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New H_2O Masers associated with Main-line OH Masers in the Galactic Longitude Range 3° to 60°

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Abstract

A search in the direction of OH masers emitting at 1665 or 1667 MHz has yielded 11 new H_2O masers. The new sources are discussed individually. The overall statistics of the search show that out of a total of 55 OH masers in the 3° to 60° galactic longitude range at least 36 have H_2O maser counterparts.

1. Introduction

Caswell and Haynes (1983, present issue p. 419) recently made a compilation of all known OH masers that emit predominantly on the main-line transitions (1665 or 1667 MHz) of the ground state and are located in the galactic plane between longitude 3° and 60°. In April 1982 we conducted a search for associated H_2O maser emission in the direction of those OH sources which are either new or now have greatly improved position estimates (Caswell and Haynes 1983). We used the Parkes 64 m radio telescope equipped with a new 22 GHz maser receiver and a 1024-channel correlator. The correlator was configured to give a total coverage of 24 MHz (320 $km\,s^{-1}$) with a resolution of 40 kHz (0·53 $km\,s^{-1}$) near the centre of the spectrum and 48 kHz near the edges. Five-minute integrations were used and our sensitivity (at the 3σ detection level) was between 1 and 2 Jy (1 Jy $\equiv 10^{-26}\,W\,m^{-2}\,Hz^{-1}$) depending on weather conditions and telescope elevation angle. The OH maser r.m.s. position uncertainties are typically 20″ arc and a search was made only at the nominal positions. Our beam size at 22 GHz is 100″ arc. When an H_2O maser was detected we measured its position from a grid of observations to give an r.m.s. uncertainty of ~12″ arc in each coordinate. Further details of the equipment and observing procedure are given in Caswell *et al.* (1983, present issue p. 401), which describes a similar H_2O search in another region.

2. Results

Table 1 lists the newly discovered H_2O masers and Fig. 1 shows the spectra of most of the sources. The sources are discussed individually below. Note that where several H_2O maser features lie close together, the uncertainty in their relative positions is only a few seconds of arc, nearly an order of magnitude better than the absolute position; in contrast, the relative positions of H_2O and OH masers have r.m.s.

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uncertainties of ~30″ arc and thus nominal separations of this amount are to be interpreted as coincidences within the errors. Remarks on nearby HII regions generally refer to maps at 5 GHz in the galactic plane surveys of Altenhoff *et al.* (1978) and Haynes *et al.* (1978), supplemented by hydrogen recombination-line data from Downes *et al.* (1980).

Table 1. H_2O maser measurements, 1982 April

H_2O maser (*l*, *b*)	Position (1950)[A] R.A. h m s	Dec. ° ′ ″	Radial velocity[B] ($km s^{-1}$)	Velocity width[B] ($km s^{-1}$)	Peak intensity (Jy)
H_2O 3·91−0·01	17 51 35·6	−25 34 19	+8	2	2
H_2O 8·68−0·36	18 03 21·5	−21 37 40	+37	See Fig. 1	101
H_2O 11·90−0·14	18 09 15·2	−18 42 25	+40	1	7·9
H_2O 16·58−0·05	18 18 17·7	−14 33 19	+63	See Fig. 1	32
H_2O 16·61−0·05	18 18 21·3	−14 32 11	+46	2	4·4
H_2O 23·01−0·41	18 31 56·2	−09 03 04	+80	See Fig. 1	89
H_2O 23·44−0·18	18 31 55·6	−08 33 54	+101	See Fig. 1	19
H_2O 31·25−0·11	18 46 10·5	−01 36 32	+17	See Fig. 1	280
H_2O 32·75−0·08	18 48 48·3	−00 15 36	+33	See Fig. 1	96
H_2O 35·03+0·35	18 51 29·5	+01 57 43	+67	See Fig. 1	63
H_2O 45·46+0·05	19 12 02·6	+11 04 23	+58	See Fig. 1	11·5
H_2O 45·44+0·07	19 11 56·8	+11 03 33	+56	See Fig. 1	9·2

[A] The r.m.s. uncertainty is ~12″ arc, with the exception of H_2O 3·91−0·01 (r.m.s. error of ~30″ arc) and H_2O 45·44+0·07 (r.m.s. error of 10″ arc; position from Genzel and Downes 1977).
[B] The centre velocity and width of the strongest feature.

H_2O 3·91−0·01

The corresponding OH maser (OH 3·91−0·01) is readily detectable and has an r.m.s. position error of 18″ arc. The H_2O maser is weak and near the limit of our sensitivity and has a correspondingly larger position uncertainty of 30″ arc. In the direction of the masers there is no distinct peak in the 5 GHz radio continuum emission (Altenhoff *et al.* 1978). No reliable kinematic distance estimate can be made because the velocity is near zero and the source lies close to the direction of the galactic centre.

H_2O 8·68−0·36

An OH maser is at R.A. $18^h 03^m 24^s·1$, Dec. −21° 37′ 34″ (1950), with r.m.s. position uncertainty of ~20″ arc; the H_2O maser is quite strong and its position uncertainty is 12″ arc. The total positional discrepancy between the two masers is 37″ arc and is compatible with the true positions being coincident. Genzel and Downes (1979) reported a maser H_2O 8·67−0·36 at R.A. $18^h 03^m 18^s·6$, Dec. −21° 37′ 59″, with r.m.s. error of 5″ arc, which is separated by 44″ arc from our H_2O position and nearly 80″ arc from the nominal OH position. If the errors are realistic it appears to be a different source from the one which we have detected. Our spectrum of H_2O 8·68−0·36 taken 1982 April shows a peak approximately twice as strong as the Genzel and Downes (1979) maser (as measured in 1977 November) and no similarity in detailed velocity structure. At the Genzel and Downes position

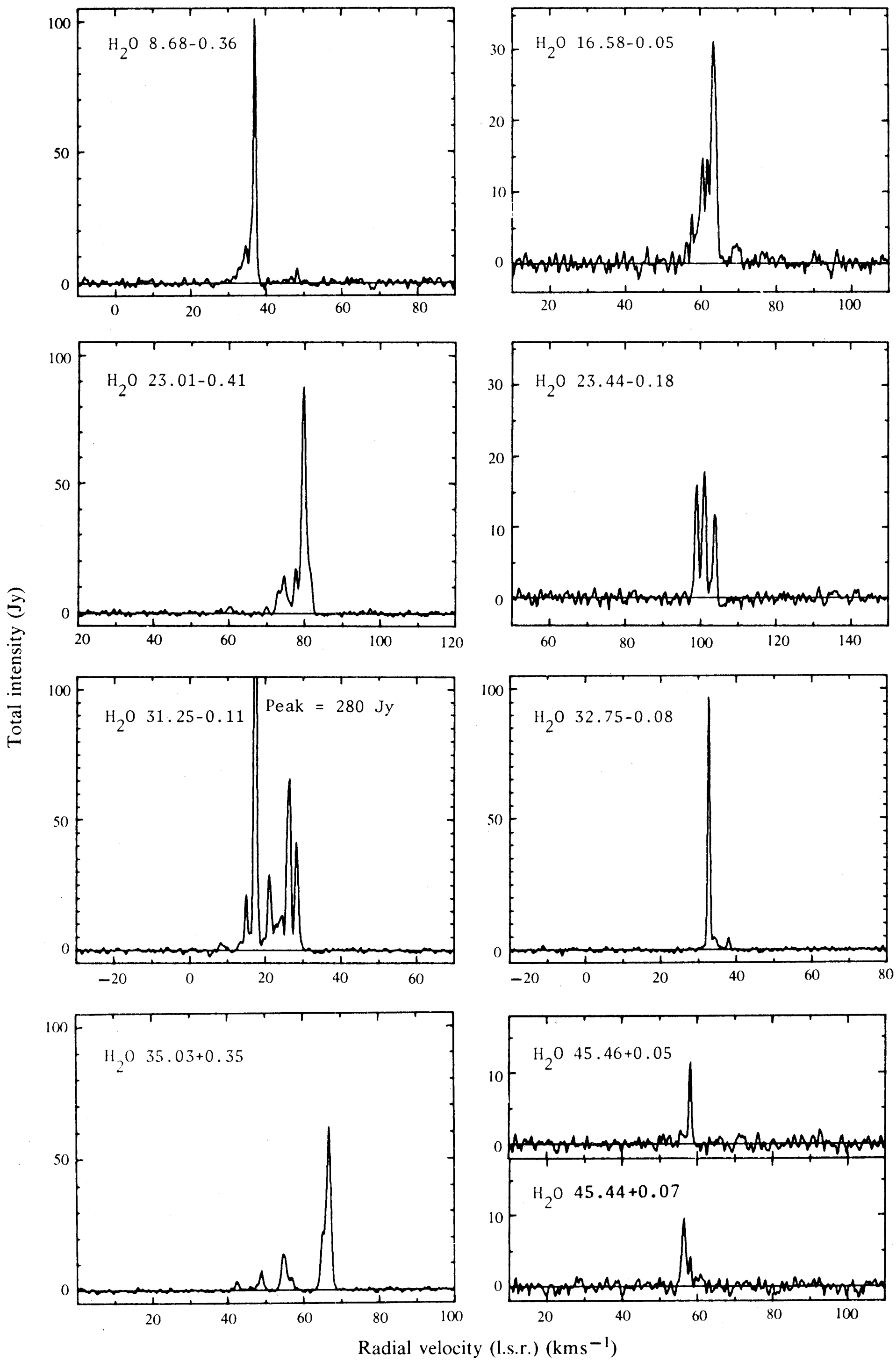

Fig. 1. Spectra of H_2O masers. The source names are shown within each frame and the observations were made in the period 1982 April 7–10. The velocity resolution is 0·53 km s^{-1} (40 kHz). The velocity coverage of each spectrum was 320 km s^{-1} but the outer regions where no emission was found are not shown.

in 1982 April we could detect only the source H_2O 8·68−0·36, with the intensity reduced by the amount expected from the offset relative to the beam centre. A weak HII region, G8·666−0·351, is located at R.A. $18^h 03^m 17^s \cdot 2$, Dec. $-21° 37' 55''$, and is likely to be associated with the masers.

H_2O 11·90−0·14

Nominal positions of the H_2O and OH masers differ by a total of 41″ arc, compatible with coincidence. The 5 GHz continuum map of Altenhoff *et al.* (1978) shows an HII region, G 11·944−0·037, with its peak position displaced 7′ arc from the masers but with a similar velocity of $+41 \cdot 5 \text{ km s}^{-1}$ (Downes *et al.* 1980). Any compact HII region precisely coinciding with the maser must be weaker than ~0·1 Jy at 5 GHz. Note that the nearby continuum source, G 12·0−0·1, is non-thermal and believed to be a supernova remnant (Clark *et al.* 1975).

H_2O 16·58−0·05 and H_2O 16·61−0·05

These two sources are separated from each other by $86'' \pm 5''$ arc and are also separated significantly in velocity. The nearby OH maser, OH 16·59−0·06, is at R.A. $18^h 18^m 20^s \cdot 3$, Dec. $-14° 33' 18''$, a nominal separation of 38″ arc from H_2O 16·58−0·05 but compatible with a precise coincidence in view of the position uncertainties. By contrast, the weaker H_2O maser, H_2O 16·61−0·05, is significantly displaced from the OH maser (by 68″ arc) and its velocity is also offset from that of the OH maser; H_2O 16·61−0·05 has, in addition to the feature at $V = +46 \text{ km s}^{-1}$ (see Table 1), a slightly weaker feature of 2·9 Jy at $V = +50 \cdot 5 \text{ km s}^{-1}$, with width of 1 km s^{-1}. Continuum emission in the vicinity of the masers is weak, being ~0·1 Jy at 5 GHz (Altenhoff *et al.* 1978).

H_2O 23·01−0·41

The maser OH 23·01−0·41 is in good positional agreement with the H_2O maser (nominal separation 16″ arc). In the direction of the masers there is diffuse emission from an HII region with a recombination-line velocity of $+78 \text{ km s}^{-1}$ (near that of the masers), but no compact HII component has been detected.

H_2O 23·44−0·18

The position of the maser OH 23·43−0·19 agrees well with that of the H_2O maser (nominal separation 23″ arc). A nearby strong HII region, G 23·421−0·214, has a velocity of $+101 \text{ km s}^{-1}$, similar to that of the two masers, and is clearly associated with them. The velocity indicates a distance of nearly 10 kpc with no ambiguity, and the HII region, which is extended, may be comprised of several components not resolved with a beam size of several minutes of arc.

H_2O 31·25−0·11

The maser OH 31·24−0·11 essentially coincides with the H_2O maser (nominal separation 9″ arc). The mean velocity of both the OH and H_2O masers is $\sim 22 \text{ km s}^{-1}$, leading to a kinematic distance estimate of either 1·6 or 15·5 kpc. The maser H_2O 31·25−0·11 has the largest received flux density of the sources reported here, and if it were at the far distance its luminosity would be an order of magnitude greater than the median of all sources observed to date (Genzel and Downes 1977); however, if it were at the near distance it would be one of the lowest luminosity sources amongst those with complex spectra. On balance, we slightly favour the far distance estimate of 15·5 kpc. Outlying portions of the extensive HII region W 43 lie in the same general direction as the masers but we assume W 43 to be unrelated on account of its grossly different velocity, with components present near 50 and 100 $km\,s^{-1}$. The W 43 continuum emission hampers the detection of any weak HII region which might be related to the masers.

H_2O 32·75−0·08

The nominal separation of H_2O 32·75−0·08 from OH 32·74−0·07 is 35″ arc, not significantly greater than the uncertainty. The major continuum emission in this direction is from a supernova remnant, according to Caswell *et al.* (1975), at a distance estimated to be ~8 kpc from the surface-brightness/linear-diameter relationship of Caswell and Lerche (1979). The kinematic distance to the masers is either 2·5 or 14·3 kpc and the masers seem unlikely to be related to the supernova remnant. Any compact HII region in the direction of the masers appears to be weaker than ~0·1 Jy at 5 GHz.

H_2O 35·03+0·35

This H_2O maser is in good positional agreement with OH 35·03+0·35 (nominal separation 18″ arc). A compact continuum source, G 35·027+0·332, coincides to better than 1′ arc and seems likely to be a compact HII region associated with the masers; unfortunately, since the source is quite weak, 0·4 Jy at 5 GHz, a recombination-line measurement has not been obtained. The velocity structure of the masers is quite extensive, with the strongest H_2O feature at $V = +67\ km\,s^{-1}$ and the OH emission extending from 40 to 50 $km\,s^{-1}$. We adopt +50 $km\,s^{-1}$ as our (rather uncertain) estimate of the systemic velocity; this is at one extremity of the OH emission and near the mid-range of the H_2O emission. The corresponding kinematic distance is either 3·4 or 12·9 kpc.

H_2O 45·46+0·05 and H_2O 45·44+0·07

Spectra for both sources are shown in Fig. 1. The first source is a newly discovered H_2O maser displaying a single narrow feature at +58 $km\,s^{-1}$; its position agrees well (nominal separation 27″ arc) with the maser OH 45·47+0·05. The second source, H_2O 45·44+0·07, was reported (as 45·44+0·1) by Genzel and Downes (1977) and is 100″ arc from H_2O 45·46+0·05; it can also be seen from our Fig. 1 that the peak intensity is at +56 $km\,s^{-1}$, significantly displaced (by 2 $km\,s^{-1}$) from the velocity peak of H_2O 45·46+0·05. It is also worth noting, in order to minimize confusion between these sources in the future, that when Genzel and Downes measured their 1977 spectrum for H_2O 45·44+0·07 the peak was at +58 $km\,s^{-1}$ (whereas it is now at +56 $km\,s^{-1}$), which is the velocity at which we now find the peak of the other source H_2O 45·46+0·05. A weak continuum 'point' source, G 45·47+0·05, has been measured by Habing *et al.* (1974) with flux density at 5 GHz of 92 mJy; it coincides with the OH maser and is believed to be a compact HII region situated amongst more extended HII regions with larger flux densities.

Table 2. H_2O masers associated with main-line OH masers between longitudes 3° and 60°

OH maser *l* *b*		OH maser Position (1950) R.A.	OH maser Position (1950) Dec.	H_2O maser[A] *l* *b*		H_2O maser[A] Position (1950) R.A.	H_2O maser[A] Position (1950) Dec.	Peak intensity	References
°	°	h m s	° ′ ″	°	°	h m s	° ′ ″	(Jy)	
3·91	−0·01	17 51 35·6	−25 34 19	3·91	−0·01	17 51 35·6	−25 34 19	2	This paper
5·88	−0·39	17 57 26·7	−24 04 01	5·89	−0·40	17 57 28·7	−24 03 53	200	Batchelor *et al.* (1980)[B]
8·68	−0·37	18 03 24·1	−21 37 34	8·68	−0·36	18 03 21·4	−21 37 39	101	This paper
9·62	+0·19	18 03 17·6	−20 31 54	9·62	+0·19	18 03 16·0	−20 32 01	90	Genzel and Downes (1979)
10·62	−0·38	18 07 30·4	−19 56 28	10·62	−0·38	18 07 30·3	−19 56 38	490	Genzel and Downes (1977)[B]
11·03	+0·06	18 06 43·3	−19 22 01	11·03	+0·06	18 06 42·2	−19 21 56	27	Genzel and Downes (1979)
11·91	−0·15	18 09 18·1	−18 42 25	11·90	−0·14	18 09 15·2	−18 42 25	7·9	This paper
12·03	−0·04	18 09 07·4	−18 32 39	—		—	—	<2·4	
12·22	−0·12	18 09 48·4	−18 25 13	12·21	−0·12	18 09 48·6	−18 25 17	85	Batchelor *et al.* (1980)[B]
12·68	−0·18	18 10 59·6	−18 02 47	12·68	−0·18	18 10 58·9	−18 02 39	270	Johnston *et al.* (1973)
12·91	−0·26	18 11 44·3	−17 52 57	12·91	−0·26	18 11 44·0	−17 53 09	10	Genzel and Downes (1977)
14·17	−0·06	18 13 32·3	−16 40 53	14·17	−0·06	18 13 32·9	−16 40 43	15	Batchelor *et al.* (1980)
15·04	−0·68	18 17 31·9	−16 12 51	15·04	−0·67	18 17 31·1	−16 12 51	30	Batchelor *et al.* (1980)[B]
16·59	−0·06	18 18 20·3	−14 33 18	16·58	−0·05	18 18 17·7	−14 33 19	32	This paper
18·46	−0·01	18 21 48·0	−12 53 02	—		—	—	<3	
19·48	+0·16	18 23 10·3	−11 54 31	—		—	—	<20	
19·61	−0·23	18 24 49·9	−11 58 31	19·61	−0·23	18 24 50·1	−11 58 22	60	Batchelor *et al.* (1980)[B]
20·08	−0·13	18 25 22·7	−11 30 47	—		—	—	<20	
20·24	+0·08	18 24 55·8	−11 16 24	—		—	—	<3	
20·86	+0·48	18 24 39·8	−10 32 18	—		—	—	<20	
22·44	−0·18	18 30 01·0	−09 27 00	—		—	—	<3	
23·01	−0·41	18 31 56·7	−09 03 18	23·01	−0·41	18 31 56·2	−09 03 04	89	This paper
23·43	−0·19	18 31 55·8	−08 34 17	23·44	−0·18	18 31 55·6	−08 33 54	19	This paper
24·33	+0·11	18 32 32·3	−07 38 24	—		—	—	<20	
24·78	+0·08	18 33 30·6	−07 15 07	24·79	+0·08	18 33 30·3	−07 14 42	130	Batchelor *et al.* (1980)[B]

27·35−0·20	18 39 16·0	−05 06 35	—	—	—	<2·5	
28·21−0·05	18 40 21·6	−04 16 26	—	—	—	<20	
28·83−0·25	18 42 12·4	−03 49 08	—	—	—	<2·5	
28·87+0·06	18 41 10·2	−03 38 36	28·86+0·07	18 41 07·9	−03 38 41	150	Genzel and Downes (1979)
30·22−0·15	18 44 24·0	−02 32 00	—	—	—	<2·5	
30·39−0·70	18 46 42·0	−02 38 14	—	—	—	<20	
30·60−0·06	18 44 45·0	−02 09 15	?	—	—		
30·70−0·06	18 44 58·9	−02 04 27	?	—	—		
30·79−0·06	18 45 08·8	−01 59 12	?	—	—		
30·82+0·28	18 44 00·5	−01 48 29	—	—	—	<3	
31·21−0·18	18 46 20·9	−01 40 13	31·21−0·18	18 46 20·7	−01 40 10	15	Batchelor *et al.* (1980)[B]
31·24−0·11	18 46 10·4	−01 36 41	31·25−0·11	18 46 10·5	−01 36 32	280	This paper
31·29+0·06	18 45 38·6	−01 29 26	31·29+0·07	18 45 36·8	−01 29 12	120	Genzel and Downes (1979)
32·74−0·07	18 48 46·0	−00 15 28	32·75−0·08	18 48 48·3	−00 15 36	96	This paper
33·13−0·09	18 49 33·6	+00 04 25	33·13−0·09	18 49 34	+00 04 30	23	Genzel and Downes (1977)
34·26+0·15	18 50 46·1	+01 11 12	34·25+0·16	18 50 46·4	+01 11 10	400	Batchelor *et al.* (1980)[B]
35·03+0·35	18 51 30·3	+01 57 30	35·03+0·35	18 51 29·5	+01 57 43	63	This paper
35·19−0·74	18 55 40·0	+01 36 22	35·20−0·74	18 55 40·8	+01 36 30	65	Batchelor *et al.* (1980)
35·20−1·73	18 59 12·5	+01 09 16	35·23−1·79	18 59 12·8	+01 09 13	30	Genzel and Downes (1977)[B]
35·58−0·03	18 53 51·7	+02 16 31	35·58−0·03	18 52 51·1	+02 16 27	120	Genzel and Downes (1977)[B]
40·62−0·14	19 03 34·9	+06 41 55	40·62−0·14	19 03 34·9	+06 41 55	27	Evans *et al.* (1979)
43·16−0·03	19 07 58·2	+08 59 58	43·16−0·03	19 07 58·2	+09 00 03	550	Genzel and Downes (1977)[B]
43·17+0·01	19 07 49·9	+09 01 18	43·17+0·01	19 07 49·8	+09 01 17	10000	Genzel and Downes (1977)[B]
43·80−0·13	19 09 30·8	+09 30 47	43·80−0·12	19 09 31·2	+09 30 51	330	Genzel and Downes (1977); Batchelor *et al.* (1980)
45·07+0·13	19 11 00·4	+10 45 44	45·10+0·12	19 11 00·3	+10 45 42	30	Genzel and Downes (1977)[B]
45·10+0·12	19 11 06	+10 46 48	?	—	—		
45·47+0·13	19 11 46·1	+11 07 06	45·47+0·13	19 11 46	+11 07 03	1	Genzel and Downes (1977)
45·47+0·05	19 12 04·4	+11 04 15	45·46+0·05	19 12 02·6	+11 04 23	11·5	This paper
48·61+0·02	19 18 13·0	+13 49 46	48·61+0·02	19 18 13·1	+13 49 44	35	Genzel and Downes (1977)[B]
49·49−0·39	19 21 26·3	+14 24 37	49·49−0·39	19 21 26·2	+14 24 44	3000	Genzel and Downes (1977)[B]

[A] In four cases (indicated by a ?) we are not aware of a sensitive H_2O search at the OH position.
[B] Other observations of the source are available in the literature, mostly cited in the reference given.

3. Statistics of OH/H_2O Maser Associations

In Table 2 we list the OH main-line masers in the galactic longitude range 3° to 60° (for more details see Caswell and Haynes 1983) and the corresponding H_2O data. This embodies the H_2O detections of Table 1 and some upper limits (of <3 Jy) obtained in the present series of observations. For some of the sources we list previously unpublished null results from our earlier observations with a less sensitive receiver (Batchelor *et al.* 1980), the upper limits being typically 20 Jy if we take into account possible pointing errors.

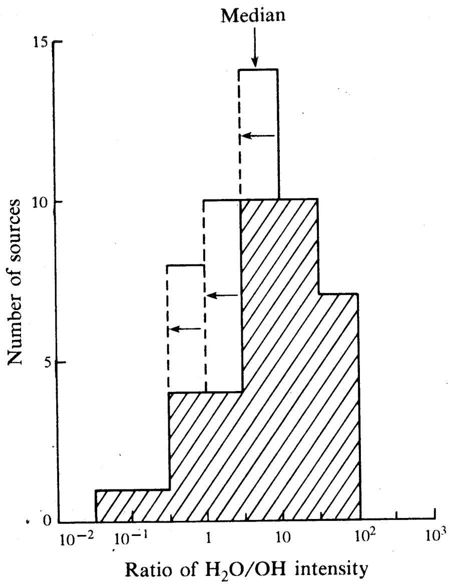

Fig. 2. Distribution of the ratio of peak H_2O flux density to peak flux density of the associated OH maser. The hatched area corresponds to detected H_2O counterparts, and the unhatched area to H_2O upper limits.

Overall, H_2O detections have been made at 36 of the 55 (65%) maser sites; this high success rate is much better than that achieved when searching at the sites of HII regions and slightly better than when searching at the sites of far-infrared sources; thus Jaffe *et al.* (1981) cite a detection rate of about 12% at the positions of HII regions and 60% at the position of far-infrared sources. Caswell *et al.* (1983) achieved an even higher success rate at the positions of OH masers in the longitude range 340° to the galactic centre, where 38 out of 46 (80%) OH masers had H_2O counterparts. Following Caswell *et al.* (1983) we show a histogram (Fig. 2) of the distribution of the ratio of H_2O to OH intensity (using the peak flux density as the intensity measure). The median value is ~3 and the histogram is essentially identical to that for the longitude range 340° to the galactic centre, when we allow for the fact that some of the upper limits available for the present sample are rather cruder than those obtained in our other survey. When we look at the distribution of upper limits we see that an H_2O maser somewhat below our detection limit would still be well within the distribution defined by detected masers. Thus the histogram gives strong support for an intrinsic near one-to-one correspondence of H_2O masers with OH masers.

Most of the OH/H_2O maser pairs of Table 2 have positions coincident to within the uncertainty of typically 30″ arc; higher precision measurements are needed to discover whether on a much smaller scale there are significant displacements of perhaps several seconds of arc, such as occur in a few well-investigated pairs (Forster *et al.* 1978; Norris *et al.* 1982). If such displacements turn out to be common, then, as we suggested elsewhere (Caswell *et al.* 1983), this might be accounted for if in the process of star formation a dense molecular cloud fragments into two major portions, one forming a new star with a compact HII region and OH maser, and the other (not necessarily undergoing transformation to a star) becoming the site of the H_2O emission.

The ratio of H_2O to OH intensity may prove to be a useful parameter for investigating the evolution of the masing regions. The ratio may change systematically with age, with the onset of H_2O emission perhaps preceding that of the OH emission or possibly lasting for a longer period. Certainly our high detection rate of H_2O counterparts suggests that the *OH maser phase* does *not* last (much) longer than the H_2O maser phase. It may prove possible to use as a measure of age either the diameter of an associated compact HII region or even the separation of the OH and H_2O masers if these turn out to be in relative motion.

Finally we note that there is an urgent need for extensive unbiased surveys of H_2O masers, to be followed by searches for OH masers, compact HII regions and IR counterparts. The data of this type already available, although meagre (e.g. Caswell *et al.* 1977; Caswell *et al.* 1983), suggest that H_2O masers may be more prevalent than OH masers. The conditions required for the H_2O masers may be less stringent than those required for OH masers, and some support for this is given by the high-velocity ejecta which show H_2O maser emission but no OH emission. Thus, while it is generally accepted that the OH masers mark the sites of recently formed stars, the H_2O masers may merely mark the sites of compact molecular clouds which are not necessarily undergoing star formation—perhaps they are less massive. Jaffe *et al.* (1981) in their discovery of new H_2O masers associated with far-infrared sources were unable to reach a firm conclusion on the nature of the sources, and the issue is an important one requiring further investigation.

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