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

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Outline

1. Introduction
2. Observations and analysis
3. Abundance trends
4. Discussion
5. Summary

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Correlated phenomena?

Debris discs: Signatures of planetesimals systems

Continuously produced by collisions of such solid bodies

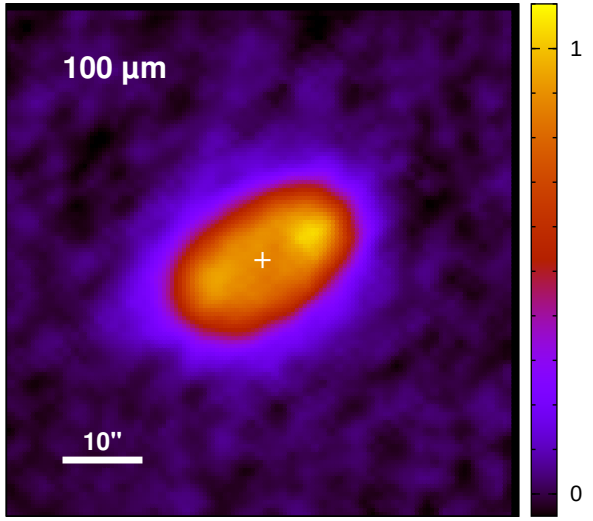
Frequency around solar-type stars

- *Spitzer:* $\sim$ 16% **(e.g. Trilling et al. 2008)**
- *Herschel:* $\sim$ 20% **(DUNES sample)**

Planets frequency

- $>$ 50% planets of any mass, period up to 100 days
- 14% planets with $M_p > 50\ M_\oplus$, period shorter than 10 years

(Mayor et al. 2011)



Herschel view of the HD 207129 debris disc

(Marshall et al. 2011)

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)**

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In this study:

Chemical abundances of four samples of solar-like stars

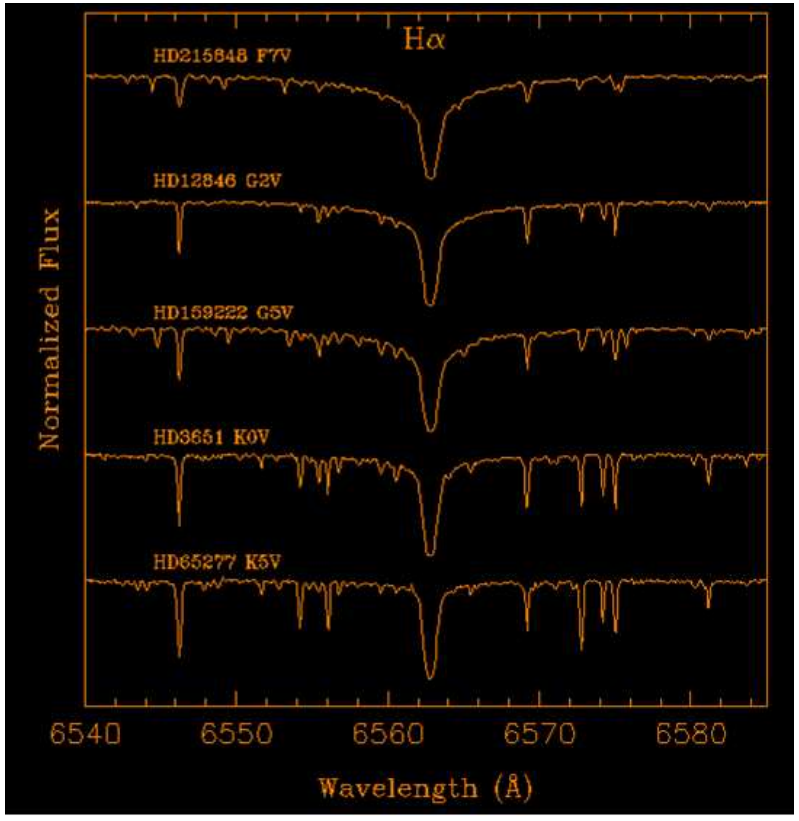
1. **Stars with known debris discs (SWDs)**
   IRAS, ISO, Spitzer, Herschel data (68 stars)
2. **Stars with known debris discs and planets (SWDPs)**
   $\sim$ 55% more SWDPs w.r.t. previous works (31 stars)
3. **Stars with known planets (SWPs)**
   Stars hosting gas-giant/low-mass planets (32 stars)
4. **Comparison sample (SWODs)**
   No IR-excess found at Spitzer/Herschel's λs (119)

Telescopes and instruments

- FOCES 2.20 m
  Calar Alto
- SARG-TNG 3.56 m
  La Palma
- FIES-NOT 2.56 m
  La Palma
- HERMES-MERCATOR 1.2 m
  (La Palma)
- + Public Archives
  S^4N
  ESO-Archive

IRAF-echelle package

overscan, flat-fielding, scattered light, blazeshape removing, order extraction, wavelength calibration



Example of FOCES spectra in the H_α region

(Maldonado et al. 2010)

Stellar parameters

- Code *TGVIT* (Takeda et al. 2005)
- Iron ionisation 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 (Kurucz 1993)
- Statistical uncertainties from the converged solution

Elemental abundances

- C, O, Na, Mg, Al, Si, S, Ca, Sc, Ti I, Ti II, V, Cr I, Cr II, Mn, Co, Ni, Cu, Zn
- *MOOG* program + ATLAS9 model atmospheres
- HFS: V, C, Cu
- Oxygen: nLTE
- Line list mainly from Neves et al. 2009, Ramírez et al. 2014

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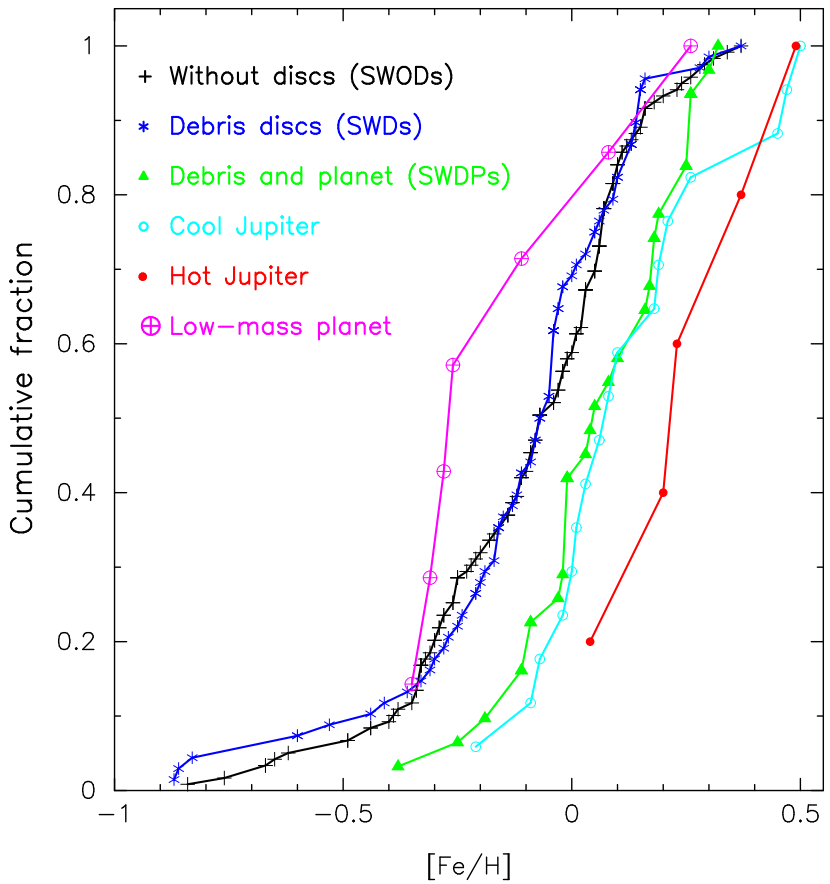
Transition towards higher [Fe/H]

SWODs ⇒ SWPs



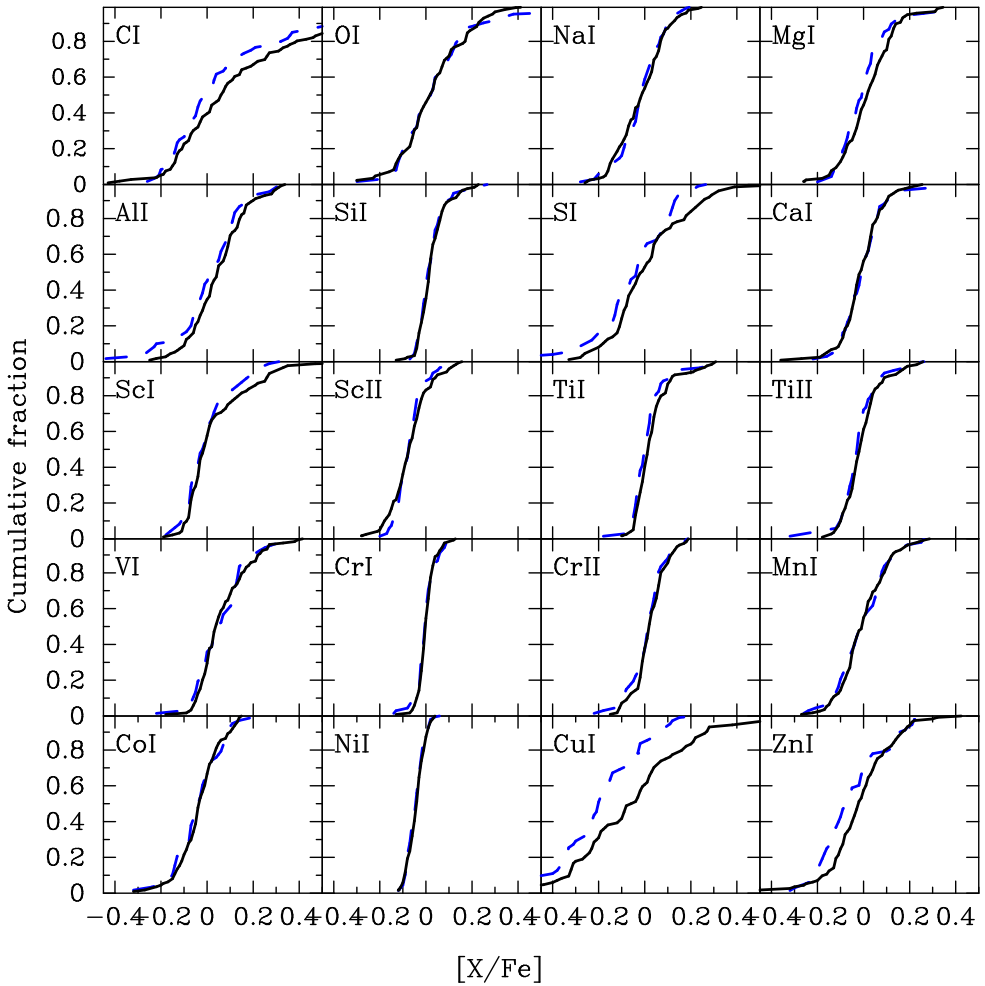
Results

- SWDs similar to SWODs
- SWDPs behave as SWPs (no matter the planet's mass)
- Hot-giant hosts tend to be more metal-rich than cool-giant hosts

31 solar-like SWDPs:

- 47% multiplanet systems, 6 stars with low-mass planets
- 8 stars host at least one low mass planet
- 2/24 SWDPs hosting only gas giant planets, host "hot"-Jupiters ($a < 0.1$ AU)

No obvious differences SWDs/SWODs

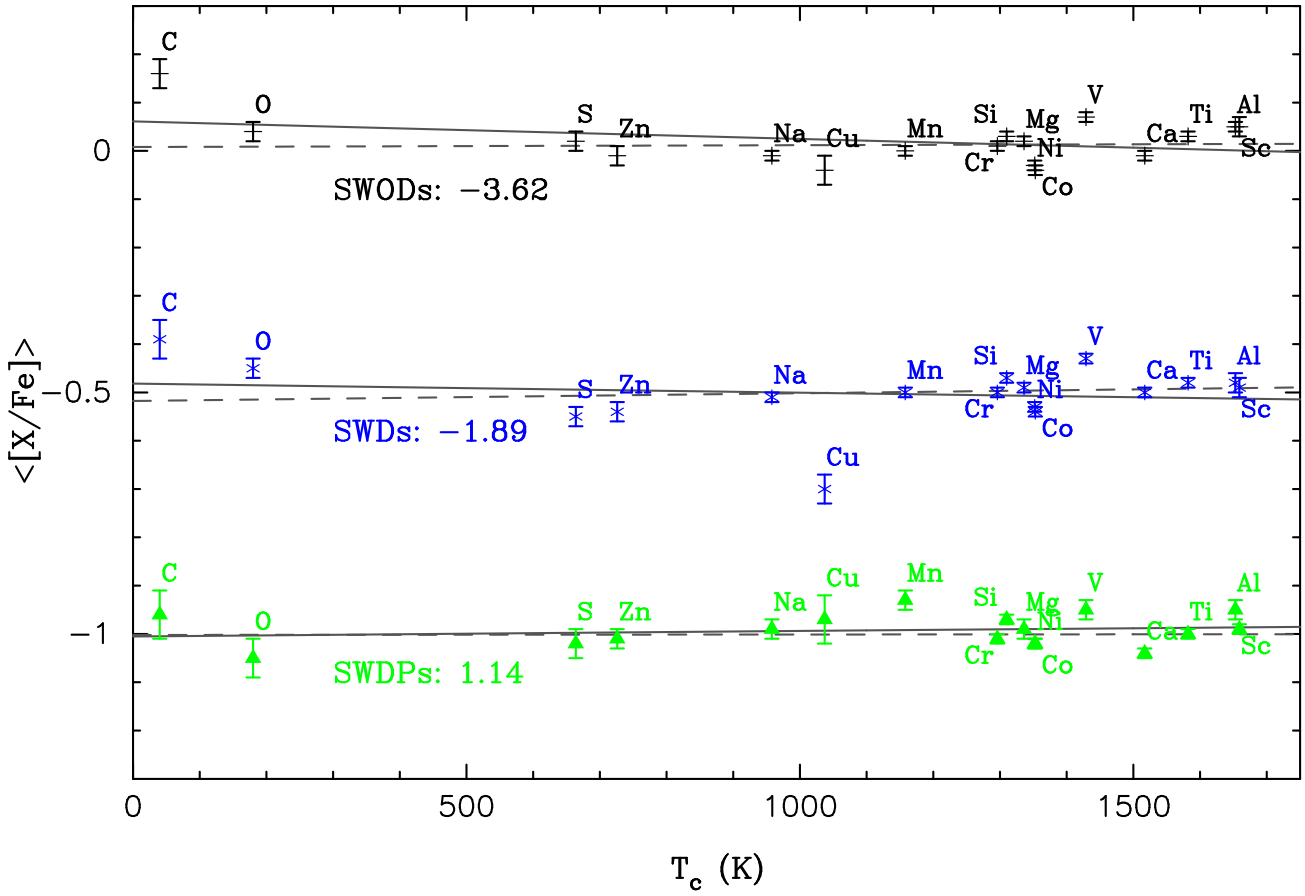


Kolmogorov-Smirnov probabilities

[X/Fe]	*p*-value	[X/Fe]	*p*-value
C	0.30	Ti	0.08
O	0.96	V	0.88
Na	0.82	Cr	0.56
Mg	0.10	Mn	0.91
Al	0.55	Co	0.83
Si	0.63	Ni	0.86
S	0.25	Cu	<0.01
Ca	>0.99	Zn	0.04
Sc	0.80		

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

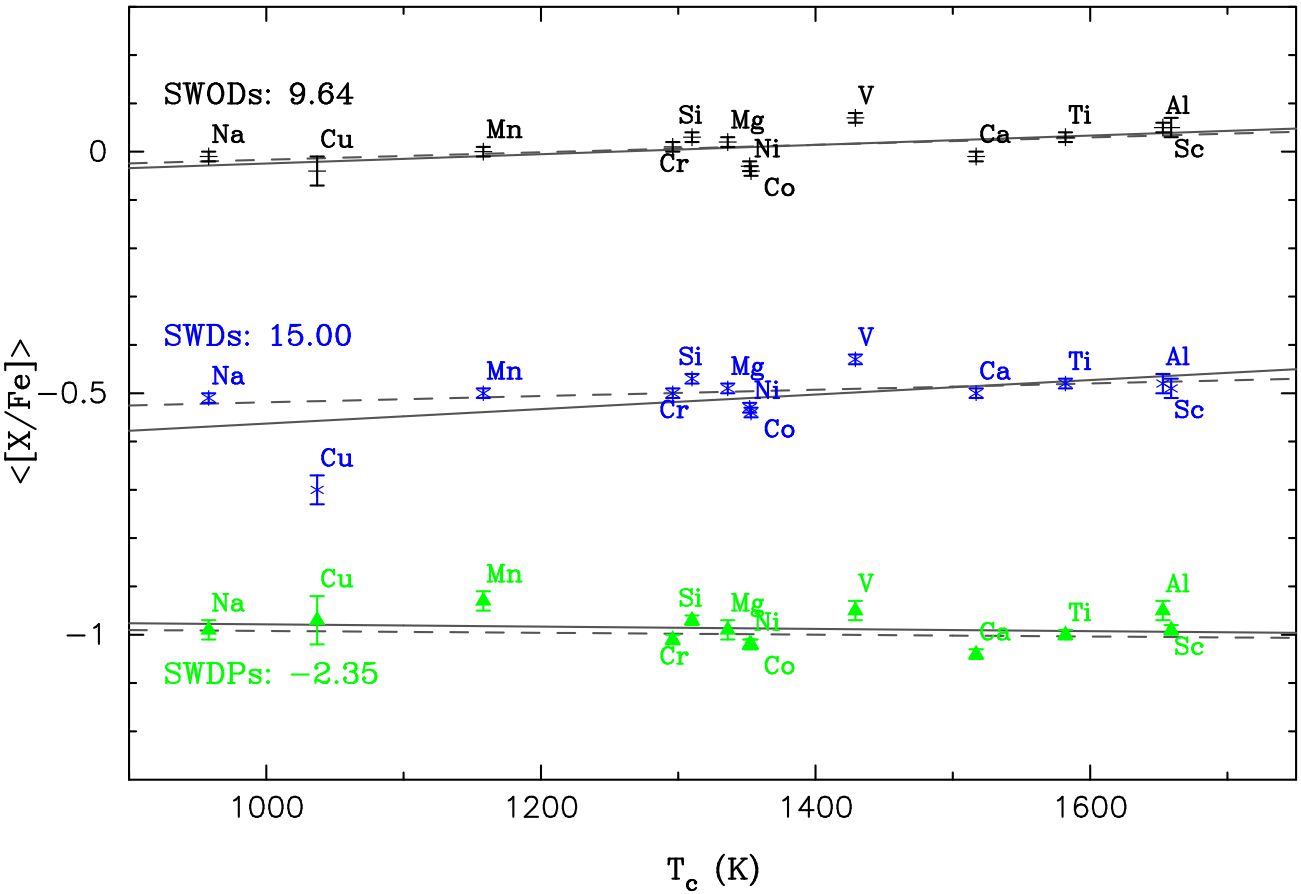
All elements



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

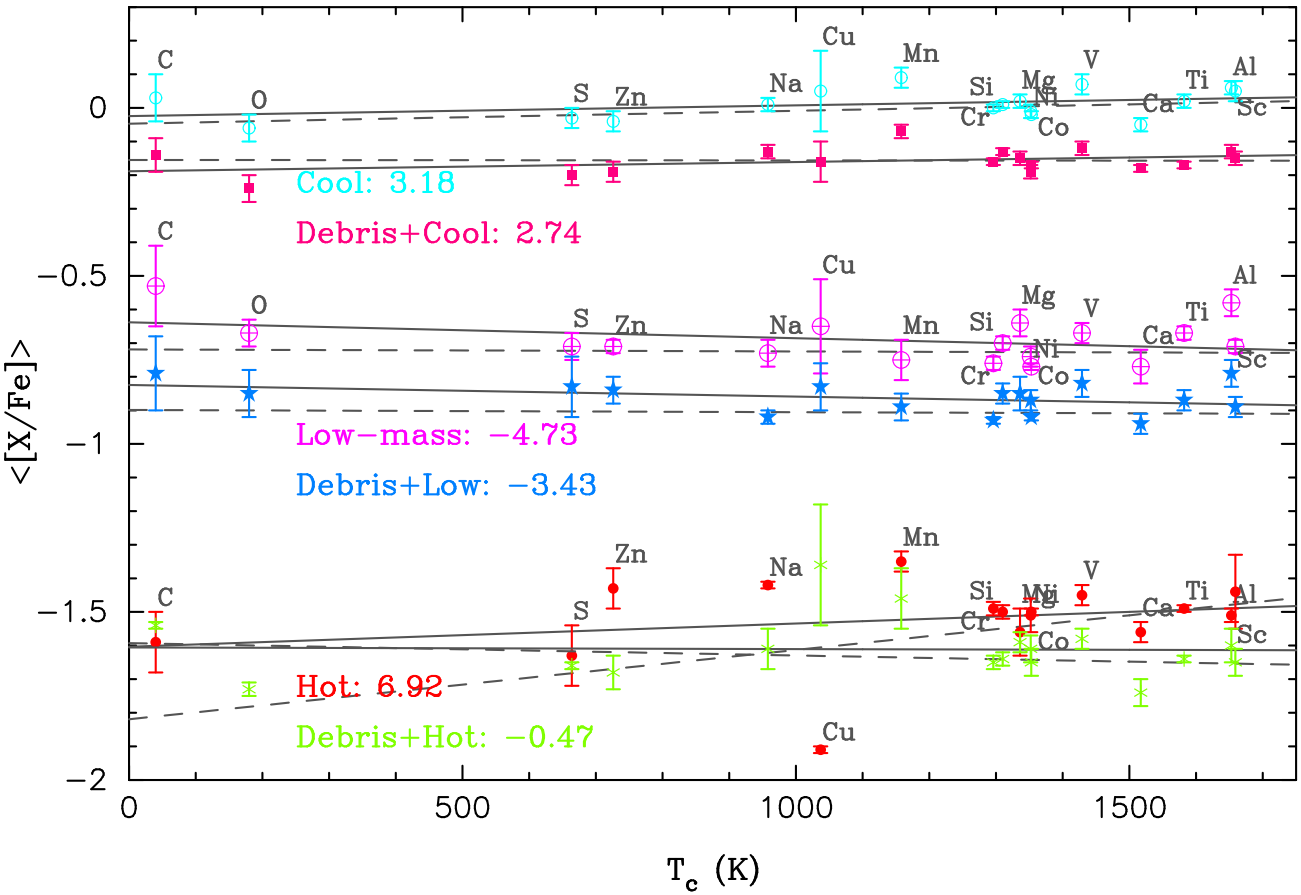
Abundances of volatiles not as reliable as refractories' ones

Only $T_C > 900$ K



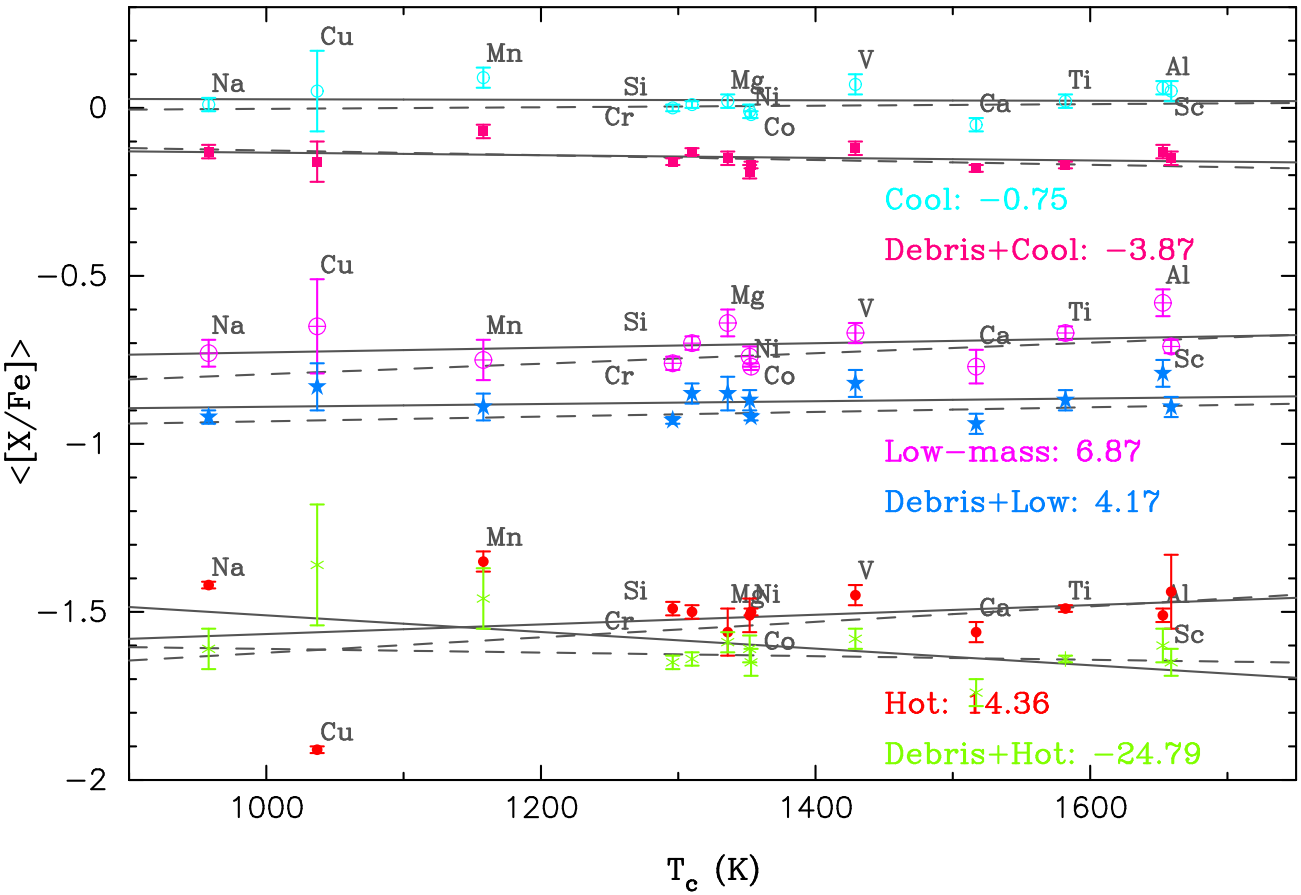
- **Slope change their signs, but still there is a difference in SWDPs wrt SWDs/SWODs**

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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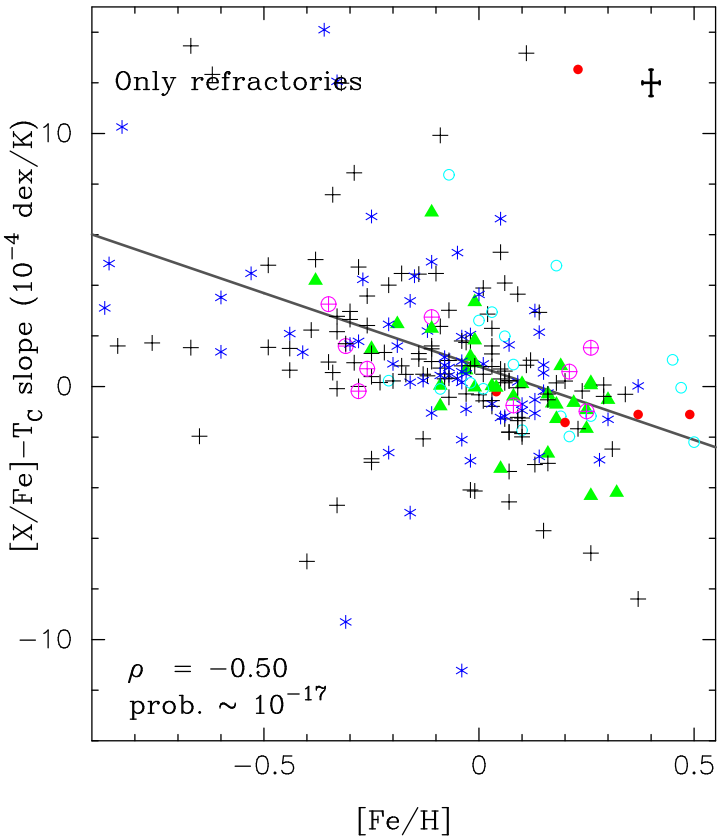
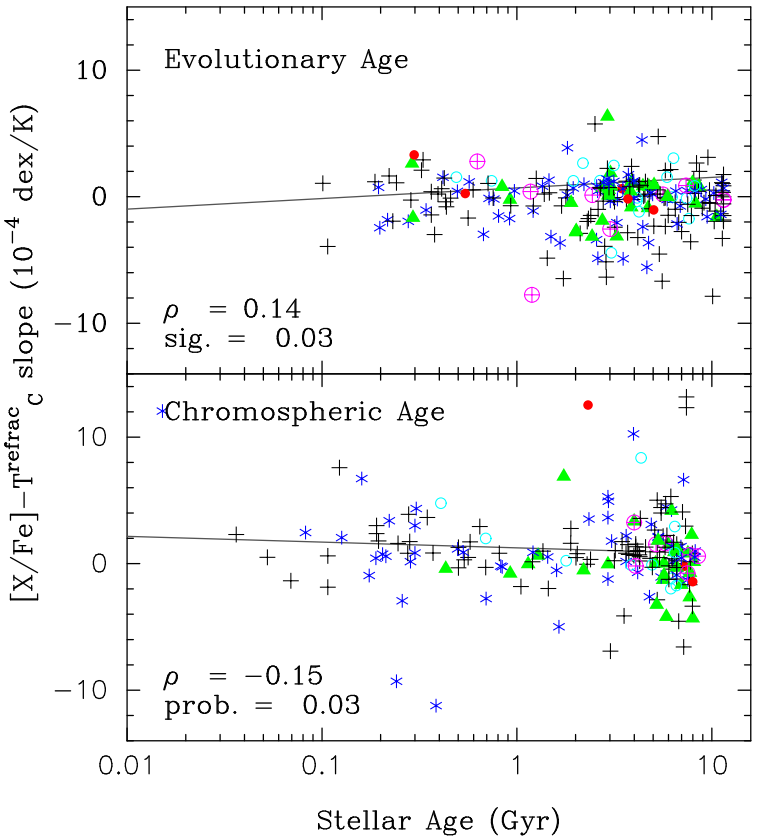
Key questions:

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?

Abundance patterns may be affected by GCE effects

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





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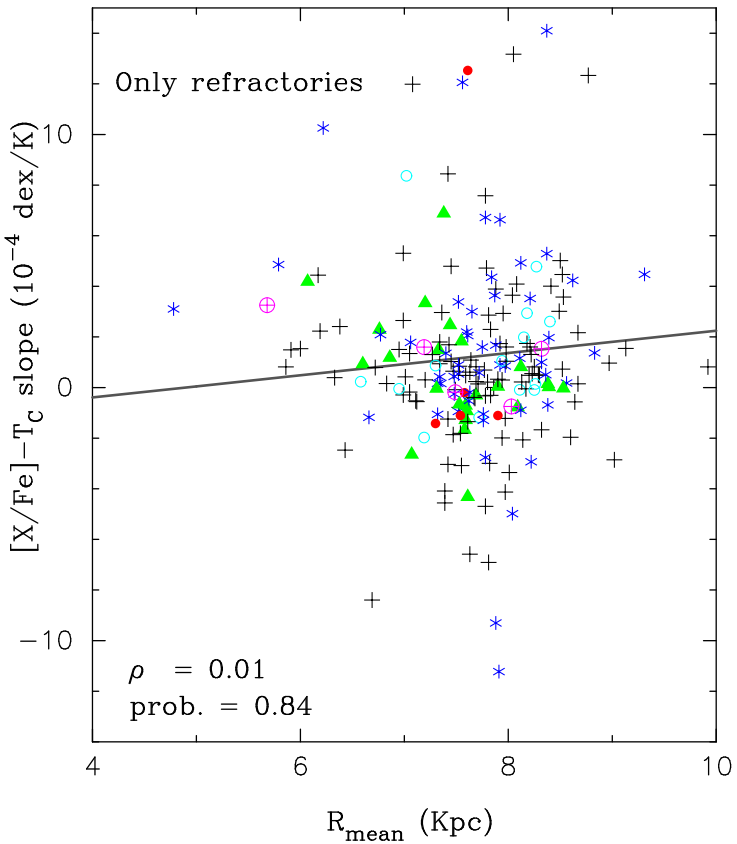

[Fe/H]	Moderate, significant
Age	Weak, but significant
R_{mean}	Not clear correlation

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?

1. **Similar behaviour SWDs/SWODs**
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Do the <[X/Fe]>-T_C trends fit in the ME09 hypothesis?

1. **Similar behaviour SWDs/SWODs**
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3. **No differences in stars with low-mass planets (wrt SWODs/SWDs)**

- **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)**

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

3. **No differences in stars with low-mass planets (wrt SWODs/SWDs)**
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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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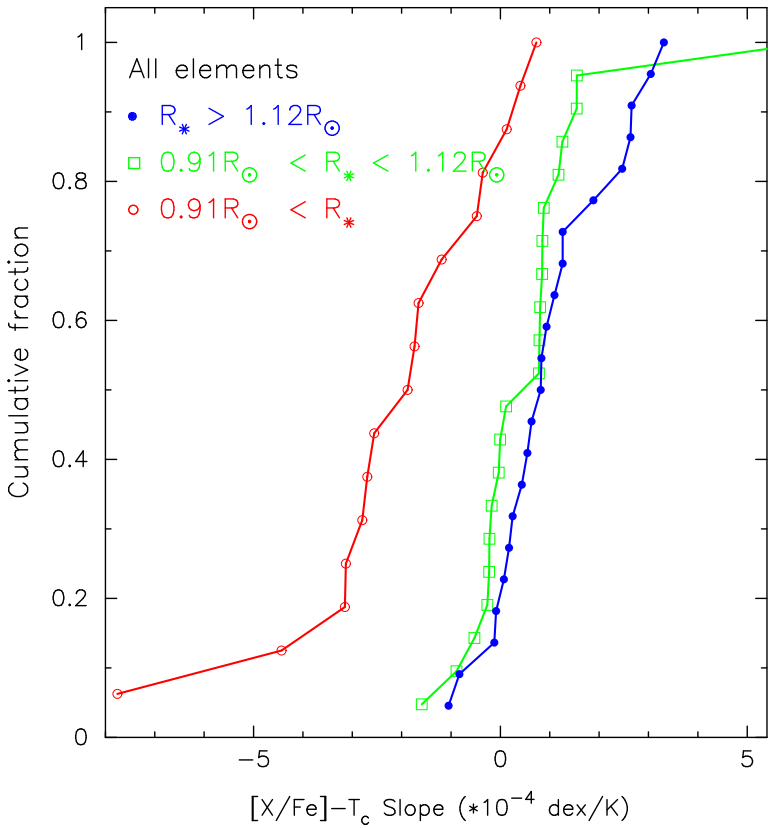
5. **Positive slopes in stars with hot-Jupiters**

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

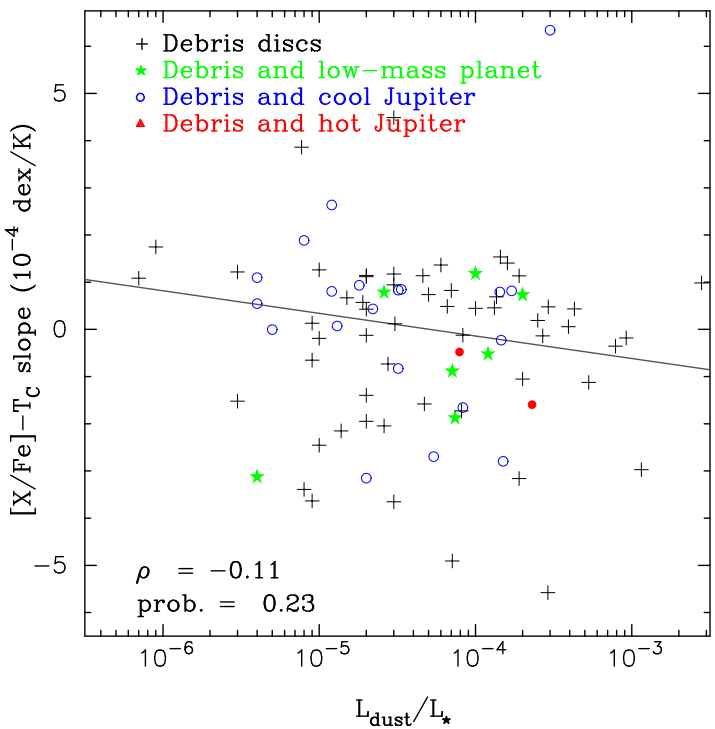
[X/Fe]-T_C slope correlation: natural prediction of self-enrichment hypothesis

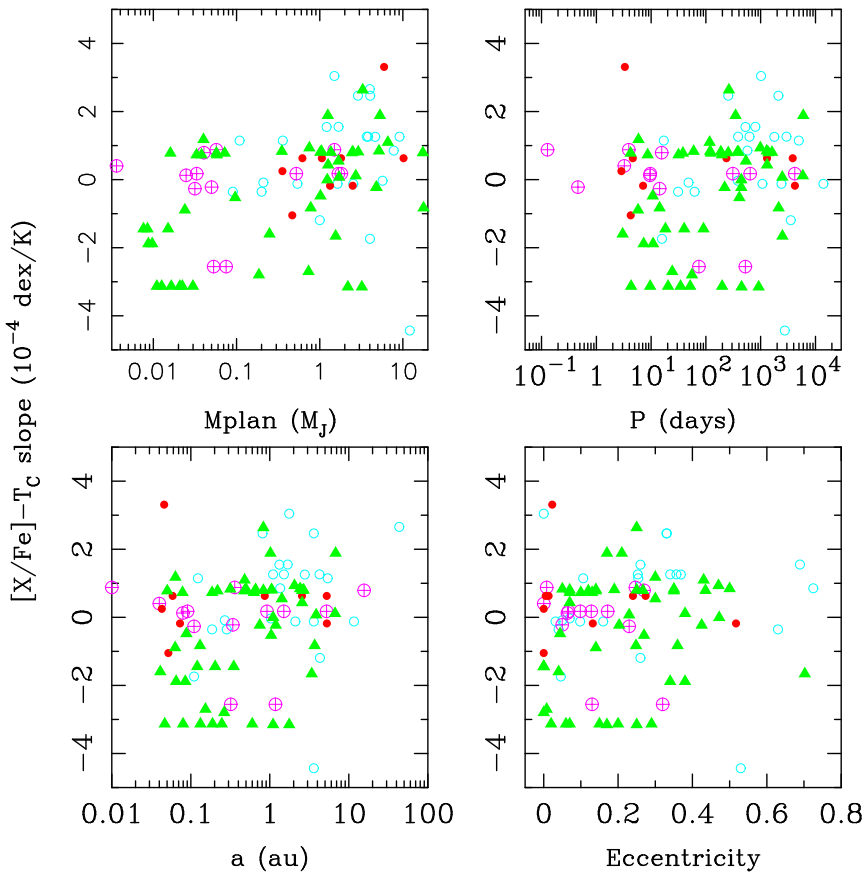


- **$R_\star$:** proxy of the convective envelope size
  Early-type: $\Uparrow R_\star$, $\Downarrow$ CZ
  Late-type: $\Downarrow R_\star$, $\Uparrow$ CZ

- **K-stars show larger negative slopes**
  - **But, only in T_C^{all} analysis**
  - **Against the pollution hypothesis**

No apparent trends between disc/planet properties with [X/Fe]-T_C slope





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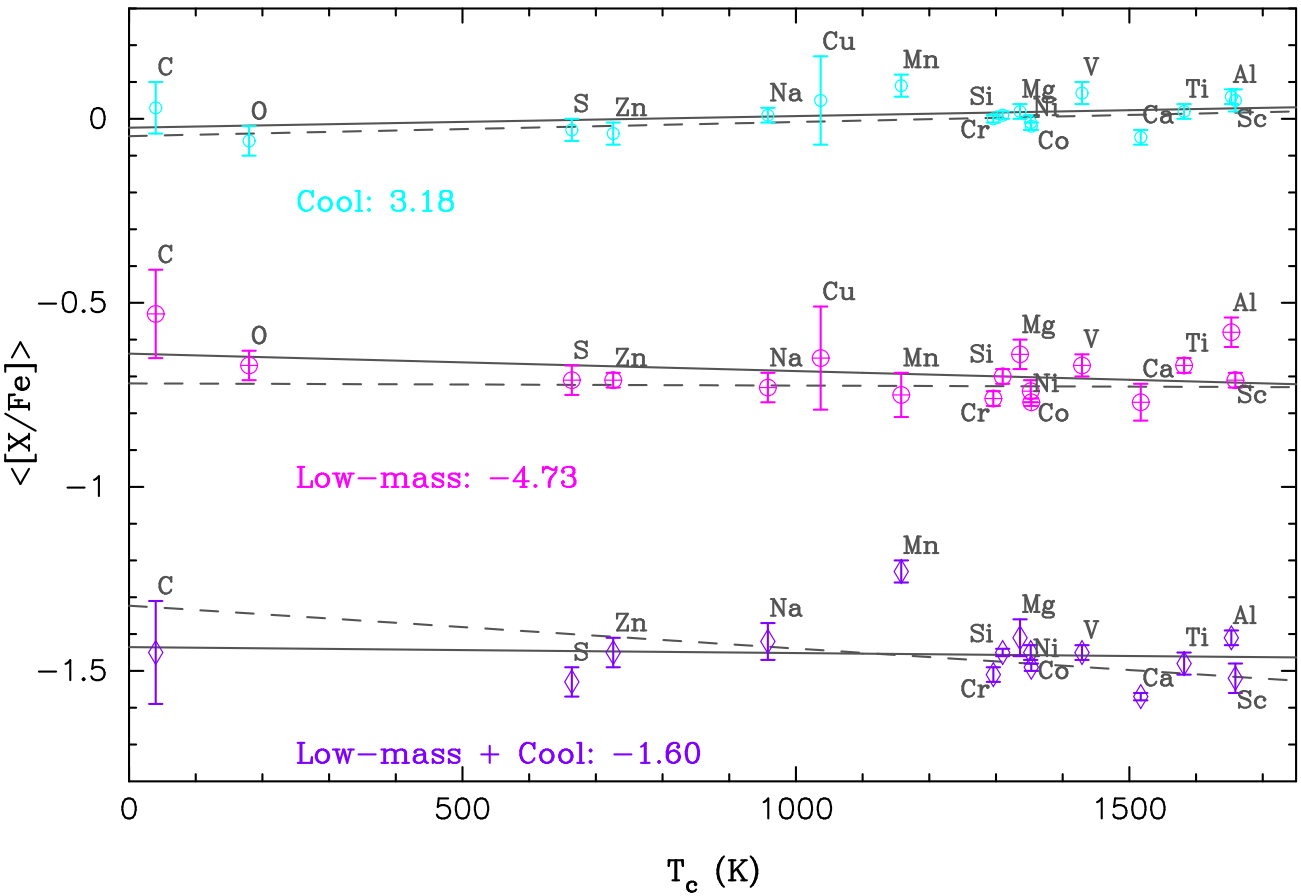
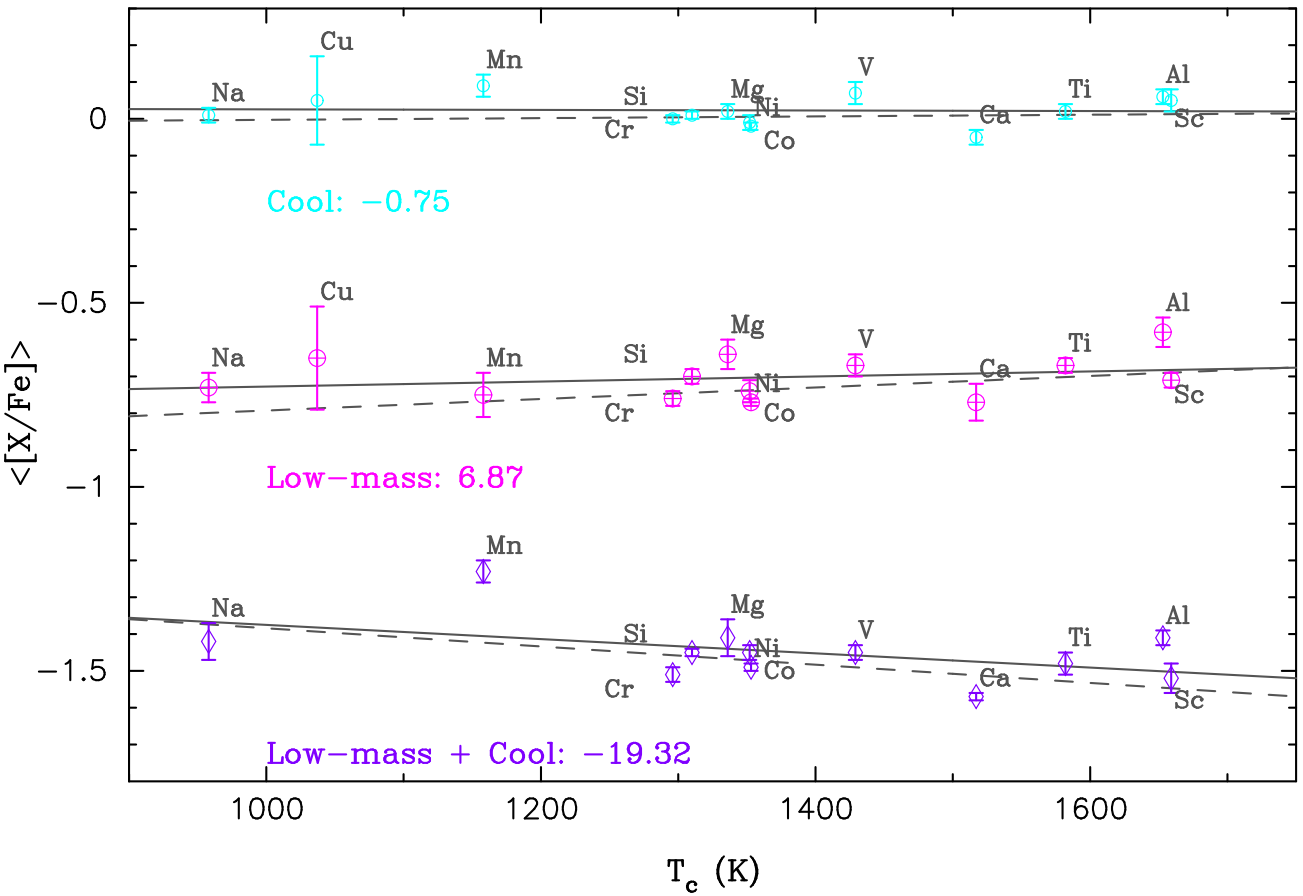
Ref: Maldonado et al. 2015, A&A, 579, A20

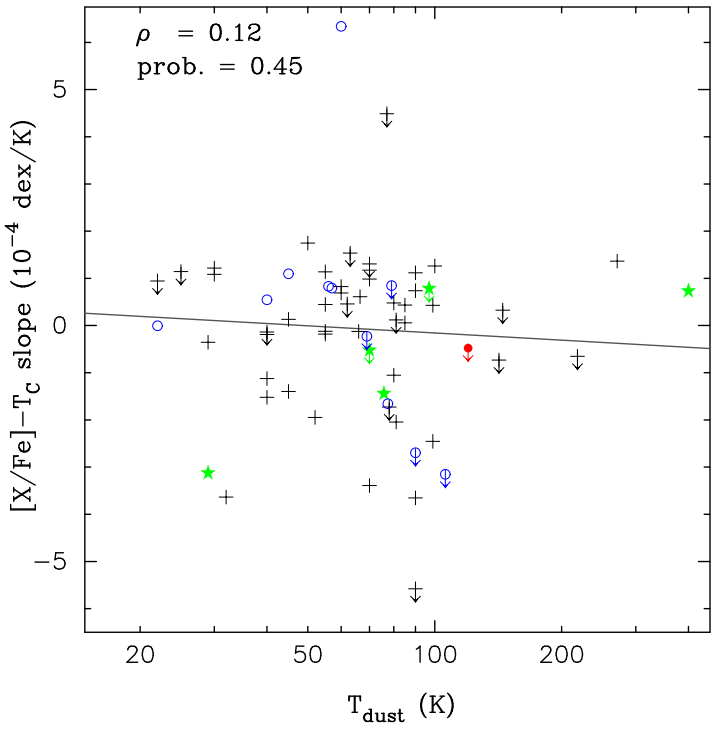
Summary

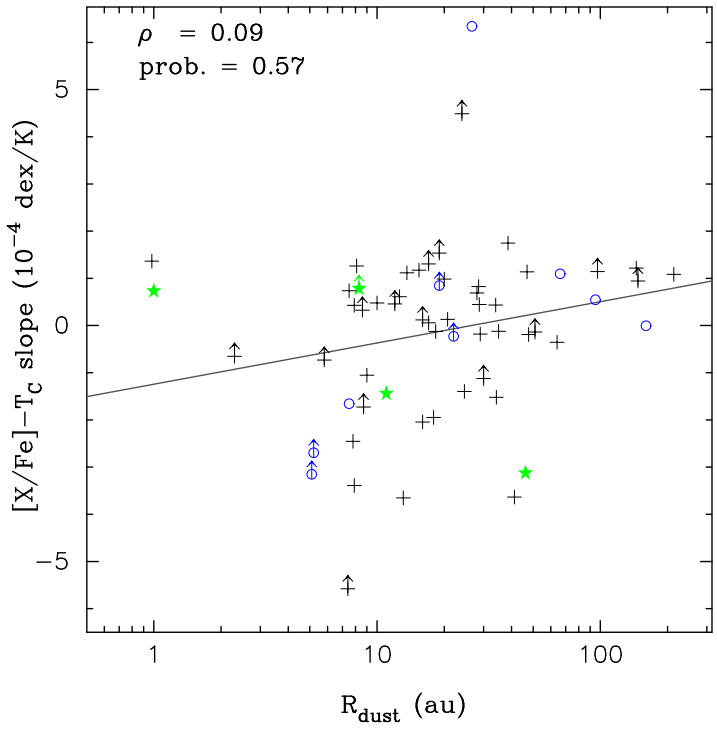
Detailed chemical analysis of SWDs and SWDPs

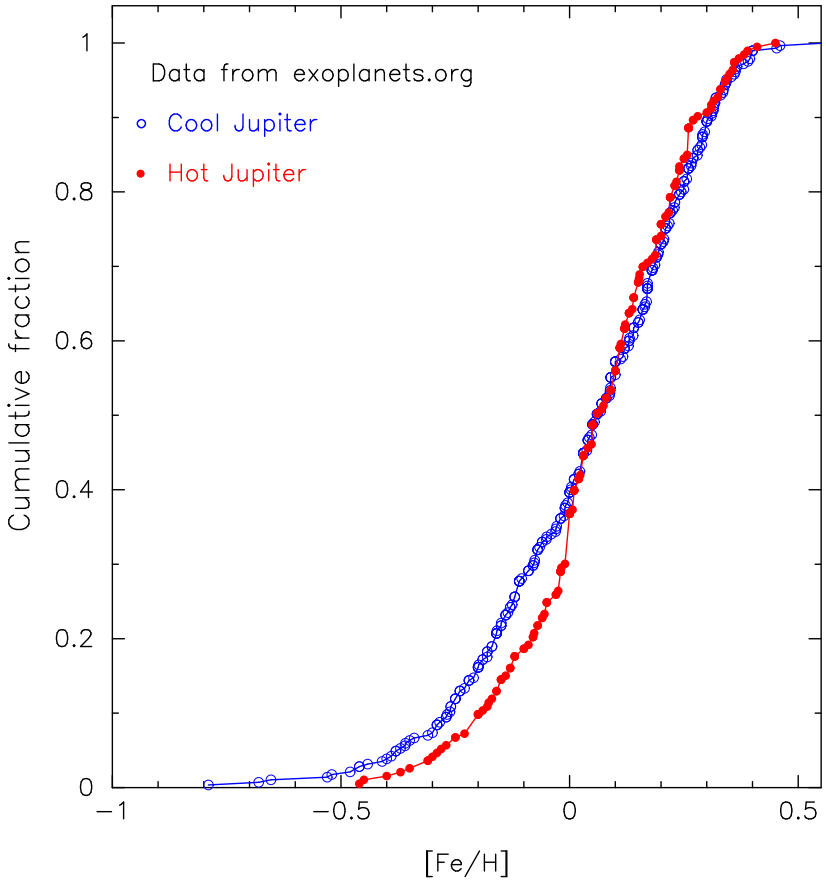
- **No differences SWDs/SWODs**
- **SWDPs driven by the type of planet**
  - In agreement with core-accretion models
  - Correlation debris disc/low-mass planets?
  - Lack correlation debris discs/giant planets?
- **Tentative [X/Fe]-T_C trends in SWPs**
  - Different behaviour in stars with cool-planets
  - 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

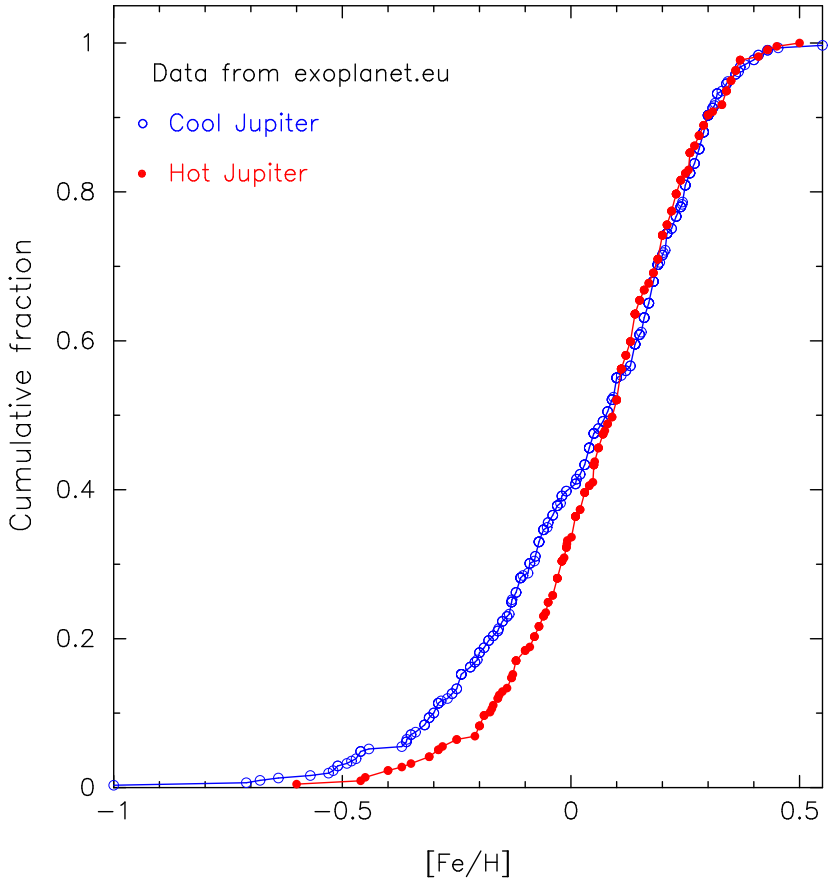

Cool: 3.18
Low−mass: −4.73
Low−mass + Cool: −1.60
<[X/Fe]>
T_c (K)
0
−0.5
−1
−1.5
0
500
1000
1500
C
O
S
Zn
Na
Cu
Mn
Si
Mg
Ni
Cr
Co
V
Ca
Ti
Al
Sc


Cu
Mn
Na
Si
Mg
V
Ni
Ti
Al
Cr
Co
Ca
Sc
0
Cool: −0.75
−0.5
Low−mass: 6.87
−1
Low−mass + Cool: −19.32
−1.5
<[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
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Cumulative fraction
[Fe/H]
0
0.2
0.4
0.6
0.8
1
−1
−0.5
0
0.5