Searching for signatures of planet formation in stars with circumstellar debris discs

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Connecting Stellar Abundances and Planet Habitability @ Pathways II

Collaborators:

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- **B. Montesinos** (Department of Astrophysics, Centro de Astrobiología (CAB, CSIC-INTA))
- **A. Mora** (ESA-ESAC Gaia SOC)

Outline

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Correlated phenomena?

Planetesimals are the "building blocks" of planets $\Rightarrow$ Do their host stars have similar properties?

Discs

- Incidence no higher around planet-host stars
- No correlation with stellar properties
  (e.g. Bryden et al. 2009, Kóspál et al. 2009)

Planets

- Trend of $\Uparrow$ [Fe/H] of stars hosting gas-giant planets
- Low-mass planets $M_p < 30\ M_\oplus$ do not follow this trend
- Puzzling results in evolved stars hosting planets **(e.g. Maldonado et al. 2013)**

Low-mass planets: a major challenge

- $\sim$ 55% more SWDPs w.r.t. previous works
- Debris discs and low-mass planets: "Good neighbours?"
  (e.g. Maldonado et al. 2012, Wyatt et al. 2012, Marshall et al. 2014)
- "Fingerprints" of terrestrial planet formation in the stellar photospheric abundances? **(e.g. Meléndez et al. 2009; Ramírez et al. 2009, 2010, 2014)**

Outline

In this study:

Chemical abundances of four samples of solar-like stars

1. **Stars with known debris discs (SWDs)**
   IRAS, ISO, Spitzer, Herschel data (68 stars)
2. **Stars with known debris discs and planets (SWDPs)**
   $\sim$ 55% more SWDPs w.r.t. previous works (31 stars)
3. **Stars with known planets (SWPs)**
   Stars hosting gas-giant/low-mass planets (32 stars)
4. **Comparison sample (SWODs)**

   No IR-excess found at Spitzer/Herschel's λs (119)

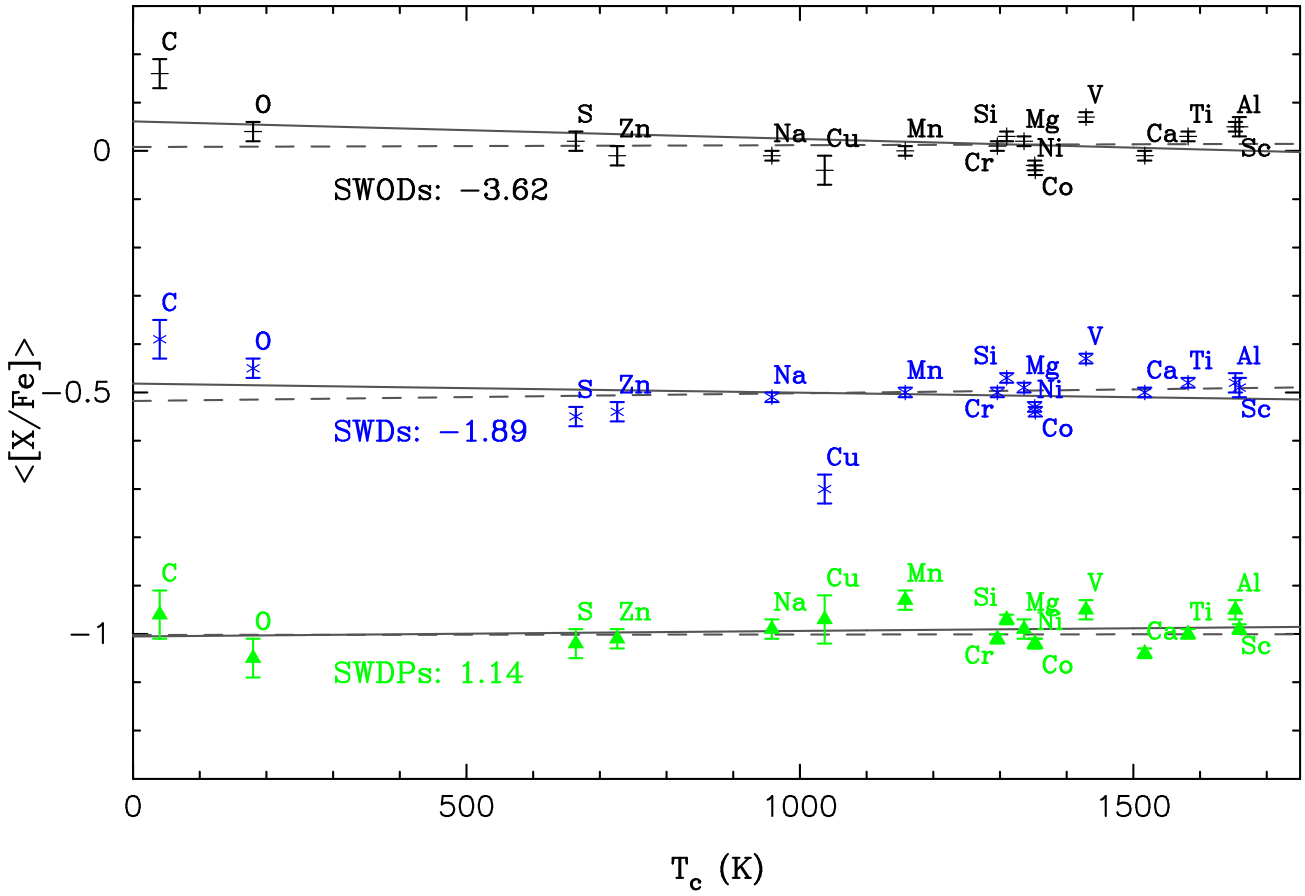
Spectroscopic Analysis

- **Stellar parameters, code TGVIT (Takeda et al. 2005)**
  Iron ionisation and excitation conditions, match of the curve of growth
- **MOOG code (Sneden 1973) + ATLAS9 models**
  C, O, Na, Mg, Al, Si, S, Ca, Sc, Ti I, Ti II, V, Cr I, Cr II, Mn, Co, Ni, Cu, Zn

Outline

Different behaviour <[X/Fe]>-T_C slope in SWDPs

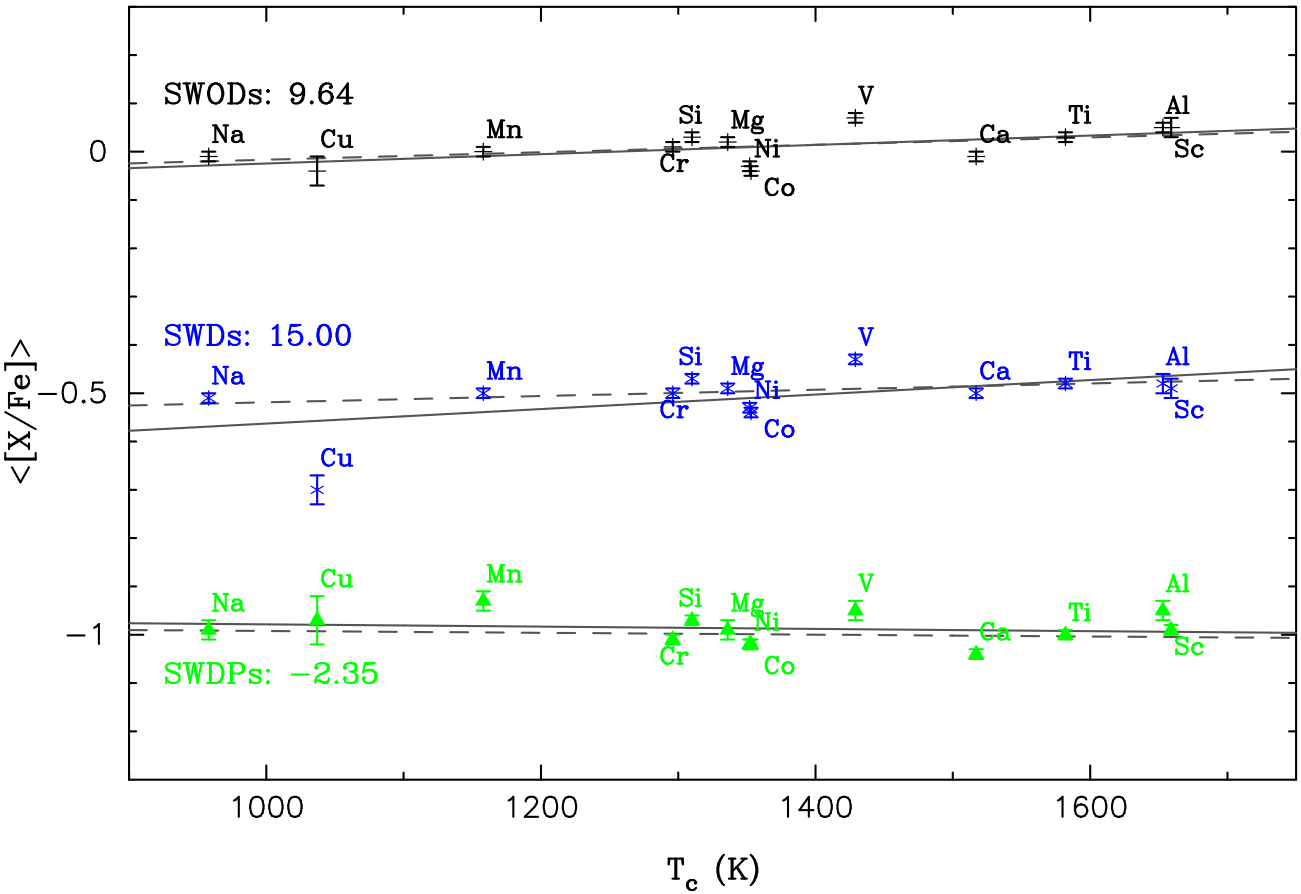
All elements



- **SWDs/SWODs < slopes; SWDPs > slopes**

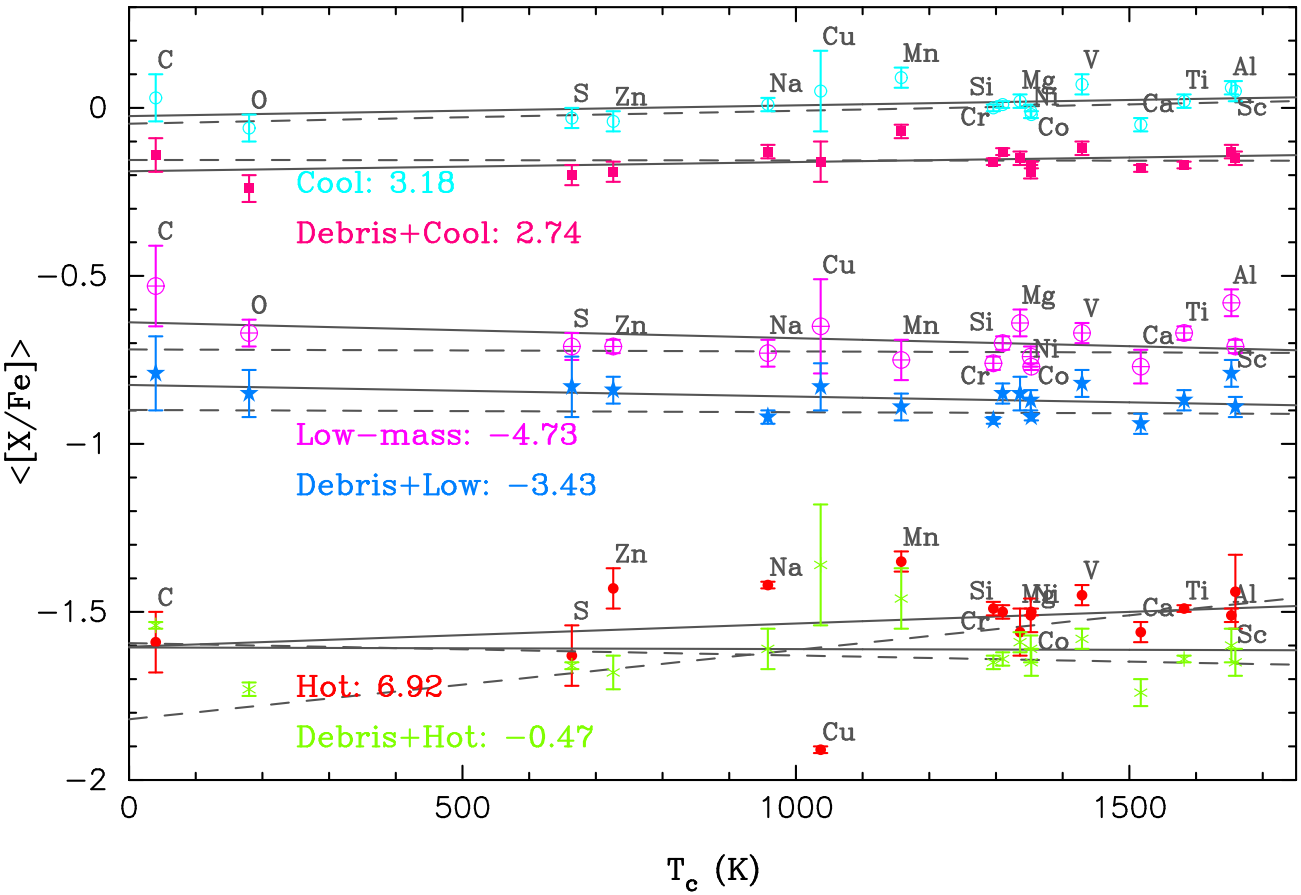
Abundances of volatiles not as reliable as refractories' ones

Only $T_C > 900$ K



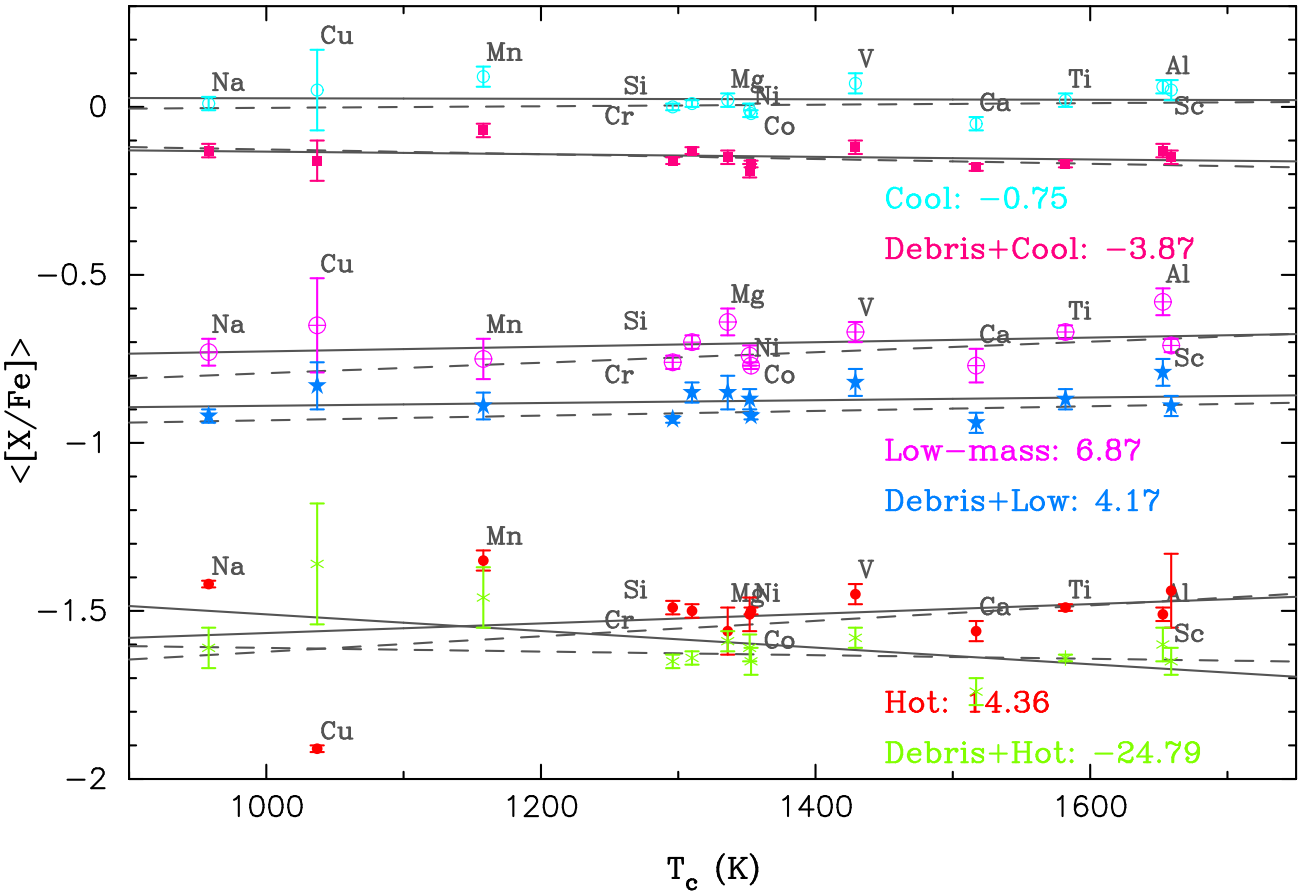
- **Slope change their signs, but still there is a difference in SWDPs wrt SWDs/SWODs**

Comparison with planet hots (all elements)



- **SWDPs behave as stars with planets**
- **Differences between stars with cool and low-mass planets**

Comparison with planet hots (only refractories)



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Previous analysis:

- **Meléndez et al. 2009:** Deficit of refractory in the Sun wrt other solar twins.
  Related to the formation of low-mass planets
- **González Hernández et al. 2012, 2013; Adibekyan et al. 2014:**
  Galactic chemical evolution effects age/Galactic birth place explanation

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In this work:

1. **Similar behaviour SWDs/SWODs**
2. **Similar behaviour SWDPs/SWPs**
3. **No differences in stars with low-mass planets (wrt SWODs/SWDs)**
4. **Different behaviour in stars with cool-Jupiters**
5. **Positive slopes in stars with hot-Jupiters**

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Key questions:

1. Might the <[X/Fe]>-T_C trends be influenced by GCE effects?
2. Do the <[X/Fe]>-T_C trends fit in the ME09 hypothesis?

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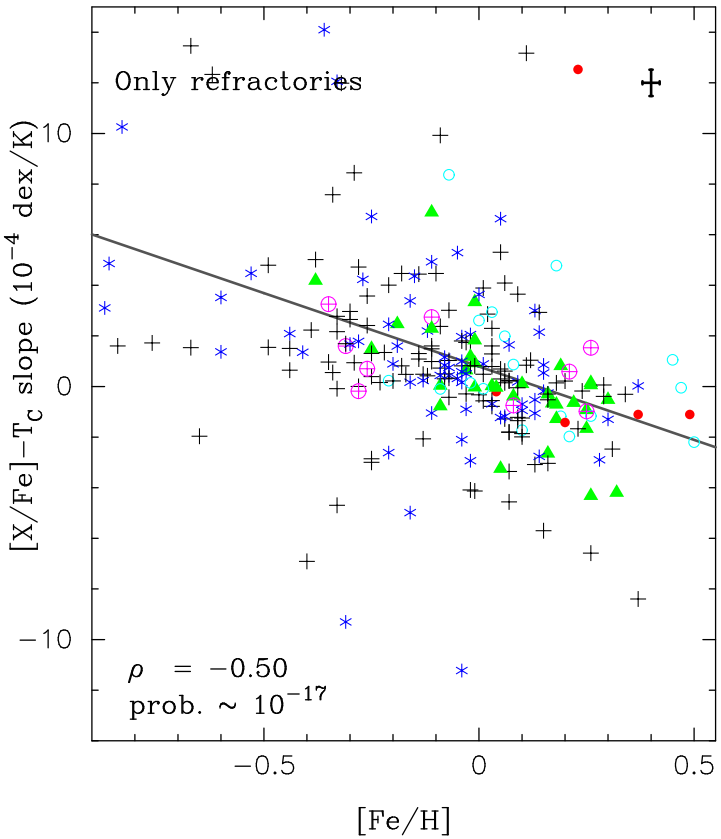
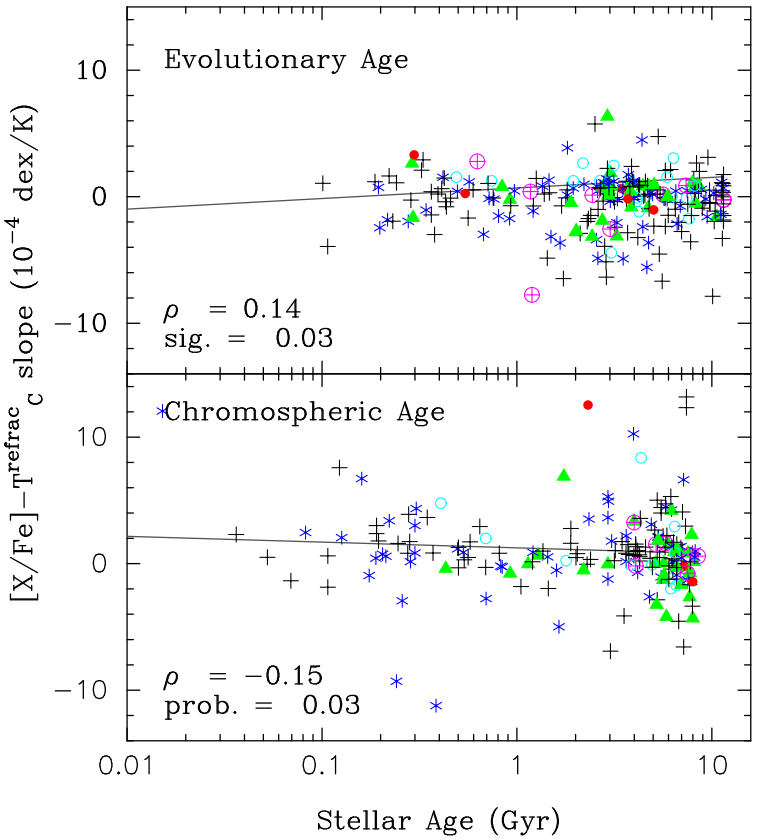
Abundance patterns may be affected by GCE effects

T_C slope vs. [Fe/H], age, and R_{mean}





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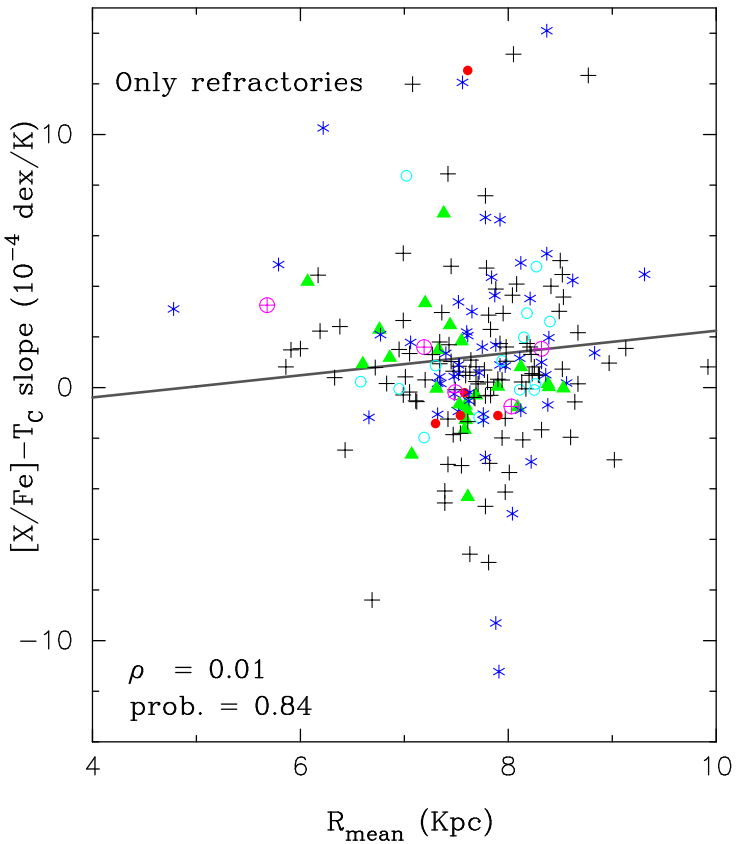

[Fe/H]	Moderate, significant
Age	Weak, but significant
R_{mean}	Not clear correlation

GCE corrections

[X/H] vs. [Fe/H] linear fits

- Still correlations with the chromospheric age and the stellar radius remain
- Might this correction “delete” possible chemical depletions?

Do the <[X/Fe]>-T_C trends fit in the ME09 hypothesis?

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- **Planet: key factor in revealing the chemical behaviour of the star**
  Consistent with core-accretion model of planet formation.
- **Correlation between dust and low-mass planets?**
  Significant fraction of low-mass hosts among the SWDPs.
  In agreement with recent results **(e.g. Wyatt et al. 2012, Marshall et al. 2014)**

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- **Not in agreement with ME09**
  Low-mass planet hosts: only $<$ slopes for all elements, but similar to SWDs/SWODs
  Cool-Jupiter hosts: differences in T_C^{all} and T_C^{ref}; $<$ slopes in T_C^{ref} analysis

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- **Caution, small sample size!**
  Also SWDs/SWODs show $>$ slopes in T_C^{ref}
  Indication of non low-mass planets?

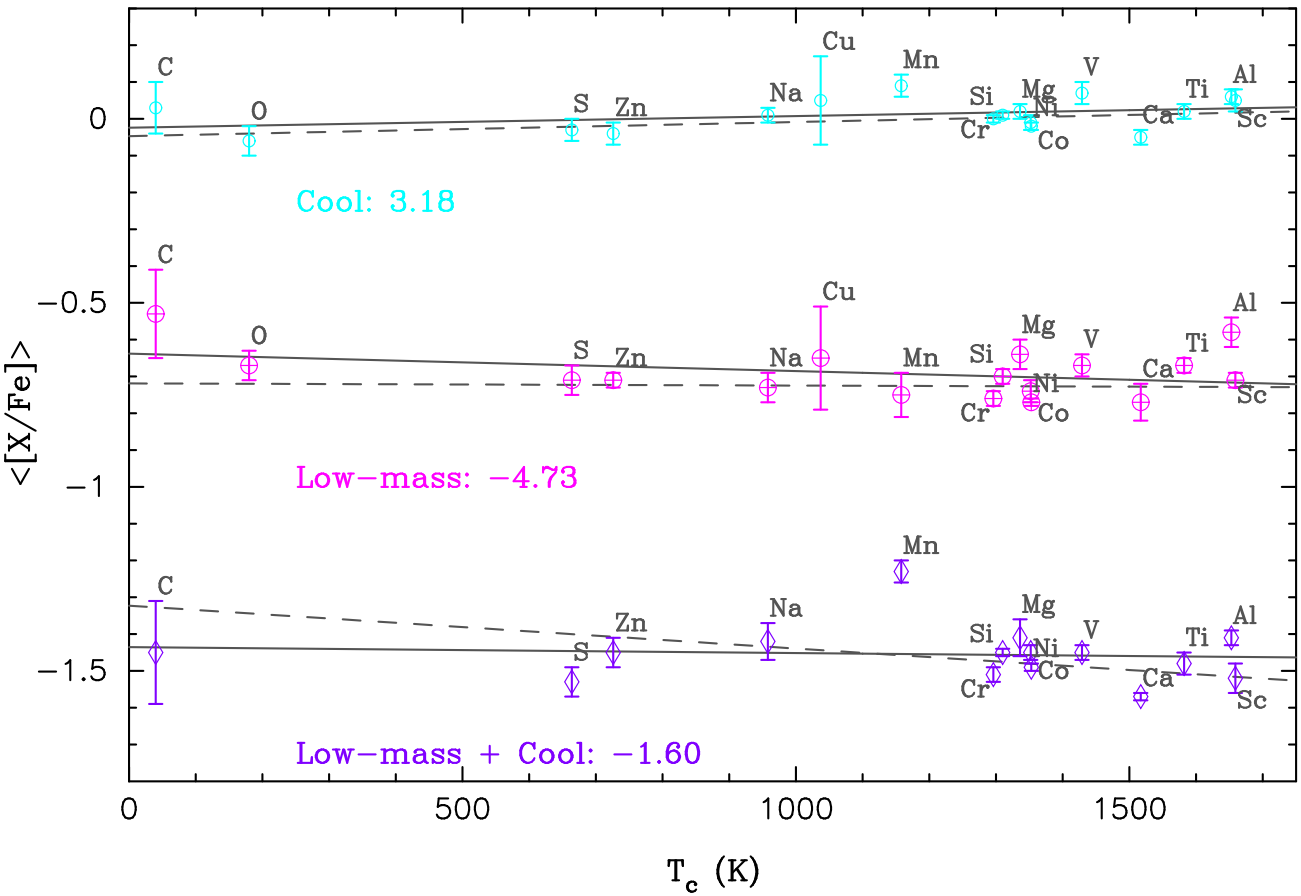
Outline

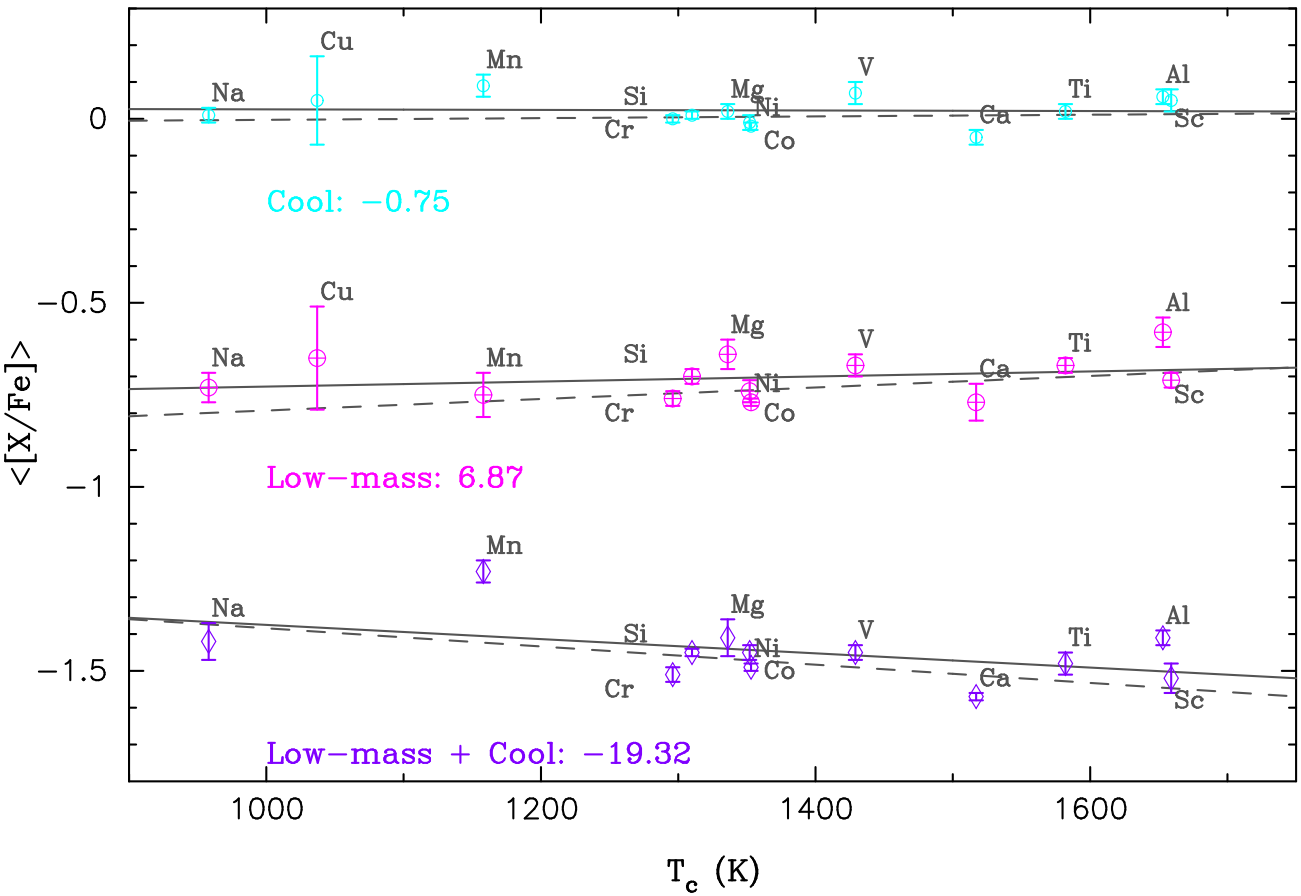
Ref: Maldonado et al. 2015, A&A, 579, A20

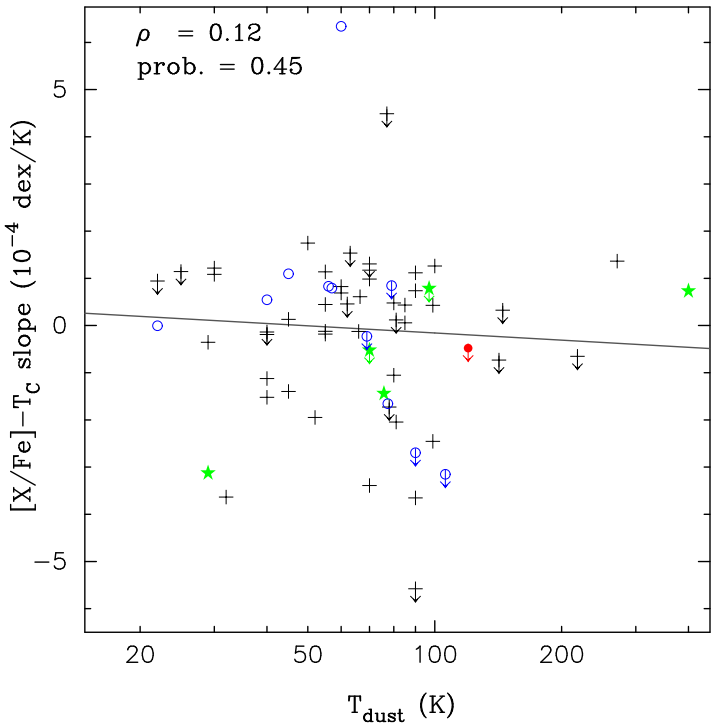
Summary

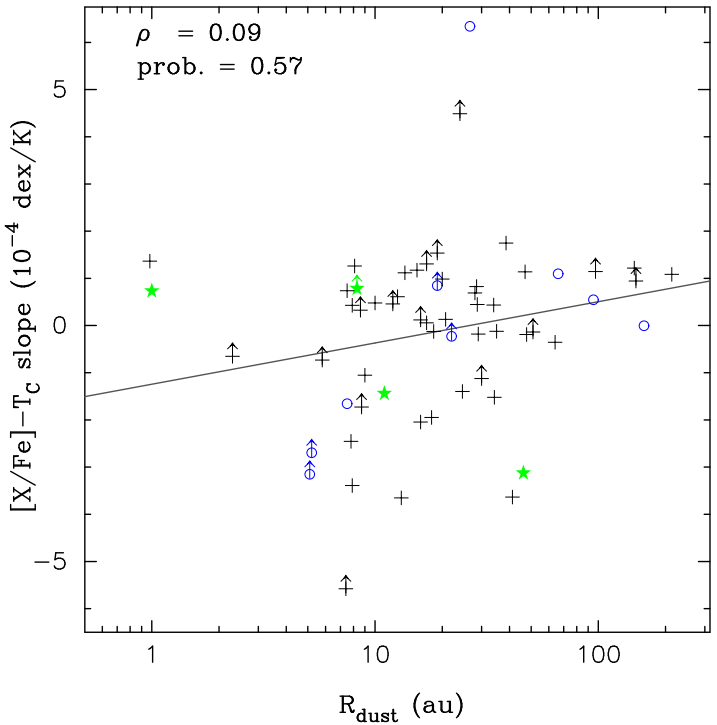
Detailed chemical analysis of SWDs and SWDPs

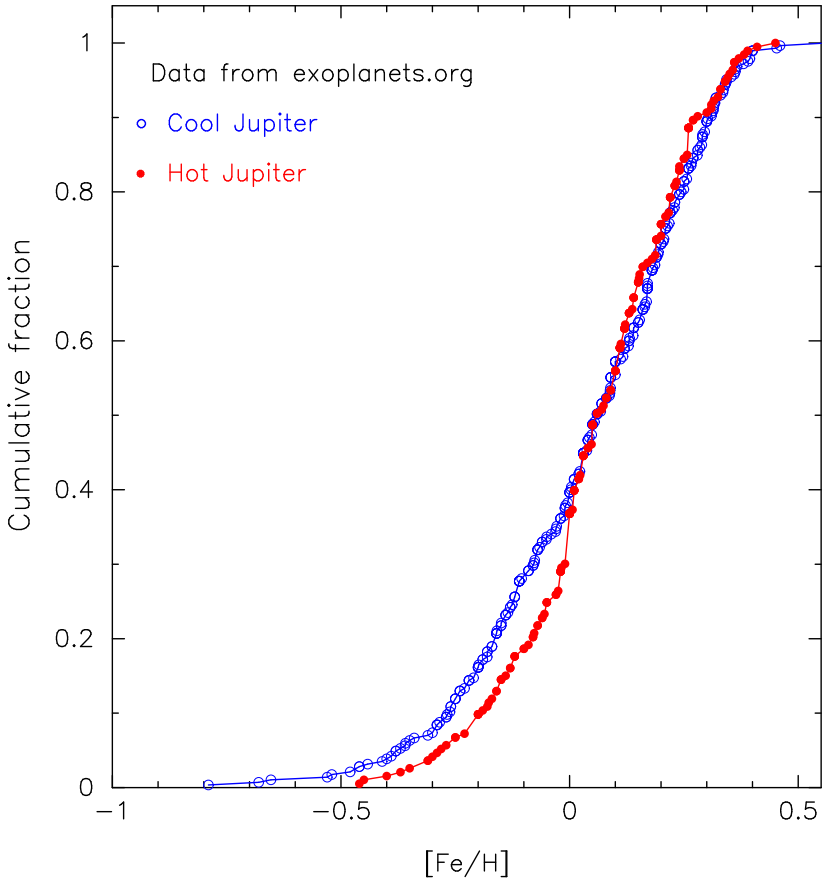
- **No differences SWDs/SWODs**
- **SWDPs driven by the type of planet**
  - In agreement with core-accretion models
  - Correlation debris disc/low-mass planets?
  - Lack correlation debris discs/giant planets?
- **Tentative [X/Fe]-T_C trends in SWPs**
  - Different behaviour in stars with cool-planets
  - Similar behaviour low-mass planets hosts / non-planets samples
  - Stars with hot Jupiters: higher [Fe/H], positive slopes?
- **Chemical depletions/Planet formation?**
  - Low statistical significances
  - Correlation T_C-[Fe/H]
  - After GCE corrections: still correlations with age, radius

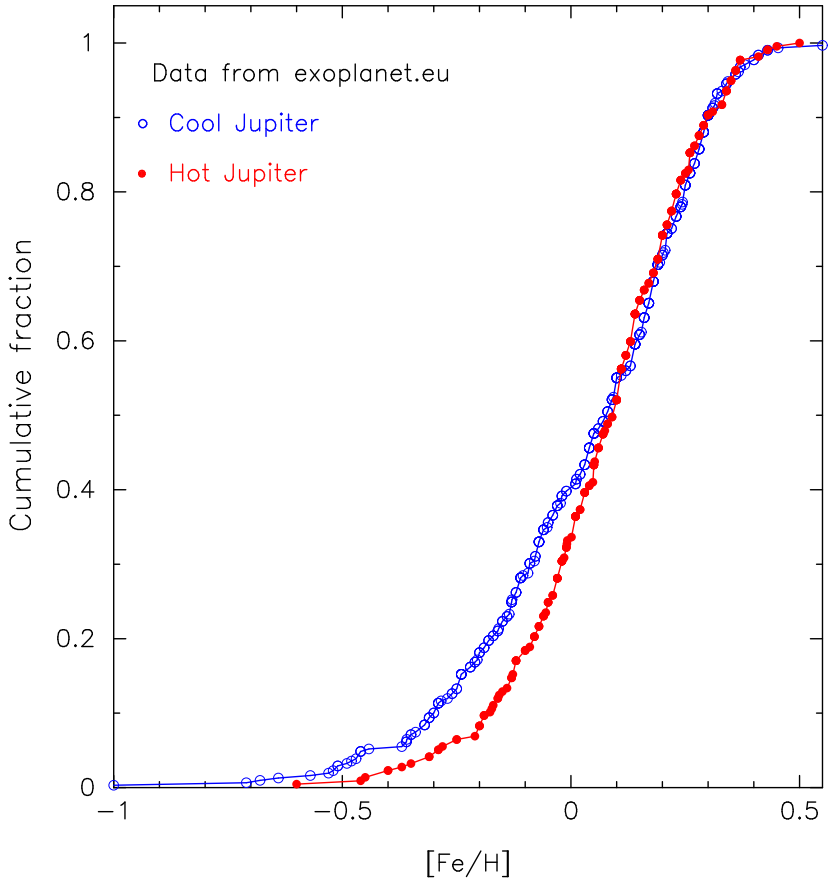

C
O
S
Zn
Na
Cu
Mn
Si
Mg
Ni
Cr
Co
V
Ca
Ti
Al
Sc
Cool: 3.18
Low−mass: −4.73
Low−mass + Cool: −1.60
<[X/Fe]>
0
−0.5
−1
−1.5
0
500
1000
1500
T_c (K)


Cu
Mn
Na
Si
Mg
V
Ni
Ti
Al
Ca
Cr
Co
Sc
0
Cool: −0.75
−0.5
Low−mass: 6.87
−1
−1.5
Low−mass + Cool: −19.32
<[X/Fe]>
1000
1200
1400
1600
T_c (K)


ρ = 0.12
prob. = 0.45
[X/Fe]−T_C slope (10^−4 dex/K)
T_dust (K)
5
0
−5
20
50
100
200


ρ = 0.09
prob. = 0.57
[X/Fe]−T_C slope (10^−4 dex/K)
R_dust (au)
5
0
−5
1
10
100


Data from exoplanets.org
Cool Jupiter
Hot Jupiter
Cumulative fraction
[Fe/H]
0
0.2
0.4
0.6
0.8
1
−1
−0.5
0
0.5


Data from exoplanet.eu
Cool Jupiter
Hot Jupiter
Cumulative fraction
[Fe/H]
0
0.2
0.4
0.6
0.8
1
−1
−0.5
0
0.5