9 | -55.12 ± 1.21 | 0.48 | 3.3 | 1.72 | 1.61 | 0.56 | -9.88 ± 0.024 | 0.164 |
| I16172-5028 C1 | 16:21:02.64 | -50:35:00.4 | 0.25 ± 0.065 | 95.6 ± 9.7 | -52.32 ± 9.85 | 0.72 | 4.68 | 2.6 | 2.14 | 1.74 | -9.42 ± 0.042 | 0.159 |
| C2 | 16:21:03.14 | -50:35:49.6 | 0.26 ^a | 14.3 ± 1.9 | -49.82 ± 31.3 | 0.36 | 8.79 | 1.47 | 1.3 | 0.98 | -10.24 ± 0.054 | 0.159 |
| C3 | 16:20:59.42 | -50:35:53.1 | 0.26 ^a | 6.78 ± 0.94 | -50.55 ± 82.11 | 0.76 | 22.34 | 6.1 | 5.43 | 22.08 | -10.57 ± 0.056 | 0.159 |
| I16272-4837 | 16:30:58.27 | -48:43:45.2 | 0.32 ± 0.056 | 66.6 ± 8.7 | -46.32 ± 7.23 | 0.53 | 5.95 | 2.48 | 2.37 | 1.54 | -9.75 ± 0.053 | 0.163 |
| I16297-4757 | 16:33:29.23 | -48:03:45.6 | 0.36 ^a | 3.85 ± 0.26 | -80.13 ± 0.06 | 0.43 | 1.84 | 1.16 | 1.15 | 0.16 | -10.51 ± 0.028 | 0.168 |
| I16318-4724 | 16:35:33.72 | -47:31:10.1 | 0.54 ^a | 12.9 ± 0.64 | -121.48 ± 0.41 | 0.43 | 2.98 | 1.68 | 1.65 | 0.48 | -9.62 ± 0.021 | 0.174 |
| I16344-4658 | 16:38:09.36 | -47:04:59.4 | 0.86 ^a | 3.23 ± 0.16 | -49.88 ± 0.6 | 0.64 | 2.25 | 1.57 | 1.65 | 0.2 | -9.83 ± 0.021 | 0.172 |
| I16348-4654 | 16:38:29.27 | -47:00:39.0 | 0.86 ^a | 33.7 ± 3.5 | -47.53 ± 2.12 | 0.45 | 3.6 | 2.27 | 2.37 | 0.6 | -8.81 ± 0.043 | 0.157 |
| I16351-4722 | 16:38:50.40 | -47:27:58.3 | 0.18 ± 0.069 | 79.4 ± 8 | -40.4 ± 4.29 | 0.23 | 6.61 | 2.42 | 2.1 | 2.46 | -9.64 ± 0.042 | 0.177 |
| I16385-4619 | 16:42:13.74 | -46:25:29.8 | 0.51 ^a | 9.84 ± 0.59 | -119.57 ± 0.64 | 0.53 | 2.96 | 1.76 | 1.66 | 0.49 | -9.81 ± 0.025 | 0.176 |
| I16424-4531 | 16:46:06.26 | -45:36:39.0 | 0.18 ^a | 1.78 ± 0.14 | -31.75 ± 30.16 | 0.17 | 6.37 | 2.6 | 1.37 | 5.17 | -11.41 ± 0.033 | 0.173 |
| I16445-4459 | 16:48:04.54 | -45:05:03.9 | 0.55 ^a | 1.3 ± 0.08 | -121.08 ± 0.23 | 0.24 | 1.09 | 0.8 | 0.85 | 0.05 | -10.59 ± 0.026 | 0.164 |
| I16458-4512 C1 | 16:49:29.22 | -45:18:09.3 | 0.25 ^a | 11.4 ± 1.8 | -50.77 ± 1.97 | 0.36 | 4.93 | 1.63 | 1.53 | 0.89 | -10.34 ± 0.064 | 0.167 |
| C2 | 16:49:32.31 | -45:17:30.0 | 0.25 ^a | 0.78 ± 0.08 | -49.19 ± 0.15 | 0.24 | 1.88 | 0.56 | 0.53 | 0.07 | -11.51 ± 0.042 | 0.167 |
| I16484-4603 | 16:52:02.10 | -46:08:16.6 | 0.15 ^a | 17.1 ± 1.5 | -33.15 ± 1.62 | 0.65 | 3.53 | 1.57 | 1.4 | 0.48 | -10.63 ± 0.037 | 0.165 |
| I16487-4423 | 16:52:23.92 | -44:27:47.9 | 0.23 ^a | 3.36 ± 0.3 | -42.69 ± 0.23 | 0.17 | 1.22 | 0.74 | 0.84 | 0.1 | -10.95 ± 0.037 | 0.169 |
| I16489-4431 | 16:52:34.13 | -44:36:26.0 | 0.22 ^a | 6.98 ± 0.6 | -40.45 ± 1.61 | 0.3 | 2.67 | 1.69 | 1.77 | 0.35 | -10.63 ± 0.036 | 0.162 |

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Table A1 – continued

| IRAS | RA (J2000) | DEC (J2000) | R_a (pc) | $\int F_\nu d\nu$ (Jy km s ⁻¹) | v (km s ⁻¹) | σ_v (km s ⁻¹) | | | | | $\log L_{\text{SiO}}$ (L_\odot) | σ (Jy beam ⁻¹) |
|----------------|---------------|----------------|-------------------|---|------------------------------|-------------------------------------|------------------|-------------------|---------------------|------------------|--|--------------------------------------|
| | | | | | | D_{min} | D_{max} | D_{mean} | D_{median} | D_{std} | | |
| I16524-4300 C1 | 16:56:03.80 | -43:04:59.7 | 0.24 ± 0.083 | 12.4 ± 2.2 | -41.45 ± 1.8 | 0.35 | 2.17 | 1.24 | 1.36 | 0.22 | -10.34 ± 0.071 | 0.106 |
| C2 | 16:56:02.36 | -43:04:18.9 | 0.15 ± 0.089 | 7.7 ± 1.2 | -40.73 ± 2.38 | 0.17 | 2.33 | 1.09 | 0.95 | 0.38 | -10.55 ± 0.063 | 0.106 |
| C3 | 16:56:06.55 | -43:04:12.5 | 0.25 ^a | 0.81 ± 0.1 | -42.1 ± 0.2 | 0.23 | 1.09 | 0.63 | 0.62 | 0.05 | -11.52 ± 0.051 | 0.106 |
| I16547-4247 C1 | 16:58:16.79 | -42:52:03.0 | 0.17 ± 0.057 | 50.7 ± 5.2 | -29.37 ± 1.77 | 0.51 | 4.58 | 2.26 | 2.32 | 1.25 | -9.92 ± 0.042 | 0.119 |
| C2 | 16:58:18.11 | -42:52:37.2 | 0.2 ^a | 3.81 ± 0.92 | -36.64 ± 2.34 | 0.57 | 5.02 | 2.12 | 1.75 | 0.95 | -11.05 ± 0.094 | 0.119 |
| I16562-3959 C1 | 16:59:41.33 | -40:03:37.6 | 0.14 | 36.8 ± 3.9 | -11.74 ± 5.39 | 0.46 | 4.95 | 2.36 | 2.3 | 1.65 | -10.18 ± 0.044 | 0.115 |
| C2 | 16:59:38.93 | -40:04:11.0 | 0.1 ± 0.033 | 20.9 ± 1.6 | -11.4 ± 0.44 | 0.3 | 1.53 | 1.01 | 1.05 | 0.11 | -10.43 ± 0.032 | 0.115 |
| C3 | 16:59:43.59 | -40:03:08.5 | 0.16 | 22.2 ± 3 | -10.53 ± 2.6 | 0.37 | 2.55 | 1.44 | 1.54 | 0.26 | -10.4 ± 0.055 | 0.115 |
| I16571-4029 | 17:00:32.34 | -40:34:08.0 | 0.17 ^a | 15.2 ± 0.68 | -13.78 ± 1.32 | 0.48 | 4.71 | 2.55 | 2.44 | 1.22 | -10.57 ± 0.019 | 0.112 |
| I17006-4215 | 17:04:11.88 | -42:19:50.0 | 0.16 ^a | 2.39 ± 0.22 | -21.78 ± 0.2 | 0.23 | 2.23 | 1.21 | 1.19 | 0.35 | -11.44 ± 0.038 | 0.117 |
| I17008-4040 C1 | 17:04:22.96 | -40:44:19.6 | 0.16 ± 0.056 | 15.6 ± 2.8 | -18.15 ± 2.77 | 0.23 | 2.54 | 1.35 | 1.36 | 0.4 | -10.56 ± 0.072 | 0.120 |
| C2 | 17:04:25.22 | -40:44:28.4 | 0.17 ^a | 5.44 ± 0.74 | -12.02 ± 5.12 | 0.68 | 2.82 | 1.72 | 1.72 | 0.35 | -11.01 ± 0.055 | 0.120 |
| I17016-4124 C1 | 17:05:10.61 | -41:29:18.9 | 0.14 ± 0.037 | 122 ± 18 | -26.25 ± 33.11 | 0.65 | 6.52 | 3.5 | 3.25 | 2.81 | -10.14 ± 0.06 | 0.116 |
| C2 | 17:05:11.25 | -41:28:52.7 | 0.09 | 96.1 ± 9.2 | -31.02 ± 14.83 | 0.63 | 7.13 | 3.97 | 3.81 | 3.41 | -10.25 ± 0.04 | 0.116 |
| I17143-3700 | 17:17:45.50 | -37:03:12.5 | 0.87 ^a | 1.58 ± 0.13 | -31.18 ± 0.24 | 0.36 | 1.38 | 0.87 | 0.92 | 0.04 | -10.1 ± 0.034 | 0.140 |
| I17158-3901 | 17:19:20.41 | -39:03:49.5 | 0.12 ± 0.062 | 19.7 ± 2.1 | -17.54 ± 2.0 | 0.34 | 3.11 | 1.65 | 1.59 | 0.6 | -10.15 ± 0.044 | 0.159 |
| I17160-3707 C1 | 17:19:26.61 | -37:10:21.4 | 0.66 | 14 ± 1.9 | -69.0 ± 7.56 | 0.42 | 2.89 | 1.69 | 1.72 | 0.42 | -9.31 ± 0.055 | 0.151 |
| C2 | 17:19:25.83 | -37:10:02.8 | 0.72 ^a | 6.9 ± 1.4 | -69.92 ± 26.24 | 0.62 | 18.32 | 6.3 | 4.71 | 25.68 | -9.62 ± 0.08 | 0.151 |
| C3 | 17:19:26.60 | -37:11:12.6 | 0.72 ^a | 1.11 ± 0.09 | -69.17 ± 0.21 | 0.35 | 1.38 | 0.88 | 0.87 | 0.13 | -10.41 ± 0.034 | 0.151 |
| I17175-3544 C1 | 17:20:52.71 | -35:47:04.9 | 0.09 ^a | 65.5 ± 9.8 | -9.18 ± 13.26 | 0.35 | 9.7 | 3.8 | 3.01 | 9.74 | -10.43 ± 0.061 | 0.155 |
| C2 | 17:20:54.55 | -35:46:46.8 | 0.09 ^a | 7.7 ± 2.1 | 1.17 ± 0.5 | 0.91 | 4.44 | 2.93 | 3.14 | 1.17 | -11.36 ± 0.105 | 0.155 |
| C3 | 17:20:50.26 | -35:46:40.7 | 0.09 ^a | 6.48 ± 0.42 | 0.88 ± 10.1 | 0.84 | 6.37 | 3.71 | 3.62 | 1.58 | -11.44 ± 0.027 | 0.155 |
| I17204-3636 | 17:23:50.18 | -36:38:56.7 | 0.23 ^a | 3.21 ± 0.29 | -19.79 ± 0.68 | 0.36 | 2.23 | 1.29 | 1.48 | 0.24 | -10.95 ± 0.038 | 0.132 |
| I17220-3609 | 17:25:25.09 | -36:12:40.6 | 0.48 ± 0.222 | 25.6 ± 3.4 | -94.88 ± 2.66 | 0.46 | 3.94 | 1.72 | 1.6 | 0.74 | -9.29 ± 0.054 | 0.154 |
| I17233-3606 C1 | 17:26:40.91 | -36:09:26.8 | 0.14 ± 0.008 | 213.8 ± 9.6 | 1.68 ± 0.65 | 0.31 | 8.77 | 4.75 | 5.28 | 3.71 | -9.92 ± 0.019 | 0.169 |
| C2 | 17:26:42.53 | -36:09:17.3 | 0.07 | 159 ± 19 | 2.47 ± 0.51 | 0.83 | 10.5 | 4.77 | 4.35 | 7.03 | -10.05 ± 0.049 | 0.169 |
| C3 | 17:26:45.55 | -36:09:20.4 | 0.15 ± 0.031 | 53.3 ± 8.9 | 0.99 ± 0.51 | 0.67 | 5.03 | 2.83 | 2.54 | 1.81 | -10.52 ± 0.067 | 0.169 |
| I17244-3536 | 17:27:50.28 | -35:38:57.8 | 0.09 ^a | 0.59 ± 0.04 | -10.43 ± 0.28 | 0.46 | 1.44 | 1.15 | 1.15 | 0.04 | -12.46 ± 0.028 | 0.148 |
| I17258-3637 C1 | 17:29:18.35 | -36:40:27.8 | 0.15 ± 0.051 | 12.1 ± 1.6 | -13.37 ± 2.06 | 0.36 | 1.86 | 1.1 | 1.06 | 0.16 | -10.59 ± 0.054 | 0.161 |
| C2 | 17:29:18.65 | -36:40:50.0 | 0.18 ^a | 3.13 ± 0.49 | -10.86 ± 5.07 | 0.26 | 1.45 | 0.89 | 0.85 | 0.09 | -11.18 ± 0.063 | 0.161 |
| I17269-3312 | 17:30:14.47 | -33:15:01.1 | 0.3 ^a | 10.73 ± 0.69 | -24.11 ± 2.5 | 0.35 | 3.08 | 1.59 | 1.62 | 0.64 | -10.19 ± 0.027 | 0.149 |
| I17271-3439 | 17:30:26.8 | -34:41:48.9 | 0.37 ± 0.091 | 51.6 ± 8 | 4.81 ± 0.0 | 0.24 | 3.71 | 1.66 | 1.77 | 0.72 | -9.81 ± 0.063 | 0.148 |
| I17278-3541 C1 | 17:31:15.88 | -35:44:15.3 | 0.09 ^a | 6.45 ± 0.46 | 4.54 ± 2.61 | 0.37 | 3.29 | 1.97 | 2.22 | 0.84 | -11.45 ± 0.03 | 0.151 |
| C2 | 17:31:13.08 | -35:43:41.8 | 0.09 ^a | 3.55 ± 0.17 | -8.39 ± 4.01 | 0.58 | 4.03 | 2.57 | 2.78 | 1.14 | -11.7 ± 0.02 | 0.151 |
| C3 | 17:31:16.02 | -35:43:27.2 | 0.09 ^a | 1.08 ± 0.12 | 0.94 ± 0.25 | 0.17 | 6.92 | 0.99 | 0.63 | 1.32 | -12.22 ± 0.046 | 0.151 |
| C4 | 17:31:16.52 | -35:43:46.0 | 0.09 ^a | 2.54 ± 0.49 | 9.51 ± 27.86 | 0.57 | 4.06 | 2.03 | 1.66 | 0.75 | -11.85 ± 0.077 | 0.151 |
| C5 | 17:31:13.26 | -35:44:07.9 | 0.09 ^a | 0.66 ± 0.03 | -8.82 ± 0.74 | 0.35 | 2.19 | 1.58 | 1.79 | 0.32 | -12.44 ± 0.019 | 0.151 |
| C6 | 17:31:14.42 | -35:43:58.0 | 0.09 ^a | 0.43 ± 0.05 | 0.44 ± 0.03 | 0.17 | 0.81 | 0.51 | 0.61 | 0.05 | -12.62 ± 0.048 | 0.151 |
| I17439-2845 | 17:47:10.18 | -28:45:44.2 | 0.53 ^a | 0.44 ± 0.01 | 22.74 ± 1.63 | 0.74 | 3.6 | 2.29 | 2.63 | 0.73 | -11.05 ± 0.01 | 0.105 |
| I17441-2822 C1 | 17:47:22.78 | -28:23:15.1 | 0.54 ^a | 71 ± 14 | 60.87 ± 22.29 | 0.45 | 9.32 | 3.82 | 3.08 | 8.19 | -8.83 ± 0.078 | 0.526 |
| C2 | 17:47:18.57 | -28:23:15.8 | 0.54 ^a | 53 ± 11 | 58.9 ± 50.44 | 0.48 | 10.36 | 4.02 | 3.68 | 9.57 | -8.96 ± 0.082 | 0.526 |
| C3 | 17:47:22.06 | -28:22:49.4 | 0.54 ^a | 28.1 ± 4.9 | 64.93 ± 40.02 | 0.74 | 5.85 | 3.16 | 2.65 | 2.7 | -9.24 ± 0.07 | 0.526 |
| C4 | 17:47:18.30 | -28:22:46.6 | 0.54 ^a | 16.3 ± 3.4 | 59.47 ± 14.94 | 0.42 | 4.28 | 1.62 | 1.21 | 1.07 | -9.47 ± 0.082 | 0.526 |
| C5 | 17:47:20.82 | -28:22:59.5 | 0.54 ^a | 4.75 ± 0.69 | 45.77 ± 0.4 | 0.54 | 2.07 | 1.33 | 1.33 | 0.18 | -10.01 ± 0.059 | 0.526 |
| I17455-2800 | 17:48:41.59 | -28:01:56.2 | 0.67 ^a | 6.33 ± 0.53 | -15.74 ± 0.48 | 0.24 | 2.02 | 1.11 | 1.07 | 0.27 | -9.7 ± 0.035 | 0.129 |
| I17545-2357 | 17:57:34.59 | -23:57:32.5 | 0.2 ^a | 1.43 ± 0.38 | 7.56 ± 0.3 | 0.17 | 1.28 | 0.42 | 0.3 | 0.05 | -11.41 ± 0.102 | 0.100 |
| I17589-2312 C1 | 18:01:59.12 | -23:12:56.7 | 0.21 ^a | 3.83 ± 0.65 | 23.84 ± 3.49 | 0.32 | 1.96 | 1.03 | 0.92 | 0.15 | -10.97 ± 0.068 | 0.098 |
| C2 | 18:01:58.39 | -23:12:21.1 | 0.21 ^a | 3.78 ± 0.45 | 19.88 ± 1.68 | 0.35 | 2.31 | 1.01 | 0.97 | 0.23 | -10.98 ± 0.049 | 0.098 |
| I18032-2032 | 18:06:15.05 | -20:31:37.7 | 0.18 | 64.8 ± 3.1 | 5.08 ± 5.54 | 0.38 | 10.76 | 4.26 | 3.77 | 8.97 | -9.27 ± 0.02 | 0.088 |
| I18056-1952 C1 | 18:08:38.16 | -19:51:50.1 | 0.21 | 36.9 ± 1.7 | 66.88 ± 0.82 | 0.54 | 4.08 | 2.45 | 2.48 | 0.96 | -9.07 ± 0.02 | 0.099 |
| C2 | 18:08:38.00 | -19:51:12.5 | 0.6 ^a | 11.32 ± 0.56 | 65.47 ± 5.17 | 0.3 | 4.86 | 2.5 | 2.67 | 1.95 | -9.59 ± 0.021 | 0.099 |
| C3 | 18:08:36.37 | -19:52:14.3 | 0.6 ^a | 2.75 ± 0.2 | 70.98 ± 4.31 | 0.37 | 1.51 | 1.08 | 1.09 | 0.09 | -10.2 ± 0.03 | 0.099 |
| I18079-1756 C1 | 18:10:51.58 | -17:55:46.5 | 0.13 ^a | 3.31 ± 0.43 | 18.02 ± 1.27 | 0.17 | 1.09 | 0.63 | 0.67 | 0.08 | -11.46 ± 0.053 | 0.139 |
| C2 | 18:10:49.38 | -17:56:01.7 | 0.13 ^a | 1.37 ± 0.1 | 11.65 ± 0.35 | 0.29 | 1.43 | 0.93 | 1.01 | 0.06 | -11.84 ± 0.031 | 0.139 |
| I18089-1732 | 18:11:51.58 | -17:31:25.6 | 0.18 ^a | 5.83 ± 0.28 | 33.25 ± 0.97 | 0.3 | 2.74 | 1.54 | 1.46 | 0.43 | -10.94 ± 0.02 | 0.136 |
| I18117-1753 | 18:14:39.21 | -17:52:08.6 | 0.21 ± 0.066 | 31.6 ± 3.9 | 35.6 ± 9.08 | 0.42 | 4.11 | 1.94 | 1.64 | 1.03 | -10.18 ± 0.051 | 0.138 |
| I18139-1842 | 18:16:51.47 | -18:41:39.5 | 0.22 ^a | 3.15 ± 0.17 | 39.36 ± 0.27 | 0.17 | 1.8 | 1.0 | 1.01 | 0.27 | -11.04 ± 0.023 | 0.134 |
| I18159-1648 | 18:18:54.84 | -16:47:50.4 | 0.09 | 47.1 ± 3.5 | 20.13 ± 4.86 | 0.36 | 5.89 | 2.36 | 2.24 | 1.92 | -10.49 ± 0.031 | 0.138 |
| I18182-1433 | 18:21:09.03 | -14:31:46.0 | 0.34 ^a | 12.24 ± 0.78 | 59.76 ± 0.63 | 0.4 | 2.82 | 1.61 | 1.64 | 0.52 | -10.07 ± 0.027 | 0.130 |
| I18236-1205 | 18:26:26.50 | -12:03:53.4 | 0.16 ^a | 1.84 ± 0.16 | 27.13 ± 6.9 | 0.17 | 2.97 | 1.15 | 1.27 | 0.44 | -11.57 ± 0.036 | 0.144 |
| I18264-1152 | 18:29:14.91 | -11:50:25.6 | 0.17 ± 0.061 | 19.4 ± 2.7 | 43.35 ± 4.27 | 0.55 | 4.88 | 1.78 | 1.35 | 1.04 | -10.17 ± 0.057 | 0.137 |
| I18290-0924 | 18:31:43.13 | -09:22:32.9 | 0.39 ^a | 1.87 ± 0.24 | 84.15 ± 0.46 | 0.3 | 1.38 | 0.81 | 0.8 | 0.08 | -10.78 ± 0.052 | 0.101 |
| I18311-0809 | 18:33:53.54 | -08:07:12.2 | 0.45 ^a | 3.35 ± 0.18 | 113.7 ± 0.19 | 0.32 | 2.3 | 1.44 | 1.47 | 0.33 | -10.41 ± 0.023 | 0.096 |
| I18316-0602 C1 | 18:34:21.17 | -06:00:14.5 | 0.16 ^a | 28.3 ± 1.3 | 35.61 ± 12.71 | 0.29 | 8.83 | 4.23 | 3.88 | 7.48 | -10.41 ± 0.02 | 0.093 |
| C2 | 18:34:20.52 | -05:59:33.6 | 0.16 ^a | 25.4 ± 2.5 | 43.5 ± 33.06 | 0.42 | 6.5 | 2.74 | 2.3 | 2.76 | -10.46 ± 0.041 | 0.093 |
| C3 | 18:34:20.52 | -05:59:33.6 | 0.05 ± 0.131 | 6.6 ± 2.6 | 29.93 ± 5.4 | 1.05 | 7.78 | 2.48 | 1.91 | 2.37 | -11.04 ± 0.144 | 0.093 |
| I18341-0727 | 18:36:49.87 | -07:24:53.6 | 0.45 ^a | 9.6 ± 1.1 | 112.5 ± 3.89 | 0.29 | 2.97 | 1.52 | 1.45 | 0.52 | -9.96 ± 0.047 | 0.096 |
| I18411-0338 | 18:43:46.11 | -03:35:31.2 | 0.57 ^a | 5.23 ± 0.33 | 103.62 ± 0.06 | 0.23 | 1.82 | 1.08 | 1.18 | 0.22 | -10.04 ± 0.027 | 0.115 |
| I18434-0242 | 18:46:03.58 | -02:39:24.7 | 0.39 ^a | 19.81 ± 0.49 | 97.65 ± 0.11 | 0.42 | 4.24 | 2.19 | 2.06 | 1.29 | -9.78 ± 0.011 | 0.094 |
| I18461-0113 | 18:48:41.74 | -01:10:01.3 | 0.39 ^a | 14.65 ± 0.59 | 95.48 ± 0.34 | 0.46 | 2.53 | 1.58 | 1.63 | 0.35 | -9.91 ± 0.017 | 0.094 |

Table A1 – continued

| IRAS | RA (J2000) | DEC (J2000) | R_a (pc) | $\int F_\nu dv$ (Jy km s ⁻¹) | v (km s ⁻¹) | σ_v (km s ⁻¹) | | | | | $\log L_{\text{SiO}}$ (L_\odot) | σ (Jy beam ⁻¹) |
|----------------|---------------|----------------|-------------------|---|------------------------------|-------------------------------------|------------------|-------------------|---------------------|------------------|--|--------------------------------------|
| | | | | | | D_{min} | D_{max} | D_{mean} | D_{median} | D_{std} | | |
| I18469-0132 | 18:49:33.05 | -01:29:02.1 | 0.39 ^a | 4.57 ± 0.24 | 86.96 ± 0.12 | 0.17 | 1.72 | 1.04 | 0.92 | 0.18 | -10.42 ± 0.022 | 0.123 |
| I18479-0005 | 18:50:30.63 | -00:01:58.9 | 0.99 ^a | 8.42 ± 0.57 | 14.64 ± 3.11 | 0.45 | 2.84 | 1.83 | 1.85 | 0.46 | -9.35 ± 0.028 | 0.097 |
| I18507p0110 C1 | 18:53:18.50 | +01:15:01.2 | 0.08 ± 0.039 | 35.1 ± 6.1 | 58.9 ± 1.88 | 0.32 | 5.8 | 2.01 | 1.95 | 1.8 | -10.57 ± 0.07 | 0.126 |
| C2 | 18:53:16.67 | +01:15:11.1 | 0.08 ± 0.029 | 32.4 ± 3.9 | 61.56 ± 5.32 | 0.5 | 6.48 | 2.9 | 2.88 | 1.78 | -10.61 ± 0.049 | 0.126 |
| C3 | 18:53:15.62 | +01:14:20.1 | 0.12 ^a | 4.6 ± 1.4 | 54.97 ± 2.24 | 0.44 | 3.3 | 1.12 | 1.11 | 0.2 | -11.45 ± 0.115 | 0.126 |
| I18507p0121 C1 | 18:53:18.02 | +01:25:24.8 | 0.12 ^a | 48.7 ± 4.8 | 59.29 ± 8.86 | 0.23 | 4.78 | 2.29 | 2.19 | 2.27 | -10.43 ± 0.041 | 0.110 |
| C2 | 18:53:17.90 | +01:24:48.1 | 0.09 ± 0.03 | 29 ± 3.3 | 57.25 ± 7.38 | 0.67 | 7.04 | 2.71 | 2.44 | 2.13 | -10.65 ± 0.047 | 0.110 |
| I18517p0437 | 18:54:14.50 | +04:41:39.3 | 0.18 ^a | 8 ± 1 | 43.85 ± 0.23 | 0.23 | 1.43 | 0.72 | 0.7 | 0.09 | -10.85 ± 0.051 | 0.110 |
| I18530p0215 | 18:55:33.42 | +02:19:01.6 | 0.36 ^a | 0.41 ± 0.06 | 77.43 ± 3.21 | 0.17 | 3.22 | 0.97 | 0.67 | 0.62 | -11.55 ± 0.059 | 0.099 |
| I19079p0901 | 19:10:13.24 | +09:06:14.0 | 0.97 ± 0.099 | 278 ± 17 | 6.46 ± 2.0 | 0.88 | 6.91 | 3.81 | 4.0 | 2.27 | -7.97 ± 0.026 | 0.122 |
| I19095p0930 | 19:11:53.85 | +09:35:50.7 | 0.43 ^a | 18.7 ± 1 | 43.51 ± 0.18 | 0.95 | 3.32 | 2.16 | 2.22 | 0.4 | -9.67 ± 0.023 | 0.116 |
| I19097p0847 | 19:12:09.04 | +08:52:12.2 | 0.6 ^a | 6.51 ± 0.45 | 57.27 ± 0.38 | 0.31 | 2.83 | 1.6 | 1.76 | 0.56 | -9.83 ± 0.029 | 0.139 |

Notes. R_a : the linear radius of SiO clump. $\int F_\nu dv$: the integrated intensity of SiO clump. v : the velocity of SiO clump. σ_v : the velocity dispersion of SiO clump. L_{SiO} : the luminosity of the SiO clump. σ : rms in one source.

^a symbol after radius of SiO clump indicates that this SiO clump is unresolved by CASA.

Table A2. SiO (2-1) line parameters and clump properties in the region without clear detections.

| IRAS | RA J2000 | DEC J2000 | R_a (pc) | $\int F_\nu dv$ (Jy km s ⁻¹) | v (km s ⁻¹) | σ_v (km s ⁻¹) | $\log L_{\text{SiO}}$ (L_\odot) | σ (Jy beam ⁻¹) |
|-------------|-------------|--------------|-------------------|---|------------------------------|-------------------------------------|--|--------------------------------------|
| I12383-6128 | 12:41:18.18 | -61:44:17.4 | 0.25 ^a | 1.08 ± 0.38 | -39 ± 2 | 1.3 ± 1.7 | -11.44 ± 0.13 | 0.14 |
| I13080-6229 | 13:11:12.81 | -62:45:02.1 | 0.58 ± 0.4 | 3.6 ± 1.4 | -35.7 ± 8.1 | 2.6 ± 6.6 | -10.79 ± 0.143 | 0.122 |
| I13291-6229 | 13:32:32.54 | -62:45:22.6 | 0.35 ± 0.18 | 2.35 ± 0.5 | -37.6 ± 3.8 | 0.99 ± 3.1 | -11.21 ± 0.08 | 0.125 |
| I14050-6056 | 14:08:40.89 | -61:11:18.4 | 0.28 ^a | 3.81 ± 0.99 | -53 ± 3 | 1.8 ± 2.4 | -10.85 ± 0.1 | 0.154 |
| I14382-6017 | 14:42:03.76 | -60:30:30.9 | 0.39 ± 0.59 | 3.6 ± 1.7 | -60.7 ± 2.6 | 1.2 ± 2.1 | -10.17 ± 0.095 | 0.153 |
| I15254-5621 | 15:29:18.84 | -56:31:38.4 | 0.28 ^a | 4.1 ± 1 | -68.5 ± 2.3 | 2.1 ± 1.8 | -10.69 ± 0.095 | 0.16 |
| I15437-5343 | 15:47:33.06 | -53:52:39.4 | 0.46 | 4.9 ± 1.4 | -83.1 ± 2.8 | 1.8 ± 2.3 | -10.69 ± 0.109 | 0.163 |
| I15502-5302 | 15:54:03.32 | -53:11:37.9 | 0.43 ^a | 3.91 ± 0.74 | -92.4 ± 1.7 | 2 ± 1.4 | -10.38 ± 0.08 | 0.176 |
| I16304-4710 | 16:34:05.19 | -47:16:33.0 | 0.8 ^a | 1.42 ± 0.48 | -62.3 ± 2.3 | 0.93 ± 1.9 | -10.24 ± 0.126 | 0.211 |
| I16313-4729 | 16:34:54.38 | -47:35:33.6 | 0.33 ^a | 5.4 ± 1.2 | -74.3 ± 2.2 | 3 ± 1.8 | -10.42 ± 0.087 | 0.188 |
| I16330-4725 | 16:36:43.25 | -47:31:25.9 | 0.78 ^a | 4.1 ± 1.2 | -71.4 ± 2.7 | 2.5 ± 2.2 | -9.81 ± 0.111 | 0.205 |
| I16372-4545 | 16:40:54.07 | -45:50:52.3 | 0.3 ^a | 2.8 ± 0.5 | -58.2 ± 2.4 | 2 ± 2 | -10.82 ± 0.071 | 0.204 |
| I16506-4512 | 16:54:13.35 | -45:17:54.7 | 0.07 ± 0.05 | 5.74 ± 0.88 | -35.3 ± 1.9 | 3.8 ± 1.6 | -10.98 ± 0.062 | 0.181 |
| I17136-3617 | 17:17:02.31 | -36:20:49.4 | 0.09 ^a | 2.64 ± 0.48 | -10.5 ± 2.7 | 2.8 ± 2.2 | -11.83 ± 0.073 | 0.176 |
| I18110-1854 | 18:14:02.41 | -18:53:14.1 | 0.39 ± 0.157 | 13.5 ± 4.1 | 38.5 ± 2.5 | 3 ± 2 | -10.32 ± 0.115 | 0.144 |
| I18116-1646 | 18:14:36.17 | -16:45:45.7 | 0.29 ^a | 1.43 ± 0.52 | 48.6 ± 2.5 | 1.3 ± 2 | -11.16 ± 0.135 | 0.145 |
| I18223-1243 | 18:25:11.12 | -12:42:21.1 | 0.24 ^a | 1.31 ± 0.33 | 48.3 ± 2.4 | 2 ± 2 | -10.95 ± 0.076 | 0.168 |
| I18228-1312 | 18:25:41.66 | -13:10:11.6 | 0.29 | 4.24 ± 0.93 | 31.7 ± 2.7 | 0.77 ± 2.2 | -10.86 ± 0.086 | 0.148 |

Notes. R_a : The linear radius of SiO clump. $\int F_\nu dv$: The integrated intensity of SiO clump. v : SiO line central velocity. σ_v : The velocity dispersion of SiO clump. L_{SiO} : The luminosity of the SiO clump. σ : rms in one source.

^a symbol after radius of SiO clump indicates that this SiO clump is unresolved by CASA.

Table A3. SiO (2-1) line parameters and clump properties.

| IRAS | L_{bol}/M | $\log n$ | [SiO]/[H ¹³ CO ⁺] | D_{d} | H40 α | SiO | Wing HCO ⁺ | CS | outflow | type |
|----------------|----------------------------|---------------------|--|----------------|--------------|-----|--------------------------|----|---------|------|
| | ($L_\odot M_\odot^{-1}$) | (cm ⁻³) | | (pc) | | | | | | |
| I08076-3556 | 3.16 | 5.51 | - | 0.01 | - | ✓ | - | - | ✓ | C |
| I08303-4303 | 25.12 | 5.4 | 0.41 ± 0.01 | 0.16 | - | ✓ | ✓ | ✓ | ✓ | D |
| I08448-4343 C1 | 25.12 | 5.68 | 1.86 ± 0.07 | 0.06 | - | ✓ | - | - | ✓ | D |
| C2 | 25.12 | 5.68 | 3.35 ± 0.37 | 0.08 | - | ✓ | - | - | ✓ | D |
| I08470-4243 | 39.81 | 5.4 | 2.98 ± 0.1 | 0.02 | - | ✓ | ✓ | ✓ | ✓ | C |
| I09002-4732 C1 | 158.49 | 5.78 | 0.74 ± - | 0.2 | ✓ | - | - | - | - | B |
| C2 | 158.49 | 5.78 | - | 0.15 | ✓ | - | - | - | - | B |
| C3 | 158.49 | 5.78 | - | 0.08 | ✓ | - | - | - | - | B |
| I09018-4816 C1 | 50.12 | 5.59 | 0.9 ± - | 0.05 | - | - | - | - | - | C |
| C2 | 50.12 | 5.59 | - | 0.48 | - | - | - | - | - | D |
| I09094-4803 | 31.62 | 4.18 | 1.39 ± 0.16 | 0.93 | - | - | - | - | - | D |
| I10365-5803 | 39.81 | 5.29 | 0.32 ± - | 0.11 | - | ✓ | ✓ | - | ✓ | D |
| I11298-6155 | 63.1 | 4.52 | 3.97 ± 0.19 | 0.37 | ✓ | - | ✓ | ✓ | ✓ | A |
| I11332-6258 | 39.81 | 5.28 | 0.22 ± 0.05 | 0.03 | - | - | ✓ | - | ✓ | C |
| I11590-6452 | 3.98 | 6.29 | - | 0.04 | - | - | - | - | - | D |

Table A3 – continued

| IRAS | L_{bol}/M ($L_{\odot}M_{\odot}^{-1}$) | $\log n$ (cm^{-3}) | [SiO]/[H ¹³ CO ⁺] | D_{d} (pc) | H40 α | SiO | Wing HCO ⁺ | CS | outflow | type |
|----------------|---|----------------------------------|--|------------------------|--------------|-----|--------------------------|----|---------|------|
| I12320-6122 | 398.11 | 3.61 | 0.7 ± 0.25 | 0.25 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I12326-6245 | 79.43 | 4.36 | 6.16 ± 0.12 | 0.07 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I12383-6128 | 5.01 | 4.32 | 0.99 ± 0.25 | 0.37 | ✓ | – | – | – | – | B |
| I12572-6316 | 5.01 | 3.88 | 0.42 ± 0.05 | 0.12 | ✓ | – | – | – | – | A |
| I13079-6218 | 39.81 | 4 | 4.77 ± 0.05 | 0.11 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I13080-6229 | 79.43 | 3.78 | 0.15 ± 0.01 | 0.17 | ✓ | ✓ | – | – | ✓ | B |
| I13111-6228 | 50.12 | 3.77 | 0.09 ± – | 0.04 | ✓ | – | ✓ | – | ✓ | A |
| I13134-6242 | 31.62 | 4.45 | 3.04 ± 0.14 | 0.08 | – | ✓ | ✓ | ✓ | ✓ | C |
| I13140-6226 | 7.94 | 4.42 | 1 ± – | 0.05 | – | ✓ | ✓ | ✓ | ✓ | C |
| I13291-6229 | 39.81 | 4.09 | 0.13 ± 0.01 | 0.38 | ✓ | – | – | – | – | B |
| I13291-6249 | 31.62 | 3.6 | 1.85 ± 0.05 | 0.5 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I13295-6152 | 3.98 | 4.64 | 0.09 ± – | 0.14 | – | – | – | – | – | C |
| I13471-6120 | 79.43 | 4 | 0.62 ± 0.09 | 0.43 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I13484-6100 | 50.12 | 3.94 | 1.24 ± 0.05 | 0.14 | – | ✓ | ✓ | ✓ | ✓ | C |
| I14013-6105 | 63.1 | 4.1 | – | 0.08 | ✓ | – | – | – | – | A |
| I14050-6056 | 79.43 | 3.95 | – | 0.61 | ✓ | – | – | – | – | B |
| I14164-6028 | 31.62 | 5.12 | 0.94 ± 0.04 | 0.04 | – | – | – | – | – | C |
| I14212-6131 | 10.0 | 4.35 | 1.75 ± 0.12 | 0.36 | – | ✓ | ✓ | ✓ | ✓ | D |
| I14382-6017 | 39.81 | 3.54 | – | 0.58 | ✓ | – | – | – | – | B |
| I14453-5912 | 19.95 | 3.82 | 1.65 ± 0.45 | 0.33 | ✓ | – | – | – | – | B |
| I14498-5856 C1 | 25.12 | 4.01 | 0.52 ± 0.01 | 0.12 | – | – | ✓ | – | ✓ | D |
| C2 | 25.12 | 4.01 | – | 0.59 | – | – | – | – | – | D |
| I15254-5621 | 100.0 | 3.87 | – | 0.35 | ✓ | ✓ | – | ✓ | ✓ | B |
| I15290-5546 | 79.43 | 3.65 | 2.31 ± 0.03 | 0.18 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I15394-5358 | 6.31 | 4.53 | 1.75 ± 0.03 | 0.02 | – | ✓ | ✓ | ✓ | ✓ | C |
| I15408-5356 | 100.0 | 4.16 | 3.85 ± 0.54 | 0.26 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I15411-5352 C1 | 63.1 | 4.05 | 0.22 ± – | 0.08 | ✓ | ✓ | – | ✓ | ✓ | B |
| C2 | 63.1 | 4.05 | 0.33 ± – | 0.34 | ✓ | – | – | – | – | B |
| I15437-5343 | 39.81 | 3.95 | 0.42 ± 0.11 | 0.11 | – | – | – | – | – | C |
| I15439-5449 C1 | 25.12 | 4.1 | 0.77 ± 0.001 | 0.57 | ✓ | – | – | – | – | B |
| C2 | 25.12 | 4.1 | 0.04 ± 0.003 | 0.41 | ✓ | – | – | – | – | B |
| I15502-5302 | 125.89 | 3.65 | 1.04 ± 0.02 | 0.81 | ✓ | – | – | ✓ | ✓ | B |
| I15520-5234 C1 | 79.43 | 4.34 | 16.45 ± 4.935 | 0.18 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C2 | 79.43 | 4.34 | 4.06 ± 0.005 | 0.06 | ✓ | ✓ | – | ✓ | ✓ | A |
| I15522-5411 | 7.94 | 4.09 | 0.33 ± 0.002 | 0.04 | – | ✓ | – | ✓ | ✓ | C |
| I15557-5215 | 5.01 | 4.07 | 4.81 ± 0.144 | 0.04 | – | ✓ | ✓ | ✓ | ✓ | C |
| I15567-5236 | 158.49 | 3.76 | 0.38 ± 0.051 | 0.29 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I15584-5247 | 12.59 | 3.91 | 0.62 ± 0.043 | 0.4 | – | ✓ | ✓ | ✓ | ✓ | D |
| I15596-5301 | 39.81 | 3.74 | 0.87 ± 0.033 | 0.34 | – | – | – | – | – | C |
| I16026-5035 | 79.43 | 3.89 | 0.36 ± 0.07 | 0.31 | – | – | – | – | – | D |
| I16037-5223 | 63.1 | 3.42 | 0.23 ± 0.028 | 0.1 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I16060-5146 | 79.43 | 4.23 | – | 0.08 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I16065-5158 | 50.12 | 3.87 | 1.5 ± 0.061 | 0.08 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I16071-5142 | 12.59 | 3.07 | 2.77 ± 0.022 | 0.08 | – | ✓ | ✓ | ✓ | ✓ | C |
| I16076-5134 | 50.12 | 3.63 | 5.61 ± 0.016 | 0 | – | ✓ | ✓ | ✓ | ✓ | C |
| I16119-5048 | 12.59 | 3.91 | 2.08 ± 0.141 | 0.07 | – | ✓ | ✓ | ✓ | ✓ | C |
| I16164-5046 | 63.1 | 3.9 | 0.92 ± 0.091 | 0.05 | ✓ | ✓ | – | ✓ | ✓ | A |
| I16172-5028 C1 | 63.1 | 4.08 | 1.27 ± 0.03 | 0.23 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C2 | 63.1 | 4.08 | – | 0.65 | ✓ | – | – | ✓ | ✓ | B |
| C3 | 63.1 | 4.08 | – | 0.89 | ✓ | ✓ | – | ✓ | ✓ | B |
| I16272-4837 | 12.59 | 4.04 | 2.53 ± 0.861 | 0.14 | – | ✓ | – | ✓ | ✓ | D |
| I16297-4757 | 31.62 | 3.11 | 0.73 ± 0.055 | 0.14 | ✓ | – | – | – | – | A |
| I16304-4710 | 25.12 | 3.7 | 0.26 ± 0.01 | 0.22 | ✓ | – | – | – | – | A |
| I16313-4729 | 100.0 | 4.37 | 0.7 ± 0.04 | 0.13 | – | – | – | – | – | C |
| I16318-4724 | 31.62 | 3.83 | 1.02 ± 0.042 | 0.09 | – | ✓ | ✓ | ✓ | ✓ | C |
| I16330-4725 | 100.0 | 3.14 | 0.23 ± – | 0.19 | ✓ | – | – | – | – | A |
| I16344-4658 | 19.95 | 3.42 | 0.63 ± 0.028 | 0.24 | – | ✓ | – | ✓ | ✓ | C |
| I16348-4654 | 10.0 | 3.87 | 2.14 ± 0.008 | 0.3 | ✓ | ✓ | – | ✓ | ✓ | A |
| I16351-4722 | 50.12 | 4.3 | 2.27 ± 0.114 | 0.05 | – | ✓ | – | ✓ | ✓ | C |
| I16372-4545 | 19.95 | 3.92 | 0.51 ± 0.02 | 0.2 | – | – | – | – | – | D |
| I16385-4619 | 79.43 | 3.43 | 1.51 ± 0.126 | 0.06 | ✓ | ✓ | ✓ | ✓ | ✓ | A |

Table A3 – continued

| IRAS | L_{bol}/M ($L_{\odot}M_{\odot}^{-1}$) | $\log n$ (cm^{-3}) | [SiO]/[H ¹³ CO ⁺] | D_{d} (pc) | H40 α | SiO | Wing HCO ⁺ | CS | outflow | type |
|----------------|---|----------------------------------|--|------------------------|--------------|-----|--------------------------|----|---------|------|
| I16424-4531 | 15.85 | 4.12 | 0.74 ± 0.143 | 0.12 | – | ✓ | – | ✓ | ✓ | D |
| I16445-4459 | 12.59 | 3.3 | 0.33 ± 0.07 | 0.39 | – | – | – | – | – | D |
| I16458-4512 C1 | 7.94 | 3.76 | 4.39 ± 0.054 | 0.46 | ✓ | ✓ | – | ✓ | ✓ | B |
| C2 | 7.94 | 3.76 | – | 0.47 | ✓ | – | – | – | – | B |
| I16484-4603 | 100.0 | 4.39 | 2.65 ± 0.346 | 0.33 | – | ✓ | – | – | ✓ | D |
| I16487-4423 | 25.12 | 3.6 | 1.31 ± 0.071 | 0.4 | – | ✓ | – | – | ✓ | D |
| I16489-4431 | 7.94 | 3.96 | 1.09 ± 0.007 | 0.24 | – | ✓ | – | ✓ | ✓ | D |
| I16506-4512 | 79.43 | 3.91 | 3.58 ± 0.67 | 0.55 | ✓ | – | – | ✓ | ✓ | B |
| I16524-4300 C1 | 10.0 | 3.94 | 1.48 ± 0.13 | 0.3 | – | – | – | – | – | D |
| C2 | 10.0 | 3.94 | 3.11 ± 0.262 | 0.47 | – | – | – | – | – | D |
| C3 | 10.0 | 3.94 | – | 0.87 | – | – | – | – | – | D |
| I16547-4247 C1 | 39.81 | 4.3 | 0.73 ± 0.06 | 0.08 | – | ✓ | ✓ | ✓ | ✓ | C |
| C2 | 39.81 | 4.3 | 16.68 ± 7.892 | 0.43 | – | ✓ | ✓ | ✓ | ✓ | D |
| I16562-3959 C1 | 316.23 | 4.24 | 0.8 ± 0.197 | 0.05 | – | ✓ | ✓ | – | ✓ | C |
| C2 | 316.23 | 4.24 | – | 0.5 | – | – | – | – | – | D |
| C3 | 316.23 | 4.24 | – | 0.47 | – | – | – | – | – | D |
| I16571-4029 | 25.12 | 4.77 | 2.59 ± 0.083 | 0.02 | – | ✓ | ✓ | ✓ | ✓ | C |
| I17006-4215 | 39.81 | 4.32 | 0.61 ± 0.087 | 0.14 | ✓ | ✓ | – | – | ✓ | B |
| I17008-4040 | 39.81 | 3.31 | 0.57 ± 0.025 | 0.05 | – | ✓ | – | – | ✓ | C |
| C2 | 39.81 | 3.31 | 42.78 ± 31.127 | 0.3 | – | – | – | – | – | D |
| I17016-4124 C1 | 31.62 | 4.79 | 6.61 ± 0.19 | 0.09 | – | ✓ | ✓ | ✓ | ✓ | D |
| C2 | 31.62 | 4.79 | 8.95 ± 1.579 | 0.08 | – | ✓ | ✓ | ✓ | ✓ | D |
| I17136-3617 | 125.89 | 4.15 | – | 0.14 | ✓ | ✓ | – | ✓ | ✓ | B |
| I17143-3700 | 63.1 | 3.0 | 0.19 ± 0.007 | 0.11 | ✓ | – | – | ✓ | ✓ | A |
| I17158-3901 | 25.12 | 3.8 | 0.88 ± 0.02 | 0.04 | – | ✓ | – | – | ✓ | C |
| I17160-3707 C1 | 79.43 | 4.03 | 1.16 ± 0.11 | 2.15 | ✓ | ✓ | – | – | ✓ | B |
| C2 | 79.43 | 4.03 | – | 1.4 | ✓ | – | – | ✓ | ✓ | B |
| C3 | 79.43 | 4.03 | 0.21 ± 0.024 | 3.35 | ✓ | ✓ | – | ✓ | ✓ | B |
| I17175-3544 C1 | 50.12 | 5.08 | 1.9 ± 0.014 | 0.07 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C2 | 50.12 | 5.08 | – | 0.12 | ✓ | ✓ | – | – | ✓ | B |
| C3 | 50.12 | 5.08 | 1.66 ± 0.274 | 0.29 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I17204-3636 | 19.95 | 4.18 | 0.28 ± 0.009 | 0.06 | – | ✓ | – | ✓ | ✓ | C |
| I17220-3609 | 25.12 | 3.77 | – | 0.22 | ✓ | ✓ | – | ✓ | ✓ | A |
| I17233-3606 C1 | 39.81 | 4.91 | 8.93 ± 0.712 | 0.15 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C2 | 39.81 | 4.91 | 2.91 ± 0.241 | 0.01 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| C3 | 39.81 | 4.91 | 1.87 ± 0.235 | 0.22 | ✓ | ✓ | – | ✓ | ✓ | B |
| I17244-3536 | 39.81 | 4.28 | 0.79 ± 0.182 | 0.16 | ✓ | – | – | – | – | B |
| I17258-3637 C1 | 398.11 | 4.02 | – | 0.3 | ✓ | ✓ | – | – | ✓ | B |
| C2 | 398.11 | 4.02 | – | 0.57 | ✓ | – | – | – | – | B |
| I17269-3312 | 12.59 | 3.66 | 25.06 ± 2.55 | 0.04 | – | ✓ | ✓ | ✓ | ✓ | C |
| I17271-3439 | 39.81 | 4.23 | 1.16 ± 0.094 | 0.1 | ✓ | ✓ | – | ✓ | ✓ | A |
| I17278-3541 C1 | 19.95 | 4.64 | – | 0.16 | – | ✓ | – | ✓ | ✓ | D |
| C2 | 19.95 | 4.64 | – | 0.15 | – | ✓ | – | ✓ | ✓ | D |
| C3 | 19.95 | 4.64 | 1.32 ± 0.118 | 0.25 | – | – | – | – | – | D |
| C4 | 19.95 | 4.64 | – | 0.21 | – | ✓ | – | – | ✓ | D |
| C5 | 19.95 | 4.64 | – | 0.08 | – | – | ✓ | ✓ | ✓ | D |
| C6 | 19.95 | 4.64 | – | 0.02 | – | ✓ | ✓ | – | ✓ | C |
| I17439-2845 | 79.43 | 3.66 | – | 1.39 | ✓ | – | – | ✓ | ✓ | B |
| I17441-2822 C1 | 15.85 | 4.81 | 0.6 ± 0.063 | 1.37 | ✓ | – | – | – | – | B |
| C2 | 15.85 | 4.81 | 0.52 ± 0.046 | 0.96 | ✓ | – | – | – | – | B |
| C3 | 15.85 | 4.81 | 0.28 ± 0.057 | 1.13 | ✓ | – | – | – | – | B |
| C4 | 15.85 | 4.81 | 0.16 ± 0.017 | 1.26 | ✓ | – | – | – | – | B |
| C5 | 15.85 | 4.81 | – | 0.36 | ✓ | – | – | – | – | B |
| I17455-2800 | 63.1 | 3.7 | 3 ± 0.401 | 0.78 | ✓ | ✓ | – | – | ✓ | B |
| I17545-2357 | 10.0 | 3.89 | – | 0.49 | ✓ | – | – | – | – | B |
| I17589-2312 C1 | 10.0 | 4.17 | – | 0.45 | – | – | – | – | – | D |
| C2 | 10.0 | 4.17 | 1.16 ± 0.105 | 0.23 | – | – | – | – | – | D |
| I18032-2032 | 79.43 | 3.8 | 2.45 ± 0.016 | 0.24 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I18056-1952 C1 | 19.95 | 3.92 | 1.02 ± 0.017 | 0 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| C2 | 19.95 | 3.92 | 2.08 ± 0.012 | 1.55 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C3 | 19.95 | 3.92 | 0.39 ± 0.026 | 0.73 | ✓ | ✓ | – | – | ✓ | B |

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Table A3 – continued

| IRAS | L_{bol}/M ($L_{\odot}M_{\odot}^{-1}$) | $\log n$ (cm^{-3}) | [SiO]/[H ¹³ CO ⁺] | D_{d} (pc) | H40 α | SiO | Wing HCO ⁺ | CS | outflow | type |
|----------------|---|----------------------------------|--|------------------------|--------------|-----|--------------------------|----|---------|------|
| I18079-1756 C1 | 19.95 | 4.28 | 0.34 ± 0.026 | 0.05 | – | – | – | – | – | C |
| C2 | 19.95 | 4.28 | 0.47 ± 0.099 | 0.26 | – | – | – | – | – | D |
| I18089-1732 | 15.85 | 3.85 | 0.62 ± 0.069 | 0.03 | – | ✓ | ✓ | ✓ | ✓ | C |
| I18110-1854 | 39.81 | 3.99 | 0.87 ± 0.13 | 0.35 | ✓ | ✓ | – | – | ✓ | B |
| I18116-1646 | 100.0 | 3.73 | 0.09 ± - | 0.18 | ✓ | – | – | – | – | B |
| I18117-1753 | 12.59 | 4.09 | 1.52 ± 0.171 | 0.11 | – | ✓ | ✓ | ✓ | ✓ | D |
| I18139-1842 | 251.19 | 4.15 | 0.6 ± 0.103 | 0.14 | ✓ | ✓ | – | – | ✓ | B |
| I18159-1648 | 10.0 | 4.37 | 2.31 ± 0.259 | 0.03 | – | ✓ | ✓ | ✓ | ✓ | C |
| I18182-1433 | 15.85 | 4.16 | 0.92 ± 0.08 | 0.04 | – | ✓ | – | – | ✓ | C |
| I18223-1243 | 19.95 | 3.76 | 2.47 ± 0.68 | 0.81 | – | – | ✓ | – | ✓ | D |
| I18228-1312 | 50.12 | 3.89 | 0.57 ± 0.24 | 0.19 | ✓ | – | – | – | – | B |
| I18236-1205 | 3.98 | 4.14 | 0.71 ± 0.153 | 0.11 | – | ✓ | – | ✓ | ✓ | D |
| I18264-1152 | 5.01 | 4.09 | 1.24 ± 0.015 | 0.14 | – | ✓ | ✓ | ✓ | ✓ | D |
| I18290-0924 | 6.31 | 3.7 | 1.59 ± 0.245 | 0.24 | – | – | – | – | – | D |
| I18311-0809 | 19.95 | 3.33 | 1.05 ± 0.091 | 0.12 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I18316-0602 C1 | 12.59 | 4.27 | 42.04 ± 1.271 | 0.09 | – | ✓ | – | ✓ | ✓ | D |
| C2 | 12.59 | 4.27 | 1.53 ± 0.103 | 0.17 | – | ✓ | ✓ | ✓ | ✓ | D |
| C3 | 12.59 | 4.27 | – | 0.07 | – | – | – | ✓ | ✓ | C |
| I18341-0727 | 25.12 | 3.4 | 1.49 ± 0.084 | 0.45 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| I18411-0338 | 25.12 | 3.42 | 0.42 ± 0.002 | 0.07 | – | ✓ | – | – | ✓ | C |
| I18434-0242 | 125.89 | 3.7 | 1.04 ± 0.026 | 0.2 | ✓ | ✓ | – | ✓ | ✓ | A |
| I18461-0113 | 19.95 | 4.27 | 0.73 ± 0.004 | 0.1 | – | ✓ | ✓ | ✓ | ✓ | C |
| I18469-0132 | 63.1 | 4.12 | 0.34 ± 0.002 | 0.44 | – | ✓ | – | – | ✓ | D |
| I18479-0005 | 79.43 | 3.65 | 0.56 ± 0.027 | 0.12 | ✓ | – | – | – | – | A |
| I18507p0110 C1 | 39.81 | 4.88 | 0.75 ± 0.008 | 0.03 | ✓ | ✓ | – | ✓ | ✓ | A |
| C2 | 39.81 | 4.88 | – | 0.24 | ✓ | ✓ | ✓ | ✓ | ✓ | B |
| C3 | 39.81 | 4.88 | – | 0.18 | ✓ | – | – | – | – | B |
| I18507p0121 C1 | 7.94 | 4.83 | 3.42 ± 0.067 | 0.01 | – | ✓ | ✓ | ✓ | ✓ | C |
| C2 | 7.94 | 4.83 | 3.42 ± 0.399 | 0.12 | – | ✓ | – | ✓ | ✓ | D |
| I18517p0437 | 50.12 | 5.43 | 0.5 ± 0.022 | 0.05 | – | – | – | – | – | C |
| I18530p0215 | 25.12 | 3.84 | 0.13 ± 0.029 | 0.23 | ✓ | ✓ | – | – | ✓ | B |
| I19078p0901 | 79.43 | 3.73 | 2.12 ± 0.02 | 0.16 | ✓ | ✓ | ✓ | ✓ | ✓ | A |
| I19095p0930 | 100.0 | 4.29 | 0.8 ± 0.014 | 0.06 | – | ✓ | ✓ | ✓ | ✓ | C |
| I19097p0847 | 15.85 | 3.5 | 1.18 ± 0.166 | 0.31 | – | ✓ | ✓ | ✓ | ✓ | D |

Note. L_{bol}/M : The bolometric luminosity to mass ratio. n : The particle number density. [SiO]/[H¹³CO⁺]: The integrated intensity ratio of SiO emission and H¹³CO⁺ emission, and the - symbol indicates that the source has absorption features in their spectra. D_{d} : The separated linear distance between the central position of SiO clumps and the peak position of the 3 mm continuum emission. H40 α column: the ✓ symbol indicates that the SiO clump is associated with H40 α emission. Wing columns: The ✓ symbol represents that the SiO clump shows line wing emission; the sources with - symbol are excluded in analysis. outflow column: The ✓ symbol indicates that the SiO clump is with outflow. Type column: A is the SiO clumps associated with both H40 α emission and 3 mm continuum emission. B is the SiO clumps separated from both H40 α emission and 3 mm continuum emission. C is the SiO clumps associated with 3mm continuum emission undetected H40 α emission. D is the SiO clumps partly separated from 3mm continuum emission undetected H40 α emission.

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