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Shocked gas in RR Telescopii

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Abstract. RR Telescopii is the slowest of all known novae and the prototype of the "Symbiotic Nova" class. ROSAT PSPC spectra shown, in addition to the supersoft emission from the White Dwarf, a harder component. We have observed the system with XMM-Newton, and we have unambiguosly detected the presence of a hot, collisionally ionised plasma whose more plausible origin is the collision of the winds of the two stars.

Key words. Stars: individual: RR Telescopii – Stars: binaries: symbiotic – novae – X-rays: binaries

1. Introduction

RR Telescopii is a very well studied object. It is the prototype of the "symbiotic novae" class, and the slowest system in this group. RR Tel underwent a nova-like optical outburst in 1944, rising from magnitude 14 to magnitude 7 in more than one year. It stayed at maximum during five years, and then started a slow decline. More than 67 years after the outburst, the system is still evolving and it is currently at visual magnitude 11.6 (see the AAVSO website).

The system consists of a hot White Dwarf, an extended nebula and a M5 III Mira-type cool giant, with a pulsation period of 387 days, surrounded by a dust envelope. The orbital period is unknown, as well as the distance between the two stars.

Its optical and ultraviolet spectrum is extraordinarily rich and complex, with emission lines spanning a wide range in ionisation and excitation, and it has undergone remarkable changes over the years. Examples can be seen in Selvelli & Bonifacio (2000) and Selvelli et al. (2007). In the UV range, Penston et al. (1983) made a thorough study of the IUE spectrum of RR Tel, where they identified more than 400 emission lines.

The commonly adopted distance to RR Tel is 2.6 kpc. This value was estimated from the pulsation period of the Mira (Whitelock 1988). Nevertheless, there are indications that the absorption could have been overestimated in the past. Selvelli et al. (2007) used the intensity ratios of the HeII Fowler lines to derive the extinction, obtaining a value of E(B-V)≈0.00, while values previously adopted were in the

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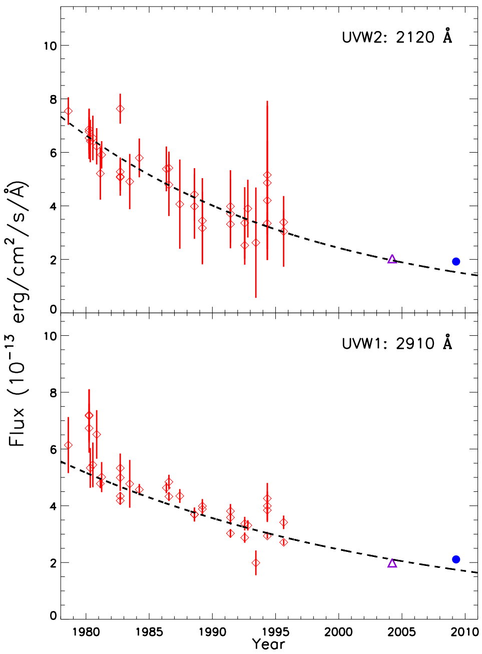

Fig. 1. Evolution of the ultraviolet continuum of RR Tel in two of the XMM Optical Monitor bands. Fluxes derived folding IUE spectra through the OM filters responses are shown as diamonds. The IUE data have been fitted with an exponential function. The OM data (circle) agree well with the extrapolation of the IUE decay curve. The fluxes derived from STIS spectra taken in March 2004 are shown as triangles.

range 0.08-0.10. This low reddening would place the system at a distance of 3.5 kpc.

2. X-rays from RR Tel

RR Telescopii was detected in the late 70's and early 80's by EINSTEIN and EXOSAT. EINSTEIN data were interpreted by Kwok & Lehay (1984) as a breemstrahlung with a temperature of 5 MK.

Jordan et al. (1994) analysed the ROSAT PSPC observations of RR Tel obtained in 1992. The PSPC spectrum is dominated by a supersoft component. These authors, using model atmosphere, derived an effective temperature of 142 kK and a luminosity of 3500 $L_\odot$. They describe the presence of a much weaker component, peaking around ≈1 keV, but the low signal-to-noise ratio prevented them to make a more detailed analysis, although they speculated that it could be due to shocks between the winds of the two stars.

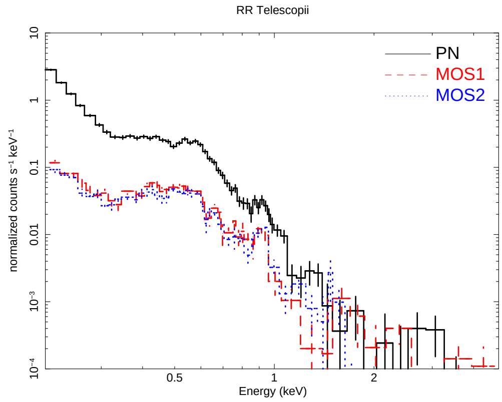

Fig. 2. XMM-Newton EPIC spectra of RR Tel.

SWIFT detected RR Tel in 2007, at a countrate of 0.005 cts s^{-1} (Ness et al. 2007). All the few photons detected were below 1 keV, confirming the presence of the soft component at a flux level similar to that detected by ROSAT 15 years before.

In what follows, we will describe the observations of RR Telescopii obtained with XMM-Newton in April 2009.

3. XMM-Newton observations

3.1. The UV data

Nussbaumer & Dumm (1997) presented the evolution of the UV continuum of RR Telescopii from 1978 until 1995 in two spectral bands, around 1400 and 2600 Å. The first band is dominated by the spectrum of the hot star, while the nebular recombination continuum is the main contributor to the second one. Both bands showed a slow decrease until ≈ 1990, and remained more or less constant afterwards.

Unfortunately, the flux of the hot star cannot be estimated from the XMM Optical Monitor data, as the shortest wavelength OM filter has an effective wavelength of 2100 Å,

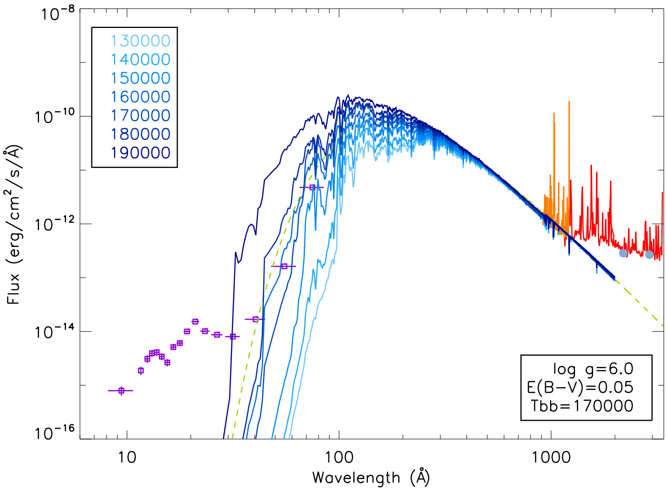

Fig. 3. Spectral Energy Distribution of RR Tel from X-rays to the near UV. The data shown are: XMM EPIC-pn fluxed spectra (10-70 Å), ORPHEUS data taken in November 1996 (900-1150 Å), IUE data taken in August 1995 (1200-3300 Å), and XMM OM photometry (circles). A blackbody of 170 kK is shown as reference as a dashed line, as well as a set of model atmospheres with temperatures ranging from 130 to 190 kK (see text for details).

where the contribution of the recombination continuum is still significant.

In order to study the evolution of the nebular continuum, we have folded the IUE spectra through the response of the OM filters, and compared these values with the OM fluxes. We have fitted an exponential decay function to the IUE data. Fig. 1 shows that the OM fluxes fit very well in the extrapolation of this function to 2009, so we can conclude that the emission of the nebula has been steadily decreasing during the last three decades.

3.2. The EPIC spectra

The spectra obtained with the three XMM EPIC cameras are shown in Fig. 2. Two components are clearly visible: a steep continuum below 0.4 keV, and a flatter emission that goes up to ≈ 1 keV, and declines at higher energies.

3.2.1. The hot component

The first of these two components clearly corresponds to the soft component detected by ROSAT. We show in Fig. 3 the Spectral Energy Distribution of the hot component of RR Tel using data from XMM-Newton EPIC-pn and OM, ORPHEUS (Krautter et al. 1997), and IUE. The EPIC-pn data represented in this figure have been computed with the SAS task 'efluxer', that derives fluxes from the EPIC-pn observed count spectra and the redistribution matrix without making any a priori assumption about the true shape of the spectrum (i.e. these fluxes are not model-dependent).

Apart from the hot star, two additional components dominate below ≈ 40 Åand above ≈ 1200 Å. The latter corresponds to the nebular recombination continuum (see e.g. Mürset et al. 1991). We'll discuss the high energy component below.

We have compared this SED with the model atmospheres provided by T. Rauch[1]. We show in the figure models for solar abundance, log g=6.0, and effective temperatures ranging from 130 to 190 kK. We also plot, for comparison, a blackbody with a tempera-

[1] http://astro.uni-tuebingen.de/~rauch/TMAF/TMAF.html

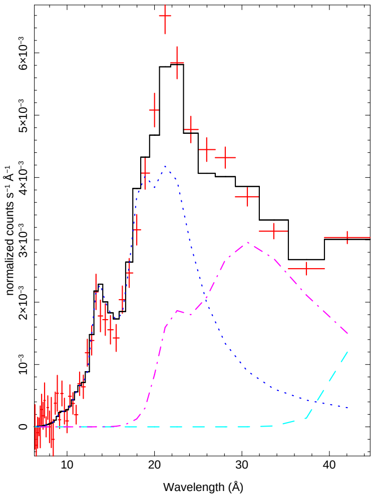

Fig. 4. XMM EPIC-pn spectrum of RR Tel in the region dominated by the ionised gas. The Raymond Smith spectra of two plasmas with different temperatures are shown: the dotted line corresponds to a temperature of 1.5 MK, and the dashed-dotted line to a temperature of 0.5 MK. These two plasmas are absorbed by Hydrogen column densities of 2.7 and 4.0 10^{21} cm^{-2}, respectively, in addition to the much lower interstellar absorption.

ture of 170 kK. Both the blackbody and the model atmospheres have been normalised to the ORPHEUS continuum near 1020 Å, where the contribution of the nebular recombination continuum is negligible. Models with effective temperature below 160 kK fail to reproduce the observed X-ray flux. We then conclude that the temperature of the hot star is higher than this value, between 170 and 180 kK. For a distance of 2.6 kpc, these temperatures would imply a WD radius of 0.08 $R_{\odot}$ and a luminosity between 4500 and 6000 $L_{\odot}$. Conversely, assuming a WD radius of 0.1 $R_{\odot}$, the distance to the system would be between 3.0 and 3.3 kpc.

3.2.2. The ionised gas

For energies above ≈ 0.4 keV the 'hard' component barely detected by ROSAT PSPC can be seen in detail in the EPIC spectra. We have fitted this region of the spectrum with two Raymond-Smith plasmas (the contribution of the hot component is negligible in this range). To get a meaningful fit we needed two plasmas with different temperatures: 0.045 and 0.125 keV (0.5 and 1.5 MK), respectively (Fig. 4). While the first one is the main contributor below 0.5 keV, the second one is required to reproduce the peaks around 0.6 and 0.9 keV, which correspond to the the He-like triplets of O VII and Ne IX (see below). What is particularly interesting is these two plasmas are affected by different Hydrogen column densities (2.7 and 4.0 10^{21} cm^{-2}, respectively), both at least ten times higher than the interstellar column density.

3.3. The XMM RGS spectrum

More detailed information about the physical state of this gas can be derived from the high resolution spectra taken with the XMM 'Reflection Grating Spectrographs' (RGS). Despite the low signal to noise, it is easy to identify in the spectrum emission lines of O VIII (Lyman α), O VII (He-like triplet), N VII (Lyman α), N VI (He-like triplet) and C IV (Lyman α).

The He-like triplet is a powerful spectral diagnostic. The relative intensities of the lines that form this triplet are very sensitive to the conditions of the emitting plasma (see the extensive discussion in Porquet & Dubau 2000; Porquet at al. 2010), and they allow an accurate estimation of the electron temperature and density, as well as the determination of the main ionisation mechanism. In particular, a strong recombination line, as is observed in the O VII and N VI triplets of RR Tel, is a clear indication of the importance of the collisional ionisation in the emitting plasma. The ratio between the sum of the intensities of the forbidden and intercombination lines and the intensity of the resonance line (the 'G' ratio) is very sensitive to the electron temperature. In a purely ionised plasma, this ratio is larger than 4. On the other hand, the ratio of the intensities of the forbidden and intercombination lines (the 'R' ratio) is sensitive to the electron density. We have measured in the O VII triplet in RR Tel values of 1.0 and ≥ 2.3 for the 'G' and 'R' ratios, respectively. As the intercombination line is extremely weak (as it is in the N VI triplet

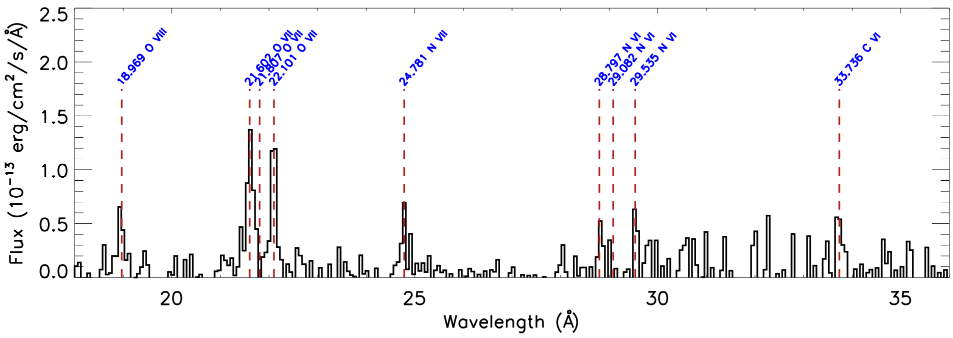

Fig. 5. RGS fluxed spectrum of RR Tel. The most prominent emission lines are Lyman α of O VIII (18.97 Å), N VII (24.78 Å) and C VI (33.73 Å), and the He-like triplets of O VII (21.60,21.80,22.10 Å) and N VI (28.78,29.08,29.54 Å).

as well), we can put only an upper limit to the electron density. Using the diagnostic diagrams given in Porquet & Dubau (2000) and Porquet at al. (2010), we derive an electron density $\leq 2\ 10^{10}$ cm^{-3}, and an electron temperature of 1.6 MK, the latter in good agreement with the estimations from the EPIC spectra for the hottest gas.

4. Discussion

Broad foots underneath the CIV 1550 Å and NV 1240 Å resonance lines of RR Tel were detected by Nussbaumer & Dumm (1997) in GHRS spectra of RR Tel taken in 1995. While these profiles could be interpreted as formed in a high velocity wind, these authors are in favour of the interpretation of electron scattering of line photons on free electrons instead. Alternatively, Contini & Formiggini (1999) argue that these broad components could be due a high-velocity shock (v$\approx$500 km s^{-1}), heating the gas to a temperature of several MK.

However, the XMM data of RR Tel do not show any evidence of the presence of gas at this temperature in the system. We have detected instead a slightly cooler, collisionally ionised plasma. This plasma has two components with different temperatures. Each of these components is affected by a different absorption, which points out to the inhomogeneity of the emitting gas. If the emission is due to shocks, the required velocities would be $\approx$ 60 and 100 km s^{-1}, respectively. These values are consistent with the velocities of the reverse and expanding shocks estimated by Contini & Formiggini (1999) in their colliding winds model of RR Tel.

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