Surface activity of the G dwarf primary in the quaternary star system V815 Her

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Abstract

We investigate the magnetic activity of the G dwarf primary star in the multiple system V815 Herculis. Recently, TESS Sector 26 data have revealed that V815 Her is in fact a four-star system consisting of two close binaries in a long-period orbit. We give preliminary orbital solution for the long-known but unseen "third body" V815 Her 'B', which is itself a close eclipsing binary of two M dwarfs. Long-term spot activity of the G dwarf is presented along with the very first Doppler image reconstructions of its spotted surface.

1 V815 Her: A multiple system in the solar neighborhood

Close binaries that contain magnetically active component may be regarded as astrophysical laboratory for studying the effect of binarity on activity. Especially interesting are those binaries and multiple star systems which contain active G-type main-sequence (MS) stars with inner structure (convective zone) similar to that of the Sun, making it possible to investigate how the solar-type dynamo would work under different circumstances. Accordingly, in the following study, we investigate the magnetic activity of the G primary star in the quaternary star system V815 Her (=HD 166181), which is 32 pc from the Sun.

The primary G-type dwarf star together with an unseen, but very likely M-dwarf companion form the $P_{\mathrm{orb}} = 1.8\,\mathrm{d}$ orbital period close binary system V815 Her 'A'. It has long been known that the active G (most probably G5-6 V) component V815 Her 'Aa' rotates synchronously with the orbital period and features cool spots on its surface (Mekkadan *et al.*, 1980). Moreover, the strong Li line in the optical spectrum (Fekel *et al.*, 2005) indicates that the G star is young, near the zero-age main sequence (ZAMS). This observation is consistent with the star being listed in the Two Micron All Sky Survey Point Source Catalog (Haakonsen & Rutledge, 2009) due to its infrared excess, most probably related to primordial protoplanetary material.

Fekel (2004) calculated long-period orbital elements for the outer companion V815 Her 'B' for the first time with a preliminary period of 6.3 yr. With additional radial velocity measurements from 2003 this value was refined to 5.73 yr (Fekel *et al.*, 2005). From their mass estimates for the system components of the long-period orbit Fekel *et al.* (2005) also suggested that the third (still unseen) component might also be a close binary.

2 Long-term photometric behavior

In the top panel of Fig. 1 we plot the V observations of V815 Her between 1984-98 from Jetsu *et al.* (2000). In these data we found a long-term brightness modulation, which showed a very good agreement with the approximate period of $\approx 2100\,\mathrm{d}$ of the wide orbit. In the bottom panel of Fig. 1 we plot the V data along with the folded light curve phased with the period of the long orbit taken from Fekel *et al.* (2005). At this point we speculate that this modulation may be related in some way to the presence (precession?) of a protoplanetary disk.
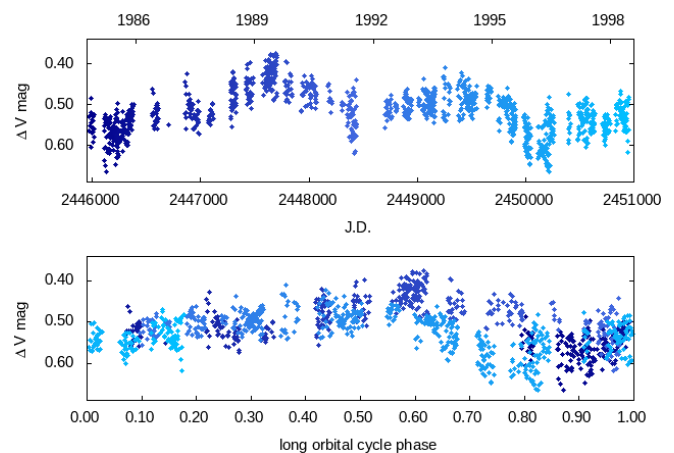

Figure 1: *Top*: APT V light curve of V815 Her between 1984-98. *Bottom*: Folded light curve using the 2092.2 d period of the wide orbit. As zero phase the time of the periastron passage was set. The continuous color gradient helps to distinguish successive phases.
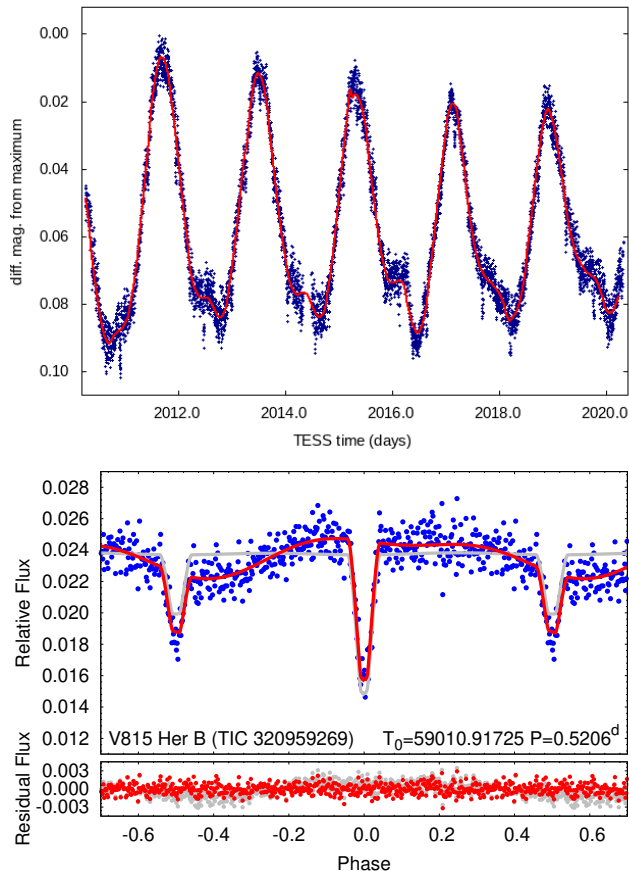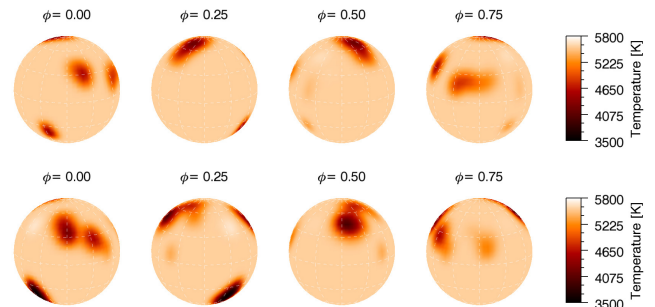
Figure 3: Two Doppler images of V815 Her Aa from 2018. The respective mid HJDs of the images are 2458274.624 (top) and 2458280.067 (bottom). Note the significant change in the spot distribution during the $\approx 3P_{\rm rot}$ time interval, which may partially reflect surface differential rotation.

4 Doppler images and surface evolution of the G-dwarf component

Here we show preliminary results of a Doppler imaging study for the G star for the very first time. We used high-resolution optical spectra from the STELLA-II telescope of the STELLA robotic observatory taken during the 2018 observing run. For the inversion we used the *iMap* code (Carroll *et al.*, 2012) with adopting $i = 75°$ inclination of the rotational axis and $v \sin i$ of $30\,\mathrm{km s}^{-1}$ (Fekel *et al.*, 2005). In Fig. 3 two surface spot reconstructions are plotted as examples. The two consecutive maps reflect significant spot activity and spot distribution change on a time scale comparable to rotation (cf. Fig. 2, top). Some of the changes are probably due to differential rotation, which we will report in more detail in our forthcoming paper (Kővári *et al.*, 2023).

Acknowledgments

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Figure 2: Top: *TESS* Sector 26 light curve of V815 Her (blue dots). The 1.8-d rotational modulation is fitted with a time-series three-spot model (red line). Bottom: Cleaned and folded *TESS* light curve (blue dots) for the wide binary companion V815 Her 'B'. The original orbital solution without assuming surface inhomogeneities is drawn with grey line, while the model drawn with red line fits also the light curve variations arising from stellar spots. Below are the residuals.

3 New orbital solution for V815 Her Ba+Bb

V815 Her (=TIC 320959269) is listed as a *TESS* planet host candidate with a supposed planetary orbit of 0.26 d. So far, *TESS* has observed V815 Her during Sector 26, 40, and 53. However, after removing the spot variability of the G star using the 1.8 d rotational period (see Fig. 2, top), from a closer inspection it became clear to us that the depths of successive minima are slightly different, i.e., primary and secondary minima alternate. Evidently, instead a planet orbiting with a period of 0.26 d we found a close eclipsing binary with a double-length period of 0.52 d bound to V815 Her 'A' in the outer orbit. The eclipsing binary light curve analysis for V815 Her 'B' was carried out with the software package Lightcurvefactory (see Borkovits *et al.*, 2019, 2020, and further references therein). The resulting model fit for the *TESS* Sector 26 data is plotted in the bottom panel of Fig.2 and the parameters of the orbital solution are given in Table 1.

Table 1: Model parameters for V815 Her Ba+Bb

Orbital elements		
P [days]	0.5206	
a [$R_\odot$]	$2.33^{+0.29}_{-0.24}$	
e	0	
ω [deg]	—	
i [deg]	$89.17^{+0.69}_{-1.45}$	
T_0 [BJD - 2400000]	$59011.04717^{+0.0002}_{-0.0002}$	
mass ratio [$q = m_{\mathrm{sec}}/m_{\mathrm{pri}}$]	$0.48^{+0.12}_{-0.08}$	
Stellar parameters		
	Ba	Bb
fractional radius [R/a]	$0.1603^{+0.0046}_{-0.0057}$	$0.1102^{+0.0053}_{-0.0060}$
temperature relative to $(T_{\mathrm{eff}})_{\mathrm{Ba}}$	1	$0.8736^{+0.0222}_{-0.0293}$
fractional flux [in *TESS*-band]	$0.0179^{+0.0020}_{-0.0021}$	$0.0038^{+0.0003}_{-0.0003}$
m [$M_\odot$]	$0.444^{+0.198}_{-0.158}$	$0.185^{+0.053}_{-0.022}$
R [$R_\odot$]	$0.377^{+0.047}_{-0.051}$	$0.256^{+0.026}_{-0.023}$
T_{eff} [K]	3702^{+369}_{-174}	3245^{+174}_{-91}
L_{bol} [$L_\odot$]	$0.024^{+0.019}_{-0.010}$	$0.007^{+0.003}_{-0.002}$
M_{bol}	$8.77^{+0.54}_{-0.64}$	$10.20^{+0.34}_{-0.41}$
M_V	$10.47^{+1.04}_{-1.31}$	$13.20^{+0.34}_{-0.41}$
$\log g$ [dex]	$4.94^{+0.05}_{-0.08}$	$4.91^{+0.07}_{-0.06}$

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