

ATOMS: ALMA three-millimeter observations of massive star-forming regions – XIX. The origin of SiO emission

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ABSTRACT

The production of silicon monoxide (SiO) can be considered as a fingerprint of shock interaction. In this work, we use high-sensitivity observations of the SiO (2–1) and H¹³CO⁺ (1–0) emission to investigate the broad and narrow SiO emission towards 146 massive star-forming regions in the ATOMS (ALMA Three-millimeter Observations of Massive Star-forming regions) survey. We detected SiO emission in 136 regions and distinguished broad and narrow components across the extension of 118 sources (including 58 UC H II regions) with an average angular resolution of 2.5 arcsec. The derived SiO luminosity (L_{SiO}) across the whole sample shows that the majority of L_{SiO} (above 66 per cent) can be attributed to broad SiO, indicating its association with strong outflows. The comparison of the ALMA SiO images with the filamentary skeletons identified from H¹³CO⁺ and in the infrared data (at 4.5, 8, and 24 μm), further confirms that most SiO emission originates from outflows. However, note that for nine sources in our sample, the observed SiO emission may be generated by expanding UC H II regions. There is a moderate positive correlation between the bolometric luminosity (L_{bol}) and L_{SiO} for both components (narrow and broad). The UC H II sources show a weaker positive correlation between L_{bol} and L_{SiO} and higher L_{SiO} compared to the sources without UC H II regions. These results imply that the SiO emission from UC H II sources might be affected by UV-photochemistry induced by UC H II regions.

Key words: stars: formation – ISM: clouds – ISM: molecules – ISM: H II regions.

1 INTRODUCTION

The process of massive star formation provides a variety of feedback to their hosting clouds and the interstellar medium (ISM). The protostellar outflows and the ionizing radiation generated by ultra-compact (UC) H II regions profoundly influence their natal cloud. These processes inject mass, momentum, and energy into their nearby environments (Bally 2016; Kuiper, Turner & Yorke 2016). Indeed, the jets and outflows powered by massive stars interact with the surrounding medium forming shock waves (Bally 2016; Li et al. 2019b), and the ultraviolet radiation from the central massive stars ionizes and dissociates the surrounding ISM. The expansion of UC H II regions is also expected to produce shocks that compress the ambient medium (Hosokawa & Inutsuka 2006; Zhu et al. 2023). These processes change the density and gas turbulence of the clouds, promoting or inhibiting future star formation. Therefore, studying protostellar feedback is essential to deepen our understanding not only of the physical and chemical processes involved in massive

star formation but also on how it affects the formation of the future generation of stars in the Milky Way and in external galaxies.

The shock activity in molecular clouds could serve as a fossil record of star formation feedback (Duarte-Cabral et al. 2014; Cosentino et al. 2020). Thus, it is crucial for us to unveil the origin of the shocks in star-forming regions (SFRs). SiO is the perfect tracer of interstellar shock waves because it experiences high depletion in quiescent regions compared to shocked regions (Martín-Pintado, Bachiller & Fuente 1992). In particular, the SiO abundance can be enhanced by up to six orders of magnitude in outflow regions (Martín-Pintado et al. 1992). Dust grains are known to be partially (or totally) destroyed through sputtering in shocks, producing the release of significant amounts of Si atoms and/or Si-bearing molecules into the gas phase (Caselli, Hartquist & Havnes 1997; Schilke et al. 1997; Jiménez-Serra et al. 2008).

Previous observations have reported that the line profiles of SiO emission frequently present two Gaussian velocity components: a bright broad component, and a weak narrow component, centred at velocities similar to the velocity of the ambient cloud (Martín-Pintado et al. 1992; Schilke et al. 1997; Lefloch et al. 1998; Jiménez-Serra et al. 2004, 2005, 2006, 2008, 2009, 2010; Louvet et al. 2016; Cosentino et al. 2018, 2019, 2020; Liu et al. 2022; Towner

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et al. 2024). These two components are considered to have different origins. The broad components are attributed to the powerful outflows from protostellar objects (Qiu et al. 2007; Duarte-Cabral et al. 2014), and the narrow components are often related to the production of low-velocity shocks from either decelerated entrained material (Lefloch et al. 1998), young shocks through the interaction of the magnetic precursor (Jiménez-Serra et al. 2004, 2005), cloud–cloud collisions (Jiménez-Serra et al. 2010; Louvet et al. 2016; Cosentino et al. 2018), large-scale gas inflows, and expansion of UC H II regions or supernova remnants (Cosentino et al. 2019, 2020; Cosentino et al. 2022). Jiménez-Serra et al. (2009) modelled the evolution of SiO line profiles along the evolution of magnetohydrodynamic (MHD) shock in young molecular outflows, showing that changes in the SiO line profiles are expected. At early times, the SiO emission is characterized by a narrow SiO component centred at ambient velocities (with line widths of 0.5 km s^{-1} , linked to the magnetic precursor) that evolves into a broad component line profile peaking at high velocities.

Liu et al. (2022) conducted a study on SiO (2–1) emission using the observations from the Atacama Compact Array (ACA) 7 m Array to understand better the properties of the SiO shocked gas in different regions across the Galaxy and at different evolutionary stages. They found that a large amount of the observed SiO line profiles (60 per cent) within the sample presents two velocity components (one narrow and another one broad) in the large field of view ($2'$) and the low angular resolution ($13''$) of the ACA observations. In this work, we now utilize the 12 and 7 m combined data from the ATOMS survey to disentangle these different SiO components and investigate their origin. To do this, we image the SiO emission with a higher angular resolution (2.5 arcsec) towards 146 massive SFRs using ALMA. In Section 2, we provide details about the selected source sample and performed ALMA observations. The analysis method is presented in Section 3. Section 4 describes the results of our analysis for the whole sample. The origin of the SiO emission is discussed in Section 5. The summary is presented in Section 6.

2 OBSERVATIONS

2.1 The ATOMS Sample

This paper investigates 146 massive SFRs from the ATOMS (ALMA Three-millimeter Observations of Massive Star-forming regions) survey (Liu et al. 2020a, b). The sources were selected from UC H II region candidates located in the Galactic plane and that contain bright CS $J = 2-1$ emission ($T_b > 2 \text{ K}$; Bronfman, Nyman & May 1996). The physical parameters of 146 sources were taken from (Liu et al. 2020a, b). Sources I08076-3556 and I11590-6452 are in reality low-mass SFRs, with mass values of 5.01 and $12.59 M_\odot$, respectively. These two low-mass sources were excluded from the analysis. Source I08448-4343 is an intermediate-mass SFRs with an estimated mass of $39 M_\odot$. The remaining sources (143 sources) are massive SFRs with estimated masses ranging from 126 to $2.5 \times 10^5 M_\odot$. The distance of these sources covered in our sample ranges from 0.4 to 13.0 kpc . The bolometric luminosity ranges from 16 to $8.1 \times 10^6 L_\odot$, while the dust temperature ranges from 18 to 46 K . Outflow activity were found in 97 sources through HCO⁺ and SiO emission (Baug et al., in preparation). Seventy-six sources were identified as UC H II regions using H40 α emission (Liu et al. 2021; Zhang et al. 2023). Zhou et al. (2022) searched for filamentary structures, as plotted in below, towards all sources making use of H¹³CO⁺ $J = 1-0$ line data.

2.2 ALMA observations

We use ALMA Band 3 data from the ATOMS survey (Project ID: 2019.1.00685.S; PI: Tie Liu). This survey has obtained both 12-m array and 7-m array data, and the details of the observations can be found in Liu et al. (2020a, b). The spectral setup consisted of six narrow spectral windows (SPWs 1–6) at the lower sideband and two wide spectral windows (7–8) at the upper sideband. The narrow SPWs are in the range of $86.31\text{--}89.2 \text{ GHz}$, with a spectral resolution of $\sim 0.2 \text{ km s}^{-1}$, and the wide SPWs 7 and 8 are in the range of $97.52\text{--}99.39 \text{ GHz}$ and $99.46\text{--}101.33 \text{ GHz}$, respectively, and employ a spectral resolution of $\sim 1.6 \text{ km s}^{-1}$. The wide SPWs 7 and 8 are used for continuum measurements. All data reductions were carried out using the CASA software package version 5.6 (McMullin et al. 2007). The 7-m array data and 12-m array data are calibrated separately and then combined and cleaned. All images are primary-beam corrected. In this paper, the SiO $J = 2-1$ and H¹³CO⁺ $J = 1-0$ lines are included in SPWs 1–6 with spectral resolutions of 0.21 and 0.211 km s^{-1} , respectively. The maximum recoverable scale is about $1'$. The typical beam size and channel rms noise level of these two lines are 2.5 arcsec and 8 mJy beam^{-1} , respectively (Liu et al. 2020a, b). The pixel angular size in each image is about 0.4 arcsec . This implies that there are about 40 pixels per synthesized beam. Since our ALMA images do not include total power (TP) data, they may suffer from missing flux. However, note that as discussed by Liu et al. (2020a), the 12-m array observations recover more than 92 per cent of the flux measured in the ACA images as inferred by averaging the H¹³CO⁺ emission over a 30-arcsec region in one example source.

3 METHODS

The goal of this study is to investigate the different origins of the SiO emission towards the 146 massive SFRs in our sample. The basic parameters (distances from the sun, distance; systemic velocities, v_{LSR} ; bolometric luminosity, L_{bol} ; clump masses, M) of these sources are provided in Appendix A, taken from Liu et al. (2020a). First, we inspect the SiO emission in CASA to determine the velocity ranges in the observed spectra for each source. Then, we generate the moment 2 maps of the SiO emission and identify the locations where SiO presents the broadest and the narrowest-line widths. Fig. 1 shows the SiO and H¹³CO⁺ spectra extracted from these positions for four representative sources. The spectra were extracted over the aperture within a specific area, as described below. Fig. 2 presents the variations in the line widths of SiO and H¹³CO⁺ at these positions. The corresponding positions are marked by orange and blue rectangles in Fig. 3 for the broadest and narrowest SiO line width, respectively.

Due to the complex line profiles observed for the SiO emission, the broad and narrow velocity components were separated by carrying out a Gaussian spectral decomposition with the PYTHON analysis tool SCOUSEPY (Henshaw et al. 2016). SCOUSEPY is a semiautomated multicomponent spectral line decomposition tool that can fit the SiO spectra in every detected source. Initially, the fitted areas were defined in the generated moment 0 maps, constraining the SiO emission within the fitted areas above 3σ rms noise. The fitted areas correspond with the green rectangle in Fig. 3. We calculated σ rms noise values using the standard deviation from ten free channels without SiO emission and have listed these values in Table A1. After this, we semi-automatically fitted the average spectra extracted from subareas of size 2×2 , 4×4 , 6×6 , or $8 \times 8 \text{ pixels}^2$. The subareas are used for the spectra extraction through the observed SiO emission. The

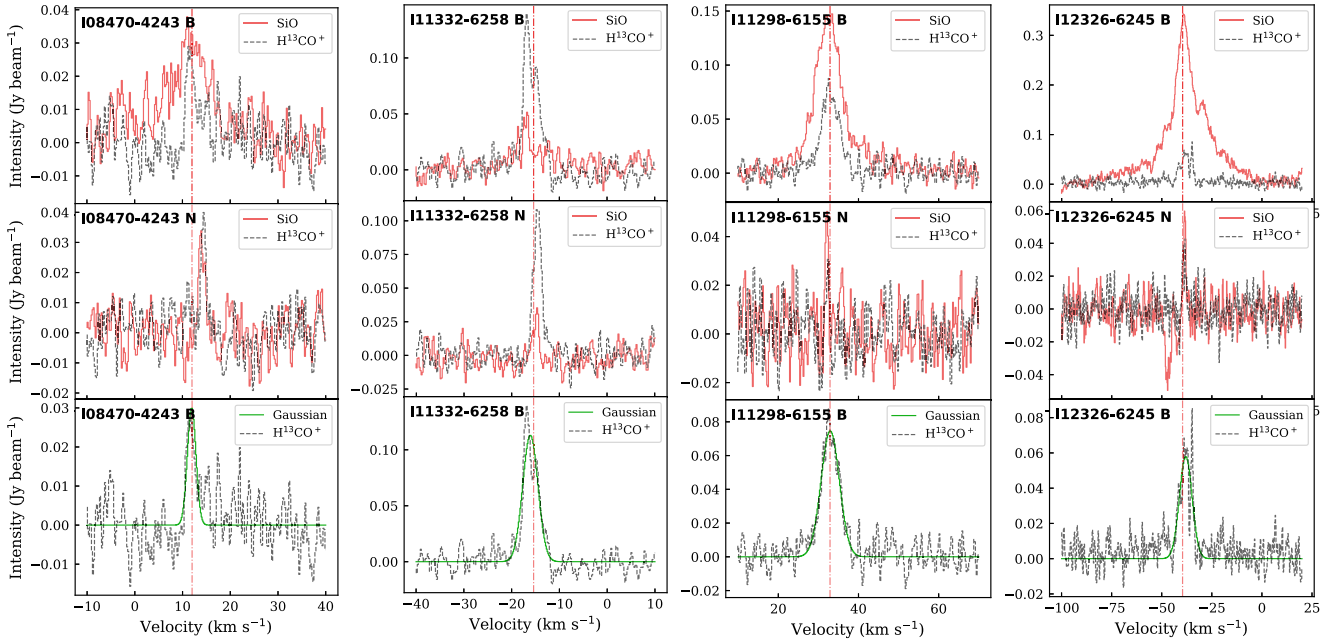


Figure 1. *Upper and middle panels:* Comparison between the line profiles of SiO and H^{13}CO^+ emission extracted from the positions associated with the broadest and the narrowest SiO line widths (top and middle panels). The labels ‘B’ and ‘N’ after the source name in the upper left part of each panel, correspond to the positions with the broadest and narrowest SiO emission marked by solid rectangles in Fig. 3, respectively. Solid histograms represent the SiO spectra. The spectra of H^{13}CO^+ emission are shown in dashed histograms. The dashed–dotted vertical line indicates the systemic velocity of the source reported by Liu et al. (2020a). *Bottom panels:* Dashed histograms show the H^{13}CO^+ spectra extracted from position ‘B’. Solid curves report the Gaussian fits to the H^{13}CO^+ spectra. The spectra for all sources are available as supplementary material.

output of these Gaussian fits was then used as input information for the Gaussian fitting of the line profiles extracted pixel-by-pixel (see the details of the method in Henshaw et al. 2016). We have added the size of subareas and the number of subareas where the broad and narrow components were detected in Table A1.

The criteria for a successful fitting of two Gaussian components included the narrow component having a peak flux above 3σ and the velocity offset between these two components smaller than the line width of the broad component. If the observed spectrum did not satisfy this condition, we retained a single Gaussian fit and ensured its peak flux laid above 3σ . We obtain the Gaussian fitting parameters (peak flux, central velocity, and velocity dispersion) provided by SCOUSEPY. In Fig. 4, we show an example of the fitting procedure with SCOUSEPY used to decompose the broad and narrow components of the observed SiO emission. To better disentangle the broad and narrow SiO components, we compare the measured SiO line widths with the derived H^{13}CO^+ line width, following a similar method to that described in Cosentino et al. (2018, 2020). Its high critical density and low optical depth make H^{13}CO^+ a good tracer of dense gas. In addition, the abundance of H^{13}CO^+ is not expected to vary substantially with time. Indeed, by using a large sample of IRDC clumps at different evolutionary stages, Sanhueza et al. (2012) found that the HCO^+ abundance varies by less than a factor of 3. In addition, chemical fractionation models show that the $\text{HCO}^+/\text{H}^{13}\text{CO}^+$ abundance ratio varies by less than a factor of 2 for time-scales between 10^5 and 10^6 yr (Roueff, Loison & Hickson 2015). The H^{13}CO^+ spectra were extracted from the positions with the broadest SiO emission detected towards each source, as representative of the emission arising from the ambient gas. In our analysis, we consider that SiO emission with line widths larger than that of the H^{13}CO^+ emission can be attributed to stronger shock activity. To better analyse the kinematic structure

and the origin of the shocked gas, we show the spatial distribution of the broad and narrow components in the next section.

4 RESULTS

4.1 Line profiles of SiO and H^{13}CO^+ emission in active and quiescent regions

The positions associated with the broadest and the narrowest SiO line widths were identified using the results from SCOUSEPY and SiO moment 2 maps. In the top and middle panels of Fig. 1, we present the line profiles of SiO and H^{13}CO^+ emission extracted from these positions towards four selected sources. The upper panels show the spectra extracted from the positions with the broadest SiO line widths, thought to mark the location with the strongest shock activity in each source. The middle panels present the spectra extracted from the position with the narrowest SiO line widths. These regions are likely undergoing a more gentle shock interaction. These regions are, respectively, labelled ‘B’ and ‘N’ after their source name in the upper left part of the top and middle panels of Fig. 1. Towards position ‘B’, the SiO emission exhibits broader and more complex spectra than towards the ‘N’ positions, while the H^{13}CO^+ emission shows small variations across both positions.

In the bottom panels of Fig. 1, we show the H^{13}CO^+ spectra (dashed curves) with their Gaussian fits superimposed using green lines extracted from position ‘B’. The Gaussian fits have been carried out with the MADCUBA analysis tool (Martin et al. 2019). Table A1 lists the H^{13}CO^+ line widths measured towards each source. The H^{13}CO^+ line widths varies from 0.7 to 12.2 km s^{-1} , with a mean value of 3.3 km s^{-1} .

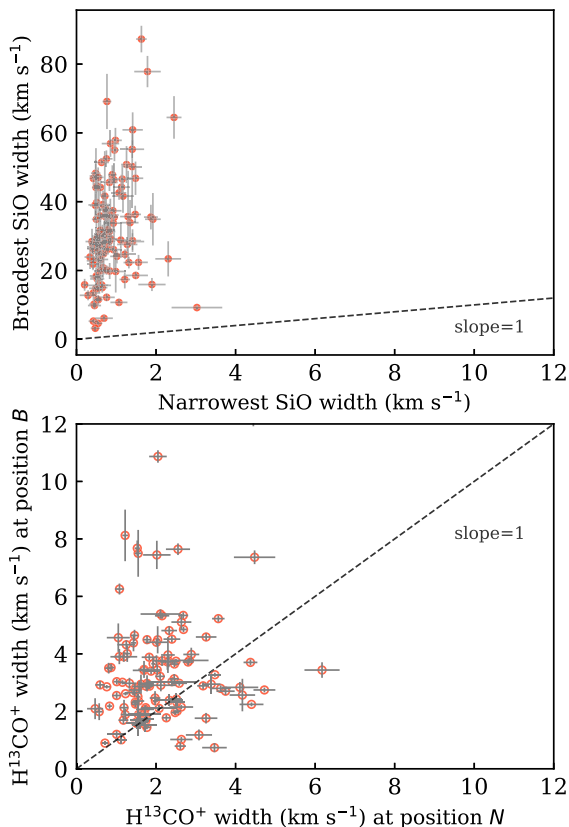


Figure 2. Top panel: Comparison between the broadest SiO line width compared to the narrowest SiO line width measured for each source (see filled circles). Bottom panel: Comparison between the H^{13}CO^+ line width extracted from position ‘B’ versus the H^{13}CO^+ line width extracted from position ‘N’. The empty circles show each source. In both panels, the dashed line represents a 1:1 slope. The error bars in both plots represent the uncertainties associated with the measured line widths.

In Fig. 2, we compare the range in the measured line widths of SiO and H^{13}CO^+ at positions ‘B’ and ‘N’ for each source. From this figure, it is clear that the narrowest SiO component measured at position ‘N’ is clearly narrower than the broadest SiO emission observed at position ‘B’ towards each source. The difference in linewidths is apparent since narrow SiO shows linewidths narrower than 2 km s^{-1} for the majority of sources, while the broadest SiO emission lies typically above 10 km s^{-1} . For SiO, the line width at position ‘B’ ranges from 3.2 to 87.3 km s^{-1} , while at position ‘N’, it varies from 0.2 to 3 km s^{-1} . For the H^{13}CO^+ emission, the line width displays only slight variations between the two positions, and its measured line widths are typically below 5 km s^{-1} for most sources. The maximum line width ratio across both positions is approximately six.

To analyse the SiO line profiles, we employed the `SCOUSEPY` analysis tool. This tool performs the Gaussian fitting of the SiO line profiles pixel by pixel within the ALMA maps towards the observed sources. Multiple velocity components are fitted using multiple Gaussian profiles. After performing the Gaussian fitting, we compared the H^{13}CO^+ line width at position ‘B’ with SiO line widths measured pixel by pixel to differentiate between the broad and narrow components of SiO for each spectrum. As mentioned above, if the linewidth of the SiO velocity component measured by `SCOUSEPY` is broader than the one of H^{13}CO^+ , then that SiO component is classified as broad, while if the measured SiO linewidth is narrower

than (or similar to) the line width of H^{13}CO^+ , we consider that the SiO emission is narrow. We note that we use the H^{13}CO^+ linewidth measured towards position ‘B’ because it represents an upper limit to the distribution of H^{13}CO^+ linewidths across each source, as this is the location with the strongest shock interaction found in each region. In any case, as shown in Fig. 2, the H^{13}CO^+ linewidth upper limits typically cluster between 0.5 and $5\text{--}6 \text{ km s}^{-1}$, which indicates that the H^{13}CO^+ linewidths will be restricted to a narrow linewidth range.

4.2 The general spatial distribution of SiO emission

SiO (2–1) emission was detected towards 136 out of the 146 sources in our sample, whereas 10 sources had no SiO emission measured above the 3σ level. We classified the 136 detected sources into four different categories based on them hosting UC H II regions and on the presence of SiO emission associated with filament skeletons seen in H^{13}CO^+ (Zhou et al. 2022): (1) six sources without UC H II regions and not associated with filament skeletons; (2) 60 sources without UC H II regions but associated with filament skeletons; (3) three sources hosting UC H II regions but not associated with filament skeletons; (4) 66 sources hosting UC H II regions and associated with filament skeletons.

Fig. 3 shows the morphology of the SiO emission as seen from the moment 0 maps towards four sources representative of the above categories. Source I08470-4243 is representative of category (1), with no $\text{H}40\alpha$ emission being detected and no filament skeletons identified using H^{13}CO^+ emission. The SiO emission is associated with 3 mm continuum emission (see larger dashed rectangle). Category (2) is exemplified by source I11332-6258, where the SiO emission is clearly associated with filament skeletons and 3 mm continuum emission but no $\text{H}40\alpha$ emission is detected. We consider the lack of $\text{H}40\alpha$ emission in these two categories as a strong indicator that these sources are not associated with UC H II regions. Therefore, in these sources the 3 mm continuum emission measured with ALMA is dominated by thermal dust emission. Sources I11298-6155 and I12326-6245 are illustrative of categories (3) and (4), respectively. Both sources exhibit $\text{H}40\alpha$ emission, implying the presence of UC H II regions. Towards source I11298-6155, the detected SiO emission coincides spatially with the 3 mm continuum emission and it is very compact. In addition, it is not associated with any filament skeletons. Towards source I12326-6245, the SiO emission is associated with filament skeletons and 3 mm continuum emission. SiO also displays a more extended distribution than in category (3). Similar images are available for all sources in the supplementary material.

4.3 Broad and narrow components of SiO emission

Using the fitting results provided by `SCOUSEPY` and considering the H^{13}CO^+ line widths, we generated the histograms of the velocity and line width distributions for the narrow and broad SiO components to illustrate the velocity structure across the sample (see Section 4.3.1). We also produced the integrated intensity maps for both the narrow and broad components of SiO to investigate their spatial distribution and their association with the measured 3 mm continuum emission (see Sections 4.3.2 and 4.3.3). In this analysis, we have only used 118 out of the 136 sources with SiO emission. The exclusion of 18 sources from this analysis is due to absorption features in SiO line profiles caused by the presence of strong continuum sources (Ohashi et al. 2022; Codella et al. 2024). We show the SiO spectra of the excluded sources in Appendix B, and a list of these sources is available in Table A1.

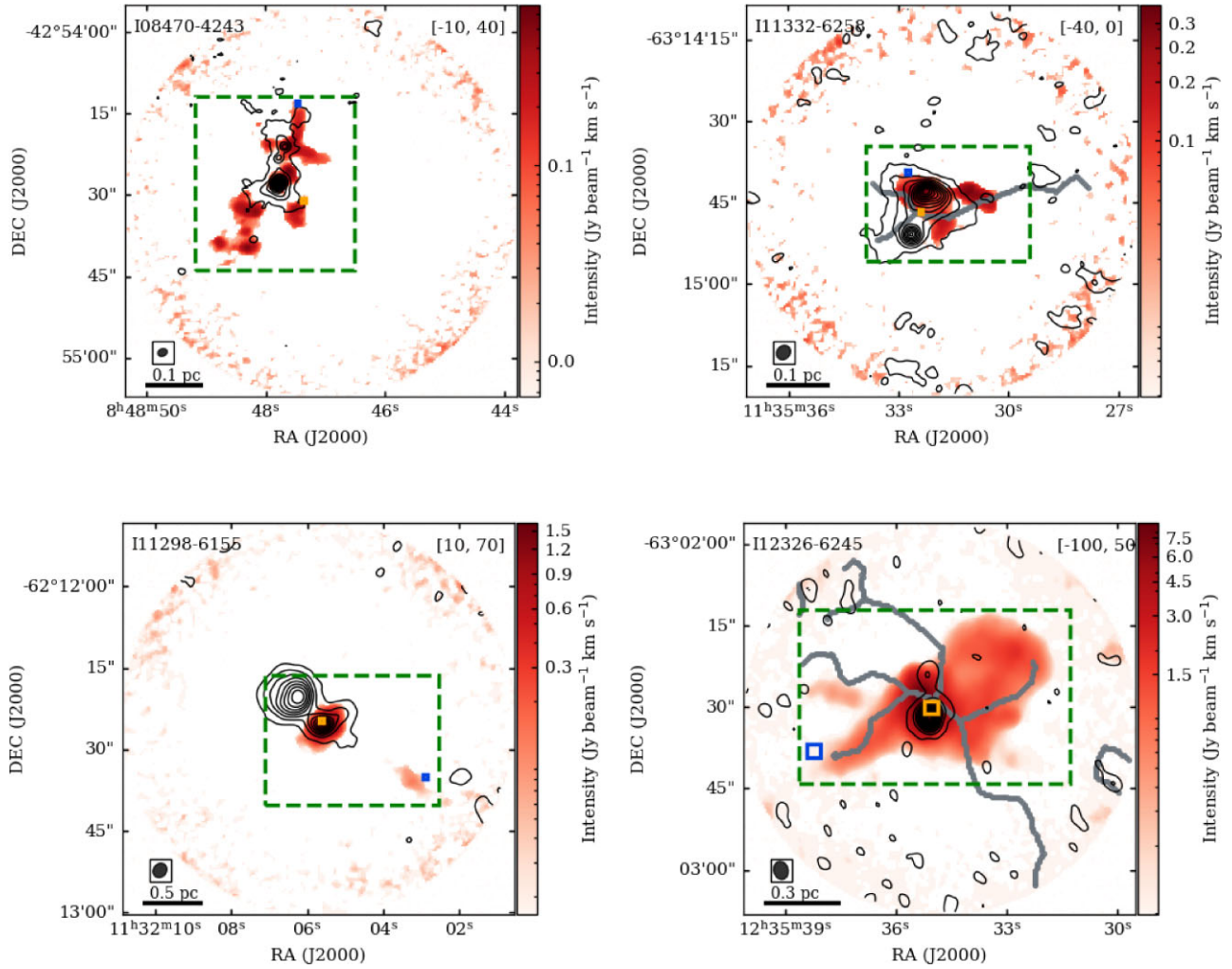


Figure 3. Four representative sources imaged with ALMA within the ATOMS programme. The background corresponds to the SiO (2–1) integrated intensity maps. Contours show the 3 mm continuum emission detected with ALMA, and contours are from 5σ to the peak values in steps of 10σ . The bold lines represent the filament skeletons identified using H^{13}CO^+ as reported by Zhou et al. (2022). The larger dashed rectangle is the area of the SiO emission maps where the SiO line profiles have been decomposed into different velocity components. The smaller solid rectangles, with the broadest and narrowest SiO line widths, respectively, indicate the locations where SiO and H^{13}CO^+ have been extracted. The field of view (FOV) is $72''$ corresponding with the FOV of the ALMA observations. All images have been primary-beam corrected. The source name and integrated velocity ranges (in km s^{-1}) are shown on the upper left and right corners, respectively. The beam size is reported in the lower left corner. The same images are provided for all sources within the supplementary material.

4.3.1 General statistics across the whole sample

We investigate the velocity and line width distribution of the broad and narrow components across the 118 sources for which we have performed the analysis with *SCOUSEPY*. Fig. 5 shows the distribution of sources as a function of velocity offset with respect to the systemic velocity of the cloud (Faúndez et al. 2004; Urquhart et al. 2018; Liu et al. 2020a) and as a function of line width. Because the count of fitted spectra is different from source to source, to avoid any statistical bias produced by sources with many fitted spectra we normalize the counts of fitted spectra per velocity bin by the total number of counts obtained for each source. The y-axes in Fig. 5 represent the sum of normalized counts in each source falling into the same velocity bin. The unfilled blue histograms correspond to the sources without known outflow activity, and the orange-filled histograms represent the sources exhibiting known outflow activity as inferred by Baug et al. (in preparation). To identify the outflows, Baug et al. (in preparation) have employed the ALMA SiO and HCO^+ maps whose emission is brighter than the 5σ rms noise threshold. In our images,

the extension of the lobes was marked by arrows. The location of the triggering star was identified by the peak of 3 mm continuum emission and the centrally positioned between the blue and red lobes. The sources with known outflow activity are indicated in Table A1.

We used the Kolmogorov–Smirnov (KS) test to analyse the velocity offset and line width across sources with and without outflows considering both broad and narrow components together. The p -values generated by the KS test indicate the probability that the two samples originated from the same distribution. If the p -value is less than 0.05, this suggests that the samples likely come from different distributions. In our analysis, the velocity offset comparison between sources with and without outflows returned a p -value of 4.05×10^{-31} from the KS test. For the line width across these two categories, the p -value was 1.62×10^{-10} . These results confirm that the sources with and without outflows come from distinct distributions. For the narrow component (see Fig. 5, left panels), most of the emission with or without outflow present velocity offsets that lie within $\pm 10 \text{ km s}^{-1}$, indicating that this emission arises from molecular gas close to ambient cloud velocities. In contrast, the velocity offset of the broad

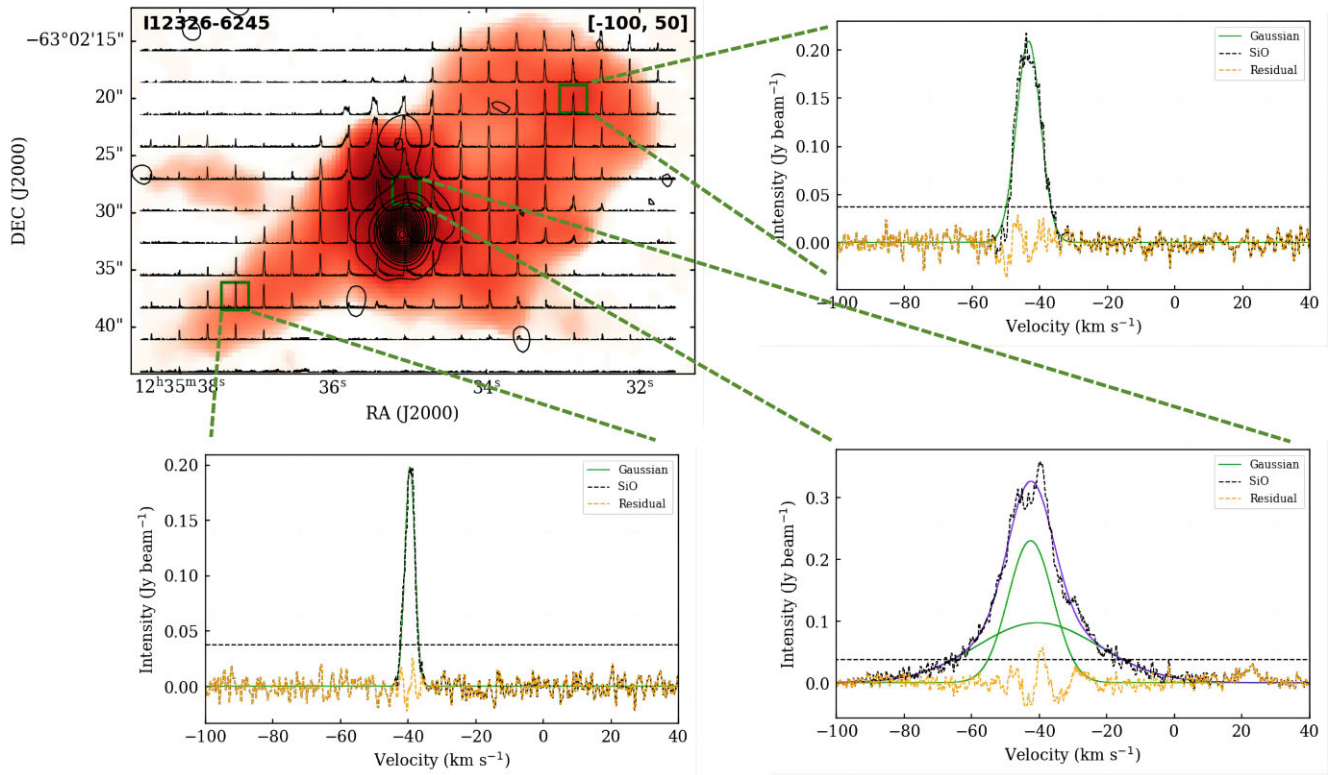


Figure 4. Output of *SCOUSEPY* for source I12326-6245. In the upper left panel, we show the SiO (2–1) integrated intensity map where the SiO spectral grid map is overlaid. The grid size corresponds to the smaller solid rectangle size (6×6 pixels²) used in the fitted average spectra in *SCOUSEPY*. Contours report the 3 mm continuum emission, and contours are from 5σ to the peak values in steps of 10σ . The displayed field of view corresponds to the larger dashed rectangle in Fig. 3. Dashed thick lines indicate the regions for which example spectra are also shown (see right upper panel and lower panels). In the latter, the dashed and green solid lines represent the average SiO spectra and the Gaussian fit lines of the different components, respectively. The purple solid line (see right lower panel) is the total Gaussian fit obtained for these lines. The dashed curve indicates the residuals and the horizontal dashed lines show the 3σ rms noise levels.

SiO components is distributed across a wider range of velocities compared to the narrow SiO emission, even reaching values above 60 km s^{-1} . For the line width distribution of narrow SiO emission (the left lower panel of Fig. 5), we find that the vast majority of fitted spectra have line widths $\leq 5\text{--}6 \text{ km s}^{-1}$, suggesting that the gas may have been affected either by low-velocity shocks or by young shocks at the magnetic precursor stage (Jiménez-Serra et al. 2004, 2005; Duarte-Cabral et al. 2014). For the broad SiO emission, however, its line widths can be as large as 60 km s^{-1} , with a maximum of 87 km s^{-1} . Note that a few extreme values are omitted in Fig. 5 to better display the details of the distributions. For a full view of the line widths, refer to Fig. 2.

4.3.2 The spatial distribution of the different components of the SiO emission

In this section, we aim to elucidate the diverse spatial distribution between the narrow and broad SiO components across all observed categories. Fig. 6 presents the two distinct spatial distributions of the narrow and broad SiO components. The images for all the velocity-decomposed sources are available as supplementary material.

We classified the morphology between the narrow and broad components into two cases by comparing the spatial extension of the emission (in pixel counts) across the 118 decomposed sources: (A) broad SiO emission is more extended than the narrow emission (94 sources) and (B) narrow SiO emission is more extended than the broad SiO emission (24 sources). The pixel counts for the broad and narrow components and the classification of each source can

be found in Tables A1 and A2. As an example, Fig. 6 shows two representative sources of the *group A* and *group B* cases. Both sources are associated with 3-mm continuum emission and along the filamentary structures. In the case of I16071-5142, representative of *group A*, the broad component exhibits a more extended distribution than the narrow one, while towards I12326-6245 (representing *group B*) the narrow component is distributed across a wider extension than the broad component.

We have performed the statistics about the number of sources from *group A* and *group B* that fall into the categories presented in Section 4.2, i.e. within Categories (1), (2), (3), and (4). This can be seen from Table 1. Fewer sources fall into categories (1) and (3), where sources with broad and narrow SiO emission tend not to be associated with filament skeletons (regardless they present UC H II regions or not). Within these two categories, we find that five sources without UC H II regions and one source with UC H II regions present a more extended distribution of the broad SiO emission than for the narrow components (sources from *group A*; see Table 1). In contrast, only one source without an UC H II region and two sources containing UC H II regions display a more extended distribution of the narrow SiO component than for the broad SiO emission. For categories (2) and (4), for which sources are associated with filament skeletons, 42 objects without UC H II regions and 46 sources with UC H II regions present more extended broad SiO emission, while 12 sources without UC H II regions and 9 sources with UC H II regions sources exhibit more extended narrow SiO emission. Therefore, SiO emission (both narrow and broad) tend to appear for sources associated with filaments (categories 2 and 4) with similar percentages of *group A*

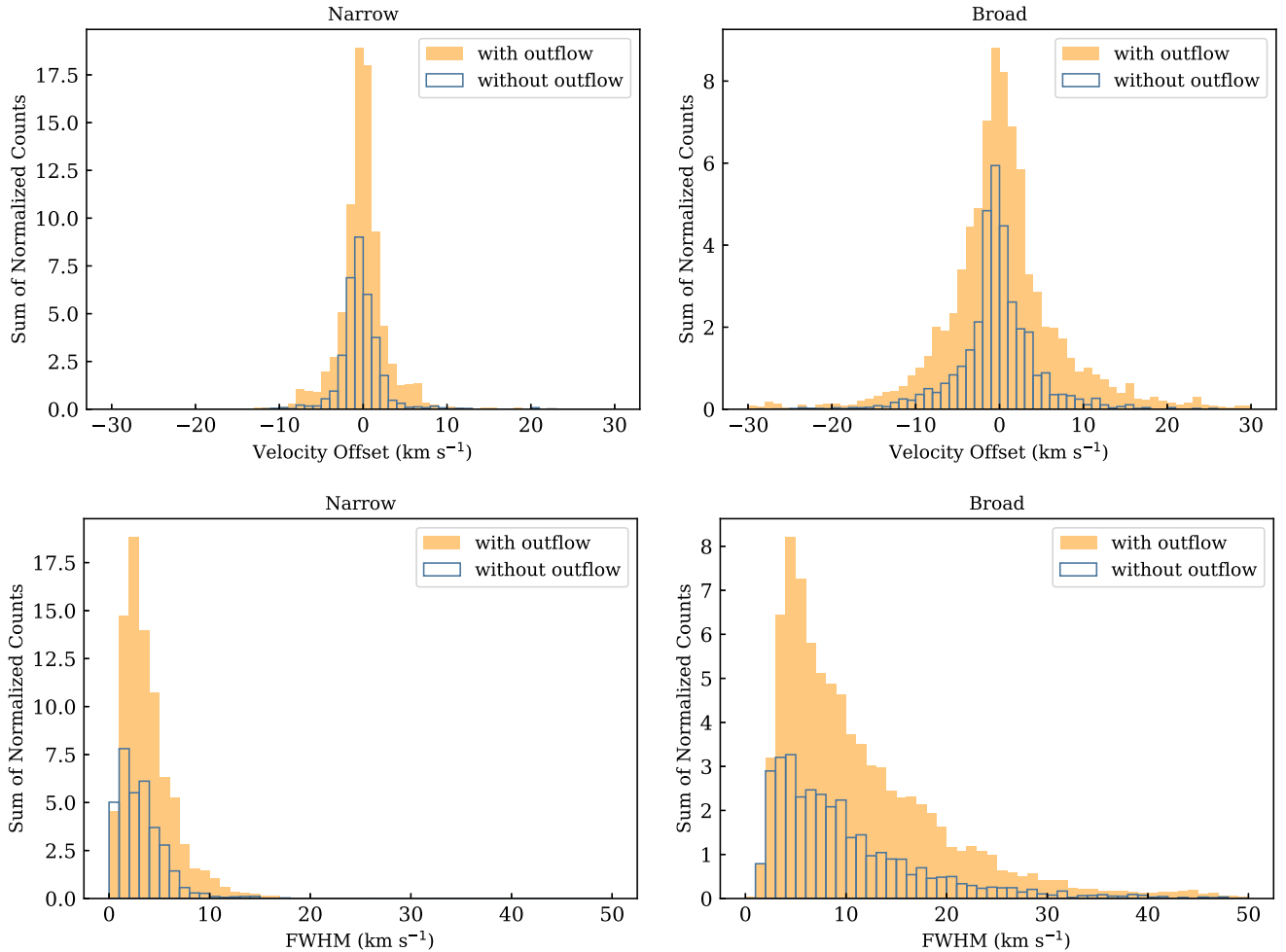


Figure 5. The histogram shows the velocity offset compared to the systemic velocity and line width distribution of the broad and narrow components of the SiO emission for the entire sample. The open blue histograms correspond to the sources without outflow activity, and the orange-filled histograms represent the sources exhibiting outflow activity. The outflow sources can be found in Table A1.

sources (75–85 per cent, i.e. 42 sources out of 54 in category 2 and 46 objects out of 55) and of *group B* sources [15–25 per cent, i.e. 12 sources out of 54 in category 2 and 9 objects out of 55].

4.3.3 Properties of the narrow and broad SiO emission in sources hosting UC H II regions

Cosentino et al. (2020) found narrow SiO emission in molecular clouds affected by the expansion of nearby H II regions. However, in that study, the lack of high-angular resolution observations prevents us from establishing the origin of the narrow SiO emission. Therefore, an interesting item to analyse using the high-angular resolution data of the ATOMS programme is the emission of narrow and broad SiO towards sources hosting UC H II regions. In this way, we can understand the properties of the SiO emission such as incidence of the broad and narrow components, spatial distribution and kinematics of the gas, in regions affected by expanding H II regions with much higher resolution as done by Cosentino et al. (2020). In Fig. 7, we depict three representative sources of the subsample of 58 sources with UC H II regions, which present different spatial distributions between SiO and 3 mm continuum emission. Due to the contribution of free-free emission, the 3 mm continuum emission is spatially associated with H40 α emission, as reported by Liu et al. (2022). In

Fig. 7, we use the half-peak value of the 3 mm continuum emission to validate the spatial relationship between SiO and the material associated with the UC H II region as seen at these wavelengths. We classify these sources with UC H II regions into three groups: (i) the SiO emission peak falls within the half-intensity peak contour of the 3 mm continuum emission; we name these sources as ‘*coincident*’ (9 sources); (ii) the SiO emission peaks offset with respect to the half-intensity peak contour of the 3 mm continuum emission; we name these sources as ‘*offset*’ (40 sources); and (iii) the SiO emission surrounds the 3 mm continuum emission and it is clearly associated with extended emission either at 1.3 GHz (obtained from Goedhart et al. 2024) and/or 8 μ m emission, as if material had been compressed by the expansion of the H II region; we label these sources as ‘*surrounded*’ (9 sources). In Appendix C, we present the spatial distribution of the 1.3 GHz and 8 μ m emission. The classification of UC H II sources is provided in Table A2.

In Fig. 7, the case of I11298-6155 (*coincident*) demonstrates that both broad and narrow components coincide with 3 mm continuum emission, and the narrow components are more extended than the broad ones in the coexisting position. Towards I15411-5352 (*offset*), it is clear that both components are separated from the peak position of 3 mm continuum emission, and the narrow ones present more compact distribution than the broad ones, similar to

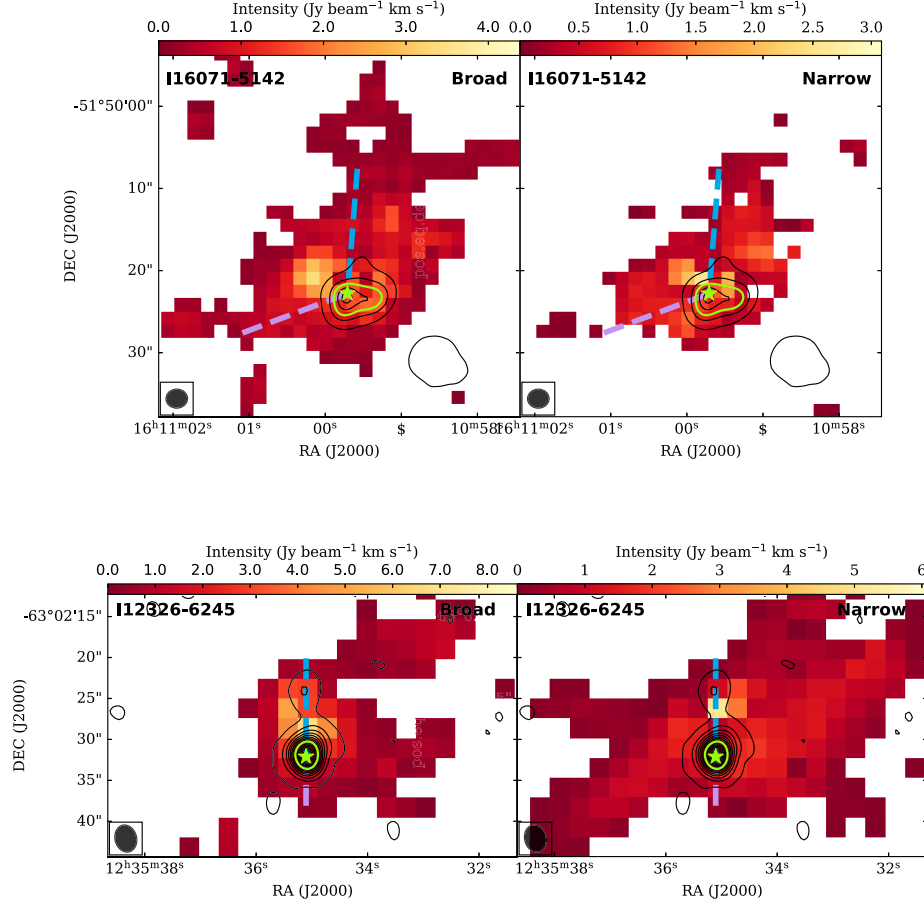


Figure 6. The two cases of decomposed sources are based on the different morphology of narrow and broad SiO components. The upper panels display the SiO integrated intensity maps of broad (left) and narrow (right) components for a source from *Group A* and the lower panels present the SiO integrated intensity maps of broad (left) and narrow (right) components for a source from *Group B*. Contours are 3 mm continuum emission, and contours are from 5σ to the peak values with a step of 10σ . The dashed thick lines represent the blue and red lobes of identified outflows from Baug et al. (in preparation), and the star is the position of the protostar centrally positioned between the two lobes. The single green thick contour is the half-peak value of the 3 mm continuum emission. The source name is shown on the upper left of the panel and the beam size is reported in the lower left corner. The shown field of view is the area of the dashed rectangle presented in Fig. 3.

Table 1. The number of sources from *groups A and B* that fall into the four categories defined in Section 4.2.

Category	Group A	Group B
(1)	5	1
(2)	42	12
(3)	1	2
(4)	46	9

Note. (1) Sources without UC H II regions and not associated with filament skeletons. (2) Sources without UC H II regions but associated with filament skeletons. (3) Sources hosting UC H II regions but not associated with filament skeletons. (4) Sources hosting UC H II regions and associated with filament skeletons. *Group A:* The broad SiO is distributed more extensively than the narrow SiO. *Group B:* The narrow SiO is distributed more extensively than the broad SiO.

the source I16071-5142. In source I09002-4732 (*surrounded*), the broad SiO components are distributed around but far away from the 3 mm continuum emission, as if it were associated with compressed material produced by the expansion of the H II region seen at 1.3 GHz and/or 8 μ m emission in Fig. C1. The sources I09002-4732 and I15411-5352 exhibit associations with filamentary structures.

We utilize the distribution of sources with UC H II regions as a function of velocity offset in comparison with the systemic velocity of the cloud, and as a function of line width to study the kinetic structure for three categories statistically. In Fig. 8, the distributions of both SiO components are similar to the SiO distributions in Fig. 5 (see Section 4.3.1). We employed the KS test to compare the velocity offset and line width across these three categories considering both broad and narrow components together. For the velocity offset comparisons between *coincident* and *offset*, *offset* and *surrounded*, and *coincident* and *surrounded*, the p -values returned by the KS test were 2.44×10^{-9} , 2.49×10^{-3} , and 5.89×10^{-6} , respectively. For the line width comparisons among these three categories, the p -values returned by the KS test from these three categories were 0.09, 6.98×10^{-18} , and 8.41×10^{-11} , respectively. These results suggest that line widths from *surrounded* sources are likely drawn from different distributions with line widths from *coincident* and *offset* sources. Notably, the line widths of *surrounded* sources tend to be narrower than those of *coincident* and *offset* sources, with median values of 3.17, 3.84, and 3.80 km s^{-1} for narrow components, and 6.48, 9.82, and 9.07 km s^{-1} for broad components, respectively. However, the velocity offset distributions across the three categories do not exhibit significant differences.

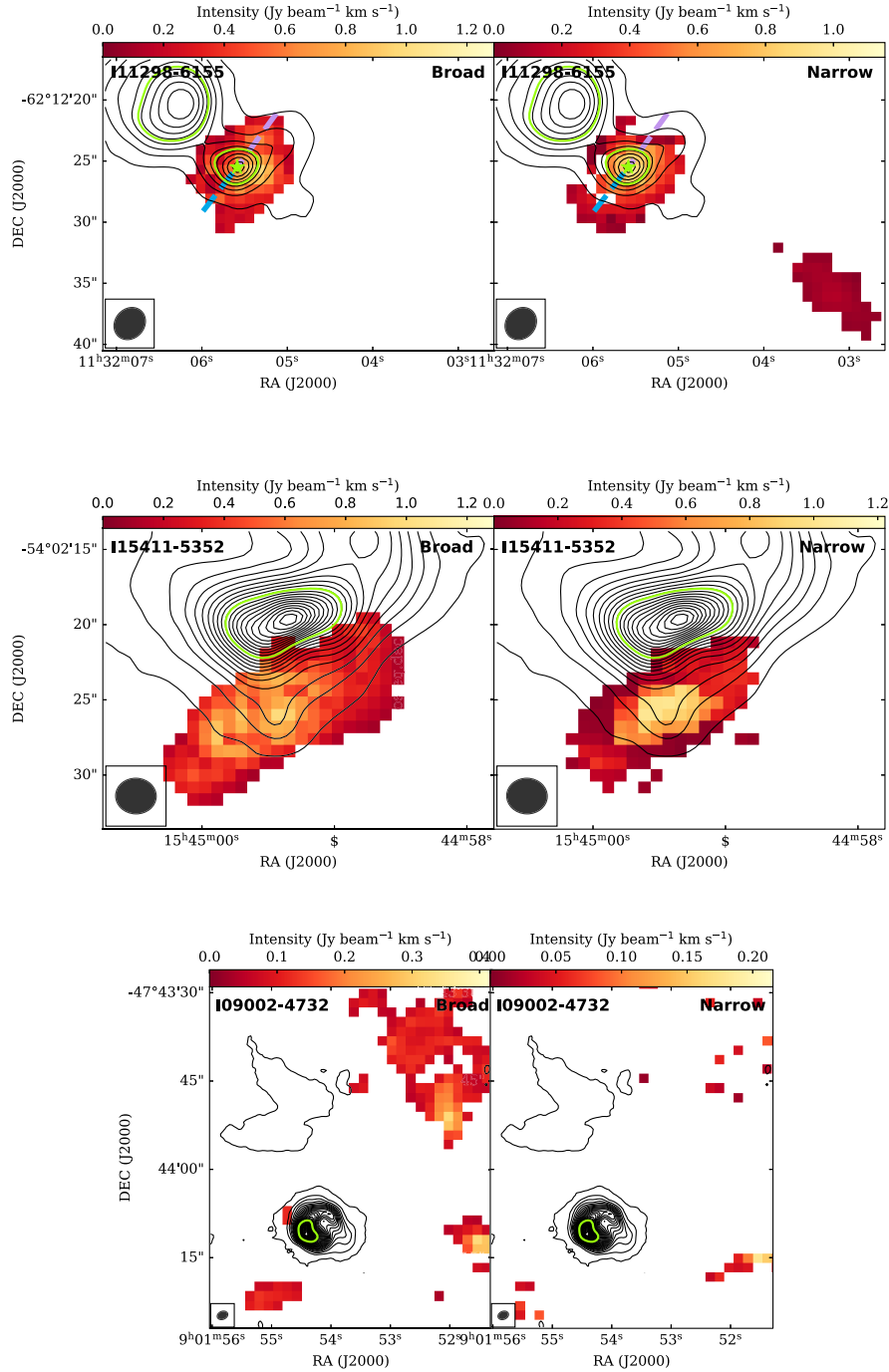


Figure 7. The three classes of decomposed sources that host UC H II regions based on their spatial distribution of the SiO and 3 mm continuum emission: (i) a ‘coincident’ source (upper panels); (ii) an ‘offset’ source (middle panels); and (iii) an ‘surrounded’ source (lower panels). The background image displays the SiO integrated intensity maps of the broad and narrow SiO components. The dashed thick lines represent the blue and red lobes of identified outflows from Baug et al. (in preparation), and the star indicates the position of the protostar centrally positioned between the two lobes (see also Fig. 6). Contours show the 3 mm continuum emission detected with ALMA, and contours are from 5σ to the peak values in steps of 10σ . The single green thick contour is the half-peak value of the 3 mm continuum emission. The source name is shown on the upper left of the panel and the beam size is reported in the lower left corner.

4.4 SiO luminosity

We calculated the luminosity of SiO emission (L_{SiO}) for the broad and narrow components across each velocity decomposed source. L_{SiO} is estimated using the following formula (Nguyễn Lúong et al. 2013):

$$L_{\text{SiO}} = 4\pi d^2 \times \int T_{\text{MB}} dv \simeq 1.9 \times 10^{-5} L_{\odot} \times \left(\frac{d}{6 \text{ kpc}} \right)^2 \frac{\int T_{\text{MB}} dv}{1 \text{ K km s}^{-1}}, \quad (1)$$

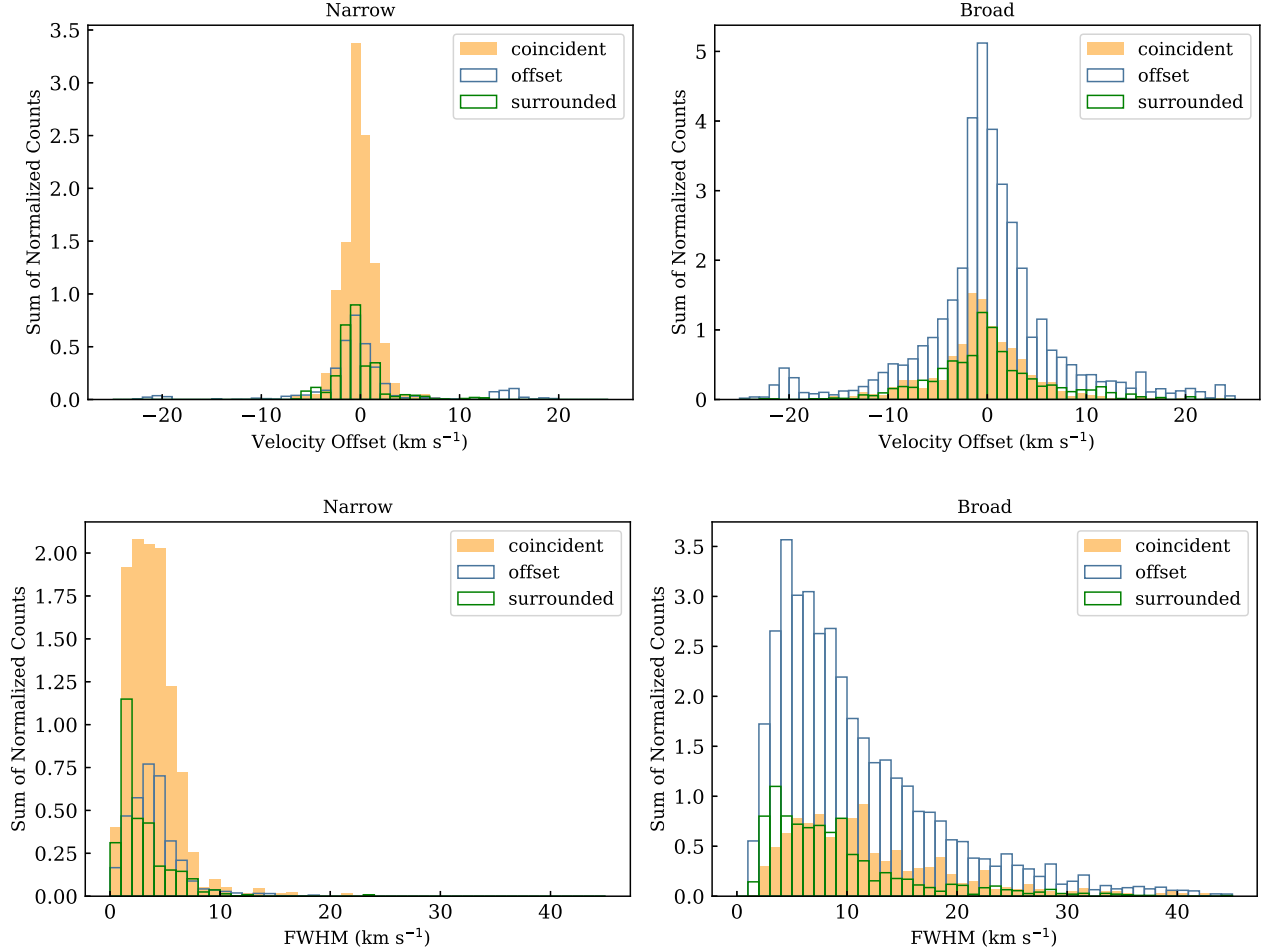


Figure 8. Histograms of the velocity offset compared with the systemic velocity and line width distribution of the broad and narrow components of SiO emission for the three UC H II categories. The filled histograms correspond to *coincident* sources, and the open blue histograms represent the *offset* sources. The open green histograms show the *surrounded* sources. The three UC H II categories can be found in Table A2.

$$\begin{aligned}
 \int T_{\text{MB}} d\nu [\text{K km s}^{-1}] &= Q(\nu_0) \int F d\nu [\text{Jy km s}^{-1}] \\
 Q(\nu_0) &= \frac{c^2}{2k\nu_0^2} \times \frac{4 \ln 2}{\pi \theta_b^2} \\
 &\simeq 1.22 \times 10^6 \left(\frac{\theta_b}{\text{arcsec}} \right)^{-2} \left(\frac{\nu_0}{\text{GHz}} \right)^{-2}, \quad (2)
 \end{aligned}$$

where d is the distance to the source and $\int F d\nu$ and $\int T_{\text{MB}} d\nu$ is the integrated intensity of SiO emission in units of $[\text{Jy km s}^{-1}]$ and $[\text{K km s}^{-1}]$, respectively. k is the Boltzmann constant and c is the speed of light. The SiO line frequency ν_0 is 86.847 GHz. θ_b is the beam FWHM. We calculated $\int T_{\text{MB}} d\nu$ using the results obtained from SCOUSEPY. First, we multiplied the intensity peak value by the linewidth (FWHM) obtained for the SiO line profile towards each pixel and inferred from the Gaussian fitting results of SCOUSEPY, and by a constant factor of 1.064. Then, we added all these values for all pixels in each source. After this, we considered the number of beams contained within our source area, so that we converted the integrated spectrum from units of $\text{Jy beam}^{-1} \text{ km s}^{-1}$ to Jy km s^{-1} . Subsequently, we applied equation (2) to convert these values from Jy km s^{-1} to K km s^{-1} .

L_{SiO} for both components, d , and $\int F d\nu$ values can be found in Table A1. The derived range of L_{SiO} (as derived from the SiO 2–1 transition) for the broad SiO emission in the sources across the

massive sample is $2.2 \times 10^{-6} - 1.3 \times 10^{-3} L_{\odot}$, with a median value of $7.6 \times 10^{-5} L_{\odot}$, and the range of L_{SiO} for the narrow SiO emission is $1.5 \times 10^{-6} - 9.7 \times 10^{-4} L_{\odot}$, with a median value of $3.9 \times 10^{-5} L_{\odot}$. For the two low-mass sources, I08076-3556 and I11590-6452, the L_{SiO} values for the broad SiO emission are 2.2×10^{-6} and $2.7 \times 10^{-7} L_{\odot}$, respectively. For the narrow SiO emission, these values are 2.2×10^{-6} and $2.2 \times 10^{-7} L_{\odot}$, respectively.

Towards source I17136-3617, no narrow SiO emission is observed. Except for this source, the mean contribution of the narrow SiO component to the total L_{SiO} is 33.78 per cent. Note, however, that the L_{SiO} estimated for the narrow SiO component towards sources I08076-3556 and I16297-4757 represent, respectively, 50.8 per cent and 52.2 per cent of the total, i.e. more than half of the total emission of SiO observed towards these two sources. This result may imply that I08076-3556 and I16297-4757 are at an early stage of evolution characterized by young shocks and by the interaction of the magnetic precursor (Jiménez-Serra et al. 2004, 2005). The fact that narrow SiO emission represents more than half of the total SiO emission towards two sources in our large sample may indicate that this early stage in the evolution of massive stars is short and, as a result, the statistics are small. Our analysis of the luminosity of SiO (2–1) emission therefore indicates that the majority of L_{SiO} (above 66 per cent) can be attributed to broad SiO emission, consistent with strong outflows being its most probable origin.

4.5 SiO column densities and abundances derived towards the ATOMS sample

In this section, we estimate the SiO total column densities and molecular abundances with respect to H₂ for the broad and narrow SiO components detected towards all decomposed sources. Assuming local thermodynamic equilibrium (LTE), the total column density of SiO can be calculated as follows (Csengeri et al. 2016):

$$N_{\text{tot}} = \frac{3k^2}{4\pi^3 h \nu^2} \frac{1}{S\mu^2} T_{\text{ex}} e^{\frac{E_u}{kT_{\text{ex}}}} \int T_{\text{MB}} d\nu \frac{\tau}{1 - e^{-\tau}}, \quad (3)$$

where h represents the Planck constant and k is the Boltzmann constant. Dipole moment term ($S\mu^2$) is 19.2 for the SiO (2–1) line, and the SiO line frequency ν is 86.847 GHz. The upper level energy E_u/k is 9 K, and τ is the optical depth. We use the excitation temperature (T_{ex}) of 15 K for the narrow component, which is slightly higher than the 9 K value estimated for IRDCs (Jiménez-Serra et al. 2010), and which is likely closer to the actual value in the UC HII candidate sample; and 50 K for the broad component, as estimated for the shocked gas in molecular outflows (Jiménez-Serra et al. 2005). Note that the derived column densities for narrow SiO change by less than a factor of 1.2 when assuming 10 K instead of 15 K, and that the SiO column densities change by more than a factor of 1.4 when assuming 75 K instead of 50 K for broad SiO emission.

Assuming optically thin emission, the equation (3) can thus be written as

$$N_{\text{SiO}} \simeq 2 \times 10^{11} \frac{2kT_{\text{ex}}}{h\nu} e^{\frac{E_u}{kT_{\text{ex}}}} \int T_{\text{MB}} d\nu [\text{cm}^{-2}]. \quad (4)$$

The estimated SiO column densities (N_{SiO}) calculated using equation (4), range from 1.4×10^{13} to $1.9 \times 10^{14} \text{ cm}^{-2}$ for the broad component, and from 1.6×10^{12} to $5.9 \times 10^{13} \text{ cm}^{-2}$ for the narrow component. N_{SiO} for both components in sources with UC HII regions range from 1.6×10^{13} to $2.2 \times 10^{14} \text{ cm}^{-2}$, and N_{SiO} for both components in sources without UC HII regions range from 1.9×10^{13} to $2.5 \times 10^{14} \text{ cm}^{-2}$. This implies that the derived N_{SiO} values are similar in sources with and without UC HII regions. We derived a range of N_{SiO} from 1.6×10^{13} to $2.5 \times 10^{14} \text{ cm}^{-2}$, with a median value of $6.4 \times 10^{13} \text{ cm}^{-2}$. Csengeri et al. (2016) and Kim et al. (2023), using the same T_{ex} of 10 K, derived N_{SiO} values ranging from 1.6×10^{12} to $7.9 \times 10^{13} \text{ cm}^{-2}$ from SiO (2–1) and 2.2×10^{12} to $7.9 \times 10^{13} \text{ cm}^{-2}$ from SiO (1–0), similar to our results for the narrow component for an approximate excitation temperature.

We calculated the H¹³CO⁺ column density at the positions with the broadest and narrowest SiO line width as mentioned in Section 4.1. Under the optically thin emission and LTE assumptions, considering an excitation temperature of 50 K for the position with the broadest SiO line width and 15 K for the position with the narrowest SiO line width, the H¹³CO⁺ column density can also be calculated using equation (3). This time, however, $S\mu^2$ is 15.2, as obtained from the Cologne Database for Molecular Spectroscopy (Müller et al. 2001); the frequency ν , is 86.75 GHz for H¹³CO⁺ ($J = 1-0$), and the upper level energy E_u/k is 4.169 K. The column densities of H¹³CO⁺ derived across our sample range from 6.1×10^{11} to $2.8 \times 10^{14} \text{ cm}^{-2}$.

In order to derive the SiO abundance relative to H₂, we calculate the ratio of $N_{\text{SiO}}/N_{\text{H}^{13}\text{CO}^+}$ and consider a H¹³CO⁺ abundance of 4.2×10^{-11} . This is consistent with reported H¹³CO⁺ abundances relative to H₂ in the Aquila, Ophiuchus, and Orion B clouds, which have mean values ranging from 1.5 to 5.8×10^{-11} (Shimajiri et al. 2017), and in OMC 2-FIR 4 and Sagittarius A, the H¹³CO⁺ abundance also estimates $1.1 \pm 0.1 \times 10^{-11}$ (Shimajiri et al. 2015) and $1.8 \pm 0.4 \times 10^{-11}$ (Tsuboi et al. 2011). Additionally, Peretto et al. (2013) derived H¹³CO⁺ abundance of 5×10^{-11} from Mopra

observations towards SDC335. By doing this, the SiO abundance is estimated to range from 1.5×10^{-11} to 1.3×10^{-9} towards the positions with the broadest SiO line widths. Towards the positions with the narrowest SiO line widths, the SiO abundance varies from 6.4×10^{-11} to 4.5×10^{-9} , factors of 3–4 higher than those found for the broad components of SiO. This is consistent with what has been found in both low-mass and high-mass SFRs (see e.g. Jiménez-Serra et al. 2004, 2005, 2010; Cosentino et al. 2018, 2020). We report the derived values of the SiO abundance in Table A2. The SiO abundance for each decomposed source falls within the range of the values calculated towards the positions with the broadest and narrowest SiO line widths found for each source.

5 DISCUSSION

5.1 The origin of the SiO emission

To gain a deeper understanding on the origin of SiO emission (especially on the origin of narrow SiO), in this work we have used higher angular resolution data towards a larger sample of sources (and in different physical environments) than used in previous works. From previous observations, it has been established that the broad components of SiO emission in high-mass SFRs are likely generated by high-velocity shocks ($v_s \geq 20 \text{ km s}^{-1}$) associated with powerful outflows from massive protostars (Qiu et al. 2007; Duarte-Cabral et al. 2014). The narrow component of SiO, however, can be attributed to different mechanisms: (i) less powerful outflows driven by low-mass protostars (Lefloch et al. 1998); (ii) young shocks characterized by the interaction of the magnetic precursor of MHD shocks (Jiménez-Serra et al. 2004, 2005); (iii) cloud–cloud collisions (Jiménez-Serra et al. 2010; Sanhueza et al. 2013; Louvet et al. 2016); (iv) gas inflows (Sanhueza et al. 2013); and (v) the expansion of UC HII regions or supernova remnants (Cosentino et al. 2020; Cosentino et al. 2022). In this section, we evaluate the possible origins for the broad and narrow SiO components detected across the source sample of the ATOMS survey.

5.1.1 SiO emission as a probe of outflows

For our sample, we have decomposed the emission of SiO detected across the ATOMS sources to investigate the morphology, spatial extent and kinematics of the broad and narrow SiO components (see Section 4). To distinguish the bright point sources in the mid-IR, we created the SiO moment 0 maps overlaid with multiple wavelengths (4.5, 8, and 24 μm) in Fig. C1. Towards sources without UC HII regions, by comparing the SiO moment 0 maps and the H¹³CO⁺ filament skeletons with the mid-IR images (4.5, 8, and 24 μm), we can assess the fraction of SiO arising from molecular outflows. Towards sources with UC HII regions, we use mid-IR images (4.5 and 8 μm) and the maximum SiO line width to measure the SiO from UC HII regions or molecular outflows.

The mid-IR 4.5 μm emission is believed to be generated by H₂ vibrationally excited emission typically associated with molecular outflows (Noriega-Crespo et al. 2004), and the 8 μm emission probes dust heated by protostars (Wynn-Williams 1982) or PAH emission from PDRs. The 24 μm emission is usually used as the SFRs tracer (Kennicutt & Evans 2012). Therefore, we consider that the SiO emission from the sources without UC HII regions but spatially coincident in the plane of the sky with one of the mid-IR emission (4.5, 8, and 24 μm) is likely generated by shocks in molecular outflows. From our 58 sources without UC HII regions,

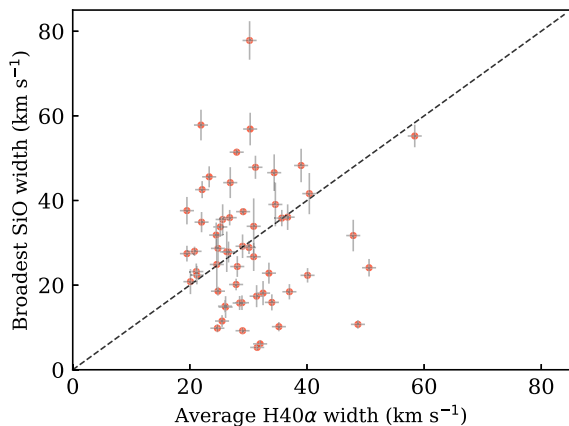


Figure 9. The broadest SiO line width compared to the average H40 α line width. The error bars in both plots represent the uncertainties associated with the line width.

we have found that 51 sources show SiO emission (especially the broad component) both again spatially coincident in the plane of the sky with H¹³CO⁺ filament skeletons (indicating the presence of high-density molecular gas, essential for forming new stars) and point objects in 4.5/8/24 μ m emission (potential outflow driving sources). Five sources I08448-4343, I08470-4243, I09094-4803, I17269-3312, and I18290-0924 only exhibit 4.5/8/24 μ m emission, while one source I16026-5035 only displays SiO emission associated with H¹³CO⁺ filament skeletons but no mid-IR emission. We note that only one source I18134-1942 lacks associations with dense filament skeletons and 4.5/8/24 μ m emission.

The average line width of the hydrogen recombination line (RRL) H40 α is 28.06 km s⁻¹ from the Zhang et al. (2023). We consider that SiO emission with a maximum SiO line width larger than that of RRL H40 α arise from molecular outflows, while those with a maximum SiO line width smaller than that of RRL H40 α may originate from outflows or UC H II regions. In Fig. 9, we plot the variation between the SiO line width at the positions ‘B’ and the average line width of H40 α . The average line widths for the H40 α lines have been calculated from the Gaussian fits of the source-averaged spectra (Zhang et al. 2023). Among 58 sources with UC H II regions, approximately half of the sources (27 sources) exhibit a maximum SiO line width larger than that of RRL H40 α , while the remaining 31 sources have a maximum SiO line width narrower than that of RRL H40 α . These results suggest that the SiO emission in half of the sources may be associated with outflows, while for the other half of sources the SiO emission may be produced either by outflows or by the expansion of UC H II regions. This will be investigated further below.

As shown in Section 4.3.3, broad components dominate the emission of SiO across the ATOMS sample with linewidths as large as 60 km s⁻¹ and offset velocities going beyond ± 40 km s⁻¹ with respect to the rest ambient velocity. All this suggests that the majority of the SiO emission in the ATOMS sample (above 66 per cent in SiO luminosity; see Section 4.4) is related to outflow activity from embedded protostars.

5.2 Dependence of SiO on the evolutionary stage of the source

In this section, we investigate whether there is any dependence of the measured SiO luminosity with the evolutionary stage of the ATOMS sources. To do this, we have used the luminosity to mass

ratio (L_{bol}/M) parameter proposed by (Molinari et al. 2008, 2016) as a proxy of the evolutionary stage for high-mass protostars. Broad and narrow SiO luminosity against bolometric luminosity (L_{bol}) and L_{bol}/M are presented in Fig. 10. The values for L_{bol}/M and L_{bol} are given in Liu et al. (2020a).

From Fig. 10 (upper panel), there is no significant difference between sources from the A (in stars) and B groups (in circles), while B group sources may present a stronger correlation than sources from the A group, with the Spearman rank correlation coefficients of 0.55 and 0.89, respectively.

Considering the evolution of SiO line profiles in molecular outflows, where narrow SiO is dominant at early stages and broad SiO becomes more prevalent as the evolution progresses (Jiménez-Serra et al. 2009), we propose that sources in B group may be younger than those in A group. As shown in Fig. 10, B group exhibits a strong correlation between L_{SiO} and L_{bol} . These findings indicate a positive correlation between the outflow activity or the ability to detect SiO emission and the evolutionary stages at the early times, and during the evolutionary process, this correlation weakens. In Fig. 10, there may be a slight trend for sources with H II regions (in red) to present higher SiO luminosities than sources without H II regions (in grey), although the two groups seem to be well mixed. The p -value returned by the KS test for L_{SiO} between sources with H II regions and those without is 0.02, indicating that the L_{SiO} from these two groups likely come from different distributions, and the median L_{SiO} for sources with H II regions is $1.5 \times 10^{-4} L_{\odot}$, and for sources without H II regions, these values is $1 \times 10^{-4} L_{\odot}$.

If all sources are taken together, Fig. 10 (upper panel) reveals a moderate positive trend between L_{SiO} and L_{bol} for both the broad and narrow SiO components, with Spearman rank correlation coefficients of 0.63 and 0.61, respectively. The positive correlation indicates that the brighter luminosity sources exhibit stronger SiO emission, implying more intense outflow activity. Kim et al. (2023) investigated SiO (1–0) emission towards 104 regions that consist of 57 IRDCs, 21 high-mass protostellar objects, and 26 UC H II regions, using the Korean VLBI Network. In that paper, they found that sources with higher L_{SiO} tend to be associated with higher L_{bol} , which is consistent with our results. However, note that for a given L_{bol} , warmer sources in their sample tend to have lower L_{SiO} . This trend can also be hinted at in our data by the lower slope obtained in the $L_{\text{SiO}}-L_{\text{bol}}$ relation for the sources with UC H II regions shown in Fig. 10. The SiO broad and narrow components in sources lacking UC H II regions exhibit a stronger correlation between L_{SiO} and L_{bol} with a Spearman rank correlation coefficient of 0.67. In contrast, this correlation appears slightly weaker in sources with UC H II regions with a Spearman rank correlation coefficient of 0.55. These results suggest that the ability to detect SiO emission in sources at later stages diminishes. Furthermore, the weak trend in these correlations and higher L_{SiO} values, implies that the SiO emission from sources with UC H II regions might be affected by the photochemistry (i.e. photodissociation) induced by the UV field produced by the UC H II regions.

In the upper panel of Fig. 10, we also plot six low-mass stars so that their L_{SiO} and L_{bol} can be compared to the relationship between L_{SiO} and L_{bol} found for our sample. This subgroup of six low-mass sources include objects I08076-3556 and I11590-6452 also contained within the ATOMS sample, and four other sources NGC 1333 IRAS 4, L1448-mm, L1157 B1, and I04166+2706 (Santiago-García et al. 2009; Jiménez-Serra et al. 2011; Lee 2020; Spezzano et al. 2020; De Simone et al. 2022). Low-mass stars are represented by filled squares in Fig. 10. From this figure, it is clear that they exhibit lower

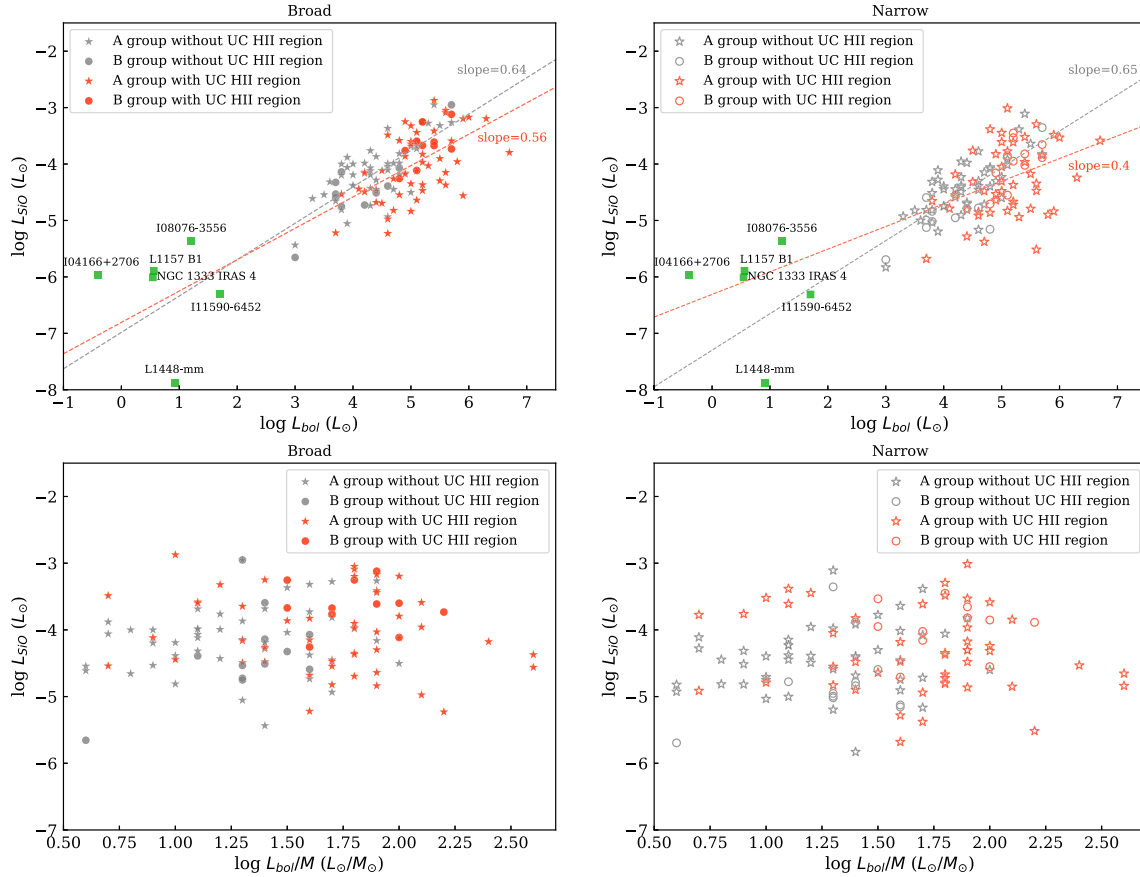


Figure 10. *Upper panels:* The SiO luminosity (L_{SiO}) versus bolometric luminosity (L_{bol}). The filled and empty grey stars present broad and narrow SiO components in *A groups* without UC H II regions, and the filled and empty grey circles depict broad and narrow SiO components in *B groups* without UC H II regions. The filled and empty red stars show broad and narrow SiO components in *A groups* hosting UC H II regions, while the filled and empty red circles display broad and narrow SiO components in *B groups* with UC H II regions. The filled rectangles show the low-mass stars (Santiago-García et al. 2009; Jiménez-Serra et al. 2011; Lee 2020; Spezzano et al. 2020; De Simone et al. 2022). In the upper left panel, the grey line shows a linear fit of $\log (L_{\text{SiO}}/L_{\odot}) = (0.64 \pm 0.07) \log (L_{\text{bol}}/L_{\odot}) - 6.98 \pm 0.32$ obtained for sources without UC H II regions, while the red line shows the linear fit $\log (L_{\text{SiO}}/L_{\odot}) = (0.56 \pm 0.11) \log (L_{\text{bol}}/L_{\odot}) - 6.81 \pm 0.58$ obtained for sources hosting UC H II sources. In the upper right panel, the grey line displays the linear fit $\log (L_{\text{SiO}}/L_{\odot}) = (0.65 \pm 0.08) \log (L_{\text{bol}}/L_{\odot}) - 7.30 \pm 0.33$ derived for sources without UC H II regions, while the red line is used to show the linear fit $\log (L_{\text{SiO}}/L_{\odot}) = (0.40 \pm 0.13) \log (L_{\text{bol}}/L_{\odot}) - 6.31 \pm 0.68$ inferred for sources hosting UC H II regions. *Lower panels:* L_{SiO} versus L_{bol}/M . No apparent correlation is seen either for the broad or for the narrow components. The symbols are the same as in the upper panels.

values of L_{SiO} and L_{bol} when compared to the high-mass sources of the ATOMS sample. Note that only one source, I11590–6452 fall into our trend. For the rest of low-mass sources, there is no obvious correlation between these two parameters. The number of low-mass sources to compare with is, however, very limited, and therefore, we cannot draw any robust conclusions.

Duarte-Cabral et al. (2014) suggested an evolutionary trend for the younger sources in the Cygnus X star-forming cluster to present a higher fraction of narrow SiO emission (up to ~ 60 per cent) with respect to more evolved sources. To test this idea using the ATOMS source sample, in Fig. 10 (lower panels), we plot the derived SiO luminosity, L_{SiO} , as a function of the L_{bol}/M ratio, considered a proxy of the evolutionary stage of the source (see Molinari et al. 2008). If we just only consider the information about the SiO luminosity, from the lower panels of Fig. 10, it is clear that there is no trend between L_{SiO} and L_{bol}/M either within all groups or for both the narrow and broad components of SiO. This is consistent with the results reported by Csengeri et al. (2016), Li et al. (2019a), and Kim et al. (2023). In these papers, SiO abundance does not vary significantly at different evolutionary stages. However, as discussed

in Sections 5.3 and 5.4, if the spatial distribution of the broad and narrow SiO emission is taken into account for individual sources, the location and fraction of narrow SiO detected towards high-mass SFRs (and in particular towards sources hosting UC H II regions) may depend on the evolutionary stage of the source.

5.3 The effect of UC H II regions on the observed SiO emission

The UC H II regions inject large amounts of ultraviolet photons into their surrounding medium, profoundly impacting the hosting molecular cloud. This interaction can cause both positive feedback (by triggering new star formation) and negative feedback (by disrupting and dispersing the parental molecular cloud where the UC H II region is embedded, inhibiting future star formation). In our velocity decomposed source sample, Zhang et al. (2023) identified 58 UC H II regions and calculated the emission measure (EM) using the H40 α emission. In Section 4.3.2, we classified these sources into three groups: ‘*coincident* (9 sources)’, ‘*offset* (40 sources)’, and ‘*surrounded* (9 sources)’. Based on the morphology of the three example sources presented in Fig. 7, we could imagine an

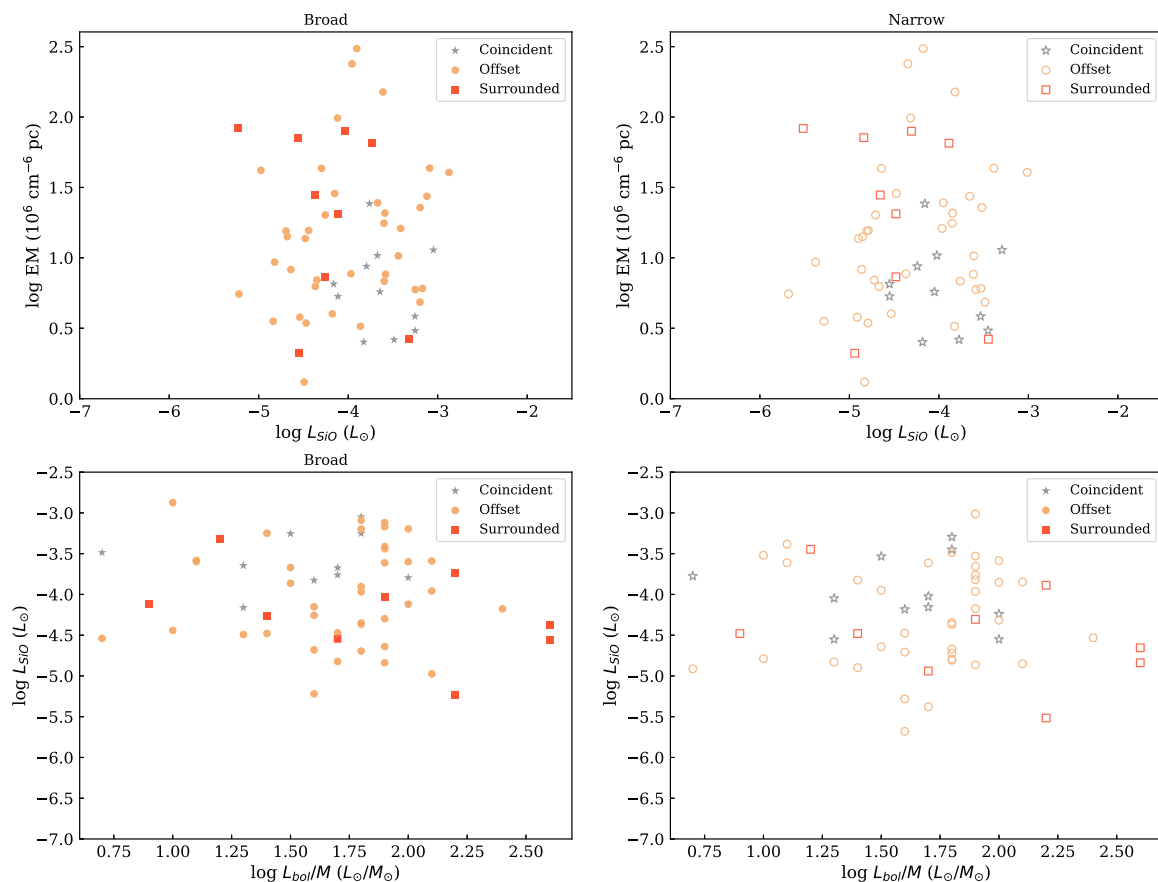


Figure 11. *Upper:* The emission measure (EM) value versus SiO luminosity (L_{SiO}). The filled and empty stars indicate the broad and narrow SiO components associated with *coincident* sources. The filled and empty circles designate the broad and narrow SiO components for *offset* sources, and the filled and empty rectangles display the broad and narrow SiO components for *surrounded* sources. *Lower:* L_{SiO} versus L_{bol}/M . Symbols are the same as in the upper panel.

evolutionary scenario in which (i) massive stars are formed first and drive powerful outflows. This would be consistent with what we see towards I13291-6249, where the SiO emission peaks towards the 3 mm continuum emission peak. (ii) A subsequent stage in which low-mass stars are formed in the surroundings of massive stars. This would explain why the SiO emission peak appears offset with respect to the peak of the 3 mm continuum emission (as seen in source I15411-5352). Note that this is a similar scenario to what has been observed in IRDCs, with massive protostars forming before their low-mass counterparts (see Zhang et al. 2015). The shocks at the evolutionary stages (i) and (ii) would be young so that the narrow SiO emission could be attributed to the interaction of the magnetic precursor of MHD shock waves, as suggested by Jiménez-Serra et al. (2004, 2009). (iii) The most evolved stage in which the UC HII region has expanded disrupting the molecular cloud. The expansion of the HII region generates SiO emission away from the 3 mm continuum emission, and that surrounds the UC HII region being seen at the edge of the photon-dominated regions (PDRs) probed by 8 μm emission (this would be the case of source I09002-4732). The mostly broad SiO emission, although some narrow emission is also detected, can be seen towards certain regions at the PDR interface (see Fig. 7).

In Fig. 11, we plot the EM against L_{SiO} for the broad and narrow components (upper panels), and L_{SiO} versus L_{bol}/M also for the broad and narrow components of SiO (lower panels). From the

upper panels, we find that there are no apparent differences in EM values between the *coincident* and *offset* groups for both SiO velocity components. By comparing each pair of groups, we obtained p -values from the KS test for L_{SiO} across these three categories. Notably, only L_{SiO} from *offset* and *surrounded* sources may originate from the same distributions with the p -value of 0.512. All other comparisons presented p -values of 0.046 and 0.036, suggesting that L_{SiO} from those sources likely come from different distributions. Furthermore, for both the broad and narrow components, their derived L_{SiO} values for *coincident* sources are larger than those inferred for *offset* and *surrounded* sources, with median values of $3.1 \times 10^{-4} L_{\odot}$, $1.4 \times 10^{-4} L_{\odot}$, and $8.8 \times 10^{-5} L_{\odot}$, respectively. As suggested in Section 4.3.3, this may be due to the *coincident* sources being at an earlier stage of evolution, driving more powerful outflows.

From the lower panels of Fig. 11, one can find a trend for the *surrounded* sources to present lower SiO luminosities than *coincident* sources. Since the SiO luminosity is lower for evolved UC HII regions in the *surrounded* group, this implies that the expansion of HII regions has a negative effect on subsequent star formation activity as probed by SiO. The *coincident* and *offset* groups appear relatively well mixed although there is a small trend for the *offset* sources to be older than the *coincident* ones as postulated above. The median L_{bol}/M values are 50 and 63, respectively, with circles reaching higher L_{bol}/M values than the stars (see Fig. 11), which is consistent with our discussion before.

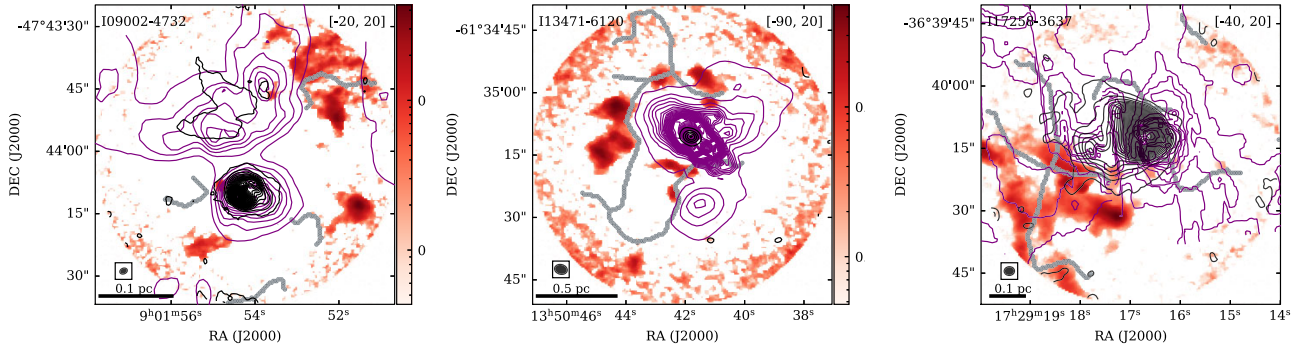


Figure 12. Three sources with expanding UC H II regions. The background in red is SiO (2–1) integrated intensity maps. The black thick contours are 3 mm continuum emission, and contours are from 5σ to the peak values in the step of 10σ . The purple contours are $8\ \mu\text{m}$ emission, and contours are from 5σ to the peak values in the step of 50σ . The bold lines represent the filament skeleton identified by H^{13}CO^+ emission. The shown field of view is 72 arcsec corresponding to the FOV of the ALMA observations. The source name and integrated velocity ranges (in km s^{-1}) are shown on the upper left and right corners of each panel, respectively. The beam size and the scale bar are presented in the lower left corner.

5.4 SiO emission produced by the expansion of UC H II regions

We identified nine sources hosting UC H II regions that present SiO emission not associated with 3 mm continuum emission and that appear surrounding the ionized gas (these sources are classified as *surrounded* as described in Section 4.3.3). The ID of these sources in Table A2 is 5, 12, 18, 24, 47, 77, 98, 143, and 146. We hypothesize that the SiO emission detected towards these sources is generated by the expansion of UC H II regions. In Fig. 12, we show the SiO moment 0 maps overlaid on the $8\ \mu\text{m}$ emission for these sources showing the full extension of the material affected by the UV radiation coming from the H II region. Black contours and bold grey lines mean the same as in Fig. 3.

From Fig. 12, it is clear that the $8\ \mu\text{m}$ emission engulfs the 3 mm continuum emission and delineates the interface between the ionized gas and the SiO emission in these sources. This suggests that the expansion of the UC H II region pushes molecular gas against the surrounding molecular cloud inducing low-velocity shocks and generating SiO emission by the sputtering of dust grains. In our *surrounded* sources, only in source I15567-5236, the narrow SiO dominates and presents more extended emission than the broad SiO. For the rest of the objects, broad SiO is more dominant than narrow SiO.

6 CONCLUSIONS

In this work, we used ALMA data to investigate the origin of SiO (2–1) emission towards 146 massive SFRs. We decomposed the SiO line profiles into broad and narrow Gaussian velocity components, and studied their relative spatial distribution and kinematics to study their different origin. The main results are summarized as follows:

(1) Among the entire sample, we detected SiO emission in 136 sources and decomposed 118 sources. We calculated the L_{SiO} in broad and narrow components across each decomposed source and found the majority of L_{SiO} (above 66 per cent) is attributed to the broad components arising from strong outflows. By comparing the filamentary skeletons in SiO moment 0 maps with 4.5, 8, and $24\ \mu\text{m}$ emission, and considering the broad components dominating the emission of SiO across the sample, we conclude that most SiO emission from our sources originates from the outflow activity. This conclusion supports the idea that SiO emission is a good outflow

tracer. We found that SiO emission in nine sources may arise from the expansion of UC H II regions.

(2) According to the different spatial distribution of the broad and narrow SiO emission, we classified 118 sources into two groups: (A) The broad SiO is distributed more extensively than the narrow SiO in 94 sources and (B) The narrow SiO is distributed more extensively than the broad SiO in 24 sources. Across all groups, We observed a moderate positive correlation between L_{SiO} and L_{bol} in both broad and narrow components, suggesting that higher luminosity sources show more intense outflow activity. Sources from B groups present a stronger correlation than sources from A groups. These findings indicate a positive correlation between the outflow activity and the evolutionary stages at the early times, and during the evolutionary process, this correlation weakens. Furthermore, the A and B groups did not display clear evolutionary stages. The sources without UC H II regions seem to show a stronger correlation between L_{SiO} and L_{bol} and the lower L_{SiO} values compared with the UC H II sources. This suggests that SiO emission might be influenced by UV-photochemistry induced by UC H II regions.

(3) Among the 58 sources hosting UC H II regions, we divided them into three groups depending on the separation between the 3 mm continuum emission and SiO emission: (1) The SiO emission coincides with the 3 mm continuum emission in 9 sources, named ‘*coincident*’; (2) The SiO emission is separated with the 3 mm continuum emission in 40 sources, labelled ‘*offset*’; (3) The SiO emission surrounds the 3 mm continuum emission in 9 sources, named ‘*surrounded*’. The *coincident* group exhibited higher SiO luminosity values than the other groups in both broad and narrow components. This implies that UC H II regions could have a negative effect on the shock activity within the *offset* and *surrounded* groups.

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DATA AVAILABILITY

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

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APPENDIX A

Table A1 presents the basic parameters of the observed sources, including the systemic velocity (v_{LSR} km s⁻¹), distance from the sun (kpc), bolometric luminosity (L_{bol} , $L_{\odot}$), luminosity to mass ratio ($L_{\text{bol}}/M L_{\odot} M_{\odot}^{-1}$), velocity integrated intensity for SiO broad components ($\int F_B d\nu$ Jy km s⁻¹), velocity integrated intensity for SiO narrow components ($\int F_N d\nu$ Jy km s⁻¹), velocity integrated intensity for H¹³CO⁺ extracted from ‘B’ ($\int F_B d\nu$ Jy km s⁻¹), H¹³CO⁺ line width extracted from ‘B’ position (FWHM_B km s⁻¹), H¹³CO⁺ line width extracted from ‘N’ position (FWHM_N km s⁻¹), the contribution of SiO narrow components in total velocity

integrated intensity (Contribution_N per cent), the number of subareas for detected SiO broad components in each source (B), the number of subareas for detected SiO narrow components in each source (N), the size of subareas used to extract average spectra in each source (area), 1 σ rms noise (Jy km s⁻¹), identified outflow activity from Baug et al. (in preparation).

Table A2 shows the basic parameters of the velocity decomposed sources, including the SiO luminosity for broad and narrow components (L_{SiO} , $L_{\odot}$), the SiO column density for broad and narrow components ($N(\text{SiO})$ cm⁻²), the abundance in the position with the broadest SiO line width and in the position with narrowest SiO line width ($X(\text{SiO})$), the SiO emission is associated with filaments skeleton, the infrared emission (4.5, 8, and 24 μm), the two cases based on the morphology between the narrow and broad components (A and B groups), and the three conditions of decomposed sources that host UC HII regions based on their spatial distribution of the SiO and 3 mm continuum emission (*coincident*, *offset*, and *surrounded*).

Table A1. Basic parameters of the detected sources in the ATOMS survey.

ID	IRAS	Distance (kpc)	v_{LSR} (km s ⁻¹)	log L_{bol} (L _⊙)	L_{bol}/M (L _⊙ M _⊙ ⁻¹)	SiO(2-1)			H ¹³ CO ⁺ (1-0)		Contributions _N		Number		σ rms (Jy km s ⁻¹)	Outflow
						$\int T_{\text{SiO}} dv$ (Jy km s ⁻¹)	$\int T_{\text{N}} dv$ (Jy km s ⁻¹)	$\int T_{\text{SiO}} dv$ (Jy km s ⁻¹)	FWHM _B (km s ⁻¹)	FWHM _N (km s ⁻¹)	(per cent)	B	N	Area		
1	108076-3556	0.4	5.9	1.2	3.16	0.359±0.002	0.370±0.002	0.059±0.004	0.89±0.07	0.72±0.07	50.8	136	58	2	0.008	✓
2	108303-4303	2.3	14.3	3.8	25.12	0.376±0.001	0.075±0.001	0.120±0.009	3.7±0.3	2.29±0.17	16.6	47	59	2	0.01	✓
3	108448-4343	0.7	3.7	3	25.12	0.209±0.001	0.084±0.001	0.067±0.006	2.38±0.2	2.3±0.3	28.7	165	86	4	0.01	✓
4	108470-4243	2.1	12	4	39.81	0.265±0.002	0.113±0.003	0.062±0.008	2.1±0.3	1.20±0.11	29.9	244	140	2	0.009	✓
5	109002-4732	1.2	3.1	4.6	158.49	0.119±0.001	0.062±0.001	0.039±0.007	1.7±0.3	1.59±0.24	34.1	153	30	4	0.01	✓
6	109018-4816	2.6	10.3	4.7	50.12	0.154±0.001	0.083±0.001	0.162±0.009	2.93±0.15	1.81±0.13	35.0	103	66	4	0.01	✓
7	109094-4803	9.6	74.6	4.6	31.62	0.137±0.002	0.054±0.001	0.056±0.012	2.6±0.6	4.2±0.3	28.1	68	34	2	0.01	✓
8	110365-5803	2.4	-19	4.3	39.81	0.229±0.004	0.155±0.004	0.274±0.013	1.44±0.07	1.77±0.09	40.3	94	54	4	0.009	✓
9	111298-6155	10	32.9	5.2	63.1	0.430±0.005	0.273±0.001	0.428±0.013	5.39±0.16	2.1±0.5	38.8	86	123	2	0.012	✓
10	111332-6258	1.9	-15.4	3.7	39.81	0.55±0.01	0.161±0.004	0.451±0.023	3.76±0.19	2.01±0.08	22.6	47	86	6	0.012	✓
11	111590-6452	0.4	-4.3	1.7	3.98	0.136±0.001	0.112±0.001	0.049±0.009	2.1±0.4	0.5±0.2	45.1	134	148	2	0.012	✓
12	112320-6122	3.43	-42.5	5.6	39.81	0.362±0.006	0.188±0.006	0.217±0.011	2.7±0.13	3.75±0.23	34.2	161	87	4	0.012	✓
13	112326-6245	4.61	-39.6	5.4	79.43	1.167±0.007	0.724±0.001	0.46±0.03	7.4±0.5	2.0±0.4	38.3	80	155	6	0.012	✓
14	112383-6128	3.27	-39.1	3.8	5.01	0.270±0.007	0.11±0.02	0.087±0.013	2.0±0.3	0.57±0.09	29.7	88	23	2	0.013	✓
15	112572-6316	11.57	30.9	4.6	5.01	0.243±0.003	0.125±0.003	0.224±0.012	1.75±0.09	1.75±0.19	34.0	165	65	2	0.012	✓
16	113079-6218	3.8	-42.6	5.1	39.81	1.269±0.005	0.654±0.003	1.02±0.03	6.26±0.19	1.08±0.11	34.0	132	127	6	0.012	✓
17	113080-6229	3.8	-35.6	5.1	79.43	0.155±0.003	0.093±0.003	0.668±0.014	3.27±0.07	3.48±0.16	37.5	59	45	2	0.013	✓
18	113111-6228	3.8	-38.8	4.8	50.12	0.191±0.002	0.077±0.003	0.69±0.03	2.89±0.12	3.18±0.15	28.8	153	51	2	0.012	✓
19	113134-6242	3.8	-31.5	4.6	31.62	0.614±0.006	0.336±0.006	0.099±0.011	2.9±0.3	1.62±0.08	35.3	120	77	6	0.012	✓
20	113140-6226	3.8	-33.9	3.8	7.94	0.426±0.003	0.205±0.002	0.409±0.013	3.0±0.1	1.01±0.08	32.5	155	116	4	0.012	✓
21	113291-6249	7.61	-34.7	5.2	31.62	0.357±0.006	0.187±0.002	0.199±0.013	4.4±0.3	1.43±0.07	34.5	89	104	6	0.013	✓
22	113295-6152	3.89	-44.4	3.3	3.98	0.154±0.004	0.075±0.003	0.600±0.013	2.85±0.06	0.76±0.08	32.6	71	64	4	0.012	✓
23	113471-6120	5.46	-56.7	5.3	79.43	0.260±0.003	0.138±0.012	0.244±0.008	1.64±0.06	1.70±0.09	34.6	111	15	4	0.013	✓
24	113484-6100	5.4	-55	4.8	50.12	0.432±0.014	0.235±0.006	1.11±0.04	4.32±0.15	1.25±0.22	35.2	109	107	6	0.013	✓
25	114013-6105	4.12	-48.1	5	63.1	0.213±0.002	0.091±0.002	0.409±0.012	2.24±0.07	4.4±0.3	29.8	61	32	4	0.013	✓
26	114013-6105	4.12	-48.1	5	63.1	0.213±0.002	0.091±0.002	0.409±0.012	2.24±0.07	4.4±0.3	29.8	61	32	4	0.013	✓
27	114013-6105	4.12	-48.1	5	63.1	0.213±0.002	0.091±0.002	0.409±0.012	2.24±0.07	4.4±0.3	29.8	61	32	4	0.013	✓
28	114164-6028	3.19	-46.5	3.7	31.62	0.372±0.006	0.200±0.004	0.710±0.021	4.49±0.13	1.8±0.1	35.0	65	69	4	0.013	✓
29	114206-6151	3.29	-50	3.7	19.95	0.22±0.01	0.075±0.007	0.147±0.012	1.69±0.14	1.18±0.12	25.7	23	24	2	0.012	✓
30	114212-6131	3.44	-50.5	4	10	0.435±0.004	0.271±0.004	0.346±0.015	4.6±0.2	1.46±0.09	38.4	126	98	6	0.012	✓
31	114382-6017	7.69	-60.7	5.2	39.81	0.194±0.003	0.085±0.003	0.268±0.009	1.92±0.06	1.7±0.4	30.6	115	77	2	0.011	✓
32	114453-5912	2.82	-40.2	4.2	19.95	0.309±0.001	0.142±0.001	0.23±0.01	2.10±0.09	2.1±0.5	31.5	103	46	6	0.011	✓
33	114498-5856	3.16	-49.3	4.4	25.12	0.234±0.003	0.124±0.001	0.65±0.03	3.03±0.12	2.4±0.6	34.5	115	125	4	0.011	✓
34	115122-5801	9.26	-60.9	5	12.59	0.179±0.004	0.051±0.005	0.160±0.011	2.83±0.19	4.1±0.5	22.2	41	19	2	0.011	✓
35	115254-5621	4	-67.3	5.1	100	0.345±0.002	0.219±0.002	0.098±0.009	3.0±0.3	1.77±0.17	38.9	131	55	2	0.011	✓
36	115290-5546	6.76	-87.5	5.7	79.43	1.187±0.009	0.346±0.003	1.88±0.04	10.87±0.22	2.05±0.22	22.6	53	102	4	0.011	✓
37	115394-5358	1.82	-41.6	3.7	6.31	0.487±0.003	0.338±0.002	0.936±0.024	3.8±0.1	2.8±0.5	41.0	128	73	8	0.011	✓
38	115408-5356	1.82	-39.7	4.9	100	-	-	-	-	-	-	-	-	-	0.012	✓
39	115411-5352	1.82	-41.5	4.5	63.1	0.447±0.002	0.345±0.002	0.328±0.013	2.5±0.1	1.54±0.06	43.6	171	117	2	0.012	✓
40	115411-5352	1.82	-41.5	4.5	63.1	0.447±0.002	0.345±0.002	0.328±0.013	2.5±0.1	1.54±0.06	43.6	171	117	2	0.012	✓
41	115437-5343	4.98	-83	4.6	39.81	0.230±0.002	0.103±0.002	0.39±0.03	2.74±0.21	1.46±0.16	31.0	161	83	2	0.012	✓
42	115439-5449	3.29	-54.6	4.4	25.12	0.224±0.002	0.085±0.002	0.312±0.013	1.96±0.08	2.5±0.1	27.6	73	35	4	0.012	✓
43	115502-5302	5.8	-91.4	5.8	125.89	0.237±0.003	0.097±0.007	0.321±0.012	2.8±0.1	3.6±0.3	29.0	46	14	4	0.012	✓
44	115520-5234	2.65	-41.3	5.1	79.43	-	-	-	-	-	-	-	-	-	0.012	✓
45	115522-5411	2.73	-46.7	3.8	7.94	0.285±0.002	0.148±0.001	0.23±0.01	2.18±0.09	0.83±0.06	34.1	132	114	2	0.012	✓
46	115557-5215	4.03	-67.6	3.9	5.01	0.583±0.003	0.344±0.004	0.040±0.006	1.01±0.15	1.12±0.14	37.1	124	53	6	0.012	✓
47	115567-5236	5.99	-107.1	5.7	158.49	0.368±0.002	0.258±0.001	0.84±0.03	7.7±0.3	1.53±0.07	41.2	51	126	4	0.012	✓
48	115584-5247	4.41	-76.8	4.2	12.59	0.379±0.002	0.131±0.002	0.163±0.008	1.67±0.08	1.74±0.08	25.7	113	50	4	0.012	✓
49	115584-5247	4.41	-76.8	4.2	12.59	0.379±0.002	0.131±0.002	0.163±0.008	1.67±0.08	1.74±0.08	25.7	113	50	4	0.012	✓
50	115596-5301	10.11	-72.1	5.5	39.81	0.336±0.001	0.160±0.001	0.356±0.011	3.4±0.1	1.88±0.22	32.3	184	105	4	0.012	✓

Table A1 – *continued*

ID	IRAS	Distance (kpc)	v_{LSR} (km s ⁻¹)	log L_{bol} (L _⊙)	L_{bol}/M (L _⊙ M _⊙ ⁻¹)	SiO(2-1)		H ¹³ CO ⁺ (1-0)		Contributions		Number		σ rms (Jy km s ⁻¹)	Outflow	
						$\int T_B dv$ (Jy km s ⁻¹)	$\int T_N dv$ (Jy km s ⁻¹)	$\int T_B dv$ (Jy km s ⁻¹)	FWHM _B (km s ⁻¹)	FWHM _N (km s ⁻¹)	(per cent)	B	N			Area
51	I16026-5035	4.53	-78.3	4.9	79.43	0.237±0.002	0.171±0.002	0.170±0.011	2.98±0.19	1.33±0.17	41.9	108	66	2	0.012	
52	I16037-5223	9.84	-80	5.6	63.1	0.603±0.002	0.307±0.001	0.867±0.021	4.51±0.11	2.40±0.21	33.7	143	108	2	0.012	
53	I16060-5146	5.3	-91.6	5.8	79.43	—	—	—	—	—	—	—	—	—	0.013	✓
54	I16065-5158	3.98	-63.3	5.4	50.12	0.940±0.004	0.420±0.003	1.63±0.04	7.6±0.2	2.6±0.3	30.9	161	175	4	0.012	✓
55	I16071-5142	5.3	-87	4.8	12.59	0.652±0.007	0.605±0.007	0.16±0.01	2.07±0.13	1.72±0.23	48.1	250	131	4	0.013	✓
56	I16076-5134	5.3	-87.7	5.3	50.12	1.312±0.003	1.022±0.002	0.555±0.017	3.65±0.11	2.5±0.1	43.8	122	85	4	0.012	✓
57	I16119-5048	3.1	-48.2	4.3	12.59	0.549±0.002	0.424±0.002	0.590±0.013	2.61±0.06	1.23±0.06	43.6	90	50	4	0.012	
59	I16158-5055	3.57	-49.2	5.2	50.12	0.184±0.002	0.088±0.002	0.11±0.01	2.46±0.24	1.98±0.13	32.3	54	24	4	0.012	✓
60	I16164-5046	3.57	-57.3	5.5	63.1	0.676±0.001	0.363±0.002	0.677±0.021	3.72±0.12	2.81±0.13	34.9	208	90	4	0.014	✓
61	I16172-5028	3.57	-51.9	4.3	63.1	—	—	—	—	—	—	—	—	—	0.023	✓
62	I16177-5018	3.57	-50.2	5.5	79.43	0.272±0.002	0.123±0.009	0.164±0.015	2.43±0.22	2.51±0.14	31.2	55	4	1	0.013	
63	I16272-4837	2.92	-46.6	4.3	12.59	0.650±0.002	0.316±0.002	0.120±0.009	2.91±0.21	2.1±0.4	32.7	223	93	6	0.012	✓
64	I16297-4757	5.03	-79.6	4.9	31.62	0.349±0.005	0.381±0.003	0.816±0.016	3.74±0.07	2.50±0.08	52.2	146	114	2	0.012	✓
65	I16304-4710	11.32	-62.8	4.9	25.12	0.282±0.003	0.130±0.001	0.295±0.011	2.9±0.1	1.84±0.09	31.5	44	37	2	0.012	
66	I16313-4729	4.71	-73.7	6.7	100	0.464±0.001	0.166±0.001	0.888±0.017	5.3±0.1	2.15±0.18	26.4	113	63	2	0.012	
67	I16318-4724	7.68	-119.8	5.2	31.62	0.606±0.005	0.318±0.002	1.141±0.023	5.34±0.11	2.68±0.12	34.4	85	100	4	0.012	
68	I16330-4725	10.99	-75.1	6.3	100	0.337±0.002	0.160±0.002	1.78±0.05	3.7±0.1	4.37±0.17	32.2	59	26	2	0.012	
69	I16344-4658	12.09	-49.5	5.4	19.95	0.490±0.005	0.340±0.003	1.33±0.03	5.23±0.11	3.57±0.16	41.0	154	138	2	0.012	✓
70	I16348-4654	12.09	-46.5	5.4	10	0.583±0.003	0.424±0.002	0.660±0.018	4.40±0.12	2.0±0.3	42.1	183	104	4	0.012	✓
71	I16351-4722	3.02	-41.4	4.9	50.12	1.213±0.002	0.489±0.002	0.83±0.09	7.5±0.8	1.55±0.09	28.7	76	137	6	0.012	✓
72	I16362-4639	3.01	-38.8	3.6	12.59	0.338±0.003	0.070±0.002	0.102±0.006	1.78±0.11	2.26±0.11	17.1	70	25	1	0.012	
73	I16372-4545	4.16	-57.3	4.2	19.95	0.262±0.002	0.094±0.002	0.49±0.03	3.13±0.17	2.46±0.12	26.4	70	26	2	0.012	✓
74	I16385-4619	7.11	-117	5.1	79.43	0.456±0.005	0.309±0.003	0.337±0.016	3.76±0.18	2.2±0.1	40.4	70	63	4	0.012	
75	I16424-4531	2.63	-34.2	3.9	15.85	—	—	—	—	—	—	—	—	—	0.012	✓
76	I16445-4459	7.95	-121.3	5	12.59	0.252±0.002	0.172±0.001	0.272±0.012	2.55±0.11	1.01±0.11	40.7	40	18	4	0.012	
77	I16458-4512	3.56	-50.4	4.5	7.94	0.380±0.002	0.165±0.002	0.15±0.01	2.86±0.19	1.57±0.17	30.2	122	65	6	0.012	✓
78	I16484-4603	2.1	-32	5	100	0.451±0.002	0.360±0.002	0.43±0.01	3.01±0.07	1.15±0.09	44.4	83	31	6	0.012	✓
79	I16487-4423	3.26	-43.4	4.4	25.12	0.310±0.001	0.123±0.001	0.266±0.012	2.92±0.13	0.59±0.12	28.5	116	54	4	0.012	✓
80	I16489-4431	3.26	-41.3	3.8	7.94	0.588±0.002	0.285±0.002	0.31±0.05	4.0±0.6	2.30±0.17	32.6	134	71	4	0.012	✓
81	I16506-4512	2.42	-26.2	5	79.43	0.155±0.002	0.056±0.001	0.075±0.008	1.89±0.21	1.23±0.11	26.4	35	19	4	0.012	✓
82	I16524-4300	3.43	-40.8	4.4	10	0.244±0.001	0.134±0.001	0.480±0.019	1.92±0.08	1.6±0.3	35.5	190	45	6	0.012	✓
83	I16547-4247	2.74	-30.4	4.8	39.81	—	—	—	—	—	—	—	—	—	0.012	✓
84	I16562-3959	2.38	-12.6	5.7	31.623	—	—	—	—	—	—	—	—	—	0.012	✓
85	I16571-4029	2.38	-15	4.3	25.12	0.903±0.001	0.547±0.001	0.315±0.019	3.98±0.23	2.9±0.2	37.7	128	85	4	0.012	✓
86	I17006-4215	2.21	-23.2	4.4	39.81	0.346±0.002	0.234±0.004	0.071±0.006	1.02±0.09	2.6±0.3	40.3	87	25	4	0.012	✓
87	I17008-4040	2.38	-17	4.6	39.81	—	—	—	—	—	—	—	—	—	0.012	✓
88	I17016-4124	1.37	-27.1	5.3	31.62	0.353±0.001	—	—	—	—	—	—	—	—	0.012	✓
89	I17136-3617	1.34	-10.6	4.6	125.89	0.333±0.003	0	0.278±0.013	2.25±0.11	1.5±0.1	0.0	81	81	2	0.011	✓
90	I17143-3700	12.67	-31.1	5.6	63.1	0.333±0.003	0.189±0.002	1.51±0.03	4.85±0.09	2.69±0.08	36.2	114	107	2	0.011	✓
91	I17158-3901	3.38	-15.2	4.8	25.12	0.346±0.001	0.214±0.002	0.032±0.005	1.18±0.19	3.1±0.3	38.3	172	34	6	0.011	✓
92	I17160-3707	10.53	-69.5	6	79.43	0.372±0.003	0.162±0.005	0.447±0.013	3.88±0.11	1.83±0.19	30.4	97	45	4	0.011	✓
93	I17175-3544	1.34	-5.7	4.8	50.12	—	—	—	—	—	—	—	—	—	0.013	✓
94	I17204-3636	3.32	-18.2	4.2	19.95	0.375±0.001	0.153±0.001	0.447±0.014	2.65±0.08	1.42±0.18	28.9	84	44	4	0.011	✓
95	I17220-3609	8.01	-93.7	5.7	25.12	—	—	—	—	—	—	—	—	—	0.013	✓
96	I17233-3606	1.34	-2.7	4.6	39.81	0.196±0.001	0.068±0.002	0.119±0.011	1.2±0.1	1.01±0.24	25.7	68	7	4	0.011	✓
97	I17244-3536	1.36	-10.2	3.7	39.81	0.246±0.006	0.130±0.002	0.686±0.022	2.32±0.07	1.5±0.1	34.5	105	55	6	0.012	✓
98	I17258-3637	2.59	-11.9	5.9	39.81	0.320±0.002	0.221±0.003	0.036±0.006	1.5±0.3	1.7±0.3	40.8	158	46	4	0.011	✓
99	I17269-3312	4.38	-21	4.7	12.59	0.439±0.001	0.208±0.001	0.177±0.018	1.76±0.18	3.3±0.3	32.2	148	66	8	0.011	✓
100	I17271-3439	3.1	-18.2	5.6	39.81	—	—	—	—	—	—	—	—	—		

Table A1 – continued

ID	IRAS	Distance (kpc)	$\log L_{\text{bol}}$ ($L_{\odot}$)	L_{bol}/M ($L_{\odot} M_{\odot}^{-1}$)	SiO(2–1)			$\text{H}^{13}\text{CO}^{+}(1-0)$			Contribution _N		Number		σ rms ($\mu\text{Jy km s}^{-1}$)	Outflow ^a
					$\int T_{\text{B}} dv$ ($\mu\text{Jy km s}^{-1}$)	$\int T_{\text{B}} dv$ ($\mu\text{Jy km s}^{-1}$)	$\int T_{\text{B}} dv$ ($\mu\text{Jy km s}^{-1}$)	$\int T_{\text{B}} dv$ ($\mu\text{Jy km s}^{-1}$)	FWHM_{B} (km s^{-1})	FWHM_{N} (km s^{-1})	(per cent)	B	N	Area		
101	I17278-3541	1.33	−0.4	3.8	19.95	0.605±0.006	0.327±0.003	0.112±0.012	8.1±0.9	1.22±0.07	35.1	85	110	6	0.012	✓
102	I17439-2845	8	18.7	5.7	79.43	0.392±0.001	0.108±0.001	0.10±0.01	4.5±0.5	2.04±0.05	21.6	51	22	4	0.009	✓
104	I17455-2800	10	−15.6	5.9	63.1	0.293±0.001	0.151±0.001	0.140±0.007	1.76±0.14	1.76±0.14	34.0	116	61	4	0.009	✓
105	I17545-2357	2.93	7.9	4.1	10	0.279±0.003	0.126±0.002	0.098±0.011	4.6±0.5	1.1±0.3	31.0	86	78	4	0.011	✓
106	I17589-2312	2.97	21.3	4	10	0.308±0.001	0.133±0.001	0.205±0.012	3.66±0.21	1.93±0.05	30.2	84	75	6	0.011	✓
107	I17599-2148	2.99	18.6	5.2	63.1	0.320±0.003	0.160±0.002	0.641±0.015	2.37±0.05	1.98±0.06	33.3	39	18	2	0.011	✓
108	I18032-2032	5.15	4.3	5.4	79.43	0.950±0.001	0.268±0.001	1.42±0.04	4.59±0.12	3.3±0.3	22.0	97	81	6	0.01	✓
109	I18056-1952	8.55	66.7	5.7	19.95	1.002±0.003	0.397±0.001	3.04±0.08	12.2±0.3	4.5±0.3	28.3	67	189	4	0.011	✓
111	I18079-1756	1.83	18	3.9	19.95	0.148±0.001	0.107±0.003	0.054±0.009	0.79±0.13	2.61±0.14	42.0	177	26	4	0.011	✓
112	I18089-1732	2.5	33.5	4.3	15.85	0.334±0.002	0.288±0.002	0.347±0.018	2.31±0.12	2.52±0.21	46.3	73	45	4	0.011	✓
113	I18110-1854	3.37	37	4.8	39.81	0.273±0.004	0.097±0.001	0.148±0.012	3.4±0.3	6.2±0.4	26.1	14	57	4	0.011	✓
114	I18116-1646	3.94	48.5	5.1	100	0.279±0.003	0.102±0.003	0.498±0.015	2.98±0.09	2.6±0.2	26.8	17	18	2	0.011	✓
115	I18117-1753	2.57	36.7	4.6	12.59	0.347±0.004	0.142±0.002	0.36±0.02	5.1±0.3	2.6±0.3	29.1	162	192	6	0.011	✓
116	I18134-1942	1.25	10.6	3	3.98	0.079±0.001	0.072±0.001	0.028±0.011	1.9±0.7	1.6±0.3	47.8	5	25	2	0.011	✓
117	I18139-1842	3.02	39.8	4.9	251.19	0.409±0.003	0.181±0.002	0.500±0.018	3.52±0.13	0.87±0.08	30.7	136	116	2	0.011	✓
118	I18159-1648	1.48	22	3.8	10	0.397±0.001	0.237±0.002	0.082±0.009	1.58±0.18	1.52±0.07	37.4	173	59	6	0.011	✓
119	I18182-1433	4.71	59.1	4.3	15.85	0.441±0.002	0.282±0.001	0.82±0.05	3.74±0.21	2.3±0.2	39.1	82	81	4	0.011	✓
120	I18223-1243	3.37	44.8	4.2	19.95	0.094±0.001	0.056±0.001	0.333±0.024	4.0±0.3	1.28±0.07	37.2	1	13	2	0.011	✓
121	I18228-1312	3.21	32.3	4.7	50.12	0.083±0.001	0.023±0.001	0.05±0.01	0.74±0.16	3.5±0.3	21.8	50	7	2	0.011	✓
122	I18236-1205	2.17	25.9	3.5	3.98	0.344±0.004	0.181±0.005	0.216±0.015	3.9±0.3	1.08±0.13	34.5	124	60	4	0.011	✓
123	I18264-1152	3.33	43.2	3.9	5.01	0.446±0.003	0.270±0.005	0.18±0.01	2.36±0.13	1.56±0.14	37.7	112	54	6	0.011	✓
124	I18290-0924	5.34	84.2	4	6.31	0.194±0.001	0.069±0.001	0.137±0.015	3.0±0.3	3.39±0.23	26.4	72	16	4	0.01	✓
126	I18311-0809	6.06	113	5	19.95	0.341±0.001	0.135±0.001	0.414±0.013	2.74±0.09	4.7±0.3	28.4	54	28	4	0.01	✓
128	I18316-0602	2.09	42.8	4	12.59	—	—	—	—	—	—	—	—	—	0.01	✓
129	I18317-0513	2.18	42.1	4.8	39.81	1.000±0.003	0.082±0.001	0.103±0.009	3.5±0.3	1.70±0.15	7.6	24	64	2	0.01	✓
130	I18317-0757	4.79	80.7	5.2	63.1	0.260±0.003	0.103±0.003	0.236±0.012	3.44±0.17	2.03±0.08	28.4	32	22	2	0.01	✓
131	I18341-0727	6.04	112.7	5.1	25.12	0.315±0.007	0.184±0.006	0.231±0.008	3.43±0.11	1.7±0.3	36.9	103	63	4	0.01	✓
132	I18411-0338	7.41	102.8	5.1	25.12	0.282±0.002	0.146±0.001	0.490±0.015	4.81±0.15	2.3±0.2	34.1	60	70	4	0.01	✓
133	I18434-0242	5.16	97.2	5.7	125.89	0.590±0.001	0.327±0.001	0.423±0.015	2.13±0.08	1.74±0.05	35.7	96	63	4	0.01	✓
135	I18445-0222	5.16	86.9	4.6	15.85	0.233±0.002	0.094±0.002	0.509±0.027	3.50±0.19	0.81±0.09	28.6	17	14	2	0.01	✓
136	I18461-0113	5.16	96.1	4.4	19.95	0.314±0.002	0.243±0.001	0.27±0.01	3.22±0.12	2.10±0.12	43.7	101	82	4	0.01	✓
137	I18469-0132	5.16	87	4.8	63.1	0.239±0.001	0.202±0.001	0.168±0.007	2.01±0.08	2.53±0.09	45.7	92	42	4	0.01	✓
138	I18479-0005	12.96	14.6	6.1	79.43	—	—	—	—	—	—	—	—	—	0.01	✓
140	I18507+0110	1.56	57.2	4.8	39.81	—	—	—	—	—	—	—	—	—	0.011	✓
141	I18507+0121	1.56	57.9	3.5	7.94	—	—	—	—	—	—	—	—	—	0.01	✓
142	I18517+0437	2.36	43.9	4.6	50.12	0.135±0.001	0.079±0.001	0.34±0.01	1.61±0.05	1.49±0.23	37.0	92	41	6	0.01	✓
143	I18530+0215	4.67	74.1	4.7	25.12	0.157±0.002	0.095±0.001	0.359±0.012	2.15±0.07	2.6±0.3	37.7	65	46	4	0.01	✓
144	I19078+0901	11.11	2.9	6.9	79.43	—	—	—	—	—	—	—	—	—	0.011	✓
145	I19095+0930	6.02	43.7	5.1	100	0.443±0.002	0.248±0.001	0.599±0.019	7.36±0.24	4.5±0.5	35.9	82	137	4	0.011	✓
146	I19097+0847	8.47	58	5	15.85	0.425±0.002	0.319±0.001	0.303±0.014	3.90±0.17	1.2±0.3	42.9	70	38	4	0.011	✓

Notes. Symbol “–” indicates that this source exhibits absorption feature.

^aThe identified outflow source from Baig et al. (in preparation).

Table A2. Basic parameters of the velocity decomposed sources in the ATOMS survey.

ID	IRAS	$L_{\text{SiO}} \times 10^{-5}$			$N(\text{SiO}) \times 10^{12}$			$X(\text{SiO}) \times 10^{-10}$			Filaments				A group			B group		Concident	UC H II	
		$(L_{\odot})$			(cm^{-2})			Broad	Narrow	Narrow	B position	N position	Infrared emission		24 μm	Offset	surrounded					
		Broad	Narrow	Narrow	4.5 μm	8 μm	24 μm															
1	108076-3556	0.216 $\pm$ 0.001	0.224 $\pm$ 0.001	0.224 $\pm$ 0.001	13.56 $\pm$ 0.06	5.62 $\pm$ 0.02	5.62 $\pm$ 0.02	5.9 $\pm$ 0.4	16.8 $\pm$ 0.8				✓	✓	✓		✓					
2	108303-4303	7.25 $\pm$ 0.02	1.45 $\pm$ 0.02	1.45 $\pm$ 0.02	13.75 $\pm$ 0.05	1.10 $\pm$ 0.01	1.10 $\pm$ 0.01	2.3 $\pm$ 0.1	7.6 $\pm$ 0.4				✓	✓	✓		✓					
3	108448-4343	0.367 $\pm$ 0.002	0.148 $\pm$ 0.002	0.148 $\pm$ 0.002	7.50 $\pm$ 0.04	1.21 $\pm$ 0.01	1.21 $\pm$ 0.01	2.5 $\pm$ 0.2	7.2 $\pm$ 0.3	N				✓	✓	✓						
4	108470-4243	4.21 $\pm$ 0.04	1.80 $\pm$ 0.05	1.80 $\pm$ 0.05	9.57 $\pm$ 0.09	1.64 $\pm$ 0.04	1.64 $\pm$ 0.04	3.4 $\pm$ 0.3	11.7 $\pm$ 1.5	N				✓	✓	✓						
5	109002-4732	0.589 $\pm$ 0.004	0.305 $\pm$ 0.004	0.305 $\pm$ 0.004	4.10 $\pm$ 0.03	0.85 $\pm$ 0.01	0.85 $\pm$ 0.01	2.5 $\pm$ 0.1	5.8 $\pm$ 0.3				✓	✓	✓		✓			✓		
6	109018-4816	3.56 $\pm$ 0.03	1.91 $\pm$ 0.02	1.91 $\pm$ 0.02	5.27 $\pm$ 0.04	1.14 $\pm$ 0.01	1.14 $\pm$ 0.01	0.8 $\pm$ 0.1	4.7 $\pm$ 0.5				✓	✓	✓		✓					
7	109094-4803	42.9 $\pm$ 0.6	16.8 $\pm$ 0.5	16.8 $\pm$ 0.5	4.67 $\pm$ 0.07	0.73 $\pm$ 0.02	0.73 $\pm$ 0.02	2.0 $\pm$ 0.1	4.5 $\pm$ 0.9	N				✓	✓	✓		✓				
8	110365-5803	1.84 $\pm$ 0.03	1.24 $\pm$ 0.04	1.24 $\pm$ 0.04	3.20 $\pm$ 0.06	0.87 $\pm$ 0.03	0.87 $\pm$ 0.03	0.7 $\pm$ 0.3	2.4 $\pm$ 0.9				✓	✓	✓		✓					
9	111298-6155	56.0 $\pm$ 0.6	35.50 $\pm$ 0.17	35.50 $\pm$ 0.17	5.61 $\pm$ 0.06	1.43 $\pm$ 0.01	1.43 $\pm$ 0.01	0.9 $\pm$ 0.3	20.0 $\pm$ 0.8	N				✓	✓	✓		✓				
10	111332-6258	2.57 $\pm$ 0.05	0.75 $\pm$ 0.02	0.75 $\pm$ 0.02	7.12 $\pm$ 0.13	0.83 $\pm$ 0.02	0.83 $\pm$ 0.02	0.9 $\pm$ 0.3	5.1 $\pm$ 2.5				✓	✓	✓		✓					
11	111590-6452	0.0270 $\pm$ 0.0003	0.0220 $\pm$ 0.0002	0.0220 $\pm$ 0.0002	1.68 $\pm$ 0.02	0.554 $\pm$ 0.004	0.554 $\pm$ 0.004	2.5 $\pm$ 0.1	12.4 $\pm$ 0.3				✓	✓	✓		✓			✓		
12	112320-6122	4.25 $\pm$ 0.07	2.21 $\pm$ 0.07	2.21 $\pm$ 0.07	3.62 $\pm$ 0.06	0.76 $\pm$ 0.03	0.76 $\pm$ 0.03	1.4 $\pm$ 0.5	2.7 $\pm$ 0.8				✓	✓	✓		✓					
13	112326-6245	24.43 $\pm$ 0.14	15.14 $\pm$ 0.02	15.14 $\pm$ 0.02	11.52 $\pm$ 0.07	2.867 $\pm$ 0.004	2.867 $\pm$ 0.004	2.2 $\pm$ 0.2	38.0 $\pm$ 1.1				✓	✓	✓		✓					
14	112383-6128	2.88 $\pm$ 0.08	1.22 $\pm$ 0.22	1.22 $\pm$ 0.22	2.70 $\pm$ 0.07	0.46 $\pm$ 0.08	0.46 $\pm$ 0.08	2.5 $\pm$ 0.8	22 $\pm$ 7				✓	✓	✓		✓					
15	112572-6316	32.6 $\pm$ 0.4	16.8 $\pm$ 0.4	16.8 $\pm$ 0.4	2.44 $\pm$ 0.03	0.51 $\pm$ 0.01	0.51 $\pm$ 0.01	0.9 $\pm$ 0.3	3.4 $\pm$ 0.5				✓	✓	✓		✓					
16	113079-6218	18.68 $\pm$ 0.07	9.63 $\pm$ 0.04	9.63 $\pm$ 0.04	12.97 $\pm$ 0.05	2.68 $\pm$ 0.01	2.68 $\pm$ 0.01	1.0 $\pm$ 0.1	44.6 $\pm$ 1.7				✓	✓	✓		✓					
17	113080-6229	2.29 $\pm$ 0.05	1.37 $\pm$ 0.04	1.37 $\pm$ 0.04	1.59 $\pm$ 0.04	0.38 $\pm$ 0.01	0.38 $\pm$ 0.01	0.2 $\pm$ 0.2	1.4 $\pm$ 0.7				✓	✓	✓		✓					
18	113111-6228	2.85 $\pm$ 0.04	1.15 $\pm$ 0.05	1.15 $\pm$ 0.05	1.98 $\pm$ 0.02	0.32 $\pm$ 0.01	0.32 $\pm$ 0.01	0.2 $\pm$ 0.1	1.9 $\pm$ 0.7				✓	✓	✓		✓					
19	113134-6242	9.14 $\pm$ 0.09	4.99 $\pm$ 0.09	4.99 $\pm$ 0.09	6.34 $\pm$ 0.07	1.39 $\pm$ 0.03	1.39 $\pm$ 0.03	5.2 $\pm$ 0.5	9.8 $\pm$ 2.5				✓	✓	✓		✓					
20	113140-6226	6.35 $\pm$ 0.04	3.06 $\pm$ 0.02	3.06 $\pm$ 0.02	4.41 $\pm$ 0.03	0.85 $\pm$ 0.01	0.85 $\pm$ 0.01	0.9 $\pm$ 0.2	35.7 $\pm$ 2.9				✓	✓	✓		✓					
22	113291-6249	21.3 $\pm$ 0.3	11.21 $\pm$ 0.14	11.21 $\pm$ 0.14	3.69 $\pm$ 0.06	0.78 $\pm$ 0.01	0.78 $\pm$ 0.01	1.5 $\pm$ 0.3	6.4 $\pm$ 1.9				✓	✓	✓		✓					
23	113295-6152	2.44 $\pm$ 0.06	1.18 $\pm$ 0.05	1.18 $\pm$ 0.05	1.62 $\pm$ 0.04	0.32 $\pm$ 0.01	0.32 $\pm$ 0.01	0.2 $\pm$ 0.3	4.8 $\pm$ 1.1				✓	✓	✓		✓			✓		
24	113471-6120	9.3 $\pm$ 0.1	4.9 $\pm$ 0.4	4.9 $\pm$ 0.4	3.13 $\pm$ 0.03	0.67 $\pm$ 0.06	0.67 $\pm$ 0.06	0.9 $\pm$ 0.6	2.4 $\pm$ 1.1				✓	✓	✓		✓					
25	113484-6100	15.3 $\pm$ 0.5	8.30 $\pm$ 0.22	8.30 $\pm$ 0.22	5.25 $\pm$ 0.17	1.15 $\pm$ 0.03	1.15 $\pm$ 0.03	0.3 $\pm$ 0.3	25.9 $\pm$ 4.5				✓	✓	✓		✓					
26	114013-6105	4.46 $\pm$ 0.04	1.90 $\pm$ 0.04	1.90 $\pm$ 0.04	2.64 $\pm$ 0.02	0.45 $\pm$ 0.01	0.45 $\pm$ 0.01	0.4 $\pm$ 0.2	1.9 $\pm$ 0.3				✓	✓	✓		✓					
28	114164-6028	4.73 $\pm$ 0.07	2.55 $\pm$ 0.05	2.55 $\pm$ 0.05	4.66 $\pm$ 0.07	1.01 $\pm$ 0.02	1.01 $\pm$ 0.02	0.4 $\pm$ 0.3	4.6 $\pm$ 1.3				✓	✓	✓		✓					
29	114206-6151	2.93 $\pm$ 0.14	1.01 $\pm$ 0.09	1.01 $\pm$ 0.09	2.72 $\pm$ 0.13	0.38 $\pm$ 0.04	0.38 $\pm$ 0.04	1.2 $\pm$ 0.7	4.4 $\pm$ 2.1				✓	✓	✓		✓					
30	114212-6131	6.43 $\pm$ 0.06	4.01 $\pm$ 0.05	4.01 $\pm$ 0.05	5.44 $\pm$ 0.05	1.36 $\pm$ 0.02	1.36 $\pm$ 0.02	1.1 $\pm$ 0.3	9.2 $\pm$ 1.5				✓	✓	✓		✓					
31	114382-6017	14.91 $\pm$ 0.23	6.57 $\pm$ 0.21	6.57 $\pm$ 0.21	2.53 $\pm$ 0.04	0.45 $\pm$ 0.01	0.45 $\pm$ 0.01	0.6 $\pm$ 0.3	8.5 $\pm$ 0.6				✓	✓	✓		✓					
32	114453-5912	3.21 $\pm$ 0.01	1.48 $\pm$ 0.01	1.48 $\pm$ 0.01	4.05 $\pm$ 0.02	0.75 $\pm$ 0.01	0.75 $\pm$ 0.01	1.1 $\pm$ 0.1	20.9 $\pm$ 0.4				✓	✓	✓		✓					
33	114498-5856	3.08 $\pm$ 0.03	1.63 $\pm$ 0.02	1.63 $\pm$ 0.02	3.10 $\pm$ 0.04	0.66 $\pm$ 0.01	0.66 $\pm$ 0.01	0.3 $\pm$ 0.1	8.4 $\pm$ 0.4				✓	✓	✓		✓					
34	115122-5801	20.6 $\pm$ 0.5	5.9 $\pm$ 0.5	5.9 $\pm$ 0.5	2.41 $\pm$ 0.06	0.28 $\pm$ 0.03	0.28 $\pm$ 0.03	0.9 $\pm$ 0.4	2.7 $\pm$ 0.8				✓	✓	✓		✓					
35	115254-5621	7.58 $\pm$ 0.05	4.82 $\pm$ 0.05	4.82 $\pm$ 0.05	4.75 $\pm$ 0.03	1.21 $\pm$ 0.01	1.21 $\pm$ 0.01	3.0 $\pm$ 0.2	4.1 $\pm$ 0.3				✓	✓	✓		✓					
36	115290-5546	75.9 $\pm$ 0.6	22.14 $\pm$ 0.18	22.14 $\pm$ 0.18	16.65 $\pm$ 0.13	1.95 $\pm$ 0.02	1.95 $\pm$ 0.02	0.5 $\pm$ 0.2	26.5 $\pm$ 1.9				✓	✓	✓		✓					
38	115394-5358	2.20 $\pm$ 0.01	1.53 $\pm$ 0.01	1.53 $\pm$ 0.01	6.67 $\pm$ 0.04	1.86 $\pm$ 0.01	1.86 $\pm$ 0.01	0.5 $\pm$ 0.1	26 $\pm$ 1				✓	✓	✓		✓					
40	115411-5352	2.02 $\pm$ 0.01	1.56 $\pm$ 0.01	1.56 $\pm$ 0.01	6.11 $\pm$ 0.03	1.90 $\pm$ 0.01	1.90 $\pm$ 0.01	1.2 $\pm$ 0.2	4.4 $\pm$ 0.5				✓	✓	✓		✓					
41	115437-5343	7.80 $\pm$ 0.08	3.50 $\pm$ 0.08	3.50 $\pm$ 0.08	3.15 $\pm$ 0.03	0.57 $\pm$ 0.01	0.57 $\pm$ 0.01	0.5 $\pm$ 0.1	4.7 $\pm$ 0.5				✓	✓	✓		✓					
42	115439-5449	3.32 $\pm$ 0.03	1.27 $\pm$ 0.03	1.27 $\pm$ 0.03	3.08 $\pm$ 0.03	0.47 $\pm$ 0.01	0.47 $\pm$ 0.01	0.6 $\pm$ 0.1	1.5 $\pm$ 0.4				✓	✓	✓		✓					
43	115502-5302	11.02 $\pm$ 0.15	4.5 $\pm$ 0.3	4.5 $\pm$ 0.3	3.28 $\pm$ 0.05	0.54 $\pm$ 0.04	0.54 $\pm$ 0.04	0.6 $\pm$ 0.4	3.6 $\pm$ 1.1				✓	✓	✓		✓					
45	115522-5411	2.94 $\pm$ 0.02	1.52 $\pm$ 0.01	1.52 $\pm$ 0.01	3.96 $\pm$ 0.03	0.82 $\pm$ 0.01	0.82 $\pm$ 0.01	1.0 $\pm$ 0.2	7.8 $\pm$ 0.8				✓	✓	✓		✓					
46	115557-5215	13.14 $\pm$ 0.07	7.75 $\pm$ 0.08	7.75 $\pm$ 0.08	8.11 $\pm$ 0.04	1.92 $\pm$ 0.02	1.92 $\pm$ 0.02	12.5 $\pm$ 0.5														

Table A2 – continued

ID	IRAS	$L_{SiO} \times 10^{-5}$ ($L_{\odot}$)		$N(SiO) \times 10^{12}$ (cm^{-2})		$X(SiO) \times 10^{-10}$		Filaments		Infrared emission			A group		B group		UC H II	
		Broad	Narrow	Broad	Narrow	B position	N position			4.5 μm	8 μm	24 μm					Concident	Offset
62	I16177-5018	5.04 $\pm$ 0.03	2.29 $\pm$ 0.18	3.96 $\pm$ 0.02	0.72 $\pm$ 0.06	1.4 $\pm$ 0.3	3 $\pm$ 1			✓	✓		✓					✓
63	I16272-4837	8.56 $\pm$ 0.02	4.15 $\pm$ 0.03	10.06 $\pm$ 0.03	1.96 $\pm$ 0.02	4.5 $\pm$ 0.2	25.2 $\pm$ 0.5			✓	✓	✓	✓					✓
64	I16297-4757	13.7 $\pm$ 0.2	14.96 $\pm$ 0.12	5.44 $\pm$ 0.08	2.38 $\pm$ 0.02	0.4 $\pm$ 0.3	3.9 $\pm$ 1.6			✓	✓		✓					✓
65	I16304-4710	56.3 $\pm$ 0.6	25.91 $\pm$ 0.24	4.40 $\pm$ 0.05	0.81 $\pm$ 0.01	0.8 $\pm$ 0.2	3.7 $\pm$ 0.8			✓	✓		✓					✓
66	I16313-4729	16.04 $\pm$ 0.05	5.74 $\pm$ 0.05	7.25 $\pm$ 0.02	1.04 $\pm$ 0.01	0.4 $\pm$ 0.1	6.7 $\pm$ 0.3			✓	✓		✓					✓
67	I16318-4724	55.7 $\pm$ 0.5	29.25 $\pm$ 0.17	9.47 $\pm$ 0.08	2.00 $\pm$ 0.01	0.4 $\pm$ 0.2	6.8 $\pm$ 1.1			✓	✓		✓					✓
68	I16330-4725	63.7 $\pm$ 0.4	30.2 $\pm$ 0.4	5.28 $\pm$ 0.03	1.01 $\pm$ 0.01	0.16 $\pm$ 0.04	0.6 $\pm$ 0.1			✓	✓		✓					✓
69	I16344-4658	112.1 $\pm$ 1.3	77.9 $\pm$ 0.6	7.69 $\pm$ 0.09	2.14 $\pm$ 0.02	0.3 $\pm$ 0.2	7.5 $\pm$ 1.8			✓	✓	✓	✓					✓
70	I16348-4654	133.6 $\pm$ 0.6	97.2 $\pm$ 0.5	9.16 $\pm$ 0.04	2.68 $\pm$ 0.01	0.8 $\pm$ 0.1	13.2 $\pm$ 0.4			✓	✓		✓					✓
71	I16351-4722	17.29 $\pm$ 0.03	6.97 $\pm$ 0.02	19.01 $\pm$ 0.03	3.08 $\pm$ 0.01	1.17 $\pm$ 0.02	9.8 $\pm$ 0.3			✓	✓		✓					✓
72	I16362-4639	4.82 $\pm$ 0.04	1.00 $\pm$ 0.03	5.33 $\pm$ 0.04	0.44 $\pm$ 0.01	2.5 $\pm$ 0.4	5 $\pm$ 1			✓	✓		✓					✓
73	I16372-4545	7.19 $\pm$ 0.07	2.58 $\pm$ 0.06	4.16 $\pm$ 0.04	0.60 $\pm$ 0.02	0.4 $\pm$ 0.1	1.8 $\pm$ 0.4			✓	✓		✓					✓
74	I16385-4619	36.3 $\pm$ 0.4	24.53 $\pm$ 0.22	7.19 $\pm$ 0.09	1.95 $\pm$ 0.02	1.2 $\pm$ 0.3	4.7 $\pm$ 1.1			✓	✓		✓					✓
76	I16445-4459	25.24 $\pm$ 0.15	17.28 $\pm$ 0.09	4.00 $\pm$ 0.02	1.10 $\pm$ 0.01	0.8 $\pm$ 0.1	11.6 $\pm$ 0.6			✓	✓		✓					✓
77	I16458-4512	7.64 $\pm$ 0.03	3.31 $\pm$ 0.04	6.04 $\pm$ 0.03	1.05 $\pm$ 0.01	2.0 $\pm$ 0.2	7.5 $\pm$ 0.4			✓	✓		✓					✓
78	I16484-4603	3.14 $\pm$ 0.01	2.51 $\pm$ 0.02	7.14 $\pm$ 0.03	2.29 $\pm$ 0.01	1.0 $\pm$ 0.2	8.1 $\pm$ 0.4			✓	✓		✓					✓
79	I16487-4423	5.20 $\pm$ 0.02	2.07 $\pm$ 0.02	4.91 $\pm$ 0.02	0.79 $\pm$ 0.01	0.9 $\pm$ 0.1	30.9 $\pm$ 0.7			✓	✓		✓					✓
80	I16489-4431	9.99 $\pm$ 0.03	4.84 $\pm$ 0.03	9.43 $\pm$ 0.03	1.83 $\pm$ 0.01	1.54 $\pm$ 0.04	7.4 $\pm$ 0.4			✓	✓		✓					✓
81	I16506-4512	1.45 $\pm$ 0.02	0.52 $\pm$ 0.01	2.49 $\pm$ 0.03	0.36 $\pm$ 0.01	1.6 $\pm$ 0.2	2.5 $\pm$ 0.3			✓	✓		✓					✓
82	I16524-4300	3.57 $\pm$ 0.02	1.96 $\pm$ 0.01	3.04 $\pm$ 0.02	0.67 $\pm$ 0.01	0.4 $\pm$ 0.1	8.2 $\pm$ 0.2			✓	✓		✓					✓
85	I16571-4029	6.42 $\pm$ 0.01	3.88 $\pm$ 0.01	11.36 $\pm$ 0.02	2.76 $\pm$ 0.01	2.5 $\pm$ 0.1	8.0 $\pm$ 0.2			✓	✓		✓					✓
86	I17006-4215	2.09 $\pm$ 0.01	1.41 $\pm$ 0.03	4.28 $\pm$ 0.02	1.16 $\pm$ 0.02	4.3 $\pm$ 0.4	6.6 $\pm$ 0.5			✓	✓		✓					✓
89	I17136-3617	1.060 $\pm$ 0.003	0	5.91 $\pm$ 0.02	0	0.9 $\pm$ 0.1	5.6 $\pm$ 0.2			✓	✓		✓					✓
90	I17143-3700	89.5 $\pm$ 0.7	50.8 $\pm$ 0.4	5.59 $\pm$ 0.05	1.27 $\pm$ 0.01	0.2 $\pm$ 0.1	2.3 $\pm$ 0.6			✓	✓		✓					✓
91	I17158-3901	6.49 $\pm$ 0.03	4.02 $\pm$ 0.03	5.69 $\pm$ 0.02	1.42 $\pm$ 0.01	9.2 $\pm$ 0.3	8.4 $\pm$ 0.4			✓	✓		✓					✓
92	I17160-3707	67.7 $\pm$ 0.6	29.5 $\pm$ 0.9	6.12 $\pm$ 0.05	1.07 $\pm$ 0.03	0.7 $\pm$ 0.3	6.5 $\pm$ 0.7			✓	✓		✓					✓
94	I17204-3636	6.89 $\pm$ 0.02	2.80 $\pm$ 0.02	6.26 $\pm$ 0.02	1.02 $\pm$ 0.01	0.7 $\pm$ 0.1	14.9 $\pm$ 0.4			✓	✓		✓					✓
97	I17244-3536	0.603 $\pm$ 0.007	0.21 $\pm$ 0.01	3.27 $\pm$ 0.02	0.45 $\pm$ 0.02	1.3 $\pm$ 0.1	7.6 $\pm$ 0.3			✓	✓		✓					✓
98	I17258-3637	2.75 $\pm$ 0.07	1.45 $\pm$ 0.03	4.11 $\pm$ 0.11	0.87 $\pm$ 0.02	0.3 $\pm$ 0.2	3 $\pm$ 1			✓	✓		✓					✓
99	I17269-3312	10.31 $\pm$ 0.05	7.11 $\pm$ 0.08	5.39 $\pm$ 0.03	1.49 $\pm$ 0.02	7.9 $\pm$ 0.3	22.4 $\pm$ 0.8			✓	✓		✓					✓
100	I17271-3439	7.06 $\pm$ 0.02	3.35 $\pm$ 0.02	7.37 $\pm$ 0.02	1.40 $\pm$ 0.01	2.0 $\pm$ 0.1	7.4 $\pm$ 0.2			✓	✓		✓					✓
101	I17278-3541	1.77 $\pm$ 0.02	0.96 $\pm$ 0.01	10.05 $\pm$ 0.09	2.18 $\pm$ 0.02	4.5 $\pm$ 0.4	10.0 $\pm$ 1.6			✓	✓		✓					✓
102	I17439-2845	54.27 $\pm$ 0.17	14.98 $\pm$ 0.11	8.50 $\pm$ 0.03	0.94 $\pm$ 0.01	3.1 $\pm$ 0.1	2.5 $\pm$ 0.4			✓	✓		✓					✓
104	I17455-2800	63.37 $\pm$ 0.21	32.7 $\pm$ 0.3	6.35 $\pm$ 0.02	1.32 $\pm$ 0.01	1.7 $\pm$ 0.1	7.0 $\pm$ 0.4			✓	✓		✓					✓
105	I17545-2357	3.61 $\pm$ 0.03	1.63 $\pm$ 0.02	4.22 $\pm$ 0.04	0.76 $\pm$ 0.01	2.3 $\pm$ 0.2	17.3 $\pm$ 0.6			✓	✓		✓					✓
106	I17589-2312	4.11 $\pm$ 0.02	1.78 $\pm$ 0.01	4.68 $\pm$ 0.02	0.81 $\pm$ 0.01	1.2 $\pm$ 0.1	1.7 $\pm$ 0.3			✓	✓		✓					✓
107	I17599-2148	4.29 $\pm$ 0.03	2.15 $\pm$ 0.02	4.81 $\pm$ 0.04	0.97 $\pm$ 0.01	0.4 $\pm$ 0.2	1.6 $\pm$ 0.5			✓	✓		✓					✓
108	I18032-2032	38.52 $\pm$ 0.03	10.86 $\pm$ 0.03	14.56 $\pm$ 0.01	1.65 $\pm$ 0.01	0.51 $\pm$ 0.02	10.2 $\pm$ 0.1			✓	✓		✓					✓
109	I18056-1952	111.84 $\pm$ 0.31	44.20 $\pm$ 0.09	15.34 $\pm$ 0.04	2.43 $\pm$ 0.01	0.26 $\pm$ 0.03	8.9 $\pm$ 0.4			✓	✓		✓					✓
111	I18079-1756	0.88 $\pm$ 0.01	0.64 $\pm$ 0.02	2.64 $\pm$ 0.02	0.77 $\pm$ 0.02	2.4 $\pm$ 0.2	1.3 $\pm$ 0.3			✓	✓		✓					✓
112	I18089-1732	3.72 $\pm$ 0.02	3.20 $\pm$ 0.02	5.96 $\pm$ 0.04	2.06 $\pm$ 0.01	0.9 $\pm$ 0.1	9.9 $\pm$ 0.7			✓	✓		✓					✓
113	I18110-1854	5.53 $\pm$ 0.07	1.96 $\pm$ 0.03	4.89 $\pm$ 0.06	0.69 $\pm$ 0.01	1.5 $\pm$ 0.2	1.9 $\pm$ 0.3			✓	✓		✓					✓
114	I18116-1646	7.69 $\pm$ 0.08	2.81 $\pm$ 0.08	4.97 $\pm$ 0.05	0.73 $\pm$ 0.02	0.4 $\pm$ 0.2	4.3 $\pm$ 0.7			✓	✓		✓					✓
115	I18117-1753	4.07 $\pm$ 0.04	1.67 $\pm$ 0.03	6.18 $\pm$ 0.06	1.02 $\pm$ 0.02	0.8 $\pm$ 0.2	7.2 $\pm$ 0.8			✓	✓		✓					✓
116	I18134-1942	0.220 $\pm$ 0.004	0.202 $\pm$ 0.002	7.31 $\pm$ 0.05	0.52 $\pm$ 0.01	0.7 $\pm$ 0.1	13.0 $\pm$ 0.9			✓	✓		✓					✓
117	I18139-1842	6.65 $\pm$ 0.04	2.94 $\pm$ 0.03	7.08 $\pm$ 0.02	1.30 $\pm$ 0.01	0.7 $\pm$ 0.1	4.1 $\pm$ 0.3			✓	✓		✓					✓
118	I18159-1648	1.55 $\pm$ 0.01	0.93 $\pm$ 0.01	7.80 $\pm$ 0.02	2.01 $\pm$ 0.01	0.47 $\pm$ 0.03	15.7 $\pm$ 0.7			✓	✓		✓					✓
119	I18182-1433	17.27 $\pm$ 0.07	11.07 $\pm$ 0.03	7.80 $\pm$ 0.03	2.01 $\pm$ 0.01	0.47 $\pm$ 0.03	15.7 $\pm$ 0.7			✓	✓		✓					✓
120	I18223-1243	1.88 $\pm$ 0.02	1.11 $\pm$ 0.02	1.66 $\pm$ 0.02	0.40 $\pm$ 0.01	0.24 $\pm$ 0.04	1.9 $\pm$ 0.4			✓	✓		✓					✓

Table A2 – *continued*

ID	IRAS	$L_{\text{SiO}} \times 10^{-5}$		$N(\text{SiO}) \times 10^{12}$		$X(\text{SiO}) \times 10^{-10}$		Filaments			A group		B group		UC H II	
		Broad	Narrow	Broad	Narrow	B position	N position	4.5 μm	8 μm	24 μm	Concident	Offset	surrounded			
		$(L_{\odot})$														
121	118228-1312	1.51 $\pm$ 0.03	0.42 $\pm$ 0.02	1.47 $\pm$ 0.02	0.16 $\pm$ 0.01	1.4 $\pm$ 0.1	1.4 $\pm$ 0.3				✓				✓	
122	118236-1205	2.86 $\pm$ 0.03	1.51 $\pm$ 0.04	6.08 $\pm$ 0.07	1.29 $\pm$ 0.03	1.3 $\pm$ 0.3	18.7 $\pm$ 2.1	✓		✓		✓				
123	118264-1152	8.72 $\pm$ 0.05	5.3 $\pm$ 0.1	7.88 $\pm$ 0.05	1.92 $\pm$ 0.04	2.2 $\pm$ 0.3	8.6 $\pm$ 0.8	✓		✓		✓				
124	118290-0924	10.00 $\pm$ 0.04	3.58 $\pm$ 0.04	3.52 $\pm$ 0.01	0.51 $\pm$ 0.01	1.11 $\pm$ 0.05	2.3 $\pm$ 0.2		N							
126	118311-0809	22.59 $\pm$ 0.08	8.94 $\pm$ 0.06	6.17 $\pm$ 0.02	0.98 $\pm$ 0.01	0.7 $\pm$ 0.1	5.3 $\pm$ 0.4	✓		✓		✓			✓	
129	118317-0513	8.49 $\pm$ 0.02	0.70 $\pm$ 0.01	17.91 $\pm$ 0.05	0.59 $\pm$ 0.01	6.9 $\pm$ 0.2	20.5 $\pm$ 0.7	✓		✓			✓			
130	118317-0757	10.74 $\pm$ 0.11	4.26 $\pm$ 0.12	4.69 $\pm$ 0.05	0.75 $\pm$ 0.02	0.9 $\pm$ 0.2	2.4 $\pm$ 0.8	-	N	-					✓	
131	118341-0727	20.7 $\pm$ 0.5	12.1 $\pm$ 0.4	5.68 $\pm$ 0.13	1.34 $\pm$ 0.04	1.2 $\pm$ 0.9	17.3 $\pm$ 2.6	✓		✓		✓				
132	118411-0338	25.48 $\pm$ 0.18	13.16 $\pm$ 0.09	4.65 $\pm$ 0.03	0.97 $\pm$ 0.01	0.5 $\pm$ 0.1	7.9 $\pm$ 0.7	✓		✓			✓			
133	118434-0242	25.69 $\pm$ 0.05	14.23 $\pm$ 0.02	9.67 $\pm$ 0.02	2.151 $\pm$ 0.004	1.2 $\pm$ 0.1	3.6 $\pm$ 0.2	✓		✓		✓			✓	
135	118445-0222	10.2 $\pm$ 0.1	4.08 $\pm$ 0.07	3.83 $\pm$ 0.04	0.62 $\pm$ 0.01	0.4 $\pm$ 0.1	10 $\pm$ 1	✓		✓		✓				
136	118461-0113	13.57 $\pm$ 0.07	10.51 $\pm$ 0.04	5.11 $\pm$ 0.03	1.59 $\pm$ 0.01	1.0 $\pm$ 0.1	6.8 $\pm$ 0.6	✓		✓		✓				
137	118469-0132	10.38 $\pm$ 0.06	8.75 $\pm$ 0.03	3.91 $\pm$ 0.02	1.32 $\pm$ 0.01	1.3 $\pm$ 0.2	3.0 $\pm$ 0.4	✓		✓		✓				
142	118517+0437	1.17 $\pm$ 0.01	0.68 $\pm$ 0.01	2.10 $\pm$ 0.01	0.49 $\pm$ 0.01	0.3 $\pm$ 0.1	4.3 $\pm$ 0.2	✓		✓		✓				
143	118530+0215	5.47 $\pm$ 0.06	3.31 $\pm$ 0.05	2.51 $\pm$ 0.03	0.61 $\pm$ 0.01	0.4 $\pm$ 0.1	6.4 $\pm$ 0.7	✓		✓		✓			✓	
145	119095+0930	25.15 $\pm$ 0.09	14.06 $\pm$ 0.07	6.96 $\pm$ 0.02	1.56 $\pm$ 0.01	0.6 $\pm$ 0.1	12.9 $\pm$ 0.4	✓		✓			✓		✓	
146	119097+0847	47.67 $\pm$ 0.18	35.77 $\pm$ 0.12	6.66 $\pm$ 0.02	2.01 $\pm$ 0.01	1.3 $\pm$ 0.1	27.7 $\pm$ 0.3	✓		✓		✓			✓	

Notes: The symbol “-” indicates that the corresponding emission is not detect in this source.

The symbol “N” in the Filaments column indicates that the SiO emission is not associated with the filament skeleton identified by Zhou et al. (2022) in this source.

The 4.5, 8, and 24 μm emission were obtained from the GLIMPSE and MIPSAL (Benjamin et al. 2003; Carey et al. 2003; Churchwell et al. 2009).

APPENDIX B

Fig. B1 shows the SiO and H^{13}CO^+ spectra with absorption features. Sources with negative features around systemic velocity in both SiO and H^{13}CO^+ line profiles are caused by the presence of strong

continuum sources (Ohashi et al. 2022; Codella et al. 2024). These sources (I15520-5234, I16424-4531, and I18479-0005) only show SiO absorption, which may be due to the effects of large optical depth in the SiO (2–1) line emission.

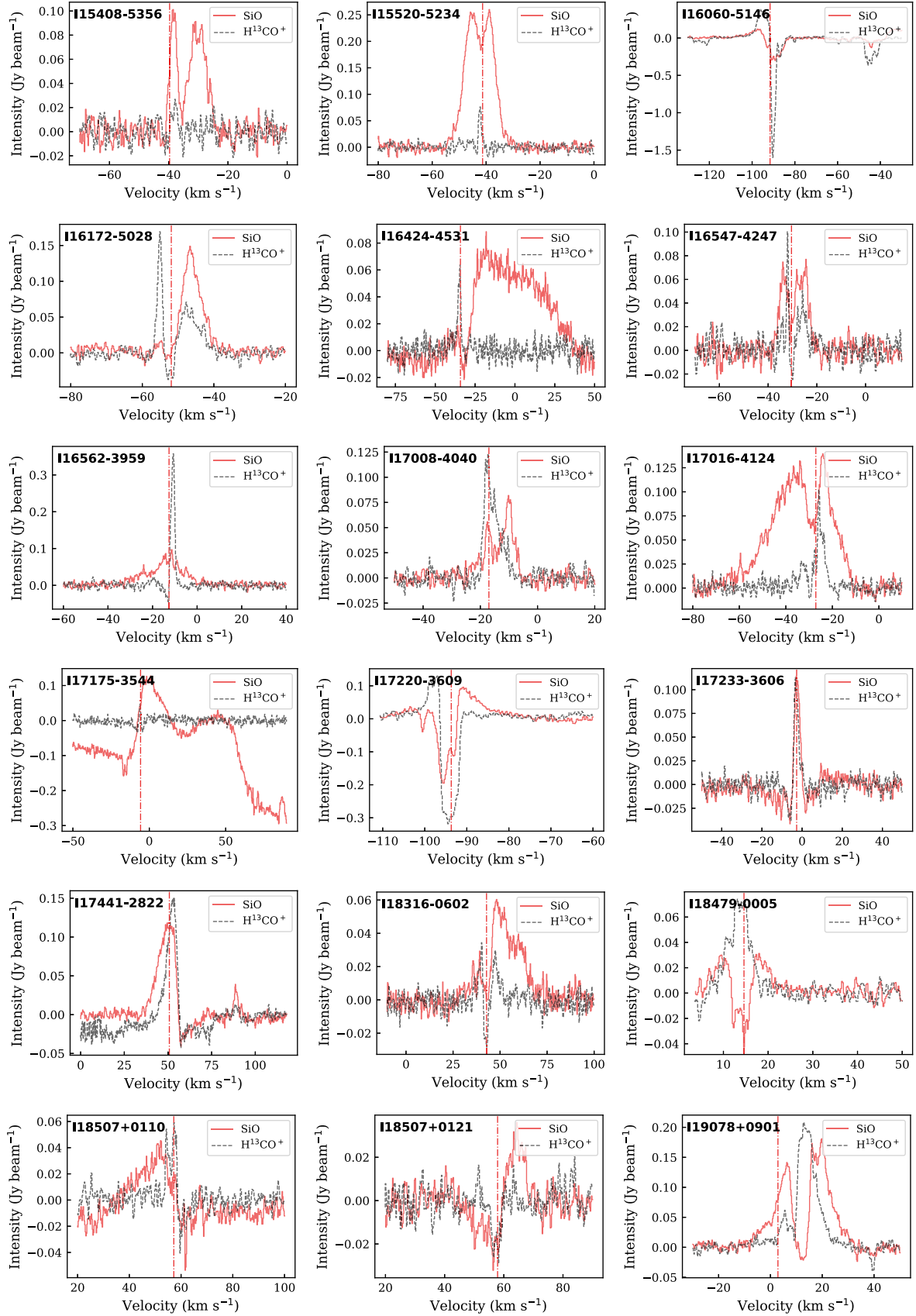


Figure B1. The observed SiO spectra with negative features. Solid histograms and dashed histograms represent the SiO and H^{13}CO^+ spectra, respectively.

APPENDIX C

Fig. C1 shows the SiO (2–1) integrated intensity maps overlaid with 4.5, 8, and 24 μm emission towards sources lacking UC H II regions

and the SiO (2–1) integrated intensity maps overlaid with 4.5, 8, and 1.3 GHz emission towards sources with UC H II regions, respectively. The images for decomposed sources, both with and without UC H II regions, are available within the supplementary material.

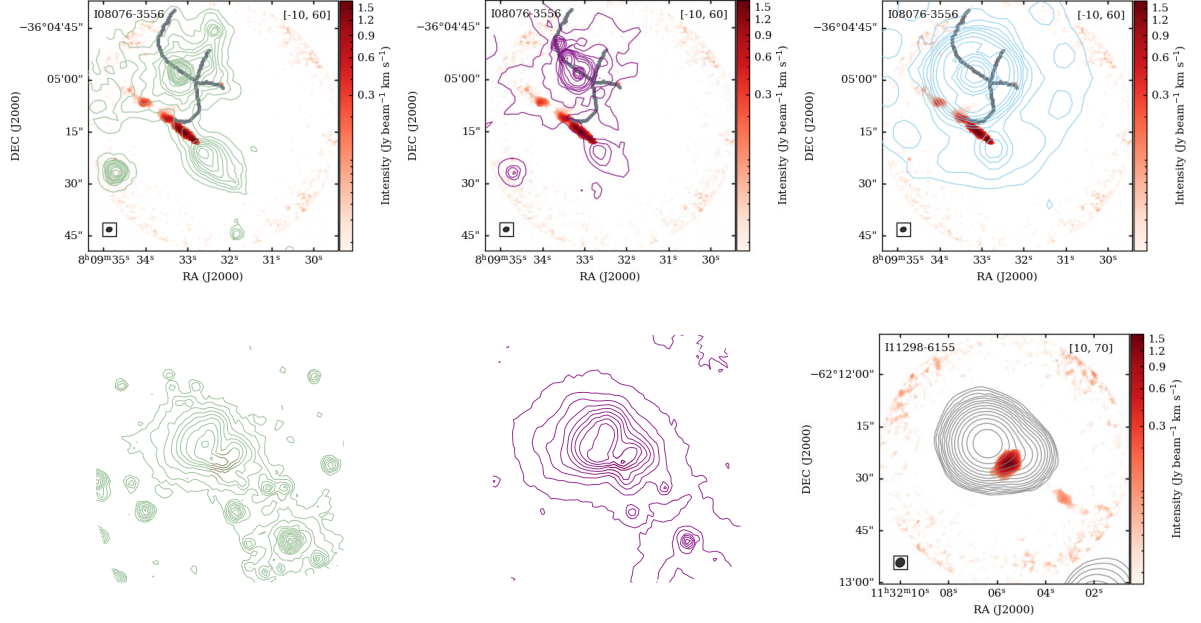


Figure C1. The background images correspond to the SiO (2–1) integrated intensity maps obtained within the ATOMS survey. *Upper panels:* One representative source without an UC H II region. *Lower panels:* One representative source with an UC H II region. The green, purple, blue, and grey contours are 4.5 μm , 8 μm , 24 μm , and 1.3 GHz emission (see upper/lower left, upper/lower middle, upper right, and lower right), respectively. Contours range from 5σ to the peak values, divided into 15 logarithmic steps (base 10). The 4.5, 8, and 24 μm emission were obtained from the GLIMPSE and MIPS GAL (Benjamin et al. 2003; Carey et al. 2003; Churchwell et al. 2009), and the 1.3 GHz emission were utilized from Goedhart et al. (2024). The bold lines represent the filament skeleton identified in H^{13}CO^+ emission. The shown field of view is 72 arcsec corresponding to the FOV of the ALMA observations. The source name and integrated velocity ranges (in km s^{-1}) are shown on the upper left and right corners of each panel, respectively. The beam size is presented in the lower left corner. The same images are provided for all decomposed sources within the supplementary material.

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