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Galactic methanol masers at 12 GHz

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ABSTRACT

We have detected 12-GHz methanol maser emission from 131 of 238 6.6-GHz masers searched. The peak flux densities at 12 GHz range from 1200 to 0.4 Jy with a median value of 7 Jy. Individual spectral features of the two transitions often coincide, although with a wide range of relative intensities, so that the detailed appearances of the 12- and 6.6-GHz spectra often differ considerably. Where an individual spot (or spectral feature) does mase at both transitions, the relative intensities can indicate the physical conditions in the spot. The 12-GHz features are typically several times weaker than their 6.6-GHz counterparts, but there are instances where they are stronger, and these most likely delineate spots of higher than average density. From many masers, in both transitions, at least a quarter of the features show significant intensity variations on a time-scale of several months. Although the quiescent features are probably saturated, some of the more variable features, especially those at 12 GHz, may not be saturated.

Key words: masers – stars: formation – ISM: molecules – radio lines: ISM.

1 INTRODUCTION

In the vicinity of star-forming regions, several transitions of methanol exhibit strong maser emission. The masers fall into two varieties (Menten 1991a), the 'class II' category studied here showing especially intense emission on transitions near 6.6 and 12 GHz. In high-resolution studies of a few methanol masers, Menten et al. (1992) and Norris et al. (1993) confirmed that a typical methanol maser source with an overall velocity range of 10 km s^{-1} consists of a cluster of small-diameter maser spots, each emitting over a single narrow velocity range (less than 0.5 km s^{-1}). Thus the masers can reveal the kinematics with high spatial detail in the immediate environs of recently formed stars. An additional discovery from these studies is that some individual narrow spectral features seen at precisely the same velocity on these two transitions are also spatially coincident to high accuracy; the study of masers at these two transitions is thus especially useful in probing physical conditions in the masing regions.

In an earlier paper (Caswell et al. 1995a, hereafter C + 95a) we completed a survey of 6.6-GHz methanol masers, and here we give details of our complementary observations of the 2_0–3_{-1}E transition at 12 GHz. We draw special attention to a comparison with the 6.6-GHz masers and to the variability of the masers. The present results include new data, an order of magnitude more sensitive and at additional epochs, for the 57 sources reported in an earlier 12-GHz survey (Caswell et al. 1993, hereafter C + 93) that pre-dated the discovery of 6.6-GHz methanol masers.

2 OBSERVATIONS

Observations were made with the Parkes 64-m telescope in the periods 1992 March 8 and 9, June 8, September 27 and 28, and December 21–23. A dual-channel receiver was used, accepting two circular polarizations; for each polarization the new Parkes correlator was configured to record 2048 channels over 4 MHz. The adopted rest frequency was 12 178.595 MHz (Gaines, Casleton & Kukolich 1974). The intensity calibration was relative to Virgo A, with a 12-GHz flux density of 33.5 Jy (yielding a peak of 31.4 Jy when observed with our 2.0-arcmin beamwidth). For individual spectra, the accuracy of the calibration was between 5 and 10 per cent. The system noise was typically 275 Jy. The search was made at 238 of the sites of 6.6-GHz methanol maser emission reported in our recent survey (C + 95a). Integration times were typically 10 min and most positions were observed at two epochs or more. The upper limits for sites with non-detections are typically 0.5 Jy (5 × rms noise) and are listed in C + 95a.

3 RESULTS

To indicate the range of characteristics of the masers, we first show some representative results in Fig. 1. The 12-GHz spectra of four sources are aligned with their 6.6-GHz spectra (from C+95a). In each of the cases shown, the strongest 12-GHz spectral feature is narrow (less than 0.5 km s^{-1}) and coincides in velocity with a strong 6.6-GHz feature to quite high accuracy. In 351.77 − 0.54, the emission at 12 GHz has only 1/100 of the intensity at 6.6 GHz, whereas in 59.78 + 0.06 the strongest feature at 12 GHz is slightly stronger than its 6.6-GHz counterpart. In every source, the 6.6-GHz spectra show more individual spectral features (often overlapping and blended) than are seen at 12 GHz. In 23.44 − 0.18, where the number of 12-GHz features approaches the number of 6.6-GHz features, the spectra are broadly similar. Despite this, the overlap of features, in combination with the varying intensity ratio, hinders recognition of a one-to-one correspondence of features at the two transitions for any but the strongest at 12 GHz.

The 12-GHz spectra for all 131 sources detected are shown in Figs 2–14. The spectra have been Hanning-smoothed to give a resolution of 4 kHz (= 0.1 km s^{-1}), the same resolution as the spectra in the figures in C+93, and they are thus directly comparable, despite using a different correlator. The spectra may also be readily compared with those at 6.6 GHz shown in C+95a, which have very similar velocity resolutions, 0.09 km s^{-1}. The 'empty' portion of a spectrum is often as important as the emission peaks, since it reveals that there are no 12-GHz counterparts to some of the strongest 6.6-GHz peaks.

We summarize the results in Table 1, which contains the 131 distinct maser sites, ordered by Galactic longitude. In subsequent remarks we refer to a source by its Galactic

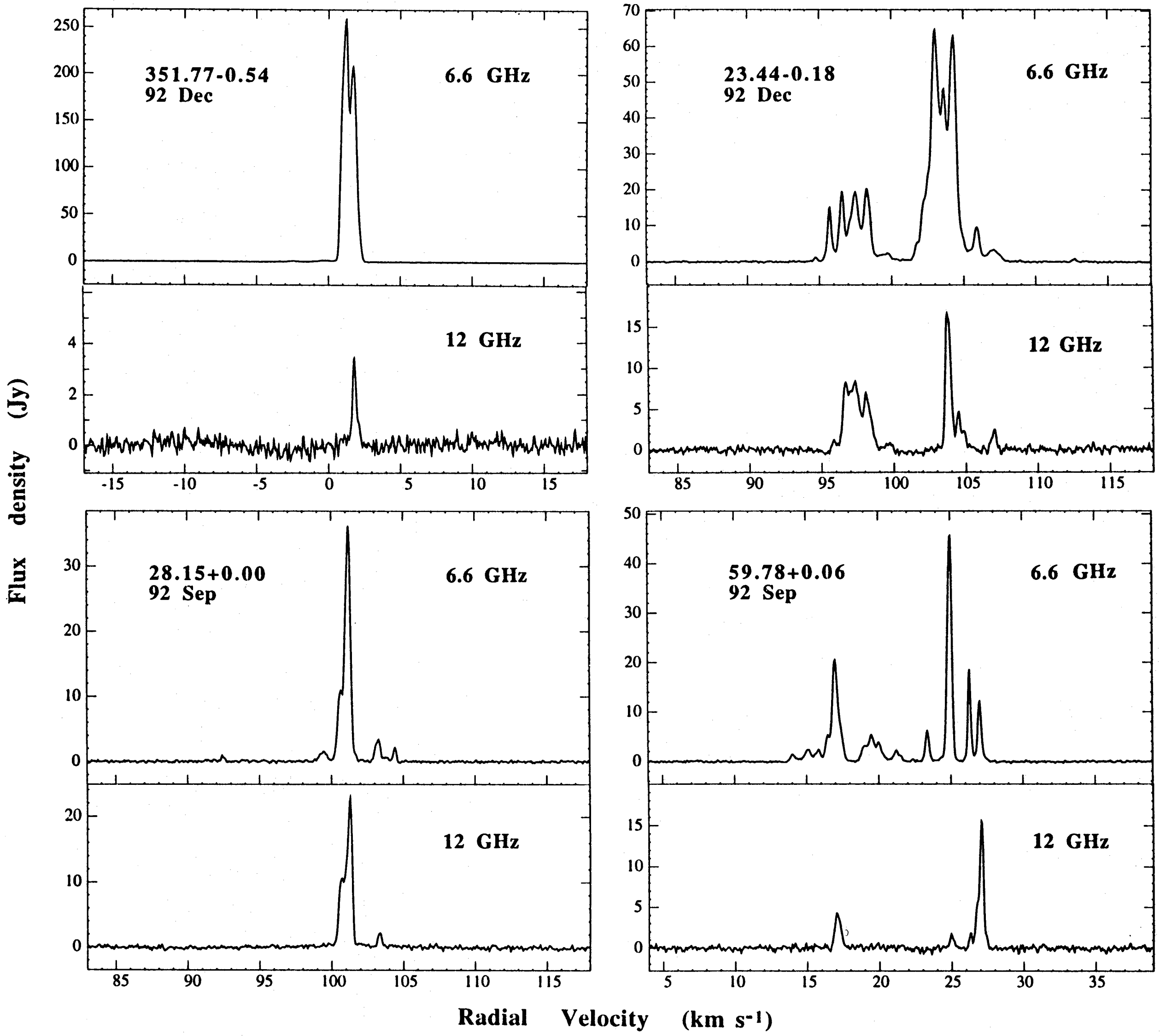

Figure 1. Spectra of the four methanol masers 351.77 − 0.54, 23.44 − 0.18, 28.15 + 0.00 and 59.78 + 0.06. Note the different intensity scales for the two transitions. Both 6.6- and 12-GHz transitions are shown at the same epoch. 12-GHz spectra for these sources at a different epoch are given in Figs 9, 12 and 14, and show considerable variability in the case of the first two sources.

Table 1. 12-GHz methanol masers located south of declination 24°.

Methanol maser (l,b)	RA (1950) (h m s)	Dec (1950) (° ′ ″)	Radial peak (km s-1)	Velocity range (km s-1)	12-GHz intensity (Jy)	Epoch* 12 GHz	6-GHz intensity (Jy)	Variable# 12 GHz	No. of features var	total
188.95+0.89	06 05 53.5	+21 39 02	+10.4	+9, +12	235	mjsd	495	sv	2	4
196.45−1.68	06 11 47.1	+13 50 34	+15.2	+15, +16	1.35	m d	61			
213.71−12.60	06 05 21.7	−06 22 28	+10.9	+10, +14	4.2	mjsd	90	v	2	3
213.71−12.60			+11.8		0.5		337			
232.62+0.99	07 29 54.6	−16 51 48	+22.8	+22, +23	24	mjsd	162	v	2	2
284.35−0.42	10 22 20.0	−57 37 25	+3.4	+3, +4	0.7	sd	2.1			
291.28−0.71	11 09 46.7	−61 02 06	-29.7	-31, -28	41	mjsd	107	v	3	3
300.97+1.15	12 32 02.6	−61 23 06	-37.0	-38, -36	0.63	m d	5.5			
305.20+0.02	13 08 05.7	−62 29 58	-32.4	-34, -31	10.3	mjsd	30	v	2	4
305.20+0.02			-33.1		7		52			
305.20+0.21	13 07 58.60	−62 18 42.3	-45.0	-46, -43	2.3	mjsd	15	v	2	2
305.20+0.21			-44.0		1.9		50			
305.21+0.21	13 08 01.72	−62 18 45.3	-37.1	-41, -35	5.1	mjsd	31	nv	0	3
305.21+0.21			-38.3		0.2		480			
305.37+0.19	13 09 26.3	−62 19 15	-34.2	-35, -34	0.85	d	1			
308.92+0.12	13 39 35.4	−61 53 47	-53.3	-55, -53	10	mjsd	14	nv	0	2
308.92+0.12			-54.8		1		54			
309.92+0.48	13 47 11.85	−61 20 18.8	-59.8	-61, -57	156	mjsd	780	v	3	5
313.47+0.19	14 16 00.5	−60 38 01	-9.3	-13, -7	4.2	mjsd	17			
316.36−0.36	14 39 22.6	−60 04 32	+3.6	+1, +8	10.5	mjsd	96	nv	0	4
316.38−0.38	14 39 34.7	−60 04 57	-1.1	-6, +1	1.8	sd	12			
316.38−0.38			-0.6		1.6		38			
316.64−0.09	14 40 31.6	−59 42 40	-19.8	-23, -16	25	mjsd	128	v	3	6
316.81−0.06	14 41 39.3	−59 36 35	-46.8	-48, -41	1.2	m sd	4	v	1	3
316.81−0.06			-45.7		0.5		12			
318.05+0.08	14 49 54.0	−58 56 43	-52.0	-57, -51	0.45	m d	4			
318.95−0.20	14 57 03.81	−58 47 01.2	-34.5	-36, -32	180	mjsd	780	nv	0	5
321.15−0.53	15 12 55.3	−57 58 51	-66.1		0.9	mjsd	9.6			
322.16+0.64	15 14 45.7	−56 27 28	-63.4	-65, -52	17	mjsd	160	v	2	4
322.16+0.64			-63.0		15.5		211			
323.46−0.08	15 25 27.7	−56 21 02	-66.8	-68, -66	12.2	mjsd	22	nv	0	2
323.74−0.26	15 27 51.97	−56 20 39.5	-50.8	-54, -47	500	mjsd	2550	sv	4	8
323.74−0.26			-51.1		250		2860			
327.12+0.51	15 43 44.3	−53 43 26	-89.6	-90, -89	5	mjsd	25			
327.12+0.51			-87.2		<0.4		90			
327.29−0.58	15 49 16.0	−54 28 14	-48.1	-49, -47	0.9	m sd	1	v	1	1
327.29−0.58			-48.5		0.75		2.6			
327.40+0.44	15 45 30.4	−53 36 10	-82.9	-84, -82	55	mjsd	83	nv	0	3
327.40+0.44			-82.6		30		93			
328.24−0.55	15 54 06.11	−53 50 47.0	-44.8	-45, -44	13	mjsd	400	v	1	1
328.25−0.53	15 54 07.58	−53 49 25.0	-37.0	-38, -36	3.3	m sd	220	nv	0	1
328.25−0.53			-37.4		1		430			
328.81+0.63	15 52 00.32	−52 34 22.2	-46.4	-47, -43	25	mjsd	170	nv	0	5
328.81+0.63			-43.9		1		380			
329.03−0.21	15 56 42.0	−53 04 22	-37.5	-38, -37	17.5	mjsd	200	v	1	1
329.03−0.20	15 56 40.6	−53 03 58	-39.7	-42, -39	7.2	mjsd	28	v	1	1
329.03−0.20			-42.0		<0.2		30			
329.18−0.31	15 57 55.5	−53 03 26	-58.2	-60, -57	1.7	mjsd	7.5	nv	0	2
329.18−0.31			-55.8		0.3		13			
329.41−0.46	15 59 40.8	−53 01 13	-65.6	-73, -63	0.6	mjsd	0.4			
329.41−0.46			-66.8		<0.3		156			
331.28−0.19	16 07 38.14	−51 34 12.2	-78.9	-85, -77	145	mjsd	64	v	2	5
331.28−0.19			-78.2		50		207			
331.56−0.12	16 08 40.6	−51 19 59	-104.1	-105, -96	6	jsd	17	nv	0	2
331.56−0.12			-103.6		1.6		47			
333.07−0.45	16 17 02.4	−50 31 22	-54.5	-55, -54	1	sd	10			

Table 1 – *continued*

Methanol maser (l,b)	RA (1950) (h m s)	Dec (1950) (° ′ ″)	Radial Velocity peak (km s-1)	range (km s-1)	12-GHz intensity (Jy)	Epoch* 12 GHz	6-GHz intensity (Jy)	Variable# 12 GHz	No. of features var	total
333.16–0.10	16 15 55.4	–50 12 41	-95.2	-96, -94	3.8	sd	6.3	nv	0	1
335.55–0.31	16 27 11.3	–48 39 28	-114.7	-117, -110	5	sd	3.6	nv	0	2
335.55–0.31			-116.4		0.9		23			
335.73+0.19	16 25 46.0	–48 11 23	-44.6	-45, -44	12.5	jsd	74	nv	0	2
335.79+0.17	16 26 06.0	–48 09 22	-46.2	-51, -45	126	mjsd	110	v	5	6
335.79+0.17			-48.5		14		167			
336.36–0.14	16 29 47.9	–47 57 28	-74.7	-80, -73	2.3	jsd	4.5			
336.36–0.14			-73.6		1.6		21			
336.43–0.26	16 30 37.59	–47 59 18.9	-93.4	-95, -86	36	mjsd	46	v	1	1
336.83+0.02	16 31 00.6	–47 30 20	-76.8	-77, -76	1.4	m d	16			
336.86+0.01	16 31 11.2	–47 29 39	-75.6	-77, -74	0.6	m sd	4.5			
336.86+0.01			-76.1		0.3		34			
337.41–0.40	16 35 09.8	–47 22 07	-39.5	-43, -38	3.5	m sd	67	nv	0	1
337.61–0.06	16 34 29.4	–46 58 57	-41.9	-54, -40	12	mjsd	21	nv	0	3
337.63–0.08	16 34 38.7	–46 58 53	-56.9	-63, -55	1.5	sd	13	nv	0	1
337.71–0.05	16 34 49.6	–46 54 43	-54.7	-56, -44	84	mjsd	145	nv	0	4
337.92–0.46	16 37 25.0	–47 01 21	-37.8	-39, -36	0.55	m sd	47			
338.08+0.01	16 35 58.2	–46 35 28	-53.1	-54, -52	14.7	mjsd	18	v	1	1
338.46–0.25	16 38 36.1	–46 28 38	-52.1	-53, -49	8.5	mjsd	70	v	1	1
338.46–0.25			-50.6		<0.3		83			
338.87–0.08	16 39 28.7	–46 03 38	-41.4	-42, -39	2.2	jsd	19			
338.93–0.06	16 39 36.5	–46 00 05	-42.2	-43, -42	3.8	jsd	12			
339.62–0.12	16 42 26.5	–45 31 18	-33.4	-37, -31	18.4	mjsd	35	v	1	3
339.62–0.12			-36.1		0.3		83			
339.88–1.26	16 48 24.76	–46 03 33.9	-38.7	-40, -32	850	mjsd	1820	sv	1	9
340.05–0.24	16 44 35.2	–45 16 24	-59.7	-62, -58	16	mjsd	42	v	1	1
340.79–0.10	16 46 38.35	–44 37 18.5	-105.2	-112, -88	43	mjsd	132	v	1	4
340.79–0.10			-106.7		2		242			
341.22–0.21	16 48 42.1	–44 21 53	-37.3	-50, -36	5.1	mjsd	54	v	3	3
341.22–0.21			-37.8		5		167			
341.28+0.06	16 47 43.9	–44 08 41	-73.8	-78, -71	0.85	d	5.5			
343.93+0.12	16 56 38.7	–42 02 58	+13.7	+13, +15	3.9	sd	6.1			
343.93+0.12			+14.4		0.5		11			
344.23–0.57	17 00 35.0	–42 14 29	-19.6	-33, -18	2.7	sd	118			
344.42+0.05	16 58 37.1	–41 42 36	-71.5	-74, -70	0.55	sd	16			
345.00–0.22	17 01 38.5	–41 24 59	-22.4	-31, -21	20	mjsd	448	v	2	2
345.01+1.79	16 53 19.69	–40 09 46.0	-21.8	-24, -16	310	mjsd	338	v	3	3
345.01+1.79			-17.9		2		508			
345.01+1.80	16 53 18.9	–40 09 29	-12.8	-14, -10	14	mjsd	31	v	2	2
345.50+0.35	17 00 54.2	–40 40 18	-17.7	-19, -13	4.7	sd	174			
347.58+0.21	17 07 59.5	–39 05 58	-102.6	-104, -101	0.7	sd	2.7			
347.86+0.02	17 09 39.1	–38 59 16	-36.4	-38, -22	0.9	d	1.9			
347.86+0.02			-29.3		0.5		7.2			
347.90+0.05	17 09 39.4	–38 56 02	-27.2	-31, -27	2	d	4			
347.90+0.05			-27.6		1.6		5.3			
348.55–0.98	17 15 53.0	–39 00 53	-10.0	-23, -7	5.6	mjsd	41	v	2	3
348.55–0.98			-12.9		<0.4		74			
348.70–1.04	17 16 37.1	–38 55 31	-3.5	-17, -3	34.5	mjsd	60	v	1	1
348.72–1.04	17 16 38.9	–38 54 31	-7.4	-9, -6	11	mjsd	85	v	1	2
348.72–1.04			-7.8		6		90			
349.07–0.02	17 13 25.5	–38 02 07	+11.7	+11, +12	0.75	d	1.4			
349.07–0.02			+6.9		<0.4		1.9			
350.10+0.09	17 16 02.9	–37 07 48	-74.0	-76, -66	5	sd	41			
351.42+0.64	17 17 32.35	–35 44 04.2	-11.2	-12, -7	1210	mjsd	2250	sv	1	3
351.42+0.64			-10.4		1100		3300			
351.44+0.66	17 17 33.58	–35 42 11.1	-9.8	-12, -7	88	jsd	250	v	1	1
351.77–0.54	17 23 20.67	–36 06 45.4	+1.8	0, +3	8.5	mjsd	225	v	1	1
353.41–0.36	17 27 06.6	–34 39 30	-22.3	-23, -19	19.5	mjsd	29	nv	0	3
353.41–0.36			-19.9		4.2		90			

Table 1 – *continued*

Methanol maser (l,b)	RA (1950) (h m s)	Dec (1950) (° ′ ″)	Radial Velocity peak (km s-1)	range (km s-1)	12-GHz intensity (Jy)	Epoch* 12 GHz	6-GHz intensity (Jy)	Variable# 12 GHz	No. of features var	total
354.61+0.47	17 26 59.8	−33 11 34	-16.5	-25, -14	28	mjsd	40	v	3	3
354.61+0.47			-23.1		12		216			
359.61−0.24	17 42 27.2	−29 22 18	+22.7	+19, +24	13.5	mjsd	16	v	1	5
359.61−0.24			+19.9		2		48			
0.55−0.85	17 47 04.4	−28 53 39	+18.4	+10, +20	3.9	mjsd	9	v	2	2
0.55−0.85			+13.8		3.6		68			
0.65−0.05	17 44 11.0	−28 23 23	+48.0	+47, +49	7.2	mj d	33	nv	0	1
8.68−0.37	18 03 22.6	−21 37 24	+42.2	+41, +45	14	mjsd	14	v	2	5
8.68−0.37			+43.0		2.8		148			
9.62+0.20	18 03 15.98	−20 31 52.9	+1.3	-4, +4	180	mjsd	5090	v	1	8
10.45−0.02	18 05 47.0	−19 55 01	+71.9	+68, +74	7	d	19			
10.45−0.02			+73.3		6.4		25			
10.47+0.03	18 05 40.0	−19 52 24	+75.0	+73, +77	17	mjsd	61	nv	0	3
10.62−0.38	18 07 31.0	−19 56 19	+5.8	-9, +7	1.2	d	2			
10.62−0.38			+4.7		0.5		3.6			
11.90−0.14	18 09 15.2	−18 42 21	+42.9	+41, +44	21	mjsd	67	v	1	1
11.94−0.62	18 11 04.1	−18 54 21	+39.8	+30, +44	6.8	sd	26	sv	2	5
11.94−0.62			+32.1		5.2		47			
12.03−0.03	18 09 06.3	−18 32 43	+108.6	+105, +111	13.5	mjsd	46	v	1	1
12.03−0.03			+107.7		0.8		82			
12.68−0.18	18 10 59.6	−18 02 29	+57.0	+50, +60	16.5	mjsd	195	v	2	2
12.68−0.18			+52.2		0.5		544			
12.89+0.49	18 08 56.4	−17 32 14	+39.3	+38, +40	62	sd	93			
12.91−0.26	18 11 43.8	−17 53 04	+39.8	+38, +41	11.5	mjsd	317	v	1	1
15.03−0.68	18 17 31.6	−16 13 02	+21.3	+21, +24	17	mjsd	39			
16.59−0.05	18 18 18.5	−14 33 16	+59.3	+59, +67	1.1	m sd	21			
19.48+0.15	18 23 12.7	−11 54 16	+20.8	+20, +24	2.9	jsd	3.2	nv	0	3
19.48+0.15			+21.2		1.6		19.3			
19.61−0.14	18 24 29.5	−11 55 39	+50.6	+50, +56	2.8	mjsd	4.3			
19.61−0.14			+56.6		0.3		18			
19.61−0.12	18 24 26.6	−11 55 18	+53.1		1	d	3.6			
20.23+0.07	18 24 56.9	−11 16 59	+73.2	+71, +76	2.7	mjsd	19	v	2	3
20.23+0.07			+71.8		0.9		100			
22.43−0.16	18 29 57.5	−09 26 41	+37.8	+26, +40	5	mjsd	14	nv	0	3
22.43−0.16			+29.3		0.8		20			
23.01−0.41	18 31 55.6	−09 03 09	+74.9	+70, +84	28	mjsd	280	v	2	4
23.01−0.41			+75.3		8		405			
23.44−0.18	18 31 55.3	−08 34 01	+103.8	+95, +108	17	mjsd	38	v	3	7
23.44−0.18			+103.0		0.5		77	v	10	15
24.33+0.14	18 32 26.8	−07 37 25	+110.3	+108, +112	20	d	10.8			
27.36−0.16	18 39 11.0	−05 04 43	+99.8	+96, +101	20	sd	29	nv	0	2
28.15+0.00	18 40 02.2	−04 18 26	+101.3	+99, +105	21	sd	34	nv	0	3
28.83−0.25	18 42 13.1	−03 49 01	+82.3	+82, +92	3.1	mjsd	1.2	nv	0	2
28.83−0.25			+83.4		1.7		73			
29.86−0.05	18 43 22.9	−02 48 26	+100.3	+99, +103	13	mjsd	35	v	3	3
29.86−0.05			+101.3		3.5		67			
29.95−0.02	18 43 26.7	−02 42 38	+96.8	+95, +99	53	mjsd	75	v	2	2
29.95−0.02			+96.0		39		206			
29.98−0.04	18 43 34.9	−02 42 19	+98.4		4	d	20			
30.20−0.17	18 44 25.8	−02 33 57	+110.2	+101, +111	10	sd	15.5	nv	0	5
30.20−0.17			+108.5		6.7		18.7			
30.22−0.18	18 44 31.3	−02 32 50	+112.8	+111, +115	2.8	sd	9.8	v	1	2
30.22−0.18			+113.6		1.2		11.7			
30.76−0.05	18 45 02.8	−02 00 46	+91.7	+90, +94	1.5	mjsd	14			
30.76−0.05			+92.0		0.9		68			
30.78+0.23	18 44 05.7	−01 51 48	+49.1	+48, +49	9	m sd	24	nv	0	1
30.79+0.20	18 44 12.3	−01 52 04	+87.8	+75, +89	11.5	m sd	19	v	4	4
30.79+0.20			+85.9		3.2		23			
30.82−0.05	18 45 10.5	−01 57 46	+108.3	+107, +109	0.8	sd	6			
30.82−0.05			+101.3		0.1		18			

Table 1 – *continued*

Methanol maser (l,b)	RA (1950) (h m s)	Dec (1950) (° ′ ″)	Radial Velocity peak (km s-1)	range (km s-1)	12-GHz intensity (Jy)	Epoch* 12 GHz	6-GHz intensity (Jy)	Variable# 12 GHz	No. of features var	total
31.28+0.06	18 45 37.2	−01 30 00	+110.3	+103, +113	59	mjsd	81	v	1	4
31.41+0.31	18 44 57.9	−01 15 59	+95.6	+93, +96	2.1	sd	10.5			
31.41+0.31			+103.5		<0.1		11			
32.74−0.08	18 48 47.8	−00 15 50	+30.5	+29, +39	10.5	mjsd	14	v	1	3
32.74−0.08			+38.5		7.5		47			
33.09−0.07	18 49 25.1	+00 02 51	+104.4	+103, +105	0.4	m d	12			
33.09−0.07			+95.6		<0.1		30			
33.13−0.09	18 49 33.6	+00 04 25	+73.1	+71, +80	0.6	m d	12.4			
34.24+0.13	18 50 49.0	+01 09 57	+61.2	+55, +62	0.9	sd	5.1			
34.24+0.13			+55.4		0.4		20			
34.26+0.15	18 50 46.6	+01 11 06	+57.8	+58, +59	3.5	d	29			
35.20−0.74	18 55 41.1	+01 36 26	+30.6	+26, +31	31	mjsd	12	v	4	4
35.20−0.74			+28.5		29		125			
35.20−1.74	18 59 13.1	+01 09 07	+44.6	+39, +47	109	mjsd	260	v	5	7
35.20−1.74			+42.3		22		560			
43.15+0.02	19 07 47.0	+09 00 30	+13.6		3.7	d	26			
43.17+0.01	19 07 51.0	+09 01 21	+21.9	+19, +22	1	jsd	3			
43.17+0.01			+20.2		<0.4		12.8			
43.17−0.00	19 07 52.6	+09 01 04	−1.1	−2, 0	1.7	sd	3.4			
45.47+0.05	19 12 02.5	+11 04 31	+56.6	+56, +58	2.2	d	5.3			
49.49−0.37	19 21 21.8	+14 25 08	+56.1		21	mjsd	33	v	1	2
59.78+0.06	19 41 03.6	+23 36 51	+27.1	+16, +28	15.8	sd	13	v	1	2
59.78+0.06			+25.0		1.7		42			

*'m', 'j', 's' and 'd' denote 1992 March, June, September and December.
'sv' denotes slightly variable, up to 10 per cent; 'v' denotes variable, greater than 10 per cent and 'nv' denotes not variable.

coordinates with the understanding that we refer to the 12-GHz methanol maser at this position unless indicated otherwise.

Most of the positions of Table 1 are taken from our 6.6-GHz measurements obtained with the Parkes telescope and have errors generally less than 10 arcsec (2 × rms error) in each coordinate. A few of the positions are more accurate values measured with the Australia Telescope Compact Array (ATCA) as published by Norris et al. (1993). In most cases, no 12-GHz position has been measured, with the following notable exceptions: the 57 previously known masers had positions measured at both 12 and 6.6 GHz and have been found to be coincident within the errors; and for the newly discovered 12-GHz masers where there is more than one nearby 6.6-GHz maser, we measured a 12-GHz position so as to distinguish the true 6.6-GHz counterpart.

The peak intensity at 12 GHz, and its velocity, is listed in Table 1 and is taken from the spectra shown in Figs 2–14. The corresponding 6.6-GHz intensity at this velocity is also listed. For nearly half of the sources, the 6.6-GHz peak coincides with the 12-GHz peak. For the remaining sources, the table contains a second entry where we have listed the 6.6-GHz peak and its velocity together with the 12-GHz intensity at this velocity (which in 10 cases is an upper limit). These measurements are discussed further in Section 5.2.

Apart from the 57 12-GHz masers studied by C+93, most of the sources were first observed in 1992 March and then, usually, on at least one subsequent occasion. Interference near 12 GHz is rarely seen at the Parkes site and the repeated observations of a source are an additional safeguard against spurious detections. The epoch of observations is given in column 7 of the Table ('m', 'j', 's' and 'd' denote 1992 March, June, September and December). Variations in intensity are common and are briefly summarized in the table. For sources observed well enough to study variability, we use groupings into the classes 'v' (variable), 'sv' (slightly variable) and 'nv' (not variable), as discussed in Section 5.3. The number of variable features and the total features that are sufficiently strong for variability to have been detectable are also tabulated. In view of the intensity variations, the quoted peak intensities are representative and correspond to the spectra shown in the figures.

The spectra chosen for display were selected from any one of our observing epochs and, for a few weak sources, a spectrum averaged over several epochs is shown. The source spectra are ordered by increasing Galactic longitude with minor variations to allow better comparison of sources that are confused.

The sources range in peak intensity from more than 200 Jy (188.95 + 0.89 at 235 Jy; 323.74 − 0.26 at 500 Jy; 339.88 − 1.26 at 850 Jy; 345.01 + 1.79 at 310 Jy; 351.42 + 0.64 at 1210 Jy) to less than 0.5 Jy (318.05 + 0.08 and 33.09 − 0.07). The very strong sources often contain additional, much weaker, features and thus the dynamic range needed for an adequate portrayal of the data is very large; to achieve this we have shown some spectra plots with superimposed expanded-scale spectra.

The velocity spread for each source is quoted in Table 1 and is sometimes larger than that apparent on the spectra, owing to the presence of weak features not readily seen, but

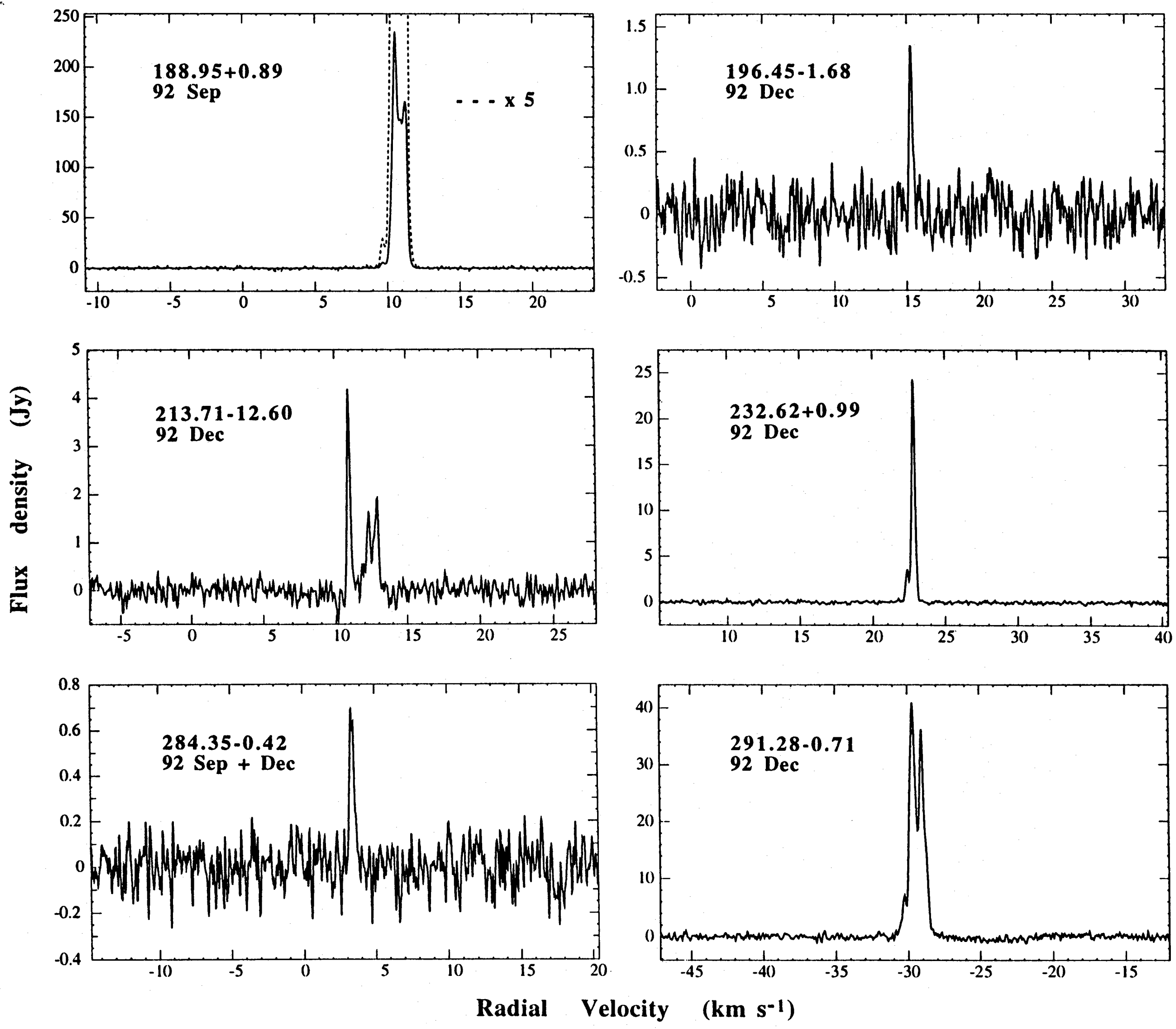

Figure 2. Spectra of 12-GHz methanol masers. All spectra have been Hanning-smoothed to a velocity resolution of 0.1 km s^{-1}. The date of observation is shown. The broken line shown on the spectrum of strong sources is an expanded scale, added to show the weak features more clearly; the magnification of this expanded intensity scale is indicated within the frame. Pairs of spectra are bracketed together in several cases to draw attention to the blending of adjacent sources.

confirmed at different epochs. On the other hand, the tabulated spread is occasionally smaller because a feature seen on the spectrum is from a different nearby source – as remarked in the notes of Section 4. In some instances, a second source very nearby is adequately portrayed on the same spectrum and is labelled as a separate source, e.g. 305.20 + 0.21 is seen on the same spectrum as 305.21 + 0.21. In other instances, such as the pair of sources 328.24 + 0.55 and 328.25 − 0.53 separated by 82 arcsec, two spectra are shown but each source is also seen on the spectrum of the other. In such cases, we have aligned the spectra, bracketed them together, and indicated the emission unrelated to the principal source by a cross.

Absorption is prominent on some of the spectra (e.g. 316.81 − 0.06), and is discussed for individual sources in Section 4 and summarized in Section 5.5.

4 NOTES ON INDIVIDUAL SOURCES

Here we present notes on many of the sources. We have compared 12-GHz spectra with the 6.6-GHz spectra from C + 95a, and use the term 'coincident features' to refer to their velocities (not the spatial separation for which we have no precise measurements). We also remark on variability, both within the 1992 observations from March to December and relative to the 1988 and 1989 observations reported by C + 93. More detailed discussion of variability for a subset of the highly variable sources is given by Caswell, Vaile & Ellingsen (1995b, hereafter C + 95b).

188.95 + 0.89. The intensity of the weaker features has changed by less than 10 per cent between 1988 (C + 93) and 1992. The strongest peak is certainly variable relative to the other features and, assuming them to be constant, the

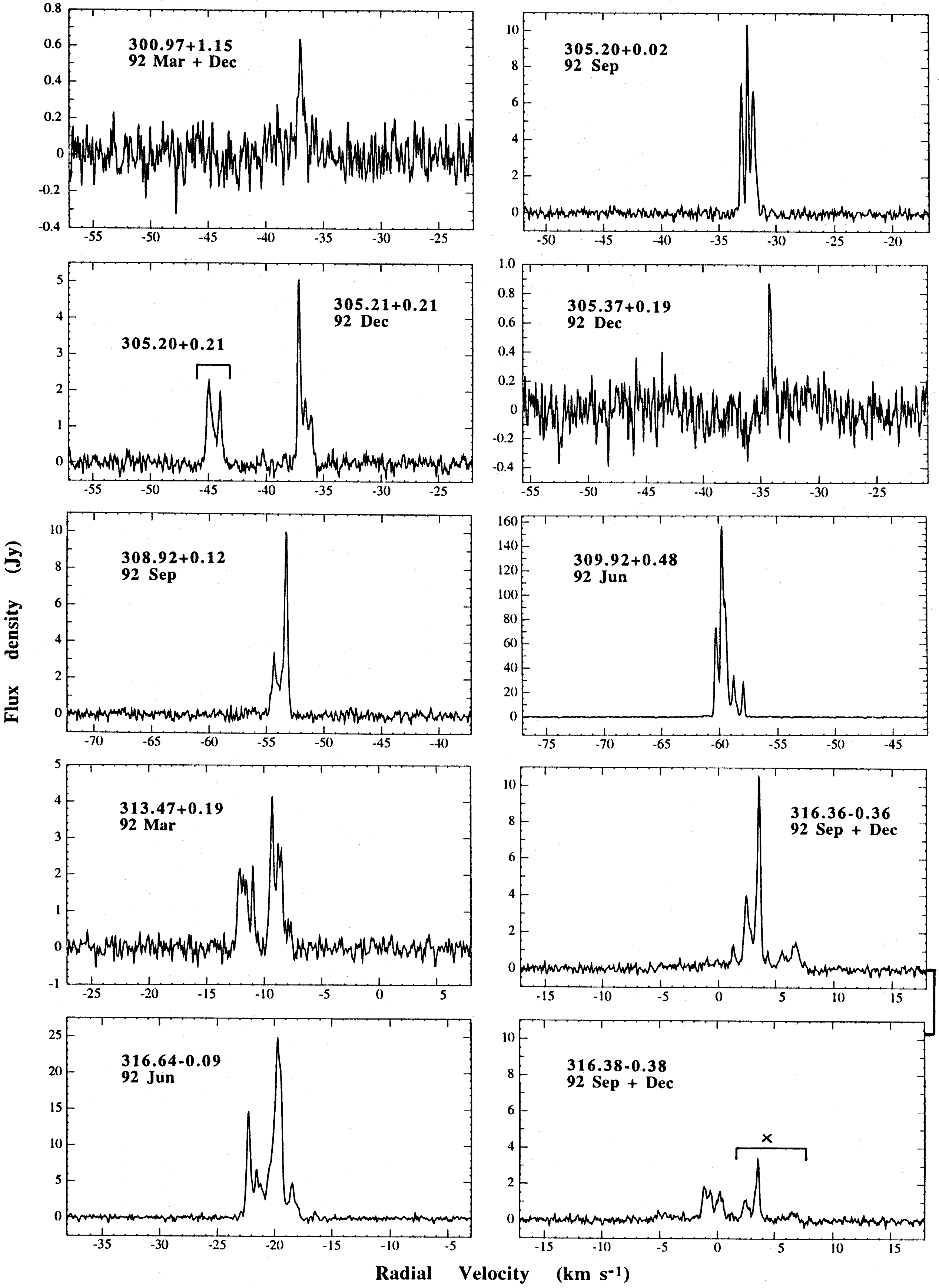

Figure 3. Spectra of 12-GHz methanol masers; details as for Fig. 2.

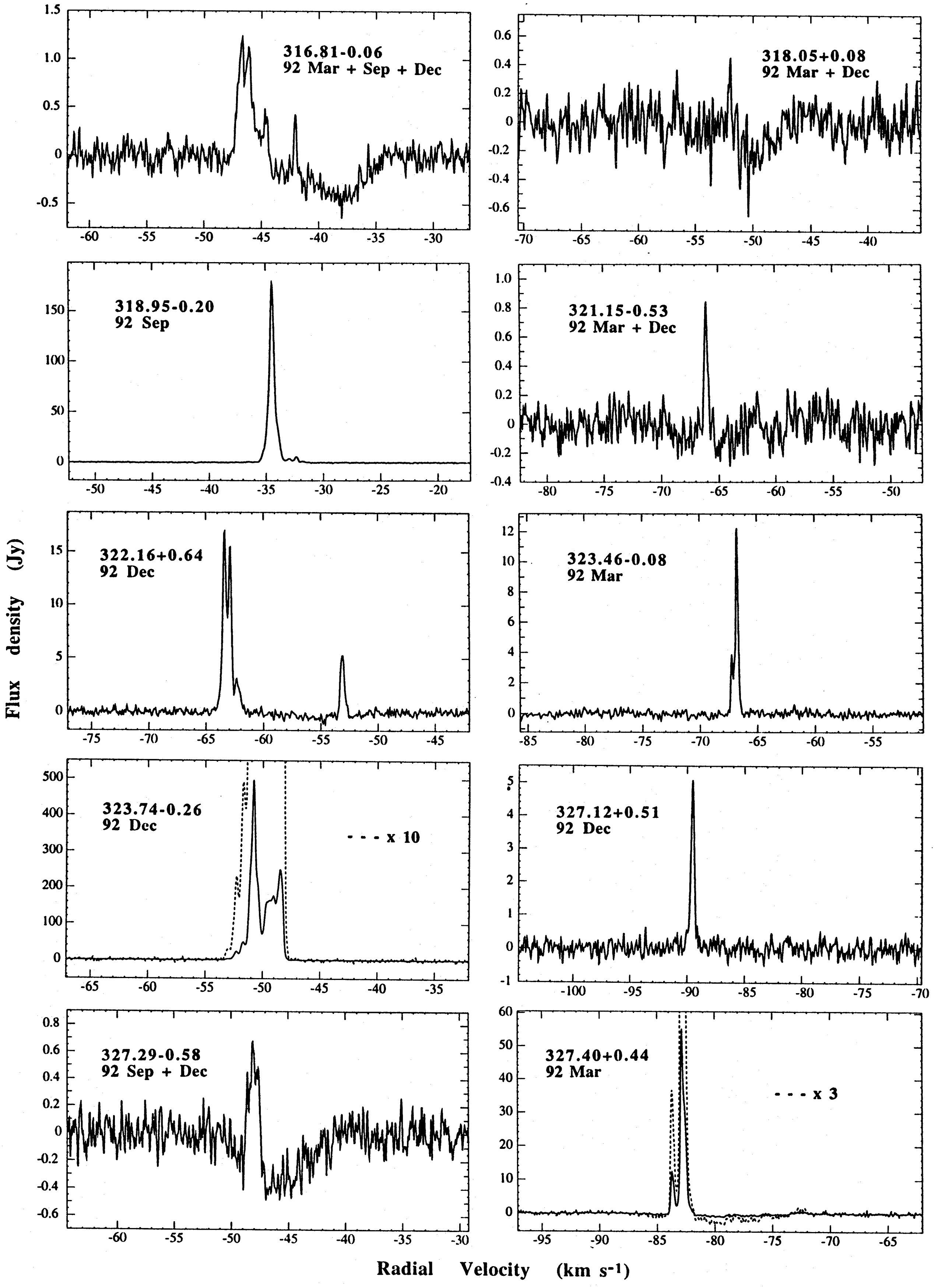

Figure 4. Spectra of 12-GHz methanol masers; details as for Fig. 2.

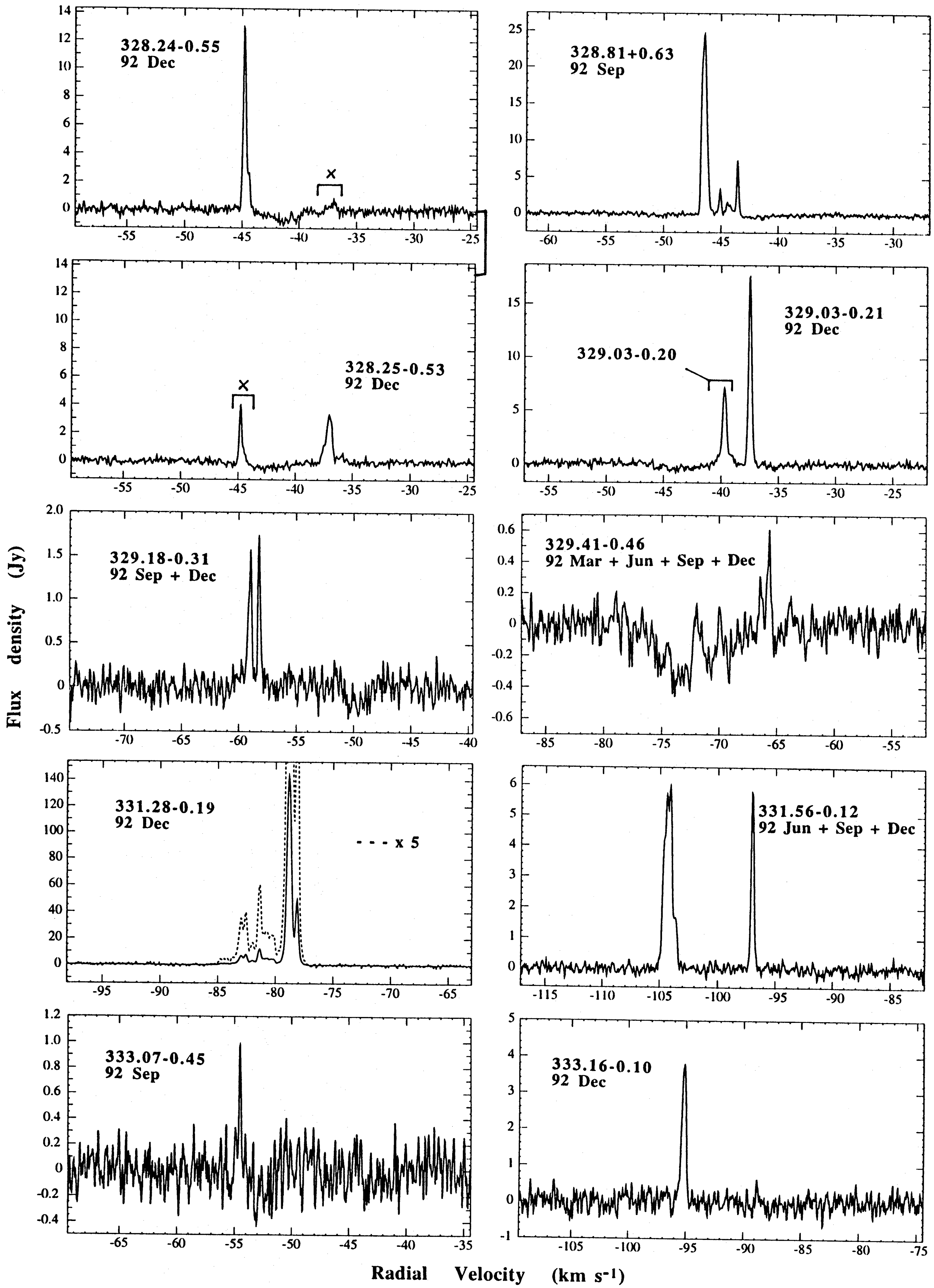

Figure 5. Spectra of 12-GHz methanol masers; details as for Fig. 2.

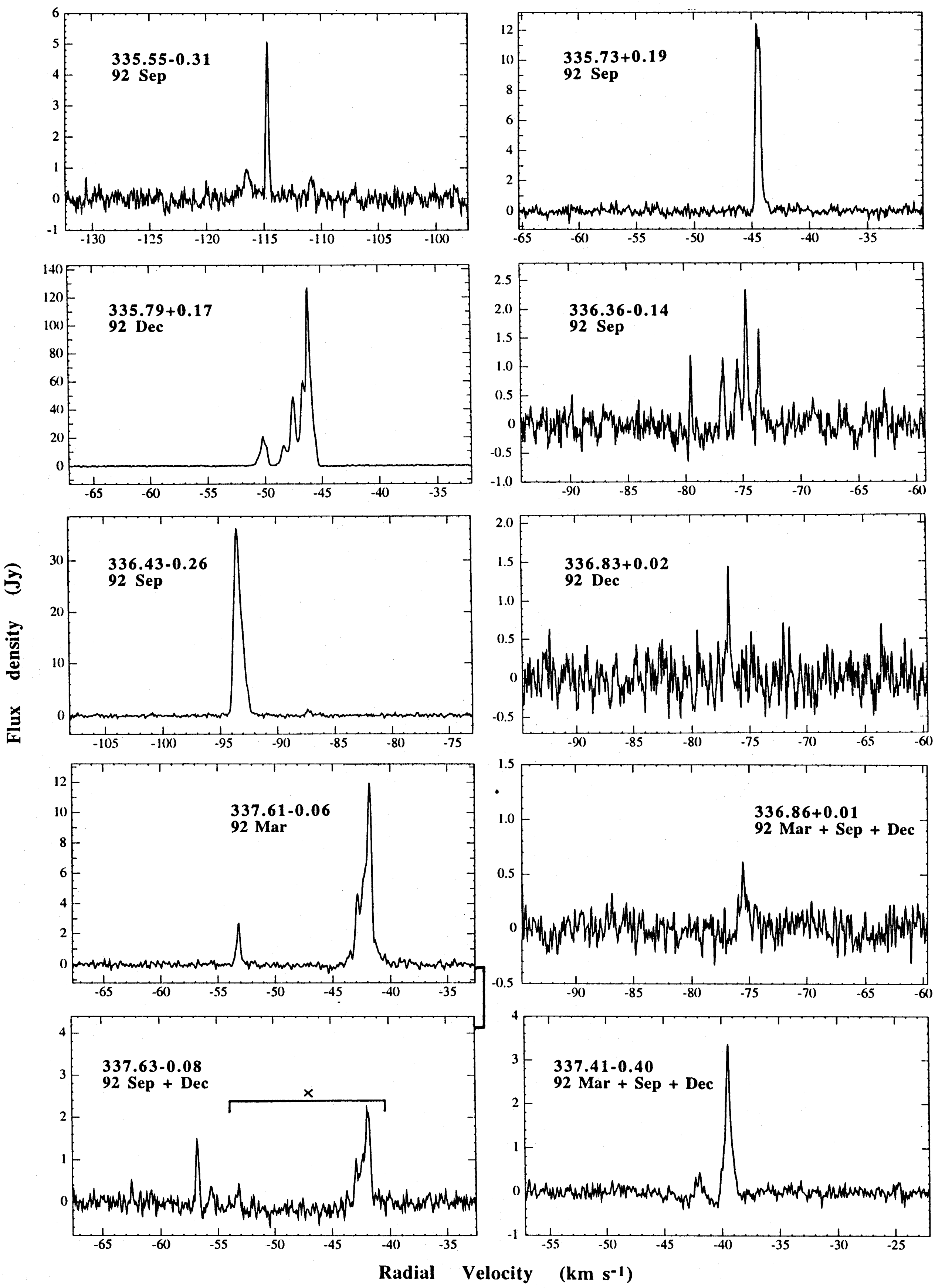

Figure 6. Spectra of 12-GHz methanol masers; details as for Fig. 2.

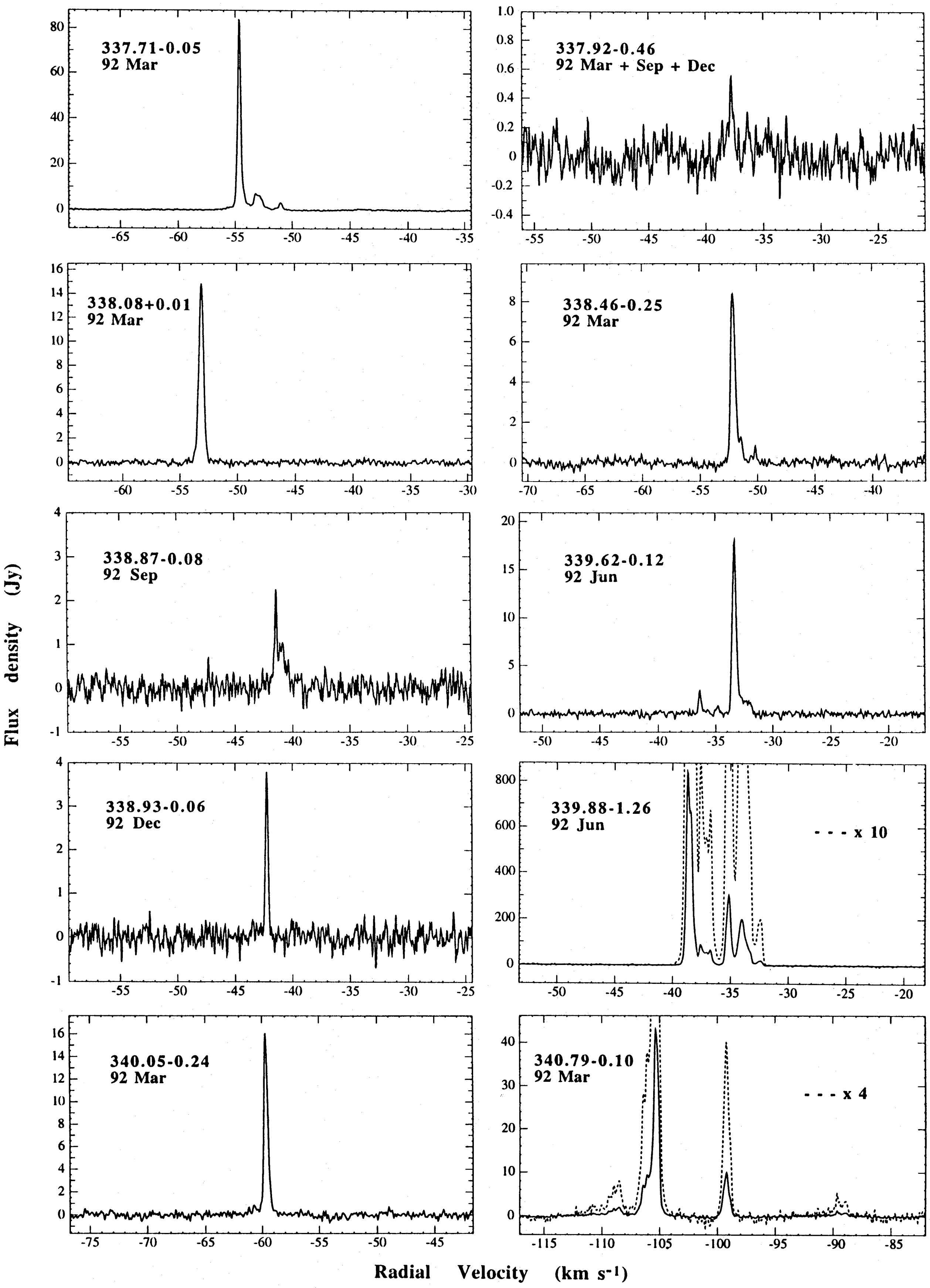

Figure 7. Spectra of 12-GHz methanol masers; details as for Fig. 2.

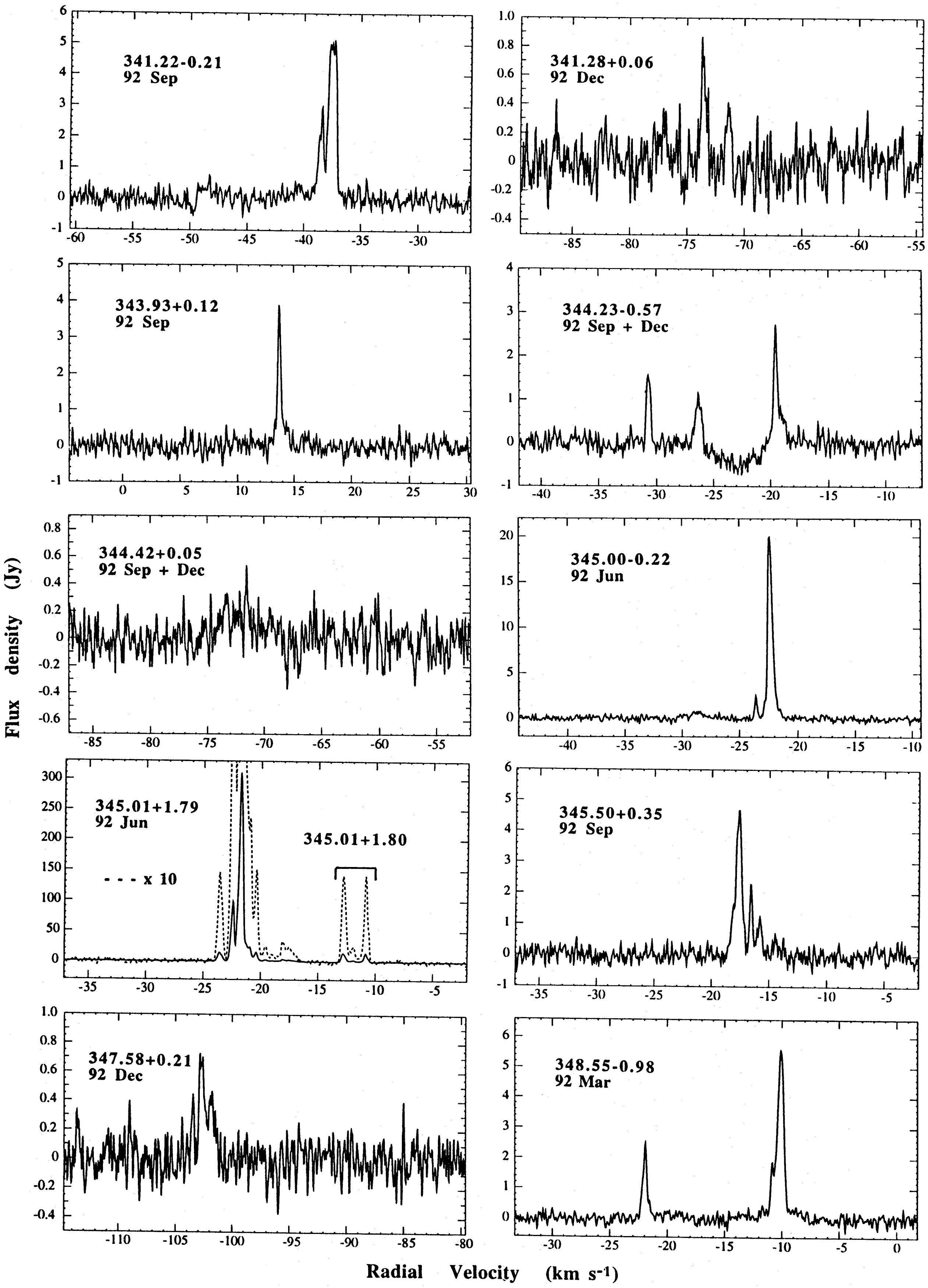

Figure 8. Spectra of 12-GHz methanol masers; details as for Fig. 2.

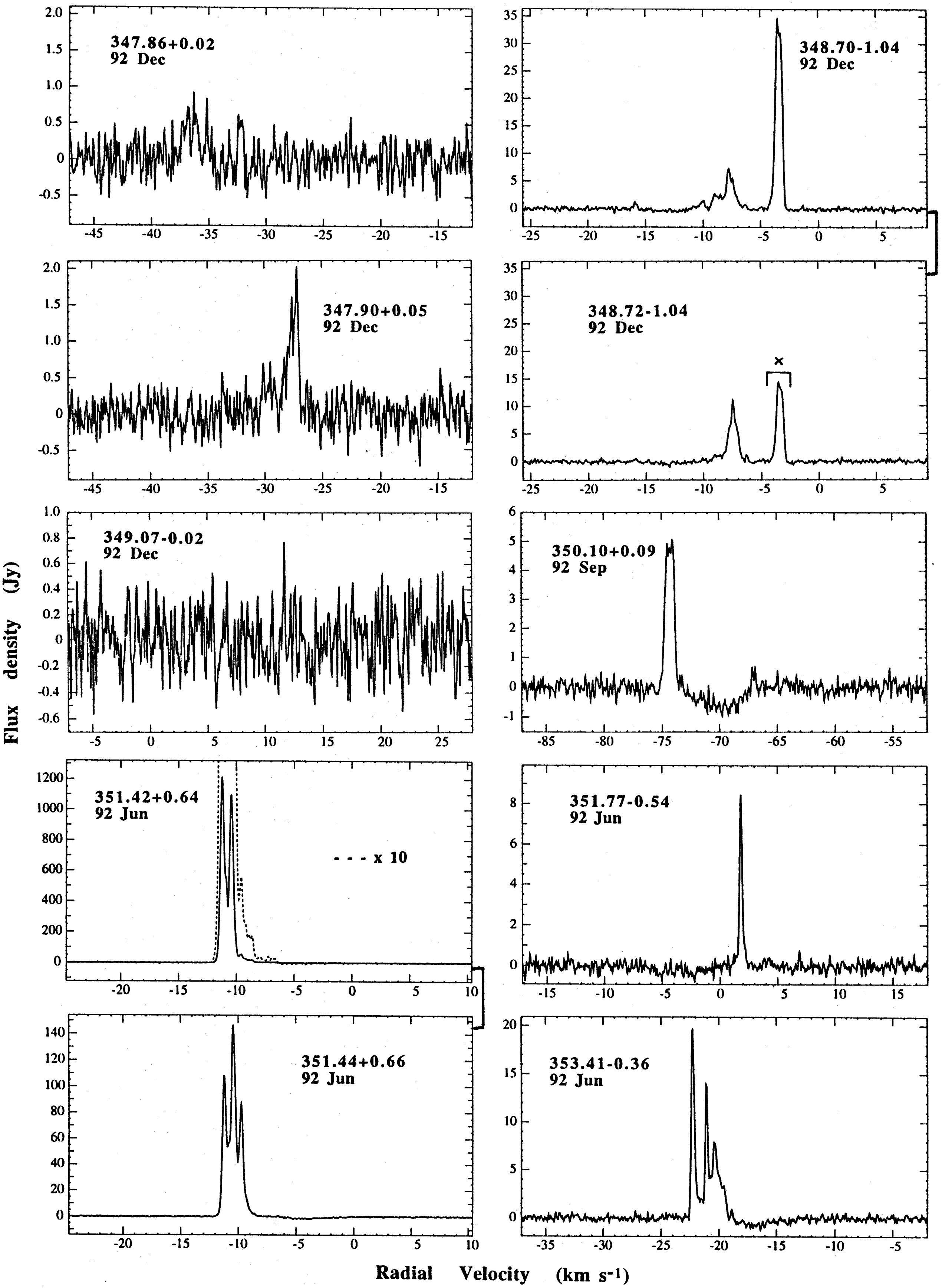

Figure 9. Spectra of 12-GHz methanol masers; details as for Fig. 2.

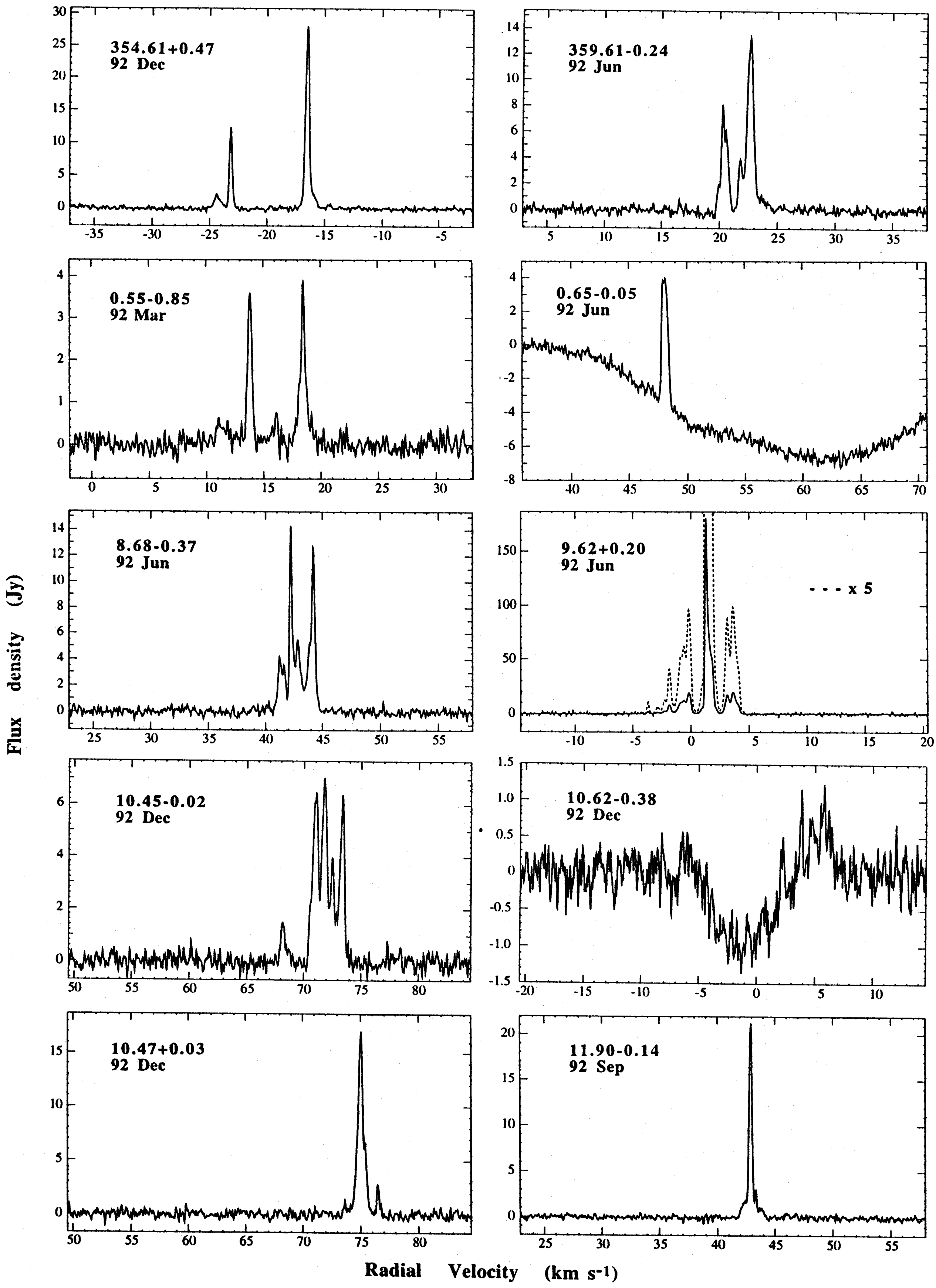

Figure 10. Spectra of 12-GHz methanol masers; details as for Fig. 2.

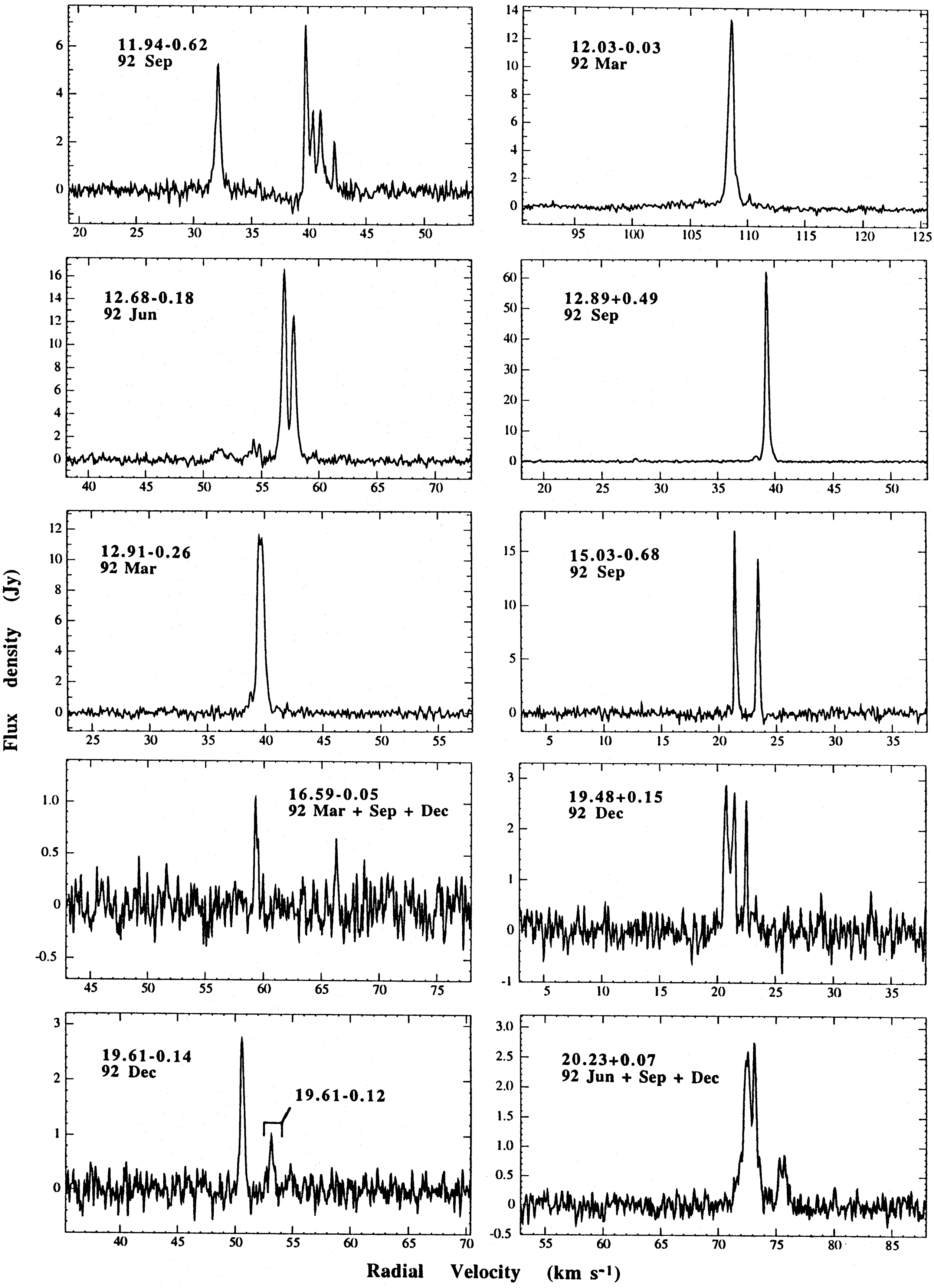

Figure 11. Spectra of 12-GHz methanol masers; details as for Fig. 2.

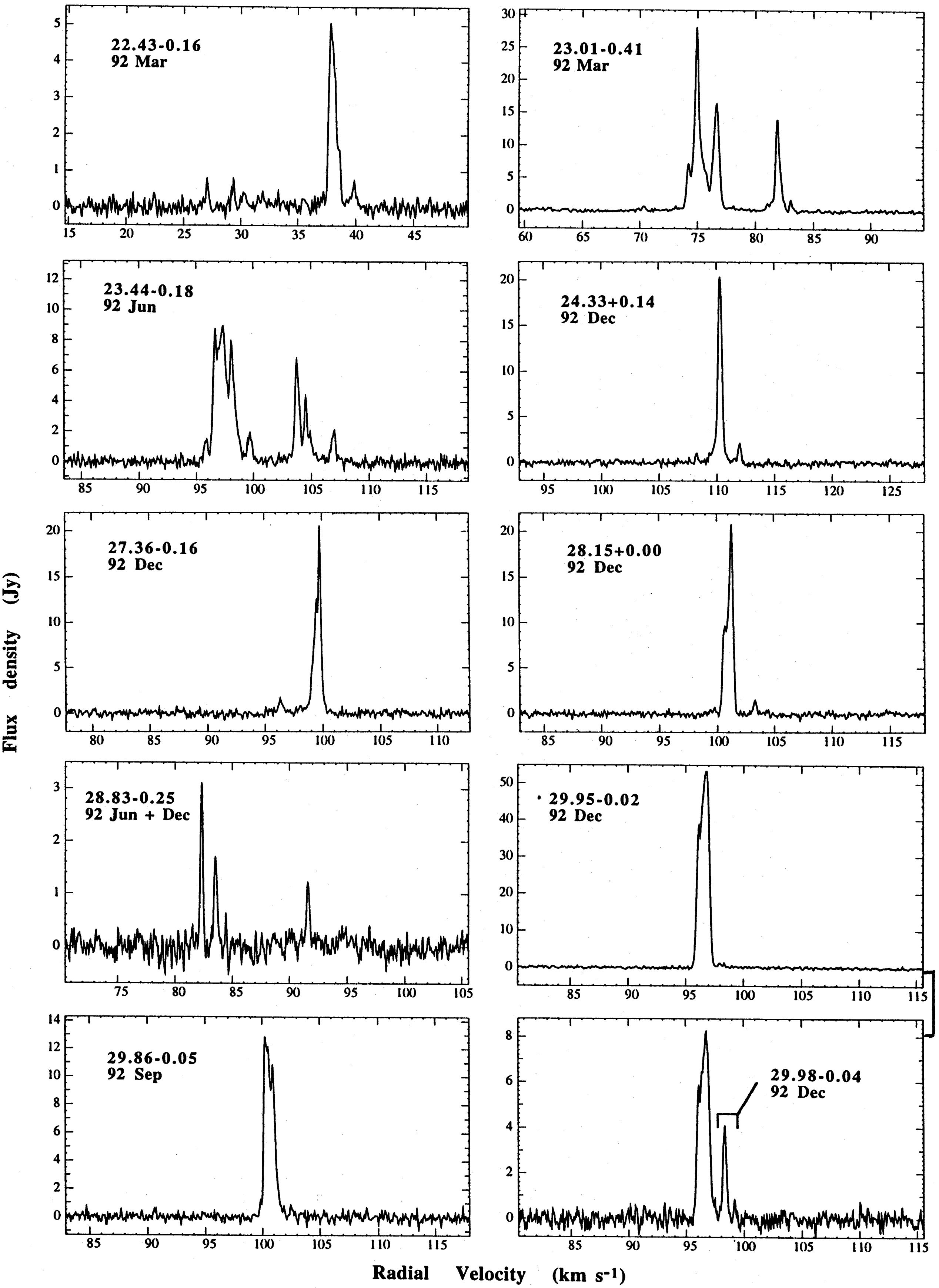

Figure 12. Spectra of 12-GHz methanol masers; details as for Fig. 2.

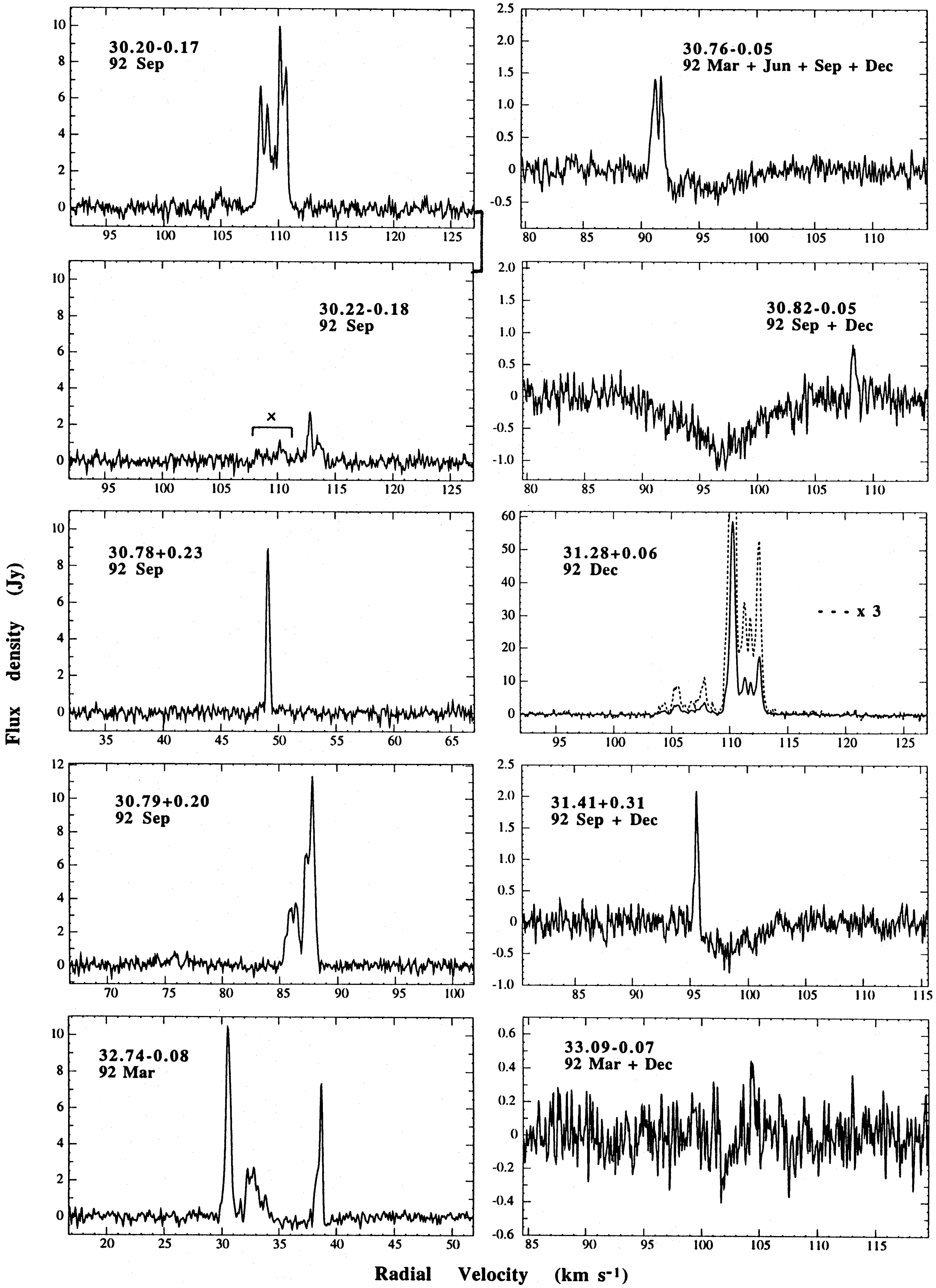

Figure 13. Spectra of 12-GHz methanol masers; details as for Fig. 2.

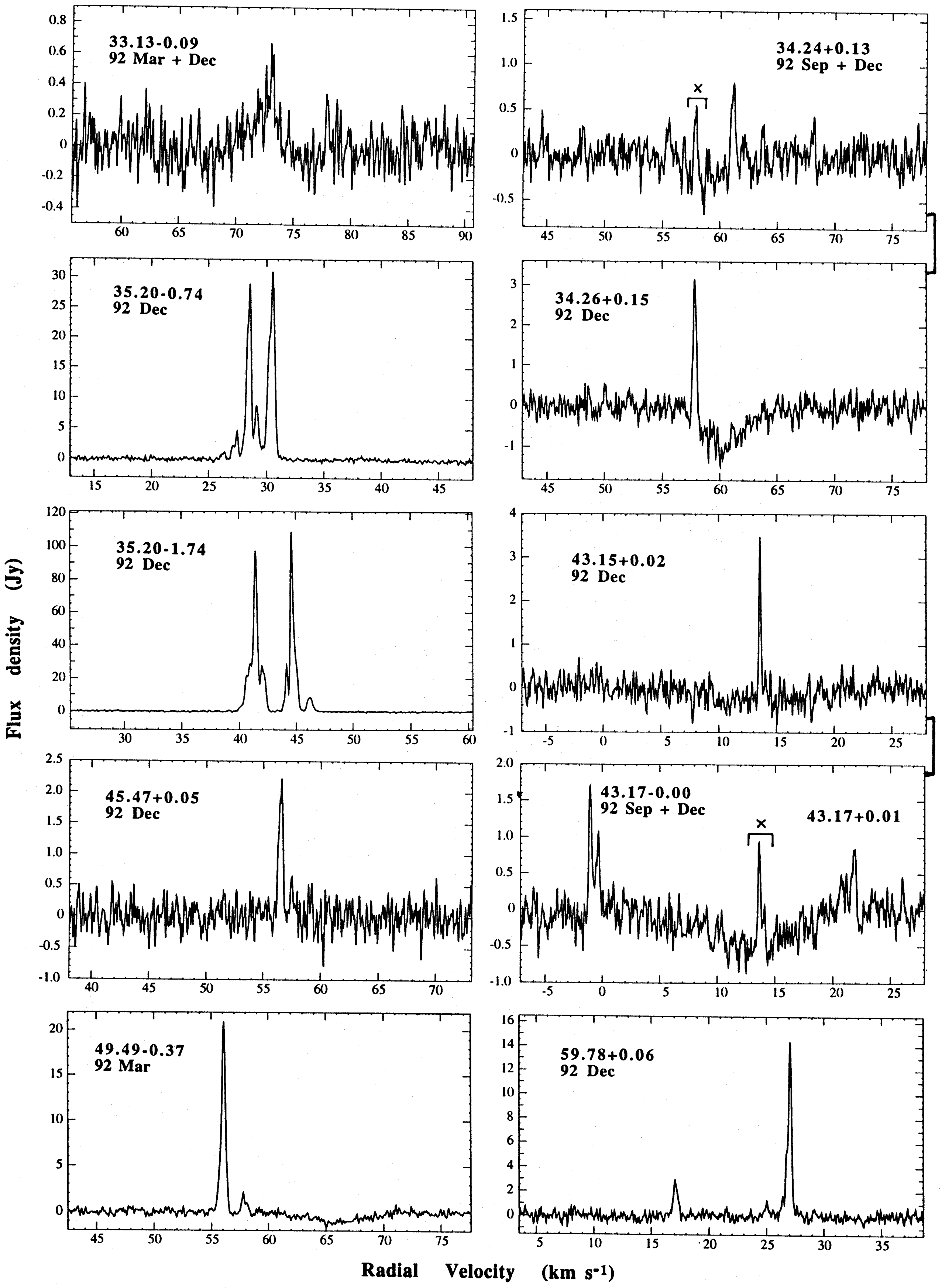

Figure 14. Spectra of 12-GHz methanol masers; details as for Fig. 2.

strongest peak has increased by 10 per cent. MacLeod, Gaylard & Kemball (1993) found no variability to a limit of 17 per cent.

213.71 − 12.60. Features at 12 GHz are in the same velocity range as at 6.6 GHz but do not correspond precisely. The second and third strongest features increased by nearly 30 per cent between 1992 March and December.

232.62 + 0.99. This source was weak when first detected in 1992 March and doubled in intensity by 1992 September. The two features closely correspond with 6.6-GHz velocities.

291.28 − 0.71. This maser was variable on the 12-GHz methanol transition from 1987 to 1989 (C + 93) and variations have continued. In particular there was a further, much greater, increase in the intensity of the strongest feature from 3 to 25 Jy in the subsequent 2.5 yr. There is now a fairly close similarity to the 6.6-GHz spectrum, although the latter is twice as strong.

305.20 + 0.02. There has been essentially no change in the main peak from 1988 (C + 93) to 1992, but the intensity of the feature near velocity -32 km s^{-1} has doubled.

305.21 + 0.21 and 305.20 + 0.21. The 6.6-GHz emission from these two sources has been measured with the ACTA (Norris et al. 1993) revealing a separation of 22 arcsec. At 12 GHz, we confirm this positional separation of the features in the two velocity ranges. The separation is sufficiently small that a single spectrum suffices to show emission from both sources. A third source seen at 6.6 GHz (305.25 + 0.25) has not yet been searched for 12-GHz emission. A feature seen at velocity -45 km s^{-1} in our 1992 December spectrum of 305.20 + 0.21 was absent in 1992 March and gradually increased.

305.37 + 0.19. Near this source (observed only in 1992 December) there is, at 6 GHz, a second stronger source (305.36 + 0.15) with no 12-GHz counterpart.

308.92 + 0.12. No significant change occurred between 1988 (C + 93) and 1992 December. There is poor correspondence with major 6.6-GHz features.

309.92 + 0.48. There is correspondence between 12- and 6-GHz features, but with 6.6-GHz showing additional strong emission in the velocity range -63.5 to -60.5 km s^{-1}. Several 12-GHz features show changes of up to 20 per cent between 1988 and 1992 (C + 95b).

313.47 + 0.19. The 12-GHz emission shows fairly close correspondence with 6.6-GHz features and very little intensity variation.

316.36 − 0.36 and 316.38 − 0.38. The two sources are separated by less than the telescope beamwidth, but fortunately there is very little overlap in their velocities, as can be seen from the aligned spectra. Weak emission from 316.36 − 0.36 is seen on the spectrum of 316.38 − 0.38. Intensity variations have been negligible.

316.64 − 0.09. The spectrum in 1992 remained similar in shape to 1988 (C + 93) but, whereas the feature at velocity -22.2 km s^{-1} was stable at 14 Jy, other features showed significant changes of at least 20 per cent (see C + 95b).

316.81 − 0.06. The spectrum at 12 GHz shows prominent absorption, together with several emission features that have 6.6-GHz counterparts. Emission is strongly variable at velocity -42 km s^{-1}; the feature seen at 12 GHz in the average spectrum was a 1.4-Jy spike in 1992 March and was absent in both 1992 September and December. At 6.6 GHz, at this same velocity, the feature was strong in 1992 March and decreased by 50 per cent by 1992 December, and thus the two transitions may be varying in synchronism (see C + 95b).

318.05 + 0.08. Two very weak emission peaks coincide with the strongest 6.6-GHz peaks.

318.95 + 0.20. This strong source (also observed in 1988 by C + 93) has shown no marked variability at 12 or at 6.6 GHz.

322.16 + 0.64. The main feature, with intensity 22 Jy in 1988 (C + 93), weakened to only 12.5 Jy in 1992 June, while at velocity -53 km s^{-1} the intensity was still 5.5 Jy. From consideration of the 6.6-GHz emission and other available data, we have suggested (C + 95a) that -53 km s^{-1} is the systemic velocity and the other, variable, feature is a blue-shifted outflow.

323.46 − 0.08. This source has remained very stable with no perceptible change from 1988 (C + 93) to 1992. The 6.6-GHz counterpart is also very stable.

323.74 − 0.26. This is one of the three strongest methanol masers at both 6.6 and 12 GHz, with a similar appearance at both transitions. The many strong features allow a quite sensitive search for relative variability (C + 93; MacLeod et al. 1993). At 12 GHz, 5 per cent changes occur in a 3-month interval, and at velocity -48.2 km s^{-1} it is weaker in 1992 than in 1988 by 15 per cent. In contrast, we could detect no variability at 6.6 GHz.

327.12 + 0.51. The single 12-GHz feature of 5 Jy corresponds to the second strongest, 25-Jy, 6.6-GHz feature. The 90-Jy 6.6-GHz feature has no detectable 12-GHz counterpart (less than 0.4 Jy).

327.29 − 0.58. The feature near velocity -48 km s^{-1} is quite variable, as is the 6.6-GHz counterpart; flaring in 1992 September appears synchronized on the two transitions. In 1992 March the only 12-GHz emission was a weak (0.4 Jy), narrow (0.2 km s^{-1}) feature at velocity -47.8 km s^{-1} (see C + 95b). Absorption is strong.

327.40 + 0.44. In addition to strong emission in the velocity range -82 to -84 km s^{-1}, weak features from -72 to -80 km s^{-1}, which are barely discernible on our 1988 spectra, are confirmed on our 1992 spectra and correspond with weak features on the 6.6-GHz transition.

328.24 − 0.55 and 328.25 − 0.53. These are two nearby centres of activity, but each emits in a different velocity range. The aligned spectra make it clear which features belong to each source. 328.24 − 0.55 was also studied in 1988 (C + 93) and is now weaker by 20 per cent. 328.25 − 0.53 has been stable over the period 1992 March to December, but emits at a level that would have been too weak to detect in our 1988 observations (C + 93).

328.81 + 0.63. No variations occurred over the whole observing interval from 1988 to 1992.

329.03 − 0.21 and 329.03 − 0.20. Both sources are displayed in a single spectrum. The second, weaker, source is offset from the first by 27 arcsec and has weakened since 1988; the stronger source has increased by more than 50 per cent between 1988 and 1992.

329.18 − 0.31. The two 12-GHz features have shown no variability and match the velocity of the third and fourth most prominent 6.6-GHz features.

329.41 − 0.46. In contrast to the previous source, the major 12-GHz feature, at velocity -65.8 km s^{-1}, does not match the velocity of any prominent 6.6-GHz feature.

331.28 − 0.19. This is one of the few methanol masers where the 12-GHz emission rivals that at 6.6 GHz. In fact, there are two major peaks at both 6.6 and 12 GHz, with the stronger at 12 GHz matching the second strongest at 6.6 GHz and vice versa. The full velocity range of the weaker features is similar on both transitions. Modest intensity changes of up to 25 per cent from 1988 to 1992 have occurred (e.g. the second strongest feature has increased from 40 to 50 Jy from 1988 to 1992 and, at velocity −81.5 km s^{-1}, a feature increased from 10 to 12 Jy between 1992 March and December).

331.56 − 0.12. There has been negligible variation at 12 GHz and a spectrum averaged over three epochs is shown to improve the signal-to-noise ratio. Each of the two features has a strong 6.6-GHz counterpart.

333.07 − 0.45. The only detectable 12-GHz peak coincides with the strongest 6.6-GHz peak. Two nearby 6.6-GHz masers, 333.12 − 0.43 and 333.13 − 0.44, have no 12-GHz counterpart.

333.16 − 0.10. The only detectable 12-GHz peak coincides with the strongest 6.6-GHz peak. Two nearby 6.6-GHz masers, 333.20 − 0.08 and 333.23 − 0.06, have no detected 12-GHz counterpart.

335.55 − 0.31. The most prominent 12-GHz peak is in the centre of the range of 6.6-GHz emission but does not coincide in velocity with any of the strongest 6.6-GHz peaks.

335.73 + 0.19. At 12 GHz this source is not confused with the following one (in contrast to observations at 6.6 GHz with larger beamwidth). No variability has been detected.

335.79 + 0.17. This maser showed variability in 1988 (C + 93) and continued to vary in 1992 but all peaks remained readily recognizable. Its 6.6-GHz counterpart is also variable (C + 95a). It is one of the few methanol masers in which the 12-GHz intensity rivals that at 6.6 GHz.

336.36 − 0.14. Several features are present at 12 GHz, with a velocity range of emission similar to 6.6 GHz.

336.43 − 0.26. The intensity increased by 50 per cent in 1992 September relative to 1988 and 1992 March. Note the weak feature at velocity −87 km s^{-1}, which was below the noise level in the less sensitive 1988 observations. The nearby 6.6-GHz maser at 336.41 − 0.26 shows no 12-GHz emission.

336.83 + 0.02 and 336.86 + 0.01. These two adjacent sources are clearly seen as separate with our beamsize of 2 arcmin at 12 GHz, although they are blended in our 6.6-GHz observations.

337.61 − 0.06. The spectrum in 1992 remains similar to its appearance in 1988 (C + 93) but note the weak feature at velocity −53 km s^{-1}, outside the velocity range covered by the 1988 observations.

337.63 − 0.08. This is a weak new source near the previous one. The spectra are aligned so as to make clear which peaks of the emission arise from 337.61 − 0.06 rather than 337.63 − 0.08.

337.71 − 0.05. No noticeable variations occurred from 1988 to 1992 and there were likewise no variations at 6.6 GHz. A very weak feature of 0.5 Jy at velocity −44 km s^{-1} matches a relatively weak (12-Jy) 6.6-GHz feature.

337.92 − 0.46. The emission is weaker at 12 GHz than at 6.6 GHz by a factor of nearly 100.

338.08 + 0.01. This is one of the few methanol masers in which the 12-GHz intensity has exceeded that at 6.6 GHz, but it has slowly decreased by 25 per cent from 1988 to 1992.

338.46 − 0.25. The intensity in 1992 March was similar to 1988 (C + 93) but then increased from 8 Jy to 10 Jy in 1992 December.

338.87 − 0.08 and 338.93 − 0.06. Although the separation of the sources is small, there is no confusion at 12 GHz.

339.62 − 0.12. There have been only slight variations in the main feature between 1988 (C + 93) and 1992. Weaker features between velocities −34 and −38 km s^{-1} have varied markedly between 1992 March and December; for example, the feature at velocity −36.4 km s^{-1} seen with flux density 2.5 Jy in 1992 June was only 0.8 Jy in 1992 March, September and December (see C + 95b).

339.88 − 1.26. This is one of the strongest methanol masers. It is slightly variable: for example, we find at velocity −34 km s^{-1} that the intensity increased from 178 to 200 Jy between 1992 March and December. MacLeod et al. (1993) also remarked on an increase for this feature from 120 to 150 Jy but this is not supported by their figure. Note also that our scaling indicates overall stronger intensities than reported by MacLeod et al. by a factor of between 1.3 and 1.5. Near velocity −34 km s^{-1}, a 6.6-GHz feature increased at the same time as the 12-GHz feature.

340.05 − 0.24. At 12 GHz, the single feature is at the same velocity as the 6.6-GHz peak, and has shown marked variability: 16 Jy in 1992 March, 5.8 Jy in 1992 June, and 10 Jy in 1992 September and December. In contrast, the corresponding feature at 6.6 GHz showed no significant change.

340.79 − 0.10. The velocity spread of 24 km s^{-1} is the widest yet discovered at 6.6 GHz; weak features at the edge of the 12-GHz spectrum, near −89 and −109 km s^{-1}, show that this is also true at 12 GHz. Variability of 10–20 per cent has occurred between 1992 March and December, especially near velocity −99 km s^{-1}, but 1988 intensities fall in the same range, which is indicative of quasi-periodic fluctuations rather than monotonic changes (see C + 95b).

341.22 − 0.21. The major feature near velocity −37.5 km s^{-1} comprises at least three components, all of which are highly variable, with peaks of 5 Jy in 1988 dropping to 1.8 Jy in 1992 June, increasing to 5 Jy in 1992 September, and then falling again (see C + 95b). A weak feature is present near velocity −49 km s^{-1}. Both strong and weak features are at the velocities of prominent 6.6-GHz emission.

343.93 + 0.12. The single 12-GHz feature coincides with the velocity of the fourth strongest 6.6-GHz peak (the other three have no detectable 12-GHz emission).

344.23 − 0.57. Three 12-GHz features are present, at −19.6, −26.5 and −31 km s^{-1}; the first two coincide with the strongest 6.6-GHz emission and the third with very weak 6.6-GHz emission. 12-GHz absorption is present at −23 km s^{-1}.

344.42 + 0.05. 12-GHz emission is very weak, with even the strongest feature, at velocity −71.6 km s^{-1}, only marginally above the noise level; however, its coincidence with the strongest 6.6-GHz feature suggests that it is a reliable detection.

345.00 − 0.22. This maser is highly variable at 12 GHz (as well as at 6.6 GHz), with peak values of only 5 Jy in 1988 (C + 93), increasing to 20.3 Jy in 1992 June, and subsiding to 4.9 Jy in 1992 September. The peak appears to be a blend of at least two features which vary independently and there is also weak emission near velocity -30 km s^{-1}.

345.01+1.79 and 345.01+1.80. Both sources, separated by 20 arcsec, are shown on a single spectrum. The 6.6-GHz counterparts have been observed with the ATCA (Norris et al. 1993), confirming the spatial separation. Interestingly, both centres have 12-GHz methanol intensity similar to the 6-GHz intensity (a rare occurrence); thus the unusual conditions are similar at both sites despite the large offset. There was little intensity change in the period 1992 March to December, but between 1988 April and 1992, the peak intensity at velocity -21.8 km s^{-1} showed a large decrease, from 430 Jy (1988 April) to 308 Jy (1992 June). Variability of the feature at -23.8 km s^{-1} in this time interval was even greater, from 60 to 15 Jy; MacLeod et al. (1993) also reported variability of the -23.8 km s^{-1} feature (but they remark on significant uncertainties in their absolute calibration and, indeed, it appears incompatible with ours for this and several other sources).

345.50+0.35. This source was chosen by C+95a as representative of the 6.6- and 12-GHz surveys, and was shown to display several aspects of the results. The spectrum of the 12-GHz methanol transition shows emission much weaker than at 6.6 GHz, as is common. At 12 GHz it was observed only at the epochs 1992 September and December; the 1992 December spectrum was shown by C+95a and we showed here the 1992 September spectrum, which reveals that no significant variations occurred. Variability at 6.6 GHz was recognizable over a longer time-span (C+95b).

347.58+0.21. This source shows weak emission at 12 GHz, but there is no emission from the adjacent 6.6-GHz sources 347.63+0.15 and 347.63+0.21.

347.90+0.05 and 347.86+0.02. For both sources, 12-GHz emission corresponds well with 6.6-GHz emission. 12-GHz observations were made at a single epoch (1992 December) and the emission from 347.86+0.02 is very weak, but the excellent correspondence in velocity with 6.6-GHz features corroborates the detection. From the adjacent 6.6-GHz source, 347.82+0.02, there is no clear 12-GHz emission.

348.55−0.98. At 12 GHz, the feature at velocity -22 km s^{-1} has not varied between 1988 and 1992 but the feature at -10 km s^{-1} has decreased from 20 to 5 Jy. A 1-Jy feature at velocity -12.7 km s^{-1} appeared in 1992 June but was absent 3 months later (see C+95b). Likewise, at 6.6 GHz, the emission near -22 km s^{-1} is not variable but the emission near -10 km s^{-1} is highly variable. From the 6.6-GHz data (C+95a) we found that emission at velocities -22 and -20 km s^{-1} is 2 arcsec north of features at velocities -10 to -13 km s^{-1}.

348.70−1.04 and 348.72−1.04. The two centres are separated by 63 arcsec and at each position there is a weak response to the other source. The source spectra are aligned so as to readily distinguish the features of each source. 348.70−1.04 increased from 25 Jy (1988) to 42 Jy (1992 March) and fell again to 35 Jy in 1992 December. Note also the weak emission, 1 Jy, at velocity -16 km s^{-1}. The major peak of 348.72−1.04 at velocity -7.4 km s^{-1} has not changed significantly, but at -7 km s^{-1} the emission has fallen from 10 to 5 Jy.

349.07−0.02. The weak single feature was observed only in 1992 December but agrees well in velocity with the third strongest 6.6-GHz feature.

350.10+0.09. In addition to the strong feature at velocity -74 km s^{-1} (coincident with strong 6.6-GHz emission) there is weaker emission at -67 km s^{-1} and absorption between these features.

351.42+0.64 [NGC6334A(f)] and 351.44+0.66. The two centres are separated by 107 arcsec and the 6.6-GHz counterparts have been mapped with the ATCA (Norris et al. 1993). 351.42+0.64 is the strongest 12-GHz methanol maser in our sample and has a velocity range of -12 to -7 km s^{-1}. The weaker source, 351.44+0.66, overlaps in velocity with the stronger one, as can be seen from the aligned spectra shown here and from the 'corrected' spectrum shown by C+93. 351.44+0.66 is variable at both 6.6 and 12 GHz; for example, the 12-GHz intensity at velocity -9.6 km s^{-1} fell from 87 (1992 June) to 63 Jy (1992 September). Note that MacLeod et al. (1993) mention variability of NGC6334f, but that their remarks apply to the offset source 351.44+0.66, perhaps with variability exaggerated by the offset position.

351.77−0.54. The 12-GHz spectrum is shown in Fig. 1 for comparison with 6.6-GHz emission, and also in Fig. 9 at a different epoch in order to demonstrate the variation. The 12-GHz emission is a single peak at velocity $+1.8$ km s^{-1}, which matches one of the strong 6.6-GHz peaks. The 12-GHz emission was not detected in 1988 (C+93) and was thus less than 3 Jy; it then increased from 4.4 Jy in 1992 March to 8.4 Jy in 1992 June and subsequently decayed to 5.3 Jy (1992 September) and then 3.5 Jy (1992 December). Near this velocity the 6.6-GHz emission is similarly variable, flaring in 1992 June, but by only 25 per cent (see C+95b).

353.41−0.36. The features seen in 1988 have remained essentially constant at all observing epochs over 4 yr. Note the absorption in the velocity range -15 to -19 km s^{-1}.

354.61+0.47. At velocity -16.5 km s^{-1}, the emission has shown variations of up to 20 per cent. At velocity -23.1 km s^{-1}, rapid changes occurred in 1988 (C+93) and have continued (7.5 Jy in 1992 March, 9 Jy in 1992 June, 18 Jy in 1992 September and 12 Jy in 1992 December), as shown in C+95b).

359.61−0.24. Intensity changes of typically 25 per cent occurred within the period 1992 March to December, and, in the longer period from 1988 (C+93) to 1992, the feature at $+20.2$ km s^{-1} decreased by a factor of 2 (C+95b).

0.55−0.85. Variability is present in both features: at velocity $+13.8$ km s^{-1} the emission has dropped to half its 1988 intensity (C+93), and at $+18.4$ km s^{-1} it has increased by a factor of 2, but with a temporary reduction in 1992 September (C+95b).

Sgr B2. The component 0.65−0.05 is the only one of several 6.6-GHz masers in the Sgr B2 complex to show 12-GHz emission. The 12-GHz emission was detected in 1988 (Whiteoak et al. 1988), but its position was uncertain at that time and the flux density was probably underestimated so that apparent variability is questionable. Broad absorption dominates the 12-GHz spectrum and is discussed in detail by Whiteoak et al. (1988).

8.68−0.37. Spectra in 1992 are similar to those of 1988 but some features, e.g. at velocity $+42.2$ km s^{-1}, show up to 30 per cent variation over 3-month periods. The 6.6-GHz maser, 8.67−0.36, offset 60 arcsec, has no 12-GHz counterpart.

9.62+0.20. Noted as variable in 1988 (C+93), the main feature again flared in 1992, from 130 Jy (March) to 180 Jy

(June) and back to 126 Jy (December) with the other features relatively stable. The 6.6-GHz emission was much less variable over this period.

10.47+0.03 and 10.45−0.02. The first source remains similar to its 1988 appearance and showed no variations greater than 20 per cent within the four observations in 1992. Note that, at 6.6 GHz, a huge reduction in the strongest feature occurred between 1991 June (843 Jy according to Menten 1991b) and 1992 March (60 Jy), but we do not have 12-GHz observations at the time of the 6.6-GHz maximum. The nearby source 10.45−0.02 has 12-GHz emission closely corresponding in velocity with its 6.6-GHz counterpart. A third 6.6-GHz maser in the vicinity, 10.48+0.03, has no 12-GHz emission.

10.62−0.38. 12-GHz emission is weak but shows the same general pattern as at 6.6 GHz, namely prominent absorption with weak emission at adjacent velocities on either side. The nearby 6.6-GHz maser 10.63−0.34 shows no 12-GHz emission.

11.90−0.14. The 12-GHz peak intensity was 17 Jy in 1988 and has increased slightly from 19 Jy in 1992 March to 24 Jy in 1992 December. The nearby sources, 11.93−0.15 and 11.91−0.11, show emission at 6.6 GHz but none at 12 GHz.

11.94−0.62. The masers at 12 and 6.6 GHz are strikingly similar in the appearance of their spectra.

12.03−0.03. The 6.6-GHz spectrum (C+95a) has two prominent strong features, slightly blended, of which only one has a 12-GHz counterpart. The 12-GHz intensity has varied from 12 Jy in 1992 June to 18 Jy in 1992 December, with the 1988 value in-between.

12.68−0.18. The two major features seen in 1988 are still present, with both increasing in 1992 June and subsequently falling to their previous values. Weak emission is also present between +50 and +55 km s^{-1}, matching other 6.6-GHz features which are much stronger.

12.89+0.49. In addition to the intense emission near velocity +39 km s^{-1} matching the main 6.6-GHz peak, there is weak emission at +28 km s^{-1} matching weak 6.6-GHz emission.

12.91−0.26. The 20-Jy peak seen in 1988 fell to 11.5 Jy by 1992 March, but then increased to 15.9 Jy in 1992 December.

15.03−0.68 (part of M17). The two features match the 6.6-GHz appearance. There has been no relative variation of the two features in the 1988 measurements or the four measurements of 1992, but there was an overall increase by 20 per cent from 1992 March to December.

16.59−0.05. 12-GHz emission at velocity +59.3 km s^{-1} matches the 6.6-GHz strongest feature, but the slightly weaker emission at +66.2 km s^{-1} has no prominent 6.6-GHz counterpart.

19.48+0.15. All the emission seen at 12 GHz is from this source and there is none from the nearby 6.6-GHz maser 19.47+0.17 (the two are confused at 6.6 GHz).

19.61−0.14 and 19.61−0.12. A single spectrum at the average of these two positions suffices to show the main source at velocity +50.6 km s^{-1} and the weaker offset source at velocity +53.1 km s^{-1}. There is no 12-GHz counterpart to the strongest 6.6-GHz emission at velocity +56.6 km s^{-1}.

20.23+0.07. 1992 observations show this source to be weaker than in 1988 by a factor of 2. The main peak is offset from the velocity of the 6.6-GHz major peaks.

22.43−0.16. The major peak at velocity +37.8 km s^{-1} is similar in 1988 and 1992, and matches a strong 6.6-GHz peak. Our 1992 spectra show weak features between +27 and +31 km s^{-1}, of which the one at +29.3 km s^{-1} matches the strongest 6.6-GHz peak.

23.01−0.41. Significant variations occurred between 1988 (C+93) and 1992; in particular, at velocity +82 km s^{-1}, the intensity more than doubled, and a further 10 per cent variation occurred between 1992 September and December. The weak feature at +70 km s^{-1} was present throughout 1992.

23.44−0.18. Comparison spectra at 12 and 6.6 GHz are shown in Fig. 1 and reveal emission over a wide velocity range on both transitions. The strongest feature at 12 GHz at velocity +103.8 km s^{-1} is close to the velocity of the third strongest 6.6-GHz feature, whereas there is only weak 12-GHz emission corresponding with the strongest 6.6-GHz peak at +103.0 km s^{-1}. The maser is highly variable at 12 GHz (C+93) and also at 6.6 GHz (C+95a; C+95b). Emission in the velocity range +95 to +100 km s^{-1} is stable, with variations of less than 20 per cent between 1988 and 1992. The emission at velocity +103.8 km s^{-1} flared in 1988 April but subsided to a low level in 1989 November. In 1992 March it was again at a low level but then increased steadily by a factor of 4 in 1992 between March and December; comparison of the 12-GHz spectra of Figs 1 and 12 shows an increase from 6.5 Jy in 1992 June to 17 Jy in 1992 December. There is some hint that variability is synchronized at 12 and 6.6 GHz, but more pronounced at 12 GHz.

24.33+0.14. This methanol maser is one of the few in which the 12-GHz peak intensity significantly exceeds that at 6.6 GHz (by nearly a factor of 2). The three major 6.6-GHz features are variable and all have 12-GHz counterparts, but our 12-GHz observation is at a single epoch, so no variability comparison is possible.

27.36−0.16. The 12-GHz peak rivals the intensity at 6.6 GHz. No variation occurred between 1992 September and December.

28.15+0.00. This source is displayed as a representative source in Fig. 1 for comparison with its 6.6-GHz counterpart, as well as in Fig. 12 at a different epoch. There is a close match in appearance of 12- and 6.6-GHz masers, with the 6.6-GHz emission stronger, typically by a factor of 1.5. No significant 12-GHz variations occurred from 1992 September to December.

28.83−0.25. 12-GHz emission between velocities +82 and +84 km s^{-1} remained the same in 1992 as it was when first observed in 1988; the more sensitive 1992 observations show additional emission at +91.6 km s^{-1} where there is also another 6.6-GHz counterpart.

29.86−0.05. In general appearance, this source has remained similar to the 1988 spectrum (C+93) but was at least 10 per cent weaker in 1992 September. The feature at velocity +100.9 km s^{-1} further decreased by at least 20 per cent between 1992 September and December (C+95b).

29.95−0.02 and 29.98−0.04. The two sources are close and the stronger one, 29.95−0.02, is detected weakly at the position of 29.98−0.04, as seen on the aligned spectra. 29.98−0.04 has a clearly distinct feature of 4.1 Jy at velocity +98.4 km s^{-1}. The features of 29.95−0.02 are typically 20 per cent stronger in 1992 than they were in 1988.

30.20−0.17 and 30.22−0.18. The aligned spectra show that, to a good approximation, the sources emit over different velocity ranges and are not confused.

30.76−0.05. The two peaks of emission between +91 and +92 km s^{-1} are at the same velocity as the strongest 6.6-GHz emission.

30.78+0.23. The 12-GHz emission matches the 6.6-GHz emission, with no variation from 1992 March to December.

30.79+0.20. The 12-GHz emission is in three velocity ranges: +87 to +88.5 km s^{-1}, matching strong 6.6-GHz emission; +85 to +87 km s^{-1}, where weak 12-GHz emission matches strong 6.6-GHz emission; and +74 to +77 km s^{-1}, where very weak 12-GHz emission matches weak 6.6-GHz emission. Intensity increases at 12 GHz occurred between 1992 March and September, with the most pronounced reaching a factor of 2 at velocities +85 to +87 km s^{-1} (see C+95b).

30.82−0.05. The single peak, at velocity +108.3 km s^{-1}, corresponds to the third strongest 6.6-GHz peak, and there is absorption from velocity +95 to +104 km s^{-1}.

31.28+0.06. This is one of the strong methanol masers in which the peak flux density on the 12-GHz transition exceeds that on the 6.6-GHz transition. Features at both transitions match quite well over the velocity range +104 to +113 km s^{-1}. The intensity of the strongest peak at 12 GHz has fallen nearly 50 per cent between 1988 and 1992.

31.41+0.31. The single weak emission feature at velocity +95.6 km s^{-1} matches one of the strongest 6.6-GHz features. The 12-GHz spectrum shows absorption from +96 to +102 km s^{-1}.

32.74−0.08. Features in the velocity range +30 to +40 km s^{-1} are present at 12 GHz, matching those at 6.6 GHz. The feature at +38.6 km s^{-1} was 6 Jy in 1988 (C+93), increased to 7.4 Jy in 1992 March and then steadily fell again to 4.6 Jy in 1992 December (see C+95b).

33.09−0.07. Weak 12-GHz emission is at the velocity of the second strongest 6.6-GHz peak.

33.13−0.09. Weak 12-GHz emission is at the velocity of the strongest 6.6-GHz peak.

34.26+0.15 and 34.24+0.13. The spectra of the two close sources are aligned to show that the feature at velocity +57.8 km s^{-1}, which is seen on both spectra, really arises in the stronger source, 34.26+0.15. Comparison with C+95a shows that it matches the velocity of the strongest 6.6-GHz peak in 34.26+0.15. 34.24+0.13 shows a weak 12-GHz feature which has a weak 6.6-GHz counterpart. Both sources also show absorption at 12 GHz.

35.20−0.74. Since 1988, the emission at velocity +30.6 km s^{-1} has decreased by 30 per cent and the emission at +28.5 km s^{-1} has increased by 40 per cent. The 6.6-GHz emission remained constant from 1992 March to December.

35.20−1.74. The variability at 12 GHz seen during 1988–1989 (C+93) has continued, but all features are still recognizable, and changes over the 3 yr are less than the 50 per cent change seen between 1988 April and 1989 November. The maser is also variable at 6.6 GHz (C+95b).

W49N. This well-known molecular complex contains a number of H II regions and OH masers as tabulated by Gaume & Mutel (1987). From our single-dish measurements, we were able to distinguish at least four methanol centres of activity at 6.6 GHz, of which three also show 12-GHz emission (displayed on two aligned spectra).

43.15+0.02 shows a 12-GHz feature at velocity +13.6 km s^{-1}, matching the strongest feature seen at 6.6 GHz.

43.17−0.00 is a weak source at velocity −1.1 km s^{-1}, with matching features at 12 and 6.6 GHz; it is clearly distinct from all other features at both 12 and 6.6 GHz.

43.17+0.01 is a 6.6-GHz centre, near but quite distinct from the previous site (offset 30 arcsec); the 12-GHz emission at velocity +20 to +22 km s^{-1} is from this position.

45.47+0.05. The 12-GHz emission matches the stronger of the two 6.6-GHz features. The nearby source 45.44+0.07 shows nothing above our noise level at 12 GHz.

W51. This well-known complex of H II regions and molecular clouds contains several 6.6-GHz methanol masers, with three clearly distinguishable in our single-dish observations. Of these, only one, 49.49−0.37, has a clearly detectable 12-GHz counterpart. The main peak increased from 15 Jy in 1988 March to 21 Jy in 1992 March and by 1992 December had fallen again to 15 Jy. Broad absorption is present between velocities +62 and +70 km s^{-1}.

59.78+0.06. This is one of the representative sources shown in Fig. 1 for comparison with 6.6-GHz emission, and again, in Fig. 14, at another epoch. We find that each of the four 12-GHz features is at the same velocity as a 6.6-GHz feature but that the relative intensities differ greatly. Variability for the feature at velocity +17 km s^{-1} is clearly seen, dropping by 20 per cent between 1992 September and December.

5 DISCUSSION

5.1 General

The present sample of 12-GHz masers has been obtained from a search at the position of 6.6-GHz masers; these in turn have been taken from the positions of OH masers plus a few other objects (C+95a). Thus the distribution of these methanol masers within the Galactic disc is largely determined by the original OH surveys (Caswell & Haynes 1987, and references therein), and the relevance to the distribution of star-forming regions in our Galaxy is discussed in C+95a. In the following section, we show that the 12-GHz masers are only rarely brighter than their 6.6-GHz counterparts, and that it is therefore likely that an unbiased Galactic survey of 12-GHz masers would consist chiefly of the same sources as discovered by a survey, such as the present one, at the positions of 6.6-GHz masers. The fact that our observations yielded no chance discoveries of 12-GHz masers unrelated to the 6.6-GHz methanol masers is a further indication that there is no significant population of masers emitting principally at 12 GHz rather than 6.6 GHz.

5.2 Comparison of methanol masers at 12 and 6.6 GHz

Fig. 1 shows comparisons of spectra of the 6.6- and 12-GHz methanol transitions for four representative masers. Source 23.44−0.18 has a 12-GHz intensity lower than its 6.6-GHz intensity, with some features showing a precise coincidence in the two transitions, and other features having no exact counterpart in the other transition. This is common. However, as noted by Norris et al. (1993), in a few sources there is a strong similarity, with 12-GHz emission only slighly weaker, and an example of this behaviour is shown in the source 28.15 + 0.00. In some other cases, the 12-GHz emission is much weaker, as in 351.77 − 0.54, and occasionally a feature seen at 6.6 GHz has a stronger counterpart at 12 GHz, as occurs at velocity +27.1 km s^{-1} in 59.78 + 0.06. Detailed comparison for all individual sources can be made from the 12-GHz data here, and the 6.6-GHz data from C + 95a; remarks on such comparisons have been made in the preceding notes, with generalizations discussed in the following sections.

5.2.1 *Comparison of velocities*

Very close inspection of the complete sample of 12- and 6.6-GHz spectra reveals that, with the current choice of rest frequencies for the two transitions, there is a slight systematic offset of approximately 0.07 km s^{-1} between corresponding features, with the 12-GHz features at apparently more positive velocity, as noted in a preliminary analysis by C + 95a. Examples of this are seen in Fig. 1 in the spectra of 28.15 + 0.00, 351.77 − 0.54 and the strongest feature at 12 GHz in 59.78 + 0.06. An even more striking individual example occurs in 188.95 + 0.89, where the effect is seen in all features and is repeatable over four epochs.

Quantitatively, we find that 80 of the features in Table 1 appear sufficiently isolated or strong to make this comparison, and the median offset for these is 0.07 km s^{-1}, with half of the features having offsets in the range 0.04 to 0.10 km s^{-1}. This median offset would be eliminated if the adopted rest frequency at 12 GHz were decreased by 3 kHz, or the rest frequency at 6.6 GHz increased by 1.5 kHz. The fact that there is a scatter in the offsets is partly attributable to measurement error but can also be caused by the apparently matching features being close but not coincident. This latter explanation seems necessary to account for prominent features, such as those in 351.42 + 0.64, which coincide with the present rest-frequency choice, yet would be slightly discrepant with our suggested change; and at the other extreme, the prominent feature in 318.95 − 0.20 has a velocity discrepancy of 0.2 km s^{-1}, which is only partially 'corrected' by our suggested shift.

The width of individual maser features can be as small as 0.2 km s^{-1} to half-intensity, as noted for 12-GHz masers by C + 93, and for 6.6-GHz masers by C + 95a. Comparison of matching individual features at the two transitions in the present sample shows that the widths at 12 GHz are sometimes narrower and almost never larger. Our velocity resolution is slightly better than 6.6 than at 12 GHz (0.09 compared to 0.10 km s^{-1}) and the tendency for the 6.6-GHz features to be very slightly broader cannot be instrumental. It might be caused by the higher probability of confusion in the generally more complex 6.6-GHz spectra. Interferometer observations with high spatial resolution could reveal whether this is so, or whether the 12-GHz spectral features are intrinsically narrower, as might result if a larger fraction of them were not fully saturated.

The velocity ranges of the 12-GHz masers, as seen on the spectra and given in Table 1, are typically smaller than the ranges for 6.6-GHz masers. The median range for the whole sample of 131 12-GHz masers is 5 km s^{-1}; for the strongest 40 sources, greater than 17 Jy, the median is only slightly larger, at 6 km s^{-1}. This may be compared with a median of 12 km s^{-1} for the strongest 6.6-GHz masers, falling to 5 km s^{-1} for the weakest (with peaks of less than 5.8 Jy; C + 95a). The comparison is compatible with a typical masing region having fewer spots favourable for 12-GHz than for 6.6-GHz emission; the 6.6-GHz spots with no 12-GHz counterparts would sometimes be those at extreme velocity, and the apparent width of emission at 12 GHz would then be smaller than at 6.6 GHz.

5.2.2 *Comparison of intensities*

Our search of a sample of 238 6.6-GHz masers has led to detections of a 12-GHz counterpart towards 131 of these. The 12-GHz peak flux densities range from over 1000 Jy (351.42 + 0.64) to less than 0.5 Jy (33.09 − 0.07) with a median peak flux density of 7 Jy. For the remaining 6.6-GHz masers we have 12-GHz upper limits or uncertain detections of typically 0.5 Jy. The detection rate of 12-GHz masers is smaller from the weaker 6.6-GHz masers, as noted by C + 95a. From the point of view of the detectability of 12-GHz counterparts to 6.6-GHz masers, we found (C + 95a) that the median ratio of 12-GHz peak intensity to 6.6-GHz peak intensity in a corresponding source (but not necessarily a corresponding spectral feature) was 1/9, i.e. there is a 50 per cent chance of finding a 12-GHz maser at the position of a 6.6-GHz maser with peak intensity of at least 1/9 of the 6.6-GHz intensity. The corresponding statistic for the 131 sources selected at 12 GHz is 5.4, i.e. there is a 50 per cent chance of finding a 6.6-GHz maser at the position of a 12-GHz maser with intensity at least 5.4 times the intensity of the 12-GHz maser. Both of these statistics are concerned with the detectability of sources and do not translate directly to conditions in the masing spots.

We may, in addition, compare the relative intensities of individual peaks which correspond in velocity and apparently emanate from the same masing spot. This has the potential of revealing the physical conditions in the masing spot.

We chose the highest peak at 12 GHz for all 131 sources detected at 12 GHz and compared this with the corresponding 6.6-GHz intensity at the same velocity (as given in Table 1). We found a 6.6-GHz counterpart in nearly all cases, with intensity ratios of 6.6 to 12 GHz ranging from 0.39 to 85. The median value is 3.2, i.e. given a 12-GHz feature, there is a 50 per cent chance that it will have a corresponding 6.6-GHz feature stronger by a factor of 3.2. The quartiles of the distribution are at 1.7 and 8.2, and in nine of the 131 features the ratio is less than or equal to unity, i.e. the 12-GHz emission is stronger. Although the initial selection of sources was at 6.6 GHz, the overall distribution of intensity ratios suggests that it is unlikely that many 12-GHz masers exist with much weaker 6.6-GHz counterparts, and the results should therefore be equally valid for a sample from a survey of 12-GHz masers.

The corresponding distribution for features selected at 6.6 GHz is most meaningful if based on a sample with a defined 6.6-GHz cut-off rather than the present sample. To obtain a median ratio, it is necessary to restrict the sample to the stronger 6.6-GHz masers so as to avoid the occurrence of large numbers of 12-GHz non-detections. For the 121 strongest 6.6-GHz masers, taken from C + 95a, the median ratio of 6.6- to 12-GHz intensity at the velocity of the strongest 6.6-GHz feature is 26, with quartiles at 5.3 and 500. (These statistics include the 26 non-detections of a 12-GHz counterpart.) Thus for an individual maser feature from a sample selected at 6.6 GHz, there is a 50 per cent chance that it will have a 12-GHz counterpart with intensity greater than 1/26 of the 6.6-GHz intensity.

The pumping model for 6.6- and 12-GHz methanol masers described by Cragg et al. (1992) operates in the density regime from 10^2 to 10^5 cm^{-3} (of H_2, assumed to be the dominant species). Furthermore, it predicts that the 6.6-GHz maser turns on, and peaks, at a lower density than the 12-GHz line, but with the latter up to 5 times stronger under favourable conditions. This suggests that the masers with higher ratios of 12- to 6.6-GHz intensity delineate the higher density maser spots; our observations would then imply that these are less prevalent than the lower density spots. With some experimentation in varying the frequency distribution of spots with differing size and density, and incorporating this with a pumping model, it should be possible to find a distribution of density that predicts a match to the observed distribution of 6.6- and 12-GHz intensities.

We have also inspected the intensity of the second brightest feature relative to the brightest for both the 12-GHz and the 6.6-GHz masers. We find that a second feature at least half as bright as the brightest is found for 71 per cent of the 6.6-GHz masers and for 57 per cent of the 12-GHz masers. So in neither case is there usually a dominant main feature and, as argued in Section 5.4, this supports the interpretation that the features are mostly saturated.

5.3 Variability

Our absolute calibration has uncertainties of up to 10 per cent, but, within sources possessing complex spectra, intensity variability of some features is readily seen even at a level of a few per cent, since relative variability does not rely on the accuracy of the absolute calibration. The principal purposes of the observations were to discover 12-GHz counterparts to the 6.6-GHz masers and to confirm them, but the resulting data set has proved to be valuable for initial variability investigations on a number of time-scales. Changes were commonly seen on the time-scale of the 3-month interval between observing sessions and relative to the measurements 4 yr earlier. However, when measuring positions of strong complex sources no variability was found on a time-scale of ~15 min during which six spectra were obtained, and when system checks were made on strong sources at intervals of 1 or 2 d, no perceptible changes were seen above the noise level.

For the 57 sources first measured by C+93 in 1988, our measurements 4 yr later, reported here, show similar peak intensities for 20 (within 10 per cent), larger peaks for 21 and smaller peaks for 16. There is a slight bias where our choice of current spectra for display is made partly on the basis of demonstrating changes over the 4-yr period, and a preference for spectra with a higher signal-to-noise ratio.

Interestingly, the changes over 4 yr were typically no greater than those seen over 3 months, which shows that increases or decreases are usually followed by a return to the original value, and is suggestive of quasi-periodic fluctuations.

In our earlier study of 12-GHz sources (C+93), we remarked on the frequently seen variations at the level of about 10 per cent within a month, and drew attention to eight sources showing much stronger variability. In the present study we have attempted to quantify the incidence of variability.

For each source we estimated the number of individual peaks that showed variability in our observations, and the total number of distinguishable peaks suitable for a variability investigation. The number of variable peaks is necessarily a lower limit in view of (1) our limited number of observations, (2) the signal-to-noise ratio limitation, and (3) the calibration uncertainty, which allows us to recognize with confidence only relative variations (whole source variations are significant only if larger than about 10 per cent).

We have also summarized the variability with a single index, 'v', 'sv' or 'nv', in column 9 to indicate: 'nv' (not variable), 'sv' (slightly variable, with variations generally less than about 10 per cent), and 'v' (variable with more than 10 per cent change in at least one feature). Overall, we find that the fraction of features classified as 'v' or 'sv' is 0.28. This is the same as the fraction found for 6.6-GHz features in C+95a.

The large percentage variation found in only a few features suggests that, in these, the maser gain may be exponentially rather than linearly dependent on path length – usually, but not always (Reid & Moran 1988), argued to be the signature of unsaturated masers. A detailed investigation of a subset of the sources discovered here is given by C+95b. They conclude that the variations can best be described as quasi-periodic, on a time-scale of, typically, 1 yr, and could be satisfactorily accounted for by path-length changes in the maser-emitting region. This explanation is similar to that proposed for H_2O masers in an extensive study by Peng (1989a,b).

Are there velocity changes? As was the case for 6.6-GHz masers (C+95a), we have seen no obvious changes in which features retain the same appearance but shift in velocity. However, we do occasionally see changes of shape, but these can be accounted for by changes in the *intensity* of blended features, with no need to invoke velocity shifts.

5.4 Saturation of the masers

In an earlier study of 12-GHz methanol masers (C+93), it was suggested that the significant linear polarization found in many strong sources was evidence for the masers being saturated, that is, they are limited in their output by the maser pump. Certainly, it is likely that the brightest features are saturated, and this is supported by our statistic that the second brightest feature is usually within a factor of 2 of the brightest (Section 5.2.2) and thus that the range of gain is not enormous, as it might be if it were exponentially dependent on path length (as is expected for the unsaturated case).

On the other hand, the occurrence of strong variability in some features is an indication that these variable features, at least, might be unsaturated. These conclusions are not necessarily in conflict; although we concentrated our attention on the most variable features in Section 5.3, this should be put into perspective by noting that three-quarters of the features have not shown significant variations in our monitoring period, and thus the highly variable features are the exception rather than the rule.

In a study of the most variable masers at 6.6 and 12 GHz, C+95b noted that features that are variable at both 6.6 and 12 GHz are almost always more variable at 12 GHz, perhaps indicating that the 12-GHz masers are less saturated and hence more heavily affected by path-length changes. Highly variable features at 6.6 GHz often have no 12-GHz counterpart, which perhaps indicates that the masing region in these features is less saturated and less likely to support a 12-GHz maser.

5.5 Absorption at 12 GHz

Absorption is evident in 19 of the spectra that we show in Figs 2–14. In most cases, the absorption is close to the maser emission velocity and is likely to arise from a molecular cloud more extensive than the masing region but closely associated with it. Individual examples of absorption are discussed in the notes, and include Sgr B2 discussed by Whiteoak et al. (1988), the 11 sources, 291.28 − 0.71, 316.81 − 0.06, 322.16 + 0.64, 327.29 − 0.58, 328.24 − 0.55, 333.07 − 0.45, 353.41 − 0.36, 10.62 − 0.38, 34.26 + 0.15, 43.17 + 0.01 and 49.49 − 0.37, listed by Peng & Whiteoak (1992), plus the eight additional sources, 318.05 + 0.08, 329.41 − 0.46, 344.23 − 0.57, 350.10 + 0.09, 351.77 − 0.54, 11.94 − 0.62, 30.82 − 0.05 and 31.41 + 0.31. Of the above 20 sources, Srg B2 (see Houghton & Whiteoak 1995), 291.28 − 0.71, 327.29 − 0.58 and 10.62 − 0.38 also show absorption at 6.6 GHz. The 12-GHz absorption is usually as strong or stronger than the absorption seen at 6.6 GHz; this is not merely the effect of 6.6-GHz absorption being masked by the generally stronger emission and is discussed in more detail by Houghton & Whiteoak (1995). We also detected 12-GHz absorption, but with no obvious accompanying maser, towards 321.71 + 1.17, 330.88 − 0.37, 351.16 + 0.70, 19.61 − 0.23 and 30.70 − 0.07; of these, Peng & Whiteoak (1992) cite only 351.16 + 0.70 amongst their total of 38 detections. We refer to Peng & Whiteoak for a more complete discussion of 12-GHz absorption.

The occurrence of readily detectable absorption at both 6.6 and 12 GHz supports the common assumption (e.g. Cragg et al. 1992) that the A and E symmetry species of methanol are well mixed and comparably populated. Given this fact, and the analysis of maser-pumping models by Cragg et al. who suggest that any pumping scheme will support both 12- and 6.6-GHz masers simultaneously, the initial surprise that was expressed at their frequently being found to be coincident now seems unwarranted.

6 CONCLUSIONS

The present results represent a comprehensive search for 12-GHz methanol from a large sample of 6.6-GHz methanol masers. Detections were made at more than half of the sites and the properties of many individual masers have been discussed. The coincidence in velocity of individual spectral features in the two transitions is common. We conjecture that they are mostly spatially coincident as well, and high-resolution interferometry is needed to ascertain whether this is so. Variability appears to be equally common on the two transitions, but individual features that vary on both transitions are more variable at 12 GHz. It is likely that most quiescent masers on both transitions are saturated, that some of the more highly variable ones may be less saturated, and that the variable 12-GHz masers are even less saturated than the 6.6-GHz masers.

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