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Spectroscopic follow-up of the colliding-wind binary WR140 during the 2009 January periastron passage

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Abstract: We present the results from the spectroscopic follow-up of WR140 (WC7 + O4-5) during its last periastron passage in January 2009. This object is known as the archetype of colliding wind binaries and has a relatively large period ($\simeq$8 years) and eccentricity ($\simeq$0.9). We provide updated values for the orbital parameters, new estimates for the WR and O star masses and new constraints on the mass-loss rates.

1 Introduction

WR140 is a very eccentric WC7+O5 colliding-wind binary (CWB) system with an eccentricity of nearly 0.9 (Marchenko et al. 2003 (= M03) and this paper) and a long period of about 7.9 years. It is also the brightest Wolf-Rayet star in the northern hemisphere and is considered as the archetype of CWB. We present here the results from a spectroscopic follow-up, unique in time coverage and resolution. The observation campaign was a worldwide collaboration involving professional and amateur (pro-am) astronomers and took place during a period of 4 months around periastron passage in January 2009.

2 Observations

A list of the sources of the campaign is presented in Table 1.

Table 1: List of the different sources in the 2009 campaign. Names marked with an asterisk are amateur astronomers/organisations equipped with their personal instrumentation.

Observatory / Telescope	Dates	Wavelength Range (Å)	Resolution (Å/ pixel)	Nb. of spectra
IAC / MONS 50 cm	1.12.08 - 23.03.09	5530-6000	0.35	34
OHP / 193 cm	12.12.08 - 23.3.09	4000-6800	0.01	63
DAO / 120 cm	22.4.08 - 9.1.09	5350-5900	0.37	13
OMM / 160 cm	5.7.09 - 8.8.09	4500-6000	0.63	18
Three Hills* (UK) Amateur telescope	10.12.07 - 20.3.09	5600-6000	0.68	38
Berthold Stober* (Germany) Amateur telescope	26.8.08 - 29.2.09	5500-6100	0.53	12

3 Radial velocities

The WR star radial velocities were estimated by cross correlation with a reference spectrum and the O star radial velocities by measuring the centroid of the photospheric absorption lines (see Fig. 1a). We notably find a higher eccentricity than previously published (e=0.896 $\pm$ 0.002 cf. 0.881 $\pm$ 0.005 from M03) and an updated value for the period (2896.5 $\pm$ 0.7 d instead of 2899.0 $\pm$ 1.3 d).

4 Excess emission

The presence of a shock cone around the O star induces an excess emission that we measured on the C III 5696 flat top line. This excess emission appears first, just before periastron passage, on the blue side of the line, and then moves quickly to the red side and grows, just after periastron passage, before it disappears (Fig.2). We fitted the radial velocity and the width of this excess as a function of orbital phase using a simple geometric model (Luehrs 1997) which enables us to constrain the half opening angle of the shock cone θ, the velocity of the fluid along the cone $v_{\rm strm}$, the orbital inclination i and an angular shift due to Coriolis forces $\delta\phi$ (see Fig.3). To be able to use the Luehrs model, which is originally designed for circular orbits, we fitted the excess as a function of the true anomaly instead of phase. By doing this, we implicitly assume that the $\delta\phi$ parameter stays constant throughout the periastron passage. This hypothesis is of course questionable and a more general model would be needed. Meanwhile, the resulting fit (shown in Fig. 4) seems quite good. We find a value for the inclination of 52$\pm$8° (cf. 58$\pm$5° from Dougherty et al. 2005) which gives the following estimation for the stellar masses : M_{WR} = 18.4$\pm$1.8 M$_\odot$ and M_O = 45.1$\pm$4.4 M$_\odot$ (cf. 19 M$_\odot$ and 50 M$_\odot$ from M03). From the half opening angle of the shock cone (Canto, Raga & Wilkin 1996), we also find a wind momentum ratio η = 0.028$\pm$0.009 (cf. 0.045 from M03 and 0.22 from Dougherty et al. 2005).

5 Conclusion

The 2009 periastron campaign on WR140 provided updated values for the orbital parameters, new estimates for the WR and O star masses and new constraints on the mass-loss rates. It is also a very encouraging success in term of professional-amateur collaboration and we hope it will give rise to similar initiatives in the future. However, our capability to measure the shock cone parameters with confidence and to understand its underlying physics is limited by the over simplistic approach

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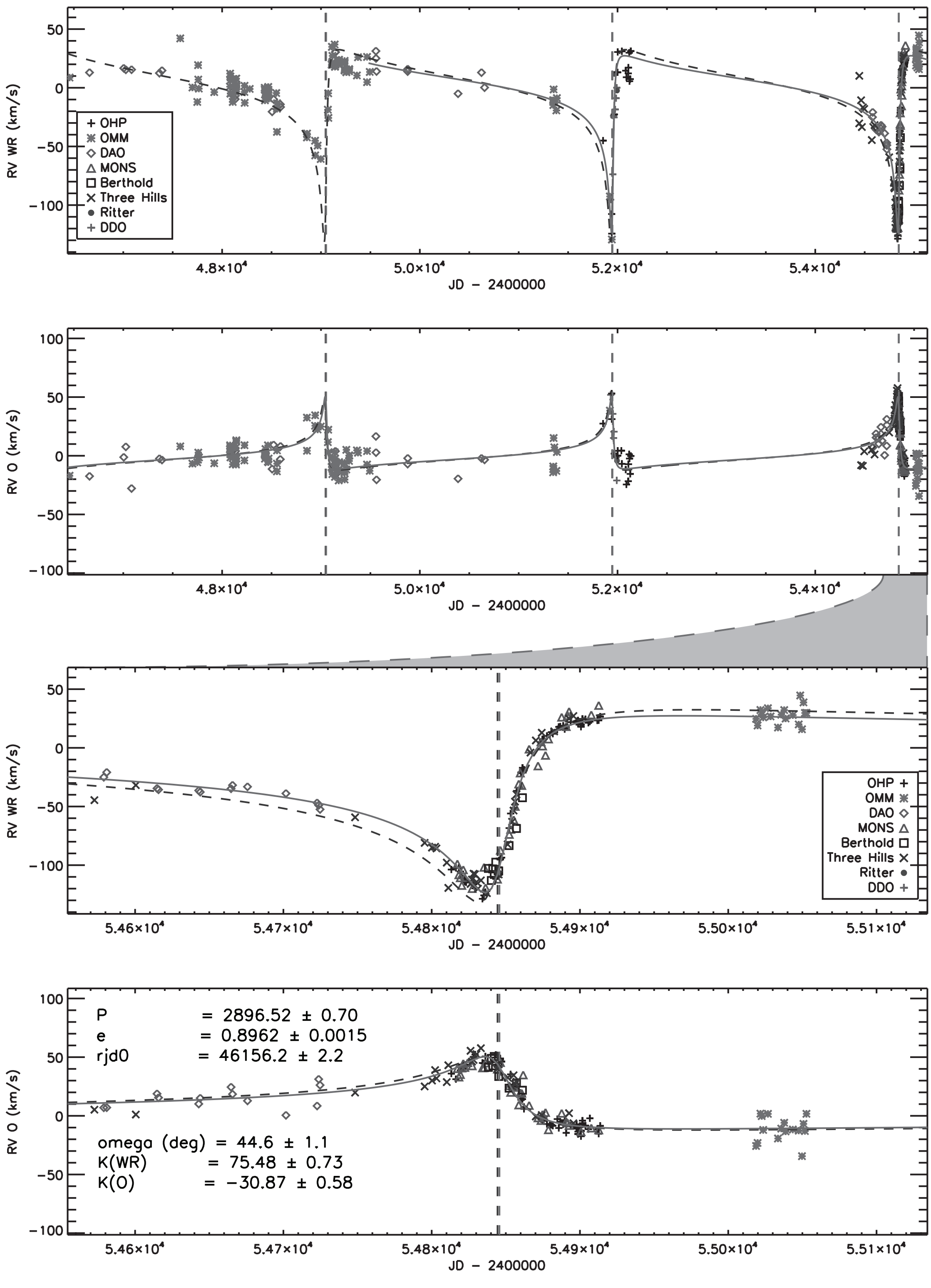

Figure 1: Top two panels: measured radial velocities of the WR star and of the O star together with the fit for the orbital solution (full line). We included data from the last periastron campaigns in 1993-2001 (M03), taken at David Dunlap Observatory (DDO), OHP, Ritter Observatory, DAO and OMM. The black dashed line is the orbital solution from M03. The dashed vertical lines show the position of the periastron passage. Bottom two panels: same plots but zoomed on the 2009 campaign (the filled curve between panel 2 and 3 illustrates the X axis expansion). The best fit parameters are indicated in panel 4.

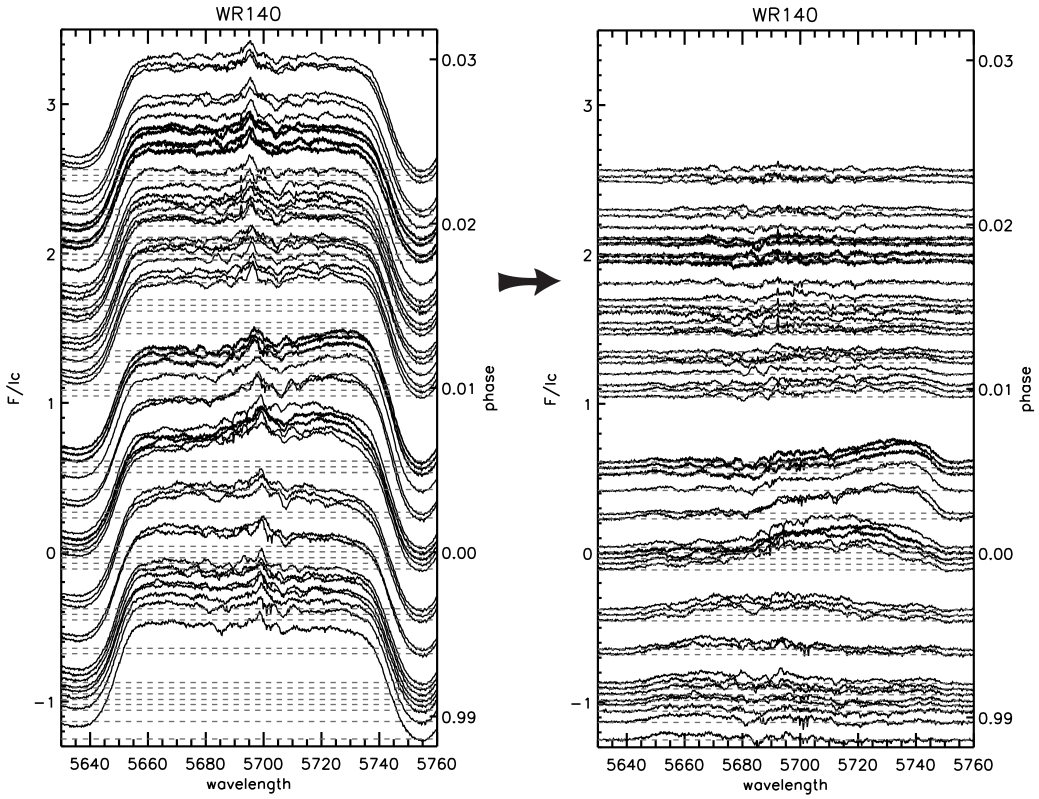

Figure 2: Left: the C III 5696 flat top line as a function of the orbital phase (OHP data). Right: excess emission as a function of the phase, obtained by substraction of a reference profile, unaffected by wind collision.

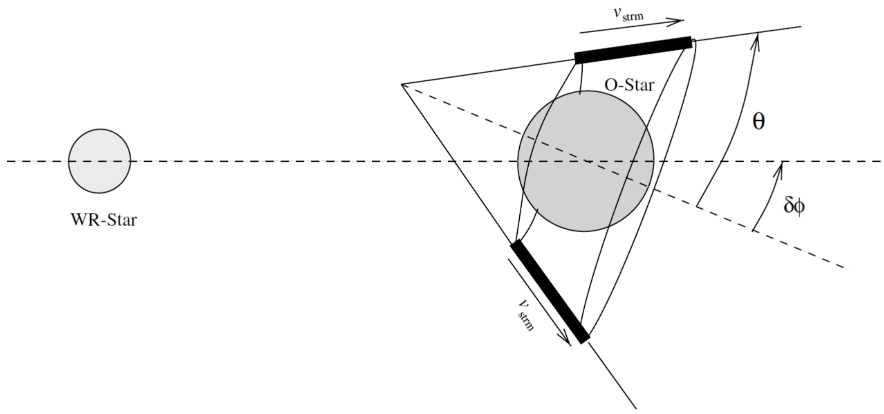

Figure 3: Schematic view of the geometric model by Luehrs (1997). The full width and radial velocity of the excess will then be given by : $FW_{ex} = C_1 + 2\,v_{\rm strm}\,\sin(\theta)\sqrt{1-\sin^2(i)\,\cos^2(\phi-\delta\phi)}$ and $RV_{ex} = C_2 - v_{\rm strm}\,\cos(\theta)\,\sin(i)\,\cos(\phi-\delta\phi)$

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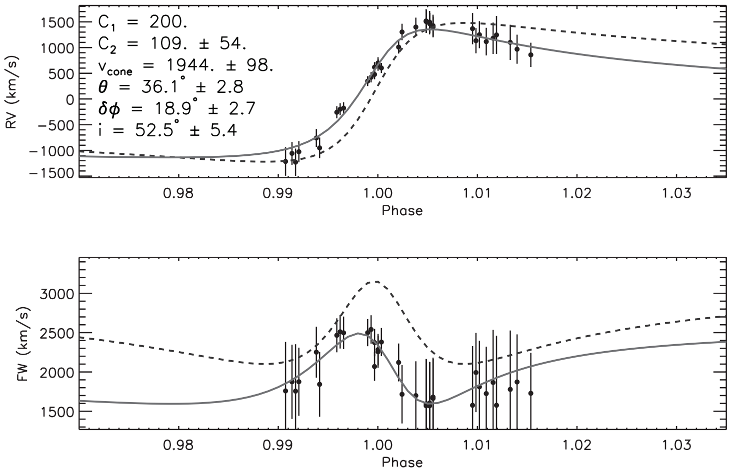

Figure 4: Fit of the radial velocity and width of the excess using the Luehrs model (full grey line). The black dashed line shows the solution from M03.

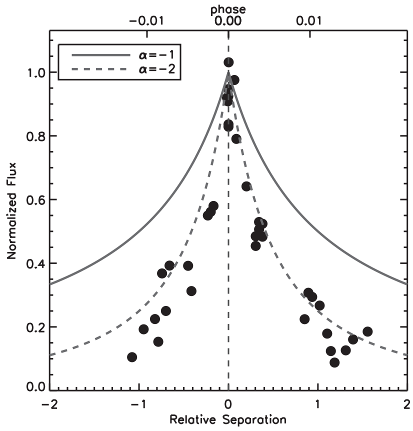

Figure 5: Normalized flux of the excess as a function of the relative separation of the two stars ($[d - d_{min}]/d_{min}$). The full line shows a d^{-1} dependence, expected for an adiabatic emission process. The dashed line shows a d^{-2} dependence, possibly more in line with an isothermal process.

of our model. A more sophisticated theoretical investigation should be done. Meanwhile, the d^{-2} dependence of the excess, shown in Fig. 5, strongly suggests that some kind of isothermal process is involved here. Links with observations in other spectral domains (X-ray, IR and radio) will certainly provide valuable clues about the physics. Finally, we will attempt to isolate the WR spectrum from the O-star spectrum from our data in order to identify the spectral type of the latter more precisely. We also have some photometric and spectropolarimetric data to analyse to complete our view of this system.

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