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Precise Positions of Methanol Masers

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Abstract: The Australia Telescope Compact Array (ATCA) has been used to determine positions for many southern methanol maser sites, with accuracy better than 1 arcsec. The results are presented here as a catalogue of more than 350 distinct sites, some of them new discoveries, and many others with positional precision 10-times better than existing published values. Clusters of 2 or 3 sites are occasionally found to account for single previously listed sources. This in turn reveals that the velocity range for each individual site is sometimes smaller than that of the originally tabulated (blended) source. Only a handful of examples then remain with a velocity range of more than 16 km s^{-1} at a single compact (less than 2 arcsec) site. The precise methanol positions now allow apparent coincidences with OH masers to be confidently accepted or rejected; this has led to the important conclusion that, where a 1665-MHz OH maser lies in a massive star formation region, at more than 80 percent of the OH sites there is a precisely coincident methanol maser. The methanol precision achieved here will also allow clear comparisons with likely associated IR sources when the next generation of far-IR surveys produce precise positions.

Keywords: ISM: molecules — masers — methanol — stars: formation

1 Introduction

Over the past decade, methanol maser emission at the 6668-MHz transition has become recognised as a valuable tracer of young stellar objects — the sites where massive stars have recently formed but are not directly detectable owing to their obscuring mantle of dust and molecules.

Existing work has discovered a large number of methanol masers in our Galaxy by an inhomogeneous mixture of targeted searches (especially towards OH masers, and IR sources, e.g. Caswell et al. 1995a), and unbiased surveys towards some portions of the Galactic plane (e.g. Ellingsen et al. 1996). However, there is a need to consolidate this work and provide accurate positions for the known sources in preparation for a new sensitive search for methanol masers that is currently being conducted with the Parkes Radio Telescope (Green et al. 2009a).

2 Observations and Data Reduction

The methanol maser observations described here were obtained with the ATCA in many sessions since 1993 February, chiefly in any of the four standard '6-km' configurations (instantaneously yielding 15 baselines ranging from 76 to 6000 m). The correlator was configured to give a 2048-channel spectrum across a 4-MHz bandwidth for each of the 2 orthogonal linear polarizations. Typically, a target was observed for at least four periods of several minutes each, within a 10-hour timespan. Targets selected for study included methanol sites with positions known only approximately from single dish observations, and the positions of some new OH masers (chiefly from Caswell 1998) not previously searched for methanol. Some new serendiptious discoveries, made while investigating the chosen targets, are also reported. The masers selected for observation lie primarily in the Galactic longitude range 232° through 360° to 16° which is the region covered by extensive southern observations of OH masers (Caswell 1998). Indeed, a major objective was to ensure that the precise position was obtained for all methanol masers that appeared to have a nearby maser counterpart of OH at either (or both) 1665 (or 1667) MHz and 6035 MHz. The region investigated was expanded to include some additional targets that lie between longitudes 16° and 50°, and between 188° and 232°; these extensions were prompted by the absence until recently of a northern hemisphere instrument able to efficiently perform such measurements. The procedures for observing and data reduction closely follow those of Caswell (1996a, 1996b, 1997).

3 Results

The synthesised beamsize of approximately 2 arcsec enables not only an accurate position measurement for the brightest maser feature in the spectrum of the target, but also enables mapping of the maser spot distribution. Past studies have shown that the maser spots are generally confined to groups with typical maximum extent of less than 1 arcsec (Caswell 1997; Forster & Caswell 1989). Where distances are known, the calculated linear extent rarely exceeds 30 mpc (= 6000 au). Sometimes the maps of maser spot positions show a cluster of two or more maser groups, with separations clearly exceeding group sizes. It is likely that each compact maser group within

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such a cluster has an embedded embryonic massive star as its source of excitation.

For the current analysis. we do not list each detected maser spot, but we do list, as separate, the site of each compact group of maser spots that is separated more than a few arcsec from any other group in the same cluster. In a few rare cases there is a cluster of three or more groups; somewhat more commonly there is a pair, and the majority of sites are single.

The emphasis of the current work is to provide a catalogue of precise positions. In order to increase its usefulness, Table 1 lists not only our new previously unpublished positions, but also: the 19 sources earlier listed only with 1950 coordinates by Caswell, Vaile & Forster (1995b), results from Caswell (1996a,b, 80 sources), and results from Caswell (1997, 42 sources). In addition, some of our new positions, although not published in tabular form, have been referred to in source notes concerning related OH masers at 1665 MHz (Caswell 1998) and at 6035 MHz (Caswell 2003). For some sources, we made new measurements confirming or replacing the previous published values. The present positions are recommended for future studies and, unless otherwise noted, have RMS uncertainties of 0.4 arcsec. These errors arise chiefly from residual atmospheric phase instabilities between calibration measurements as discussed by Caswell (1997).

The peak intensity and its velocity at our observing epoch is shown in Columns 4 and 5 of Table 1. However, variability occurs in many sources, primarily on timescales of months to years (see e.g. Caswell, Vaile & Ellingsen 1995c). Consequently, the peak intensity at our observing epoch is often different from that of published spectra (and sometimes a different velocity peak is stronger). Earlier published spectra (e.g. Caswell et al. 1995a) sometimes have a better signal-to-noise ratio than our measurements, and show features over a larger velocity range. In Column 6 we quote the larger ranges in such cases if there is no evidence that any emission comes from an offset position. The resulting velocity ranges are approximate, and are generally underestimated for weak sources with low signal-to-noise ratio, but occasionally overestimated if two sources are blended. A better assessment of velocity ranges will be possible from spectra being obtained in a new methanol multibeam survey, which is now well under way (Green et al. 2009a).

The Table assigns a name to each maser based on its Galactic coordinates (to the nearest millidegree). Where separations of approximately 2 arcsec occur, it is not clear whether the features represent distinctly separate maser sites, or an unusually extended one. The difficult cases are discussed for individual sources in the next section.

The methanol masers listed here include the results of searches towards a comprehensive list of southern OH masers (Caswell 1998) in the Galactic longitude range 232° through 360° to 16°. Some of the methanol masers detected towards OH targets are coincident with the OH and others are not. Coincidences are identified in the column 'OH?' by citing a reference to the OH data; most references are to Caswell (1998), but there are others positioned more recently. Some associations require more extensive comment, and 'text' in the 'OH?' column refers to notes in section 4. The resulting detection statistics of methanol masers towards 1665-MHz masers are discussed later in the paper.

The final column of the Table identifies the epoch of our methanol position measurement or, where the measurement has been discussed in an earlier publication, a reference is given. Published positions have sometimes been improved by additional data at a later epoch.

There are, of course, multiple individual publications on many previously reported sources but we have not attempted to cite these since they are of varying quality and are mostly included in a comprehensive compilation of older methanol maser data (Pestalozzi, Minier & Booth 2005). Many of the positions listed here supersede the earlier approximate positions, and others confirm independently obtained positions of high accuracy. Amongst the positions in the Pestalozzi compilation with accuracy comparable to ours, those obtained by Walsh et al. (1998) were derived from ATCA observations in 1994 and 1995, and used a strategy similar to the present one (but with lower spectral resolution). For most of those sources, the strongest features, tabulated by Pestalozzi et al. (2005) from the full Walsh et al. (1998) dataset, are in agreement with our values to within 0.4 arcsec and provide a useful corroboration of both datasets.

Some northern sources have recently been measured with the Arecibo telescope, with an RMS position uncertainty of 7 arcsec (Pandian, Goldsmith & Deshpande 2007). Comparison with our data confirms this precision, but also reveals a bias in the Arecibo Right Ascensions, suggesting that the values should be reduced by an average of 0.6 s (9 arcsec).

4 Discussion

4.1 Notes on Some Individual Sources

We first draw attention to corrections needed for earlier published data. A source listed by Caswell (1996a) as 335.603–0.078 is now believed to be spurious and is accounted for as a weak distant side-lobe of another maser. The site listed here as 0.475–0.010 is the corrected value for a source listed by Caswell (1996b) as 0.393–0.034.

Problems of this type can occur when sparse antenna arrays are used to observe weak sources for only short periods, but such errors are rare and it is expected that no similar examples remain in the current catalogue.

The remaining notes draw attention to some anomalies regarding the information on a few of the sites, and draw attention to sites with neighbours less than 20 arcsec away, which mostly represent individual stars within a cluster. A few of the sites are as close as a few arcsec and the alternative interpretations of two close separate sites, or a single site of larger extent, are discussed.

Table 1. Positions of methanol masers

Galactic name (l,b)	RA(2000) (h m s)	Dec(2000) (deg arcmin arcsec)	I(pk) (Jy)	v(pk) (km s^{-1})	v(range) (km s^{-1})	OH?	Refs, epoch[a]
188.946+0.886	06 08 53.32	+21 38 29.1	495	+11	−4, +12		99feb
189.030+0.783	06 08 40.65	+21 31 07.0	17	+9	+8, +10		99feb
189.778+0.345	06 08 35.28	+20 39 06.7	15	+6	+2, +6		99feb
192.600−0.048	06 12 53.99	+17 59 23.7	72	+5	+2, +6		99feb
196.454−1.677	06 14 37.03	+13 49 36.6	61	+15	+13, +16		99feb
213.705−12.597	06 07 47.85	−06 22 55.2	337	+12	+8, +13		99feb
232.621+0.996	07 32 09.79	−16 58 12.4	162	+22.7	+21, +24	c98	96dec
263.250+0.514	08 48 47.84	−42 54 28.4	60	+12.3	+11, +15	c98	96dec
264.289+1.469	08 56 26.80	−43 05 42.1	0.4	+9.2	+6, +10		99may
269.153−1.128	09 03 33.46	−48 28 02.6	1.6	+16.0	+7, +16		99may
270.255+0.835	09 16 41.51	−47 56 12.1	0.6	+3.9	+3, +5		99oct
284.352−0.419	10 24 10.89	−57 52 38.8	1.7	+3.3	+3, +11		C97
285.337−0.002	10 32 09.64	−58 02 05.2	10	+0.5	−8, +3		93nov
287.371+0.644	10 48 04.40	−58 27 01.7	80	−1.8	−3, 0	c98	93nov
290.374+1.661	11 12 18.10	−58 46 21.5	0.6	−24.2	−28, −22	c98	99feb
291.274−0.709	11 11 53.35	−61 18 23.7	100	−29.6	−31, −28	c04	C04
291.270−0.719	11 11 49.44	−61 18 51.9	4	−26.5	−32, −26		C04
291.579−0.431	11 15 05.76	−61 09 40.8	0.7	+14.5	+11, +16	c98	C04
291.582−0.435	11 15 06.61	−61 09 58.3	1.7	+10.5	+8, +11		C04
294.511−1.621	11 35 32.25	−63 14 43.2	12	−10.2	−14, −9	c98	C97
294.990−1.719	11 39 22.88	−63 28 26.4	18	−12.3	−13, −11		99oct
296.893−1.305	11 56 50.07	−63 32 05.5	2.5	+22.2	+21, +23		99oct
298.213−0.343	12 09 55.18	−62 50 01.1	1.4	+37.2	+33, +39		97may
299.013+0.128	12 17 24.60	−62 29 03.7	7	+18.4	+18, +20	c98	99may
300.504−0.176	12 30 03.58	−62 56 48.7	4.7	+7.5	+4, +11	c98	99may
300.969+1.148	12 34 53.29	−61 39 40.0	5.5	−37.2	−40, −35	c98	C97
301.136−0.226	12 35 35.14	−63 02 32.6	1.2	−39.8	−41, −37	c98	99feb
302.032−0.061	12 43 31.92	−62 55 06.7	11	−35.3	−43, −33		99oct, 00jun
305.200+0.019	13 11 16.93	−62 45 55.1	44	−33.1	−38, −29	c98	C97
305.199+0.005	13 11 17.20	−62 46 46.0	2.3	−42.8	−45, −38		C97
305.202+0.208	13 11 10.49	−62 34 38.8	20	−43.9	−47, −43	c98	CVF95
305.208+0.206	13 11 13.71	−62 34 41.4	320	−38.3	−42, −34	c98	CVF95
305.248+0.245	13 11 32.47	−62 32 09.1	4	−32.0	−36, −28		99oct
305.362+0.150	13 12 35.86	−62 37 17.9	3	−36.5	−38, −35	c98	99may
305.366+0.184	13 12 36.74	−62 35 14.7	2.5	−33.8	−35, −33		99may
305.799−0.245	13 16 43.23	−62 58 32.9	0.7	−39.5	−40, −36	c98	99feb
305.887+0.017	13 17 15.53	−62 42 23.0	5.5	−34.0	−35, −33		99oct
306.322−0.334	13 21 23.01	−63 00 29.5	1.2	−24.4	−25, −22	c98	99feb
308.754+0.549	13 40 57.60	−61 45 43.4	5	−51.0	−52, −39	c04	C04
308.918+0.123	13 43 01.85	−62 08 52.2	54	−54.7	−56, −52	c98	96dec
309.384−0.135	13 47 23.98	−62 18 12.0	1	−49.6	−51, −49	c98	99feb
309.921+0.479	13 50 41.78	−61 35 10.2	635	−59.8	−65, −54	c98	C97
310.144+0.760	13 51 58.43	−61 15 41.3	120	−55.6	−59, −54	c98	96dec, 99oct
311.643−0.380	14 06 38.77	−61 58 23.1	11.6	32.5	+31, +36	c98	C97
311.947+0.142	14 07 49.72	−61 23 08.3	0.6	−38.3	−39, −38	text	99feb

312.108+0.262	14 08 49.31	−61 13 25.1	15	−50.0	−54, −49		99oct
312.598+0.045	14 13 15.03	−61 16 53.6	9	−67.9	−69, −64	c98	99feb
312.597+0.045	14 13 14.35	−61 16 57.7	1	−60.0	−61, −59		99feb
313.469+0.190	14 19 40.94	−60 51 47.3	16	−9.4	−13, −3	c98	99may
313.577+0.325	14 20 08.58	−60 42 00.8	70	−47.9	−54, −46	c98	96oct
313.705−0.190	14 22 34.82	−61 08 27.1	1.2	−41.5	−46, −41	c98	96dec
313.767−0.863	14 25 01.73	−61 44 58.1	15	−54.6	−57, −53	c98	96dec
313.774−0.863	14 25 04.78	−61 44 50.3	7	−41.2	−46, −40		96dec
314.320+0.112	14 26 26.20	−60 38 31.3	24	−43.7	−59, −43	c98	96oct
316.359−0.362	14 43 11.20	−60 17 13.3	52	+3.5	+1, +8	c98	96dec
316.381−0.379	14 43 24.21	−60 17 37.4	38	−0.7	−6, +1		96dec
316.412−0.308	14 43 23.34	−60 13 00.9	9	−5.7	−7, −2	c98	96dec
316.640−0.087	14 44 18.45	−59 55 11.5	60	−19.8	−25, −15	c98	96dec
316.811−0.057	14 45 26.43	−59 49 16.3	10	−46.3	−49, −42	c98	96dec
317.701+0.110	14 51 11.69	−59 17 02.1	9	−43.6	−46, −40		99may
318.043−1.404	14 59 08.61	−60 28 25.5	6	+46.2	+44, +47	c98	99oct
318.050+0.087	14 53 42.67	−59 08 52.4	10	−46.5	−59, −46	c98	99feb
318.948−0.196	15 00 55.39	−58 58 52.8	690	−34.7	−39, −31	c98	CVF95
319.836−0.197	15 06 54.65	−58 33 00.0	0.4	−9.1	−14, −9	c98	99may
320.123−0.504	15 10 00.17	−58 40 18.0	2.5	−10.1	−12, −9		96dec
320.231−0.284	15 09 51.94	−58 25 38.5	21	−62.0	−71, −58	c98	99may
321.030−0.485	15 15 51.79	−58 11 18.0	6	−66.5	−68, −56	c98	96dec
321.033−0.483	15 15 52.63	−58 11 07.7	50	−61.6	−69, −54		96dec
321.148−0.529	15 16 48.39	−58 09 50.2	7.5	−66.1	−67, −65	c98	96dec
322.158+0.636	15 18 34.64	−56 38 25.3	225	−63.3	−66, −51	c98	CVF95, 99oct
323.459−0.079	15 29 19.33	−56 31 22.8	19.2	−66.9	−69, −66	c98	C97
323.740−0.263	15 31 45.45	−56 30 50.1	3000	−51.1	−58, −45	c98	CVF95
324.716+0.342	15 34 57.47	−55 27 23.6	7	−46.0	−51, −45	c98	99feb
326.475+0.703	15 43 16.64	−54 07 14.6	60	−38.3	−51, −37		96dec, 00mar
326.476+0.695	15 43 18.90	−54 07 35.5	2.5	−43.6	−44, −43		00mar
326.641+0.611	15 44 33.33	−54 05 31.5	16	−42.8	−46, −36		96dec
326.662+0.521	15 45 02.95	−54 09 03.1	7	−38.6	−42, −38		96dec
326.859−0.677	15 51 14.19	−54 58 04.8	10	−58.0	−60, −57		00mar
327.120+0.511	15 47 32.73	−53 52 38.4	85	−87.0	−90, −83	c98	97may
327.291−0.578	15 53 07.70	−54 37 06.5	2.5	−36.8	−44, −36	c98	96dec
327.392+0.199	15 50 18.48	−53 57 06.3	7	−84.6	−86, −79		00mar
327.395+0.197	15 50 20.06	−53 57 07.5	1.7	−89.0	−90, −88		00mar
327.402+0.444	15 49 19.50	−53 45 13.9	65	−82.6	−84, −72	c98	99may
327.590−0.094	15 52 36.82	−54 03 18.7	3.2	−86.2	−87, −85		00mar
327.618−0.111	15 52 50.22	−54 03 00.5	3.1	−97.6	−99, −97		00mar
327.945−0.115	15 54 33.91	−53 50 44.3	6.9	−51.6	−52, −51		00mar
328.237−0.547	15 57 58.31	−53 59 23.0	360	−44.5	−47, −31	c98	CVF95
328.254−0.532	15 57 59.78	−53 58 00.8	440	−37.5	−51, −36	c98	CVF95
328.808+0.633	15 55 48.45	−52 43 06.6	240	−43.8	−47, −42	c98	C97
328.809+0.633	15 55 48.70	−52 43 05.5	53	−44.2	−45, −43	c98	C97
329.029−0.205	16 00 31.80	−53 12 49.6	138	−37.4	−42, −34	c98	CVF95
329.031−0.198	16 00 30.32	−53 12 27.3	11	−45.5	−49, −42	c98	CVF95
329.066−0.308	16 01 09.93	−53 16 02.6	20	−43.8	−46, −43	c98	CVF95
329.183−0.314	16 01 47.01	−53 11 43.3	10	−55.7	−60, −50	c98	99feb

(*Continued*)

Table 1. (Continued)

Galactic name (l,b)	RA(2000) (h m s)	Dec(2000) (deg arcmin arcsec)	I(pk) (Jy)	v(pk) (km s^{-1})	v(range) (km s^{-1})	OH?	Refs, epoch[a]
329.339+0.148	16 00 33.13	−52 44 39.8	18	−106.6	−108, −105	c01	00mar
329.405−0.459	16 03 32.16	−53 09 30.5	33	−70.5	−73, −63	c98	98nov
329.407−0.459	16 03 32.65	−53 09 26.9	72	−66.7	−68, −66		98nov
329.469+0.502	15 59 40.76	−52 23 27.7	8	−72.0	−74, −65		99oct
329.610+0.114	16 02 03.14	−52 35 33.5	30	−60.0	−69, −59		99oct
329.622+0.138	16 02 00.33	−52 33 59.4	1.9	−84.8	−86, −83		99oct
330.070+1.064	16 00 15.43	−51 34 25.6	8	−38.8	−56, −37		99oct
330.878−0.367	16 10 19.79	−52 06 07.8	0.6	−59.3	−60, −58	c98	97may
330.875−0.383	16 10 23.09	−52 06 58.7	0.4	−56.5	−72, −56		97may
330.953−0.182	16 09 52.37	−51 54 57.6	7	−87.6	−90, −87	c01	97may
331.120−0.118	16 10 23.05	−51 45 20.1	9.4	−93.2	−95, −90		C96a
331.132−0.244	16 10 59.76	−51 50 22.6	40	−84.3	−92, −81	c98	97may
331.278−0.188	16 11 26.59	−51 41 56.7	190	−78.2	−87, −77	c98	CVF95, C96a
331.342−0.346	16 12 26.45	−51 46 16.4	56	−67.4	−70, −62	c98	99may
331.425+0.264	16 10 09.33	−51 16 04.3	18	−88.7	−91, −78		00mar
331.442−0.187	16 12 12.49	−51 35 10.1	81	−88.4	−93, −84	c98	C96a
331.542−0.066	16 12 09.02	−51 25 47.6	7	−85.9	−87, −85	c98	C96a, C97
331.543−0.066	16 12 09.14	−51 25 45.3	11.6	−84.1	−85, −83	c98	C96a, C97
331.556−0.121	16 12 27.21	−51 27 38.2	35	−103.4	−105, −96	c98	C96a, C97
332.094−0.421	16 16 16.45	−51 18 25.7	11	−58.6	−62, −58		00mar
332.295+2.280	16 05 41.72	−49 11 30.3	113	−24.0	−27, −20	c98	97may
332.295−0.094	16 15 45.38	−50 55 53.4	6.3	−47.0	−48, −42		95jul
332.351−0.436	16 17 31.51	−51 08 22.0	2.6	−53.2	−55, −52		00mar
332.352−0.117	16 16 07.08	−50 54 31.0	1	−41.8	−43, −41	c98	94may, 95jul
332.560−0.148	16 17 12.11	−50 47 12.3	5.1	−55.6	−56, −55		C96a
332.604−0.167	16 17 29.31	−50 46 12.5	6.8	−50.9	−52, −50		C96a
332.653−0.621	16 19 43.51	−51 03 36.9	7.1	−50.6	−52, −49		99may
332.701−0.587	16 19 47.42	−51 00 09.5	2.1	−62.7	−63, −62		99may
332.726−0.621	16 20 03.00	−51 00 32.5	2.7	−49.5	−57, −44	c98	99may
332.826−0.549	16 20 10.85	−50 53 14.1	1.6	−61.7	−62, −55		97may
332.942−0.686	16 21 19.00	−50 54 10.2	10.3	−52.8	−55, −52		00mar
332.963−0.679	16 21 22.92	−50 52 58.5	35	−45.8	−49, −45		00mar
333.029−0.015	16 18 44.18	−50 21 50.6	3.6	−55.2	−62, −52		C96a
333.029−0.063	16 18 56.73	−50 23 54.1	3.9	−40.4	−41, −40		C96a
333.068−0.447	16 20 48.95	−50 38 40.2	14.1	−54.5	−57, −51		C97
333.121−0.434	16 20 59.66	−50 35 51.9	18.9	−49.3	−51, −48		C97
333.126−0.440	16 21 02.61	−50 35 54.7	3.9	−43.9	−44, −41		C97
333.128−0.440	16 21 03.26	−50 35 49.4	3.6	−44.6	−47, −44		C97
333.128−0.560	16 21 35.38	−50 40 56.5	14.5	−52.7	−61, −52		00mar
333.130−0.560	16 21 35.73	−50 40 51.0	17	−56.8	−64, −56		00mar
333.135−0.431s	16 21 02.82	−50 35 12.0	1	−53.0	−54, −51	c98	C97
333.163−0.101	16 19 42.67	−50 19 53.2	7.7	−95.3	−96, −90		C96a
333.184−0.091	16 19 45.62	−50 18 35.0	7.1	−84.7	−91, −81		C96a
333.234−0.062	16 19 51.25	−50 15 14.1	1.9	−91.9	−93, −79		C96a
333.315+0.105	16 19 29.01	−50 04 41.3	9.6	−45.0	−51, −40	c98	C96a

333.387+0.032	16 20 07.59	−50 04 46.5	3.4	−73.9	−75, −60	c98	95jul
333.466−0.164	16 21 20.18	−50 09 48.6	63	−42.5	−49, −37	c98	C96a
333.562−0.025	16 21 08.80	−49 59 48.0	46.7	−35.8	−45, −33		C96a
333.646+0.058	16 21 09.14	−49 52 45.9	2.9	−87.3	−89, −82		C96a
333.683−0.437	16 23 29.78	−50 12 08.6	20	−5.3	−8, 0		00mar
333.931−0.135	16 23 14.83	−49 48 48.9	10.9	−36.7	−39, −36		C96a
334.635−0.015	16 25 45.73	−49 13 37.4	36.4	−30.0	−31, −27		C96a
334.935−0.098	16 27 24.25	−49 04 11.3	7.1	−19.5	−22, −17		C96a
335.060−0.427	16 29 23.13	−49 12 27.1	20	−47.0	−48, −25	c98	97may
335.556−0.307	16 30 55.98	−48 45 50.2	23	−116.4	−119, −110	c98	96oct
335.585−0.285	16 30 57.28	−48 43 39.7	19.8	−49.3	−51, −43	c98	CVF95, C96a
335.585−0.289	16 30 58.67	−48 43 50.7	31	−51.4	−56, −50	c98	CVF95, C96a
335.585−0.290	16 30 58.79	−48 43 53.4	108	−47.3	−48, −45		CVF95, C96a
335.726+0.191	16 29 27.37	−48 17 53.2	78	−44.4	−55, −43		CVF95, C96a
335.789+0.174	16 29 47.33	−48 15 51.7	118	−47.6	−59, −45	c98	CVF95, C96a
336.018−0.827	16 35 09.26	−48 46 47.4	300	−53.4	−55, −39	c98	97may
336.358−0.137	16 33 29.17	−48 03 43.9	18.3	−73.6	−82, −72	c98	C96a
336.409−0.257	16 34 13.20	−48 06 20.9	8	−85.6	−87, −84		96dec
336.433−0.262	16 34 20.22	−48 05 32.2	46	−93.3	−95, −86		96dec
336.496−0.271	16 34 38.02	−48 03 03.9	11	−23.9	−25, −19		96dec
336.822+0.028	16 34 38.28	−47 36 32.2	19.5	−76.7	−78, −76	c98	C96a
336.830−0.375	16 36 26.19	−47 52 31.1	36	−22.7	−28, −21		99oct
336.864+0.005	16 34 54.44	−47 35 37.3	32	−76.1	−83, −73	c98	C96a
336.941−0.156	16 35 55.19	−47 38 45.4	33.9	−67.3	−79, −64	c98	C96a
336.983−0.183	16 36 12.41	−47 37 58.2	18.8	−80.8	−82, −78	c98	C96a
336.994−0.027	16 35 33.98	−47 31 11.7	28.2	−125.8	−127, −118	c98	C96a
337.176−0.032	16 36 18.84	−47 23 19.8	9.4	−64.7	−74, −64		C96a
337.258−0.101	16 36 56.32	−47 22 26.4	15	−69.3	−74, −67	c98	C96a
337.404−0.402	16 38 50.52	−47 28 00.2	67	−39.7	−43, −37	c98	97may
337.613−0.060	16 38 09.54	−47 04 59.9	20	−42.0	−54, −38	c98	C96a, C97
337.632−0.079	16 38 19.12	−47 04 53.3	13.7	−56.9	−64, −54		C96a, C97
337.686+0.137	16 37 35.42	−46 53 47.6	2.1	−74.9	−76, −74		C96a
337.703−0.053	16 38 29.12	−47 00 43.2	6	−44	−52, −43		C96a
337.705−0.053	16 38 29.63	−47 00 35.5	145	−54.6	−57, −49	c98	CVF95, C96a
337.710+0.089	16 37 53.41	−46 54 40.8	5	−72.6	−74, −72		C96a
337.920−0.456	16 41 06.05	−47 07 02.5	28	−38.8	−41, −36	c98	00jun
337.966−0.169	16 40 01.09	−46 53 34.5	10.6	−60.4	−61, −54		C96a
337.997+0.136	16 38 48.50	−46 39 57.5	4	−32.3	−36, −31	c98	99feb
338.075+0.012	16 39 39.07	−46 41 28.1	18.8	−53.0	−55, −43	c98	C96a
338.075+0.009	16 39 39.81	−46 41 33.1	3.5	−38.2	−42, −35		C96a
338.280+0.542	16 38 09.08	−46 11 03.3	4.8	−56.8	−59, −56	c98	C97
338.287+0.120	16 40 00.13	−46 27 37.1	11.9	−39.3	−44, −38		C96a
338.432+0.058	16 40 49.79	−46 23 37.0	49.6	−30.2	−34, −27		C96a
338.461−0.245	16 42 15.50	−46 34 18.4	74	−50.4	−57, −49	c98	C96a
338.472+0.289	16 39 58.91	−46 12 35.4	0.7	−30.5	−35, −29	c98	99feb
338.561+0.218	16 40 37.96	−46 11 25.8	35	−40.8	−43, −37		99feb
338.566+0.110	16 41 07.03	−46 15 28.3	6.1	−75.0	−80, −73		C96a
338.875−0.084	16 43 08.25	−46 09 12.8	19.4	−41.4	−42, −39	c98	C96a
338.925+0.557	16 40 33.53	−45 41 37.1	5	−62.3	−66, −59	c98	97may

(*Continued*)

Table 1. (Continued)

Galactic name (l,b)	RA(2000) (h m s)	Dec(2000) (deg arcmin arcsec)	I(pk) (Jy)	v(pk) (km s^{-1})	v(range) (km s^{-1})	OH?	Refs, epoch[a]
338.920+0.550	16 40 34.01	−45 42 07.1	55	−61.4	−68, −59		97may
338.935−0.062	16 43 16.01	−46 05 40.2	22.6	−41.9	−44, −41		C96a
339.053−0.315	16 44 48.99	−46 10 13.0	141	−111.6	−114, −111	c98	C96a
339.064+0.152	16 42 49.56	−45 51 23.8	6.9	−85.6	−90, −83		C96a
339.282+0.136	16 43 43.11	−45 42 08.0	8.8	−69.1	−72, −68	c98	C96a
339.294+0.139	16 43 44.95	−45 41 28.0	5	−74.6	−76, −65		C96a
339.477+0.043	16 44 50.98	−45 36 56.1	2	−9.3	−11, −5		C96a
339.582−0.127	16 45 58.82	−45 38 47.2	8.7	−31.3	−32, −29		C96a
339.622−0.121	16 46 05.99	−45 36 43.3	95	−32.8	−39, −32	c98	C96a
339.681−1.208	16 51 06.21	−46 16 02.9	41	−21.5	−39, −20		CVF95, 97may
339.682−1.207	16 51 06.23	−46 15 58.1	5.8	−34.0	−35, −33	c98	97may
339.762+0.054	16 45 51.56	−45 23 32.6	12.9	−51.0	−52, −49		C96a
339.884−1.259	16 52 04.66	−46 08 34.2	1650	−38.7	−41, −27	c98	CVF95, 97may
340.054−0.244	16 48 13.89	−45 21 43.5	40	−59.7	−63, −46	c98	97may
340.518−0.152	16 49 31.36	−44 56 54.6	6.4	−48.2	−51, −43		00mar
340.785−0.096	16 50 14.84	−44 42 26.3	144	−105.1	−110, −86	c98	C97
341.218−0.212	16 52 17.84	−44 26 52.1	137	−37.9	−50, −35	c98	CVF95
341.276+0.062	16 51 19.41	−44 13 44.5	4	−73.8	−77, −66	c98	99feb
342.484+0.183	16 55 02.30	−43 12 59.8	101	−41.8	−45, −38		00mar
343.929+0.125	17 00 10.91	−42 07 19.3	12	14.3	+9, +19	c98	C97
344.227−0.569	17 04 07.78	−42 18 39.5	90	−19.8	−33, −16	c98	CVF95
344.419+0.044	17 02 08.62	−41 47 10.3	1.5	−63.5	−66, −63	c98	98nov
344.421+0.045	17 02 08.77	−41 46 58.5	14	−71.5	−73, −70		98nov
344.581−0.024	17 02 57.71	−41 41 53.8	3	+1.4	−6, +3	c98	99feb
345.003−0.223	17 05 10.89	−41 29 06.2	240	−22.5	−25, −20		C97
345.003−0.224	17 05 11.23	−41 29 06.9	73	−26.2	−34, −25	c98	C97
345.010+1.792	16 56 47.58	−40 14 25.8	410	−18	−24, −16	c98	C97
345.012+1.797	16 56 46.82	−40 14 08.9	31	−12.7	−16, −10		C97
345.407−0.952	17 09 35.42	−41 35 57.1	1	−14.4	−15, −14	c98	98nov
345.424−0.951	17 09 38.56	−41 35 04.6	1.8	−13.5	−19, −13		98nov
345.498+1.467	16 59 42.84	−40 03 36.1	2.4	−14.2	−15, −13	c98	97may
345.505+0.348	17 04 22.91	−40 44 21.7	130	−17.7	−23, −11	c98	CVF95, 99oct
345.487+0.314	17 04 28.24	−40 46 28.7	1.3	−22.6	−24, −22		99oct
346.481+0.132	17 08 22.72	−40 05 25.6	1.9	−5.5	−12, −5	c98	99may, 99oct
346.480+0.221	17 08 00.11	−40 02 15.9	30	−18.9	−20, −14		99feb, 00mar
346.517+0.117	17 08 33.20	−40 04 14.3	1	−0.1	−3, +1		99oct
346.522+0.085	17 08 42.29	−40 05 07.8	0.6	+5.5	+5, +6		99oct
347.583+0.213	17 11 26.72	−39 09 22.5	2.4	−102.5	−103, −96		C97
347.628+0.149	17 11 50.92	−39 09 29.2	13.5	−96.6	−98, −95	c98	C97
347.631+0.211	17 11 36.05	−39 07 07.0	11.2	−91.9	−94, −89		C97
347.817+0.018	17 12 58.05	−39 04 56.1	3.4	−25.6	−26, −23		96dec
347.863+0.019	17 13 06.23	−39 02 40.0	7.2	−29.3	−38, −28		96dec
347.902+0.052	17 13 05.11	−38 59 35.5	5.3	−27.8	−31, −27		96dec
348.550−0.979	17 19 20.41	−39 03 51.6	37	−10.0	−19, −7	c98	CVF95, C97
348.550−0.979n	17 19 20.45	−39 03 49.4	32	−20.0	−23, −14		CVF95, C97

348.579−0.920	17 19 10.61	−39 00 24.2	0.5	−15	−16, −14	c98	96oct
348.703−1.043	17 20 04.06	−38 58 30.9	60	−3.3	−17, −3	c98	96dec
348.727−1.037	17 20 06.54	−38 57 09.1	90	−7.6	−12, −6	c98	96dec
348.884+0.096	17 15 50.13	−38 10 12.4	5	−76.2	−77, −73	c98	99feb
348.892−0.180	17 17 00.23	−38 19 28.9	2	+1.4	+1, +2	c98	99oct, 00jun
349.067−0.017	17 16 50.74	−38 05 14.3	1.9	+6.9	+6, +16	c98	99feb
349.092+0.105	17 16 24.74	−37 59 47.2	30	−76.5	−78, −74		96dec
349.092+0.106	17 16 24.59	−37 59 45.8	6	−80.4	−83, −78	c98	96dec
350.011−1.342	17 25 06.54	−38 04 00.7	0.4	−25.8	−28, −25	c98	99feb, 99may
350.015+0.433	17 17 45.45	−37 03 11.9	3.2	−31.7	−37, −29	c98	99may
350.105+0.083	17 19 27.01	−37 10 53.3	16	−74.0	−76, −61		96oct
350.104+0.084	17 19 26.68	−37 10 53.1	2.5	−68.4	−69, −68		96oct
350.116+0.084	17 19 28.83	−37 10 18.8	1.8	−68.0	−69, −67		96oct
350.299+0.122	17 19 50.87	−36 59 59.9	26	−62.1	−67, −61		96oct
350.344+0.116	17 20 00.03	−36 58 00.1	17	−65.5	−66, −59		96dec
350.686−0.491	17 23 28.63	−37 01 48.8	19	−13.8	−15, −13	c98	97may
351.160+0.697	17 19 57.50	−35 57 52.8	9	−5.2	−7, −2	c98	99oct, 00jun
351.417+0.645	17 20 53.37	−35 47 01.2	2500	−10.4	−12, −6	c98	C97
351.417+0.646	17 20 53.18	−35 46 59.3	1600	−11.2	−12, −7		C97
351.445+0.660	17 20 54.61	−35 45 08.6	120	−9.2	−14, +1		C97
351.581−0.353	17 25 25.12	−36 12 46.1	44	−94.4	−97, −92	c98	C97
351.581−0.353n	17 25 25.18	−36 12 44.5	2.3	−91.1	−100, −88		C97
351.775−0.536	17 26 42.57	−36 09 17.6	230	1.3	−9, +3	c98	CVF95, C97
352.083+0.167	17 24 41.22	−35 30 18.6	1.7	−66.0	−68, −64		99may
352.111+0.176	17 24 43.56	−35 28 38.4	8	−54.8	−61, −53		99may
352.133−0.944	17 29 22.32	−36 05 00.2	17.2	−16.0	−19, −6		99oct
352.517−0.155	17 27 11.34	−35 19 32.3	6.3	−51.2	−52, −49	c98	97may
352.525−0.158	17 27 13.42	−35 19 15.5	0.75	−53.0	−62, −52		97may
352.630−1.067	17 31 13.91	−35 44 08.7	160	−2.8	−7, −2	c98	96dec
352.624−1.077	17 31 15.31	−35 44 47.7	35	+5.8	−2, +7		96dec
353.273+0.641	17 26 01.59	−34 15 14.6	24	−5.2	−6, −2		96dec
353.410−0.360	17 30 26.18	−34 41 45.6	86.8	−19.9	−23, −19	c98	CVF95, C97
353.464+0.562	17 26 51.53	−34 08 25.7	18	−50.7	−53, −49	c98	97may
354.615+0.472	17 30 17.09	−33 13 55.1	151	−24.6	−27, −13	c98	CVF95, C97
354.724+0.300	17 31 15.55	−33 14 05.7	16	+93.8	+91, +95	c98	C97
355.344+0.147	17 33 29.07	−32 47 58.6	7.6	+20	+19, +21	c98	C97
355.343+0.148	17 33 28.79	−32 47 59.7	0.8	+5.7	+4, +7		C97
355.346+0.149	17 33 28.92	−32 47 49.0	9.2	+10.0	+9, +11		C97
356.662−0.263	17 38 29.16	−31 54 38.8	5	−53.9	−57, −44	c98	99feb
357.967−0.163	17 41 20.26	−30 45 06.9	35	−3.2	−6, 0	c98	97may
357.965−0.164	17 41 20.14	−30 45 14.4	1.5	−8.8	−9, +3		97may
358.263−2.061	17 49 37.63	−31 29 18.0	10	+4.9	+1, +6		99oct
358.371−0.468	17 43 31.95	−30 34 10.7	29	+1.0	−1, +13		97may
358.386−0.483	17 43 37.83	−30 33 51.1	2.5	−6.0	−7, −5	c98	97may
359.138+0.031	17 43 25.67	−29 39 17.3	15.6	−3.9	−7, +1	c98	C96b, C97
359.436−0.104	17 44 40.60	−29 28 16.0	26.8	−52.0	−53, −45	c98	C96b
359.436−0.102	17 44 40.21	−29 28 12.5	4.4	−53.6	−58, −54		C96b
359.615−0.243	17 45 39.09	−29 23 30.0	89	+22.5	+14, +27	c98	C96b

(*Continued*)

Table 1. (Continued)

Galactic name (l,b)	RA(2000) (h m s)	Dec(2000) (deg arcmin arcsec)	I(pk) (Jy)	v(pk) (km s^{-1})	v(range) (km s^{-1})	OH?	Refs, epoch[a]
359.970−0.457	17 47 20.17	−29 11 59.4	1.3	+23.0	+20, +24	c98	C96b
0.212−0.001	17 46 07.63	−28 45 20.9	3.5	+49.2	+41, +50		C96b
0.315−0.201	17 47 09.13	−28 46 15.7	41.2	+18	+14, +27		C96b
0.316−0.201	17 47 09.33	−28 46 16.0	1.3	+21	+20, +22		C96b
0.376+0.040	17 46 21.41	−28 35 40.0	0.7	+37.1	+35, +40	c98	99feb
0.475−0.010	17 46 47.05	−28 32 07.1	2.9	+28.7	+23, +30		C96b
0.496+0.188	17 46 03.96	−28 24 52.8	10	+0.8	−12, +2	c98	C96b
0.546−0.852	17 50 14.35	−28 54 31.1	50	+13.8	+8, +20	c98	97may
0.645−0.042	17 47 18.67	−28 24 24.8	65	+49.1	+46, +53		C96b
0.647−0.055	17 47 22.07	−28 24 42.3	3.4	+51.0	+49, +52		C96b
0.651−0.049	17 47 21.13	−28 24 18.1	31.7	+48.0	+46, +49		C96b
0.657−0.041	17 47 20.08	−28 23 47.1	3	+52.0	+48, +56	text	C96b
0.665−0.036	17 47 20.04	−28 23 12.8	2.1	+60.4	+58, +62	text	C96b
0.666−0.029	17 47 18.64	−28 22 54.6	33.7	+72.2	+68, +73	text	C96b, C97
0.672−0.031	17 47 20.03	−28 22 41.7	4.5	+58.2	+55, +59	text	C96b
0.677−0.025	17 47 19.29	−28 22 14.6	4.4	+73.4	+70, +77		C96b
0.695−0.038	17 47 24.76	−28 21 43.2	26	+68.5	+64, +75		C96b
0.836+0.184	17 46 52.86	−28 07 34.8	8.1	+3.5	+2, +5		C96b
2.143+0.009	17 50 36.14	−27 05 46.5	6	+62.7	+55, +65	c98	96dec
2.536+0.198	17 50 46.47	−26 39 45.3	40	+3.2	+2, +20		00mar
3.910+0.001	17 54 38.75	−25 34 44.8	2.4	+17.8	+17, +24	c98	97may
5.900−0.430	18 00 40.86	−24 04 20.8	5.3	+10.0	+4, +11		99oct
6.539−0.108	18 00 50.86	−23 21 29.8	0.9	+13.4	+13, +14		00mar
6.610−0.082	18 00 54.03	−23 17 02.1	10.8	+0.7	0, +1		00mar
6.795−0.257	18 01 57.75	−23 12 34.9	37	+26.6	+12, +31	c98	96dec
8.139+0.226	18 03 00.75	−21 48 09.9	3.5	+20.0	+19, +21		00mar
8.669−0.356	18 06 18.99	−21 37 32.2	8.5	+39.3	+39, +40	c98	96dec
8.683−0.368	18 06 23.49	−21 37 10.2	70	+42.9	+40, +46	c98	96dec
9.621+0.196	18 06 14.67	−20 31 32.4	5000	+1.3	−4, +9	c98	96dec
9.619+0.193	18 06 14.92	−20 31 44.3	72	+5.5	+5, +7	c98	96dec
9.986−0.028	18 07 50.12	−20 18 56.5	28	+47.1	+40, +52		00mar
10.287−0.125	18 08 49.36	−20 05 59.0	27	+5.0	+4, +6		00mar
10.299−0.146	18 08 55.54	−20 05 57.5	3.5	+20.0	+19, +21		00mar
10.320−0.259	18 09 23.30	−20 08 06.9	7.5	+38.8	+35, +40		00mar
10.323−0.160	18 09 01.46	−20 05 07.8	126	+10.0	+4, +14		00mar
10.342−0.142	18 08 59.99	−20 03 35.4	12	+14.8	+6, +18		00mar
10.444−0.018	18 08 44.88	−19 54 38.3	14.8	+73.2	+68, +79	c98	CVF95
10.473+0.027	18 08 38.20	−19 51 50.1	120	+75.0	+58, +77	c98	CVF95
10.480+0.033	18 08 37.88	−19 51 16.0	9.7	+65.0	+58, +66	c98	CVF95
10.627−0.384	18 10 29.22	−19 55 41.1	3.1	+4.6	−6, +7		98nov
10.629−0.333	18 10 17.98	−19 54 04.8	4.2	−7.5	−13, +1		98nov
10.958+0.022	18 09 39.32	−19 26 28.0	16.4	+24.4	+23, +26		00mar
11.034+0.062	18 09 39.84	−19 21 20.3	0.5	+20.6	+15, +21	c98	98nov
11.497−1.485	18 16 22.13	−19 41 27.1	167	+6.7	+4, +17		00mar
11.904−0.141	18 12 11.44	−18 41 28.6	56	+42.8	+40, +45	c98	C97
11.903−0.102	18 12 02.70	−18 40 24.7	1.8	+36.0	+32, +37		C97

11.936−0.150	18 12 17.29	−18 40 02.6	1.9	+48.5	+47, +50		C97
11.936−0.616	18 14 00.89	−18 53 26.6	41	+32.2	+30, +44		00mar
12.025−0.031	18 12 01.86	−18 31 55.7	85	+107.7	+105, +112	text	00mar
12.209−0.102	18 12 39.92	−18 24 17.9	9.2	+19.8	+16, +22	text	97may
12.202−0.120	18 12 42.93	−18 25 11.8	1.7	+26.4	+26, +27		97may
12.203−0.107	18 12 40.24	−18 24 47.5	2.4	+20.5	+20, +32		97may
12.181−0.123	18 12 41.00	−18 26 21.9	1.35	+29.7	+29, +31		97may
12.199−0.034	18 12 23.44	−18 22 50.9	12.5	+49.3	+48, +53		97may
12.265−0.051	18 12 35.40	−18 19 52.3	6	+68.0	+58, +70		97may
12.625−0.017	18 13 11.30	−17 59 57.6	11.2	+23.8	+21, +28		00mar
12.681−0.182	18 13 54.75	−18 01 46.6	450	+57.6	+50, +61	c98	97may
12.889+0.489	18 11 51.40	−17 31 29.6	27	+39.3	+28, +42	c98	96dec
12.909−0.260	18 14 39.53	−17 52 00.0	300	+39.9	+35, +47	c98	97may
13.657−0.599	18 17 24.27	−17 22 12.5	32	+51.2	+47, +53	text	05mar
14.101+0.087	18 15 45.81	−16 39 09.4	146	+15.2	+4, +17		00mar
15.034−0.677	18 20 24.78	−16 11 34.6	28	+21.2	+20, +24	c98	C97
17.638+0.157	18 22 26.30	−13 30 12.1	9.5	+20.7	+20, +22	c04	2003mar
19.472+0.170	18 25 54.70	−11 52 34.6	8.5	+21.7	+17, +23		99oct
19.472+0.170sw	18 25 54.49	−11 52 36.5	1.7	+13.7	+13, +14		99oct
19.486+0.151	18 26 00.39	−11 52 22.6	12.5	+20.9	+19, +25		99oct
19.496+0.115	18 26 09.16	−11 52 51.7	5.3	+121.0	+120, +122		99oct
20.237+0.065	18 27 44.56	−11 14 54.2	77	+71.8	+68, +78	c03	99oct
20.239+0.065	18 27 44.95	−11 14 48.9	5.5	+70.6	+60, +71		99oct
22.335−0.155	18 32 29.40	−09 29 30.1	43	+35.7	+35, +37		99oct
22.435−0.169	18 32 43.82	−09 24 33.2	16	+29.3	+22, +40		99oct
23.010−0.411	18 34 40.27	−09 00 38.3	300	+75.0	+72, +83		99feb
23.437−0.184	18 34 39.25	−08 31 38.5	45	+103.0	+101, +108		99feb
23.440−0.182	18 34 39.18	−08 31 24.3	25	+96.6	+94, +100		99feb
24.329+0.144	18 35 08.09	−07 35 03.6	7	+110.5	+109, +120		05oct
24.493−0.039	18 36 05.83	−07 31 20.6	12	+115.0	+109, +116		05oct
28.146−0.005	18 42 42.59	−04 15 36.5	61	+101.2	+99, +105	text	99oct
28.201−0.049	18 42 58.08	−04 13 56.2	3.5	+98.9	+94, +100	text	99oct
40.425+0.700	19 02 39.62	+06 59 10.5	15	+15.7	+5, +16		99oct
40.623−0.138	19 06 01.63	+06 46 36.5	12.5	+31.1	+29, +37		99oct
43.149+0.013	19 10 11.06	+09 05 20.0	18	+13.5	+13, +15		99oct
43.165+0.013	19 10 12.89	+09 06 11.9	26	+9.3	+7, +21		99oct
43.171+0.004	19 10 15.36	+09 06 15.2	10	+20.2	+18, +22		99oct
43.167−0.004	19 10 16.72	+09 05 50.6	2.4	−1.1	−2, 0		99oct
43.796−0.127	19 11 53.97	+09 35 53.5	50	+39.5	+39, +43		99oct
45.467+0.053	19 14 24.15	+11 09 43.0	4.1	+56.4	+55, +59		99oct
45.473+0.134	19 14 07.36	+11 12 15.7	6.1	+65.5	+65, +67		99oct
45.493+0.126	19 14 11.35	+11 13 06.2	10	+57.1	+56, +58		99oct
45.445+0.069	19 14 18.31	+11 08 59.4	0.84	+50.0	+49, +51		99oct
49.470−0.371	19 23 37.90	+14 29 59.4	9.2	+64.0	+63, +76		98nov, 99oct
49.471−0.369	19 23 37.60	+14 30 05.4	4.1	+73.2	+72, +75		99oct
49.482−0.402	19 23 46.19	+14 29 47.0	7	+50.0	+47, +52		99oct
49.489−0.369	19 23 39.83	+14 31 05.0	26	+56.1	+55, +61		98nov, 99oct
49.490−0.388	19 23 43.95	+14 30 34.2	650	+59.2	+51, +61		98nov, 99oct

[a]Refs abbreviated in the following format: CVF95 is Caswell, Vaile & Forster 1995; C97 is Caswell 1997 etc.
Epochs abbreviated as year and month.

291.579−0.431 and 291.582−0.435. As noted previously (Caswell 2004a) these two sites, with separation nearly 20 arcsec, are sufficiently close to lie within the same star cluster, but are quite distinct, with one site accompanied by water, and the other accompanied by both water and OH.

311.947+0.472. This has a possibly associated OH maser but the OH position still has an uncertainty larger than 10 arcsec (Caswell 1998).

312.598+0.045 and 312.597+0.045. The first of these sites is stronger and coincides with an OH maser. The second methanol site is offset 6 arcsec and appears to be distinct, and has no detected OH counterpart.

319.836−0.197. The apparent OH counterpart is offset 3 arcsec, but is weak, and its position uncertainty may account for the discrepancy; we provisionally regard the two species of maser as coincident.

321.030−0.485 and 321.033−0.483. The separation is more than 10 arcsec and only the first, weaker, site has a detected OH counterpart.

327.392+0.199 and 327.395+0.197. The separation of these sources is 14 arcsec and neither has a detected OH counterpart.

328.808+0.633 and 328.809+0.633. These were treated by Caswell (1997) as possibly separate sites, partly on the basis of an overlay with continuum emission, and despite their small separation of only 2.4 arcsec. The spectral features of the second source lie within the velocity range of those from the first source, but we retain them as distinct sources pending more evidence.

329.339+0.148. The discovery of the 1665-MHz maser at this site was reported by Caswell (2001) and it turns out to be an especially interesting distant site with OH maser emission also at 1720 MHz (Caswell 2004b) and 13441 MHz (Caswell 2004c).

329.405−0.459 and 329.407−0.459. The separation of the sites is 5.7 arcsec and only the first site coincides with an OH maser.

330.953−0.182. As noted by Caswell (2001), the methanol coincides with an OH 6035-MHz maser site, but the major OH 1665- and 1667-MHz masers are offset 3 arcsec.

331.542−0.066 and 331.543−0.066. The separation is only 3 arcsec, but at a likely distance of 6 kpc this correponds to 90 mpc, and there is further evidence that they represent two distinct sites since there is no obvious velocity overlap, and each has an OH counterpart (Caswell 1997, 1998).

333.126−0.440 and 333.128−0.440. The separation is 7 arcsec and OH emission has not been detected at either site.

333.135−0.431s. The suffix denoting south was added by Caswell (1997) to distinguish this site from another site, offset nearly 3 arcsec, which has OH without methanol.

333.128−0.560 and 333.130−0.560. The sites are distinct with separation more than 6 arcsec and neither has a detected OH counterpart.

335.585−0.289 and 335.585−0.290. These appear to represent two distinct sites, but with a separation of barely 3 arcsec, this is uncertain. The first site has coincident OH. The second is a single strong feature at an offset velocity and without OH emission.

337.703−0.053 and 337.705−0.053. Only the second, stronger, maser of this pair has a detected OH counterpart.

338.075+0.012 and 338.075+0.009. Only the first, stronger, maser of this pair has a detected OH counterpart.

339.681−1.208 and 339.682−1.207. As noted by Caswell (1998) there is an OH counterpart to the second site straddling the methanol position. The first methanol site which lies more than 3 arcsec south is stronger, has a wide velocity range encompassing the small range of the second source and although it seems to be spatially distinct, this is not certain.

344.419+0.044 and 344.421+0.045. These are clearly distinct and only the first, weaker, methanol site has an OH counterpart.

345.003−0.223 and 345.003−0.224. The second of these agrees well in position with an OH counterpart at both the 1665- and 6035-MHz transitions. The velocity ranges of the two sources do not noticeably overlap and an overlay on continuum emission argues strongly that the two sites are quite distinct despite their small separation of only 3 arcsec (Caswell 1997).

345.010+1.792 and 345.012+1.797. These are clearly distinct and only the first has a detected OH counterpart.

348.550−0.979 and 348.550−0.979n. The first of these has a continuum and OH counterpart at both the 1665- and 6035-MHz transitions. There is evidence (Caswell 1997) that the second source (offset 2.2 arcsec to the north), detected only on the methanol transition, is quite likely a site with its own source of excitation. The sites have overlapping velocity ranges.

349.092+0.105 and 349.092+0.106. The second source coincides with an OH maser. The first source, with no OH, has a clearly distinct velocity range and seems to be a separate site despite the smallness of its offset, slightly more than 2 arcsec, from the second.

350.105+0.083 and 350.104+0.084. Separated nearly 4 arcsec, neither site has an OH counterpart. The small velocity range of the second source lies wholly within the range of the first.

351.417+0.645 and 351.417+0.646. The separation of these sites is more than 3 arcsec. The first one coincides with the well-known H ɪɪ region NGC6334F and its OH maser emission. The second lies clearly offset and appears to be a distinct separate site (Caswell 1997).

351.581−0.353. Caswell (1997) queried whether there was an additional distinct source to the north (351.581−0.353n). The separation of slightly less than 1.8 arcsec leaves this unclear, and the extra maser spots have velocities within the range of the main site. We list the positions of both sites, but note that the 1665-MHz OH counterpart and a compact H ɪɪ region lie between the positions, which hints that we are more likely dealing with an extended single site. Recent recognition that the site is most likely in the near portion of the expanding 3-kpc arm (Green et al. 2009b) would imply a distance of 5.3 kpc, and thus a linear extent of 45 mpc which, for a single site, is large but not exceptional.

353.273+0.641. This strong methanol maser was first detected 1993 but was reported only recently (Caswell & Phillips 2008) when an association with a remarkable water maser was confirmed. No OH maser has been detected at the site.

355.344+0.147, 355.343+0.148 and 355.346+0.149. The third maser is quite distinct spatially, with an offset of 10 arcsec from the other sites. The first two sites have no overlap in velocity but are separated spatially only 3.7 arcsec, and the likelihood that they are distinct sites depends on an estimate of their distance. Crovisier, Fillit & Kazes (1973) argue, on the basis of intervening absorption features near $+100\,\mathrm{km\,s^{-1}}$, that the radio continuum emission and the OH 1665-MHz maser emission are at a distance beyond the Galactic Centre. This evidence subsequently passed unnoticed in the literature, attracting no relevant citations, and in particular was overlooked by Caswell (1997) and Forster & Caswell (1989, 1999, 2000) who assigned the complex to a distance of only 2 kpc. If we reject the nearby location, the alternative distances then include: outside the solar circle and thus beyond 17 kpc; near the Galactic Centre at 8.5 kpc which might account for unusual velocities; or (perhaps most likely) a location in the far-side counterpart to the 3-kpc expanding arm at 11.5 kpc (Dame & Thaddeus 2008; Green et al. 2009b). At any distance beyond 8.5 kpc, the separation of 3.7 arcsec then corresponds to more than 150 mpc, indicative of clearly distinct sites for all three methanol masers.

357.967−0.163 and 357.965−0.164. Two clearly distinct sites, separated 7.6 arcsec, of which only the first has an OH counterpart.

359.436−0.104 and 359.436−0.102. Clearly distinct and separated 6 arcsec, the first has a well-known OH counterpart (Caswell 1998) and the second also now has a more recently reported OH maser counterpart (Argon, Reid & Menten 2000).

0.315−0.201 and 0.316−0.201. These are separated by 2.5 arcsec and listed as distinct sites by Caswell (1996b), despite the weak features of the second lying wholly within the range of the first source. At neither position is there any detected OH counterpart. Pending further evidence, we list both sites, but caution that they may in fact be components of a more than usually extended single site.

0.475−0.010. This source was discovered as a new source in the Galactic centre survey by Caswell (1996b) but was incorrectly reported as 0.393−0.034. Re-analysis of the data showed that the position error arose because the sparse uv-coverage caused a side-lobe to be of comparable amplitude to the main lobe and was incorrectly interpreted as the source position. The source is closer to the target pointing than first estimated, and so its flux density correction for the offset is not as large, and the new estimate of peak flux density is therefore lower, 2.9 Jy.

0.645−0.042 to 0.695−0.038. These nine sites within the Sgr B2 complex were distinguished by both Houghton and Whiteoak (1995) and Caswell (1996b); they are all clearly distinct sites. Existing OH 1665 and 1667-MHz observations towards Sgr B2 remain incomplete, and those by Argon et al. (2000) are some of the best currently available. The detailed information in their datasets show counterparts at 1665 and 1667 MHz for 0.657−0.041 and 0.672−0.031, and an OH 1720 MHz counterpart for 0.665−0.036. One of the other methanol sites, 0.666−0.029, is accompanied by a 6035-MHz maser (Caswell 1997).

Two weak additional methanol sites in the Sgr B2 complex were reported by Houghton and Whiteoak (1995) and are believed reliable but were too weak to confirm in the present observations. They are omitted from the present listing which is intended to present only the results of our independent observations.

9.621+0.196 and 9.619+0.193. The first of these is the strongest known methanol maser, and the second is a clearly distinct site offset more than 10 arcsec. Both have OH counterparts and ucH II regions (Forster & Caswell 2000).

11.034+0.062. Note that the weak feature seen on the spectrum of Caswell et al. (1995a) at velocity $24.4\,\mathrm{km\,s^{-1}}$ is a side-lobe of 10.958+0.022.

12.025−0.031. There is an OH 1665–MHz maser counterpart at $18^{\mathrm{h}}12^{\mathrm{m}}01.88^{\mathrm{s}}$, $-18°31'55.6''$ (Caswell unpublished; this is a precise position for a source previously listed as 12.03−0.04 by Caswell 1998) and it is thus now confirmed to coincide with the methanol.

12.209−0.102. A 1665-MHz OH maser counterpart lies at this position (Argon et al. 2000; Caswell unpublished).

12.889+0.489. Spectral features over the velocity range 28 to $42\,\mathrm{km\,s^{-1}}$ mostly lie within 0.5 arcsec of the tabulated position, but a single strong feature at velocity $+33.5\,\mathrm{km\,s^{-1}}$ is offset 2 arcsec northeast, at $18^{\mathrm{h}}11^{\mathrm{m}}51.49^{\mathrm{s}}$, $-17°31'28.0''$. The OH counterpart is offset from both methanol features by slightly more than 1 arcsec and we treat this as a single site.

13.657−0.609. This source was first reported by MacLeod et al. (1998) but is not in the compilation of Pestalozzi et al. (2005). As also noted by MacLeod et al., there is associated OH emission at 1665 and 1667 MHz which new observations (Caswell in preparation) show to be at $18^{\mathrm{h}}17^{\mathrm{m}}24.27^{\mathrm{s}}$, $-17°22'13.4''$, effectively coincident with the methanol.

19.472+0.170 and 19.472+0.170sw. The second source is offset 3.7 arcsec south-west from the first, and offset to smaller velocity. No other maser is known at these positions so it is not clear whether the sites are distinct, or simply a larger than usual single site.

20.237+0.065 and 20.239+0.065. The two sites are separated more than 7 arcsec. The first coincides with OH maser emission at 1665 MHz, 6035 MHz and 1720 MHz (Caswell 2003, 2004b), whereas the second is solitary.

23.437−0.184 and 23.440−0.182. The clear separation of more than 10 arcsec establishes these as distinct sites with distinct velocity ranges.

28.146−0.005 and 28.201−0.049. The proximity of these sources to declination zero causes the beamsize in declination to be large, and the declinations to have larger than usual uncertainties, estimated to be 1 arcsec. The correspondence in each case with an OH maser (Argon et al. 2000) to better than 2 arcsec suggests that our errors are indeed no greater than 2 arcsec.

43.149+0.013 to 49.161+0.004. These four sites are part of the W49 complex and were noted as distinct in the single dish observations of Caswell et al. (1995a). Pandian et al. (2007) detect all four, plus an additional weak one which has a peak less than 1 Jy.

49.470−0.371 to 49.490−0.388. These five sites are part of the complex W51. Caswell et al. (1995a) recognised that there were at least three sites here and Pandian et al. (2007) recognised four. Our higher resolution now distinguishes five sites with clearly defined separate positions, although the velocity ranges of weak features are uncertain owing to side-lobe confusion.

4.2 Association with OH Masers

The precise methanol maser positions reported here allow an improved study of the association of methanol masers and 1665-MHz OH masers in regions of Massive Star Formation. However, beyond the 16 degree Galactic longitude limit of the Caswell (1998) catalogue, the OH information is incomplete, although some individual sources can be studied using the OH positions available in Forster & Caswell (1989, 1999) and in Argon et al. (2000).

Therefore, for statistical purposes in the evaluation of the discovery statistics of methanol towards OH masers, we consider only the Galactic longitude range 232° through 360° to 16°, covered by the OH catalogue of Caswell (1998). A preliminary analysis was performed by Caswell (1998), but accurate positions for some of the methanol masers were not known and some of the possible associations were therefore uncertain. Furthermore, there are several more recent OH results in this region as noted in section 4.1. We find that for the (updated) list of 207 star-formation-region OH masers with precise positions known in this longitude range, 168 (81 percent) possess a methanol counterpart. Of course, the interpretation of methanol and OH associations in terms of common conditions and evolutionary stages for methanol and OH co-existence requires a closer inspection of line ratios and investigation of co-propagation.

However, a practical consequence of this 81 percent statistic is that when a new, deep, unbiased survey for methanol masers has been completed (Green 2009a), and the positions used as targets for an OH search, we may expect the results to be a useful proxy for a deep unbiased survey for OH, and perhaps to recover at least 80 percent of the full OH population.

4.3 Unusually Wide Velocity Spreads

We have explored the velocity widths of the methanol masers and find that only 10 of our sample have velocity widths exceeding 16 km s^{-1}. The largest are 24 and 23 km s^{-1}, shown by 340.785−0.096 and 335.060−0.427. For both sites, red-shifted emission is weaker, most noticeably for 340.785−0.096 (Caswell et al. 1995a; Caswell 1997). The two sources with extent 17 km s^{-1} (344.227−0.569 and 340.054−0.244) also have only weak emission at one of their extreme velocities, one blue, the other red. The six sources with velocity ranges of 18 or 19 km s^{-1} (339.681−1.208, 330.070+1.064, 10.473+0.027, 2.536+0.198, 6.795−0.257 and 22.435−0.155) have somewhat stronger emission near both extremes of velocity, the intensity ratio of blue to red ranging from 1.8 to 0.1.

Since velocity extents greater than 16 km s^{-1} are rare (less than 3 percent of the total), this lends validity to the practice of using methanol velocities (e.g. the mid-values of the range) as the systemic velocity, with the expectation that the uncertainty is rarely as large as 10 km s^{-1}, and most commonly less than 5 km s^{-1}.

The systemic velocity is dominated by Galactic rotation for the Galactic disk population of young massive stars, and is thus suitable for estimating kinematic distances. Velocity ranges of individual sources often match those of OH counterparts quite well, and confirm the likely systemic velocities.

5 Conclusion

The precise positions reported here confirm that more than 80 percent of OH masers in regions of massive star formation have associated methanol masers.

We have also explored the velocity widths of the methanol masers and find that values greater than 16 km s^{-1} are rare (less than three percent of the total), in marked contrast to water masers where more than half the sources have velocity widths exceeding 20 km s^{-1}.

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