**Astronomy
&
Astrophysics**

Abundance ratios of volatile vs. refractory elements in planet-harbouring stars: hints of pollution?[*]

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ABSTRACT

We present the [X/H] trends as a function of the elemental condensation temperature T_C in 88 planet host stars and in a volume-limited comparison sample of 33 dwarfs without detected planetary companions. We gathered homogeneous abundance results for many volatile and refractory elements spanning a wide range of T_C, from a few dozen to several hundred kelvin. We investigate possible anomalous trends of planet hosts with respect to comparison sample stars to detect evidence of possible pollution events. No significant differences are found in the behaviour of stars with and without planets. This is consistent with a "primordial" origin of the metal excess in planet host stars. However, a subgroup of 5 planet host and 1 comparison sample stars stands out as having particularly high [X/H] vs. T_C slopes.

1. Introduction

The announcement of the first planet orbiting around the solar type star 51Peg by Mayor & Queloz (1995) marked the beginning of a steadily growing series of extrasolar planet discoveries. Radial velocity programmes have now found more than 150 planetary systems in the solar neighborhood. The study of these planets and their stellar parents opens new opportunities to understand the mechanisms involved in planet formation and evolution. Current analyses are providing the first statistically significant results about the properties of the new systems (e.g. Jorissen et al. 2001; Zucker & Mazeh 2002; Udry et al. 2003; Eggenberger et al. 2004).

The first strong link established between the planetary companions and their host stars is the fact that planet-harbouring stars are on average more metal-rich than field stars. This idea

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[*] Based on data from the FEROS spectrograph at the 2.2-m ESO/MPI telescope (observing run ID 074.C-0135), at the La Silla Observatory, ESO (Chile), and the UVES spectrograph at VLT/UT2 Kueyen telescope (observing run ID 074.C-0134), at the Paranal Observatory, ESO (Chile), and on observations made with the SARG spectrograph at 3.5-m TNG, operated by the Fundación Galileo Galilei of the INAF, and with the UES spectrograph at the 4-m William Hershel Telescope (WHT), operated by the Isaac Newton Group, both at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

was proposed by Gonzalez (1997), while the first clear evidence was published by Santos et al. (2001). Further studies have confirmed this result as new planet host candidates have been discovered (e.g. Gonzalez et al. 2001; Laws et al. 2003; Santos et al. 2003, 2004b, 2005; Fischer & Valenti 2005; for a review see Santos et al. 2004a). This characteristic led to the suggestion that gas giant planet formation is favored by high stellar metallicity (Santos et al. 2000, 2001), so that planetary systems would be more likely to form out of metal-enriched primordial clouds. Alternatively, the metal excess in these stars may be attributed to the pollution by the late ingestion of planetary material (Laughlin 2000; Gonzalez et al. 2001).

Several results supporting the "self-pollution" scenario have been published. Murray & Chaboyer (2002) concluded that stochastic pollution by ∼5 $M_\oplus$ of iron-rich material, together with selection effects and high intrinsic metallicity, may explain the observed metallicities in planet-harbouring stars. Israelian et al. (2001, 2003) found evidence for a planet (planets or planetary material) having been engulfed as suggested by the discovery of a significant amount of ^{6}Li in the stellar atmosphere of the parent star HD 82943. However, the amount of accreted matter was not enough to explain the global stellar metallicity. Ingestion of planetary material may also explain the lithium and iron enhancement found by Gonzalez (1998) and Laws & Gonzalez (2001) in the primary component of the

binary system 16 Cyg. However, most studies today suggest that a primordial origin is much likelier to explain the metallicity excess in planet host stars. Pinsonneault et al. (2001) ruled out the "self-pollution" hypothesis since the iron excess did not show the expected T_{eff} dependence. However, some different premises proposed by Vauclair (2004) might invalidate their argument. An additional point in favour of the primodial scenario is the fact that the frequency of planets is a rising function of [Fe/H] (Santos et al. 2001, 2004b; Reid 2002). Moreover, despite their very large convective envelopes, giants with planets do not present [Fe/H] lower than other planet hosts. We thus cannot completely rule out any of the different hypotheses proposed to explain the metallicity excess in planet host stars. Note also the strange behaviour reported for [α/Fe] at supersolar [Fe/H], hard to explain by Galactic chemical evolution (e.g. Bodaghee et al. 2003; Gilli et al. 2006; for a review see Israelian 2004, 2006).

The abundance analyses of elements other than iron may give clues to this open question. Light elements are very important tracers of the internal structure and history of solar-type stars and therefore they can help to distinguish between different planet formation theories (Sandquist et al. 2002; Santos et al. 2002, 2004c; Israelian et al. 2004). Volatile (with lower condensation temperatures T_C) and refractory (with higher condensation temperatures T_C) elements can also give information about the role played by pollution events in the global stellar chemical composition. The elements of the former group are expected to be deficient in accreted materials relative to the latter. If the infall of large amounts of rocky planetary material was the main cause of the metallicity excess in planet host stars, as the "self-pollution" scenario claims, an overabundance of refractory elements with respect to volatiles should be observed. This would imply an increasing trend of abundance ratios [X/H] with the elemental condensation temperature T_C. However, the engulfment of a whole planet (or the rapid infall of planetary material) may avoid the evaporation of volatile elements before reaching the inside of the star, leading to no peculiar trend of the stellar abundance with T_C.

Smith et al. (2001) reported that a small subset of stars with planets exhibited an increasing [X/H] trend with T_C and concluded that this trend pointed to the accretion of chemically fractionated solid material into the outer convective layers of these solar-type stars. They made use of the abundance results of 30 stars with planets reported by Gonzalez et al. (2001) and Santos et al. (2001), and compared them to those of 102 field stars from Edvardsson et al. (1993) and Feltzing & Gustafsson (1998). Takeda et al. (2001) also searched for a correlation between chemical abundances and T_C. They found that all volatile and refractories elements behave quite similarly in a homogeneously analysed set of 14 planet-harbouring stars and 4 field stars. Sadakane et al. (2002) confirmed this result in 12 planet host stars, supporting a likelier primordial origin for the metal enhancement. Unfortunately, more results for planet-harbouring stars and a homogeneous comparison with field stars are needed to perform a more convincing test.

In this paper, we study the T_C dependence of abundance ratios [X/H] uniformly derived in a large set of 105 planet host stars and in a volume-limited comparison sample of 88 stars

without known planets. Some preliminary results were reported by Ecuvillon et al. (2006b). The large range of different T_C covered by the analysed elements, which spans from 75 to 1600 K, permits us to investigate possible anomalies in targets with planets beside comparison sample stars, and to detect hints of pollution. Our results offer new clues to understand the relative contribution of fractionated accretion to the metallicity excess observed in planet host stars.

2. Data and analysis

We derived abundance ratios in an almost complete set of 105 planet host targets and in 88 comparison sample stars for the volatile elements CNO, S and Zn (Ecuvillon et al. 2004a,b, 2006a) and the refractories Cu, Si, Ca, Sc, Ti, V, Cr, Mn, Co, Ni, Na, Mg and Al (Ecuvillon et al. 2004b; Beirao et al. 2005; Gilli et al. 2006). All these abundances were computed using the homogeneous set of atmospheric parameters spectroscopically derived by Santos et al. (2004b, 2005). We refer the reader to these papers for a description of the data and for the details of the spectral analysis. The uniform analyses applied to all the targets avoid possible errors due to differences in the line lists, atmospheric parameters, applied procedures, etc.

For each target we obtained the [X/H] trend as a function of the elemental condensation temperature T_C. The T_C values for all the elements were taken from Lodders (2003). We characterized each trend by computing the slope value corresponding to a linear least-squares fit, as proposed by Smith et al. (2001). The targets with less than 14 abundance determinations were excluded from our study, in order to rely on the abundance ratios of at least two volatile elements. The selected targets, 88 planet host and 33 comparison sample stars, have [X/H] vs. T_C trends spanning a large range of elemental condensation temperatures, from a few dozen up to several hundred kelvin, and thus leading to better constrained and more reliable T_C slopes. Figure 1 shows the [X/H] vs. T_C trends for the targets HD 20367 and HD 39091, and HD 23484 and HD 69830, with and without planets, respectively.

3. Results and discussion

The slopes derived from [X/H] vs. T_C for all the planet host and comparison sample stars are shown in Fig. 2. Error bars reflect the statistical uncertainty in the derived slopes. A subsample of 19 and 1 stars with and without planets, respectively, stands out as having slopes larger than the average plus one standard deviation (see Table 1). The slopes are such that species with low condensation temperatures are 0.2 dex lower in abundance than the more refractory species. These targets might be candidates for having been polluted by the ingestion of fractionated material (see the [X/H] vs. T_C trends for HD 20367 and HD 23484 in Fig. 1). This subgroup shows on average a higher metallicity, of the order of 0.2 dex.

Another group of 9 planet hosts and 11 comparison sample stars emerges from the same representation as having slopes lower than the average minus one standard deviation (see Table 2). These targets correspond to a quite low average metallicity of the order of −0.2 dex. This characteristic, together
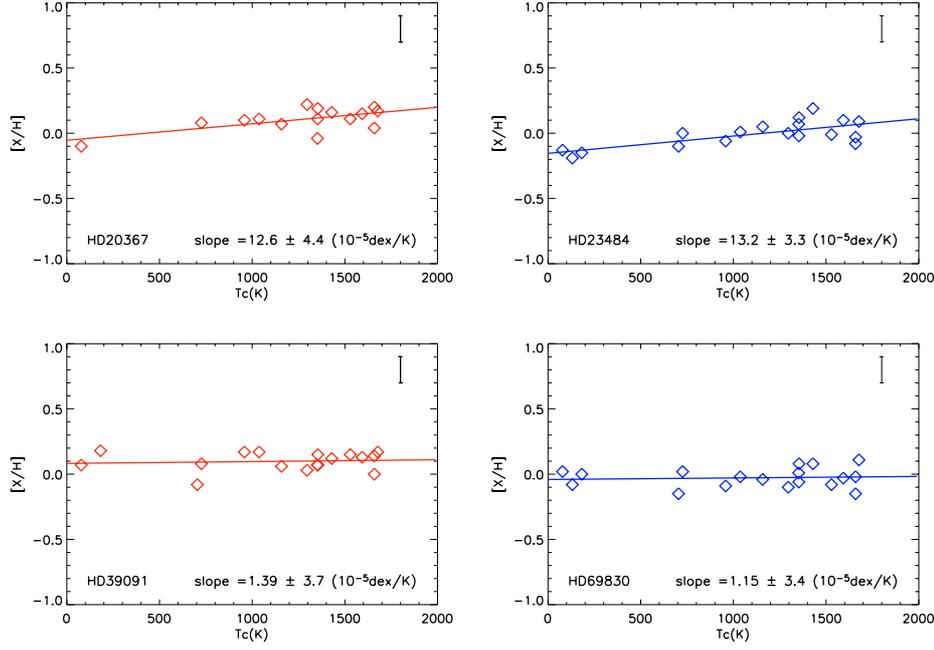
Fig. 1. Abundance ratios [X/H] plotted vs. the elemental condensation temperatures T_C for the planet host HD 20367 and HD 39091 (*left panels*), and for the comparison sample stars HD 23484 and HD 69830 (*right panels*). The solid lines represent the linear least-squares fits to the data. The slopes values and the typical error bars associated with the [X/H] ratios are indicated at the bottom and the top of each plot, respectively.
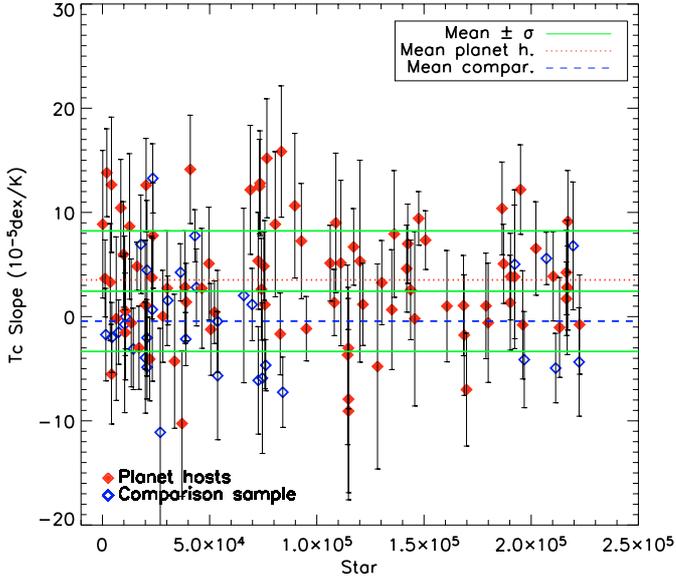

Fig. 2. Slopes derived from [X/H] vs. T_C for all the planet host (*filled symbols*) and comparison sample (*open symbols*) stars. The solid lines represent the average slope of the two samples, and the average slope ± one standard deviation. The dotted and dashed lines indicate the average slope of stars with and without planets, respectively.

Table 1. Targets with T_C slopes larger than the average ($2.4 \pm 5.8 \times 10^{-5}$ dex K^{-1}) plus one standard deviation.

Object	Type	T_C slope (10^{-5} dex K^{-1})	[Fe/H]
HD 8574	plan	10.43	0.06
HD 12661	plan	8.66	0.36
HD 40979	plan	14.13	0.21
HD 68988	plan	12.17	0.36
HD 73256	plan	12.48	0.26
HD 80606	plan	8.87	0.32
HD 83443	plan	15.84	0.39
HD 89744	plan	10.64	0.22
HD 108874	plan	9.00	0.23
HD 147513	plan	9.42	0.08
HD 186427	plan	10.38	0.08
HD 195019	plan	12.19	0.09
HD 217107	plan	9.14	0.37
HD 142	plan	8.86	0.14
HD 2039	plan	13.81	0.32
HD 4203	plan	12.65	0.40
HD 20367	plan	12.62	0.17
HD 73526	plan	12.79	0.27
HD 76700	plan	15.19	0.41
HD 23484	comp	13.27	0.06

with the similar one pointed out for the subgroup with higher slopes, suggests that this is related to the underlying chemical evolutionary effects. The fact that a large number of comparison sample stars behaves in the same way as planet host stars adds a further argument to the consideration that galactic chemical evolution, instead of fractionated accretion, contributes the most.

Table 2. Targets with T_C slopes lower than the average ($2.4 \pm 5.8 \times 10^{-5}$ dex K^{-1}) minus one standard deviation.

Object	Type	T_C slope (10^{-5} dex K^{-1})	[Fe/H]
HD 22049	plan	−4.07	−0.13
HD 37124	plan	−10.25	−0.38
HD 114762	plan	−7.92	−0.70
HD 4208	plan	−5.52	−0.24
HD 33636	plan	−4.28	−0.08
HD 169830	plan	−7.00	0.21
HD 114386	plan	−3.67	0.04
HD 114783	plan	−9.06	0.09
HD 128311	plan	−4.78	0.03
HD 20010	comp	−3.94	−0.19
HD 20807	comp	−4.86	−0.23
HD 72673	comp	−6.12	−0.37
HD 74576	comp	−5.90	−0.03
HD 76151	comp	−4.66	0.14
HD 84117	comp	−7.25	−0.03
HD 211415	comp	−4.94	−0.17
HD 222335	comp	−4.35	−0.16
HD 26965	comp	−11.10	−0.31
HD 53706	comp	−5.67	−0.26
HD 196761	comp	−4.13	−0.29

Fig. 3. [X/H] vs. T_C slopes plotted vs. [Fe/H] for all the planet host (*filled symbols*) and comparison sample (*open symbols*) stars. The solid lines represent the linear least-squares fit $\pm 2\sigma$ for all the targets, while the dotted and dashed lines indicate the linear least-squares fits $\pm 2\sigma$ for stars with and without planets, respectively. The slopes of each linear fit are shown at the bottom.

3.1. T_C slopes as a function of [Fe/H]

In order to disentangle the effects due to chemical evolution from those related to the fractionated accretion, we analysed the dependence of T_C slopes on the stellar metallicity. Figure 3 shows the T_C slopes vs. [Fe/H] and the linear least-squares fits corresponding to all the targets, and to the two samples of stars with and without planets, independently. All the linear least-squares fits were obtained by weighting each point for its statistical uncertainty. There is a clear global trend of slopes to increase with metallicity, which is an expected signature of the Galactic chemical evolution. In fact, [C/Fe] and [O/Fe] rise steeply toward lower metallicities (e.g. Gustafsson et al. 1999; Ecuvillon et al. 2004b, 2006a; Takeda & Honda 2005), and they thus tend to produce negative slopes in [X/H] vs. T_C for targets with [Fe/H] < 0.1.

The set of planet host stars seems to behave quite similarly to the comparison sample. Both groups present similar dispersions and slopes, even if the number of included comparison sample stars (33) is much lower than planet host targets (88). However, the fit corresponding to the planet host set is shifted towards higher T_C slope values. We see 10 planet hosts and 1 comparison sample star with particularly high T_C slopes at supersolar metallicities, which fall above the general scatter. Their abundance pattern is slightly enhanced than the rest of the stars, probably due to the general chemical evolutionary effects. These targets may be the main effects responsible for the shift observed in the fit of planet host stars, and they could contain possible signatures of selective accretion.
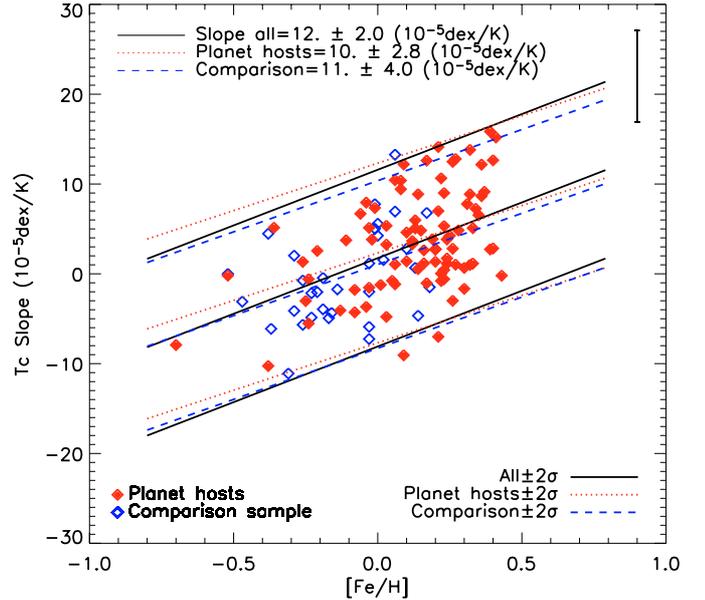
In order to explore this possibility, we checked which targets fall beyond the limits traced by the fits $\pm 2\sigma$. Due to the much larger number of stars with planets than comparison sample stars, the mean trend of both samples together is strongly marked by the behaviour of the targets with planets, especially at high metallicities. The fit of the two samples is hence shifted toward high T_C slope values, in the same way as the fit of planet hosts (see the solid and dotted lines in Fig. 3). Only the target HD 23484 belonging to the comparison sample presents a T_C slope of more than 2σ above the global fit. Another two targets with known planets, HD 114783 and HD 169830, have T_C slopes more than 2σ below the global fit. All these targets were reported in Tables 1 and 2 as having T_C slopes more than one standard deviation away from the average. The atmospheric parameters and chemical abundances of these peculiar stars are listed in Tables 3 and 4, while their [X/H] vs. [Fe/H] trends are shown in Fig. 1 (HD 23484, *top right panel*) and Fig. 4 (HD 114783 and HD 169830).

An interesting feature is that several planet host stars show slopes more than 2σ above the fit corresponding to the comparison sample. In particular, T_C slopes more than 2σ above the fit of the comparison sample are observed in the comparison sample target HD 23484 and in 5 planet host stars, all reported in Table 1. All the atmospheric parameters and chemical abundances of these peculiar stars are listed in Table 3. The same two planet host stars previously reported as having slopes more than 2σ below the global fit, HD 114783 and HD 169830, also fall more than 2σ below the fit of the comparison sample (see Table 4).

The global trend is heavily influenced by the behaviour of the planet host stars. If a subset of planet host stars had some

Table 3. Targets with T_C slopes more than 2σ above the comparison sample fit. The atmospheric parameters are taken from Santos et al. (2004b, 2005); the metallic abundances are from Ecuvillon et al. (2004a,b, 2006a) and Gilli et al. (2006). The Li and Be abundances are those from Israelian et al. (2004) and Santos et al. (2004c).

|	HD 20367	HD 23484	HD 40979	HD 76700	HD 83443	HD 195019
Type	plan	comp	plan	plan	plan	plan
T_C slope (10^{-5} K^{-1})	12.62	13.27	14.13	15.19	15.84	12.19
T_{eff} (K)	6138 ± 79	5176 ± 45	6145 ± 42	5737 ± 34	5454 ± 61	5842 ± 35
$\log g$	4.53 ± 0.22	4.41 ± 0.17	4.31 ± 0.15	4.25 ± 0.14	4.33 ± 0.17	4.32 ± 0.07
[Fe/H]	0.17 ± 0.10	0.06 ± 0.05	0.21 ± 0.05	0.41 ± 0.05	0.35 ± 0.08	0.08 ± 0.04
[C/H]	−0.10 ± 0.09	−0.13 ± 0.10	0.10 ± 0.07	0.21 ± 0.07	0.35 ± 0.08	0.06 ± 0.07
[N/H]	–	−0.19 ± 0.12	0.10 ± 0.16	0.32 ± 0.14	0.26 ± 0.14	–
[O/H]	–	−0.15 ± 0.11	−0.18 ± 0.08	–	0.15 ± 0.09	−0.20 ± 0.14
[S/H]	–	−0.10 ± 0.09	0.00 ± 0.08	0.10 ± 0.08	0.52 ± 0.10	−0.15 ± 0.06
[Zn/H]	0.08 ± 0.11	0.00 ± 0.08	−0.04 ± 0.12	–	–	0.02 ± 0.06
[Cu/H]	0.11 ± 0.11	0.01 ± 0.09	0.01 ± 0.09	–	–	0.12 ± 0.07
[Si/H]	0.11 ± 0.08	−0.01 ± 0.04	0.22 ± 0.05	0.38 ± 0.03	0.44 ± 0.06	0.09 ± 0.05
[Ca/H]	0.04 ± 0.12	−0.08 ± 0.11	0.15 ± 0.07	0.29 ± 0.10	0.19 ± 0.12	−0.03 ± 0.10
[Sc/H]	0.20 ± 0.13	−0.03 ± 0.12	0.18 ± 0.10	0.47 ± 0.08	0.55 ± 0.11	0.15 ± 0.09
[Ti/H]	0.15 ± 0.12	0.10 ± 0.08	0.18 ± 0.06	0.45 ± 0.05	0.46 ± 0.10	0.13 ± 0.06
[V/H]	0.16 ± 0.13	0.19 ± 0.09	0.24 ± 0.13	0.53 ± 0.08	0.61 ± 0.12	0.12 ± 0.06
[Cr/H]	0.22 ± 0.09	0.00 ± 0.05	0.18 ± 0.10	0.36 ± 0.08	0.33 ± 0.08	0.03 ± 0.06
[Mn/H]	0.07 ± 0.14	0.05 ± 0.09	0.17 ± 0.16	0.51 ± 0.12	0.58 ± 0.16	0.12 ± 0.05
[Co/H]	−0.04 ± 0.15	0.07 ± 0.07	0.10 ± 0.11	0.57 ± 0.10	0.63 ± 0.09	0.06 ± 0.06
[Ni/H]	0.11 ± 0.09	−0.02 ± 0.05	0.16 ± 0.08	0.41 ± 0.06	0.49 ± 0.07	0.03 ± 0.04
[Na/H]	0.10 ± 0.05	−0.06 ± 0.08	0.34 ± 0.04	0.40 ± 0.06	–	0.04 ± 0.03
[Mg/H]	0.19 ± 0.08	0.12 ± 0.05	0.33 ± 0.05	0.54 ± 0.05	0.49 ± 0.05	0.13 ± 0.03
[Al/H]	0.17 ± 0.05	0.09 ± 0.04	–	0.52 ± 0.04	0.53 ± 0.06	0.19 ± 0.02
$\log \epsilon$(Li)	3.02	<0.44	–	–	<0.56	1.46
$\log \epsilon$(Be)	–	<0.70	–	–	<0.70	1.15
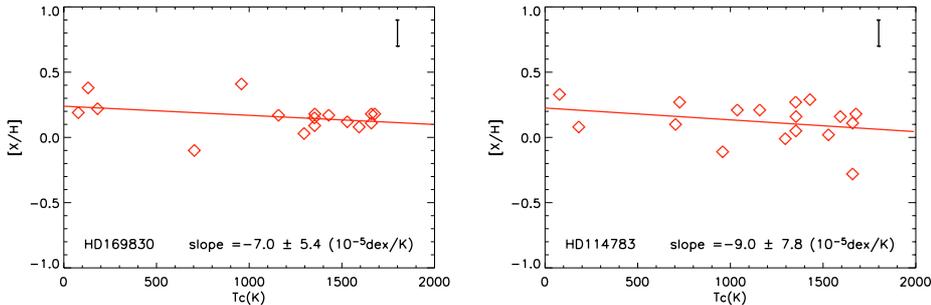
Fig. 4. Abundance ratios [X/H] plotted vs. the elemental condensation temperatures T_C for the planet host stars HD 169830 and HD 114783, having T_C slopes more than 2σ below the T_C slopes vs. [Fe/H] fit. The solid lines represent the linear least-squares fits to the data. The slopes values and the typical error bars associated with the [X/H] ratios are indicated at the bottom and the top of each plot, respectively.

signature of fractionated accretion, the global trend would reveal the same effect. This would affect the resulting fit to a greater extent if the pollution sign was more evident in metal-rich objects, since the lack of comparison sample targets drastically increases at supersolar metallicities. In this framework, the subsample of planet host stars more than 2σ above the linear least-squares fit traced by the comparison sample might be interpreted as tentative candidates for having been strongly polluted by fractionated material and whose photospheres still keep the signature of these events. The fact that these same objects do not fall 2σ out the global fit may be explained by the large effect that planet host stars at high metallicities have on the fit. However, these suggestions are only tentative, and the possibility of accretion signatures in these targets must be confirmed by other information, such as detailed abundance studies of light elements, and in particular of the isotopic ratio ^{6}Li/^{7}Li.

When available, the abundances of Li and Be were extracted from Israelian et al. (2004) and Santos et al. (2004c) and listed in Tables 3 and 4. Although the planet host target HD 20367 stands out as having very high Li content, this value
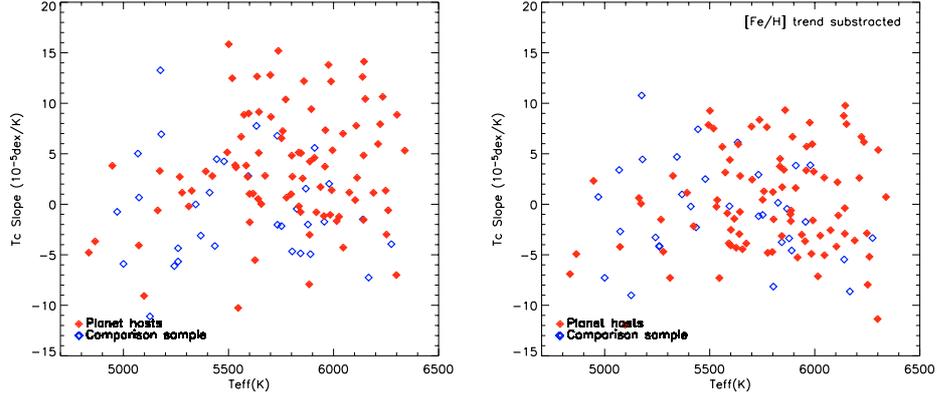
Fig. 5. [*X*/H] vs. T_C slopes plotted vs. $T_{\rm eff}$ for all the planet host (*filled symbols*) and comparison sample (*open symbols*) stars.

Table 4. Targets with T_C slopes more than 2σ below the fit. The atmospheric parameters are taken from Santos et al. (2004b, 2005) and the metallic abundances are from Ecuvillon et al. (2004a,b, 2006a) and Gilli et al. (2006). The Li and Be abundances are those published by Israelian et al. (2004) and Santos et al. (2004c).

	HD 114783	HD 169830
Type	plan	plan
T_C slope (10^{-5} K^{-1})	−9.07	−7.00
$T_{\rm eff}$ (K)	5098 ± 36	6299 ± 41
$\log g$	4.45 ± 0.11	4.10 ± 0.02
[Fe/H]	0.09 ± 0.04	0.21 ± 0.05
[C/H]	0.33 ± 0.13	0.19 ± 0.04
[N/H]	–	0.38 ± 0.12
[O/H]	0.08 ± 0.18	0.22 ± 0.12
[S/H]	0.10 ± 0.07	−0.10 ± 0.06
[Zn/H]	0.27 ± 0.07	–
[Cu/H]	0.21 ± 0.07	–
[Si/H]	0.02 ± 0.06	0.12 ± 0.05
[Ca/H]	−0.28 ± 0.07	0.11 ± 0.07
[Sc/H]	0.11 ± 0.08	0.18 ± 0.07
[Ti/H]	0.16 ± 0.08	0.08 ± 0.04
[V/H]	0.29 ± 0.10	0.17 ± 0.13
[Cr/H]	−0.01 ± 0.04	0.03 ± 0.03
[Mn/H]	0.21 ± 0.06	0.17 ± 0.10
[Co/H]	0.27 ± 0.10	0.15 ± 0.08
[Ni/H]	0.05 ± 0.09	0.09 ± 0.05
[Na/H]	−0.11 ± 0.04	0.41 ± 0.02
[Mg/H]	0.16 ± 0.04	0.18 ± 0.06
[Al/H]	0.18 ± 0.06	0.18 ± 0.03
$\log \epsilon$(Li)	−0.12	1.16
$\log \epsilon$(Be)	–	<−0.40

is "normal" in main-sequence stars with $T_{\rm eff}$ above 6000 K, which preserve a significant fraction of their original lithium. The Li deficiency in HD 83443, HD 23484 and HD 114783 is not surprising either because of their $T_{\rm eff}$ lower than 5500 K. The planet host HD 195019 shows the significant Li depletion reported by Israelian et al. (2004) in solar-type stars with

planets. Some mechanism might exist that makes stars with planets more efficient in depleting lithium than "single" stars. However, this result does not confirm that our targets have a signature of fractionated accretion. Moreover, none of these targets was reported by these authors to present an anomalous correlation of the lithium content with the orbital parameters.

3.2. T_C slopes as a function of T_{eff}

If pollution of the outer layers by infall is important, then a trend with $T_{\rm eff}$ also should be observed, since the convection zone decreases rapidly with increasing mass – and $T_{\rm eff}$ – for main-sequence stars. Pollution effects are expected to be much more evident in stars with $T_{\rm eff} > 6000$ K, where the surface convective zones have little mass and even slight accretion would result in apparent metallic abundances. Figure 5 (*left panel*) shows the slopes derived from [*X*/H] vs. T_C as a function of $T_{\rm eff}$. The two groups of stars with and without planets show considerable scatter, but a large number of planet host stars with high T_C slope values for $T_{\rm eff}$ above 5500 K are seen. This would be consistent with the behaviour predicted by the "self-pollution" hypothesis. Nevertheless, these slopes are affected by the trend with [Fe/H] due to Galactic chemical evolutionary effects. In order to remove this componenet from the plot of T_C slopes vs. $T_{\rm eff}$, we substracted the linear trend with [Fe/H] from the data (see Fig. 5, *right panel*), as proposed by Gonzalez (2003). The results do not show the previously observed incidence of planet host stars with high T_C slope values at $T_{\rm eff} > 5500$ K. Stars with planets present T_C slopes spanning the same range of values as the comparison sample with a similar scatter. The only noticeable difference is that the $T_{\rm eff}$ distribution of the set of stars with planets is shifted toward higher $T_{\rm eff}$. This is due to the fact that our comparison sample is particularly rich in cooler stars. This suggests that fractionated pollution may not be the main cause of the chemical anomalies found in planet host stars, and would support a "primordial" origin as much likelier.

3.3. T_C slopes as a function of planetary parameters

The physical parameters of exoplanets can give new hints to investigate the importance of pollution events on the chemical
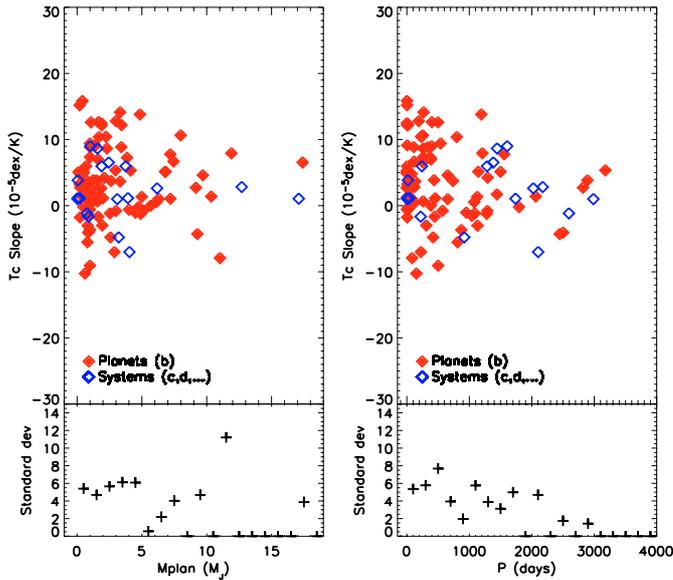
Fig. 6. [X/H] vs. T_C slopes plotted vs. the planetary mass in M_J units (*left panel*) and the planetary period in days (*right panel*) for all the planets: b components (*filled symbols*) and c, d, ... components of planetary systems (*open symbols*). The lower panels show the standard deviations per bin corresponding to the above representations.

Fig. 7. [X/H] vs. T_C slopes plotted vs. the orbital semi-major axis in AU (*left panel*) and the orbital eccentricity (*right panel*) for all the planets: b components (*filled symbols*) and c, d, ... components of planetary systems (*open symbols*). The lower panels show the standard deviations per bin corresponding to the above representations.

abundances of the planet host targets studied in this work. Some studies (Gonzalez 1998; Queloz et al. 2000; Sozzetti 2004) reported a possible relation between the stellar metallicity and the orbital separation, observing that stars hosting hot Jupiters tended to be more metal-rich than the rest. However, Santos et al. (2001, 2003) did not find a significant trend. Smith et al. (2001) found that the subgroup of stars reported as bearing possible accretion signatures had smaller orbital separations, and possibly smaller eccentricities and companion masses. A recent work by Sozzetti (2004) investigated the correlation between the stellar metallicity and the orbital period. They reported the absence of very short period planets around stars with [Fe/H] < 0 as possible evidence of the metallicity dependence of the migration rates of giant planets in protoplanetary discs.

In Figs. 6 and 7 the stellar [X/H] vs. T_C slopes are represented as a function of the planetary mass, orbital period, semi-major axis and eccentricity. The parameters of planets were obtained from the Extrasolar Planets Encyclopaedia (http://www.obspm.fr/encycl/encycl.html) compiled by Jean Schneider. No particular correlation emerges between the slope values and any planetary parameters. By visual inspection, the dispersion of T_C slopes seems to decrease with the planetary mass and period (see Fig. 6). However, we computed the standard deviation per bin to quantify the dispersion and visualize its behaviour as a function of the parameter studied (see *lower panels*), and no peculiar trends appeared. The observed distributions are simply related to the number of planets with a given value of the planetary parameter.

All the planetary parameters corresponding to peculiar stars with slopes more than 2σ above and below the fits are listed in Tables 5 and 6, respectively. Comparing with the distributions of all the analysed planet host stars, these objects are orbited by
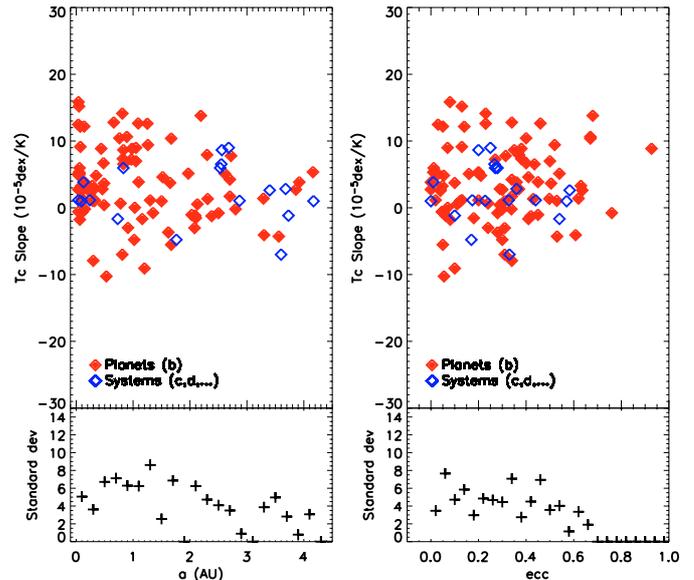
Table 5. Planetary parameters of targets with T_C slopes more than 2σ above the comparison sample fit, from the Extrasolar Planets Encyclopaedia (http://www.obspm.fr/encycl/encycl.html) compiled by Jean Schneider.

Planet	Mass (M_J)	Period (days)	a (AU)	Ecc.
HD 20367b	1.1	500	1.25	0.23
HD 40979b	3.3	267	0.81	0.23
HD 76700b	0.2	4	0.05	0.13
HD 83443b	0.4	3	0.04	0.08
HD 195019b	3.4	18	0.14	0.05

Table 6. Planetary parameters of targets with T_C slopes more than 2σ below the comparison sample fit, from the Extrasolar Planets Encyclopaedia (http://www.obspm.fr/encycl/encycl.html) compiled by Jean Schneider.

Planet	Mass (M_J)	Period (days)	a (AU)	Ecc.
HD 114783b	1.0	501	1.2	0.1
HD 169830b	2.9	226	0.8	0.3

low mass planetary companions at short periods. HD 76700, HD 83443 and HD 195019 have planets orbiting with particularly short periods and separations, that makes the infall of large amounts of planetary material much likelier to occur. Moreover, smaller orbital separations suggest the possibility of more interaction between planet, disk and star, as the planet presumably migrated inward to its current position around its parent star when it formed. All this supports the suggestion that these stars bear the signature of fractionated pollution.

4. Conclusions

After gathering detailed and uniform abundance ratios of volatile and refractory elements in a large set of planet host stars and a volume-limited comparison sample of stars without any known planets, we derived the [X/H] vs. T_C trend and the slope value corresponding to the linear fit for each target. Planet host stars present an average slope higher than the comparison sample. However, this characteristic is mainly due to chemical evolutionary effects, more evident in planet host stars because of their metal-rich nature. The obtained increasing trend of T_C with metallicity is a consequence of the Galactic chemical evolution. There does not seem to be any remarkable difference in the behaviour of stars with and without planetary companions. However, a subset of 5 planet host stars and 1 comparison sample target with slopes falling outside the trends are proposed as possible candidates for exhibiting signatures of fractionated accretion. The larger number of planet host stars than in the comparison sample and the statistical uncertainties affecting the slope values do not allow a conclusive interpretation.

Further evidence of pollution is investigated by looking for any possible dependence on T_{eff} and planetary parameters. No clear trends emerge with the stellar T_{eff}, contrary to the results of Gonzalez (2003). We did not observe any significant relation to the planetary mass, orbital period, separation and eccentricity. Similar results were obtained by Santos et al. (2003) when looking for possible correlations between the physical parameters of the exoplanets and the metallicity excess of their parent stars. Some of the targets we reported as candidates for possible selective accretion show planetary parameters compatible with a "self-pollution" scenario.

In conclusion, these possible candidates for self-pollution have to be carefully analyzed and submitted to further tests. Our results do not support a solely "primordial" or "self-pollution" scenario to explain the observed trends. Although in most cases a mainly primordial origin of the metallic excess in planet host stars seems likelier, a more complex mechanism combining both scenarios may underlie the observations.

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