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ANOMALOUS WATER MASERS IN OH/IR STARS

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RESUMEN

En este trabajo presentamos observaciones de máseres de OH (1612 MHz) y H_2O (22.2 GHz) hechas en el VLA con una resolución angular de $\sim 1''$ hacia tres estrellas OH/IR: OH12.8–0.9, OH37.1–0.8 y OH42.3–0.1. Estas estrellas muestran las componentes del máser de H_2O en un intervalo de velocidad mayor que el intervalo de velocidad de las componentes de OH, situación que está en desacuerdo con el modelo estándar de la emisión máser en estrellas tipo tardío. Las posiciones obtenidas para los máseres de OH y H_2O en cada una de las estrellas coinciden dentro de $\sim 0\rlap{.}''5$ lo que nos hace pensar que ambos máseres estan asociados a la misma estrella. Este resultado descarta la posibilidad de una superposición fortuita de dos fuentes distintas. Se presenta una discusión de los posibles mecanismos que podrían estar produciendo la emisión anómala del máser de H_2O. La explicación más viable es que estas estrellas poseen vientos anisotrópicos (axisimétricos) y que la emisión de H_2O se origina en las regiones polares del viento que tienen mayor velocidad que las cercanas al ecuador de donde se originaría la emisión de OH. Se requieren observaciones de interferometría de base muy larga para poner a prueba esta explicación.

ABSTRACT

We present OH (1612 MHz) and H_2O (22.2 GHz) maser observations made with the VLA at an angular resolution of $\sim 1''$ toward three OH/IR stars: OH12.8–0.9, OH37.1–0.8 and OH42.3–0.1. These stars exhibit the H_2O maser components in a velocity range that exceeds the OH velocity range, a situation in disagreement with the standard model for maser emission in late-type stars. We find that the OH and H_2O maser positions agree within $\sim 0\rlap{.}''5$ and that most likely both masers arise from the same source, ruling out the possibility of a fortuitous superposition of two different sources. We discuss some of the possible mechanisms that could explain the anomalous H_2O maser emission. The most likely explanation is that these stars have axisymmetric winds and that the H_2O emission originates in the polar regions with larger velocities than the regions closer to the equator where the OH emission arises. Very long baseline observations are required to test this explanation.

Key words: **CIRCUMSTELLAR MATTER — MASERS — STARS - INDIVIDUAL (OH12.8 -0.9, OH37.1–0.8, OH42.3–0.1) — STARS - LATE - TYPE**

1. INTRODUCTION

The OH/IR stars represent an evolutionary stage :hought to precede that of planetary nebulae. They ıre long-period variable stars near the end of the ısymptotic giant branch. They have oxygen-rich :ircumstellar shells and maser emission at radio wavelengths from OH, and sometimes H_2O and SiO molecules. The masers appear stratified in the envelope with the SiO maser emission occurring closest to the stellar surface, at $\sim 3\times10^{14}$ cm, the H_2O masers appear farther out at $\sim 3\times10^{15}$ cm, and the OH maser emission usually comes from a shell at large distances from the star, $\sim 3\times10^{16}$ cm (Bowers 1985; Chapman & Cohen 1986; Herman & Habing 1987).

Simple models of circumstellar envelopes around OH/IR stars suggest that the envelope is expanding radially with the expansion velocity increasing monotonically with distance to the star and finally reaching a terminal value (Kwok 1976; Reid

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TABLE 1

OH AND H_2O MASER PARAMETERS

Source	OH Position		H_2O Position		V_P(OH)	$V_P(H_2O)$	V^a_{LSR}
	α (1950)	δ (1950)	α (1950)	δ (1950)	(km s^{-1})	(km s^{-1})	(km s^{-1})
OH 12.8–0.9	$18^h13^m53^s.42$	$-18^\circ16'08''.8$	$18^h13^m53^s.44$	$-18^\circ16'09''.2$	–67.4	–78.6	–56
					–44.0	–36.3	...
OH 37.1–0.8	18 59 36.21	+03 15 52.9	18 59 36.23	+03 15 52.6	+75.9	+65.7	+87
					+101.0	...	...
OH 42.3–0.1	19 06 43.77	+08 11 41.2	...	...	+43.6	...	+57
					+48.7	...	...
					+75.1	...	...

[a] Systemic radial velocities are from the midpoint of the OH maser emission.

et al. 1977). Since the OH (1612 MHz) maser emission arises at very large distance from the star, it is believed that the OH is moving at nearly the terminal expansion velocity. The terminal velocity is taken equal to one-half the velocity separation of the OH (1612 MHz) profile components (Kwok 1976; Goldreich & Scoville 1976; Reid et al. 1977). The H_2O maser velocity range generally covers about 80% of the OH maser velocity interval (Engels, Schmid-Burgk, & Walmsley 1986), a result that is consistent with the H_2O masers occurring inside the OH maser emission shell, with expansion velocities smaller or at most equal to those of OH.

In the literature, we found three OH/IR stars where the H_2O maser features fall outside the OH maser velocity range: OH 12.8–0.9, OH 37.1–0.8 and OH 42.3–0.1. It is clear that these stars cannot be understood by the standard expanding shell model. Similar anomalous H_2O maser emission has been found in the Mira stars U Her and RR Aql (Bowers, Johnston, & De Vegt 1989), and in the peculiar sources W43A (Diamond et al. 1985) and *IRAS* 16342–3814 (Likkel & Morris 1988). We made VLA observations of OH and H_2O toward OH12.8-0.9, OH37.1–0.8 and OH42.3–0.1 stars in order to confirm that emission from both maser species is associated with the same star and does not arise from different objects that are close together in angle. If this were the case, these stars would require a kinematical model for their envelopes that differs from the standard one.

2. OBSERVATIONS

We made observations of OH (1612 MHz) and H_2O (22235 MHz) using the VLA of the NRAO[5] during 1991 July 24 and 25, and 1992 May 19 and 21, respectively. During the OH observations the array was in the A configuration, and we observed at the rest frequency of 1612.231 MHz in the spectral line mode with Hanning smoothing, using 128 channels of 6.104 kHz (1.1 km s^{-1}) spacing and a total bandwidth of 0.7813 MHz. The synthesized beam at this frequency was $\sim 1''$. The H_2O observations were made in the C configuration at the rest frequency of 22235.08 MHz, in the normal spectral line mode with 64 channels of 195.313 kHz (2.6 km s^{-1}) spacing and a total bandwidth of 12.5 MHz. The synthesized beam at this frequency was also $\sim 1''$. The data were edited and calibrated in the standard manner using the Astronomical Image Processing System (AIPS) developed by the NRAO. The flux density scale was determined from observations of the amplitude calibrator 1328+307, for which flux densities of 13.8 Jy at 1612 MHz and 2.6 Jy at 22235 MHz were assumed.

[5] The National Radio Astronomy Observatory is operated by Associated Universities Inc., under cooperative agreement with the National Science Foundation.

3. RESULTS

We detected unresolved ($\leq 1''$) OH and H_2O maser emission in all sources except in OH42.3–0.1 where the H_2O maser emission was below our detection limit of $\sim$ 0.04 Jy. In the cases where two or more velocity features were detected in the same molecule we found that they coincided spatially within $0''.1$ and an average of these positions is given in Table 1. Note that the relative positions of the masers are not affected by any systematic errors to first order (e.g., atmosphere, baseline errors, calibrator position errors, etc.) and they can be determined to a limit set by the signal-to-noise ratio. The relative position accuracy is approximately the angular resolution over two times the signal-to-noise ratio (Reid et al. 1988). The coincidence in absolute position of OH and H_2O emission (within $0''.5$) suggest that both arise in the same stellar

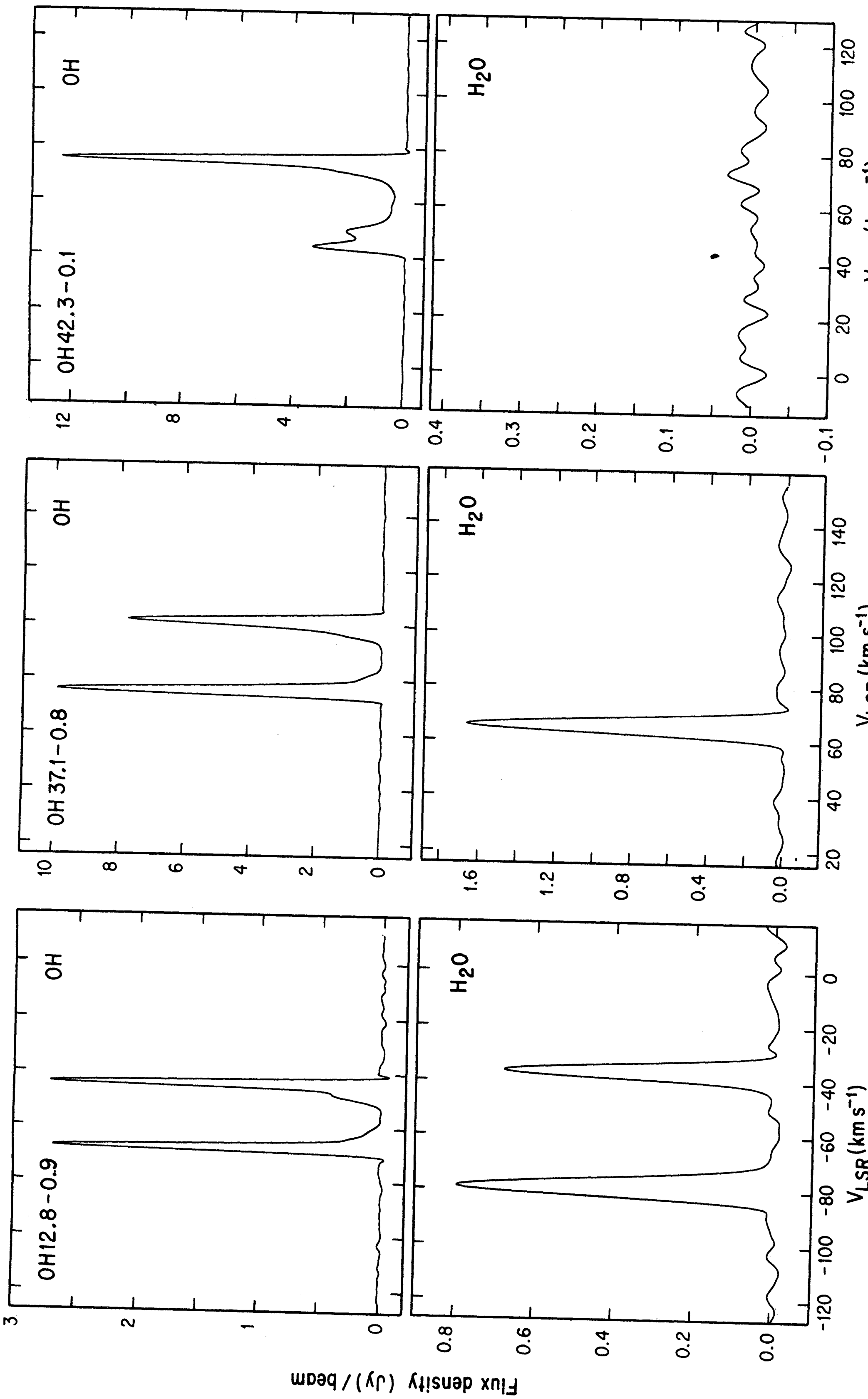

Fig. 1. Spectra of the OH and H_2O maser emission from the OH/IR stars taken with the VLA. These spectra were obtained at the position of maximum emission given in Table 1.

envelope. In Table 1 we also include the LSR velocity of the detected features in OH and H_2O as well as the LSR velocity of the system taken from the OH maser emission (Morris & Bowers 1980; Johansson et al. 1977). In Figure 1 we show the spectra of the OH and H_2O maser emission from the OH/IR stars obtained with the VLA. These spectra were obtained at the position of maximum emission given in Table 1 using the task SLICE of AIPS.

3.1. Comments on Individual Objects

3.1.1. OH 12.8–0.9

The OH and H_2O maser emissions were detected by Baud et al. (1979) and Engels, Schmid-Burgk, & Walmsley (1986), respectively. The SiO maser emission has not been detected toward this source (Jewell et al. 1985; Gómez, Moran, & Rodríguez 1990; Jewell et al. 1991). This star shows the typical double-peaked profile structure at 1612 MHz concentrated at two velocities (–67.4 and –44.0 km s^{-1}; see Figure 1). The H_2O maser also exhibits a double-peaked profile and its components (at –78.6 and –36.3 km s^{-1}) appear clearly outside the velocity range of the OH maser. The OH maser position presented in this work (see Table 1) agrees (within $2''$) with the OH position obtained also at the VLA by Bowers & De Jong (1983).

3.1.2. OH 37.1–0.8

The OH maser emission was detected by Winnberg et al. (1975). An H_2O maser component was first observed by Engels, Schmid-Burgk, & Walmsley (1986), who did not consider it to be associated with the star, because its radial velocity appears outside the OH velocity range. However, Gómez et al. (1990) suggested that the H_2O maser was associated with the star. Since the OH and H_2O maser positions coincide within $0\overset{''}{.}5$ we confirm this suggestion. Jewell et al. (1985) report a probable detection of SiO maser emission (at 3σ-level, σ = 0.4 Jy). Previous single dish observations of H_2O maser emission toward OH 37.1–0.8 were taken by us using the 36.6-m antenna of the Haystack Observatory[6]. This spectrum is shown in Figure 2 where two components at LSR velocities of 66.8 and 112.9 km s^{-1} with flux densities of 5 and 2 Jy respectively, are evident. This is the first H_2O spectrum of this source that shows two velocity components at very different velocities. The H_2O maser emission does fall outside the OH velocity range of 75.9 to 101.0 km s^{-1}.

[6] Radio Astronomy at the Haystack Observatory of the Northeast Radio Observatory Corporation is supported by a grant from the National Science Foundation.

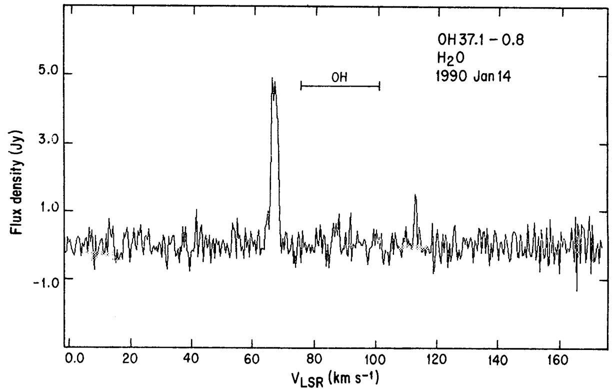

Fig. 2. H_2O spectrum toward OH37.1–0.8 taken in January 14, 1990 at the Haystack Observatory. The OH velocity range is also shown with a horizontal line.

3.1.3. OH 42.3–0.1

The OH and H_2O maser emissions have been detected toward this source by Winnberg et al. (1975) and Olnon et al. (1980), respectively. The SiO maser emission was detected by Jewell et al. (1985), at an LSR velocity of 64 km s^{-1}. As noted before, we did not detect H_2O maser emission in OH 42.3-0.1 with the VLA. However in this source there has been H_2O emission present in the past with velocities outside the OH range. In Figure 3 we show single dish observations made by us with the Haystack antenna that shows H_2O emission at 10 and 78 km s^{-1}, outside the OH range of 48.7 to 75.1 km s^{-1}.

4. DISCUSSION

It is clear from the spectra of these three OH/IR stars that the H_2O maser emission appears outside the OH velocity range, and cannot be easily explained by the standard ex-

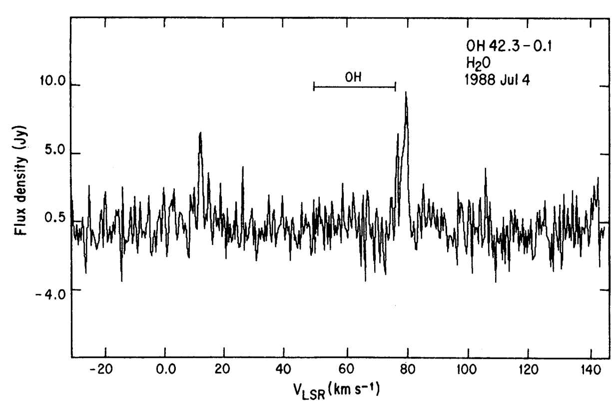

Fig. 3. H_2O spectrum toward OH42.3–0.1 taken in July 4, 1988 at the Haystack Observatory. The OH velocity range is also shown with a horizontal line.

anding shell model. In this simple expanding hell model the maximum velocity sequence exected for the different masing molecular species $V_{max}(SiO) \leq V_{max}(H_2O) \leq V_{max}(OH)$ (e.g., Goldeich & Scoville 1976). This model also predicts small radial acceleration at large distances from he star, since the distance at which the dust grains orm is relatively large. However, several authors ad suggested significant acceleration at small radii Chapman & Cohen 1986; Bujarrabal et al. 1986; Bowers 1992; Bowers, Claussen & Johnston 1993). n particular Bowers (1992) found comparable values of V_{max} for the SiO, H_2O, and OH masers n a sample of 15 Mira and semiregular variables tars, which he interpreted as acceleration of some f the gas in the SiO shell, close to the star. In these tars $V_{max}(H_2O)$ and $V_{max}(OH)$ are usually simiar within a few km s^{-1}, while in the case of the OH/IR stars studied here we find $V_{max}(H_2O)$ to be ~10 km s^{-1} larger than $V_{max}(OH)$. In the next aragraphs we discuss some of the possible mechaisms that could explain the anomalous H_2O maser mission.

Several models can be considered in an attempt o explain the observed anomalous H_2O maser mission. We discuss three possibilities in what ollows.

i) We could have a close binary system (with eparation less than 1″), with two OH/IR stars, one responsible for the OH maser emission and he other for the H_2O maser emission. However, he OH/IR evolutionary stage is thought to be ery short ($\sim 10^4$ years), when compared with he lifetime of a star with a few solar masses $\sim 10^9$ years) and it appears unlikely that the omponents of a binary would be in the OH/IR tage simultaneously.

ii) Another possibility could be that the central tar has started to contract on its way to be a planetary nebula nucleus. In this case, the object vould be in, or very close to, the protoplanetary nebula stage, with the wind from the central star ncreasing in velocity with time and with the lower elocity, denser envelope becoming detached. In his situation the wind closer to the star is faster han that farther away. On the basis of its period nd *IRAS* (color [25μm - 12μm] $\sim$ 0.33), Lewis & te Lintel Hekkert (1991) have proposed that OH37.1–0.8 is a protoplanetary nebula candidate, and this explanation may account for the anomalous H_2O naser emission in this source. We note that the imescale for variation of the OH radial velocities is ~ 300 years and that this model does not conflict vith available OH observations. However, the other two sources in our sample, OH12.8–0.9, and OH42.3–0.1, have *IRAS* [25μm – 12μm] colors of -0.24 and 0.06 respectively (Gómez et al. 1990), both values below 0.2, the color that is believed to mark the beginning of the protoplanetary nebulae stage.

iii) Finally, several authors have proposed that many of the outflows from evolved stars are not isotropic but axisymmetric (e.g., Morris 1987; Bowers, Johnston, & De Vegt 1989; Morris 1990). Even when the cause of this axisymmetric structure is unclear, it is believed that the presence of an equatorial concentration of matter is enough to produce a bipolar symmetry making the outflow faster in the poles than in the equator (Morris 1990). This kind of model has been proposed to explain the high velocity H_2O components in W43A and IRAS 16342-3814 (Diamond et al. 1985; Likkel & Morris 1988; Morris 1990; Likkel, Morris, & Maddalena 1992), where $V_{max}(H_2O)$ is $\sim$70 – 80 km s^{-1} larger than $V_{max}(OH)$. These authors propose that the H_2O maser emission arises in the poles of the wind as a result of shock excitation, whereas the OH maser emission probably comes from lower latitudes nearer to the plane of the equator (for a schematic view of this model see Fig. 5 of Likkel, Morris, & Maddalena 1992).

The three OH/IR stars presented in this work (OH12.8–0.9, OH37.1–0.8, and OH42.3–0.1) are probably related to objects such as W43A and *IRAS* 16342–3814 in the sense that members of the former group may evolve to the latter group. These objects could be the progenitors of planetary nebulae such as Fleming 1 (López, Meaburn, & Palmer 1993) that exhibit symmetrical, collimated flows. The axisymmetric model predicts that the OH and H_2O spots could be significantly separated in space with a bipolar kinematical structure (Diamond et al. 1985). High resolution interferometric observations of OH and H_2O maser emission with milliarcsecond resolution are necessary to clarify if the wind from these sources is indeed axisymmetric.

5. CONCLUSIONS

We presented OH and H_2O maser observations for three OH/IR stars made with the VLA. These OH/IR stars present H_2O maser components in a velocity range that exceeds the OH velocity range. We detected unresolved ($\leq$1″) OH and H_2O maser emission in all sources except in OH42.3–0.1 where the H_2O maser emission was turned off at the time of observation. The coincidence in position of OH and H_2O maser emission (within 0″.5) suggests that both arise in the same stellar envelope. It is clear that the standard expanding shell model cannot explain the H_2O maser emission observed toward these sources. Several mechanisms could explain the anomalous emission. In particular we favor an axisymmetric model for these three OH/IR stars similar to that proposed by Likkel, Morris, & Maddalena (1992) to explain objects with much faster winds such as *IRAS* 16342–3814. The OH/IR stars studied here could be precursors of sources of the *IRAS* 16342–3814 type. Very long baseline interferometric observations of the OH/IR stars studied here are required to test if they show the bipolar kinematic structure expected from an axisymmetric wind.

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