Revista Mexicana Astron. Astrof., 17, 121-125 (1989)

RESULTS OF A SEARCH FOR H_2O–MASERS IN THE ρ OPHIUCHI CLOUD (Research Note)

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Received 1989 May 23

RESUMEN

Presentamos límites superiores para el flujo de densidades en la línea de 22.2 GHz de vapor de H_2O en varias posiciones seleccionadas dentro de la nube de ρ Oph. Los espectros de emisión en la línea de H_2O y en las líneas de 1667 y 1665 MHz de OH, fueron obtenidas en la posición del maser de H_2O IRAS 16293 – 2422.

ABSTRACT

We present upper limits for the flux densities in the 22.2 GHz line of H_2O-vapor at several positions selected within the ρ Oph cloud. Spectra for the emission in the H_2O-line and in the 1667 and 1665 MHz lines of OH were obtained at the position of the H_2O maser IRAS 16293 – 2422.

Key words: INTERSTELLAR-CLOUD – MASERS – RADIO LINES-MOLECULAR

I. INTRODUCTION

In this note we present the results of a search for H_2O masers, including also some OH-observations made in B42, the well-known ρ Oph dark cloud. This is the most conspicuous area of current star formation within the Sco OB2 association (cf. for example Cappa de Nicolau and Pöppel 1986 as well as the references given there). The cloud contains an embedded population of 16 T Tauri stars (Rydgren 1980), as well as more than 40 objects discovered through IR-observations (Grasdalen, Strom, and Strom 1972; Elias 1978; Wilking and Lada 1983). They include probable T Tauri stars, protostellar objects and low luminosity pre-main-sequence objects surrounded by dust shells (Lada and Wilking 1984). In addition, Montmerle *et al.* (1983) discovered 47 highly variable X-ray sources, several of which seem to be closely connected with pre-main-sequence objects.

The ρ Oph dark cloud is associated with the denser parts of a nearby molecular cloud complex which has been sampled by Javanaud (1979) in the 6-cm lines of H_2CO. It has been mapped at larger scales by Wouterloot (1981, 1984) in the 18-cm lines of OH and has also been intensively studied through the detection of enhanced emission from numerous molecular species. From high resolution observations ($\Delta v \sim 0.17$ km s^{-1}) Lada and Wilking (1980) suggested that ^{13}CO emission in B42 is optically thick. Wilking and Lada (1983) produced a new map of the cloud in emission of $^{12}C\,^{18}O$, which appears to be optically thin, thus permitting to derive column densities. Moreover, from observations in the 2-cm and 2-mm lines of H_2CO and from detailed models of the radiative transport, Loren, Sandquist and Wootten (1983) were able to derive the density structure in the cloud and to compare it with the thick CO measurements (Loren *et al.* 1980). In addition, several DCO^+ and HCO^+ transitions at frequencies between 72 and 289 GHz have been detected in emission, indicating the presence of a very dense and cold molecular cloud core (Loren and Wootten 1982).

As a conclusion of the observations in IR and radio waves, it has been suggested that the conditions are given for the imminent formation of a gravitationally bound star cluster in the ρ Oph cloud (Wilking and Lada 1983; Loren and Wootten 1986). In particular, three different cores have been identified. They are known as cores A, B1, and B2, respectively. Each one has sizes less than $4' \times 2'$, i.e., < 0.2 pc $\times$ 0.1 pc, assuming a distance r = 160 pc. The densities range at values which are larger than 5×10^5 cm^3 and the velocity dispersions at ~ 1 km s^{-1}. The separation between B1 and B2 is about $5'$, and from them to A about $15'$. The densities in the cores of the ρ Oph cloud seem to be much higher than in

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any core of the well known Taurus dark complex, where massive star formation is also lacking (cf. for example Olano and Pöppel 1987, as well as the references given there). We refer to Loren and Wootten (1986) as well as to Klose (1986) and to the references given there for a more detailed information about the ρ Oph cloud.

On the other hand, the existence of maser sources is one of the indicators of recent star formation occurring in molecular clouds. There are presently more than 300 H_2O vapor sources known and the total number in the Galaxy with a flux density $S > 1$ Jy is estimated to be $\sim$ 1000 (Braz and Epchtein 1983, Wouterloot and Walmsley 1986).

Both the high star formation efficiency in the ρ Oph cloud and its proximity make it an adequate object for a search of H_2O vapor masers. The IR observations are consistent with an embedded cluster predominantly composed of low-luminosity objects with luminosities L in the range 0.1 to 25 $L_\odot$ (Lada and Wilking 1984). The possibility of incipient massive stars embedded in the cloud cannot be ruled out however, especially regarding the existence of the three dense cores, and the high extinctions measured there. In addition, the presence of an incipient compact H II region among the small radio sources with ascending radio frequency spectra detected by André, Montmerle and Feigelson (1987) at 1.4 GHz and 5 GHz cannot be disregarded (cf. Falgarone and Gilmore 1981).

For all these reasons, a search for H_2O masers in the ρ Oph dark cloud was found worthful to be made, even for the case of negative results, since in that case useful upper limits could be expected. Actually, we did not detect any maser in our original search. When preparing the data for publication, a preprint by Wilking and Claussen (1987) with the detection of two H_2O-masers became available to us. We therefore decided to also include in the present note new H_2O- and OH-observations of the more intense one, which is coincident with IRAS 16293-2422. The weaker one however, namely YLW 16, is below our sensitivity limits.

II. OBSERVATIONS AND RESULTS

Observations were started in the 1667 MHz line of OH in order to map the cloud distribution in the vicinity of the OH-intensity peak. The 30-m dish of the Instituto Argentino de Radioastronomía (IAR), at Villa Elisa, Argentina was used (HPBW = 30′). The receiver has a system temperature on cold sky of 80 K. No information on polarization can be obtained. A factor of 8.7 Jy/K has to be used to convert antenna temperatures T_A into flux densities S. At the back-end, either of two filter banks can be used, namely one of 112 channels of 10 kHz width (= 1.7 km s^{-1}) and another one of 74 channels of 2.2 kHz width (= 0.4 km s^{-1}). The latter filter bank has its first 24 filters spaced at 3 kHz and the rest at 2.2 kHz. The frequency switching technique was used. For a full description of the equipment we refer to Bajaja *et al.* (1987).

The observations in the 1667 MHz line were made in 1987, between August 11 and September 10 on a $1^\circ \times 1^\circ$ field with a half-beam width sampling and a bandwidth of 10 kHz. The resulting contour lines are shown in Figure 1. At the position of the intensity peak longer integrations were made at 1667 and 1665 MHz. Further spectra were obtained at 1612 and 1720 MHz, but without detecting any significant signal within a 3σ level of $\sim$ 1 Jy. Finally, two additional spectra at 1665 and 1667 MHz were obtained with the 2.2 kHz spectrometer. The measured profiles are shown in Figure 2*a*. Calibrations have been made by observing the maser sources G331.5 − 0.1 and NGC 6334. We also computed the ratios R of the line areas 1667 to 1665. Results are presented in Table 1, where we also indicate the total integration time t, the peak velocity V, and the filter width Δv. As can be seen, the emission at the OH intensity peak is consistent with thermal emission in LTE conditions.

Observations of the $6_{16} - 5_{23}$ rotational transition of H_2O at 22.235 GHz have been made with the 13.7-m radome-enclosed radio telescope of the Itapetinga Radio Observatory (IRO), in Brazil, equipped with a room-temperature K-band mixer that gives a system temperature of about 1600 K. The HPBW is 4′ with a pointing accuracy better than 10″. The beam switching technique was used with an acousto-optic spectrometer of 750 channels of 70 Khz width each (0.96 km s^{-1}) at the backend. We refer to Scalise *et al.* (1986) for further details of the equipment.

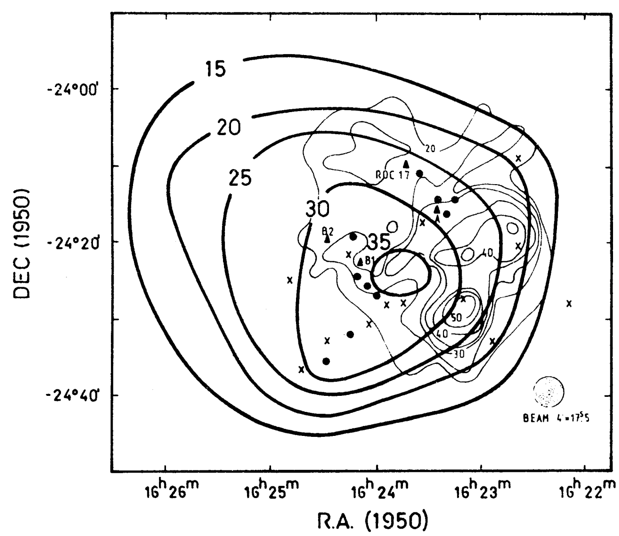

Fig. 1. Positions which have been tested for H_2O-radiation (Table 2). They are indicated by crosses for IRAS sources, or otherwise, by filled circles or triangles (in the cases of ρ Oph A, B1, B2 and ROC17). The thick contours correspond to peak antenna temperatures T_A (in K-units %100) of the 1667 MHz line of OH as measured with the 10 kHz-filters. The thin contours correspond to peak T_A (CO) as taken from Loren *et al.* 1980. See the text for more details.

The H_2O-observations were made in 1987 between September 25 and October 2. The positions to be tested for H_2O-radiation were selected within the 1° × 1° field according to several criteria. On one hand, we have chosen the most intense point sources of the Infra Red Astronomical Satellite (IRAS) catalog in the bands centered at

TABLE 1

RESULTS OF LONG OH-INTEGRATIONS (1667 AND 1665 MHz)

Position	R	t (hours)	V_{LSR} 1667 km s^{-1}	V_{LSR} 1665 km s^{-1}	Δv km s^{-1}
OH-intensity	2.1 ± 0.2	4.5	+3.8	+3.5	1.7
Peak at l = 353.00,	2.0 ± 0.3	6.0	+4.2	+4.4	0.4
b = +16.75	...	...	...	...	...
IRAS 16293-2422	1.5 ± 0.2	24.0	+4.2	+4.3	0.4

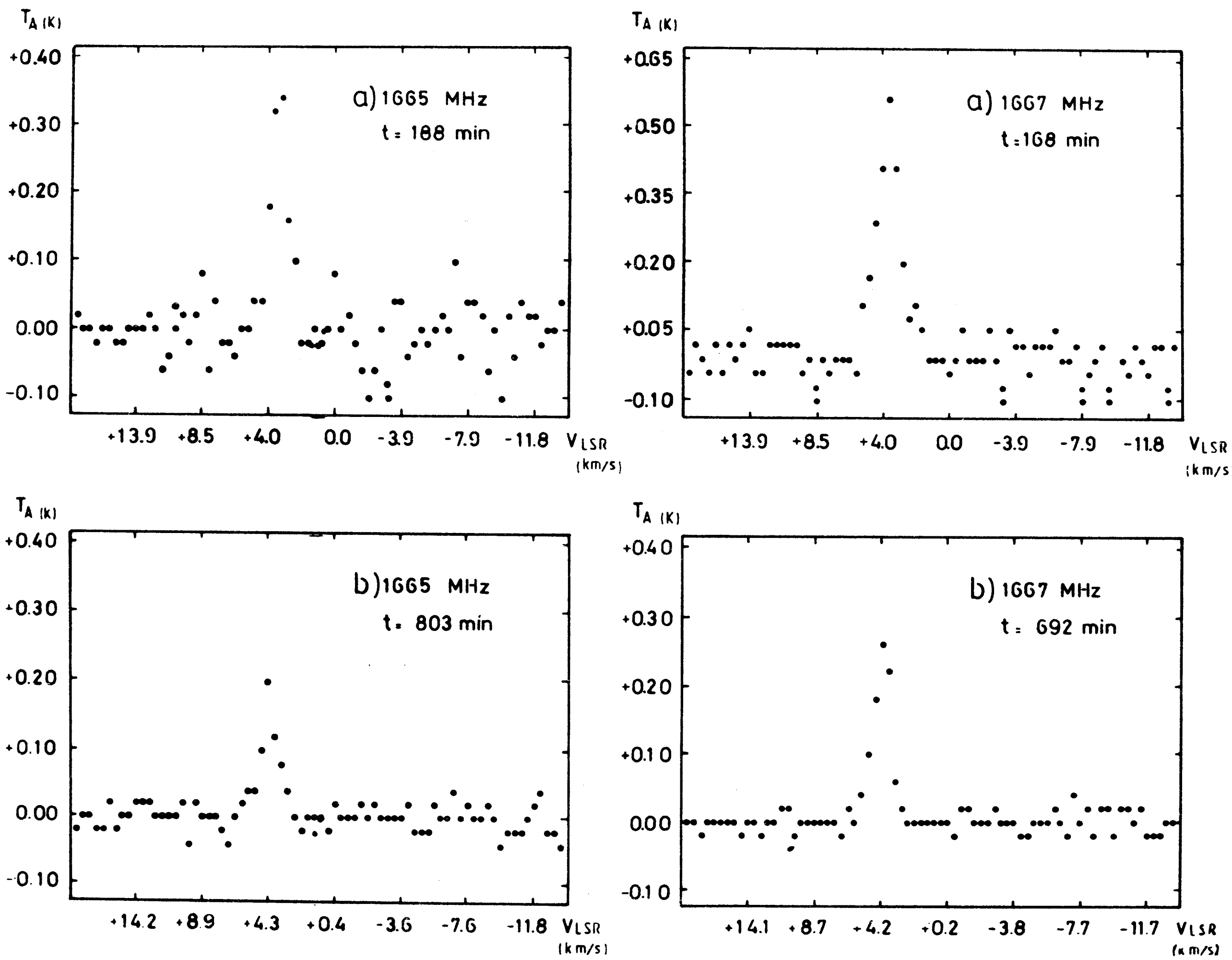

Fig. 2. Spectra of the OH-lines at 1665 and 1667 MHz respectively, which have been measured with the 2.2 kHz-filters at the position of: a) the intensity peak of the 1667 contours of the ρ Oph molecular cloud at l = 353.00, b = +16.75, (cf. Figure 1) and b) the H_2O maser IRAS 16293−2422.

12, 25, 60 and 100μ, with colors in the range which is characteristic for H_2O-masers according to Wouterloot and Walmsley (1986, cf. their Figure 3). They are indicated in Figure 1 by crosses. Some of these sources are also apparent in the far-infrared maps by Fazio *et al.* (1976, cf. their Figure 2) and Harvey, Campbell and Hoffmann (1979, cf. their Figure 1).

On the other hand, several radio features were chosen from the maps of $C^{18}O$ (Wilking and Lada 1983, cf. their Figure 2), $C^{16}O$ (Loren *et al.* 1980, cf. their Figure 2), and H_2CO at 2-cm and 2-mm (Loren *et al.* 1983, cf. their Figures 1 and 2). The selected positions are indicated in Figure 1 by filled circles. Integration times of one hour were used in all these cases. Finally, the ρ Oph cores A, B1 and B2, as well as the interesting radio source ROC17 (André *et al.* 1987) were checked with integration times of 5 to 6 hours. Positions are indicated in Figure 1 by filled triangles. As usual, all the observations were corrected for gain and atmospheric attenuation.

No significant evidence for any maser source could be found. Upper boundaries S_{max} for flux densities are given in Table 2. They were computed simply as three times the rms dispersion σ. Assuming that a H_2O maser, which is located at a distance r/160 pc, is radiating isotropically with a mean flux density S_{max}/10 Jy and a velocity width Δv/3.8 km s^{-1} (i.e., 4 channels), its luminosity $L/L_\odot$ would be

$$L/L_\odot = 2.3 \times 10^{-8} \ (r/160 \ pc)^2 \cdot (\Delta v/3.8 \ km \ s^{-1}) \cdot (S_{max}/10 \ Jy).$$

For the case that all the quantities in parentheses should be ~ 1, we would obtain $L/L_\odot \sim 2.3 \times 10^{-8}$. This is about 8 times the luminosity of a weak maser like T Tauri as measured by Genzel and Downes (1977).

As mentioned above, we also obtained H_2O-spectra of the maser detected by Wilking and Claussen (1987) at the position of IRAS 16293−2422. It is located out of our original 1° x 1° field. In Figure 3 we show a

TABLE 2

UPPER LIMITS FOR FLUX DENSITIES S_{MAX}

R.A. (1950.0)	Dec. (1950.0)	S_{max} (= 3σ)[a] (Jy)	Comments
16^h 22^m 08.9^s	−24° 28' 04"	10.8	IRAS 16221−2428
16 22 38.7	−24 08 52	12.0	IRAS 16266−2408
16 22 39.5	−24 20 28	10.8	IRAS 16226−2420
16 22 51.9	−24 31 58	9.6	IRAS 16228−2432
16 23 9.6	−24 27 35	12.0	IRAS 16231−2427
16 23 15	−24 14 45	9.6	...
16 23 20	−24 16 15	12.0	...
16 23 25	−24 15 49	10.8	ρ Oph A
16 23 25.0	−24 14 45	12.0	...
16 23 31.5	−24 16 56	15.6	IRAS 16235−2416
16 23 35	−24 11 26	13.2	...
16 23 42.5	−24 09 50	16.8	ROC 17
16 23 44.2	−24 28 07	12.0	IRAS 16237−2428
16 23 53.5	−24 28 12	12.0	IRAS 16238−2428
16 24 00	−24 27 00	10.8	...
16 24 03.6	−24 30 43	9.6	IRAS 16240−2430
16 24 05	−24 25 48	12.0	...
16 24 09	−24 22 49	9.6	ρ Oph B1
16 24 11	−24 24 36	15.6	...
16 24 13	−24 19 49	14.4	...
16 24 15	−24 32 09	10.8	...
16 24 15.7	−24 22 06	14.4	IRAS 16242−2422
16 24 26.2	−24 32 53	9.6	IRAS 16244−2432
16 24 26.3	−24 19 49	8.4	ρ Oph B2
16 24 26.9	−24 35 36	18.0	...
16 24 38.6	−24 36 36	12.0	IRAS 16246−2436
16 24 47.7	−24 24 59	15.6	IRAS 16247−2424

a. Computed as 3σ, obtained in the H_2O line at 22.3 GHz.

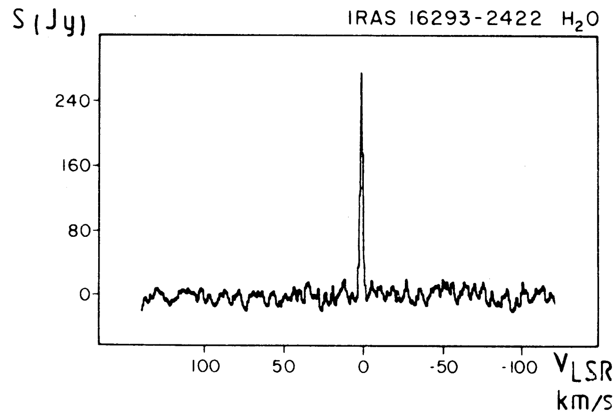

Fig. 3. Spectrum of the H_2O-vapor line at 22.3 GHz, as obtained at the position of IRAS 16293−2422 on June 8, 1988. The integration time was 20 minutes.

spectrum obtained on June 8, 1988. The position of the source in the IR color diagram is rather anomalous as compared with Figure 3 of Wouterloot and Walmsley (1986), since the color ratio $R_{25-60} \sim 1.7$. Possibly, this means that the source is deeply embedded in dust. In addition, we obtained some OH-spectra at 1665 and 1667 MHz during several days between April 23 and June 10, 1988. The averaged results are shown in Figure 2*b* and in Table 1. As can be seen from Table 1, the line ratio 1667 to 1665, R, seems to be somewhat lower at the position of IRAS 16293−2422 than at the intensity peak of the OH-contour maps in Figure 1. Anyway, there is no significant evidence for any 1665 MHz maser emission superposed on the thermal background of the molecular cloud.

Financial support for this program came from CONICET, Argentina and INPE Brazil. We would like to thank all the technical staff of the IAR and especially to Ing. J.J. Larrarte and Mr. Hurrell for their efficient work during the observations at the IAR. We would also like to thank all the technical staff of IRO. We are indebted to J.L. Monteiro do Vale from IRO for developing new computer programs for the data reduction. We appreciate very much the comments made by the referee of this paper.

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