RR Tel: MASS LOSS RATE OF THE COOL COMPONENT

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ABSTRACT. The Fe II emission lines in the optical spectrum of the symbiotic star RR Tel, observed by Crawford et al. (1999), have been analysed applying the SAC method. We obtain information about the relative populations of the lower levels of the lines and, assuming them to be in LTE, we determine the column densities of Fe+ and of H. The mass loss rate has been calculated using the mean cool component radius obtained from the bolometric properties of Mira variables with a pulsation period similar to that of the cool component of RR Tel.

Key words: Stars: binary: symbiotic; stars: individual: RR Tel.

1. Introduction

The symbiotic nova RR Tel had one single observed major outburst in 1944, followed by a long recovery phase which has not yet finished. Extensive spectroscopic investigations during this period have indicated that it is an interacting binary, consisting of a Mira variable of a late spectral type and a white dwarf. There is evidence of a planetary nebula-like plasma and additional hot plasma due to colliding winds from the two components as well as a circumstellar dust shell due to which RR Tel has been classified as a D-type symbiotic. The Mira variable loses mass at high rates via a spherically symmetric stellar wind which expands at low velocity and is ionized by the hot component. The mass loss rate is important for the evolution of the binary system and may play a causal role in producing its symbiotic behaviour.

The mass loss rate for RR Tel has been determined by use of different methods: from the flux of thermal radio emission (Seaquist et al. 1993), by use of infrared flux ratios derived from IRAS satellite observations (Kenyon et al. 1988), from a mean relation for miras involving their luminosities (Whitelock et al. 1994) and from the proportion of O VI resonance line emission which is Raman scattered in parts of the wind where hydrogen is neutral (Birriel et al. 2000).

In our present approach we find a limit to the mass loss rate of the cool mira in RR Tel by the Self Absorption Curve (SAC) method.

2. Observations

We have analysed the flux calibrated high resolution optical spectrum of RR Tel observed in 1996 (Crawford et al. 1999) in the $\lambda\lambda 3180 - 9455$ Å spectral region.

The spectrum displays a large number of narrow emission lines including those of singly ionized iron which have been analyzed in this work.

The database of Crawford et al. was checked critically regarding the line identifications (Selvelli and Bonifacio 2000) as well as the line intensities (Keenan 2001, Mc Kenna et al. 1997). A total number of 131 permitted and forbidden Fe II lines with reliable atomic parameters have been selected for this study. They belong to different multiplets and originate from transitions between the lowest levels with an excitation potential up to 9 eV.

3. Methods

The mass loss rate can be calculated by use of the continuity equation:

$$\dot{M} = 4\pi r^2 \rho(r) v(r) \qquad (1)$$

which can be expressed in terms of hydrogen column density N_H by

$$\dot{M} = 4\pi r N_H m_H v(r) \qquad (2)$$

where $N_H = rn(r)$ and $n(r) = \rho(r)/m_H$. m_H is the mass of the hydrogen atom, n(r) the hydrogen number density and v(r) the outward velocity which can be directly measured as the mean velocity broadening of the line profile. The remaining two unknowns in the expression for $\dot{M}$ (2), $randN_H$, have been determined by use of the SAC method which has proved to be effective in determining limits to relative populations of upper and lower terms, as well as in deriving other information about the line formation region (Friedjung and Muratorio 1980, Friedjung and Muratorio 1987, Muratorio and Friedjung 1988, Baratta et al. 1998).

The Self Absorption Curve (SAC), whose shape is determined by self absorption effects, is the observational log-log plot of the quantity Fλ^3 /gf versus (gfλ). F is the line flux emitted in a transition which is related to the optical thickness of that transition.

Simple theory gives

$$log\frac{F\lambda^3}{gf} = log\left(\frac{2\pi^2e^2hR^2}{m_ed^2}\right) + log\left(\frac{N_u}{g_u}\right) + Q\left(\tau_0\right) \quad (3)$$

and

$$log\ \tau_0 = log(gf\lambda) + log\frac{N_l}{g_l} + log\frac{\pi e^2}{m_ec} - log\ v_d \quad (4)$$

Q(τ_0) is the self absorption function depending on the optical thickness τ_0; N$_u$ and N$_l$ are the column densities of the upper and the lower level and g$_u$, g$_l$ their statistical weights. R is the size of the emitting region perpendicular to the line of sight and d the distance of the star. A type of excitation temperature of the line emitting region can be defined by

$$\frac{\frac{N_u}{g_u}}{\frac{N_l}{g_l}} = e^{-\frac{E_u-E_l}{kT}} = e^{-\frac{\Delta E}{kT}} \quad (5)$$

.

4. Results

4.1. Determination of R

The lower and upper limits to the radius of the emitting line region of RR Tel have been determined by the SAC method in the previous paper (Kotnik-Karuza and Friedjung 2001), yielding values of 26 and 2300 solar radii respectively. However, when estimating the mass loss rate, it is more realistic to take for r in equation (1) the radius of the cool component instead of the minimum radius of the line emitting region. Using bolometric corrections to the K magnitude for M giants (Houdashelt et al. 2000), measured properties of "group 1" Mira variables with a 387 day pulsation period (Barthès et al. 1999) and an M7 spectral class of the cool component (Mürset and Schmid 1999), we can expect a mean cool component radius of the order of $1.5 \cdot 10^{13}$ cm to $3.0 \cdot 10^{13}$ cm which gives a mean value of about 300 $R_\odot$. The smaller of these radii is less than the maximum radius obtained by the SAC method. In fact we expect line formation outside the region of dust condensation (Kotnik-Karuza et al. 2001), which is expected to be at 5 mira radii or averageing 1500 solar radii. We take it for justified to calculate the mass loss rate by assuming this value of $r = R$.

Table 1: Parameters of the cool component of RR Tel from this work

R_{dust} (cm)	N_{Hmin} (cm^{-2})	v (kms^{-1})	$\dot{M}_{min}$ (M$_\odot$ yr $^{-1}$)
$1.0 \cdot 10^{14}$	$7.5 \cdot 10^{22}$	14	$3 \cdot 10^{-6}$

4.2. Column density

The column density has been obtained starting from the SAC of multiplet 27 (Fig.1).

The minimum optical thickness of 1 at log($gf\lambda$)=1 leads from (4) to a minimum N$_l$/ g$_l$ of $5.3 \cdot 10^{14}$ cm^{-2} for the lower metastable term at 2.68 eV. This term is the upper term of the forbidden line multiplet 4F, so we obtain from (5) the ground level N/g of $5.9 \cdot 10^{16}$ atoms cm^{-2}. In this calculation we used the temperature of 6600 K which is an upper limit to the permitted line region temperature (Kotnik-Karuza and Friedjung 2001) and is near to the maximum temperature of the forbidden line formation region. The latter was obtained by plotting $log\frac{F\lambda^3}{gf}$ versus upper level excitation potential for all forbidden lines, assumed to be optically thin (Fig.2).

This temperature of 6600 K, being an upper limit to the permitted line region excitation temperature, together with the interpolated value of the partition function of antilog 1.71 at this temperature, leads to a minimum column density of $3.0 \cdot 10^{18}$ atoms cm^{-2} for Fe+ and so for Fe since iron is present also in higher degrees of ionization. By assuming standard abundances we obtain $7.5 \cdot 10^{22}$ atoms of hydrogen per cm^2.

4.3. Mass loss rate

By inserting the calculated parameters and the value of 14 kms^{-1} for the mean velocity broadening of the emission line profile in (2), we obtain $3 \cdot 10^{-6}$ M$_\odot$ yr^{-1} for the minimum mass loss rate of the cool component as shown in Table 1.

An agreement with estimates by other authors, using other methods, can be seen from Table 2.

The adopted geometry of RR Tel which agrees with the model of Taylor and Seaquist (Taylor and Seaquist 1984), is represented in Fig.3. Beside the determined sizes, it shows clearly that Fe II is especially present near the boundary of the ionized and neutral regions. While the permitted lines are formed not too far from the boundary of the ionized zone, the forbidden lines are most probably formed further out, in that part of an accelerated wind which is ionized by the hot component. The ionization front cannot penetrate the dust region. Our determinations are consistent with line formation in the cool star wind.

Table 2: Mass loss rates for RR Tel and some normal Miras

Mass loss rate ($M_\odot$ yr $^{-1}$)						
RR Tel					normal Miras Loup et al.1993	
this paper	Whitelock et.al.1994	Seaquist et.al.1993	Kenyon et.al.1988	Birriel et.al.2000	carbon rich	oxygen rich
$3 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$	$5.3 \cdot 10^{-6}$	$8.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$2.8 \cdot 10^{-7}$ $1.4 \cdot 10^{-7}$ $4.1 \cdot 10^{-7}$

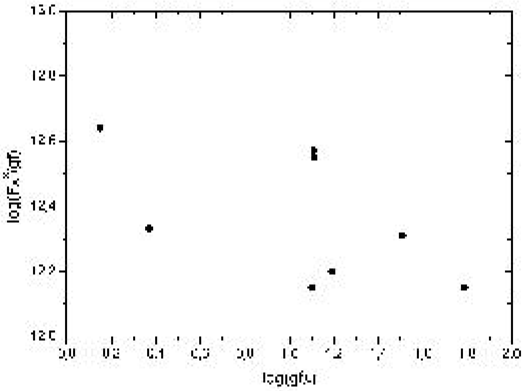

Figure 1: Self absorption curve of the permitted line multiplet 27

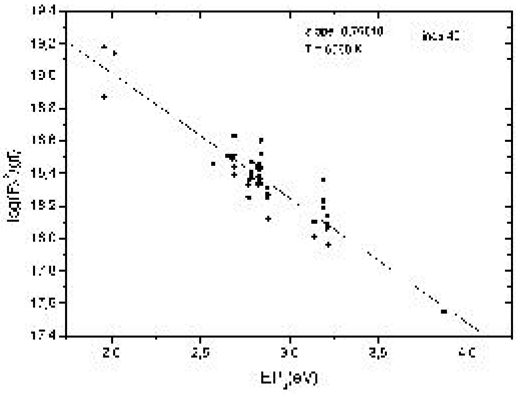

Figure 2: Determination of excitation temperature of the forbidden line region

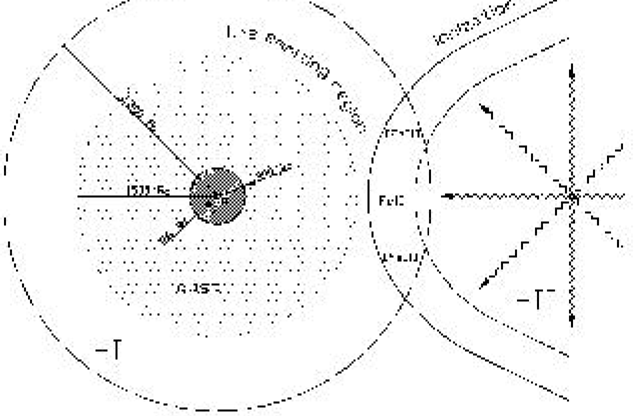

Figure 3: The adopted geometry of RR Tel

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