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Poetry in motion: Asteroseismology of δ Scuti Stars in Binaries using *Kepler* Data

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Abstract: The results of our six year systematic observational survey on candidate eclipsing binaries with a δ Sct component are briefly presented. A new catalogue for this kind of systems as well as the properties of their δ Sct members are also presented. The comparison between the components-pulsators and the single δ Sct stars shows that both the evolution and the pulsating properties differ significantly. Finally, we introduce the new era of studying stellar pulsations using high accuracy data from *Kepler* mission and emphasizing the great opportunities that are now opened for a deep knowledge of the properties of stellar pulsations.

1 Introduction

Eclipsing binary systems (hereafter EBs) can be considered as extremely powerful tools for calculating the absolute parameters (i.e. masses, radii, temperatures, evolutionary status) of their members. Especially, when photometric analysis is combined with radial velocities curves analysis the results are become extremely accurate. Moreover, the $O-C$ analysis (i.e. Eclipse Timing Variation – ETV) provides the means to study the EB's orbital period variations and connect them directly to various physical mechanisms (e.g. existence of tertiary component, mass transfer, mass loss etc).

Pulsating stars show light variations originated from intrinsic causes, such as pause of hydrostatic equilibrium. δ Scuti stars are pulsating stars that show both radial and non-radial pulsations. Pulsations are generated and preserved in the partial ionized zones inside the stellar interior and can be described quite well by the κ and γ mechanisms. Their mathematical description is based on the spherical harmonics.

Therefore, the study of pulsating stars in binary systems is quite useful for calculating the absolute parameters and the evolutionary status of pulsators. In addition, binarity effects (e.g. mass transfer, mass loss and tidal interactions) play an important role to the evolution and the oscillations of the pulsating stars-members of binaries, a fact which is a quite new subject of modern Astrophysics and is not well investigated so far. The first definition of this new subcategory of binaries was given by [4, 5] as *oEA* (oscillating EA) stars. These systems are in semidetached configuration and they contain a (B)A-F spectral type, mass-accreting main-sequence pulsator. So far, many pulsating stars in binaries have been found [10], but our study focuses on the cases of binaries with a pulsating star of δ Scuti type.

The history of these systems is relatively short. [7], based on a sample of 20 systems, mentioned for the first time the possible existence of a connection between pulsation (P_{pul}) and orbital (P_{orb}) periods for EBs with a δ Sct member. [8] published two catalogues, one with confirmed systems of this type and a second with candidates. A new catalogue with 75 confirmed systems with a δ Sct member and new correlations between their fundamental stellar characteristics were later published by [1]. [9] made the first theoretical attempt to correlate P_{pul}-P_{orb}. Finally, [3] published a new catalogue containing 107 cases in total and noticed for the first time that there is a threshold of $P_{\mathrm{orb}} \sim 13$ days below which P_{pul} and P_{orb} are strongly correlated, while above that these quantities seem to be independent.

In the present study we outline the results of our observational campaign, we present an updated catalogue and correlation for $P_{\rm pul} - P_{\rm orb}$, and finally we briefly present our method for finding new systems using *Kepler's* mission databases.

2 The observational campaign (2006-2012)

We used the catalogue of [8] for selecting candidate systems including a δ Sct component. The campaign began in 2006 and lasted until 2012. Photometric observations were obtained using the telescopes (40 cm, 25 cm, 20 cm) of the Gerostathopoulion Observatory of the University of Athens and the 1.2 m telescope of the Kryonerion Astronomical Station of the National Observatory of Athens. Limited spectroscopic observations were made at Skinakas Observatory using the 1.3 m telescope. In total, we observed 108 candidate systems from which 13 were found to be new cases, while for other 8 we are not certain about their possible pulsational behaviour mostly due to instrumentation limits. Moreover, we observed systematically other 9 known oEA systems for better multiband light curve coverage in order to determine more accurately their pulsation properties. Summarizing the above, complete multi-colour light curves and systematic observations were made for 21 systems with a δ Sct component. The results of the individual systems as well as details for the methods of analyses we applied can be found in [1, 2, 3]. Finally, the results are also available online[1].

3 Updated catalogue, statistical results and $P_{\rm pul}$-$P_{\rm orb}$ correlation

In fig. 1-left the statistics for binaries with a δ Sct component is presented, while the linear fit on the $P_{\rm pul}$-$P_{\rm orb}$ data points for systems with $P_{\rm orb} < 13$ days is given in fig. 1-right. The new catalogue of all the currently known systems (111 in total) is presented in Table 1 and includes the name and the orbital period ($P_{\rm orb}$) of the binary and the dominant pulsation frequency ($f_{\rm pul}$) of the δ Sct star. The catalogue is available online[2] and is being updated systematically. The online version of the catalogue contains also the absolute parameters (i.e. mass, radius, effective temperature) of the δ Sct star, the geometrical type, the mass ratio and all the relevant references for each system.

The new correlation between orbital and pulsation periods, based on the sample of 95 systems with $P_{\rm orb} < 13$ days, is the following:

$$\log P_{\rm puls} = 0.56(6) \log P_{\rm orb} - 1.52(3) \qquad (1)$$

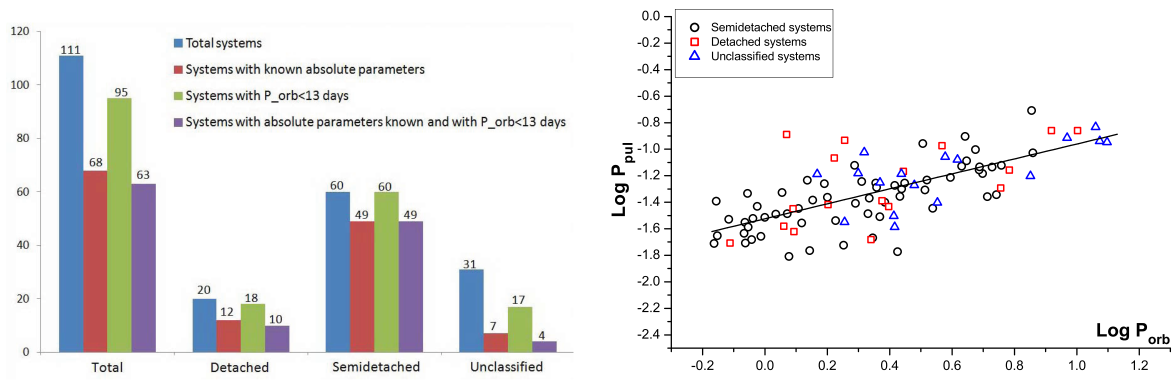

Figure 1: Left: The statistics of the currently known binaries with a δ Sct component. Right: $P_{\rm pul}$-$P_{\rm orb}$ correlation for systems with $P_{\rm orb} < 13$ days.

[1]http://alexiosliakos.weebly.com/binaries-with-a-delta-sct-member.html
[2]http://alexiosliakos.weebly.com/catalogue.html

Table 1: The updated catalogue of binaries with a δ Sct member

Name	$P_{\rm orb}$ [days]	$f_{\rm pul}$ [c/d]	Name	$P_{\rm orb}$ [days]	$f_{\rm pul}$ [c/d]	Name	$P_{\rm orb}$ [days]	$f_{\rm pul}$ [c/d]
Systems with $P_{\rm orb}$ <13 days								
Aqr CZ	0.86275	35.508	Eri AS	2.66410	59.172	Lep RR	0.91543	33.280
Aqr DY	2.15970	23.370	Eri TZ	2.60610	18.718	Lyn CL	1.58606	23.051
Aql QY	7.22954	10.656	Gru RS	11.5	6.803	Lyn CQ	12.50736	8.868
Aql V0729	1.28191	28.034	GSC 3889-0202	2.71066	22.676	Mic VY	4.43637	12.234
Aql V1464	0.69777	24.621	GSC 4293-0432	4.38440	8.000	Oph V0577	6.07910	14.388
Aur KW (14)	3.78900	11.429	GSC 4588-0883	3.25855	20.284	Oph V2365	4.86560	14.286
Aur V0551	1.17320	7.727	HD 061199	3.57436	25.257	Ori FL	1.55098	18.178
Boo EW	0.90630	48.008	HD 062571	3.20865	9.051	Ori FR	0.88316	38.600
Boo YY	3.93307	16.318	HD 099612	2.77876	14.714	Ori V0392	0.65928	40.578
Cam Y	3.30570	17.065	HD 172189	5.70165	19.608	Ori V1004	2.74050	15.365
Cap TY	1.42346	24.222	HD 207651	1.47080	15.434	Pav MX	5.73084	13.227
Cas AB	1.36690	17.153	HD 220687	1.59425	26.169	Peg BG	1.95267	25.544
Cas IV	0.99852	32.692	Her BO	4.27281	13.430	Peg GX	2.34100	17.857
Cas RZ	1.19530	64.197	Her CT	1.78640	52.937	Per AB	7.16030	5.107
Cas V0389	2.49477	27.100	Her EF	4.72920	10.070	Per IU	0.85700	43.131
Cep XX	2.33732	32.258	Her LT	1.08404	30.800	Pup HM	2.58972	31.900
Cet WY	1.93969	13.211	Her TU	2.26690	17.986	Pyx XX	1.15000	38.110
Cha RS	1.66987	11.628	Her V0644	11.85859	8.688	Ser AO	0.87930	21.505
CMa R	1.13590	21.231	Her V0994	2.08309	10.563	Sge UZ	2.21574	46.652
[a]105906206	3.69457	9.417	HIP 7666	2.37232	24.450	Tau AC	2.04340	17.535
Cyg UW	3.45078	27.841	Hor TT	2.60820	38.700	Tel IZ	4.88022	13.558
Cyg V0346	2.74330	19.920	Hya AI	8.28970	7.246	Tri X	0.97151	45.455
Cyg V0469	1.31250	35.971	Hya RX	2.28170	19.380	Tuc θ	7.10360	15.946
Del BW	2.42319	25.100	KIC 03858884	10.04860	7.231	UMa IO	5.52017	22.015
Dra HL	0.94428	26.914	KIC 04544587	2.18909	48.022	UMa VV	0.68738	51.299
Dra HN	1.80075	8.558	KIC 06629588	2.26447	13.396	UNSW-V-500	5.35048	13.624
Dra HZ	0.77294	51.068	KIC 06669809	0.73374	32.564	[b]0975-17281677	3.01550	18.702
Dra OO	1.23837	41.867	KIC 10661783	1.23136	28.135	[b]1200-03937339	1.17962	30.668
Dra SX	5.16957	22.742	Lac AU	1.39259	58.217	Vel AW	1.99245	15.200
Dra TW	2.80690	17.986	Leo DG	4.14675	11.994	Vel BF	0.70400	44.940
Dra TZ	0.86603	50.993	Leo WY	4.98578	15.267	Vul 18	9.31	8.230
Dra WX	1.80186	35.468	Leo Y	1.68610	34.484			
Systems with $P_{\rm orb}$ >13 days								
Cas β	27	9.911	Hya KZ	9782	16.807	Tau ϱ	460.7	14.925
CVn 4	124.44	8.595	KIC 11754974	343	16.342	Tau θ^2	140.72816	13.228
Del δ	40.58	6.378	Lyn SZ	1181.1	8.299	Tau V0777	5200	5.486
Dra GK	16.96	8.790	Ori EY	16.78781	9.709	Vir FM	38.324	13.908
HD 050870		17.162	Ori FO	18.80062	34.247			
HD 051844	33.49830	12.213	Peg IK	21.72400	22.727			

[a]CoRoT ID, [b]USNO A2.0 ID

4 Kepler's era

The *Kepler* mission has contributed a lot to asteroseismology and has been proved as a very powerful tool for obtaining long time-series of data. The main advantages of *Kepler's* data for asteroseismic studies are: a) their high photometric accuracy (order of 10^{-4} mag), b) their high time resolution (short cadence data have $\sim$ 1 min resolution), and c) the continuous recording (no time gaps), which is very critical for eliminating alias effects during the frequency search. In addition, there is an excellent open database[3] for eclipsing binaries, created by [6], which can be easily used for searching, finding and downloading instantly data for further analysis.

Using this database we have found more than 40 eclipsing binaries candidates for including a δ Sct component. For the present study, we selected two of them for analysis, namely KIC 06629588 and KIC 06669809, and we present preliminary results. For KIC 06629588 we used $\sim$106K data points in a time span of $\sim$ 97 days. Using standard methods of analysis (see e.g. [1]) the system is found to be detached with a mass ratio of $\sim$ 0.83. We found 10 independent pulsation frequencies for

[3]http://keplerebs.villanova.edu/

its primary (hotter and more massive) component, with the dominant one to be f_1 =13.396 c/d. Moreover, 203 more frequencies-combinations of the first 10 were also detected. For KIC 06669809 there are ∼32K data points available covering a time span of ∼ 30 days. The binary is identified as a classical Algol system with a mass ratio of ∼ 0.42 and its primary component was found to pulsate in 7 independent oscillation modes (f_1 =32.564 c/d) and in another 44 combination-frequencies. The light curve modelling as well as the Fourier fit on individual data points after removing the binary solution for both systems are plotted in fig. 2. Detailed results for both systems will be presented in a future study.

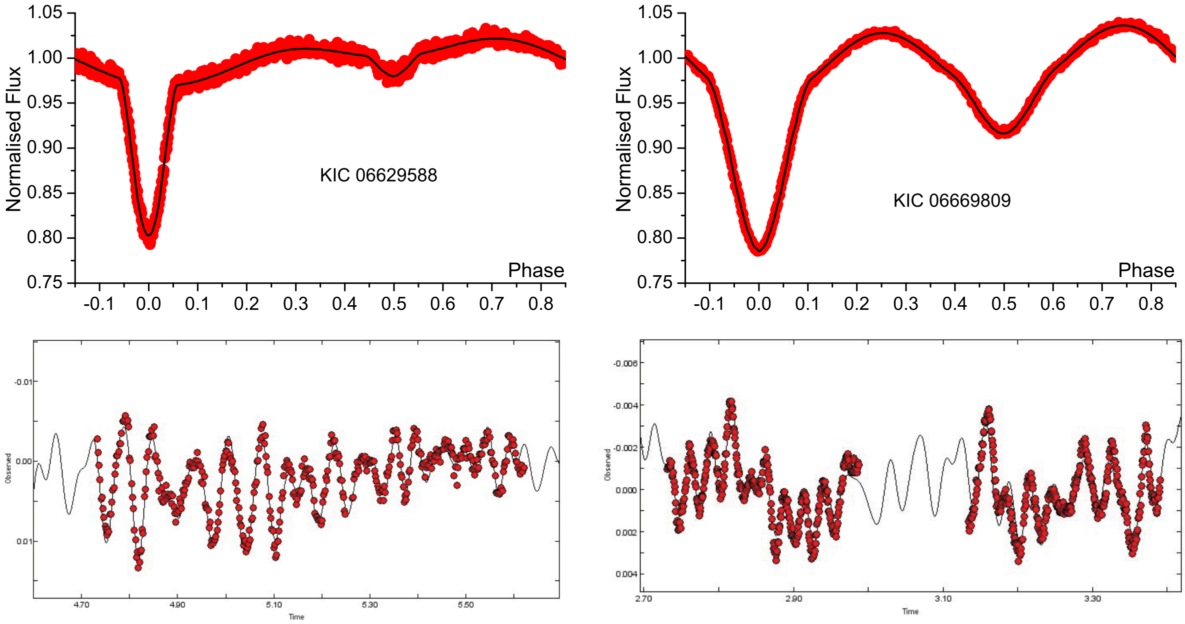

Figure 2: Light curve modelling (up) and Fourier fitting (bottom) on the residuals for KIC 06629588 (left) and KIC 06669809 (right). Red filled circles denote observed points, while theoretical curves are represented by solid lines.

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