Testing the effects of opacity and the chemical mixture on the excitation of pulsations in B stars

Sébastien Salmon

Collaborators: J. Montalbán, T. Morel, A. Miglio, M-A. Dupret, A. Noels

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Pulsations across the HR diagram

- OP/OPAL
- MCs B stars
- Galactic B stars
- Others?
- K mechanism
- OP / OPAL
- β Cephei - SPB
- Ni opacity

- β Cep
- SPB
- δ Scu
- γ Dor
- Solar-like

Log $L/L_\odot$ vs Log $T_{\text{eff}}$
The Kappa mechanism

Second He partial ionization zone

(see Zheka59, Baker & Kippenhahn 1962)
The Kappa mechanism

Iron group opacity bump

\(\beta\) Cephei: main-sequence B stars; low-order p and g modes; \(P \sim 2-8\) h

SPB: less massive; high-order g modes; \(P \sim 1-3\) d

(see Moskalik & Dziembowski 1992; Cox et al. 1992; Dziembowski & Pamyatnykh 1993; Dziembowski, Moskalik & Pamyatnykh 1993)
The iron bump

Very high number of atomic transitions of iron-group elements

e.g. for Fe

\[
K_{\text{Fe}} (\%) = \begin{cases} 
7\% & \text{at } \log T = 7.2 \\
27\% & \text{at } \log T = 6.4 \\
57\% & \text{at } \log T = 5.3 \\
31\% & \text{at } \log T = 4.4 
\end{cases}
\]
Historical review...

<table>
<thead>
<tr>
<th>Group</th>
<th>Date</th>
<th>Chemical elements</th>
<th>Physics input</th>
<th>Result/Trouble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Alamos</td>
<td>Before 1991</td>
<td>12 (H-He-C-N-O-Ne-Na-Mg-Al-Si-Ar-Fe)</td>
<td>Missed bound-bound transitions of heavy elements</td>
<td>Cepheids mass problem</td>
</tr>
<tr>
<td>OPAL (Rogers &amp; Iglesias 1991)</td>
<td>1991</td>
<td>14 (H-He-C-N-O-Ne-Na-Mg-Al-Si-S-Ar-Ca-Fe)</td>
<td>Bound-bound transitions of heavy elements + spin-orbit interaction</td>
<td>300 % increase of iron bump of opacity : κ mech. of β Cephei / SPBs</td>
</tr>
<tr>
<td>OP (Seaton et al. 1994)</td>
<td>1994</td>
<td>17 (OPAL ones + Ni-Cr-Mn)</td>
<td>Iron-group elements</td>
<td>Iron bump ≠ from OPAL</td>
</tr>
<tr>
<td>OPAL (Iglesias &amp; Rogers 1996)</td>
<td>1996</td>
<td>21 (+ P-Cl-K-Ti-Ni-Cr-Mn)</td>
<td>More elements + improved EoS</td>
<td></td>
</tr>
<tr>
<td>OP (Badnell et al. 2005)</td>
<td>2005</td>
<td>17</td>
<td>New treatment of inner-shell transitions</td>
<td>Iron bump enhanced by 18%</td>
</tr>
</tbody>
</table>
... also for the chemical mixture

**Chemical mixture: from GN93** (Grevesse & Noels 1993) **to AGS05** (Asplund & Grevesse & Sauval 2005)

<table>
<thead>
<tr>
<th>Element</th>
<th>Z</th>
<th>GN93</th>
<th>AGS05</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>6</td>
<td>8.55 ± 0.05</td>
<td>8.39 ± 0.05</td>
</tr>
<tr>
<td>N</td>
<td>7</td>
<td>7.97 ± 0.05</td>
<td>7.78 ± 0.06</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>8.87 ± 0.04</td>
<td>8.66 ± 0.05</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
<td>8.07 ± 0.06</td>
<td>7.84 ± 0.06</td>
</tr>
<tr>
<td>Na</td>
<td>11</td>
<td>8.88 ± 0.03</td>
<td>8.67 ± 0.04</td>
</tr>
<tr>
<td>Mg</td>
<td>12</td>
<td>7.58 ± 0.05</td>
<td>7.53 ± 0.00</td>
</tr>
<tr>
<td>Al</td>
<td>13</td>
<td>6.47 ± 0.07</td>
<td>6.37 ± 0.06</td>
</tr>
<tr>
<td>Si</td>
<td>14</td>
<td>7.55 ± 0.05</td>
<td>7.51 ± 0.04</td>
</tr>
<tr>
<td>P</td>
<td>15</td>
<td>5.45 ± 0.04</td>
<td>5.36 ± 0.04</td>
</tr>
<tr>
<td>S</td>
<td>16</td>
<td>7.21 ± 0.06</td>
<td>7.14 ± 0.05</td>
</tr>
<tr>
<td>Cl</td>
<td>17</td>
<td>5.50 ± 0.30</td>
<td>5.50 ± 0.30</td>
</tr>
<tr>
<td>Ar</td>
<td>18</td>
<td>6.60 ± 0.14</td>
<td>6.18 ± 0.03</td>
</tr>
<tr>
<td>K</td>
<td>19</td>
<td>5.12 ± 0.13</td>
<td>5.08 ± 0.07</td>
</tr>
<tr>
<td>Ca</td>
<td>20</td>
<td>6.36 ± 0.02</td>
<td>6.31 ± 0.04</td>
</tr>
<tr>
<td>Ti</td>
<td>22</td>
<td>5.04 ± 0.02</td>
<td>4.90 ± 0.06</td>
</tr>
<tr>
<td>Cr</td>
<td>24</td>
<td>5.67 ± 0.03</td>
<td>5.64 ± 0.10</td>
</tr>
<tr>
<td>Mn</td>
<td>25</td>
<td>5.30 ± 0.03</td>
<td>5.30 ± 0.03</td>
</tr>
<tr>
<td>Fe</td>
<td>26</td>
<td>7.51 ± 0.01</td>
<td>7.45 ± 0.05</td>
</tr>
<tr>
<td>Ni</td>
<td>28</td>
<td>6.23 ± 0.04</td>
<td>6.23 ± 0.04</td>
</tr>
</tbody>
</table>

Z/X = 0.0344 ± 0.0014 | 0.0165 ± 0.001

For a given Z, Fe \( \uparrow \) 20%

C, N, O \( \downarrow \) 35-45%

AGS05 in combination with OP enlarges instability strip and domain of frequency (Miglio et al. 2007)

K mechanism

OP / OPAL

β Cephei - SPB

Ni opacity
Pulsating B stars: troubleshooting?

The answer is no:

- Galactic hybrids (both β Cep/SPB pulsations) => trouble to reproduce high period modes (e.g. Pamyatnykh, Handler & Dziembowski 2004; Dziembowski & Pamyatnykh 2008; Daszynska-Daszkiewicz & Walczak 2010)

- B-type pulsators in the Magellanic Clouds $Z_{SMC}=0.0027$ and $Z_{LMC}=0.0046$ (metallicities from Buchler 2008)

Z too low for excitation of pulsations! (e.g. Miglio et al. 2007)
Effect of the chemical mixture

We made a compilation (from literature) of chemical abundances of B stars for the SMC (Salmon et al. 2012) + a stability analysis of stellar models with that mixture

\[ Z_{\text{SMC}} = 0.0027 \]

- **K mechanism**
- **OP / OPAL**
- **β Cephei - SPB**
- **Ni opacity**
Effect of the chemical mixture

We made a compilation (from literature) of chemical abundances of B stars for the SMC (Salmon et al. 2012) + a stability analysis of stellar models with that mixture

\[ Z_{SMC} = 0.0027 \]

\[ Z \geq 0.007 \] to excite \( \beta \) Cep modes \( \sim 2.5 Z_{SMC} \)

\[ Z > 0.004 \] to excite SPB modes \( \sim 1.5 Z_{SMC} \)
Increasing the opacity

- Fe
- Cr
- Mn
- Ni

10 M⊙ model

- K mechanism
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- Ni opacity
Increasing the opacity

We made an *ad hoc* increase of the Ni opacity (also of Fe and Cr/Mn opacities, see Salmon et al. 2012; see also Jeffery & Saio 2006 in the case of the sdBs)

![Graph showing log P (d) vs. Ni opacity](image)

- **K mechanism**
- **OP / OPAL**
- **β Cephei - SPB**
- **Ni opacity**

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Increasing the opacity

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κ ↗ by 2 in the Ni region => excitation of both β Cep and SPB modes at Z_{SMC}

K mechanism

OP / OPAL

β Cephei - SPB

Ni opacity
Increasing the opacity

We made an *ad hoc* increase of the Ni opacity (also of Fe and Cr/Mn opacities, see Salmon et al. 2012; see also Jeffery & Saio 2006 in the case of the sdBs)

\[ \kappa \uparrow \text{by 1.5 in the Ni region} \rightarrow \text{increases instability domain to higher periods at} \]

\[ Z_{\text{Galaxy}}=0.014 \] (metallicity from Przybilla, Nieva & Butler 2008)
Conclusion

An underestimation < 2 of Ni opacity could explain the difficulties encountered for B-type pulsators of the Galaxy and Magellanic Clouds.

This is strengthened by the facts:

- Ni opacity is partially extrapolated from Fe opacity in OP computations.
- Recent results from computations of Ni opacity and plasma laboratory measurements (Turck-Chièze et al., LIAC 2012).

We thus call for a reexamination of Ni opacity computations.