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A Protoplanetary Disk in V645 Cyg As Seen with H_2O and Methanol Masers

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Abstract. Radio images of maser spots in the infrared source RAFGL 2789, connected with the young stellar object V645 Cyg, have been obtained as a result of radio interferometric observations of the H_2O maser at 22 GHz and the methanol maser at 6.7 GHz, with the VLBI arrays VLBA and EVN. It is shown that the position of the masers coincides with the optical object within $0\farcs2$. The maser spots are located along the line North-South, and their position and radial velocity can be described by a model of a Keplerian disk with a maximum radius of 40 AU for the H_2O maser and 800 AU for the methanol maser. The H_2O and methanol maser spots have not been resolved, and lower limits of the brightness temperature are 2×10^{13} K and 1.4×10^9 K, respectively. A model of the maser is suggested in which the maser emission is generated in extended water and methanol envelopes of icy planets orbiting the young star.

1. Introduction

RAFGL 2789 is an infrared source that coincides with the optical reflection nebula and star-like object V645 Cyg (Cohen 1977). On the optical image there is a star-like condensation N0 and several filamentary nebulae, the brightest of them named N1. Cohen (1977) proposed that this object is connected with a young O7 star, at a distance of 6 kpc (3.5 kpc in Goodrich 1986), and with a mass of $10\,M_\odot$. V645 Cyg is located at the center of a molecular cloud emitting in CO and NH_3 molecular lines (bipolar outflow in CO: Schulz et al. 1989; Torrelles et al. 1987), and at the center of a $7''$ thermal continuum radio source (Skinner, Brown, & Stewart 1993). Lada et al. (1981) have found an H_2O maser at two

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velocities, $-48.9\,\mathrm{km\,s^{-1}}$ and $-44.5\,\mathrm{km\,s^{-1}}$, coinciding in position with the optical object V645 Cyg within 0."2. Thirteen years later, Tofani et al. (1995) have observed this maser with the VLA at velocities $-43.3\,\mathrm{km\,s^{-1}}$ and $-41.0\,\mathrm{km\,s^{-1}}$ at the same position. OH maser emission at frequency 1665 MHz was found by Morris & Kazes (1982) in the radial velocity interval from $-45\,\mathrm{km\,s^{-1}}$ to $-41.6\,\mathrm{km\,s^{-1}}$. Slysh et al. (1999) found a methanol maser at 6.7 GHz in the transition $5_1 - 6_0\,A^+$ in the interval from $-43.5\,\mathrm{km\,s^{-1}}$ to $-40.5\,\mathrm{km\,s^{-1}}$. Since maser emission is associated with early stages of stellar evolution, V645 Cyg must be a protostar or very young star. Study of the fine structure of maser sources, connected with V645 Cyg, could help to understand a mechanism of the interaction between young stars or protostars and surrounding matter. In this presentation we give results of the VLBI study of the H_2O and methanol masers with high (milliarcsec) angular resolution.

2. Observations

The H_2O observations were made on June 6, 1996, as part of a 24-hour VLBA survey of potential VSOP targets of continuum sources at 5 GHz and H_2O maser targets (Migenes et al. 1999). The source RAFGL 2789 was observed at 22.235 GHz for 5 minutes; the polarization was left-hand circular. The data reduction was made using the AIPS software system with details given in Migenes et al. (1999). The synthesized beam was 1.0×0.3 mas, with the position angle 7″. The bandwidth of 8 MHz was divided into 512 spectral channels, providing a spectral resolution of 15.6 kHz per channel or $0.21\,\mathrm{km\,s^{-1}}$. The noise of the cleaned image corresponded to the weakest details of about $3\,\mathrm{Jy\,beam^{-1}}$ ($3\,\sigma$ level).

Methanol observations were made in the transition $5_1 - 6_0\,A^+$ at the frequency 6.7 GHz with the EVN (European VLBI) in 1998 and 2000. Five telescopes have taken part: Effelsberg 100 m, Jodrell Bank 25 m, Medicina 32 m, Onsala 25 m, Torun 32 m. In 1998, RAFGL 2789 was observed during four 10-minute intervals, in 2000 during three. The synthesized beam was 4.3×8.2 mas. The bandwidth of 2 MHz was divided into 1024 spectral channels, providing a spectral resolution of 1.95 kHz per channel or $0.088\,\mathrm{km\,s^{-1}}$. The noise of the cleaned image corresponded to the weakest details of about $3\,\mathrm{Jy\,beam^{-1}}$ ($3\,\sigma$). The post-processing was done in standard VLBA manner (Diamond 1995) with the AIPS package including amplitude calibration, fringe fitting, determination of absolute position and mapping of the maser spots.

Relative positions of the H_2O and methanol maser spots are given in Table 1. Fig. 1 shows positions of the H_2O maser spots relative to the reference feature at velocity $-51.8\,\mathrm{km\,s^{-1}}$, and spectra of both the methanol and water vapor masers. The maps of methanol masers obtained for two epochs are shown in Fig. 2. The map of the H_2O maser, as well as the relative positions of the methanol and H_2O masers, are shown in Fig. 3. Finally, Fig. 4 presents a velocity-position diagram for masers in both molecules and a sketch of the proposed disk model explaining the observed velocity and positional properties of these masers.

Table 1. Relative positions of the H_2O and CH_3OH maser spots.

		CH_3OH (1998)			CH_3OH (2000)		
Feature	V_{LSR} km s^{-1}	$\Delta\alpha cos\delta$ mas	$\Delta\delta$ mas	Flux density Jy	$\Delta\alpha cos\delta$ mas	$\Delta\delta$ mas	Flux density Jy
A	−43.4	76.0	−45.1	2.0	77.7	−45.4	2.5
B	−42.5	85.0	−65.0	2.5	83.5	−64.4	1.2
B_1^*	−42.8	83.7	−63.2	1.0	82.8	−64.7	0.9
C	−40.8	82.9	−134.2	2.0	82.8	−134.5	1.7
D	−40.4	94.2	−143.2	2.2	94.1	−143.3	3.0
		H_2O (1996)					
	−54.3	0.40	0.22	4.7			
	−51.8	0.03	0.00	36.0			
	−50.5	−3.76	−4.16	1.8			
	−49.5	−0.27	−0.04	10.0			
	−48.2	−0.80	−0.06	0.6			
	−41.6	0.38	8.10	6.6			
	−41.0	0.40	8.04	6.4			
	−39.0	0.45	7.71	7.3			

* This feature corresponds to the wings of the line at $-42.5\,\mathrm{km\,s^{-1}}$.

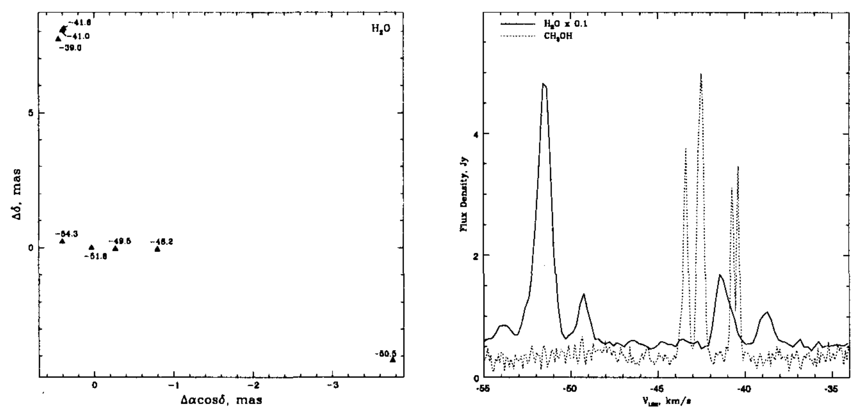

Figure 1. Positions of the H_2O maser spots relative to the reference feature at velocity $-51.8\,\mathrm{km\,s^{-1}}$ *(left)*. Spectra of the H_2O (*solid line*) and CH_3OH (*dashed line*) masers are shown in the *right panel.*

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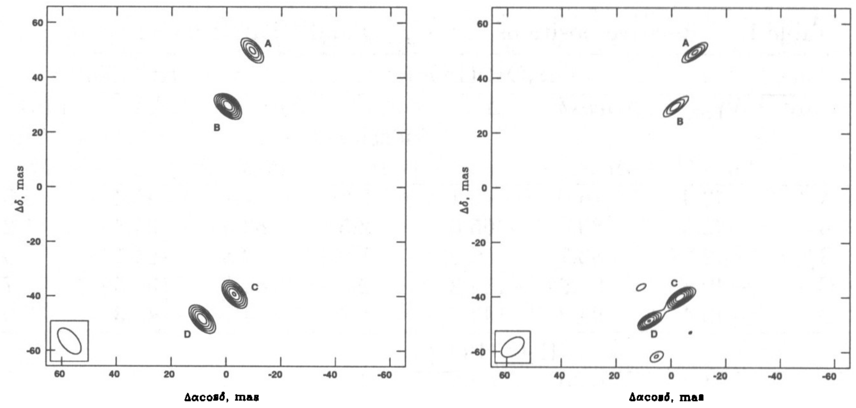

Figure 2. Map of the methanol maser. *Left panel:* observations of 1998, with contours at 0.22×(4, 5, 6, 7, 8, 9) Jy/beam. *Right panel:* observations of 2000, contours are 0.35×(4, 5, 6, 7, 8, 9) Jy/beam. A, B, C, D – components at velocities −43.4, −42.5, −40.7 and −40.4 km s^{-1}, respectively.

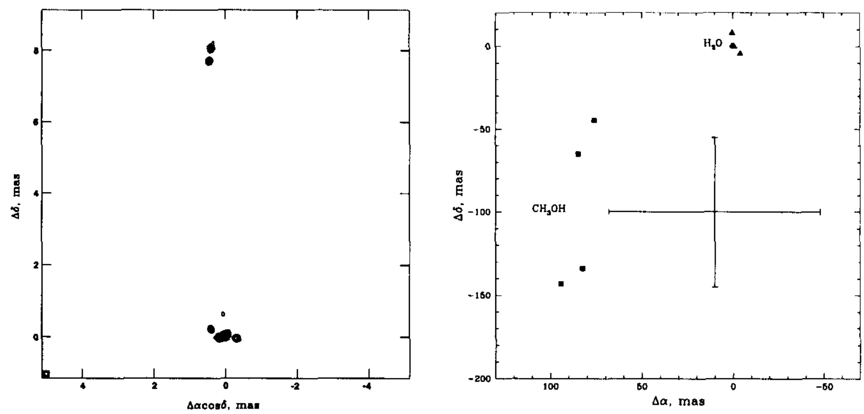

Figure 3. The *left figure* is a map of the H_2O maser. The brightness of every point is the maximum brightness of the maps in every spectral channel at every definite point. The *right figure* shows relative positions of the methanol and H_2O maser spots. The positional uncertainty between the H_2O and methanol masers is indicated by cross bars.

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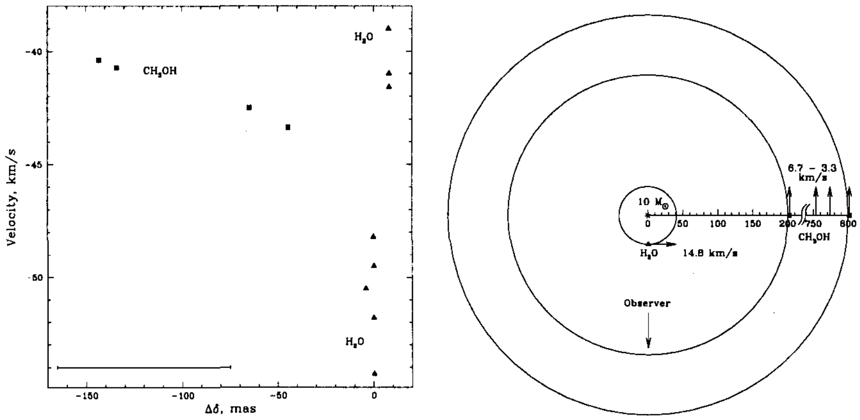

Figure 4. The *left figure* is a declination – velocity diagram for the maser spots in the direction North-South. The uncertainty of the relative position of the H_2O and methanol masers is shown in the left lower corner. The *right figure* is a sketch of the disk in RAFGL 2789. *Numbers:* distance from the star in AU; *arrows:* direction and value of the orbital velocity of the H_2O and methanol masers.

3. Discussion and Conclusion

The linear structure of the H_2O and methanol masers can be modeled by a disk rotating around a central protostar N0. If the mass of the central young star (or protostar) is $10\,M_{\odot}$, and the distance is 6 kpc, the H_2O maser components are located at a distance 40 AU from the star and the methanol maser components at a distance 200 – 800 AU. Physical objects responsible for the maser emission could be solid bodies with ice covered surfaces. The sublimation of ice composed of a mixture of water and methanol, as in mantles of interstellar dust particles and comets (Dartois et al. 1999, Shutte et al. 1996), could be a source of gaseous methanol and OH (from H_2O dissociation) in a shell around the solid bodies. The OH and methanol masers are generated in these shells. The proposed planets are rather similar to Edgeworth-Kuiper belt objects in the solar system (Slysh et al. 1999). So far as the thermal emission from the proposed planets is strongly masked by the emission from hot dust in the compact HII region, it seems that, at present, there are no other means of detecting very distant planetary bodies except by their maser emission.

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