Study of short period variables and small amplitude periodic variables

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supervised by:
Laurent Eyer, Nami Mowlavi
Is Gaia able to detect short periodic phenomena?
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How to assess the performance of Gaia on short period variability?
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Properties of objects

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Properties of objects

Detection Algorithm + Statistics
false positive
false negative

Mission Properties
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Tests on simulated data

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## Types & Properties Of Short Period Variables

<table>
<thead>
<tr>
<th>TYPE</th>
<th>periods [minute]</th>
<th>amplitudes [mag]</th>
</tr>
</thead>
<tbody>
<tr>
<td>β Cep</td>
<td>96 - 480</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>δ Scuti stars</td>
<td>28 - 480</td>
<td>0.003 - 0.9</td>
</tr>
<tr>
<td>roAp stars</td>
<td>6 - 21</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>EC14026 stars</td>
<td>1.3 - 8.3</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td>Betsy stars (PG1716)</td>
<td>33 - 150</td>
<td>&lt; ~0.01</td>
</tr>
<tr>
<td>ZZ Ceti stars (DAV)</td>
<td>0.5 - 25</td>
<td>0.001 - 0.3</td>
</tr>
<tr>
<td>V777 Her stars (DBV)</td>
<td>2 - 16</td>
<td>0.001 - 0.2</td>
</tr>
<tr>
<td>GW Vir stars (DOV + PNNVs)</td>
<td>5 - 85</td>
<td>0.001 - 0.2</td>
</tr>
<tr>
<td>Brown Dwarf pulsators</td>
<td>~60 - ~210</td>
<td>?</td>
</tr>
<tr>
<td>eclipsing white dwarfs</td>
<td>&gt; 6</td>
<td>&lt; 0.75</td>
</tr>
</tbody>
</table>

DQV, ...  

Short period < 120 min
Properties Of Objects

short periods: $< 120$ min

High astrophysical interest

- pulsation theories
- stellar evolution
- physics of degenerate matter
- gravitational waves
Properties Of Objects - Complex Lightcurves

A typical ZZ Ceti star GD29-38

ZZ Ceti lightcurve simulator:
- work of D. Koester, S. Schlundt
- code implemented by M. Varadi
- collaboration with S. Jordan
Pulsating DA white dwarf star EC 14012–1446 Handler et al. (2008)
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Mission Properties
Gaia Mission Properties

• All sky observations (one billion stars)

• Multi-epoch data over 5 years
  ‣ photometric (G band)
  ‣ spectrophotometric
  ‣ radial velocity (<17 mag)

• Resolution in time:
  ‣ around 70 transit measurements per source in average
  ‣ 1 transit: 9×4.4 sec integration

Tens of millions of variables expected
Gaia Mission Properties: Photometric Precision

<table>
<thead>
<tr>
<th>$V$ [mag]</th>
<th>$\sigma$ [mmag]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sim 14$</td>
<td>3</td>
</tr>
<tr>
<td>$\sim 16.6$</td>
<td>10</td>
</tr>
<tr>
<td>$\sim 20$</td>
<td>60</td>
</tr>
</tbody>
</table>

C. Jordi modified by M. Varadi
An example on **asteroseismology**: the EC14026 stars

<table>
<thead>
<tr>
<th>BASIC PROPERTIES OF PG 0014+067 ($V = 15.9 \pm 0.1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantity</strong></td>
</tr>
<tr>
<td>log $g$ ..........</td>
</tr>
<tr>
<td>$T_{\text{eff}}$ (K) ............</td>
</tr>
<tr>
<td>$M_*/M_\odot$ ..........</td>
</tr>
<tr>
<td>log ($M_{\text{env}}/M_*$) ..........</td>
</tr>
<tr>
<td>$R/R_\odot$($M_*$, $g$) ..........</td>
</tr>
<tr>
<td>$L/L_\odot$($T_{\text{eff}}$, $R$) ..........</td>
</tr>
<tr>
<td>$M_V$($g$, $T_{\text{eff}}$, $M_*$) ..........</td>
</tr>
<tr>
<td>$d(V$, $M_V)$ (pc) ..........</td>
</tr>
<tr>
<td>$P_{\text{rot}}$ (hr) ..........</td>
</tr>
<tr>
<td>$V_{\text{eq}}$($R$, $P_{\text{rot}}$) (km s$^{-1}$)</td>
</tr>
</tbody>
</table>

Complete asteroseismological analysis of PG 0014+67 - Brassard et al. (2001)

- Astrophysical parameters determination, mode identification
- ~10 hr measurements in 5 days with the 3.6m CFHT

**BUT With Gaia we focus on detection of short period variables**
An example on **asteroseismology**: the EC14026 stars

**Basic Properties of PG 0014+067 ($V = 15.9 \pm 0.1$)**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Asteroseismology</th>
<th>Spectroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log g$</td>
<td>$5.780 \pm 0.008$ (0.14%)</td>
<td>$5.77 \pm 0.1$ (1.73%)</td>
</tr>
<tr>
<td>$T_{\text{eff}}$ (K)</td>
<td>$34500 \pm 2690$ (7.80%)</td>
<td>$33550 \pm 380$ (1.13%)</td>
</tr>
<tr>
<td>$M_*/M_\odot$</td>
<td>$0.490 \pm 0.019$ (3.88%)</td>
<td>...</td>
</tr>
<tr>
<td>$\log (M_{\text{env}}/M_*)$</td>
<td>$-4.31 \pm 0.22$ (5.10%)</td>
<td>...</td>
</tr>
<tr>
<td>$R/R_\odot(M_*, g)$</td>
<td>$0.14 \pm 0.04$ (2.68%)</td>
<td>...</td>
</tr>
<tr>
<td>$L/L_\odot(T_{\text{eff}}, R)$</td>
<td>$28.5 \pm 10.4$ (36.5%)</td>
<td>$25.5 \pm 2.5$ (9.90%)</td>
</tr>
<tr>
<td>$M_V(g, T_{\text{eff}}, M_*)$</td>
<td>$4.43 \pm 0.24$ (5.42%)</td>
<td>$4.48 \pm 0.12$ (2.68%)</td>
</tr>
<tr>
<td>$d(V, M_*)$ (c)</td>
<td>$1950 \pm 305$ (15.6%)</td>
<td>$1925 \pm 195$ (10.1%)</td>
</tr>
<tr>
<td>$P_{\text{rot}}$ (yr)</td>
<td>$29.2 \pm 0.9$ (3.08%)</td>
<td>...</td>
</tr>
<tr>
<td>$V_{\text{eq}}(R, P_{\text{rot}})$ (km s$^{-1}$)</td>
<td>$6.20 \pm 0.36$ (5.81%)</td>
<td>...</td>
</tr>
</tbody>
</table>

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Algorithm + Statistics

Which algorithm to use to detect short period variability?

- Period search
- Chi square value
- Structure functions
Algorithm + Statistics

Which algorithm to use to detect short period variability?

- **Period search**
- **Chi square value**
- **Structure functions**

Does the maximum peak correspond to a real frequency in a star?
Algorithm + Statistics

Threshold: 99th percentile

Error type II: 0.053
Error type I: 0.014

Snr=2.0 p=10min sample size=5320

Cdf & ccdf

Max peaks amplitude / mean amplitude of the periodogram
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Tests on simulated data
Tests on simulated data - Increasing Complexity

- times $\rightarrow$ inverse scanning law $\rightarrow$ AGISLab BH, LE, DH- Lund

- signal $\rightarrow$ 1. monoperiodic
  Eyer & Mignard 2005

  2. multiperiodic
  Mary et al. 2006

  3. ZZ Ceti model
  Varadi et al. 2009

  4. Non-Stationary Spectrum

- noise $\rightarrow$ Gaussian
Test On Simulated Data: Monoperiodic

SNR ~ 2.5

Period recovery percentages

Periods [minutes]

- FOV data
- CCD data
Test on simulated data: Example 1

- 7 input periods
- 5 year long data set
- 82 field transits
- 738 ccd observations
- ZZ Ceti light curve with noise

Up to 3 frequencies with highest amplitudes can be recovered
Example 2: Partial data with stationary spectra

2.5 year, CCD Timeseries with stationary spectrum
Noise: 0.0321 [mag] FOVTRN.ID: 080.0004

Simulated Signal [mag]

Amplitude [mag]

Frequencies [c/d] - 2004April, ZZ Ceti star EC 14012-1446
Freq: 127.36 Amp: 0.009
Freq: 140.25 Amp: 0.011
Freq: 141.99 Amp: 0.014
Freq: 119.71 Amp: 0.024
Freq: 141.32 Amp: 0.048

Amplitude [mag]

Frequencies [c/d] - 2007April, ZZ Ceti star EC 14012-1446
Freq: 163.09 Amp: 0.015
Freq: 140.24 Amp: 0.019
Freq: 118.44 Amp: 0.020
Freq: 119.69 Amp: 0.044
Freq: 112.37 Amp: 0.064

A_{max} = 0.045 at 141.12 [c/d]

A_{max} = 0.074 at 112.37 [c/d]
Example 2: Combined Non-Stationary Spectrum

Success! Gaia photometric error corresponds to 19 mag
## Test On Simulated Data: Period Recovery Statistics

<table>
<thead>
<tr>
<th>Signal Description</th>
<th>Periods</th>
<th>Recovery Rate [Percentages]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Noise-Free</td>
</tr>
<tr>
<td>Multiperiodic Sum of Sines</td>
<td>P1</td>
<td>74.5</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>57.5</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>56.5</td>
</tr>
<tr>
<td>ZZ Ceti Model</td>
<td>P1</td>
<td>72.0</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>30.0</td>
</tr>
<tr>
<td>Non-Stationary Spectrum</td>
<td>P1 partial</td>
<td>17.5</td>
</tr>
</tbody>
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Mission properties
• We assessed the performance of Gaia on short period variables → short periodic phenomena can be detected
Future work

- On variability detection method:
  - per-ccd slopes
  - calibrate the detection threshold

- Do complete asteroseismological study of a short period variable
Thank You For Your Attention!

Questions?