Close Binaries with δ Scuti components: New discoveries, analysis techniques and recent results

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**Introduction – Close & eclipsing binaries**

**Detached**

**Semidetached**

**Contact**

*Algol type* → *β Lyrae type* → *W UMa type*
Introduction – Pulsating stars

Internal and surface oscillations $\rightarrow \kappa$ and $\gamma$ mechanisms

Pulsation types

Radial
- fundamental – modes

Non-radial
- pressure – modes
- gravity – modes
Introduction – δ Scuti pulsators

- A - F spectral classes
- III - V luminosity classes
- 1.5 – 2.5 M☉
- Pulsation period range: 20 min – 8 hrs

Types

High Amplitude (HADS)
- Subgiants
- Amplitude > 0.1 mag
- Radial Pulsations

Low Amplitude (LADS)
- No standard evolutionary stage
- Amplitude < 0.1 mag
- Radial & Non-Radial Pulsations
Motivation for studying binaries with pulsators

Pulsating stars $\rightarrow$ Asteroseismology-Physics of the stellar pulsations

+ 

Binaries $\rightarrow$ Absolute parameters, evolutionary status and eclipses as spatial filter for better mode identification (Mkrtichian et al. 2004)

= 

Knowledge about this extraordinary path of stellar lifetime
Brief history

• Mkrtichian et al. (2004) ➔ the oEA (oscillating EA) stars as the (B)A-F spectral type mass-accreting MS pulsators in semi-detached Algol-type eclipsing binaries

• Soydugan et al. (2006a) ➔ connection between pulsation and orbital periods of systems with δ Scuti member with a sample of 20 systems

• Soydugan et al. (2006b) ➔ catalogue with candidate such systems

• Zhou (2010) ➔ catalogue with confirmed systems with a pulsating (in general) member

• Liakos et al. (MNRAS, in prep.) ➔ updated catalogue with 75 confirmed systems with a δ Scuti companion & NEW correlations between fundamental stellar characteristics
Surveys for $\delta$ Sct components in EBs

Instrumentation & Sites

<table>
<thead>
<tr>
<th>Observatory</th>
<th>Location</th>
<th>Telescope</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gerostathopoulion</td>
<td>University of Athens</td>
<td>40 cm</td>
<td>Photometry</td>
</tr>
<tr>
<td>Gerostathopoulion</td>
<td>University of Athens</td>
<td>25 cm</td>
<td>Photometry</td>
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<tr>
<td>Gerostathopoulion</td>
<td>University of Athens</td>
<td>20 cm</td>
<td>Photometry</td>
</tr>
<tr>
<td>Kryonerion</td>
<td>Kyllini Mt., Corinthia</td>
<td>1.2 m</td>
<td>Photometry</td>
</tr>
<tr>
<td>Skinakas</td>
<td>Ida Mt., Crete</td>
<td>1.3 m</td>
<td>Spectroscopy</td>
</tr>
</tbody>
</table>

Main Observing Site (Athens)

Advantages
• More than 200 **TOTALLY** clear nights per year
• Plenty of observational time
• Simultaneous observations

Disadvantages
• Small diameter of the telescopes
• Light pollution

Ideal for long term projects
Surveys for δ Sct components in EBs

Log of observations & statistics

<table>
<thead>
<tr>
<th>Survey No.</th>
<th>Years</th>
<th>Total systems observed</th>
<th>New discoveries</th>
<th>Complete LC of already known</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2007-2009</td>
<td>30</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>2009-2011</td>
<td>68</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2011-.......</td>
<td>9</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Total nights~500 - Total hours~2100

Bar chart:
- Total: 107
- New discoveries: 11
- Ambiguous: 8
- Known: 6
**Surveys for δ Sct components in EBs**

List of the 17 observed systems with δ Sct component

<table>
<thead>
<tr>
<th>System</th>
<th>Period [days]</th>
<th>Frequencies found</th>
<th>Total nights</th>
<th>Total hrs</th>
<th>Filters</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aql QY</td>
<td>7.22954</td>
<td>In prog.</td>
<td>31</td>
<td>200+</td>
<td>BVI</td>
<td>New</td>
</tr>
<tr>
<td>Aqr CZ</td>
<td>0.86275</td>
<td>1</td>
<td>10</td>
<td>25+</td>
<td>B</td>
<td>New</td>
</tr>
<tr>
<td>Cap TY</td>
<td>1.42346</td>
<td>2</td>
<td>11</td>
<td>35+</td>
<td>BVRI</td>
<td>New</td>
</tr>
<tr>
<td>Cet WY</td>
<td>1.93969</td>
<td>1</td>
<td>16</td>
<td>50+</td>
<td>BVRI</td>
<td>New</td>
</tr>
<tr>
<td>Cyg UW</td>
<td>3.45080</td>
<td>2</td>
<td>26</td>
<td>90+</td>
<td>BVI</td>
<td>New</td>
</tr>
<tr>
<td>Del BW</td>
<td>2.42314</td>
<td>In prog.</td>
<td>In prog.</td>
<td>In prog.</td>
<td>In prog.</td>
<td>New</td>
</tr>
<tr>
<td>Dra HL</td>
<td>0.94400</td>
<td>3</td>
<td>17</td>
<td>60+</td>
<td>BVRI</td>
<td>New</td>
</tr>
<tr>
<td>Dra HZ</td>
<td>0.77294</td>
<td>1</td>
<td>8</td>
<td>25+</td>
<td>BVRI</td>
<td>New</td>
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<tr>
<td>Dra TZ</td>
<td>0.86603</td>
<td>In prog.</td>
<td>10</td>
<td>25+</td>
<td>BVRI</td>
<td>Known</td>
</tr>
<tr>
<td>Eri TZ</td>
<td>2.60610</td>
<td>2</td>
<td>26</td>
<td>80+</td>
<td>BV</td>
<td>Known</td>
</tr>
<tr>
<td>Her BO</td>
<td>4.27283</td>
<td>2</td>
<td>25</td>
<td>120+</td>
<td>BVI</td>
<td>Known</td>
</tr>
<tr>
<td>Lac AU</td>
<td>1.39243</td>
<td>2</td>
<td>19</td>
<td>80+</td>
<td>BVRI</td>
<td>New</td>
</tr>
<tr>
<td>Lyn CL</td>
<td>1.58604</td>
<td>3</td>
<td>12</td>
<td>80+</td>
<td>BVI</td>
<td>New</td>
</tr>
<tr>
<td>Peg BG</td>
<td>1.95243</td>
<td>3</td>
<td>15</td>
<td>100+</td>
<td>BVRI</td>
<td>Known</td>
</tr>
<tr>
<td>Per IU</td>
<td>0.85703</td>
<td>2</td>
<td>11</td>
<td>40+</td>
<td>BVRI</td>
<td>Known</td>
</tr>
<tr>
<td>UMa IO</td>
<td>5.52039</td>
<td>In prog.</td>
<td>47</td>
<td>150+</td>
<td>BVRI</td>
<td>New</td>
</tr>
<tr>
<td>UMa VV</td>
<td>0.68738</td>
<td>1</td>
<td>3</td>
<td>15+</td>
<td>BVRI</td>
<td>Known</td>
</tr>
</tbody>
</table>
Surveys for δ Sct components in EBs

Sample of light curves obtained during the surveys

Taken from Liakos et al., MNRAS, in prep.
Data Analysis methods – The case of BO Her

Light curve modelling and 3D simulation

PHOEBE software (Prša & Zwitter 2005) which uses the W-D code

$P = 4.2728088 \text{d}$
Data Analysis methods – The case of BO Her

Absolute parameters & Evolutionary Status

<table>
<thead>
<tr>
<th>Par.</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>M [$M_{\odot}$]</td>
<td>2.43*</td>
<td>0.56 (1)</td>
</tr>
<tr>
<td>R [$R_{\odot}$]</td>
<td>2.7 (1)</td>
<td>4.2 (2)</td>
</tr>
<tr>
<td>T [K]</td>
<td>7800*</td>
<td>4380 (50)</td>
</tr>
<tr>
<td>L [$L_{\odot}$]</td>
<td>24 (2)</td>
<td>5.9 (5)</td>
</tr>
<tr>
<td>Log $g$</td>
<td>3.97 (3)</td>
<td>2.93 (3)</td>
</tr>
</tbody>
</table>

*assumed
Data Analysis methods – The case of BO Her

Light curve residuals

- Eclipse and proximity effects are excluded
- Data near the eclipses are not used
Data Analysis methods – The case of BO Her

Frequency analysis

Fourier Analysis with the software Period04 (Lenz & Breger 2005)

\[ m = Z + \sum A_i \sin [2\pi(\omega_i t + \Phi_i)] \]

After each frequency computation the residuals are pre-whitened for the next one
Data Analysis methods – The case of BO Her

Frequency analysis – Fourier Amplitude spectra

- $f_1 = 13.43 \ (1) \ \text{c/d}$
- $f_2 = 2f_1$
- $f_3 = 23.057 \ (1) \ \text{c/d}$
- $f_4 = 3f_1$
Data Analysis methods – The case of BO Her

Frequency analysis – Fourier modelling
Data Analysis methods – The case of BO Her

Pulsation mode approach

• FAMIAS software (Zima 2008)
• Comparison with δ Sct theoretical models
• Calculation of $l$-degree of spherical harmonics based on static plane-parallel models of stellar atmospheres and on linear non-adiabatic computations of stellar pulsation

$l=1$ or $2$ for $f_1$

$l=0$ or $2$ for $f_3$
Data Analysis methods – The case of BO Her

Synthetic model

Observations
Data Analysis methods – The case of BO Her

Synthetic model

Binary model
Data Analysis methods – The case of BO Her

Synthetic model

Pulsations model

Phase

V+0.2

I+0.4

B
Data Analysis methods – The case of BO Her

Synthetic model

Binary & Pulsation model
11 out of 75 (~15% in total) have been discovered by our surveys
Correlations

Orbital Period – Dominant Pulsation period

\[ \log P_{\text{puls}} = -1.56(4) + 0.62(8) \log P_{\text{orb}} \]

Liakos et al., MNRAS, in prep.
Correlations

Orbital Period – Dominant Pulsation period

\[
\log P_{\text{puls}} = -1.4(1) + 0.5(2) \log P_{\text{orb}}
\]

Liakos et al., MNRAS, in prep.

\[ r = 0.69 \]
Correlations

Orbital Period – Dominant Pulsation period

\[ \log P_{\text{puls}} = -1.53(3) + 0.58(7) \log P_{\text{orb}} \]

Liakos et al., MNRAS, in prep.

\[ r = 0.74 \]
Correlations

Location of the pulsators in the Mass-Radius diagram

Liakos et al., MNRAS, in prep.
Correlations

Pulsation frequency & Mass-Radius diagram

Liakos et al., MNRAS, in prep.
Correlations

Pulsation frequency vs evolutionary status

\[
\text{logg} = 3.7(2) - 0.3(1) \log P_{\text{puls}} \Rightarrow \text{For } \delta \text{ Sct binary-members}
\]

\[
\text{logg} = 2.7(1) - 1.2(1) \log P_{\text{puls}} \Rightarrow \text{For single } \delta \text{ Sct (Claret et al. 1994)}
\]
Surveys for binaries with $\delta$ Sct component are highly encouraged for enriching the current sample.

Correlation between pulsation frequencies and fundamental stellar characteristics have been found for $\delta$ Sct stars in binaries.

Mass gain of the pulsating star is affecting the pulsations.

The evolution is different for single and binary members $\delta$ Sct stars.

Theoretical establishment for the correlations is needed.

Surveys for binaries with $\delta$ Sct component are highly encouraged for enriching the current sample.

Monitoring for several decades for cases with rapid mass transfer is proposed.

Our surveys revealed 11 out of 75 (in total) such systems.

$\delta$ Sct stars in binaries are mostly MS stars.
References

Claret, A., Rodríguez, E., Rolland, A., Lopez de Coca, P., 1990, ASPC, 11, 481
Lenz, P., Breger, M. 2005, CoAst, 146, 53
Zima, W., 2008, CoAst, 155, 1