Spectroscopy of binary and multiple systems of stars

SLOVAK RESEARCH AND DEVELOPMENT AGENCY

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Abstract Spectroscopic observations of binary and multiple systems of stars with a MUSICOS-clone echelle spectrograph on the 1.3m telescope at the Skalnaté Pleso Observatory are presented. The observations focused on neglected bright ($V < 11$ mag) systems and include contact binaries CW Lyn, V1119 Her, detached systems GK Boo, HIP13026, IN Vir, binaries with hot components HD192907, alpha CrB, and multiple stellar systems found from the TESS photometry. Preliminary results for individual systems and plans to improve the spectrograph throughput to include fainter binaries are also presented. Caveats of relatively low-SNR spectroscopic data analysis are discussed.

Motivation Medium and high-dispersion spectra are necessary to measure the radial velocity of components of binary and multiple systems of stars. Modelling of RVs brings us the minimum masses of the component stars. If the system is eclipsing, and we can determine the orbital inclination angle, we can arrive at the true size of the component orbits and their masses. This also enables us to reliably determine other parameters such as radii and surface gravities. Having separate spectra of the components we can determine their effective temperatures and luminosities. This is the only reliable way to check and calibrate models of stellar structure and evolution. The method to determine the RVs from the observed spectra strongly depends on the spectral type of the system and the relative brightness of the components. For objects of late A to K spectral type it is usual to either use the cross-correlation (CCF) or broadening function (BF) technique. The latter technique was used in this analysis. In spite of a rapid increase in quantity and quality of the photometric data (mainly thanks to the satellite missions like Kepler, CoRoT or TESS), many bright eclipsing binaries and multiple systems do not have spectroscopic elements and their absolute parameters are estimated based on the stellar models. Having almost unlimited access to a medium-size telescope at the Skalnaté Pleso observatory (1.3m Nasmyth Cassegrain, equipped with a high-resolution echelle, R = 38,000), we selected a number of bright and neglected binary and multiple systems to be observed. Preliminary results for 6 selected systems are given.

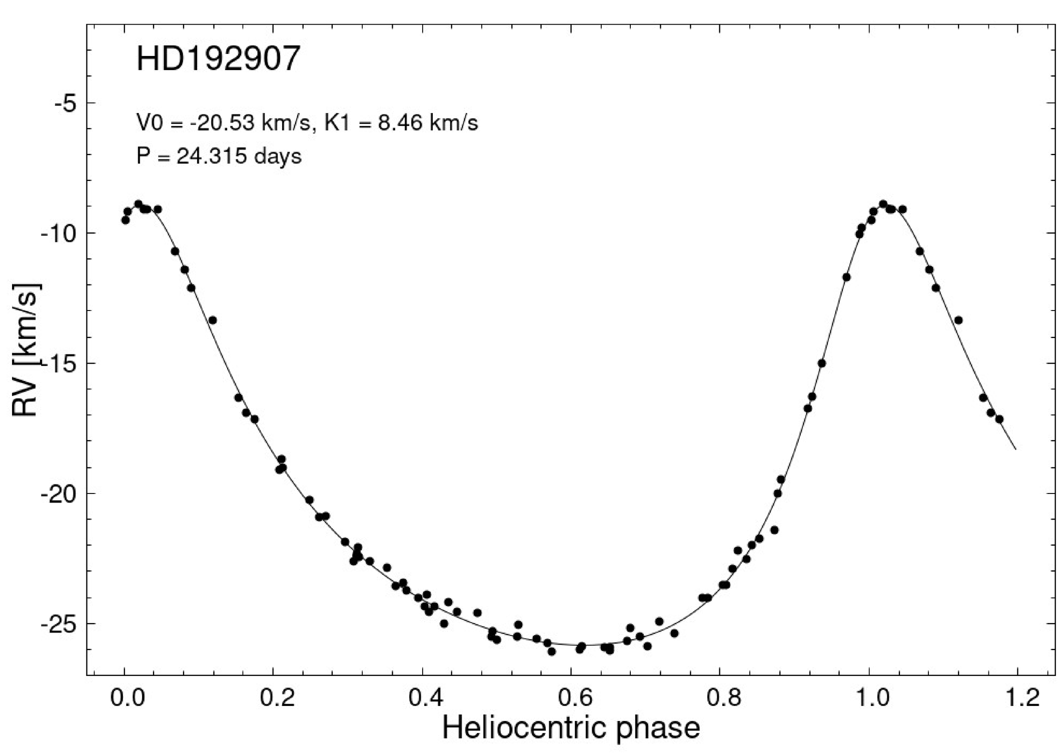

Fig. 1 Radial-velocities of the primary component of HD192907 and their best model. The phases were computed using the optimum orbital period.

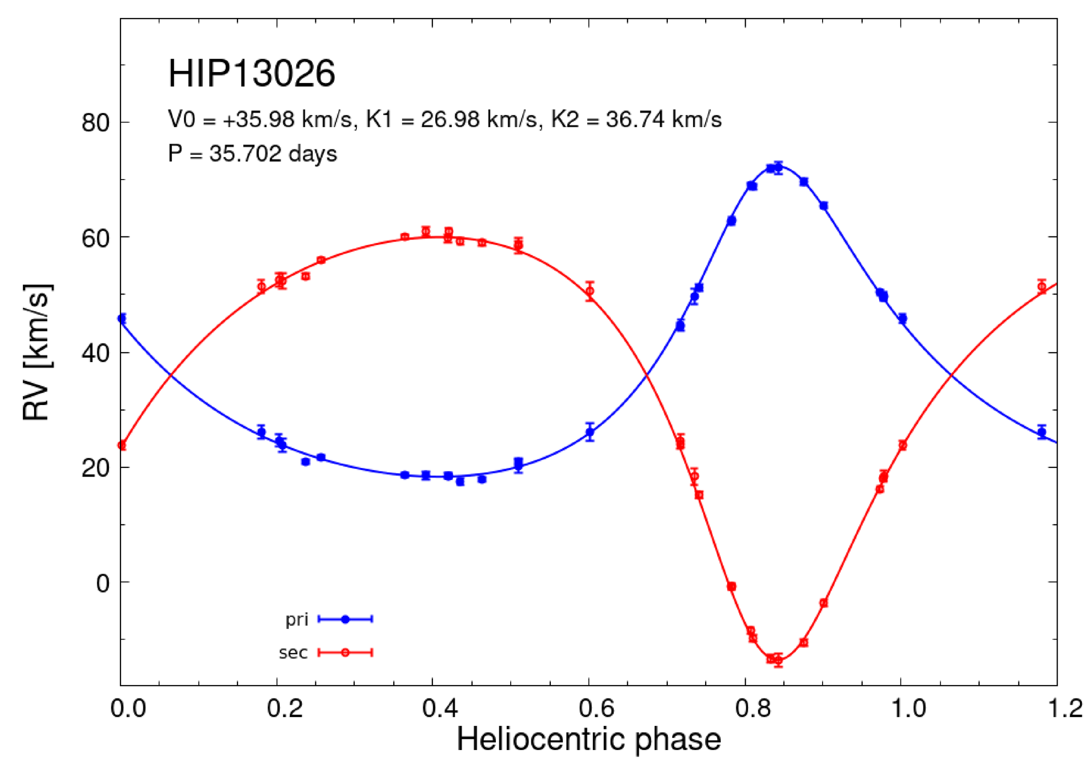

Fig. 2 Radial-velocities of the primary component of HD192907 and their best model. The phases were computed using the optimum orbital period.

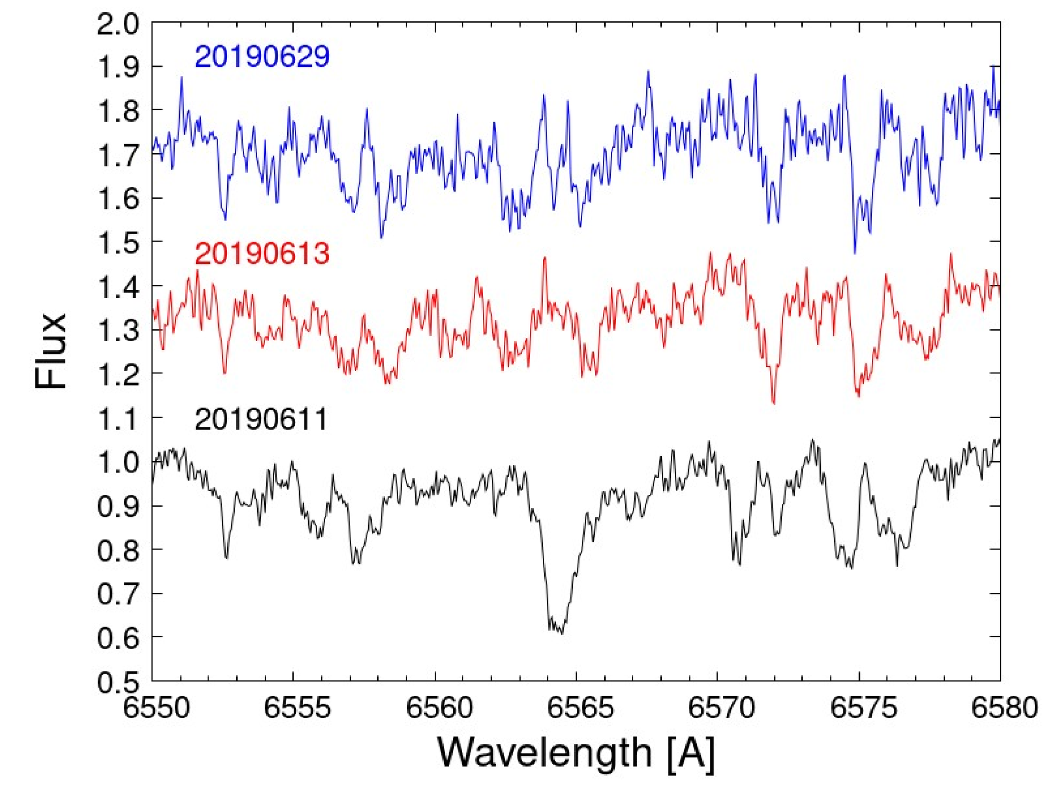

Fig. 3 Strong flare on the secondary component (June 13, 2019) visible in the white light is also seen by filling of the Hα line.

HD192907 (B9III, V = 4.39) was used as a spectrophotometric standard at the SP observatory. Adelman (1996) noticed that RV of HD192907 varies. He did not give its spectroscopic elements and did not detect the secondary component. According to the Gaia DR3 the object is a single star with RV= -22.5±1.3 km/s, Teff=10344 K and log g = 3.617. Small RV amplitude indicates a low inclination angle (see Fig.1). BFs conclusively show a faint secondary component.

HIP13026 (F6V, V = 7.91). The object was found to be a double-lined spectroscopic binary by Pribulla+ (2014). According to the Gaia DR3 the object is a single star with Teff=5949 K and log g = 4.192. The object has a relatively low declination of about +1 degree which resulted in period aliasing indicating the orbital period close to 1 day. Long-term spectroscopy finally showed that the system is a relatively wide binary with a substantial eccentricity of 0.36 (see Fig. 2).

HIP116544 = IN Vir (K4IV+G8V, V = 9.131). The object is a non-eclipsing close active binary star also detected as an X-ray source. Strassmeier (1997) found that it is an SB1 and performed Doppler imaging of its primary component. BF technique clearly shows both components. In spite of a relatively long orbital period, P = 8.19 days, its orbit is circular. The secondary component occasionally shows strong flares. The Hα line profile has variable EQW due to the enhanced chromospheric and flaring activity (see Fig. 3).

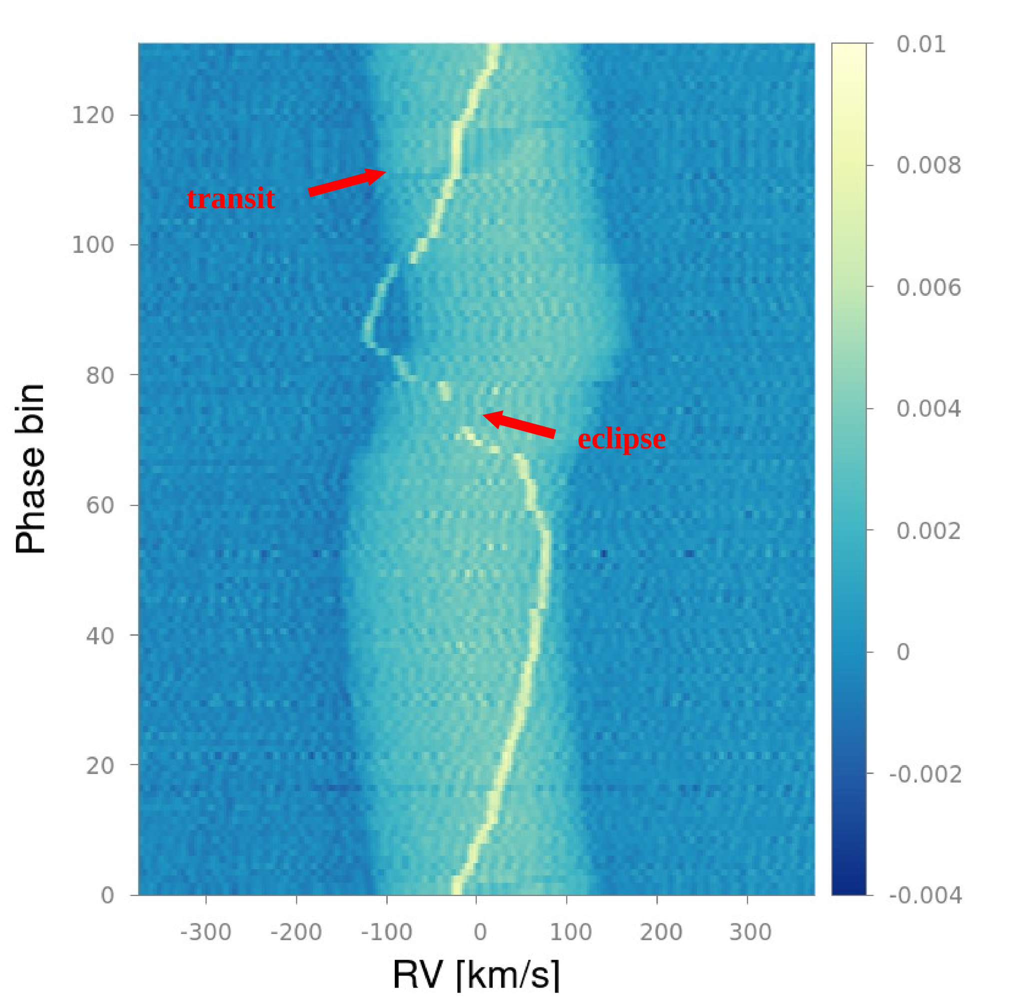

Fig. 4 Trailing "spectrum" of BFs extracted from the yellow spectral region. BFs are sorted out in phase. The narrow yellow line corresponds to the slow-rotating secondary component. Its transit and eclipse are indicated by the red arrows.

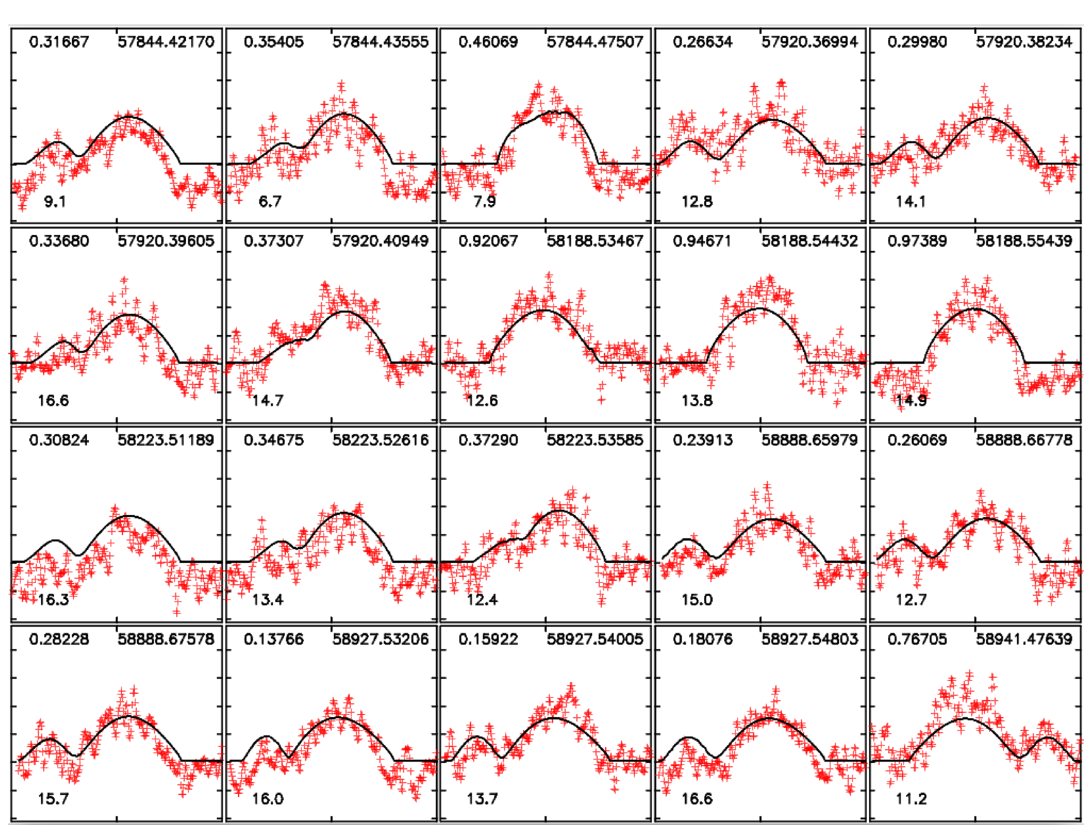

Fig. 5 Direct fit to 39 BFs (20 shown) using code Roche (Pribulla, 2004). RVs could not be not measured but the global parameters were determined: q=0.17, (K_1+K_2) =348 km/s, V_0=-1.46 km/s, inclination angle was fixed to 86 deg.

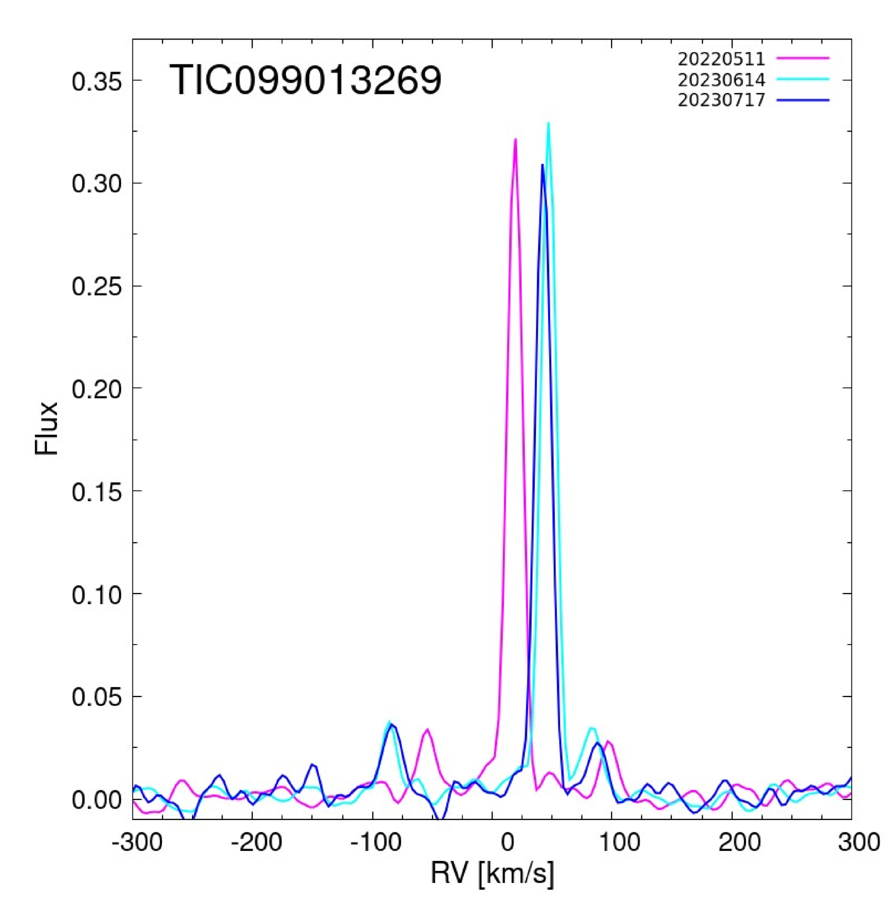

Fig. 6 Selected BFs of TIC099013269 showing the dominant third component and two much fainter components of the close binary.

HD139006 = alpha CrB (A1IV+G) is one of the brightest eclipsing binaries in the sky (V = 2.24). The system was well characterized by Schmitt et al. (2016, 2023). It is composed of a fast-rotating primary and a slowly-rotating secondary (see Fig. 4). Although the system is well detached (P = 17.36 days), slow apsidal motion is seen. It is still not clear if the rotational axes of the components are perpendicular to the orbital plane. The secondary eclipses are total.

XY Boo (F5V, V = 10.54) is a short-period contact binary with P = 0.3705702 days. There is a lot of published photometry but no spectroscopic orbit. A strong phase smearing and shallow spectral lines make it a difficult object for our 1.3m telescope. Ten-minute exposures resulted in an SNR < 20 and extremely noisy BFs. Individual BFs are difficult to model or determine RVs. A global modeling using code ROCHE (Pribulla, 2004) was necessary to arrive at robust parameters.

TIC099013269 (G5V, V = 9.92) is a triply-eclipsing triple system discovered by Rappaport et al. (2023). It is composed of a 6.535-day binary and another body on a 604-day orbit (also detected astrometrically in Gaia DR3). The authors spectroscopically detected only the dominant third component. BFs extracted from the SP observatory spectra clearly show all three components. The object is relatively easy because of its late spectral type. The SNR of the spectra was only 15 to 35.

Future plans Current observations suffer from a relatively low optical throughput of the telescope and spectrograph. This effectively limits observation to about V = 11 for objects of late spectral types. The telescope-spectrograph throughput is mainly affected by a poor and variable seeing at the site (typically 2-5 arcsec). Using a 50-micron object fiber (corresponds to 1.6 arcsec with a f/5 fiber foreoptics) is the main limitation. Therefore, we plan to use a 100 micron fiber and a 50 micron slit to increase the optical throughput will keeping the same spectral resolution (nominally around 38,000 in the best-focused spectral regions). Later an image slicer is planned to preserve the resolution while increasing the optical throughput. To a smaller extent the system's throughput can be improved by minimizing vignetting inside the spectrograph and improving the coating of the telescope mirrors.

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