Metallicity trends in evolved stars

Unraveling the planet metallicity correlation

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Outline

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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

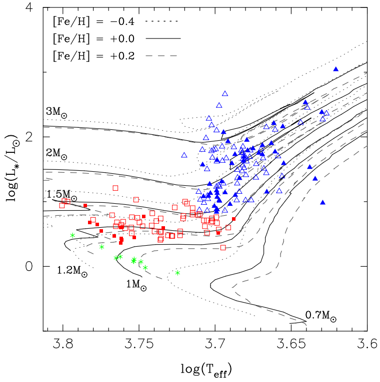
- Disentangling the gas-giant planet-[Fe/H] correlation
  - Previous results based on small or inhomogeneous samples
  - Primordial origin vs late-stage accretion of material
- Different planetary properties?

To achieve a full picture of planetary evolution from MS stars to the latest stages of the stellar evolution

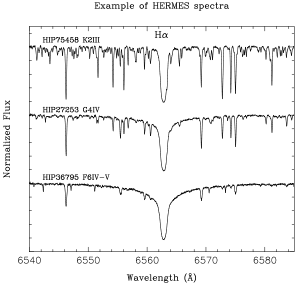
Outline

Observations

142 evolved stars (70 planet hosts)



Giants; Subgiants; Late-MS



Spectroscopic observations

Instrument	R	$\lambda\lambda$ (nm)	S/N
FIES NOT (2.6 m)	67000	364-736	200
HERMES MERCATOR (1.2 m)	87000	380-900	150

Stellar parameters

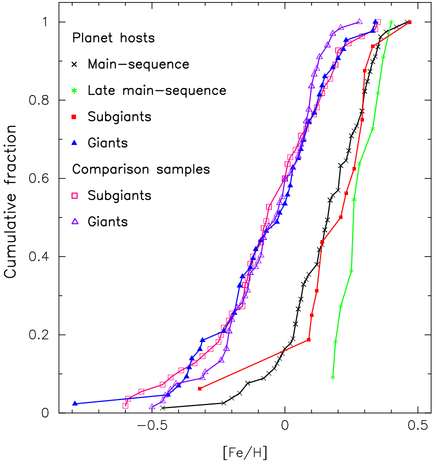
- Code *TGVIT* (Takeda et al. 2005)
- Iron ionization and excitation conditions, match of the curve of growth
- 302 Fe I and 28 Fe II lines
- EWs measurements using *ARES* (Sousa et al. 2007)
- ATLAS9, plane-parallel, LTE model atmospheres (Kurucz 1993)
- Statistical uncertainties from the converged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

Outline

The metal-rich nature of planet hosts tends to disappear as the star evolves



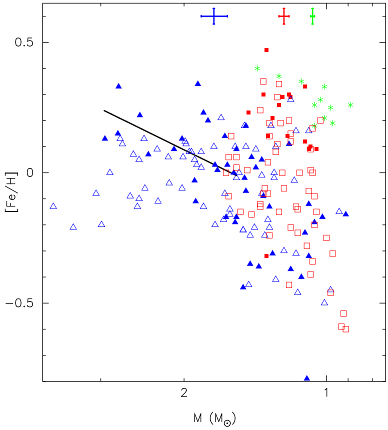
Results

- Giant stars with planets similar to giants without planets
- Subgiants with planets shifted towards ⇑ [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

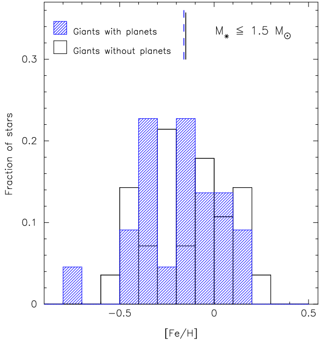
Stellar mass: the parameter that changes the most between giants and MS samples



Giants; Subgiants; Late-MS

Giant stars with: $M_\star \leq 1.5\ M_\odot$

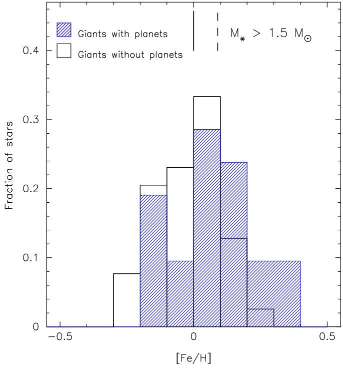
- Giants with/without planets mixed, covering the whole range of [Fe/H]
- Similar abundance patterns in all the elements



Metallicity as a function of the stellar mass II

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

Metallicity as a function of the stellar radius

Can the metallicity signature be erased as the star evolves?

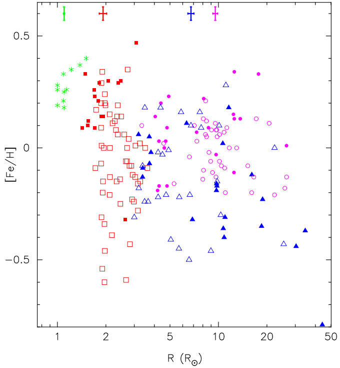
- Metal-rich signature seen in planet hosts due to accretion of gas depleted material (Lind et al. 1996; Gonzalez 1997)

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 $M_\star \lesssim 1.5\ M_\odot$?

[Fe/H]-Radius plane

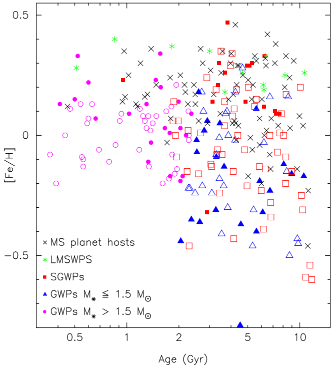
- No obvious trend found



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



Giants $M_\star \leq 1.5\ M_\odot$; Giants $M_\star > 1.5\ M_\odot$; Subgiants; Late-MS

[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)

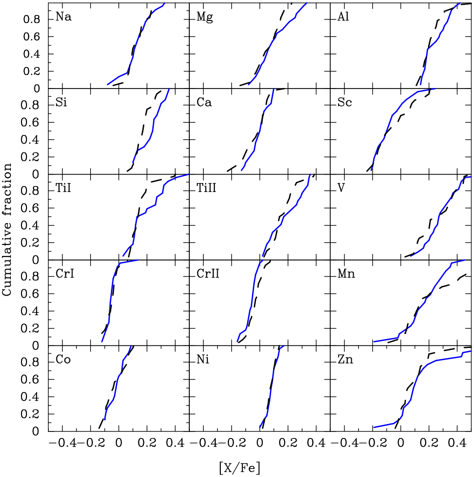
Outline

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 $M_\star \leq 1.5\ M_\odot$ 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

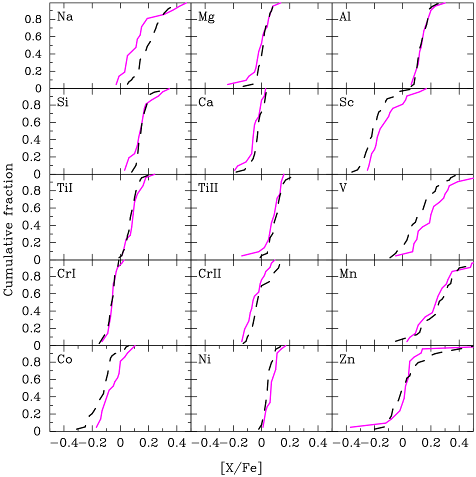


Giants with: $M_\star < 1.5\ M_\odot$

Similar abundance patterns in all the elements

[X/Fe]	*p*-value	[X/Fe]	*p*-value
Na	0.96	V	0.71
Mg	0.39	Cr I	0.86
Al	0.42	Cr II	0.18
Si	0.04	Mn	0.26
Ca	0.90	Co	0.87
Sc	0.75	Ni	0.96
Ti I	0.17	Zn	0.71
Ti II	0.30		

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



Giants with: $M_\star > 1.5\ M_\odot$

Differences in some elements

[X/Fe]	*p*-value	[X/Fe]	*p*-value
Na	0.01	V	0.04
Mg	0.73	Cr I	0.98
Al	0.95	Cr II	0.24
Si	0.66	Mn	0.84
Ca	0.06	Co	0.02
Sc	0.11	Ni	0.01
Ti I	0.59	Zn	0.49
Ti II	0.70		

Trends with the planetary properties