Pulsating stars in binaries: highlights from *Kepler*

*Kepler/K2 SciConV, 7th Mar 2018*

Presented by
Simon Murphy
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Double-lined spectroscopic binaries (SB2s)
Introducing PB2s: Luke and Leia

(PB = pulsating binary)

White et al. (2017), A&A 601, 82
More solar-like oscillators:

Miglio et al. (2014) ApJL 784, 3

Figure 2. Left-hand panel: Hertzsprung–Russell diagram of a synthetic population computed with TRILEGAL. Single stars with predicted detectable oscillations are shown as open circles. Primary components of binaries in which oscillations can only be detected in one component are represented by stars. Couples of filled circles and diamonds connected by solid lines indicate members of binary systems for which oscillations are expected to be detectable in both components, i.e., asteroseismic binaries. Color illustrates the evolutionary state of each component. Right-hand panel: same as left-hand panel, but showing results obtained with BiSEPS assuming $s = 0$ (see Section 2.2).

(A color version of this figure is available in the online journal.)

we would expect to make an asteroseismic detection. The procedure uses as input the fundamental properties of each modeled target—be it a single field star or both components of a binary—allowing us to simulate Kepler apparent magnitude, and the assumed duration of the observations, to estimate what would be the observed photometric signal amplitude due to solar-like oscillations, granulation, and shot noise. From these estimates we may calculate the likelihood of making a robust detection of solar-like oscillations. As in Chaplin et al. (2011b), we flag a detection as made when the estimated probability of detection is higher than 90%.

We corrected the predicted amplitudes of the oscillations and granulation signals of targets in binaries to allow for the dilution of the observed signal due to the presence of the companion star. These corrections were made in the Kepler bandpass, using the bolometric corrections in Ballot et al. (2011).

We adopted two different assumed observation durations, depending on the type of target. The 58.85 s Kepler short-cadence (SC) data are needed to detect oscillations in cool main-sequence and subgiant stars, since the dominant oscillations have periods of the order of minutes. These short periods are not accessible to the 29.4 minute long-cadence (LC) data (for which the Nyquist frequency is $\approx 283 \mu$Hz). Due to the target-limited nature of the SC data, around 2000 targets identified in the KIC as solar-type stars were observed for only one month at a time during the asteroseismic survey conducted in the first 10 months of science operations. To mimic this limitation of the real target sample, we therefore set the observation time to 1 month for a simulated star to detect its oscillations. The threshold for detection in SC lies at the base of the red giant branch (RGB). We set the observation time for LC data to 3 months to simulate its typical long cadence.

Figure 3. Stacked histograms showing the evolutionary state of the secondary component of detectable seismic binaries as a function of the evolutionary state of the primary.

(A color version of this figure is available in the online journal.)
**RG+dSct binaries: KIC9773821**

(dSct = main-sequence pressure-mode pulsators, 1.5 to 2.5 Msun)
RG+dSct binaries: KIC9773821

Parameter

$P_{\text{orb}}$
$t_p$
$a_1 \sin i/c$
e
$\omega$
f$(m_1, m_2, \sin i)$

Same parameters as RV analysis (can even calculate $K_1$)
dSct ‘asteroseismic’ binaries (PB2): KIC4471379

- Mode attribution
- Comparative asteroseismology
- Directly measured mass ratios

\[ q = \frac{m_2}{m_1} \approx 0.99 \]
Even in the middle of the instability strip, only 70% of stars pulsate (Murphy et al., arxiv1903.00015)

6500 < $T_{\text{eff}}$ (K) < 10,000

EBs are easily detected – selection bias. Require manual treatment: Dan Hey PhD
Mass ratio distribution (MS companions)

assume $m_1 = 1.8 \pm 0.3$ $\text{M}_\odot$, where $m_1$ is the pulsator.

but 21% of the companions are WDs in 200-1500 d period range (not shown on plot)

Consistent with disc fragmentation, e.g.

...but 21% of the companions are WDs in 200-1500 d period range (not shown on plot)
Pulsation timing planets?

- Roberto Silvotti’s sdB planet is now “putative” (Silotti et al. 2016 A&A 611, 85)
- One pulsation timing planet remains (Murphy et al. 2016 ApJL 827, 17)
- Sensitivity depends on pulsator type (Compton et al. 2016 MNRAS 461, 1943)
- Sensitivity increases towards longer periods (larger semi-major axis)

Adapted from Hermes (2017) in Handbook of Exoplanets
Analysis of g modes in KIC 10080943

Figure 1. Fourier amplitude spectrum of KIC 10080943 from Kepler long cadence data, showing the clearly separated g-mode and p-mode regions. Inset: close-up of the g modes.

Figure 2. Top: amplitude spectrum of the g-mode region, plotted as a function of period, showing the identified peaks. Dashed lines connect neighbouring peaks in the same g-mode series. Bottom: period spacings between adjacent modes in each series.

Figure 3. Identification of rotationally split g-mode multiplets in KIC 10080943. Dashed lines connect peaks in each multiplet. Colours and symbols used match those of Fig. 2.

Keen et al. (2015) MNRAS 454, 1792

**gDor PB2: KIC10080943**

(gDor = main-sequence gravity mode pulsators, ~1.4 Msun)
The exponential description, the region immediately outside the core, thus decreasing the integral core overshooting mainly increases the size of the convective-fusion mixing as free parameters into our models. Convective-cosmic regions, we included convective-core overshooting and diffusion co-efficient as determined by

$$D_{\text{conv}} = \exp(-|x|/\mu_{\text{X}})$$

and increasing either parameter leads to a wider diffusion co-efficient throughout the star. As a step function, where the extent of the overshooting layer does not fall below this value. The higher it is, the more the chemical composition gradient is washed out in the radial direction, leading to fewer dips in the period spacing pattern. Apart from a given age when only the mixing strength is increased.

The asymptotic period spacing, which is defined by

$$P_N^{(2)} = \pi \frac{2}{R} \frac{|x|}{\mu_{\text{X}}}$$

where

$$x = \frac{R_m}{R}$$

and hence the minimum diffusion co-efficient is

$$\mu_{\text{X}} \geq \frac{R}{R_m}$$

where neither convection nor overshooting is active, we set a different definitions that both depend on the

$$P_N^{(1)} = \frac{\pi}{\mu_{\text{X}}}$$

and therefore extending the time the stars spend on the main sequence. In other words, otherwise equal stars have a higher period ($m$-modes) and period spacing ($g$-modes). This can be illustrated by the asymptotic period spacing, which is defined by

$$P_N^{(2)} = \pi \frac{2}{R} \frac{|x|}{\mu_{\text{X}}}$$

for different symbols. The yellow stars denote the top modes in the same $g$-mode series. Bottom: period spacings between adjacent modes in each series. Figure 1. Fourier amplitude spectrum of KIC 10080943 from Kepler long cadence data, showing the clearly separated $g$-mode and $p$-mode regions. Inset: close-up of the $g$ modes.

Figure 2. Identification of rotationally split $g$-mode multiplets in KIC 10080943. Dashed lines connect peaks in each multiplet. Colours and symbols used different symbols. The yellow stars denote the top $g$-modes in frequency ($m$-mode frequencies as a function of degree $l$).

$$P_N^{(1)} = \frac{\pi}{\mu_{\text{X}}}$$

where

$$x = \frac{R_m}{R}$$

and $N$ is the local pressure scale height,

$$H_\text{p} = \frac{\mu_0}{\mu_\text{X}}$$

and hence the above expression differs from the classical definition

$$P_N^{(1)} = \frac{\pi}{\mu_0}$$

$$P_N^{(2)} = \frac{\pi}{\mu_\text{X}}$$

It is implemented such that the diffusion co-efficient also have the same dependence on the convective-core overshooting layer, and period ($m$-modes).

$$P_N^{(2)} = \frac{\pi}{\mu_{\text{X}}}$$

Alternatively, overshooting can also be defined

$$D_{\text{ov}}(x) = \begin{cases} 1 & x > x_0 \\ \exp(-|x|/\mu_{\text{ov}}) & x \leq x_0 \end{cases}$$

It is implemented such that the diffusion co-efficient also have the same dependence on the convective-core overshooting layer, and period ($m$-modes) as a free parameter.
Naturally, it’s an SB2 (Schmid et al. 2015 A&A 584, 35)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>PM + RV</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_{\text{orb}})</td>
<td>d</td>
<td>(15.336 \pm 0.0004)</td>
</tr>
<tr>
<td>(t_p)</td>
<td>d</td>
<td>(55782.245 \pm 0.018)</td>
</tr>
<tr>
<td>(a_1 \sin i/c)</td>
<td>s</td>
<td>(43.22 \pm 0.02)</td>
</tr>
<tr>
<td>(a_2 \sin i/c)</td>
<td>s</td>
<td>(45.02 \pm 0.02)</td>
</tr>
<tr>
<td>(e)</td>
<td></td>
<td>(0.4539 \pm 0.0003)</td>
</tr>
<tr>
<td>(\varpi)</td>
<td>rad</td>
<td>(6.0187 \pm 0.0008)</td>
</tr>
<tr>
<td>(f(m_1, m_2, \sin i))</td>
<td>(M_\odot)</td>
<td>(0.3687 \pm 0.0006)</td>
</tr>
<tr>
<td>(q)</td>
<td></td>
<td>(0.960 \pm 0.001)</td>
</tr>
</tbody>
</table>
Eclipsing binaries

Eclipses give you:
1. fractional radii (i.e. $R_A/a$)
2. orbital inclination angles

With RVs / pulsations:
3. de-projected masses
4. fundamental radii

With Teff:
5. luminosities
6. distances
Red giants in eclipsing binaries

Testing asteroseismic scaling relations

**EB analysis with RVs**
- Masses
- Radii

**Asteroseismology**
- Masses
- Radii

Agreement?
Red giants in eclipsing binaries

Testing asteroseismic scaling relations

EB analysis with RVs
- Masses
- Radii

Agreement?

Asteroseismology
- Masses
- Radii

RG oscillations suppressed in close binaries

see also Meredith Rawls PhD.T
Red giants in eclipsing binaries

Testing asteroseismic scaling relations

**EB analysis with RVs**
- Masses
- Radii

**Asteroseismology**
- Masses
- Radii

**Agreement?**

**RG oscillations suppressed in close binaries**

see also Meredith Rawls PhD.T

**Need non-linear scaling relations for red giants**

Kallinger et al. (2018)
A&A 616, 104

**adopt a different $\Delta v_{\text{ref}}$**

Themeßl et al (2018)
MNRAS 478, 4669
dSc t stars in eclipsing binaries (Kepler data)
dScF stars in eclipsing binaries: KIC4150611

The University of Sydney

The triple eclipse occurs when one star passes quickly in front of the pulsator, and the eclipsed component is obscured. It happens when the two stars eclipse each other, and the obscured area of the deeper part there is a small brightening. It is therefore easy to associate these transiting stars eclipse each other, and the obscured area of the deeper part of the event, when larger area of the pulsator, therefore this transit is relatively long.

During the cause of the deeper part of the event, when larger area of the pulsator, which help to constrain the ratio of the radii. From the parameterization (due to its orbital motion) occurs when it is still in front of the pulsator, then is followed by a transit of the other star, and again by a passage of the first one, which this time is moving in the opposite direction. In the deep event, the first star starts to transit the pulsator, but the change of the observed di-
crection (due to its orbital motion) occurs when it is still in front of the pulsator. Those eclipses come in two shapes: "triple" with three small brightenings occur exactly at 2, 3, 5, one can see that the components (F1-type pulsator) with the 94.2-day period. As it was mentioned before, the related eclipses have quite peculiar shapes, which is due to the binary character of the object revolving around this pulsator.

In Sect. 3.4. The 94.2 and 1.52-day periods respectively. We can only determine the detection limit of the centre of mass of the 1.52-day period, proving that this is the system revolving around the pulsator.

The 1.43-day period and the star C model curve of this pair is shown in blue (scaled and shifted for clarity). The brightening events in the deep eclipses coincide with the eclipses of the F1 V primary. The brightening events with eclipses that occur with one of the other star behind them is smaller. It is therefore easy to associate these transiting stars eclipse each other, and the obscured area of the deeper part there is a small brightening. It happens when the two stars eclipse each other, and the obscured area of the deeper part of the event, when larger area of the pulsator, therefore this transit is relatively long.

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Conclusions

- Pulsating Binaries (PBs) are analogous to Spectroscopic Binaries (SBs)
  - PB1s give time-delay orbits – just like SB1s give RV orbits
  - PB2s contain two pulsators – just like SB2s contain two stellar spectra
  - PB2s can give mass ratios – just like SB2s give mass ratios from RV curves

- PBs are found all over the HR diagram

Stuff I didn’t get to cover:

- Eclipsing Binaries offer fundamental stellar masses and radii
  - calibration of asteroseismic scaling relations
  - can study tidal effects, core overshoot, etc.
- Many other classes of PBs

[Review paper on this: Murphy (2018) arxiv1811.12659]