Asteroseismology of dwarfs and massive stars

Valentina Schmid: binaries
Péter Pápics: SPB stars
Conny Aerts: all the rest

Highest mass: 24 M☉ (CoRoT)
Lowest mass: 0.8 M☉ (Kepler)

Solar-like pulsators: [0.8, 2.0] M☉
Heat-driven pulsators: >1.5 M☉
Two global aims of asteroseismology

- Deliver **mass, radius, age** to exoplanet, binary, cluster, galactic archeology ... studies far better than classical observables (photometric indices, spectroscopy, interferometry, polarimetry, ...)

- Improve **stellar physics & stellar evolution** theory: this talk’s focus
Solar-like p-mode pulsators
in-depth seismic probing à-la Helioseismology


Seismic current Helium abundances of
0.24±0.01(2) for A(B)
Verma et al. (2014)

Analysis of acoustic glitches (sharp features): gives depth of convective envelope & extent of He ionisation zone
(Mazumdar et al. 2014)
“Easy cases”: solar-like p-mode pulsators fulfill scaling relations with Sun as calibrator

Ensemble asteroseismology + spectroscopy:
M: 3.7%, R: 1.3%, age: 12%, Chaplin et al. (2014)

When Gaia distance arrives, we get model-independent seismic mass & better age

Age-$P_{\text{rot(surf)}}$ relation from seismic modelling
Metcalfe et al. (2014)
García et al. (2015)
Suprising Stellar Flaring AF-type stars
Impact on exoplanetary atmospheres?

Balona (2015): Incidence of flares for AF-type stars much higher than thought so far from spectro-polarimetry (Donati & Landstreet 2009)
Heat-driven p&g modes in massive stars

need for core overshoot and/or extra mixing: 20% longer life (Aerts 2014)
Gravity modes in B-type & F-type stars

Tkachenko et al. (2013) Van Reeth et al. (2014 & coming soon…)}
New way to derive mixing & $\Omega(r)$ in F stars

Bouabid et al. (2013) & Van Reeth et al. (soon)
Great asset: hybrid AF-type pulsators

Saio et al. (2015): $<\text{Prot}> \approx 65$ days, slightly slower envelope-than-core rotation
Hybrid pulsators KIC 11145123 & KIC 9244992

Kurtz et al. (2014): p- and g-mode triplets & quintuplets:

$<\text{Prot}> \approx 100 \text{ days},$ slightly faster envelope-than-core rotation
KIC 11145123 & KIC 9244992: IGW in action?

Physical mechanism must be efficient in AM transport inside the star + give opportunity to introduce faster-envelope and counter-envelope rotation: internal gravity waves

(Talon & Charbonnel 2005, Mathis et al. 2013, Rogers et al. 2013)
Internal rotation of unevolved dwarfs?

\(\Omega/2\pi\) (\(\mu\)Hz)

\(\log g\) (cgs)

\(\triangle: \Omega_{\text{envelope}}\)

\(\circ: \Omega_{\text{core}}\)

Sun
Internal rotation of massive stars?
Asteroseismology of pre-MS stars

Seismic evidence for multiple epochs of star formation
Rotation is slower than assumed
Zwintz et al. (2014)
Asteroseismology: near future with K2

K2 (3 months monitoring/field) ecliptic mission: MASSIVE consortium focuses on under-represented targets

<table>
<thead>
<tr>
<th>Sub-class</th>
<th>PI</th>
<th>Prio 1</th>
<th>Prio 2</th>
<th>Prio 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be stars</td>
<td>Neiner</td>
<td>34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>magnetic stars</td>
<td>Briquet</td>
<td>35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>pre-MS stars</td>
<td>Zwintz</td>
<td>24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OB supergiants</td>
<td>Moravveji</td>
<td>82</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>O stars</td>
<td>Aerts</td>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>single B stars</td>
<td>Pápics</td>
<td>66</td>
<td>307</td>
<td>636</td>
</tr>
<tr>
<td>binary OB stars</td>
<td>Tkachenko</td>
<td>51</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
K2’s first view on O-type pulsations

![Graphs showing brightness variation and Fourier amplitude for EPIC 202060092, EPIC 202060179, and EPIC 202061164 with corresponding frequency distributions.](image)
Asteroseismology: mid-term future

Add Gaia distance (mid-2016 to 2020) or interferometric radius to seismic modelling to eliminate one dimension in parameter space
Asteroseismology: farther future

Beyond 2024: 
PLATO main mission & its Complementary Science Programme, step-and-stare phase with targets of choice

I welcome suggestions from this community: 
https://fys.kuleuven.be/ster/Projects/plato-cs/

Credits: DLR (Susanne Pieth)
Education in asteroseismology

“Now is (still!) a good time to become an asteroseismologist…”

because the best is yet to come for stellar physics…
Some Open Questions in Stellar Physics

- How do stars rotate at birth? Does it matter for their future evolution?
- How does interior rotation change with evolution?
- What are the physical mechanisms of core-envelope coupling during core H burning?
- Asteroseismology of OBA supergiants with mass loss?
- How does AM loss/redistribution affect star-planet interactions?
- How does stellar activity/variability interact with exoplanetary atmospheres?
- To Galaxy evolution researchers: upgrade your input from stellar evolution to seismically calibrated versions!...