A survey of CO emission in molecular regions of different types†∗

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Abstract Using a recently installed system on the 13.7-m radio telescope of the Qinhai Station of Purple Mountain Observatory at Delingha, we searched for $^{12}$CO J=1–0 emission in a group of sources including H II region candidates, dense cores, Bok globules and pre-main sequence stars and late-type stars. The emission was detected in all the star-forming regions of different masses. The discovery of such features as large line widths, red and blue wings, variations in the core velocity and multiple emission indicates probable existence of double jets, expansion or multiple knots. The emission line was seen in two evolved late-type stars, indicating dense circumstellar gas envelopes.

Key words: interstellar molecule—interstellar medium—circumstellar envelope

1. INTRODUCTION

The CO molecule in the interstellar medium is next only to the main component $H_2$ in abundance, and as its rotational transition dipole moment is small and its excitation temperature low, it serves as the most generally used, effective molecular probe. And because of its function in radiative transfer it plays an important role in the molecular processes of heavenly bodies.

During the twenty-odd years since the discovery of the interstellar CO molecule[1], the CO line has yielded a vast amount of information on the properties and processes of astronomical bodies, making it possible to diagnose molecular regions which eluded optical observations, bringing in breakthroughs in the studies of star formation and the evolution

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in the late stage, thus demonstrating its power in the exploration of heavenly bodies and processes. At present detection of the CO emission is still being carried forth. There remain many molecular regions yet unexamined for CO, including regions with deeply embedded infrared sources or known ionized gas emission, even some in which high-velocity phenomena have already been found in the optical or other ranges. We have selected a sample comprising H II region candidates, dense cores of clouds, young emission-line stars and circumstellar envelopes of evolved, late-type stars and carried out a search for the CO J=1–0 emission at 115.27120 GHz. In the next two Sections we describe the observation and the results and a brief discussion.

2. THE OBSERVATION

Our observation was carried out between 1996–09–19 and 09–23 on the newly installed 3-mm system on the 13.7-m telescope of Qinhai Station of Purple Mountain Observatory. At this frequency, the antenna efficiency is 27%, beamwidth 53", the pointing accuracy is better than 14", tracking accuracy better than 10", the receiver system used a cooled frequency-mixing, low-noise amplification, the system noise temperature was 600–800 K, the AOS spectrograph had a bandwidth of 170 MHz and a resolution of 280 kHz. The telescope was controlled by Forth system and real-time data treatment was made using the POPS software.

The observation was position-modulated, each scan lasted 6–8 minutes, each source was scanned 1–4 times, noise tube calibration, the detected flux was corrected for atmospheric absorption and expressed as an antenna temperature.

3. RESULTS AND DISCUSSION

Table 1 lists the observed sample and results. Col. 1 is our serial number, Col. 2, the name of the source, Cols. 3 and 4 give the right ascension and declination, Col. 5 gives the type, I for H II region candidate or large-mass star-forming region, II for dense cloud core or Bok globule, III for emission-line star and IV, late-type evolved star. Col. 6 lists V_{\text{sr}}, Col. 7, the whole half-width, and Col. 8, the base width and/or profile feature. The table shows that we observed 11 molecular complexes, of which previous CO J=1–0 observation was made by Shepherd et al.\cite{2} for two: IRAS 02455+6034 and 18110–1854.

Our observed spectra for these two sources are shown in Fig. 1a. The left panels are, successively, for IRAS 02455+6034 at the positions (2,0), (0,0), (0,-2), (-2,0), (0,2) and the right panels are for 18110–1854 at (0,0), (0,-2), (2,0). The core velocities of these two sources and the half-width of 18110–1854 agree with the results observed using the NRAO 12-m telescope\cite{2}, while for 02455+6034, our measured half-width is smaller than theirs, because we used a two-component fit and we took one of them. From the spectra shown we see that the 02455+6034 source has a clear wing at the reference point (the location of the counterpart infrared source);—whether it signifies a jet of a young object remains to be clarified by more refined imaging, while the profile of 18110–1854 indicates a fast expanding gas. The spectra for 4 other H II region candidates are shown in Fig. 1b. The spectra for IRAS 23140+6121 refer to successive positions (0,0), (0,-2), (0,2), (-2,0), (2,0). This source
has two components separated by about 42.7 km/s, both components have wings, thus a strong possibility of an outflow. Wouterloot et al.\textsuperscript{[3]} have made the CO observations of the central point and they found three components, with, for the main peak, a $V_{\text{LSR}}$ of -50.8 km/s and an equivalent half-width of 4.9 km/s (we measured -51.2 and 4.6, see Table 1). Their stronger secondary peak has $V_{\text{LSR}} = -8.94$ km/s (we measured -8.5, see Fig. 1b). They also found a weaker secondary peak at -6.18 km/s, which we do not see except some line widening at the position. Although our velocity measurements have error of 1–2 channels, the disappearance of the -6.18 km/s secondary peak does not seem to be caused by measuring errors. On the other hand, in our spectra at (0,2) and (-2,0), we can see another secondary peak at about -4 km/s, these weak peaks await further observations for confirmation. The CO emission of the source IRAS 19588+3320 is weak, the other two sources, 19471+2641 and 20216+4107 both have wings and are outflow candidates. For 20216+4107, McCutcheon et al.\textsuperscript{[4]} have made the CO observation at 5 locations, they detected emission at -1 km/s and 12 km/s, with varying intensities at the different locations. Our results are more consistent with their 12 km/s component, which should be further studied with finer imaging.

### Table 1 Observed Molecular Regions

<table>
<thead>
<tr>
<th>No.</th>
<th>Source Name</th>
<th>R.A.(1950) h m s</th>
<th>Dec. $\circ$ $\arcmin$ $\arcsec$</th>
<th>Type</th>
<th>$V_{\text{LSR}}$ (km/s)</th>
<th>$\Delta V_{\text{mean}}$ (km/s)</th>
<th>$\Delta V$(km/s) or profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>02455+6034</td>
<td>02 45 30.1</td>
<td>60 34 35</td>
<td>I</td>
<td>-41.3</td>
<td>4.9</td>
<td>$\geq 20$. Two components</td>
</tr>
<tr>
<td>2</td>
<td>07335+6034</td>
<td>07 33 21.3</td>
<td>-18 38 51</td>
<td>I</td>
<td>47.1</td>
<td>2.9</td>
<td>$\geq 12$. Two components</td>
</tr>
<tr>
<td>3</td>
<td>18110–1854</td>
<td>18 11 03.7</td>
<td>-18 54 18</td>
<td>I</td>
<td>39.5</td>
<td>4.8</td>
<td>$\geq 21$. Expanding</td>
</tr>
<tr>
<td>4</td>
<td>18403–0417</td>
<td>18 40 19.5</td>
<td>-04 17 01</td>
<td>I</td>
<td>78.5</td>
<td>9.0</td>
<td>Multiple, blend</td>
</tr>
<tr>
<td>5</td>
<td>18431–0312</td>
<td>18 43 09.5</td>
<td>-03 12 36</td>
<td>I</td>
<td>78.4</td>
<td>5.8</td>
<td>Multiple, blend</td>
</tr>
<tr>
<td>6</td>
<td>18454+0136</td>
<td>18 45 28.0</td>
<td>-01 36 46</td>
<td>I</td>
<td>39.4</td>
<td>15.1</td>
<td>Two components</td>
</tr>
<tr>
<td>7</td>
<td>19471+2641</td>
<td>19 47 06.1</td>
<td>26 41 16</td>
<td>I</td>
<td>20.9</td>
<td>5.5</td>
<td>$\geq 15$. blue wing</td>
</tr>
<tr>
<td>8</td>
<td>19366+2301</td>
<td>19 36 40.0</td>
<td>23 01 43</td>
<td>I</td>
<td>46.2</td>
<td>4.0</td>
<td>$\geq 9.9$</td>
</tr>
<tr>
<td>9</td>
<td>19588+3320</td>
<td>19 58 37.0</td>
<td>33 20 47</td>
<td>I</td>
<td>-22.2</td>
<td>4.7</td>
<td>$\geq 10$</td>
</tr>
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<td>10</td>
<td>20216+4107</td>
<td>20 21 37.0</td>
<td>41 07 55</td>
<td>I</td>
<td>12.0</td>
<td>5.4</td>
<td>$\geq 3.0$. Two components</td>
</tr>
<tr>
<td>11</td>
<td>23140+6121</td>
<td>23 14 01.9</td>
<td>61 21 22</td>
<td>I</td>
<td>-51.2</td>
<td>4.6</td>
<td>22.0. Two components</td>
</tr>
<tr>
<td>12</td>
<td>CepC</td>
<td>23 04 58.0</td>
<td>62 12 55</td>
<td>I</td>
<td>-9.0</td>
<td>4.5</td>
<td>$\geq 22.0$. $V_{\text{LSR}}$ shift</td>
</tr>
<tr>
<td>13</td>
<td>L1521E</td>
<td>04 26 12.5</td>
<td>20 07 47</td>
<td>II</td>
<td>6.5</td>
<td>1.8</td>
<td>14.2, asymmetry</td>
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<tr>
<td>14</td>
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<td>15 36 47.0</td>
<td>-07 00 27</td>
<td>II</td>
<td>3.9</td>
<td>1.6</td>
<td>$\geq 5.8$, asymmetry</td>
</tr>
<tr>
<td>15</td>
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<td>16 18 09.6</td>
<td>-20 00 00</td>
<td>II</td>
<td>4.9</td>
<td>1.6</td>
<td>$\geq 16.5$</td>
</tr>
<tr>
<td>16</td>
<td>L1689A</td>
<td>16 29 10.0</td>
<td>-24 56 32</td>
<td>II</td>
<td>5.1</td>
<td>4.7</td>
<td>$\geq 11.9$</td>
</tr>
<tr>
<td>17</td>
<td>CB108</td>
<td>18 00 05.0</td>
<td>-20 51 07</td>
<td>II</td>
<td>21.1</td>
<td>3.5</td>
<td>Three components</td>
</tr>
<tr>
<td>18</td>
<td>L11148</td>
<td>20 40 00.0</td>
<td>67 10 10</td>
<td>II</td>
<td>3.2</td>
<td>2.4</td>
<td>Single</td>
</tr>
<tr>
<td>19</td>
<td>UXOri</td>
<td>05 02 00.0</td>
<td>-03 51 20</td>
<td>III</td>
<td>...</td>
<td>...</td>
<td>In identification</td>
</tr>
<tr>
<td>20</td>
<td>05328+2443</td>
<td>05 32 53.8</td>
<td>24 43 04</td>
<td>III</td>
<td>...</td>
<td>...</td>
<td>In identification</td>
</tr>
<tr>
<td>21</td>
<td>06183+1135</td>
<td>06 18 19.3</td>
<td>11 35 42</td>
<td>IV</td>
<td>102.9</td>
<td>7.1</td>
<td>$\geq 17.0$</td>
</tr>
<tr>
<td>22</td>
<td>15341+1515</td>
<td>15 34 08.0</td>
<td>15 15 55</td>
<td>IV</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>23</td>
<td>16011+4722</td>
<td>16 01 07.9</td>
<td>47 22 36</td>
<td>IV</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>24</td>
<td>17334+1537</td>
<td>17 33 25.0</td>
<td>15 37 07</td>
<td>IV</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>25</td>
<td>18273–0738</td>
<td>18 27 24.0</td>
<td>-07 38 37</td>
<td>IV</td>
<td>5.1</td>
<td>3.0</td>
<td>Weak</td>
</tr>
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</table>
Sources Nos. 3–8 of Table 1 are located in the regions surveyed by Clemens et al.[5] and Cohen et al.[6]. There are no comparable spectra with precise positions, but the spectral type and velocities are the same as in the neighbouring regions.

Fig. 1a  CO $J(1 - 0)$ spectra of HII region candidates IRAS 02455+6034(2, 0), (0, 0), (0, −2), (−2, 0), (0, 2), and IRAS 18110−1854(0, 0), (0, −2), (2, 0)
Fig. 2 displays the spectrum of the known outflow source Cep C[?] at (0, 0) and (30, 0). We see variation in the core velocity, which may be caused either by rotation or by two separate components;—and further imaging analysis is required. The CO emission was
detected also in 5 small-mass star formation regions and in one Bok globule, and Fig. 3
displays the spectra of two small-mass sources. Myers et al.[8] have made $^{13}$CO and $^{18}$O
$J$=1-0 observations, with accordant core velocities. The two profiles are asymmetric. Our
results for two pre-main sequence emission-line stars are in the course of identification.

![Fig. 2 CO (J = 1 - 0) spectra of CepC (0, 0), (30, 0)](image1)

![Fig. 3 CO (J = 1 - 0) spectra of L1719D and L1689A](image2)

Our observation also included the circumstellar envelopes of 6 AGB stars, and the CO
emission was detected in two of them, IRAS 06183+1135 and 18273-0738. Their spectra
are shown in Fig. 4. IRAS 06183+1135 has a low-resolution spectral index of 44 and CO
emission, indicating that its envelope is indeed carbon-rich. IRAS 18273-0738 has an index
of 31 and a thick, oxygen-rich envelope. We observed the CO emission, but our spectrum
was quite noisy and should be confirmed by further observation. Our results also show that
the CO line is often broader in large-mass than in small-mass star-forming regions, and are
more often multiply componented, while the CO detection rate around late-type stars is
lower than in star-forming regions.

Fig. 4 CO \((J = 1 - 0)\) spectra of late type stars IRAS 06183+1135 and 18273-0738

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References