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A SEARCH FOR HIGH-VELOCITY WATER MASERS IN REGIONS OF STAR FORMATION

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RESUMEN

La mayoría de las búsquedas por máseres de agua se han hecho usando anchos de banda relativamente angostos. Recientemente se han detectado varios máseres con toda o casi toda su emisión desplazada substancialmente respecto a la velocidad de la nube molecular asociada. Para poner a prueba si los máseres de alta velocidad son un fenómeno común que ha sido desdeñado debido a una selección instrumental, hicimos una búsqueda por máseres de alta velocidad en 42 sitios en los que se sospecha está ocurriendo formación de estrellas. Se detectaron nuevos máseres relacionados con S88 y W42. También detectamos emisión máser previamente reportada en la literatura en otras once regiones. Sólo uno de éstos máseres clasifica como de alta velocidad.

ABSTRACT

Most searches for water maser emission are made with relatively narrow bandwidths. Recently, several masers have been detected with all or most of the maser emission substantially shifted with respect to the velocity of the associated molecular cloud. To test if high-velocity water masers were actually a common phenomenon overlooked by an instrumental selection, we searched for high-velocity H_2O maser emission in 42 suspected sites of star formation. New masers related to S88 and W42 were detected. Maser emission reported previously in the literature was detected from other eleven regions. Only one of these masers qualifies as a high-velocity maser.

Key words: INTERSTELLAR-MOLECULES – MASERS – STARS-FORMATION.

I. INTRODUCTION

During a search for water masers in the vicinity of the red nebulosities of Gyulbudaghian, Glushkov, and Denisyuk (1978), referred to hereafter as GGD objects, Rodríguez *et al.* (1978, 1980) detected several masers whose emission is all, or almost all, shifted substantially (by more than 20 km s^{-1}) from the velocity of the associated molecular cloud. We refer to this type of maser as a high-velocity water maser. Although the presence of high-velocity components is not uncommon in water masers associated with regions of star formation (Genzel and Downes 1977, 1979), these

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masers usually have most of their emission at velocities close to that of the associated molecular cloud.

The H_2O masers near to GGD objects were detected using a wide bandwidth of 20 MHz, which at a frequency of 22.2 GHz corresponds to a coverage of 270 km s^{-1}. Most of the surveys made since the initial detection of H_2O maser emission by Cheung *et al.* (1969) have been conducted using narrower bandwidths, typically giving velocity coverages of 50 to 100 km s^{-1}. It is thus possible that high-velocity water masers are actually a common phenomenon, overlooked by an instrumental selection. To test this possibility we searched for high-velocity H_2O masers in 42 sites of star formation. In §II we describe the observations and present the results. In §III we discuss these results and summarize our conclusions.

II. OBSERVATIONS

The observations were made in 1978 October and 1979 February with the 36.6-m radio telescope of the Haystack Observatory. At the frequency of the 6_{16}-5_{23} transition of water vapor, 22235.080 MHz, the antenna half-power beamwidth was 1ʹ.5 and the aperture efficiency varied from 0.22 at an elevation of 45° to 0.12 at an elevation of 10°. The receiver consisted of a maser amplifier and a 512 channel autocorrelator spectrometer. A bandwidth of 16.7 MHz was used, a compromise between velocity coverage and spectral resolution. The effective coverage was 180 km s^{-1} in velocity at a spectral resolution of 0.88 km s^{-1} after Hanning weighting. The spectrometer was centered at the velocity of the associated molecular cloud or at the centroid of previously reported H_2O emission. When this information was not available it was centered at 0 km s^{-1}. System temperatures were in the range of 150-250 K. We made seven-point maps centered at the source position. These maps consist of one observation at the position of the source and six others distributed symmetrically around a circle of radius 0.87 times the beamwidth at intervals of 60°. With this procedure all positions within a nearly circular area having a diameter of about 3ʹ.8 were sampled by the antenna beam within its half power response. Two-minute integrations were used, resulting in 4σ upper limits of typically 10 to 20 Jy.

In Tables 1 and 2 we give the sources observed. Table 1 gives the 29 sources where no maser emission was detected and Table 2 gives the 13 sources where emission was detected. New masers were detected in S88 and W42. These results are described below.

TABLE 1

SOURCES SEARCHED WITH NEGATIVE RESULTS

Source	α(1950)	δ(1950)
S186	$01^h05^m34^s$	62°51ʹ36ʺ
S201	02 59 10	60 13 36
S228	05 10 01	37 23 42
S255	06 09 29	18 00 00
S309	07 33 19	− 19 21 00
S307	07 29 36	− 18 38 33
NGC 6357	17 21 24	− 34 08 24
G359.99 + 0.02	17 42 20	− 28 55 06
G0.07 + 0.01	17 42 34	− 28 51 05
G0.09 + 0.01	17 42 37	− 28 49 54
G12.79 − 0.15	18 11 05	− 17 56 15
OH1821	18 21 17	− 12 28 00
W42(1)	18 31 30	− 07 21 11
W42(4)	18 34 51	− 06 44 39
W42(6)	18 34 51	− 06 16 47
W42(5)	18 35 22	− 06 27 40
W42(3B)	18 35 26	− 06 48 39
S69	18 41 40	− 00 22 04
HM Sge	19 39 41	16 37 33
S93	19 52 58	27 04 50
IC 4954	20 02 52	29 04 00
MWC349	20 30 57	40 29 21
S138	22 31 44	58 13 06
S146	22 47 30	59 39 00
S152	22 56 39	58 29 48
S156	23 01 37	60 07 10
S159	23 13 23	60 50 36
S157	23 13 53	59 45 18
S168	23 50 35	60 07 49

a) *S88B*

S88B is a small (∿ 1ʹ) Hα knot which has been studied carefully in the optical, infrared and radio by Pipher *et al.* (1977) and Deharveng and Maucherat (1978). Pipher *et al.* (1977) found a small (~ 15ʺ) compact radio H II region displaced by about 1ʹ to the northeast of the Hα knot. This radio H II region is embedded in a molecular cloud and obscured by ∿19 magnitudes of visual extinction. The Hα knot and the compact radio H II region probably share the same source of ionization. Pipher *et al.* suggest that this could be an O7 or O8 ZAMS star. Deharveng and Maucherat favor the argument of a common excitation source for both the compact radio source and the optical nebula. The reason for this is that the excitation of the optical nebula increases in the direction of the strong infrared source at 2.2 μm and of the compact H II region. The heavily obscured compact radio H II region and the more diffuse optical knot probably constitute a "blister" H II region (Israel 1978) that recently reached the surface of its molecular cloud and is beginning to

TABLE 2

SOURCES THAT SHOWED WATER MASER EMISSION

Source	α(1950)	δ(1950)	S(Jy)	V_{LSR} (km s^{-1})	V cloud* (km s^{-1})	Reference for V_{cloud}
NGC 281	$00^h49^m29^s$	56°17′37″	13, 7	– 30, –27	– 31.0	Elmegreen and Moran 1979
Orion B	05 39 12	– 01 56 42	160	13	11.0	Wilson *et al.* 1974
S269	06 11 46	13 50 25	143, 53	17, 19	17.5	Blair *et al.* 1975
NGC 6334B	17 16 34	– 35 56 24	23, 117	– 11, –5	– 6.0	Dickel *et al.* 1977
NGC 6334A	17 17 33	– 35 45 35	400	– 11	– 5.0	Dickel *et al.* 1977
W42(2A)	18 33 30	– 07 14 42	15, 12, 12, 90, 6, 5	53, 57, 95, 112, 121, 126	110.0	Jaffe 1980
W42(3A)†	18 35 37	– 06 52 24	7	6.6	64.0	Jaffe 1980
G28.86 + 0.07	18 41 07	– 03 38 41	37	107	∿105.0‡	Wilson *et al.* 1974
S88B†	19 44 41	25 05 02	6, 22	5.1, 6.8	22.9	Blair *et al.* 1975
NGC 7129(1)	21 41 52	65 49 40	20, 11	– 13, –6	– 10.0	Loren 1977
NGC 7129(2)	21 41 58	65 53 10	25	– 8	– 10.0	Loren 1977
Cep A	22 54 20	61 44 42	39, 190, 475, 88, 25, 12	– 20, –11, –8, –7, –6, 14	– 10.3	Sargent 1977
NGC 7538S	23 11 37	61 10 20	45, 12, 105, 35	–62, –60, –55, –43	– 57.0	Wilson *et al.* 1974

* CO Velocity of the associated molecular cloud with respect to the LSR.
† New water masers.
‡ Value adopted from measurements of W43.

expand toward the surrounding lower-density medium. The velocity gradient found by Deharveng and Maucherat from the Hα emission is consistent with this interpretation. Blair *et al.* (1978) have detected an H_2O maser in the vicinity of S88 for which they do not give a position. The position we measured (Table 2) is offset from the compact radio H II region by about 30″ to the southwest. Unfortunately, this offset is equal to our positional error and we could not determine whether or not the H_2O maser is associated with the radio H II region. An interferometric measurement is needed to establish this association. The H_2O emission measured by Blair *et al.* (1978) in 1976 February had components at 13.6, 14.8, and 30.0 km s^{-1}. We found components at 5.1 and 6.8 km s^{-1} in 1978 October. Since the cloud velocity is 22.9 km s^{-1} the maser does not qualify as a high velocity maser. A spectrum of the S88B maser is given in Figure 1.

b) W42 (3A)

Recently, Maxson *et al.* (1980) mapped the W42 region in the far-infrared. They detected seven sources, some of which have multiple components. From their data Mason *et al.* concluded that W42 (3A) is part of a very luminous (~ $10^7 L_\odot$) OB cluster located at 13.4 kpc from the Sun. We observed all their sources except W42(7) but we detected H_2O maser emission only from W42(2A) and W42(3A). The source associated with W42(2A) was detected by Genzel and Downes (1979) and has a centroid of emission at ∿112 km s^{-1}. This is close to the radial velocity of the strongest CO line found in that region which is ∿110 km s^{-1} (Jaffe 1980). The new maser associated with W42(3A)

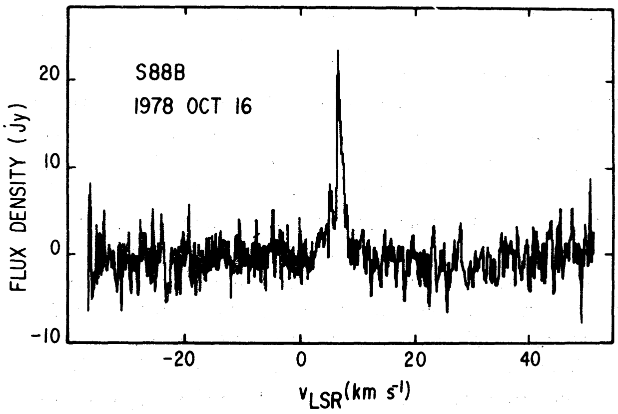

Fig. 1. Spectrum of the H_2O maser associated with S88B. The velocity axis is referred to the local standard of rest (LSR) and a rest frequency of 22235.080 MHz. We corrected for tropospheric absorption and elevation-dependent gain variation. The conversion from corrected antenna temperature to flux density was 13 Jy K^{-1}.

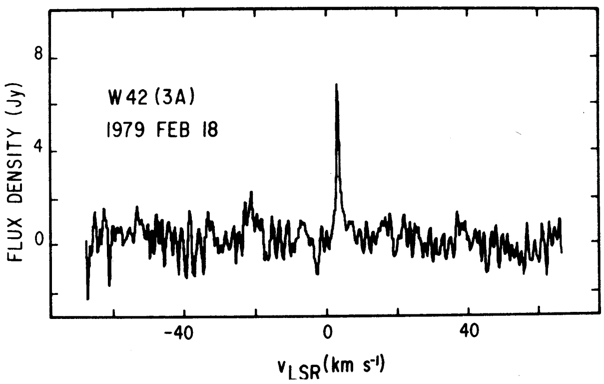

Fig. 2. Spectrum of the H_2O maser associated with W42(3A).

has $v_{LSR} \cong 7.0$ km s^{-1} and shows a weak ($\sim$ 7 Jy) feature. The H109α line in the W42 H II region (Schraml and Mezger 1969) has v_{LSR} = 59.9 km s^{-1} for the ionized gas, and Jaffe measured v_{LSR} = 64.0 km s^{-1} for the strongest CO line. This suggests that this H_2O maser may be displaced in velocity by $\sim$55 km s^{-1} from the velocity of the associated molecular cloud and would thus qualify as a high-velocity maser. A spectrum of this H_2O maser is shown in Figure 2.

III. CONCLUSIONS AND SUMMARY

Five of the ten masers detected by Rodríguez *et al.* (1980) near GGD objects are high-velocity water masers. In contrast, only one of the thirteen masers observed in this experiment can be placed in this category. Although the number of objects included in the sample is small, these results suggest that H_2O masers near GGD objects show a tendency to have high-velocity features exclusively. The GGD objects have been suggested to be Herbig-Haro objects by their discoverers. Unfortunately, the identifications in most cases are based only on morphological appearance and lack spectroscopic confirmation. During a recent survey for H_2O emission near spectroscopically-confirmed H-H objects, Haschick *et al.* (1980*b*) found only three masers (associated with H-Hl, H-H7-11 and H-H19-27). They suggested that H_2O masers near GGD objects are in general more luminous, and therefore more easily detectable, than H_2O masers near H-H objects.

If the GGD objects are visible as emission from shocked gas, as the H-H objects are believed to be, then the possible correlation between GGD objects and the high-velocity H_2O masers could be explained as a result of high-mass-loss from young stars. Strong stellar winds from embedded pre-main sequence stars or protostars could account for both the high-velocity H_2O maser emission and the optically observable shocked gas, i.e., the GGD object. As a result of this correlation we would expect the H_2O masers associated with classical H-H objects to have high-velocity components. Unfortunately, with only three known masers it is difficult to reach a definite conclusion. The H_2O masers associated with H-Hl and H-H19-27 are not high-velocity masers. Of the three H_2O masers found by Haschick *et al.* (1980a) in the vicinity of H-H7-11, only maser A has the appearance of a high-velocity maser at some epochs.

In conclusion, our search for high-velocity water masers in sites of star formation suggests that this type of maser is not common and that previous searches made with narrower bandwidths probably did not overlook a large number of sources.

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