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ASTRONOMY AND ASTROPHYSICS

OH eruptive Mira stars

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Abstract. We report the evolution of new OH flares detected from four Miras. These eruptive stars possess in common the fact that they have very thin envelopes. Except for one of them, each eruptive feature has a velocity near that of the star. Preferentially, the eruptive lines are at 1612 and 1665 MHz. It is likely that OH flares take place in a zone of the envelope closer to the star than standard emission.

Key words: stars: AGB, post-AGB – radio lines: stars – stars: individual: R Leo; U Her; R Cnc; R LMi

1. Introduction

Miras are AGB stars with an optical counterpart. They are surrounded by an envelope of dust and gas. OH molecules found in the gas can produce maser lines. These masers are called type I if main lines are stronger than the 1612 MHz satellite line or type II in the opposite case.

Their OH spectra usually exhibit a so-called "standard" two-peaks profile generally more complicated than the one of OH/IR objects. The expansion velocity estimated as half of the width between the two peaks of the spectrum increases with the period of pulsation of the star and varies from 2 to 7 km/s (Dickinson & Chaisson 1973, Le Squeren et al. 1979).

Some of these stars might have a profile exhibiting also OH emission in the range of the stellar velocity. This might reveal a turbulent and/or accelerated region in the shell. Indeed, as calculated by Chapman & Cohen (1985), in the standard models, the spectrum profile shows emission near the stellar velocity if there is a strong acceleration in the shell. Also, emission at the stellar velocity might be seen in a model in which material is flowing away from the star in a radially ellipsoidal expanding configuration (Bowers et al. 1989).

It has been shown that the OH variations of these stars follow the infrared and optical periodicity with a delay of some tens of days (Harvey et al. 1974, Fillit et al. 1977, Herman & Habing 1985).

The Miras are located in the blue part of region II of the IRAS color-color diagram presented by van der Veen & Habing (1988). This region is filled with oxygen-rich circumstellar shells of variable stars. This position in the diagram indicates an infrared excess, signature of a surrounding dust shell formed by mass loss, but the excess is smaller than for OH/IR objects located in the red part of this diagram.

It is commonly accepted that OH pumping of Miras and OH/IR stars is achieved by far infrared radiation (FIR) coming from the dust of the circumstellar envelope (Elitzur 1982, Bujarrabal et al. 1980). Recent calculations about OH maser pumping undertaken by Collison & Nedoluha (1993), which are a distinct improvement over earlier works, strongly support the suggestion that a near infrared radiation (NIR) line overlapping is affecting inversion of the main lines in the Miras.

Until now, U Ori was the only Mira known for which the large amount of data relating an eruptive event has been widely studied and reported in the literature (Pataki & Kolena 1974, Reid et al. 1977, Cimerman 1979, Garrigue & Menessier 1980, Jewell et al. 1981, Chapman & Cohen 1985, Bowers & Johnston 1988). With the Nançay radio telescope, we have detected over 12 years five other stars which have shown a drastic change in their emission profile. Some of these events consist of the birth of new components in a previously detected line that had vanished after some months or years; others are characterized by an occurence in a line not previously detected. These objects are: U Her, R Leo, R Cnc, X Oph and R LMi.

Their OH variations are presented here. Data for the flare of X Oph have already been reported by Etoka & Le Squeren (1996) (hereafter Paper I) and will not be presented here. Observations are described in section II. The results obtained for each star are given in section III. We discuss the flares as a whole and try to give some clues about this type of phenomena in section IV. The conclusion is given in section V.

2. Observations

After having performed a high-sensitivity search in order to find OH emission in a sample including all nearby Miras (distance < 1 kpc) in a large part of the sky (Sivagnanam et al., 1988), we have studied their OH variations. Because of the overloading on the Nançay radio telescope we only could observe during about twelve years at certain intervals of time (between twice a month and once every six months) fifteen Miras. Specifically, we have monitored R Aql, RR Aql, R Cas, R Cet, R Cnc, S CrB, UX Cyg, U Her, R Leo, R LMi, X Oph, U Ori, R Peg, Z Pup and RS Vir. Some of them appear very stable, such as R Aql or S CrB. On the contrary, for five of them we have detected a transient and strong emission whose amplitude of variation is completely independent of the light curve.

As mentioned above, the OH observations were made with the Nançay transit radio telescope, yielding a half-power beamwidth of 3.5' in α by 18' in δ. The system temperature was about 50 K. The ratio of flux to antenna temperature was 1.1 Jy.K^{-1} at 0^{o} declination. A frequency switching mode was used. Each observation lasted one hour. Except when mentioned, the autocorrelator was split into four banks of 256 velocity channels each, and the velocity resolution was about 0.14 km/s in the main lines and 0.145 km/s in the satellite line.

We also have been monitoring for three years (from 1981 to 1984) ten OH Miras with a back end that consisted of four banks of 64 by 6 KHz filters each. These Miras are R Aql, RR Aql, RU Ari, R Cas, R Cet, S CrB, UX Cyg, U Her, R LMi, U Ori, R Peg, SS Pup, Z Pup, RS Vir and T Vir. We also have some sparse observations between 1976 and 1980 for the same sample, generally made near the maximum of the light curve with the same back-end. The spectral resolution of about 1 km/s was not very suited to detection of weak and narrow flare. Thus, during this period no eruption was detected. Nevertheless, these spectra are a useful reference for this period to compare with the more recent observations.

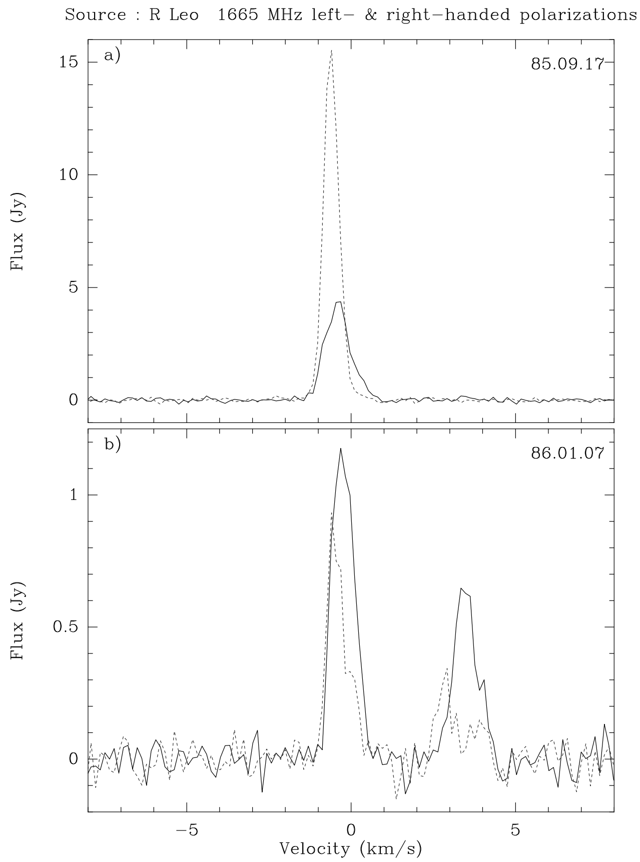

Fig. 1a and b. Spectra at 1665 MHz of R Leo in left- (solid lines) and right- (dashed lines) handed polarizations. **a** Spectra of the detection and **b** after the inversion of polarization of the eruptive feature.

3. Results

In this section, we present the flare spectra, the OH variations along the eruptions, and the main characteristics of each event.

3.1. R Leo

R Leo is one of the nearest Miras. Its distance, measured from trigonometric parallax, is 78 pc (van Altena et al., 1991). OH emission in main lines was discovered in 1972 by Fillit et al. (1973). No 1612 MHz emission was observed. The spectra displayed a single peak centered at 3.9 km/s and 3.2 km/s respectively at 1667 and 1665 MHz. From its discovery (1972) to 1980, our observations show that this feature was strong and normally periodic. Nevertheless, from 1981 until 1983, a peculiar behaviour could be seen: both OH main lines decreased cycle after cycle down to a complete disappearance. Then, in 1984, emission reappeared in the same velocity range (Le Squeren & Sivagnanam, 1985).

In 1985 September, in addition to the previously detected feature located around 3.5 km/s, a strong and narrow 1665 MHz polarized feature appeared centered at a velocity of −0.41 km/s and −0.61 km/s in the left- and right-handed polarizations respectively during an ascent toward a maximum of the light curve. Fig. 1a shows these spectra at 1665 MHz in both circular polarizations. Their full width half maximum (FWHM) is about 1 km/s. No 1667 MHz signal could be detected in the same velocity range.

R Leo was observed in both main lines and circular polarizations, from September 1985 to July 1986 every month, and from December 1986 to March 1989 more sparsely with one to 4 months between 2 observations. The r.m.s was about 0.07 K for the whole set of observations. Some observations at 1612 MHz in left-handed polarization were made with the same integrated time, resolution and r.m.s, during this period, but they did not give any evidence of emission.

Fig. 2 displays the variations of the eruptive feature in both circular polarizations in relation to the light curve. This flare is the shortest we have detected, with a duration of only five months that is less than a period of variation of the optical curve (312 days). Thus, the intensity of the eruptive feature does not follow the optical cycle since it has such a fast decline that it disappears before next maximum. No perturbation in the light curve could be seen before or during the event.

The decrease was regular and very fast; in two months the right-handed polarized peak emission decreases from 16.5 to 3.75 Jy. Moreover, we have made a gaussian fitting which shows a drift of about −0.2 km/s in both polarizations during the flare, respectively leading to a velocity of −0.20 km/s

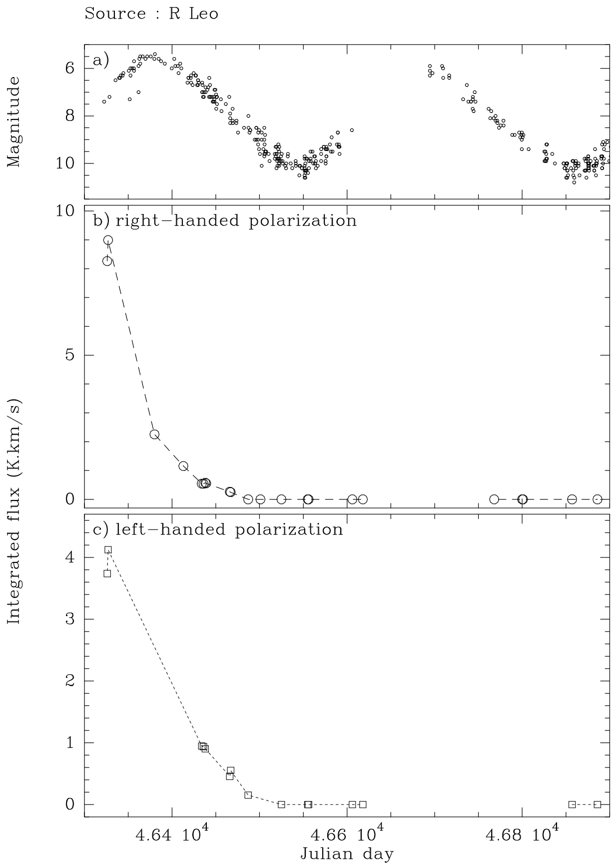

Fig. 2a–c. OH variations at 1665 MHz of the eruptive feature of R Leo with the corresponding part of the optical curve (AASVO, private communication). **a** Light curve and integrated flux in **b** right- and **c** left-handed polarizations.

and −0.45 km/s in the left- and right-handed polarization at the end of the event. Although the resolution in velocity was only 0.14 km/s, we believe that the small velocity displacement of about 0.20 km/s is real. This velocity variation likely indicates a change in the relative intensity of the components of the feature, which perhaps could have been distinguished with a better resolution. The separation of 0.20 km/s between the left- and right-handed polarized features might be the signature of a Zeeman effect. According to the Zeeman splitting factor of 3.27 HzμG^{-1} given by Kazès & Crutcher (1986), this splitting leads to a magnetic field of 0.34 mG at the location of the OH emissive molecules.

Let us define the degree of polarization as follows:

$$I_L - I_R / I_L + I_R, \qquad (1)$$

where I_L is the integrated flux in left-handed polarization and I_R the integrated flux in right-handed polarization.

The feature was very right-handed polarized at the beginning of the flare with a degree of polarization of −0.58. But it becomes left-handed polarized in less than 3 months, reaching a degree of polarization of about 0.16. This ratio persisted until the complete disappearance of the feature. The change in polarization ratio occured at the maximun of the light cycle.

The estimated stellar velocity deduced from CO emission (Young, private communication) is −1.0 km/s (cf. Table 2). Thus, this eruptive feature is located very near the stellar velocity with a separation of less than 0.8 km/s.

The eruption did not modify the pre-existent red feature which followed the cycle variations with the typical lag of about 50 days. However, this feature, located at about +3.5 km/s, never reached a value higher than 0.65 Jy during the flare. It was faintly left-handed polarized at 1665 MHz as well as at 1667 MHz, exactly the same as before the flare.

3.2. U Her

U Her is also a nearby Mira. Its distance is estimated at 280 pc from Alvarez & Menessier (1996). It is a type I emitter too, but in addition this star exhibits emission in the 1612 MHz satellite line. We have a lot of OH observations of this star for the last fifteen years (i.e., 1981-1996).

The spectrum in main lines is very complex. Features have multiple components spread over a large range of velocity: about 6.5 km/s for the blue part of the spectra and 5.5 km/s for the red part. Moreover, some of the components are very polarized but nevertheless rather stable for they take several cycles for significant change. From the beginning of our observations (1978), the spectrum at 1612 MHz exhibits a double-peaked profile quite narrow in comparison with the main-line one, with only 2 km/s of velocity width. The blue feature, centered at a velocity of −20 km/s, displays three narrow components, while the red one at −9 km/s is more simple.

Observations made in 1984 May at 1612 MHz in horizontal polarization, after a gap of ten months, showed the existence of a third component at a velocity of −16.5 km/s. This flare lasted for five years. It vanished between 1989 September and 1990 December.

Fig. 4 displays the variations of the eruptive feature and the corresponding part of the light curve. The first data points obtained between 1984 May and 1984 December in the horizontal polarization are plotted on the same graph as the following ones obtained in the left-handed polarization, because from spectra obtained in these two polarizations with an interval of five days, we notice that the intensity in horizontal and left-handed polarization was about the same.

Some gaps exist in the course of the observations of this event; the biggest ones are from 1984 December to 1985 September, 1986 July to 1986 November, and from 1987 July to 1988 October, with a single observation in August 1988. From 1984 to 1989 the autocorrelator was split such that the two main lines and the satellite line could be observed at the same time. Only at 1667 MHz do we have both circular or linear polarizations. The 1665 MHz observations was performed in right-handed or vertical polarization and the 1612 MHz ones in left-handed or horizontal polarization. Thus, we have no ob-

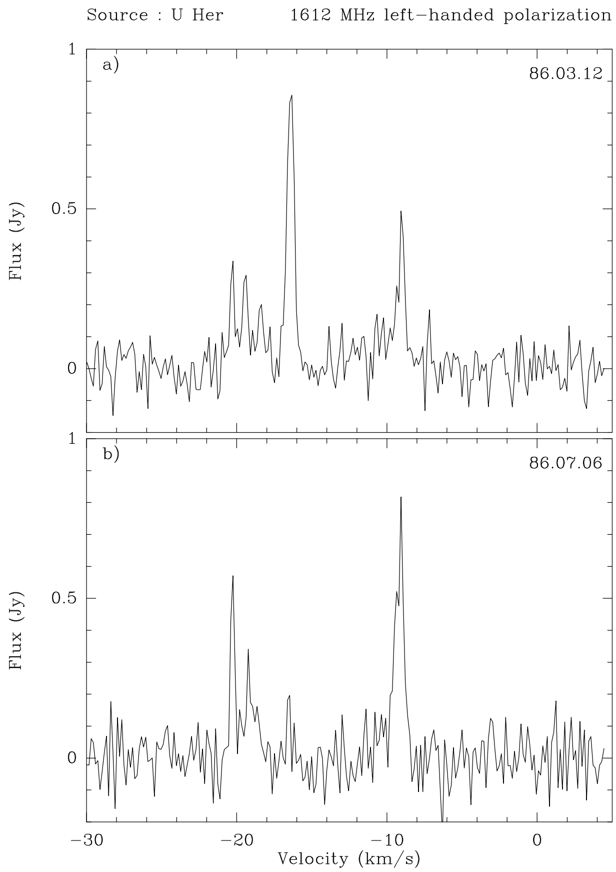

Fig. 3a and b. Spectra of U Her at 1612 MHz in left-handed polarization around **a** a minimum and **b** a maximum of the light curve.

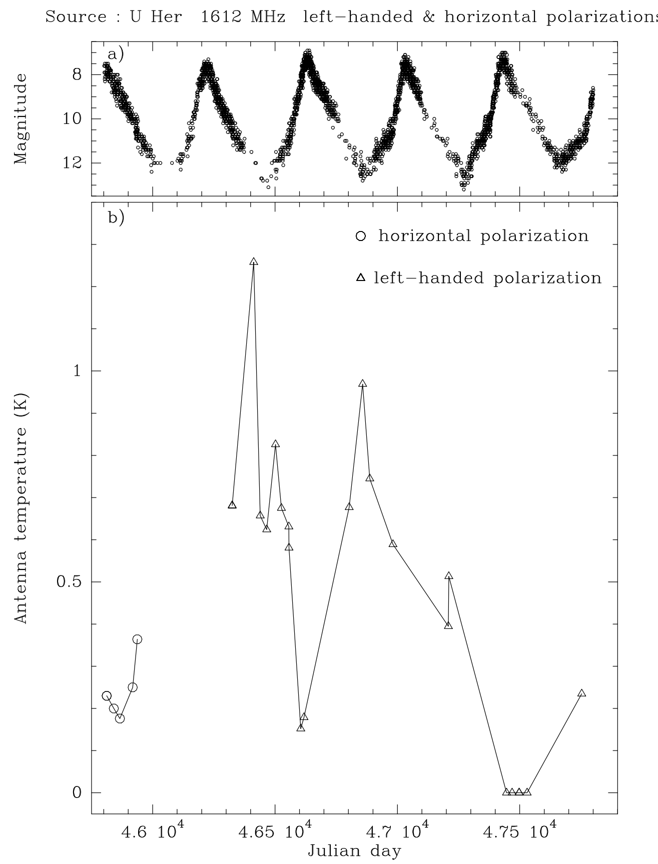

Fig. 4a and b. OH variations of the eruptive feature of U Her at 1612 MHz with the corresponding part of the light curve (AASVO, private communication). **a** Light curve, **b** OH variations in horizontal and left-handed polarizations.

servations in the right-handed polarization at 1612 MHz for this period of time.

From the comparison between the optical and OH light curves and in spite of our gaps of observation, Fig. 4 clearly shows that the OH variations of the eruptive feature are surprisingly in phase opposition with the optical curve and thus with both blue and red standard 1612 MHz peaks. This behaviour can be seen in the 1612 MHz profile spectrum. So, for each observation obtained around a maximum of the light curve, one can see that both standard blue and red peaks are stronger than the eruptive feature. On the contrary, near the light curve minimum, the opposite phenomenon is observed. In Fig. 3 is displayed a spectrum at 1612 MHz around a minimum and a maximum of the light curve illustrating clearly this result.

The feature corresponding to the flare is twice as narrow as both standard ones, with a FWHM of only 1 km/s. The stellar velocity estimation from the OH emission is -14.5 km/s as given in Table 2. This gives a separation between the stellar velocity and this new feature of 2 km/s, so the eruptive OH molecules belong to the front part of the shell in a standard model.

Emission in the main lines, in this range of velocity could already be seen for long, but it is hard to know if any changes occurred during the period of the flare, because of the blended components - at least 7 - in the blue peak. Nevertheless, while the degree of polarization changed for other components at 1667 MHz during the entire period of the flare, the component in the range of velocity of its eruptive counterpart at 1612 MHz was always left-handed polarized. It seems that this tendency was true at 1665 MHz too, but because of the very sparse sampling in the right-handed polarization, we can not claim it in a categorical way.

We have not observed any particular change in the light curve for the cycles before or after the first observations of the flare.

3.3. R Cnc

Observations sparsely made with the Nançay radio telescope in the direction of this nearby Mira (170 pc from Alvarez & Menessier, 1996) between 1978 and 1985 January do not display any OH emission in the satellite or the main lines. The first observation showing an eruptive feature toward R Cnc was obtained in 1985 January. Five years later, it was still emitting. This emission was noted by Sivagnanam et al. (1988).

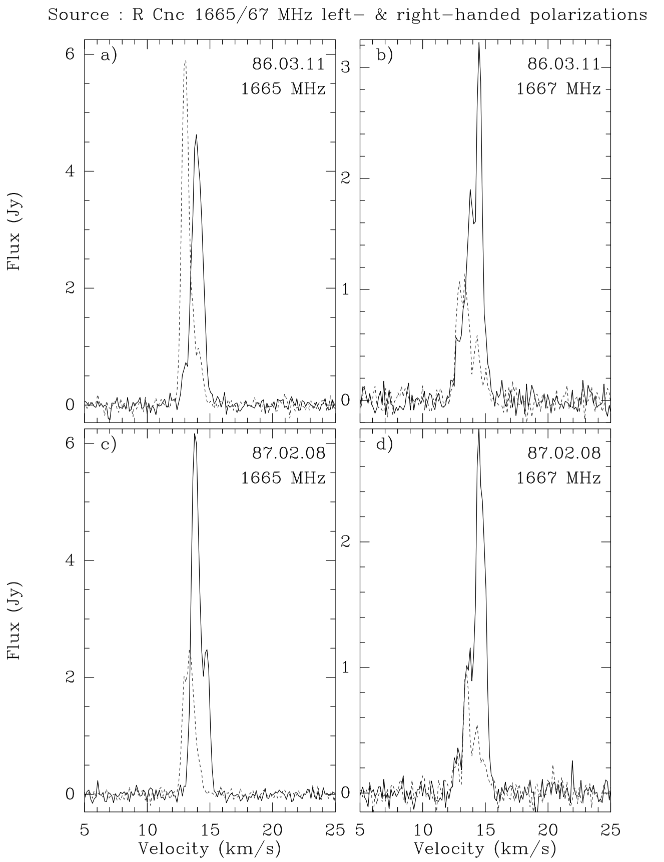

Fig. 5a–d. Spectra of R Cnc in both main lines in left- (solid lines) and right- (dashed lines) handed polarizations around the two strongest OH maxima. **a** Spectra at 1665 and **b** at 1667 MHz around the first OH maximum. **c** Spectra at 1665 and **d** at 1667 MHz around the second OH maximum.

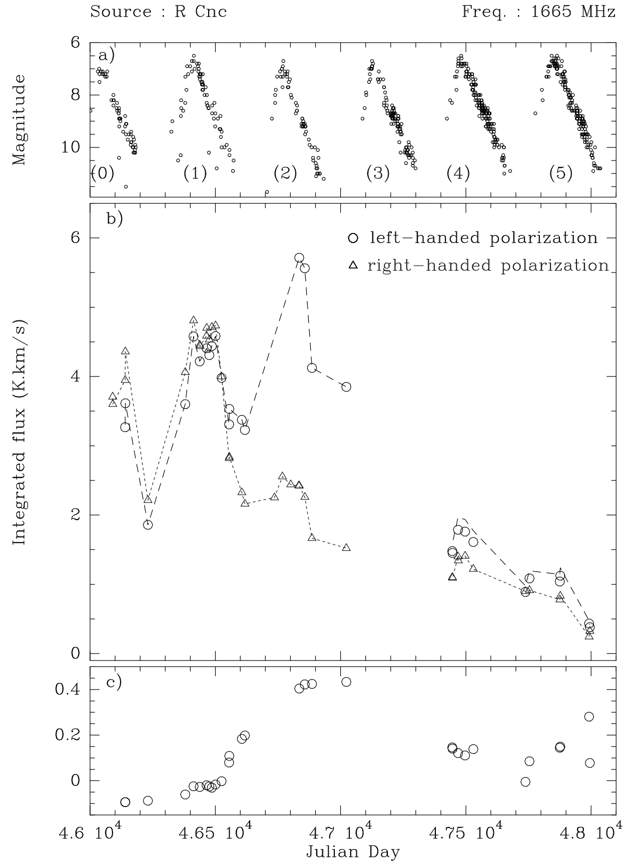

Fig. 6a–c. OH variations at 1665 MHz of R Cnc with the correpond-ing part of the light curve (AASVO, private communication). **a** Light curve, **b** OH variations in left- and right-handed polarization. Also displayed is **c** the degree of polarization as defined in relation (1).

R Cnc was observed at 1665 and 1667 MHz in both circular polarizations. The observations encompass about five years from 1985 January to 1990 April, but the sampling was not regular, with intervals between two observations of about one to five months and with a wide gap from 1987 August to 1988 October. Some observations at 1612 MHz were performed but did not give any evidence of emission.

This flare started around an optical maximum and no particular event modified the light curve.

As for all flares, the eruptive feature was narrow with a FWHM of less than 2 km/s in both main lines (cf. Fig. 5).

At 1667 MHz we could clearly see 3 components in the right as well as in the left-handed polarization (cf. Figs. 5b and d). These 3 components are centered at 14.65, 13.55 and 12.75 km/s in the left-handed polarization and at 14.40, 13.50 and 12.60 km/s in the right-handed one. Thus the splitting is different for the three components. We notice that the splitting is maximum - with a value of 0.25 Km/s - for the component with the velocity closest to the stellar one, considering the stellar estimation given Table 2. At this frequency, the signal was highly left-handed polarized all along the flare when detectable. The degree of polarization, as defined in relation (1), varied from 0.4 to 1 from the beginning until the end of the flare (cf. Fig. 7).

At 1665 MHz, 2 components could be seen in each circular polarization, at about +13.65 km/s and +14.80 km/s. As a whole, the degree of polarization changed during the flare. The emission was slightly right-handed polarized at the beginning of the flare but became quickly left-handed polarized (cf. Fig. 6). More precisely, the component at +14.80 km/s was very faint at the beginning of the flare with a maximun intensity of less than 0.5 K in the cycle called (0) in Fig. 6a and was right-handed polarized up to cycle (1). From cycle (2) it became solely left-handed polarized and reached values higher than 2 K. For the component at +13.65 km/s the scheme is a bit more complicated, since the polarization of the component changed at least three times: for cycle (0) and cycle (1) it was slightly right-handed polarized, for cycle (2) it became deeply left-handed polarized, and for cycles (4) and (5) it was right-handed polarized again. Moreover, we could see an inversion in the strengh of the 2 components at maximum intensity in the left-handed polarization: the component at +14.80 km/s was very faint in cycle (1) it then strengthened in cycle (2) but was still domi-

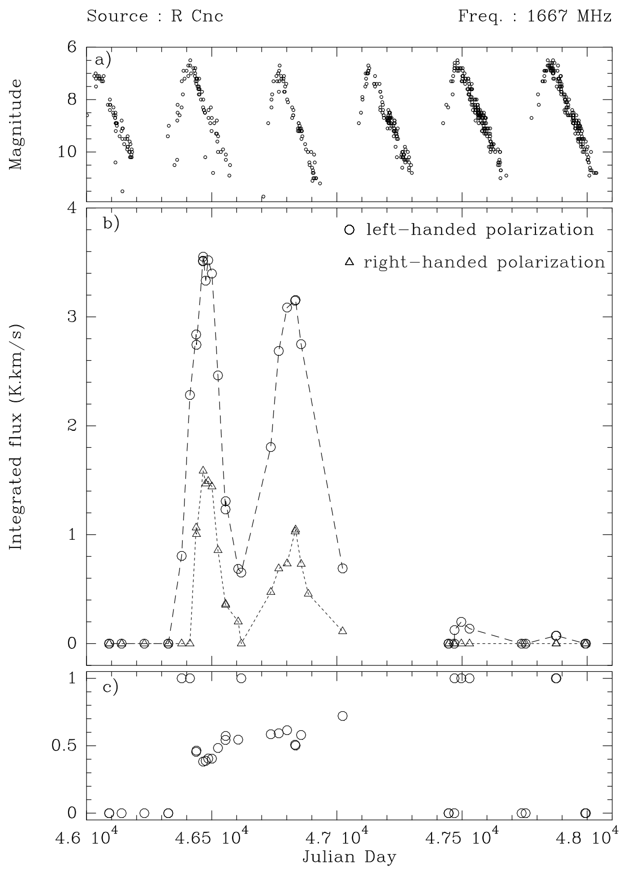

Fig. 7a–c. The same as for the previous figure but for the 1667 MHz.

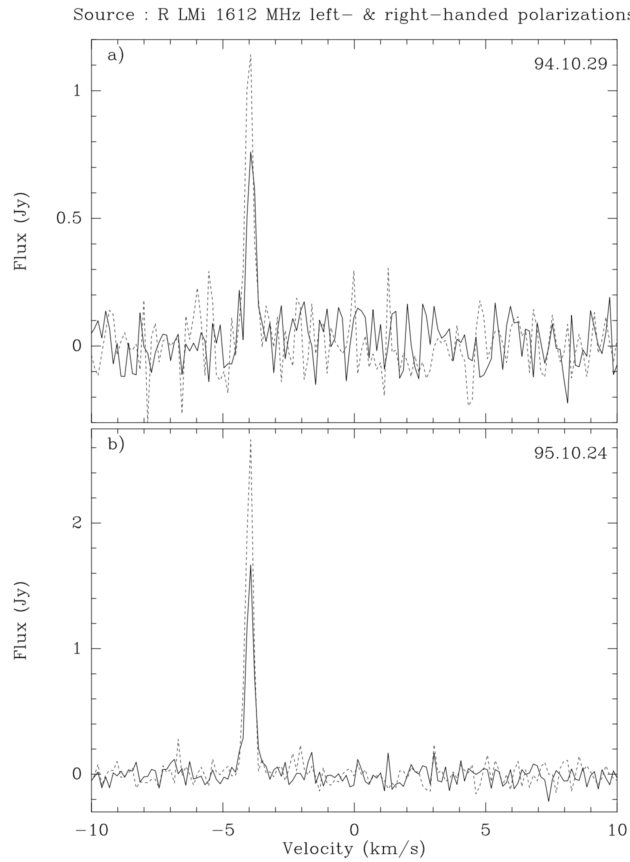

Fig. 8a and b. Spectra at 1612 MHz of R LMi in left- (solid lines) and right- (dashed lines) handed polarizations at **a** the first OH maximum and at **b** the second one.

nated by the component at +13.65 km/s. In cycles (4) and (5) this component exceeded the one at +13.65 km/s.

At 1665 MHz as well as at 1667 MHz, the difference between the eruptive component velocities and the stellar one, according to the stellar velocity estimation given Table 2, is less than 2.5 km/s.

3.4. R LMi

So far, R LMi was known as an emitter in main lines. In fact, we have already detected some 1612 MHz emission coming from this star in the past in 1990 September and in 1992 May, about 60 days after and 50 days before a maximum of the light curve, respectively. This emission was very faint and hardly detectable out of the noise level. Thus, we might think that 1612 MHz emission was already present in the star for a long time but mostly below the detection level.

An increase of this 1612 MHz emission occurred in 1994 June. From June 1994 to September R LMi observations were made every month at 1612 MHz in left-handed polarization, 1667 MHz in right-handed polarization and at 1665 MHz in both cicular polarizations. From November 1994, R LMi was observed every 2 weeks at 1612 MHz in both circular polarizations and every month at 1665 and 1667 MHz in both circular polarizations. The r.m.s for the whole spectra was about 0.085 K.

The spectra at 1612 MHz in both circular polarizations at the OH maxima are displayed Fig. 8. One can see a single component in both circular polarizations located at −3.95 km/s. Here again it is evident that the feature is narrow, with a FWHM even less than 1 km/s. No splitting could be measured between the left- and the right-handed polarization, but a calculation of the degree of polarization as given in relation (1) shows a faint right-handed polarization of about 0.2. No change could be detected in the degree of polarization (cf. Fig. 9d). In Fig. 9 the OH variations of this emission up to November 1995, which includes the second maximum, is presented. It is clear that the second maximum is at least two times higher than the first one. At the moment, after more than 2 years of emission, the 1612 MHz is still emitting.

The R LMi eruption exhibited the most peculiar behaviour in comparison with the other sources. Indeed, its flux increases very slowly, since it has still not reached its maximum value after more than a whole cycle, contrary to other flares. Secondly, the difference between the stellar velocity and the flare one is larger than for the other stars presented here. Added to this peculiarity,

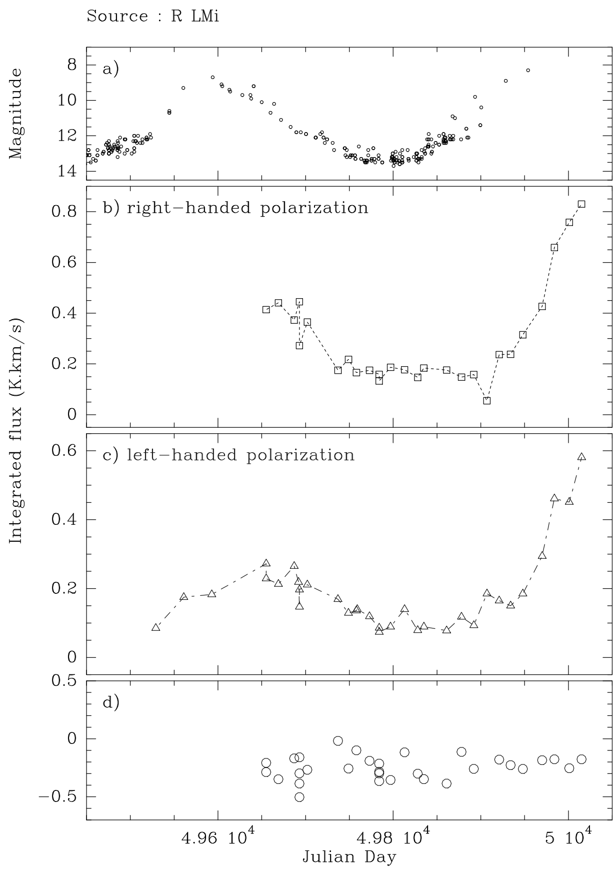

Fig. 9a–d. OH variations at 1612 MHz of R LMi with the corresponding part of the light curve (AASVO and AFOEV, private communications). **a** Light curve, OH variations in **b** right- and **c** left-handed polarizations. Also displayed is **d** the degree of polarization as defined in relation (1).

it seems that the event affected the main-line emission too, at the same velocities.

We have 7 years of continual observations for this star, most of all in the main lines, from 1989 and up to now. Unfortunately, the sample before the eruption was detected is not so good, especially at 1667 MHz, with some gaps that can be as wide as 8 months between 2 observations. So, one can only get a general trend of the emission rather than a complete description of cycles. Nevertheless, with a pulsation period of about one year (372 days), the general trend of the 5 previous cycles before the beginning of the flare could be obtained in the main lines. The result is a regular decline of the integrated flux in both main lines, almost to extinction just the cycle before the start of the flare for the high peak. For the low peak, the one corresponding to the velocity range of the eruptive feature at 1612 MHz, a steeper decrease could be seen, but only for the 3 oldest cycles. This was followed by an increase of the maxima for the next 3 cycles, including the first OH maximum corresponding to the 1612 MHz eruption. This tendency shows a pumping independence between the front and back part of the shell. Finally, for the present cycle a suprising behaviour is the new decrease of the OH maximum observed for the low-peak integrated flux in both main lines, while the corresponding maximum at 1612 MHz is clearly increasing.

3.5. X Oph

For a complete description of the flare see Paper I.

4. Discussion

First, we present the main characteristics of all the detected flare events. In Table 1, a summary of the flare parameters such as frequency of the line, polarization and velocity of the eruptive feature or of its components as well as duration of the event and phase of the light curve at the beginning of the event are given. Estimates of the stellar and expansion velocity derived preferentially from OH observations are given in Table 2. When this was not possible, i.e., when OH profiles are known to exhibit only a single peak, velocity estimations from CO are given instead. We choose CO thermal emission rather than H_2O or SiO maser emission because the CO comes from a more external part of the shell where the amount of turbulence is supposedly less, and moreover, CO gives a reliable estimation of the terminal velocity. The difference of the eruptive feature velocity and the stellar velocity also is given . In Table 3, we have summarized the general properties of the known eruptive stars such as their period, spectral type, $[60-25]$ and $[25-12]$ color-color index values and estimates of the mass-loss rate. From all these parameters a synthesis of all flare data is made and an attempt to find the necessary conditions for the existence of such flares is undertaken.

4.1. Main characteristics of flares and eruptive stars

We noticed that the components of the eruptive spectra are almost always polarized. The flare of X Oph was right-handed polarized during all the duration of the event (cf. paper I). R Leo was right-handed polarized at the beginning of the eruption and left-handed polarized at the end. We observed the reverse phenomenon for R Cnc. The -39 km/s eruptive feature of U Ori was strongly right-handed polarized (Reid et al. 1977). The flare component of R LMi is right-handed polarized. Thus a general trend is a predominance of the right-handed polarization.

The eruptive feature profile sometimes has multiple components. With a FWHM of less than 2.5 km/s, the most blended eruptive profiles exhibit a maximum of 3 components. The amplitude of these components varies separately, which can be interpreted as a difference in the degree of saturation of the maser.

In Table 1, column 4, we give either the centroid velocity shift when we observed such a phenomenon (i.e., X Oph and R Leo) or the velocity of each detected eruptive component. Except the 1612 MHz flare of R LMi and the second feature of U Ori located at -47 km/s, all the eruptive components have velocities very near the stellar one. The difference is less than

2.5 km/s, and is always lower than the terminal outflow velocity given by CO observations. In the standard model of Chapman & Cohen (1985), emission near the stellar velocity can be due to a location of the maser in the accelerated zone near the star. In the model of Bowers (1993) it is possible to have such a spectrum if the site of the maser is a thin and warm envelope. In both cases the OH emission region is in the inner part of the circumstellar outflow. However, a special geometry such as axisymmetric outflow might also explain such a feature near the systemic velocity (Bowers et al. 1989).

The durations of these events can be very different: from only five months for the shortest (R Leo) up to eleven years for the longest (U Ori). Nevertheless, the increase is often very short, of the order of several months.

In the last column of Table 1 are given the phases of the beginnings of the flare events. Except for U Her, for which we have an observational gap of 10 months between the detection of the flaring feature and the previous observation exhibiting only the 2 standards peaks, all the other phases are known with less than 3-4 months of uncertainty. This lapse of time roughly corresponds to a maximum of −0.28 phase uncertainty for a one year periodic variation, which is about the periodicity of the eruptive stars. The phases are all quite close to zero; thus, one may conclude that the beginning of such flare events seems to be tied with a maximum of the light curve and likely with the shock wave that appears at this moment of the cycle. Nevertheless, we have not observed any change in the behaviour of the light curve linked to the eruption. Thus the change of the conditions that are at the origin of the flare do not affect the periodic variation of the overall luminosity of the star.

In addition to a general modulation specific to every flare, the OH light curve of the X Oph, R Cnc, U Ori and R LMi flares follows the optical light curve. The delay between both optical and OH maxima is between 30 and 50 days, the usual delay found for Miras. U Her is the only flaring star which clearly exhibits a phase opposition relative to the optical curve.

The preferential eruptive lines seem to be at 1612 and 1665 MHz; thus, one may conclude that 1667 MHz maser emission is more stable when it is established in the shell and less affected by any perturbation undergone by the star. We also notice that the two lines most affected by the eruptive events, i.e., 1612 and 1665 MHz, share the same upper level: $^2\Pi_{3/2} J = 3/2$. Thus, these events may be linked with an asymmetry in the population of the maser levels resulting in an overpopulation of this specific level at the expense of its doublet.

We take note that all eruptive stars are nearby (less than 280 pc). It is likely that we cannot detect the more distant eruptions for lack of sensitivity. On the other hand, an interesting result is that all the eruptive Miras are characterized by very low [60-25] and [25-12] IRAS color indexes (the color indexes definition is the same as the one given by Sivagnanam et al., 1989). Fig. 10 displays The location of the eruptive Miras in relation to all the nearby Miras (distance < 1 kpc). It is clear that they are localized in the extreme left part of the color-color diagram. On this figure, the [25-12] color indexes of the whole Miras extend from −0.75 to −0.45 while those eruptive Miras are less than −0.70. Thus, it is obvious that the eruptive stars have a very thin dust shell.

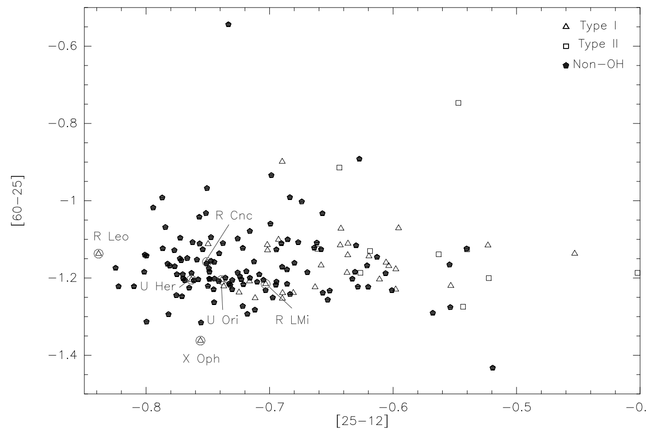

Fig. 10. Color-color diagram of the nearby Miras (distance < 1 kpc). The color index definition used here is the same as the one used by Sivagnanam et al. (1989). The location of the 5 eruptive Miras is indicated.

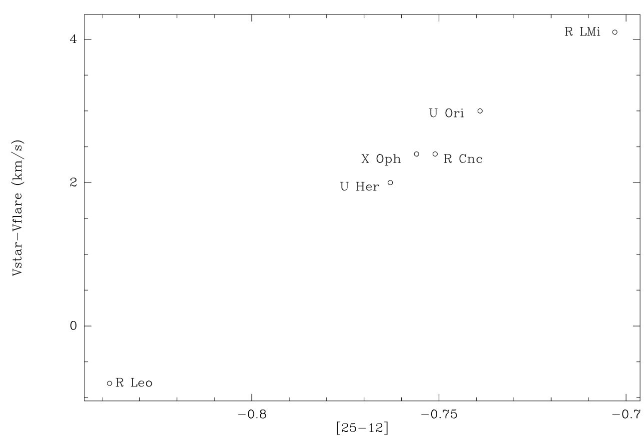

Fig. 11. (V_{star}- V_{flare}) versus [25-12]

The eruptive stars are all type I Miras. The main-line eruptive ones have a period less than 362 days and a spectral type M6, while the 1612 MHz eruptive stars have a period < 406 days and a spectral type M7 (except R LMi with a spectral type M6), which is near the limit of having either predominance of main-line OH emission (type I) or predominance of satellite line emission (type II) (Sivagnanam et al. 1988).

4.2. Interpretation

Huggins & Glassgold (1982) and Netzer & Knapp (1987) have investigated the structure of OH shells formed from photodestruction of H_2O by ambient UV photons in the expanding envelopes around cool evolved stars. They have determined the location of the OH density peak as well as the thickness of the OH envelope. All these parameters depend on the dust shielding which in turn is controlled by the mass-loss rate and the

Table 1. Eruptive event characteristics

Source	Line MHz	Pol.	V_{flare} km/s	Duration	Phase of beginning
U Her	1612	left*	-16.5	5.3 years	0[2]
R Leo	1665	left	-0.41 => -0.20[1]	5 months	-0.14
		right	-0.61 => -0.45[1]		
R Lmi	1612	left & right	-3.95	> 2 year	-0.15
R Cnc	1665	left & right	13.65 & 14.80	6 years	0.14
	1667	left	14.65 & 13.55 & 12.75		
		right	14.40 & 13.50 & 12.60		
X Oph	1665	left	-56.90 => -56.20[1]	1.5 years	0.12
		right	-56.80 => -56.50[1]		
U Ori	1612	circular & linear	-42.0 & -47.0	more than 11 years	-0.24

*: No observations in the right-handed polarization
1: drift of the centroid velocity along the flare
2: date of detection

Table 3. General star characteristics

Source	Period[1] days	Distance[1] pc	Spectral type[2]	OH maser type[3]	[60-25]	[12-25]	$\dot{M}$ $10^{-7} M\odot/yr$	note
U Her	406	280	M7.5	I	-1.204	-0.763	< 3.4	a
R Leo	312	80	M6	I	-1.137	-0.838	0.9	b
							0.2	a
R Lmi	372	210	M6	I	-1.215	-0.703	1.5	a
R Cnc	362	170	M6	I	-1.158	-0.751	< 3.2	a
X Oph	334	170	M6.5	I	-1.362	-0.756		
U Ori	372	200	M7	I	-1.205	-0.739	2.5	c

1: Alvarez R., Menessier M.O., 1996, A&A, in press
2: Lockwood G.W., 1972, ApJ Suppl. 24, 375
3: Type I when the main lines are predominant. Type II when the 1612 MHz satellite line is predominant
a: Knapp G.R., 1985, ApJ 293, 273
b: Knapp G.R., Morris M., 1985, ApJ 292, 640
c: Netzer N., Knapp G.R., 1987, ApJ 323, 734

expansion velocity. The smaller the mass-loss, the thinner is the dust shell and the deeper the UV photons can penetrate. Mass-loss rates estimated for the eruptive stars are very low: less than $3.4 \times 10^{-7} M_\odot$/year (cf. Table 3). For such a small mass-loss rate, ($1 \times 10^{-7} M_\odot$/year), the Netzer & Knapp (1987) model gives a radius of the OH density peak of about 7×10^{14} cm, corresponding to 10 to 20 times the radius of the star. This is not very far from the dust condensation area. For instance, Danchi et al. (1994) have obtained direct interferometric measurement of the shell of U Ori. They found it to be 11 times the diameter of the star. Thus, because of the thin thickness of their envelopes, OH maser shell radii of the eruptive Miras may be located closer to the star than most of the quiet stars which exhibit standard variations.

In Fig. 11 we have plotted the difference between the stellar velocity and the velocity of the most external eruptive component versus the [25-12] color index. One can see the existence of a correlation between ($V_{star} - V_{flare}$) and the [25-12] color-index. In spite of the small number of stars, we believe this correlation to be true. Such correlation does not exist with the [60-25] color-index as can be seen from Fig. 12. In the standard model, the velocity in relation to the one of the star is proportional to the distance from the star. Then, according to this model, the relation observed in Fig. 11 might be interpreted as follows: the smaller the mass loss, the nearer to the star is the peak density of the OH molecules and in the same way the flare, which is in agreement with the calculations of Huggins & Glassgold (1982) and Netzer & Knapp (1987).

The two formerly observed peaks of U Her, which we consider to be the standard ones, normally vary with the light curve, while the flare emission independently evolves and varies in the opposite sense. The coexistence of such features attests to the existence of two maser zones which are not located in the same area of the envelope and/or are pumped in a different way corresponding to uncorrelated pump input. Furthermore, it is reasonable to think that the eruptive zone belongs to a more inner shell, because the farther from the star the matter is located, the less turbulent is the outflow. One may notice that concern-

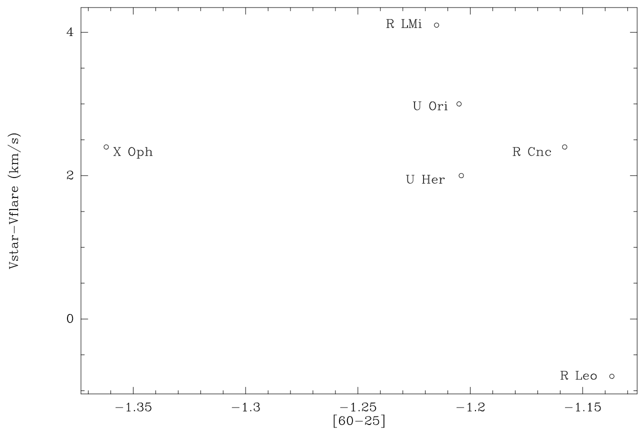

Fig. 12. (V_{star}- V_{flare}) versus [60-25]

Table 2. Stellar and expansion velocity estimations

Source	V_{star} km/s	V_{exp} km/s	note(1)	V_{star}- $V^{(2)}_{flare}$ km/s
U Her	-14.5	5.4	OH, a	2
R Leo	-1.0	7.5	CO, c	-0.8
R Lmi	0.2	4.1	OH, a	4.1
R Cnc	15.0	3.5	CO, c	2.4
X Oph	-55.0	6.0	CO, c	2.4
U Ori	-39.0	2.7	OH, ab	3 & 8(3)

1: OH indicates that stellar and expansion velocity estimations come from OH maser observations. Otherwise, estimations come from thermal CO observations

2: For cases of eruptive features with multiple components, we took the most external eruptive component to calculate the given velocity difference

3: For U Ori we give the velocity differences for both eruptives components, because of their wide velocity separation

a: Sivagnanam P., le Squeren A.M., Foy F., Tran Minh F., 1989, A&A 211, 341

b: Wilson W.J., Schwartz P.R., Neugebauer G., Harvey P.M., Becklin E.E., 1972, ApJ 177, 523

c: Young (private communication)

ing U Ori, interferometric observations were made by Chapman & Cohen (1985) and Bowers & Johnston (1988). Chapman & Cohen (1985) observations were made in 1982 December. The authors found that at this epoch the standard 1665 MHz was lying at a radius of 10^{15} cm while the 1612 MHz eruptive feature was found closer to the star. Bowers & Johnston (1988) observations were made in 1985 January. They found that the 1612 and 1665 MHz masers were at comparable radii.

Furthermore, we claim that all these eruptions are the result of radiative processes rather than matter outflow. The speed of appearance of the R Leo and X Oph flares or the fast decrease for R Leo can only be explained by radiative phenomena. Additionally, the intensity of several features are modulated by the light curve (Paper I). That argues for a radiative pump. The plausible direct agent is likely a variation of the OH maser pump. A possible scheme is a sudden variation of the pumping with an efficiency that increases quickly and undergoes a relaxation. However, the nature of these phenomena is still not very clear.

Collison & Nedoluha (1993) have comprehensively investigated the pumping of type I OH masers in the circumstellar envelopes of Miras. They include pumping effects from direct stellar radiation, collisions, dust FIR emission and FIR line overlaps. Their resulting models are always dominated by 1612 MHz emission. A possible pump mechanism which does produce main-line emission as well as satellite lines can be provided by the absorption of stellar NIR photons due to other molecules, for instance H_2O closer to the star. This effect was formerly suggested by Cimerman & Scoville (1980). In fact, if the discriminatory effect of selection rules on radiative transitions between the hyperfine sublevels can be used to amplify satellite lines, it cannot be used for main lines. This effect cannot be exploited because there is a full symmetry between the two sublevels of the Λ-doublet. Thus, Collison & Nedoluha (1993) have compared the relative importance of the pumping rates at 35 μm and 2.8 μm photons. At r=10^{15} cm and for a mass loss of $1.7 \times 10^{-7} M_{\odot}/$year, the pumping rates are comparable. Collison & Nedoluha (1993) have taken into account the influence of the H_2O molecule. According to their calculation, this effect is all the more important because the envelope is thin. If the amplification of the type I OH masers in the Miras is dominated by the 2.8 μm, one might expect that the rate of the different OH lines and their intensity vary with the number of the 2.8 μm photons: emission coming either from the star or from the hot dust; and also with the relative velocity of the H_2O and OH molecules. OH flares might be due, for instance, to a new, exceptional formation of dust or to a weak change of the velocity of H_2O. Danchi et al. (1994) have suggested, from interferometric observations in near infrared wavelengths, some strong and episodic formation of dust in the red giant stars. Moreover, Bowers & Johnston (1994) have observed that short term changes (less than a few years) could take place in the pumping conditions of some H_2O circumstellar masers.

In their models, Cimerman & Scoville (1980) suggest the existence of two high-emissivity zones, the first one near the dust condensation region, which has a strong variable emissivity in relation with stellar radiation, and the other one farther from the star. The variation of the emissivity of the second zone is smaller. We can suppose that the standard emission comes from the second zone and the eruptive emission from the nearer zone. In that case, the strong polarization of the eruptive emission could be due to a stronger magnetic field near the star and the predominance of the right-handed polarization could be due to a favoured direction of the magnetic field. The instability of the different components of the spectra could be explained by a greater turbulence expected in this zone.

In Table 2, the last column gives the difference between the flare velocity and the stellar velocity (V_{star}-V_{flare}). We almost always observe a positive value for this difference. The interpretation in a standard model is that the observed flares are always located in the front part of the shell. At the present time, we have no simple explanation to give, except that this fact implies most likely a directional phenomenon.

For R Leo and U Her we note that the pre-existing standard features are not affected by the flare event and that the eruptive emission usually extends over only 1 or 2 km/s. This fact means that only a part of the envelope is affected by the phenomenon. We especially note that the change does not modify the full OH shell, since we have not observed any emission at a symmetrical velocity in relation to the stellar one. We have some evidence that the flare phenomenon is anisotropic. Thus, the most reasonable explanation is a sudden change of local conditions of pumping which affects a part of the shell.

We have not observed any change in the behaviour of the optical light curve linked to the eruption. It is likely that the conditions needed to trigger the flares influence such a limited part of the envelope that it do not affect the brightness of the object as a whole.

The multiplicity of the components observed generally in the flare spectra can be due to separate clumps of gas or to the presence of a velocity gradient that breaks up the spectrum into multiple narrow lines, as shown by Nedoluha & Watson (1988).

5. Conclusion

We have reported and described here the flares undergone by five Miras between 1984 and 1996. Except for R LMi, for which the eruptive feature is rather external, all the eruptive features took place at a velocity very close to the stellar one. All these stars have very low [25-12] and [60-25] color index values, indicating a very thin dust shells and flares likely take place closer to the star than standard emission. It seems that the preferential lines are 1612 and 1665 MHz; thus one may conclude that 1667 MHz maser emission is more stable and less affected by any perturbation undergone by the star. Although these flares are rather exceptional they are numerous enough and for some of them, long enough to motivate a more complete study. In particular, it should be of great interest to establish interferometric maps of these kinds of events, as only undertaken for U Ori events. Such observations could lead to an interesting comparison between the eruptive molecular zone and the standard one.

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