Search for Binaries in the Kepler K2 Fields Using Pulsation Timing Method

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Abstract

Finding orbital solutions of binaries which have small mass ratios (<0.4) and long periods (>50 days) is challenging using traditional techniques. The radial velocity method is a good way to detect such binary stars, however it requires large telescopes. Therefore, the search for binaries in those regions is still incomplete. For binaries in this regime with at least one component that pulsates, pulsation timing is a better approach. Orbital solutions for such systems can be obtained from the periodic change in pulse arrival times as the star’s reflex motion is manifested by the changing distance along the line of sight. We present a search for binaries with δ Scuti variables in the Kepler K2 extended mission fields. We used the K2 long-cadence (sampling time = 29.45-min) light curves, which are suitable to detect pulsation periods of a few hours as in δ Scuti stars. The observation span for the Kepler K2 mission is about 80 days. Binary candidates which show evidence of periods longer than the K2 temporal window can be observed using space telescopes like TESS and ground-based 1-m class telescopes.

Introduction

More than two third of the stars in the universe are in binaries (Duchêne & Kraus 2013; Guszejnov et al. 2017). Therefore, the study of binary stars is essential to understand stellar formation, evolution and structure. The radial velocity method is a good way to detect binary stars, however it requires large telescopes. For binaries that contain at least one component with stable pulsations, the timing of pulsations provides an alternative way to obtain orbital solutions. A star’s position in space wobbles due to the gravitational perturbations of a companion. From an observer’s point of view the light from the pulsating star is periodically delayed when it is on the far side of its orbit and advanced on the near side.

The pulsation periods of δ Scuti variables are usually stable and therefore are good chronometers. Murphy et al. (2017) examined the original Kepler light curves and found 341 non-eclipsing binaries containing at least one pulsating δ Scuti variable. In this paper, we present the result of a search for pulsations among binaries in Kepler K2 fields. The Kepler K2 observation window limits detection of orbital periods to less than ~ 80 days. According to Murphy et al. (2017), only about 15 of 341 their sample binary systems have orbital periods less than 80 days. Therefore, although we expected a low yield among the K2 sample, the current sample is so small that any additional short period systems are useful.

Figure 1. The sensitivity of traditional techniques to companions of 2M6 stars, as a function of orbital period (P) and mass ratio (Figure 1 of Murphy et al. 2017). P1/2s (double-pulsator binaries) found by their timing method are shown as red squares. The P1 (single-pulsator binary) systems are shown as blue circles for which they assumed orbital inclinations of 60°. This plot shows that only the pulsation timing method is sensitive to small mass ratio binaries with periods about 60 days or longer.

Data and Methods

To find the δ Scuti variables in the K2 archive, we used the same method as Murphy et al. (2017). Long cadence (exposure time = 29.45-min) light curves were extracted for all targets in the K2 Campaign 1 and 2 with effective temperatures between 6600 K and 10000 K. This temperature range includes all δ Scuti pulsator. It also avoids the rapidly increasing number of stars without coherent pressure modes beyond the instability strip’s lowest temperature edge, and also excludes the pulsating B stars. The discrete Fourier transform DFT (between 5.0 -43.9 d-1 (which is the lowest and the highest possible p-mode δ Scuti variable frequencies) was calculated for each light curve obtained. Although the light curve Nyquist frequencies are 24.48 d-1 and 43.9 d-1, for Kepler and K2 data, respectively, they are easily distinguishable from expected pulsational peaks (Murphy et al. 2014). The stars which have pulsation amplitudes below 0.01 mmag were removed as non-pulsators. Otherwise, up to two peaks (which has pulsation amplitude larger than 0.01 mmag) were used in the pulsation timing analysis. Did you mean 0.01?

We used the phase modulation (PM) method of Murphy et al. (2014) in our analysis of the DFT spectra. The traditional pulsation timing method, Observed minus Calculated method, uses only pulsation maxima only, but the PM method uses all of the data. Since K2 data is continuous, each 80-day light curve was divided into eight, 10, or 16 segments. We then obtained the pulsation phase for each segment. The phase variations over time impose a pulsation timing delay due to the orbital motion of the visible star according to the relation:

\[ T = \frac{A_g}{2\pi f} \]

Where \( A_g \) and \( f \) are amplitude of the phase variation and frequency of the pulsation, respectively. The procedure to obtain other orbital parameters such as semimajor-axis, mass functions, and eccentricity are described in Murphy et al. (2014).

Results

Figure 2. (top) DFT of the light curve of the pulsating δ Scuti star EPIC 201238932. (bottom) Light arrival time delays for the two largest amplitude pulsations in the top panel. The frequency of the largest amplitude pulsation is 17.5360 ± 0.0001 day-1.

We found only one pulsating binary system in which the orbital period is less than the observation time span ~ 80 days. Figure 2 displays the DFT spectrum of the light curve for this pulsating δ Scuti star (EPIC 201238932) and the pulse arrival light-time delays. This periodic change indicates the existence of a companion with mass and orbital parameters listed in Table1.

Table 1. Orbital solution for EPIC 20123932 (note: \( a \) is the mass of the pulsating star).

<table>
<thead>
<tr>
<th>Target Name</th>
<th>Period (days)</th>
<th>( a \sin i / c ) (( M_\odot ))</th>
<th>Mass function (( M_\odot ))</th>
<th>Eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPIC 201238932</td>
<td>64.8 ± 1.2</td>
<td>15.0 ± 4.5</td>
<td>(8.9 ± 1.1)x10^-4</td>
<td>0.76 ± 0.19</td>
</tr>
</tbody>
</table>

Conclusion and Future Research

We searched all K2 Campaign 1 and 2 long-cadence (sampling time = 29.45-min) light curves. These data are suitable to detect pulsation periods of a few hours, typical of δ Scuti stars. Among 815 stars with 6600 < \( T_{eff} < 10000 \), only 69 stars showed pulsations. Among these 69 pulsating stars, only 1 is clearly a binary with period of less than 80 days. We are planning to obtain the orbital solutions of all stars in the K2 field using the pipeline we made. Also, some of the TESS observation fields will be observed for more than 80 days, stars in those field also will be good targets for this survey. So far, only a few binary systems with orbital periods around 100 days are known. Therefore, each new discovery substantially improves the statistical significance of the present sample. For stars with large pulsation amplitudes (> 1 mmag), we can also use 1-m class ground-based telescopes for the follow-up observations. This project is well-suited for undergraduate student participation.

References

Duchêne G., & Kraus A. 2013, ARA&A, 51, 269

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