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Doppler imaging of the contact binary DU Boo

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Abstract. The early-type contact binary DU Boo exhibits consistent O'Connell effect for many years. Studies in the literature of the system are insufficient to explain this consistency in the observed O'Connell effect. Based on this gap in the literature, the aim of this study is to investigate the surface brightness distribution of the system using the Doppler imaging technique as well as the mid-resolution time series spectra.

Key words: binary stars – O'Connell effect – Doppler imaging technique

1. Introduction

Asymmetries can be observed in the light curves of binary stars, due to various astrophysical reasons. The difference in the maximum levels of the light curve is called the O'Connell effect. The most widely accepted theory for the causes of this asymmetry is the presence of either hot or cool photospheric spots.

With a relatively long orbital period (P = 1.056 days), DU Boo binary system, which consists of two A7V-type (Pribulla et al., 2006) components, exhibits a significant O'Connell effect in addition to the total eclipse in its light curve (See Fig. 1). Unlike typical late-type contact binaries, DU Boo exhibits a highly stable spot configuration and hence light curve asymmetry. The asymmetry has been addressed using the cool spot approach placed near the neck region (Djurašević et al., 2013). In the case of cool spots, the formation of these asymmetries is associated with the thickness of the convective layer and the presence of differential rotation.

However, in A-type contact binary stars, the outer convective zone is very thin (Rucinski, 1974). Nevertheless, cool spot modeling has been still applied in the literature to explain the observed asymmetries in such early-type systems. In the case of hot spots, the asymmetry is generally explained by extra flux in light curves resulting from mass transfer (Shaw, 1994). Another study by Pribulla et al. (2011), who performed the spectral analysis of the system, suggested that the bump in the BF profiles, especially at the 0.25 phase, could be due to the presence of a hot spot.

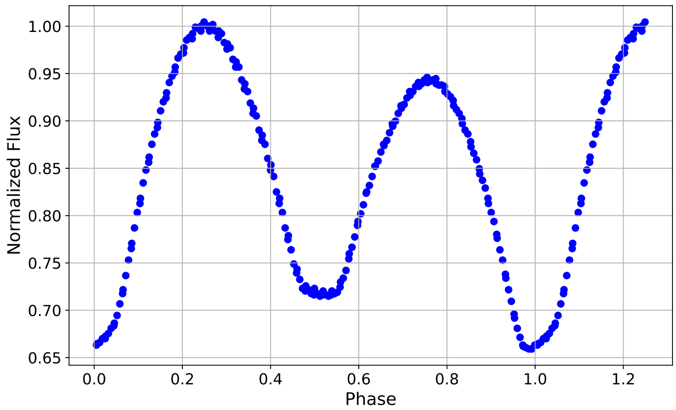

Figure 1. An example TESS light curve of DU Boo plotted using a part of sector 16 data.

2. Observations & methods

The mid-resolution (R $\sim$ 15000) spectra of DU Boo and standard stars were obtained using the Whoppshel spectrograph attached to the T80 Prof. Dr. Berahitdin Albayrak Telescope, covering the wavelength range between 4000-7800 Å. All spectra were reduced using standard IRAF packages. Normalization procedure was carried out using a python code improved by our research group (NSpec).

The iLSD code (Kochukhov et al., 2010) was used to create LSD profiles to enhance the SNR (Signal-to-Noise Ratio) values of spectra. This was done using a line list from the VALD3 database (Pakhomov et al., 2017) that is suited to the astrophysical properties of the components. The observation log of spectra and SNR values are given in Table. 1.

Table 1. Spectral observation log and SNR values.

Date	HJD (2450000+)	Phase	Exposure (s)	SNR (Spectra)	SNR (LSD)
16/07/2022	9777.3958	0.1469	3600	56	2300
14/07/2022	9775.3718	0.2301	3600	73	2800
14/07/2022	9775.4136	0.2697	3600	71	2800
12/07/2022	9773.3735	0.3375	3600	75	3900
12/07/2022	9773.4156	0.3774	3600	72	3500
24/04/2022	9694.4844	0.6241	3600	74	3900
20/04/2022	9690.2843	0.6463	3600	83	4600
20/04/2022	9690.3314	0.6909	3600	76	4600
21/07/2022	9782.3271	0.8172	3600	62	3700
21/07/2022	9782.3690	0.8569	3600	56	3600

In order to reconstruct surface brightness distribution of both components, we used the modified version of the dots code (Collier Cameron, 1997) which is based on a 3-temperature approximation that represents photosphere, hot and cool spots. Since the photospheric temperatures of the components are 7800 K and 7600 K, the maximum and minimum temperatures are defined as 8800 K and 6700 K for the primary component, and 8600 K and 5900 K for the secondary component, respectively.

The presence of a dip structure in the LSD velocity profile corresponding to the component is indicative of a hot spot, whereas the presence of a bump structure is associated with a cool spot (e.g. Rozelot & Neiner (2016)).

LSD profiles and the surface brightness distribution maps of the system are shown in Fig. 2 and Fig. 3, respectively.

3. Results & conclusion

In this study, the surface brightness distributions of the components of DU Boo have been reconstructed using Doppler imaging technique to investigate whether the asymmetry in the system is due to a hot or cool spot. In Fig. 2, blue arrows indicate a hot spot in the neck region around phase 0.25, pointing a stream of matter or a bright region, consistent with the suggestion made by Pribulla et al. (2011).

The surface brightness distribution map of the system and the TESS light curve both consistently suggest that the flux increase observed at phase 0.25 on the light curve is likely caused by a hot spot. In the case of DU Boo, hot spot on the neck region of the components can be explained using the mass transfer scenario proposed by Shaw (1994).

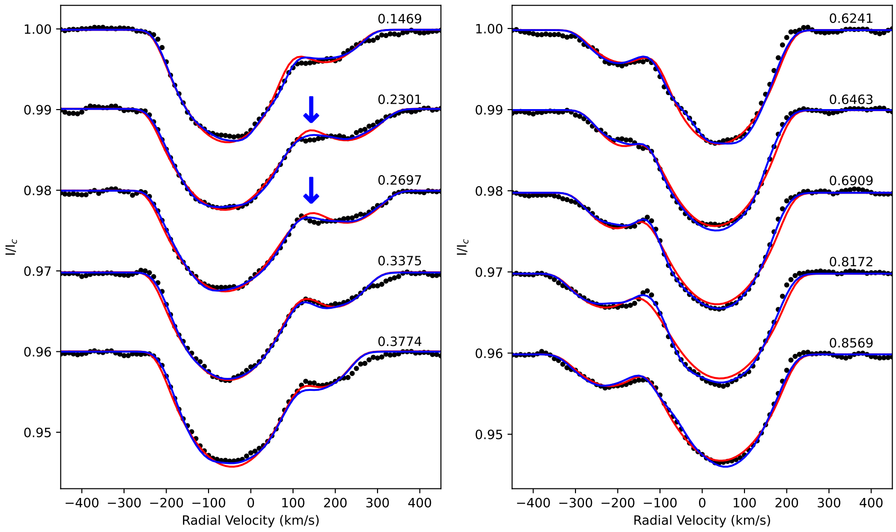

Figure 2. Observational LSD profiles (black dots), synthetic model fit (red solid line) and best fit models generated by the reconstructed process (blue solid line).

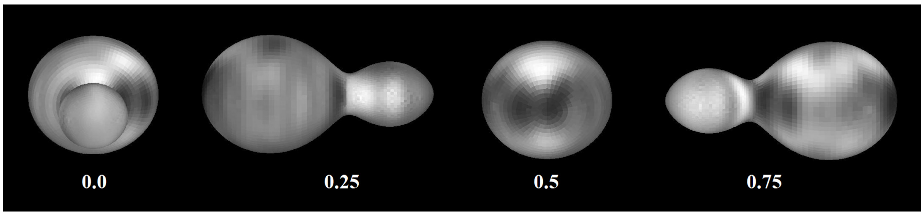

Figure 3. Surface brightness distrubution of the system at four main phases.

Although longer exposure times result in phase smearing, they do not significantly affect the determination of dominant spot characteristics at a specific stage. However, shorter exposure times can help produce higher-resolution maps of the spots.

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