The DBV White Dwarf
EC 20058−5234
the continuing story

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A brief history of EC 20058–5234

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- **2006+** Seasonal observations from Chile (Delassio & Provencal)
EC 20058 Discrete Fourier Transform

amplitude [mm/s]

frequency [μHz]

0 2000 4000 6000 8000 10000
Mt John 1.0 m light curve

Mt John 1.0–m photometry of EC20058 (12 Jul 04)
WET photometry xcov15 light curves

UT [hours]

[2 July 97]

[3 July 97] 632

[10 July 97] 639

[11 July 97] 640

fractional Julian day
Asteroseismology of EC 20058

EC 20058 dominant periodicities and $P_{\text{dot}}$

xcov15 EC20058 photometry 2 – 10 July 1997

(281 s)  (257 s)

(333 s)

$\text{frequency [\mu Hz]}$

$\text{amplitude [mma]}$
Mt John 1.0 m telescope (NZ)
Mt John 1.0 m telescope + 3ch photometer
EC 20058 observing season at Mt John

EC20058 (Mt John)

ut (hours) - local time at top

15 Oct, 15 Jul, 15 Apr

altitude (degrees)

airmass
EC 20058 dominant periodicities

Mt John EC20058 photometry July 2004

(281 s) (257 s)

(333 s)

amplitude [mma]

frequency [$\mu$Hz]
White cooling: photons vs neutrinos

Effective Temperature ($T_{\text{eff}}$)

$\log(L_{\nu}/L_\odot)$ and $\log(L_{\text{ph}}/L_\odot)$

$logT_{\text{eff}}$

$T_{\text{eff}}$
EC 20058 (He atmos) and flux standard (H atmos)

EC 20058 spectrum (Magellan 6.5m, 8 July 04)

DA flux standard (EG 274)
Plasmon Neutrino Processes – Feynman diagrams

(i) \( \gamma \rightarrow e^+ \rightarrow \gamma \rightarrow e^- \rightarrow \bar{\nu}_e \)

(ii) \( \gamma^* \rightarrow e^+ \rightarrow e^- \rightarrow W^- \), \( W^+ \rightarrow \nu_e \)

(iii) \( \gamma^* \rightarrow e^+ \rightarrow e^- \rightarrow Z^0 \rightarrow \bar{\nu}_{e,\mu,\tau}, \nu_{e,\mu,\tau} \)
Neutrino physics in hot WD plasmas


3. Essentially all these virtual pairs recombine back into a photon as dictated by the energy-time uncertainty principle.

4. But every now and then (1 in $10^{19}$!), electroweak theory predicts the transformation of a virtual $e^- e^+$ pair into a neutrino pair via a charged $W^\pm$ boson exchange (electron neutrinos) or neutral $Z^0$ boson creation and subsequent annihilation (neutrinos of any flavour).

5. Real final state energetic neutrinos can be produced if both energy and momentum conservation are satisfied.

6. Energy conservation is satisfied for the low energy photons (eg, $\sim 1\,\text{keV}$) due to the small mass of neutrinos (used to be zero!)

7. Momentum conservation requires another “particle” in the initial state $\rightarrow$ among several mechanisms plasmons dominate.
White dwarf cooling and $P_{\text{dot}}$

1. The decreasing temperature of a white dwarf affects the periods of the pulsation modes.
White dwarf cooling and $P_{\text{dot}}$

1. The decreasing temperature of a white dwarf affects the periods of the pulsation modes.

2. Measurable in principle . . . . . . in human lifetimes!
Theoretical evolutionary white dwarf $\dot{P}$ values

\[
\frac{\dot{P}}{P} = a \frac{\dot{R}}{R} - b \frac{\dot{T}}{T}
\]

<table>
<thead>
<tr>
<th>Type</th>
<th>$\dot{P}$</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOV</td>
<td>$\sim 10^{-11}$ s s$^{-1}$</td>
<td>If $\dot{T}$ dominates, but $\dot{R}$ important</td>
</tr>
<tr>
<td>DBV</td>
<td>$\sim 10^{-13}$ s s$^{-1}$</td>
<td>$\dot{R}$ unimportant</td>
</tr>
<tr>
<td>DAV</td>
<td>$\sim 10^{-15}$ s s$^{-1}$</td>
<td>$\dot{R}$ unimportant</td>
</tr>
</tbody>
</table>
## Actual measured pulsating white dwarf $\dot{P}$ values

<table>
<thead>
<tr>
<th>Object</th>
<th>Type</th>
<th>Mode</th>
<th>$\dot{P}$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 1159</td>
<td>DOV</td>
<td>516 s</td>
<td>$-1.21 \pm 0.06 \times 10^{-11}$</td>
<td>Winget et al. (1985)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$-2.49 \pm 0.06 \times 10^{-11}$</td>
<td>Winget et al. (1991)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$+13.0 \pm 2.60 \times 10^{-11}$</td>
<td>Costa et al. (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>539 s</td>
<td>$-0.34 \pm 0.02 \times 10^{-11}$</td>
<td>Costa &amp; Kepler (2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>... various ...</td>
<td>Costa &amp; Kepler (2008)</td>
</tr>
<tr>
<td>G 117–B15A</td>
<td>DAV</td>
<td>215 s</td>
<td>$+3.6 \pm 0.80 \times 10^{-15}$</td>
<td>Kepler et al. (2005)</td>
</tr>
<tr>
<td>ZZ Ceti</td>
<td>DAV</td>
<td>213 s</td>
<td>$\leq 5.5 \pm 1.90 \times 10^{-15}$</td>
<td>Mukadam et al. (2003)</td>
</tr>
</tbody>
</table>
Determining realistic uncertainties via MC methods

To properly implement the O-C period change method we require realistic assessments of the specific mode phases (time of maxima: \( t_{\text{max}} \)) for each light curve:

1. Prewhiten light curve using a multiple frequency linear least squares (LLSQ) fit with all known frequencies.
2. Examine ensemble of light curve deviations to determine statistical noise model \( \rightarrow \) gaussian model with given \( \sigma \).
3. Create model noiseless light curve using LLSQ fit parameters.
4. Create synthetic noisy light curve by adding random gaussian noise from model \((0, \sigma)\) to noiseless model light curve.
5. Perform multiple frequency LLSQ fit on synthetic light curve and extract parameters (eg \( t_{\text{max}} \)) of interest.
6. Repeat 4 and 5 as many times as desired (eg 1000).
Light curve statistics – WET run

prewhitened xcov15.ts data

std devn = 16.5
Mode timing uncertainties

xcov15 data (257s mode)

number per bin

$T_{\text{max}}$ [sec]
Mode timing uncertainties

jun04 data (257s mode)
Mode amplitude stability

EC20058 mode amplitude stability

- 257 s
- 281 s
- 333 s

mode amplitude

days

0 500 1000 1500 2000 2500
Mode timing uncertainties

EC20058 phase timing uncertainties

- Blue line: 257 s
- Red line: 281 s

Plot showing phase uncertainty (T_{max}) over days.
## Data set phase uncertainties

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Site</th>
<th>$\sigma_t$ [mmi]</th>
<th>$\sigma_{257}$ [s]</th>
<th>$\sigma_{281}$ [s]</th>
<th>$\sigma_{333}$ [s]</th>
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</thead>
<tbody>
<tr>
<td>xcov15</td>
<td>WET</td>
<td>13.4</td>
<td>0.59</td>
<td>0.48</td>
<td>1.56</td>
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<tr>
<td>jul03_mag</td>
<td>Magellan</td>
<td>5.9</td>
<td>0.56</td>
<td>0.57</td>
<td>-</td>
</tr>
<tr>
<td>jul04</td>
<td>Mt John</td>
<td>15.9</td>
<td>0.78</td>
<td>1.07</td>
<td>2.6</td>
</tr>
<tr>
<td>jun04</td>
<td>Mt John</td>
<td>17.1</td>
<td>1.13</td>
<td>1.25</td>
<td>16.3</td>
</tr>
<tr>
<td>jul03</td>
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<td>15.9</td>
<td>1.22</td>
<td>1.48</td>
<td>4.28</td>
</tr>
<tr>
<td>aug02</td>
<td>Mt John</td>
<td>20.5</td>
<td>1.27</td>
<td>1.45</td>
<td>1.48</td>
</tr>
<tr>
<td>...</td>
<td>Mt John</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>jun00</td>
<td>Mt John</td>
<td>16.8</td>
<td>1.93</td>
<td>1.92</td>
<td>18.7</td>
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<tr>
<td>...</td>
<td>Mt John</td>
<td>...</td>
<td>...</td>
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<tr>
<td>aug03</td>
<td>SSO</td>
<td>39.8</td>
<td>7.90</td>
<td>32.3</td>
<td>11.4</td>
</tr>
<tr>
<td>...</td>
<td>Mt John</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
The end

continued . . .