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Letter to the Editor

Detection of 1612 MHz OH emission in the semiregular variable stars RT Vir, R Crt and W Hya

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Abstract. We present evidence of 1612 MHz emission in SR variable stars. The two SRb, RT Vir and R Crt, as well as the SRa W Hya have been monitored with the upgraded Nançay radio telescope since February 2001. All three objects have shown a weak 1612 MHz emission occuring in the velocity range of the strongest emission observed in the main-lines. Such a detection is the second observational evidence for emission in the 1612 MHz OH maser satellite line from SRb stars. It also confirms the presence of 1612 MHz emission in the SRa W Hya discovered by Etoka et al. (2001). Such a finding strongly suggests that the shell properties of those three objects are quite similar to those of the Mira stars with similar IR characteristics.

Key words. masers – stars: variable – stars: AGB and post-AGB – circumstellar matter – stars: individual: RT Vir, R Crt, W Hya

1. Introduction

Semiregular variable stars (SR) are at the centre of various recent studies and their location in the evolutionary scheme is still not clear. They were primarily thought to precede the Mira phase (Kershbaum & Hron 1992) but new results suggest that they may be as evolved as Miras (Etoka et al. 2001). The semiregulars were originally separated into 4 groups in the GCVS catalogue: SRa, SRb, SRc and SRd according to their optical periodicities. The SRa and SRb groups are composed of late-type giants with optical periodicities quite close to those of Miras. Their optical variabilities and infrared properties are currently studied by various authors (cf. Kerschbaum et al. 2001, and references within) in an attempt to classify them in a more sophisticated way. As for many semiregulars, RT Vir, R Crt and W Hya are all CO (Kahane & Jura 1994; Kerschbaum & Olofssson 1999) and H_2O emitters (Szymczak & Engels 1995; Mendoza-Torres et al. 1997; Lekht et al. 1999). RT Vir, R Crt and W Hya have been monitored for 20 years at the Nançay radio telescope and their OH variability and polarization behaviour over the period 1982–1995 have been studied by Etoka et al. (2001) and Szymczak et al. (2001) respectively. All three stars show multi-periodicity in OH (Etoka et al. 2001). Overlap of mass-loss properties of SR and O-rich Mira variables has been mentioned by Kerschbaum et al. (1996). In particular, the IR characteristics of semiregulars are quite close to those of type I Miras, i.e., emitting only in the 1665/67 MHz main-lines. Therefore, their circumstellar shell was so far thought to be too thin to sustain any 1612 MHz emission. Nevertheless, a few SR have already been successfully detected at 1612 MHz so far: the SRb AU Vul (Eder et al. 1988), the two SRa U Men and VZ Vel (teLintel Hekkert 1991) and recently W Hya has been found to be faintly emissive at 1612 MHz by Etoka et al. (2001). In this note, we confirm that emissivity and present the 1612 MHz variability observed over more than 1.5 year. Also, we report the second observational evidence for OH 1612 MHz emission from SRb.

2. Observations

Observations were made with the Nançay radio telescope. The half-power beamwidth at 1.6 GHz is 3.5′ in α and 19′ in δ. A cooled dual channel receiver was used to record both left- and right-handed circular polarizations (LHC, RHC). The 8192−channel autocorrelation spectrometer was divided into 8 banks of 1024 channels each, allowing simultaneous observations of the three OH lines at 1612, 1665 and 1667 MHz in both circular polarizations with a high velocity resolution. For RT Vir and W Hya a bandwidth of 195 kHz was used leading to a velocity resolution of 0.0355 km s^{-1} at 1612 MHz and 0.0343 km s^{-1} at 1665/67 MHz. For R Crt a bandwith twice larger was used leading to a velocity resolution of 0.0709 km s^{-1} at 1612 MHz and 0.0686 km s^{-1} at 1665/67 MHz. Most of the observations lasted from 40 to 60 min providing typical 3σ sensitivities of 0.12 and 0.10 Jy respectively. A few observations were taken for only 20 min reaching a typical 3σ sensitivity of about 0.2 Jy. All the radial velocity given hereafter are relative to the Local Standard of Rest (LSR).

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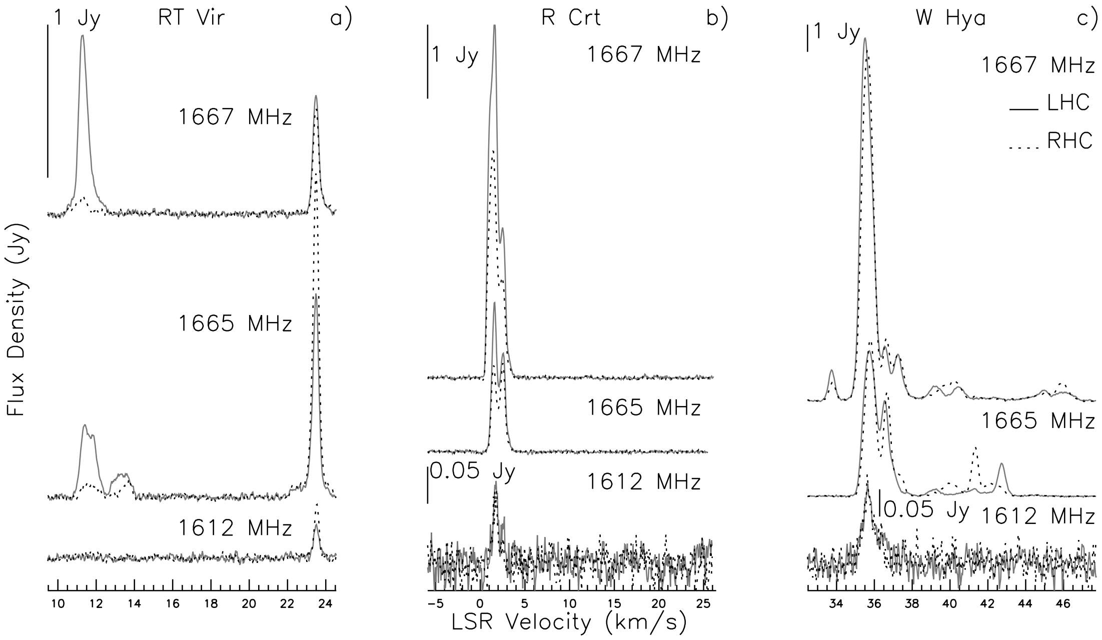

Fig. 1. **a)** Integration-time weighted average of all RT Vir spectra taken from 2001/04/19 to 2002/10/15 at 1667, 1665 and 1612 MHz in both LHC and RHC polarization. **b)** Same for R Crt between 2001/08/26 and 2002/10/08. **c)** Same for W Hya between 2001/02/27 and 2002/10/15. The 3σ for the averaged spectra range from 0.037 Jy to 0.04 Jy.

3. Results

3.1. Spectra

Figure 1 shows the average of all the spectra taken, weighted according to the integration time, for all the three sources in the three OH maser-lines in LHC and RHC polarization. In each case 1612 MHz emission was detected at the velocity of the strongest 1665 and 1667 MHz emission.

RT Vir 1612 MHz, only detected in the red-shifted peak, shows right-handed polarization of the same order as that observed at 1665 MHz ($m_{\rm C(1612\ red\ peak)} = (F_{\rm LHC} - F_{\rm RHC})/(F_{\rm LHC} + F_{\rm RHC}) \simeq -23.5\%$, and $m_{\rm C(1665\ red\ peak)} \simeq -22.7\%$ where "F" stands for the Flux Density).

The spectral profile of the R Crt OH maser lines did not show any red counterpart for the duration of the monitoring. The 1612 MHz maser emission detected from R Crt shows a similar spectral shape to that observed in the main-lines: the blue-shifted peak is composed of 2 spectral components centred at $V \simeq 1.75$ and 2.65 km s^{-1}. The mean degree of circular polarization ranges from $m_{\rm C} = -6\%$ (for the spectral component centred at $V \simeq 1.75$ km s^{-1}) to $m_{\rm C} = -29\%$ (for the spectral component centred at $V \simeq 2.65$ km s^{-1}) leading to a similar mean degree of circular polarization to that observed at 1665 MHz, though interchanging the relative strength of the 2 spectral components (i.e., $m_{\rm C} = -6\%$ for the spectral component centred at $V \simeq 2.50$ km s^{-1} and $m_{\rm C} = -27\%$ for the spectral component centred at $V \simeq 1.50$ km s^{-1}).

For W Hya, the 1612 MHz blue-shifted peak is composed of 2 spectral components as at 1665 MHz. Those spectral components, centred at $V \simeq 35.66$ and 36.08 km s^{-1}, have a similar intensity ratio to the 2 spectral components observed at 1665 MHz.

3.2. OH variability

The variation of the peak intensities measured during the whole period of the observations for each source for all the three lines is shown Fig. 2. For RT Vir, the stronger and therefore better defined 1612 MHz variability curve in RHC polarization shows roughly a similar trend to that observed for the main-lines for the same peak with somewhat fainter amplitude variation ($\Delta I_{\rm 1612(red)}$ = Max_amplitude/Min_amplitude $\simeq 2$, $\Delta I_{\rm 1665(red)} \simeq 3.5$ and $\Delta I_{\rm 1667(red)} \simeq 10$) suggesting greater maser saturation.

The number of points of observations for R Crt is unfortunately not sufficient to reveal a significant trend. Nevertheless, a lower limit for the amplitude variation can be inferred: $\Delta I_{\rm 1612(blue)} \geq 2.3$, $\Delta I_{\rm 1665(blue)} \geq 2.5$ and $\Delta I_{\rm 1665(blue)} \geq 1.8$ suggesting a fairly similar saturation rate for all the three OH maser lines.

The peak intensity variability curves of W Hya reveal a surprising trend: there is a phase opposition between the variability curve of the 1612 MHz satellite line and that of the main-lines. This behaviour is similar to that studied by Etoka & Le Squeren (1997) during the flare event undergone by U Her at 1612 MHz between 1984 and 1989. This trend cannot be explained if the 1612 MHz emission originates from the same part of the shell as the main-lines, unless a competitive maser pumping scheme is involved between the 1612 MHz satellite line and the main-lines, or two uncorrelated pumping inputs are at work.

4. Discussion

In Table 1 we summarize some of the velocity characteristics of the OH maser emission for the peak where the 1612 MHz has been detected for all the three sources.

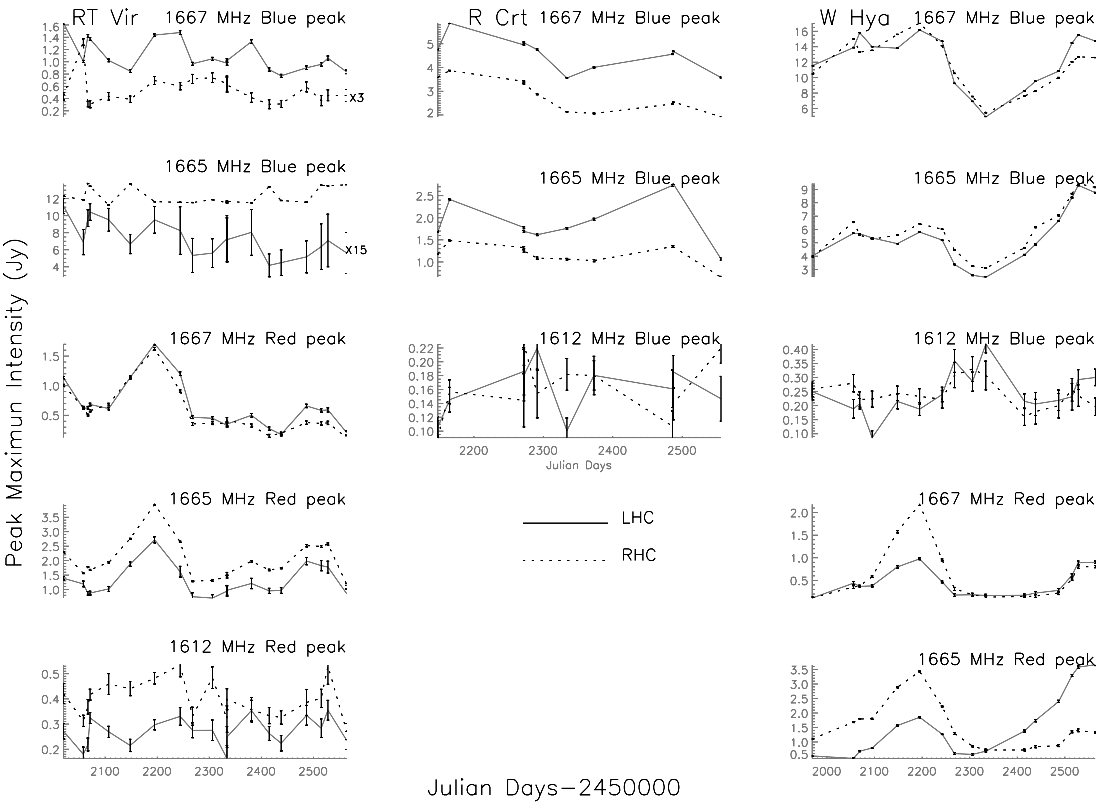

Fig. 2. Variability of the peak maximum intensity of the 3 sources over the period of the observations. The σ reached for each observation is given by the size of the error bars displayed.

Table 1. Peak intensity ratios and velocity of the peak for the 3 OH maser lines for which the 1612 MHz emission has been detected.

	Peak*	Peak_int						V_{peak}					
		1612/1665		1612/1667		1665/1667		1667		1665		1612	
		LHC	RHC	LHC	RHC	LHC	RHC	LHC	RHC	LHC	RHC	LHC	RHC
RT Vir	red	0.165	0.166	0.285	0.515	1.723	3.101	23.501	23.504	23.489	23.489	23.510	23.560
R Crt	blue	0.055	0.082	0.023	0.032	0.417	0.391	1.576	1.430	1.607	1.485	1.751	1.801
W Hya	blue	0.028	0.029	0.011	0.013	0.399	0.446	35.506	35.629	35.741	35.765	35.661	35.611

* corresponding to the doppler-shifted peak where the 1612 MHz maser emission has been detected.

Considering the standard model (cf. Reid et al. 1977) in which the expansion velocity of the shell increases with the radius (Olnon 1977; Elitzur 1981; Chapman & Cohen 1986), the peak velocities inferred for RT Vir (given Cols. 9–14 of Table 1) agree with the expected sequence in maser emission: 1665/1667/1612 MHz (i.e., where the 1665 MHz emission is the closest to the star and that at 1612 MHz the furthest). On the other hand, R Crt 1612 MHz emission peaks at a velocity 0.15–0.3 km s^{-1} closer to the stellar velocity ($V_* = 10.2 \pm 0.6$ km s^{-1}, Wallerstein & Dominy 1988) than the 1665 MHz emission. This would put the 1612 MHz emission internal to that of the main-lines. For W Hya – excluding the very-blue-shifted components observed at 1667 MHz which most probably comes from a detached shell (cf. Etoka et al. 2001) – the peak velocities inferred in the three lines are not inconsistent with an external 1612 MHz emission.

For both R Crt and W Hya, no significant circular polarization at 1612 MHz has been found (cf. Fig. 2). Only RT Vir shows a significant circular polarization at 1612 MHz of about $m_C = -23\%$, of the same order to that observed at 1665 MHz for the same velocity range.

1612 MHz emission has been detected only for the range of velocity where strong 1665 MHz emission is observed. Indeed, for RT Vir no 1612 MHz emission has been detected in the blue-shifted part of the spectrum even though the 1667 MHz blue-shifted peak is 1.5 stronger than the red-shifted one in the LHC polarization. Nevertheless, the strong circular polarization observed for that part of the spectrum in the main-lines may play a role in the quenching of the 1612 MHz which usually shows faint polarized emission for Miras and OH/IR stars (cf. Zell & Fix 1991 for the OH/IR & Etoka et al. 2000 for the Miras).

Columns 3–8 show the ratios of the peak maximum intensity of the averaged spectra relative to the three OH lines for the peak in which 1612 MHz has been detected. The strongest ratios of the 1612 MHz satellite line flux over the main-line flux was surprisingly found for the SRb's (as high as 0.5 for "1612/1667" and 0.166 for "1612/1665" for RT Vir) while the SRa W Hya shows the faintest one (less than 0.03 for both "1612/1667" and "1612/1665"). Applying those ratios for the peak where no signal has been detected at 1612 MHz for RT Vir and W Hya gives an expected emissivity threshold of 0.016 Jy (in RHC) and 0.083 Jy (in LHC) for RT Vir and 0.014 Jy (in RHC) and 0.033 Jy (in LHC) for W Hya, all smaller than the 0.1 Jy 3σ reached after one hour of observation.

Cohen's review (1989; Fig. 1) presents a plot of the ratio of OH peak flux density at 1667 and 1612 MHz against the ratio of IRAS fluxes at 25 and 12 μm from Kirrane's work (1987) on Miras and OH/IR stars. The ratios "1612/1667" inferred here and the 12 and 25 μm IRAS fluxes of all the three sources are consistent with the track drawn by the Type I Miras.

Sivagnanam et al. (1988; Fig. 2) present a color-color diagram based on uncorrected 12, 25 and 60 μm IRAS fluxes of Miras. Using the same definition for the color indices as the previously mentioned authors (i.e., $[\lambda_1 - \lambda_2] = \log(\frac{\nu_1 S_\nu(\lambda_1)}{\nu_2 S_\nu(\lambda_2)})$) R Crt and RT Vir with similar [25−12] and [60−25] color indices (with mean values of $[25{-}12] = -0.63$ and $[60{-}25] = -1.15$) would lie in that thin area of transition between Type I and Type II Miras. W Hya (with $[25{-}12] = -0.86$ and $[60{-}25] = -1.16$) would lie in the far left end of the track in that diagram where non-OH Miras are found, which rather suggests a very hot dust shell (cf. Szymczak et al. 1995). A hotter dust shell for W Hya than for the two SRb is actually consistent with fainter intensity ratios "1612 MHz/main−lines" since a hotter environment means less favourable conditions for the 1612 MHz inversion.

Lorenz-Martin & Pompeia (2000) modelled oxygen-rich dust envelopes for 3 categories of objects, namely the *Broad* class stars, *intermediate* class stars and *Sil* stars following the classification suggested by Little-Marenin & Little (1988, 1990) which was based on the shape of the IRAS LRS spectra. Lorenz-Martin & Pompeia modelling sustains the proposition of Little-Marenin & Little of an evolutionary sequence from the first type of objects to the third one respectively. In this scenario, RT Vir & R Crt, belonging to the *intermediate* class would therefore be already quite evolved stars.

The fact that the circumstellar shell of SR can sustain 1612 MHz emission shows that there is enough OH on the amplification path to invert the line. This is another conclusive hint (with their long OH periods and great OH expansion velocities, cf. Etoka et al. 2001) that those three particular stars and probably all the semiregulars with a thick enough circumstellar shells to exhibit OH maser emission, are most certainly as evolved as Miras. The non-detection of 1612 MHz emission toward these objects so far is solely due to the fact that this emission is quite faint. Undoubtedly, the increased sensitivity of the upgraded Nançay telescope allowed us to bring to light this phenomenon.

5. Conclusion

We have presented observational evidence for 1612 MHz emission in SR. The variability curve of the 1612 MHz emission of W Hya is in phase opposition with that observed in the main-lines, implying either a competitive maser pumping scheme or two uncorrelated pumping inputs. Surprisingly, the strongest ratio of the 1612 MHz satellite line flux over the main-line fluxes was found for the SRb's while the SRa W Hya shows the faintest one. The peak velocities for both RT Vir and W Hya are consistent with 1612 MHz emission originating further out than the main-lines, assuming the standard expansion model. For R Crt, the peak velocities are such that the 1612 MHz emission could be interior to that of the main-lines. Monitoring of this emission continues in order to make a detailed comparative study of the main-line variability and spectral changes with those of the newly detected 1612 MHz line.

Some interferometric mapping of the emission would be of great use to determine the location of the 1612 MHz satellite emission in comparison with that of the main-lines and provide a deeper insight of the structure and dynamics of those objects.

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