TIME VARIATIONS OF INTERSTELLAR WATER MASERS IN HII REGIONS

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1. Introduction

Previous studies of time variations in water vapour sources associated with HII regions by Sullivan (1971, 1973) and Gammon (1976) have revealed variability on time-scales of 10^6-10^7s. Sullivan monitored nine sources over a period of 14 months and Gammon observed W49 (H_2O) for 13 months. In an attempt to gather more complete information on the variability of interstellar water masers we have monitored 18 sources for the 32-month period 1974 September-1977 May. The sources selected are listed in Table 1. They were the strongest known at the beginning of the programme above declination -20^o.

Table 1. The 18 H_2O maser sources monitored in the period 1974 September - 1977 May.

SOURCE	RIGHT ASCENSION (1950)			DECLINATION (1950)			DISTANCE (kpc)	MAXIMUM FLUX (Jy) 1969-70	MAXIMUM FLUX (Jy) 1974-77	VELOCITY RANGE OBSERVED (km s^{-1})	VELOCITY WIDTH (km s^{-1})	NO. OF COMPONENTS 1974-77
	h	m	n	o	'	"						
W3	02	21	53	61	52	22	3	3000	1560	-48 to -25	11	> 7
W3OH	02	23	17	61	38	57	2.5	10000	8000	-56 to -46	15	blended
NGC 1333	03	25	59	31	06	05	0.5		160	-40 to 0	3	2
ORION A	05	32	47	-05	24	08	0.5	15000	35000	-10 to +30	37	>10
S255	06	09	58	18	00	02	1 - 3		780	-10 to +40	7	2
S269	06	11	47	13	50	24	2		200	0 to +40	1	1
W31	18	07	34	-19	5	3	6		1420	-10 to +10	6	4
W33	18	10	54	-18	03	12	4.5		235	+48 to +68	1	1
M17	18	17	29	-16	13	42	2.5	3200	150	-17 to +27	1	1
W49N	19	07	50	9	01	15	14	80000	40000	-220 to +160	380	many
W51M	19	21	26	14	24	41	8	4000	12000	0 to +160	160	many
ON1	20	08	10	31	22	39	6	500	515	-10 to +30	9	4
ON2	20	19	51	37	16	24	5.5		400	-21 to +23	20	> 5
CRL 2591	20	27	36	40	01	11	>2		580	-40 to 0	17	5
W75S	20	37	15	42	12	00	3	5000	655	-20 to +20	9	4
S140	22	17	42	63	03	45	-		530	-20 to +20	26	3
S152	22	55	38	58	33	02	3.2		55	-61 to -42	1	1
NGC 7538	23	11	36	61	10	20	3.5		540	-65 to -45	10	3

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2. Long-term variability of individual sources

The present data can be compared with that obtained by Sullivan (1971, 1973) during 1969-70 for the sources W3, W3(OH), Orion A, W49N, W51M, ON1 and W75S. The integrated flux from the averaged spectra over these two periods is given in Table 2 together with the ratio of integrated flux between the two periods for each source.

Table 2. A comparison of the average integrated flux of W3, W3(OH), Orion A, W49N, W51M, ON1 and W75S during 1975-76 with Sullivan's data of 1969-70.

Source	Velocity range (km/s)	Integrated flux 1969–70 (Jy km/s)	Integrated flux 1975–76 (Jy km/s)	Ratio of integrated flux (1975–76) : (1969–70)
W3	$-45 \rightarrow -30$	2.5×10^3	1.2×10^3	0.48
W3(OH)	$-9 \rightarrow -45$	1.2×10^4	1.2×10^4	1.0
Orion A	$-9 \rightarrow 20$	6.1×10^4	8.1×10^4	1.33
W49N	$-15 \rightarrow 30$	2.3×10^5	1.3×10^5	0.57
W51M	$52 \rightarrow 72$	1.5×10^4	3.5×10^4	2.33
ON1	$2 \rightarrow 22$	1.1×10^3	1.1×10^3	1.0
W75S	$-6.5 \rightarrow 6.5$	1.3×10^3	4.7×10^2	0.36

It is apparent from Table 2 that significant long-term variations are found in W3, W49N, W51M and W75S and that while some sources have decreased (W3, W49N, W75S) others have increased (Orion A, W51M) in integrated flux.

Long-term variations imply that the source of excitation is common to many maser components. Little et al. (1977) have discussed the implications of these variations for models of W51M and W49N. They conclude that the flux of radiation from the common exciting object must vary on a time-scale of ~10 or <100 years, depending on whether the masers are saturated or unsaturated. Recent VLBI observations (Genzel et al. 1978) have shown that at least 10 separate centres of activity exist in W49N. If each of these centres indicates the site of a young stellar object responsible for pumping the nearby maser components, it is surprising that systematic long-term variability should be detected. However, it appears from the present data that only the low-velocity components have varied significantly. Inspection of the VLBI map of Genzel et al. (1978) shows that most of the integrated low-velocity flux in W49N is emitted by four of the 10 centres of activity. It is therefore plausible that the observed long-term variations are due to changes in one or more of these centres of activity.

This conclusion is strongly supported by the recent detection of correlated short-term variability in the maser components associated with one of these centres (White, 1979). This striking result is illustrated in Figure 1 which shows the time variations during the period 1975 January-1976 October for the six velocity components found to be spatially associated in a VLBI map made from observations in 1976 March (Walker et al., 1977). All six components showed significant increases at this time with one, at -45 km s^{-1} velocity, becoming the second most intense component in the W49 spectrum by 1976 October.

VLBI maps of W51M (Genzel et al., 1978; Walker et al., 1977) show that in this source most of the emission arises from a single centre of activity. Changes in the pump rate of the central object would readily account for the long-term variations observed.

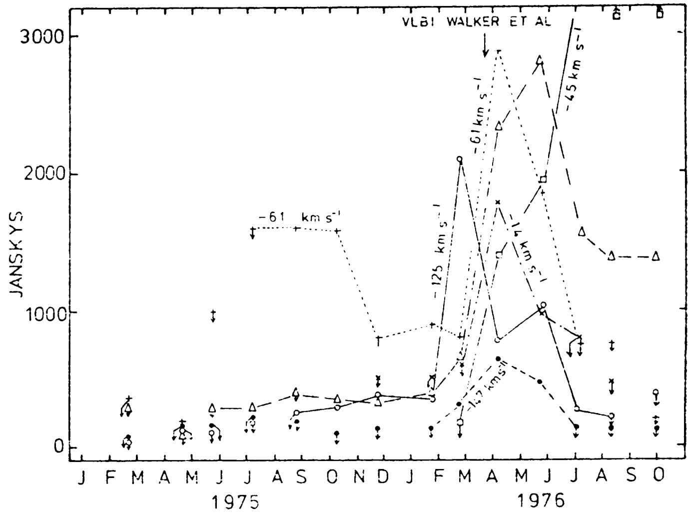

Figure 1. Intensity variations in those velocity components spatially associated with one centre of activity in W49.

3. Short-term variability in the whole sample

A statistical analysis of the short-term variability in the whole sample was made by computing the percentage change in certain selected velocity components between consecutive observations, which were 46 ± 4 days apart. Strict selection criteria were applied in choosing velocity components for this analysis to avoid the effects of blending, particularly in low-velocity components. Histograms showing the percentage variations over the interval 46 ± 4 days for the velocity components selected are given in Figure 2.

It can be seen that large flux variations (>100%) over the ~46-day interval are found in sources other than W49N although the largest variations are found in this source which showed changes >100% in ~25% of samples.

The largest short-term flux variation observed was in the -19 km s^{-1} component in NGC 1333 which decreased by a factor of 2.5 over 3 days.

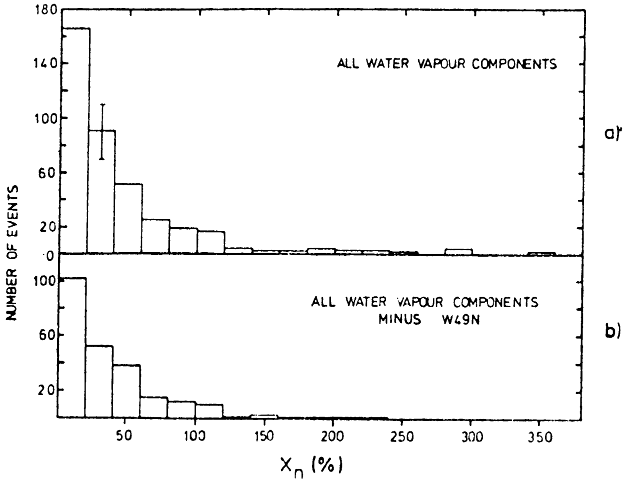

Figure 2. a) Histogram showing the short-term variability in all water maser components in the present sample.
b) As a) but without data on W49N.

4. Related variability in features of similar velocity

Genzel and Downes (1977) have noted related variability in pairs of low-velocity components in several sources (W51M, W75N, W75S(3), 10.5 + 0.0) which from their double-peaked spectra they believe to be shell sources. They interpret this behaviour in terms of a saturated travelling-wave maser with several modes and suggest the term "mode switching" for the phenomenon.

We have observed this effect in two sources. The -84 and -82 km s^{-1} high-velocity features in W49N peaked within six weeks of each other and the -4.6 and -5.7 km s^{-1} components in W75S interchanged intensity between 1975 November and 1976 February.

These results may be interpreted by the mechanism proposed by Genzel and Downes (1977) in terms of the kinematics of circumstellar shells. Alternatively, if the pump radiation is beamed and the direction of this beam varies, possibly due to movement of an obscuring dust cloud between the pump source and the masing regions, then different clouds of water vapour may be successively excited.

5. Interpretation

The time-dependent equations of radiative transfer for a masing region longer than it is wide have been solved recently by Salem and Middleton (1978). They find that there is no inherent feature in these non-linear equations which leads to variations in the output of the maser, provided that physical conditions such as the number density and pump rate remain constant. It follows that the observed time variations in astrophysical masers must be due to changes in pump rate or source geometry or possibly a combination of both.

Changes in source geometry can give rise to an effective change in pump rate where the pump radiation is beamed, for example by changes in opacity in an obscuring dust cloud moving between the pump source and maser volumes. Alternatively, relative movement of water vapour clouds can give rise to favourable velocity alignments such that the effective length of the maser region is enhanced for an interval of time.

Of the various pumping schemes proposed for water maser sources, none is found to satisfy completely the constraints imposed by the present observational data. The shock front excited, radiative pump model of Litvak (1969) cannot supply sufficient pump power for maser sources with photon emission rates $>10^{45}s^{-1}$ (Goldreich and Kwan, 1974). The collisional pump model of de Jong (1973) can provide more pump power but predicts dimensions of the maser regions which are several orders of magnitude larger than those observed. The hot-dust-cool-gas model of Goldreich and Kwan (1974) predicts levels of infrared radiation from the hot dust significantly greater than observed. Oka (1973) has proposed a mechanism of selective predissociation by absorption of ultraviolet radiation, which is particularly attractive for water masers in the vicinity of HII regions, but an important feature of this model is the presence of OH more than 10 times more abundant than H_2O. There is some doubt that the OH can exist in the strong ultraviolet radiation field necessary to selectively dissociate the H_2O.

It must be concluded that at present no completely satisfactory model exists which combines defined geometrical and physical properties with the dynamics of maser regions in the vicinity of an early-type stellar object.

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DISCUSSION FOLLOWING MACDONALD

Gold: You spoke of the conflict with respect to the size of the maser. I presume, again, that you had no knowledge of the physical size at all, but that you merely observed some phase-front scatter.

Macdonald: Although I agree one cannot interpret the angular size of maser "hot spots" in terms of physical dimensions, I believe we can reliably derive a physical size from the overall angular extent of the maser spots on a VLBI map.

Scalise: Did you study the polarization of these H_2O maser sources? How did it vary in the long term?

Macdonald: We have made some observations of these H_2O masers in linear polarization, but not over a long period. This work has not been published since we were not confident of our calibration of polarization angle.

Dickinson: You mentioned one "center of activity", as defined by VLBI observations, where the six velocity components all varied in the same way. It sounds as though you have delineated the pump source for these six lines. Have you other examples of this kind?

Macdonald: After applying selection criteria to avoid the effects of blending of velocity components, we had sufficient data on only two of the four "centres of activity" responsible for the majority of the low-velocity emission in W49. Of these two centres, only one showed the remarkable correlated variability I have described.

Schwartz: Is there any evidence for variations of any of the IR sources associated with the HII-region masers you have studied, and if so, on what time scales?

Macdonald: I do not know of any systematic monitoring of IR sources associated with H_2O masers in HII regions that would be comparable to the work done on H_2O masers associated with late-type stars. Such a study would be worthwhile.