Metallicity trends in evolved stars
Unraveling the planet metallicity correlation

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Outline

1. Introduction
2. Observations and analysis
3. Planet metallicity correlation in evolved stars
4. Summary
1 Introduction

2 Observations and analysis

3 Planet metallicity correlation in evolved stars

4 Summary
Astrophysical context

After 20 years of the first exoplanet discoveries ...

- Properties of planet hosts still not well known
- Current knowledge mainly based on observations of MS stars

Planets around evolved stars: new questions

- Disentangling the gas-giant planet-[Fe/H] correlation
  - Previous results based on small or inhomogeneous samples
  - Primordial origin vs late-stage accretion of material
- Different planetary properties?

To achieve a full picture of planetary evolution from MS stars to the latest stages of the stellar evolution
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142 evolved stars (70 planet hosts)

Metallicity trends in evolved stars

Spectroscopic observations

<table>
<thead>
<tr>
<th>Instrument</th>
<th>R</th>
<th>λλ (nm)</th>
<th>S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIES</td>
<td>67000</td>
<td>364-736</td>
<td>200</td>
</tr>
<tr>
<td>NOT (2.6 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HERMES</td>
<td>87000</td>
<td>380-900</td>
<td>150</td>
</tr>
<tr>
<td>MERCATOR (1.2 m)</td>
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</tbody>
</table>
Basic stellar properties and abundances

Stellar parameters

- Code *TGVIT* (Takeda et al. 2005)
- Iron ionization and excitation conditions, match of the curve of growth
- 302 Fe I and 28 Fe II lines
- EWs measurements using *ARES* (Sousa et al. 2007)
- ATLAS9, plane-parallel, LTE model atmospheres (Kurucz 1993)
- Statistical uncertainties from the converged solution

Elemental abundances

- Na, Mg, Si, Ca, Ti, Cr, Co, Ni, Zn
- *WIDTH9* program + ATLAS9 model atomospheres
- Line list mainly from Neves et al. (2009)
- Propagation of the errors in the stellar parameters + line-to-line scatter errors
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The metal-rich nature of planet hosts tends to disappear as the star evolves.

Results

- Giant stars with planets similar to giants without planets
- Subgiants with planets shifted towards \([\text{Fe/H}]\) with respect to subgiants without planets
- Subgiants without planets behave as giants (in general)
- Subgiants with planets similar to main sequence with planets

Implications

- Subgiants: Core-accretion models
- Giants: hard to explain
**Stellar mass**: the parameter that changes the most between giants and MS samples

- **Giant stars with**: \( M_\star \leq 1.5 M_\odot \)
  - Giants with/without planets mixed, covering the whole range of \([\text{Fe/H}]\)
  - Similar abundance patterns in all the elements
Giant stars with: $M_\star > 1.5 \, M_\odot$

- Lower scatter in the [Fe/H] axis, giants with planets on the metal-rich part of the plot
- Differences in some elements, Na, Co, Ni

Can massive proto-planetary discs explain the observed trends?

- Massive stars likely to harbour more massive proto-planetary discs
- Giant planet formation can occur in low-[Fe/H] but high-mass proto-planetary discs (Alibert et al. 2001; Mordasini et al., 2012)

× Giant stars with planets in the mass domain $M_\star < 1.5 \, M_\odot$ do not have more massive proto-planetary discs
Can the metallicity signature be erased as the star evolves?

- Metal-rich signature seen in planet hosts due to accretion of gas depleted material (Lind et al. 1996; Gonzalez 1997)

Difficulties

- Subgiants with planets should show lower metallicities than main-sequence with planets but we do not find this
- Why convection should play a role erasing the metal signature for giants only in the mass domain $M_\star \leq 1.5 M_\odot$?

$[\text{Fe/H}]$-Radius plane

- No obvious trend found

Giants $M_\star \leq 1.5 M_\odot$; Giants $M_\star > 1.5 M_\odot$; Subgiants; Late-MS
Is our sample biased?

No bias identified in distance or kinematics

[Fe/H] as a function of the age

- Giants $M_\star > 1.5 \, M_\odot$ are systematically located in the left part of the plot (younger ages)
- All the other samples tend to be in the right part of the plot (older ages)

× No galactic radial mixing

Colour cut-off in exoplanet searches

Are high-metal giant stars left out the the samples? (Mortier et al. 2013)

Giants $M_\star \leq 1.5 \, M_\odot$; Giants $M_\star > 1.5 \, M_\odot$; Subgiants; Late-MS
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Conclusions
High-resolution spectra of 142 evolved stars

1 Spectroscopic analysis: stellar parameters, abundances, kinematics, and stellar age

2 [Fe/H] vs presence/absence of planets
   - Subgiants and high-mass giants show planet-metallicity correlation
   - Giants with $M_* \leq 1.5 M_\odot$ planet hosts do not show metal enrichment

3 Implications
   - Core-accretion? Low-mass giants do not have more massive proto-planetary discs
   - Pollution? Why only in low-mass giants?
   - Possible biases?
     - No in age, distance, or kinematics
     - Colour cut-off in the samples

Ref: Maldonado et al. 2013, A&A 554, A84
Other chemical signatures I

**Late-stage accretion of material:** Overabundance of refractory elements in MS which disappears as the star evolves

Giants with: $M_\star < 1.5 \, M_\odot$

Similar abundance patterns in all the elements

<table>
<thead>
<tr>
<th>Element</th>
<th>$p$-value</th>
<th>$[X/Fe]$</th>
<th>$p$-value</th>
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</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.96</td>
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<td>0.71</td>
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<tr>
<td>Mg</td>
<td>0.39</td>
<td>Cr I</td>
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<tr>
<td>Al</td>
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<td>Cr II</td>
<td>0.18</td>
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<tr>
<td>Si</td>
<td>0.04</td>
<td>Mn</td>
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<tr>
<td>Ca</td>
<td>0.90</td>
<td>Co</td>
<td>0.87</td>
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<tr>
<td>Sc</td>
<td>0.75</td>
<td>Ni</td>
<td>0.96</td>
</tr>
<tr>
<td>Ti I</td>
<td>0.17</td>
<td>Zn</td>
<td>0.71</td>
</tr>
<tr>
<td>Ti II</td>
<td>0.30</td>
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</table>
Late-stage accretion of material: Overabundance of refractory elements in MS which disappears as the star evolves

<table>
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<th>[X/Fe]</th>
<th>p-value</th>
<th>[X/Fe]</th>
<th>p-value</th>
</tr>
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<tbody>
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<td>V</td>
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<tr>
<td>Mg</td>
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<td>Cr I</td>
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<tr>
<td>Al</td>
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<td>Cr II</td>
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<tr>
<td>Si</td>
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<td>Mn</td>
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<tr>
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<tr>
<td>Sc</td>
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<td>Ni</td>
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<td>Zn</td>
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</tr>
<tr>
<td>Ti II</td>
<td>0.70</td>
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</tr>
</tbody>
</table>
Trends with the planetary properties

[Graphs showing metallicity trends with semimajor axis (AU) and $M_p sini (M_\odot)$]