The H_2O Super Maser Outburst Region in the Orion Nebula

L. I. MATVEYENKO[1] and P. J. DIAMOND[2]

[1] *Space Research Institute/IKI RAN, Profsojuznaja 84, 117810 Moscow, Russia*
[2] *National Radio Astronomy Observatory, Socorro, New Mexico 87801, U.S.A.*

Abstract. VLBI studies of the H_2O super maser outburst region structure, show that it contains four groups of compact components, lying along an approximate EW line with a total length of 8.5 AU. The component sizes are $\approx$0.1 AU, brightness temperature $\approx 10^{17}$ K. The emission has linear polarization, $P > 80\%$. The polarization position angle and velocity of the compact components systemically change from one component to another. The linewidth of the component emission is <10 kHz, corresponding to a maser kinetic temperature of 100–150 K. The most plausible model to explain the properties of the maser emission is one of rotating and expanding protoplanetary rings.

1. Introduction

Several star-forming regions have exhibited super maser H_2O outbursts. This phenomenon was first observed in June 1971 in the gas-dust complex W49. The maximum flux density observed was 2×10^5 Jy, component velocity was 1.8 km/s, the emission region size was $\approx$1 AU and the brightness temperature $T_b > 10^{16}$ K (BURKE *et al.*, 1972). From 1979 to 1988 H_2O super maser emission was also observed in the Orion KL nebula, $V = 7.9$ km/s, the flux density of the outbursts reached a maximum of 7×10^6 Jy in 1984 (ABRAHAM *et al.*, 1981; MATVEENKO, 1981; MATVEENKO *et al.*, 1988; GARAY *et al.*, 1989). The maser emission was concentrated inside narrow profile, $\Delta V \approx 0.5$ km/s FWHM, had strong linear polarization, $P \approx 60\%$, the polarization position angle was −16°. Each of these parameters were slowly time variable (ABRAHAM *et al.*, 1986).

The first VLBI measurements with a radio interferometer using the baseline Simeiz-Puschino showed a complex spatial structure of the super maser region. The sizes of the compact components were <0.2 AU (MATVEENKO, 1981). We have conducted a VLBI campaign to monitor the H_2O supermaser emission region (MATVEENKO *et al.*, 1988). We report here on observations performed in 1985.8.

2. Structure of the Super Maser Region

The VLBI measurements in 1985.8 were the most extensive of our series. We used antennas at Simeiz (22 m), Onsala (20 m), Effelsberg (100 m), Haystack (37 m), Green Bank (43 m), VLA (25 m) and Owens Valley (40 m). The angular resolutions of the interferometers (fringe spacings) were from 0.3 to 0.6 mas or 0.15–0.3 AU at the 500 pc distance of the Orion Nebula, and enabled us to image the complex region of the H_2O supermaser. A 500 kHz and 250 kHz bandwidth were used, providing a frequency resolution of 5 and 2.5 kHz or 0.07 and 0.035 km/s, respectively. The data were correlated on the MKII correlator of the NRAO at Socorro. The calibration and imaging were performed within the AIPS package.

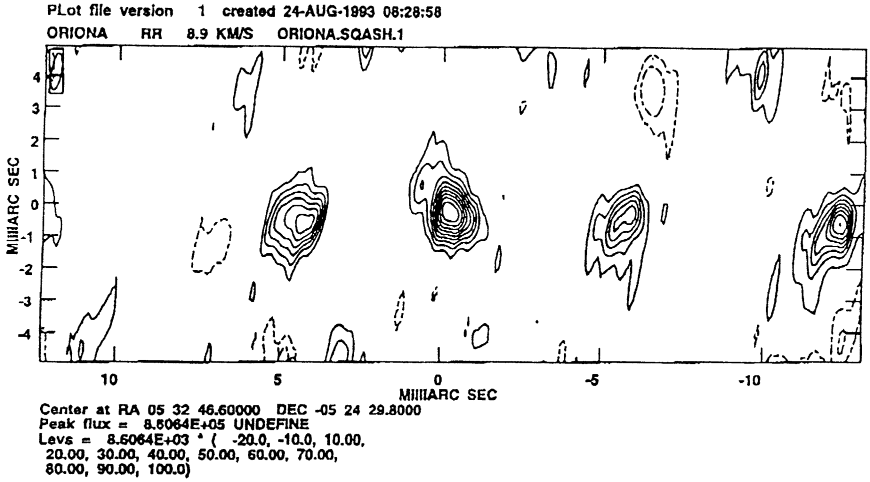

Fig. 1(a). The structure of the H_2O super maser region—4 component chain.

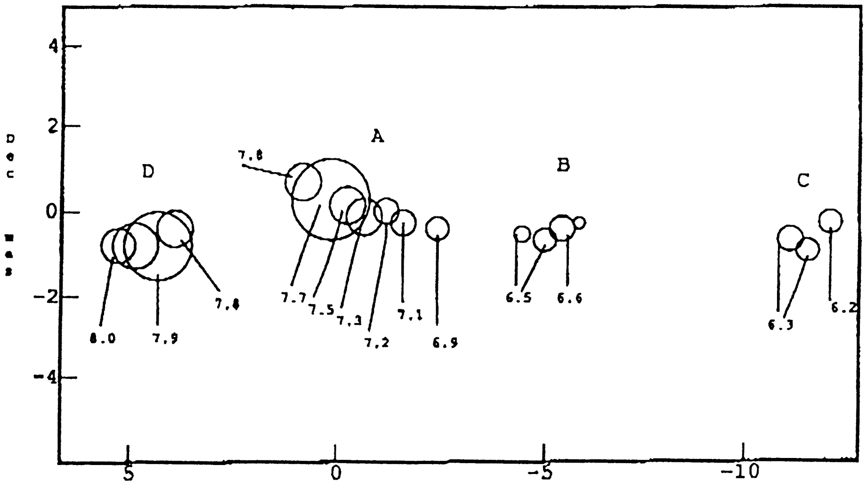

Fig. 1(b). The fine structure of each component of the chain.

The structure of the supermaser region is shown in Figs. 1(a) and 1(b). It consists of four groups of compact components lying along an approximate EW line with a total length of ≈8.5 AU. The size of the each region is ≈0.5 AU (Fig. 1(a)) and the emission corresponds to a flux density of $0.6 \rightarrow 1 \times 10^6$ Jy. The total flux density in the central part of the profile is 2.2×10^6 Jy, the linewidth is 0.65 km/s.

Figure 1(b) shows the distribution of the compact components inside each region. The angular size of the compact components is 0.2 mas or 0.1 AU. The emission of the compact components is concentrated in a narrow line $\Delta V \leq 10$ kHz, with polarization, $P > 85\%$, the flux density of the strongest components is $\approx 10^6$ Jy, corresponding to a brightness temperature $T_b \approx 10^6 \rightarrow 10^{17}$ K. A correlation of location and component velocity is observed (Fig. 2(a)). The velocity gradient of the main group of compact components is 0.32 km/s/mas or 0.64 km/s/AU.

A polarization study of the H_2O supermaser emission showed that the polarization is linear, the value and position angle of the polarization change with velocity (Fig. 2(b)). The maximum polarization is 72% and the position angle at this point is

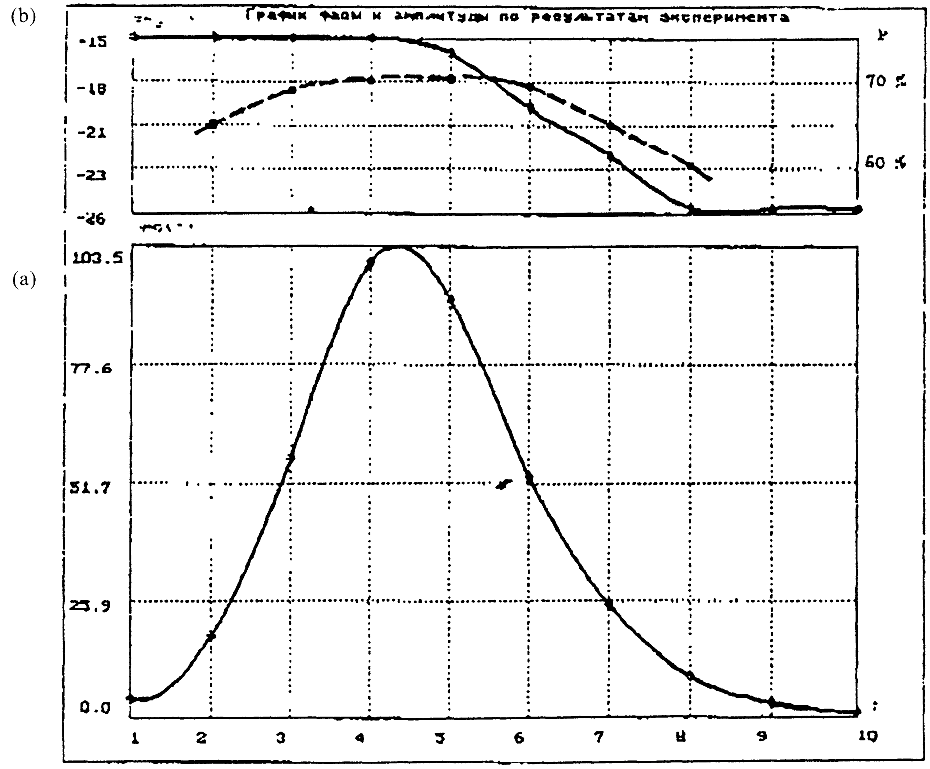

Fig. 2. (a) Profile of the H_2O super maser emission 7.10.1985—bottom. (b) Polarization position angle, (X) - - - - line, polarization value, (P) - ***** line, above.

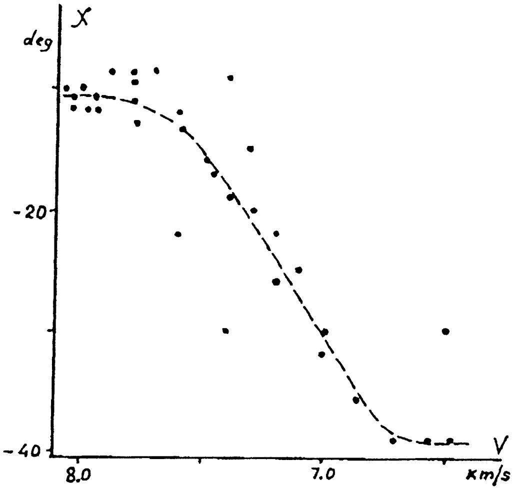

Fig. 3. Polarization position angle—combined from all data.

−16° (7.10.85). A combination of the polarization measurements in period 1983–1987 is shown in Fig. 3. The variation of the polarization position angle as function of velocity is 26°/mas or 13°/AU.

3. Interpretation

The H_2O supermaser emission is much stronger than the IR pumping source so that high directivity of the maser emission is required. The same conclusion follows from the high brightness temperatures of the compact components, which are much higher than the Stark limit. The directivity of the emission should be $<10^{-4}$. The directivity can be determined by a source geometry such as a cylinder or a filament.

The linewidth of the compact component emission corresponds to a cooled gas. For the unsaturated maser regime the kinetic temperature is 100–150 K, that is an optimum temperature for protoplanetary rings formation (PRENTICE, 1980).

The supermaser region has a highly organized structure; a chain of compact components with a velocity and polarization position angle gradient. A magnetic field can not organize parallel filaments of neutral material such as H_2O molecules, but a gravity field can. We propose that we are observing a plotoplanetary disc divided into separate rings. The velocity and position angle gradient of the compact components correspond to rotating and expanding rings (WESTERN and WATSON, 1983, 1984). The strong supermaser emission of the compact components arise along the edge of the rings where the longest path lengths (optical depth) are present. An isotropic IR emission of a protostar would be an anisotropical pump as viewed from the maser rings, because the visible angle of the rings from star is small. The radius of the rings is ≈5 AU and ring thickness is about 0.1 AU. An unsaturated maser with an anisotropical pump has strong linear polarization emission, $P \approx< 100\%$ (WESTERN and WATSON, 1983, 1984).

The H_2O molecules are distributed in the rings inhomogeneously. A rotation of the rings changes the visible part of the ring edge—the optical depth that changes maser emission. The compact components are unsaturated masers with optical depth ≈40. The variation of the optical depth by a few percent would result in emission variability of large magnitude. The optical depth variability is independent for the different rings, that explains the absence of correlation of emission variability of different components, and results in the observed variations of the total-power profile, velocity, polarization value, and position angle of the total emission.

REFERENCES

ABRAHAM, Z., COHEN, N. L., OPHER, R., RAFFAELLI, J. C., and ZISK, S. H., 1981, *Astron. Astrophys.*, **100**, L10–L13.

ABRAHAM, Z., VILAS BOAS, J. W. S., and GIAMPO DEL, L. F., 1986, *Astron. Astrophys.*, **167**, 311.

BURKE, B. F., JOHNSTON, K. J., EFANOV, V. A., CLARK, B. G., KOGAN, L. R., KOSTENKO, V. I., LO, K. Y., MATVEENKO, L. I., MOISEEV, I. G., MORAN, J. M., KNOWLES, S. H., PAPA, D. C., PAPADOPOULOS, G. D., ROGERS, A. E. E., and SCHWARTZ, P. R., 1972, *Soviet Astronomy*, **16**, 379–382.

GARAY, G., MORAN, J. M., and HASCHICK, A. D., 1989, *Astrophys. J.*, **338**, 244.

MATVEENKO, L. I., 1981, *Pis'ma Astron. Zh.*, **7**, 100–105.

MATVEENKO, L. I., GRAHAM, D. A., and DIAMOND, P. J., 1988, *Sov. Astron. Lett.*, **14**, 468–477.

PRENTICE, A. J. R., 1980, *Aust. J. Phys.*, **33**, 623–637.

WESTERN, L. R. and WATSON, W. D., 1983, *Astrophys. J.*, **275**, 195–200.

WESTERN, L. R. and WATSON, W. D., 1984, *Astrophys. J.*, **285**, 158-173.