To Pulse or not to Pulse? That is the question.

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Abstract.
We present reduction and analysis of two eclipsing Algol-type binary systems from data obtained by the *Kepler* Satellite. KIC star A with parameters more indicative of an evolved Algol system (q = 0.36; $T_{Primary}$ = 7300K, $T_{Secondary}$ = 4900K) shows no pulsation of the primary component of any description, whilst KIC star B, a theoretically less evolved system (q = 0.105; $T_{Primary}$ = 7950K, $T_{Secondary}$ = 4800K) shows strong pulsation frequencies down to a level of 8 x 10^{-4} magnitudes. We suggest possible reasons for the lack of pulsation in KIC A and address the shortfalls in our understanding of Algol systems.

Introduction; Oscillating Eclipsing Algols
Algol systems are a class of eclipsing binary stars. The designation of an 'Algol system' is used specifically to refer to eclipsing binary systems which are young enough that neither component has yet become degenerate, but close (and old) enough that some mass transfer of one component to another has already taken place. In some Algol systems, one of the components has been found to undergo stellar pulsation. All pulsating Algols detected and analysed thus far lie inside the classical δ Scuti star instability strip, very close to the ZAMS [1]. These authors also adopted the oEA (oscillating EA) designation for mass accreting, pulsating components in Algols. Rapid Mass Transfer or Accretion (RMT/RMA) evolutionary stages see low-mass progenitors of oEA stars accreting a large portion of mass from Roche lobe overflow of the formerly massive secondary component. These stars have by now evolved rapidly - on thermal time scales - to higher mass and luminosity. They are presently situated close to the ZAMS on the HR diagram, in the hot end of the classical instability strip. They are of spectral type A– F, and are at a slow mass accretion (SMA) stage in their evolution. SMA maintains a thermal imbalance and ensures a slow evolution along the MS towards higher masses and earlier spectral type. In the mass accretion process they do not follow standard evolutionary tracks of normal main-sequence (MS) or post-MS δ Scuti stars.

1. The *Kepler* Satellite

Launched in March 2009, the *Kepler* satellite is NASA's first mission designed to identify Earth- and smaller-sized planets [2].The satellite has a 0.95 meter Schmidt telescope with 42 CCD's having a fixed field of view of 105 square degrees aimed at the constellations of Cygnus and Lyra. The design made it possible to continuously monitor the brightness of ~150 000 stars during the first year and thereafter reduced to 100 000 stars as the mission drew to a close. The results are extremely high quality light curves of interest in both planet detection and asteroseismology. Of significance is that the CCDs are not designed to take pictures. The images are intentionally de-focussed to 10 arc seconds to improve photometric precision [3]

The instruments collect data in the 430-890 nanometre range, with a dynamic range of 9th to 16th magnitude stars and a near 100% duty cycle. The duty cycle is not 100% as the telescope is rolled every 90 days to maintain the sun on the solar arrays and the radiator pointed into deep space.

From May 12 2009, *Kepler* observed ~150 000 stars for close on four years. The observing intervals were 29.4 minutes (Long Cadence) for the primary purpose of detecting planetary transits. Only 512 targets were sampled at 1 minute intervals to support asteroseismic characteristics [4]. Of particular importance is that *Kepler* was required to obtain a signal to noise ratio (S/N) of 4:1 for an 84 parts per million (ppm) deep, 6.5 hour transit of a G2V star. The implications of this are that the noise on the 6.5 hour intervals must be below 20 ppm, which is to include stellar variability contributions.

2. Candidate selection

KIC A and KIC B were selected from a group of eclipsing binary stars initially identified by the *Kepler* Asteroseismic Science Consortium (KASC) and made available by the ninth working group (Binary stars). At the time of selection the pulsation characteristics of the binary pairs were not evident in the available light curves. These pulsations only became apparent after the initial binary model had been subtracted from ten quarters (i.e 2.5 years) of *Kepler* data.

3. KIC A and KIC B

3.1 KIC A

3.1.1 Light curves

The best fit initial binary model (solid line superimposed on the phased data - figure 1) was generated in Binary Maker 3 [5] with minor adjustments in Phoebe (Physics of Eclipsing binaries) – [6]. Derived parameters, whilst not unique (without accurate mass ratios from spectroscopy), give the mass ratio of the components as $q = 0.36$, while $T_1 = 7300$ K and $T_2 = 4900$ K.

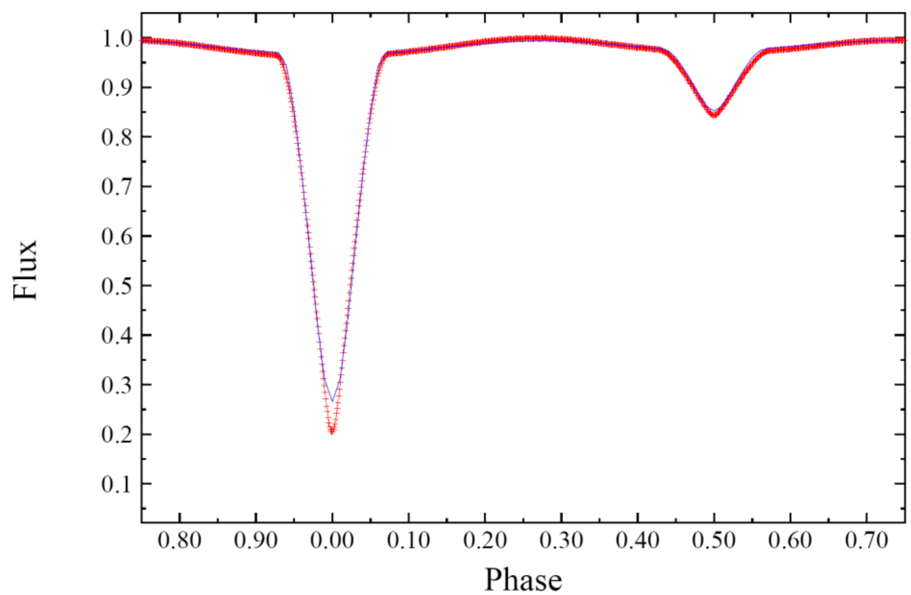

Figure 1: Phased flux for KIC A with binary fit superimposed. 'Phase" refers to the phase of the binary orbit, while 'Flux' is a measure of intensity.

3.1.2. Looking for pulsations

An iterative procedure was followed to separate the binary signal from any potential pulsation signatures in the light curve. Residuals were created by subtracting the binary model from all ten quarters of detrended data. The process converged upon a stable model after three iterations.

Two standard packages for binary system analysis, viz. Binary Maker 3 (BM3) and PHOEBE, were employed for the task. Figure 2 shows a small section of the residuals generated by removal of the synthetic curve from the first ten quarters of data using the first binary model.

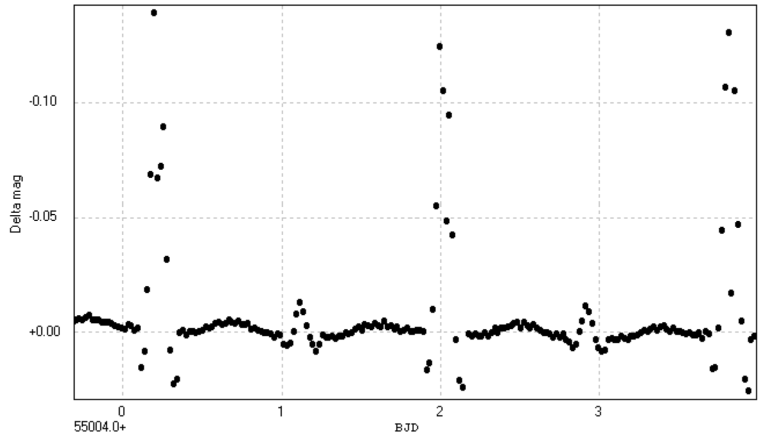

Figure 2: A section of the residuals generated by subtracting the first PHOEBE-generated binary model from the detrended data. The abscissa is indexed in days relative to Baryocentric Julian Date 2455004.

3.1.3. Pulsation signatures

The initial periodogram of the residuals from KIC A, after consecutive refinement of the binary model, is shown in figure 3.

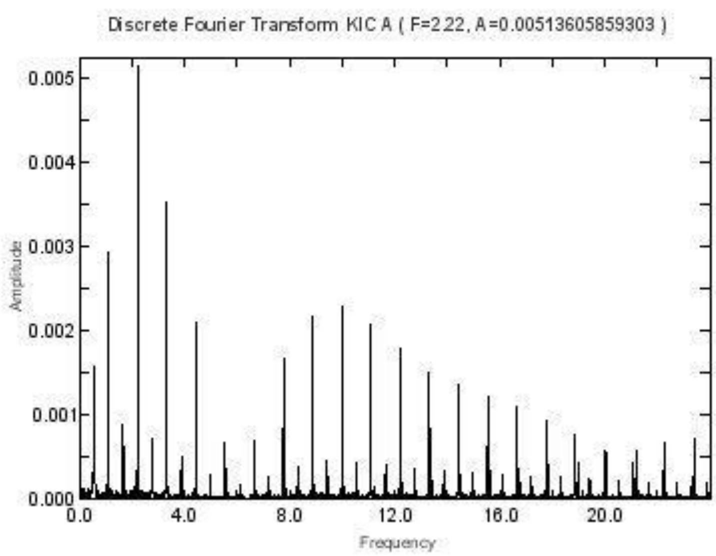

Figure 3: The initial Discrete Fourier Transform (DFT) periodogram of the residuals from KIC A, after consecutive refinement of the binary model.

If there are detectable pulsations present in one of the components of the system, corresponding peaks will appear in the periodogram. However, Figure 3 only shows the expected decaying envelope of Fourier components associated with the binary orbit. When a sine function with the orbital frequency (and ampltide and phase determined by a least-squares fit) is subtracted from these residuals, the periodogram shown in Figure 4 is obtained. A Fourier envelope is still visible, though much reduced in amplitude.

3.2 KIC B

3.2.1 Light curves

The best fit initial binary model (solid line superimposed on the phased data - figure 5) was generated in Binary Maker 3, with minor subsequent adjustments then applied with PHOEBE. The fit is here shown against magnitude, and illustrates the contrast with the flux fit that was shown for KIC A in Figure 1. Derived parameters of the best fit, whilst not unique (without accurate mass ratios from spectroscopy), give the mass ratio q = 0.105, angle of inclination of the orbit i = 70.8 degrees, effective temperature of the primary T_1 = 7950 K and that of the secondary T_2 = 4800 K.

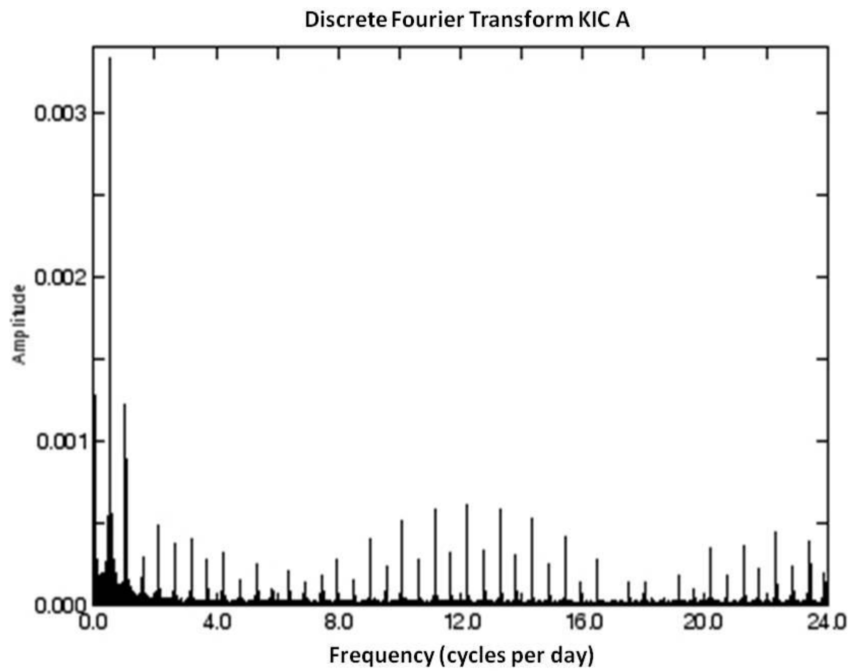

Figure 4: The DFT periodogram of the residuals from KIC A after removal of a sine curve with the orbital frequency

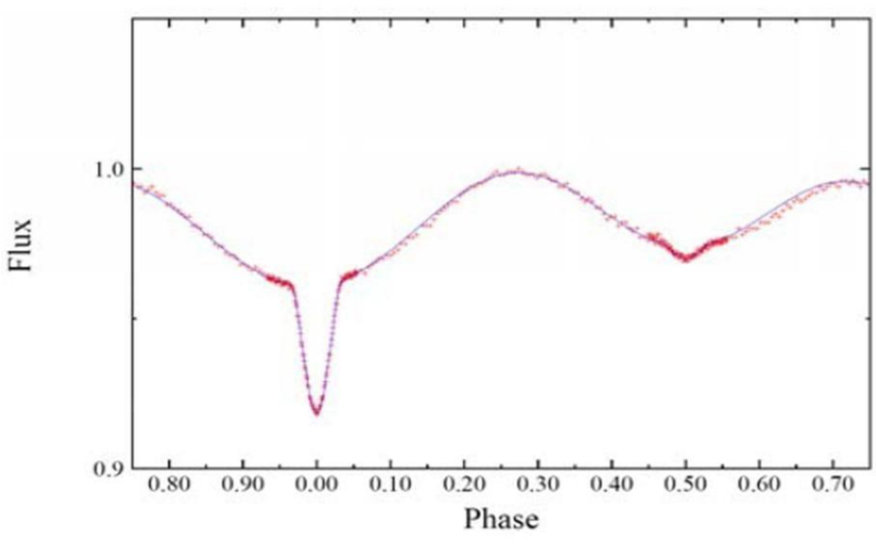

Figure 5: Phased flux for KIC B with binary fit superimposed. ‘Phase” refers to the phase of the binary orbit, while ‘Flux’ is in magnitudes.

3.2.2. Looking for pulsations

As alluded to above, we followed an iterative process, where the residuals obtained - after subtraction of the initial binary fit – are tested for periodic signals. If any are found, a least-squares fit of harmonic components with these periods is subtracted from the original data and a binary fit is performed once again. This cyclic procedure is continued until no further changes occur (i.e. the procedure has converged to a stable solution). The residuals obtained after subtraction of this final (convergent) binary solution are then interrogated for any remaining periodic signals, beyond the obvious declining envelope of harmonic overtones (i.e. the Fourier components) of the orbital period.

3.2.3. Pulsation signatures

The periodogram obtained for the residuals after subtraction of the initial binary fit is shown in Figure 6. Compare this with the behaviour of KIC A as shown in Figure 4. Although there is still a remnant of the binary period and a few low-order harmonics, a separate periodicity at about 15 cycles per day is clearly evident. This is a classic (albeit new!) pulsation signature in an Algol system.

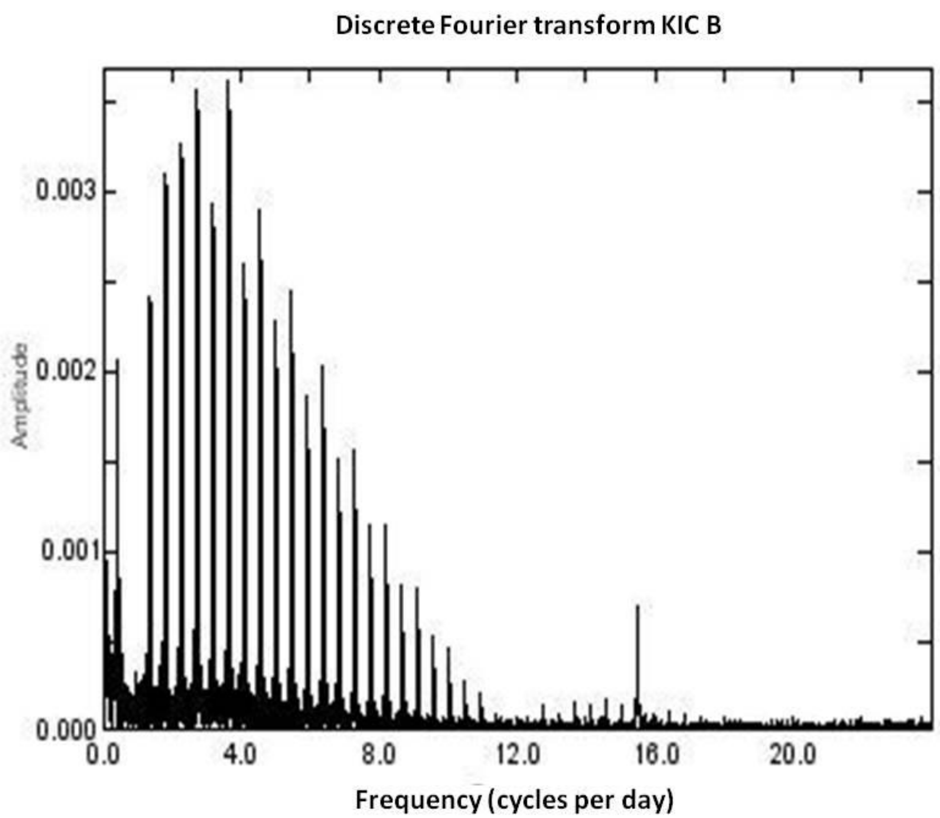

Figure 6: DFT Periodogram of residuals obtained after subtraction of first binary fit for KIC B and after removal of a sine curve with the orbital frequency

3.2.4 Binary: Pulsation resonances

When comparing the pulsation signal obtained from the residuals of the final, convergent fit, with the orbital period, it transpires that $f_{pulsation} : f_{orbit} = 34$. It can not yet be theoretically proven that the pulsation is actually driven by a resonance with the orbital period, but it is a compelling possibility that requires pulsation modelling of the primary star in this system to be confirmed (the secondary is too cool and small to be pulsating with a period of 15 c/d). Spectroscopy of this star is currently being analysed with this goal in mind.

4 Discussion and Conclusion

We have shown the results of a search for pulsations conducted in two very similar Algol systems, observed contemporaneously with the same instrument. KIC A shows no evidence of pulsations while KIC B shows a clear pulsation signal at 15 c/d, which is also 34 x the orbital frequency. In order to ascertain the reason for this difference, we first need to obtain radial-velocity time series for the two systems to pin down the actual masses more accurately and appropriate spectroscopy to determine the effective temperatures of the components, so that a satisfactory comparison with stellar pulsation models may be made. Spectra for KIC B have already been obtained and are being analysed at present. We hope to also obtain spectra for KIC A. Once the masses of the components have been accurately obtained, we shall proceed to modelling of the respective primary components' pulsation behaviour. The existence of an actual pulsation:rotation resonance (and the causes thereof) may then be considered.

We speculate that one or more of the following causes might be responsible for the difference in behaviour that has been reported above: i) The primary in KIC A falls just outside the classical instability strip and pulsations are therefore damped in the interior. This conjecture can be tested once detailed spectra of KIC A have been obtained; ii) Both KIC A and KIC B fall outside the classical instability strip, but the presence of a companion allows driving of the 15 c/d pulsation seen in KIC B to overcome the normal damping effects; iii) A sufficiently high rate of mass transfer might inhibit pulsations in KIC A. Improved modelling of Algol systems will be required to test the latter two conjectures.

A few dozen similar systems have been selected from the *Kepler* database and are undergoing similar analysis at present.

References

[1] Mkrtichian DE et al. 2002 *ASP Conference Series* **259** 96
[2] Borucki WJ et al. 2010 *Science* **327** 977
[3] Koch D et al. 2010 *38th Cospar Scientific Assembly* (Bremen, Germany) 4
[4] Gilliland RL et al. 2010 *The Astrophysical Journal* **713** L160
[5] Bradstreet D 2005 *Society for Astronomical Sciences24th Annual Symposium on Telescope Science* (Society for Astronomical Sciences) 23
[6] Prsa A 2006 Phoebe Scientific Reference *Online Manual* www.phoebe-project.org