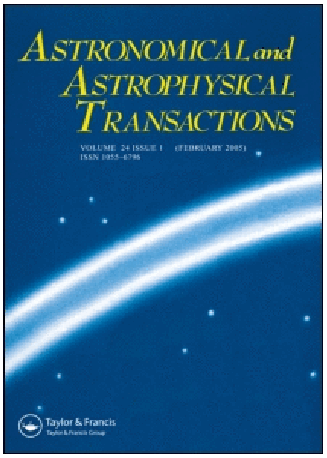

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The question of the abundance of metals in stars with planets

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The question of the abundance of metals in stars with planets

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The metal-poor stars with planets were compared with the metal-rich stars also with planets. The high [Fe]/[H] values obtained from the spectroscopic analysis for most stars with planets can be consequence of the fact that the models used are inadequate for real stellar atmospheres.

Keywords: Stars; Metal abundances; Late-type stars; Evolution of stars

The planets discovered thus far, mainly by the radial-velocity technique, differ from the planets of our Solar System. Thus it is clear that the search for the characteristic features of planet-host (PH) stars is of great interest. During the last few years a fair number of different detailed spectroscopic studies of stars with planets have been carried out. One of the results of these investigation is that PH stars are on average more metal rich than dwarf stars in the solar neighbourhood [1–3]. This anomaly is believed to be an indication of the link between high metallicity and the presence of planets. This result has an enormous impact on theories of planetary formation. Mechanisms have already been proposed for an explanation of this correlation and the search for planets has become concentrated towards metal-rich stars.

The goal of the current study is to show that there are no reliable arguments confirming a connection between the presence of planets and the high metallicities of PH stars. Firstly, the PH stars detected to date are not probably a representative sample of all PH stars in our Galaxy. Secondly, high-precision radial-velocity studies have detected small, but periodic, variations in the motion of stars, which is interpreted as indicating the presence of companions with minimum masses ranging from approximately 1 to 10 Jupiter masses M_J. Radial-velocity observations cannot determine the true mass of these companions.

The use of astrometric data from the Hipparcos spacecraft, as well as radial-velocity data allowed us to determine the inclination of the companion orbital planes to the line of sight of the observer and to estimate the preliminary masses for the 30 proposed extrasolar companions. The obtained results showed that some of the companions can be brown dwarfs, double stars or low-mass stars rather than planets [4].

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Finally, it is necessary to note that the high metal content of PH stars are based mainly on detailed spectroscopic analysis. Unfortunately, the spectroscopic [Fe]/[H] values for the almost all PH stars were obtained only from two papers [2, 3]. Other researchers [5–7] have defined metal abundances for only some PH stars, therefore it is difficult to estimate the reliability of the [Fe]/[H] values.

High-resolution spectroscopy is believed to provide the most precise method for definitions of metal abundance. Indeed, high-resolution spectroscopy provides a chance for precise definitions of metal abundance. However, the detailed spectroscopic analysis of elemental abundances requires the introduction of atmospheric models. The data obtained from the results depends on the models adopted. Today, most elemental abundance analyses of late-type stars (PH stars belong to these types) rely on very simplified models for the stellar atmospheres and the spectral line formation processes [8, 9]. The detailed spectroscopic analysis of elemental abundances is a differential analysis with respect to the Sun. The use of the solar lines *gf* values (where *gf* is the oscillator strength) for all late-type stars may cause systematic errors.

However, not all PH stars show metal excesses, some of these stars were found to be metal deficient. Therefore we decided to compare PH star with metal excesses and those with metal deficiencies. We have gathered together all the physical characteristics of 111 PH stars available in the literature and have divided these stars into two groups according to the values of [Fe]/[H] obtained from spectroscopy (denoted $[Fe]/[H]_{spc}$). The first group contains PH stars with $[Fe]/[H] \leq 0.10$ dex; the second group contains PH stars with $[Fe]/[H] > 0.10$ dex.

The characteristics of these PH are presented in tables 1 and 2. The first column identifies the Henry Draper Catalogue (HD) numbers. For some stars we have added binary letters d and A to HD numbers. The second and third columns give the effective temperatures $T_{\rm eff}^{\rm irfm}$ determined by the infrared flux method (IRFM) [10] and the temperatures $T_{\rm eff}^{\rm spc}$ derived from high–resolution spectroscopy [2, 3] respectively. The ranges of effective temperatures are the same for both PH star samples (4700–6400 K). The $T_{\rm eff}^{\rm irfm}$ values are systematically 100–150 K lower than $T_{\rm eff}^{\rm spc}$ (figure 1). Ramierez and Melendez [11] have determined the direct effective temperatures $T_{\rm eff}^{\rm dir}$ for 13 stars, using directly measured stellar diameters and bolometric fluxes and show that the IRFM temperature scale is a very good match to $T_{\rm eff}^{\rm dir}$.

Because of close correlation between the effective temperature and the metal abundance in the spectroscopic analysis, the systematic error of +100 K in the effective temperature for late-type stars will result in an error of about 0.1 dex in the abundance definition [9]. It is necessary to explain the reason for such a discrepancy between these temperature scales.

The fourth to sixth columns contain the [Fe]/[H] values obtained from spectroscopy (denoted $([Fe]/[H])_{spc}$) [2, 3] and the [Fe]/[H] values derived from two photometric calibrations (denoted $([Fe]/[H])_{MS}$ [12] and $(([Fe]/[H])_{SN}$ [13]).

The photometric *UVBY* [Fe]/[H] calibrations are frequently used for the analysis of distribution of metallicity of the F to K stars in the solar neighbourhood, as there are more than 63 600 stars with *UVBY*-photometry. Schuster and Nissen [13] have published a calibration which uses the standard *UVBY* indices, $B - Y$, m_1, and c_1 to estimate the metallicity of a stars. The m_1 index is believed to be a good indicator of metallicity in late-type stars, if no modification due to chromospheric activity is expected. This calibration is applicable to the dwarf stars of spectral type ranging from F to early K-type stars and covers the metallicity range $-3.5 < [Fe]/[H] < 0.4$. More recently, Martell and Smith (MS) [12] have presented, as they believed, the improved *UVBY* [Fe]/[H] calibration. These calibrations are based on the [Fe]/[H] values from detailed spectroscopic analysis collected in the catalogues [14, 15] and by *UVBY* photometry.

In the seventh and eighth columns the chromospheric activity indices $\log R'_{\rm HK}$ [16] and the rotation periods $P_{\rm rot}$ [16], respectively of the PH stars are listed. As most PH stars are inactive,

Table 1. The physical characteristic of stars with planets and with $([Fe]/[H])_{spc} \leqslant 0.10$ dex.

HD	T_{eff}^{irfm} (K)	T_{eff}^{spc} (K)	$([Fe]/[H])_{spc}$	$([Fe]/[H])_{MS}$	$([Fe]/[H])_{SN}$	$\log R'_{HK}$	P_{rot} (day)	$B-V$	Spectral type	Age (G years)	Estimated mass of planetary companion
142d	6152	6312	0.09			−4.95	—	0.52	G1IV	4	
3651	5264	5173	0.12	—	—	−5.02	45	0.85	K0V	6–8	
4208	5586	5626	−0.24	−0.23	−0.22	−4.95	26	0.66	G5V	5–9	
6434	5741	5835	−0.52	−0.57	−0.54	−4.89	19	0.61	G3IV	4–13	$296M_J$
8574	5942	6151	0.06	−0.10	−0.23	−5.07	18	0.58	F8	4–8	
10647	—	6143	−0.03	−0.11	−0.10	−4.72	7	0.55	F8V	5–7	
13445d	5128	5163	−0.24	—	—	−4.74	31	0.81	K1V	6–8	
22049	5012	5073	−0.13	—	—	−4.51	17	0.88	K2V	1–2	
23079	5961	5959	−0.11	0.14	−0.11	−4.94	—	0.58	F8/G0V	8	
33636†	5811	6046	−0.08	−0.21	−0.20	−4.85	15	0.59	G0V	3–8	
37124	5424	5546	−0.38	−0.38	−0.37	−4.90	25	0.67	G4V	4–12	$119M_J$
39091†	6022	5991	0.10	0.07	0.09	−4.97	—	0.60	G3IV	4–6	
50554	5907	6026	0.01	−0.08	−0.14	−4.95	16	0.58	F8	5	
65216	5561	5666	−0.12	−0.20	−0.19	—	—	0.67	G5V	—	
89307	5972	—	−0.16	−0.16	−0.13	−4.95	18	0.59	G0V	5–9	
95128	—	5954	0.06	−0.00	0.02	−5.02	23	0.62	G0V	6–9	$2.9M_J$
106252	5907	5899	−0.01	−0.13	0.13	−4.97	23	0.64	G0V	9	
111232	5480	5494	−0.36	−0.45	−0.41	−4.98	31	0.70	G5V	5–9	
114386	—	4834	−0.06	—	—	—	—	0.98	K3V	—	
114729	5783	5886	−0.25	−0.43	−0.56	−5.05	19	0.59	G0V	>10	
114762d	5824	5884	−0.70	−0.73	−0.75	—	—	0.53	F9V	14	$145M_J$
114783	5039	5089	0.09	—	—	−4.96	—	0.52	K0	4–5	
117618	5948	6013	0.06	−0.02	−0.02	−5.01	—	0.60	G2V	7	
128311	4812	4835	0.03	—	—	−4.49	—	0.97	K3V	0.5–1	
130322	5323	5392	0.03	—	—	−4.78	9	0.78	K0V	2–9	
141937	5808	5909	0.10	0.24	0.24	−4.94	21	0.63	G2–3V	2–4	$10M_J$
143761	5754	5853	−0.21	−0.24	−0.27	−5.08	22	0.61	G0–2V	7–12	$115M_J$
147513	5852	5883	0.06	0.00	0.02	−4.52	5	0.62	G3–5V	1–8	
150706	5792	5961	−0.01	−0.20	−0.18	−4.51	–	0.61	G0	2–8	
162020†	4578	4858	−0.04	—	—	—	–	0.96	K2V		$13M_J$
168746	5468	5601	−0.08	−0.15	−0.09	−5.05	34	0.71	G5	7–10	
186427d	5633	5772	0.08	0.03	0.07	−5.08	29	0.66	G3V	8	$14M_J$
192263	4888	4947	−0.02	—	—	−4.56	21	0.94	K2V	7	$82M_J$
196885A	6065	6071	−0.05			−5.01	15	0.56	F8IV	6	
208487	6028	6141	0.06	−0.08	0.07	−4.90	–	0.57	G2V	7	
209458v	5993	6117	0.02	−0.08	−0.08	−5.00	19	0.59	G0V	>5	
222582	5702	5843	0.05	−0.09	−0.08	−5.00	25	0.65	G5	5–11	$59M_J$
Stars outside the main sequence											
11964A	5142	—	−0.10	−0.10	−0.02	−5.16	45	0.82	G5	9	
72659	5789	5995	0.03	−0.07	−0.10	−5.02	21	0.61	G0V?	4–7	
117176	5328	5560	−0.06	−0.18	−0.10	−4.99	32	0.71	G5V	5–7	$27M_J$
136118†	6059	6222	−0.04	−0.08	−0.20	−4.97	13	0.53	F9V	4–5	$11.9M_J$
154857	5594	5610	−0.23	−0.32	−0.28	−5.14	–	0.70	G5V	4	
168443	5491	5617	0.06	−0.16	−0.06	−5.12	38	0.72	G5	2–10	$17M_J$
190228	5081	5327	−0.26	−0.40	−0.27	−5.18	47	0.79	G5IV	5–10	$45M_J$
195019d	5506	5842	0.08	−0.13	−0.11	−5.09	29	0.64	G3IV–V	7–10	$713M_J$

†Minimum masses of companions in the range from 10 to 15 M_{Jup}.

we used two photometric calibrations to estimate the distribution of the metallicities in PH stars using the *UVBY* photometry from [17]. The results are listed in the fifth and sixth columns of tables 1 and 2. The [Fe]/[H] values derived from the photometric calibrations are fairly consistent with each other. The [Fe]/[H] values derived from both photometric calibrations are systematically lower than those obtained from spectroscopy and the discrepancies strongly increase towards higher [Fe]/[H] values (figure 2). The photometric calibrations result in [Fe]/[H] values that are less accurate but, as they are based on [Fe]/[H] values obtained from

Table 2. The physical characteristic of stars with planets and with $([Fe]/[H])_{spc} > 0.10$.

HD	T_{eff}^{irfm} (K)	T_{eff}^{spc} (K)	$([Fe]/[H])_{spc}$	$([Fe]/[H])_{MS}$	$([Fe]/[H])_{SN}$	$\log R'_{HK}$	P_{rot} (days)	$B-V$	Spectral type	Age (G years)	Estimated mass of planetary companion
Stars inside the band of the main sequence											
2638	—	5192	0.16	—	—	−4.83	—	0.89	G5		
17051	6065	6252	0.26	0.12	0.16	−4.65	—	0.56	G3IV	2–4	
20367	5989	6138	0.17	−0.02	0.01	−4.50	6	0.57	G0	0.9	
27894	—	4875	0.30	—	—	—	—	1.00	K2V	—	
37605	5216	5391	0.31	—	—	—	—	0.83	K0V	—	
40979d	6081	6145	0.21	0.07	−0.03	−4.63	9	0.57	F8V?	2–6	
49674	5509	5644	0.33	0.18	0.22	−4.80	27	0.74	G5V?	3–5	
52265	6007	6103	0.23	0.15	0.15	−5.02	16	0.57	G0V?	6–4	$41M_J$
63454	—	4841	0.11	—	—	—	—	1.01	K4V	—	
68988	5778	5988	0.36	0.35	0.36	−5.04	26	0.65	G0	4–6	
70642	5620	5693	0.18	0.11	0.14	—	—	0.69	G5IV–V	>10	
73256	5344	5518	0.26	0.12	0.13	−4.49	—	0.78	G8–K0V	>10	
75289d	6089	6143	0.28	0.16	0.17	−5.00	15	0.58	G0V	4–5	
80606d	5461	5574	0.32	0.22	0.20	−5.09	41	0.76	G5	8	
82943	5952	6016	0.30	0.25	0.27	−4.92	20	0.62	G0	3–4	$36M_J$
92788	5590	5821	0.32	0.18	0.22	−5.05	32	0.69	G5V?	3–9	$54M_J$
93083	—	4995	0.15	—	—	−5.02	48	0.94	K3V	6	
99492d	4695	4810	0.26	—	—	−4.93	45	1.00	K2V	—	
101930	—	5079	0.17	—	—	—	46	0.91	K1V	5	
108147	6191	6248	0.20	0.06	0.07	−4.78	9	0.54	F8–G0V	2–4	
120136d	6307	6339	0.23	0.19	0.12	−4.70	6	0.51	F7V	2	
121504	5962	6075	0.16	−0.02	−0.02	−4.73	9	0.59	G2V	3	
142415	5894	6045	0.21	0.16	0.13	−4.66	10	0.62	G2V	2–5	
178911d	5366	5600	0.27	0.09	0.11	−4.89	36	0.75	G5	2–5	
179949	6169	6260	0.22	0.12	0.06	−4.79	10	0.55	F8V	3	
187123	5665	5845	0.13	0.14	0.17	−5.03	27	0.66	G2V	6–7	
210277	5410	5532	0.19	0.04	0.11	−5.06	41	0.74	G8V	6–7	$18M_J$
217014	5690	5804	0.20	0.14	0.18	−5.08	29	0.67	G2IV	4–7	
Stars outside the main sequence											
2039	5847	5976	0.32	0.07	0.09	−4.91	—	0.66	G2IV/V	2–3	
9826d	6184	6212	0.13	0.07	−0.04	−5.04	12	0.54	F7V	4–6	$108M_J$
16141d	5679	5801	0.15	−0.06	−0.02	−5.11	31	0.67	G5IV	8–5	$111M_J$
19994d	5999	6190	0.24	0.10	−0.01	−4.88	14	0.57	F8V	4–5	
23596	5977	6108	0.31	0.18	0.10	−5.06	25	0.63	F8	7–4	
27894	—	4875	0.30	—	—	—	—	1.00	K2V	—	
28185	5594	5656	0.22	0.21	0.21	−4.82	30	0.75	G5	>10	
30177	5500	5588	0.39	0.16	0.20	−5.08	—	0.77	G8V	>10	
41004d	5047	5242	0.16	—	—	−4.66	27	0.89	K1V	—	
45350	5446	5616	0.13	0.14	0.19	−5.10	39	0.74	G5IV	8–12	
46375d	5267	5268	0.20	—	—	−4.94	43	0.86	K1IV	5–11	
74156	5910	6112	0.16	−0.03	−0.06	−5.08	19	0.58	G0	4–7	
75732d	5247	5279	0.33	—	—	−5.04	47	0.87	G8V	6–9	
83443	5386	5478	0.37	—	—	−4.85	35	0.81	K0V	4–8	
89744d	6106	6234	0.22	0.19	0.12	−4.94	11	0.53	F5V	2–5	$97M_J$
102117	5458	5690	0.32	0.02	0.09	−5.03	34	0.72	G6V	>10	
108874	5443	5596	0.23	0.09	0.14	−5.08	38	0.74	G5	>10	
117207	5483	5654	0.23	−0.01	0.07	−5.06	36	0.72	G8IV/V	6–10	
134987	5674	5776	0.30	0.18	0.22	−5.09	33	0.69	G5V	6	$34M_J$
142022d	5402	5499	0.19	—	—	−4.95	38	0.79	K0V	>10	
145675	5129	5311	0.43	—	—	−5.06	48	0.88	K0V	8	
160691	5600	5806	0.32	0.15	0.20	−5.02	31	0.69	G3IV	7	
169830	6227	6299	0.21	0.15	0.07	−5.12	11	0.52	F8/9V	7	$102M_J$
183263	5755	5991	0.34	0.09	0.10	−5.11	32	0.68	G2IV	8–3	
188015	5557	5793	0.30	0.19	0.21	−5.05	36	0.73	G5IV	7	
190360d	5552	5584	0.24	0.11	0.17	−5.09	40	0.75	G6IV	7	
196050	5789	5918	0.22	0.06	0.09	−5.04	16	0.67	G3V	4	

(*continued*)

Table 2. Continued.

HD	$T_{\text{eff}}^{\text{irfm}}$ (K)	$T_{\text{eff}}^{\text{spc}}$ (K)	([Fe]/[H])$_{\text{spc}}$	([Fe]/[H])$_{\text{MS}}$	([Fe]/[H])$_{\text{SN}}$	log R'_{HK}	P_{rot} (days)	$B-V$	Spectral type	Age (G years)	Estimated mass of planetary companion
213240A	5899	5984	0.17	0.00	−0.02	−5.00	15	0.60	G4IV	3–5	
216435	5931	5938	0.24	−0.01	−0.05	−5.00	—	0.62	G3IV	5	
216437	5733	5887	0.25	0.08	0.11	−5.04	27	0.66	G4IV–V	>8	
216770	5353	5423	0.26	—	—	−4.92	39	0.82	K1V	>10	
217107	5598	5646	0.37	0.31	0.28	−5.08	39	0.74	G8IV	7	
4203	5546	5636	0.40	0.19	0.22	−5.18	45	0.77	G5	10–4	
10697	5510	5641	0.14	0.01	0.08	−5.08	36	0.73	G5IV	7	38M_{J}
12661	5501	5702	0.36	—	—	−5.08	35	0.71	K0V?	8	56M_{J}
27442	4613	4825	0.39	—	—	−5.27	—	1.08	K2IV	7	
38529	5487	5674	0.40	0.26	0.23	−4.96	37	0.77	G4V	4–5	435M_{J}
76700	5645	5737	0.41	0.12	0.14	−4.90	—	0.74	G6V?	>10	
88133	5160	5438	0.33	0.47	−0.05	—	—	0.81	G5IV	9	

spectroscopic analysis, we expected to find only large random errors when comparing with spectroscopic values. We believe that unreliable definitions of the [Fe]/[H] values obtained from spectroscopy could be the reason for such discrepancies.

In figure 3 the locations of both PH groups in a colour–absolute magnitude diagram relative to the average main sequence (obtained by MS) in the solar neighbourhood are shown. To determine the locations of the average MS values we used A9 to K2V stars within 20 pc with a V magnitude of not more than 8 from the Hipparcos catalogue. The absolute magnitudes of PH stars are calculated on the basis of the trigonometric parallaxes and UBV photometry from the Hipparcos catalogue. The data for the metal-deficient PH stars are plotted as full circles, those for the metal-rich PH stars are plotted as full triangles, and the location of the Sun is shown by an arrow. On the basis of the theoretical isochrones, it was estimated [18] that a star with $[\text{Fe}]/[\text{H}] = +0.3$ will lie at a magnitude of 0.45 above the MS value of a star with solar metallicity, and a star with $[\text{Fe}]/[\text{H}] = -0.3$ will lie at a magnitude of 0.45 beneath

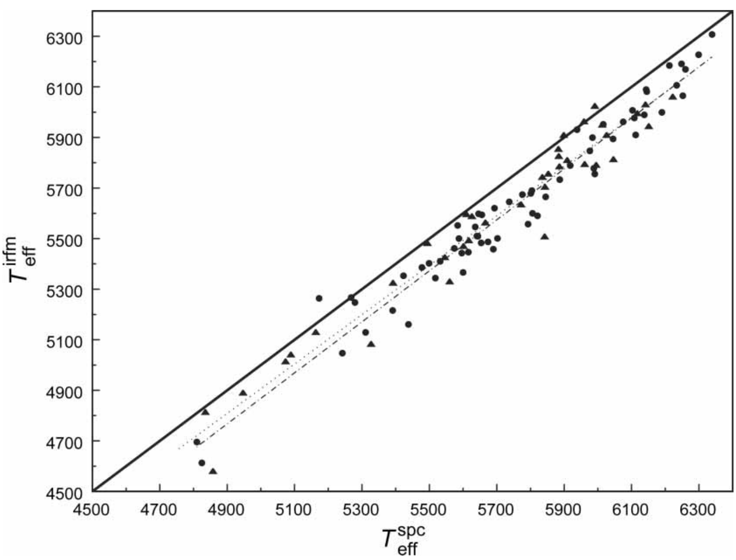

Figure 1. The comparison of the $T_{\text{eff}}^{\text{spc}}$ values derived from high-resolution spectroscopy [2, 3] with the $T_{\text{eff}}^{\text{irfm}}$ values obtained from IRFM calibration [10]. The one-to-one relation is drawn as a solid line.

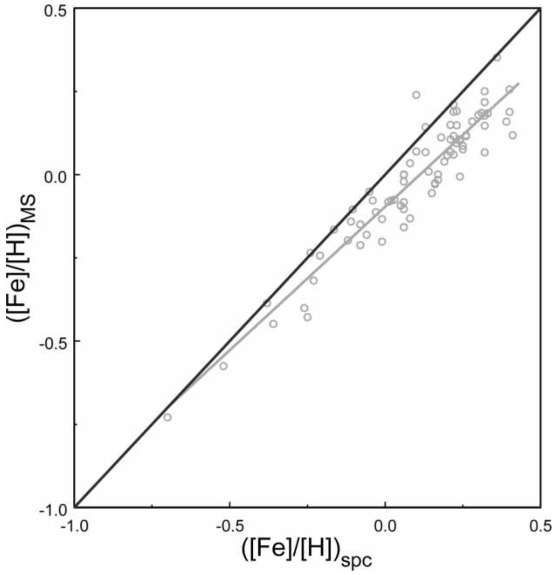

Figure 2. The comparison of [Fe]/[H] values derived from high-resolution spectroscopy [2, 3] with those obtained from *UVBY* [Fe]/[H] calibration [12]. The one-to-one relation is drawn as solid line.

it. We plotted these limits in figure 3 as the dotted and dot-dashed lines respectively. As seen in figure 3, almost all the stars in the first group lie within the MS values. These PH stars belong mainly to the early spectral subclasses G. Their levels of activity are similar to the average level for the Sun ($\log R'_{\rm HK} = -4.96$). The inactive, slowly rotating stars of this group lie outside the MS values.

Some of the stars in the second group which are located within the MS values have higher levels of activity and faster rotations than the Sun. This could be an indicator of a young age

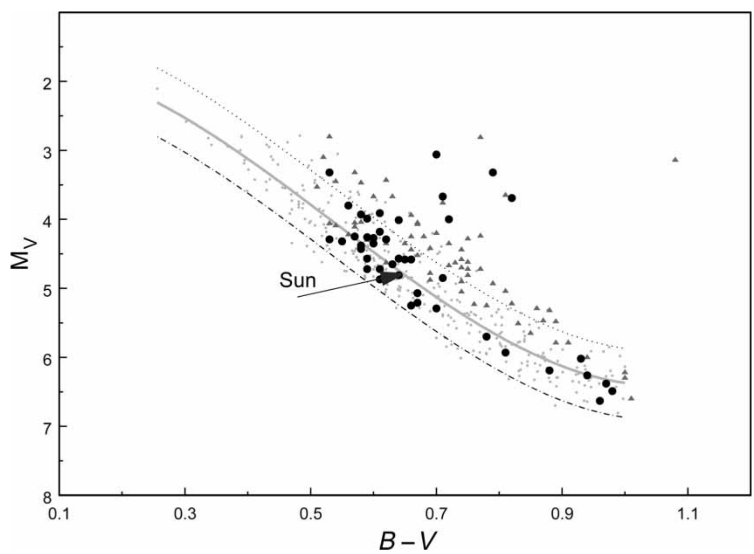

Figure 3. Colour – magnitude diagram for PH stars. Metal-poor PH stars are plotted as full circles, metal-rich PH stars are plotted as full triangles, and the location of the Sun is shown by an arrow.

and the presence of a massive companion. Most stars in this group lie outside the MS values. They are the inactive, slowly rotating stars. The stars which belong to a binary stellar system and subgiants are among these. Some stars are displaced from the MS values by a magnitude of more than 1. These inactive, slowly rotating stars have the highest [Fe]/[H] values from the spectroscopic analysis.

In the last two columns of both tables are given the estimations of the stellar ages from [16, 19] and the preliminary estimations of the masses of planetary companions from [4]. Usually the age of star is estimated from comparison of the position of a star on the Hertzsprung–Russell diagram with a series of accepted isochrones [19]. The alternative method uses the age-activity relation [16]. Isochronic and chromospheric ages sometimes differ by a factor of almost 2. The levels of activity, the periods of rotation and the estimations of age show that most of the PH stars are older than the Sun.

As a result of the above work, we have found the following.

- (i) There is a systematic distinction between the effective temperatures obtained from the IRFM and those found from spectroscopic analysis.
- (ii) There is a systematic distinction between the distributions of metallicities in PH stars obtained from spectroscopic analysis and photometric calibrations.
- (iii) Comparison of the metal-poor and metal-rich stars has shown that the first group of stars as a whole belong to the earlier subclasses G.
- (iv) The high abundances obtained from the spectroscopic analysis are found mainly for old inactive late-type subclasses G to K stars, for subgiants and for stars found to belong to binary stellar systems.

Thus, we believe that the metal abundances for late-type stars can be overestimated because of incompleteness of the applied models of stellar atmospheres.

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