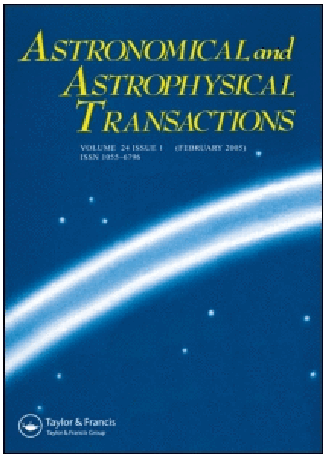


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# Water masers in red supergiants

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Results of long-term monitoring of circumstellar water maser sources in red supergiants are reviewed. The observations were carried out in 1980–2006 on the RT-22 radio telescope at Pushchino Radio Astronomy Observatory. We discuss the results for the semiregular variable M-supergiant VX Sgr and non-variable M-supergiant IRC–10414. In addition to our single-dish data, very-long-baseline interferometry results are invoked. VX Sgr and IRC–10414 display a characteristic water line profile, which suggests the presence of a rotating circumstellar disc and a bipolar outflow.

*Keywords*: Red supergiants; Mass loss; Circumstellar envelopes; Molecular lines; Masers

## 1. Introduction

Several hundreds of late-type variable stars are known to be sources of maser radio emission in molecular lines (OH, water ($H_2O$) and SiO) (see the references in [1, 2]). This emission is highly time variable, especially in the $6_{16}-5_{23}$ $H_2O$ rotational line at $\lambda = 1.35$ cm. To understand the nature of the $H_2O$ maser variability, in 1980 our team began $H_2O$ line monitoring of a sample of circumstellar masers including several M-supergiants (NML Cyg, VY CMa, VX Sgr, S Per and some others). Most of these are classified as semiregular variable stars with slow optical variations. Their variability differs from those of late-type giants by considerably longer periods (or timescales) of light variations. The $H_2O$ maser emission of M-supergiants is also variable, and changes in the $H_2O$ line flux density may exceed two orders of magnitude.

In supergiant stars the structure of the $H_2O$ line profile is by far richer and more diverse than in giants. In supergiants, the $H_2O$ line profile may contain up to a dozen emission peaks,

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spread in a radial-velocity interval $\Delta V_{LSR}$ of $30\,km\,s^{-1}$ or broader. In the $H_2O$ line profile of giants, in contrast, usually only one or two features are observable, and $\Delta V_{LSR}$, as a rule, does not exceed $5\,km\,s^{-1}$. This reflects a more complicated structure in circumstellar envelopes of the supergiants and higher expansion velocities of their circumstellar material compared with the giant stars. A study of the $H_2O$ maser variations in M-supergiants and comparison with their light variations in the optical range can give a deeper insight into the problem of circumstellar $H_2O$ masers in these stars.

In this report, we discuss our results on two stars: VX Sgr and IRC–10414.

## 2. Observations

Radio observations of the $H_2O$ line at $\lambda = 1.35$ cm have been performed since 1980 on the 22 m radio telescope at Pushchino Radio Astronomy Observatory (Astro Space Center of the Lebedev Institute of Physics, Russian Academy of Sciences) [1]. We use a 1.35 cm wavelength receiver with a helium-cooled field-effect transistor amplifier and a 128-channel filter-bank spectrometer with a resolution of $0.1\,km\,s^{-1}$. Since December 2005 we also use for spectral analysis of the signal a 2048-channel autocorrelator with a total bandwidth of $168\,km\,s^{-1}$ and a velocity resolution of $0.082\,km\,s^{-1}$. Intervals between consecutive observing sessions normally do not exceed 1–2 months.

## 3. VX Sagittarii

The $H_2O$ maser in VX Sgr was detected first by Dickinson *et al.* [3]. We have extensively observed this star since 1981. Some results were published in [4, 5]. A sample profile of the $H_2O$ line in VX Sgr is given in figure 1. The $H_2O$ very-long-baseline interferometry (VLBI) data [6] suggest that the $H_2O$ masers in VX Sgr trace a structure consisting of a ‘circumstellar disc + bipolar outflow’. In [4] we proposed such a model (figure 2(a)) to fit the observed

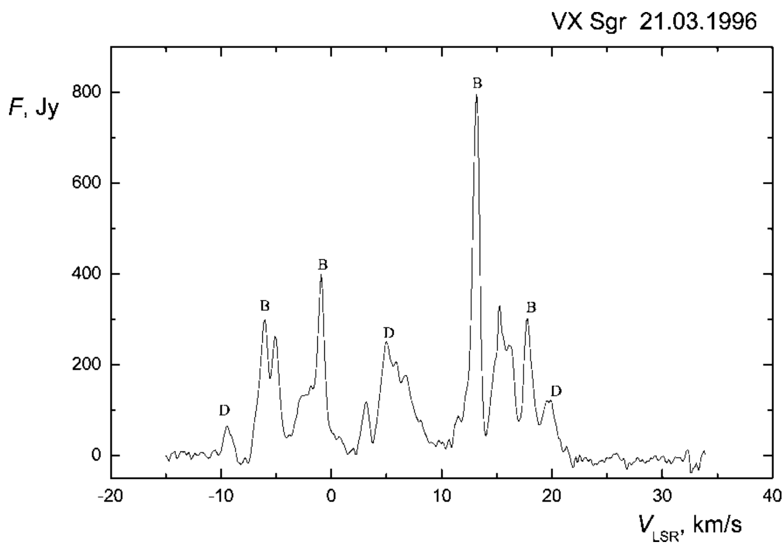


Figure 1. $H_2O$ line profile of the star VX Sgr measured on 21 March 1996.

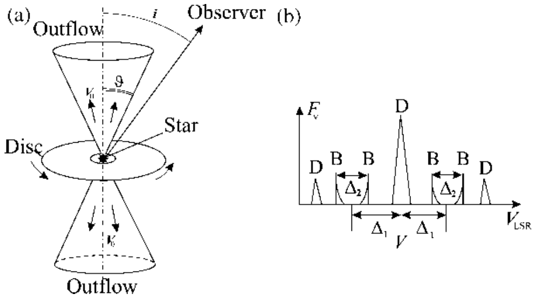


Figure 2. (a) The model for the $H_2O$ maser in VX Sgr. (b) The line profile in this model; emission features produced by the disc are labelled D, and those radiated in the bipolar outflow are labelled B.

profile with the groups of emission features in figure 1. Lateral peaks (labelled D) are formed in the limb parts of the disc. In a Keplerian disc their line-of-sight velocities are

$$V_D = V_* \pm \left(\frac{GM_*}{R_e}\right)^{1/2} \sin i,$$

where $V_*$ is the stellar systemic velocity, $G$ is the gravity constant, $M_*$ is the stellar mass and $R_e$ is the external radius of the disc. The central D peak is at the stellar velocity $V_*$ (+5.5 km s$^{-1}$ for VX Sgr [5]). In a bipolar outflow expanding at velocity $V_0$, pairs of B features are formed with spacing $2\Delta_1 = 2V_0 \cos i$ between pair centres and spacing $\Delta_2 = 2V_0 \sin\vartheta \sin i$ between the features in each pair (figure 2(b)). Estimates in [4] show that that the opening angle $\vartheta$ of the bipolar outflow of VX Sgr is about 60°, and the angle of inclination $i$ of the outflow axis to the line of sight is also 60°. Another source, IRC–0414, has quite a similar $H_2O$ line profile to that of VX Sgr.

## 4. IRC–10414

IRC–10414 is an interesting object, for which it was not clear until recently whether it is a young stellar object or an evolved star. The distance is 710 pc [7]. It is quite close to the Galactic plane, $b = -0.1°$, and its $z$ coordinate with respect to the plane is only 1 pc. It is observed towards the association Sco OB3 and probably belongs to it. It is a star classified by Jura and Kleinmann [7] as an object with a very dusty ('dust-enshrouded') circumstellar envelope. The optical spectrum is M6.5 [8]. The star is not variable. Photometric observations [9] from Julian date (JD) 2 449 824 to 2 450 716 showed no variations in *JHKL* bands exceeding a magnitude of ±0.05. This object is an infrared source according to the infrared camera survey; in the optical region it is a star of magnitude $V = 8.8$ (SIMBAD database). Other names for this object are IRAS 18204–1344, OH 17.55–0.13 and RAFGL 2139. The $H_2O$ maser emission was detected by Kleinmann *et al.* [10] on 13 July 1977. Lada *et al.* [11] made a VLBI observation of IRC–10414 (named GL 2139 in their paper). The exact maser position was measured. It coincides with that of the optical star. However, the maser itself remained unresolved. The only result is that all maser features are concentrated within 0.02″ of the position of the main feature at 45 km s$^{-1}$. The $H_2O$ line profile of IRC–10414 is quite similar to that of VX Sgr. This also suggests a model with a rotating circumstellar disc and a bipolar outflow (figure 2(a)). The model is supported by VLBI observations of SiO masers in IRC–10414 [12], which imply that SiO masers are localized in a circumstellar ring. However,

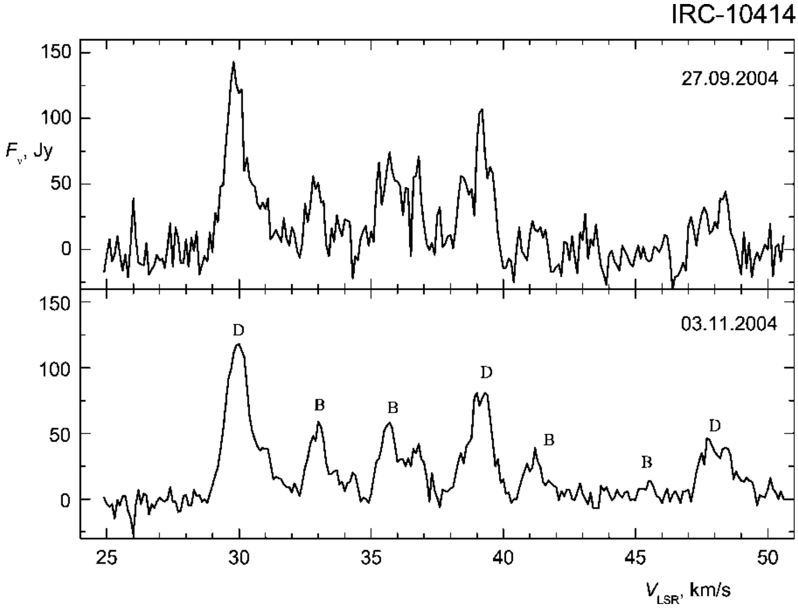


Figure 3. $H_2O$ line profiles of the star IRC–10414 measured in September and November 2004.

in view of the lack of a VLBI map of the $H_2O$ maser in IRC–10414, we cannot estimate the parameters of the disc or outflow in this star. The *lower limit* that can be set from the $H_2O$ profile of figure 3 (spacings $\Delta_1$ and $\Delta_2$ in figure 2(b)) on the bipolar outflow velocity $V_0$ is about 3–5 km s$^{-1}$. The minimum Keplerian velocity estimated from the half-difference between $V_{LSR}$ of the lateral D peaks is 6.5 km s$^{-1}$.

## 5. Conclusions

Our observations of the $H_2O$ masers in the circumstellar envelopes of the M-supergiants VX Sgr and IRC–10414 demonstrate their close similarity. A model is proposed in which the complex profiles of the $H_2O$ lines emitted by these stars fit into a model of a rotating circumstellar disc and bipolar outflow.

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