Tracing WR wind structures by using the orbiting companion in the 29d WC8d + O8-9IV binary CV Ser

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Abstract: We have obtained continuous, high-precision, broadband visible photometry from the MOST satellite of CV Ser over more than a full orbit in order to link the small-scale light-curve variations to extinction due to wind structures in the WR component, thus permitting us to trace these structures. The light-curve presented unexpected characteristics, in particular eclipses with a varying depth. Parallel optical spectroscopy from the Mont Megantic Observatory and Dominion Astrophysical Observatory was obtained to refine the orbital and wind-collision parameters, as well as to reveal line emission from clumps.

1 Introduction

The primary aim of our project was to probe the structures in the wind of the WR component in the CV Ser WR + O binary by using high-precision photometry. The basic idea is shown in Fig. 1. According to the phase, clumps with different sizes will go through the O star's line of sight, thus producing random dips in the light curve. We can then analyze these dips to find constraints on the sizes and shapes of the clumps.

In early studies (Hjellming & Hiltner 1963, Stepień 1970, Kuhi & Schweizer 1970, Cowley et al. 1971), CV Ser has proved to be a misbehaving binary system, with the depth of its eclipse varying with time. It was even reported to have stopped eclipsing. The most plausible explanation is that the wind of the dust-forming Wolf-Rayet component changed its structure between observations. However, for the first time, we show evidence for two consecutive eclipses with different depths, which might suggest a rapidly varying mass-loss rate.

1.1 Observations

The MOST space telescope observed CV Ser continuously for a period of approximately 45 days during summer 2009. The light curve includes 2 minima of the 29.7d binary. Curiously, both minima
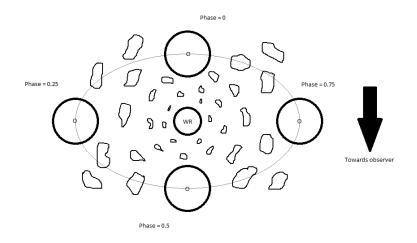
Figure 1: Intuitive model of the effects of clumps on the light curve. Seen here is the projection of the orbital plane along the observer's plane. This figure is not to scale.

have different depths. The light curve was binned to one data point per orbit (101 min) and a 3-sigma clipping was performed. The result is presented in the next section.

As for the spectroscopy, two Canadian observatories were used : Observatoire du Mont-Mégantic (OMM), as well as the Dominion Astrophysical Observatory (DAO). The observing campaigns were synchronous with MOST's, but due to poor weather, long gaps are present in the spectral data. Nevertheless, the RV points obtained from DAO were sufficient to determine that the orbit of CV Ser is circular and well-behaved, as can be seen in Fig. 2.
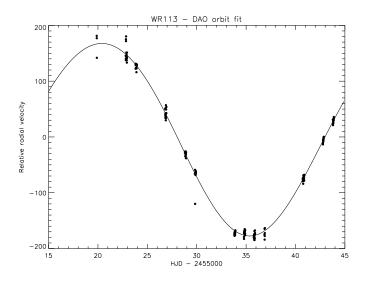

Figure 2: Elliptical fit to DAO radial velocity data yields e=0. The scatter of the data points about the fitted curve is due to a combination of the effects of the random instrumental error and stochastic clumps on the line profiles.

1.2   Theoretical background

Assuming an atmospheric eclipse, we use a first-order model for WR+O binaries, with a $\beta = 0$ wind (constant) velocity law, as described and justified (the $\beta = 0$ wind velocity law is shown to explain atmospheric eclipses of all observed WR+O systems) in Lamontagne et al. (1996):

$$\Delta m = \Delta m_0 + A \left(\frac{\pi/2 + \arcsin \epsilon}{\sqrt{1 - \epsilon^2}} \right) \tag{1}$$

with $\epsilon = (\sin i) \cos (2\pi\phi)$, $A = \frac{(2.5 \log e)k}{(1 + I_{WR}/I_O)}$ and $k = \frac{\alpha \sigma_e \dot{M}}{4\pi m_p v_\infty a}$, in which Δm_0 is a constant, i is the orbital inclination, I_{WR}/I_O is the intensity ratio of the 2 stars in the observed bandpass, $\alpha \simeq 0.5$ free electrons per He nucleus, σ_e is the Thomson electron-scattering cross section, $\dot{M}$ is the WR mass-loss rate, m_p is the proton mass, v_∞ is the terminal wind speed and a is the orbital separation.

Eq.1 only takes into account the electron scattering of the O star's light along the line of sight but it has revealed itself to be a powerful tool to derive the mass-loss rates of WR stars in close binaries.

2   Preliminary results

We tried to fit our light curve using the Lamontagne et al. model. However, since our two eclipses do not have the same depth, it was necessary to make a small adjustment. We let A vary linearly with time, which could indicate a change in the mass loss parameters (most probably $\dot{M}$ and/or v_∞). We also had to allow Δm_0 to vary linearly with time (with slope B_1, most likely due to detector drift):

$$\Delta m = B_0 + B_1 \cdot t + (A_0 + A_1 \cdot t) \left(\frac{\pi/2 + \arcsin \epsilon}{\sqrt{1 - \epsilon^2}} \right) \tag{2}$$

The best fit is shown in Fig. 3. The scatter in magnitude around the fit is quite significant and may be related to intervening clumps in the WR wind.
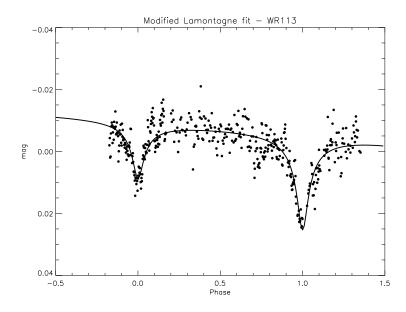

Figure 3: Best fit to the modified Lamontagne et al. model. The scatter in the light curve of CV Ser is most likely intrinsic (pulsations and/or intervening clumps).

Assuming the values given in Lamontagne et al. (1996) for most parameters for CV Ser except $\dot{M}$, the fit yields a mass-loss rate of about $2.9 \cdot 10^{-5}\,\mathrm{M_{\odot}\,yr^{-1}}$ for the first eclipse. If we assume that the variation of the depth of the eclipse is entirely due to the variation of the mass-loss rate, we then find that the Wolf-Rayet mass-loss rate increases by 70% from the first eclipse to the second eclipse! However, it is possible that other parameters of the wind structure could change at the same time, thus probably setting a 70% increase as an upper limit to the change in $\dot{M}$.

The fit was also done through the average level of the lightcurve. This conservative approach was used since the nature of the scatter was not yet known. Indeed, we suspect that the clumps going through the O star's light path should produce an absorption signature, but there also might be features related to possible pulsations which cannot be ignored. If pulsations are not detected, then the fit might be biased to too low a level, although this should not affect the relative eclipse depths, since the bias is about constant for all phases.

3   What's next?

There is still much to be done with CV Ser. First, Fourier and wavelet analyses will help detect coherent or random variations in the light curve (which can hopefully be linked to clumps). The spectra of both components of the binary system can be separated using the "shift and add" method (Demers et al. 2002). We will also check for changes in the spectra which could be linked to variations in the properties of the WR wind (mass-loss rate, temperature, terminal velocity, ionisation, etc.). Lührs' model (Lührs 1997) can be applied to the excess emission to model the shock cone and compare the value of i obtained to the one given by Lamontagne's model. Ultimately, the goal of this project is to characterize the clumping phenomenon. New data (MOST and ground-based spectra) taken during summer 2010 will help us complete our analysis. A third eclipse was observed, which will be compared to the two obtained during summer 2009.

Acknowledgements

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