# THE SYMBIOTIC NOVAE

R. VIOTTI

Istituto Astrofisica Spaziale, CNR
Via E.Fermi 21, 00044 Frascati RM, Italy

ABSTRACT. Symbiotic Novae are composite spectrum variables, whose light history is characterized by a single nova-like outburst. Their behaviour and time evolution is rather similar to that of classical novae, except for the much longer time scale, and the associated physics could be the same. We give an overview of the basic characteristics of the symbiotic novae, and their time behaviour in different frequencies. We find that the observed amplitude of outburst is mostly determined by the red star visual luminosity. The actual luminosity increase of the compact object might be much larger than that observed, and closer to that of classical novae. In some systems, the red star luminosity is possibly weakened by circumstellar dust. In symbiotic novae accretion should occur from the red star wind. Although the actual value of the accretion rate is still uncertain, thermonuclear runaway seems to better describe the symbiotic novae phenomenon. But new observational and theoretical work is needed.

## 1. INTRODUCTION

Among symbiotic stars there is a small group of objects whose historical light curve is characterized by only one major outburst, with a lumninosity increase of several magnitudes, followed by a luminosity and spectral evolution frequently resembling that of classical novae, excpet for the much longer time scale. These objects were named <u>very slow novae</u> by Allen (1980), and <u>symbiotic novae</u> by Kenyon and Truran (1983). In the following we shall adopt the latter denomination. The main properties of symbiotic novae (=SyN) were discussed among others by Kenyon (1986) and Viotti (1988, 1989). Table 1 summarizes the main data on the known SyN. Our interest in these objects is not only related to their nature, if they in particular represent an extreme case of symbiotic stars with strong and very rare outbursts, or are to be considered as a class of very slow novae. We are also interested to understand the physics of the symbiotic nova phenomenon, which might be very similar to that of classical novae.

Table 1. The symbiotic novae

| object name | outburst To | outburst Tmax | visual magn pre | visual magn max | visual magn post | spectr max | IR type | rad vel | galactic l'' | galactic b'' | remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AG Peg | 1855 | 1871 | 9 | 6 | 8.3 | == | S | -16 | 69.3 | -30.8 | SB |
| RT Ser | 1909: | 1923: | >16 | 9.5 | 13 | A8 | S | 92 | 13.9 | 9.9 | RN |
| V2110 Oph | ==== | 1940: | === | 11: | 22 | == | D | === | 5.0 | 3.6 | (1) |
| RR Tel | 1944 | 1948 | 14v | 6 | 11 | F5 | D | -61 | 342.2 | -32.2 | Mira |
| V1016 Cyg | 1964 | 1967 | 15 | 11 | 11 | em | D | -64 | 75.2 | 5.6 | Mira (2) |
| V1329 Cyg | 1964-66 | 1967 | 14v | 11.5 | 13-14 | em | S | -37 | 77.8 | -5.4 | EB (3) |
| HM Sge | 1975 | 1975 | 18(4) | 11 | 11 | em | D | (-10) | 53.6 | -3.1 | Mira |
| PU Vul | 1978 | 1982-83 | 15v | 8.8 | 9 | A7 | S | var | 62.6 | -8.5 | (5) |

SB = spectroscopic binary. RN = recurrent nova. Mira = Mira-type IR variability. EB = eclipsing binary. (1) AS 239. (2) $MH_\alpha$328-116. (3) HBV 475. (4) Photographic magnitude (Arkhipova et al. 1990). (5) Deep minimum in 1980.

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## 2. BASIC CHARACTERISTICS OF SYMBIOTIC NOVAE

### 2a. The pre-outburst phase

The period preceding the outburst is generally very poorly known. Two SyN were known for their peculiarity before outburst, V1016 Cyg, which was classified as MH 328-116 for its M-type spectrum with strong Ha emission (Merrill and Burwell 1950), and RR Tel which was discovered as variable by Fleming (1908) many decades before outburst. The light curve of RR Tel was described by Mayall (1949), who found little evidence of periodic variations from 1889 to 1930, although the photographic magnitude varied irregularly between 12.4 and 14. After 1930 the variations became more regular, with a mean period of about 387 d, and an amplitude of -3 . This variability is still presently observable in the visual with a very small amplitude (Heck and Manfroid 1982; Kenyon and Bateson 1984), but it is much more evident at IR frequencies (Feast et al. 1983). According to Feast et al., in the IR the light curve is typical of a Mira variable with an amplitude of $1.5^m$ in J and of $1^m$ in K. The presence of a late type component is confirmed by the marginal presence of TiO bands in the red (Thackeray 1977), and of steam and CO absorption bands in the IR (Allen et al. 1978; Feast et al. 1983). We shall discuss later on the important implications of this result. As for the other objects, the available information is only based on archive material, which is in general more abundant for objects located in well studied regions, such as V1329 Cyg. From the analysis of archive plates, Stienon et al. (1974) found that the star during 1891 to 1965 remained at minimum with $m_{pg} \sim 15.1$. During this phase the star displayed many recurrent deep minima with $m_{pg}$ fainter than 17. The recurrence period was of about 959 d, which Stienon et al. attributed to periodic eclipses of a binary system. The binary model was later supported by the radial velocity curve measured by Grygar et al. (1979) in the optical, and by Nussbaumer et al. (1986) in the UV. In the case of PU Vul Liller and Liller (1979) found that prior 1960 the system was around $B \sim 16.5$, with occasional brightenings to B=15. An M4 giant spectrum was visible in 1958 and again in 1978 (Honda et al. 1979), the same as that observed during the deep 1980 fading (Belyakina et al. 1985). No pre-outburst data are available for RT Ser, V2110 Oph and HM Sge, while AG Peg probably had a magnitude close to the present one (Kenyon 1986).

### 2b. The outburst.

There is a large variety of behaviour of SyN during outburst. The rise to maximum was rather short (much less than one year) in HM Sge and RR Tel, but very slow in V1016 Cyg, and especially in AG Peg and RT Ser (Table 2). The brightening of V1329 Cyg was characterized by a gradual luminosity increase during 1960-64, followed by a steeper brightening in July 1966. As for the amplitude of the outburst, it ranged from 3 to more than 6 mag, without a clear correlation with the time scales and other features such as the radio and IR emission. We shall come back to this point in the discussion. The spectral information during the earlier phases of the symbiotic nova outburst is quite poor. In most cases the <u>first spectroscopic observation</u> was made well after the visual maximum, and could therefore be not representative of the spectrum at maximum. An intermediate spectral type (A-F) was observed in RT Ser, RR Tel and PU Vul, while in the other symbiotic novae the first spectroscopic observations revealed an emission line spectrum (Table 1). In RR Tel the F-type absorption spectrum was observed several years after the outburst in April 1949. Few months later, between August and September 1949 all the absorption lines disappeared, and a rich emission line spectrum appeared with prominent H, CaII and FeII emissions (Thackeray 1950). Thus the spectrum underwent a dramatic change in a few days which has not been recorded in other SyNs probably because of the lack of spectroscopic observations of their earlier phases. In PU Vul the A/F-type spectrum remained visible for several years (out of the deep 1980 minimum) until recent times (e.g. Belyakina et al. 1985). This star displayed a minimum about 5 mag deep in the visual, during which the A-F spectrum was replaced by an M4-5III spectrum with some emissions. Later the star recovered its previous spectrum and brightness.

## 2c. The post-outburst phase

Photometry. As can be seen in Fig.1 of Viotti (1988) the decline of SyN after maximum is very slow. The e-folding decline time varied from 7-9 yr for RT Ser and RR Tel to 12-40 yr for AG Peg, V1329 Cyg, and PU Vul (Table 2). The light curve of V1329 Cyg showed, in addition to the gradual decay, large oscillations with a period in agreement with the orbital one discussed above. The same behaviour was shown by the UV emission lines (Nussbaumer et al. 1986). In the case of V1016 Cyg and HM Sge the objects are still at maximum visual luminosity 1-2 decades after outburst. Note that in these and similar objects, the line emission largely contributes to the broad band flux, so that the photometric time behaviour in some bands may reflect the behaviour of the hot ionizing source, rather than that of the visual continuum.

Spectroscopic observations. In RR Tel, V1016 Cyg, V1329 Cyg, and HM Sge the spectral evolution was characterized by the gradual increase of the ionization level of the emission line spectrum. This is best illustrated by the sequential appearence of lines of higher and higher ionization stages of iron, from $Fe^{+}$ to $Fe^{+6}$ (e.g. Thackeray 1977). We recall that, unlike classical novae, the spectral evolution of V1016 Cyg and HM Sge towards higher ionization occurred at constant visual luminosity. A very slow spectral evolution was also observed in recent years in PU Vul (Gershberg and Shakovskoj 1988; Maitzen et al. 1987). WR features were observed in AG Peg, RR Tel, V1016 Cyg, HM Sge, and V1329 Cyg a few years after outburst, and are still present in the UV spectrum of AG Peg (e.g. Viotti 1989). A hot continuum has been observed in the IUE spectra of many SyN, with black body temperatures up to 1-2 $10^{5}$ K. The failure to detect any photospheric absorption feature in these spectra makes the identification of their nature (hot WD, sdO, inner edge of an accretion disk, or hot spot) difficult.

Radio. As in the other frequency bands, radio observations do not give a homogeneous picture of the phenomenon. HM Sge which was observed since 1977, i.e. 2 yr after the outburst, showed a steady increase of the radio flux at 15 Ghz from 40 mJy in 1977 to 150 mJy in 1985. The radio spectrum remained optically thick all the time indicating that, unlike classical novae, the expanding HII region was still dense several years after the outburst (Kwok et al. 1981; Kwok 1988). An optically thick radio spectrum is also displayed by V1016 Cyg. This star was first observed in 1973 - 9 yr after the outburst - but no significant flux change was detected since then, probably because a stationary stage was reached also in the radio band during its early SyN stages. A very different behaviour was shown by V1329 Cyg with large and irregular radio variability (e.g. Viotti 1989). Of particular interest was the discovery of radio nebulae around several SyN with complex structures, such as jets, halos and bipolar nebulae (Taylor 1988) similar to those observed in classical novae and in the recurrent nova RS Oph (Taylor 1988). It is important to compare these observations with the radio behaviour the symbiotic star CH Cyg. This star underwent a "radio outburst" in the fall 1984 very similar to that observed in RS Oph (Taylor et al. 1986; 1988). This event was coincident with a sudden and permanent luminosity decline of CH Cyg from V=6 to 8. Following the outburst, a small radio nebula appeared which evolved from a bipolar structure up to 5 aligned components. It should be noted that this radio outburst and the luminosity decline was followed by an increase of the ionization of the emission line spectrum (e.g. Selvelli 1988).

X-rays. Weak fluxes were detected in RR Tel, V1016 Cyg, and HM Sge (Allen 1981). The comparison of the fluxes might indicate a very slow decrease after the outburst with an e-folding decay time of 5 to 50 yr (Willson et al. 1984). But this result is at present quite uncertain. X-rays were also detected in the symbiotic star CH Cyg after its 1984 radio outburst (Leahy and Taylor 1987).

## 3. DISCUSSION AND MODELS

### 3a. Cool component and binarity

Observations suggest that symbiotic novae include an M giant star. When not clearly detectable in the visual, the late-type spectrum is put in evidence by the preoutburst spectra, or by the IR observations as discussed above (see Whitelock 1987, Viotti 1989). In PU Vul the M-spectrum appeared during its 1980 deep minimum. Indeed, in the earlier studies the unclear presence of M-type absorptions in the visual spectrum of the Mira-type SyN led some authors (e.g. Baratta et al. 1974; Ahern et al. 1977; Kwok and Purton 1979) to hypothize for these objects a single star model of a recently evolved red giant. As a result of the outburst, the cool star atmosphere was pushed away leaving out a hot nucleus whose UV radiation is presently ionizing the circumstellar material formed in previous phases by the intense red giant wind. Baratta et al. also suggested that the bolometric magnitude of V1016 Cyg did not change after the outburst. Present observations indicate that the M giant should have remained unaffected by the outburst, while there is a large UV excess (and the strong emissions as well) which cannot be produced by a kind of "superactivity" of the M star, but should rather be associated with another source, a closeby dwarf star, or a hot region (accretion disk, hot spot) near it, which is the actual bursting object. However the identification of the nature of this object is difficult for there are no detectable photospheric absorption lines which might be attributed to a hot star. While the WR features observed during some phases are probably due to a variable hot wind produced somewhere near the hot object. The broad wings of the strongest emission lines could be attributed to an accretion disk, but this needs to be confirmed by higher quality spectroscopic data (e.g. from the HST). Only in two SyN (AG Peg and V1329 Cyg) there is a clear evidence of binarity. In AG Peg the binarity is indicated by the periodic variations of the M-star absorption lines (Hutchings et al. 1975; Garcia and Kenyon 1988; Slovak and Lambert 1988), and confirmed by the small photometric variability found by Meinunger (1981) and Fernie (1985). In V1329 Cyg the orbital parameters are derived from the emission line radial velocity curve. But, as discussed by Nussbaumer et al. (1986) and Baratta and Viotti (1989), in this system the emission line regions are probably located in between the two stars. In addition the shape of the emissions vary with activity and orbital phase, thus affecting the radial velocity curve. Therefore in V1329 Cyg the emission line radial velocity does not necessarily represent the motion of the hot source, and the mass function could be very different from the derived value of 23 Mo (Table 2). As concerns the other SyN, no periodic radial velocity variation has been so far found which suggests a period in excess of a few to several decades.

### 3b. Outburst amplitude and circumstellar dust

At maximum, the visual luminosity is dominated by the hot continuum masking the red spectrum which is visible during minimum. If this is true for all SyN, the observed amplitude should only be a lower limit of the actual visual luminosity increase of the exploding source. To check this point we have computed the visual and blue magnitudes of the red component in the absence of the hot source continuum. For this purpose we have used (Table 2) the observed K-magnitude, which are less affected by the hot source, the (V-K)o colours corresponding to the M-star spectral type, and the published colour excesses (see Viotti 1989). The results given in the last columns of Table 2 show that for AG Peg and V1329 Cyg the computed magnitudes are in fair

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agreement with their magnitudes at minumum, implying that in these objects the brightening in the blue-visual of the outbursting component has been larger, and probably much larger than that observed, possibly close to that of classical novae. In the case of PU Vul the computed magnitudes are roughly close to those observed during the deep 1980 minimum (V=13.5; B=14.0), while the star was much fainter during the pre-outburst phase (Table 1). A similar result is also found for RT Ser, RR Tel, V1016 Cyg, and especially HM Sge which appeared quite faint before outburst (see also Arkipova et al. this Volume). This is difficult to explain, unless in these objects the red giant is largely obscured by circumstellar dust. Indeed Kenyon et al. (1986), from an analysis of the IR energy distribution of SyN based on the IRAS observations, concluded that the red component should be affected by a large local extinction, which is as high as Ak=1 for HM Sge. Our considerations seem to confirm this hypothesis, and lead to the conclusion that there should be an effective process of dust formation in the atmosphere of the Mira components of these SyN. Also the mass loss should probably be quite large, and help the mass accretion of the companion, in spite of the larger components' separation with respect to the non-Mira SyN. We should remind the case of PU Vul which displayed a deep minimum in 1980. Friedjung et al. (1984) attributed it to a transient occultation of the A-F component by dust produced by the M-giant, while Men'shchikov et al. (1985) suggested a transient extinction of the A-F star by dust formed in the same stellar envelope. Kenyon (1986b) proposed an eclipse of a very long period system. It should be noted that, according to Friedjung et al., no large change of the near-IR flux occurred in 1980, while the minimum was deeper and broader in the UV, and this might favour their model.

## 4. CONCLUSIONS

In conclusion, symbiotic novae are subject to large outbursts, partly masked by the red giant luminosity, followed by the appearence of intense emission lines and UV continuum implying a large energy production. As discussed by Kenyon (1988) thermonuclear runaway models seem to better explain these features, but the mass accretion rate is very uncertain because of our poor knowledge of the SyN parameters. In those objects in which the binary components are more separated (the Mira-type SyN), the mass loss rate of the M star appears much larger, so that the accretion rate could be comparable to that of the non-Mira systems. The larger mass loss rate of the M star is also put in evidence by the presence of circumstellar dust. The total number of SyN objects so far identified is too poor to allow any statistical treatment. We should however consider that, because of the long time scales involved, and of the strong selection effects (several objects have been discovered in well studied regions of the sky) we might have not recorded many other SyN. A systematic search of these events, and in particular a study of their earliest phase, would be of crucial importance to better investigate the nature of the outburst, and the associated processes of mass ejection and of the interaction of the matter and radiation with the circumstellar environment.

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Table 2. Characteristic parameters of symbiotic novae

| object | --- outburst --- | | | --- cool component --- | | | | | computed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| name | rise | max | decay | sp type | Mira(d) | K | V-K | E(B-V) | B | V | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | |
| AG Peg | 16 | 10-30 | 40 | M3 III | === | 3.9 | 4.6 | 0.12 | 12.0 | 9.9 | (11) |
| RT Ser | 14 | === | 7: | M5.5 | === | 6.9 | 6.5 | (0.) | 15.1 | 13.5 | |
| RR Tel | <0.3 | 3 | 9 | >M5 | 374.2 | 3.6v | 7.0 | 0.10 | 12.5v | 10.9v | |
| V1016 Cyg | 2-3 | >30 | >125 | >M4 | 472 | 4.7v | 7.0 | 0.28 | 14.3v | 12.5v | |
| V1329 Cyg | 0.3 | 1-2 | 12-20 | >M4 | === | 6.9 | 7.0 | 0.37 | 16.8 | 14.9 | (12) |
| HM Sge | <0.4 | 20 | >65 | >M4 | 527 | 3.6v | 7.0 | 0.5 | 14.0v | 12.0v | |
| PU Vul | 1 | 7 | 15-35 | M4-5 III | === | 5.9 | 4.9 | 0.49 | 14.2 | 12.1 | |

(1) Total rise time (in years). (2) Time of permanence at maximum. (3) e-folding decay time. (4) Spectral types from Kenyon and Fernandez-Castro (1987) and Schulte-Ladbeck (1988). (5) Mira-type period in the IR (Whitelock 1987). (6) Observed K-magnitude. (7) Adopted V-K colour of the M-star. (8) Interstellar extinction (see Viotti 1989). (9) and (10) computed reddened B and V magnitude. (11) Binary system with T=816 d, K=5.0 km/s, e=0.28 and f(m)=0.009. (12) Binary system with T=950 d, K=62 km/s, e=0.17, and f(m)=23.

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