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Spectroscopic metallicities for planet-host stars: Extending the samples*

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Abstract. We present stellar parameters and metallicities for 29 planet-host stars, as well as for a large volume-limited sample of 53 stars not known to be orbited by any planetary-mass companion. These stars add to the results presented in our previous series of papers, providing two large and uniform samples of 119 planet-hosts and 94 "single" stars with accurate stellar parameters and [Fe/H] estimates. The analysis of the results further confirms that stars with planets are metal-rich when compared with average field dwarfs. Important biases that may compromise future studies are also discussed. Finally, we compare the metallicity distributions for single planet-hosts and planet-hosts in multiple stellar systems. The results show that a small difference cannot be excluded, in the sense that the latter sample is slighly overmetallic. However, more data are needed to confirm this correlation.

Key words. stars: abundances – stars: fundamental parameters – stars: chemically peculiar – stars: planetary systems – stars: planetary systems: formation

1. Introduction

The discovery that stars with giant planet companions are particularly metal-rich when compared to single field dwarfs is providing crucial clues to our understanding of the processes of planetary formation and evolution. This fact, first discussed by Gonzalez (1997) and Gonzalez (1998), was later proved by the uniform analysis of large samples of planet-host and field "single" stars (Santos et al. 2001).

Further refinements to these studies have shown that the probability of finding (and presumably forming) a planet, at least of the kind now discovered by radial-velocity surveys, is a strong function of the stellar metal content (Santos et al. 2001, 2003, 2004b; Reid 2002; Fischer & Valenti 2005). Although the exact dependence is still not completely settled (see Santos et al. 2004b, and references therein), it was shown that about 25% of solar type stars with twice the solar metallicity are orbited by a planet, while less than 5% of stars with the metal content of the Sun have an orbiting planetary-mass companion.

Interestingly, these observational results are now being corroborated by theoretical models of planet formation, and give support to the core-accretion model to explain the origin of the now discovered giant planets (Pollack et al. 1996; Alibert et al. 2004). Current models can even reasonably explain the observed [Fe/H] distribution of planet-host stars (Ida & Lin 2004a,b). However, and as discussed in Santos et al. (2004b), current data still cannot exclude that giant planets may also be formed by the disk instability model (Boss 1997, 2002; Mayer et al. 2002), in particular planets orbiting low metallicity stars.

In the last few years we have published a series of papers regarding the study of the stellar metallicity-giant planet connection (Santos et al. 2000, 2001, 2003, 2004b) (hereafter Papers I, II, III and IV, respectively). In the last three of these papers we have presented a spectroscopic analysis of a sample of 41 "single" field stars, used as a reference to study the excess metallicity observed in planet hosts. In Paper IV we presented a uniform spectroscopic analysis of 98 extra-solar planet-host stars, including most of the known objects. The continuation of this work is extremely important, since the search for new possible correlations between the presence (and properties) of exoplanets and the chemical abundances of their host stars needs increased samples.

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* Based on observations collected at La Silla Observatory, ESO, Chile, with the FEROS spectrograph at the 2.2-m MPI/ESO telescope (programs 72.C-0033 and 74.C-0135) and the CORALIE spectrograph at the 1.2-m Euler Swiss Telescope, with the UVES spectrograph at the VLT 8.2-m Kueyen telescope (programs 074.C-0134), and with the SARG spectrograph at the TNG telescope, operated at the island of La Palma.

In this paper we add 53 new stars to our "comparison" sample, as well as precise and uniform metallicity estimates for a further 29 known planet-hosts, most of which have no previous spectroscopic metallicity estimate. In Sects. 2 and 3 we present the observed samples, and in Sect. 4 we review the metallicity distribution of planet-host stars, as well as of the whole volume-limited comparison sample of 94 solar-type F-G-K dwarfs. The analysis confirms, as expected, that stars with planets are clearly metal-rich when compared to average field dwarfs. In Sect. 4.1 we review a few possible biases that should be considered when studying the metallicity of planet-host stars. In Sect. 5 we compare the metallicity distributions for "single" planet-host stars with that found for planet-hosts in multiple stellar systems. We conclude in Sect. 6.

2. The samples

2.1. New comparison sample

In Papers II through IV we compared the metallicity distribution for stars with planets with a volume-limited sample of stars having right-ascensions (RA) between $20^{\rm h}$ and $9^{\rm h}$, and a distance below 20 pc as derived from Hipparcos parallaxes (ESA 1997). All these stars belong to the CORALIE southern planet search sample (Udry et al. 2000), have spectral types between F8 and M1, and were not found to harbor any planetary companion.

In order to extend the number of comparison stars in our samples, we have now observed a complementary sample of CORALIE stars with RA between $9^{\rm h}$ and $20^{\rm h}$ (and $d < 20$ pc). These stars were observed using the FEROS spectrograph at the 2.2-m ESO/MPI telescope (ESO, La Silla) in March 2004 (observing run ID 072.C-0033). Data reduction was done using the FEROS pipeline, and the wavelength calibration was done using the spectrum of a ThAr lamp. The final spectra have a resolution $R = \Delta\lambda/\lambda = 48\,000$, and the S/N between ~200 and 400.

A few stars from the former comparison sample for which we could not obtain a spectrum before were also observed, both using FEROS and the CORALIE spectrograph at the 1.2-m Euler Swiss telescope, also at La Silla observatory ($R = 50\,000$).

The comparison sample presented in this paper is listed in Table 2. Together with Table 5 of Paper IV, this constitutes a large volume-limited sample of 94 "single" stars (with no known planetary-mass companions). Amid the stars in this new volume-limited comparison sample there is HD 147513 and the very metal rich planet-host star HD 160691 (Butler et al. 2001; Santos et al. 2004a). For the list of other planet-hosts that belong to the whole volume-limited comparison sample we refer to Santos et al. (2004b).

2.2. Planet-host stars

In addition to the new comparison sample, spectra of some planet hosts was also obtained, both during the March run and in two complementary runs, one in October 2004 (using FEROS – observing run ID 074.C-0135) and another in December 2004, using the UVES spectrograph at the VLT 8.2-m Kueyen telescope (run ID 074.C-0134). These latter spectra were reduced using the UVES pipeline and have a resolution $R \sim 75\,000$.

For HD 104985 and HD 219449 we further obtained spectra with a resolution of 57 000 using the SARG spectrograph, at the TNG telescope (La Palma Observatory, Spain). For a few other recently-announced planet-hosts, stellar parameters were derived using the HARPS spectrograph ($R \sim 100\,000$ – for details see e.g. Pepe et al. 2004). These parameters were also presented in the papers announcing the discovery of the exoplanets (see Table 1).

The list of planet-host stars presented in this paper is shown in Table 1. For planet-discovery references see the Geneva Planet-Search web pages[1].

Adding the 97 planet-host stars whose [Fe/H] values were listed in Paper IV[2] to the results listed in Table 1, we now have a uniform sample of metallicities and stellar parameter for 119 stars with orbiting planets. From the whole known planet-host star sample, the only 4 objects for which we could not obtain metallicity estimates are GJ 876 and GJ 436 (both M-dwarfs – see Bonfils et al. 2005), HD 45350 and HD 13189 (a giant star). To these we add the transiting planets detected by the OGLE survey (Konacki et al. 2003; Bouchy et al. 2004; Pont et al. 2004), three currently with poor estimates given the low quality of the now available spectra, as well as TrEs-1 (Alonso et al. 2004).

3. Spectroscopic analysis

The spectroscopic analysis was done in LTE using the 2002 version of the code MOOG (Sneden 1973)[3] and a grid of Kurucz Atlas plane-parallel model atmospheres (Kurucz 1993).

Stellar parameters and metallicities were derived as in Santos et al. (2004b), based on the Equivalent Widths (EW) of 39 Fe I and 12 Fe II week lines, and by imposing excitation and ionization equilibrium. The line EW were measured using IRAF [4] "splot" and "bplot" routines within the `echelle` package. A Fortran 77 code that uses a Downhill Simplex Method (Press et al. 1992) was then used to find the best solution in the (stellar) parameter space once the line EWs are measured.

The results of this analysis are presented in Tables 1 and 2. As shown in Paper IV, this methodology gives excellent results for the derived stellar parameters, compatible with other spectroscopic results. A comparison between the EW and stellar parameters derived from these spectra and data obtained using other instruments also shows that no significant differences exist (e.g. Santos et al. 2004b) – see also Table 1.

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[1] `http://obswww.unige.ch/exoplanets`

[2] HD 219542 B was excluded from the list of planet hosts presented in Paper IV, as its planet has been denied (Desidera et al. 2004).

[3] The source code of MOOG2002 can be downloaded at `http://verdi.as.utexas.edu/moog.html`

[4] IRAF is distributed by National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation, USA.

Table 1. Planet-host stars studied in this paper. See text for more details.

HD number	$T_{\rm eff}$ [K]	$\log g_{\rm spec}$ [cm s^{-2}]	$\xi_{\rm t}$ [km s^{-1}]	[Fe/H]	N(Fe I, Fe II)	σ(Fe I, Fe II)	Instr.†	Mass [$M_\odot$]	$\log g_{\rm hipp}$ [cm s^{-2}]
BD−10 3166	5325 ± 45	4.36 ± 0.21	0.95 ± 0.05	0.35 ± 0.05	35, 9	0.05, 0.10	[a]	–	–
HD 2638	5192 ± 38	4.29 ± 0.25	0.86 ± 0.04	0.16 ± 0.04	35, 6	0.04, 0.12	[g]	0.82	4.50
HD 27894	4875 ± 81	4.22 ± 0.26	0.65 ± 0.14	0.30 ± 0.07	35, 5	0.07, 0.10	[g]	0.68	4.43
HD 37605	5391 ± 49	4.37 ± 0.18	0.97 ± 0.06	0.31 ± 0.06	38, 6	0.05, 0.08	[a]	0.95	4.54
HD 41004 A	5242 ± 57	4.35 ± 0.22	1.01 ± 0.07	0.16 ± 0.07	39, 6	0.06, 0.10	[a]	0.80	4.39
HD 59686	4871 ± 135	3.15 ± 0.41	1.85 ± 0.12	0.28 ± 0.18	39, 10	0.16, 0.18	[a]	–	–
HD 63454	4841 ± 65	4.23 ± 0.30	0.89 ± 0.09	0.11 ± 0.07	35, 5	0.06, 0.15	[g]	0.69	4.57
HD 70642	5671 ± 46	4.39 ± 0.27	1.01 ± 0.06	0.20 ± 0.06	39, 12	0.05, 0.11	[a]	0.98	4.42
HD 70642	5693 ± 26	4.41 ± 0.09	1.01 ± 0.04	0.18 ± 0.04	36, 8	0.03, 0.04	[c]	0.99	4.43
HD 70642	5682	4.40	1.01	0.19	–	–	avg.	0.98	4.42
HD 83443	5501 ± 63	4.46 ± 0.36	1.07 ± 0.08	0.39 ± 0.07	39, 11	0.07, 0.16	[a]	0.96	4.41
HD 83443	5454 ± 61	4.33 ± 0.17	1.08 ± 0.08	0.35 ± 0.08	38, 7	0.07, 0.08	[c]	0.93	4.37
HD 83443	5478	4.40	1.08	0.37	–	–	avg.	0.94	4.39
HD 88133	5438 ± 34	3.94 ± 0.11	1.16 ± 0.03	0.33 ± 0.05	35, 7	0.04, 0.04	[d]	0.98	3.83
HD 92788	5758 ± 37	4.30 ± 0.16	1.10 ± 0.04	0.34 ± 0.05	38, 11	0.04, 0.07	[a]	1.06	4.44
HD 92788	5821 ± 41	4.45 ± 0.06	1.16 ± 0.05	0.32 ± 0.05	37, 5	0.04, 0.02	[c]	1.12	4.49
HD 92788	5790	4.38	1.13	0.33	–	–	avg.	1.09	4.46
HD 93083	4995 ± 50	4.26 ± 0.19	0.66 ± 0.08	0.15 ± 0.06	36, 5	0.05, 0.08	[h]	0.70	4.43
HD 99492	4810 ± 72	4.21 ± 0.21	0.72 ± 0.13	0.26 ± 0.07	33, 4	0.07, 0.09	[d]	–	–
HD 101930	5079 ± 62	4.24 ± 0.16	0.73 ± 0.08	0.17 ± 0.06	36, 5	0.05, 0.06	[h]	0.74	4.40
HD 102117	5708 ± 46	4.34 ± 0.10	1.15 ± 0.06	0.33 ± 0.06	39, 8	0.05, 0.03	[a]	1.05	4.25
HD 102117	5672 ± 22	4.27 ± 0.07	1.05 ± 0.02	0.30 ± 0.03	37, 8	0.03, 0.03	[h]	1.03	4.23
HD 102117	5690	4.30	1.10	0.32	–	–	avg.	1.04	4.24
HD 104985	4773 ± 62	2.76 ± 0.14	1.71 ± 0.07	−0.28 ± 0.09	33, 9	0.09, 0.05	[b]	–	–
HD 106252	5834 ± 37	4.22 ± 0.12	1.06 ± 0.06	−0.03 ± 0.05	39, 11	0.04, 0.06	[a]	0.98	4.35
HD 106252	5899 ± 35	4.34 ± 0.07	1.08 ± 0.06	−0.01 ± 0.05	37, 6	0.04, 0.04	[c]	1.02	4.39
HD 106252	5866	4.28	1.07	−0.02	–	–	avg.	1.00	4.37
HD 114386	4865 ± 93	4.30 ± 0.30	0.86 ± 0.12	−0.04 ± 0.07	37, 8	0.06, 0.13	[a]	0.66	4.52
HD 114386	4804 ± 61	4.36 ± 0.28	0.57 ± 0.12	−0.08 ± 0.06	35, 4	0.06, 0.14	[c]	0.54	4.40
HD 114386	4834	4.33	0.72	−0.06	–	–	avg.	0.60	4.46
HD 117207	5654 ± 33	4.32 ± 0.05	1.13 ± 0.04	0.23 ± 0.05	37, 7	0.04, 0.02	[d]	0.99	4.33
HD 117618	6013 ± 41	4.39 ± 0.07	1.73 ± 0.09	0.06 ± 0.06	37, 7	0.05, 0.03	[d]	1.10	4.35
HD 142022 A	5499 ± 27	4.36 ± 0.04	0.94 ± 0.03	0.19 ± 0.04	36, 6	0.03, 0.03	[i]	0.90	4.33
HD 147513	5894 ± 31	4.43 ± 0.17	1.26 ± 0.05	0.08 ± 0.04	39, 11	0.04, 0.07	[a]	1.13	4.54
HD 147513	5883 ± 25	4.51 ± 0.05	1.18 ± 0.04	0.06 ± 0.04	36, 7	0.03, 0.03	[c]	1.11	4.53
HD 147513	5888	4.47	1.22	0.07	–	–	avg.	1.12	4.54
HD 154857	5610 ± 27	4.02 ± 0.12	1.30 ± 0.05	−0.23 ± 0.04	38, 8	0.03, 0.05	[a]	1.29	3.79
HD 160691	5813 ± 42	4.25 ± 0.07	1.30 ± 0.05	0.32 ± 0.05	37, 8	0.04, 0.03	[e]	1.10	4.25
HD 160691	5798 ± 33	4.31 ± 0.08	1.19 ± 0.04	0.32 ± 0.04	36, 7	0.04, 0.03	[c]	1.10	4.25
HD 160691	5806	4.28	1.24	0.32	–	–	avg.	1.10	4.25
HD 183263	5991 ± 28	4.38 ± 0.17	1.23 ± 0.04	0.34 ± 0.04	38, 8	0.03, 0.07	[a]	1.18	4.36
HD 188015	5793 ± 39	4.49 ± 0.10	1.14 ± 0.05	0.30 ± 0.05	38, 7	0.04, 0.04	[a]	1.08	4.41
HD 208487	6141 ± 29	4.52 ± 0.15	1.54 ± 0.07	0.06 ± 0.04	38, 8	0.03, 0.06	[a]	1.17	4.41
HD 219449	4757 ± 102	2.71 ± 0.25	1.71 ± 0.09	0.05 ± 0.14	31, 8	0.12, 0.09	[b]	–	–
HD 330075	5017 ± 53	4.22 ± 0.11	0.69 ± 0.08	0.08 ± 0.06	35, 5	0.05, 0.20	[f]	0.69	4.37

† The instruments used to obtain the spectra were: [a] 2.2-m ESO/FEROS; [b] TNG/SARG; [c] From Paper IV (Santos et al. 2004b); [d] VLT Kueyen/UVES; [e]–[i] HARPS – From Santos et al. (2004a), Pepe et al. (2004), Moutou et al. (2005), Lovis et al. (2005) and Eggenberger et al. (2005), respectively (stellar parameters and [Fe/H] derived by our team).

Table 2. Comparison sample stars presented in this paper. See text for more details.

HD number	$T_{\rm eff}$ [K]	$\log g_{\rm spec}$ [cm s^{-2}]	$\xi_{\rm t}$ [km s^{-1}]	[Fe/H]	N(Fe I, Fe II)	σ(Fe I, Fe II)	Instr.[a]	Mass [$M_\odot$]	$\log g_{\rm hipp}$ [cm s^{-2}]
HD 2151	5837 ± 30	4.00 ± 0.12	1.36 ± 0.05	−0.08 ± 0.04	36, 6	0.03, 0.05	[1]	1.24	4.01
HD 4747	5316 ± 38	4.48 ± 0.10	0.79 ± 0.06	−0.21 ± 0.05	36, 6	0.04, 0.05	[1]	0.79	4.54
HD 21175	5274 ± 58	4.46 ± 0.15	0.86 ± 0.07	0.16 ± 0.06	35, 6	0.05, 0.08	[1]	0.88	4.55
HD 32147	4705 ± 75	4.12 ± 0.31	0.60 ± 0.17	0.30 ± 0.08	35, 4	0.07, 0.15	[1]	–	–
HD 52698	5177 ± 51	4.44 ± 0.09	0.98 ± 0.06	0.16 ± 0.06	37, 6	0.05, 0.03	[1]	0.83	4.54
HD 52919	4740 ± 49	4.25 ± 0.15	1.03 ± 0.09	−0.05 ± 0.06	37, 6	0.07, 0.06	[2]	0.76	4.72
HD 53143	5462 ± 54	4.47 ± 0.16	1.08 ± 0.07	0.22 ± 0.06	39, 8	0.06, 0.06	[2]	1.00	4.59
HD 57095	4945 ± 54	4.45 ± 0.29	1.09 ± 0.08	−0.03 ± 0.06	38, 9	0.06, 0.15	[2]	0.62	4.29
HD 61606	4958 ± 80	4.45 ± 0.19	1.01 ± 0.12	0.01 ± 0.08	38, 9	0.07, 0.07	[2]	0.78	4.62
HD 64606	5351 ± 68	4.62 ± 0.42	0.92 ± 0.19	−0.71 ± 0.09	39, 10	0.07, 0.19	[2]	0.69	4.59
HD 65277	4843 ± 80	4.39 ± 0.58	0.99 ± 0.13	−0.26 ± 0.08	37, 9	0.07, 0.31	[2]	0.74	4.70
HD 65486	4660 ± 66	4.55 ± 0.21	0.82 ± 0.16	−0.33 ± 0.07	38, 6	0.08, 0.10	[2]	0.61	4.61
HD 67199	5136 ± 56	4.54 ± 0.13	0.84 ± 0.08	0.06 ± 0.06	38, 9	0.05, 0.05	[2]	0.80	4.55
HD 82342	4907 ± 78	4.46 ± 0.51	0.74 ± 0.15	−0.40 ± 0.08	35, 5	0.07, 0.25	[2]	0.74	4.75
HD 85512	4505 ± 176	4.71 ± 0.96	0.32 ± 1.15	−0.18 ± 0.19	41, 4	0.17, 0.54	[2]	0.63	4.65
HD 100623	5246 ± 37	4.54 ± 0.23	1.00 ± 0.06	−0.38 ± 0.05	39, 11	0.04, 0.11	[2]	0.75	4.60
HD 101581	4646 ± 96	4.80 ± 0.39	0.58 ± 0.35	−0.37 ± 0.09	37, 6	0.09, 0.20	[2]	0.74	4.75
HD 102365	5667 ± 27	4.59 ± 0.14	1.05 ± 0.06	−0.27 ± 0.04	39, 11	0.03, 0.06	[2]	0.85	4.43
HD 102438	5639 ± 51	4.60 ± 0.16	1.12 ± 0.10	−0.23 ± 0.06	39, 12	0.06, 0.07	[2]	0.88	4.50
HD 103932	4874 ± 125	4.44 ± 0.69	1.30 ± 0.17	0.09 ± 0.13	39, 7	0.12, 0.37	[2]	0.84	4.81
HD 104304	5562 ± 50	4.37 ± 0.14	1.10 ± 0.06	0.27 ± 0.06	39, 10	0.05, 0.06	[2]	0.93	4.40
HD 109200	5103 ± 46	4.47 ± 0.23	0.75 ± 0.07	−0.24 ± 0.05	37, 10	0.05, 0.11	[2]	0.70	4.51
HD 111261	4529 ± 62	4.44 ± 0.64	0.78 ± 0.17	−0.35 ± 0.08	34, 5	0.08, 0.37	[2]	0.51	4.57
HD 115617	5577 ± 33	4.34 ± 0.11	1.07 ± 0.04	0.01 ± 0.05	39, 11	0.04, 0.05	[2]	0.90	4.43
HD 118972	5241 ± 66	4.43 ± 0.42	1.24 ± 0.08	−0.01 ± 0.08	39, 11	0.07, 0.20	[2]	0.90	4.63
HD 125072	5001 ± 115	4.39 ± 0.52	1.21 ± 0.15	0.24 ± 0.11	38, 10	0.11, 0.27	[2]	0.84	4.63
HD 128620	5844 ± 42	4.30 ± 0.19	1.18 ± 0.05	0.28 ± 0.06	39, 12	0.05, 0.08	[2]	1.09	4.32
HD 128621	5199 ± 80	4.37 ± 0.27	1.05 ± 0.10	0.19 ± 0.09	39, 9	0.08, 0.12	[2]	0.81	4.47
HD 130992	4751 ± 73	4.32 ± 0.29	0.72 ± 0.13	−0.06 ± 0.07	37, 6	0.07, 0.14	[2]	0.40	4.30
HD 131977	4693 ± 80	4.36 ± 0.25	0.97 ± 0.16	0.07 ± 0.10	38, 8	0.09, 0.11	[2]	0.55	4.49
HD 135204	5332 ± 37	4.31 ± 0.13	0.84 ± 0.05	−0.11 ± 0.05	38, 10	0.04, 0.06	[2]	0.76	4.37
HD 136352	5667 ± 43	4.39 ± 0.07	1.08 ± 0.09	−0.31 ± 0.06	38, 10	0.05, 0.03	[2]	0.83	4.33
HD 140901	5645 ± 37	4.40 ± 0.25	1.14 ± 0.05	0.13 ± 0.05	39, 11	0.04, 0.11	[2]	0.99	4.50
HD 142709	4806 ± 106	4.60 ± 0.59	1.09 ± 0.19	−0.17 ± 0.12	38, 6	0.11, 0.31	[2]	0.78	4.85
HD 144628	5071 ± 43	4.41 ± 0.19	0.82 ± 0.07	−0.36 ± 0.06	38, 8	0.05, 0.08	[2]	0.70	4.59
HD 145417	5045 ± 111	4.74 ± 0.36	0.90 ± 0.43	−1.10 ± 0.15	34, 4	0.13, 0.16	[2]	0.62	4.73
HD 146233	5786 ± 35	4.31 ± 0.19	1.18 ± 0.05	0.08 ± 0.05	38, 12	0.04, 0.08	[2]	1.01	4.43
HD 149661	5290 ± 52	4.39 ± 0.21	1.11 ± 0.07	0.04 ± 0.06	39, 11	0.06, 0.10	[2]	0.90	4.60
HD 150689	4867 ± 87	4.43 ± 0.34	1.12 ± 0.13	−0.08 ± 0.08	36, 7	0.07, 0.16	[2]	0.78	4.69
HD 152391	5521 ± 43	4.54 ± 0.24	1.29 ± 0.06	0.03 ± 0.05	38, 12	0.04, 0.12	[2]	1.04	4.64
HD 154088	5414 ± 60	4.28 ± 0.24	1.14 ± 0.07	0.33 ± 0.07	39, 11	0.07, 0.11	[2]	0.93	4.46
HD 154577	4973 ± 55	4.73 ± 0.14	0.94 ± 0.12	−0.63 ± 0.07	36, 7	0.05, 0.06	[2]	0.68	4.68
HD 156026	4568 ± 94	4.67 ± 0.76	0.60 ± 0.26	−0.18 ± 0.09	36, 5	0.09, 0.44	[2]	0.70	4.75
HD 156274	5300 ± 32	4.41 ± 0.19	1.00 ± 0.05	−0.33 ± 0.04	39, 9	0.04, 0.09	[2]	0.72	4.48
HD 156384	4819 ± 110	4.66 ± 1.02	1.04 ± 0.22	−0.43 ± 0.12	39, 6	0.11, 0.53	[2]	0.45	4.41
HD 165185	5942 ± 85	4.53 ± 0.13	1.39 ± 0.16	0.02 ± 0.10	35, 10	0.08, 0.05	[2]	1.12	4.52
HD 165499	5950 ± 45	4.31 ± 0.13	1.14 ± 0.08	0.01 ± 0.06	39, 11	0.05, 0.05	[2]	1.06	4.30
HD 170493	4854 ± 120	4.49 ± 0.43	1.36 ± 0.20	0.15 ± 0.13	39, 8	0.12, 0.21	[2]	0.81	4.68
HD 170573	4767 ± 89	4.44 ± 0.5	1.07 ± 0.14	−0.07 ± 0.09	38, 6	0.09, 0.27	[2]	0.77	4.78
HD 170657	5115 ± 52	4.48 ± 0.28	1.13 ± 0.07	−0.22 ± 0.06	39, 9	0.06, 0.14	[2]	0.77	4.60
HD 172051	5634 ± 30	4.43 ± 0.14	1.06 ± 0.05	−0.21 ± 0.04	39, 11	0.04, 0.05	[2]	0.90	4.53
HD 177565	5664 ± 28	4.43 ± 0.09	1.02 ± 0.04	0.14 ± 0.04	38, 12	0.03, 0.05	[2]	0.98	4.46
HD 190248	5614 ± 34	4.29 ± 0.07	1.10 ± 0.04	0.36 ± 0.04	38, 8	0.04, 0.04	[1]	1.02	4.31

[a] The instruments used to obtain the spectra were: [1] 1.2-m Swiss Telescope/CORALIE; [2] 2.2-m ESO/FEROS.

The errors in $T_{\rm eff}$, $\log g$, $\xi_{\rm t}$ and [Fe/H] were derived as in Paper IV, and are typically of the order of 50 K, 0.2 dex, 0.1 km s^{-1} and 0.05 dex, respectively. Higher uncertainties are found for lower temperature stars.

In the tables we also present the stellar masses. These were derived from an interpolation of the theoretical isochrones of Schaller et al. (1992), Schaerer et al. (1993a) and Schaerer et al. (1993b), using M_V computed using Hipparcos parallaxes (ESA 1997), a Bolometric Correction (BC) from Flower (1996) and the $T_{\rm eff}$ obtained from the spectroscopy. Although this method to estimate individual stellar masses may suffer from important uncertainties (Fernandes & Santos 2004), from a statistical point of view it should provide good results. We adopt a typical relative error of 0.05 $M_\odot$ for the masses. In some cases, no mass estimates are presented, since these involved large extrapolations of the isochrones.

From the derived stellar mass, the spectroscopic temperature and BC, we could also obtain "trigonometric" surface gravities for our stars using the basic formula presented in Paper IV. The results (see Tables 1 and 2) show that the two gravity estimates are perfectly compatible within the errors, as expected from our previous studies (see Paper IV). Considering also all planet-hosts and comparison sample stars presented in Paper IV, the average difference between the two estimates is nearly zero (0.004 dex), with a stardard deviation of 0.14 dex.

The stellar parameters for HD 41004 A may suffer from the fact that the spectrum of this star is blended with the spectrum of the fainter M-dwarf companion HD 41004 B (see e.g. Santos et al. 2002). The separation between the two components of the binary is only 0.5″, smaller than the diameter of the FEROS fiber. However, given the magnitude difference between the two components, the flux of HD 41004 B should represent a mere 3% of the total flux of the primary; the impact on the determination of the line *EW* for HD 41004 A is thus probably limited.

3.1. Temperature scale

In a recent paper, Ramírez & Meléndez (2004) derived temperatures and radii for extra-solar planet-host stars using the IRFM technique. In their work they compare the temperatures derived in Paper IV, as well as by Ribas et al. (2003) (who used infra-red photometry), with the ones obtained by them, and conclude that our values are systematically shifted by ~100 K.

One argument used by Ramírez & Meléndez (2004) in favor of their temperature scale is the fact that for 5 stars that have accurate stellar radii measured (and thus accurate temperatures Ramírez & Meléndez 2004), the results from the IRFM differ by only 14 K with respect to the measured "direct" temperatures (see their Table 1).

Four of the stars in their Table 1 were also analyzed by us. These are HD 128620, HD 128621 (see Table 2), HD 10700 and HD 209458 (see Paper IV). Interestingly, a comparison of the obtained $T_{\rm eff}$ shows that the difference between our estimates and the "direct" temperatures listed by Ramírez & Meléndez (2004) is only of 7 K. In other words, we do not find any strong reason to support that the IRFM scale of temperatures is more accurate than the one derived from the method used in our studies (Paper IV and this paper).

The major goal of the current study is to compare the [Fe/H] values for planet-host stars and "single" field dwarfs in an uniform way. The crucial point is thus to use uniform samples, analyzed using the same line-lists, model atmospheres and techniques to derive stellar parameters and metallicities. This goal is already achieved, and thus our conclusions are not dependent on the temperature scale used. The definition of a correct scale, which is indeed very important when an absolute study is needed, is thus not a limitation in our case.

4. Metallicity distributions

In Fig. 1 we present the metallicity distribution for the 119 planet-host stars with metallicity estimates (Paper IV and Table 1), as well as for the whole volume-limited comparison sample of 94 "single" dwarfs (Paper IV and Table 2).

As it is well seen from the plot, and confirming previous studies, planet hosts have, on average, a [Fe/H] that is 0.24 dex higher than that found for stars with no detected planetary mass companions. The Kolmogorov-Smirnov probability that the two samples belong to the same population is of the order of 10^{-12}.

Although it is not our goal here to study in detail the metallicity distribution of planet-hosts (see next section), or to study the frequency of planets as a function of stellar metallicity (see Paper IV), the addition of new stars to our comparison sample reinforces the results presented in previous works (e.g. Papers II and IV). For instance, the average [Fe/H] of the stars in Table 2 is −0.11, similar to the one found for the 41 comparison stars presented in Paper IV.

The metallicity distribution for our 94 comparison sample stars though symetrical, seems to have a small depression for stars with [Fe/H] values between −0.1 and −0.2 dex. A similar scarcity of planet-host stars seems to exist at the same [Fe/H] interval. The cause for this feature, also tentatively observed in our previous samples (for iron and for other elements – Santos et al. 2001; Bodaghee et al. 2003) as well as in the volume-limited sample of Fischer & Valenti (2005), is not clear, but may be simply related to small number statistics. It is interesting to note that this metallicity regime is at the frontier of the Galactic thin and thick disk populations (e.g. Fuhrmann 2004). Further studies of the UVW velocities of the stars in our sample as well as of other chemical elements are necessary to better tackle this issue.

4.1. Sampling biases

In Paper III we have shown that the whole metallicity "excess" observed for stars with giant planets cannot be explained by any observational or sampling bias. However, the striking fact that stars with planets are particularly metal-rich has led some planet-search programs to base their samples on metal-rich stars (e.g. Tinney et al. 2002; Fischer et al. 2004). Such surveys, now giving their first results, are adding to the lists of known planet hosts some objects that should be considered with care if

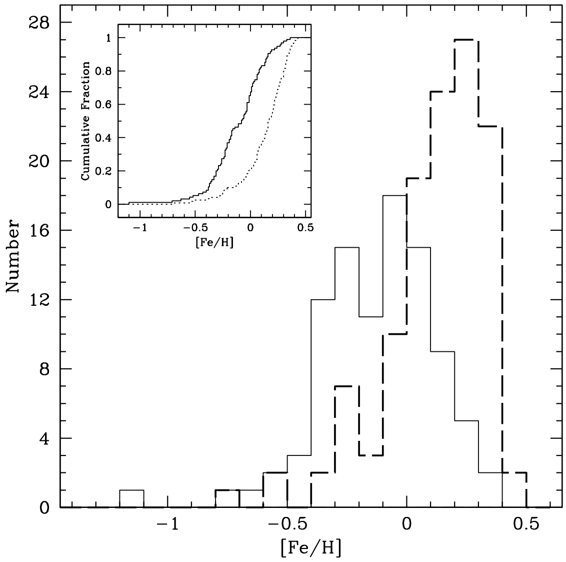

Fig. 1. Metallicity distribution for 119 planet-host stars (dashed line) and for a volume-limited "comparison" sample of 94 stars with no known planetary-mass companions (continuous line). The metallicities were taken from Table 1, Table 2 and from Tables 2–5 of Santos et al. (2004b). The difference between the average metallicity of two samples is 0.24 dex. *Inset*: cumulative functions for both distributions. A Kolmogorov-Smirnov test shows that the probability that both distributions belong to the same population is of the order of 10^{-12}.

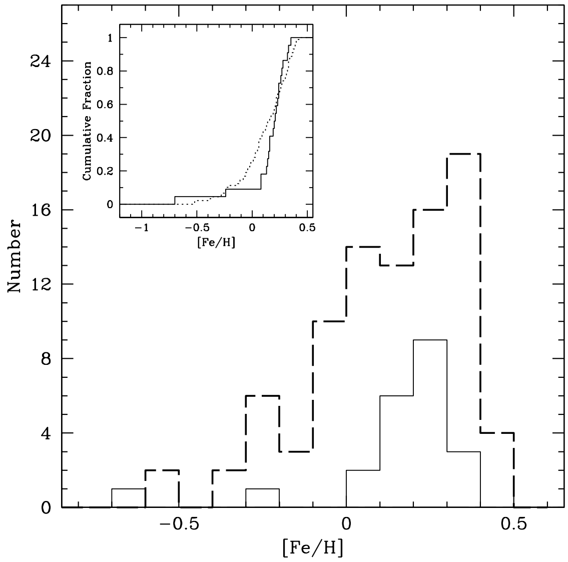

Fig. 2. Metallicity distribution for 22 planet-host stars in binary stellar systems (PIB – filled line) when compared with the same distribution for single planet-hosts (dashed line). The metallicities were taken from Table 1 and from Santos et al. (2004b). The difference between the average metallicity of two samples is ~0.03 dex, PIB stars being slighly overabundant. *Inset*: cumulative functions for both distributions. A Kolmogorov-Smirnov test shows that the probability that both distributions belong to the same population is of the order of 0.08.

a consistent statistical study about the stellar metallicity-giant planet connection is pursued.

The impact of these surveys may have consequences on any future statistical studies of the properties of exoplanets orbiting stars with different chemical composition. For example, the first result of these metallicity-biased surveys will be the discovery of short period giant planets (hot-Jupiters). Any study of the relation between the metallicity of the stars and the orbital period of the orbiting planet (Gonzalez 1998; Queloz et al. 2000; Santos et al. 2003; Sozzetti 2004) will thus be seriously compromised, as such systematic errors are very difficult to take into account.

Such was not taken in consideration when plotting stars in Fig. 1, as the goal of the present paper is simply to present stellar metallicities for an extended comparison sample, and for a few planet-host stars whose stellar parameters and [Fe/H] were not presented in Paper IV. A detailed and unbiased comparison of the [Fe/H] distributions for planet-hosts and "single" stars implies the use of samples for which we are sure not to have any important bias. This was the case of our previous studies (e.g. Paper IV), where we have compared planet-hosts found amid the stars in the CORALIE planet-search sample (Udry et al. 2000) with the [Fe/H] distribution of the whole sample itself; with CORALIE, a target was never chosen based on its high metal content.

5. Planets in multiple stellar systems

In Fig. 2 we present a comparison between the [Fe/H] distributions of 22 stars with planets that are currently known to belong to multiple stellar systems[5] – mostly binary systems, hereafter PIB – with the same distribution for "single" planet-host stars. See Eggenberger et al. (2004) and Eggenberger et al. (in prep.) for references.

The comparison shows that no major difference seems to exist between the two samples. Even if PIB stars seem to be slighly over-metallic when compared to single planet-hosts, the Kolmogorov-Smirnov probability that the two samples belong to the same population is 0.08. If we exclude HD 114762 from the PIB sample (this star has a companion with a minimum mass above 10 times the mass of Jupiter, likely a brown dwarf Latham et al. 1989), this probability decreases to 0.04, only marginally significant.

It has been proposed that planet migration processes may act differently in single and multiple stellar systems, and that migration rates may be increased if the planet-host has a stellar companion (for a discussion see Eggenberger et al. 2004). Increasing the migration efficiency could then increase the scattering within the disc of planetesimals (e.g. Murray et al. 1998). In such a case, we could expect that PIB stars, or at least those with "close" stellar companions, could have been polluted by a larger amount of planetesimal (metal-rich) material.

The fact that we do not find a clear difference between PIB stars and single planet-hosts suggests that strong planetesimal accretion is not usual both for single planet-hosts

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[5] Namely HD 142, HD 9826, HD 13445, HD 16141, HD 19994, HD 40979, HD 41004 A, HD 46375, HD 75289, HD 75732, HD 80606, HD 89744, HD 99492, HD 114762, HD 120136, HD 142022 A, HD 178911 B, HD 186427, HD 190360, HD 195019, HD 222404 and BD -10 3166.

(Pinsonneault et al. 2001; Santos et al. 2003; Cody & Sasselov 2004) nor for planet-host stars in multiple stellar systems. However, if the slight correlation discussed above is real it may imply, for example, that stellar pollution played some role (although probably small) in planet-hosts in multiple stellar systems. A follow-up of these results as more planets are discovered is necessary to resolve this issue.

We also checked if within the PIB star sample there was any correlation between stellar metallicity and the separation of the stellar components. No major correlation was found.

6. Concluding remarks

In this paper we have presented accurate stellar metallicities for a volume-limited sample of 53 comparison "single" stars. This sample was observed to complement the already existing list of 41 comparison dwarfs presented in Papers II and IV.

We further present metallicities and stellar parameters for 29 planet-host stars, most of which were not studied in our previous series of papers (Papers I–IV). Together with the 97 planet host stars studied in Paper IV, we now have a large sample of 119 stars with planets (almost all the known targets) with precise metallicity and stellar parameter estimates.

These two large samples (of planet-hosts and "single" stars) were analyzed using the same line-lists, model atmospheres and techniques to derive stellar parameters and [Fe/H]. Therefore, they constitute very uniform samples, unique and appropriate for future studies of the stellar metallicity-giant planet connection.

We have used these samples to investigate whether stars with planets belonging to multiple stellar systems have a different [Fe/H] distribution when compared with single planet-hosts. The results show that a slight tendency, although not statistically significant, may exist. The enlargement of the samples is needed to resolve this issue.

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