Binary Stars as Critical Tools & Tests
in Contemporary Astrophysics
Proceedings IAU Symposium No. 240, 2006
W.I. Hartkopf, E.F. Guinan & P. Harmanec, eds.

doi:10.1017/S1743921307004012

Line-Profile Variations on Massive Binary Systems: Determining η Carinae Orbital Parameters

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Abstract. When the winds of two massive stars orbiting each other collide, an interaction zone is created consisting of two shock fronts at both sides of a contact surface. During the cooling process, elements may recombine generating spectral lines. These lines may be Doppler shifted, as the gas stream flows over the interaction zone. To calculate the stream velocity projected into the line of sight we use a simplified conical geometry for the shock fronts and, to determine the synthetic line profile, we have to sum the amount of emitting gas elements with the same Doppler shifted velocity. We show that the stellar mass loss rates and wind velocities, and the orbital inclination and eccentricity, are the main parameters on this physical process. By comparing observational data to the synthetic line profiles it is possible to determine these parameters. We tested this process to Brey 22 WR binary system, and applied to the enigmatic object of η Carinae.

Keywords. binaries: general, Wolf-Rayet, winds, line: profiles

1. Introduction

Wolf-Rayet (WR) stars are believed to be at the end of the evolutionary history of massive stars. For this reason, they play a key role in the stellar evolution theories. Typically, they present fast winds (~ 3000 km s^{-1}) with extreme mass-loss rates, ranging from 10^{-6} to 10^{-4} M$_\odot$yr^{-1} (Lamers 2001). WR stars are also known as variable stars, due to strong variability in their spectral lines. This variability is believed to be originated by wind clumpiness. However, in some objects, the spectral lines present periodic variability, possibly revealing duplicity (Bartzakos, Moffat & Niemela 2001). In some objects, these lines present anomalous behaviour, varying not only their intensity, but their velocity and profile and, eventually, presenting a 2-peaked profile.

In Falceta-Gonçalves, Abraham & Jatenco-Pereira (2006), we presented a model to explain the periodic variability of the line profiles for WR binary systems. We assumed that these lines are not generated in the stellar wind, but in the shock region between the winds of both stars. In a WR+O system, both stars present high velocity winds, leading to a strong shock region, which can be understood as a high temperature and density gas. In Figure 1 (left panel) we show the contact surface (S_C), calculated as the momentum equilibrium region for the ratio $\eta = \dot{M}_2 v_2 / \dot{M}_1 v_1 = 0.1$. Neglecting the curvature due to the orbital motion of the secondary star, the shock becomes asymptotically conical with an opening angle $\beta \simeq 44°$. The dashed line represent the line of sight intercepting two fluid elements of the cone, resulting in two different Doppler-shifted velocities. This explains the double-peaked profiles in some WR stars.

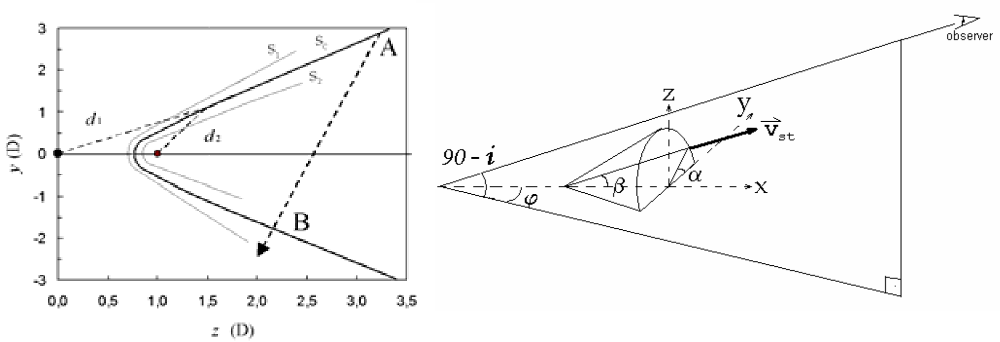

Figure 1. Schematic view of the shock surfaces and the assumed geometry.

2. The Model

To calculate the stream velocity projected into the line of sight we use the schematic geometry shown in the right panel of Figure 1. The stream velocity projected over the line of sight, as shown in Figure 1, is given by:

$$\mathrm{v_{obs}} = \mathrm{v_{flow}}(-\cos\beta\cos\varphi\sin i + \sin\beta\cos\alpha\sin\varphi\sin i - \sin\beta\sin\alpha\cos i), \qquad (2.1)$$

where $\mathrm{v_{flow}}$ is the stream velocity, i is the inclination of the orbital plane with respect to the line of sight, α is the cone azimuthal angle and φ is the orbital phase, defined here as the angle between x and the projection of the line of sight on the orbital plane. As these shocks are strongly radiative, they present high turbulence amplitudes. To account for the line broadening we used Equation 2.2:

$$I(\mathrm{v}) = \mathcal{C}\int_0^{\pi} \exp\left[-\frac{(\mathrm{v}-\mathrm{v_{obs}})^2}{2\sigma^2}\right] d\alpha, \qquad (2.2)$$

where $\mathcal{C}$ is the normalization constant and $\sigma = \delta\mathrm{v_{turb}}/\mathrm{v_{flow}}$. Substituting the mean value $\mathrm{v_{obs}}$, given by Equation 2.1, and integrating the right-hand side of the equation over α, we obtain the relative line intensity for each projected velocity into the line of sight v. In the computation of the syntetic line profiles we also take into account the optical depth of the shock region. If $\tau \gg 1$, the redshifted peak is absorbed, resulting in a single peaked profile.

3. The case of η Carinae

η Carinae is one of the most interesting objects in our Galaxy. Famous by the eruptions in the 19th Century, it presents complex light curves at all frequencies. Damineli (1996), using the HeI 10830 Å line light curve, first determined the periodic behaviour of this object. He found the system to have a period of 5.52yr and, using the HeII 4686 Å (Steiner & Damineli 2004) an eccentricity of ~ 0.8, assuming that the line is produced by the wind of the primary at 500 km s^{-1}, and that the periastron occurs in opposition.

However, Falceta-Gonçalves, Abraham & Jatenco-Pereira (2005) analysing the X-ray data, and Abraham *et al.* (2005a,b) using radio light curves, determined that the orbit should have a higher eccentricity ($e = 0.9 - 0.95$) and that the periastron should occur near conjuntion. In order to verify which orbital model is correct, we decided to apply the last to reproduce the HeII 4686 Å used by Steiner & Damineli (2004). Also, instead of assuming the line to be generated by the wind of the primary star, we assume that the

https://doi.org/10.1017/S1743921307004012 Published online by Cambridge University Press

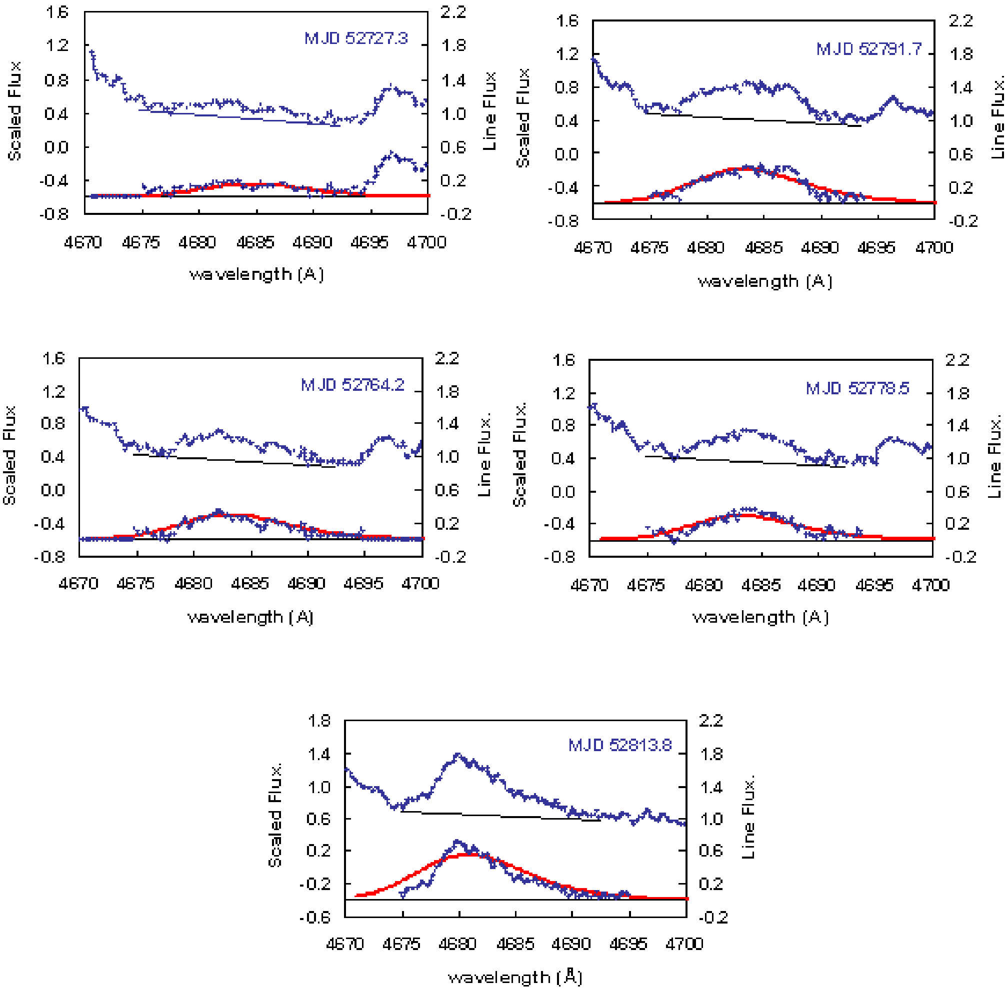

Figure 2. For different epochs, the observed HeII 4686 line profiles (up) and (bottom) the subtracted data and the adjust from the present model (red line).

line is generated at the shock cone. We calculated the synthetic line profiles for different orbital phase angles, and identified the best fitting of each of them to the more complete set of data from Martin & Davison (2006).

In Figure 2 we show the observational data from Martin & Davison (2006), and the best fitting results for $i = 90°$, $\beta = 56°$, $\sigma = 0.2$, $v_{flow} = 450$km s^{-1} and $\tau \gg 1$. To determine the orbit shape, we have to determine the phase angle at each orbital phase. From the fitting of the observed epochs, we found an eccentricity $e = 0.95$, and we determined that the periastron, supposed to occur in 2003 June, 28th, occurs with an angle of $\sim 30°$ regarding the conjunction. These results are in full agreement with the previous works on X-rays and radio frequencies.

Acknowledgements

D.F.G thanks FAPESP (No. 04/12053-2) for financial support. Z.A. and V.J.P. thank FAPESP, CNPq and FINEP for support.

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