Spectral imaging of the Sagittarius B2 region in multiple 3-mm molecular lines with the Mopra telescope

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ABSTRACT

Using the Mopra telescope, we have undertaken a 3-mm spectral-line imaging survey of a 5 arcmin square area around Sgr B2. We covered almost the complete spectral range from 81.7 to 113.5 GHz, with 2.2 MHz wide spectral channels or ∼6 km s⁻¹ and have observed 24 lines, with 0.033 MHz wide, or ∼0.1 km s⁻¹ channels. We discuss the distribution of around 50 lines, and present velocity-integrated emission images for 38 of the lines. In addition, we have detected around 120 more lines, mostly concentrated at the particularly spectral line-rich Sgr B2(N) source.

There are significant differences in molecular emission, pointing to both abundance and excitation differences throughout the region. Seven distinct spatial locations are identified for the emitting species, including peaks near the prominent star forming cores of Sgr B2(N), (M) and (S) that are seen in IR-to-radio continuum images. The other features are a 'North Ridge' and a 'North Cloud' to the north of the Sgr B2 N-M-S cores, a 'South-East Peak' and a 'West Ridge'.

The column density, as evident through C¹⁸O, peaks at the Sgr B2(N) and (M) cores, where strong absorption is also evident in otherwise generally-bright lines such as HCO⁺, HCN and HNC. Most molecules trace a ridge line to the west of the Sgr B2 N-M-S cores, wrapping around the cores and extending NE to the North Cloud. This is most clearly evident in the species HC₃N, CH₃CN, CH₃OH and OCS. They are found to be closer in distribution to the cooler dust traced by the sub-mm continuum than either the warmer dust seen in the mid-IR or to the radio continuum. The molecule CN, in contrast, is reasonably uniform over the entire region mapped, aside from strong absorption at the positions of the Sgr B2(N) and (M) cores.

Key words: ISM:individual (Sagittarius B2) – ISM:molecules – radio lines:ISM – ISM:kinematics and dynamics.

1 INTRODUCTION

Sagittarius B2 (Sgr B2) (G0.7-0.0) is a very massive and well-studied molecular cloud complex near the centre of the Galaxy. It contains multiple centres of (in many cases) spectacular star formation activity. The name derives from low resolution radio observations where Sagittarius A is the strong source at the Galactic Centre proper (Piddington & Minnett 1951) and B1, B2, C, D and E refer to other radio and mid-IR features nearby (Lequeux 1962, Hoffmann, Frederick & Emery 1974), albeit with some confusion in the literature (Palmer & Goss 1996).

Sgr B2 is about 100 pc in projected distance from the Galactic Centre and we assume its distance from the Sun to be identical to the latter’s, R₀. An R₀ of 7.1 ± 1.5 kpc was measured by Reid et al. (1988) using a kinematic parallax method. A more precise distance is the ‘best-estimate’ value of 8.0 ± 0.5 kpc that Reid (1993) derived by combining this with other data for the Galactic Centre. The latter is corroborated by the value of R₀ = 7.9 ± 0.4 kpc that has

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recently been determined from orbital solutions of a star moving around the super-massive central black hole, Sgr A* (Eisenhauer et al. 2003). In the following we assume $R_o = 8$ kpc.

Sgr B2 presents itself as the strongest feature in images of emission in $^{12}$CO, $^{13}$CO (Oka et al. 1998) and CS (Tsuboi, Handa & Ukita 1999) that define the bar-shaped (Sawada et al. 2004) Central Molecular Zone (CMZ), which stretches over the central few hundred pc of the Galaxy. The total mass of Sgr B2 is $> 5 \times 10^5$ M$_\odot$, and its peak H$_2$ column density $\geq 10^{23}$ cm$^{-2}$ (Lis & Goldsmith 1990).

Recent star formation is indicated by a giant H II region (Mehringer et al. 1993), with many compact and ultra-compact H II regions (Gaume et al. 1997). There are multiple centres of maser emission from the water (McGrath, Goss & De Pree 2004), hydroxyl (Gaume & Claussen 1990) and formaldehyde (Mehringer, Goss & Palmer 1994) molecules, as well as class I and class II methanol masers (Chewell 1996; Mehringer & Menten 1997). The region’s huge far-IR luminosity requires several young O-type stars as power sources, which are deeply embedded in the molecular cores.

The star-forming centres are located in a north-south line about 2 arcmin (~5 pc) long, in components labelled (north to south) Sgr B2(N), Sgr B2(M) and Sgr B2(S). All have prominent radio H II free-free, millimetre and sub-millimetre (Gordon et al. 1993; Pierce-Price et al. 2000) and infrared (Goldsmith et al. 1992) emission. These cores have been extensively studied with millimetre spectral-line surveys (Cummins, Linke & Thaddeus 1986; Turner 1985; Nummelin et al. 1998, 2000; Belloche et al. 2003, 2007).

Sgr B2(N) is particularly rich in complex molecules: it has been called the ‘Large Molecule Heimat’ (Snyder, Kuan & Miao 1993; Miao et al. 1993) or LMH. Sgr B2(N) is considered to be in a more recent stage of star formation than Sgr B2(M) (Miao et al. 1993), due to the presence of the complex molecules, stronger H$_2$O masers, and the relatively large amount of dust.

The surrounding molecular cloud has complex kinematics. The densest core emits around 60–65 km s$^{-1}$, but there is a ‘hole’ in the CO and CS emission around 40–50 km s$^{-1}$ in this area (Sato et al. 2000). This has been attributed (Hasegawa et al. 1994) to a collision between the 40–50 km s$^{-1}$ cloud and a cloud at 70–80 km s$^{-1}$, triggering the star formation activity. There is also a cloud 2 arcmin north of Sgr B2(M), and 1 arcmin north of Sgr B2(N), with chemical enhancement in HNCO and HOCO$^+$ (Minh et al. 1995), which may be associated with the shock from this collision.

We present here a multi-line spectral study in the 3-mm band of the central 12 pc of the Sgr B2 complex, to probe the chemistry and kinematics with a wide range of molecular tracers. The data were obtained with a new 8 GHz wide spectrometer on the Mopra millimetre wave telescope in Australia. These are the initial results of a project to map the CMZ in a variety of molecular species emitting in the 3-mm band.

2 OBSERVATIONS AND DATA REDUCTION

The observations were made with the 22-m Mopra radio telescope, in on-the-fly mapping mode (Ladd et al. 2003).

During 2005 a new wide-bandwidth digital filterbank, MOPS, was installed. This takes advantage of the wide bandwidth of the MMIC receiver, also installed in 2005, which covers the range from 77 to 117 GHz and has a wide front-end bandwidth. The MOPS can cover 8 GHz of bandwidth simultaneously, in either a broad band mode covering the whole band in four 2.2 GHz wide spectra, or a zoom mode where several narrower spectral bands of 137 MHz can be selected within the overall 8 GHz. In both the broad band and zoom modes, two polarisations are detected.

The observations made in 2006 June had 1024 channels in each 2.2 GHz in the broad band mode giving channel width 2.15 MHz or about 6.4 km s$^{-1}$ (at 100 GHz). This is coarser velocity sampling than desirable, but does allow the whole 8 GHz spectrum to be covered for a single tuning, and most of the 3-mm band in 4 tunings. The narrow band mode allowed a maximum of 8 zoom spectra of 137 MHz with 4096 channels (0.033 MHz or 0.10 km s$^{-1}$ at 100 GHz) to be observed (with a maximum of 4 zooms in each 2.2 GHz section) or 8 lines to be selected at high spectral resolution within the 8 GHz band covered by a single tuning.

This period was while the MOPS was still being upgraded, and the performance has since improved to allow up to 8192 channels of 0.27 MHz for each 2.2 GHz window in the broad band mode and up to 16 zoom spectra simultaneously. Further observations in this Mopra CMZ mapping project in 2007 and onwards use this increased performance.

The on-the-fly (OTF) observations covered an area $5 \times 5$ arcmin$^2$ centred on ($\alpha, \delta$)$_{2000} = 17^h 47^m 19.8^s, -28^\circ 22' 17''$, i.e., close to Sagittarius B2(N). We observed this area in both the broad band and zoom modes, in several tunings, as summarised in Table I. The broad band ranges are calculated assuming an overall range of 8 GHz: the data cover a bit more spectral range with 2.2 GHz sub-band spectra separated by 2.0 GHz, but are poor at the sub-band edges.

The OTF observations were made in a similar mode as for the Mopra G333-0.5/RCW106 survey (Bains et al. 2004). We used position switching for bandpass calibration with an off-source reference position ($\alpha, \delta$)$_{2000} = 17^h 51^m 03.6^s, -28^\circ 22' 47''$, or $l = 1.093$ deg., $b = -0.735$ deg. observed before each 5 arcmin long source scan. The spectra were read out with 2 seconds of integration time. The scan lines were separated by about 10 arcsec, so around 30 scan lines were needed, taking around an hour in total. Observations of SiO maser positions were used to correct the telescope pointing, before every map, giving a pointing accuracy better than 10 arcsec. The system temperature was calibrated with a noise diode, and hot load (paddle).

The OTF data were reduced into FITS data cubes with the LIVEDATA and GRIDZILLA packages. LIVEDATA is the processing software originally designed for the Parkes HII multibeam survey and is used to apply system tempera-

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1 In 2007 we have observed the frequency range 85.3 to 93.3 GHz in broad band mode, over the area longitude $-0.2$ to $0.9$ deg., and latitude $-0.2$ to $0.12$ deg., and will discuss these observations in a later paper.

2 http://www.atnf.csiro.au/people/mcalabre/livedata.html
ture calibration, bandpass calibration, heliocentric correction, spectral smoothing, and to write out the data in sfdits (Garwood 2000) format. GRIDZILLA is a re-gridding software package that is used to form three dimensional (RA-Dec-frequency) data cubes from bandpass-calibrated sfdits files (usually from LIVEDATA). The raw data files in rpfits format, were corrected with LIVEDATA for bandpass by the off-source spectra, a robust second order polynomial fit to the baseline subtracted and output as sfdits spectra. These were then regridded into data cubes using GRIDZILLA, with a gaussian smoothing function for the interpolation.

The resolution of the Mopra beam varies between 36 arcsec at 86 GHz and 33 arcsec at 115 GHz (Ladd et al. 2005), so the resolution in the final data varies between 39 and 36 arcsec after convolution with the 15 arcsec FWHM gaussian in the GRIDZILLA interpolation. The main beam efficiency of Mopra varies between 0.49 at 86 GHz, 0.44 at 100 GHz and 0.42 at 115 GHz (Ladd et al. 2003). These parameters were measured, however by Ladd et al. (2003) with a previous receiver and correlator. Since we are more concerned in this paper with the spatial and velocity structure, we have left the intensities throughout in this paper in the T_A^* scale, without correction for the beam efficiency onto the T_{MB} scale (except for the rms noise in Table 1).

The zoom mode data, with high resolution in velocity, were output as cubes over the velocity range −30 to 170 km s^{-1}, to reduce the file size, using the appropriate rest frequency of the line targeted. The broad band mode cubes were made with frequency as the third axis, over the whole 1024 channels of each sub-band. The pixel size was 12 arcsec. The FITS cubes were then read into the MIRIAD package for further analysis.

The integrated spectra over the region were plotted for the broad band mode data cubes, to identify the lines detected. Because of ripples in the spectra, particularly at the bandpass edges (mostly correlator ringing or 30 MHz ripples due to standing waves between the main dish and the secondary), we did not always reach the expected thermal noise sensitivity of around T_{MB} = 0.1 K (see Table 1). However, we identified several dozen strong lines (see Table 2) in the average spectra over the broad-band data cubes. These lines were identified using the NIST on-line database (Lovas 2002). For these lines we extracted sub-regions of 100 channels (~ 650 km s^{-1}) from the frequency cubes, and relabelled the scale as velocity, by putting the appropriate rest frequency into the file headers. These made low velocity resolution data cubes for the broad band mode data.

Since the lines are broad compared to the 0.033 MHz frequency channels of the zoom mode data cubes, we also made smoothed versions of the zoom mode cubes, with a 9-point Hanning function, to improve the signal-to-noise of the spectra, and using every fourth channel to reduce the file size, making 0.13 MHz channels.

For both the zoom mode and broad band mode data cubes, we then made integrated emission images, by summing the data over velocity, using velocity range over which the emission was well above the noise level. This velocity range differed depending on whether the particular line had strong line wings. These images are plotted and discussed in Section 3.

In addition, we searched the broad band data cubes, visually plane-by-plane, to identify line emission which was weak or not very extended, and so was not obvious in the spectrum integrated over the whole area. There are around 120 of these additional lines, which are listed in Table 3. Most of these are known lines, in the NIST on-line database (Lovas 2002). The line around 107.63 GHz is attributed to multiple blended transitions of CH_{3}CH_{3}CN ν = 1 (John Pearson, private communication).

The additional lines (Table 3) are discussed below, in Section 3 but as the line emission is weak and noisy, and mostly confined to a small area, the images are not plotted here.

The mapped area of 5 arcmin corresponds to 12 pc, and the resolution is 1.4 to 1.5 pc (using the Galactic Centre distance R_{G} = 8.0 kpc).

### Table 1. Log of Mopra observations. The rms noise of the zoom bands is given for the 9-point Hanning smoothed data with 0.13 MHz channels, whereas for the broad band data it is 2.15 MHz per channel.

| Date       | Time UT | Mode | Central Freq. | Broad band range and sub-band centres | rms T_{MB} |
|------------|---------|------|---------------|---------------------------------------|------------|
| 2006 Jun   | h m     |      | GHz           | GHz                                   | K          |
| 27         | 13 05   | broad| 85.70         | 81.70 − 89.70 and 82.662, 84.734, 86.664, 88.736 | 0.12, 0.16, 0.11, 0.09 |
| 27         | 15 20   | broad| 94.13         | 90.13 − 98.13 and 91.093, 93.165, 95.095, 97.167 | 0.14, 0.16, 0.13, 0.17 |
| 27         | 16 26   | broad| 102.78        | 98.78 − 106.78 and 99.742, 101.814, 103.744, 105.816 | 0.21, 0.33, 0.23, 0.18 |
| 28         | 00 19   | broad| 109.48        | 105.48 − 113.48 and 106.452, 108.524, 110.454, 112.526 | 0.15, 0.17, 0.24, 0.35 |
| 27         | 11 51   | zoom | 85.70         | 85.146, 85.560, 86.112, 86.802, 87.354, 87.906, 88.596, 89.148 | 0.22 − 0.29 |
| 29         | 12 09   | zoom | 94.13         | 90.678, 90.954, 91.920, 93.162, 94.404, 96.750, 97.302, 97.992 | 0.26 − 0.38 |
| 27         | 17 50   | zoom | 102.78        | 99.328, 100.018, 100.570, 101.536, 102.088, 102.502, 103.054, 104.572 | 0.32 − 0.42 |

³ http://www.atnf.csiro.au/computing/software/rpfits.html
Table 2. Summary of strong lines detected from the broad band mode observations. The flag Z in the last column indicates lines for which there is zoom mode data with higher velocity resolution. For most of these lines we show integrated images in Figs. 1 to 3.

| Rough Freq. | line ID   | molecule | transition | Exact Rest Freq. GHz |
|-------------|-----------|----------|------------|---------------------|
| 81.88 GHz   | HC$_3$N   | 9 – 8    | 81.881462  |
| 84.52 GHz   | CH$_3$OH  | 5(-1.5) – 4(0.4) E | 84.521206 |
| 85.14 GHz   | OCS       | 7 – 6    | 85.139104 Z |
| 85.27 GHz   | CH$_3$CH$_2$OH | 6(0.6) – 5(1.5) | 85.265507 |
| 85.34 GHz   | c-C$_2$H$_2$ | 2(1,2) – 1(0,1) | 85.338906 |
| 85.46 GHz   | CH$_3$CCH | 5(3) – 4(3) | 85.442600 |
| 86.34 H$_{13}$CN | 1 – 0 F = 1-1 | 86.338735 |
| 86.75 H$_{13}$CO$^+$ | 0 | 86.754330 |
| 86.85 SO    | 2 – 1 v = 0 | 86.847010 Z |
| 87.09 NH$_{13}$C | 1 – 0 F = 0-1 | 87.090735 |
| 87.32 C$_2$H | 1 – 0 3/2-1/2 F = 2-1 | 87.316925 Z |
| 87.40 C$_2$H | 1 – 0 1/2-1/2 F = 1-1 | 87.402004 Z |
| 87.93 HNCO | 4(0,4) – 3(0,3) | 87.925338 |
| 88.63 HCN   | 1 – 0 F = 1-1 | 88.6304157 |
| 89.19 HCO$^+$ | 0 | 89.188526 Z |
| 90.66 HNC   | 1 – 0 F = 0-1 | 90.6634530 |
| 90.98 CH$_3$N | 10 – 9 | 90.978899 Z |
| 91.99 CH$_3$CN | 5(3) – 4(3) F = 6-5 | 91.971310 Z |
| 92.49 $^{13}$CS | 2 – 1 | 92.494303 |
| 93.17 N$_2$H$^+$ | 1 – 0 F$_1$ = 1-1 F = 0-1 | 93.171621 Z |
| 94.41 $^{13}$CH$_3$OH | 2(-1,2) – 1(-1,1) E | 94.405223 Z |
| 95.17 CH$_3$OH | 8(0.8) – 7(1.7) A+ | 95.169516 |
| 95.91 CH$_3$OH | 2(1,2) – 1(1,1) A+ | 95.914310 |
| 96.41 C$_3$S$^{4}$S | 2 – 1 | 96.412961 |
| 97.30 OCS    | 8 – 7    | 97.301290 Z |
| 97.58 CH$_3$OH | 2(1,1) – 1(1,0) A- | 97.582808 |
| 97.98 CS     | 2 – 1    | 97.980653 Z |
| 100.08 H$_2$NCN | 11 – 10 | 100.076385 Z |
| 100.63 NH$_2$CN | 5(1,4) – 4(1,3) | 100.629500 |
| 101.48 H$_2$CS | 3(1,3) – 2(1,2) | 101.477764 |
| 102.07 NH$_2$CHO | 5(1,5) – 4(1,4) | 102.064263 Z |
| 102.55 CH$_3$CCH | 6(3) – 5(3) | 102.530346 Z |
| 103.04 H$_2$CS | 3(0,3) – 2(0,2) | 103.040416 Z |
| 103.40 SO    | 3(1,3) – 2(0,2) | 103.409410 |
| 103.62 H$_2$CS | 3(1,2) – 2(1,1) | 103.616988 Z |
| 105.79 NH$_2$CN | 4(0,4) – 3(1,3) | 105.794057 |
| 106.91 HOCO$^+$ | 5(0,5) – 4(0,4) | 106.913524 |
| 108.89 CH$_3$OH | 0(0,0) – 1(1,1) E | 108.893292 |
| 109.17 H$_2$CN | 12 – 11 | 109.173638 |
| 109.25 SO    | 2(3) – 2(2) | 109.252212 |
| 109.46 OCS   | 9 – 8    | 109.463064 |
| 109.78 C$^{18}$O | 1 – 0 | 109.782173 |
| 110.91 HNCO  | 5(0,5) – 4(0,4) | 110.905753 |
| 112.36 C$^{17}$O | 1 – 0 | 112.358988 |
| 113.17 CN    | 1 – 0 1/2-1/2 F = 1/2-3/2 | 113.144192 |
| 113.49 CN    | 1 – 0 1/2-1/2 F = 3/2-1/2 | 113.191371 |
| 113.508944 |

of Hunt et al. (1999) obtained with the Australia Telescope Compact Array (ATCA), supplemented by a few positions of peaks from 20-cm Very Large Array (VLA) data for sources outside the area of Hunt et al. (1999). Note in particular that the peak near the centre is Sgr B2(N) at J2000 17 47 20.4 – 28 22 12, with Sgr B2(M) at 17 47 20.5 – 28 23 05 and Sgr B2(S) at 17 47 20.5 – 28 23 44 in a line almost exactly to the south (labelled in Fig. 1). We also plot with open squares, some mid-infrared sources with positions fitted from the 21 μm (band E) Midcourse Space Experiment (MSX) data (Price et al. 2003). Note that the four mid-IR...
Table 3, continued. Summary of weaker lines detected from the broad band mode observations. We do not show the integrated images for these lines here. The flags in the last column indicate the spatial distribution of the line: N = peak at Sgr B2(N); M = peak at Sgr B2(M); B = peaks at both Sgr B2(N) and Sgr B2(M); E = extended. Lines marked as ‘unidentified’ in column 2, have been noted in previous surveys and included in the NIST database [Lovas 2002] with the rest frequency in column 4. Lines marked as ‘U’ in column 2 are not in the NIST database. These rest frequencies are quoted to the nearest MHz assuming radial velocity around 61 km s⁻¹ appropriate for Sgr B2(N) and Sgr B2(M), Section 4.

| Rough Freq. | line ID molecule | transition | Exact Rest Freq. GHz |
|-------------|------------------|------------|---------------------|
| 82.46 CH₃OCH₃ | 11(1,10)–11(0,11) | 100.32 HC 3 101.03 CH 2 101.98 CH 2 103.57 CH 2 104.24 SO 2 104.41 CH 2CNCH 2 105.06 CH 3OH 105.37 CH 2CNCH 2 105.76 CH 2CNCH 2 106.03 CH 3OH 106.04 unidentified | 82.456986 N |
peaks all correspond to radio sources, including Sgr B2(M) and Sgr B2(S) but that Sgr B2(N) does not have strong emission at 21 μm. See Section 4 for plots of the radio and mid IR continuum, and discussion of the alignment of the different molecular lines with the radio and mid-IR continuum features.

In the figure captions we give peak integrated brightness and contour level steps, in K km s⁻¹, on the Tₐ scale, that is not corrected for beam efficiency. The contours are in equal linear steps. In most cases the lowest contour level is the same as the step size, but this is not the case for some of the strongest lines (such as ¹³CO) where the whole 5 arcmin square area is filled with emission well above the zero level.

In this section we present maps for many of the lines measured. We summarise these line maps in Table 2 whereas in Table 3 we list all the other (weaker) lines detected, for which we do not present maps. We also discuss the velocities and line widths at the emission peaks for the various maps presented. These are summarised in Table 4. We use the rough frequency in GHz, rounded to two decimal places, in the figures, Tables 2 and 3 and text below, as a convenient shorthand to refer to the lines.

### 3.1 ¹³CO, C¹⁸O and C¹⁷O

The isotopic carbon monoxide ¹³CO 1–0 (110.20 GHz) and C¹⁸O 1–0 (109.78 GHz) integrated emission is shown in Fig. 1. The ¹³CO emission is optically thick in the densest regions, with the ratio of the peak integrated emission of ¹³CO/C¹⁸O of around 5, rather than ~ 0 for optically thin emission near the Galactic Centre (Lis & Goldsmith 1989). The dense peaks are therefore better traced by C¹⁸O, which shows two peaks associated with Sgr B2(M) and Sgr B2(N), with fitted positions (J2000) 17 47 20.3, -28 23 06 and 17 47 20.3, -28 23 06.
47 19.5, -28 22 15, LSR velocities 63 and 68 km s$^{-1}$ and full width at half maximum 21 and 22 km s$^{-1}$ respectively.

The $^{13}$CO data cube, with intensity as a function of velocity (Fig. 2), agrees well with the results of Sato et al. (2000) and Hasegawa et al. (2007), showing the low velocity ‘hole’ at 40–50 km s$^{-1}$ and the high velocity ‘clump’ at 70–80 km s$^{-1}$. However, the broad band data here are with poorer velocity and spatial resolution than that of Sato et al. (2000) or Hasegawa et al. (2007), so we do not resolve details in the spatial and velocity structure that they attribute to their cloud-cloud collision model (Hasegawa et al. 1994).

The integrated $^{13}$CO and C$^{18}$O images (Fig. 1) also show the northern emission ridge or ‘Edge’ (Hasegawa et al. 1994) with peak at 17 47 24.2, -28 20 49 (in $^{13}$CO with central velocity 65 km s$^{-1}$ (width 42 km s$^{-1}$) from $^{13}$CO and 63 km s$^{-1}$ (width 36 km s$^{-1}$) from C$^{18}$O. There is also the higher-velocity ridge to the west in $^{13}$CO (Fig. 2) with peak at 17 47 14.0 -28 22 14, velocity 109 km s$^{-1}$ (width 32 km s$^{-1}$).

We have also imaged the weaker C$^{17}$O 1 – 0 (112.36 GHz) data, which shows the densest CO peak near Sgr B2(M) at around 64 km s$^{-1}$. However, the C$^{17}$O data are affected by the bandpass ripples, so we do not show the integrated image here, or consider further quantitative analysis (such as line ratios).

### 3.2 CS, $^{13}$CS and C$^{18}$S

The carbon monosulphide CS 2 – 1 (97.98 GHz) integrated emission is shown in Fig. 3. The CS data cube (not shown here) shows that the main peak near Sgr B2(M) has a minimum around velocity 62 km s$^{-1}$, due to self-absorption at the position and velocity where the brightest CO is found. The CS also traces the low velocity ‘hole’ at a velocity range. Fitting spectra at the east edge of the imaged area, away from the strong absorption in the centre, we find a peak velocity of 70 km s$^{-1}$, width 71 km s$^{-1}$ for HCO$^+$, velocity 69 km s$^{-1}$, width 77 km s$^{-1}$ for HCN and velocity 55 km s$^{-1}$, width 67 km s$^{-1}$ for HNC. This component is enhanced in the area of the north ridge in HCN, with peak position 17 47 22.0, -28 20 55, and single component fit velocity 59 km s$^{-1}$, width 54 km s$^{-1}$ (but there is some self-absorption at this position, making the single component gaussian not a very good fit). The west ridge adds to this wide component, in the integrated images (Fig. 3), but is not well separated in velocity. Multi-component fits to the spectra show that it peaks at 17 47 14.8 -28 22 36 in HCO$^+$ (we cannot get a good fit to this component in velocity), peak 17 47 14.7 -28 22 34, velocity 119 km s$^{-1}$, width 24 km s$^{-1}$ in HCN and peak 17 47 14.9 -28 22 34, velocity 112 km s$^{-1}$, width 21 km s$^{-1}$ in HNC.

The HCO$^+$, HCN and HNC data cubes show a peak near Sgr B2(M), much like that in CS, with self-absorption around 65 km s$^{-1}$. The spectra from this area show two components around 46 km s$^{-1}$ and 90 km s$^{-1}$, which are interpreted as a single component with an absorption dip. There is also absorption of the Sgr B2 continuum emission, by gas along the line of sight, giving a broad negative feature to the spectra between velocities -120 and 20 km s$^{-1}$.

Quantitative analysis of the peak near Sgr B2(M) is affected by the absorption.

The fitted peak positions (at around 90 km s$^{-1}$) are 17 47 20.1, -28 22 34 in HCO$^+$, 17 47 20.1, -28 22 32 in HCN and 17 47 19.8, -28 22 56 in HNC. This is near the CS peak and the C$^{18}$O peak, but as for CS, there may be a gradient of position with velocity. We also have data (not plotted here) of the corresponding weaker isotope line H$^{13}$CO$^+$ 1 – 0 (86.75 GHz), H$^{13}$CN 1 – 0 (86.34 GHz) and HN$^{13}$C 1 – 0 (87.09 GHz) which also show some self-absorption, but are less affected, and hence better for the velocity fits. The velocities are peak 50 km s$^{-1}$, width 8 km s$^{-1}$ for H$^{13}$CO$^+$, peak 47 km s$^{-1}$, width 12 km s$^{-1}$ for H$^{13}$CN and peak 52 km s$^{-1}$, width 16 km s$^{-1}$ for HN$^{13}$C. The HN$^{13}$C fit is in good agreement with the fit to the CS peak but the other two are a bit lower in velocity and narrower, presumably due to the effect of the absorption.

Note that the HCN, HNC, H$^{13}$CN and HN$^{13}$C lines are triplets with hyperfine splitting, but that the spread of frequency for HNC and HN$^{13}$C is only 0.21 MHz, so this will have negligible effect on the fitted velocity widths. For HCN and H$^{13}$CN however, the frequency range is 3.5 MHz, corresponding to velocity range 12 km s$^{-1}$, so that the blending
of the hyperfine components would contribute to increasing the fitted velocity width.

3.4 SiO

The integrated silicon monoxide SiO 2 – 1 (86.85 GHz) emission is also shown in Fig. 3.

The SiO data cube and integrated image shows similar features to the CS 2 – 1 data, but the SiO line is weaker and, thus, has lower lower signal to noise ratio. The integrated emission peak near Sgr B2(M) shows absorption at around 65 km s⁻¹. The emission peak is at 17 47 18.9, -28 22 49, velocity 50 km s⁻¹, width 11 km s⁻¹, but this is affected by the absorption with a second velocity component to the fit at 87 km s⁻¹, width 31 km s⁻¹, on the redshifted side of the absorption. There are also the north ridge, peak 17 47 22.5, -28 21 06, velocity 58 km s⁻¹, width 41 km s⁻¹, and the southeast ‘CS peak’ at 17 47 27.1, -28 23 12, velocity 45 km s⁻¹, width 29 km s⁻¹. These three peaks in integrated SiO, and the absorption near Sgr B2(M) and Sgr B2(N) are also seen in the integrated SiO image of Martin-Pintado et al. (1997).

Higher resolution BIMA data of the peak near Sgr B2(M) are interpreted by Liu et al. (1998) as an outflow (like the CS data.)

3.5 CN

Emission from the cyanide radical is observed in two groups of blended hyperfine components at CN 1 – 0 J=1/2–1/2 (113.17 GHz) and 1 – 0 J=3/2–1/2 (113.49 GHz), each of which consists of several components. The distribution of the integrated emission from the two sets of lines is very similar, so the sum of the two sets is plotted here, in Fig. 3. The most striking feature of the data is the strong absorption associated with Sgr B2(M) and Sgr B2(N) giving a deficit in the integrated emission in Fig. 3. This absorption is due to spiral clouds along the line of sight against the strong continuum of the Sgr B2(M) and Sgr B2(N) cores, rather than absorption in the Sgr B2 complex itself.

Because of the multiple components, the data cubes are rather complicated with overlapping velocity and frequency structure. The J=3/2–1/2 (113.49 GHz) data cube shows the peak near Sgr B2(M) with position 17 47 20.1, -28 22 50, velocity 94 km s⁻¹ (from the strongest component), width 19 km s⁻¹. There is also absorption over a wide velocity range down to -100 km s⁻¹, at the continuum peaks. We therefore interpret the velocity of the peak fit as being biased high due to the absorption. This is confirmed by the optically thin 13CN lines having velocity around 52 km s⁻¹ (Gerin et al. 1984). There is widespread CN emission over the whole area, with velocity 52 km s⁻¹, fitted at the north ridge position, with broad lines (but the fitted velocity width of 113 km s⁻¹ includes the confusion of the multiple components). The CN emission is widespread compared to the distribution of other molecules studied here. The J=1/2–1/2 (113.17 GHz) data cube shows deep absorption features at Sgr B2(M) and Sgr B2(N) but is too complicated to do much more interpretation, with the multiple components blended.

We also detect (Table 3) the weak lines of the 13CN isotopologue J=1/2–1/2 (108.65 GHz) and J=3/2–1/2 (108.78 GHz) in extended emission and absorption at Sgr B2(N) and Sgr B2(M).

3.6 HC₃N

The integrated emission from cyanoacetylene HC₃N 9 – 8 (81.88 GHz), 10 – 9 (90.98 GHz), 11 – 10 (100.08 GHz) and 12 – 11 (109.17 GHz) is shown in Fig. 3. All four transitions show similar structure, which is a ridge of emission to the west of radio continuum peaks Sgr B2(N), Sgr B2(M) and Sgr B2(S), looping to the east, north of Sgr B2(N).

This is similar to the single-dish results of Lis & Goldsmith (1991) for the 12 – 11 transition, Chung, Ohishi & Morimoto (1994) for the 10 – 9 and 12 – 11 transitions, and de Vicente, Martin-Pintado & Wilson (1997) for the 11 – 10 transition. Higher resolution interferometer images of the HC₃CCN 9 – 8 transition at 81.53 GHz are given by Kuan & Snyder (1996) and multiple transitions are given by de Vicente et al. (2000). The high resolution interferometer observations of the HC₃N 1 – 0 transition at 9.10 GHz by Hunt et al. (1996) show weak...
Figure 2. Velocity channel images of $^{13}$CO, separated by the channel spacing of 6 km s$^{-1}$. Note the west ridge peaking at 117 km s$^{-1}$, the north ridge at 64 km s$^{-1}$, and how the hole at 40 – 50 km s$^{-1}$ matches the clump at 70 – 80 km s$^{-1}$. The contours are steps of 0.5 K, and the peak is 5.45 K. The crosses and squares are the same as for Figure 1.
maser emission, and so preferential emission at the radio continuum peaks. While interesting in its own right, this does not trace the molecular distribution well.

The data cubes show that the emission has several peaks with different velocities, which are merged together in the integrated emission images. We fit four peaks, from north to south, with a systematic velocity gradient: (a) the north cloud at 17 47 21.4, -28 21 29, north of Sgr B2(N), velocity 68 km s$^{-1}$, width 23 km s$^{-1}$; (b) peak at 17 47 18.7, -28 22 12, near Sgr B2(N), velocity 67 km s$^{-1}$, width 23 km s$^{-1}$; (c) peak at 17 47 18.6, -28 23 04, near Sgr B2(M), velocity 60 km s$^{-1}$, width 22 km s$^{-1}$; and (d) peak at 17 47 19.9, -28 23 55, near Sgr B2(S), velocity 58 km s$^{-1}$, width 20 km s$^{-1}$.

In addition to these four peaks we fit the north ridge at peak 17 47 21.0, -28 20 54, velocity 62 km s$^{-1}$, width 27 km s$^{-1}$, and the south-east peak at 17 47 26.3, -28 23 04, velocity 55 km s$^{-1}$, width 23 km s$^{-1}$.

We can calculate column densities of molecules in the upper level $N_u$ from the intensities of the transitions, using the simple assumption that lines are optically thin and in local thermodynamic equilibrium (LTE) by

$$N_u = \frac{(8\pi\nu^2k/hc^3A_{ul})}{\int T_Bdv}$$

where $A_{ul}$ is the Einstein coefficient, and $\int T_Bdv$ is the integral over velocity of the brightness temperature $T_B$ of the emission line. Using the multiple HC$_3$N transitions we can, in principle, plot an excitation diagram of column density in that level (expressed as $E_u/k$) versus the energy of the level (expressed as $E_u/k$), to determine the total column density $N$ and excitation temperature $T_{ex}$, using the equation

$$N_u/g_u = (N/Q_T) \exp(-E_u/kT_{ex})$$

where $Q_T$ is the partition function at excitation temperature $T_{ex}$, and $g_u$ is the statistical weight of the upper level. In practice, for the lines here in the 3-mm band, we do not have enough range in the energy levels for this to be very reliable ($E_u/k = 20$ to 34 K for these lines). However, we can determine that there are spatial variations in the excitation temperature, between the peaks, with the cloud north of Sgr B2(N) giving $T_{ex} = 28$ K (20 – 46 K in the 1$\sigma$ range) and the others hotter with limits $> 43$ K, $> 76$ K and $> 41$ K (at the 1$\sigma$ level) for the peaks near Sgr B2(N), Sgr B2(M) and Sgr B2(S) respectively. This is confirmed by considering the spatial variation in ratios of the different transitions, and is consistent with the results of Chung, Ohishi & Morimoto (1994) and the higher kinetic temperature in these hot dense cores (de Vicente, Martin-Pintado & Wilson 1997). This analysis is complicated towards Sgr B2(N), as the IRAM 30-m survey of Belloche et al. (2003, 2007) shows that the HC$_3$N is somewhat optically thick there.

We also detect (Table 3) seven vibrationally excited lines of HC$_3$N at 91.20, 91.33, 100.32, 100.71, 109.44, 109.60 and 109.87 GHz, concentrated at Sgr B2(N), as the higher upper energy transitions are excited in this hot region. We detect weak lines of the isotopologues H$^{13}$CCCN, HC$^{13}$CCN...
and HCC$^{13}$CN at 88.17, 90.60, 99.65 and 108.71 GHz, many of which appear to peak at Sgr B2(N), but as the lines are weak the spatial distribution is not clear.

### 3.7 CH$_3$CN

The integrated emission from methyl cyanide CH$_3$CN 5 – 4 (91.99 GHz) and 6 – 5 (110.38 GHz) is shown in Fig. 3. There are multiple components for each of these transitions. The integrated emission for the two sets of lines is similar, and similar to that of the four HCC$^{13}$N lines. It is also similar to the single-dish results of de Vicente, Martin-Pintado & Wilson (1997) for the 5 – 4 transition. We fit five components similar to that in HCC$^{13}$N above: (a) the north cloud at 17 47 21.3, -28 21 28, velocity 68 km s$^{-1}$, width 33 km s$^{-1}$; (b) peak near Sgr B2(N) at 17 47 19.1, -28 22 12, velocity 66 km s$^{-1}$, width 30 km s$^{-1}$; (c) peak near Sgr B2(M) at 17 47 18.8, -28 23 11, velocity 61 km s$^{-1}$, width 33 km s$^{-1}$; (d) peak near Sgr B2(S) at 17 47 19.9, -28 23 54, velocity 59 km s$^{-1}$, width 32 km s$^{-1}$; and (e) the north ridge at 17 47 23.5, -28 21 01, velocity 64 km s$^{-1}$, width 41 km s$^{-1}$. The ratio of integrated emission of the two lines indicates that the peaks near Sgr B2(N) and Sgr B2(M) have higher excitation temperature than the surrounding area, but the overlapping components and low signal to noise make more quantitative analysis difficult.

We also detect weak emission (Table 3) from several more transitions of CH$_3$CN at 92.26, 110.33, 110.35, 110.69 and 110.71 GHz, and the isotopologues $^{13}$CH$_3$CN at 107.19 GHz and possibly CH$_3^{15}$CN at 110.33 GHz (as a blend). These are concentrated at the position of Sgr B2(N).

### 3.8 CH$_3$OH and $^{13}$CH$_3$OH

In Fig. 5, we show the integrated emission of five transitions of methanol CH$_3$OH: 5(1,5) – 4(0,4) E (84.52 GHz), 8(0,8) – 7(1,7) A+ (95.17 GHz), 2(1,2) – 1(1,1) A+ (95.91 GHz), 2(0,2) – 1(0,1) A+ blend (96.74 GHz) and 2(1,1) – 1(0,0) A- (97.58 GHz). In addition, we show the integrated emission of the isotopologue $^{13}$CH$_3$OH 2(0,2) – 1(0,1) A+ blend (94.41 GHz), and we have data, not plotted here, for the CH$_3$OH 0(0,0) – 1(-1,1) E (108.89 GHz) transition. The distribution of integrated emission is quite different for the different transitions.

Methanol is a very useful tracer of physical conditions, described as ‘the Swiss army knife of star formation’ (Leurini et al. 2005), particularly when using simultaneous fits to multiple lines (Leurini et al. 2004). However, the excitation conditions of methanol can be very complicated, with collisional and radiative excitation. For example, both the 84.52 GHz and 95.17 GHz transitions here can be masers (Cragg et al. 1992). Also the A- and E-types can be considered separate species, which have different abundances. We do not attempt to model the different CH$_3$OH lines here, but restrict ourselves to describing their overall features.

The different lines mostly trace the same spatial and velocity structure, despite the different relative intensities of the features. These are: (a) the north cloud at 17 47 21.4, -28 21 20, velocity 68 km s$^{-1}$, width 25 km s$^{-1}$; (b) the peak near Sgr B2(N) at 17 47 18.8, -28 22 14, velocity 67 km s$^{-1}$, width 19 km s$^{-1}$; (c) the peak near Sgr B2(M) at 17 47 18.2, -28 23 11, velocity 61 km s$^{-1}$, width 22 km s$^{-1}$; and (d) the peak near Sgr B2(S) at 17 47 19.9, -28 23 57, velocity 59 km s$^{-1}$, width 20 km s$^{-1}$. The 96.74 GHz CH$_3$OH line and the 94.41 GHz $^{13}$CH$_3$OH line are blends of multiple transitions, so the velocity structure is confused. The 96.74 GHz line also shows absorption at Sgr B2(N) and Sgr B2(M). Because it is the strongest line, however, it shows features not seen in the other weaker lines: the south-east peak (seen in CS) at 17 47 26.7, -28 23 07, velocity 56 km s$^{-1}$, width 34 km s$^{-1}$; the western ridge at 17 47 15.0, -28 22 44, velocity 120 km s$^{-1}$, width 21 km s$^{-1}$; and a peak to the north-west of the main ridge-line at 17 47 14.5, -28 21 41, velocity 70 km s$^{-1}$ (and width unclear due to blending with other features).

There are thirteen more weak CH$_3$OH lines detected here (Table 3) concentrated at the position of Sgr B2(N), that are higher upper energy lines excited in the hot core.

### 3.9 CH$_3$CH$_2$OH

We have also detected and imaged the ethanol CH$_3$CH$_2$OH 6(0,6) – 5(1,5) (85.27 GHz) transition, but as the line is weak, and the data are affected by scanning stripes, the integrated emission is not shown here. The emission is centred on the north cloud, and the line fit gives velocity 68 km s$^{-1}$, width 21 km s$^{-1}$. We expect from Requena-Torres et al. (2003) that the ethanol CH$_3$CH$_2$OH column density follows that of methanol CH$_3$OH, but the distributions of line emission here differ due to excitation differences.

The CH$_3$CH$_2$OH 7(0,7) – 6(1,6) and 5(1,5) – 4(0,4) (104.49 and 104.80 GHz) transitions show weak extended emission (Table 3).

### 3.10 HNCO

The integrated emission from isocyanic acid HNCO 4(0,4) – 3(0,3) (87.93 GHz) and 5(0,5) – 4(0,4) (109.91 GHz) is shown in Fig. 6. The cloud 2 arcmin north of Sgr B2(M) is particularly prominent in HNCO, as pointed out by Wilson et al. (1996) from observations of the 21.98 GHz 1 – 0 line, and as discussed in Minh et al. (1998) including observations, as here, of the 4(0,4) – 3(0,3) and 5(0,5) – 4(0,4) lines. We find similar integrated emission in the 4(0,4) – 3(0,3) to Minh et al. (1998), and the velocity gradient in the data cubes, which they attribute to collapse. The 5(0,5) – 4(0,4) line at 109.91 GHz here also shows the ridge west of the Sgr B2(N), Sgr B2(M) and Sgr B2(S) radio and infrared continuum peaks, but the ridge is less clearly broken into clumps than in other molecules, such as HCC$^{13}$N. We fit the north cloud at peak 17 47 21.6, -28 21 20, velocity 65 km s$^{-1}$, width 25 km s$^{-1}$ and the peak near Sgr B2(M) at 17 47 18.2, -28 23 01, velocity 66 km s$^{-1}$, width 29 km s$^{-1}$. From the ratio of the two lines, the peak near Sgr B2(M) has a higher excitation temperature, but the difference in energy of the upper levels is too small ($E_u/k = 10.5$ to 15.8 K) to get reliable excitation temperatures from this comparison.

We detect four more weak lines of HNCO at 88.24, 109.49, 109.87 and 110.29 GHz (Table 3) concentrated at Sgr B2(N) and Sgr B2(M), which are higher upper energy transitions excited in the hot core.

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3.11 HOCO$^+$

The integrated emission from protonated CO$_2$ HOCO$^+$ $4(0,4) - 3(0,3)$ (85.53 GHz) is shown in Fig. 6. The distribution is similar to that of HNCO, with the north cloud prominent, as also shown in Minh, Irvine & Ziurys (1988) and Minh et al. (1998). We also have data for the $5(0,5) - 4(0,4)$ (106.91 GHz) transition, but this is not shown here, as the image is qualitatively similar, but poorer quality, being affected by scanning stripes. There is a ridge west of Sgr B2(N), Sgr B2(M) and Sgr B2(S), similar to that for HNCO. We fit (a) the north cloud at peak 17 47 21.3, -28 21 29, velocity 67 km s$^{-1}$, width 23 km s$^{-1}$; (b) the peak near Sgr B2(N) at 17 47 18.4, -28 23 12, velocity 66 km s$^{-1}$, width 21 km s$^{-1}$; (c) the peak near Sgr B2(M) at 17 47 18.6, -28 23 08, velocity 62 km s$^{-1}$, width 21 km s$^{-1}$; and (d) the peak near Sgr B2(S) at 17 47 19.5, -28 23 53, velocity 58 km s$^{-1}$, width 19 km s$^{-1}$. Despite having three transitions, we cannot get reliable excitation temperatures due to the small range of upper energy levels ($E_u/k = 16.3$ to 26.3 K) and the low signal to noise, but we do note that the peaks near Sgr B2(N) and Sgr B2(M) have higher excitation temperatures than the north cloud.

We also detect (Table 3) the OCS $9 - 8$ line at 96.98 GHz, which has a similar extended distribution, with the strongest peak near Sgr B2(N), although the IRAM 30-m survey of Belloche et al. (2005, 2007) indicates this line is blended with several other lines at Sgr B2(N) and Sgr B2(M).

3.13 SO

The integrated emission from sulphur monoxide SO $2(2) - 1(1)$ (86.09 GHz), $3(2) - 2(1)$ (99.30 GHz) and $2(3) - 1(2)$ (109.25 GHz) is shown in Fig. 7. The distribution of the 86.09 GHz and 109.25 GHz transitions is similar, with compact peaks near Sgr B2(N) and Sgr B2(M), as shown by
Figure 5. Integrated emission for CH$_3$OH (84.52 GHz, contour step 10 K km s$^{-1}$, peak 93 K km s$^{-1}$; 95.17 GHz, step 4 K km s$^{-1}$, peak 23 K km s$^{-1}$; 95.91 GHz, step 5 K km s$^{-1}$, peak 30 K km s$^{-1}$; 96.74 GHz, step 10 K km s$^{-1}$, peak 131 K km s$^{-1}$; 97.58 GHz, step 5 K km s$^{-1}$, peak 30 K km s$^{-1}$; 98.41 GHz, step 2 K km s$^{-1}$, peak 16.4 K km s$^{-1}$). These lines show the arc from the north cloud, west of the radio and mid-IR continuum peaks, with differences in the relative intensities of the peaks related to the complicated excitation of the different levels.

Goldsmith et al. (1987) at higher resolution for the 109.25 GHz transition. The 99.30 GHz transition, however, shows quite a different distribution tracing the north cloud and ridge-line to the west, and with absorption in the data cube at Sgr B2(N) and Sgr B2(M). This is presumably because the 86.09 GHz and 109.25 GHz transitions trace the more excited gas ($E_u/k = 19.3$ and 21.0 K) than the 99.30 GHz transition ($E_u/k = 9.2$ K). We fit: (a) the north cloud (99.30 GHz) at peak 17 47 21.3, -28 21 20, velocity 66 km s$^{-1}$, width 25 km s$^{-1}$; (b) peak near Sgr B2(N) (86.09 and 109.25 GHz) at 17 47 19.3, -28 22 08, velocity 66 km s$^{-1}$, width 27 km s$^{-1}$; and (c) peak near Sgr B2(M) at 17 47 19.8, -28 22 56, velocity 61 km s$^{-1}$, width 20 km s$^{-1}$.

We also detect the SO $4(5) - 4(4)$ line at 100.03 GHz, concentrated at Sgr B2(M) and Sgr B2(N), and the isotopologue $^{34}$SO $3(1,3) - 2(0,2)$ at 97.72 and 106.74 GHz, at Sgr B2(M).

3.14 SO$_2$

The integrated emission from sulphur dioxide SO$_2$ $3(1,3) - 2(0,2)$ (104.03 GHz) is also shown in Fig. 7. The peak near Sgr B2(M) dominates, but there is also weak emission seen from the north cloud. The peak near Sgr B2(M) is at 17 47 20.4, -28 23 04, velocity 52 km s$^{-1}$, width 26 km s$^{-1}$, which is lower velocity than as seen in other lines. The north cloud has velocity 68 km s$^{-1}$, width 21 km s$^{-1}$, and near Sgr B2(N) velocity 61 km s$^{-1}$, width 29 km s$^{-1}$. The low level east-west extension is an artifact of the east-west scanning and baseline variations.

We detect eight more lines of SO$_2$ at 83.69, 91.55, 97.70, 100.88, 104.24, 107.06, 107.84 and 109.75 GHz (Table 3) concentrated at Sgr B2(N) and Sgr B2(M).

3.15 N$_2$H$^+$

The integrated emission from diazenylium N$_2$H$^+$ $1 - 0$ (93.17 GHz) is shown in Fig. 7. The data cube shows complicated structure, with deep absorption at Sgr B2(N) and Sgr B2(M) at around 66 km s$^{-1}$, and double-peaked spectra over most of the area (Fig. 8), which we attribute to widespread absorption at a similar velocity. There are multiple components to the $1 - 0$ line, which contributes to broadening the fitted line width, but the frequency range is too small to explain the double profiles. The major features are fitted as: (a) the north cloud at 17 47 21.4, -28 21 23, velocity 51 and 81 km s$^{-1}$; (b) peak to the west of Sgr B2(M) at 17 47 17.2, -28 22 06, velocity 47 and 79 km s$^{-1}$; (c) peak south of Sgr B2(S) at 17 47 20.1, -28 24 09, velocity 46 and 71 km s$^{-1}$; (d) west ridge at 17 47 15.1, -28 22 38, velocity 120 km s$^{-1}$, width 22 km s$^{-1}$; and (e) south-east peak at 17 47 27.2, -28 23 22, velocity 43 km s$^{-1}$, width 29 km s$^{-1}$.
Figure 6. Integrated emission for HNCO (contour step 10 K km s$^{-1}$; 87.93 GHz, peak 84 K km s$^{-1}$; 109.91 GHz, peak 113 K km s$^{-1}$), HOCO$^+$ (85.53 GHz, step 2 K km s$^{-1}$, peak 13.4 K km/s) and OCS (85.14 GHz, step 2 K km s$^{-1}$, peak 15.6 K km s$^{-1}$; 97.30 GHz, step 2 K km s$^{-1}$, peak 24 K km s$^{-1}$; 109.46 GHz, step 4 K km s$^{-1}$, peak 24 K km s$^{-1}$).

3.16 CH$_3$CCH

The integrated emission from propyne or methyl acetylene CH$_3$CCH 6 – 5 (102.55 GHz) is shown in Fig. 7. We also have data for the CH$_3$CCH 5 – 4 (85.46 GHz) transition, not shown here as it is qualitatively similar, but weaker and noisier. The distribution shows the north cloud, and ridge-line west of the radio continuum peaks. The fitted features are: (a) the north cloud at 17 47 21.5, -28 21 23, velocity 73 km s$^{-1}$, width 23 km s$^{-1}$; (b) peak near Sgr B2(N) and Sgr B2(M) at 17 47 18.9, -28 22 33, velocity 70 km s$^{-1}$, width 24 km s$^{-1}$; (c) peak near Sgr B2(M) and Sgr B2(S) at 17 47 19.5, -28 23 22, velocity 65 km s$^{-1}$, width 25 km s$^{-1}$; and (d) peak south of Sgr B2(S) with velocity 61 km s$^{-1}$, width 23 km s$^{-1}$. There are multiple blended line components, so the spectra are a fit to the line blend with the velocity calculated using the rest frequency of one of the components. The velocity therefore is offset, but the gradient is shown similar to that found in CH$_3$CCH by Churchwell & Hollis (1983) with lower resolution, but over a larger area.

3.17 NH$_2$CHO and H$_2$COH$^+$

The integrated emission from the line at 102.07 GHz is shown in Fig. 7. We identify this as a blend of formamide NH$_2$CHO 5(1,5) – 4(1,4) and protonated formaldehyde H$_2$COH$^+$ 4(0,4) – 3(1,3), as noted by Ohishi et al. (1996). We identify four peaks, as for other lines like CH$_3$CCH 6 – 5 (102.55 GHz) above, but because the line is weak, we do not get good positional fits for all of them. The features are: (a) the north cloud with velocity 65 km s$^{-1}$, width 24 km s$^{-1}$; (b) peak near Sgr B2(N) and Sgr B2(M) at 17 47 20.1, -28 22 27, velocity 64 km s$^{-1}$, width 13 km s$^{-1}$; (c) peak near Sgr B2(M) and Sgr B2(S) at 17 47 20.4, -28 24 04, velocity 61 km s$^{-1}$, width 23 km s$^{-1}$. There are multiple blended line components, so the spectra are a fit to the line blend with the velocity calculated using the rest frequency of one of the components. The velocity therefore is offset, but the gradient is shown similar to that found in CH$_3$CCH by Churchwell & Hollis (1983) with lower resolution, but over a larger area.

3.18 NH$_2$CN

The integrated emission from cyanamide NH$_2$CN 5(1,4) – 4(1,3) (100.63 GHz) is shown in Fig. 8. The line is rather weak, and the data affected by scanning ripples, so we do not fit the positions, but we do see the four peaks in the data cube and fit velocities: (a) the north cloud with velocity 59 km s$^{-1}$, width 27 km s$^{-1}$; (b) peak near Sgr B2(N) and Sgr B2(M) with velocity 60 km s$^{-1}$, width 35 km s$^{-1}$; (c) peak near Sgr B2(M) and Sgr B2(S) with velocity 55 km s$^{-1}$, width 35 km s$^{-1}$.
Figure 7. Integrated emission for SO (86.09 GHz, contour step 2 K km s\(^{-1}\), peak 11.1 K km s\(^{-1}\); 99.30 GHz, step 4 K km s\(^{-1}\), peak 25 K km s\(^{-1}\); 109.25 GHz, step 5 K km s\(^{-1}\), peak 36 K km s\(^{-1}\), SO\(_2\) (step 5 K km s\(^{-1}\), peak 35 K km s\(^{-1}\)), N\(_2\)H\(^+\) (step 5 K km s\(^{-1}\), peak 52 K km s\(^{-1}\)) and CH\(_3\)CCH (step 5 K km s\(^{-1}\), peak 35 K km s\(^{-1}\)).

Figure 8. Spectra of N\(_2\)H\(^+\) and HC\(_3\)N near Sgr B2(M) illustrating how some spectral lines show absorption at around 60 km s\(^{-1}\), from gas seen in emission at this velocity in other lines. There are multiple components to the N\(_2\)H\(^+\) line, which contributes to broadening the line, but the frequency range is too small to explain the double profile.

width 26 km s\(^{-1}\); and (d) peak south of Sgr B2(S) with velocity 55 km s\(^{-1}\), width 17 km s\(^{-1}\).

3.19 CH\(_2\)NH

The integrated emission from methylenimine CH\(_2\)NH 4(0,4) – 3(1,3) (105.79 GHz) is shown in Fig. 9. The peak close to Sgr B2(N) is strong, and we detect the north cloud and the ridge line, with fits: (a) the north cloud with velocity 66 km s\(^{-1}\), width 19 km s\(^{-1}\); (b) peak near Sgr B2(N) at 17 47 20.0, -28 22 21, velocity 61 km s\(^{-1}\), width 27 km s\(^{-1}\); and (c) peak near Sgr B2(M) and Sgr B2(S) with velocity 59 km s\(^{-1}\), width 18 km s\(^{-1}\). This line is probably blended with HC\(^{13}\)CCN 12 – 11 at rest frequency 105.799093 GHz.

3.20 H\(_2\)CS

The integrated emission from thioformaldehyde H\(_2\)CS 3(0,3) – 2(0,2) (103.04 GHz) is shown in Fig. 9. We also have data (not plotted here as the images are similar, but noisy) for H\(_2\)CS 3(1,3) – 2(1,2) (101.48 GHz) and 3(1,2) – 2(1,1) (104.62 GHz). We fit four peaks as: (a) the north cloud at
17 47 21.4, -28 21 25, velocity 68 km s$^{-1}$, width 21 km s$^{-1}$; (b) peak near Sgr B2(N) at 17 47 19.1, -28 22 23, velocity 67 km s$^{-1}$, width 20 km s$^{-1}$; (c) peak near Sgr B2(M) and Sgr B2(S) at 17 47 19.2, -28 23 21, velocity 59 km s$^{-1}$, width 19 km s$^{-1}$; and (d) peak south of Sgr B2(S) at 17 47 20.2, -28 24 05, velocity 57 km s$^{-1}$, width 17 km s$^{-1}$.

3.21 $\text{C}_2\text{H}$

The integrated emission from ethynyl $\text{C}_2\text{H}$ 1 – 0 J=1/2–1/2 (87.32 GHz) and 1 – 0 J=3/2–1/2 (87.40 GHz), is shown in Fig. 9. As for CN, above, each set consists of components and the integrated emission of two sets of lines are very similar, but weak, so the sum of the two sets is plotted here. The integrated emission image in Fig. 9 shows widespread emission peaked at the north ridge and west of Sgr B2(M), and a deficit of emission at the continuum peaks Sgr B2(N) and Sgr B2(M). The fitting of velocity components in the data cubes is complicated by the blended components, and the weakness of the emission, but the emission is peaked around 60 – 65 km s$^{-1}$. The deficit of integrated emission near Sgr B2(N) and Sgr B2(M) could be explained by a real deficit of the molecule in this area, but is more likely simply be due to absorption, as Greaves & Nyman (1996) show absorption features due to intervening clouds along the line of sight to Sgr B2. The offset between the absorption and the radio continuum peaks is not considered significant, but rather due to the baseline stripes in the east-west scanning direction causing north-south shifts in centres of the weak features.

3.22 c-C$_3$H$_2$

The integrated emission from the cyclic molecule cyclopropenylidene c-C$_3$H$_2$ 2(1,2) – 1(0,1) (85.34 GHz) is shown in Fig. 9. This shows similar features to C$_2$H, that is widespread emission with a deficit at continuum peaks Sgr B2(N) and Sgr B2(M). The emission is weak, however, so the integrated emission does show some spurious stripping due to the RA scanning. Vrtilek, Gottlieb & Thaddeus (1987) find rotation temperature $T_{\text{rot}} = 11 \pm 2$ K for c-C$_3$H$_2$ in Sgr B2, so absorption against the continuum is quite plausible. As for C$_2$H, above, the position offset between the absorption and continuum peaks is not considered significant.

3.23 Other molecules

We list in Table 3 nine more molecules, and dozens more lines, than we have plotted and discussed above, as well as weaker transitions of the molecules already discussed. Most of these lines are confined to Sgr B2(N) or Sgr B2(M). Some of the weaker transitions are higher energy states, some vibrationally excited, of molecules already discussed, which trace these hot cores.

Since the main aim of this paper is the wider scale spatial distribution, we do not concentrate here on quantitative
analysis of the weaker lines. Our Mopra OTF mapping sacrifices sensitivity on a single position to get the spatial coverage. Therefore our data on the spectra at the Sgr B2(N) and Sgr B2(M) positions are not particularly sensitive compared to previous (Turner 1989) and current (Belloche et al. 2005; Hiere et al. 2002; Belloche et al. 2007) dedicated spectral line surveys of these well studied sources. However, by mapping it is useful to determine whether a particular line is confined to Sgr B2(N), Sgr B2(M), or both, or whether it is distributed more widely. Of the weaker lines (Table 3) a substantial fraction are identified with blends of different species, complicating the analysis.

Four molecules in Table 3 have extended spatial distribution: acetaldehyde CH$_3$CHO (93.60, 95.95, 95.96 and 98.90 GHz), dicarbon monosulphide CCS (93.87 and 106.35 GHz), methanethiol CH$_2$SH (101.03 and 101.14 GHz) and ketene CH$_2$CHO (101.03 GHz). These distributions appear similar to that of some other molecules, such as HC$_3$N, with the north cloud and ridge line to the west of the radio continuum peaks, but with much lower signal to noise.

The other five molecules are confined to Sgr B2(N), as this region is known to be particularly rich in large molecules (Snyder, Kuan & Miao 1994; Miao et al. 1995). These molecules are: ethyl cyanide or propionitrile CH$_3$C$_2$H$_2$CN (22 lines), acrylonitrile CH$_2$CHCN (92.43, 94.28, 94.91, 95.33, 103.57, 104.21 and 106.64 GHz), methyl formate CH$_3$OCHO (89.32, 98.18 and 107.54 GHz), dimethyl ether CH$_2$OCH$_3$ (82.46, 100.46 and 105.77 GHz) and formaldehyde H$_2$CO (101.33 GHz).

More sensitive observations of Sgr B2(N) and Sgr B2(M) with the IRAM 30-m (Belloche et al. 2003; 2005) have been modelled with the XCLASS software (Comito et al. 2003), which simultaneously fits multiple lines with the LTE approximation and handles line blends well. We note here that for Sgr B2(N), in particular, this allows us to identify some extra lines that may confuse the Mopra images. These lines are: CH$_2$CHCN 10(1,10) − 9(1,9) at 86.819848 GHz for SiO; CH$_3$CHCN multiplet around 85.5329236 GHz for HOCO$^+; \text{HC}_3\text{N} 12 - 11 \nu_3 = 1l = 1f$ at 109.244339 GHz for SO; CH$_2$CHCN 9(1,8) − 8(1,7) at 87.31287 GHz for C$_2$H. However, the effect of this line confusion does not appear to be significant.

4 DISCUSSION

We now consider the comparison of spatial and velocity structure in the Sgr B2 complex, as traced by the different 3-mm lines. Figure 10 shows the positions of the molecular peaks listed in Section 3 and Table 4 lists these fitted peaks.

The strongest lines, such as $^{13}$CO, C$^{18}$O, CS, HCN, HCO$^+$, HNC, SiO, N$_2$H$^+$ and CH$_3$OH (96.74 GHz) show up three features, which we have called here the north ridge, the west ridge and the south-east peak (Tables 3 and 6). These features are detected in the strongest transitions, which are also the lines which are optically thick in the denser regions of the complex (near Sgr B2(N) and (M)), so the relative prominence of these three features (Figure 2) is partly due to this optical depth effect. However, they do trace the weaker surrounding structure of the complex. We have not imaged a large enough area to show the ‘hole’ around 40 km s$^{-1}$.

We note that the south-east peak is much more obvious in the CS, than in say $^{13}$CO or C$^{18}$O, as noted by Yusef-Zadeh et al. (1994), indicating that there is a chemical difference from the main sources.

The west ridge and south-east peak are offset both spatially and in velocity (at around 117 and 48 km s$^{-1}$ respectively) from the main north-south axis of the Sgr B2 complex. The other features (Table 5), that we have called the north ridge, the north cloud, and the three groups of peaks near Sgr B2(N), Sgr B2(M) and Sgr B2(S) are in a north-south line, with a velocity gradient, as shown on the right of Figure 10 and in Table 5.

The north ridge is (as noted) seen only in the strongest lines, while the other four features are best traced by weaker, optically thin lines. We find a spatial and velocity difference between the north ridge and, nearby chemically enriched (Minh et al. 1998) north cloud. The north ridge is elongated east-west, so there is a scatter of the peak positions along this axis, but the north cloud has a surprisingly tight distribution of peaks fitted from the different lines.

The feature near Sgr B2(S) also has a fairly tight distribution of fitted peak positions, given the 36 to 39 arcsec beamsize of the observations. However, there is a significant difference in the peak positions, for the groups of fitted peaks near Sgr B2(N) and Sgr B2(M). This is attributed to a real difference in the positions of the peaks in different lines, where some more excited lines are associated with the compact hot cores Sgr B2(N) and Sgr B2(M), or particularly for Sgr B2(N) some molecules are concentrated there. Other lower excitation lines peak in the ridge further to the west of Sgr B2(N) and Sgr B2(M) and avoid the hot core positions as the molecules are destroyed there. The excitation effect can be seen clearly in the SO (Figure 7) where the 86.09 and 109.25 GHz lines are concentrated at Sgr B2(M), while the 99.30 GHz line traces the ridge-line more to the west.

From some of the stronger lines in Table 3 which are concentrated at Sgr B2(N) and Sgr B2(M) we fit the hot core positions and velocities as: Sgr B2(N) 17 47 19.9, -28 22 11, velocity 63 km s$^{-1}$, width 24 km s$^{-1}$; and Sgr B2(M) 17 47 20.3, -28 22 58, velocity 59 km s$^{-1}$, width 22 km s$^{-1}$. From these lines (mostly CH$_3$OH and CH$_3$CH$_2$CN for Sgr B2(N) and SO and SO$_2$ for Sgr B2(M)) we find that the hot cores are unresolved relative to the 36 to 39 arcsec Mopra beam.

The distribution of optically thin C$^{18}$O, which should be a good tracer of CO column density, and hence H$_2$ column density, peaks at the Sgr B2(N) and Sgr B2(M) cores, whereas there are several molecules, such as HC$_3$N, CH$_3$CN, CH$_3$OH and OCS, which peak in the ridge-line to the west of the cores. This is shown in Figure 11 and in the integrated emission images, by the alignment of the distributions relative to the reference crosses (radio peaks) and squares (mid-IR peaks).

We also show in Figure 12 the 20-cm radio, from the
Figure 10. The position (left) of the peaks fitted for the 3-mm molecular lines, and (right) the velocity as a function of declination. Note that in the velocity-declination plot, the points for the SE peak have been shifted 1 arcmin north for clarity, to avoid overlapping the points near Sgr B2(M). In the left diagram, the points are the 3-mm molecular peaks, the crosses radio sources and the open boxes mid-IR sources.

Table 5. Summary of molecular features in the Sgr B2 complex, from the Mopra 3-mm peaks. We give the mean and standard deviation of position, velocity and velocity width, from the fits to different lines, and include positions in galactic coordinates for reference.

| Feature            | R.A. (J2000) | Dec. (J2000) | σ(R.A.) arcsec | σ(Dec.) arcsec | lat. degree | long. degree | Velocity km s$^{-1}$ | σ(Vel.) km s$^{-1}$ | Width km s$^{-1}$ | σ(Width) km s$^{-1}$ |
|-------------------|-------------|-------------|----------------|----------------|-------------|--------------|---------------------|-------------------|-------------------|---------------------|
| north ridge       | 17 47 22.6  | -28 20 56   | 15             | 7              | 0.702       | -0.024       | 62                  | 3                | 43                | 10                  |
| north cloud       | 17 47 21.4  | -28 21 24   | 2              | 4              | 0.693       | -0.024       | 66                  | 3                | 24                | 4                   |
| near Sgr B2(N)    | 17 47 19.3  | -28 22 18   | 7              | 8              | 0.676       | -0.026       | 65                  | 3                | 25                | 5                   |
| near Sgr B2(M)    | 17 47 19.2  | -28 23 04   | 11             | 15             | 0.665       | -0.032       | 59                  | 4                | 22                | 5                   |
| near Sgr B2(S)    | 17 47 20.0  | -28 24 00   | 4              | 6              | 0.653       | -0.043       | 58                  | 2                | 21                | 6                   |
| west ridge        | 17 47 14.8  | -28 22 34   | 5              | 9              | 0.664       | -0.014       | 117                 | 5                | 22                | 6                   |
| south-east peak   | 17 47 26.9  | -28 23 12   | 5              | 7              | 0.678       | -0.057       | 48                  | 7                | 27                | 6                   |

VLA [4], the 850-µm sub-mm from SCUBA [5], and 21-µm mid-IR, from MSX [6].

We point out that, for the many molecules here that peak in the ridge-line to the west of the Sgr B2(N) and Sgr B2(M) cores, this distribution of molecular emission ‘wraps around’ the north and west side, where there is little radio and mid-IR emission tracing recent star formation, and avoids the south-east area where there is recent star formation. The north cloud, in particular, is quite isolated from the recent star formation activity. In contrast, the SCUBA sub-mm emission, tracing cooler dust than the mid-IR, shows extended emission around the Sgr B2(N) and Sgr B2(M) cores, to the north and west which matches well the north cloud and the molecular ridge-line.

Each line that we have imaged here has its own particular distribution, corresponding to the spatial distribution of the molecule, and the effect of the excitation of the different levels. There is also a complicated velocity structure in the region. However, we can make some generalisations and comments here to bring some order to the overall results.

Figure 11. The C$^{18}$O integrated emission as grey-scale, with the 90.98 GHz HC$_3$N integrated emission as contours, showing how molecules such as HC$_3$N peak in the ridge-line to the west of the hot cores.

The CO ($^{13}$CO, C$^{18}$O and C$^{17}$O) shows that the densest region is around Sgr B2(M) at velocity 63 km s$^{-1}$. The $^{13}$CO is optically thick at this core, so the density there is better traced by the C$^{18}$O. The column density, would be further concentrated at Sgr B2(N) and Sgr B2(M), than the
C$^{18}$O 1–0 integrated line emission shown here. The higher temperature at the cores ($\sim 200$ K, compared to $\sim 20$ K for the surrounding gas) leads to an extra factor there, when converting, with the standard LTE analysis, from integrated line emission to total CO column density, and hence total $H_2$ column density.

The HCO$^+$, HCN and HNC are strong and widespread with absorption at the Sgr B2(M) and Sgr B2(N) cores. The column density is likely to be peaked at these cores, but the integrated emission is strongly affected by this absorption, leading to local minima in the emission intensity at the cores. There are differences in the detailed distribution of these three lines, as expected: HCN should be a good tracer of high gas density ($\geq 10^4$ cm$^{-3}$), the isomer HNC should trace cool quiescent gas, and the ion HCO$^+$ should trace ionisation due to cosmic rays. We have further Mopra data of these lines over a larger area, from broad-band observations over the 85.3 to 93.3 GHz range, which show the differences more clearly, so we postpone further discussion for a later paper.

The CS and SiO distributions are also affected by absorption at the Sgr B2(M) and Sgr B2(N) cores, so the column density distribution is hard to determine from the integrated emission images. CS is expected to be, like HCN, a good tracer of high density gas, and SiO is expected to trace shocks, but is quite widespread here.

The CN emission is quite uniform over the 5 x 5 arcmin area observed here, except for the absorption at the Sgr B2(M) and Sgr B2(N) cores. It is expected to be associated with an enhanced ultraviolet (UV) field, so this would indicate a widespread UV field in the Sgr B2 complex. The weak lines of $C_2H$ and $c-C_3H_2$ also have absorption at the Sgr B2(M) and Sgr B2(N) cores and widespread emission, but some excess emission on the ridge-line west of the cores.

Most of the lines imaged here trace the ridge-line west of the Sgr B2(M), Sgr B2(N) and Sgr B2(S) cores, and north-east to what we are calling the north cloud. These lines include HC$_3$N, CH$_3$CN, CH$_3$OH, HNCO, OCS, N$_2$H$^+$, CH$_3$CCH, NH$_2$CHO/H$_2$COH$^+$, NH$_2$CN, CH$_3$NH and H$_2$CS. These more complex molecules, as noted above, trace the cooler dust seen at sub-mm wavelengths, and avoid the areas with the warmer dust (mid-IR) and radio continuum associated with the active star formation. N$_2$H$^+$ and the 96.74 GHz transition of CH$_3$OH are strong, and also show some absorption at the Sgr B2(M) and Sgr B2(N) cores.

The relative prominence of the peaks in the ridge-line west of the Sgr B2(M), Sgr B2(N) and Sgr B2(S) cores in these different molecules, and between different transitions of the same molecule (e.g.CH$_3$OH), indicate differences in chemistry and excitation conditions.

The lines of HNCO and HOCS$^+$ highlight the north cloud, and are tracers of shock chemistry.

The lines of SO and SO$_2$ are also tracers of shocks, and are concentrated at Sgr B2(M), although the lower excitation 99.30 GHz SO line also traces the more extended gas in the north cloud and ridge to the west.

5 SUMMARY

We have undertaken a 3-mm spectral-line imaging survey of the Sgr B2 area, of 5 arcmin square, with the Mopra telescope, at resolution $\sim 36$ arcsec. We covered almost the complete spectral range 81.7 to 113.5 GHz, with 2.2 MHz or $\sim 6$ km s$^{-1}$ spectral channels, and have observed 24 lines, with 0.033 MHz, or $\sim 0.1$ km s$^{-1}$ channels. We have discussed the distribution of around 50 lines, and presented integrated emission images for 38 of the lines. In addition, we have detected around 120 more lines, mostly concentrated at Sgr B2(N).

By fitting the peak position and velocity of the emission in the various lines, we find that there are seven distinct molecular features in the region, which show distinct differences in both molecular abundances and excitation conditions.

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Table 4. Compilation of fitted peaks of the molecular features in the Sgr B2 complex. We are mostly considering here the spatial and velocity structure, but include in this table, for completeness, the intensity of the fitted peaks in the $T_A^*$ scale. For some molecules with multiple transitions, where we have used the mean spatial position and velocity for higher signal to noise, we list the intensities for the different transitions in consecutive lines, in order of frequency, as given in Table 2.

| Feature / Molecule | R.A. (J2000) | Dec. (J2000) | Vel. km s$^{-1}$ | Width km s$^{-1}$ | $T_A^*$ K |
|--------------------|-------------|-------------|-----------------|-----------------|-----------|
| **N ridge**        |             |             |                 |                 |           |
| $^{13}$CO          | 17 47 24.2  | -28 20 49   | 65              | 42              | 3.03      |
| C$^{18}$O          |             | 63          | 36              | 0.56            |           |
| CS                 | 17 47 22.3  | -28 20 49   | 61              | 57              | 1.01      |
| HNC                | 17 47 22.0  | -28 20 55   | 59              | 54              | 0.96      |
| SiO                | 17 47 22.5  | -28 21 06   | 58              | 41              | 0.32      |
| HC$_3$N            | 17 47 21.0  | -28 20 54   | 62              | 27              | 1.15      |
| CH$_3$CN           | 17 47 23.5  | -28 21 01   | 64              | 41              | 0.37      |
| **N cloud**        |             |             |                 |                 |           |
| HC$_3$N            | 17 47 21.4  | -28 21 29   | 68              | 23              | 1.48      |
| CH$_3$CN           | 17 47 21.3  | -28 21 28   | 68              | 35              | 0.51      |
| CH$_3$OH           | 17 47 21.4  | -28 21 20   | 68              | 25              | 3.53      |
| **$^{13}$CH$_3$OH**|             |             |                 |                 |           |
| HNCO               | 17 47 21.6  | -28 21 20   | 65              | 25              | 2.94      |
| HOCO$^+$           | 17 47 21.1  | -28 21 29   | 67              | 23              | 0.54      |
| OCS                | 17 47 21.3  | -28 21 18   | 65              | 23              | 0.54      |
| SO                 | 17 47 21.3  | -28 21 20   | 66              | 25              | 0.68      |
| SO$_2$             | 17 47 21.4  | -28 21 23   | 68              | 21              | 0.33      |
| N$_2$H$^+$         |             | 68          | 21              | 0.30            |           |
| CH$_3$CCH          | 17 47 21.5  | -28 21 23   | (73)            | (23)            | 1.39      |
| NH$_2$CHO          |             | (65)        | (24)            | 0.16            |           |
| NH$_2$CN           |             | 59          | 27              | 0.30            |           |
| CH$_2$NH           |             | 66          | 19              | 0.22            |           |
| H$_2$CS            | 17 47 21.4  | -28 21 25   | 68              | 21              | 0.66      |
| **near Sgr B2(M)** |             |             |                 |                 |           |
| C$^{18}$O          | 17 47 20.3  | -28 23 06   | 63              | 21              | 1.87      |
| CS                 | 17 47 19.2  | -28 23 03   | 54              | 15              | 0.35      |
| CH$_3$OH           | 17 47 20.1  | -28 22 27   | (64)            | (13)            | 0.42      |
| CH$_3$CN           | 17 47 21.8  | -28 22 56   | (50)            | (8)             | 0.48      |
| HNCO               | 17 47 21.8  | -28 22 34   | 40              | 32              | 1.37      |
| SO                 | 17 47 20.1  | -28 22 49   | 62              | 22              | 2.02      |
| SO$_2$             | 17 47 20.1  | -28 22 50   | 60              | 22              | 2.95      |
| N$_2$H$^+$         | 17 47 21.4  | -28 21 23   | 68              | 21              | 0.48      |
| CH$_3$CN           | 17 47 18.8  | -28 23 11   | 61              | 33              | 0.74      |
| CH$_3$OH           | 17 47 18.2  | -28 23 11   | 61              | 22              | 3.01      |
| HNCO               | 17 47 18.8  | -28 23 01   | 66              | 29              | 1.83      |
| HOCO$^+$           | 17 47 18.4  | -28 23 21   | 63              | 22              | 0.35      |
| SO                 | 17 47 19.8  | -28 22 56   | 61              | 20              | 0.95      |
| SO$_2$             | 17 47 20.4  | -28 23 04   | 52              | 26              | 1.00      |
| **near Sgr B2(N)** |             |             |                 |                 |           |
| C$^{18}$O          | 17 47 19.5  | -28 22 15   | 68              | 22              | 1.60      |
| CH$_3$N            | 17 47 18.7  | -28 22 12   | 67              | 23              | 1.66      |
| HNCO               | 17 47 18.2  | -28 23 01   | 66              | 29              | 1.83      |
| HOCO$^+$           | 17 47 18.4  | -28 23 21   | 63              | 22              | 0.35      |
| SO                 | 17 47 19.8  | -28 22 56   | 61              | 20              | 0.95      |
| SO$_2$             | 17 47 20.4  | -28 23 04   | 52              | 26              | 1.00      |
| Feature / Molecule | R.A. (J2000) | Dec. (J2000) | Vel. km s$^{-1}$ | Width km s$^{-1}$ | T$^*$ K |
|-------------------|-------------|-------------|-----------------|-----------------|-------|
| N$_2$H$^+$        | 17 47 17.4  | -28 23 06   | (65)            | (25)            | 0.92  |
| CH$_3$COH         | 17 47 19.5  | -28 23 22   | (58)            | (12)            | 0.40  |
| NH$_2$CHO/H$_2$COH$^+$ | 55 26   | 0.21        |                 |                 |       |
| CH$_2$NH          | 59 18      | 0.35        |                 |                 |       |
| H$_2$CS           | 17 47 19.2  | -28 23 21   | 59              | 19              | 0.90  |
| AIF               | 17 47 19.7  | -28 22 56   |                 |                 | 0.29  |
| near Sgr B2(S)    |             |             |                 |                 |       |
| HC$_3$N           | 17 47 19.9  | -28 23 55   | 58              | 20              | 1.53  |
| CH$_3$CN          | 17 47 19.9  | -28 23 54   | 59              | 32              | 0.73  |
| CH$_3$OH          | 17 47 19.9  | -28 23 57   | 59              | 20              | 0.75  |
| $^{13}$CH$_3$OH   | 17 47 19.5  | -28 23 53   | 58              | 19              | 1.10  |
| OCS               | 17 47 19.5  | -28 23 53   | 58              | 19              | 1.07  |
| N$_2$H$^+$        | 17 47 20.1  | -28 24 09   | (61)            | (23)            | 1.41  |
| CH$_3$CCH         | 17 47 20.4  | -28 24 04   | (53)            | (12)            | 0.20  |
| NH$_2$CHO/H$_2$COH$^+$ | 55 17   | 0.25        |                 |                 |       |
| NH$_2$CN          | 17 47 20.2  | -28 24 05   | 57              | 17              | 0.66  |
| W ridge           |             |             |                 |                 |       |
| $^{13}$CO         | 17 47 14.0  | -28 22 14   | 109             | 32              | 1.68  |
| CS                | 17 47 14.9  | -28 22 37   | 119             | 14              | 0.42  |
| HCO$^+$           | 17 47 14.8  | -28 22 36   |                 |                 |       |
| HCN               | 17 47 14.7  | -28 22 34   | 119             | 24              | 0.63  |
| HNC               | 17 47 14.9  | -28 22 34   | 112             | 21              | 0.27  |
| CH$_3$OH          | 17 47 15.0  | -28 22 44   | 120             | 21              | 0.60  |
| N$_2$H$^+$        | 17 47 15.1  | -28 22 38   | 120             | 22              | 0.35  |
| SE peak           |             |             |                 |                 |       |
| CS                | 17 47 27.1  | -28 23 13   | 41              | 20              | 1.53  |
| SiO               | 17 47 27.1  | -28 23 12   | 45              | 29              | 0.36  |
| HC$_3$N           | 17 47 26.3  | -28 23 04   | 55              | 23              | 0.70  |
| CH$_3$OH          | 17 47 26.7  | -28 23 07   | 56              | 34              | 1.72  |
| N$_2$H$^+$        | 17 47 27.2  | -28 23 22   | 43              | 29              | 0.89  |

Table 4 continued.

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