A COLLIDING WIND MODEL FOR WR 79

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Abstract. The variable peaks on the flat-topped C III–569.6 nm line of the WC–star in the WR 79–system are interpreted as additional emissions, produced in the colliding wind region of the two stars. The minimum and maximum distances of the appertaining radial velocity curves yield the important parameter i and so the system–masses. Synthetic profiles strongly support the present model.

WR 79 is a double–lined spectroscopic WC– and O–star–binary system. The flat–topped profile of the C III (569.6 nm) line originates in an optically thin region, where the WR-wind has reached its terminal velocity (Beals 1931).

Seggewiß (1974) and Schumann & Seggewiß (1975) found variable emission peaks superimposed on the flat–topped section ('plateau') of the C III-line. UV spectra of WR 79 indicate that the C III 190.9 nm line shows essentially the same behaviour as the optical line. The field of WR 79 was observed during the ROSAT–survey. The poor photon statistics does not yet allow to confirm the phase–dependent modulation of the X-ray radiation, which is expected on the base of the following model.

The peaks on the optical C III–line were originally interpreted as edges of an overlying narrower absorption (Neutsch 1979, Neutsch *et al.* 1979, 1981). The present model interprets these structures as additional emissions which originate in the region of the WR– and O–star wind interaction. With both stars having radially symmetric outflows, the winds, after collision near the O–star, are diverted from their radial directions (Fig. 1). If balance of the dynamical pressures is assumed for all points of the boundary layer, the corresponding limiting curves are obtained from a first order differential equation. Their shapes are completely determined by the parameter $Q = (\dot{M}_{\rm O} v_{\rm O}) \cdot (\dot{M}_{\rm WR} v_{\rm WR})^{-1}$, as was already shown by Huang & Weigert (1982). A nearly cone–shaped region is built up around the O–star.

In the region of head–on collision the gas is heated to X–ray temperatures. If the cooling times are sufficiently short, an extended additional C III line–emitting region exists in the system. Assuming a plasma of 75% H and 25% He in mass and adopting the radiation function Λ of Cox & Tucker (1969), we find short cooling times, which are even smaller when heavy elements are present. Up to temperatures $5 \cdot 10^6$ K the cooling time is less than one hour, if the scale factor $r_{10}^2\, v_{2000} \cdot (\dot{M}_{-5})^{-1}$ lies in the range 2 – 40. This shows that the temperatures for C III line formation exist almost throughout the region of wind interaction.

We now consider the different aspects of this region, which produces the

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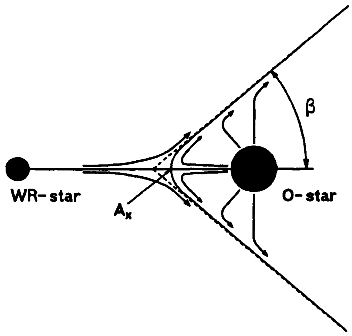

Fig. 1. Schematic model of the stationary case. Coriolis forces are neglected.

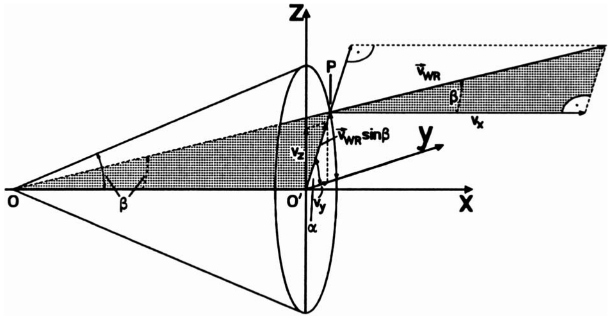

Fig. 2. Components v_x, v_y, v_z of the wind velocity vector $\mathbf{v}_{WR}$: v_x in the direction of the x–axis, v_y and v_z as the projections of the radius vector onto the y– and z–axes.

emission peaks seen by the observer. In the rectangular coordinate system the positive x–axis coincides with the line connecting the centers of the stars, the z–axis is perpendicular to the orbital (x,y)–plane. The components of the wind velocity vector in the line of sight and within the cone, which approximately represents the shock front region, can be determined (Fig. 2). The radial velocity curve (RV) of the red peak is given by v'_{red} and that of the blue peak by v'_{blue}:

$$v'_{red} = v_{WR}(-\cos\beta\sin i\cos\varphi^\star + \sin\beta\sqrt{1-\sin^2 i\cos^2\varphi^\star}) \quad (1)$$

$$v'_{blue} = v_{WR}(-\cos\beta\sin i\cos\varphi^\star - \sin\beta\sqrt{1-\sin^2 i\cos^2\varphi^\star}) \quad (2)$$

v_{WR} is the wind velocity, 2β the aperture angle of the cone, i the inclination angle and $\varphi^\star$ the phase angle of the emission peaks (see Lührs (1994) for details). The same relations were found by Neutsch et al. (1979) on the basis of their model. The theoretical RV curves v'_{red} and v'_{blue} are shown in Fig. 3.

The mean values $\bar{v} = (v'_{red} + v'_{blue})/2$ yield the radial velocity curve of the center of gravity of the total profile (dashed curve in Fig. 3). We also define $v^\star = (v'_{red} - v'_{blue})/2$. The minimum and maximum values $v^\star_{min}$ and $v^\star_{max}$ are indicated in Fig. 3. Equations (1) and (2) then yield $\cos i = v^\star_{min}\cdot(v^\star_{max})^{-1}$.

The amplitude of the $\bar{v}$–curve is $v_{WR}\cos\beta\sin i$ and the known inclination gives $v_{WR}\cos\beta$. With this, we derive $v_{WR} = \sqrt{(v^\star_{max})^2 + (v_{WR}\cos\beta)^2}$ and finally β from $\tan\beta = (v_{WR}\sin\beta)\cdot(v_{WR}\cos\beta)^{-1}$, where $v_{WR}\sin\beta = v^\star_{max}$. $v^\star_{min}$ and $v^\star_{max}$ are observables, but one needs a large data base at the corresponding two phases. Alternatively, we can compare all RV data with model curves. This method is applied in Fig. 4. The excellent fit of the data confirms the orbital period derived from the flat C III line. The system parameters obtained in this investigation are given in Table I.

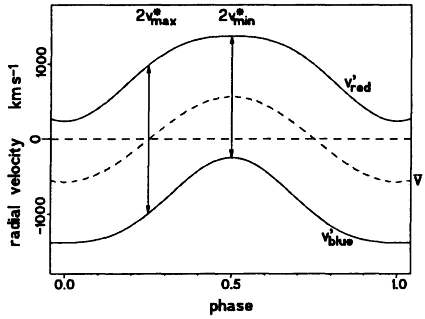

Fig. 3. Radial velocity curves of $v'_{\rm red}$ and $v'_{\rm blue}$ (solid lines) and of the line profile center of gravity (dashed line) as a function of the phase of $\varphi^{\star}$.

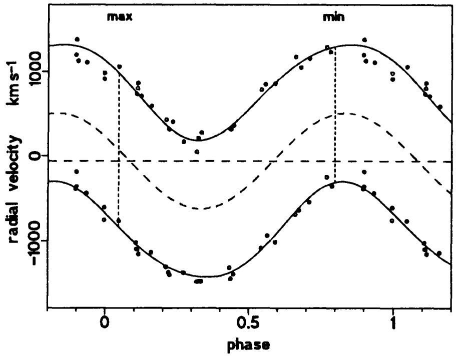

Fig. 4. Radial velocity data of the C III 569.59 nm peaks in WR 79 fitted by the curves explained in Fig. 3.

The colliding wind model assumes that the wind interaction occurs in a cone of thickness $\Delta\beta$ and aperture 2β (Fig. 5), filled with a luminous fluid, whose density declines towards the boundaries. With this model synthetic profiles were computed for one whole orbital cycle and are shown in Fig. 6. For an example of the fit to a single measured line profile see Fig. 7; more figures are given by Lührs (1994).

Some computed profiles show larger deviations from the measured profile, both in position and size of the peaks, than the profile shown here, but the basic structure always persists. Tests with small additional emissions superimposed on the main peaks by Monte–Carlo simulations show that the fits can be somewhat improved.

The colliding wind model was derived using high resolution spectra of the C III 569.59 nm line of WR 79 over the years 1985 – 1989, and literature data. It is expected that a similar model may be used for other WR binaries. Suitable systems are those which are not too widely separated and where the WC–star shows a sufficiently broad C III–line to permit an accurate study of variable features on the plateau of the line. Such variations were already

TABLE I

Period	P	(8.891037 ± 0.00018) d
System velocity	γ	-55.0 km s^{-1}
WR–star amplitude	K_2	132.6 km s^{-1}
Wind velocity in cone	$v_{\rm WR}$	(1416.9 ± 21.6) km s^{-1}
Inclination angle	i	$(28\overset{\circ}{.}0 \pm 1\overset{\circ}{.}1)$
Cone aperture	2β	$(79\overset{\circ}{.}6 \pm 1\overset{\circ}{.}6)$
Shift due to Coriolis forces	θ	$(16\overset{\circ}{.}8 \pm 2\overset{\circ}{.}2)$
Mass of WR–star	M(WR)	(11.1 ± 3.9) M$_\odot$
Mass of O–star	M(O)	(35.6 ± 9.0) M$_\odot$

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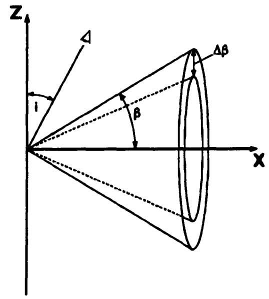

Fig. 5. The wind cone with aperture 2β and thickness $\Delta\beta$.

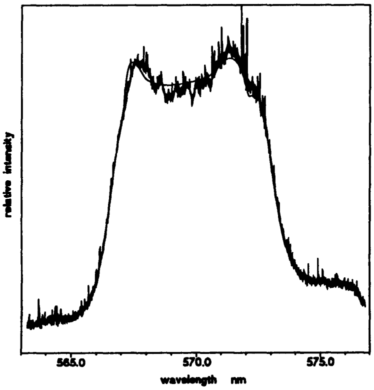

Fig. 7. Profile based on the colliding wind model (solid line) superimposed on the observed C III–line at phase 0.06 .

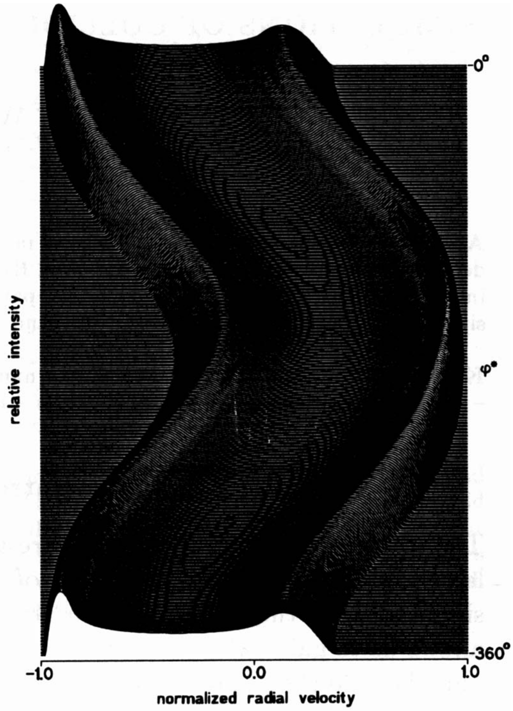

Fig. 6. Synthetic profiles as a function of $\varphi^\star$ for the case in which $\Delta\beta$ (see Fig. 5) is filled with a luminous fluid which declines continuously to zero at the boundaries of the cone. The two peaks change their profiles with phase $\varphi^\star$, with an offset of 180° relative to each other.

found in WR 140, WR 48 and WR 11, as well as in the suspected single star WR 90. The last example shows that it may be possible by systematic C III–observations to decide whether apparently single stars might be binary systems with strongly interacting winds.

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