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Abundances of Na, Mg and Al in stars with giant planets[⋆,⋆⋆]

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Abstract. We present Na, Mg and Al abundances in a set of 98 stars with known giant planets, and in a comparison sample of 41 "single" stars. The results show that the [X/H] abundances (with X = Na, Mg and Al) are, on average, higher in stars with giant planets, a result similar to the one found for iron. However, we did not find any strong difference in the [X/Fe] ratios, for a fixed [Fe/H], between the two samples of stars in the region where the samples overlap. The data was used to study the Galactic chemical evolution trends for Na, Mg and Al and to discuss the possible influence of planets on this evolution. The results, similar to those obtained by other authors, show that the [X/Fe] ratios all decrease as a function of metallicity up to solar values. While for Mg and Al this trend then becomes relatively constant, for Na we find indications of an upturn up to [Fe/H] values close to 0.25 dex. For metallicities above this value the [Na/Fe] becomes constant.

Key words. stars: abundances – stars: fundamental parameters – stars: planetary systems: formation – galaxy: abundances – solar neighbourhood

1. Introduction

The study of the chemical abundances of planet-host stars is providing important clues about the processes of planet formation and evolution. Soon after the discovery of the first exoplanets, it had been suggested that their host stars were particularly metal-rich compared to average field dwarfs (Gonzalez 1998). As new planets were added to the lists, this fact became more and more clear (e.g. Santos et al. 2001, 2003, 2004c; Gonzalez et al. 2001; Reid 2002). Today, it is well accepted that the probability of finding a planet is a strongly increasing function of the stellar metallicity, at least for [Fe/H] values above solar (Santos et al. 2004a).

Besides the analysis of the global metal content of the planet-host stars, some efforts have also been made to analyze the chemical abundances of specific elements. These include light element abundances (e.g. Garcia Lopez & Perez de Taoro 1998; Gonzalez & Laws 2000; Ryan 2000; Deliyannis et al. 2000; Israelian et al. 2003, 2004; Santos et al. 2002, 2004b), as well as other metals (e.g. Santos et al. 2000; Gonzalez & Laws 2000; Gonzalez et al. 2001; Smith et al. 2001; Takeda et al. 2001; Sadakane et al. 2002; Bodaghee et al. 2003; Ecuvillon et al. 2004a,b). In general, these studies agree that planet host stars are globally metal-rich compared to single field dwarfs. With a few exceptions (e.g. Gonzalez et al. 2001; Israelian et al. 2003) no major unexpected trends were suggested.

In their study of Na, Mg and Al abundances in stars harboring giant planets, Gonzalez et al. (2001) have presented evidence that the ratios [Na/Fe], [Mg/Fe] and [Al/Fe] may be smaller, for a given [Fe/H], in stars with planets when compared to "single" dwarfs. Unfortunately, Gonzalez et al. (2001) had to compare their Na, Mg and Al abundances for planet-hosts with those derived by other authors for field stars. The cause of the observed difference, not seen by other authors (Sadakane et al. 2002), may thus be simply due to the use of non-uniform samples.

To address this issue, we present in this paper a uniform analysis of the abundances of Na, Mg and Al in a sample of 98 stars with planets and a comparison sample of 41 "single" field stars. Stellar parameters for both samples have been obtained from a very uniform spectroscopic analysis (Santos et al. 2004c). Furthermore, the abundances of the three elements studied were derived from the analysis of high-resolution

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[⋆] Based on observations collected at the La Silla Observatory, ESO (Chile), with the CORALIE spectrograph at the 1.2-m Euler Swiss telescope and the FEROS spectrograph at the 1.52-m and 2.2-m ESO telescopes, with the VLT/UT2 Kueyen telescope (Paranal Observatory, ESO, Chile) using the UVES spectrograph (Observing run 67.C-0206, in service mode), with the TNG and William Herschel Telescopes, both operated at the island of La Palma, and with the ELODIE spectrograph at the 1.93-m telescope at the Observatoire de Haute Provence.

[⋆⋆] Tables 4–6 are only available in electronic form at `http://www.edpsciences.org`

Table 1. List of Na, Mg and Al lines and atomic parameters.

λ (Å)	χ_l	$\log gf$	λ (Å)	χ_l	$\log gf$
Na ($\log \epsilon_\odot = 6.33$)			8736.02	5.946	−0.224
5688.22	2.104	−0.625	8923.57	5.394	−1.652
6154.23	2.102	−1.607	Al ($\log \epsilon_\odot = 6.47$)		
6160.75	2.104	−1.316	6696.03	3.143	−1.570
Mg ($\log \epsilon_\odot = 7.58$)			6698.67	3.143	−1.879
5711.09	4.346	−1.706	7835.31	4.022	−0.728
6318.72	5.108	−1.996	7836.13	4.022	−0.559
6319.24	5.108	−2.179	8772.87	4.022	−0.425
8712.69	5.932	−1.204	8773.91	4.022	−0.212

Table 2. Abundance sensitivity to changes of 50 K in effective temperature, 0.15 dex in log g, 0.10 km s^{-1} in microturbulence and 0.10 dex in [Fe/H].

	$\Delta T_{\rm eff}$ +50 K	$\Delta\log g$ +0.15 dex	$\Delta\xi$ +0.10 km s^{-1}	Δ[Fe/H] +0.10 dex
HD128311 (4835 K; 4.44 dex; 0.89 km s^{-1}; 0.03 dex)				
Na	0.04	−0.04	−0.02	0.02
Mg	0.01	−0.03	−0.02	0.01
Al	0.03	−0.01	−0.02	0.00
HD 38529 (5674 K; 3.94 dex; 1.38 km s^{-1}; 0.40 dex)				
Na	0.03	−0.03	−0.01	−0.01
Mg	0.02	−0.03	−0.02	0.00
Al	0.02	−0.01	−0.01	−0.01
HD 17051 (6252 K; 4.61 dex; 1.18 km s^{-1}; 0.26 dex)				
Na	0.03	−0.02	0.00	0.01
Mg	0.03	−0.02	0.00	0.01
Al	0.03	0.00	0.00	0.00

spectra using the same line-lists for every star. The results show that planet host stars have, on average, [X/H] values (with X = Na, Mg and Al) above those found in field dwarfs. However, no major differences were found to exist between the [X/Fe] ratios in planet hosts and those found in our comparison sample stars for a given value of [Fe/H].

2. Data and spectral analysis

With the exception of HD 330075 (Pepe et al. 2004), the spectra used in this paper were those taken by Santos et al. (2004c) in their study of 98 planet-host stars and 41 comparison sample "single" dwarfs. For a more thorough presentation of the samples see Santos et al. (2004c, and references therein). HD 219542 B was excluded from the planet-host star list as the presence of a planet around this star has been disproved (Desidera et al. 2004).

The stellar parameters used are also the same has listed by Santos et al. (2004c) and Pepe et al. (2004)[1]. These were derived in a very uniform way, using high resolution spectra and the same line-lists and model atmospheres for all the stars.

Abundances for the elements studied here were derived from the analysis of a list of spectral lines initially taken from the literature (Edvardsson et al. 1993; Feltzing & Gustafsson 1998; Gonzalez & Laws 2000; Gonzalez et al. 2001; Smith et al. 2001; Sadakane et al. 2002; Chen et al. 2003). A careful choice of these was done based on the analysis of the Kurucz Solar Flux Atlas (Kurucz et al. 1984) to include only those lines that are not blended in the solar spectrum. All the lines used have wavelengths between 5000 and 9000 Å.

To derive semi-empirical atomic $\log gf$ values for the lines, we used their Equivalent Widths (EW) measured in the solar spectrum, and performed an inverted solar analysis. The solar abundances for each element were taken from Anders & Grevesse (1989), and the solar model was considered to have $T_{\rm eff}$ = 5777 K, $\log g$ = 4.44 dex, ξ_t = 1.00 km s^{-1} and $\log \epsilon$(Fe) = 7.47 dex. The final list of lines with their atomic parameters is presented in Table 1.

For each star, line EW were then measured in the stellar spectra using the IRAF "splot" task within the `echelle` package. The analysis was done in Local Thermodynamic Equilibrium (LTE) using a revised version of the code MOOG (Sneden 1973) (with the `abfind` driver) and a grid of (Kurucz 1993) ATLAS9 atmospheres. In a few particular cases, some lines were not used in the analysis due to the poor quality of the spectrum in the region of interest.

In Tables 4 through 6 we summarize the derived abundances for all stars with and without planetary-mass companions.

2.1. Errors

Errors and uncertainties can affect abundance measurements in various ways. Individual lines can be affected by errors in the EW, caused by unnoticed blends or a poor location of the continuum. Given that we have usually measured more than one line of each element in a given star, the dispersion around the average abundance gives us an idea about the errors due to these effects. Tables 4 through 6 show that the observed dispersions are usually below 0.05 dex, attesting to the quality of the line-list used.

Table 2 shows the abundance sensitivity to changes in effective temperature, $\log g$, microturbulence and [Fe/H] in three of our targets. A perturbation of 50 K in effective temperature, 0.15 dex in log g, 0.10 km s^{-1} in microturbulence and 0.05 dex in [Fe/H] (typical uncertainties on our parameters – Santos et al. 2004c) leads to a total typical uncertainty below 0.06 dex in the derived abundances.

Systematic errors in the stellar parameters and/or NLTE effects (the latter not taken into account in the current analysis) may also affect the derived abundances (see e.g. Shi et al. 2004). In Figs. 1 and 2 we present the abundance ratios [Na/Fe], [Mg/Fe] and [Al/Fe] as functions of the effective temperature and surface gravity. The results show that a very small dependence seems to exist for the abundances as a function of $T_{\rm eff}$, in particular for [Na/Fe]. A fit to the points in Fig. 1 shows, however, that the dependence is always below 0.10 dex/1000 K. Shi et al. (2004) have shown that the Na lines used in the current paper are particularly insensitive to NLTE effects.

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[1] Whose stellar parameters have also been obtained by our team.

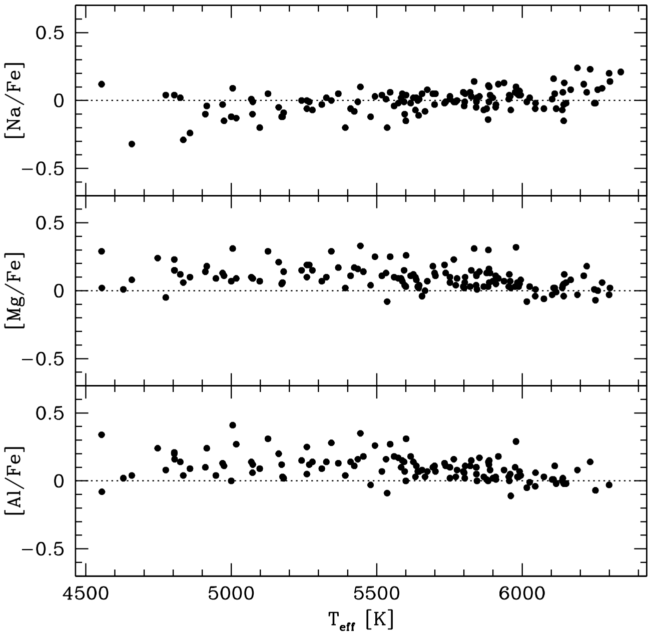

Fig. 1. [X/Fe] as a function of T_{eff}. The dotted line represents the solar [X/Fe] value.

3. Na, Mg and Al in planet-host stars

In Fig. 3 we present the distributions of [X/H] (with X = Na, Mg and Al) for stars with planets and comparison stars, as well as their cumulative functions. These histograms are similar to those presented for [Fe/H] in Santos et al. (2004c), and indicate that the excess metallicity for stars with planets is, as expected, not unique to iron. In Table 3, we list the average abundances for each element in the two samples, as well as its mean standard deviation and the differences in abundances between stars with planets and comparison stars. These differences vary between 0.20 dex (Mg) and 0.28 dex (Na), and are comparable to those found for other metals (Bodaghee et al. 2003; Ecuvillon et al. 2004a,b; Santos et al. 2004c).

The [Na/H] and [Al/H] distributions for planet-host stars also reveal an interesting feature already discussed in the literature (e.g. Santos et al. 2001; Bodaghee et al. 2003) for other elements: the distributions are not symmetrical, increasing as a function of increasing [X/H]. Possible interpretations for this are discussed in e.g. Santos et al. (2001, 2004c). The [Mg/H] distribution also looks slightly bimodal. The reason for the lack of stars with [Mg/H] ~ 0.3 is not clear, and may be simply due to small number statistics.

We have investigated possible dependences of the Na, Mg and Al abundances with the parameters of the orbiting planets (period, mass, eccentricity). No statistically significant differences were found.

3.1. [X/Fe] vs. [Fe/H]

In Gonzalez & Laws (2000) and Gonzalez et al. (2001) some possible anomalies concerning Na, Mg and Al were discussed. These authors have found that the [X/Fe] abundance ratios (with X = Na, Mg and Al) for stars with planets seemed to be slightly lower than those found for field dwarfs. Such a difference was, however, not found by other authors (Sadakane et al. 2002).

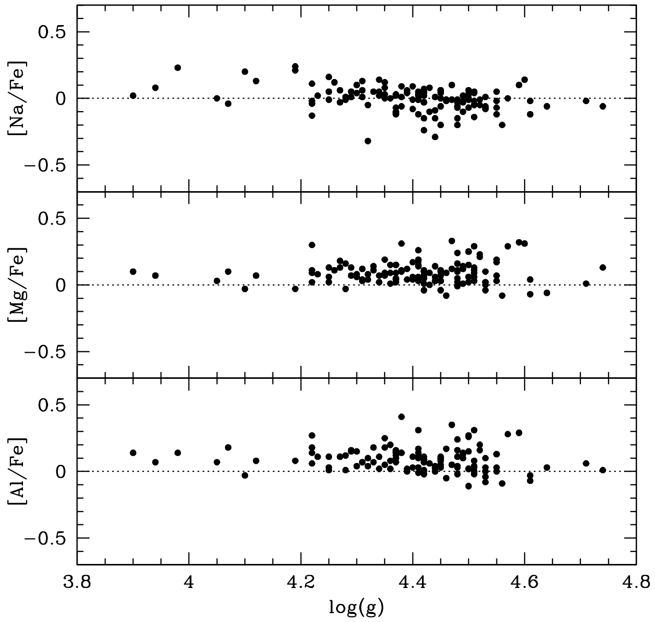

Fig. 2. Same as Fig. 1 but for log g.

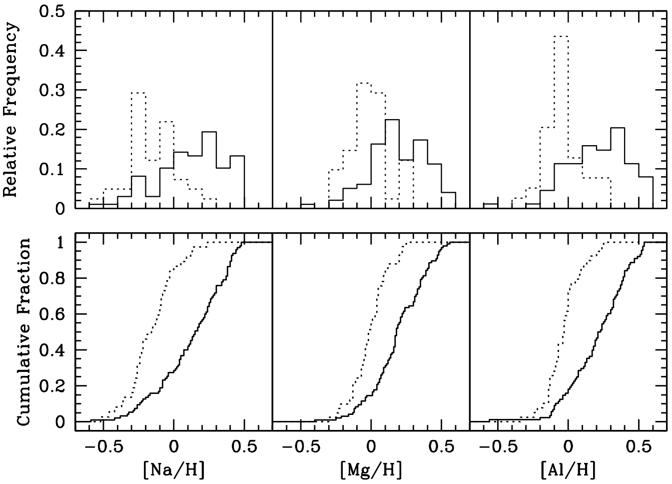

Fig. 3. *Upper panels*: distributions of [Na/H], [Mg/H] and [Al/H] for stars with planets (solid histogram) and for the comparison sample (dashed histogram). *Lower panels*: cumulative functions for both samples. In all cases, Kolmogorov-Smirnov probabilities are of the order of 10^{-8} that the two samples belong to the same population.

Table 3. Average abundances ⟨[X/H]⟩ for stars with planets and for comparison sample stars. The rms around the mean and the abundance difference between the two samples for each element are also listed.

Element	Stars with planets		Stars without planets		Average
(X)	⟨[X/H]⟩	σ	⟨[X/H]⟩	σ	difference
Na	0.12	0.24	−0.16	0.17	0.28
Mg	0.19	0.19	−0.01	0.13	0.20
Al	0.21	0.21	−0.03	0.13	0.24

In Figs. 4 and 5 we present plots of [X/Fe] and [X/H] vs. [Fe/H] for the three elements. Filled circles represent

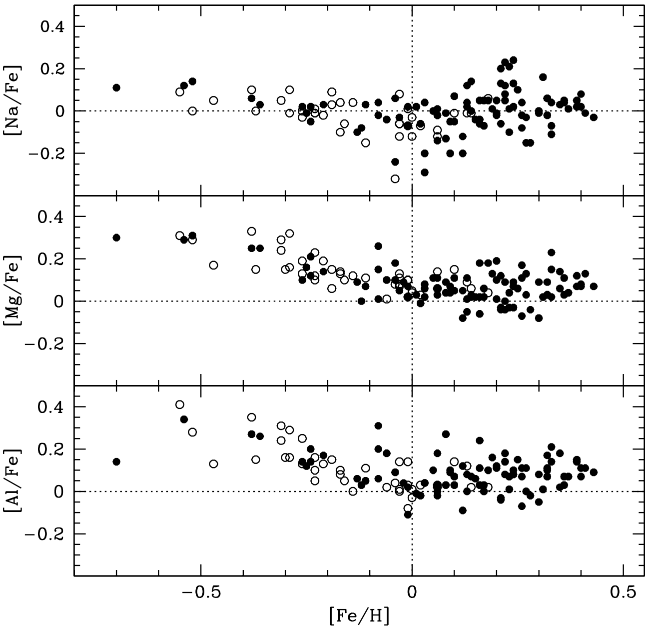

Fig. 4. Abundance ratios [X/Fe] for Na, Mg and Al as functions of metallicity. Filled circles are planet-host stars and the empty triangles are comparison stars. Dotted lines represent solar values.

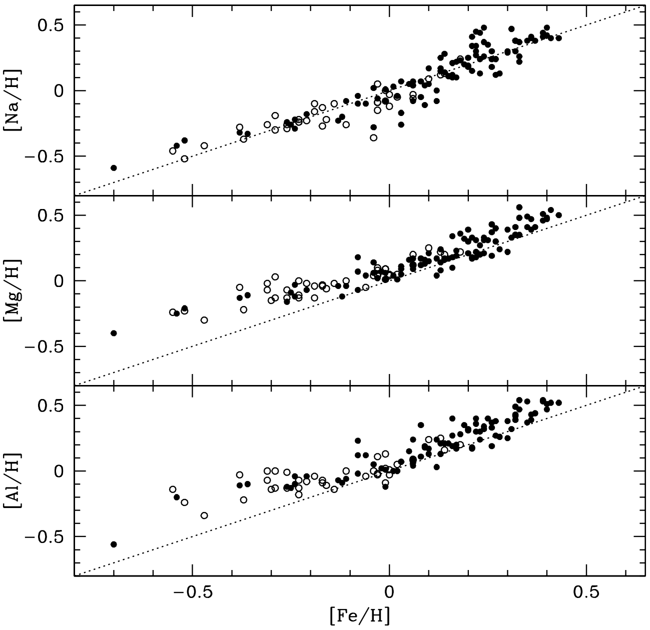

Fig. 5. Abundance ratios [X/H] for Na, Mg and Al as functions of [Fe/H]. Symbols as in Fig. 4.

planet-host stars, while open circles denote "single" field dwarfs. As we can see from the plots, there is no clear and distinctive difference between the two samples. We do not confirm that planet-host stars have lower [X/Fe] ratios for a given metallicity ([Fe/H]). The abundance distributions of stars with planets are high-[Fe/H] extensions to the curves traced by the field dwarfs, and no discontinuity seems to exist.

We should caution, however, that the number of comparison stars plotted is quite small, in particular for the metal-rich domain. An extension of the samples may thus be needed to support this discussion. Such a study is currently in progress.

Aluminum and magnesium were shown to be good tracers of the thin- and thick-disk populations, the latter presenting higher [X/Fe] values for a given [Fe/H] (e.g. Bensby et al. 2003; Fuhrmann 2004). The fact that no clear difference exists between planet-hosts and single field dwarfs suggests that both groups of objects belong (statistically) to the same population (the thin disk).

4. Galactic chemical evolution trends

Although the main goal of this work is to compare the abundances of Na, Mg and Al for planet-hosts and stars without giant planets, the results presented also give us a chance to study the chemical evolution trends of the Galaxy, and in particular in the metal-rich domain. Given the absence of significant differences between stars with planets and comparison stars, we will consider the samples as a whole for the rest of the paper.

4.1. Sodium

From Fig. 4, we can see that the distribution of [Na/Fe] presents a shallow decrease as a function of [Fe/H] in the domain $-0.7 <$ [Fe/H] < 0.0. For solar metallicity the average [Na/Fe] abundances are clearly below solar. For [Fe/H] > 0, we notice an uptrend. Interestingly, there is some hint that the [Na/Fe] values may become constant (and near the solar value) for [Fe/H] above ~0.25 dex. The average [Na/Fe] of the stars with [Fe/H] > 0.0 is solar (0.00 dex, with a dispersion of 0.10 dex). Unfortunately, the abundance distribution is affected by the dispersion of the points. It is not clear whether this dispersion is real or an artifact of the analysis (see Sect. 2.1).

The global trend observed in this paper confirms the results presented by other authors (e.g. Edvardsson et al. 1993; Feltzing & Gustafsson 1998; Reddy et al. 2003; Bensby et al. 2003; Shi et al. 2004), with the exception of Chen et al. (2000). The possible constance of the [Na/Fe] values for [Fe/H] above ~0.25 dex is also tentatively seen in Fig. 13 of Bensby et al. (2003), although it is not present in the NLTE study of Shi et al. (2004).

Sodium, as well as aluminum, is though to be mostly a product of Ne and C burning in massive stars, the same objects that will later give rise to SN II, the major producers of Mg (Arnett 1996). As we can see from Fig. 4, however, Na and Mg do not behave similarly as a function of stellar metallicity. This difference, also discussed in Bensby et al. (2003), may indicate the existence of different sources for one or both of these elements (SN Ia and AGB stars – Mowlavi 1999; Karakas & Lattanzio 2003; Tsujimoto et al. 1995), a dependence of the SNe yields of both elements with stellar metallicity, or a variation in the spectrum of the progenitor masses inside the metallicity regime studied here. Interestingly, Na abundances increase (globaly) almost exactly as iron (see Fig. 5), which may indicate a similar origin for both elements.

4.2. Magnesium

As for Na, the [Mg/Fe] distribution decreases with increasing metallicity until [Fe/H] $\sim$ 0.0, although the decrease is stronger than for Na (the [Na/Fe] values always remain close to solar for [Fe/H] $<$ 0.0). For higher metallicities, however, the [Mg/Fe] values become constant at an average of 0.06 ± 0.06 dex (where the error bar represents the rms), and no clear upturn in observed, although a slight increase of [Mg/Fe] as a function of [Fe/H] cannot be excluded. The average [Mg/Fe] (for a given [Fe/H]) remains above solar for the whole metallicity regime studied.

The Mg trend observed in Fig. 4 is very similar to the one presented by other authors (e.g. Feltzing & Gustafsson 1998; Chen et al. 2000; Bensby et al. 2003; Reddy et al. 2003).

Comparison of the Mg abundances thought to be produced by massive stars (Arnett 1996) with the ones found for other alpha-elements like Si, Ca and Ti, also produced by SN Ia events (e.g. Thielemann et al. 2002), should provide evidence about the origin of these elements. If we compare the Mg abundances derived in the current paper with those for other alpha elements presented in Bodaghee et al. (2003) (see their Fig. 2), we see a global agreement with silicon, although for metallicities below solar, the [Si/Fe] abundances tend to be lower than those found for [Mg/Fe]. For calcium (presenting a constant downward trend as a function of [Fe/H]), and to a lesser extent for Ti, however, we do not find the same trends for [Fe/H] $>$ 0.0. This may indicate that the yields for these two latter elements may be metallicity-dependent (e.g. due to a progenitor mass-metallicity dependence), or that different sources for these different elements give important contributions (e.g. SN Ia and AGB stars – Thielemann et al. 2002; Karakas & Lattanzio 2003). Our result regarding this issue is similar to the one found by Bensby et al. (2003).

4.3. Aluminum

The Al distribution is very similar to the one observed for Mg, with the [Al/Fe] values decreasing with increasing [Fe/H] up to solar values, then becoming relatively constant for metallicities above solar at an average value of 0.07 ± 0.07 dex. Contrary to Mg, however, for solar metallicities the average [Al/Fe] of our stars is close to 0.0 dex. Again, we cannot exclude a very shallow uptrend for above-solar metallicities.

Globally, the trend observed for Al is similar to the one already presented by other authors (e.g. Edvardsson et al. 1993; Feltzing & Gustafsson 1998; Reddy et al. 2003), although the slight upturn seen in Fig. 13 of Bensby et al. (2003) for [Fe/H] above solar is not clear in our data. Also, as for Na, our results are considerably different from those obtained by Chen et al. (2000).

The very similar trend observed for Al and Mg suggests a similar origin for both elements.

4.4. Anomalies and planets

In Sect. 3.1 we have seen that no large differences in the [X/Fe] ratios were found between planet-hosts and single stars. However, it is still possible that some specific trends found for the metal-rich tail of the Galactic chemical evolution are due to the presence of planets. Indeed, planets are more frequent around metal-rich stars (e.g. Santos et al. 2004c). It should thus be no surprise if their presence influences the yields of certain elements for metal-rich stars in the AGB phase responsible for the chemical enrichment of the Galaxy.

It is known that in addition to the CNO elements, Na, Mg and Al abundances are correlated in a large number of globular cluster stars (Kraft 1994) showing the general effects of mixing. It also became clear that Na and Al enhancements observed in many globular-cluster giants (Kraft 1994) can be produced by the ^{22}Ne(p, γ)^{23}Na reaction of the NeNa-cycle (Langer et al. 1993,and references therein). For this to occur, one would need material that had undergone significant O$\rightarrow$N or C$\rightarrow$N processing, while in the O-depleted layers we could expect a transformation of the ^{26}Mg and ^{25}Mg isotopes into Al in the MgAl-cycle (Langer et al. 1993). Langer et al. (1997) have also shown that the use of updated rates of Ne–Na cycle reactions can explain the Na-O abundance anticorrelation observed in globular-cluster giants, and the Na–N correlation observed in field halo giants. It is thus apparent that giants are not reliable for studying the primordial abundances of CNO-cycle elements. Clearly, it is not safe to use CNO, Na, Al and Mg elements in giants as probes of Galactic chemical evolution since rotation and mixing can alter surface abundances of these elements.

Furthermore, it is not clear how the yields of these elements will be altered in metal-rich giants due to the presence of planets. As a tentative example, if a star during its AGB evolution engulfs (short period) planets (many such planets have been found by current radial-velocity surveys[2]), it will change its angular momentum and rotation. As a consequence, its internal mixing history may be changed, possibly bringing different quantities of produced elements to the stellar outer layers, thus changing the chemical yields. Planet engulfment, eventually followed by extra-mixing, has already been suggested to explain the existence of Li-rich giant stars (e.g. Alexander 1967; Siess & Livio 1999). Overall, these processes could produce important changes in the chemical evolution trends of the Galaxy, in particular for the metal-rich domain.

5. Concluding remarks

In this paper we have derived abundances of Na, Mg and Al in a set of 98 planet-host stars and 41 comparison stars without known planets. The results were derived through a detailed and uniform spectroscopic analysis and gave us the possibility to compare the two samples. The main goal of this comparison is to look for differences connected to the presence of giant planets, but it was also used to explore chemical evolution trends in the Galaxy.

Through a comparison of Na, Mg and Al abundances of planet-hosts and stars without planets, we found an overabundance similar to that already found in iron. However, the abundance ratios [X/Fe] (with X = Na, Mg and Al) found for

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[2] See e.g. table at `http://obswww.unige.ch/exoplanets`

planet-hosts were not found to be significantly different from those obtained for our comparison stars for a given [Fe/H]. Finally, the trends in the [X/Fe] vs. [Fe/H] plots derived in this paper are similar to the ones presented in the literature, although some new interesting details seem to appear in the metal-rich domain. A discussion of possible implications for the chemical evolution of the Galaxy is presented.

Given the lack of "single" comparison stars with $[Fe/H] > 0.2$ dex, the conclusions presented above must be seen as preliminary. Indeed, future studies of elemental abundances in planet-host stars should include a comparison with a more significant number of "single" dwarfs having metallicities above solar. Such work is currently in progress.

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References

Alexander, J. B. 1967, The Observatory, 87, 238
Anders, E., & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Arnett, D. 1996, Supernovae and nucleosynthesis. an investigation of the history of matter, from the Big Bang to the present, Princeton series in astrophysics (Princeton, NJ: Princeton University Press)
Bensby, T., Feltzing, S., & Lundström, I. 2003, A&A, 410, 527
Bodaghee, A., Santos, N. C., Israelian, G., & Mayor, M. 2003, A&A, 404, 715
Chen, Y. Q., Nissen, P. E., Zhao, G., Zhang, H. W., & Benoni, T. 2000, A&AS, 141, 491
Chen, Y. Q., Zhao, G., Nissen, P. E., Bai, G. S., & Qiu, H. M. 2003, ApJ, 591, 925
Deliyannis, C. P., Cunha, K., King, J. R., & Boesgaard, A. M. 2000, AJ, 119, 2437
Desidera, S., Gratton, R. G., Endl, M., Claudi, R. U., & Cosentino, R. 2004, A&A, 420, L27
Ecuvillon, A., Israelian, G., Santos, N. C., et al. 2004a, A&A, 418, 703
Ecuvillon, A., Israelian, G., Santos, N. C., et al. 2004b, A&A, 426, 619
Edvardsson, B., Andersen, J., Gustafsson, B., et al. 1993, A&A, 275, 101
Feltzing, S., & Gustafsson, B. 1998, A&AS, 129, 237
Fuhrmann, K. 2004, Astron. Nachrichten, 325, 3
Garcia Lopez, R. J., & Perez de Taoro, M. R. 1998, A&A, 334, 599
Gonzalez, G. 1998, A&A, 334, 221
Gonzalez, G., & Laws, C. 2000, AJ, 119, 390
Gonzalez, G., Laws, C., Tyagi, S., & Reddy, B. E. 2001, AJ, 121, 432
Israelian, G., Santos, N. C., Mayor, M., & Rebolo, R. 2003, A&A, 405, 753
Israelian, G., Santos, N. C., Mayor, M., & Rebolo, R. 2004, A&A, 414, 601
Karakas, A. I., & Lattanzio, J. C. 2003, PASA, 20, 279
Kraft, R. P. 1994, PASP, 106, 553
Kurucz, R. 1993, ATLAS9 Stellar Atmosphere Programs and 2 km s^{-1} grid, Kurucz CD-ROM No. 13, Cambridge, Mass.: Smithsonian Astrophysical Observatory, 13
Kurucz, R. L., Furenlid, I., & Brault, J. T. L. 1984, Solar flux atlas from 296 to 1300 nm (National Solar Observatory Atlas, Sunspot, New Mexico: National Solar Observatory)
Langer, G. E., Hoffman, R., & Sneden, C. 1993, PASP, 105, 301
Langer, G. E., Hoffman, R. E., & Zaidins, C. S. 1997, PASP, 109, 244
Mowlavi, N. 1999, A&A, 350, 73
Pepe, F., Mayor, M., Queloz, D., et al. 2004, A&A, 423, 385
Reddy, B. E., Tomkin, J., Lambert, D. L., & Allende Prieto, C. 2003, MNRAS, 340, 304
Reid, I. N. 2002, PASP, 114, 306
Ryan, S. G. 2000, MNRAS, 316, L35
Sadakane, K., Ohkubo, M., Takeda, Y., et al. 2002, PASJ, 54, 911
Santos, N. C., Israelian, G., & Mayor, M. 2000, A&A, 363, 228
Santos, N. C., Israelian, G., & Mayor, M. 2001, A&A, 373, 1019
Santos, N. C., García López, R. J., Israelian, G., et al. 2002, A&A, 386, 1028
Santos, N. C., Israelian, G., Mayor, M., Rebolo, R., & Udry, S. 2003, A&A, 398, 363
Santos, N. C., Bouchy, F., Mayor, M., et al. 2004a, A&A, 426, L19
Santos, N. C., Israelian, G., García López, R. J., et al. 2004b, A&A, 427, 1085
Santos, N. C., Israelian, G., & Mayor, M. 2004c, A&A, 415, 1153
Shi, J. R., Gehren, T., & Zhao, G. 2004, A&A, 423, 683
Siess, L., & Livio, M. 1999, MNRAS, 308, 1133
Smith, V. V., Cunha, K., & Lazzaro, D. 2001, AJ, 121, 3207
Sneden, C. 1973, Ph.D. Thesis, Univ. of Texas
Takeda, Y., Sato, B., Kambe, E., et al. 2001, PASJ, 53, 1211
Thielemann, F.-K., Argast, D., Brachwitz, F., et al. 2002, Ap&SS, 281, 25
Tsujimoto, T., Nomoto, K., Yoshii, Y., et al. 1995, MNRAS, 277, 945

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Table 4. Atmospheric parameters (from Santos et al. 2004c) and abundances of Na, Mg and Al for stars with planets from HD 142 to HD 95128. The number of spectral lines used is given by n while σ denotes the rms around the average.

Star	[Na/H]	σ	n	[Mg/H]	σ	n	[Al/H]	σ	n	[Fe/H]	$T_{\rm eff}$	log g	ξ_t
HD 142	0.28	0.06	2	0.16	0.03	2	n.d.	n.d.	0	0.14	6302	4.34	1.86
HD 1237	−0.08	0.06	3	0.04	0.03	3	0.03	0.06	2	0.12	5536	4.56	1.33
HD 2039	0.38	0.05	2	0.35	0.03	3	0.42	0.02	2	0.32	5976	4.45	1.26
HD 3651	0.00	0.00	1	0.17	0.05	3	0.24	0.03	4	0.12	5173	4.37	0.74
HD 4203	0.42	0.02	3	0.48	0.05	3	0.51	0.02	2	0.40	5636	4.23	1.12
HD 4208	−0.22	0.03	3	−0.12	0.08	3	−0.10	0.01	2	−0.24	5626	4.49	0.95
HD 6434	−0.38	0.06	2	−0.21	0.06	3	n.d.	n.d.	0	−0.52	5835	4.60	1.53
HD 8574	0.04	0.03	3	0.12	0.06	3	0.04	0.06	2	0.06	6151	4.51	1.45
HD 9826	0.25	0.02	2	0.24	0.05	3	n.d.	n.d.	0	0.13	6212	4.26	1.69
HD 10647	−0.06	0.06	3	0.02	0.06	2	n.d.	n.d.	0	−0.03	6143	4.48	1.40
HD 10697	0.14	0.02	3	0.17	0.06	3	0.21	0.03	2	0.14	5641	4.05	1.13
HD 12661	0.41	0.06	3	0.47	0.03	3	0.43	0.02	4	0.36	5702	4.33	1.05
HD 13445	−0.29	0.06	3	−0.03	0.03	3	−0.04	0.01	2	−0.24	5163	4.52	0.72
HD 16141	0.11	0.03	3	0.17	0.02	3	0.21	0.03	2	0.15	5801	4.22	1.34
HD 17051	0.24	0.01	3	0.19	0.04	3	0.19	0.01	2	0.26	6252	4.61	1.18
HD 19994	0.48	0.02	3	0.21	0.00	1	0.32	0.00	1	0.24	6190	4.19	1.54
HD 20367	0.10	0.01	3	0.19	0.06	3	0.17	0.01	2	0.17	6138	4.53	1.22
HD 22049	−0.23	0.04	3	−0.04	0.04	3	−0.07	0.01	2	−0.13	5073	4.43	1.05
HD 23079	−0.08	0.03	3	−0.04	0.05	3	−0.06	0.02	2	−0.11	5959	4.35	1.20
HD 23596	0.47	0.05	3	0.33	0.05	3	0.32	0.04	4	0.31	6108	4.25	1.30
HD 27442	0.41	0.06	2	0.51	0.04	2	0.53	0.02	2	0.39	4825	3.55	1.18
HD 28185	0.27	0.04	3	0.18	0.04	3	0.30	0.02	2	0.22	5656	4.45	1.01
HD 30177	0.44	0.03	3	0.46	0.05	4	0.54	0.03	5	0.39	5588	4.29	1.08
HD 33636	−0.10	0.04	3	−0.07	0.01	3	−0.02	0.01	2	−0.08	6046	4.71	1.79
HD 37124	−0.32	0.05	3	−0.13	0.02	3	−0.11	0.02	4	−0.38	5546	4.50	0.80
HD 38529	0.48	0.01	3	0.47	0.02	3	0.47	0.03	2	0.40	5674	3.94	1.38
HD 39091	0.17	0.03	3	0.15	0.03	3	0.17	0.03	2	0.10	5991	4.42	1.24
HD 40979	0.34	0.00	1	0.33	0.04	2	n.d.	n.d.	0	0.21	6145	4.31	1.29
HD 46375	0.19	0.03	2	0.39	0.02	3	0.32	0.05	4	0.20	5268	4.41	0.97
HD 47536	−0.42	0.03	3	−0.25	0.04	6	−0.20	0.07	6	−0.54	4554	2.48	1.82
HD 49674	0.22	0.04	2	0.35	0.06	3	n.d.	n.d.	0	0.33	5644	4.37	0.89
HD 50554	0.03	0.05	3	0.04	0.02	3	0.00	0.01	2	0.01	6026	4.41	1.11
HD 52265	0.24	0.04	3	0.20	0.04	3	0.24	0.00	1	0.23	6103	4.28	1.36
HD 65216	−0.20	0.00	3	−0.12	0.03	4	−0.09	0.05	6	−0.12	5666	4.53	1.06
HD 68988	0.40	0.00	1	0.39	0.02	3	0.39	0.04	4	0.36	5988	4.45	1.25
HD 70642	0.23	0.05	2	0.36	0.04	3	0.28	0.02	2	0.18	5693	4.41	1.01
HD 72659	0.07	0.02	3	0.11	0.05	4	0.07	0.05	6	0.03	5995	4.30	1.42
HD 73256	0.30	0.05	3	0.37	0.03	4	0.33	0.05	6	0.26	5518	4.42	1.22
HD 73526	0.24	0.00	2	0.40	0.04	4	0.38	0.05	6	0.27	5699	4.27	1.26
HD 74156	0.21	0.01	3	0.18	0.01	3	0.27	0.00	1	0.16	6112	4.34	1.38
HD 75289	0.13	0.00	2	0.24	0.01	2	0.26	0.01	2	0.28	6143	4.42	1.53
HD 75732	0.26	0.03	2	0.48	0.05	3	0.47	0.01	2	0.33	5279	4.37	0.98
HD 76700	0.40	0.04	3	0.54	0.04	6	0.52	0.03	6	0.41	5737	4.25	1.18
HD 80606	0.30	0.05	2	0.41	0.04	3	0.49	0.03	3	0.32	5574	4.46	1.14
HD 82943	0.29	0.01	2	0.22	0.03	2	0.25	0.04	2	0.30	6016	4.46	1.13
HD 83443	n.d.	0.00	0	0.49	0.03	3	0.53	0.04	2	0.35	5454	4.33	1.08
HD 89744	0.45	0.02	2	n.d.	n.d.	0	0.36	0.05	5	0.22	6234	3.98	1.62
HD 92788	0.38	0.06	3	0.35	0.01	3	0.43	0.02	2	0.32	5821	4.45	1.16
HD 95128	0.07	0.02	2	0.09	0.04	3	0.09	0.03	4	0.06	5954	4.44	1.30

Table 5. Same as Table 4 for stars with planets from HD 106252 to HD 330075.

Star	[Na/H]	σ	n	[Mg/H]	σ	n	[Al/H]	σ	n	[Fe/H]	$T_{\rm eff}$	log g	ξ_t
HD 106252	0.01	0.01	3	0.06	0.05	2	0.01	0.00	1	−0.01	5899	4.34	1.08
HD 108147	0.18	0.05	3	0.21	0.01	2	n.d.	n.d.	0	0.20	6248	4.49	1.35
HD 108874	0.13	0.06	3	0.27	0.02	5	0.30	0.03	5	0.23	5596	4.37	0.89
HD 111232	−0.33	0.05	3	−0.11	0.02	3	−0.1	0.04	6	−0.36	5494	4.50	0.84
HD 114386	n.d.	n.d.	0	0.07	0.05	3	0.12	0.01	2	−0.08	4804	4.36	0.57
HD 114729	−0.26	0.04	3	−0.09	0.04	4	−0.13	0.05	4	−0.25	5886	4.28	1.25
HD 114762	−0.59	0.02	2	−0.40	0.00	2	−0.56	0.02	2	−0.70	5884	4.22	1.31
HD 114783	−0.11	0.01	2	0.16	0.03	3	0.18	0.05	4	0.09	5098	4.45	0.74
HD 117176	−0.10	0.02	3	0.04	0.03	3	0.12	0.06	2	−0.06	5560	4.07	1.18
HD 120136	0.44	0.00	1	n.d.	n.d.	0	n.d.	n.d.	0	0.23	6339	4.19	1.70
HD 121504	0.10	0.02	3	0.10	0.05	3	0.19	0.06	2	0.16	6075	4.64	1.31
HD 128311	−0.26	0.04	2	0.09	0.05	5	0.07	0.03	4	0.03	4835	4.44	0.89
HD 130322	−0.17	0.06	2	0.05	0.06	3	0.07	0.00	1	0.03	5392	4.48	0.85
HD 134987	0.30	0.04	2	0.39	0.04	3	0.38	0.03	3	0.30	5776	4.36	1.09
HD 136118	0.02	0.00	1	0.14	0.01	2	n.d.	n.d.	0	−0.04	6222	4.27	1.79
HD 137759	0.17	0.07	2	0.08	0.04	3	0.21	0.02	2	0.13	4775	3.09	1.78
HD 141937	0.05	0.02	3	0.21	0.04	3	0.13	0.03	4	0.10	5909	4.51	1.13
HD 142415	0.15	0.03	3	0.17	0.03	5	0.17	0.03	6	0.21	6045	4.53	1.12
HD 143761	−0.18	0.00	1	−0.07	0.01	3	−0.04	0.05	4	−0.21	5853	4.41	1.35
HD 145675	0.40	0.03	2	0.50	0.04	3	0.52	0.03	2	0.43	5311	4.42	0.92
HD 147513	−0.08	0.02	3	0.09	0.04	3	0.06	0.00	2	0.06	5883	4.51	1.18
HD 150706	−0.08	0.03	3	0.01	0.06	3	−0.12	0.03	3	−0.01	5961	4.50	1.11
HD 160691	0.38	0.04	3	0.35	0.04	3	0.39	0.02	2	0.32	5798	4.31	1.19
HD 162020	−0.28	0.04	2	0.06	0.04	3	0.05	0.00	2	−0.04	4858	4.42	0.86
HD 168443	0.04	0.01	2	0.17	0.03	3	0.24	0.02	3	0.06	5617	4.22	1.21
HD 168746	−0.04	0.04	3	0.18	0.02	3	0.23	0.04	2	−0.08	5601	4.41	0.99
HD 169830	0.41	0.01	2	0.18	0.05	2	0.18	0.02	2	0.21	6299	4.10	1.42
HD 177830	0.37	0.03	2	0.56	0.05	3	0.54	0.04	2	0.33	4804	3.57	1.14
HD 178911	0.12	0.06	2	0.30	0.04	3	0.27	0.00	1	0.27	5600	4.44	0.95
HD 179949	0.30	0.01	3	0.22	0.05	2	n.d.	n.d.	0	0.22	6260	4.43	1.41
HD 186427	0.07	0.00	1	0.12	0.05	3	0.11	0.03	3	0.08	5772	4.40	1.07
HD 187123	0.15	0.00	1	0.14	0.01	3	0.13	0.01	3	0.13	5845	4.42	1.10
HD 190228	−0.24	0.01	3	−0.16	0.02	3	−0.12	0.00	1	−0.26	5327	3.90	1.11
HD 190360	0.26	0.04	2	0.33	0.04	4	0.34	0.04	4	0.24	5584	4.37	1.07
HD 192263	n.d.	n.d.	0	0.07	0.05	3	0.02	0.01	2	−0.02	4947	4.51	0.86
HD 195019	0.04	0.02	3	0.13	0.02	3	0.19	0.01	2	0.09	5842	4.32	1.27
HD 196050	0.34	0.02	3	0.31	0.04	3	0.40	0.02	2	0.22	5918	4.35	1.39
HD 202206	0.38	0.02	2	0.41	0.06	2	0.37	0.00	2	0.35	5752	4.50	1.01
HD 209458	−0.04	0.00	2	0.01	0.02	2	0.00	0.01	2	0.02	6117	4.48	1.40
HD 210277	0.2	0.03	3	0.32	0.05	3	0.35	0.02	2	0.19	5532	4.29	1.04
HD 213240	0.22	0.04	3	0.23	0.03	3	0.20	0.00	1	0.17	5984	4.25	1.25
HD 216435	0.37	0.01	3	0.31	0.04	3	0.32	0.01	2	0.24	5938	4.12	1.28
HD 216437	0.35	0.05	3	0.31	0.02	3	0.40	0.02	2	0.25	5887	4.30	1.31
HD 216770	0.18	0.00	1	0.43	0.00	1	0.37	0.05	4	0.26	5423	4.40	1.01
HD 217014	0.25	0.04	3	0.3	0.03	3	0.31	0.01	2	0.20	5804	4.42	1.20
HD 217107	0.38	0.04	3	0.41	0.05	3	0.44	0.02	2	0.37	5646	4.31	1.06
HD 222404	0.12	0.00	1	0.34	0.04	2	0.40	0.04	3	0.16	4916	3.36	3.36
HD 222582	0.05	0.02	3	0.16	0.02	3	0.15	0.03	2	0.05	5843	4.45	1.03
HD 330075	−0.05	0.02	2	0.17	0.00	2	0.35	0.01	2	0.08	5017	4.22	0.69

Table 6. Same as Table 4 for the comparison sample of stars without known planets.

Star	[Na/H]	σ	n	[Mg/H]	σ	n	[Al/H]	σ	n	[Fe/H]	$T_{\rm eff}$	$\log g$	ξ_t
HD 1581	−0.10	0.05	3	−0.02	0.00	2	−0.14	0.01	2	−0.14	5956	4.39	1.07
HD 4391	−0.09	0.05	3	0.10	0.01	2	−0.02	0.00	1	−0.03	5878	4.74	1.13
HD 5133	−0.27	0.04	2	−0.03	0.04	3	−0.07	0.01	2	−0.17	4911	4.49	0.71
HD 7570	0.24	0.03	3	0.22	0.01	3	0.20	0.01	2	0.18	6140	4.39	1.5
HD 10360	−0.29	0.05	2	−0.13	0.04	3	−0.13	0.01	2	−0.26	4970	4.49	0.76
HD 10700	−0.52	0.03	2	−0.23	0.01	3	−0.24	0.02	2	−0.52	5344	4.57	0.91
HD 14412	−0.42	0.04	3	−0.3	0.03	3	−0.34	0.03	2	−0.47	5368	4.55	0.88
HD 17925	−0.03	0.05	3	0.20	0.04	2	0.08	0.01	2	0.06	5180	4.44	1.33
HD 20010	−0.10	0.03	3	−0.13	0.05	2	n.d.	n.d.	0	−0.19	6275	4.4	2.41
HD 20766	−0.23	0.01	3	−0.02	0.01	2	−0.08	0.02	2	−0.21	5733	4.55	1.09
HD 20794	−0.28	0.04	3	−0.05	0.03	3	−0.03	0.02	2	−0.38	5444	4.47	0.98
HD 20807	−0.24	0.02	3	−0.11	0.05	3	−0.18	0.03	2	−0.23	5843	4.47	1.17
HD 23249	0.12	0.05	3	0.22	0.04	3	0.25	0.03	2	0.13	5074	3.77	1.08
HD 23356	−0.26	0.01	0	0.00	0.04	3	0.00	0.01	2	−0.11	4975	4.48	0.77
HD 23484	−0.06	0.06	3	0.12	0.04	3	0.09	0.02	2	0.06	5176	4.41	1.03
HD 26965	−0.26	0.02	2	−0.02	0.03	3	0.00	0.01	2	−0.31	5126	4.51	0.60
HD 30495	−0.05	0.03	3	0.05	0.03	3	0.05	0.01	2	0.02	5868	4.55	1.24
HD 36435	−0.12	0.05	3	0.04	0.01	3	−0.03	0.02	2	0.00	5479	4.61	1.12
HD 38858	−0.22	0.01	3	−0.13	0.04	3	−0.13	0.00	2	−0.23	5752	4.53	1.26
HD 40307	n.d.	n.d.	0	−0.15	0.05	3	−0.14	0.04	2	−0.3	4805	4.37	0.49
HD 43162	−0.08	0.04	3	0.09	0.00	2	0.02	0.02	2	−0.01	5633	4.48	1.24
HD 43834	0.09	0.02	3	0.25	0.02	3	0.24	0.05	2	0.10	5594	4.41	1.05
HD 50281	−0.36	0.04	2	0.04	0.06	3	0.00	0.01	2	−0.04	4658	4.32	0.64
HD 53705	−0.16	0.02	3	−0.04	0.04	3	−0.04	0.01	2	−0.19	5825	4.37	1.20
HD 53706	−0.26	0.04	3	−0.07	0.00	2	−0.01	0.00	2	−0.26	5260	4.35	0.74
HD 65907	−0.19	0.04	3	0.03	0.03	2	0.00	0.00	2	−0.29	5979	4.59	1.36
HD 69830	−0.09	0.04	3	0.08	0.00	2	0.11	0.01	2	−0.03	5410	4.38	0.89
HD 72673	−0.37	0.04	3	−0.22	0.06	3	−0.22	0.02	2	−0.37	5242	4.50	0.69
HD 74576	−0.15	0.04	2	0.04	0.04	3	−0.03	0.01	2	−0.03	5000	4.55	1.07
HD 76151	0.13	0.02	3	0.20	0.05	3	0.16	0.03	2	0.14	5803	4.50	1.02
HD 84117	0.05	0.05	3	0.05	0.05	2	n.d.	n.d.	0	−0.03	6167	4.35	1.42
HD 189567	−0.24	0.02	3	0.00	0.04	2	−0.07	0.00	1	−0.23	5765	4.52	1.22
HD 191408	−0.46	0.06	3	−0.24	0.00	2	−0.14	0.02	2	−0.55	5005	4.38	0.67
HD 192310	0.00	0.03	2	0.09	0.02	2	0.13	0.00	2	−0.01	5069	4.38	0.79
HD 196761	−0.3	0.03	3	−0.13	0.03	3	−0.13	0.02	2	−0.29	5435	4.48	0.91
HD 207129	−0.03	0.03	3	0.05	0.03	3	0.01	0.01	2	0.00	5910	4.42	1.14
HD 209100	n.d.	n.d.	0	−0.05	0.01	2	−0.04	0.01	2	−0.06	4629	4.36	0.42
HD 211415	−0.13	0.04	3	−0.04	0.02	2	−0.09	0.04	2	−0.17	5890	4.51	1.12
HD 216803	n.d.	n.d.	0	0.01	0.05	3	−0.09	0.03	2	−0.01	4555	4.53	0.66
HD 222237	n.d.	n.d.	0	−0.07	0.02	2	−0.07	0.03	2	−0.31	4747	4.48	0.40
HD 222335	−0.22	0.03	3	−0.06	0.04	3	−0.11	0.01	2	−0.16	5260	4.45	0.92