Gaia: Perspectives for determining stellar surface parameters

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Interplay between determination of stellar atmospheric parameters and development of model atmospheres in the light of Gaia

- effective temperature $T_{\text{eff}}$
- surface gravity $\log g$
- chemical abundances
- leaving out: rotational velocity

Application of model atmospheres play a role on many levels of Gaia data analysis

- e.g., libraries of stellar spectra
- stellar atmospheres well developed theoretical tool

Accurate observational constraints necessary to make model shortcomings apparent

HIPPARCOS based results and stories from own projects
BIPM ideas of accuracy...
Conclusions

- Gaia will sharpen the constraints model atmospheres have to fulfill

- Desirable improvements on the stellar $T_{\text{eff}}$ scale demand for new discoveries – which Gaia will likely make – and accompanying observational and theoretical efforts

- Gaia can help to provide non-standard observables of particular interest to 3D model atmospheres
Personal bias

- Modellist, cool stars, development of 3D hydrodynamical model
- Stellar abundance work, Sun, metal-poor stars
- Member of CU6, WP on radial velocity zero point definition
CIFIST 3D model atmosphere grid

(Ludwig, Caffau, Steffen, Freytag, Bonifacio, Kučinskas, 2009)
## Solar 3D abundances in comparison

<table>
<thead>
<tr>
<th>Element</th>
<th>Caffau et al.</th>
<th>AG89</th>
<th>GS98</th>
<th>AGS05</th>
<th>AGSS09</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>1.02 ± 0.02</td>
<td>1.16 ± 0.10</td>
<td>1.10 ± 0.10</td>
<td>1.05 ± 0.10</td>
<td>1.05 ± 0.10</td>
</tr>
<tr>
<td>C</td>
<td>8.50 ± 0.11</td>
<td>8.56 ± 0.04</td>
<td>8.52 ± 0.06</td>
<td>8.39 ± 0.05</td>
<td>8.43 ± 0.05</td>
</tr>
<tr>
<td>N</td>
<td>7.86 ± 0.12</td>
<td>8.05 ± 0.04</td>
<td>7.92 ± 0.06</td>
<td>7.78 ± 0.06</td>
<td>7.83 ± 0.05</td>
</tr>
<tr>
<td>O</td>
<td>8.76 ± 0.07</td>
<td>8.93 ± 0.035</td>
<td>8.83 ± 0.06</td>
<td>8.66 ± 0.05</td>
<td>8.69 ± 0.05</td>
</tr>
<tr>
<td>P</td>
<td>5.46 ± 0.04</td>
<td>5.45 ± 0.04</td>
<td>5.45 ± 0.04</td>
<td>5.36 ± 0.04</td>
<td>5.41 ± 0.03</td>
</tr>
<tr>
<td>S</td>
<td>7.15 ± 0.06</td>
<td>7.21 ± 0.06</td>
<td>7.33 ± 0.11</td>
<td>7.14 ± 0.05</td>
<td>7.12 ± 0.03</td>
</tr>
<tr>
<td>Eu</td>
<td>0.52 ± 0.03</td>
<td>0.51 ± 0.08</td>
<td>0.51 ± 0.08</td>
<td>0.52 ± 0.06</td>
<td>0.52 ± 0.04</td>
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<tr>
<td>Hf</td>
<td>0.87 ± 0.04</td>
<td>0.88 ± 0.08</td>
<td>0.88 ± 0.08</td>
<td>0.88 ± 0.08</td>
<td>0.85 ± 0.04</td>
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<tr>
<td>Th</td>
<td>0.08 ± 0.03</td>
<td>0.12 ± 0.06</td>
<td>0.09 ± 0.02</td>
<td>0.06 ± 0.05</td>
<td>0.02 ± 0.10</td>
</tr>
<tr>
<td>K</td>
<td>5.10 ± 0.09</td>
<td>5.12 ± 0.13</td>
<td>5.12 ± 0.13</td>
<td>5.08 ± 0.07</td>
<td>5.03 ± 0.09</td>
</tr>
<tr>
<td>Fe</td>
<td>7.51 ± 0.08</td>
<td>7.67 ± 0.03</td>
<td>7.50 ± 0.05</td>
<td>7.45 ± 0.05</td>
<td>7.50 ± 0.04</td>
</tr>
<tr>
<td>Os</td>
<td>1.15 ± 0.06</td>
<td>1.45 ± 0.10</td>
<td>1.45 ± 0.10</td>
<td>1.45 ± 0.10</td>
<td>1.25 ± 0.07</td>
</tr>
<tr>
<td>Z</td>
<td>0.0154</td>
<td>0.0189</td>
<td>0.0171</td>
<td>0.0122</td>
<td>0.0134</td>
</tr>
<tr>
<td>Z/X</td>
<td>0.0211</td>
<td>0.0267</td>
<td>0.0234</td>
<td>0.0165</td>
<td>0.0183</td>
</tr>
</tbody>
</table>

AG89 Anders & Grevesse Geochemica et Cosmochimica acta, 1989 Vol. 53 (6th place)
AGS05: Asplund et al.; ASP Conferences Series, Vol. 336, 2205
AGGS09: Asplund, Grevesse, Sauval, & Scott, 2009, ARAA 47, 481

’excess: model atmospheres and spectral synthesis (NLTE) enter on the 0.05 ... 0.1 dex level
Absolute chemical abundances and fundamental atmospheric parameters

- Solar abundances from spectroscopy benchmark demand model atmospheres of highest fidelity
- Differences between Caffau et al. and AGSS09 dominated by systematics in model atmospheres and assumptions in NLTE spectral synthesis
  - same spectra, same atomic parameters used . . .
- $T_{\text{eff}}$ and $\log g$ obviously well constrained in the case of the Sun
- Constraining physics of atmosphere models (late-type stars) using chemistry in other stars needs
  - $T_{\text{eff}}$ to better than 1%
  - $\log g$ to better than 0.1 dex
- Would make model systematics apparent like in the solar case
  - left out fine print on abundance cross-talk, extinction, rotation, micro-turbulence
High precision atmospheric parameters?

Gaia’s photometry perhaps up to the task for $G < 15$ and zero extinction? (Bailer-Jones, 2010, MNRAS 403, 96)

Combine with ground-based measurements

Effective temperatures from (in order of decreasing model dependence)

- spectroscopy: (excitation equilibrium), Balmer line profiles
- photometry: infra-red flux method
- angular diameters: $T_{\text{eff}} \propto \theta_{\text{LD}}^{\frac{1}{2}} f_{\text{bol}}^{\frac{1}{4}}$ (weak model dependence)
  rather few measurements, none for very metal-poor stars

Surface gravities from

$$\log \frac{g}{g_\odot} = \log \frac{M(L, T_{\text{eff}})}{M_\odot} + 4 \log \frac{T_{\text{eff}}}{T_{\text{eff}}_\odot} + 0.4 (M_{\text{bol}} - M_{\text{bol}}_\odot)$$

Gaia provides accurate distances and and estimates of the extinction
Fuhrmann 2004: mid-F to K stars within 25 pc

- $T_{\text{eff}}$ from Balmer lines, $\log g$ from HIPPARCOS distances
- Uncertainty in $T_{\text{eff}}$ 1.3%, $\log g$ 0.1 dex
- Error budget on gravity dominated by distance error
Metal-poor stars: lack of fundamental $T_{\text{eff}}$

Colour-magnitude diagram globular cluster NGC6397, $[\text{M/H}] \approx -2$

80 MS + 80 SG stars with FLAMES/GIRAFFE
Metal-poor stars: lack of fundamental $T_{\text{eff}}$

$T_{\text{eff}}$ from Balmer lines in 3D, log $g$ from colours and cluster isochrone

$\Delta A(\text{Li})/\Delta T_{\text{eff}} = 0.07 \text{ dex}/100 \text{ K}$, apparent trends real?

Fuhrmann-like precision for metal-poor population for model calibration?

(González Hernández et al. 2010)
Instead of one take two – detached eclipsing binaries

Photometric and spectroscopic analysis of eclipsing system provides radii

Known distances and extinction provide luminosities $\rightarrow T_{\text{eff}}$

Popper 1998: 14 analysed systems with HIPPARCOS distances to better than 10 %
Instead of one take two – detached eclipsing binaries

- Gaia expected to discover eclipsing binaries
  - photometry $0.5 \ldots 7 \times 10^6$ (Laurent Eyer),
  - RVS 25 000 SB2s (David Katz)
  - good chances for metal-poor systems
  - substantial ground-based follow-up work necessary

- Certainly also helpful for the less well-charted regions of the HRD
  - temperature scale of very late M-type and substellar objects uncertain
  - atmospheric and atomic physics complicated due to molecular and dust formation
Clean populations – example from HIPPARCOS & Hyades

Inclusion of proper motion information improved parallaxes 1.5 mas (top panels) to 0.3...0.5 mas (bottom panels)

Cleaned for binaries (right panels) with available kinematics and distances

Reveals fine features in the cluster main-sequence – interpretation?

(from Madsen, Lindegren, & Dravins 2000)
Hyades: chemical homogeneity versus model problems

Oxygen from forbidden 6300 Å line (no NLTE effects!) in Hyades

Chemical inhomogeneous or modelling deficit? Chemical tagging?
Astrometric versus spectroscopic radial velocities

(from Dravins 2003 base on HIPPARCOS data)
Testing dynamics predicted by 3D model atmospheres

- CIFIST 3D grid plus ASSET spectral synthesis (Koesterke, Allende Prieto, Ludwig)
- **RANGER** 65,000 core machine at Texas Advances Computing Center (USA)
FIN
Testing dynamics predicted by 3D model atmospheres

- micro-turbulence and line shifts both of convective origin