Nitrogen abundances in Planet-harbouring stars

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Abstract. We present a detailed spectroscopic analysis of nitrogen abundances in 91 solar-type stars, 66 with and 25 without known planetary mass companions. All comparison sample stars and 28 planet hosts were analysed by spectral synthesis of the near-UV NH band at 3360 Å observed at high resolution with the VLT/UVES, while the near-IR N\textsubscript{i} 7468 Å was measured in 31 objects. These two abundance indicators are in good agreement. We found that nitrogen abundance scales with that of iron in the metallicity range $-0.6 < [\text{Fe/H}] < +0.4$ with the slope $1.08 \pm 0.05$. Our results show that the bulk of nitrogen production at high metallicities was coupled with iron. We found that the nitrogen abundance distribution in stars with exoplanets is the high [Fe/H] extension of the curve traced by the comparison sample of stars with no known planets. A comparison of our nitrogen abundances with those available in the literature shows a good agreement.

Key words. stars: abundances – stars: chemically peculiar – stars: evolution – planetary systems – solar neighbourhood

1. Introduction

Knowledge of CNO abundances in main sequence stars is clearly important because of the key roles of the former in the chain of nucleosynthesis. They can give us information about the history of element production in different types of stars. Solar-type stars can be very informative as tracers of the chemical and dynamical evolution of the Galaxy (e.g. Pagel & Edmunds 1981; Edvardsson et al. 1993; Bensby et al. 2003) as they spend between $10^9$ to several times $10^{10}$ years on the main sequence.

The abundant isotope $^{14}$N is synthesized through the CNO cycles in a hydrogen-burning shell of the stellar interior. With regard to the chemistry of planet-harbouring stars, the study of the nitrogen abundances of solar-type dwarfs with and without known planets represents an important key to checking the “self-enrichment” scenario. This hypothesis attributes the origin of the overabundance of metals to the accretion of large amounts of metal-rich, H- and He-depleted rocky planetesimal materials on to the star.

On the one hand, by studying chemical abundances and planetary orbital parameters, several authors reject the possibility of pollution as the main source of the metallicity enhancement observed in planet host stars and propose instead that the metal-rich nature of stars with planets has most probably a “primordial” source in the high metallicity of the primordial cloud (Santos et al. 2001, 2002, 2003a). The effect on metal abundances of contamination in the outer convective zone by accreted planetary material in FGK main sequence stars has been discussed in Pinsonneault et al. (2001) and the same conclusion was reached. However, the possibility that pollution may occur has not been excluded. Israelian et al. (2001, 2003a) have found evidence of the infall of a planet into the planet host star HD 82943. $^6$Li and $^7$Li may provide an independent test to confirm this scenario (Israelian et al. 2003a).

On the other hand, the “self-enrichment” scenario would imply that volatile element (with low condensation temperature $T_C$) abundances do not show overabundance in the same way that refractories do, since the elements of the former group are deficient in accreted materials relative to the latter. This hypothesis has to be tested by searching for possible differences among volatile elements, such as CNO, S and Zn, and refractory ones, such as $\alpha$ Si, Mg, Ca, Ti and the iron-group elements. Smith et al.
Table 1. Observing log for the new set of stars with planets and brown dwarf companions. Near-UV and optical spectra were obtained with UVES, and with SARG and FEROS, respectively. The S/N ratio is provided at 3357 Å for near-UV data and at 7400 Å in optical spectra.

| Star  | V   | Obser. Run | S/N | Date     |
|-------|-----|------------|-----|----------|
| HD 6434 | 7.7 | UVES       | 150 | Oct. 2001|
| HD 22049 | 3.7 | UVES       | 150 | Oct. 2001|
| HD 30177 | 8.4 | FEROS     | 200 | Mar. 2003|
| HD 40979 | 6.8 | SARG      | 220 | Oct. 2003|
| HD 46375 | 7.8 | UVES       | 150 | Nov. 2001|
| HD 65216 | 9.6 | FEROS     | 250 | Mar. 2003|
| HD 68988 | 8.2 | SARG      | 160 | Oct. 2003|
| HD 72659 | 7.4 | FEROS     | 200 | Mar. 2003|
| HD 73256 | 8.1 | FEROS     | 200 | Mar. 2003|
| HD 73526 | 9.0 | FEROS     | 250 | Mar. 2003|
| HD 76700 | 8.1 | FEROS     | 200 | Mar. 2003|
| HD 83443 | 8.2 | UVES       | 120 | Nov. 2001|
| HD 10647 | 5.5 | UVES       | 160 | Oct. 2001|
| HD 142415 | 7.3 | FEROS     | 250 | Mar. 2003|
| HD 169830 | 5.9 | UVES       | 160 | Oct. 2001|
| HD 178911B | 6.7 | SARG     | 280 | Oct. 2003|
| HD 179949 | 6.3 | UVES       | 160 | Oct. 2001|
| HD 202206 | 8.1 | UVES       | 150 | Nov. 2001|
| HD 209458 | 7.7 | UVES       | 150 | Nov. 2001|
| HD 216770 | 8.1 | FEROS     | 220 | Oct. 2003|
| HD 219542B | 8.2 | SARG     | 230 | Oct. 2003|
| HD 222582 | 7.7 | UVES       | 180 | Nov. 2001|

Table 2. Observing log for the new set of comparison stars (stars without known giant planets). Near-UV spectra are obtained with UVES. The S/N ratio is provided at 3357 Å.

| Star  | V   | Obser. Run | S/N | Date     |
|-------|-----|------------|-----|----------|
| HD 4391 | 5.8 | UVES       | 240 | Oct. 2001|
| HD 7570 | 4.9 | UVES       | 150 | Oct. 2001|
| HD 10700 | 3.5 | UVES       | 200 | Oct. 2001|
| HD 14412 | 6.3 | UVES       | 130 | Oct. 2001|
| HD 20010 | 3.9 | UVES       | 240 | Oct. 2001|
| HD 20766 | 5.5 | UVES       | 140 | Oct. 2001|
| HD 20794 | 4.3 | UVES       | 130 | Oct. 2001|
| HD 20807 | 5.2 | UVES       | 180 | Oct. 2001|
| HD 23484 | 7.0 | UVES       | 160 | Oct. 2001|
| HD 30495 | 5.5 | UVES       | 120 | Oct. 2001|
| HD 36435 | 7.0 | UVES       | 110 | Oct. 2001|
| HD 38858 | 6.0 | UVES       | 80  | Oct. 2001|
| HD 43162 | 6.4 | UVES       | 180 | Nov. 2001|
| HD 43834 | 5.1 | UVES       | 180 | Nov. 2001|
| HD 69830 | 5.9 | UVES       | 130 | Oct. 2001|
| HD 72673 | 6.4 | UVES       | 110 | Nov. 2001|
| HD 76151 | 6.0 | UVES       | 90  | Oct. 2001|
| HD 84117 | 4.9 | UVES       | 200 | Nov. 2001|
| HD 189567 | 6.1 | UVES       | 140 | Oct. 2001|
| HD 192310 | 5.7 | UVES       | 90  | Oct. 2001|
| HD 211415 | 5.3 | UVES       | 120 | Oct. 2001|

(2001) found out that a small subset of stars with planets bore this accretion signature. They discovered that these stars exhibit a trend of increasing $[X/H]$ with increasing $T_C$ for a given element $X$. However, a following study by Takeda et al. (2001) showed that all the elements, volatiles and refractories alike, of fourteen planet-harbouring stars behave quite similar, suggesting that the enhanced metallicity is not caused by the accretion of rocky material but is rather of primordial origin. Recently, Sadakane et al. (2002) confirmed this result for nineteen elements, volatiles and refractories, in twelve planet host stars. Gonzalez et al. (2001) and Santos et al. (2000) did not find significant differences in the $[C/Fe]$ and $[O/Fe]$ values among planet-harbouring and field stars. Some of these authors derived nitrogen abundances from atomic lines (e.g. Gonzalez & Laws 2000; Gonzalez et al. 2001; Takeda et al. 2001; Sadakane et al. 2002). We note that most of them made no mention of their final results and conclusions concerning nitrogen.

Various studies have accumulated evidence that the production of nitrogen at low $[Fe/H]$ proceeds principally as a primary rather than a secondary process (Pagel & Edmunds 1981; Bessel & Norris 1982; Carbon et al. 1987; Henry et al. 2000). The secondary process dominates at high metallicities. Two possible primary sources of nitrogen have been proposed. The first is intermediate mass ($4–8 M_\odot$) stars during their thermally pulsing asymptotic giant branch phases; if temperature conditions are suitable,
primary nitrogen can be produced by CN processing in the convective envelope from freshly synthesized dredged up carbon (Marigo 2001; van den Hoek & Groenewegen 1997). The second source is rotating massive stars (Maeder & Meynet 2000). The latter would imply uncoupled N and Fe abundances and a nitrogen overproduction relative to iron.

Recently, Liang et al. (2001) and Pettini et al. (2002) concluded that the contribution by massive stars to the nitrogen abundance is generally very low, and that the dominant N contributors are intermediate and low mass stars (ILMS). Although the nitrogen is chiefly primary at low [Fe/H], ILMS are also sources of secondary nitrogen. The relative weights of the secondary and primary components depend on the interplay between secondary enrichment caused by dredge-up episodes and the primary contribution given by the CNO cycle during the envelope burning. Shi et al. (2002) obtained similar results by measuring N I lines in a large sample of disk stars with a metallicity range of $-1.0 < [\text{Fe/H}] < +0.2$.

However, the situation is rather confused. Other authors support the origin of primary nitrogen in massive stars (e.g. Izotov & Thuan 2000) because of the low scatter of $[\text{N/O}]$ ratios in galaxies observed at different stages of their evolution, which would imply no time delay between the injection of nitrogen and oxygen. Meynet & Maeder (2002) have discussed the effect of rotation in the production of primary and secondary nitrogen in intermediate and high mass stars, introducing axial rotation and rotationally induced mixing of chemical species in their stellar models. They concluded that ILMS are the main source of primary nitrogen at low metallicities.

The main problem that has traditionally made it difficult to measure nitrogen abundances is that there are very few atomic nitrogen lines in the red part of the spectrum. Efficient modern detectors now enable us to obtain high-resolution near-UV spectra, which allows us to carry out a precise and independent study of nitrogen abundance by using the NH band at 3360 Å.

The purpose of this work is to obtain a systematic, uniform and detailed study of nitrogen abundance in two samples of solar-type dwarfs, a large set of planet hosts and a comparison volume-limited sample of stars with no known planetary mass companions. We used two independent indicators in the abundance determination: spectral synthesis of the NH band in near-UV high-resolution spectra and the near-IR N I 7468Å line.
2. Observations

Spectra for most of the planet-harbouring stars have been collected and used to derive precise stellar parameters in a series of recent papers (e.g. Santos et al. 2001, 2003a, 2003b). For measurement of the N i 7468 Å line we used all the spectra of this set obtained with the FEROS spectrograph on the 2.2 m ESO/MPI telescope (La Silla, Chile), the SARG spectrograph on the 3.5 m TNG and the UES spectrograph on the 4.2 m WHT (both at the Roque de los Muchachos Observatory, La Palma), and other spectra from subsequent observational runs using the same instruments.

For NH band synthesis, we used the same spectra as those in Santos et al. (2002) to derive beryllium abundances. New spectra were obtained with UVES spectrograph, at the VLT/UT2 Kueyen telescope (Paranal Observatory, ESO, Chile). The observing log for the spectra from campaigns carried out after Santos et al. (2002) and Bodaghee et al. (2003) are listed in Tables 1 and 2. The obtained high S/N spectra have a minimum resolution $R \geq 50000$.

The data reduction for the SARG and UVES spectra was done using IRAF tools in the echelle package. Standard background correction, flatfield and extraction procedures were used. The wavelength calibration was performed using a ThAr lamp spectrum taken on the same night. The FEROS spectra were reduced using the FEROS pipeline software.

3. Analysis

Abundances for all elements were determined using a standard local thermodynamic equilibrium (LTE) analysis with the revised version of the spectral synthesis code MOOG (Sneden 1973) and a grid of Kurucz ATLAS9 atmospheres. All the atmospheric parameters, $T_{\text{eff}}$, $\log g$, $\xi$, and [Fe/H], and the corresponding uncertainties were taken from Santos et al. (2003b). The adopted solar abundances for nitrogen and iron were $\log \epsilon (N)_{\odot} = 8.05$ dex (Anders & Grevesse 1989) and $\log \epsilon (Fe)_{\odot} = 7.47$ dex (Santos et al. 2003b).
Table 3. Sensitivity of the nitrogen abundance, derived from the NH band at 3360 Å and from the N\textsc{i} line at 7468 Å, to changes of 100 K in effective temperature, 0.2 dex in gravity and 0.2 dex in metallicity.

| Star      | (T\text{eff}; \log g; [Fe/H]) | NH | N\textsc{i} |
|-----------|-------------------------------|----|-------------|
| HD 46375  | (5268; 4.41; 0.20)             | ±0.09 | ±0.09 |
| HD 73526  | (5699; 4.27; 0.27)             | ±0.09 | ±0.09 |
| HD 7570   | (6140; 4.39; 0.18)             | ±0.11 | ±0.08 |
| HD 19994  | (6190; 4.19; 0.24)             | ±0.2 dex | ±0.11 dex |
| HD 12661  | (5702; 4.33; 0.36)             | ±0.2 dex | ±0.08 dex |
| HD 142415 | (6045; 4.53; 0.21)             | ±0.2 dex | ±0.05 dex |
| HD 143761 | (5853; 4.41; -0.20)            | ±0.2 dex | ±0.05 dex |
| HD 187123 | (5845; 4.42; 0.13)             | ±0.2 dex | ±0.03 dex |
| HD 76700  | (5737; 4.25; 0.41)             | ±0.2 dex | ±0.03 dex |

Fig. 3. [N/Fe] vs. T\text{eff} and \log g. Filled and open diamonds represent planet host and comparison sample stars from NH band synthesis, respectively. Asterisks and open triangles denote planet host stars from N\textsc{i} line and from literature values, respectively.

3.1. Synthesis of NH band

The NH molecular feature is the strongest one in the spectral region λλ3345–3375 Å. We determined nitrogen abundances by fitting synthetic spectra to data in this wavelength range. The NH spectra were calculated with the dissociation potential $D_0(NH) = 3.37 \pm 0.06$ eV recommended in Grevesse et al. (1990).

A detailed line list from Yakovina & Pavlenko (1998) was adopted. These authors obtained a good fit to the Kurucz Solar Atlas (Kurucz et al. 1993) by changing oscillator strength values of the strongest lines and continuum level in a list of atomic and molecular lines from Kurucz’s 1993 database. In our analysis, we slightly modified log $gf$ values of this line list\(^3\) (changes smaller than 0.01 dex in most cases) in order to avoid modifying the continuum level when fitting the high-resolution Kurucz Solar Atlas (Kurucz et al. 1984) with a solar model having $T_{\text{eff}} = 5777$ K, $\log g = 4.44$ dex and $\xi_t = 1.0$ km s$^{-1}$, assuming the solar N abundance of $\log \epsilon(\text{N})_\odot = 8.05$ dex.

All our targets are solar-type dwarfs with [Fe/H] values between -0.6 and +0.4 dex and $T_{\text{eff}}$ between 5000 and 6300 K. Stars with lower $T_{\text{eff}}$ were rejected since they would have introduced great uncertainties in the abundance results. The discarded targets were HD 27442, HD 192263, HD 74576 and HD 23484, with $T_{\text{eff}}$ of 4825 K, 4947 K, 5000 K and 5176 K, respectively.

The main difficulties were the severe atomic line contamination of the NH features and the crowding of the lines in the UV region. The oscillator strengths of these lines are not known with high accuracy. The crowding of blended lines worsens with the increase of metallicity. This characteristic involves difficulties when fixing the continuum level since the whole spectral region is depressed by line absorption. Continuum was normalized with 5th order polynoma using the CONT task of IRAF. However

\(^3\) The full line list is available in www.iac.es
we could make further improvements in the placement of continuum using the Kurucz Solar Flux Atlas (Kurucz et al. [121]), and DIPSO task of the STARLINK software: continuum level was determined by superimposing observed and synthetic solar spectra and selecting some points of reference. Figure 1 shows significant points in continuum determination, selected in the spectral regions $\lambda\lambda 3344–3350$ Å, $\lambda\lambda 3350–3358$ Å and $\lambda\lambda 3362–3370$ Å for HD 17051. This method was valid for stars with $T_{\text{eff}}$ and metallicities around solar values, while in cooler objects we were not able to assure that continuum level could be scaled to the Sun.

In order to find the best synthetic spectrum for each star, we used the program FITTING. This program allows us to create a grid of synthetic spectra for several free parameters, such as abundances, atmospheric parameters, metallicity, etc., and to compare it with the observed spectrum. To generate synthetic spectra, it calls the spectral synthesis code MOOG. The best fit is determined by applying a $\chi^2$ minimization method to the spectral regions considered to be the most significant.

We used a Gaussian function with a FWHM of 0.07 Å for the instrumental broadening, and a rotational broadening function with $v_{\text{sin}i} = 4$ km s$^{-1}$. No macroturbulence broadening was used. We assumed the same rotational velocity for all the targets since small differences would affect only $\chi^2$ values, not final nitrogen abundances. Only for HD 120136 and HD 19994 we took $v_{\text{sin}i} = 14.5$ km s$^{-1}$ and $v_{\text{sin}i} = 8.2$ km s$^{-1}$ from the CORALIE database. We stress that planet searches based on the Doppler technique are biased in favour of old stars with low $v_{\text{sin}i}$ and therefore all our targets are slow rotators. In any case, precise values of $v_{\text{sin}i}$ are not required for the abundance analysis since it is well known that the rotational convolution is not affecting the EW of the line (Gray [122]). Our test with $\chi^2$ analysis confirms this assumption for the stars considered in our study. In the estimate of damping constants, the Unsold approximation was adopted for all atomic and molecular lines. We have verified that the damping effects do not affect our final abundances.

At first, the abundances of all relevant elements were fitted for a set of stars with different atmospheric parameters. Next, the same fits were performed by scaling the abundance of elements other than nitrogen to the [Fe/H] value and by changing only the nitrogen abundance. Same results were obtained in both cases, therefore all the following fittings were carried out by scaling elements other than nitrogen to iron.

The program FITTING introduced the following data in the code MOOG: the atmospheric model, the line list and the range of nitrogen abundance of the grid of synthetic spectra. Then $\chi^2$ values were calculated by comparing each synthetic spectrum with the observed one in the following spectral regions: $\lambda\lambda 3344.0–3344.7$ Å, $\lambda\lambda 3345.9–3346.9$ Å, $\lambda\lambda 3347.2–3348.2$ Å, $\lambda\lambda 3353.5–3354.5$ Å, $\lambda\lambda 3357.0–3358.0$ Å, $\lambda\lambda 3358.5–3359.0$ Å, $\lambda\lambda 3361.8–3362.5$ Å, $\lambda\lambda 3363.0–3363.75$ Å, $\lambda\lambda 3363.8–3365.5$ Å, $\lambda\lambda 3368.0–3368.8$ Å, $\lambda\lambda 3369.1–3369.9$ Å, $\lambda\lambda 3371.8–3372.8$ Å and $\lambda\lambda 3374.8–3376.0$ Å. $\chi^2_{\text{tot}}$ was the sum of $\chi^2$ values of the mentioned spectral regions.

$\chi^2 = \sum_{i=1}^{N} (F_i - S_i)^2$, where $F_i$ and $S_i$ are the observed and synthetic spectra fluxes, respectively, at the wavelength $i$.
The nitrogen abundance corresponding to minimum $\chi^2_{\text{tot}}$ value was extracted and listed in Tables 4 and 5. The fact that $\chi^2_{\text{tot}}$ is smaller for high $T_{\text{eff}}$ can be understood as the consequence of a suitable placement of continuum in stars more similar to the Sun.

Figure 2 shows fits for a short, significant spectral region. The observed solar spectrum from the Kurucz Solar Atlas (Kurucz et al. 1984) and synthetic spectrum are represented in the left panel. The case of the planet host star HD 17051 is represented in the right panel (the observed spectrum and three synthetic spectra for different values of nitrogen abundance).

Uncertainties in the atmospheric parameters are of the order of 50 K in $T_{\text{eff}}$, 0.12 dex in log $g$, 0.08 km s$^{-1}$ in the microturbulence and 0.05 dex in the metallicity (see Santos et al. 2003b). In order to know how variations in the atmospheric parameters affect NH abundances, for each parameter a set of three stars having very different parameters was selected. For each set of stars we then tested [N/H] sensitivity to changes in the parameter (±100 K in the case of $T_{\text{eff}}$, ±0.2 dex in log $g$ and [Fe/H], and 0.3 km s$^{-1}$ in $\xi_t$). The results are shown in Table 3. No microturbulence effects were included, since an increase of 0.3 km s$^{-1}$ produced an average decrease of 0.003 dex in nitrogen abundances, which is negligible with regard to the effects of other parameters. Sensitivity of NH abundance was applied in the propagation of each parameter error on abundances. Also, a continuum uncertainty effect of the order of 0.1 dex was considered. All effects were added quadratically to obtain final uncertainties for the nitrogen abundances.

3.2. The N i absorption at 7468.27 Å

Nitrogen abundance analysis based on the feature at 7468.27 Å was carried out differentially with respect to the Sun. Wavelength and excitation energies of lower level were taken from Moore et al. (1969) and a solar gf value ($\log gf = -0.15$) was computed using equivalent width measured in the Kurucz Solar Atlas (Kurucz et al. 1984) (4.2 mÅ) and a solar model with $T_{\text{eff}} = 5777$ K, log $g = 4.44$ dex and $\xi_t$ = 1.0 km s$^{-1}$, assuming the solar N abundance of log $e(N)/e(\odot) = 8.05$ dex. Equivalent widths in the observed stars were determined by Gaussian fitting using the SPLIT task of IRAF, and abundances were computed using the ABFIND driver of MOOG.

The high resolution spectra we used provided us with very reliable measurements in most cases. However, a strong fringing effect around 7468 Å prevented us from measuring high precision EW values in some cases; therefore, the corresponding EW uncertainties are more significant.

The sensitivity of the N i line to variations in atmospheric parameters was estimated in the same way as in the NH case (see Subsection 3.1). The results are shown in Table 3. In order to take into account inaccuracies caused by the continuum determination, equivalent widths for the highest and the lowest continuum levels were measured, and the corresponding abundance errors were added in quadrature to the abundance uncertainties derived from inaccuracies in the atmospheric parameters.

Dependences on $T_{\text{eff}}$ and on log $g$ of [N/Fe] performed by both methods are presented in Figure 3. We note that no characteristic trends appear in either case. This means that our results are almost free from systematic errors.

4. Nitrogen abundances from near-UV spectra

In the literature there are already a few studies that use NH band at 3360 Å to determine nitrogen abundances by spectral synthesis, but only for metal-poor dwarfs (Bessel & Norris 1982; Tomkin & Lambert 1984; Laird 1985; Carbon et al. 1987).

We analysed near-UV high-resolution spectra of 28 planet host stars and 25 comparison sample stars with the goal of checking for possible differences in nitrogen abundances between both samples. All the results for planet host and comparison sample stars are presented in Tables 4 and 5 respectively.

Figure 4 shows the [N/H] and [N/Fe] abundance ratios as functions of [Fe/H] for these two samples. These plots indicate that the abundance trend for stars with planets is almost indistinguishable from that of the comparison stars. Because of the iron enhancement that planet-harbouring stars present, their abundance distributions are the high [Fe/H] extensions of the curves traced by the comparison sample stars. No peculiar behaviour of the nitrogen abundance seems to be associated with the presence of planets.

On the whole, the [N/Fe] vs. [Fe/H] trend appears to be almost flat, since the slope value is 0.10 ± 0.05. Nevertheless, a small trend to increase with [Fe/H] cannot be excluded. The [N/H] vs. [Fe/H] plot shows that the behaviour of the N abundance is not significantly different from that of Fe; both elements keep pace with each other. Moreover, no significant nitrogen overproduction relative to iron is observed.

The [N/H] distributions for both samples are represented in Fig. 5 (upper panel). An interesting feature of the histogram is that the planet-harbouring stars set does not present a symmetrical distribution, as the comparison sample does. The distribution increases for increasing [N/H] values until reaching the highest value, not centred on the [N/H] range. However, this peculiarity could be caused by the lack of objects with metallicities higher than 0.5 dex. Santos et al. (2003, 2003) found a similar shape in iron distribution.

5. Nitrogen abundances from the N i 7468 Å line

Several studies of nitrogen abundances in metal-rich dwarfs with planets using near-IR N i lines have been published, but data for only a small number of planet host stars have been employed (fourteen planet-harbouring stars in the most extensive case, in Takeda et al. 2001).
and most of them do not even mention their nitrogen abundance results (Gonzalez & Laws 2000; Gonzalez et al. 2001; Sadakane et al. 2002). Only Takeda et al. (2001) have presented their nitrogen abundance results from the measurement of the N i line at 6863 Å, as well as abundance results for another four volatile elements (C, O, S and Zn). They did not observe the tendency predicted by the “self-enrichment” hypothesis ([X/H] < [Fe/H]) for metal-enriched planet host stars, a weak inverse trend ([X/H] > [Fe/H]) even seemed to appear for N and S.

We obtained nitrogen abundances for 31 planet host stars by equivalent width measurements of the N i line at 7468 Å. All atmospheric parameters, EW values with uncertainties and abundance results are listed in Table 5.

Table 5. Nitrogen abundances from NH band synthesis for a set of comparison stars (without giant planets). Last column lists χ²tot values.

| Star   | Teff (K) | log g (cm s⁻²) | ξt (km s⁻¹) | [Fe/H] | [N/H] | χ²tot |
|--------|----------|----------------|-------------|--------|-------|-------|
| HD 1461 | 5785 ± 50 | 4.47 ± 0.15     | 1.00 ± 0.10 | 0.18 ± 0.05 | 0.25 ± 0.13 | 6.72 |
| HD 1581 | 5856 ± 44 | 4.39 ± 0.13     | 1.07 ± 0.09 | −0.14 ± 0.05 | −0.11 ± 0.12 | 4.15 |
| HD 3823 | 5959 ± 50 | 4.12 ± 0.15     | 1.00 ± 0.10 | −0.27 ± 0.05 | −0.25 ± 0.13 | 4.89 |
| HD 4191 | 5878 ± 53 | 4.74 ± 0.15     | 1.13 ± 0.10 | −0.03 ± 0.06 | −0.04 ± 0.13 | 8.21 |
| HD 7570 | 6140 ± 41 | 4.39 ± 0.16     | 1.50 ± 0.08 | 0.18 ± 0.05 | 0.26 ± 0.12 | 6.28 |
| HD 10700 | 5344 ± 29 | 4.57 ± 0.09     | 0.91 ± 0.06 | −0.52 ± 0.04 | −0.56 ± 0.11 | 15.42 |
| HD 14421 | 5368 ± 24 | 4.55 ± 0.05     | 0.88 ± 0.05 | −0.47 ± 0.03 | −0.53 ± 0.11 | 16.58 |
| HD 20010 | 6275 ± 57 | 4.40 ± 0.37     | 2.41 ± 0.41 | −0.19 ± 0.06 | −0.14 ± 0.15 | 3.69 |
| HD 20766 | 5733 ± 31 | 4.55 ± 0.10     | 1.09 ± 0.06 | −0.21 ± 0.04 | −0.21 ± 0.11 | 8.35 |
| HD 20794 | 5444 ± 31 | 4.47 ± 0.07     | 0.98 ± 0.06 | −0.38 ± 0.04 | −0.50 ± 0.11 | 14.72 |
| HD 20807 | 5843 ± 26 | 4.47 ± 0.10     | 1.17 ± 0.06 | −0.23 ± 0.04 | −0.20 ± 0.11 | 7.44 |
| HD 23148 | 5176 ± 45 | 4.41 ± 0.17     | 1.03 ± 0.06 | 0.06 ± 0.05 | −0.19 ± 0.12 | 16.86 |
| HD 30495 | 5868 ± 30 | 4.55 ± 0.10     | 1.24 ± 0.05 | 0.02 ± 0.04 | 0.01 ± 0.11 | 7.86 |
| HD 36435 | 5479 ± 37 | 4.61 ± 0.07     | 1.12 ± 0.05 | −0.08 ± 0.05 | −0.17 ± 0.11 | 8.82 |
| HD 38858 | 5752 ± 32 | 4.53 ± 0.07     | 1.26 ± 0.07 | −0.23 ± 0.05 | −0.15 ± 0.11 | 10.46 |
| HD 43162 | 5633 ± 35 | 4.48 ± 0.07     | 1.24 ± 0.05 | −0.01 ± 0.04 | −0.16 ± 0.11 | 6.93 |
| HD 43834 | 5594 ± 36 | 4.41 ± 0.09     | 1.05 ± 0.04 | 0.10 ± 0.05 | 0.04 ± 0.11 | 11.53 |
| HD 60830 | 5410 ± 26 | 4.38 ± 0.07     | 0.89 ± 0.03 | −0.03 ± 0.04 | −0.08 ± 0.11 | 15.02 |
| HD 72673 | 5242 ± 28 | 4.50 ± 0.09     | 0.69 ± 0.05 | −0.37 ± 0.04 | −0.38 ± 0.11 | 16.37 |
| HD 76151 | 5803 ± 29 | 4.50 ± 0.08     | 1.02 ± 0.04 | 0.14 ± 0.04 | 0.25 ± 0.11 | 12.54 |
| HD 84117 | 6167 ± 37 | 4.35 ± 0.10     | 1.42 ± 0.09 | −0.03 ± 0.05 | 0.09 ± 0.12 | 4.16 |
| HD 189567 | 5765 ± 24 | 4.52 ± 0.05     | 1.22 ± 0.05 | −0.23 ± 0.04 | −0.22 ± 0.11 | 9.65 |
| HD 192310 | 5069 ± 49 | 4.38 ± 0.19     | 0.79 ± 0.07 | −0.01 ± 0.05 | −0.19 ± 0.13 | 19.83 |
| HD 211415 | 5890 ± 30 | 4.51 ± 0.07     | 1.12 ± 0.07 | −0.17 ± 0.04 | −0.11 ± 0.11 | 7.88 |
| HD 222335 | 5260 ± 41 | 4.45 ± 0.11     | 0.92 ± 0.06 | −0.16 ± 0.05 | −0.25 ± 0.12 | 12.98 |

Fig. 4. [N/H] and [N/Fe] vs. [Fe/H] plots from NH 3360 Å band synthesis. Filled and open diamonds represent planet host and comparison sample stars, respectively. Linear least-squares fits to both samples together are represented and slope values are written at the bottom of each plot.

Figure 5 shows the [N/H] and [N/Fe] abundance ratios as functions of [Fe/H] for planet host stars, from NH band and N i line sets, and for comparison sample stars. In Figure 5 (top lower panel), the [N/H] distributions are shown for both the planet host (with values from both indicators) and comparison star samples. In all the plots the added values follow the same behaviour as those resulting from NH band analysis. The previously commented trends (see Section 4) are confirmed.
Fig. 5. [N/H] distributions, from NH band values (upper panel), from NH band and N\textsc{i} line values (top lower panel), and from NH band, N\textsc{i} line and literature values (bottom panel). Solid and dotted lines represent planet host and comparison sample stars, respectively.

6. Comparison of the near-UV and 7468 Å line results

Two independent analyses were carried out, using different indicators of nitrogen abundance. We managed thereby to extend our data sample, as well as to check the agreement between both methods and to test the strength of our results.

We had available to us two different sets of data. The first consisted of near-UV spectra of planet host and comparison sample stars. The other was composed of optical and near-IR spectra of stars with planets. The compari-
Table 6. Nitrogen abundances from \textit{N}1 7468.27 Å for a set of stars with planets and brown dwarf companions.

| Star      | \(T_{\text{eff}}\) (K) | \(\log g\) (cm s\(^{-2}\)) | \(\xi_1\) (km s\(^{-1}\)) | \([\text{Fe/H}]\) | EW (mA) | \([\text{N/H}]\) |
|-----------|------------------------|-----------------------------|-----------------------------|----------------|---------|-----------------|
| HD 12661  | 5702 ± 36              | 4.33 ± 0.08                | 1.05 ± 0.04                 | 0.36 ± 0.05   | 8.5 ± 1  | 0.35 ± 0.07     |
| HD 16141  | 5801 ± 30              | 4.22 ± 0.12                | 1.34 ± 0.04                 | 0.15 ± 0.04   | 5.6 ± 1  | 0.03 ± 0.10     |
| HD 19994  | 6290 ± 58              | 4.31 ± 0.13                | 1.63 ± 0.12                 | 0.24 ± 0.07   | 13.0 ± 2 | 0.17 ± 0.09     |
| HD 23596  | 6108 ± 36              | 4.25 ± 0.10                | 1.30 ± 0.05                 | 0.31 ± 0.05   | 12.6 ± 2 | 0.22 ± 0.10     |
| HD 30177  | 5584 ± 65              | 4.23 ± 0.13                | 1.14 ± 0.07                 | 0.38 ± 0.09   | 9.0 ± 2  | 0.47 ± 0.10     |
| HD 40979  | 6145 ± 42              | 4.31 ± 0.15                | 1.29 ± 0.09                 | 0.21 ± 0.05   | 10.0 ± 3 | 0.10 ± 0.16     |
| HD 46375  | 5268 ± 55              | 4.41 ± 0.16                | 0.97 ± 0.06                 | 0.20 ± 0.06   | 4.0 ± 1  | 0.42 ± 0.15     |
| HD 50554  | 6026 ± 30              | 4.41 ± 0.13                | 1.11 ± 0.06                 | 0.01 ± 0.04   | 7.0 ± 1  | 0.06 ± 0.08     |
| HD 65216  | 5666 ± 31              | 4.53 ± 0.09                | 1.06 ± 0.05                 | −0.12 ± 0.04  | 3.0 ± 1  | −0.03 ± 0.19    |
| HD 68988  | 5088 ± 52              | 4.45 ± 0.15                | 1.25 ± 0.08                 | 0.36 ± 0.06   | 13.0 ± 3 | 0.39 ± 0.15     |
| HD 72659  | 5995 ± 45              | 4.30 ± 0.07                | 1.42 ± 0.09                 | 0.03 ± 0.06   | 7.0 ± 2  | 0.04 ± 0.16     |
| HD 73256  | 5518 ± 49              | 4.42 ± 0.12                | 1.22 ± 0.06                 | 0.26 ± 0.06   | 5.0 ± 1  | 0.27 ± 0.11     |
| HD 73526  | 5689 ± 49              | 4.27 ± 0.12                | 1.26 ± 0.06                 | 0.27 ± 0.06   | 7.5 ± 2  | 0.23 ± 0.16     |
| HD 75732  | 5279 ± 62              | 4.37 ± 0.18                | 0.98 ± 0.07                 | 0.33 ± 0.07   | 6.5 ± 1  | 0.65 ± 0.11     |
| HD 76700  | 5737 ± 34              | 4.25 ± 0.14                | 1.18 ± 0.04                 | 0.41 ± 0.05   | 9.0 ± 2  | 0.32 ± 0.14     |
| HD 80606  | 5574 ± 72              | 4.46 ± 0.20                | 1.14 ± 0.09                 | 0.32 ± 0.09   | 7.5 ± 2  | 0.44 ± 0.17     |
| HD 95128  | 5954 ± 25              | 4.44 ± 0.10                | 1.30 ± 0.04                 | 0.06 ± 0.03   | 6.2 ± 2  | 0.06 ± 0.16     |
| HD 120136 | 6339 ± 73              | 4.19 ± 0.10                | 1.70 ± 0.16                 | 0.23 ± 0.07   | 16.2 ± 2 | 0.19 ± 0.09     |
| HD 134987 | 5776 ± 29              | 4.36 ± 0.07                | 1.09 ± 0.04                 | 0.30 ± 0.04   | 10.0 ± 2 | 0.39 ± 0.12     |
| HD 142415 | 6045 ± 44              | 4.53 ± 0.08                | 1.12 ± 0.07                 | 0.21 ± 0.05   | 10.0 ± 2 | 0.24 ± 0.13     |
| HD 143761 | 5853 ± 25              | 4.41 ± 0.15                | 1.35 ± 0.07                 | −0.21 ± 0.04  | 2.5 ± 1  | −0.29 ± 0.25    |
| HD 146775 | 5311 ± 87              | 4.42 ± 0.18                | 0.92 ± 0.10                 | 0.43 ± 0.08   | 5.3 ± 2  | 0.50 ± 0.19     |
| HD 168443 | 5617 ± 35              | 4.22 ± 0.05                | 1.21 ± 0.05                 | 0.06 ± 0.05   | 6.0 ± 3  | 0.24 ± 0.23     |
| HD 178911B| 5600 ± 42              | 4.44 ± 0.08                | 0.95 ± 0.05                 | 0.27 ± 0.05   | 8.0 ± 2  | 0.46 ± 0.17     |
| HD 186427 | 5772 ± 25              | 4.40 ± 0.07                | 1.07 ± 0.04                 | 0.08 ± 0.04   | 3.4 ± 1  | −0.13 ± 0.14    |
| HD 187123 | 5845 ± 22              | 4.42 ± 0.07                | 1.10 ± 0.03                 | 0.13 ± 0.03   | 6.1 ± 2  | 0.11 ± 0.16     |
| HD 190650 | 5584 ± 36              | 4.37 ± 0.06                | 1.07 ± 0.05                 | 0.24 ± 0.05   | 6.3 ± 2  | 0.32 ± 0.16     |
| HD 216770 | 5423 ± 41              | 4.40 ± 0.13                | 1.01 ± 0.05                 | 0.26 ± 0.04   | 7.0 ± 2  | 0.54 ± 0.19     |
| HD 217107 | 5663 ± 36              | 4.34 ± 0.08                | 1.11 ± 0.04                 | 0.37 ± 0.05   | 8.7 ± 1  | 0.28 ± 0.06     |
| HD 219542B| 5732 ± 31              | 4.40 ± 0.05                | 0.99 ± 0.04                 | 0.17 ± 0.04   | 8.0 ± 1  | 0.39 ± 0.13     |
| HD 222582 | 5843 ± 38              | 4.45 ± 0.07                | 1.03 ± 0.06                 | 0.05 ± 0.05   | 6.0 ± 2  | 0.12 ± 0.16     |

Fig. 6. \([\text{N/H}]\) and \([\text{N/Fe}]\) vs. \([\text{Fe/H}]\) plots from \textit{NH} 3360 Å band and \textit{N}1 7468 Å line values. Filled diamonds and open diamonds represent planet host and comparison sample stars from \textit{NH} band synthesis, respectively, while asterisks denote planet host stars from \textit{N}1 line analysis. Linear least-squares fits to all samples together are represented and slope values are written at the bottom of each plot.

7. Reanalysis of published EW data

Several recent studies have presented measurements of \textit{N}1 lines in targets with known planets (Gonzalez & Laws 2000; Gonzalez et al. 2001; Takeda et al. 2001; Sadakane et al. 2002). We have collected all the EW values determined in these papers and used them to calculate nitrogen abundances with atmospheric parameters from Santos et al. 2003).
Table 7. Comparison of nitrogen abundances determined from NH band synthesis and from N\(\text{I}\) line analysis.

| Star         | [N/H]_{NH 3360} | [N/H]_{N\text{I} 7468} |
|--------------|-----------------|--------------------------|
| HD 16141     | 0.11            | 0.03                     |
| HD 19994     | 0.37            | 0.17                     |
| HD 46375     | 0.07            | 0.42                     |
| HD 120136    | 0.20            | 0.19                     |
| HD 134987    | 0.40            | 0.39                     |
| HD 143761    | -0.30           | -0.29                    |
| HD 217107    | 0.40            | 0.28                     |
| HD 222582    | 0.12            | 0.12                     |

Table 8. Nitrogen abundances calculated using EW values from other authors for a set of stars with planets and brown dwarf companions.

| Star         | Ref. | \(T_\text{eff}\) (K) | log \(g\) (cm s\(^{-2}\)) | \(\xi_1\) (km s\(^{-1}\)) | [Fe/H] | EW (mA) | [N/H] |
|--------------|------|----------------------|--------------------------|------------------------|--------|--------|--------|
| HD 75289     | 1    | 6143 ± 53            | 4.42 ± 0.13              | 1.53 ± 0.09            | 0.28 ± 0.07 | 10.7   | 0.15   |
| HD 9826      | 1    | 6212 ± 64            | 4.26 ± 0.13              | 1.69 ± 0.16            | 0.13 ± 0.08 | 9.2    | -0.01  |
| HD 9826      | 3    | 6212 ± 64            | 4.26 ± 0.13              | 1.69 ± 0.16            | 0.13 ± 0.08 | 19.6   | 0.14   |
| HD 9826 avg. | 2    | 6212 ± 64            | 4.26 ± 0.13              | 1.69 ± 0.16            | 0.13 ± 0.08 | 6.0    | 0.07   |
| HD 10697     | 2    | 5641 ± 28            | 4.05 ± 0.05              | 1.13 ± 0.03            | 0.14 ± 0.04 | 6.0    | 0.15   |
| HD 89744     | 2    | 6234 ± 45            | 3.98 ± 0.05              | 1.62 ± 0.08            | 0.22 ± 0.05 | 13.3   | 0.09   |
| HD 89744     | 3    | 6234 ± 45            | 3.98 ± 0.05              | 1.62 ± 0.08            | 0.22 ± 0.05 | 22.9   | 0.12   |
| HD 89744 avg.| 2    | 6234 ± 45            | 3.98 ± 0.05              | 1.62 ± 0.08            | 0.22 ± 0.05 | 0.11   |        |
| HD 217014    | 2    | 5804 ± 36            | 4.12 ± 0.07              | 1.20 ± 0.05            | 0.20 ± 0.05 | 9.0    | 0.34   |
| HD 117176    | 3    | 5560 ± 34            | 4.07 ± 0.05              | 1.18 ± 0.05            | -0.06 ± 0.05 | 4.0    | -0.21  |
| HD 106252    | 4    | 5899 ± 35            | 4.34 ± 0.07              | 1.08 ± 0.06            | -0.01 ± 0.05 | 4.9    | -0.33  |
| HD 134987    | 2    | 5776 ± 29            | 4.36 ± 0.07              | 1.09 ± 0.04            | 0.30 ± 0.04 | 10.6   | 0.43   |
| HD 13761     | 3    | 5853 ± 25            | 4.41 ± 0.15              | 1.35 ± 0.07            | -0.21 ± 0.04 | 6.1    | -0.12  |
| HD 168443    | 2    | 5617 ± 35            | 4.22 ± 0.05              | 1.21 ± 0.05            | 0.06 ± 0.05 | 4.8    | 0.12   |
| HD 186427    | 3    | 5772 ± 25            | 4.40 ± 0.07              | 1.07 ± 0.04            | 0.08 ± 0.04 | 10.8   | 0.22   |
| HD 187123    | 4    | 5845 ± 22            | 4.42 ± 0.07              | 1.10 ± 0.03            | 0.13 ± 0.03 | 6.5    | -0.14  |
| HD 95128     | 3    | 5954 ± 25            | 4.44 ± 0.10              | 1.30 ± 0.04            | 0.06 ± 0.03 | 13.0   | 0.18   |
| HD 12661     | 3    | 5702 ± 36            | 4.33 ± 0.08              | 1.05 ± 0.04            | 0.36 ± 0.05 | 9.0    | 0.38   |
| HD 217107    | 2    | 5663 ± 36            | 4.34 ± 0.08              | 1.11 ± 0.04            | 0.37 ± 0.05 | 3.9    | -0.03  |
| HD 222582    | 2    | 5843 ± 38            | 4.45 ± 0.07              | 1.03 ± 0.06            | 0.05 ± 0.05 | 4.9    | 0.02   |
| HD 75732     | 3    | 5279 ± 62            | 4.37 ± 0.18              | 0.98 ± 0.07            | 0.33 ± 0.07 | 10.5   | 0.70   |
| HD 120136    | 1    | 6339 ± 73            | 4.19 ± 0.10              | 1.70 ± 0.16            | 0.23 ± 0.07 | 16.7   | 0.21   |
| HD 130322    | 4    | 5392 ± 36            | 4.48 ± 0.06              | 0.85 ± 0.05            | 0.03 ± 0.04 | 3.2    | -0.03  |
| HD 141937    | 4    | 5969 ± 39            | 4.51 ± 0.08              | 1.13 ± 0.06            | 0.10 ± 0.05 | 7.7    | -0.06  |
| HD 168746    | 4    | 5601 ± 33            | 4.41 ± 0.12              | 0.99 ± 0.05            | -0.08 ± 0.05 | 5.6    | 0.04   |
| HD 190228    | 4    | 5327 ± 35            | 3.90 ± 0.07              | 1.11 ± 0.05            | -0.26 ± 0.06 | 3.5    | -0.07  |

Ref.1 from Gonzalez & Laws (2000)
Ref.2 from Gonzalez et al. (2001)
Ref.3 from Takeda et al. (2001)
Ref.4 from Sadakane et al. (2002)

Gonzalez & Laws (2000) and Gonzalez et al. (2001) measured N\(\text{I}\) line at 7468 Å, as we did; therefore, we could compare EW values in some of the targets that both analyses had in common. Takeda et al. (2001) and Sadakane et al. (2002) used the N\(\text{I}\) line at 8683 Å, so we were not able to compare our EW values with theirs, but only [N/H]. Besides allowing us to carry out a comparison, the literature values added new abundance measures to our data sample.

This reanalysis was carried out in the same way described in Section 3.2. In the case of the N\(\text{I}\) line at 8683 Å, the solar gf value computed using the equivalent width (7.0 mA) measured in the Solar Atlas (Kurucz et al. 1984) was log \(gf\) = 0.068. All the EW values from the literature, the atmospheric parameters from Santos et al. (2003), and the resulting nitrogen abundances are presented in Table 8. All the results for the targets in common with our data sample are listed in Table 9. We note that the results from different sources are in good agreement. Significant differences exist only for HD 186427, HD 187123 and HD 217107. The [N/H] and [N/Fe] vs. [Fe/H] trends from the literature EW values and from our data are represented in Figure 4. Figure 5 (bottom panel) shows the [N/H] distribution for comparison sample and planet host stars from all the sources. We note that the new values confirm the trends discussed in the previous sections (see Section 4).

8. Discussion and Conclusions

In the present study we have determined the nitrogen abundances in 51 planet host stars and in 25 stars from a comparison sample with no known planetary mass companion. Among the set of planet hosts, 28 targets have
been analyzed by spectral synthesis of the NH band at 3360 Å, while equivalent width measurements of the N\textsubscript{i} 7468.27 Å were carried out for 31 stars. Another 15 planet hosts were subsequently added to our study, with EW values taken from other authors’ works. Moreover, we were able to check that the different indicators are in remarkable agreement for several common targets. This result is an independent and homogeneous analysis of nitrogen abundances in 91 solar-type dwarfs, 66 with planets and 25 from a volume-limited comparison sample.

The behaviour of volatiles in planet-harbouring stars with regard to a comparison sample can be very informative for checking the “self-enrichment” hypothesis. If the accretion of metal-enriched planetary material were a key parameter for the observed enhancement of iron abundances, then volatile abundances in planet host stars would not show as much overabundance as refractories do since elements with a lower condensation temperature are expected to be deficient in accreted materials. In that case, the following trend would be observed in planet host stars: [N/H] < [Fe/H].

Our results suggest that planet hosts stars do not behave in such a way. The [N/H] vs. [Fe/H] plots show that nitrogen abundance scales with that of the iron. In the [N/Fe] vs. [Fe/H] plots, no significant trace of [N/Fe] \textless 0 appears in stars with planets. Moreover, planet host and comparison sample stars have the same behaviour. Trends from either sample are quite indistinguishable. This emphasizes that the trend predicted from the “self-enrichment” scenario is not observed at all.

Previous studies have obtained similar results for other volatiles in some planet-harbouring stars. Gonzalez et al. (2001) corrected the low [C/Fe] values found in a previous study (Gonzalez & Laws 2000) and concluded that [C/Fe] and [O/Fe] in planet hosts do not display significant differences from those in field dwarfs of the same [Fe/H]. Takeda et al. (2001) found the same trend as we did for N, C, S, O and Zn in 14 planet hosts, and in Sadakane et al. (2002) this result was confirmed for C and O in another

Table 9. Comparison of nitrogen abundances determined using EW values (in mÅ) from our data and from other authors.

| Star        | T\textsubscript{eff} (K) | log g (cm s\textsuperscript{-2}) | ξ\textsubscript{t} (km s\textsuperscript{-1}) | [Fe/H] | EW\textsuperscript{1} 7468 | EW\textsuperscript{2} 7468 | EW\textsuperscript{3} 8683 | [N/H]\textsuperscript{1} | [N/H]\textsuperscript{2} | [N/H]\textsuperscript{3} |
|-------------|--------------------------|-----------------------------|---------------------------------|------|------------------------|------------------------|------------------------|----------------|----------------|----------------|
| HD 134987   | 5776                     | 4.36                        | 1.99                            | 0.30 | 10.0                   | 10.6                   | –                      | 0.39           | 0.43          | –              |
| HD 143761   | 5853                     | 4.41                        | 1.35                            | –0.21| 2.5                    | 6.1                    | –0.29                  | –0.12          | –              | –12            |
| HD 168443   | 5617                     | 4.22                        | 1.21                            | 0.06 | 6.0                    | 4.8                    | –0.24                  | 0.12           | –              | –              |
| HD 186427   | 5772                     | 4.40                        | 1.07                            | 0.08 | 3.4                    | 10.8                   | –0.13                  | 0.22           | –              | –              |
| HD 187123   | 5845                     | 4.42                        | 1.10                            | 0.13 | 6.1                    | 6.5                    | 0.11                   | –              | –0.14         | –              |
| HD 95128    | 5954                     | 4.44                        | 1.30                            | 0.06 | 6.4                    | 13.0                   | 0.06                   | –              | 0.18          | –              |
| HD 12661    | 5702                     | 4.33                        | 1.05                            | 0.36 | 8.5                    | 9.0                    | 0.35                   | 0.38           | –              | –              |
| HD 217107   | 5663                     | 4.34                        | 1.11                            | 0.37 | 8.7                    | 3.9                    | –0.28                  | –0.03          | –              | –              |
| HD 225582   | 5843                     | 4.45                        | 1.03                            | 0.05 | 6.0                    | 4.9                    | –0.12                  | 0.02           | –              | –              |
| HD 75732    | 5279                     | 4.37                        | 0.98                            | 0.33 | 6.5                    | 10.5                   | 0.65                   | –0.70          | –              | –              |
| HD 120136   | 6339                     | 4.19                        | 1.70                            | 0.23 | 16.2                   | 16.7                   | 0.19                   | 0.21           | –              | –              |

1 EW values from our data.
2 EW values from Gonzalez & Laws (2000) and Gonzalez et al. (2001).
3 EW values from Takeda et al. (2001) and Sadakane et al. (2002).
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