ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **134**, 115–128 (1999)

The Medicina survey of methanol masers at 6.7 GHz*

V.I. Slysh[1], I.E. Val'tts[1], S.V. Kalenskii[1], M.A. Voronkov[1,2], F. Palagi[3], G. Tofani[4], and M. Catarzi[4,]**

[1] Astro Space Center of Lebedev Physical Institute, Profsoyuznaya 84/32, 117810 Moscow, Russia
[2] Moscow State University, Physical Faculty, Astronomical Department, Universitetskii pr. 13, 119899 Moscow, Russia
[3] C.A.I.S.M.I., C.N.R., Largo E. Fermi 5, 50125 Firenze, Italy
[4] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

Received May 19; accepted July 23, 1998

Abstract. A survey of Class II methanol masers at 6.7 GHz was made in the Northern hemisphere with the 32-m Medicina radio telescope. 42 objects were detected, 20 of them are new detections at 6.7 GHz. Our results show that the detection rate of 6.7 GHz masers toward the inner part of the Galaxy is higher than in other directions. It is confirmed that most of the methanol masers are associated with faint compact HII regions. The 6.7 GHz methanol masers show large velocity dispersion and large velocity offset from the velocity of parent molecular clouds.

Key words: masers — ISM: molecules; HII regions — radio lines: ISM

1. Introduction

The early phases of stellar evolution are characterized by interaction between a newly born star and its environment, resulting in the formation of molecular outflows, highly collimated jets, Herbig-Haro objects, emission or reflection nebulae and molecular masers. Methanol maser emission arises from several transitions, the strongest being the $5_0-6_1A^+$ line at 6.7 GHz, first detected by Menten (1991a) and recognized as typical of the Class II masers (Menten 1991b). Their fluxes are often larger than the associated OH masers fluxes.

Several surveys of the 6.7 GHz masers have been done in the Southern hemisphere (MacLeod et al. 1992; MacLeod & Gaylard 1993; Schutte et al. 1993; Caswell et al. 1995a), whilst in the Northern hemisphere no surveys in this line have been done since the discovery survey by Menten (1991a) who searched for the 6.7 GHz masers mostly toward OH masers.

Schutte et al. (1993) detected 35 masers at 6.7 GHz toward IRAS sources with colours typical for HII–regions, without known OH or other Class II methanol maser counterparts and showed that colour-selected IRAS objects are good candidate sources for the 6.7 GHz maser search. Schutte et al. (1993) also report different detection rates of methanol masers in different directions, supporting the idea that large-scale variations of overall methanol abundance in the Galaxy may exist. It is of interest to test with a larger sample of sources whether these variations really exist and try to understand their nature. Therefore we observed at 6.7 GHz a sample of 231 IRAS sources in the Northern hemisphere which satisfy the colour criteria by Wood & Churchwell (1989) for UC HII regions (WC objects), i.e. sources, which are not identified as stars and extragalactic objects, have good detections at 25 and 60 μm and have $\lg(F_{25}/F_{12}) > 0.57$ and $\lg(F_{60}/F_{12}) > 1.3$, independently of their relation to known OH or CH_3OH masers. Combining our results with data taken from the literature we can study the overall methanol abundance distribution in star-forming regions in a large part of the Galaxy.

In addition to colour-selected IRAS sources, we observed also objects that were identified as ultracompact HII-regions by Helfand et al. (1992) on the basis of the comparison of their IRAS and radio properties (52 objects). We extended our observations to other sources connected to the star formation process. Our source list contains 140 bipolar outflows. In addition, we observed a group of 6 objects, which consists of methanol maser and thermal sources from the surveys of Friberg et al. (1988); Slysh et al. (1994a); Peng & Whiteoak (1992). Many of these sources are associated with IRAS WC objects. The total number of the observed IRAS WC sources is 326. The others are supposed to be related to stars with low and intermediate mass. The goal of this work was to better understand the connection of methanol masers with other phenomena typical of star-forming regions. At present only the connection between the Class II

Send offprint requests to: F. Palagi

* Table 2 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

** Deceased on March 14, 1994.

Table 1. Parameters of detected sources. BO, WC and HII in the last column mean that a source is associated with a bipolar outflow, an IRAS object that satisfy the WC colour criteria, or HII object from Helfand et al. (1992), respectively

Source name	α_{1950} (h m s)	δ_{1950} (° ′ ″)	Peak velocity (km s^{-1})	Velocity range (km s^{-1})	Peak Flux (Jy)	Distance near (kpc)	Distance far (kpc)	Association
L1287	00 33 53.0	63 12 32	−22.9	−28,−20	10	2.3		BO,WC
NGC281-W	00 49 27.8	56 17 28	−29.0	−31,−27	12	2.9		BO,WC
W3-IRS5	02 21 55.4	61 52 34	−44.3	−47,−39	5	4.6		BO
02455+6034	02 45 30.1	60 34 35	−45.3	−46,−44	24	4.9		WC
AFGL 5142	05 27 27.6	33 45 37	1.8	0,5	48			BO,WC
05480+2545	05 48 04.8	25 45 29	−14.5	−16,−4	19			WC
AFGL 6366S	06 05 40.9	21 31 32	10.9	9,13	29			BO,WC
17430-2822	17 43 00.0	−28 22 22	0.0	−11,3	7			WC
17436-2806	17 43 41.0	−28 06 31	4.0	3,5	20			WC
17440-2825	17 44 04.8	−28 25 49	49.5	47,53	66			WC,HII
17463-3128	17 46 21.3	−31 28 20	5.2	1,7	31			WC
17589-2312	17 58 54.7	−23 12 39	26.9	15,30	84			WC
10.3-0.15	18 05 57.9	−20 06 26	10.6	4,18	131			WC,HII
18064-2008	18 06 26.0	−20 08 42	39.0	9,40	9			WC
18102-1800	18 10 16.7	−18 00 26	24.0	20,26	11	2.9	13.6	WC
18128-1640	18 12 51.1	−16 39 53	15.3	5,16	200	1.9	14.6	HII
18151-1208	18 15 09.0	−12 08 33	28.2	27,29	72	2.6	13.5	WC
18236-1241	18 23 36.0	−12 41 26	42.0	39,45	5	3.5	12.6	WC,HII
L379IRS2	18 27 43.4	−15 16 45	24.1	20,25	14	2.5	13.8	BO
18310-0825	18 31 03.6	−08 25 56	88.4	85,90	6	5.3	10.3	WC
18316-0602	18 31 38.9	−06 02 08	41.8	41,42	181	3.0	12.3	WC
18317-0845	18 31 45.9	−08 45 47	64.5	63,66	8	4.3	11.3	WC
18324-0820	18 32 27.3	−08 20 23	80.0	75,81	30	4.9	10.6	WC
18334-0733	18 33 28.5	−07 33 44	115.2	114,116	42	6.6	8.9	WC
18341-0727	18 34 09.3	−07 27 23	114.0	113,115	16	6.6	8.9	WC
18379-0500	18 37 55.5	−05 00 34	34.9	34,36	41	2.6	12.5	HII
18379-0546	18 37 57.4	−05 46 11	104.2	103,116	9	6.1	9.1	WC,HII
18416-0420	18 41 39.8	−04 21 00	81.5	81,84	75	5.0	10.0	WC,HII
18470-0044	18 47 02.1	−00 44 35	93.2	91,105	31	5.9	8.5	WC
18488+0000	18 48 51.1	00 00 41	92.6	90,94	21	6.0	8.3	WC,HII
18497+0022	18 49 47.0	00 22 07	105.0	100,108	26	4.5		HII
18566+0408	18 56 40.8	04 08 03	84.2	76,88	4	6.3	7.2	WC
18572+0057	18 57 16.2	00 57 21	47.5	42,48	27	3.1	10.8	WC
19220+1432	19 22 02.2	14 32 07	59.6	51,61	10	4.5		WC
19388+2357	19 38 52.6	23 57 36	38.4	36,41	31	2.7		WC
19589+3320	19 58 57.0	33 20 47	−26.4	−30,−22	22	8.8		WC
20062+3550	20 06 17.1	35 50 32	−2.8	−4,−2	32	5.7		WC
20126+4104	20 12 41.0	41 04 20	−6.5	−8,−4	61	5.0		BO,WC
20350+4126	20 35 04.8	41 26 02	−4.0	−6,−3	10			WC
GL 2789	21 38 11.3	50 00 45	−43.9	−45,−39	19			BO
L1206	22 27 12.1	63 58 21	−11.3	−12,−10	109	1.7		BO,WC
22551+6139	22 55 11.7	61 40 00	−2.4	−6,−1	43	0.6		WC

methanol masers and ultracompact HII-regions seems to be very likely. Slysh et al. (1995) suggested a connection between high-velocity motions and the Class II $J_0 - J_{-1}E$ methanol masers. However, the situation is unclear, and we expected that our survey of 6.7 GHz sources toward a large sample of bipolar outflows will clarify it.

2. Observations

Observations were carried out from March 28 to April 10 1995 using the Medicina 32-m radio telescope. We used a dual-polarization uncooled receiver with HEMT amplifiers, tuned to the $5_1 - 6_0A^+$ line rest frequency, 6668.518 MHz. The system noise temperature was about 130 K for the right circular polarization and about 140 K for the left circular polarization. The antenna gain was estimated to be about 9 Jy/K from observations of DR 21 and 3C 123 as calibrators assuming a flux density of 21 Jy and 12 Jy, respectively. Elevation gain curves were estimated to correct for small elevation gain changes, using DR21 and 3C 123 as primary calibrators and 3C 273 (42 Jy) and 3C 274 (60 Jy) as secondary calibrators.

The beamwidth at 6.7 GHz was 5.6 arcmin. The observations were made in the position-switching mode with 1° separation between *on* and *off* positions. The backend was a 512-channel autocorrelator with 3.1 MHz bandwidth which provided 0.27 km s^{-1} velocity resolution and 141 km s^{-1} velocity coverage. Some of the detected sources were additionally observed with 0.07 km s^{-1} resolution (0.78 MHz bandwidth).

3. Results

During the survey 42 maser sources were detected out of 429 observed positions. Spectra of the sources are presented in Fig. 1, and the measured parameters are given in Table 1. Columns 1 – 3 are self-explanatory; Cols. 4 – 6 present the peak velocity, velocity range of the 6.7 GHz emission, and the flux density of the strongest feature, respectively. Columns 7–8 present near and far kinematic distance of the source. No measurable difference has been found between right and left polarizations. List of non-detections is in Table 2, given in electronic form; the typical detection limit for these sources is about 3 Jy. After completion of our observations papers by Walsh et al. (1995); van der Walt et al. (1995) and Lyder & Galt (1997) appeared where independent discovery of several 6.7 GHz masers is reported.

Thirty-six masers were detected towards WC objects. In bipolar outflows nine masers were found, and all of them are associated with high-luminosity IRAS sources. Thus, the majority of the detections are associated with IRAS objects. However, not all of them satisfy the colour criteria by Wood & Churchwell. No masers were found in the vicinity of young stars of low and intermediate luminosity.

These cases are discussed in Sect. 4.

3.1. Distances

The kinematic distances were obtained using the rotation curve by Brand & Blitz (1993)

$$\frac{\theta}{\theta_0} = 1.00767 \left(\frac{R}{R_0}\right)^{0.0394} + 0.00712 \qquad (1)$$

where θ is the linear velocity at the radius R, and $\theta_0 =$ 220 km s^{-1} is the linear velocities at the solar radius $R_0 =$ 8.5 kpc.

We did not attempt to resolve the ambiguity in distance determination for several sources in which case we report both near and far solutions, although the near distances are more likely for a large number of observed sources. One can notice, that some sources have forbidden velocities and it's impossible to calculate their kinematic distances.

4. Comments on individual sources

L1287 (00338+6312). New detection. The 6.7 GHz methanol spectrum consists of two features at the velocities −23 km s^{-1} and −26.5 km s^{-1}. The source is associated with a bipolar outflow, it was observed in the CO (1 − 0) line at the velocity −18.4 km s^{-1} and mapped by Snell et al. (1990). There is an OH maser at the velocity −22.6 km s^{-1} (Wouterlout et al. 1993). The 3.6 cm VLA observations, which have been made by Anglada et al. (1994) reveal the presence of a radio continuum source close to this position.

NGC281-W (00494+5617). New detection. The 6.7 GHz methanol spectrum contains a single feature at the velocity −29 km s^{-1}. The source is associated with a bipolar outflow, it was observed in the CO (1 − 0) line at the velocity −30.5 km s^{-1} and mapped by Snell et al. (1990).

W3-IRS5 (02219+6152). New detection. Bipolar outflow; Bally & Lada (1983) detected CO emission towards this source with the velocity about −40 km s^{-1} which is close to the methanol velocity interval −47 km s^{-1}– −39 km s^{-1}.

02455+6034. The maser was also detected at 6.7 GHz by Lyder & Galt (1997). It is situated in the vicinity of W5. The spectrum obtained by Lyder & Galt in 1994 and spectrum obtained in this survey are similar. The difference in flux density, 24 Jy (this paper) and 32 Jy (Lyder & Galt 1997), can be attributed to a pointing offset of about 3 arcmin of our observation from the more accurate maser position, determined by Lyder & Galt (1997).

AFGL 5142 (174.20 − 0.08, 05274+3345). Bipolar outflow (Hunter et al. 1995). This source has been observed by Gaylard & Macleod (1993) who report a peak flus density of 85 Jy for the strongest feature at 2 km s^{-1}, while we observe a flux density of 48 Jy. The position offset of the two observations (1 arcmin) and the the different frequency resolution, 0.22 km s^{-1} instead of 0.27 km s^{-1} (present work), can only partly account for this difference which is almost a factor of two. Moreover we note that a) in Gaylard & MacLeod (1993) the 2 km s^{-1} feature is about 8 times more intense than the feature at 4 km s^{-1}, while in our spectrum this ratio is about 2.5; b) we observe a feature at 0.5 km s^{-1} which is missing in Gaylard & MacLeod observations. Therefore we conclude that AFGL 5142 is variable.

05480+2545. New detection. There are two spectral features, at −14.5 km s^{-1} and −4.5 km s^{-1}. CS (2-1) emission line is located between the methanol features at −9.4 km s^{-1} (Bronfman et al. 1996). OH maser at 1665 MHz has components in the velocity interval from −19 km s^{-1} to −4 km s^{-1} (Slysh et al. 1997).

AFGL 6366S (06056+2131). This source was also detected by Caswell et al. (1995a). The 11 km s^{-1} detail, which is the strongest in our spectrum (about 30 Jy), is obviously a sidelobe response to S252. It was present in the spectrum of Caswell et al. (1995a), but with a much weaker intensity

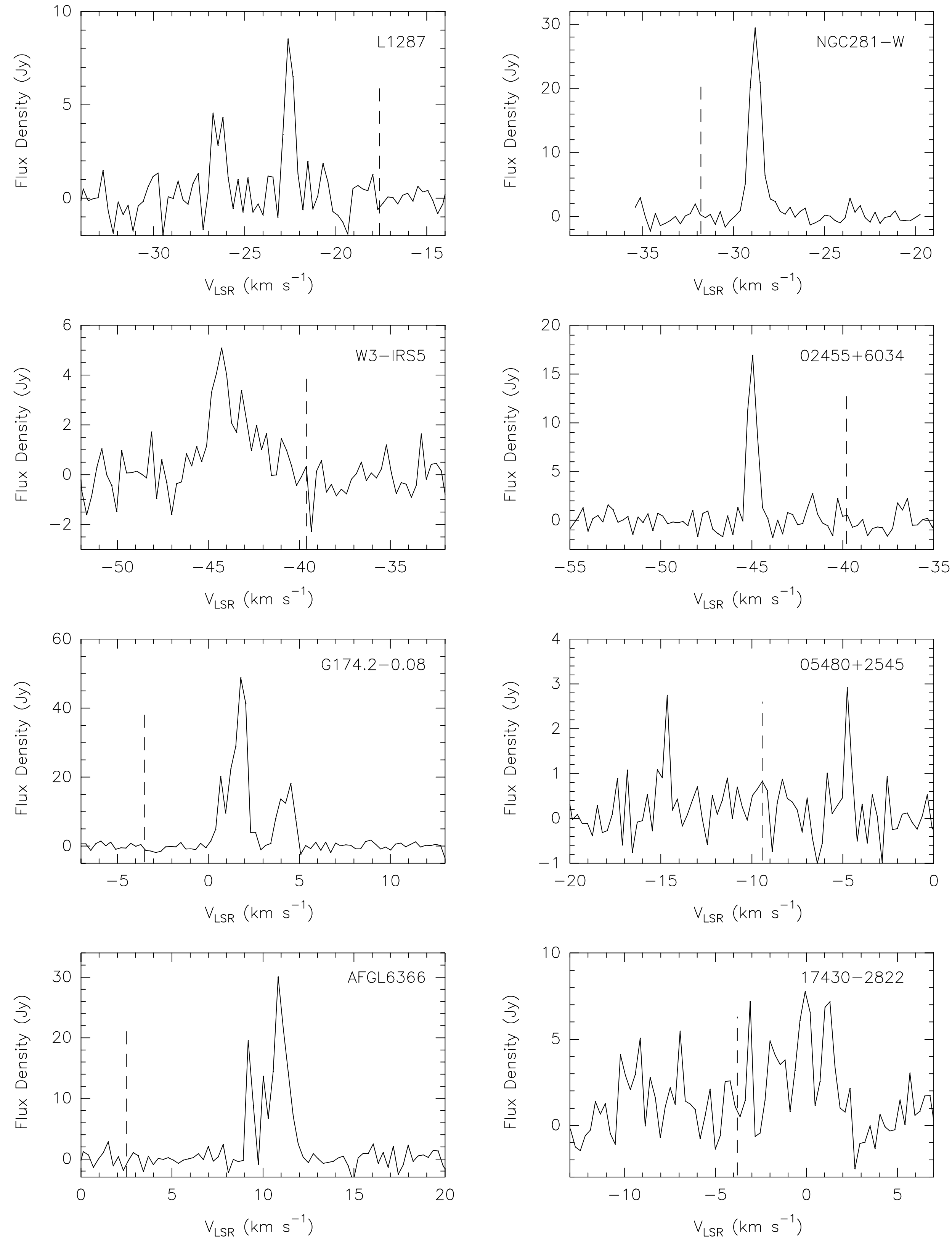


Fig. 1. Spectra of sources, observed at 6.7 GHz. Spectra of sources 17436−2806, 17463−3128, 18151−1208, L379IRS2, 18316−0602, 18572+0057, 78.12+3.63 are shown with the velocity resolution 0.07 km s^{-1}. For the rest of the sources the velocity resolution was 0.27 km s^{-1}. Dashed lines indicate CS velocity of the parent molecular cloud

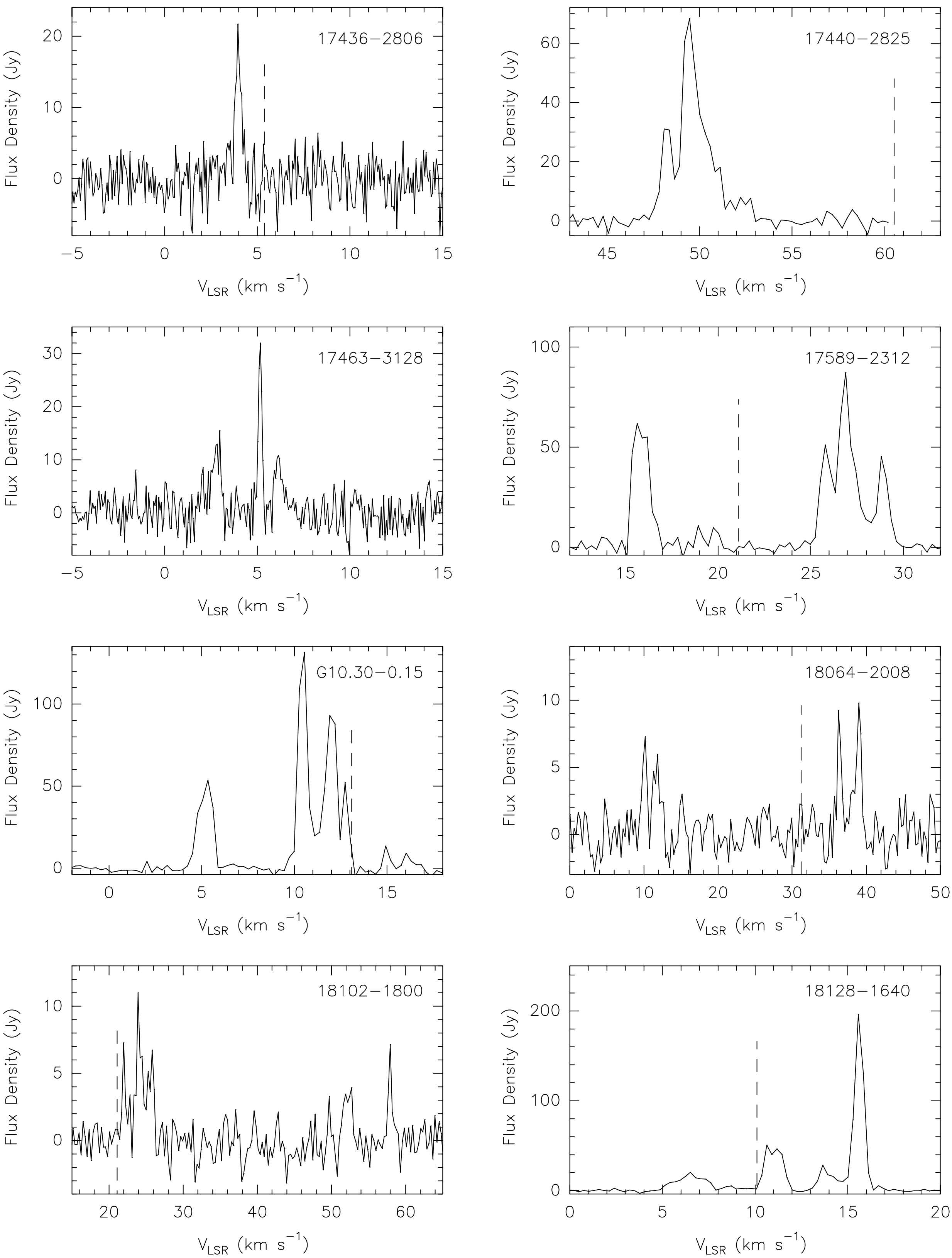


Fig. 1. continued

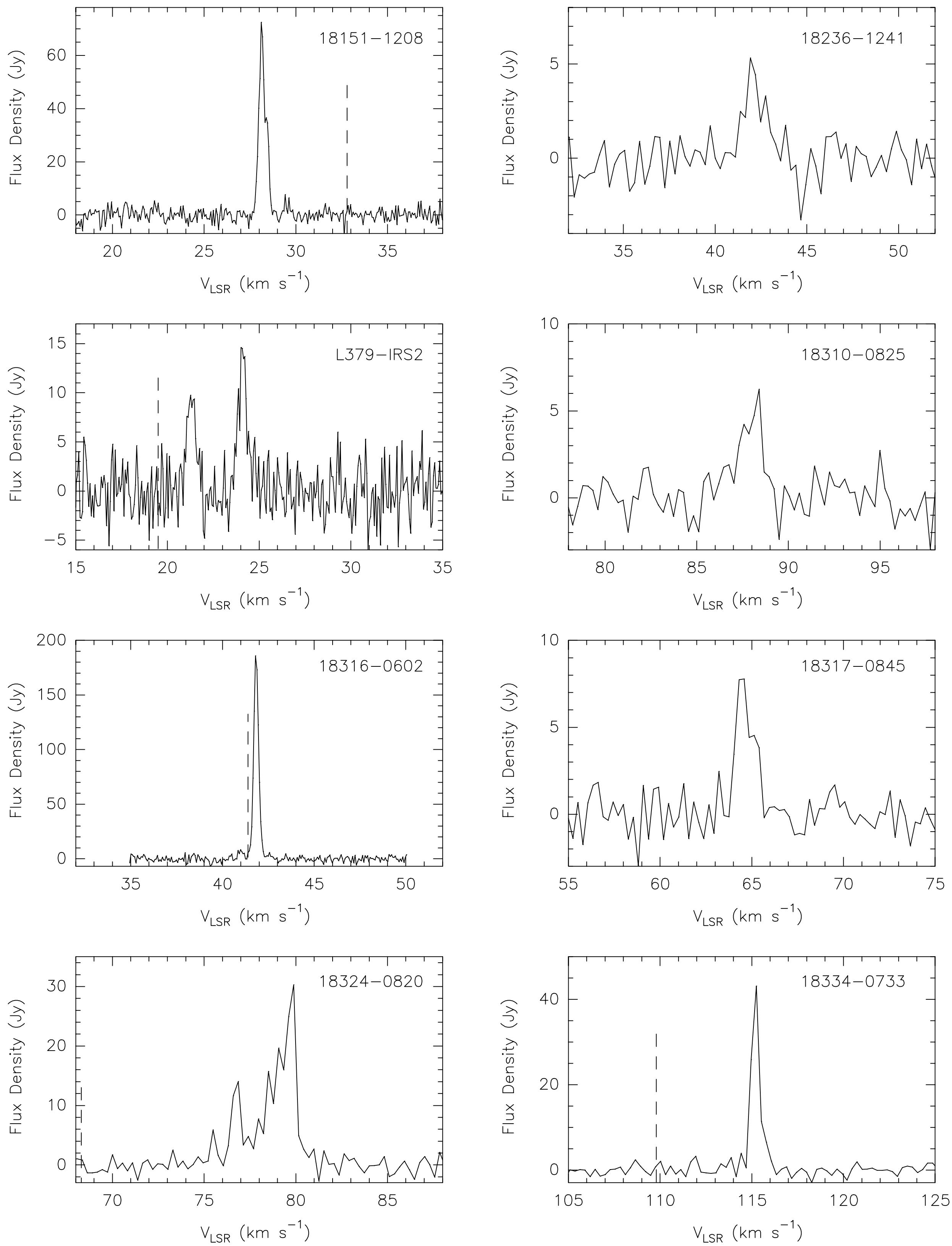


Fig. 1. continued

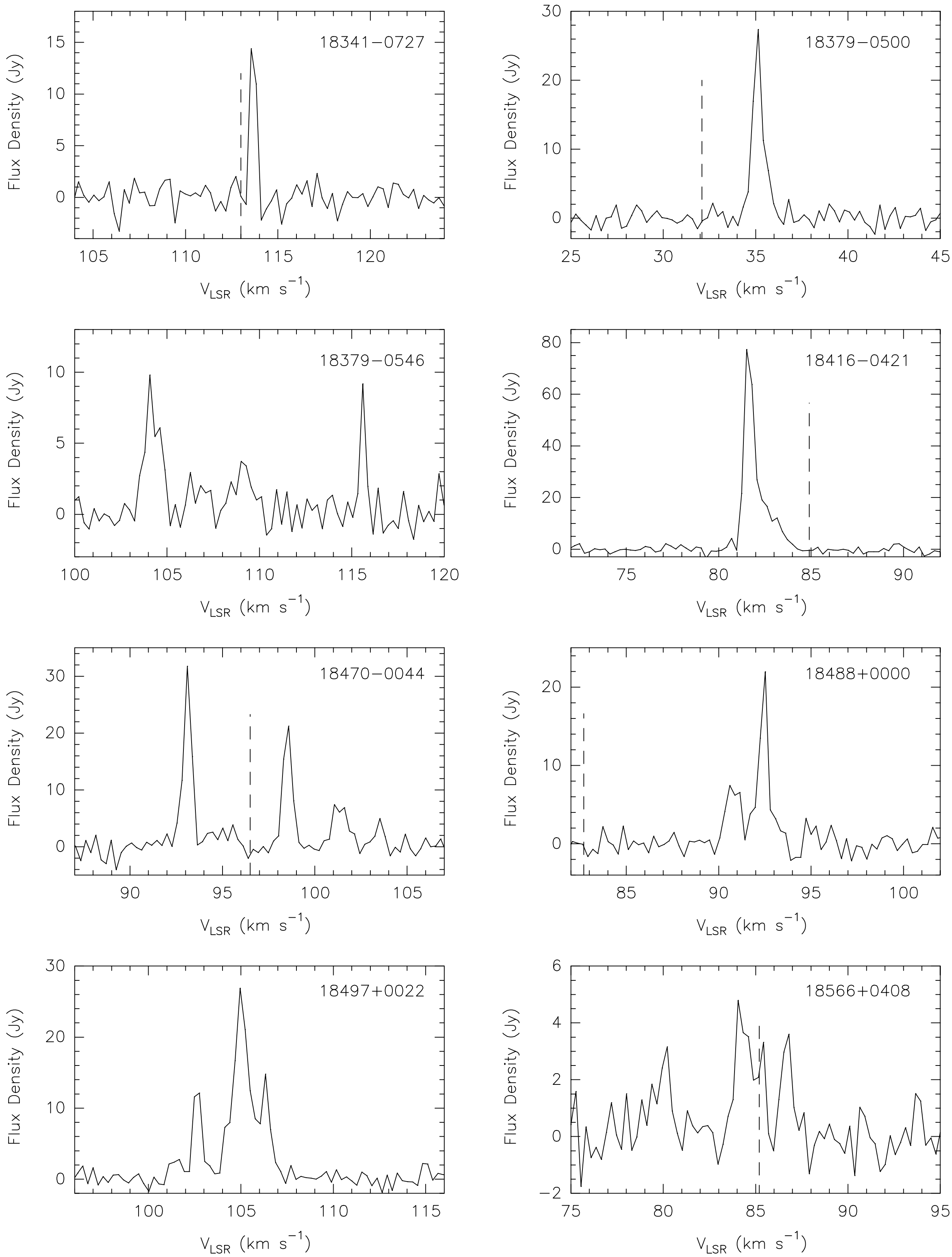


Fig. 1. continued

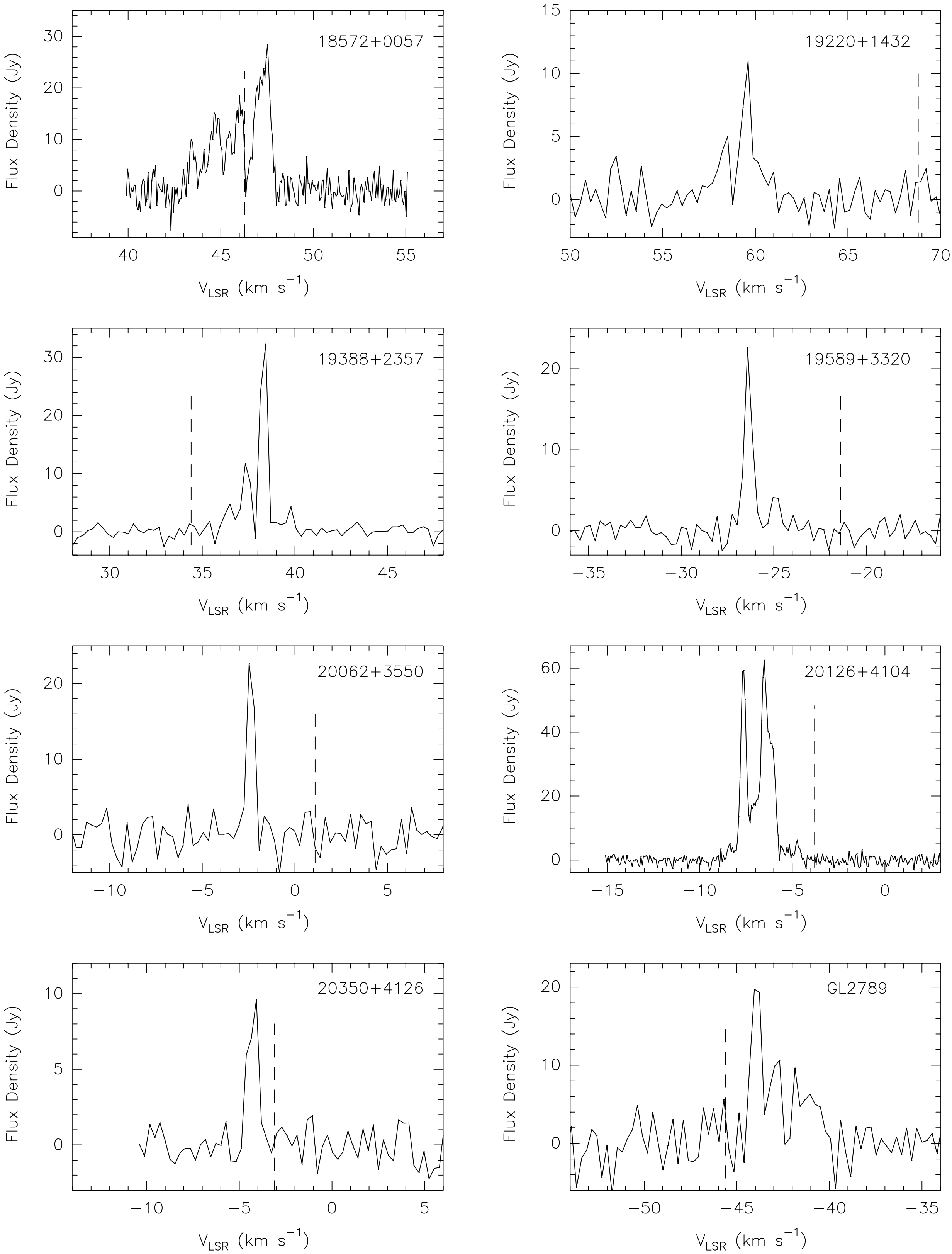
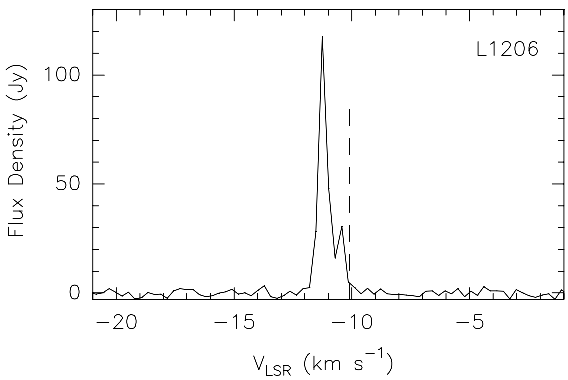


Fig. 1. continued



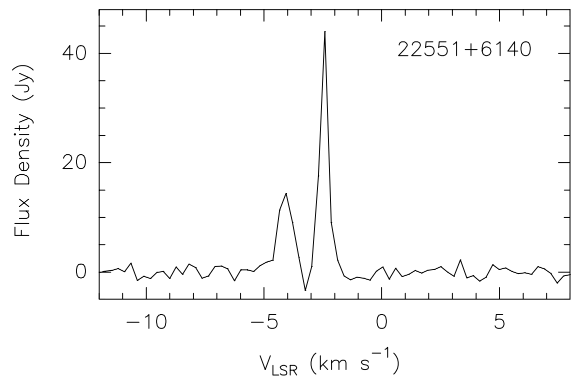


Fig. 1. continued

since the beam of their telescope was smaller. The source is a bipolar outflow (Snell et al. 1988).

17430−2822. The 6.7 GHz maser was found by Schutte et al. (1993). Our spectrum is similar to the one published by Schutte et al. (1993), and contains the same features at −10 km s^{-1}, −3 km s^{-1}, 0 km s^{-1} and 1 km s^{-1}.

17436−2806. This source was also observed by van der Walt et al. (1995). Spectrum consists of a single feature at about 4 km s^{-1}. We obtained the flux 20 Jy, about twice the flux published by van der Walt et al. This difference could be due to the higher velocity resolution 0.07 km s^{-1} in our survey compared to 0.22 km s^{-1} resolution of van der Walt et al. (1995).

17440−2825. This source belongs to the well-known molecular complex Sgr B2 where several centers of methanol maser activity exist. According to Caswell et al. (1995a) the lines, detected by us toward this IRAS object should be attributed to the centers of activity 0.64 − 0.04 and 0.65 − 0.05.

17463−3128. This IRAS source is also associated with OH maser of the Class Ib (emission only at 1667 GHz; Slysh et al. 1994b) at the velocity 9.4 km s^{-1}. The 6.7 GHz maser was also detected by van der Walt et al. (1995). Spectra look similar, but the flux of the main feature at 5 km s^{-1} is different: 31 Jy in our spectrum against 17 Jy according to van der Walt et al. (1995). This difference is a result of our higher velocity resolution and disappears when we compare our low-resolution spectrum with that of van der Walt et al. (1995).

17589−2312. This source was also observed by van der Walt et al. (1995). The spectra are slightly different: the main feature at 27 km s^{-1} is stronger relative to the adjacent features in the van der Walt's et al. spectrum than in our. However, this difference disappears if we compare our low-resolution spectrum with the spectrum by van der Walt et al. The flux densities of this feature are similar: 79 Jy, obtained by van der Walt is close to our value 84 Jy.

10.3−0.15. This source was first detected by Schutte et al. (1993). They observed the IRAS source 18060 − 2005 which is within our beam. The spectra and line intensities are close to each other.

18064−2008. New detection. This source was observed but not detected by van der Walt et al. with an upper limit of 5 Jy while we observed a feature of 9 Jy, indicating that this source may be variable. Methanol maser lines were observed near 39 km s^{-1} and 10 km s^{-1} which is close to the recombination line velocity of HII region associated with this source and observed by Lockman (1989) at the velocity 14.2 km s^{-1}.

18102−1800. New detection. The CS (2−1) line is at 21.1 km s^{-1} (Bronfman et al. 1996) which is close to the methanol velocity.

18128−1640. New detection. The CS (2−1) line is at the velocity 10.1 km s^{-1} (Larionov et al. 1998) as compared to 15.3 km s^{-1} for methanol.

18151−1208. The 6.7 GHz maser toward this source was observed by van der Walt et al. (1995) also. Both spectra consist of a single feature at 28 km s^{-1}, but fluxes are different. Van der Walt et al. obtained the flux of 46 Jy whereas our value is 72 Jy. This difference could be result of a higher velocity resolution 0.07 km s^{-1} compared to 0.22 km s^{-1} resolution of van der Walt et al. (1995).

18236−1241. New detection. The source was not previously found by van der Walt et al. (1995) with the upper limit 5 Jy and we found 5 Jy. Turner (1979) observed OH maser at the velocity 42 km s^{-1}, which is the same as the velocity of the brightest feature of methanol.

L379IRS2. New detection. The radial velocity of the strongest methanol feature 24.1 km s^{-1} is higher than the velocity of CS (2−1) line 19.5 km s^{-1} (Larionov et al. 1998).

18310−0825. The 6.7 GHz maser was first detected by Schutte et al. (1993). The spectra look quite different: Schutte et al. observed two narrow peaks between 87 and 89 km s^{-1} and we observed a single broad feature in the same velocity range. The peak flux density in the Schutte's et al. spectrum, 11 Jy is about twice as large as our value. The feature at 82 km s^{-1}, detected by Schutte et al., is probably present in our spectrum also, but our poorer signal-to-noise ratio does not allow us to confirm it.

18316−0602. Our 6.7 GHz spectrum consists of a single feature at 42 km s^{-1}. The same methanol feature was observed by van der Walt et al. (1995) and by Walsh et al. (1995) with the flux density a factor of two lower. This difference could be result of a higher velocity resolution 0.07 km s^{-1} compared to 0.22 km s^{-1} resolution of van der Walt et al. (1995).

18317−0845. This object was first detected by Schutte et al. (1993). A single feature at 64.5 km s^{-1} is present in both spectra. Schutte et al. reported the peak flux density of about 12 Jy, whereas our value is 8 Jy. However, poor signal-to-noise ratio does not allow us to conclude that the source is variable.

18324−0820. This source was first observed by Schutte et al. (1993). The main features at 80 km s^{-1} in both spectra have almost equal flux densities, whereas the feature at about 77 km s^{-1} is approximately twice as strong in our spectrum as in the Schutte's one. The observed positions differ by about 2.5′, therefore we cannot conclude if the differences in the spectra are due to variability or to a complex spatial structure of the source.

18334−0733. This source was also observed by van der Walt et al. (1995). A single line at 115 km s^{-1} is present in both spectra. A small difference in the flux densities (33 Jy obtained by van der Walt et al. and 42 Jy in the spectrum obtained in this survey) can be attributed to calibration uncertainties and/or to noise in the spectra.

18341−0727. New detection. We detected 6.7 GHz methanol emission at 113 km s^{-1}. Bronfman et al. (1996) observed the CS $(2-1)$ line exactly at the same velocity.

18379−0500. New detection. Larionov et al. (1998) observed the CS $(2-1)$ emission at the velocity 32.1 km s^{-1} close to the velocity of the brightest methanol feature 34.9 km s^{-1}.

18379−0546. The 6.7 GHz line was detected also by van der Walt et al. (1995). The feature at about 104 km s^{-1} in both spectra has approximately the same intensity of 10 Jy. In our spectrum an additional feature at 116 km s^{-1} with flux density of about 9 Jy is present.

18416−0421. This maser was first detected by Schutte et al. (1993). There is a single asymmetric line peaked at about 81.5 km s^{-1} in both spectra. The shape of the shoulder toward larger radial velocities looks different, but the difference can be caused by rather high noise in Schutte's et al. spectrum.

18470−0044. We detected the 6.7 GHz emission toward this IRAS object. However, van der Walt et al. (1995) made an offset measurements and showed that the methanol maser is most likely associated with another IRAS source 18470−0049.

18488+0000. This maser was also observed by van der Walt et al. (1995). The spectra are similar, and a small difference in the flux densities (the peak flux density is 16 Jy according to van der Walt et al. (1995) and 22 Jy according to our measurements) can be explained by calibration errors or/and noise.

18497+0022. New detection. This source is associated with the reflection nebulae GGD 30 (see Gómez de Castro & Eiroa 1991). Larionov et al. (1998) detected the CS (2−1) emission at 79.1 km s^{-1} which is well outside the velocity range of the methanol emission from 100 to 108 km s^{-1}.

18566+0408. New detection. Bronfman et al. (1996) observed CS (2−1) emission at 85.2 km s^{-1} within the methanol emission velocity range.

18572+0057. Van der Walt et al. (1995) also observed this source at 6.7 GHz. Our and their spectra look similar. Larionov et al. (1998) observed the CS (2−1) line at 46.3 km s^{-1}, within the velocity range of the methanol emission 42 to 48 km s^{-1}.

19220+1431. New detection. The source was not previously found by van der Walt et al. (1995). Bronfman et al. (1996) observed the CS (2−1) line at 68.8 km s^{-1}, outside the velocity range of the methanol emission.

19388+2357. The 6.7 GHz line at 38 km s^{-1} was observed in this source also by Schutte et al. (1993). Bronfman et al. (1996) observed the CS (2−1) line at 34.4 km s^{-1}.

19589+3320. New detection. Bronfman et al. (1996) observed the CS (2−1) line at −21.4 km s^{-1} and the methanol velocity is −26.4 km s^{-1}. Larionov et al. (1998) observed the same CS line at −20.5 km s^{-1}.

20062+3550. New detection. Radial velocity of methanol line is −2.8 km s^{-1}. Water vapor maser emission was detected at the velocity −1.6 km s^{-1} by Brand et al. (1994). Bronfman et al. (1996) observed the CS (2−1) line at 1.1 km s^{-1}.

20126+4104 (78.12+3.63). The 6.7 GHz maser was found first by MacLeod & Gaylard (1992). In November – December 1991 they detected a weak (7 Jy) emission in the velocity range −7.5 – −5.5 km s^{-1}. We detected rather strong (about 60 Jy) double-peaked line in the same velocity range. A large difference in flux densities is probably due to pointing errors of MacLeod & Gaylard (1992) observations of this Northern source from the Southern Hemisphere. Bronfman et al. (1996) detected the CS (2−1) emission at −3.8 km s^{-1}. The IRAS source is a center of well known bipolar outflow (Wilking et al. 1990).

20350+4126. New detection. OH emission was found towards this source at −8 km s^{-1} (Cohen et al. 1988). Bronfman et al. (1996) observed the CS (2−1) line towards this source at −3.1 km s^{-1} within the velocity range of methanol emission.

GL 2789 (21381+5000). New detection. The IRAS object is the center of a bipolar outflow (Rodríguez et al. 1981). A water vapor maser is located near this source (Comoretto et al. 1990) at the velocity −46.1 km s^{-1}. Plume et al. (1992) detected CS (7−6) emission towards this source at the velocity −45.6 km s^{-1} which is slightly outside the velocity range of the methanol emission.

L1206 (22272+6358). New detection. Larionov et al. (1998) detected CS (2−1) emission at −10.1 km s^{-1} while methanol velocity is −11.3 km s^{-1}. The IRAS source is probably a driving source for an unipolar outflow (Sugitani et al. 1989).

22551+6140. New detection. The velocity of 6.7 GHz methanol emision is in the interval from -5 km s^{-1} to -1 km s^{-1}. CO emission was observed at the velocity -8.7 km s^{-1} (Wouterloot & Brand 1989), outside the methanol emission velocity range.

5. Discussion

5.1. Distribution in the Galaxy

Several attempts to establish a distribution of methanol masers in the Galaxy have been done. It was shown, that the masers are concentrated mostly in the inner Galaxy (see e.g. van der Walt et al. 1995). MacLeod & Gaylard (1992) reported an asymmetry in the distribution of 6.7 GHz masers in the inner Galaxy: the number of masers, detected in the first quadrant is about 20% lower than the number of masers, detected in the fourth quadrant. MacLeod & Gaylard (1992) and Schutte et al. (1993) concluded that the probability to detect a 6.7 GHz maser toward an IRAS source with colours typical for ultracompact HII regions in the Carina arm is lower than in the inner arms. They suggested that it may be due to the combination of sensitivity limitations and the Galactic metallicity gradient. However, Gaylard & MacLeod (1993) made a deeper search at 6.7 GHz in which they detected several 6.7 GHz sources in the Carina arm and concluded that the low detection rate in the Carina arm reported by Macleod & Gaylard (1992) and Schutte et al. (1993) is due to limited sensitivity of their surveys.

It is of interest to study the detection rate of methanol masers in the whole Galaxy. As a first step, we made a histogram of the detection rate versus galactic longitude (Fig. 2). The detection rate was calculated as the ratio of the number of detections to the total number of reported observations per galactic longitude bin. The histogram shows that the probability to detect the 6.7 GHz methanol masers is higher in the inner Galaxy. It does not change very much if one uses only IRAS sources selected by Wood & Churchwell colour criteria.

The distribution of 6.7 GHz masers on the Galactic plane is shown in Fig. 3. This diagram is based on our data and the results of Menten et al. (1991a); Schutte et al. (1993); MacLeod & Gaylard (1992); Caswell et al. (1995a) and van der Walt et al. (1995). In total, 270 sources were taken into consideration. Only near kinematic distances were used in cases of ambiguity. No kinematic distances were calculated in the zone, restricted by two dashed lines, i.e., closer than 10° to the center−anticenter line, where kinematic distances are highly unreliable. The cross point of the dashed lines represents the position of the Sun; the Galactic center is located at the (0,0) position. The arc in the left part of the diagram is the Sagittarius arm.

5.2. Velocity dispersion

The 6.7 GHz methanol masers typically show a significant velocity offset from the radial velocity of host molecular clouds. Figure 4 shows the histogram of the absolute difference between the radial velocity of the strongest methanol feature and the radial velocity of thermal CS lines (in some sources it was CO) for 157 methanol masers taken from this survey and surveys by Menten (1991a); Shutte et al. (1993); van der Walt et al. (1995), and Caswell et al. (1995a) and for which the cloud velocity was available.

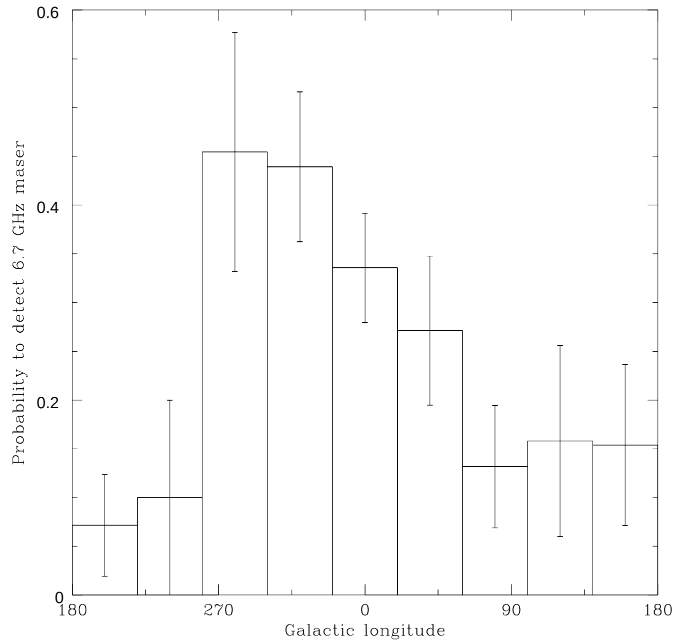


Fig. 2. 6.7 GHz methanol maser detection rate versus galactic longitude

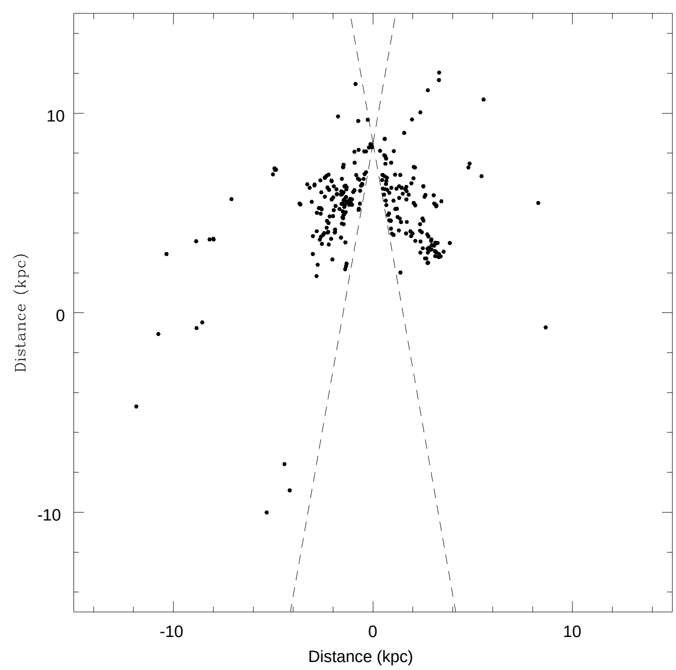


Fig. 3. The distribution of 6.7 GHz masers on the Galactic plane

The average difference is 5.5 ± 0.7 km s^{-1}, which is a factor of two to three larger than the thermal

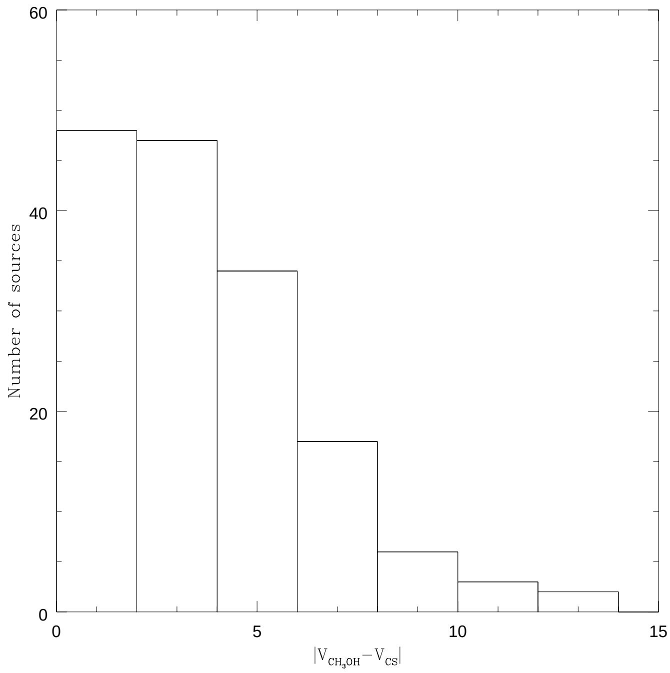


Fig. 4. Modulo of velocity difference between the 6.7 GHz peak velocity and CS velocity

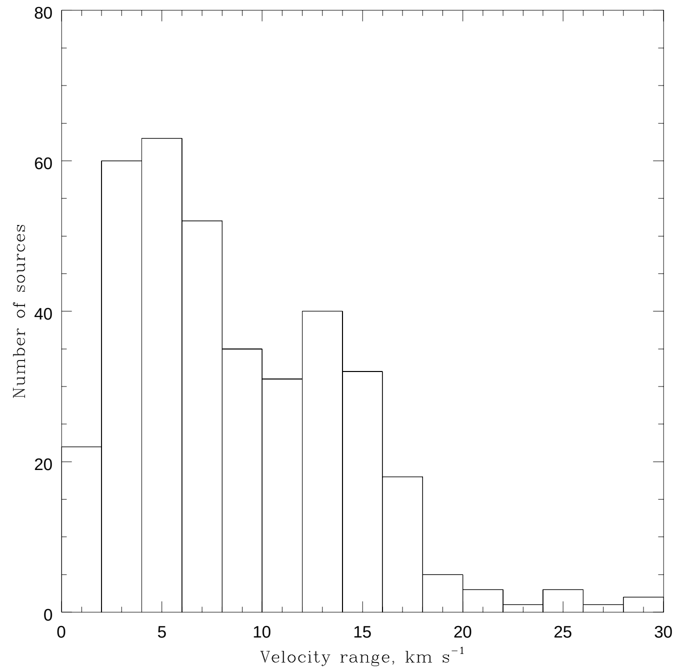


Fig. 5. The distribution of 6.7 GHz methanol masers velocity range

velocity dispersion, even in hot molecular clouds. In some sources this difference is larger than 10 km s^{-1}. The velocity shift can be seen in the spectra in Fig. 1 where the CS velocity is shown by dashed lines. The methanol spectra themselves show a large velocity dispersion, the difference between extreme spectral features is typically 5 to 15 km s^{-1}, with 25 to 30 km s^{-1} in some sources. Figure 5 shows a histogram of the velocity range for 157 6.7 GHz methanol masers taken from all available surveys (this paper, Menten 1991a; Shutte et al. 1993; van der Walt et al. 1995, and Caswell et al. 1995a).

Is is evident that the velocity range less than 2 km s^{-1} is rare, the mean velocity range is 8.0 ± 0.5 km s^{-1}, and exceeds velocity dispersion of host molecular clouds. In this respect the 6.7 GHz methanol masers are similar to H_2O masers with high velocity spectral features, although to a smaller scale. One possible explanation of the large velocity dispersion in the spectra of 6.7 GHz methanol masers could be related to the excitation mechanism. A large velocity gradient can provide easier escape of photons, a condition required in some maser models to maintain the population inversion.

Another possible explanation of the large velocity dispersion is that the maser condensations are gravitationally bound to massive stars, and are circling around them with Keplerian velocities. If the mass of the star is 30 $M_\odot$ (O-star), then the Keplerian velocity of 5 km s^{-1} corresponds to a distance from the star of 1080 A.U. The observed linear separation between 6.7 GHz maser spots is of this order of magnitude (Norris et al. 1993). Moreover, in many cases the maser spots lay along straight lines or arcs, and it was suggested (Norris et al. 1993) that they originate in circumstellar disks. The large range of methanol maser velocity features is consistent with their circumstellar origin. The massive O-stars associated with 6.7 GHz methanol masers could be very young, newly born stars embedded in a dense dust molecular core. The star itself is invisible because of a large extinction in the core, but could ionize an ultracompact HII region, which can be detected as a continuum radio source. The association of 6.7 GHz methanol masers with ultracompact HII regions established in this study (see Sect. 5.3) corroborates this conclusion.

5.3. 6.7 GHz masers and ultracompact HII regions

As noted in the introduction, our observing sample contained 326 IRAS sources which we selected with the colour criteria for ultracompact HII regions by Wood and Churchwell (1989). For this sample the methanol maser detection rate was 11 per cent. Of the total of 326 IRAS sources 76 coincided with ultracompact HII regions detected as compact continuum radio sources at 5 GHz by Becker et al. (1994) in a deep survey with the VLA. In 19 of them 6.7 GHz methanol masers were detected. The corresponding detection rate for the compact radio sources is 25 per cent which is considerably higher than the mean rate 11 per cent for the whole IRAS sample. Therefore the compact thermal continuum radio sources are much better candidates for detection of 6.7 GHz methanol masers than IRAS sources selected solely with Wood and Churchwell criteria.

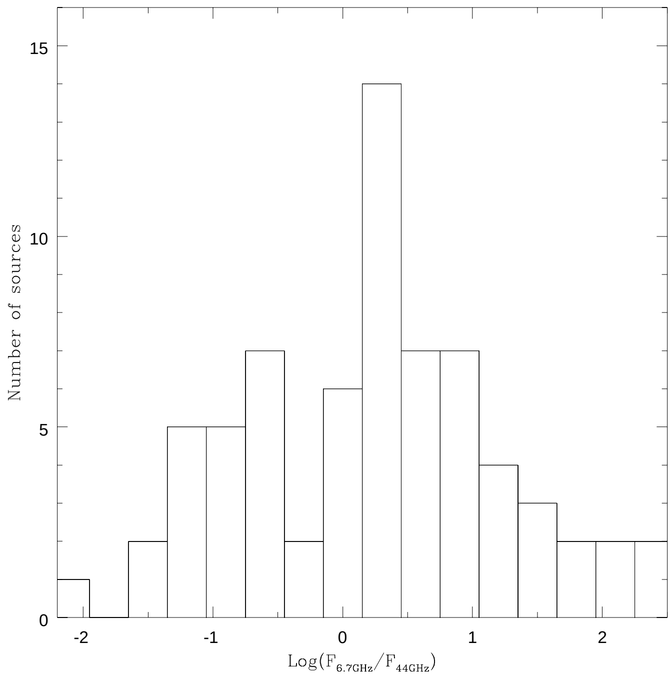


Fig. 6. The flux density ratio between 6.7 GHz and 44 GHz masers in the same sources

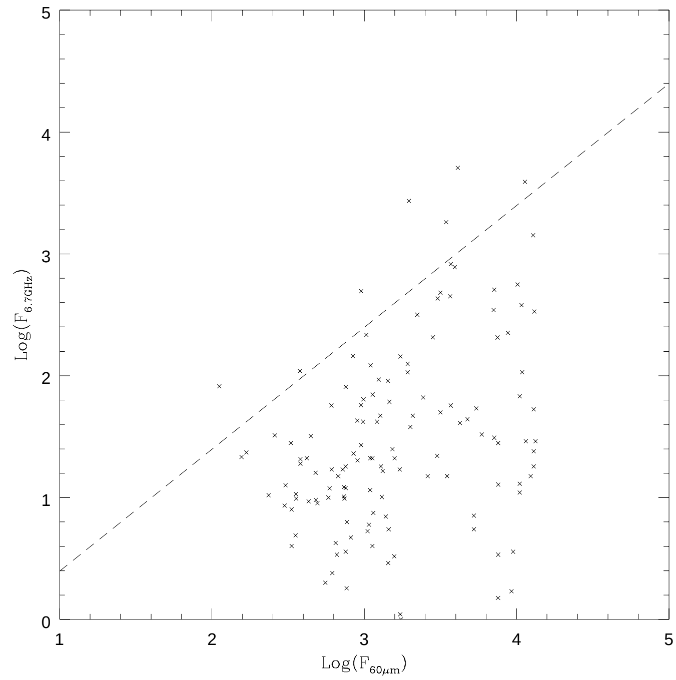


Fig. 7. Maser flux as a function of 60 μm flux of associated IRAS objects

5.4. The comparison of 6.7 GHz and 44 GHz masers

It was noted by Slysh et al. (1994c) that 6.7 GHz and 44 GHz masers co-exist in many star forming regions, although they belong to different classes of methanol masers and require different physical conditions for the inversion to take place. It was further noted that there is no one-to-one correspondence in their spectra, and there is a tendency of anticorrelation of flux densities between 6.7 GHz and 44 GHz masers, which may appear since external radiation, necessary to invert the $5_0 - 6_1 A^+$ transition, quenches the 44 GHz masers (Cragg et al. 1992). The anticorrelation can be assessed in Fig. 6 which was constructed using an extended set of sources. In Fig. 6 we show a histogram of the log flux density ratio between 6.7 GHz and 44 GHz masers in the same sources. The distribution extends from 0.01 to 200 with a dip at -0.2. Sources predominantly emitting at 44 GHz (log ratio less than -0.2) belong to Class I while those with ratio greater than -0.2 are Class II masers. So the ratio between 6.7 GHz and 44 GHz is a good parameter for the classification of methanol masers.

5.5. Far Infrared Pump

Following Kemball et al. (1988), we found a correlation between 6.7 GHz methanol flux density and 60 μm flux density of the associated IRAS sources (Fig. 7). The sample in the diagram contains all the known methanol masers which have IRAS identification. With the exception of seven masers, the 6.7 GHz flux is lower than one fourth of 60 μm flux. This result is similar to that of Kemball et al. (1988) for 12 GHz methanol masers, but is based on a larger sample of sources and confirms that there is enough far-infrared quanta to pump the 6.7 GHz methanol masers. Van der Walt et al. (1995) reached a similar conclusion based partly on the same observational results. A result of Ellingsen et al. (1996) survey, that shows that there can be a methanol maser without any FIR emission, is in contrast with this conclusion, but it may be due to confusion, as the survey has been done in the direction of the Galactic Center. An unbiased survey of a less dense portion of the galactic plane would help to clarify this point.

5.6. Variability

It is well established, that the 6.7 GHz masers are variable (see, e.g., Caswell et al. 1995b). The study of maser variability, which requires more systematic and long term observations, was beyond the scope of this work; however, a comparison of our spectra with those published in the literature shows variations larger than the estimated errors for some sources. In those cases when the spectral resolution is different, as in van der Walt et al. (1995), or when the observed positions differ by a sgnificant fraction of the telescope beamwidths, such as in the case of 02455+6034 and 18324−0820, the variability of the source cannot be asserted. MacLeod & Gaylard (1992); Gaylard & MacLeod (1993); Schutte et al. (1993); van der Walt et al. (1995) made their surveys with the 26-m Hartebeesthoek radio telescope whose beamwidth is 7 arcmin, close to the Medicina value, and their observed positions are either the same as ours or the difference is not larger than $20-30$ arcsec. Therefore when the spectra, obtained by these authors, differ from ours (in 174.20−0.08, 17589−2312, 18310−0825, 18379−0546, 78.12+3.63) these differences most likely may be attributed to the source variability. This conclusion is particularly true in the case of 174.20−0.08 where the number of the spectral components and the relative intensities are different. In the case of 17599−2148 we have a non-detection while it was observed by Schutte et al. (1993) with $S_\nu = 14.6$ Jy well over our sensitivity limit. Other examples of possible variability are our detection of weak masers towards 18064−2008, 18236−1241, and 19220+1432, where no 6.7 GHz masers were found by van der Walt et al. (1995). Thus, our results, like those by Caswell et al. (1995b), show that the 6.7 GHz masers are often variable.

6. Summary and conclusions

We detected 42 6.7 GHz methanol masers, 20 of them are new detections at 6.7 GHz.

The comparison of the spectra, obtained at Medicina with the spectra, obtained in previous searches confirmed that variability of methanol masers is a more common phenomenon than expected and deserves more monitoring observations.

Our results confirm that 6.7 GHz masers are mostly concentrated in the inner Galaxy. We find that the detection rate of 6.7 GHz masers toward the center of the Galaxy is higher than in the other directions. Association of the 6.7 GHz masers with faint ultracompact HII regions is demonstrated. The 6.7 GHz methanol masers have large velocity dispersion and large offset from the velocity of parent molecular clouds.

Acknowledgements. We are grateful to the staff of the Medicina Observatory for providing help during the observations. V.I.S., S.V.K., I.E.V. were partly supported by the ISF grant MND000. We are grateful to David A. Lyder for sending his article prior to publication.

References

Anglada G., Rodríguez L.F., Girart J.M., Estalella R., Torrelles J.M., 1994, ApJ 420, L91
Bally J., Lada C.J., 1983, ApJ 265, 824
Becker R.H., White R.L., Helfand D.J., Zoonematkermani S., 1994, ApJS 91, 347
Brand J., Blitz L., 1993, A&A 275, 67
Brand J., Cesaroni R., Caselli P., et al., 1994, A&AS 103, 541
Bronfman L., Nyman L.A., May J., 1996, A&AS 115, 81
Caswell J.L., Vaile R.A., Ellingsen S.P., Whiteoak J.B., Norris R.P., 1995a, MNRAS 272, 96
Caswell J.L., Vaile R.A., Ellingsen S.P., 1995b, PASA 12, 37
Cohen R.J., Baart E.E., Jonas J.L., 1988, MNRAS 231, 205
Comoretto G., Palagi F., Cesaroni R., et al., 1990, A&AS 84, 179
Cragg D.M., Johns K.P., Godfrey P.D., Brown R.D., 1992, MNRAS 259, 203
Ellingsen S.P., von Bibra M.L., McCulloch P.M., Deshpande A.A., Norris R.P., Phillips C.J., 1996, MNRAS 280, 378
Friberg P., Madden S.C., Hjalmarson A., Irvine W.M., 1988, A&A 195, 281
Gaylard M.J., MacLeod G.C., 1993, MNRAS 262, 43
Gómez de Castro A.I., Eiroa C., 1991, A&A 241, 589
Helfand D.J., Zoonematkermani S., Becker R.H., White R.L., 1992, ApJS 80, 211
Hunter T.R., Testi L., Taylor G.B., Tofani G., Felli M., Phillips T.G., 1995, A&A 302, 249
Kemball A.J., Gaylard M.J., Nicolson G.D., 1988, ApJ 331, L37
Larionov G.M., Val'tts I.E., Winnberg A., Johansson L.E.B., Booth R.S., Golubev, V.V., 1998, A&AS (in press)
Lockman F.J., 1989, ApJS 71, 469
Lyder D.A., Galt J., 1997, AJ 113, 1310
MacLeod G.C., Gaylard M.J., Nicolson G.D., 1992, MNRAS 254, 1p
MacLeod G.C., Gaylard M.J., 1992, MNRAS 256, 519
MacLeod G.C., Gaylard, M.J., 1993, in: Clegg A.W., Nedoluha G.E. (eds.) Proc. of a Conf. "Astrophysical Masers" held in Arlingtion, VA, U.S.A., Lecture Notes in Physics, 412. Springer-Verlag, p. 195
Menten K.M., 1991a, ApJ 380, L75
Menten K.M., 1991b, in: Haschik, A.D., Ho, P.T.P. (eds.) Proc. of the Third Haystack Observatory Meeting, MA, U.S.A., Skylines, p. 119
Norris R.P., Whiteoak J.B., Caswell J.L., Wieringa M.H., Gough R.G., 1993, ApJ 412, 222
Peng R.S., Whiteoak J.B., 1992, MNRAS 254, 301
Plume R., Jaffe D.T., Evans II N.J., 1992, ApJS 78, 505
Rodríguez L.F., Torrelles J.M., Moran J.M., 1981, AJ 86, 1245
Schutte A.J., van der Walt D.J., Gaylard M.J., MacLeod G.C., 1993, MNRAS 261, 783
Slysh V.I., Bachiller R., Berulis I.I., Val'tts I.E., Gómez-Gónzales J., Kalenskii S.V., Colomer F., Martin-Pintado J., Rodrigez-Franco A., 1994a, AZh. 71, 37
Slysh V.I., Dzura A.M., Val'tts I.E., Gerard E., 1994b, A&AS 106, 87
Slysh V.I., Kalenskii S.V., Val'tts I.E., Otrupcek R., 1994c, MNRAS 268, 464
Slysh V.I., Kalenskii S.V., Val'tts I.E., 1995, ApJ 442, 668
Slysh V.I., Dzura A.M., Val'tts I.E., Gerard E., 1997, A&AS 124, 85
Snell R.L., Huang Y.L., Dickman R.L., Claussen M.J., 1988, ApJ 325, 853
Snell R.L., Dickman R.L., Huang Y.L., 1990, ApJ 352, 139
Sugitani K., Fukui Y., Mizuno A., Ohashi N., 1989, ApJ 342, L87
Turner B.E., 1979, A&AS 37, 1
Walsh A.J., Hyland A.R., Robinson G., Bourke T.L., James S.D., 1995, PASA 12, 186
van der Walt D.J., Gaylard M.J., MacLeod G.C., 1995, A&AS 110, 81
Wilking B.A., Blackwell J.H., Mundy L.G., 1990, AJ 100, 758
Wood D.O.S., Churchwell E., 1989, ApJ 340, 265
Wouterloot J.G.A., Brand J., 1989, A&AS 80, 149
Wouterloot J.G.A., Brand J., Fiegle K., 1993, A&AS 98, 589