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The mass-loss history of the symbiotic nova RR Telescopii*

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Abstract. Mass loss in symbiotic novae is of interest to the theory of nova-like events as well as to the question whether symbiotic novae could be precursors of type Ia supernovae. RR Tel began its outburst in 1944. It spent five years in an extended state with no mass-loss before slowly shrinking and increasing its effective temperature. This transition was accompanied by strong mass-loss which decreased after 1960. IUE and HST high resolution spectra from 1978 to 1995 show no trace of mass-loss. Since 1978 the total luminosity has been decreasing at approximately constant effective temperature. During the present outburst the white dwarf in RR Tel will have lost much less matter than it accumulated before outburst. – The 1995 continuum at $\lambda \lesssim 1400$ is compatible with a hot star of T = 140 000 K, R = 0.105 $R_\odot$, and L = 3700 $L_\odot$.

Key words: binaries: symbiotic, novae – stars: individual: RR Tel – stars: mass-loss

1. Introduction

Does the outburst of a symbiotic nova always lead to a long lasting mass-loss via a fast stellar wind, or could it occur without appreciable mass-loss?

Symbiotic novae occur in binary systems. They are due to thermonuclear reactions close to the surface of a white dwarf when accretion from the wind of the red giant has led to a critical mass. Thermonuclear reactions on white dwarfs that lead to bloated atmospheres, and their possible connection to symbiotic novae have been studied on many occasions, e.g. Kenyon & Truran (1983), Kenyon & Webbink (1984), Sion & Starrfield (1986), Prialnik (1986), Livio et al. (1989), Kato & Hachisu (1989), Shara et al. (1993), Iben & Tutukov (1996). In their study on evolutionary sequences of nova outbursts Prialnik & Kovetz (1995) find that for conditions appropriate to symbiotic novae there may be cases where the outburst is accompanied by mass-loss, whereas in other cases the outburst simply leads to an extended atmosphere without appreciable mass-loss. However, there is as yet no satisfactory detailed explanation for the mechanism of mass-loss in these systems. It is therefore all the more urgent, that in order to test theoretical predictions, reliable observational evidence is collected about the presence or absence of mass-loss during outburst. Mass loss is also crucial within the debate whether symbiotic novae may be precursors of type Ia supernovae. This possibility has been advocated by Munari & Renzini (1992). For further contributions see Yungelson et al. (1995) or Iben & Tutukov (1996). The hypothesis strongly rests on the assumption that thermonuclear outbursts in symbiotic novae are not accompanied by significant mass-loss.

In this work we collect the observational information relevant to the mass-loss history of RR Tel. For the outbursting star Jordan et al. (1994) find for 1992 an effective radiative temperature of T = 140 000 K and L = 3500 $L_\odot$. Penston et al. (1983) list in its spectrum strong resonance lines of medium ionized atoms, in particular the N V $\lambda\lambda 1238.8, 1242.8$ doublet. If this doublet has its origin in a stellar wind, we expect a P Cygni absorption in the underlying stellar continuum, as was found in AG Peg (Nussbaumer et al. 1995). The limited dynamical range of IUE (International Ultraviolet Explorer) did not allow to clearly observe P Cygni features in symbiotics, that has changed with HST (Hubble Space Telescope).

2. The history of the outburst

The lightcurve of Mayall (1949) shows that the outburst began in October 1944. By the end of the year the initial phase of rapid brightness increase from $\approx 14^m$ to $\approx 8^m$ was terminated. In the middle of 1946 it had reached $\approx 7^m$, and in July 1949 the visual brightness began to fade (Thackeray 1950). The evolution is traced in Mürset & Nussbaumer (1994). Previous to the outburst the visual brightness was determined by the contribution of the Mira with its 387 days period. The outburst occurs on the white dwarf companion. In an initial fast expansion it led to a bloated atmosphere which according to Mayall (1949) seems to have mimicked a F type giant. She writes: "There is no evidence of a banded or nova-like spectrum, which should appear if the sudden rise in brightness was due to a superposed nova. The only features visible are strong absorption H and K, and many absorption lines in the violet, somewhat similar to an F-type

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* Based on observations by the *International Ultraviolet Explorer* and the NASA/ESA *Hubble Space Telescope*, retrieved from the respective archives

star." The luminosity of the outbursting object rose to 20 000 $L_\odot$. Until 1949 its temperature remained below 10 000 K. Pottasch & Varsavsky (1960) report that in the middle of 1949 the spectrum of RR Tel began to change rapidly, implying an increase in the colour temperature from 8400 K in October 1949 to 12 500 K in August 1950. It then slowly but steadily rose to attain $T \approx$ 135 000 K and $L \approx 8800\,L_\odot$ in 1978, in 1992 the temperature was at $T \approx$ 140 000 K whereas the luminosity had decreased to $L \approx 3500\,L_\odot$ (Jordan et al. 1994).

3. The evidence for mass-loss from 1944 to 1978

The early outburst data of RR Tel, obtained from the ground, are not absolutely calibrated, and Thackeray (1977) warns us even about the relative calibration. Mayall (1949) describes the spectrum from which she derived the F-type character as "The only spectra available are of short dispersion with the star at maximum brightness, and are too burned out to classify". Thus, we can at best hope for qualitative information. According to Thackeray (1950) spectra taken in June 1949 showed "pure absorption apparently supergiant F type with H and K three times as intense as Hδ". Spectra taken in September and October 1949 show a change to a "rich bright line spectrum superposed on a continuous background in which no absorption is measurable". Also Pottasch & Varsavsky (1960) report a qualitative change: in May 1949 the spectrum was entirely in absorption, corresponding to that of an early F star, whereas in August 1950 it was practically all in emission. On subsequent spectra violet displaced absorption in He I lines was seen. Pottasch & Varsavsky (1960) give displacements corresponding to -430 km/s in October 1949, and -510 km/s in August 1950. Thackeray (1953) gives -685 km/s for 1951, and -865 km/s for 1952. Thackeray (1953) also reports that by 1952 He II λ4686 is very broad and much stronger than in 1951. Thackeray and Webster (1974) show the profiles of He II λ4686. Their half widths correspond to 480 km/s in 1951-52, 700 km/s in 1953, 1100 km/s in 1955-56, and to 1300 km/s in 1958 and 1960. When discussing his spectroscopic results from 1951 to 1973, Thackeray (1977) states that no P Cyg absorption had been detected since 1952. Schmutz (1996) finds that the combination of a diminishing He I P Cygni feature and a growing broad He II emission is exactly what is expected from a mass losing star with increasing effective temperature.

He II λ4686 in emission is no proof of a stellar wind. We need to distinguish between the broad stellar wind lines and the narrow nebular emission, a distinction which is obvious when looking at the profiles of He II λ4686 shown in Thackeray and Webster (1974). The change in the profiles, including N III $\lambda4634-40$, shows that in 1955 narrower components developed on top of a broad underlying feature, and that already in 1955 the broad emission began to decline relative to the continuum.

We conclude that the outburst of 1944 produced an extended atmosphere around the white dwarf. For 1949 Mürset & Nussbaumer (1994) give a radius of 93 $R_\odot$ and T = 6500 K. There is no indication of mass-loss for that period. The spectral change in the autumn of 1949 signaled the emergence of a substantial stellar wind with terminal velocities increasing from $\approx$ 400 km/s in 1949 to $\approx$ 1300 km/s in 1960. There is no indication that it had disappeared in 1973 which is the date of the last entry of Thackeray's (1977) RR Tel publication. However, he comments about the intensity of He II λ4686: "A steady increase occurred up to 1960 and thereafter there appears to have been a slow decline". The published observational data do not permit to calculate the mass-loss for this period.

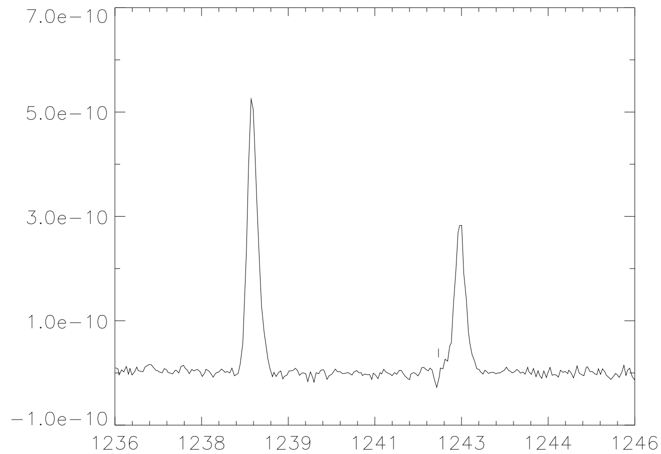

Fig. 1. N V $\lambda\lambda$1238.8, 1242.8 observed by IUE on November 21, 1978 with an exposure time of 450 seconds. The position of a reseau mark is indicated at λ1242.2. Fluxes are in erg/(cm^{2}s Å).

4. The absence of mass-loss from 1978 onward

4.1. IUE spectra

IUE began its observations in 1978, and RR Tel was a favourite target among symbiotics. We concentrate on the three multiplets N V λ1240, C IV λ1550, and He II λ1640. P Cygni profiles with absorption in the continuum of the hot star would be the most direct proof for a stellar wind from the hot star.

The resonance doublet N V λ1240 is ideal for wind diagnostics, and it is prominent in the spectrum, e.g. Fig. 1. Penston et al. (1983) measured its FWHM as 57 km/s. The doublet lies practically at rest wavelengths. The dynamical range of IUE did not allow to observe P Cygni profiles of very strong emission lines on top of a weak continuum. However, wind lines, hidden by nebular emission might still betray their presence by a wide foot. For an illustration see the example of AG Peg given in Vogel & Nussbaumer (1994) and Nussbaumer et al. (1995). An investigation of a series of IUE spectra from 1978 to 1992 confirms that the N V λ1240 doublet in RR Tel is typical of nebular emission as generally observed in symbiotic systems, but it shows no contribution from a fast stellar wind.

C IV $\lambda\lambda$1548.2, 1550.8 and He II λ1640 are well exposed on many IUE spectra. They present qualitatively the same picture as N V λ1240. They show typical nebular profiles with no broad feet or P Cygni features. There was no detectable qualitative change in the line profiles from 1978 to 1992.

Table 1. Emission observed by IUE (1978, 1992) and HST (1995). Fluxes are in erg/(cm^{2}s) for lines and erg/(cm^{2}Å s) for the continuum; $x(-y)$ stands for $x \cdot 10^{-y}$. The last column gives FWHM in km/s from the July 16, 1995 HST spectrum.

line	21/11/1978	6/11/1992	16/7/1995	
N V λ1238.8	1.3 (-10)	3.3 (-11)	5.9 (-11)	65
N V λ1242.8	7.6 (-11)	2.0 (-11)	3.2 (-11)	65
C IV λ1548.2	3.5 (-10)	1.2 (-10)	1.3 (-10)	47
C IV λ1550.8	1.9 (-10)	5.8 (-11)	6.9 (-11)	47
He II λ1640.4	2.0 (-10)	1.0 (-10)	1.4 (-10)	68
O V λ1643.7	3.8 (-12)	2.3 (-12)	2.3 (-12)	71
N IV λ1486.5	5.3 (-11)	1.3 (-11)	2.0 (-11)	42
Si III λ1892.0	2.9 (-11)	8.1 (-12)	1.1 (-11)	35
C III λ1908.7	1.1 (-10)	4.8 (-11)	5.1 (-11)	38
cont. λ1280	7.3 (-13)	4.0 (-13)	4.1 (-13)	
cont. λ1450	6.2 (-13)	3.5 (-13)	3.5 (-13)	
cont. λ1690	5.5 (-13)	3.3 (-13)	3.1 (-13)	
cont. λ2600	5.2 (-13)	2.0 (-13)	1.7 (-13)	

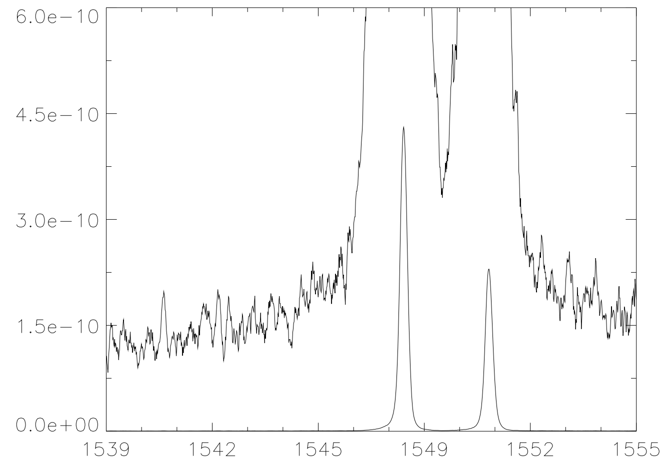

Fig. 3. C IV $\lambda\lambda$1548.2, 1550.8 taken on July 16, 1995 with HST HRS grating G140M, exposure time 381 s. Fluxes are in erg/(cm^{2}s Å). For the upper spectrum the scale has to be reduced by 400.

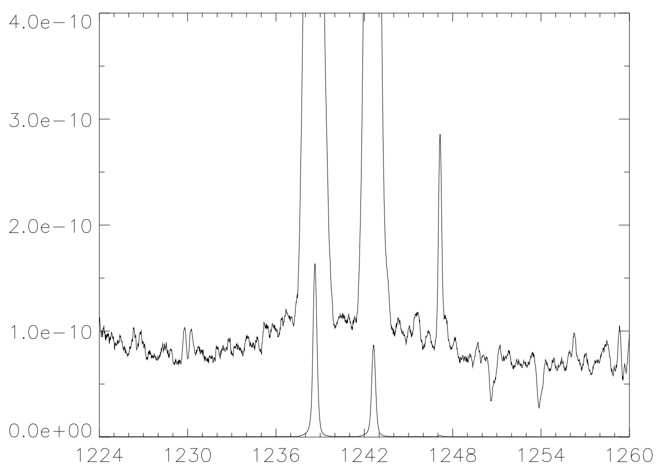

Fig. 2. N V $\lambda\lambda$1238.8, 1242.8 taken on July 16, 1995 with HST HRS grating G160M, exposure time 762 s. Fluxes are in erg/(cm^{2}s Å). For the upper spectrum the scale has to be reduced by 200.

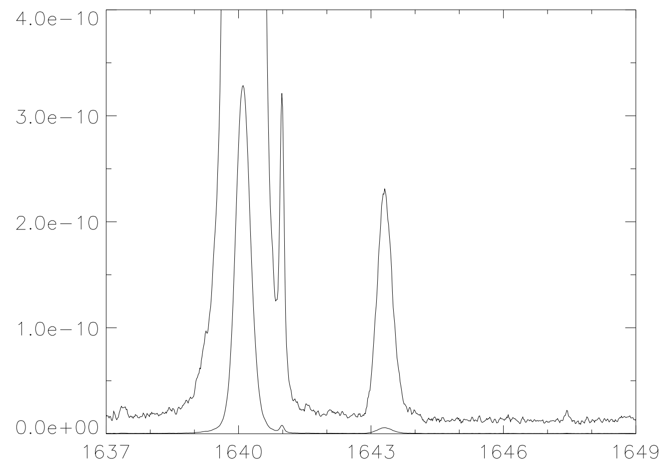

Fig. 4. He II λ1640 taken on July 16, 1995 with HST GHRS grating G160M, exposure time 1088 s. Also seen are O I λ1641.3 and O V λ1643.7. The flux is given in erg/(cm^{2}s Å). For the upper spectrum the scale has to be reduced by 40.

4.2. HST spectra: Search for wind lines of N V, C IV, and He II

HST has a much higher sensitivity and dynamic range than IUE. It is possible to obtain simultaneously high quality line profiles and a good signal/noise in the underlying continuum, see also Harper et al.(1995). In Figs. 2 and 3 we show the strong resonance doublets N V λ1240 and C IV λ1550. Both stand on a wide foot to be discussed below. None of them shows any sign of a P Cygni profile. The increase shortward of 1230 Å is due to the wing of Ly α, as is evident from a low resolution HST spectrum.

In Table 1 we give the FWHM expressed as velocities for the important lines in Figs. 2–6. At their bottom the lines reach about twice the FWHM-values. As is often seen in symbiotics, the widths increase with the degree of ionization, note that the recombination O V λ1643.7 is emitted in the O^{+5} region. None of these velocities is a candidate for a wind line from a hot white dwarf.

Table 1 shows the evolution of the nebular lines since 1978. There is no significant change in the flux ratios of lowly to highly ionized lines from 1978 to 1995.

The wide foot underneath the nebular emission of N V λ1240, C IV λ1550, and He II λ1640 could be the signature of a fast wind. However, it is much more likely that the foot is due to electron scattering of line photons on free electrons. In a nebular gas of $T_e \approx 15\,000$ K the Doppler width of electron scattering at λ1550 is $\Delta\lambda_{\rm D}$ = 3.5 Å. The flux in the wide scattering foot of N V λ1240 is $6.4 \cdot 10^{-13}$erg/(cm^{2}s). Calculations done for us by Dr.W. Schmutz confirm that this flux is compatible with model expectations.

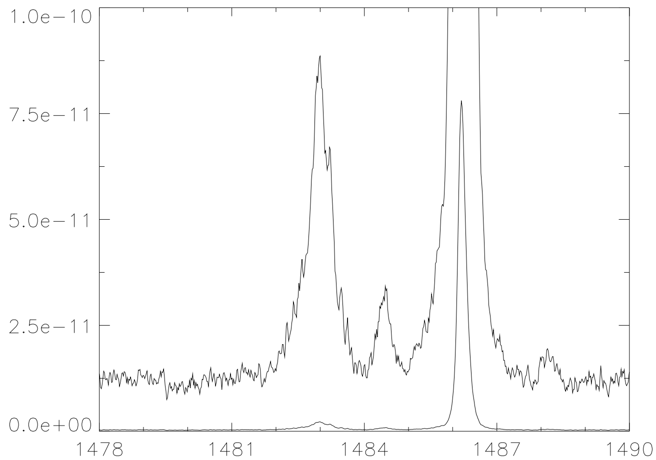

Fig. 5. N IV $\lambda\lambda$1483.3, 1486.5 taken on July 16, 1995 with HST HRS grating G160M, exposure time 979 s. Fluxes are in erg/(cm^{2}s Å). For the upper spectrum the scale has to be reduced by 40.

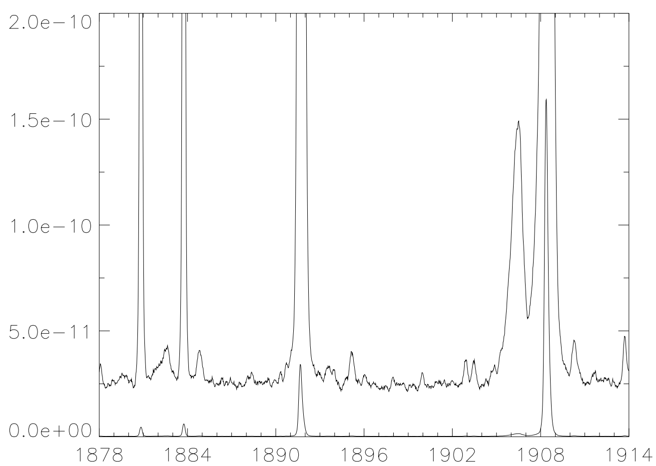

Fig. 6. Si III $\lambda\lambda$1882.7, 1892.0 and C III $\lambda\lambda$1906.7, 1908.7 taken on July 16, 1995 with HST GHRS grating G200M, exposure time 1523 s. Also seen is Fe II $\lambda\lambda$1881.2, 1884.1. Fluxes are in erg/(cm^{2}s Å). For the upper spectrum the scale has to be reduced by 100.

4.3. HST spectra: Search for a collision zone with intercombination and forbidden lines

If the hot star emits a fast wind, we expect a shock zone of high temperature where the hot wind collides with the wind from the Mira. Nussbaumer et al. (1995) have interpreted the profile of the forbidden N IV λ1483.3 transition seen in AG Peg as evidence for a collision zone. Fig. 5 shows the N IV intercombination doublet. There are four emission features centered at $\lambda\lambda$1483.0, 1484.5, 1486.2, 1488.2. For the N IV $\lambda1483.3/\lambda1486.5$ flux ratio of $\approx$ 0.06 Nussbaumer & Schild (1981) give an electron density of $N_e \approx 2 \times 10^6\,\mathrm{cm}^{-3}$. The profile of the N IV intercombination doublet is quite different from that of AG Peg, and there is no hint of a wind-wind collision zone.

Two further intercombination multiplets, Si III $\lambda\lambda$1882.7, 1892.0 and C III $\lambda\lambda$1906.7, 1908.7 are shown in Fig. 6. From

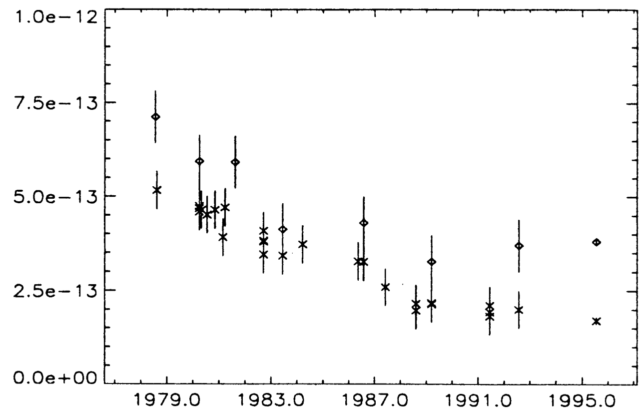

Fig. 7. Evolution of the continuum flux from 1978 to 1995 from IUE (before 1995) and HST (1995) observations. $\diamond$: mean flux of measurements at λ1280 and λ1450. $\times$: flux at λ2600. Fluxes are in erg/(cm^{2}s Å). The error in the 1995 HST value is much lower then in the IUE measurements.

Nussbaumer (1986) we find from the Si III flux ratio densities of $N_e \gtrsim 5 \cdot 10^6\,\mathrm{cm}^{-3}$ for a one-point model. Similarly we find from Nussbaumer & Schild (1979) for the observed C III flux ratio $N_e \gtrsim 2 \cdot 10^6\,\mathrm{cm}^{-3}$.

We have verified that the additional lines in Figs. 5 and 6 do not correspond to blue or red shifted components of our doublets.

For the nebula of RR Tel Espey et al. (1996) find $T_e \approx$ 18 000 K and $N_e \approx 10^6\,\mathrm{cm}^{-3}$. This supports the traditional picture (Hayes & Nussbaumer 1986) of radiative ionization and collisional excitation of the nebular spectrum. Schild & Schmid (1996) resolve the O III $\lambda\lambda$5007, 4363 line profiles into a $N_e \gtrsim 10^8\,\mathrm{cm}^{-3}$ component near zero radial velocity, and a $N_e \lesssim 10^{5.5}\,\mathrm{cm}^{-3}$ component shifted by -20 km/s. The volume ratio of the low to high density components they estimate as 1000. They did not see any evidence for high speed ($\gtrsim$ 1000 km/s) mass motion.

4.4. The flux in the continuum

In Fig. 7 we show the decline of the continuum from 1978 to 1995. We give the mean of the fluxes at $\lambda\lambda$1280, 1450, as well as the flux at λ2600. As can be seen from Fig. 8 the fluxes at $\lambda\lambda$1280, 1450 correspond to the stellar continuum, whereas λ2600 measures the nebular flux. For an approximate idea about the relative contributions of stellar and nebular fluxes to symbiotic spectra see Fig. 1 of Nussbaumer & Vogel (1989). From 1978 to 1988 there was a decline by a factor two in the stellar continuum, and of a factor three in the nebular continuum. The evolution after 1988 is compatible with the assumption of approximately constant luminosity.

We now combine the HST continuum observations at $\lambda \gtrsim$ 1100 Å of July 16, 1995 with ORFEUS (Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph) and HUT (Hopkins Ultraviolet Telescope, Espey et al. 1995) observations at 930 Å $\lesssim \lambda \lesssim$ 1200 Å; they are given in Fig. 8. Mürset & Nuss-

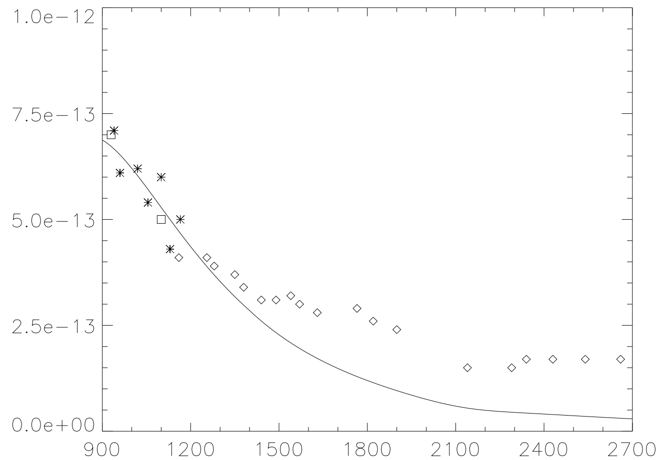

Fig. 8. The continuum flux of RR Tel. ⋄: HST observations of July 16, 1995. ∗: ORFEUS data taken in September 1993. (J. Krautter and H.M. Schmid personal communication). □: HUT observation of March 12, 1995 (Espey et al. 1995). We also show the black-body radiation for T = 140 000 K and L = 3700 $L_\odot$, reddened with E_{B-V} = 0.08. Fluxes are in erg/(cm^{2}s Å).

baumer (1994) as well as Jordan et al. (1994) find for 1992 an effective temperature of T = 140 000 K. We fit a black-body emission of T = 140 000 K, corrected for interstellar reddening with E_{B-V} = 0.08 (Jordan et al. 1994) to the observed continuum. Whitelock (1988) derived a distance of 2.6 kpc. With these parameters a best fit is obtained with L = 3700 $L_\odot$ which implies R = 0.105 $R_\odot$. A comparison between a black-body emitter and a line blanketed NLTE model appropriate to RR Tel is given in Jordan et al. (1994).

The comparison of the observed continuum with the model calculation shows that the strong nebular lines observed with IUE and HST, in particular N V λ1240 are indeed seen on top of the stellar continuum. P Cygni profiles, if present, should therefore not be much disturbed by nebular emission.

5. Conclusions

The outburst of RR Tel began in October 1944. The nova event led to an extended atmosphere with a radius of $\approx$ 90 $R_\odot$, but without noticeable mass-loss. The transition to the nebular phase began between May and August 1949. It led to a small and hot radiative core. It was accompanied by growing mass-loss. The corresponding wind had terminal velocities of $\approx$ 400 km/s in October 1949, increasing to $\approx$ 1300 km/s in 1960. After 1960 the wind diminishes, and from 1978 onward there is no trace of mass-loss. By 1960 the outbursting star had reached $T \approx$ 100 000 K. After 1960 it evolved at approximately constant effective temperature but decreasing luminosity. When in 1978 IUE began to take high resolution spectra, evidence for a fast and significant stellar wind had disappeared. The observations of HST in 1995 confirm that result.

From a combination of HST, HUT, and ORFEUS observations we see that from 930 Å to 1400 Å the observed, dereddened continuum can be well fitted with a black-body emission of T = 140 000 K and L = 3700 $L_\odot$, corresponding to a hot star with R = 0.105 $R_\odot$. At wavelengths $\gtrsim$ 1400 Å the nebular emission increasingly dominates the continuum.

Jordan et al. (1994) attribute the X-ray flux of RR Tel in 1992 mainly to a stellar atmosphere of $T_{\rm eff}$ = 142 000 K and L = 3500 $L_\odot$. In addition they postulate a hot low luminosity plasma (0.04 – 0.09 $L_\odot$) of several 10^6 K, which could be due to a mass-loss wind of 10^{-9} $M_\odot$/yr and $v \approx$ 500 km/s. That wind would be too low to be detected by our observations.– The relative C/N/O abundances found by Nussbaumer et al. (1988) are not nova-like, and they are consistent with little contamination of the nebula by nova-processed matter.

For AG Peg, the oldest still active symbiotic nova, Vogel & Nussbaumer (1994) find during a very active phase a mass-loss rate of $\dot{M} \approx 3 \times 10^{-7}$ $M_\odot$/yr. If we generously credit RR Tel with a similar wind for the period of 1950 to 1960, we arrive at a total mass-loss of $\Delta M \approx 3 \times 10^{-6}$ $M_\odot$. The lowest total accreted mass listed by Prialnik & Kovetz (1995) for candidates of symbiotic novae is 2.5×10^{-5} $M_\odot$. Thus, RR Tel will probably retain most of its formerly accreted mass.

The key to an estimate of the total mass-loss of RR Tel lies in the spectra taken between 1949 and 1960. It would be of great value if they were re-analyzed. A mass-loss analysis would require the visual magnitude, and equivalent widths and profiles of He I and He II wind lines.

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