The pulsating star, KIC "Rumple", in a close eclipsing binary system

C T Middleton and C A Engelbrecht

Department of Physics, University of Johannesburg
PO Box 524, Auckland Park, 2006, South Africa

Email: cmiddleton@uj.ac.za, chrise@uj.ac.za

Abstract.
Studying pulsating stars in eclipsing binaries has the potential to be an exacting test of theoretical stellar models as a result of the large number of constraints physically that can be imposed on individual components in the binary system. In this particular example, KIC Rumple, the measurement of the large number of frequencies in the star of precisely known mass and radius from binary modelling will enable the identification of pulsation modes. This is vital as a proper physical understanding of δ Scuti pulsations will ensue. It also holds the promise of direct detection of the spatial distribution of pulsations on stellar surfaces. Asteroseismology is the ultimate goal: the derivation of internal rotational behaviour in stars, accurate determination of stellar aging with associated metallicities and the determination of the amount of convective core overshooting in stellar interiors. The research involves the analysis of data obtained through membership of the *Kepler* Asteroseismic Consortium Working Group 9, analysing proprietary data received from the *Kepler* Space Telescope. The data are de-trended, and subject to refined sophisticated analysis routines using many software platforms based on sound physical principles in the determination of the binary parameters and pulsating frequencies of the pair. Anticipated conclusions that might be derived from the completion of this project are discussed.

1. Introduction; oEA's

All pulsating Algols detected and analysed thus far lie inside the classical δ Scuti star instability strip very close to the ZAMS (Mkrtichian et al 2002). 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 now evolved rapidly on thermal time scales to higher mass and luminosity. They are presently situated close to the ZAMS on the HR diagram, are of spectral type B – 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 MS or post MS δ Scuti stars.

The discovery of the pulsation modes in KIC Rumple swells the number of oEA stars to just over 20. The rarity of this class of star is therefore evident. (*Kepler* target stars are often given alias names until clearance is given by KASC management to disclose their co-ordinates. Hence "Rumple".)

2. The Kepler Satellite

Launched in March 2009, the *Kepler* satellite is NASA's first mission designed to identify Earth and smaller sized planets (Borucki et al. 2010).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 makes it possible to continuously monitor the brightness of ~150 000 stars during the first year and thereafter 100 000 stars as the mission draws to a close. The results are extremely high quality light curves of interest in both planet detection and asteroseismology. Of significance is that the CCD's are not designed to take pictures. The images are intentionally de-focussed to 10 arc seconds to improve photometric precision (Koch et al. 2010).

The instruments collect data in the 430-890 nanometre range with a dynamic range of 9^{th} to 16^{th} 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.

Since May 12, 2009 *Kepler* has been observing ~150 000 stars. The observing intervals are 29.4 minutes (Long Cadence) for the primary purpose of detecting planetary transits. Only 512 targets are sampled at 1 minute intervals to support asteroseismic characteristics (Gilliland et al. 2010). Of particular importance is that *Kepler* is required to obtain a signal to noise ratio (S/N) of 4 σ 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.

3. Candidate selection

KIC Rumple was 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 Rumple were not evident in the available light curves. These pulsations only become apparent after the initial binary model had been subtracted from six quarters of data.

4. KIC Rumple

4.1 Light curves

The best fit initial binary model (solid line superimposed on the phased data - figure 4.1) was generated in Binary Maker 3 (Bradstreet 2005) with minor adjustments in Phoebe (Physics of Eclipsing Binaries, Prsa (2006)). Derived parameters, whilst not unique (without accurate mass ratios from spectroscopy), give q = 0.105, i = 70.8, T_1 = 7950 K and T_2 = 4800 K. The primary star has an inner Roche lobe fillout of 37.43% while the secondary fills out at 98.85%.

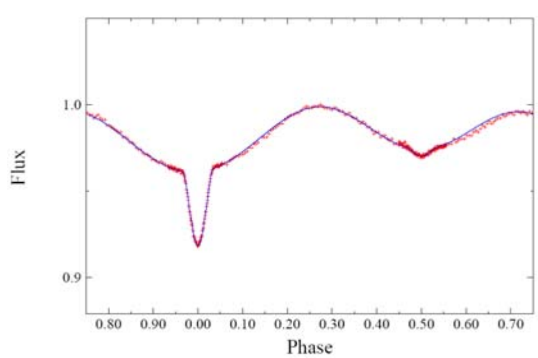

Figure 4.1: Phased magnitude KIC Rumple with binary fit superimposed

Figure 4.2. a diagram of the modelled system, shows chromospheric activity on the secondary star. This chromospheric activity made the modelling complex.

Figure 4.2: A rendition of the binary star in profile at 0.75 of phase.
Note the spots on the secondary star of KIC Rumple depicted in the polar region.
It is worth noting the distended shape of the secondary star.

4.2 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 six quarters of the BJD detrended data. A periodogram was then calculated for these residuals, and periodicities thus found were subtracted from the original data set. This adjusted dataset was then again subjected to binary modelling. This procedure was iterated six times until the process converged upon a model that could not undergo further improvement.

The use of both BM3 and Phoebe were employed for the task. Figure 4.3 shows residuals generated by removal of the fifth iteration of the binary curve from the first six quarters of data.

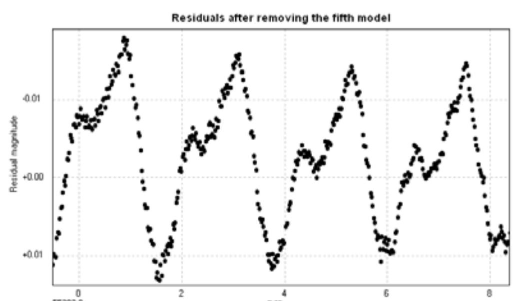

Figure 4.3: Residuals generated after the
removal of the fifth binary model

4.3 Final binary model

Figure 4.4 illustrates the differences in models between the initial and final (sixth iteration). Significantly the level of primary eclipse has not lost any depth in the pulsation removal process which is a good indication that spurious removal of frequencies has not occurred. It is interesting to note how binary light curves may have their appearance modified by stellar pulsation.

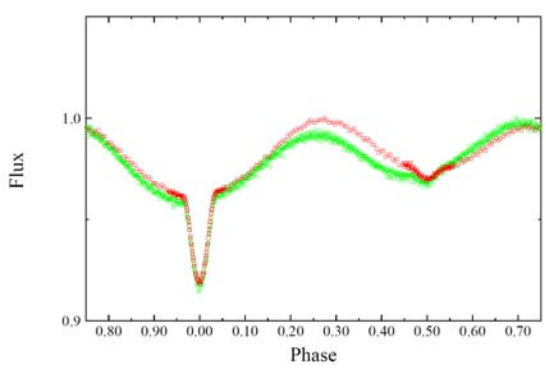

Figure 4.4: The initial model (upper curve)
versus final model (lower curve) from BM3

4.4 Pulsation signatures

The initial Fourier amplitude periodogram calculated for Rumple (using Period04 - Lenz & Breger 2005) after removal of primary and secondary minima from the light curve is shown in figure 4.5. The presence of a strong signal at approximately 15 cycles day^{-1} is clearly seen. This is far above the 4:1 signal to noise limit commonly used in Asteroseismology (Breger 1993). The peaks seen at low frequencies (below 2.5 cycles day^{-1}) are most likely due to interference with the orbital frequency.

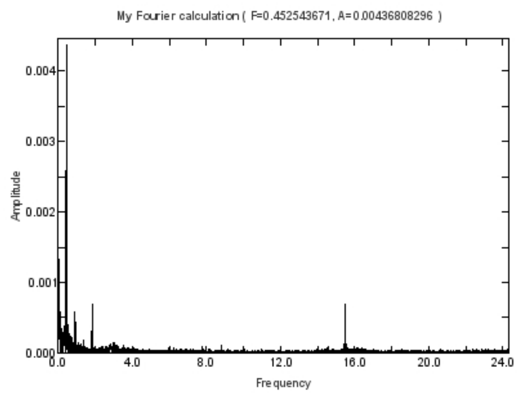

Figure 4.5: The initial periodogram of Rumple after removal of the first synthetic binary light curve.

4.5 Resonances of the orbital frequency with pulsation frequencies

It is compelling to entertain the thought that the final detected frequencies outside of the orbital signatures. viz. $f77$ (6.39 cycles day^{-1}; $f77{:}f_{orb}$ = 14), $f54$ (7.75 cycles day^{-1}; $f54{:}f_{orb}$ = 17), $f21$(8.22 cycles day^{-1}; $f21{:}f_{orb}$ = 18) , $f8$ (15.51 cycles day^{-1}; $f8{:}f_{orb}$ = 34) and $f86$ (15.46 cycles day^{-1}; $f86{:}f_{orb}$ = 34) are pulsation modes excited through resonant coupling with the orbital frequency.

5 Discussion and Conclusion

Spectroscopy for KIC Rumple has been planned for the very near future. It is anticipated that this spectroscopy, with resolution of approximately 20 000 will yield radial velocity measurements of the two stars, effective temperatures, masses, radii as well as chemical abundances despite the secondary star only contributing 11% to the total light of the system. These definitive values will constrain the model of the binary system and hopefully aid in the understanding of δ Scuti stars in binary systems.

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