Abundance trends in stars with debris discs and planets

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July 2014

Outline

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)**

In this study:

Metallicity of four samples of solar-like stars

1. **Stars with known debris discs (SWDs)**
   IRAS, ISO, Spitzer, Herschel data (67 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 (120)

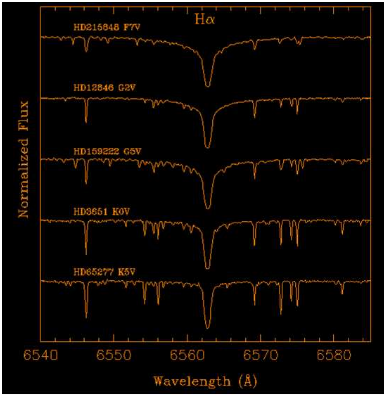
Stars with/without discs in *Spitzer-Herschel* surveys

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 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 (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*, *WIDTH9* programs + ATLAS9 model atomospheres
- Line list mainly from Neves et al. 2009, Ramírez et al. 2014

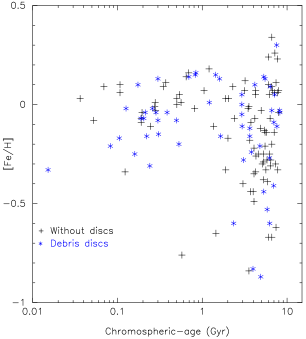
Age, distance, kinematics

SWDs

	Range	Mean	Median
Distance (pc)	3.6/134	25	22
log[Age (yr)]	7.2/9.9	9.1	9.5
Thin/thick disk (%)	86.6 (D); 4.5 (TD); 8.9 (R)		

SWODs

	Range	Mean	Median
Distance (pc)	1/49	17	17
log[Age (yr)]	3.0/9.9	9.3	9.6
Thin/thick disk (%)	80.8 (D); 4.2 (TD); 14.2 (R); 0.8 (H)		



- SWDs at ⇑ distances, (∼ 79% within 25 pc)
- Similar fraction of thin/thick disk stars
- SWDs: 15% more stars younger than 500 Myr. Do not show ⇑ [Fe/H]

32 solar-like SWDPs:

- 47% multiplanet systems, 6 stars with low-mass planets
  14-28%, (Wright et al. 2009); 70% in systems with low-mass planets, (Mayor et al. 2011)
- 8 stars host at least one low mass planet
  In all cases but in one their [Fe/H] $\leq$ 0.00
- 2/24 SWDPs hosting only gas giant planets, host "hot"-Jupiters (a < 0.1 AU)
  $\sim$ 75% have semimajor axis larger than 0.5 AU
- One giant star with debris and planets
  HD 137759, K2III, +0.22 dex, gc

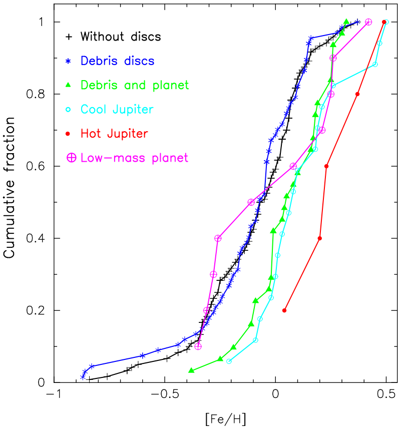
HD	SpType	[Fe/H]	Planet
210277	G0	+0.26	gc
215152	K0	+0.05	mlh
216435	G3IV	+0.17	gc

HD	SpType	[Fe/H]	Planet
142	F7V	-0.01	:mgc
1461	G0V	+0.16	m?lh
10647	F8V	-0.11	gc
19994	F8V	+0.19	gc
20794	G8V	-0.38	mlc
22049	K2V	-0.03	m?gc
38529	G4V	+0.32	mgc
38858	G4V	-0.25	lh
40307	K3V	-0.19	mlh
40979	F8	+0.18	:gc
45184	G2V	+0.03	lh
46375	K1IV	+0.26	:gh
50499	G1V	+0.29	:gc
50554	F8	-0.09	gc
52265	G0V	+0.16	mgc
69830	K0V	-0.01	mlh
73526	G6V	+0.19	:mgc
82943	G0	+0.00	mgc
104067	K2V	+0.10	gc
108874	G5	+0.26	mgc
115617	G5V	-0.02	mlh
117176	G5V	-0.11	gc
128311	K0	+0.04	mgc
130322	K0V	+0.04	gh
178911B†	G5	+0.29	:gc
150706	G0V	-0.09	gc
187085	G0V	-0.01	:gc
192263	K2	-0.01	gc
202206	G6V	+0.30	mgc

Comparing the metallicity distribution of all samples

Transition towards higher [Fe/H]

SWODs ⇒ SWPs



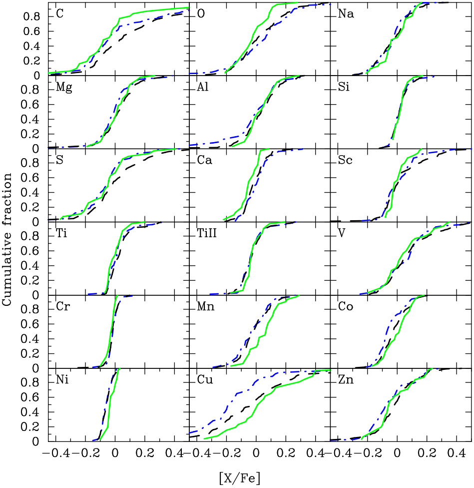
Results

- 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

Implications

- Core-accretion models
- M_{solids} in pp-discs

No obvious differences SWDs/SWODs

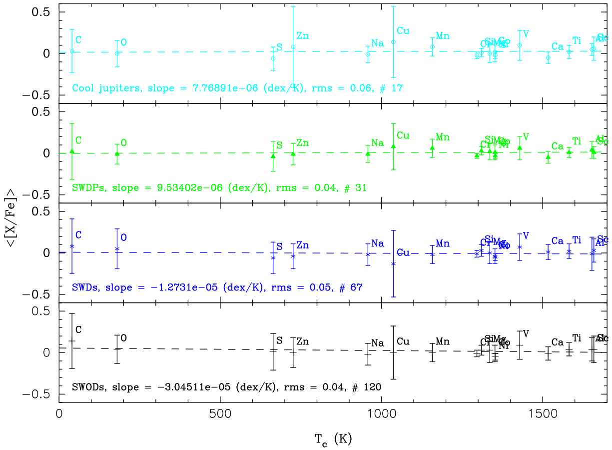


Kolmogorov-Smirnov probabilities

[X/Fe]	*p*-value	[X/Fe]	*p*-value
C	0.08	Ti	0.08
O	0.62	V	0.78
Na	0.35	Cr	0.92
Mg	0.04	Mn	0.62
Al	0.45	Co†	0.008
Si	0.93	Ni	0.85
S	0.05	Cu†	0.003
Ca	0.52	Zn	0.03
Sc	0.70		

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

All elements

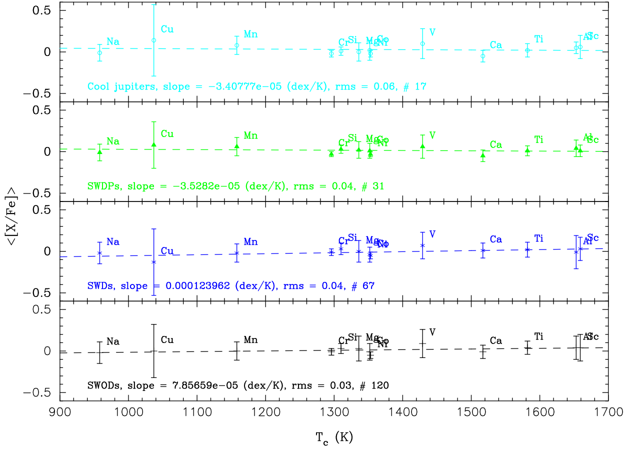


SWDs/SWODs -

SWDPs +

Abundances of volatiles not as reliable as refractories' ones

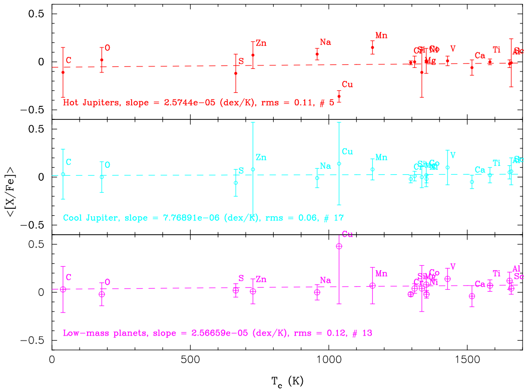
Only $T_C > 900$ K



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

Comparison with planet hosts SWDPs behaves as stars with giant cool planets

Steeper trend from stars with low-mass planets to stars with hot jupiters?

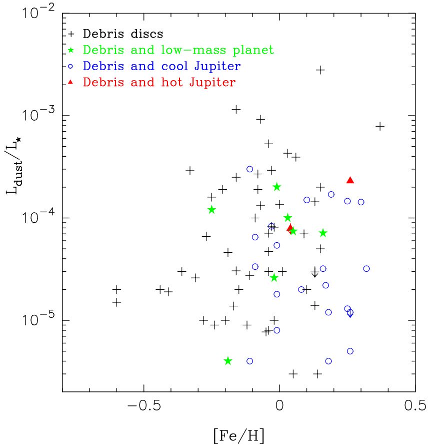


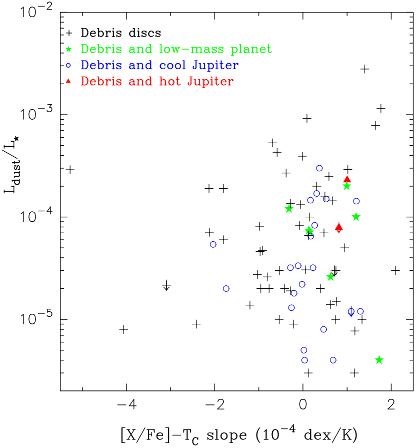
Caution!

Different [X/Fe]-T_C trend in planet hosts, subject of an **intense discussion**

Trends with the fractional dust luminosity

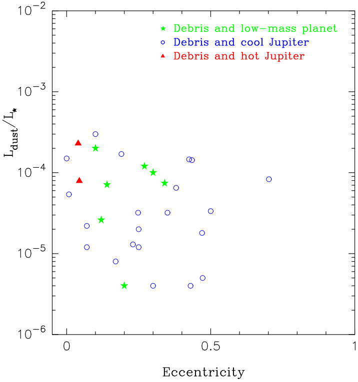
No apparent trend with [Fe/H] or [X/Fe]-T_C slope, although there seems to be a trend of lower $L/L_\star$ values in SWDs and cool giant Jupiters (K-S *p*-value $\sim$ 0.47)



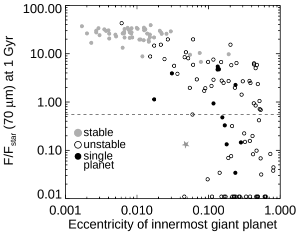


Anticorrelation between $L/L_\star$ and planet eccentricity

Innermost planet taken as reference

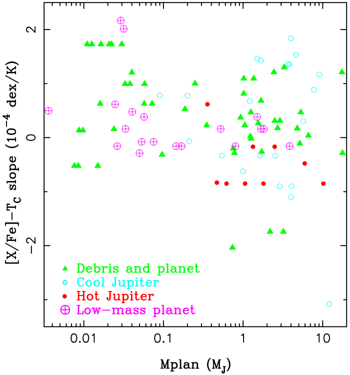


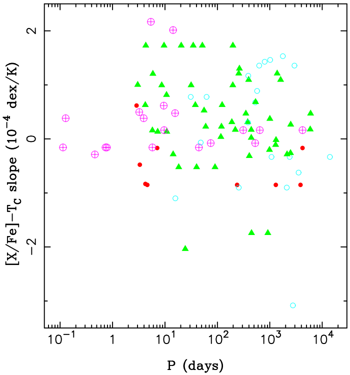
- Significant scatter
- Spearman's $P_{correlation}$ = 0.77
- No trends found with a, or P



Dynamical instabilities by eccentric giant planets (Raymond et al. 2011)

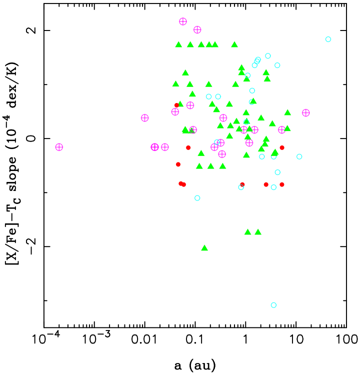
No apparent trends T_C slopes vs M_p, P, a, e

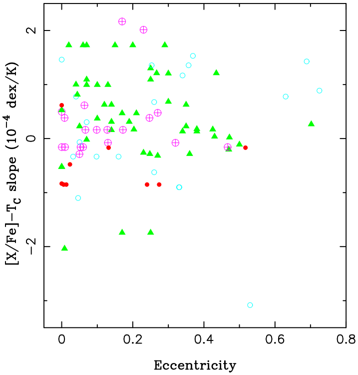




T_C slopes as a function of planetary parameters

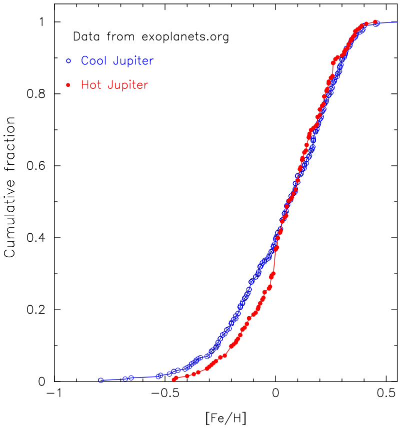
No apparent trends T_C slopes vs M_p, P, a, e

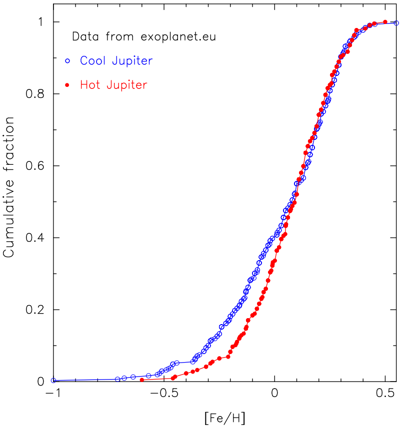




Summary

1. **SWDPs:** $\Uparrow$ fraction of SWDPs with low-mass planets in multiplanet systems
2. **Abundance distributions:** Results support core-accretion models
   - Similar behaviour SWODs/SWDs and SWDPs/SWPs
   - $\Uparrow$ [Fe/H] in SWDPs and cool giant planets
   - $\Downarrow$ [Fe/H] in SWDPs and low-mass planets
3. **Trends with $L/L_{\star}$:** Discs instabilities are needed to explain some of the suggested trends
   - Anti correlation with planet eccentricity
   - $\Downarrow$ $L/L_{\star}$ in stars with discs and cool giant planets?
4. **Trends with T_C slope:** Similar behaviour SWDPs and stars with cool giant planets
   - Subject of ongoing discussions
   - No correlation with dust/planet properties
   - Steeper trend in stars with hot close-in planets?


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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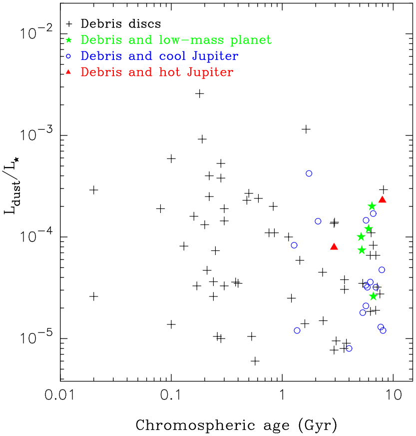
Debris discs
Debris and low−mass planet
Debris and cool Jupiter
Debris and hot Jupiter
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$L_{dust}/L_{\star}$
0.01
0.1
1
10
Chromospheric age (Gyr)