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Easy can be Deceiving: A New Look at WR 6's Periodic Variations

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Abstract

WR 6 is variable with a period around 3.7 days, but the period and the shape of the variations seem to be different in every dataset. Looking at historic light curves, we suggest that variations are mostly absorption features. Examining the BRITE satellite light curve, every feature seems to have a slightly different period from one another. We propose that the variations come from Corotating Interaction Regions in WR 6's wind and that the star shows differential rotation.

Keywords: massive stars, stellar winds, rotation

Résumé

La simplicité peut être trompeuse : un nouveau regard sur les variations périodiques de WR 6. WR 6 est une étoile variable avec une période autour de 3,7 jours. La période et la forme des variations changent cependant d'une époque d'observation à l'autre. Nous suggérons que l'étude des courbes de lumière historiques révèle que des profils d'absorption sont à l'origine des variations. L'étude de la courbe de lumière intensive obtenue par le satellite BRITE montre que chaque absorption est répétée avec une période légèrement différente des autres. Nous suggérons que la variabilité soit causée par des Régions d'Interaction en Corotation dans le vent de WR 6 et que l'étoile soit en rotation différentielle.

Mots-clés : étoiles massives, vents stellaires, rotation

1. Introduction

The Wolf–Rayet star WR 6 (EZ Canis Majoris) has been repetitively studied for more than 50 years, often portrayed as either a binary system with a low mass companion or as the prototypical example of large-scale wind density structures called Corotating Interaction Regions (CIRs). The main source of this debate is the nature of the photometric, spectroscopic and polarimetric variations. While all the published periods coincide within a 0.02 d range, the shape and amplitude of these variations differ between observing runs, challenging traditional period search using periodograms.

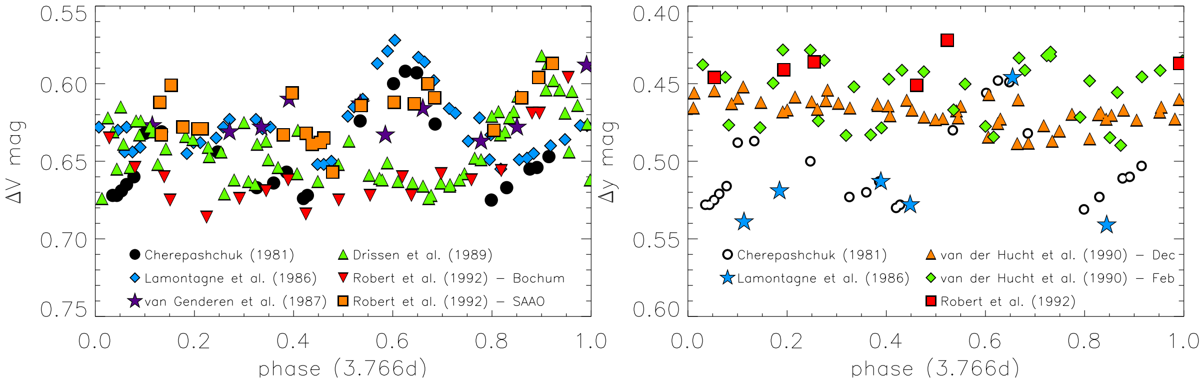

Figure 1: Historic light curves extracted from Robert et al. [11]. Only the photometry in the *V* and *y* bands were used. The relative magnitudes are obtained using WR 6 – HD 50853.

2. Brief Literature Review

2.1. The binary explanation

Firmani et al. [1], who first found a 3.76-day period in WR 6's photometry and spectroscopy, suggested a binary system with a neutron star companion. More recently, Schmutz and Koenigsberger [2] and Koenigsberger and Schmutz [3] rather proposed a close low-mass ($1.35\,R_{\odot}$), non degenerate companion. In their scenario, the interaction of the companion with the WR wind would generate a localized large-scale wind density structure that can be detected with both photometric and spectral line-profile variations. The photometric variations would be caused by the large structure seen from different angles at every rotation phase, and additional semi-regular dips would happen when the structure is eclipsed by the WR star. The origin of the epoch dependence of the variations would be a fast apsidal motion of ~ 100 d that needs to be combined with a 3.63 d period from an inner binary, although this explanation could not be confirmed spectroscopically by Barclay et al. [4].

2.2. The CIR explanation

Morel et al. [5] proposed CIRs to explain the epoch-dependent variability observed in WR 6. CIRs, revealed by Discrete (Narrow) Absorption Components (DACs/NACs) in UV spectra [6], are thought to be driven by bright spots on the photosphere [7] and are likely connected to a strong local magnetic field, non-radial pulsations or a sub-surface convection zone. WR 6 would not be a unique case, as other WR stars, such as WR 134 (WN6b, [8]), WR 1 (WN4b, [9]), and WR 110 (WN5-6b, [10]), could be harboring the same phenomenon.

3. True Nature of the Variations

Looking at the historic light curves, we find that some curves are nearly flat, as if WR 6 was showing no activity. In Fig. 1, the light curves from 11 previous studies are overlaid in two panels, one per filter (*V* and *y*). The Figure shows that the flatter curves occur when the star is the brightest. The curves with lower variation amplitudes still reach the brightest magnitudes,

Table 1: Parameters of the absorption features fitted to the BRITE light curve. The columns are the period, the time at the center of the first appearance of a feature in the model (t_0), the full width at half-maximum of the feature (FWHM), its amplitude in mmag (amp.) and the number of cycles the features are being repeated in the model (nb. cycles).

period (d)	t_0 HJD–HJD_{2000}	**FWHM** (d)	**amp.** (mmag)	**nb.** cycles
3.80 ± 0.01	5797.0	0.6	70	6
3.84 ± 0.01	5797.9	0.3	50	12
3.78 ± 0.01	5799.3	0.6	65	12
3.79 ± 0.02	5820.0	0.6	50	28
3.75 ± 0.02	5843.7	0.3	60	13
3.76 ± 0.02	5844.5	0.3	60	20
3.74 ± 0.02	5884.0	0.3	10	12

but not the faintest. The variations therefore seem to be caused by absorption features rather than emissions!

4. BRITE Light Curve

Instead of analyzing the BRITE light curve as a whole, we isolated individual absorption features. Each feature is identified on the first instance of its appearance in the light curve, and fitted with a Gaussian function. Then, a single period is determined by measuring the spacing between the multiple repetitions of the feature. The exact shape of the absorption features is not known yet, and the Gaussian function is only used for illustration purposes. Also, we did not try to make a perfect fit, but instead tried to illustrate how a few simple assumptions can replicate the observations quite well. The results are presented in Fig. 2.

We used seven different absorption features repeated exactly between six and 28 times (see Table 1 for more details). The magnitude when no features are present is assumed to be $\Delta\mathrm{mag} = -40$ mmag. Each of the seven features needed to be followed using slightly different periods from one another to reproduce the observations. The fit is not perfect, but not only because of the simplicity of the model. There are two more reasons for this. First, the features are not always identical at every cycle, as they seem to tend to fade in and fade out as they come and go. Second, one has to keep in mind that wind clumping causes an additional stochastic variability component in the curve.

With our purely phenomenological approach, based on a simple model, we see a certain number of trends:

- The wider the feature, the longer period.
- The periods tend to decrease with t_0 on the BRITE light curve.

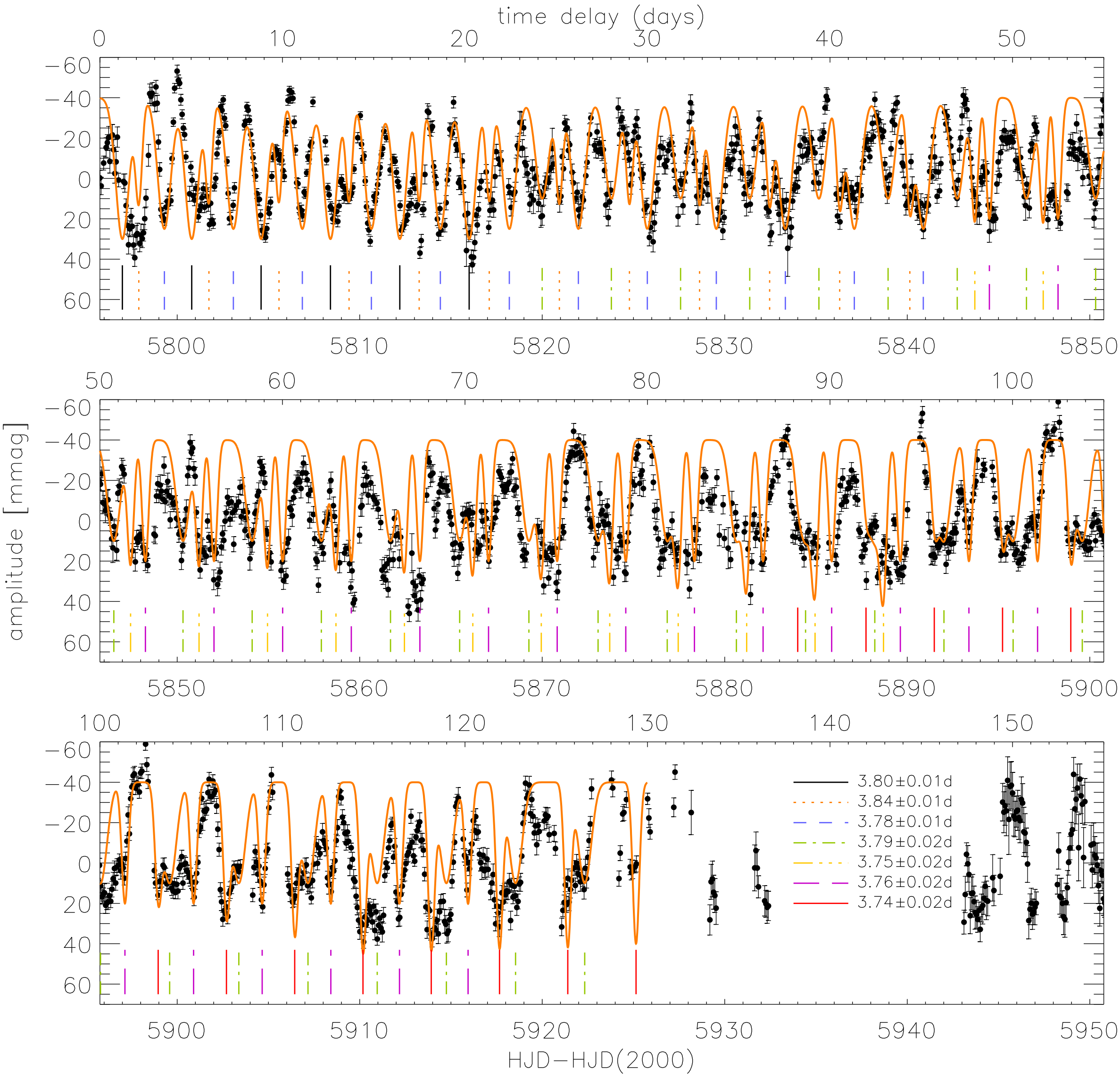

Figure 2: BRITE light curve from Moffat et al. [12]. Seven absorption features have been marked and followed from the moment they appear to when they vanish. Different periods were required for each feature. The orange curve shows the toy-modeled light curve after combining Gaussian functions representing the marked absorption features.

The exception to these trends is the second feature, with a 3.84 d period and a FWHM = 0.3 d. The median number of cycles features can repeat is 12 days. It is not excluded that features that survived for a longer time might in fact be multiple different features that were confused as one in our analysis.

5. Conclusion

Our preferred interpretation here is that CIRs are causing absorption features in the light curve. CIRs appear at stochastic times and disappear after about a dozen cycles or more, responding to the phenomenon causing them. Every CIR has a different period, suggesting differential rotation. On the BRITE light curve, the origin of the CIRs may have migrated from latitudes with slower rotation to latitudes with a faster one. Further modeling of the CIRs should inform us on the true shape of the wind variations. We are not yet completely excluding the possibility that at least some variations are due to emissions until we present a more complete analysis in a follow-up publication. Also, contemporary observation catching WR 6 during a quiet period would be key to settle that last question.

Further Information

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Conflicts of interest

The authors declare no conflict of interest.

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