A study of the H_2O maser emission from R Cas

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Abstract.   Over the past decade we observed a sample of late-type stars
(supergiants, semi-regular variables, OH/IR stars, and Mira's) 3–4 times
per year in the 1.3-cm line of H_2O. The observations were carried out with
the Medicina 32-m and the Effelsberg 100-m telescopes. In addition, a
sub-sample of these stars was observed at several epochs with the VLA.
In our analysis we also use data from the literature, for instance on mass
loss and optical variability. The aim is to investigate the properties of the
circumstellar outflows and to elucidate the maser-pumping mechanism.
In the conference poster we presented some preliminary results of a 4-
star sub-set of the data base; in the small space available here, we briefly
describe the monitoring program, and discuss the Mira-variable R Cas in
some detail.

1.   Introduction

Maser emission from the $6_{16} - 5_{23}$ rotational transition of water at 22 GHz is
a common feature in circumstellar shells; so far, it has been detected in the
envelopes of about 500 stars (DEC> $-30°$; Valdettaro et al. 2001). The masers
are strongly variable, sometimes in phase with the luminosity variations of the
central star, and sometimes erratically, including spectacular flares.
Because of the high excitation of the emitting level (650 K above ground) the
masers must be located in the circumstellar envelope fairly close to the star (at
distances of $\lesssim 10^{15}$ cm), thus tracing the mass motions close to the regions
where the mass loss starts. The high variability of the maser emission may
therefore reflect the turbulent motions in these regions, indicating that the mass
loss process is not a smooth outflow, but may occur in blobs. The individual
peaks in the spectra correspond to individual maser spots in spatial maps, and
these might be interpreted as such blobs, or density enhancements.
In 1990 we started an extensive observing program of several tens of late-type
stars, primarily with the Medicina 32-m and Effelsberg 100-m telescopes, sup-
plemented by observations with the VLA, and the ISO satellite. The scientific
aims of this monitoring campaign are to analyze the maser variability as a func-

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tion of both time and stellar parameters (optical/IR variability, mass loss rate, spectral type, IR colours). In particular we attempt to:

• determine typical sizes and numbers of maser components;
• estimate lifetimes of maser features and timescales for change;
• derive thickness and radial distance of the maser shell as a function of stellar variations (energy output and mass-loss rate);
• probe the influence of the pumping conditions on the observed maser properties.

The campaign was most active in the period 1990-1995, but we have continued single-dish observations of a sub-sample of stars up to the present day. In addition, for several of the stars we have (Medicina) observations between 1987-1990, taken from the Arcetri archives.

We have started the analysis of those stars for which we have a significant time-coverage of the maser emission. As an example of the available data, we here present preliminary results of one of these stars, R Cas (Mira). Fig. 1 gives a graphical representation of the behaviour of the maser flux density versus velocity as a function of time.
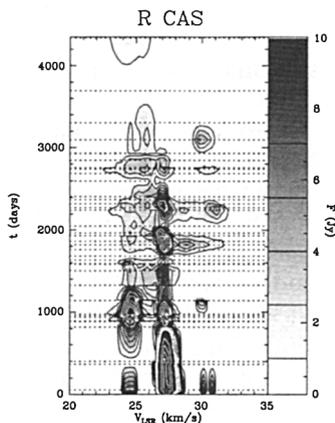

Figure 1. Grey-scale plots and contour map of the H_2O flux density versus velocity as a function of time for R Cas. The horizontal dotted lines indicate when a spectrum is available; observations separated by less than 10^d were averaged. Between adjacent observations linear interpolation was performed. Contour values (start(step)end) are 1(1.5)8.5 Jy (black); 10(5)30, 100(50)300 Jy (white). The grey scale has been adjusted to bring out the low-level emission. The velocity resolution is 0.33 km s^{-1}

2. Observations and Results

The observations were carried out with the Medicina 32-m and the Effelsberg 100-m antennas. The Medicina telescope HPBW at 22.2 GHz is $1.'9$. The pointing accuracy is better than $\sim 25''$. We estimate an uncertainty of $\sim 30\%$ on the absolute flux scale, and a typical 1σ rms noise of ~ 1.5 Jy. The Effelsberg HPBW is $40''$; the pointing accuracy is better than $\sim 8''$. Typical rms values are 0.2 Jy.

The observational results cover the period from 10 Sept. 1987 to 31 July 1999. The time-velocity-flux density plot in Fig. 1 shows that the maser emission is dominated by 2 components, at $V_{lsr} \approx 24.5$ and 27.1 km s^{-1}. This is further illustrated by the collection of spectra shown in Fig. 2.
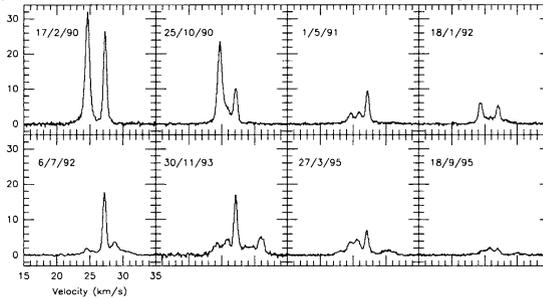

Figure 2.   A collection of representative spectra from the R Cas data base. The vertical scale is in Jy; the date of observation is indicated in each panel. The spectra are dominated by emission at $\sim$24.5 and 27.1 km s^{-1}; the remaining components are collectively called "plateau" in this paper.

Maser emission has been detected most of the time, except on three occasions when only (1σ, 0.33 km s^{-1} resolution) upper limits of 2.9 Jy (18/4/92) and 0.8 Jy (18/10/94, 15/9/95) could be determined. Over the whole observing period, emission at levels >4 Jy (at resolution 0.33 km s^{-1}) is found between 20.4 and 32.3 km s^{-1}. With time, the maser strength has gradually decreased. This is seen very clearly in Fig. 3a, where we plot the integrated H_2O emission as a function of time. The curve (least-squares fit for $t>800^d$) is a sinusoid with a period of 434 ± 5^d (equal to the optical period, as derived from AAVSO data), damped with an exponential ($\exp(\alpha t)$, $\alpha = (-6.6 \pm 1.0) \times 10^{-4}$). The maser peaks with a $\sim$115^d delay with respect to the optical maximum output (indicated by dotted lines in the figure). The points indicated as "flares" were identified as such by comparison with data from Pashchenko (1990), and were excluded from the fit. The Pashchenko data show three outbursts of the 27 km s^{-1} component between mid-1986 and mid-1989, with the flux density reaching values of 600 Jy in early 1989, with which our data are consistent (note however, that including these points in the fit changes the exponent of the damping function, but does not significantly affect the derived period). The overall decrease of the integrated flux density with time is due to the decrease in flux density of the two main components: removing their contribution from the total flux density leaves the emission in the other, less intense components that cluster around the main lines (called "the plateau"). This latter component, shown in Fig. 3b, varies with the same period, and does not show the damping effect seen in the total integrated flux density.

3.   Discussion and conclusions

The H_2O maser emission from the circumstellar envelope of R Cas might be described as a combination of a "plateau", which consists of numerous lines at a level of a few Jy, and two strong components (at $\approx$24.5 and 27.1 km s^{-1}) which

dominated the emission for several years. The "plateau" varies regularly with the period of the star, displaced in phase by ∼115 days. The superposition of "plateau" and strong components is well described in terms of a damped oscillator. The lines of the "plateau" probably originate in randomly distributed 'blobs' within the spherically symmetric wind. The strong components occasionally flared and decreased steadily since 1990; they might have traced two regions of enhanced density, which have left the H_2O maser shell recently. With a size of 3.6×10^{14} cm (Colomer et al. 2000) the typical crossing time of the R Cas maser shell is about 30 years, and the past decade we may have witnessed the passage of a density inhomogeneity through the shell. As recent as May 2001 the total maser output was still at a very low level; it will be interesting to see if and when new strong components will appear again.
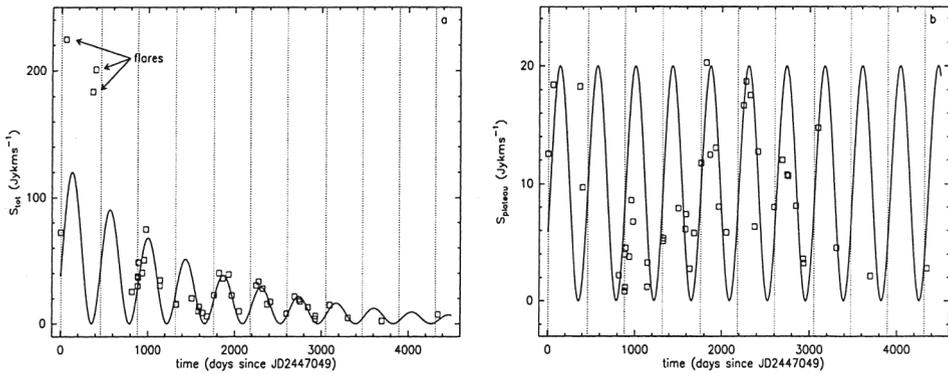

Figure 3.   **a)** Integrated (10–40 km s⁻¹) H_2O emission of R Cas versus time. Day=0 corresponds to JD2447049. The squares are the data, the curve is a fit of an exponentially damped sinusoid with a period of 434± 5^d. The vertical dotted lines mark the times of maximum optical output (AAVSO data), with respect to which the maser maximum has a delay of ∼115^d. **b)** As (a), but for the integrated emission of the "plateau" (total emission minus the contribution of the main components at 24.5 and 27.1 km s⁻¹. The curve shown has P=433^d.

References

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