Star formation sites toward the Galactic center region

The correlation of CH₃OH masers, H₂O masers, and near-IR green sources[★]

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ABSTRACT

Aims. We present a study of star formation in the central molecular zone (CMZ) of our Galaxy through the association of three star formation indicators: 6.7 GHz CH₃OH masers, 22 GHz H₂O masers, and enhanced 4.5 μ m emission (‘green’) sources. We explore how star formation in the CMZ ($|l| < 1.3^\circ$, $|b| < 10'$) compares with that of the Galactic disk ($6^\circ > l > 345^\circ$, $|b| < 2^\circ$).

Methods. Using an automated algorithm, we search for green sources toward 6.7 GHz CH₃OH masers detected in the Parkes Methanol Multibeam Survey. We combine these results with lists of 22 GHz H₂O masers, including our Mopra survey of the CMZ.

Results. We find that the correlation of CH₃OH masers with green sources is a function of Galactic latitude, with a minimum close to $b = 0$ and increasing with $|b|$ (toward the central part of the Galaxy, $6^\circ > l > 345^\circ$, $|b| < 2^\circ$). We find no significant difference between the correlation rate of CH₃OH masers with green sources in the CMZ and the disk. This suggests that although the physical conditions of the gas are different in the CMZ from that of the Galactic disk, once gravitational instability sets in at sufficiently high densities, signatures of star formation appear to be similar in both regions. Moreover, the detection of green sources, even at the distance of the Galactic center, shows that our technique can easily identify the early stages of star formation, especially in low-extinction regions of the Galaxy. Through the association of H₂O and CH₃OH masers, we identify 15 star-forming sites in the CMZ. We find a higher correlation rate of coincident H₂O and CH₃OH masers within the CMZ compared to the Galactic disk, indicating a difference in the maser evolutionary sequence for star-forming cores in these two regions.

Key words. ISM: clouds – ISM: molecules – stars: formation – Galaxy: center

1. Introduction

As the nearest galactic nucleus, our Galactic center (GC) provides us with the opportunity to study in detail the star formation process in the extreme conditions at the centers of galaxies. The inner few hundred pc of the Galactic center, known as the central molecular zone (CMZ) contains few times $10^7 M_\odot$ of molecular gas (Pierce-Price et al. 2000; Ferrière et al. 2007; Longmore et al. 2012) and hosts several prominent sites of star formation regions (e.g., Sgr A, Sgr B2 and Sgr C; see Fig. 1). By studying sites of star formation in this complex region, we can learn global characteristics of the star formation process and compare with nuclei of other galaxies.

The CMZ is characterized to be different from the Galactic disk in several ways, such as its chemistry (Martín-Pintado et al. 2000; Oka et al. 2005; Riquelme et al. 2010; Jones et al. 2011, 2012, 2013; Yusef-Zadeh et al. 2013a), a two-temperature distribution of molecular gas (e.g., Hüttemeister et al. 1998; Mills & Morris 2013), its dust temperature being lower than its gas temperature (Odenwald & Fazio 1984; Cox & Laureijs 1989; Pierce-Price et al. 2000; Ferrière et al. 2007; Molinari et al. 2011; Immer et al. 2012), stronger turbulence (cf. Morris & Serabyn 1996), and evidence that it is a region dominated by cosmic rays (Yusef-Zadeh et al. 2013a,b; Ao et al. 2013). Using thermal dust

emission data from the *Herschel* Hi-GAL Key-Project, Molinari et al. (2011) have shown that much of this mass ($\sim 3 \times 10^7 M_\odot$) resides in a filamentary, twisted ring-like structure that encircles the center of the Galaxy. This ring has a projected extent of ~ 180 pc, is comprised of a dense, cold ($T \leq 20$ K) dust cloud with high column density that encloses warmer dust ($T \geq 25$ K) with lower column density in the interior of the ring. The recent results of Jones et al. (2012), who used the Mopra telescope to map the CMZ in ~ 20 molecular transitions at ~ 3 mm, show that the clouds in the region display bright emission with large linewidths and profiles consisting of several velocity components, all indicating the complex kinematic structure and composition of the gas in the Galactic center zone.

While it is clear that physical characteristics of the gas are unique in the CMZ, it is not clear how star formation in this region compares to that of the Galactic disk. Assuming that the gas is distributed uniformly throughout the inner 400 pc of the Galaxy rather than in a ring geometry, the Kennicutt law (Kennicutt 1998) still holds in a region where tidal shear could be important (Yusef-Zadeh et al. 2009). To make the comparison between star formation in the CMZ and in the Galactic disk, we look at the correlation of two star formation indicators—maser emission (from both CH₃OH and H₂O) and extended, enhanced 4.5 μ m emission. Because of their different emission mechanisms, the correlation between the two can help constrain the evolutionary states of young stars.

[★] Appendices A and B are available in electronic form at <http://www.aanda.org>

The Class II CH₃OH maser transition at 6.7 GHz is one of the brightest known maser lines and is known to be an excellent signpost of star formation (e.g., Menten 1991; Minier et al. 2003; Caswell et al. 2010). The population inversion that gives rise to the transition is thought to be radiatively pumped, presumably by a central high-mass ($\geq 8 M_{\odot}$) protostellar object (Cragg et al. 1992). It has been shown that this maser traces only high-mass star formation (Walsh et al. 2001; Minier et al. 2003), and is typically found close to young stars (Caswell 1997; Ellingsen 2005). As such, it is used as a marker of high-mass star formation throughout the Galaxy. Another well-known signpost of star formation is the H₂O maser transition at 22.23 GHz (Genzel et al. 1978; Gwinn 1994; Claussen et al. 1998; Furuya et al. 2001). The population inversion is created in shocks and outflows (Norman & Silk 1979; Elitzur et al. 1989; Hollenbach et al. 2013), and the maser is associated with both low- and high-mass star formation (as well as AGB stars and super-massive black holes), and has been the target of many recent observations and surveys (e.g., Caswell et al. 2011; Walsh et al. 2011). Many young star forming sites in the Galaxy harbor both CH₃OH and H₂O masers.

A more recently discovered tracer of star formation activity is extended, enhanced 4.5 μ m emission, commonly known as “green fuzzies” (Chambers et al. 2009) or extended green objects (EGOs; Cyganowski et al. 2008). These sources appear green in *Spitzer*/IRAC (Fazio et al. 2004) 3-color images (8.0 μ m in red, 4.5 μ m in green, and 3.6 μ m in blue). The 4.5 μ m enhancement is likely due to a shock-excited H₂ feature in the 4.5 μ m band (Noriega-Crespo et al. 2004; De Buizer & Vacca 2010), but it could also be from a shocked CO feature (Marston et al. 2004). While its exact nature is still uncertain, this 4.5 μ m emission, frequently referred to as “green” emission throughout this paper, is a reliable tracer of the early stages of star formation (Chambers et al. 2009; Cyganowski et al. 2008, 2009).

There have been several studies that show the correlation of green sources with maser emission. Yusef-Zadeh et al. (2007) found an association of green sources with 6.7 GHz CH₃OH masers toward the Galactic center, and other studies have since found similar correlations in the Galactic disk, with both 6.7 GHz CH₃OH and 22 GHz H₂O masers (Chambers et al. 2009; Chen et al. 2009; Cyganowski et al. 2009). Using a sample of 31 green sources (15 in the CMZ, and 16 foreground to the Galactic center region), Chambers et al. (2011) searched for a difference in the correlation rate of 6.7 GHz CH₃OH masers with green sources between the CMZ and the Galactic disk. They found no significant difference in the correlation rate, but that study suffered from small-number statistics.

In this paper, we search for differences in the correlation of masers with green sources between the Galactic center and the Galactic disk using a different approach. While the studies mentioned above search for maser emission toward samples of green sources, we instead search for extended, enhanced 4.5 μ m emission toward 6.7 GHz CH₃OH maser emission. We then correlate the results with a list of 22.23 GHz H₂O masers, which is a combination of the results of our Mopra H₂O maser survey of the CMZ and H₂O masers identified by Caswell et al. (2011) and Walsh et al. (2011). This method has several advantages, such as a large sample of CH₃OH masers from the Parkes Methanol Multibeam Survey (Caswell et al. 2010, C10 hereafter). Moreover, it uses an automated, uniform approach to identifying enhanced 4.5 μ m emission. Finally, it makes use of H₂O masers as a third tracer of star formation indicator. Using this method, we explore how star formation in the Galactic

center compares with that of the Galactic disk and identify sites of star formation using three different tracers.

The structure of this paper is as follows. In Sect. 2, we present our Mopra H₂O maser survey of the Galactic center region, along with brief descriptions of earlier surveys of H₂O masers (Caswell et al. 2011; Walsh et al. 2011), CH₃OH masers (C10), and the *Spitzer*/IRAC survey of the GC region. We describe our source detection and correlation algorithms in Sect. 3. In Sect. 4, we present the results after the application of the method. We discuss these results in Sect. 5, and summarize our findings in Sect. 6.

2. Data

2.1. 6.7 GHz CH₃OH masers

The 6.7 GHz CH₃OH masers we use in our analysis were identified by C10 as part of the Parkes Methanol Multibeam Survey. Initial detections of the 6.7 GHz CH₃OH masers were made with the Parkes Observatory, and subsequent follow-up observations with the Australia Telescope Compact Array to pinpoint the maser locations to 0.4'' accuracy. The full survey covers the entire Galactic plane with a latitude range of $|b| < 2^{\circ}$. C10 published a subset of this survey, covering $6^{\circ} > \ell > 345^{\circ}$, $|b| < 2^{\circ}$ with a 1σ detection limit of 0.07 Jy.

2.2. H₂O maser data

We observed the Galactic center region with the CSIRO/CASS Mopra telescope in the period 2006 Sep. 13 to 2006 Oct. 15 and 2007 July 24 to September 17. Data were taken in the on-the-fly mode, dumping data every 2 s with the then newly installed 12mm receiver, dual polarization. We observed the Galactic longitude range of $-1.5^{\circ} < \ell < 2^{\circ}$ and Galactic latitude range of $|b| < 0.5^{\circ}$. The entire area was split into smaller, typically 18' on-the-fly subfields that were repeatedly and alternately observed in Galactic latitude and longitude directions, at least four times.

As a reference position we observed at $(\ell, b) = (4.301^{\circ}, 1.667^{\circ})$ after every row. The data were calibrated with an internal noise diode. At the time of the observations in 2006, however, the noise diode was not fully calibrated itself and we used the 2007 observations to obtain pointed observations in each on-the-fly field from which we re-calibrated the 2006 data. The absolute calibration is estimated to be accurate to $\sim 20\%$. We used the MOPS¹ backend in the mops_2208_8192_4f wide-band mode to cover a large range of molecular lines, including the 22.235120 GHz rest frequency of the $J = 6_{16}-5_{23}$ water (H₂O) transition. The full frequency coverage is 8.8 GHz (4 sub-bands) with 8096 channels within a 2.2 GHz subband. The data were processed with the ATNF packages livedata and gridzilla². Livedata calibrates the spectra using ON and OFF scans and gridzilla grids all spectra into datacubes that we specified to be 0.5' per pixel, with a FWHM of 2.4' of the Mopra beam. The final channel width after regridding on a common velocity axis was 3.6 km s⁻¹. The rms noise is typically 0.01 K per channel. For Mopra, the Jy/K conversion in the K-band is 12.3 (Urquhart et al. 2010). The velocity coverage of this survey is -250 to 300 km s⁻¹.

¹ The University of New South Wales Digital Filter Bank used for the observations with the Mopra Telescope was provided with support from the Australian Research Council.

² <http://www.atnf.csiro.au/computing/software/livedata/index.html>

Fig. 1. *Spitzer*/IRAC 3-color image (with $8.0\ \mu\text{m}$ in red, $4.5\ \mu\text{m}$ in green, and $3.6\ \mu\text{m}$ in blue) of the Central Molecular Zone. Some of the more prominent Galactic center features are labelled. Sgr A* is centered on the nuclear cluster.

To supplement these data, we also use two additional sets of H_2O masers identified by Caswell et al. (2011) and Walsh et al. (2011). Caswell et al. (2011) used the Australia Telescope Compact Array (ATCA) to survey the central $0.5\ \text{deg}^2$ of the Galaxy (covering $|\ell| \lesssim 0.4^\circ$ and $|b| \lesssim 0.4^\circ$). The survey data have a velocity resolution of $\sim 2\ \text{km s}^{-1}$, a synthesized beam of $10''$ by $7''$ and typical rms of $0.1\ \text{Jy}$. They detected 27 confirmed H_2O masers in the survey.

The H_2O Southern Galactic Plane Survey (HOPS) (Walsh et al. 2011) used Mopra to map $100\ \text{deg}^2$ of the southern Galaxy in multiple spectral lines. HOPS covered the region $30^\circ > \ell > 290^\circ$, $|b| < 0.5^\circ$ with an rms noise between 1 and 2 Jy and a channel width of $0.45\ \text{km s}^{-1}$. The beam size of these observations matches that of our Mopra observations. In total, they detected 540 H_2O masers in the survey region. We use a subset of 113 of these 540 masers, selected to be within the CH_3OH survey region covered by C10 ($6^\circ > \ell > 345^\circ$, $|b| < 2^\circ$).

2.3. *Spitzer* data

To identify enhanced $4.5\ \mu\text{m}$ sources, we use data obtained with the *Spitzer Space Telescope* using the Infrared Array Camera (IRAC; Fazio et al. 2004). In particular, we use a combination of data from the Galactic Legacy Infrared Midplane Survey Extraordinaire (GLIMPSE; Benjamin et al. 2003) and another IRAC survey toward the Galactic center (Stolovy et al. 2006; Arendt et al. 2008; Ramírez et al. 2008). Both data sets include data at all 4 IRAC wavelengths: 3.6 , 4.5 , 5.8 , and $8.0\ \mu\text{m}$. These data have an angular resolution of $\lesssim 2''$, and a pixel size of $1.2''$. In total, the coverage of the survey in Galactic coordinates is $|\ell| < 65^\circ$, $|b| < 1^\circ$, with extended b coverage (up to $|b| \sim 2^\circ$) within 5° of the Galactic center.

3. Methods

3.1. Association of CH_3OH masers with green sources

To determine which $6.7\ \text{GHz}$ CH_3OH masers are associated with green sources, we use an automated source detection algorithm.

This algorithm uses an input list of CH_3OH maser positions to search for sources with enhanced $4.5\ \mu\text{m}$ emission (“green sources”) in *Spitzer*/IRAC data. The algorithm first generates a list of candidate green sources; if the candidate green sources meet certain size and “green” thresholds, we identify them as green sources. This new technique is based on combining two methods in which green sources are detected. One method uses ratio maps (Yusef-Zadeh et al. 2009) and the other uses an automated algorithm (Chambers et al. 2009). The details of this new algorithm are described below.

We search for green sources in a “green ratio” image. We generate the green ratio image using: $R_{\text{gr}} = I(4.5)/[I(3.6)^{1.2} \times I(5.8)^{0.5}]$, an empirical relation identifying sources of enhanced $4.5\ \mu\text{m}$ emission (Yusef-Zadeh et al. 2009).

To identify green sources associated with CH_3OH masers, we find contiguous pixels of enhanced $4.5\ \mu\text{m}$ emission that are above the local background and close to the maser position. $6.7\ \text{GHz}$ CH_3OH masers are distributed in close proximity to the protostellar objects that generate them (Caswell 1997; Ellingsen 2005). As a result, we use a search radius that is comparable to the typical green source angular size of ~ 10 – $20''$ (e.g., Cyganowski et al. 2008; Chambers et al. 2009), corresponding to a linear size of ~ 0.4 – $0.8\ \text{pc}$ (assuming a distance of $8.4\ \text{kpc}$ to the Galactic center, Reid et al. 2009). Thus, for each $6.7\ \text{GHz}$ maser, we search within a $10''$ radius for a local peak in the green ratio image (R_{peak}). This same search radius of $10''$ was also used by Chambers et al. (2011) to associate these two star formation indicators. An example in which a green source is detected based on this algorithm is shown in Fig. 2.

To determine a local background ratio value near the position of the $6.7\ \text{GHz}$ maser, we draw an additional aperture with a $30''$ radius centered on the maser position (again, see Fig. 2). We define the local ratio background, R_{bg} , as the median value of the pixels within the annulus defined by the $10''$ and $30''$ apertures.

With R_{peak} and R_{bg} , we calculate the minimum ratio value, R_{cut} , required to be included as part of the candidate green source, by taking their average: $R_{\text{cut}} = [R_{\text{peak}} + R_{\text{bg}}]/2$. To find

Fig. 2. *Spitzer*/IRAC 3-color image (with 8.0 μm in red, 4.5 μm in green, and 3.6 μm in blue) toward the position of a CH₃OH maser (G352.111+0.176, $v_{\text{LSR}} = -54.8 \text{ km s}^{-1}$), which is marked by the white cross sign ($\times$). Also shown on the image are: (1) the search radius (smaller circle) used to identify the peak “green” value (R_{peak}); (2) the search radius (larger circle) used to identify the background value (R_{bg}); (3) the contour that defines the candidate green source in the image; and (4) the position of the CH₃OH maser ($\times$). Note that the cross ($\times$) indicates only the position of the maser, and the size of the cross has no meaning.

candidate green sources, we find all pixels (N_{pix}) with $R \geq R_{\text{cut}}$ that are contiguous with the peak green value (R_{peak}). In this way, we find a *candidate* green source for each 6.7 GHz maser. The contour in Fig. 2 shows the pixels identified as the candidate green source.

To determine which candidate green sources are bonafide green sources, we require that they meet two more criteria: (1) a minimum number of pixels; and (2) a minimum green value threshold, calculated by taking the average green value of the background-subtracted pixels (R_{thresh}). To arrive at a value for this threshold, we use a prior known sample of green source/CH₃OH maser pairs from Chambers et al. (2011). Using green sources that were identified by eye, Chambers et al. (2011) found that 14 of the masers from C10 were associated with their visually selected sample of green sources. To optimize our algorithm, we use a combination of number of pixels and R_{thresh} that identifies most or all of the associations found by Chambers et al. (2011), while minimizing the number of spurious associations. We find that a minimum of 9 pixels and $R_{\text{thresh}} \geq 0.2$ properly identifies 13 of the 14 (93%) green source/CH₃OH maser pairs from Chambers et al. (2011) and finds few spurious detections. This result is shown graphically in Fig. 3. Thus, we use these values to determine our final green source list from the candidate green sources.

To examine the bias in this method, we search for green sources toward random positions. These results are found in Sect. 4.1.1.

3.2. Identification of H₂O masers

To identify H₂O masers in the Mopra CMZ map, we use the Clumpfind algorithm (Williams et al. 1994). Clumpfind identifies clumps by finding local peaks within a contoured data cube. Contour intervals (used to separate blended features) and lower

Fig. 3. R_{gr} vs. the number of pixels contained in candidate green sources. To determine the values used as selection criteria in our detection algorithm, we apply different combinations of these values to a known sample of green source/maser pairs to see how many the algorithm recovers. The grayscale shows the percent of known pairs recovered for each set of values. In our algorithm, we use a minimum number of 9 pixels and $R_{\text{gr}} \geq 0.2$ as the cutoffs for green sources (marked with a black + in the image). With these values, we recover 13 of 14 (93%) green source/maser pairs.

Fig. 4. Noise in the spectrum at each position in the Mopra data cube. Because of the uneven noise throughout the data, we divide the original data cube by this 2D image, resulting in a signal-to-noise data cube. The grayscale bar on the right shows the noise temperature in units of K (the conversion to Jy is 12.3 Jy/K).

detection limits are provided by the user, and are typically a multiple of the signal-to-noise ratio (SNR) of the data.

In order to determine an appropriate contour interval and lower limit for our Mopra data, we first analyze the SNR of the input data cube. After masking the line-free channels at each position, we calculate the noise in each spectrum, resulting in the 2D “noise” image shown in Fig. 4. This 2D image clearly shows that the noise in the Mopra H₂O data is not uniform throughout the entire cube, which is likely a result of having in different integration times in some regions, as well as varying weather during the observations. Because Clumpfind works best on data with uniform noise, we divide the original data cube by the 2D SNR image, resulting in a data cube containing SNR values. This cube is then used as the input for Clumpfind. We find that, for the SNR data cube, a minimum threshold (i.e., detection limit) of 4 and a contour interval (used to separate blended features) of 4 work best for identifying the H₂O masers in the data.

In addition to the threshold and contour levels, we also select a minimum number of volume elements (voxels) required for a source to be identified. Based on the Mopra beam size at

Fig. 5. *Top:* histogram of the distribution of 6.7 GHz masers in Galactic longitude (integrated over all Galactic latitudes). The bin size is 1.5° . The peak of the distribution is largely due to the cluster of 11 masers in Sgr B2. *Bottom:* histogram of the distribution of 6.7 GHz masers in Galactic latitude (integrated over all Galactic longitudes). The bin size is 0.15° . The masers are distributed around the Galactic equator.

the frequency of the H_2O maser transition ($\text{FWHM} \sim 144''$ at 22.2 GHz) and the angular size of one pixel ($30''$ by $30''$), we require a source to have at least 18 voxels to be included in our final list of masers.

4. Results

4.1. CH_3OH masers and green sources

C10 detect 183 CH_3OH masers in their survey region ($6^\circ > \ell > 345^\circ$, $|b| < 2^\circ$), with a 1σ detection limit of 0.07 Jy. Histograms of the maser distribution as a function of ℓ and b can be seen in Fig. 5. The distribution in Galactic latitude shows that the masers have a roughly Gaussian distribution, centered on the Galactic plane. The Galactic longitude distribution displays a peak toward the Galactic center, mostly due to a large number of masers in the Sgr B star forming region. Figure 6 contains a 2D image of the maser distribution, and clearly shows the peak of the maser distribution in Sgr B.

We run the green source detection algorithm (described above) on 175 of the 183 masers in the C10 catalog (8 were excluded because we do not have corresponding IRAC data). We find that 86/175 ($49.1 \pm 5.3\%$) of the 6.7 GHz masers are associated with a green source. These green sources range in size from 9 IRAC pixels (the minimum based on our detection method) to

517 IRAC pixels, with a median of 17 IRAC pixels (IRAC pixels are $1.2''$ by $1.2''$). See Fig. 7 for a histogram of the number of pixels in green sources.

A summary of these results can be found in Table B.1, which lists, for each CH_3OH maser, the maser name (Col. 1; from C10), the velocity of peak maser emission (Col. 2; from C10), the Galactic longitude, latitude and value for the peak green pixel in each green source candidate, R_{peak} (Cols. 3–5), the background green value near each green source candidate, R_{bg} (Col. 6), the green value used to define the boundary of the green source candidate, R_{cut} (Col. 7), the average green value for the pixels within the green source candidate, R_{thresh} (Col. 8), and the number of pixels, N_{pix} , in the green source candidate (Col. 9). The final column in Table B.1 contains a flag (“Y” or “N”; Col. 10) to indicate if a green source is associated with a CH_3OH maser based on the values in Cols. 3 through 9.

Using these detected sources, we calculate the detection rates for green sources toward 6.7 GHz masers as a function of Galactic longitude and latitude. In Fig. 8, we show that the longitude distribution of detection rates varies between 20% and 86%, with typical errors of $\sim 20\%$. The distribution shows possible enhancements at $\ell \sim -2^\circ$ and $\ell \sim -8^\circ$, and a depressed rate at $\ell \sim -5^\circ$. The distribution of green source detection rates as a function of Galactic latitude, shown in Fig. 8, shows a clear deficit of green sources detected near the midplane ($b \sim 0^\circ$) of the Galaxy. The central 0.3° has a detection rate of $\sim 35 \pm 10\%$, while the regions with $|b| > 0.5^\circ$ have detection rates of $> 50\%$, with some bins at 100%.

Because we want to compare Galactic center candidate sources to Galactic disk sources, we need a method to estimate the distances to the sources. To determine if the green sources are foreground or Galactic center sources, we use their Galactic coordinates with respect to the Galactic plane and their corresponding maser velocities. First, we use the Galactic coordinates of the sources to separate our sources into GC sources and non-GC sources. To cover the CMZ, and to match the scale height of young stellar objects in the Galactic center region (Yusef-Zadeh et al. 2009), we define the GC region to be $|\ell| < 1.3^\circ$, $|b| < 10'$. Using these criteria for distance, we find that 8/23 GC CH_3OH masers ($34.8 \pm 12.3\%$) are associated with green sources, and 78/152 ($51.3 \pm 5.8\%$) non-GC CH_3OH masers are associated with green sources. These association rates are listed in Table 1, which lists the method of distance estimation in Col. 1, the location of the masers in Col. 2, the number of CH_3OH masers at that distance in Col. 3, the number of those masers that are associated with green sources in Col. 4, and the association rate calculated on those numbers in Col. 5. Figure 9 shows the positions of the CH_3OH masers, their assigned locations (based on their Galactic coordinates), and the velocities of the peak maser emission.

Next, we use the distance estimates made by C10, who based their estimates on the velocities of the CH_3OH masers and a model of circular Galactic rotation (and allowing for small deviations; see C10 for more details). In short, some maser velocities are consistent with Galactic rotation models, and are placed outside the GC region. Other masers have velocities consistent with a location within the 3 kpc arms, and are assigned that location. Those masers that fit neither of these categories, and have $|\ell| < 1.3^\circ$ (with no restriction in Galactic latitude) are placed at the distance of the GC. Using these criteria for distance, we find that 13/27 GC CH_3OH masers ($48.1 \pm 13.3\%$) are associated with green sources, and 73/148 ($49.3 \pm 5.8\%$) non-GC CH_3OH masers are associated with green sources.

Fig. 6. Distribution of the 6.7 GHz CH_3OH masers from C10. The pixel size is 0.25° . The bright peak at $(\ell, b) = (0.66, -0.04)$ is from a cluster of masers in Sgr B2.

Fig. 7. Histogram of the number of pixels in the green sources associated with 6.7 GHz CH_3OH masers. The sizes (in IRAC pixels) range from 9 (the minimum based on our detection method) to 517, with a median of 17.

Table 1. Association rates of CH_3OH masers with green sources.

Distance method	Galactic location	CH_3OH masers	Green source associations	Association rate
Position ^a	GC	23	8	$34.8 \pm 12.3\%$
	Disk	152	78	$51.3 \pm 5.8\%$
Velocity ^b	GC	27	13	$48.1 \pm 13.3\%$
	Disk	148	73	$49.3 \pm 5.8\%$
Both	GC	17	4	$23.5 \pm 11.8\%$
	Disk	158	82	$51.9 \pm 5.7\%$
Total		175	86	$49.1 \pm 5.3\%$

Notes. ^(a) Based on Galactic coordinates, with $|\ell| < 1.3^\circ$ and $|b| < 10'$ defining the GC region (see Sect. 4.1). ^(b) Based on the velocities of the masers and a model of circular Galactic rotation (see Sect. 4.1).

Finally, we also look at the subset of sources that meet the position (by Galactic coordinates) *and* velocity criteria described above. These masers all have positions with $|\ell| < 1.3^\circ$, $|b| < 10'$, and velocities that are inconsistent with both standard Galactic rotation and placement in the 3 kpc arms. Using these criteria for distance, we find that 4/17 GC CH_3OH masers ($23.5 \pm 11.8\%$) are associated with green sources, and 82/158 ($51.9 \pm 5.7\%$) non-GC CH_3OH masers are associated with green sources.

4.1.1. Random test

To determine if the association rates are true associations of green sources with 6.7 GHz masers or simply chance alignments of the two star formation indicators, we placed test masers in

Fig. 8. *Top:* histogram of the percentage of 6.7 GHz masers associated with green sources as a function of Galactic longitude. *Bottom:* histogram of the percentage of 6.7 GHz masers associated with green sources as a function of Galactic latitude. The bin size is 0.15° . Errors for the detection rates in both histograms are calculated using $\sqrt{N}$ counting statistics.

the survey longitude and latitude ranges and searched for green sources using the same method described above. Because the C10 CH_3OH masers are roughly evenly distributed in longitude, our test masers have a uniform distribution in longitude. To match the latitude distribution of masers seen in Fig. 5, we fit a Gaussian to the distribution and used its parameters to generate the Galactic latitude distribution of test masers. We placed 175 test masers in the survey region, to match the number of masers in the C10 catalog. To increase the statistics, we ran the test a total of ten times. We find a test maser-green source association rate of $1.3 \pm 0.3\%$ for our total sample of 1750 test masers. Thus, we consider the chances of our detection rates being contaminated by random chance associations to be small.

Fig. 9. *Top:* Spitzer/IRAC $8\ \mu\text{m}$ image of the Galactic center region showing 6.7 GHz CH₃OH masers. Crosses (+) indicate the positions of 6.7 GHz CH₃OH masers placed in the Galactic center region based on position. The $\times$ symbols indicate the positions of 6.7 GHz CH₃OH masers placed in the Galactic center region based on velocity. The asterisks (*) indicate the positions of 6.7 GHz CH₃OH masers placed in the Galactic center region based on both distance criteria. The squares show the locations of the masers thought to reside in the disk. Sources that are circled are associated with an enhanced $4.5\ \mu\text{m}$ emission source. Each maser is labelled with the velocity (in km s^{-1}) of the peak maser emission. *Bottom:* same as the *top* figure, but with a blank background instead of the $8\ \mu\text{m}$ image.

4.2. H₂O masers

Using the Clumpfind detection algorithm as described in Sect. 3.2, we find a total of 37 H₂O masers. These masers are listed in Table 2, which contains the identification numbers (Col. 1), the Galactic coordinates of the masers (Cols. 2 and 3), the velocity of peak emission for each maser (Col. 4), the peak intensities of the masers (Col. 5), and the number of voxels in the source (Col. 6). The peaks range from 52 mK to 9.54 K, with an average of 1.02 K and a median of 160 mK, and the velocities range from -208.5 to $129.4\ \text{km s}^{-1}$. Spectra of all 37 detections can be seen in Fig. A.1. The distribution of the water masers as a

function of Galactic longitude and latitude can be seen in Fig. 10. In Fig. 11, the positions of the water masers are overplotted on an image of the Galactic center region, along with the velocities of the peak maser emission. Some masers share the same positions but have different velocities. These likely comprise a cluster of masers, but higher angular resolution observations are needed to determine their positions more precisely.

The most notable feature in these distributions is the peak of H₂O masers at $\ell \sim 0.6^\circ$, which can be attributed to the H₂O maser emission from Sgr B2. We detect a total of 9 H₂O masers toward Sgr B, including the three strongest emission features in the survey. Figure 12 shows a spectrum toward

Table 2. H₂O masers in the survey region.

Number	ℓ^a ($^\circ$)	b^a ($^\circ$)	v^a (km s $^{-1}$)	T_{peak} (K)	Number of voxels
1	0.663	-0.036	71.3	9.54	1703
2	0.663	-0.019	53.1	6.48	1766
3	0.671	-0.019	42.2	3.64	893
4	-0.854	0.031	-1.4	5.08	372
5	-0.862	0.031	-1.4	5.01	446
6	0.671	-0.019	31.3	1.23	645
7	0.671	-0.019	100.4	0.77	673
8	0.380	0.047	38.6	0.78	218
9	-1.337	-0.053	-8.7	0.74	174
10	0.671	-0.019	111.3	0.47	243
11	1.138	-0.128	-19.6	0.46	158
12	-1.337	-0.053	-15.9	0.44	280
13	0.055	-0.219	13.2	0.54	93
14	-0.570	-0.103	-59.5	0.21	117
15	-0.679	-0.036	-110.4	0.16	79
16	0.671	-0.019	2.2	0.16	200
17	0.613	0.006	9.5	0.16	104
18	-0.704	0.031	-1.4	0.11	161
19	-1.337	-0.036	2.2	0.16	67
20	0.155	-0.561	-70.4	0.20	76
21	-0.862	0.031	-12.3	0.16	81
22	0.205	-0.011	-15.9	0.09	69
23	1.163	-0.019	-19.6	0.08	35
24	0.763	-0.253	-48.6	0.09	45
25	-0.662	0.281	-1.4	0.16	43
26	0.371	0.031	16.8	0.08	59
27	0.196	-0.153	45.9	0.06	34
28	-1.104	0.022	-15.9	0.13	26
29	-0.720	0.164	53.1	0.06	26
30	0.671	-0.019	129.4	0.09	36
31	-0.070	-0.153	-8.7	0.07	57
32	-0.070	-0.144	-19.6	0.07	21
33	-0.245	-0.378	-59.5	0.10	23
34	0.671	-0.019	122.2	0.08	22
35	-1.462	-0.194	-208.5	0.07	19
36	0.205	0.006	42.2	0.05	24
37	1.705	-0.486	-37.7	0.06	19

Notes. ^(a) Values of ℓ , b , and v are extracted from the Mopra data cube, which has a pixel size of $0.5''$ and a channel width of ~ 3.6 km s $^{-1}$.

Sgr B that indicates the velocities of these 9 masers, which are spread from ~ 0 to ~ 140 km s $^{-1}$.

4.2.1. Association of CH₃O masers and H₂O masers

To associate H₂O and CH₃OH masers, we first combine three H₂O maser lists—the list of masers we found in our Mopra CMZ survey, the list of masers identified by Caswell et al. (2011), and the list of masers from HOPS (Walsh et al. 2011). In order to see the complete results for each list, we do not remove H₂O masers that were identified in multiple lists.

We search for H₂O masers that are within one beam of CH₃OH masers. This separation corresponds to either $144''$ or $10''$, depending on the telescope used to identify the H₂O masers. Figure 13 shows the positions of H₂O and CH₃OH masers overlaid on an image of the GC region. The positions of the H₂O masers identified using Mopra are marked by circles that match the Mopra beam size, while the H₂O masers identified with ATCA are marked with a $\times$ symbol. Crosses (“+”) mark the positions of CH₃OH masers (the sizes of the $\times$ symbols and crosses have no physical meaning). We consider a H₂O and

Fig. 10. Distribution of the Mopra H₂O masers as a function of Galactic longitude (*top*) and latitude (*bottom*). The peak of the longitude distribution is due to the 9 masers associated with Sgr B.

CH₃OH maser to be associated when the position of the CH₃OH maser falls within the appropriate H₂O maser beam.

Because of the relatively large Mopra beam at 22.23 GHz ($144''$), and since most of the H₂O masers on our combined list are identified using this facility, we are unable to definitively state that a given H₂O maser arises from the same location as its “associated” CH₃OH maser. Indeed, the “associated” masers may arise from different young stars within the same star formation region, or could be aligned by chance. Nevertheless, we make associations between these two types of masers as described above, and hope for future high angular resolution observations to make a more definitive association.

The results of our H₂O-CH₃OH maser association method, including the velocity information of the masers, are listed in Table B.2. Columns 1–3 of the table list the CH₃OH maser name (from C10), and the lower and upper velocity limits of the CH₃OH maser emission (from C10). In Cols. 4–7, we list the properties of the H₂O masers that are associated with the CH₃OH masers—their Galactic coordinates, the velocities of their peak emission, and the catalog from which the maser was identified. Column 8 lists the angular separation between the associated CH₃OH and H₂O masers. Column 9 indicates if the CH₃OH maser is associated with a green source. If a CH₃OH maser is associated with multiple H₂O masers, then the CH₃OH maser information is printed only once, and a line for each of the H₂O masers is printed.

Because 22 GHz H₂O masers are found in shocks and outflows, their velocities may not match the velocities of the radiatively excited 6.7 GHz CH₃OH masers. Therefore, we do not use the velocities of the masers as association criteria. The velocities of both types of masers are listed in Table B.2.

Fig. 11. *Top:* *Spitzer*/IRAC 8 μm image of the Galactic center region. Crosses (+) indicate the positions of the H_2O masers identified in the Mopra survey. Each maser is labelled with the velocity (in km s^{-1}) of the peak maser emission. *Bottom:* same as the *top* figure, but with a blank background instead of the 8 μm image.

Some of the H_2O masers are associated with more than one CH_3OH maser. Without higher angular resolution, we are unable to tell if the masers are exactly coincident or are just nearby to one another. Nevertheless, we include these associations, along with whether or not the CH_3OH maser is coincident with a green source, to examine the star formation in the CMZ, as well as to determine candidates for potential follow-up observations at higher angular resolution.

Of the 175 CH_3OH masers in the C10 catalog, 154 fall within the combined regions of our Mopra CMZ survey, the Caswell et al. (2011) observations, and HOPS. Of these 154, 62 are associated with H_2O masers, while 92 are not. The list of these 62 CH_3OH masers can be found in the first column of Table B.2.

The combination of our Mopra CMZ survey, the Caswell et al. (2011) observations, and HOPS, yields a total of 177 H_2O masers, 63 of which are associated with

CH_3OH masers. Note that the same H_2O masers may be identified by more than one survey, and are thus counted more than once. All of these H_2O masers, along with their names or identification numbers, can be found in Table B.2. Because H_2O masers can be associated with more than one CH_3OH maser, some of the H_2O masers are listed more than once in this table. For completeness, we also include Table B.3, which lists CH_3OH masers that are not associated with H_2O masers. The first three columns of Table B.3 contain the name and Galactic coordinates of the CH_3OH masers (from C10), Cols. 4 and 5 contain the minimum and maximum velocities of the maser features (from C10), the peak intensity of the maser emission is in Col. 6, and the last column contains a flag indicating if the CH_3OH maser is associated with a green source. In addition, we list H_2O masers that are not associated with CH_3OH masers in Table B.4. The columns in this table

Fig. 12. Mopra H₂O maser spectrum toward Sgr B. The position of the spectrum (in ℓ, b) is printed at the top of the plot. The vertical lines indicate the velocities of masers identified by the Clumpfind routine. The velocities of the masers identified are 2.2, 31.3, 42.2, 53.1, 71.3, 100.4, 111.3, 122.2, and 129.4 km s⁻¹. The conversion to Jy is 12.3 Jy/K.

are: (1) the name or number of the H₂O maser; (2) the Galactic longitude of the maser; (3) the Galactic latitude of the maser; (4) the velocity of the peak emission from the maser; and (5) the peak emission of the maser. It is interesting to note that each of the 8 strongest H₂O masers from our Mopra survey (numbers 1 through 8 in Table 2) are associated with CH₃OH masers, and are thus not included in Table B.4.

5. Discussion

5.1. CH₃OH/green source association rate as a function of Galactic longitude

To search for trends in the association rate of 6.7 GHz masers and 4.5 μ m emission, we binned the sources (and association rates) by Galactic Longitude. The results are shown in Fig. 8. The association rate varies from bin to bin (from $20 \pm 14\%$ to $85 \pm 25\%$), but we find no strong trend with Galactic longitude. There appears to a decrement of associations at $\ell \sim -5^\circ$, and enhancements of associations at $\ell \sim -2^\circ$ and -8° . Because of the large error bars and the large bin-to-bin variations, we consider the likely cause of these to be the results of small number statistics and binning.

5.2. CH₃OH/green source association rate as a function of Galactic latitude

We find that CH₃OH masers near the Galactic midplane ($|b| < 10'$) are less likely ($34.8 \pm 6.4\%$) to be associated with green sources than those above or below it ($62.9 \pm 8.4\%$). While this could be a real effect, and masers outside the midplane could simply have higher association rates with 4.5 μ m sources than those in the midplane, we find it much more likely to be an optical depth effect of having two star formation tracers at very different wavelengths/frequencies.

The Galactic plane is optically thin at 6.7 GHz, making it possible to detect 6.7 GHz CH₃OH masers throughout the Galaxy, including the far side of the Galactic plane. This is not the case, however, for 4.5 μ m emission. At this much shorter wavelength, extinction plays a much larger role (see, e.g., Pandey & Mahra 1987), preventing the detection of green sources on the far side of the Galaxy (behind, e.g., the molecular clouds on the near side of the Galaxy). Because the extinction is higher in the Galactic plane, we are likely to have a cleaner

line of sight to 6.7 GHz masers that reside above or below the Galactic plane. Thus, we find a lower association rate of 4.5 μ m emission with 6.7 GHz CH₃OH masers for sources that are in the midplane of the Galaxy ($l < 10'$) than those above or below it.

5.3. Comparing the Galactic center with the Galactic disk

To see how star formation in the Galactic center region may differ from that of the disk, we compare the 6.7 GHz CH₃OH association rate with enhanced 4.5 μ m emission. As described in Sect. 4.1, we make three different distance estimates based on the positions of the masers, the velocities of the masers, and the combination of these two criteria.

Using Galactic coordinates alone ($|\ell| < 1.3^\circ$, $|b| < 10'$) to estimate the distances to the CH₃OH masers, and assuming that all masers that fit the distance criteria are indeed in the GC (and not the foreground), we find that $34.8 \pm 12.3\%$ are associated with green sources in the GC, and that $51.3 \pm 5.8\%$ of disk sources are associated with green sources. The association rate for the disk includes all Galactic latitudes. Because the GC is in the Galactic midplane, however, we should compare the GC association rate to the association rate in the rest of the midplane ($6^\circ > \ell > 345^\circ$), excluding the GC longitudes ($|\ell| < 1.3^\circ$). When we do this, we find that the disk midplane association rate is $34.9 \pm 7.4\%$, very close to the association rate for the GC. Thus, we find no differences between the two regions using position alone as a distance indicator.

When we use only the source velocity to estimate the locations of the masers, we find nearly identical association rates between the CH₃OH masers and the enhanced 4.5 μ m emission sources in the GC ($48.1 \pm 13.3\%$) and the disk ($49.3 \pm 5.8\%$). Because the positions of the masers are not considered in this distance estimate, no adjustment for the midplane is necessary. The similar association rates again point to no significant difference between the GC and disk regions.

Using both positional and velocity criteria to place sources at the distance of the Galactic center, we find a detection rate ($23.5 \pm 11.8\%$) that is lower than that of all other midplane sources ($34.9 \pm 7.4\%$). While the association rate in the GC is lower using both distance criteria, the large error bars keep this from being a significant result. When we look at the sources placed in the GC region by only *one* of the two indicators (position *or* velocity), we find that they have high association rates, $66.7 \pm 33.3\%$ for those sources whose positions match the GC, and $90.0 \pm 30.0\%$ for those whose velocities match the GC. Figure 14 shows a diagram with these association rates. These elevated rates could simply be a result of small number statistics, since when taking into account their error bars, they are consistent with the disk association rate, especially at larger Galactic latitudes. Nevertheless, this difference remains intriguing.

As described in Sect. 4.2.1, the combination of our Mopra CMZ survey, the Caswell et al. (2011) observations, and HOPS, yields a total of 177 H₂O masers within the region $30^\circ > \ell > 290^\circ$, $|b| < 0.5^\circ$. This covers the entire CMZ as well as a large part of the Galactic disk outside of the CMZ. Using this list, we can compare the association rates of CH₃OH masers with H₂O masers in the CMZ to those outside the CMZ, as determined by their positions. We find that of the 23 CH₃OH masers in the CMZ, 15 are spatially associated with H₂O masers ($65 \pm 17\%$). Outside of the CMZ, we find that 47 of the 131 CH₃OH masers ($36 \pm 5\%$) are associated with H₂O masers. Thus, there appears to be a significant difference between the correlation of CH₃OH and H₂O masers in these regions.

Fig. 13. *Top:* *Spitzer*/IRAC 8 μm image of the Galactic center region showing both CH_3OH and H_2O masers. Circles indicate the positions of the H_2O masers identified in the Mopra survey and the masers identified by [Walsh et al. \(2011\)](#). The size of the circle represents the FWHM of the Mopra beam at 22 GHz. The $\times$ symbols indicate the positions of H_2O masers identified by [Caswell et al. \(2011\)](#), and crosses (+) show the position of CH_3OH masers (the size of the $\times$ symbols and the crosses have no physical meaning). We consider a CH_3OH maser to be associated with a H_2O maser when it falls within the H_2O maser beam. For details on these associations, including their velocity information, see Table B.2. *Bottom:* same as the *top* figure, but with a blank background instead of the 8 μm image.

It is important to note that H_2O masers are also found toward AGB stars. These H_2O masers tend to be less luminous than those found toward high-mass star forming regions ([Palagi et al. 1993](#); [Caswell et al. 2011](#)). Indeed, in the [Caswell et al. \(2011\)](#) ATCA 0.5 deg^2 H_2O maser survey of the Galactic center, they found that only 3 of their 27 detected masers could be definitely attributed to AGB stars. Using this detection rate, ~ 4 of the 37 H_2O masers detected in our Mopra survey and ~ 13 of 113 H_2O masers in HOPS, may be associated with evolved AGB stars rather than sites of star formation. The H_2O masers associated with CH_3OH masers or green sources are very unlikely to also be associated with AGB stars. Thus, the effect of the small number of AGB H_2O masers in our sample is negligible.

The fact that we find significantly fewer H_2O masers toward the CH_3OH masers outside the CMZ is intriguing, and may be related to a different timescale of star formation inside the CMZ when compared to the Galactic disk. While still somewhat speculative, some recent work ([Ellingsen et al. 2007](#); [Breen et al. 2010](#)) has proposed an evolutionary sequence of CH_3OH masers in which Class I CH_3OH masers, generated by protostellar outflows, are formed before radiatively excited Class II CH_3OH masers (e.g., the 6.7 GHz CH_3OH maser). In addition, some observations have suggested that the 22 GHz H_2O maser also arises in an early phase of star formation and overlaps with the Class I CH_3OH masers, in particular toward green sources (e.g., [Chambers et al. 2009](#)). Thus, if we assume

Fig. 14. Diagram showing green source detection rates based on two different distance estimates. Sources placed in the Galactic center based on position all have $|\ell| < 1.3^\circ$ and $|b| < 10'$. Distance estimates based on velocity are taken from C10. For comparison, the green source detection rates for masers that are not at the distance of the Galactic center (based on position or velocity) is $48.6 \pm 5.9\%$ (69/142).

that the 22 GHz H_2O masers arise at an earlier evolutionary state than the 6.7 GHz CH_3OH masers, then perhaps the much higher correlation rate of the two masers in the GC (65% vs. 36%) corresponds to a longer overlap period of the two stages. This result can be tested using higher-resolution H_2O maser data to verify the GC correlations, a larger number of H_2O and CH_3OH masers in the GC (from more sensitive surveys), as well as large co-spatial surveys of H_2O and CH_3OH masers in the Galactic plane to better establish the correlation rate in the disk.

5.4. Asymmetry in the H_2O maser distribution around the Galactic center

Yusef-Zadeh et al. (2009) found an asymmetry in the distribution of young stellar object (YSO) candidates as probed by $24\ \mu\text{m}$ sources, with a larger number of YSO candidates with $\ell < 0$ relative to $\ell > 0$. The distribution of Mopra CMZ H_2O masers as a function of Galactic longitude (Fig. 10) shows no obvious asymmetry with respect to $\ell = 0$, with 19 masers having $\ell > 0$ and 18 masers having $\ell < 0$. The most striking feature in this distribution of H_2O masers is the peak at $\sim \ell = 0.7$, which is almost entirely due to masers in Sgr B2 (10 of the 11 masers in the bin have coordinates that place them within Sgr B2). If we remove these 10 masers from the distribution, we find that there are 11 H_2O masers with $\ell > 0$, and 16 with $\ell < 0$, consistent with the asymmetry found by Yusef-Zadeh et al. (2009). One explanation for the asymmetry offered by Yusef-Zadeh et al. (2009) was that higher extinction due to dense clouds may be responsible for the asymmetry in the distribution of $24\ \mu\text{m}$ sources. Extinction is not a problem at the frequency of the H_2O masers, suggesting that the asymmetry may be a real feature. The larger numbers of both $24\ \mu\text{m}$ sources and H_2O masers at $\ell < 0$ indicate an enhancement of on-going star formation in this region.

6. Conclusions

We present the results of our study of star formation in the CMZ and how it compares to the Galactic disk. We make our comparison through the correlation of 6.7 GHz CH_3OH masers, 22 GHz H_2O masers, and green sources. As part of this study, we developed an automated algorithm to identify regions of extended,

enhanced $4.5\ \mu\text{m}$ emission toward 6.7 GHz CH_3OH masers. This new technique can be a powerful tool to trace regions of star formation provided the column density along the line of sight is not too high. Moreover, we used the Mopra telescope to survey the 22 GHz H_2O maser emission in the CMZ, resulting in the detection of 37 individual water masers.

We find that the association rate of CH_3OH masers with green sources as a function of Galactic longitude is relatively flat. In Galactic latitude, on the other hand, we find that there is a significant decrease in the association rate along the Galactic midplane, which is likely an infrared extinction effect. Using two different distance estimates, we do not detect any significant difference in the association rates of green sources with CH_3OH masers between the Galactic center and the disk. This suggests that once the star formation process has begun, its observational signatures are similar in the GC and the Galactic disk, despite the different physical conditions of the gas in the two regions.

We find that CH_3OH masers are much more likely to be associated with a H_2O maser if they are located in the Galactic center rather than the Galactic disk, indicating a longer overlap period between these two masers in the GC. Future high angular resolution observations of the newly detected H_2O masers are needed to better establish the positions of the H_2O masers and test this result.

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Appendix A: Mopra H₂O spectra

Fig. A.1. Spectra of H₂O masers 1–15 detected in the survey region. The positions of the peak emission are printed on the spectra, and the numbers in the top-right of each plot correspond to the numbers in Table 2. The vertical line in each spectrum indicates the velocity of that maser.

Fig. A.1. continued.

Fig. A.1. continued.

Appendix B: Supplementary tables

Table B.1. Association of green sources with CH₃OH masers.

Maser name ^a	V_{peak}^a (km s ⁻¹)	R_{peak}			R_{bg}	R_{cut}	R_{thresh}	N_{pix}	Green source
		ℓ^b	b^b	Value					
G345.003−0.223	−23.1	345.0038	−0.2258	1.178	0.495	0.836	0.463	100	Y
G345.003−0.224	−26.2	345.0038	−0.2258	1.178	0.495	0.836	0.463	100	Y
G345.131−0.174	−28.9	345.1308	−0.1742	0.968	0.270	0.619	0.476	11	Y
G345.198−0.030	−0.5	345.1978	−0.0302	0.521	0.272	0.396	0.170	13	N
G345.205+0.317	−63.5	345.2048	0.3175	0.606	0.260	0.433	0.266	5	N
G345.407−0.952	−14.3	345.4065	−0.9518	0.429	0.170	0.299	0.167	4	N
G345.424−0.951	−13.2	345.4245	−0.9512	0.326	0.168	0.247	0.116	4	N
G345.441+0.205	0.9	345.4412	0.2048	0.695	0.276	0.485	0.312	7	N
G345.487+0.314	−22.6	345.4875	0.3152	0.513	0.240	0.377	0.184	52	N
G345.505+0.348	−17.8	345.5042	0.3465	1.029	0.351	0.690	0.437	87	Y
G345.576−0.225	−126.8	345.5762	−0.2255	0.683	0.292	0.488	0.291	13	Y
G345.807−0.044	−2	345.8068	−0.0442	0.828	0.287	0.558	0.416	7	N
G345.824+0.044	−10.3	345.8235	0.0432	0.912	0.268	0.590	0.435	10	Y
G345.949−0.268	−21.9	345.9495	−0.2678	0.671	0.294	0.483	0.295	12	Y
G345.985−0.020	−83.2	345.9852	−0.0202	1.191	0.249	0.720	0.605	13	Y
G346.036+0.048	−6.4	346.0362	0.0485	1.070	0.252	0.661	0.581	6	N
G346.231+0.119	−95	346.2325	0.1195	0.722	0.271	0.496	0.319	21	Y
G346.480+0.221	−18.9	346.4805	0.2212	1.162	0.307	0.735	0.620	13	Y
G346.481+0.132	−5.5	346.4815	0.1322	0.897	0.280	0.589	0.441	14	Y
G346.517+0.117	−1.7	346.5172	0.1175	0.402	0.223	0.312	0.129	3	N
G346.522+0.085	5.7	346.5225	0.0842	0.443	0.220	0.332	0.153	22	N
G347.230+0.016	−68.9	347.2302	0.0155	0.769	0.212	0.490	0.418	3	N
G347.583+0.213	−102.3	347.5835	0.2125	0.358	0.244	0.301	0.114	1	N
G347.628+0.149	−96.5	347.6278	0.1485	0.707	0.227	0.467	0.340	16	Y
G347.631+0.211	−91.9	347.6342	0.2082	0.343	0.232	0.287	0.101	2	N
G347.817+0.018	−24.1	347.8172	0.0178	0.926	0.264	0.595	0.449	8	N
G347.863+0.019	−34.7	347.8632	0.0185	0.632	0.234	0.433	0.291	9	Y
G347.902+0.052	−27.4	347.9042	0.0515	0.428	0.205	0.316	0.152	123	N
G348.027+0.106	−121.2	348.0268	0.1058	0.954	0.267	0.610	0.473	17	Y
G348.195+0.768	−0.8	348.1918	0.7665	1.076	0.332	0.704	0.744	1	N
G348.550−0.979	−10.6	348.5502	−0.9785	0.914	0.271	0.592	0.426	146	Y
G348.550−0.979 _n	−20	348.5502	−0.9785	0.914	0.271	0.592	0.426	146	Y
G348.579−0.920	−15.1	348.5785	−0.9198	1.062	0.440	0.751	0.411	148	Y
G348.654+0.244	16.9	348.6542	0.2445	0.747	0.275	0.511	0.355	11	Y
G348.723−0.078	11.5	348.7232	−0.0775	0.602	0.305	0.454	0.209	7	N
G348.703−1.043	−3.5	348.7032	−1.0422	0.309	0.177	0.243	0.085	36	N
G348.727−1.037	−7.4	348.7272	−1.0372	0.860	0.158	0.509	0.532	8	N
G348.884+0.096	−74.5	348.8845	0.0965	0.863	0.274	0.568	0.367	17	Y
G348.892−0.180	1.5	348.8918	−0.1795	1.140	0.282	0.711	0.630	5	N
G349.067−0.017	11.6	349.0672	−0.0168	0.593	0.262	0.427	0.241	12	Y
G349.092+0.105	−76.6	349.0915	0.1052	1.357	0.236	0.796	0.827	18	Y
G349.092+0.106	−81.5	349.0915	0.1052	1.357	0.236	0.796	0.827	18	Y
G349.151+0.021	14.6	349.1525	0.0222	0.697	0.268	0.483	0.279	7	N
G349.579−0.679	−25	349.5792	−0.6792	0.568	0.285	0.426	0.210	3	N
G349.799+0.108	−64.7	349.7985	0.1085	0.806	0.268	0.537	0.421	9	Y
G349.884+0.231	16.2	349.8832	0.2302	0.767	0.263	0.515	0.378	17	Y
G350.015+0.433	−30.3	350.0155	0.4332	0.615	0.241	0.428	0.261	16	Y
G350.104+0.084	−68.1	350.1048	0.0838	0.492	0.223	0.357	0.181	31	N
G350.105+0.083	−74.1	350.1048	0.0838	0.492	0.223	0.357	0.181	31	N
G350.116+0.084	−68	350.1168	0.0842	0.716	0.237	0.476	0.320	8	N
G350.116+0.220	4.2	350.1155	0.2205	0.997	0.279	0.638	0.541	4	N
G350.189+0.003	−62.4	350.1868	0.0022	0.711	0.268	0.489	0.343	4	N
G350.299+0.122	−62.1	350.2982	0.1198	0.700	0.231	0.465	0.334	31	Y
G350.340+0.141	−58.4	350.3402	0.1412	0.499	0.246	0.372	0.163	10	N
G350.344+0.116	−65.4	350.3438	0.1165	0.611	0.274	0.443	0.226	8	N
G350.356−0.068	−67.6	350.3562	−0.0678	0.874	0.263	0.569	0.431	19	Y
G350.470+0.029	−6.3	350.4702	0.0288	0.491	0.270	0.381	0.186	4	N
G350.520−0.350	−24.6	350.5195	−0.3492	1.017	0.269	0.643	0.547	14	Y
G350.686−0.491	−13.7	350.6855	−0.4905	1.349	0.312	0.830	0.749	10	Y
G350.776+0.138	38.7	350.7755	0.1382	0.826	0.255	0.540	0.380	4	N

Notes. ^(a) From C10. ^(b) Derived from IRAC data, which have a pixel size of 1.2″. ^(c) For CH₃OH masers not detected in the C10 follow-up data, we use their survey cube data or the value they list from [Houghton & Whiteoak \(1995\)](#).

Table B.1. continued.

Maser name ^a	V_{peak}^a (km s ⁻¹)	R_{peak}			R_{bg}	R_{cut}	R_{thresh}	N_{pix}	Green source
		ℓ^b	b^b	Value					
G351.161+0.697	-5.2	351.1602	0.6968	0.853	0.392	0.622	0.321	517	Y
G351.242+0.670	2.5	351.2425	0.6708	0.377	0.194	0.285	0.136	54	N
G351.251+0.652	-7.1	351.2522	0.6515	0.620	0.166	0.393	0.290	61	Y
G351.382-0.181	-59.7	351.3822	-0.1808	0.807	0.277	0.542	0.407	10	Y
G351.417+0.645	-10.4	351.4168	0.6462	0.587	0.187	0.387	0.273	23	Y
G351.417+0.646	-11.1	351.4168	0.6462	0.587	0.187	0.387	0.273	23	Y
G351.445+0.660	-7.1	351.4442	0.6602	0.548	0.243	0.395	0.204	27	Y
G351.581-0.353	-94.2	351.5818	-0.3532	1.574	0.337	0.956	0.885	10	Y
G351.611+0.172	-43.7	351.6115	0.1698	0.284	0.195	0.239	0.075	309	N
G351.688+0.171	-36.1	351.6878	0.1708	0.726	0.258	0.492	0.343	13	Y
G351.775-0.536	1.3	351.7752	-0.5345	1.790	0.501	1.146	0.797	20	Y
G352.083+0.167	-66	352.0835	0.1672	0.615	0.259	0.437	0.259	13	Y
G352.111+0.176	-54.8	352.1108	0.1762	0.852	0.259	0.555	0.404	16	Y
G352.133-0.944	-7.7	352.1325	-0.9425	0.977	0.359	0.668	0.378	50	Y
G352.517-0.155	-51.2	352.5175	-0.1552	0.398	0.239	0.318	0.127	6	N
G352.525-0.158	-53	352.5248	-0.1582	0.854	0.238	0.546	0.483	7	N
G352.584-0.185	-85.7	352.5835	-0.1848	0.694	0.252	0.473	0.334	6	N
G352.604-0.225	-81.7	352.6042	-0.2252	0.829	0.284	0.556	0.368	14	Y
G352.855-0.201	-51.3	352.8548	-0.2005	0.616	0.231	0.423	0.295	4	N
G353.216-0.249	-22.9	353.2132	-0.2478	0.394	0.215	0.305	0.122	8	N
G353.273+0.641	-4.4	353.2725	0.6418	0.920	0.181	0.550	0.463	19	Y
G353.363-0.166	-79	353.3635	-0.1678	0.352	0.203	0.277	0.102	7	N
G353.370-0.091	-44.7	353.3705	-0.0905	0.462	0.251	0.356	0.154	16	N
G353.378+0.438	-15.7	353.3782	0.4375	0.419	0.252	0.336	0.115	4	N
G353.410-0.360	-20.3	353.4105	-0.3602	0.566	0.258	0.412	0.235	11	Y
G353.429-0.090	-61.8	353.4268	-0.0892	0.837	0.307	0.572	0.408	7	N
G353.464+0.562	-50.3	353.4635	0.5628	1.161	0.294	0.728	0.605	29	Y
G353.537-0.091	-56.6	353.5372	-0.0912	0.971	0.269	0.620	0.518	14	Y
G354.206-0.038	-37.1	354.2052	-0.0382	0.613	0.227	0.420	0.386	1	N
G354.308-0.110	18.8	354.3075	-0.1098	0.575	0.279	0.427	0.231	5	N
G354.496+0.083	27	354.4955	0.0825	0.390	0.238	0.314	0.098	14	N
G354.615+0.472	-24.4	354.6132	0.4718	0.619	0.284	0.451	0.228	37	Y
G354.701+0.299	102.8	354.6998	0.3002	0.975	0.323	0.649	0.537	4	N
G354.724+0.300	93.9	354.7232	0.3012	1.118	0.341	0.729	0.574	4	N
G355.184-0.419	-1.4 ^c	355.1825	-0.4188	1.557	0.403	0.980	0.720	15	Y
G355.343+0.148	5.8	355.3442	0.1475	0.485	0.270	0.378	0.157	14	N
G355.344+0.147	19.9	355.3442	0.1475	0.485	0.270	0.378	0.157	14	N
G355.346+0.149	10.5	355.3455	0.1492	0.510	0.273	0.392	0.184	4	N
G355.538-0.105	3.8	355.5382	-0.1045	0.603	0.272	0.438	0.245	29	Y
G355.545-0.103	-28.2	355.5452	-0.1035	0.566	0.267	0.416	0.210	20	Y
G355.642+0.398	-7.9	355.6418	0.3978	1.064	0.286	0.675	0.778	1	N
G355.666+0.374	-3.3	355.6665	0.3735	0.428	0.264	0.346	0.123	11	N
G356.054-0.095	16.7	356.0545	-0.0972	0.442	0.281	0.361	0.139	2	N
G356.662-0.263	-53.8	356.6612	-0.2628	1.188	0.356	0.772	0.570	9	Y
G357.558-0.321	-3.9	357.5575	-0.3215	0.776	0.328	0.552	0.307	8	N
G357.559-0.321	16.2	357.5575	-0.3215	0.776	0.328	0.552	0.307	8	N
G357.922-0.337	-4.6	357.9252	-0.3368	0.800	0.279	0.539	0.385	24	Y
G357.924-0.337	-2.1	357.9255	-0.3372	0.828	0.279	0.553	0.389	23	Y
G357.965-0.164	-8.6	357.9642	-0.1638	0.911	0.274	0.592	0.476	10	Y
G357.967-0.163	-3.1	357.9645	-0.1642	0.848	0.274	0.561	0.425	14	Y
G358.371-0.468	1.3	358.3712	-0.4685	0.799	0.231	0.515	0.425	20	Y
G358.386-0.483	-6	358.3868	-0.4812	0.585	0.281	0.433	0.226	178	Y
G358.460-0.391	1.3	358.4598	-0.3935	0.981	0.329	0.655	0.458	34	Y
G358.460-0.393	-7.3	358.4602	-0.3938	0.975	0.324	0.649	0.456	36	Y
G358.721-0.126	10.6	358.7215	-0.1262	0.917	0.316	0.617	0.410	6	N
G358.809-0.085	-56.2	358.8085	-0.0852	1.466	0.492	0.979	0.673	12	Y
G358.841-0.737	-20.7	358.8405	-0.7365	0.707	0.309	0.508	0.282	31	Y
G358.906+0.106	-18.1	358.9058	0.1045	0.530	0.363	0.446	0.107	4	N
G358.931-0.030	-15.9	358.9318	-0.0305	0.519	0.299	0.409	0.158	7	N
G358.980+0.084	6.2	358.9798	0.0842	1.330	0.515	0.923	0.537	29	Y
G359.138+0.031	-3.9	359.1378	0.0325	0.503	0.306	0.404	0.142	23	N
G359.436-0.104	-47.8	359.4368	-0.1018	0.942	0.292	0.617	0.434	40	Y
G359.436-0.102	-53.3	359.4368	-0.1018	0.942	0.292	0.617	0.434	40	Y
G359.615-0.243	19.3	359.6125	-0.2415	1.154	0.328	0.741	0.559	9	Y
G359.938+0.170	-0.5	359.9382	0.1705	1.401	0.511	0.956	0.590	30	Y

Table B.1. continued.

Maser name ^a	V_{peak}^a (km s ⁻¹)	R_{peak}			R_{bg}	R_{cut}	R_{thresh}	N_{pix}	Green source
		ℓ^b	b^b	Value					
G359.970-0.457	23	359.9692	-0.4588	0.735	0.263	0.499	0.313	42	Y
G0.092+0.663	23.8	0.0902	-0.6632	1.918	0.459	1.188	0.995	19	Y
G0.167-0.446	13.8	0.1672	-0.4438	1.330	0.362	0.846	0.690	14	Y
G0.212-0.001	49.5	0.2118	-0.0008	0.314	0.229	0.271	0.066	6	N
G0.315-0.201	19.4	0.3155	-0.2002	0.536	0.190	0.363	0.239	44	Y
G0.316-0.201	21.1	0.3155	-0.2002	0.536	0.190	0.363	0.239	44	Y
G0.376+0.040	37.1	0.3762	0.0402	1.114	0.342	0.728	0.550	14	Y
G0.409-0.504	25.4	0.4085	-0.5042	0.699	0.211	0.455	0.357	15	Y
G0.475-0.010	28.8	0.4748	-0.0098	0.374	0.317	0.346	0.048	4	N
G0.496+0.188	0.9	0.4965	0.1885	0.522	0.244	0.383	0.225	8	N
G0.546-0.852	11.8	0.5462	-0.8505	0.679	0.190	0.435	0.345	9	Y
G0.645-0.042	49.5	0.6438	-0.0405	0.847	0.293	0.570	0.366	6	N
G0.647-0.055	51 ^c	0.6462	-0.0552	0.510	0.282	0.396	0.183	2	N
G0.651-0.049	48.3	0.6528	-0.0498	0.430	0.285	0.357	0.108	3	N
G0.657-0.041	49.9 ^c	0.6578	-0.0415	0.856	0.291	0.574	0.385	19	Y
G0.665-0.036	60.4	0.6668	-0.0352	1.845	0.301	1.073	1.024	9	Y
G0.666-0.029	70.5	0.6662	-0.0288	0.483	0.283	0.383	0.145	4	N
G0.667-0.034	55 ^c	0.6668	-0.0352	1.845	0.301	1.073	1.024	9	Y
G0.672-0.031	58.2	0.6735	-0.0308	0.429	0.306	0.367	0.123	1	N
G0.673-0.029	66 ^c	0.6722	-0.0285	0.454	0.287	0.370	0.111	6	N
G0.677-0.025	73.3	0.6782	-0.0242	0.477	0.288	0.382	0.152	2	N
G0.695-0.038	68.6	0.6948	-0.0378	0.562	0.307	0.434	0.197	5	N
G0.836+0.184	3.5	0.8352	0.1848	0.314	0.245	0.280	0.070	1	N
G1.008-0.237	1.6	1.0085	-0.2378	0.450	0.266	0.358	0.135	19	N
G1.147-0.124	-15.3	1.1485	-0.1268	0.704	0.226	0.465	0.328	4	N
G1.329+0.150	-12.2	1.3285	0.1502	0.287	0.191	0.239	0.096	1	N
G1.719-0.088	-8.1	1.7188	-0.0878	1.203	0.374	0.789	0.543	6	N
G2.143+0.009	62.6	2.1448	0.0098	0.676	0.319	0.498	0.267	24	Y
G2.521-0.220	-6.1	2.5205	-0.2198	0.857	0.297	0.577	0.425	10	Y
G2.536+0.198	3.1	2.5358	0.1998	1.259	0.489	0.874	0.493	130	Y
G2.591-0.029	-8.3	2.5892	-0.0282	0.472	0.263	0.368	0.209	1	N
G2.615+0.134	94.1	2.6165	0.1345	0.380	0.264	0.322	0.084	6	N
G2.703+0.040	93.5	2.7062	0.0395	0.800	0.302	0.551	0.498	1	N
G3.253+0.018	2.2	3.2532	0.0185	0.727	0.306	0.516	0.346	5	N
G3.312-0.399	0.4	3.3118	-0.3965	1.649	0.413	1.031	0.939	10	Y
G3.442-0.348	-35.1	3.4418	-0.3482	2.928	0.388	1.658	1.946	4	N
G3.502-0.200	43.9	3.5008	-0.2008	1.081	0.333	0.707	0.517	6	N
G3.910+0.001	17.8	3.9102	0.0008	0.734	0.258	0.496	0.347	9	Y
G4.393+0.079	1.9	4.3935	0.0788	0.475	0.240	0.357	0.151	7	N
G4.434+0.129	-1	4.4342	0.1288	0.595	0.261	0.428	0.258	5	N
G4.569-0.079	9.5	4.5685	-0.0792	0.729	0.268	0.498	0.302	7	N
G4.586+0.028	26.1	4.5848	0.0252	0.609	0.280	0.445	0.329	1	N
G4.676+0.276	4.5	4.6752	0.2775	0.842	0.299	0.571	0.434	4	N
G4.866-0.171	5.4	4.8658	-0.1708	0.488	0.306	0.397	0.132	9	N
G5.618-0.082	-27.1	5.6188	-0.0812	1.113	0.294	0.703	0.523	15	Y
G5.630-0.294	10.5	5.6302	-0.2938	0.586	0.286	0.436	0.231	10	Y
G5.657+0.416	20	5.6555	0.4158	0.775	0.288	0.531	0.366	11	Y
G5.677-0.027	-11.7	5.6772	-0.0272	0.531	0.274	0.403	0.208	8	N
G5.885-0.393	6.7	5.8832	-0.3935	0.641	0.208	0.424	0.263	76	Y
G5.900-0.430	10.4	5.9002	-0.4318	0.224	0.153	0.189	0.049	5	N

Table B.2. Association of H₂O masers with CH₃OH masers.

CH ₃ OH masers				H ₂ O masers			Angular separation (")	Green source
Name	v_{low}^a (km s ⁻¹)	v_{high}^a (km s ⁻¹)	ℓ (°)	b (°)	v (km s ⁻¹)	Ref ^b		
345.131-0.174	-31.0	-28.0	345.125	-0.158	-25.1	3	62	Y
345.441+0.205	-13.0	2.0	345.442	0.208	-16.6	3	13	N
345.505+0.348	-23.1	-10.5	345.500	0.358	-19.7	3	38	Y
345.807-0.044	-3.0	-0.5	345.825	-0.050	-6.9	3	68	N
345.985-0.020	-85.5	-81.7	345.975	-0.008	-77.5	3	57	Y
346.517+0.117	-3.0	1.0	346.517	0.108	3.2	3	34	N
347.230+0.016	-69.9	-68.0	347.225	0.017	-77.8	3	18	N
347.628+0.149	-98.9	-95.0	347.625	0.158	-65.2	3	36	Y
347.631+0.211	-94.0	-89.0	347.634	0.217	-90.2	3	25	N
348.892-0.180	1.0	2.0	348.892	-0.183	10.5	3	10	N
349.092+0.105	-78.0	-74.0	349.095	0.108	-79.5	3	16	Y
349.092+0.106	-83.0	-78.0	349.095	0.108	-79.5	3	15	Y
349.799+0.108	-65.5	-57.4	349.798	0.108	-60.6	3	3	Y
350.104+0.084	-69.0	-67.5	350.109	0.091	-72.9	3	30	N
350.105+0.083	-76.0	-61.0	350.109	0.091	-72.9	3	31	N
350.116+0.084	-69.0	-67.0	350.109	0.091	-72.9	3	36	N
350.520-0.350	-25.0	-22.0	350.526	-0.342	-17.3	3	35	Y
350.686-0.491	-15.0	-13.0	350.692	-0.483	-14.2	3	36	Y
351.581-0.353	-100.0	-88.0	351.583	-0.350	-94.0	3	13	Y
351.611+0.172	-46.0	-31.5	351.617	0.175	-42.2	3	24	N
353.216-0.249	-25.0	-15.0	353.217	-0.242	-19.3	3	24	N
353.378+0.438	-16.5	-14.0	353.392	0.433	-40.6	3	53	N
353.410-0.360	-23.0	-19.0	353.417	-0.367	-19.7	3	36	Y
354.308-0.110	11.0	19.5	354.308	-0.108	9.0	3	6	N
355.184-0.419	-2.0	-0.5	355.184	-0.417	0.2	3	8	Y
355.343+0.148	4.0	7.0	355.342	0.150	9.6	3	9	N
355.344+0.147	19.0	21.0	355.342	0.150	9.6	3	12	N
355.346+0.149	9.0	12.5	355.342	0.150	9.6	3	14	N
357.558-0.321	-5.5	0.0	357.567	-0.317	-8.4	3	37	N
357.559-0.321	15.0	18.0	357.567	-0.317	-8.4	3	34	N
357.922-0.337	-5.5	-4.0	357.925	-0.342	1.4	3	21	Y
357.924-0.337	-4.5	3.0	357.925	-0.342	1.4	3	19	Y
357.965-0.164	-9.0	3.0	357.967	-0.158	-50.8	3	21	Y
357.967-0.163	-6.0	0.0	357.967	-0.158	-50.8	3	17	Y
358.386-0.483	-7.0	-5.0	358.392	-0.484	-0.6	3	20	Y
358.460-0.391	-0.5	4.0	358.467	-0.384	-4.7	3	35	Y
358.460-0.393	-8.5	6.0	358.467	-0.384	-4.7	3	40	Y
359.138+0.031	-7.0	1.0	359.147	0.030	-1.4	1	33	N
			359.138	0.030	-1.4	1	4	N
			359.138	0.030	-12.3	1	4	N
			359.139	0.026	-1.7	3	21	N
359.436-0.104	-53.0	-45.0	359.430	-0.103	-59.5	1	23	Y
			359.439	-0.104	-58.4	3	10	Y
359.436-0.102	-58.0	-54.0	359.430	-0.103	-59.5	1	24	Y
			359.439	-0.104	-58.4	3	12	Y
359.615-0.243	14.0	27.0	359.616	-0.248	-15.9	3	18	Y
359.970-0.457	20.0	24.1	359.970	-0.463	26.8	3	21	Y
0.212-0.001	41.0	50.5	0.205	-0.011	-15.9	1	45	N
			0.205	0.005	42.2	1	34	N
			0.212	-0.001	46.0	2	1	N
0.315-0.201	14.0	27.0	0.315	-0.201	21.0	2	1	Y
			0.310	-0.209	21.5	3	36	Y
0.316-0.201	20.0	22.0	0.315	-0.201	21.0	2	2	Y
			0.310	-0.209	21.5	3	34	Y
0.376+0.040	35.0	40.0	0.380	0.047	38.6	1	30	Y
			0.371	0.030	16.8	1	38	Y
			0.376	0.040	37.0	2	1	Y
			0.378	0.031	40.0	3	33	Y
0.645-0.042	46.0	53.0	0.663	-0.036	71.3	1	69	N
0.651-0.049	46.0	49.0	0.663	-0.036	71.3	1	62	N

Notes. ^(a) For easier comparison with the H₂O masers, here we list the upper and lower bounds of the CH₃OH maser emission, as listed by C10.
^(b) Catalog from which the maser was identified: 1 indicates this work (Mopra survey); 2 indicates [Caswell et al. \(2011\)](#); and 3 indicates [Walsh et al. \(2011\)](#).

Table B.2. continued.

CH ₃ OH masers			H ₂ O masers			Ref ^b	Angular separation (")	Green source
Name	v_{low}^a (km s ⁻¹)	v_{high}^a (km s ⁻¹)	ℓ (°)	b (°)	v (km s ⁻¹)			
0.657–0.041	48.0	56.0	0.666	−0.038	70.7	3	65	N
			0.663	−0.036	71.3	1	29	Y
			0.666	−0.038	70.7	3	35	Y
0.665–0.036	58.0	62.0	0.663	−0.036	71.3	1	6	Y
			0.663	−0.019	53.1	1	59	Y
			0.671	−0.019	42.2	1	64	Y
			0.671	−0.019	31.3	1	64	Y
			0.671	−0.019	100.4	1	64	Y
			0.671	−0.019	111.3	1	64	Y
			0.671	−0.019	2.2	1	64	Y
			0.671	−0.019	129.4	1	64	Y
			0.671	−0.019	122.2	1	64	Y
			0.666	−0.038	70.7	3	9	Y
0.666–0.029	68.0	73.0	0.663	−0.036	71.3	1	29	N
			0.663	−0.019	53.1	1	36	N
			0.671	−0.019	42.2	1	38	N
			0.671	−0.019	31.3	1	38	N
			0.671	−0.019	100.4	1	38	N
			0.671	−0.019	111.3	1	38	N
			0.671	−0.019	2.2	1	38	N
			0.671	−0.019	129.4	1	38	N
			0.671	−0.019	122.2	1	38	N
			0.666	−0.038	70.7	3	33	N
0.667–0.034	49.0	56.0	0.663	−0.036	71.3	1	17	Y
			0.663	−0.019	53.1	1	53	Y
			0.671	−0.019	42.2	1	53	Y
			0.671	−0.019	31.3	1	53	Y
			0.671	−0.019	100.4	1	53	Y
			0.671	−0.019	111.3	1	53	Y
			0.671	−0.019	2.2	1	53	Y
			0.671	−0.019	129.4	1	53	Y
			0.671	−0.019	122.2	1	53	Y
			0.666	−0.038	70.7	3	16	Y
0.672–0.031	55.0	59.0	0.663	−0.036	71.3	1	37	N
			0.663	−0.019	53.1	1	54	N
			0.671	−0.019	42.2	1	43	N
			0.671	−0.019	31.3	1	43	N
			0.671	−0.019	100.4	1	43	N
			0.671	−0.019	111.3	1	43	N
			0.671	−0.019	2.2	1	43	N
			0.671	−0.019	129.4	1	43	N
			0.671	−0.019	122.2	1	43	N
			0.666	−0.038	70.7	3	33	N
0.673–0.029	65.5	66.5	0.663	−0.036	71.3	1	46	N
			0.663	−0.019	53.1	1	49	N
			0.671	−0.019	42.2	1	33	N
			0.671	−0.019	31.3	1	33	N
			0.671	−0.019	100.4	1	33	N
			0.671	−0.019	111.3	1	33	N
			0.671	−0.019	2.2	1	33	N
			0.671	−0.019	129.4	1	33	N
			0.671	−0.019	122.2	1	33	N
			0.666	−0.038	70.7	3	43	N
0.677–0.025	70.0	77.0	0.663	−0.036	71.3	1	64	N
			0.663	−0.019	53.1	1	54	N
			0.671	−0.019	42.2	1	28	N
			0.671	−0.019	31.3	1	28	N
			0.671	−0.019	100.4	1	28	N
			0.671	−0.019	111.3	1	28	N
			0.671	−0.019	2.2	1	28	N
			0.671	−0.019	129.4	1	28	N
			0.671	−0.019	122.2	1	28	N
			0.666	−0.038	70.7	3	61	N

Table B.2. continued.

CH ₃ OH masers			H ₂ O masers			Ref ^b	Angular separation ($''$)	Green source
Name	v_{low}^a (km s ⁻¹)	v_{high}^a (km s ⁻¹)	ℓ ($^\circ$)	b ($^\circ$)	v (km s ⁻¹)			
1.008–0.237	1.0	7.0	1.006	–0.243	3.4	3	23	N
1.147–0.124	–20.5	–14.0	1.138	–0.128	–19.6	1	34	N
			1.148	–0.130	–21.6	3	21	N
2.521–0.220	–7.5	5.0	2.526	–0.228	1.5	3	34	Y
5.630–0.294	9.0	22.0	5.625	–0.294	17.5	3	16	Y
5.657+0.416	13.0	22.0	5.659	0.415	18.3	3	9	Y
5.885–0.393	6.0	7.5	5.883	–0.391	9.4	3	12	Y
5.900–0.430	0.0	10.6	5.900	–0.433	10.1	3	12	N

Table B.3. CH₃OH masers not associated with H₂O masers.

Name	ℓ ($^{\circ}$)	b ($^{\circ}$)	v_{low}^a (km s $^{-1}$)	v_{high}^a (km s $^{-1}$)	S_{peak} (Jy)	Green source
345.003–0.223	345.003	–0.223	–25.0	–20.1	236	Y
345.003–0.224	345.003	–0.224	–33.0	–25.0	102	Y
345.198–0.030	345.198	–0.030	–4.0	1.0	2.53	N
345.205+0.317	345.205	0.317	–64.1	–59.9	0.8	N
345.407–0.952	345.407	–0.952	–15.5	–14.0	2	N
345.424–0.951	345.424	–0.951	–21.0	–5.0	2.92	N
345.487+0.314	345.487	0.314	–24.0	–21.5	2.5	N
345.576–0.225	345.576	–0.225	–127.2	–122.0	0.64	Y
345.824+0.044	345.824	0.044	–12.0	–9.0	3.17	Y
345.949–0.268	345.949	–0.268	–22.5	–21.4	1.53	Y
346.036+0.048	346.036	0.048	–14.5	–3.9	8.99	N
346.231+0.119	346.232	0.119	–96.6	–92.6	1.5	Y
346.480+0.221	346.480	0.221	–21.0	–14.0	30.15	Y
346.481+0.132	346.481	0.132	–11.6	–4.9	2.1	Y
346.522+0.085	346.522	0.085	4.7	6.1	1.9	N
347.583+0.213	347.583	0.213	–103.8	–96.0	3.18	N
347.817+0.018	347.817	0.018	–26.0	–22.8	2.52	N
347.863+0.019	347.863	0.019	–37.8	–28.0	6.38	Y
347.902+0.052	347.902	0.052	–31.5	–27.0	5.37	N
348.027+0.106	348.027	0.106	–122.8	–114.3	3.07	Y
348.195+0.768	348.195	0.768	–2.8	–0.2	4.55	N
348.550–0.979	348.550	–0.979	–19.0	–7.0	41.1	Y
348.550–0.979 _n	348.550	–0.979	–23.0	–14.0	22.6	Y
348.579–0.920	348.579	–0.920	–16.0	–14.0	0.32	Y
348.654+0.244	348.654	0.244	16.5	17.5	0.82	Y
348.723–0.078	348.723	–0.077	9.0	12.0	2.58	N
348.703–1.043	348.704	–1.044	–17.5	–2.5	65	N
348.727–1.037	348.727	–1.037	–12.0	–6.0	80.78	N
348.884+0.096	348.885	0.097	–79.0	–73.0	12.18	Y
349.067–0.017	349.067	–0.017	6.0	16.0	2.3	Y
349.151+0.021	349.151	0.021	14.1	25.0	3.36	N
349.579–0.679	349.579	–0.679	–26.0	–24.0	1.9	N
349.884+0.231	349.884	0.231	13.5	17.5	6.96	Y
350.015+0.433	350.015	0.433	–37.0	–29.0	7.2	Y
350.116+0.220	350.116	0.220	3.0	5.0	2.78	N
350.189+0.003	350.189	0.003	–65.0	–62.0	1.07	N
350.299+0.122	350.299	0.122	–70.0	–61.0	31.34	Y
350.340+0.141	350.340	0.141	–60.0	–57.5	2.5	N
350.344+0.116	350.344	0.116	–66.0	–55.0	19.9	N
350.356–0.068	350.356	–0.068	–68.5	–66.0	1.44	Y
350.470+0.029	350.470	0.029	–11.0	–5.5	1.44	N
350.776+0.138	350.776	0.138	34.5	39.0	0.65	N
351.161+0.697	351.161	0.697	–7.0	–2.0	17.02	Y
351.242+0.670	351.242	0.670	2.0	3.0	0.74	N
351.251+0.652	351.251	0.652	–7.5	–6.0	0.99	Y
351.382–0.181	351.382	–0.181	–69.0	–58.0	19.66	Y
351.417+0.645	351.417	0.645	–12.0	–6.0	3423	Y
351.417+0.646	351.417	0.646	–12.0	–7.0	1840	Y
351.445+0.660	351.445	0.660	–14.0	1.0	129	Y
351.688+0.171	351.688	0.171	–47.5	–35.0	41.54	Y
351.775–0.536	351.775	–0.536	–9.0	3.0	231	Y
352.083+0.167	352.083	0.167	–68.2	–63.6	6.77	Y
352.111+0.176	352.111	0.176	–61.0	–50.0	7.46	Y
352.133–0.944	352.133	–0.944	–18.8	–5.6	16.32	Y
352.517–0.155	352.517	–0.155	–52.0	–49.0	9.69	N
352.525–0.158	352.525	–0.158	–62.0	–52.0	0.7	N
352.584–0.185	352.584	–0.185	–92.6	–79.7	6.38	N
352.604–0.225	352.604	–0.225	–85.0	–81.0	3.3	Y
352.855–0.201	352.855	–0.200	–54.1	–50.1	1.29	N
353.273+0.641	353.273	0.641	–7.0	–3.0	8.3	Y
353.363–0.166	353.363	–0.166	–80.1	–78.3	2.79	N

Notes. ^(a) For easier comparison with the H₂O masers, here we list the upper and lower bounds of the CH₃OH maser emission, as listed by C10.

^(b) For CH₃OH masers not detected in the C10 follow-up data, we use their survey cube data or the value they list from [Houghton & Whiteoak \(1995\)](#).

Table B.3. continued.

Name	ℓ ($^{\circ}$)	b ($^{\circ}$)	v_{low}^a (km s $^{-1}$)	v_{high}^a (km s $^{-1}$)	S_{peak} (Jy)	Green source
353.370−0.091	353.370	−0.091	−56.0	−43.4	1.35	N
353.429−0.090	353.429	−0.090	−63.9	−45.0	13.39	N
353.464+0.562	353.464	0.562	−52.7	−48.7	11.88	Y
353.537−0.091	353.537	−0.091	−59.0	−54.0	2.51	Y
354.206−0.038	354.205	−0.038	−37.5	−35.0	1.11	N
354.496+0.083	354.495	0.083	17.5	27.5	8.41	N
354.615+0.472	354.615	0.472	−27.0	−12.5	166	Y
354.701+0.299	354.701	0.300	98.0	104.0	1.29	N
354.724+0.300	354.724	0.300	91.0	95.0	12.58	N
355.538−0.105	355.538	−0.105	−3.5	5.0	1.25	Y
355.545−0.103	355.545	−0.103	−31.0	−27.5	1.22	Y
355.642+0.398	355.642	0.398	−9.0	−6.9	1.44	N
355.666+0.374	355.666	0.374	−4.5	0.6	2.47	N
356.054−0.095	356.054	−0.095	15.6	17.7	0.52	N
356.662−0.263	356.662	−0.263	−57.0	−44.0	8.38	Y
358.371−0.468	358.371	−0.468	−1.0	13.0	44.01	Y
358.721−0.126	358.721	−0.126	8.8	13.9	2.99	N
358.809−0.085	358.809	−0.085	−60.3	−50.5	6.86	Y
358.841−0.737	358.841	−0.737	−30.0	−17.0	10.94	Y
358.906+0.106	358.906	0.106	−20.5	−16.5	1.7	N
358.931−0.030	358.931	−0.029	−22.0	−14.5	5.9	N
358.980+0.084	358.980	0.084	5.0	7.0	<0.2	Y
359.938+0.170	359.938	0.170	−1.5	0.2	2.34	Y
0.092+0.663	0.092	−0.663	10.0	25.0	18.86	Y
0.167−0.446	0.167	−0.446	9.5	17.0	1.33	Y
0.409−0.504	0.409	−0.504	24.5	27.0	2.61	Y
0.475−0.010	0.475	−0.009	23.0	31.0	3.14	N
0.496+0.188	0.496	0.188	−12.0	2.0	24.51	N
0.546−0.852	0.546	−0.851	8.0	20.0	61.92	Y
0.647−0.055	0.647	−0.055	49.0	52.0	2.0 ^b	N
0.695−0.038	0.695	−0.038	64.0	75.0	32.33	N
0.836+0.184	0.836	0.185	2.0	5.0	6.64	N
1.329+0.150	1.329	0.150	−13.5	−11.0	2.08	N
1.719−0.088	1.719	−0.088	−9.0	−4.5	7.82	N
2.143+0.009	2.143	0.009	54.0	65.0	7.08	Y
2.536+0.198	2.536	0.198	2.0	20.5	29.4	Y
2.591−0.029	2.591	−0.029	−9.5	−4.0	1.76	N
2.615+0.134	2.615	0.134	93.5	104.0	1.22	N
2.703+0.040	2.703	0.040	91.5	98.0	8.97	N
3.253+0.018	3.253	0.019	−1.5	3.5	3.54	N
3.312−0.399	3.312	−0.399	0.0	10.0	1.17	Y
3.442−0.348	3.442	−0.348	−35.5	−34.5	1.06	N
3.502−0.200	3.502	−0.200	43.0	45.5	1.57	N
3.910+0.001	3.910	0.001	15.0	24.5	5.04	Y
4.393+0.079	4.393	0.079	0.0	9.0	6.74	N
4.434+0.129	4.434	0.129	−1.5	8.0	3.29	N
4.569−0.079	4.569	−0.079	9.0	10.0	0.44	N
4.586+0.028	4.586	0.028	15.0	27.0	1.16	N
4.676+0.276	4.676	0.276	−5.5	6.0	2.06	N
4.866−0.171	4.866	−0.171	5.0	6.0	0.56	N
5.618−0.082	5.618	−0.082	−28.0	−18.5	3.37	Y
5.677−0.027	5.677	−0.027	−14.5	−11.0	0.79	N

Table B.4. H₂O masers not associated with CH₃OH masers.

Name/ Number	ℓ (°)	b (°)	v (km s ⁻¹)	Peak (K)
H ₂ O masers from Mopra data (this work)				(K)
9	358.663	-0.053	-8.7	0.74
12	358.663	-0.053	-15.9	0.45
13	0.055	-0.220	13.2	0.54
15	359.322	-0.036	-110.4	0.16
17	0.613	0.005	9.5	0.16
18	359.296	0.030	-1.4	0.11
19	358.663	-0.036	2.2	0.16
20	0.155	-0.561	-70.4	0.20
23	1.163	-0.019	-19.6	0.08
24	0.763	-0.253	-48.6	0.09
25	359.338	0.281	-1.4	0.16
27	0.197	-0.153	45.9	0.06
28	358.897	0.022	-15.9	0.13
29	359.280	0.164	53.1	0.06
31	359.930	-0.153	-8.7	0.07
32	359.930	-0.144	-19.6	0.07
33	359.755	-0.378	-59.5	0.10
35	358.538	-0.195	-208.5	0.07
37	1.705	-0.486	-37.7	0.07
H ₂ O masers from Caswell et al. (2011)				(Jy)
359.727-0.380	359.727	-0.380	-5.0	15.00
359.751-0.371	359.751	-0.371	-10.0	9.60
359.861-0.081	359.861	-0.081	10.0	4.30
359.865-0.085	359.865	-0.085	10.0	0.30
359.882-0.342	359.882	-0.342	95.0	0.82
359.892-0.068	359.892	-0.067	30.0	0.89
359.936-0.145	359.936	-0.145	-10.0	5.20
0.040-0.056	0.040	-0.056	55.0	1.28
0.055-0.211	0.055	-0.211	15.0	2.20
0.097-0.166	0.097	-0.166	0.0	0.95
0.108-0.097	0.108	-0.097	-30.0	0.89
0.125-0.067	0.125	-0.067	-25.0	0.74
0.179-0.108	0.179	-0.108	80.0	1.70
0.209-0.002	0.208	-0.002	35.0	0.90
0.212-0.011	0.212	-0.011	85.0	1.00
0.216-0.023	0.215	-0.022	0.0	2.50
0.218-0.156	0.218	-0.156	50.0	7.50
0.306-0.170	0.306	-0.170	10.0	95.00
0.308-0.177	0.307	-0.176	-25.0	1.26
0.335+0.100	0.335	0.100	-5.0	1.00
0.371-0.029	0.371	-0.029	5.0	1.90
0.374-0.165	0.374	-0.164	-10.0	2.20
0.380+0.041	0.380	0.041	40.0	3.60
0.382+0.056	0.382	0.056	10.0	0.40
H ₂ O masers from Walsh et al. (2011)				(Jy)
G345.25-0.03	345.250	-0.025	-23.6	16.40
G345.43-0.06	345.433	-0.058	-14.3	54.60
G345.58-0.02	345.583	-0.017	-8.8	5.80
G345.65+0.02	345.650	0.017	-11.3	48.40
G345.69-0.08	345.692	-0.075	-6.6	297.00
G345.80-0.34	345.800	-0.342	-94.6	3.60
G345.91-0.05	345.908	-0.050	-125.5	2.70
G346.18-0.08	346.183	-0.075	-14.3	7.30
G346.18+0.34	346.183	0.341	3.0	4.10
G346.47-0.23	346.467	-0.233	-76.3	2.90
G346.53-0.12	346.525	-0.117	-47.4	11.00
G347.06+0.00	347.059	-0.000	-9.7	3.70
G347.30+0.13	347.300	0.133	-82.6	42.30
G347.32+0.02	347.317	0.017	-8.5	3.20
G347.89-0.28	347.892	-0.283	-91.2	4.90
G348.18+0.48	348.175	0.484	-1.4	80.70
G348.29+0.43	348.292	0.434	-2.0	5.20
G348.32-0.18	348.317	-0.175	-100.8	6.40
G348.83+0.23	348.834	0.225	-186.6	3.50

Table B.4. continued.

Name/ Number	ℓ ($^{\circ}$)	b ($^{\circ}$)	v (km s^{-1})	Peak
G349.72+0.13	349.722	0.125	17.9	149.60
G350.42−0.06	350.417	−0.059	−36.1	62.40
G350.88−0.29	350.876	−0.292	−53.9	9.60
G351.38+0.21	351.375	0.208	7.3	5.30
G352.16+0.41	352.158	0.413	−4.3	158.70
G352.21+0.10	352.208	0.104	−28.2	7.00
G352.25−0.29	352.250	−0.287	−96.2	6.40
G352.55+0.20	352.550	0.204	−52.2	9.90
G352.93+0.07	352.925	0.071	−2.7	8.90
G353.26−0.24	353.258	−0.242	7.0	9.30
G353.82+0.32	353.817	0.317	−70.5	128.90
G355.13−0.30	355.134	−0.300	224.8	106.40
G355.79−0.18	355.792	−0.175	−2.1	9.80
G355.82+0.28	355.817	0.283	−114.5	14.20
G355.93−0.34	355.934	−0.342	−49.7	12.80
G356.43+0.10	356.425	0.095	−6.6	2.80
G356.47+0.01	356.467	0.009	1.3	17.30
G356.55+0.08	356.550	0.084	−19.0	8.30
G356.65−0.32	356.650	−0.316	4.6	11.70
G357.57+0.07	357.574	0.067	−48.0	1.30
G358.24+0.12	358.242	0.116	−13.3	94.00
G358.30+0.08	358.300	0.082	−9.2	78.40
G358.48−0.33	358.483	−0.326	0.3	10.00
G358.67−0.04	358.667	−0.043	−9.0	60.90
G358.88+0.04	358.883	0.041	−17.6	8.50
G359.30+0.03	359.304	0.030	0.9	20.10
G359.42+0.07	359.420	0.072	−5.3	4.30
G359.42+0.32	359.421	0.317	9.5	4.40
G359.51−0.15	359.510	−0.151	7.2	5.60
G359.73−0.38	359.731	−0.384	−4.8	42.20
G359.94−0.15	359.939	−0.149	−18.7	10.60
G0.05−0.22	0.053	−0.218	12.4	7.40
G0.31−0.18	0.305	−0.175	10.6	39.20
G0.34+0.09	0.337	0.091	7.1	36.60
G0.37−0.17	0.372	−0.169	−9.1	22.40
G0.53+0.18	0.527	0.182	−1.4	6.80
G0.60−0.00	0.603	−0.001	37.2	7.10
G1.05−0.07	1.045	−0.071	−37.1	11.10
G1.17−0.04	1.167	−0.037	−22.3	35.40
G2.58−0.44	2.583	−0.437	−6.0	72.60
G2.60−0.36	2.604	−0.360	−20.5	9.10
G2.90−0.43	2.898	−0.429	82.4	8.60
G2.93+0.28	2.926	0.275	−42.8	4.10
G3.88+0.27	3.879	0.267	10.3	4.30
G4.00+0.33	3.999	0.332	13.6	3.50
G4.00−0.17	4.000	−0.167	−55.0	2.80
G4.83+0.22	4.833	0.224	11.1	3.20
G4.89−0.13	4.894	−0.129	6.9	42.80
G5.37+0.05	5.369	0.053	2.5	10.00
G5.52−0.25	5.516	−0.251	21.9	2.60
G5.71−0.50	5.708	−0.500	12.3	4.20
G5.91−0.39	5.908	−0.391	−61.5	43.00