TESS light curves of low-mass detached eclipsing binaries

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Abstract. We present high-precision light curves of several M- and K-type, active detached eclipsing binaries (DEBs), recorded with 2-minute cadence by the *Transiting Exoplanet Survey Satellite* (TESS). Analysis of these curves, combined with new and literature radial velocity (RV) data, allows to vastly improve the accuracy and precision of stellar parameters with respect to previous studies of these systems. Results for one previously unpublished DEB are also presented.

Keywords. binaries: eclipsing, binaries: spectroscopic, stars: activity, stars: chromospheres, stars: fundamental parameters, stars: low-mass, stars: spots

1. Introduction

Magnetic fields in low-mass ($<$0.8 $M_\odot$) stars affect the fundamental stellar properties. In short-period, tidally locked binaries fast rotation of components strengthens the magnetic field through a form of a dynamo mechanism, enhances activity, and affects the observed radii and effective temperatures, which has been observed in low-mass detached eclipsing binaries (LMDEB) for decades. Several descriptions of this phenomenon have been proposed, but we lack good quality observational data and models of LMDEBs in order to validate or falsify them. In this paper we present improved, precise results for four already studied and one unpublished LMDEB.

2. Targets

The presented sample consists of one system that was not studied to date, ASAS J125516-3156.7 (A-125), and four LMDEBs already described in the literature. These are: ASAS J011328-3821.1 (A-011; Hełminiak *et al.* 2012), ASAS J030807-2445.6 (AE For; Różyczka *et al.* 2013), ASAS J032923-2406.1 (AK For; Hełminiak *et al.* 2014), and ASAS J093814-0104.4 (A-093; Hełminiak *et al.* 2011). All systems have component masses below 0.8 $M_\odot$, and orbital periods shorter than 4 days. All are very active, with prominent spots, occasional flares, and Hα emission lines. The four targets from literature usually have radii known with precision of ∼1.5-2% at best. Masses of A-011 and A-093 were poorly constrained ($>$4%).

3. TESS photometry

In order to obtain high accuracy and precision in stellar parameters, especially radii, one needs a very precise photometry, and the best-quality data come from space borne instruments. The high-precision, 2-minute-cadence time-series photometry of our targets comes from the *Transiting Exoplanet Survey Satellite* (TESS), and was obtained through the Guest investigator program No. G011083 (PI: Hełminiak) during the first year of TESS operations. Detrended light curves were downloaded from the Mikulski Archive for Space Telescopes (MAST). Our targets were mostly observed in one sector, except for A-011 (two sectors). TESS light curves are presented in Figure 1.

4. Spectroscopy and radial velocities

Direct determination of masses of DEBs requires radial velocity (RV) measurements, which are obtained from a series of high-resolution spectra. Our targets were initially included into a large spectroscopic survey of DEBs, identified by the All-Sky Automated Survey (Pojmański 2002).

RVs and orbital solutions of AK For and A-011 remain unchanged with respect to the literature (Hełminiak *et al.* 2012, 2014). In three other cases we used our own new spectroscopy from CHIRON and CORALIE spectrographs, and calculated the RVs with the TODCOR method Zucker & Mazeh (1994). The CHIRON data for A-093 were supplemented with measurements from Hełminiak *et al.* (2011). AE For was already described in Różyczka *et al.* (2013), but we did not use their data. The RVs for A-125 were not published to date. The orbital parameters were found with the code V2FIT (Konacki *et al.* 2010). The observed and model RV curves of AE For, A-093, and A-125 are shown in Figure 2.

5. Light curve modelling

The TESS light curves were modelled with the JKTEBOP code v34 (Southworth *et al.* 2004). To account for the out-of-eclipse modulation coming from spots we applied (in JKTEBOP) a series of sine functions (up to four) and polynomials (up to fifth degree). Because the spot-originated variation may change in time quite rapidly, data were split into several (between 2 and 6) pieces, which were analyzed separately. Parameter errors for each piece were evaluated with a Monte-Carlo procedure. As the final values we adopted weighted averages, and to get final parameter uncertainties, we added in quadrature a median of individual piece errors and the *rms* of individual results. The JKTEBOP models are sjhown as blue lines in Figure 1.

6. Results

In Table 1 we present the most important results of our analysis, including RV semi-amplitudes K, orbital period P and inclination i, and absolute values of masses M and radii R.

The variations in spot pattern, in time scales of single weeks, is the main difficulty in reaching good precision in radii. The behavior of residuals during the eclipses reflect the asymmetries and deviations of the shape of an eclipse from a "clean photosphere" case, and originate from spots on a surface of the eclipsed component. However, thanks to the TESS data, we were able to successfully model the influence of spots, and the uncertainties in radii are few times better than reported in literature. The exception is AK For, where the ratio of radii R_2/R_1 is strongly correlated with the level of third light contamination.

Spots also hamper the RV measurements, introducing additional jitter to the data. Also, components of the shortest-period ($P < 1$ d) systems rotate rapidly. Nevertheless,
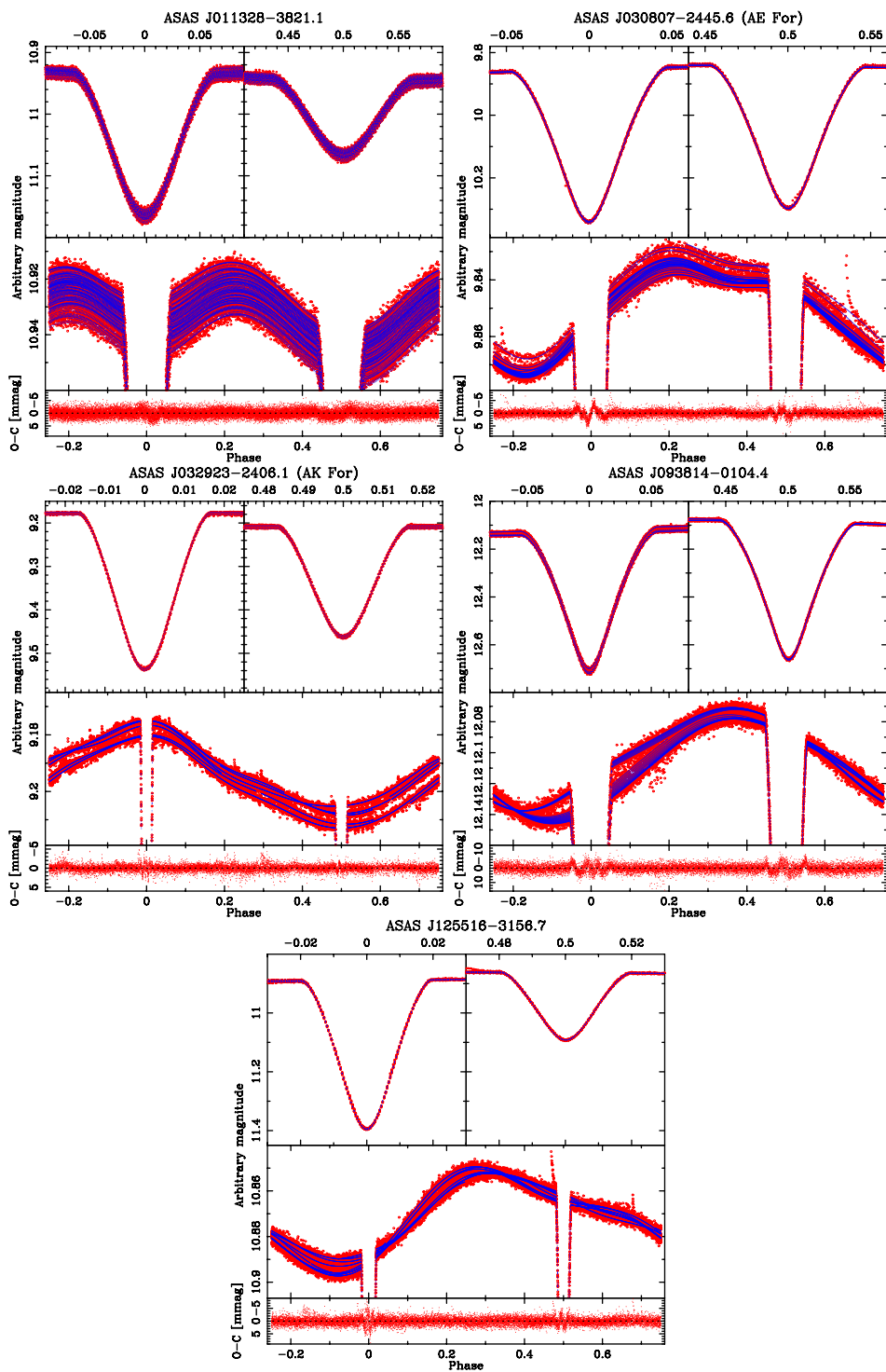
Figure 1. TESS data (red) and JKTEBOP models (blue) of the studied systems, phase-folded with orbital periods. Top rows are zooms on primary (left) and secondary (right) eclipses. Below are zooms on the out-of-eclipse modulations. Bottom panels depict the residuals. One can clearly see the evolution of spots in time, as well as flares on AE For and A-125.

Table 1. Basic orbital and stellar parameters of the studied systems.

| ASAS ID	011328-3832.1	030807-2445.6	030807-2445.6	032923-2406.1	125516-3156.7
TIC	183596242	88479623	144539611	14307980	103683084
TESS Sector	2,3	4	4	8	10
P [d]	0.44559604(18)	0.918207(7)	3.9809620(45)	0.897420(2)	3.0570393(44)
K_1 [km/s]	118.4(2.0)	118.3(5)	70.47(3)	127.55(68)	73.34(5)
K_2 [km/s]	162.9(3.3)	119.5(5)	77.16(5)	127.62(97)	87.00(15)
i [°]	87.5(1.5)	87.8(1)	87.37(3)	86.87(6)	87.56(7)
M_1 [M$_\odot$]	0.597(28)	0.644(6)	0.696(1)	0.775(12)	0.7104(25)
M_2 [M$_\odot$]	0.434(17)	0.638(6)	0.6356(7)	0.774(10)	0.5989(13)
R_1 [R$_\odot$]	0.607(12)	0.674(7)	0.684(18)	0.774(6)	0.669(4)
R_2 [R$_\odot$]	0.445(12)	0.617(10)	0.628(20)	0.771(6)	0.557(8)
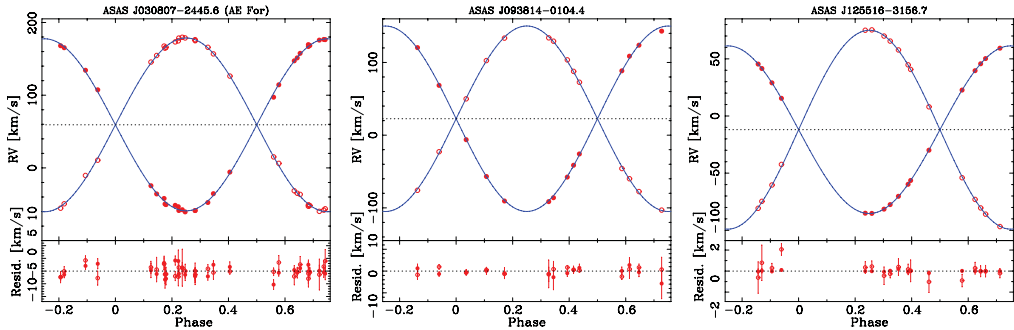
Figure 2. RV measurements (red) and model curves (blue) of three systems with our CORALIE and CHIRON observations, phase-folded with their respective orbital periods. Corresponding residuals are shown in lower panels. Solid symbols represent data for primaries, while open for secondaries. Four points with largest error bars in A-093 are data taken from Hełminiak *et al.* (2011).

new mass determination is also quite good. Errors in masses for AE For are quite low (<1%), yet larger than those from Różyczka *et al.* (2013), which is probably due to larger amount of their RV measurements. The new mass uncertainties of A-093 are 2-3 times better than in Hełminiak *et al.* (2011), at the level of 1.5%. For the new system A-125 all properties are derived with high precision.

Introduction of high-precision TESS photometry allows to improve our knowledge on the smallest, most active stars, where magnetic fields and rotation strongly influence the observed properties. The five binary systems presented here are only a sample of ~40 DEBs with K- and M-type components observed by TESS in our GI programs. Publications of the first set of final solutions is scheduled for mid-2020.

Acknowledgements

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