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Detection of Sectoral Modes in the Eclipsing Binary KIC 4851217

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Abstract. KIC 4851217 is a short period eclipsing binary ($P = 2.47$ days) in the field of the *Kepler K1* mission. As well as variability caused by the eclipses, low-amplitude pulsations are also present in the data. A frequency analysis of the residual light-curve revealed δ Sct pulsations in the frequency range from 15–21 d^{-1} with amplitudes up to 3.5 mmag. Strong linear coupling ($f_i = f_p + kf_{orb}$) to orbital frequency was found, indicating tidally locked modes. From an analysis of 5 selected groups of frequencies we identified a radial mode on the secondary component, 3 dipole modes ($l = |m| = 1$), one of them present on the secondary component, and a quadrupole mode ($l = |m| = 2$), also located on the secondary component.

Keywords. Stars: binaries: eclipsing, stars: variables, stars: pulsations

1. Introduction and Observations

KIC 4851217 is an eclipsing binary (EB) observed during the *Kepler K1* mission in both short-cadence (SC) and long-cadence (LC) modes (Borucki *et al.* 2011). Besides revealing binary variability, the light-curve also shows low-amplitude variations (Fig. 1). The phase curve of the EB is illustrated in the left panel of Fig. 1. Basic information about the object and the data can be found in Table 1. The contamination level of 0.005 means that our target suffers minimally from background light. De-trended flux data (PDCSAP_FLUX) available from the *Kepler* eclipsing binaries catalogue does not contain any significant instrumental effects; therefore, only simple sigma clipping at a 5σ threshold was performed to remove any outliers.

2. Ephemeris of the Binary System

Data from eclipses were pre-whitened with the pulsation frequencies detected during eclipses. A form of the template eclipse function published by Mikulášek (2015) was fitted to the pre-whitened primary and secondary eclipse data using a Markov chain Monte Carlo (MCMC) method. Template eclipse functions for each type of eclipse were subsequently fitted to each pre-whitened eclipse; the phase shift of the fit was used to determine the times of minima.

The orbital period of the EB was calculated from a linear fit to the times of minima. We assigned the integer epoch E to primary eclipses and epoch $E + 0.48$ to secondary eclipses (owing to the fact that the orbit of the EB is slightly eccentric). The resulting linear ephemeris of EB KIC 4851217 was then determined from

$$Min\ I = 2454953.900333(7) + 2.47028376(3) \times E. \qquad (2.1)$$

Table 1. Basic information about KIC 4851217 (epoch/equinox J2000)

RA^A	DE^A	$m^B_{kep}/[mag]$	$T^B_{eff}/[K]$	$\log(g)^B(cgs)$	Q_{SC}	Q_{LC}
$19^h\,43^m\,20,16^s$	$39°\,57'\,8.24''$	11.11	6694	4.15	2,4,9,13,15-17	1-5,7-9,11,15-17

Notes: [A]Tycho catalogue, [B]Prša *et al.* 2011, Q - data release

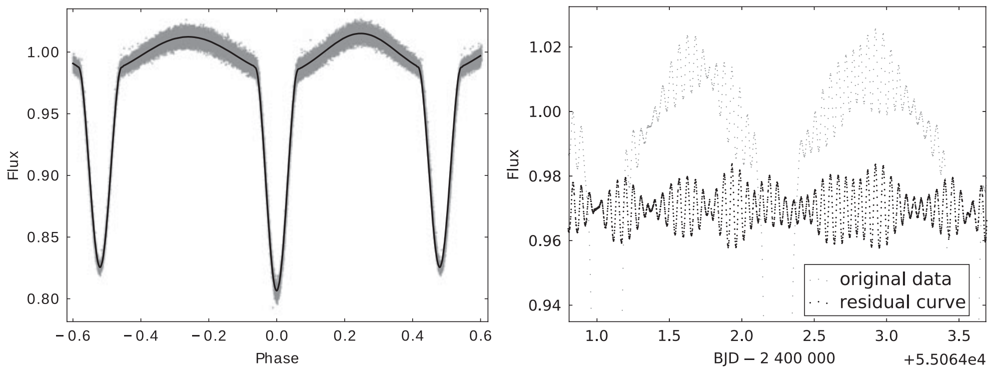

Figure 1. *Left:* Original phase curve, and the smoothed one used to create the residual light-curve. *Right:* The residual light-curve, plus the original one for comparison.

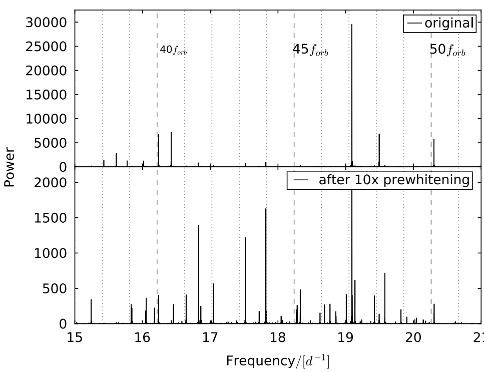

Figure 2. The frequency region containing pulsations. *Upper:* shows the original power spectrum. *Lower:* the power spectrum after pre-whitening of the 10 strongest frequencies. Multiples of orbital frequency are displayed as vertical lines.

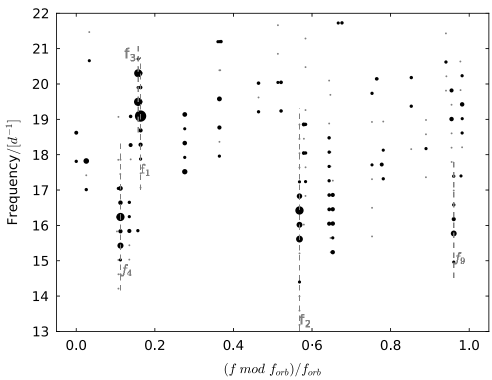

Figure 3. Echelle diagram of detected frequencies. Linear coupling to orbital frequency is represented by vertical lines formed by the detected frequencies. Selected groups of frequencies will be the subject of further analyses.

3. Analysis of the Pulsations

Residual light-curves without the binary signature (Fig. 1, *right*) were analysed using a generalised Lomb periodogram (Zechmeister & Kürster 2009). Short-cadence (SC) and long-cadence (LC) data were analysed separately. We found that all pulsation frequencies were located in the frequency range 15–21 d^{-1} (Fig. 2). That means that LC data are also fully suitable for pulsation analysis, because the pulsation domain is located well below the Nyquist frequency of the LC observations, $f^{LC}_{Ny} = 24.469\,\mathrm{d}^{-1}$. Each frequency was extracted by iterative pre-whitening of the strongest frequency until a signal-to-noise ratio of 4 was reached.

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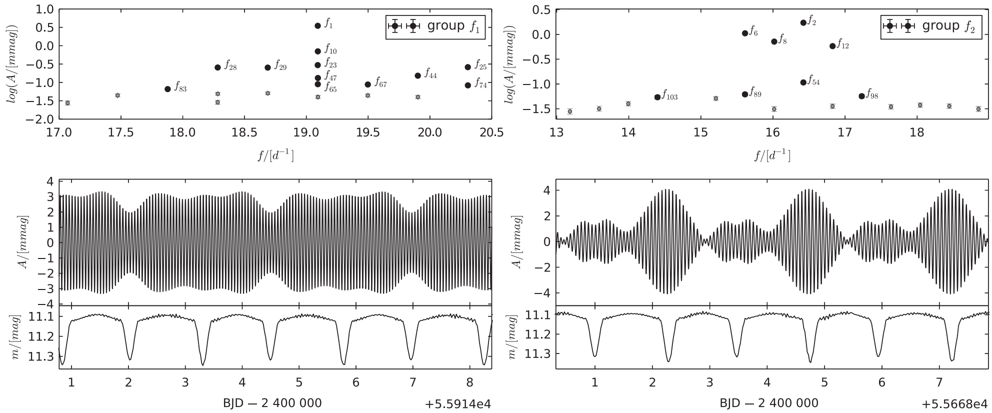

Figure 4. *Left:* Frequency group f_1 (radial mode, $l=0, m=0$). *Right:* frequency group f_2 (dipole mode, $l=1, m=1$). Both are present in the secondary component.

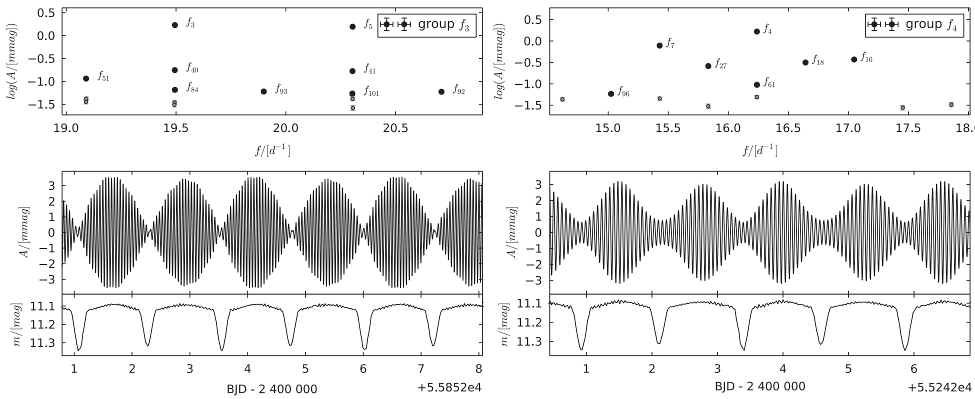

Figure 5. *Left:* Frequency group f_3 corresponding to the dipole mode ($l=1, m=1$. *Right:* frequency group f_4 corresponding to the dipole mode ($l=1, m=1$).

When we displayed the detected frequencies in the form of an echelle diagram (Fig. 3), we discovered strong linear coupling to orbital frequency f_{orb} in form:

$$f_i = f_p + k f_{orb}, \tag{3.1}$$

where f_p is the parent frequency displayed in Figs. 4–6 and k is an integer number. By analysing light-curves created from the particular groups of frequencies highlighted in Fig. 3, we concluded that those light-curves corresponded to one radial and 4 sectoral modes. In one case of one radial mode and 2 sectoral modes, we concluded that the source of pulsations was the secondary component; that was because the pulsations were reduced in amplitude during secondary minima (when part of the light coming from secondary component is blocked by the disk of primary component).

4. Conclusions

Rotational splitting of modes and a reduction in amplitude of pulsations occur during eclipses in this binary. They are are responsible for a linear coupling of frequencies to orbital frequency (Fig. 3). The detected modes are tidally locked (Fig. 7), probably because of tidal forces caused by the slight eccentricity of the EB's orbit. An analysis of the light-curve using the PHOEBE package suggests that the secondary component is a

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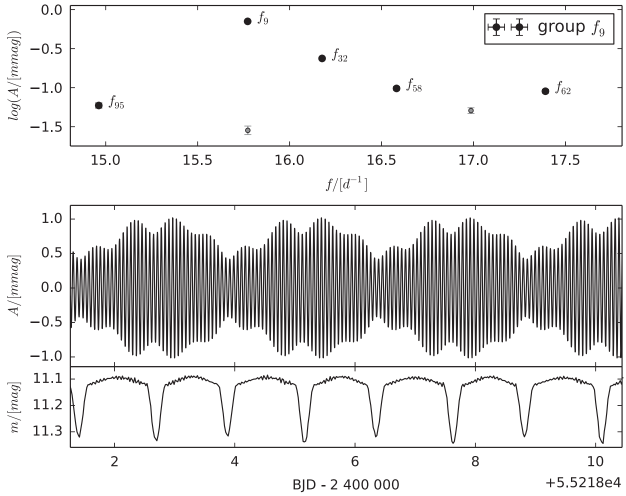

Figure 6. Frequency group f_9 (quadrupole mode, $l=2, m=2$), present in the secondary component.

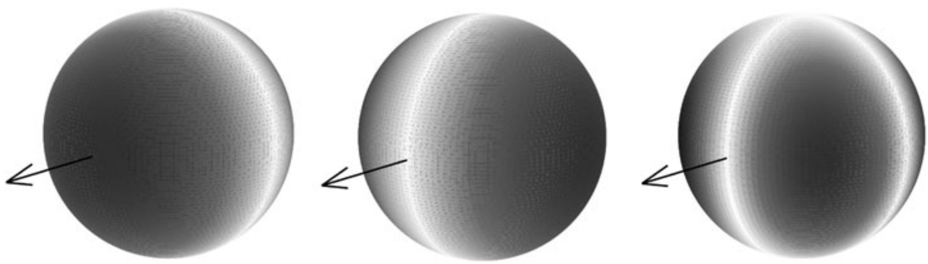

Figure 7. Representation of the modes for which light-curves are displayed in right-hand panels of Fig. 4 (*left*) and Fig. 5 (*centre*), and in the bottom panel of Fig. 6 (*right*). The arrows point towards the companion star to show the orientation of tidally-locked modes.

much larger post-MS star despite a mass ratio of 1.07. There is now an ongoing effort to identify the modes responsible for the rest of the groups in the echelle diagram.

Acknowledgement

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