The Interesting Light Curve and Pulsation Frequencies of KIC 9204718

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Abstract In previous work by Uytterhoeven *et al.* (2011) the Kepler object KIC 9204718 (HD 176843) was identified as a binary system with a δ Scuti-type component. Both long- and short-cadence data were obtained from the MAST archive and analyzed. In this paper we show the results of period analysis on one quarter of short-cadence data in which were obtained two pulsation periods, the dominant of which has a period of 0.026479 day and the secondary of 0.029068 day, respectively. We also present the interesting light curve of the object over several quarters of long-cadence data sets.

1. Introduction

The Kepler satellite has been continually monitoring about 150,000 stars in and near the constellation Cygnus since 2009 with a primary objective of detecting exoplanets, specifically planets close to Earth in size and composition. A secondary objective of the mission deals with asteroseismology. One particularly special type of system in which asteroseismology is useful occurs in binary systems where one component is an intrinsic variable. Kepler is well suited for observing these types of systems as the long-cadence (l.c.) data sequence is well suited for determining the orbital periods of binary systems if they happen to be eclipsing. On the other hand, the short-cadence (s.c.) data sequence is particularly well suited to finding low-amplitude, short-period pulsations in variables such as δ Sct stars. δ Sct stars typically have A–F spectral types and have periods between about 0.02 and 0.3 day (Breger 2000) with low amplitudes.

During a study of stars with spectral types A–F in the Kepler field, Uytterhoeven *et al.* (2011) labeled KIC 9204718 (HD 176843) as a binary system with a δ Sct component. As their goal was to perform analysis on single δ Sct stars, the authors did not attempt to determine any pulsation periods for δ Sct stars in binary systems.

2. Observations

The l.c. data are obtained by making observations every thirty minutes for a three-month span, whereas the s.c. data are taken every minute for about one month (Uytterhoeven *et al.* 2011). Typically, the number of usable data points in an l.c. data set is around 4,000. In contrast, there are about 40,000 usable points in an s.c. data set. An overview of the mission characteristics and instrumentation can be found in Borucki *et al.* (2008).

For the present study, the l.c. data were obtained from 2009 May 2 UT through 2010 September 22 (quarters 1–6 of six quarters in the study). The s.c. observations were obtained from 2009 November 21 UT through 2009 December 17 (third quarter). Table 1 shows the observation information taken from the MAST website (http://archive.stsci.edu/). KIC 9204718 has a magnitude of 8.767 and has coordinates of R.A. $19^h\ 00^m\ 03.362^s$, Dec. +45° 36' 27.54" (J2000).

3. Analysis

The s.c. data contained a total of almost 40,000 data points. The raw fluxes for this object were in the range of 10^5 for the s.c. data (photometric errors, while existent, are orders of magnitude smaller than the fluxes, and thus are neglected). Each data point was then divided by the average of the set for normalization. This allows the various pixel variations on the CCD chips on the satellite to be averaged out and the data sets strung together. The resulting data were then fit with second-degree polynomials to eliminate any effects in the light curve not due to pulsation (such as brightening or dimming apparent in the l.c. light curve, see Figure 5). Figure 1 shows a representative sample of the s.c. data after the polynomial fitting. Note the light curve shows evidence of beating. Period analysis was then performed on the resulting data set using PERANSO (Vanmunster 2007) with the Lomb-Scargle technique (Lomb 1976; Scargle 1982). The period analysis found two significant periods of 0.026479 ± 0.000003 and 0.029068 ± 0.000004 day, respectively, both of which are in the δ Sct regime and which confirms the presence of the beats. These peaks correspond to the highest thetas found in the period analysis (theta is the Lomb-Scargle statistic). The resulting period analysis was then prewhitened to remove the 0.026479-day peak. The resulting peak found was at a period of 0.029068 day, thus bolstering the likelihood that both peaks correspond to physical pulsations rather than any spurious periods. Figure 2 shows the resulting power spectrum of the initial period analysis, while Figure 3 shows the power spectrum after prewhitening. Figure 4 shows the data phased onto the 0.026479-day period. The un-normalized fluxes were then converted to a magnitude scale with all of the preceding analysis done to find the amplitude in variability. The amplitudes were measured using the half-amplitude method. The primary amplitude was found to be about 0.33 mmag while the secondary amplitude was found to be about 0.22 mmag.

The l.c. data were analyzed similarly with a total of close to 24,000 data points. An average for each data set was found and then each flux was divided by this average for normalization. Once this procedure was done, the data sets for all the quarters were strung together and plotted as shown in Figure 5. As can be seen, the light curve is very irregular with various upward and downward trends throughout. It is thought that the two significant downward trends are instrumental effects. There is also a periodicity running through the data that should be on the order of days. Uytterhoeven *et al.* (2011) labeled this object as a binary and not as an eclipsing binary; it is fairly conclusive that the periodic variability is not due to eclipsing phenomena as the amplitude of the variation (see description above) is ~ 0.2 mmag. Period analysis was performed on the data with the intervals of about 150–450 and 550–650 days with a total of almost 18,000 data points. The determined period was found to be 8.6946 ± 0.0.0141 days, which would also exclude γ Doradus-type pulsations. Therefore, at the current moment it is unknown what might be causing the variability. The power spectrum is shown in Figure 6 and the phase diagram (normalized flux) is in Figure 7. Closer inspection of the l.c. power spectrum shows some peaks at about 0.9, 1.8, 4.3, and 5.4, and 6.0 days. To investigate whether these peaks may be real or not, the power spectrum was pre-whitened, removing the ~8.7-day peak. Figure 8 shows the pre-whitened power spectrum which indicates the 4.3-day peak may be spurious while the others remain. Since γ Dor stars pulsate between about 8 hours and 3 days (Uytterhoeven *et al.* 2011), this object may be a hybrid δ Sct/γ Dor object. The periods in the γ Dor regime are found at 0.9133 ± 0.0004 and 1.8259 ± 0.0013 day. The amplitude of the 1.8259-day period was found to be about 0.01 mmag. It is assumed that the 0.9133-day peak has a similar amplitude. There is also a peak at about 5.43 days, although this is out of the γ Dor regime.

In general, the amplitudes of these periods are much smaller than periods detected from ground-based observations (which are generally on the order of a few mmag.) This is due to the precision characteristic of the Kepler satellite. On the other hand, objects are classified as hybrid stars as long as detected frequencies are in each respective regime, the amplitudes are similar, and at least two periods are found in each regime (Uytterhoeven *et al.* 2011). Thus it is concluded that this object may a hybrid pulsator.

4. Conclusion

We have presented evidence for pulsation in KIC 9204718. Uytterhoeven *et al.* (2011) indicated the system is a binary with a pulsating component but did not attempt to find any pulsation periods. Analysis of over 40,000 data points using the short-cadence method found two dominant pulsation periods, 0.026479 day and 0.029068 day, respectively.

We also wanted to investigate the behavior of the light curve over longer intervals; therefore we plotted the normalized flux of several quarters of the Kepler mission. The resulting light curve shows curious downward trends which are thought to be instrumental. A period of 8.6946 days and low amplitude also runs through the data. At the present time, the cause of the variability is unknown. Evidence for γ Dor-type variability is also given, with periods of 0.9311 and 1.8259 day shown in the pre-whitened power spectrum. Clearly this object deserves further study to uncover some of its curiosities.

5. Acknowledgement

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Table 1. Summary of the observations by Kepler for KIC 9204718. The data set designation is indicated, along with the quarter, and start and end times for each set. The data type is indicated as either long-cadence (l.c.) or short-cadence (s.c.), and the number of usable data points from each set N is given.

Data Set	*Quarter*	*Start Time*	*End Time*	*Data Type*	*N*
2009131105131	0	2009-05-02 00:54:56	2009-05-11 17:51:31	l.c.	476
2009166943257	1	2009-05-13 00:15:49	2009-06-15 11:32:57	l.c.	1639
2009259160929	2	2009-06-20 00:25:09	2009-09-16 23:09:29	l.c.	4070
2009350155506	3	2009-09-18 17:19:58	2009-12-16 23:55:06	l.c.	4133
2010078095331	4	2009-12-19 21:03:56	2010-03-19 16:53:31	l.c.	4109
2010174085026	5	2010-03:20 23:47:15	2010-06-23 15:50:26	l.c.	4499
2010265121752	6	2010-06-24 22:44:09	2010-09-22 19:03:09	l.c.	4275
2009350160919	3	2009-11-21 00:22:29	2009-12-17 00:09:19	s.c.	37992

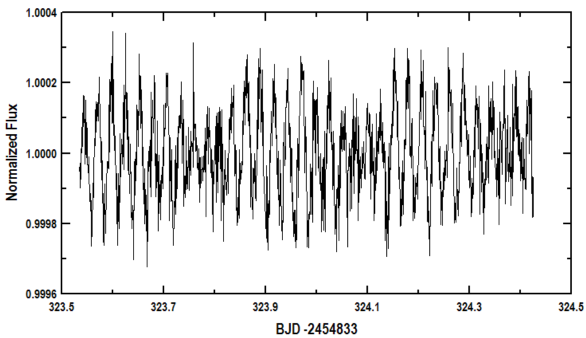

Figure 1. Sample normalized light curve of KIC 9204718 from the Q1 data set. From an initial inspection it appears there is a beat frequency.

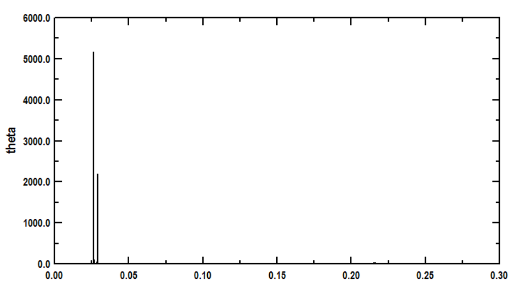

Figure 2. The power spectrum of the short-cadence data showing the 0.026479-day peak. Note the two periods found indicate beats should be observable in the light curve.

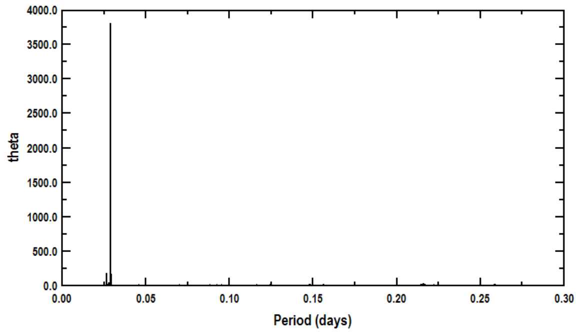

Figure 3. The power spectrum of the short-cadence data set after removing the 0.026479-day peak. The resulting peak is at 0.029068 day.

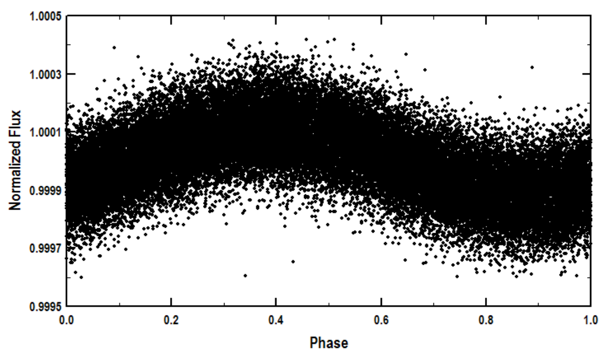

Figure 4. The result of phasing the s.c. data onto the 0.026479-day period.

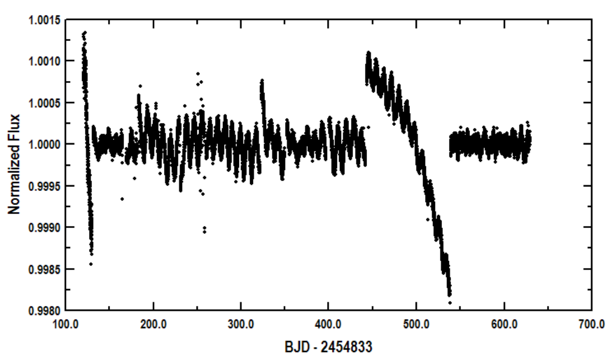

Figure 5. The l.c. light curve of KIC 9204718 over quarters 1–5 after normalization.

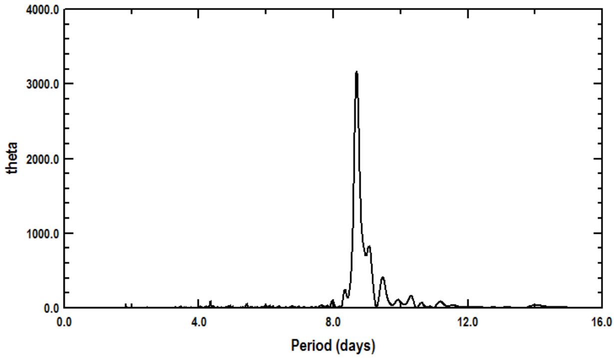

Figure 6. The power spectrum of the l.c. data. The peak is at 8.6946 days.

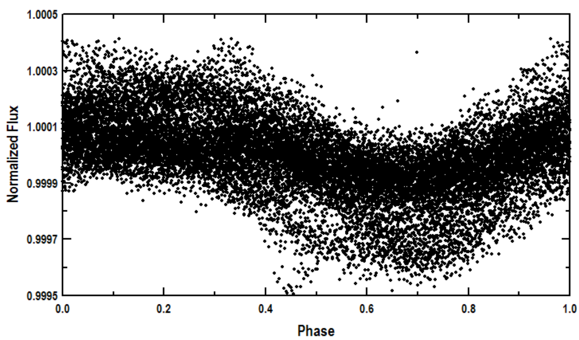

Figure 7. The l.c. data phased onto the 8.6946-day period.

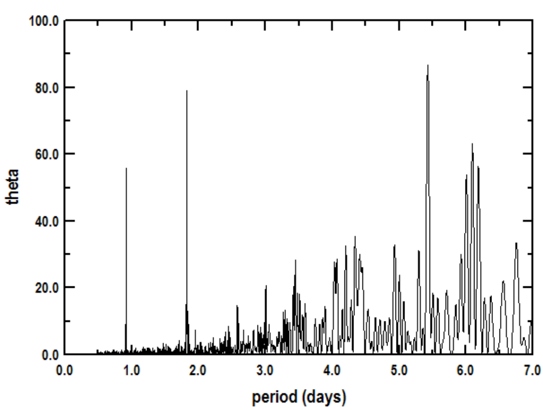

Figure 8. The pre-whitened power spectrum of the l.c. data indicating possible γ-Dor periods at 0.9133 and 1.8259 days.