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Application of broadening functions to eclipsing binaries and planetary transits

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Abstract. The broadening-function technique was applied to three binaries and a transiting exoplanet. The faint secondary component in IN Vir was detected. BD And was found to be a triple star. The rotational axis of the primary component of α CrB was found to be practically perpendicular to the orbital plane. A transiting planet signature was clearly found in Kelt-7b data.

Key words: techniques: radial velocities – binaries: eclipsing – planetary systems

1. Introduction

The broadening-function (BF) technique was developed by Rucinski (1992) to analyse close binaries with rotationally broadened spectral lines. The technique uses deconvolution of a target spectrum by a sharp-line template of the same spectral type. The information is extracted from the whole spectrum, as for the cross-correlation function (CCF). Unlike the CCF, BF extraction does not decrease the spectral resolution, allowing the identification of faint companions, planetary transits, non-radial pulsations, starspots etc.

2. Observations and data analysis

New observations were obtained using MUSICOS-clone échelle spectrograph fiber fed from 1.3m Nasmyth-Cassegrain telescope at the Skalnaté Pleso observatory of the Astronomical Institute of the Slovak Academy of Sciences. The CCD frames were first photometrically reduced and cleaned of cosmic rays. Then aperture spectra were extracted, wavelength calibrated, normalized and combined to 1D spectra (for details see Pribulla et al. (2009)).

The 1D spectra were analyzed using a package of routines in IDL. The BFs were extracted from 4900–5400 Å spectral range and 3.5 km s^{-1} radial-velocity (RV) step. The extracted BFs were then smoothed to match the spectral resolution convolving them with the Gaussian function. The RVs were obtained by fitting the Gaussian functions or limb-darkened rotational profiles to BFs as appropriate. The IDL routines were also used to determine heliocentric correction of RV and to compute heliocentric mid-exposure times.

3. Results

3.1. IN Vir

IN Vir ($V = 9.131$, K2III) is a non-eclipsing binary system with orbital period ∼8.22 days. Strassmeier (1997) performed Doppler mapping of the primary component but could not detect the secondary.

BFs of IN Vir were extracted using HD 185144 (K0V) as a template. 27 spectra obtained from March 30, 2017 to June 13, 2019 enabled detection of the secondary component for the first time (see also Volkov et al., 2019). RVs determined from BFs give the following preliminary spectroscopic elements: $V_0 = +40.2 \pm 0.3$ km s^{-1}, $K_1 = 48.9 \pm 0.4$ km s^{-1}, and $K_2 = 69.6 \pm 0.1$ km s^{-1}. It is interesting to note, that on June 13, 2019 a strong flare on the secondary component was observed (see Fig. 1(a)).

3.2. BD And

BD And ($V = 10.84$, F8V) is an eclipsing binary of β Lyr type with period ∼0.926 days. Timing variability indicated an additional component in the system with an orbital period of ∼9 years (Kim et al., 2014).

Forty-four spectra of BD And were obtained from June 3, 2017 to October 8, 2018. BFs were extracted using HD 65583 (G8V) as a template. BFs conclusively confirm the presence of another component in the system revolving on a long-period orbit. The phase-dependence of BFs of BD And showing all three components is in Fig. 1(b). This first spectroscopy of the system promises reliable determination of component parameters and orbital elements.

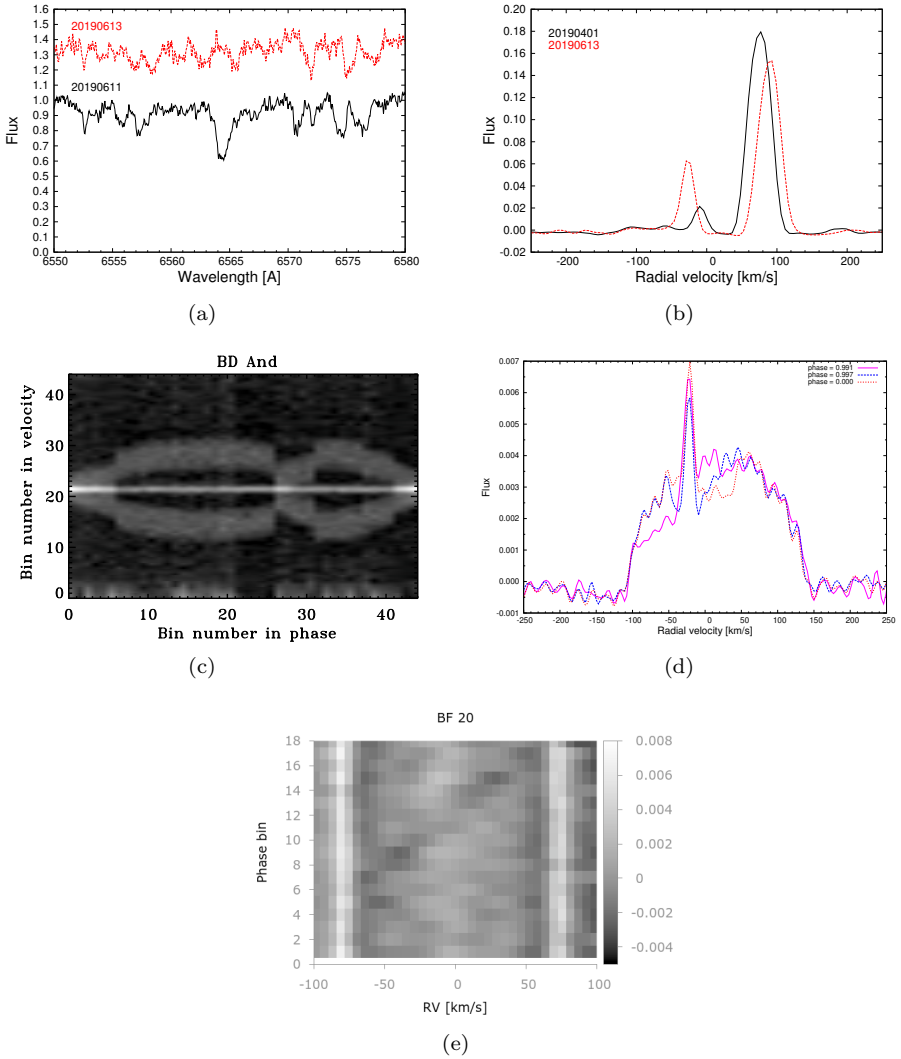

Figure 1. (a) Spectra of IN Vir during the flare (red line) and in quiescence (black line). (b) BFs of IN Vir showing both components and the increase of the BF strength during the flare on the secondary component on June 13, 2019. (c) BFs of BD And ordered in phase showing all three components. (d) Primary eclipse of Alpha CrB visible as a notch progressing from negative to positive radial velocities. The secondary component is the narrow peak on top of the primary component profile. (e) A planet crossing the disk of HD 33643 is seen as a dark streak. Vertical white bands correspond to projected rotational velocity of the parent star.

3.3. α CrB

α CrB (V=2.24, A0V+G5V), is an Algol-type eclipsing binary with period of ∼17.3599 days. The system was recently studied by Schmitt et al. (2016), who determined reliable parameters of components and orbital parameters. Moreover, historical RVs were used to estimate the apsidal-motion period as 6600–10600 yrs. No spectroscopy was, however, obtained in eclipses.

New observations of α CrB were obtained from June 3, 2017 to June 13, 2019. The observations fully cover the primary minimum. The corresponding BF sequence is shown in Fig. 1(c). The progression of the secondary component's shadow is consistent with the spin axis-orbital co-alignment.

3.4. HD 33643

HD 33643 or Kelt-7 (V = 8.54, F2) is a ∼1.5 $M_{\odot}$ star orbited by a planetary-mass companion in ∼2.73 days (Bieryla et al., 2015).

The new observations obtained on October 11, 2018 cover the planetary transit across the disk of the parent star. BFs were extracted using HD 128167 as the template. Fig. 1(d) shows residuals after modelling of BFs by limb-darkened rotational profiles. Detected transit phenomenon is clearly seen and can be modelled in the future. The signal-to-noise ratio of the event could possibly be increased by using a better matching template spectrum.

4. Conclusions

The BF deconvolution technique was found to be a method of choice for the study of binary and multiple systems of stars and exoplanets as well. Unlike CCFs, the extracted BFs can be fitted by complex models (including proximity effects, spots, exoplanet transits, non-radial pulsations or differential rotation). Although the CCF technique is primarily used to measure RVs, the BF technique can outperform it if the components are fast rotators or if faint companions are accompanying the dominant object.

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