Abundance difference between components of wide binaries

II. The southern sample^{★,★★,★★★}

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ABSTRACT

Aims. We present high-precision iron abundance differences for 33 wide binaries with similar components. They were observed with the FEROS spectrograph at ESO, looking for abundance anomalies due to the ingestion of metal rich material of a planetary origin.

Methods. An optimized data analysis technique and the high quality of the spectra allowed us to achieve an error of about 0.02 dex for pairs with small temperature differences.

Results. We found one case (HIP 64030 = HD 113984) with a large (0.27 dex) abundance difference. The primary of this binary appears to be a blue straggler, and the abundance difference might be due to the peculiar evolution of the star. A few other pairs show small abundance differences (≤ 0.09 dex). In a few cases these differences suggest the ingestion of a small amount of metal rich material, but in others they are likely spurious, because of the large temperature difference, high level of magnetic activity, or different evolutionary phases between the components. Some cases of abundance differences involving pairs with warm ($T_{\text{eff}} \geq 6000$ K) primaries might be due to the diffusion of heavy elements; dedicated theoretical models for the stellar parameters of the targets would be welcome.

Conclusions. This study confirms our preliminary result based on analysis of 23 pairs (Desidera et al. 2004) that the occurrence of large alterations in stellar abundances caused by the ingestion of metal rich, rocky material is not a common event. For at least 65% of the pairs with components warmer than 5500 K, the limits on the amount of rocky material accreted by the program stars are comparable to the estimates of rocky material accreted by the Sun during its main-sequence lifetime.

Key words. stars: abundances – stars: planetary systems – stars: binaries: visual – techniques: spectroscopic

1. Introduction

Wide visual binaries with similar components are ideal targets for high-precision differential abundance measurements. Gratton et al. (2001) and Desidera et al. (2004, hereafter Paper I) showed that errors in estimating the difference of iron content between the two components that are lower than 0.02 dex can be achieved for pairs with temperature differences smaller than 300–400 K and components with effective temperatures in the range 5300–6300 K. This opens possibilities for a detailed and quantitative study of chemical alterations in the external convective layer, which is caused by the accretion of metal-rich planetary material occurring during the main-sequence lifetime of the stars. In fact, the engulfment of $1 M_{\oplus}$ of iron (about $5 M_{\oplus}$ of meteoritic material) corresponds to an iron abundance difference of about 0.01 dex for a solar type main sequence star.

Accretion phenomena have been suggested to explain the correlation between the presence of giant planets and the high metallicity of their parent stars (Gonzalez 1997). The most recent studies (Santos et al. 2004; Fischer & Valenti 2005)

conclude that the high metallicity of a planet host is more likely primordial than due to accretion. Nevertheless, the occurrence of planetary pollution has been proposed in some cases (e.g. Israelian et al. 2003; Laws & Gonzalez 2001).

In Paper I, we studied 23 pairs from the sample of the on-going radial-velocity planet search using SARG at TNG. We did not find any pair with an abundance difference larger than 0.07 dex, and most of the pairs have identical iron content within 0.02 dex. However, the relatively small number of targets limits any inferences on the frequency of pairs with enriched components and on the origin of the planet-metallicity connection.

Therefore, we extended our sample by observing a sample of southern visual binaries using the FEROS spectrograph at ESO La Silla. The spectra were analyzed using the same technique as developed in Gratton et al. (2001) and Paper I.

2. Observations and data reduction

A sample of 56 wide binaries with similar components (main sequence or slightly evolved stars with a magnitude difference less than 1.0)¹ were observed with the FEROS spectrograph in two runs (August 2001 and March 2002). Details on the observations and data reduction are found in the companion paper Desidera et al. (2006b, hereafter Paper II), where the study of radial and

[★] Based on observations collected at the European Southern Observatory, Chile, using FEROS spectrograph (proposals ID: 69.D-0338-70.D-0081).

^{★★} Table 3 is only available in electronic form at the CDS via anonymous ftp to [cdsarc.u-strasbg.fr](ftp://cdsarc.u-strasbg.fr) (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/454/581>

^{★★★} Tables 2, 5, 6, 8–10 are only available in electronic form at <http://www.edpsciences.org>

¹ Two pairs with larger magnitude difference, HIP 76446 and HIP 78024, were also observed and included in this work.

Table 1. Visual and absolute magnitudes, $B - V$ color, Hipparcos parallaxes, stellar masses (derived iteratively during the abundance analysis using the spectroscopic temperatures and abundances), and projected binary separation for program stars. The formal errors on magnitudes and colors are probably underestimated (see Paper I).

Object	V_A	V_B	$(B - V)_A$	$(B - V)_B$	π mas	$M_{V(A)}$	$M_{V(B)}$	M_A $M_\odot$	M_B $M_\odot$	ρ "	ρ AU
HIP 3290	7.995 ± 0.004	8.986 ± 0.011	0.473 ± 0.015	0.514 ± 0.028	10.33 ± 1.22	2.95 ± 0.26	3.94 ± 0.26	1.05	0.96	6.3	645
HIP 10175	8.180 ± 0.006	8.647 ± 0.010	0.674 ± 0.026	0.732 ± 0.046	20.41 ± 1.75	4.67 ± 0.19	5.14 ± 0.19	1.00	0.92	5.9	298
HIP 20552	6.839 ± 0.004	7.238 ± 0.005	0.630 ± 0.014	0.704 ± 0.015	36.92 ± 0.84	4.67 ± 0.05	5.07 ± 0.05	1.08	1.01	5.6	152
HIP 37918/23	8.167 ± 0.012	8.266 ± 0.011	0.779 ± 0.029	0.785 ± 0.023	29.20 ± 1.91	5.46 ± 0.14	5.56 ± 0.14	0.98	0.95	23.1	802
HIP 39409	9.253 ± 0.009	9.312 ± 0.009	0.747 ± 0.053	0.669 ± 0.051	15.11 ± 2.71	4.85 ± 0.39	4.91 ± 0.39	0.99	0.98	5.1	390
HIP 44814/17	9.495 ± 0.004	9.826 ± 0.005	0.843 ± 0.049	0.859 ± 0.060	15.80 ± 2.89	5.18 ± 0.40	5.51 ± 0.40	0.97	0.92	10.6	774
HIP 49520	8.686 ± 0.009	8.849 ± 0.011	0.617 ± 0.033	0.599 ± 0.038	19.63 ± 2.11	5.06 ± 0.23	5.22 ± 0.23	1.00	0.99	9.6	508
HIP 51266	8.369 ± 0.006	8.606 ± 0.007	0.830 ± 0.024	0.818 ± 0.030	29.86 ± 1.64	5.72 ± 0.12	5.96 ± 0.12	0.93	0.89	5.9	199
HIP 55288	7.051 ± 0.006	7.814 ± 0.010	0.504 ± 0.013	0.710 ± 0.023	17.98 ± 1.60	3.26 ± 0.19	4.02 ± 0.19	1.21	1.03	9.5	542
HIP 56280	5.637 ± 0.004	5.734 ± 0.003	0.533 ± 0.008	0.523 ± 0.007	37.44 ± 1.15	3.50 ± 0.07	3.59 ± 0.07	1.23	1.21	9.5	253
HIP 58298	8.173 ± 0.008	8.288 ± 0.009	0.467 ± 0.035	0.503 ± 0.037	13.52 ± 1.74	3.69 ± 0.28	3.80 ± 0.28	1.03	1.02	4.0	316
HIP 58813/15	8.029 ± 0.010	8.718 ± 0.014	0.634 ± 0.017	0.726 ± 0.024	18.73 ± 1.88	4.31 ± 0.22	5.00 ± 0.22	1.11	0.99	23.2	1287
HIP 58862/64	9.155 ± 0.009	9.826 ± 0.014	0.449 ± 0.025	0.626 ± 0.051	7.99 ± 2.47	2.49 ± 0.69	3.16 ± 0.69	1.08	1.00	27.6	5933
HIP 59743	7.960 ± 0.005	8.234 ± 0.007	0.793 ± 0.021	0.830 ± 0.034	27.50 ± 1.54	5.13 ± 0.12	5.41 ± 0.12	0.92	0.88	7.0	256
HIP 62596	8.765 ± 0.011	8.784 ± 0.011	0.554 ± 0.030	0.561 ± 0.030	13.51 ± 2.75	4.02 ± 0.45	4.04 ± 0.45	1.18	1.20	9.0	800
HIP 64030	7.528 ± 0.004	8.095 ± 0.007	0.439 ± 0.013	0.539 ± 0.024	13.24 ± 1.99	2.94 ± 0.33	3.51 ± 0.33	1.11	1.00	7.0	580
HIP 65176	7.778 ± 0.004	8.559 ± 0.010	0.543 ± 0.013	0.686 ± 0.029	18.86 ± 1.49	4.11 ± 0.17	4.89 ± 0.17	1.21	1.07	5.0	272
HIP 65352/55	7.213 ± 0.004	7.345 ± 0.004		0.873 ± 0.013	61.76 ± 1.24	6.16 ± 0.04	6.30 ± 0.04	0.78	0.75	26.3	427
HIP 69328	8.376 ± 0.005	8.795 ± 0.007	0.580 ± 0.024	0.643 ± 0.030	15.37 ± 2.60	4.05 ± 0.37	4.47 ± 0.37	0.99	0.94	6.6	487
HIP 70269	7.554 ± 0.006	7.669 ± 0.006	0.564 ± 0.023		22.81 ± 1.89	4.39 ± 0.18	4.41 ± 0.18	1.01	1.01	5.8	260
HIP 70386	7.423 ± 0.006	7.612 ± 0.006	0.539 ± 0.016	0.604 ± 0.017	27.90 ± 2.00	4.61 ± 0.16	4.80 ± 0.16	1.13	1.01	9.3	340
HIP 73674	8.398 ± 0.011	8.418 ± 0.012	0.612 ± 0.028	0.610 ± 0.038	21.13 ± 1.74	4.97 ± 0.18	4.99 ± 0.18	0.95	0.93	7.4	360
HIP 74432/34	6.656 ± 0.006	7.500 ± 0.009	0.694 ± 0.010	0.752 ± 0.016	34.20 ± 1.78	4.30 ± 0.11	5.15 ± 0.11	0.97	0.90	23.5	693
HIP 76446	8.669 ± 0.007	9.870 ± 0.017	0.525 ± 0.051	0.759 ± 0.097	16.50 ± 1.81	4.66 ± 0.24	5.86 ± 0.24	1.03	0.86	7.9	498
HIP 76603/02	6.466 ± 0.008	6.555 ± 0.007	0.483 ± 0.014	0.515 ± 0.013	41.68 ± 2.87	4.53 ± 0.15	4.62 ± 0.15	1.10	1.13	11.8	287
HIP 78024	6.983 ± 0.004	8.621 ± 0.014	0.553 ± 0.012	0.823 ± 0.044	26.54 ± 1.08	4.09 ± 0.09	5.73 ± 0.09	1.19	0.93	6.0	227
HIP 79818	8.507 ± 0.006	9.118 ± 0.012	0.480 ± 0.025	0.577 ± 0.067	10.83 ± 2.51	3.13 ± 0.51	3.74 ± 0.51	1.06	1.00	4.9	583
HIP 80399	5.970 ± 0.004	6.733 ± 0.008			31.82 ± 1.12	3.47 ± 0.08	4.24 ± 0.08	1.24	1.09	4.7	147
HIP 84405	5.045 ± 0.005	5.212 ± 0.007	0.877 ± 0.021		167.08 ± 1.07	6.16 ± 0.01	6.33 ± 0.02	0.78	0.78	4.7	28
HIP 101292	8.459 ± 0.006	8.479 ± 0.007			20.99 ± 2.06	4.99 ± 0.21	5.01 ± 0.21	0.98	0.98	4.0	199
HIP 103438	8.448 ± 0.006	9.030 ± 0.009	0.603 ± 0.028	0.761 ± 0.048	19.63 ± 1.87	4.84 ± 0.21	5.42 ± 0.21	1.06	0.90	4.5	235
HIP 104687	8.144 ± 0.006	8.189 ± 0.006	0.638 ± 0.056	0.714 ± 0.060	20.87 ± 1.99	4.67 ± 0.21	4.71 ± 0.21	1.06	1.05	4.0	198
HIP 114914	8.174 ± 0.006	8.547 ± 0.008	0.638 ± 0.029	0.710 ± 0.044	18.30 ± 1.97	4.39 ± 0.23	4.76 ± 0.23	1.09	1.04	5.3	301

rotational velocities and of the chromospheric Ca II H&K emission is presented.

Pairs for which at least one of the components is a double-lined spectroscopic binary or which show rotational velocity higher than about 10 km s^{-1} were not included in this study because very high-precision abundance analysis is not possible for them. The sample considered in this paper consists of 33 pairs.

3. Stellar properties

Table 1 reports visual and absolute magnitudes, $B - V$ colors, parallaxes, masses, and projected separations for the program stars. As in Paper I, Hipparcos and Tycho photometries were averaged and corrected to the standard system using the calibrations by Bessell (2000). The parallaxes are from Hipparcos. When separate parallaxes were available for the two components, a weighted average was performed. The absolute magnitudes were corrected for the Lutz-Kelker effect as in Paper I.

The stellar masses were determined from the isochrones of Girardi et al. (2002) by averaging the masses obtained for 1 Gyr main-sequence stars with absolute magnitudes and temperatures equal to those of the program stars for the appropriate metallicity. To take the dependencies on temperature and metallicity into account, the masses were determined iteratively during the abundance analysis. For the pairs whose primaries show significant evolution out of the main sequence (namely HIP 3290,

HIP 74432, HIP 80399), stellar masses were taken from the suitable isochrone that fits the position of the components on the color–magnitude diagram.

Table 2 summarizes the magnitude differences for program stars, including Hipparcos, Tycho, and further ground-based photometry when available. Only literature observations reported in the standard system are included. Error estimates are assigned as in Paper I. We note that in several cases the available magnitude differences show discrepancies of 0.05–0.10 mag, and even of 0.34 mag in the worst case (HIP 76446). This has a significant impact on the analysis of some of the pairs with suspected abundance differences discussed in this work. New, high precision differential photometry would be useful in these cases.

4. Abundance analysis

4.1. Equivalent widths

Equivalent widths (hereafter *EWs*) were measured on monodimensional spectra using an automatic procedure that estimates a local continuum level and performs a Gaussian fit to the selected lines (see Bragaglia et al. 2001, for details).

The line list is the same one used in Paper I, with a small extension to the blue because of the wider spectral coverage of FEROS spectra. We did not use lines with the wavelength lower

Fig. 1. The rms scatter in equivalent-width differences ΔEW between the components of the binaries analyzed in this paper as a function of temperature difference ΔT_{eff} . Open circles represent pairs with a temperature difference larger than 400 K, and the primary clearly evolved off the main sequence and active stars. Filled circles represent the other pairs. The anomalously large scatter in EW difference for HIP 64030 (plotted as an open square) is probably due to the large abundance difference between the components.

than 4500 Å because of the severe blending and difficulty in continuum tracing.

Internal errors of EW s can be estimated by the rms in the difference of EW s between the components of pairs whose temperatures differ by less than 200 K, about 2 mÅ (Fig. 1). The absolute errors of EW s are larger. They can be estimated by considering the 6 pairs in common with those studied in Paper I. The EW s show an offset, ($EW_{\text{SARG}} = EW_{\text{FEROS}} - (3.537 + 0.121 \times EW_{\text{FEROS}})$ and $EW_{\text{SARG}} = EW_{\text{FEROS}} - (4.167 + 0.077 \times EW_{\text{FEROS}})$ for the two observing runs), with FEROS EW s being larger (Fig. 2). The dispersion of the EW s difference from these relations is about 6.0 mÅ. We were not able to identify the source of this discrepancy, possibly due to the different spectral resolution or to the different background subtraction.

For our analysis, we chose to adopt the SARG system and then we applied the measured offset, separately for the two observing runs, to FEROS EW s. The final equivalent widths are reported in Table 3, available only in electronic form at the CDS.

4.2. Analysis of primaries

The analysis technique is the same as used in Paper I and we describe it here in some detail. The primaries were analyzed differentially with respect to the Sun. An automatic procedure was used to iteratively remove outliers that yield abundances differing more than 2.5σ from the average of remaining lines.

The atmospheric parameters of the primaries were derived iteratively as follows:

- effective temperature was determined from the ionization equilibrium of iron and the difference VI vs. Fe II. At any iteration, the change in the effective temperature required for Fe I vs. Fe II and VI vs. Fe II is given by

$$\Delta T_{\text{eff}}(\text{Fe I} - \text{Fe II}) = -(A(\text{Fe I}) - A(\text{Fe II}) - 0.050)/S_{\text{Fe}} \quad (1)$$

$$\Delta T_{\text{eff}}(\text{VI} - \text{Fe II}) = -(A(\text{VI}) - A(\text{Fe II}) + 3.52)/S_{\text{V}} \quad (2)$$

where $A(\text{Fe I})$, $A(\text{Fe II})$, and $A(\text{VI})$ are the abundance of Fe I, Fe II, and VI respectively; $S_{\text{Fe}} = 0.0009 \text{ dex/K}$ and $S_{\text{V}} = 0.0015 \text{ dex/K}$ are the slopes of the T_{eff} vs. (Fe I–Fe II) and

Fig. 2. Comparison of SARG and FEROS EW s. *Upper panel:* run 1 (August 2001); *lower panel:* run 2 (March 2002).

T_{eff} vs. (VI–Fe II) relations for a solar type star². The two constants 0.050 and 3.52 represent the offset between the mean abundances derived from Fe II and VI lines, with respect to Fe I lines, in the reference solar analysis.

The high temperature sensitivity of V lines allows us to achieve better precision for determining the temperature difference. Details on the inclusion of the hyperfine splitting of V lines are given in Paper I and references therein.

The adopted temperature difference at any iteration is given by the weighted average of $\Delta T_{\text{eff}}(\text{Fe I} - \text{Fe II})$ and $\Delta T_{\text{eff}}(\text{VI} - \text{Fe II})$;

- stellar gravities were calculated from the relation (see e.g. Nissen et al. 1997)

$$\log g = \text{const.} + \log M + 0.4 (M_{\text{V}} + BC) + 4 \log T_{\text{eff}} \quad (3)$$

where the constant term includes the solar quantities. We used the absolute magnitudes from Hipparcos parallaxes, the stellar masses determined from the isochrones of Girardi et al. (2002), including the dependence of masses on metallicity, and the bolometric corrections by Kurucz (1995). Since the derived masses and gravities depend on temperatures and metallicities, an iterative procedure is required;

- stellar metallicity in the atmospheric model was assumed to be equal to the abundance of Fe I resulting from the analysis;
- microturbulent velocity adopted in the final analysis was derived, as in Paper I, from a relation between microturbulent velocity and effective temperature: $\xi = -5.98 + 0.00122 T_{\text{eff}}$.

² The slopes actually have a small dependence on effective temperature, but the impact of this on our results is negligible because of the use of an iterative procedure until convergence.

The microturbulent velocities used to derive this relation were based on a first tentative analysis, where the microturbulent velocities were modified in order to cancel any trend of abundances with expected line strength (see Magain 1984). Excluding a few outliers (evolved stars), the dispersion around the relation is 0.18 km s^{-1} . This relation is different with respect to that of Paper I, probably because of the different roles played by the deviations from a Gaussian profile by the actual spectral line-profile determined from spectra taken at different resolutions coupled with the use of a Gaussian fitting routine to extract *EWs*. For a few pairs that include evolved stars the microturbulence was instead determined individually by eliminating the trend of iron abundance with expected *EW*.

As the atmospheric parameters are not independent of each other, an iterative procedure was required. This was performed in a nearly automatic way by calculating the temperature of the successive iteration from the relations Eqs. (1), (2) and deriving the other atmospheric parameters from the new temperature and the iron abundance of the previous run. Convergence was usually achieved in about ten iterations. We checked that the final result was robust against different starting conditions.

In a few cases (HIP 3290, HIP 58862/4, HIP 76603/2, HIP 79818), for which Hipparcos parallaxes gave absolute magnitudes for the two components inconsistent with any single isochrone, we adopted spectroscopic distances that are derived by using effective temperatures from the excitation equilibrium and gravity from the ionization equilibrium for iron ($d = 84 \text{ pc}$ for HIP 3290; $d = 45 \text{ pc}$ for HIP 55288; $d = 103 \text{ pc}$ for HIP 58862/4; $d = 36 \text{ pc}$ for HIP 76603/2; $d = 82 \text{ pc}$ for HIP 79818). The location of the components of these binaries in the HR diagram and in the $T_{\text{eff}} - \log g$ diagram using these distances matched single isochrones much better than did the location obtained from the Hipparcos parallaxes (see Fig. 3).

Note that this method is optimized for the differential analysis, for which errors in the distance are of no concern (at least for pairs with a small temperature difference, see Sect. 4.4). In the analysis of primaries, this source of errors is instead relevant, especially considering that the binarity of our program stars often induces large parallax errors. This effect is clearly seen in Fig. 3: adopting a fainter absolute magnitude gives a higher gravity (Eq. (3)), and then a warmer temperature derived through ionization equilibrium. For a difference of one magnitude, the effect is about 200 K. The warmer temperature will yield larger microturbulent velocities (by about 0.25 km s^{-1}) and metallicities (by 0.10–0.15 dex); i.e. all the atmospheric parameters are significantly affected.

Table 4 summarizes the atmospheric parameters adopted in the abundance analysis. This table also lists the atmospheric parameters of the secondaries, derived as part of the differential analysis described in Sect. 4.3. Table 5 shows the results of the analysis of the primaries.

4.3. Differential analysis of secondaries

The secondary of each pair was analyzed differentially with respect to the primary, strictly using the same line set. The initial line list for the differential analysis included the lines not removed as outliers in the analysis of both components. Further iterative clipping was performed to exclude lines that gave abundance differences outside $\pm 2.5\sigma$ with respect to the average of the other lines. The whole analysis was performed working on line-by-line abundance differences between the primary and the

Fig. 3. Position of the components of the pairs for which Hipparcos parallaxes yielded inconsistent position in the HR diagram (*left panel*) and in the $T_{\text{eff}} - \log g$ diagram (*right panel*). Open circles: results of abundance analysis performed adopting the Hipparcos distance; filled circles: adopting spectroscopic distances. Isochrones by Girardi et al. (2002) of suitable ages and metallicities are overplotted. From top to bottom: HIP 3290, HIP 55288; HIP 58864/2; HIP 76603/2, HIP 79818.

secondary, therefore removing systematic errors that affect the abundance of a single line in a similar way for both components (e.g. $\log gf$ values, part of the errors on *EW* measurement, etc.). The atmospheric parameters of the secondaries were derived as differences with respect to those of the primaries (except for the microturbulence, adopted from the relation introduced in Sect. 4.2, as for the primaries):

- the difference of effective temperature with respect to the primary was derived using Eqs. (1), (2) in a differential way

$$\Delta T_{\text{eff}}(\text{Fe I} - \text{Fe II}) = -[(A_{\text{Fe I}} - A_{\text{Fe II}})_A - (A_{\text{Fe I}} - A_{\text{Fe II}})_B] / S_{\text{Fe}} \quad (4)$$

$$\Delta T_{\text{eff}}(\text{VI} - \text{Fe II}) = -[(A_{\text{VI}} - A_{\text{Fe II}})_A - (A_{\text{VI}} - A_{\text{Fe II}})_B] / S_V \quad (5)$$

Table 4. Adopted atmospheric parameters.

Object	$T_{\text{eff(A)}}$	$T_{\text{eff(B)}}$	$\log g_A$	$\log g_B$	$[A/H]_A$	$[A/H]_B$	ξ_A	ξ_B
HIP 3290	6193	6049	4.03	4.35	-0.42	-0.36	1.60	1.43
HIP 10175	5638	5338	4.33	4.36	-0.08	-0.08	0.92	0.56
HIP 20552	5880	5626	4.45	4.49	0.02	0.05	1.22	0.91
HIP 37923	5404	5337	4.54	4.54	0.18	0.12	0.64	0.56
HIP 39409	5527	5499	4.35	4.36	0.02	0.01	0.79	0.75
HIP 44817	5384	5121	4.43	4.41	0.23	0.20	0.61	0.29
HIP 49520	5890	5839	4.58	4.62	-0.23	-0.22	1.23	1.17
HIP 51266	5356	5207	4.60	4.61	0.01	0.01	0.58	0.40
HIP 55288	6211	5635	4.26	4.34	0.06	0.08	1.63	0.92
HIP 56280	6280	6206	4.17	4.17	0.01	0.02	1.71	1.62
HIP 58298	6015	5980	4.09	4.11	-0.56	-0.56	1.39	1.34
HIP 58813	5900	5523	4.32	4.41	0.07	0.06	1.24	0.78
HIP 58864	6235	5957	4.34	4.48	-0.36	-0.35	1.65	1.31
HIP 59743	5232	5073	4.31	4.32	0.01	0.00	0.43	0.23
HIP 62596	6134	6163	4.33	4.33	0.05	0.09	1.53	1.57
HIP 64030	6197	5757	3.88	3.91	-0.62	-0.35	1.61	1.07
HIP 65176	6201	5804	4.38	4.51	0.10	0.07	1.61	1.13
HIP 65352	5141	4936	4.61	4.60	-0.43	-0.45	0.32	0.06
HIP 69328	5753	5589	4.12	4.20	-0.30	-0.29	1.06	0.86
HIP 70269	5909	5904	4.32	4.33	-0.29	-0.30	1.26	1.25
HIP 70386	6112	5918	4.52	4.51	-0.03	-0.06	1.50	1.27
HIP 73674	5745	5739	4.46	4.46	-0.33	-0.36	1.05	1.05
HIP 74432	5612	5444	4.16	4.40	0.03	0.03	0.92	0.51
HIP 76446	5810	5090	4.40	4.50	-0.10	-0.05	1.13	0.25
HIP 76602	6162	6165	4.27	4.31	-0.25	-0.16	1.57	1.57
HIP 78024	6154	5298	4.35	4.58	0.06	0.10	1.56	0.51
HIP 79818	6183	5959	4.25	4.45	-0.43	-0.34	1.59	1.32
HIP 80399	6016	6032	4.08	4.33	0.08	0.10	1.75	1.41
HIP 84405	4975	4979	4.52	4.53	-0.32	-0.32	0.11	0.12
HIP 101292	5488	5496	4.39	4.40	0.04	0.03	0.74	0.75
HIP 103438	5840	5201	4.50	4.40	0.00	0.02	1.55	0.39
HIP 104687	5781	5740	4.41	4.41	0.05	0.06	1.10	1.05
HIP 114914	5826	5674	4.32	4.40	0.06	0.07	1.15	0.97

and then removing the possible source of errors caused by the constant terms in Eqs. (1), (2) (that might be due to e.g. a non solar $[V/Fe]$).

As for the primaries, the adopted temperature difference is given by the weighted average of $\Delta T_{\text{eff}}(\text{Fe I} - \text{Fe II})$ and $\Delta T_{\text{eff}}(\text{VI} - \text{Fe II})$ (hereafter in short iron and vanadium temperatures).

Internal errors for temperature difference (shown in Table 6) are derived by propagating the uncertainty in the abundances of Fe I, Fe II, and VI due to the line-by-line scatter;

- the difference of stellar gravities was calculated using Eq. (3) in a differential way:

$$\Delta \log g(A - B) = \Delta \log M + 0.4 (\Delta V + \Delta BC) + 4 \Delta \log T_{\text{eff}}(6)$$

where the terms in Eq. (3) that are equal form the components, including distance and photometric zero point, cancel out when calculating the difference. Therefore, only the error in apparent magnitude difference (Table 2) has to be considered and not the much larger one on the absolute magnitude (Table 1);

- the stellar metallicity in the atmospheric model was assumed as that of the primary plus the Fe I abundance difference between the components;
- microturbulent velocity was taken from the relation introduced in Sect. 4.2, as for the primaries.

As in the case of the primaries, the final parameters were derived by means of an iterative procedure. The internal scatter of

Fig. 4. Iron abundance derived for each line of the components of HIP 114914 A and B. A clear correlation is present, indicating that the use of a line-by-line differential analysis significantly reduces the errors on abundance difference between the components.

abundance differences is much lower than expected, if the errors of the two components were fully independent, indicating that the differential analysis allows removal of a number of possible systematic errors (Fig. 4).

Table 6 lists the temperature differences given by different methods: equilibrium of ionization for Fe, the same replacing VI to Fe I, the average of the two (the value adopted in our analysis); excitation equilibrium for Fe I lines; magnitude difference

Fig. 5. Difference between the temperature differences based on Fe and V lines as a function of the temperature of the secondary. Symbols as in Fig. 1.

(assuming that both components are on main sequence), color temperatures calibrations from $B - V$, $V - I$, $V - K$, $J - K$, and $J - H$ (from Alonso et al. 1996) and $b - y$ (from Nordstrom et al. 2004). When required, transformations between photometric systems were performed as in Paper II. The colors were taken from the following sources: $B - V$: from Table 1; $V - I$: HIP 3290, 44817, 49520, 62596, 65176, 69328, 114914: from Cuypers & Seggewiss (1999); HIP 37923, 58815, 58864, 65352, 74432, 76603: from Hipparcos (ESA 1997); HIP 103438: from Zuckerman et al. (2001); $b - y$: from Nordstrom et al. (2004); J , H , K : 2MASS all sky release (Cutri et al. 2003). The temperature difference from the magnitude difference ΔV (taken from Table 2) is estimated by considering the slope of the main sequence on the 1 Gyr solar metallicity isochrone. It does not include evolutionary effects and therefore represents an upper limit to the actual temperature difference.

Figure 5 shows the comparison between the temperature differences based on Fe and V lines as a function of the temperature of the secondary. A similar trend was obtained in Paper I from SARG data. Therefore, it seems that some systematic trend in the two-temperature scales appears below 5500 K.

This might be explained by considering that V lines are formed mostly in atmospheric regions outside those where Fe I (and Fe II) lines form. Therefore the derived V abundance is very sensitive to the temperature gradient in the external parts of the stellar atmosphere. If the temperature gradient in the adopted 1-D model is too shallow, as suggested by comparison with 3D models (Asplund 2005), then a lower effective temperature is derived. An alternative possibility is represented by deviations from local thermodynamical equilibrium (Bodaghee et al. 2003).

For a few pairs, characterized by large temperature differences, or involving active stars or with evolved primaries, the analysis depended on the adopted microturbulent velocity (mean relation vs optimization) and on the maximum EW of lines included in it. In a few cases, leaving microturbulence as a free parameter eliminates any trend of abundance difference with EW , but also introduces a significant trend of abundance difference with excitation potential. To reduce these uncertainties in all these problematic cases (except for HIP 80399A and HIP 74432A, clearly evolved off of the main sequence), we adopted the microturbulent velocity from the standard relation but we included in the analysis only those lines with an expected equivalent width smaller than about 60 mÅ.

Fig. 6. Magnitude vs. temperature differences. The dotted line represents the typical slope along the main sequence of a 1 Gyr solar-metallicity isochrone. Symbols as in Fig. 1. The three stars clearly above the mean relation are HIP 3290, HIP 74332, and HIP 80399, which all have primaries evolved off of the main sequence. The pair with a magnitude difference that is too small for the measured temperature difference is HIP 103438.

The atmospheric parameters of the secondaries are listed in Table 4. Table 7 reports the results of the differential analysis. Plots of abundance difference for Fe I as a function of temperature difference and effective temperature of the primary and of the secondary, as well as of the metallicity are shown in Figs. 7 and 9. The derivation of full error bars as shown in these figures is presented in Sect. 4.4. Final abundance and temperature differences (including the full error bars) are listed in Table 11.

4.4. Errors analysis

A careful error analysis is mandatory for evaluating the significance of several small abundance differences found in our analysis. We first consider the errors that directly affect the differential analysis, and then we discuss the indirect impact of absolute errors.

The errors due to line-by-line scatter (listed in Table 7) are always below 0.01 dex. The uncertainties in the determinations of the atmospheric parameters were also estimated. To propagate these errors into errors on abundance and temperature difference, we derived the sensitivity to abundance and temperature difference into changes of atmospheric parameters for a few selected pairs with effective temperatures spanning the range of the program stars (Table 8). Table 9 shows the adopted relations.

Errors on ΔT_{eff} include the errors due to line-by-line scatter of Fe I, Fe II, and VI (Table 6) and the errors in the other atmospheric parameters. Errors on $\Delta \log g$ include the errors in the magnitude difference between the components (Table 2), the errors on ΔT_{eff} , and the errors on $\Delta \log M$ and ΔBC . The error on $\Delta \log M$ from assuming the adopted main sequence references caused by the errors on ΔT_{eff} , $\Delta [\text{Fe}/\text{H}]$ and ΔV is below 0.01 dex. The same also holds for error on bolometric correction. To take into account the additional uncertainty due to e.g. evolutionary effects a further 0.02 dex error on $\Delta \log g$ was conservatively included. Errors on $\Delta [\text{A}/\text{H}]$ were assumed to be the same as the full errorbar on $\Delta [\text{Fe}/\text{H}]$.

The uncertainty in the microturbulent velocity was estimated by considering the rms of the difference (between the components) of the residuals from the ξ vs. T_{eff} relation. It results 0.15 km s^{-1} , smaller than the expectation from fully

Table 7. Results of differential analysis.

Object	$\Delta [\text{Fe}/\text{H}]$	rms	N_{lines}	$\Delta [\text{Fe}/\text{H}]$	rms	N_{lines}	$\Delta [\text{V}/\text{H}]$	rms	N_{lines}
HIP 3290	-0.056	0.085	103	-0.046	0.057	29	-0.021	0.072	10
HIP 10175	-0.002	0.043	123	-0.034	0.059	27	-0.063	0.046	21
HIP 20552	-0.032	0.036	123	-0.071	0.068	31	-0.122	0.065	20
HIP 37923	0.059	0.053	61	0.056	0.058	23	0.052	0.091	33
HIP 39409	0.000	0.040	130	-0.016	0.102	34	-0.028	0.058	25
HIP 44817	0.032	0.029	34	0.014	0.056	23	-0.017	0.067	26
HIP 49520	-0.012	0.035	134	-0.018	0.041	33	-0.033	0.047	12
HIP 51266	0.003	0.048	107	-0.030	0.079	25	-0.055	0.054	26
HIP 55288	-0.018	0.082	86	-0.016	0.029	18	-0.027	0.126	18
HIP 56280	-0.006	0.071	129	-0.025	0.058	27	-0.058	0.055	8
HIP 58298	0.003	0.033	113	0.002	0.023	29	0.016	0.055	11
HIP 58813	0.013	0.045	119	-0.046	0.091	35	-0.081	0.017	11
HIP 58864	-0.013	0.058	117	-0.011	0.066	34	-0.002	0.100	12
HIP 59743	0.009	0.032	125	-0.026	0.069	31	-0.081	0.068	30
HIP 62596	-0.041	0.049	121	-0.034	0.049	28	-0.022	0.057	16
HIP 64030	-0.268	0.067	96	-0.263	0.070	36	-0.084	0.225	8
HIP 65176	0.028	0.057	131	-0.009	0.052	30	-0.054	0.047	10
HIP 65352	0.019	0.029	109	-0.010	0.052	17	-0.028	0.042	27
HIP 69328	-0.007	0.054	142	-0.009	0.049	32	-0.013	0.093	19
HIP 70269	0.009	0.032	117	0.016	0.041	32	0.055	0.084	15
HIP 70386	0.032	0.075	125	0.040	0.103	26	0.058	0.148	15
HIP 73674	0.032	0.031	133	0.037	0.058	33	0.045	0.048	15
HIP 74432	0.004	0.049	122	-0.030	0.065	34	-0.064	0.060	28
HIP 76446	-0.051	0.064	74	-0.131	0.136	25	-0.208	0.108	22
HIP 76602	-0.087	0.041	120	-0.083	0.044	30	-0.058	0.089	12
HIP 78024	-0.039	0.094	115	-0.065	0.199	27	-0.181	0.144	12
HIP 79818	-0.087	0.048	93	-0.085	0.024	25	-0.033	0.131	9
HIP 80399	-0.022	0.025	92	-0.022	0.038	30	-0.021	0.019	16
HIP 84405	0.001	0.021	123	-0.004	0.043	20	-0.005	0.014	25
HIP 101292	0.010	0.028	125	0.004	0.047	32	0.001	0.035	31
HIP 103438	-0.019	0.075	74	-0.130	0.153	24	-0.228	0.096	16
HIP 104687	-0.007	0.036	119	-0.008	0.034	34	-0.008	0.055	23
HIP 114914	-0.013	0.034	134	-0.033	0.051	35	-0.068	0.055	20

Fig. 7. Iron abundance difference between the components of pairs as a function of the temperature difference. Symbols as in Fig. 1.

independent cases. This indicates that the two components of a pair systematically deviate in the same way from the adopted relation. The typical error on $\Delta\xi$ is then 0.11 km s^{-1} . The various error contributions were summed in quadrature, iterating so as to take the dependence of one source from the others into account.

We do not discuss here the absolute errors of the analysis of primaries in detail. Some of them are briefly introduced in Sect. 4.2. Such absolute errors should not be relevant for the differential analysis, as both components are affected in a similar way. However, some indirect effects are still present.

As an example, a wrong parallax would imply a systematically wrong gravity and then a wrong effective temperature derived from ionization equilibrium. We tested these effects by performing the analysis for a few pairs assuming different distances. The analysis was performed in the same way as described in Sects. 4.2 and 4.3, i.e. self-consistently deriving the atmospheric parameters and stellar masses during the analysis. For pairs with similar components ($\Delta T_{\text{eff}} < 200 \text{ K}$) the effect of a 0.25 mag error on the distance modulus (typical for the program stars) on the abundance difference is less than 0.005 dex. However, for larger temperature differences or larger distance errors they become increasingly important. We derived an approximate relation ($\text{err}_{\Delta[\text{Fe}/\text{H}]} = 6.0 \times 10^{-5} \Delta T_{\text{eff}} \sigma_{M_V}$) to include this source of error in the final abundance difference (Fig. 10).

Other systematic contributions should behave similarly. Errors introduced by the inadequacies of atmospheric models are difficult to estimate. However, as an example of the effectiveness of their minor role for pairs with similar components, we mention the case of HIP 84405, whose components are among the coolest stars in our sample ($T_{\text{eff}} < 5000 \text{ K}$ for both components). In spite of the probable inadequacies of atmospheric models at low temperatures (see Sect. 4.3), the differential analysis is not affected, because of the similar characteristics of the components.

To include the possible residual effects due to uncertainties in the atmosphere models for pairs with relatively large temperature difference, we used the systematic difference between iron and vanadium temperatures (Fig. 5). For stars with secondaries cooler than 5800 K, the typical slope of the difference

Fig. 8. Iron abundance difference between the components of pairs as a function of the effective temperature of the primary (*upper panel*) and the secondary (*lower panel*). Symbols as in Fig. 1.

Fig. 9. Iron abundance of the primary between the components of pairs as a function of the metallicity of the primary. Symbols as in Fig. 1.

$\Delta T_{\text{eff}}(\text{Fe} - \text{V})$ vs. the adopted mean ΔT_{eff} is about 0.20. Considering that we averaged the iron and vanadium temperatures, we added a term $\sigma_{T_{\text{eff}}}(\text{sys}) = 0.10$ ($5800 - T_{\text{eff}}$) for stars colder than 5800 K. For the warmer stars we considered $\sigma_{T_{\text{eff}}}(\text{sys}) = 10$ K. This additional source of error is small for pairs with very similar components but it becomes the dominant source of errors for pairs with $\Delta T_{\text{eff}} > 500$ K. The observed abundance difference observed for these pairs ($\Delta[\text{Fe}/\text{H}] \sim 0.02\text{--}0.05$ dex) is compatible with this error estimate.

Fig. 10. Estimate of the effect of errors on the absolute magnitude on the differential analysis for pairs as a function of the temperature difference between the components. The abscissa shows the slope of the variation in abundance difference between the components of the pairs as a function of the absolute distance modulus (dex/mag).

The full errorbars of stellar and atmospheric models are larger than the rough estimate given here. However, they are relevant for the differential analysis only if the components of a pair behave in different way with respect to the quantities or physical processes that are the cause of the systematic uncertainties (e.g. helium content, mixing length, etc.), which do not seem plausible when considering similar stars.

It should be noticed that in case of binaries with a real metallicity difference between the components, stellar masses were derived by using stellar models that consider the star chemically uniform, while in case of pollution the stellar interior is more metal poor. From available stellar models with polluted convective zones, we estimated in Paper I that the metal overabundance resulting from assuming unpolluted stellar models is overestimated by less than 10%.

4.5. Comparison with Paper I

Comparison of the results of this study and those of Paper I for the six pairs in both samples shows a good agreement. The FEROS-SARG difference of ΔT_{eff} between the components is 5 ± 10 K (rms 23 K) and the FEROS-SARG difference of $\Delta[\text{Fe}/\text{H}]$ between the components is -0.001 ± 0.005 dex (rms 0.011 dex). While some of the sources of error cancel out in the comparison with Paper I (e.g. model atmosphere, magnitude difference), the small dispersion we found in the difference is an indication of the reliability of the analysis.

4.6. Individual objects

We discuss here the objects that show an abundance difference larger than 0.03 dex, which is roughly twice the typical 1σ error bar on abundance differences, see Table 11, along with some other peculiar objects. In some cases (such as the pairs with a large temperature difference HIP 78024 and HIP 76446) the abundance difference is actually compatible with our error estimate. Furthermore, when assuming Gaussian distribution of errors, some cases of an abundance differences of 0.03–0.04 dex can be reasonably expected. In specific cases, additional sources of errors might be present (e.g. large activity level, contamination from an unseen companion). While the abundance

Table 11. Final abundance difference (Fe I from Table 7) and estimates of the iron possibly accreted.

Object	$\Delta T_{\text{eff(A)}}^{\text{K}}$	[Fe/H](A)	Δ [Fe/H]	int. Err.	Error	$\Delta M_{\text{Fe}}^{\text{M}_{\oplus}}$
HIP 3290	143 ± 18	-0.42	-0.056	0.008	0.018	0.33 ± 0.10
HIP 10175	299 ± 33	-0.08	-0.002	0.004	0.023	0.08 ± 0.92
HIP 20552	253 ± 22	0.02	-0.032	0.003	0.018	1.01 ± 0.55
HIP 37923	66 ± 17	0.18	0.059	0.007	0.017	3.66 ± 1.01
HIP 39409	25 ± 18	0.02	0.000	0.004	0.016	0.00 ± 0.58
HIP 44817	267 ± 29	0.23	0.032	0.005	0.023	2.82 ± 1.98
HIP 49520	50 ± 15	-0.23	-0.012	0.003	0.015	0.13 ± 0.17
HIP 51266	148 ± 20	0.01	0.003	0.005	0.018	0.15 ± 0.93
HIP 55288	579 ± 22	0.06	-0.018	0.009	0.021	0.60 ± 0.69
HIP 56280	73 ± 17	0.01	-0.006	0.006	0.017	0.09 ± 0.27
HIP 58298	34 ± 15	-0.56	0.003	0.003	0.015	0.01 ± 0.06
HIP 58813	376 ± 31	0.07	0.013	0.004	0.023	0.30 ± 0.52
HIP 58864	277 ± 18	-0.36	-0.013	0.005	0.020	0.11 ± 0.18
HIP 59743	164 ± 21	0.01	0.009	0.003	0.017	0.49 ± 0.95
HIP 62596	-29 ± 16	0.05	-0.041	0.005	0.016	0.75 ± 0.29
HIP 64030	439 ± 20	-0.62	-0.268	0.007	0.020	1.35 ± 0.07
HIP 65176	391 ± 16	0.10	0.028	0.005	0.017	0.53 ± 0.31
HIP 65352	202 ± 24	-0.43	0.019	0.003	0.019	0.43 ± 0.42
HIP 69328	163 ± 20	-0.30	-0.007	0.005	0.018	0.09 ± 0.23
HIP 70269	4 ± 15	-0.29	0.009	0.003	0.015	0.09 ± 0.16
HIP 70386	193 ± 23	-0.03	0.032	0.007	0.019	0.48 ± 0.29
HIP 73674	5 ± 15	-0.33	0.032	0.003	0.015	0.27 ± 0.13
HIP 74432	167 ± 21	0.03	0.004	0.004	0.018	0.17 ± 0.75
HIP 76446	720 ± 76	-0.10	-0.051	0.007	0.048	2.89 ± 2.69
HIP 76602	-3 ± 16	-0.25	-0.087	0.004	0.016	0.81 ± 0.14
HIP 78024	855 ± 57	0.06	-0.039	0.009	0.037	2.61 ± 2.47
HIP 79818	223 ± 16	-0.43	-0.087	0.005	0.017	0.65 ± 0.12
HIP 80399	-16 ± 14	0.08	-0.022	0.003	0.015	0.59 ± 0.40
HIP 84405	-4 ± 15	-0.32	0.001	0.002	0.015	0.04 ± 0.56
HIP 101292	-8 ± 15	0.04	0.010	0.002	0.015	0.40 ± 0.60
HIP 103438	639 ± 65	0.00	-0.019	0.009	0.042	1.19 ± 2.70
HIP 104687	40 ± 15	0.05	-0.007	0.003	0.015	0.20 ± 0.43
HIP 114914	151 ± 17	0.06	-0.013	0.003	0.016	0.41 ± 0.51

difference derived for these objects might be spurious, a dedicated discussion is useful here.

- **HIP 64030.** HIP 64030 = HD 113984 shows a large abundance difference, with the secondary more metal rich by about 0.27 dex, that is, about 15 times its error bar. Performing the analysis with different assumptions (different absolute magnitude, optimization of microturbulent velocity instead of using a $\xi - T_{\text{eff}}$ relation, using B as reference, excluding vanadium lines to derive effective temperature) does not change the abundance difference by more than 0.04 dex (peak to valley). As shown in Fig. 11, there are no trends in the abundance difference with *EW*, excitation potential and wavelength, supporting the reality of the observed difference.

The primary is most likely a blue straggler (Fig. 12). Considering the rarity of enriched pairs, it seems plausible that the abundance difference is in some way linked to the peculiar evolution of the primary. Possible scenarios are discussed in a separate paper (Desidera et al. 2006c).

- **HIP 76603/2.** The primary HIP 76603 = HD 139461 is itself a spectroscopic binary (preliminary orbit by Tokovinin & Gorynya 2001; $P = 888$ days, $e = 0.9$, $K = 14 \text{ km s}^{-1}$). The stars were also studied by Fuhrmann (2004). According to these studies, the Hipparcos distance is underestimated. Our analysis then used Fuhrmann spectroscopic distance. His spectroscopic analysis yields an abundance difference similar to ours (see Table 10). The spectroscopic

Fig. 11. Abundance difference of HIP 64030 as a function of *EW* (upper panel), *EP* (middle panel) and wavelength (lower panel). No clear trends are present.

temperatures and gravities indicate that the two components should have very similar temperatures but slightly different gravities; i.e. the primary results evolved slightly (Fig. 3). This is compatible with the old age inferred from the low level of chromospheric activity (Paper II). On the other hand, the broad band colors support the presence of some temperature difference, with the primary being bluer (see Table 6).

Fig. 12. Position of the components of HIP 64030 in the HR diagram (*left panel*) and in the $T_{\text{eff}} - \log g$ diagram (*right panel*). Open circles: results of abundance analysis performed when adopting the Hipparcos distance; filled circles: when adopting spectroscopic distances. Isochrones by Girardi et al. (2002) are overplotted.

However, Nordstrom et al. (2004) derived $\Delta T_{\text{eff}} = 0$ and $\Delta [M/H] = -0.12$ from Strömgren photometry.

We investigated the possibility that the abundance difference is caused by the contamination of the spectrum of the primary by the light of its unseen companion. This should depend on the luminosity contrast and on the velocity difference. Fuhrmann (2004) derived a minimum mass for HIP 76603B of about $0.34 M_{\odot}$. A companion contributing 5% and 1% of the light would have a mass of about 0.7 and $0.5 M_{\odot}$ respectively, corresponding to inclinations of 46 and 33 deg, respectively. The velocity difference for companions of such a mass with respect to that of HIP 76603A at the epoch of our spectrum as predicted by the Tokovinin & Gorynya (2001) preliminary orbit is 5.6 and 7.0 km s^{-1} . The FWHM of the spectral lines of the primary measured on FEROS spectrum is about 12.2 km s^{-1} . Therefore, the hypothetical spectral lines of HIP 76603B would be superimposed in a region of the line profile still within the region considered in our line-fitting procedure. The effects of such contamination on the measured equivalent widths should be small but possibly not negligible. On the other hand, the continuum contribution of HIP 76603B should make the measured EWs smaller. In the case of contamination, we would expect a trend of abundance difference with wavelength, which is not observed (Fig. 13). Furthermore, asymmetries of the line profiles are seen neither by Fuhrmann nor in our spectrum. We plan to test the possibility of contamination further by observing this system at different phases of the spectroscopic orbit, then exploring the effect of the velocity difference between HIP 76603 A and B on the abundance difference³.

The alternative hypothesis is that the observed abundance difference is real and that the B component is enriched in heavy elements with respect to the primary. This would agree with the scenario devised by Laughlin (2000), which predicts that close pairs (spectroscopic binaries) should not be affected by pollution by planetesimal infall, while isolated stars (in this case the wide companion) might be.

Note that, while the mass of the companion would be compatible with that of a white dwarf, the very high orbital eccentricity ($e = 0.9$) makes a blue straggler scenario as for HIP 64030 unlikely, since these objects typically show low

Fig. 13. Abundance difference of HIP 76602/3 as a function of EW (*upper panel*), EP (*middle panel*), and wavelength (*lower panel*). No clear trends are present.

eccentricities because of the circularization of the orbit during the mass transfer phase (Preston & Sneden 2000).

- **HIP 3290 and HIP 79818.** These two pairs show a rather large abundance difference, with the primaries more metal poor than the secondaries. Their absolute abundances are sub-solar and the position in the color–magnitude diagram indicates a rather old age (about 6 Gyr) for both pairs, with significant evolution out of the main sequence. The analysis in both cases the analysis was performed by adopting the spectroscopic distance and by considering only spectral lines with equivalent width smaller than about 60 mÅ . Nevertheless, some residual slope of abundance difference with equivalent width is still present.

A lower abundance for the relatively warm ($T_{\text{eff}} \sim 6200\text{--}6100 \text{ K}$) primaries of metal-poor pairs could be compatible with the diffusion of heavy elements, a scenario briefly discussed in Sect. 5.1.

Radial velocities of HIP 3290 from Paper II and Nordstrom et al. (2004) are constant within the errors. One of the components of HIP 79818 is instead a spectroscopic binary, since the radial velocity difference (5.0 km s^{-1}) is not compatible with the binary motion of the wide pair (Paper II). This might explain the rather large error in parallax. We cannot exclude the occurrence of some contamination by this unseen companion.

- **Active stars: HIP 37923/18, HIP 44817, HIP 70386.** Five pairs show a rather high level of chromospheric activity ($\log R'_{\text{HK}} \geq -4.5$) from our measurements (Paper II): HIP 37923/18, HIP 44817, HIP 51266, HIP 70386, and HIP 104687. Three of them (HIP 37923/18, HIP 44817, and HIP 70386) show abundance differences larger than 0.03 dex (formally significant at more than 2σ level only for HIP 37923/18).

A strong magnetic activity and correlated phenomena may cause spurious abundance differences between the components of young, active pairs for several reasons:

- the adopted magnitude difference may be affected by photometric variability;
- the presence of spots may anomalously alter the strength of the vanadium lines (Dall et al. 2005), which are used to derive effective temperatures;

³ The epoch of the observation of Fuhrmann (2004) is not reported in his paper.

- the atmospheric structure may have some systematic difference with respect to older inactive main sequence stars, introducing some effects on e.g. the adopted T_{eff} -microturbulence relation (Padgett 1996);
- differences in projected rotational velocity between the components (that are significant in our sample for HIP 37923/18 and HIP 70386) may cause spurious effects on EW measurement by Gaussian fitting.

In the individual cases, HIP 37923/18 is the most active pair in our sample ($\log R'_{\text{HK}} = -4.27$ and -4.31 for A and B components respectively; Paper II) and has relatively different line widths of the two components ($v \sin i = 6.0$ and 3.2 km s^{-1}). When analyzed in a standard way, this pair shows a difference of 0.059 dex, but with a significant trend of abundance difference as a function of the EW . The analysis optimizing the values of the microturbulent velocity shows a smaller abundance difference but a large difference in the microturbulence, which is anomalous for stars with similar temperature.

- **Pairs with a large temperature difference: HIP 76446, HIP 78024, HIP 103438.** HIP 78024 and HIP 74436 have a magnitude difference above 1 mag and temperature differences above 700 K. They were included in the sample because of the lack of suitable targets with a small magnitude difference observable at the end of the last night of the run. The abundance differences of -0.039 and -0.051 dex are compatible with the estimated errors and then are probably spurious. This confirms that the selection of pairs with similar components is mandatory to achieve a 0.02 dex error in the differential analysis.

Among the other pairs with large temperature difference, HIP 55288 and especially HIP 103438 are worth mentioning, because of the anomalous position in the HR diagram, with the secondary too bright for main sequence stars with the adopted temperature difference.

The discrepancy is fairly large for HIP 103438. The over-luminosity of the secondary might be explained by binarity. The small radial velocity difference between the components found in Paper II argues against this hypothesis, but a single-epoch spectrum is not conclusive.

An alternative possibility for explaining the anomalous position in the color magnitude diagram would be a pre-main sequence status for the secondary. HIP 103438 was indeed considered for inclusion in the young Tucana-Horologium association but eventually discarded as a member, as it does not show the signatures of extreme youth expected for a 30 Myr age star (Zuckermann & Webb 2000; Stelzer & Neuhauser 2000; Paper II). In Paper II, we noted the rather large difference in the chromospheric activity level between the components. This may play a role in explaining the observed discrepancies. A full understanding of the properties of the system would require new high-precision photometric data, as the large difference between Hipparcos and Tycho magnitude differences is an indication of some problems in the measurement.

- **HIP 20552, HIP 62596, HIP 73674.** These are three pairs with small (0.032–0.041 dex) but formally significant (at about 2σ level) abundance difference. Two of them (HIP 62596, HIP 73674) have a very small temperature and magnitude difference. We did not identify specific problems in the analysis or in the stellar properties that may cause a spurious abundance difference. However, some of them might simply represent the tail of the Gaussian error distribution.

Fig. 14. Position of the components of HIP 80399 in the HR diagram (left panel) and in the $T_{\text{eff}} - \log g$ diagram, using absolute magnitude from Hipparcos parallaxes and effective temperature and gravities from our analysis. Overplotted are the 1, 2.5, 4.0 and 6.3 Gyr isochrones of solar composition by Girardi et al. (2002).

5. Discussion

5.1. Are we observing diffusion of heavy elements?

Figure 8 shows that the scatter of abundance difference is larger for pairs with primaries warmer than 6000 K. Furthermore, most of these pairs are fairly metal poor (Fig. 9), and the abundance difference is negative (smaller iron content of the primary than for the secondary). This might occur by chance or might be due to some unrecognized systematic effect in our analysis. Another intriguing possibility is that we are observing the signature of gravitational sedimentation of heavy elements, at least in some cases.

In the case of the Sun, the occurrence of diffusion is required to fit helioseismology data. From stellar models, we expect that the effects of diffusion should be stronger for stars with higher temperature (with higher mass and/or smaller metallicity); and then they might be observable as a metal deficiency of the primary in our differential analysis.

HIP 3290 and HIP 79818 are interesting candidates for diffusion, since they are old and moderately metal-poor, and have relatively warm primaries, and relatively large mass and temperature difference between the components. However, we note that HIP 58864 shares these properties, but its abundance difference is much smaller. The diffusion hypothesis is instead not plausible for HIP 76602/3, as the two components are very similar.

A quantitative comparison would require detailed theoretical predictions for the masses, ages, and metallicities of our pairs, which in general are not available. However, in the specific case of HIP 80399, we can use the theoretical predictions developed by Michaud et al. (2004) for the open cluster M 67, as their age and metallicity are similar (Fig. 14). The masses of HIP 80399 A and B as resulting from the 4 Gyr isochrone in Fig. 14 are 1.24 and 1.09. The predicted iron abundance difference from Fig. 2 of Michaud et al. (2004) is about -0.03 and -0.02 dex for the models without and with turbulence⁴, respectively. The latter value is similar to the observed iron abundance difference of -0.022 dex, but the error bar (0.015 dex) does not allow us to claim that we detect heavy-element sedimentation with our data; however, we can reasonably conclude that the theoretical models considered here do not underestimate the diffusion of metals in stars that are slightly warmer than the Sun. A deeper investigation is postponed to a future paper.

⁴ The parameterization of turbulence used in the quoted models was fixed to minimize the surface lithium abundance changes in Population II stars.

Fig. 15. Estimate of iron accreted by the metal-rich component of each pair as a function of its effective temperature, taking the mass of the mixing zone into account as in Murray et al. (2001). Symbols as in Fig. 7. The mass of meteoritic material is about 5.5 times the mass of iron.

5.2. Clues to the accretion of metal rich material

If we assume that the observed abundance differences are due to the accretion of metal rich material, we can estimate its amount by considering the actual stellar properties (extension of the convective zone, original metallicity). As in Paper I, we follow Murray et al. (2001) to estimate the extension of the mixing zone, which includes not only the standard convective zone but also the additional mixing zone required to explain the lithium dip.

Table 11 summarizes the results for abundance difference and shows the mass of iron accreted by the components that are more metal-rich. We note that, even for the pairs with relatively large abundance difference, the amount of rocky material required to explain the observed difference is rather small. In fact, most of these pairs are relatively warm and metal poor. For these stars it is much easier to have detectable abundance alteration, since the absolute metal content of the mixing zone is small ($\sim 3 M_{\oplus}$ of iron for a star with $T_{\text{eff}} = 6000$ K and $[\text{Fe}/\text{H}] = -0.3$). Therefore, if the differences are due to the ingestion of rocky material, the amount of accreted iron remains below $1 M_{\oplus}$ (except for HIP 64030).

After combining the results of this work with those of Paper I (Fig. 16), we found that for at least 65% of the pairs with temperature higher than 5500 K, the estimated amount of iron accreted is smaller than that was expected to have been accreted by the Sun during the main sequence lifetime ($0.4 M_{\oplus}$, Murray et al. 2001). Most of the pairs have a smaller abundance difference than the amount of iron corresponding to the upper limit on the abundance difference between the inner and outer regions of the Sun according to helioseismology ($2 M_{\oplus}$, Winnick et al. 2002). These estimates are based on standard stellar models. If extramixing is induced by a metallicity enrichment of the convective envelope, as proposed by Vauclair (2004), a much larger amount of rocky material would be required to explain the observed abundance differences.

The frequency of pairs with large alteration of chemical composition appears to be small. If the abundance difference of HIP 64030 is indeed somewhat linked to the mass transfer event that lead to the formation of the blue straggler (as described in Desidera et al. 2006c), none of the 50 pairs

Fig. 16. Estimate of iron accreted by the metal-rich component of each pair as a function of its effective temperature for the pairs studied in this paper and in Paper I. The horizontal lines show the amount of iron expected to have been accreted by the Sun during the main sequence lifetime ($0.4 M_{\oplus}$, Murray et al. 2001) and the amount of iron corresponding to the upper limit on abundance difference between the inner and outer regions of the Sun according to helioseismology ($2 M_{\oplus}$, Winnick et al. 2002). The mass of meteoritic material is assumed to be about 5.5 times the mass of iron.

considered in this study and Paper I has an abundance difference larger than 0.1 dex. The few pairs with an abundance difference between 0.05 and 0.09 dex have mostly components warmer than 6000 K and with moderate metal deficiency. The amount of rocky material required to explain such abundance difference is then small.

Therefore, our study suggests that large alterations of chemical abundance caused by the ingestion of planetary material are rare and then cannot account for the strong correlation between the frequency of planets and metallicity. A possible caveat to a generalization of this conclusion is represented by the possibly lower frequency of planets in wide binaries with similar components. This is suggested by the lack of planet detection up to now in the radial velocity planet search we are performing using SARG at TNG (Desidera et al. 2006a).

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Online Material

Table 2. Magnitude difference for program stars.

Object	ΔV Hipparcos	ΔV Tycho	ΔV Other	ΔV Other	Ref. Other	ΔV Adopted
HIP 3290	1.038 ± 0.015	0.917 ± 0.021	1.034 ± 0.002		1	1.033 ± 0.008
HIP 10175	0.464 ± 0.013	0.477 ± 0.034	0.47 ± 0.01		2	0.468 ± 0.002
HIP 20552	0.410 ± 0.007	0.390 ± 0.015				0.406 ± 0.008
HIP 37923	0.106 ± 0.024	0.104 ± 0.023	0.104 ± 0.009	0.10 ± 0.02	3, 4	0.104 ± 0.001
HIP 39409	0.057 ± 0.013	0.077 ± 0.047				0.058 ± 0.005
HIP 44817	0.333 ± 0.006	0.273 ± 0.045	0.318 ± 0.005	0.296 ± 0.009	1, 3	0.320 ± 0.007
HIP 49520	0.165 ± 0.016	0.158 ± 0.033	0.151 ± 0.006		1	0.153 ± 0.003
HIP 51266	0.240 ± 0.010	0.232 ± 0.023				0.239 ± 0.003
HIP 55288	0.753 ± 0.016	0.777 ± 0.017				0.764 ± 0.012
HIP 56280	0.082 ± 0.007	0.108 ± 0.006	0.090 ± 0.009		3	0.096 ± 0.008
HIP 58298	0.121 ± 0.012	0.059 ± 0.035				0.114 ± 0.019
HIP 58813	0.687 ± 0.049	0.692 ± 0.019	0.686 ± 0.009	0.69 ± 0.02	3, 4	0.687 ± 0.001
HIP 58864	0.673 ± 0.018	0.644 ± 0.038	0.64 ± 0.02		4	0.657 ± 0.011
HIP 59743	0.273 ± 0.009	0.263 ± 0.024				0.272 ± 0.003
HIP 62596	0.029 ± 0.018	-0.006 ± 0.028	0.065 ± 0.009	0.022 ± 0.009	1, 3	0.040 ± 0.013
HIP 64030	0.566 ± 0.009	0.566 ± 0.018				0.566 ± 0.000
HIP 65176	0.801 ± 0.012	0.722 ± 0.021	0.826 ± 0.008		1	0.810 ± 0.021
HIP 65352	0.302 ± 0.007		0.290 ± 0.009	0.30 ± 0.02	3, 5	0.298 ± 0.004
HIP 69328	0.430 ± 0.009	0.380 ± 0.025	0.430 ± 0.003		1	0.429 ± 0.004
HIP 70269	0.017 ± 0.008					0.017 ± 0.008
HIP 70386	0.175 ± 0.011	0.224 ± 0.016	0.238 ± 0.009		3	0.215 ± 0.020
HIP 73674	0.016 ± 0.019	0.017 ± 0.031	0.008 ± 0.009		3	0.010 ± 0.003
HIP 74432	0.894 ± 0.020	0.833 ± 0.012	0.833 ± 0.009	0.85 ± 0.02	3, 4	0.841 ± 0.011
HIP 76446	1.231 ± 0.019	0.892 ± 0.067				1.206 ± 0.089
HIP 76603	0.120 ± 0.023	0.078 ± 0.013	0.090 ± 0.009	0.02 ± 0.02	3, 4	0.082 ± 0.014
HIP 78024	1.658 ± 0.018	1.601 ± 0.028				1.641 ± 0.026
HIP 79818	0.611 ± 0.014	0.518 ± 0.048				0.604 ± 0.025
HIP 80399	0.763 ± 0.009					0.763 ± 0.009
HIP 84405	-0.011 ± 0.010		-0.04 ± 0.02		5	-0.017 ± 0.012
HIP101292	0.020 ± 0.009					0.020 ± 0.009
HIP103438	0.599 ± 0.012	0.435 ± 0.036				0.583 ± 0.049
HIP104687	0.048 ± 0.008	-0.052 ± 0.053	0.00 ± 0.04	0.06 ± 0.04	6, 6	0.045 ± 0.010
HIP114914	0.369 ± 0.010	0.410 ± 0.034	0.391 ± 0.007		1	0.384 ± 0.008

References: 1: Cuypers & Seggewiss (1999); 2: Nakos et al. (1995); 3: Nordstrom et al. (2004); 4: Simbad; 5: Gliese & Jahreiss (1991); 6: Docobo et al. (2000).

Table 5. Results of abundance analysis for primaries.

Object	[Fe/H]I	rms	N_{lines}	[Fe/H]II	rms	N_{lines}	[V/H]I	rms	N_{lines}
HIP 3290	7.104	0.133	140	7.065	0.106	34	3.573	0.226	18
HIP 10175	7.440	0.095	137	7.340	0.187	39	3.778	0.117	33
HIP 20552	7.538	0.096	150	7.430	0.125	38	3.843	0.113	27
HIP 37923	7.704	0.126	69	7.678	0.215	30	4.192	0.223	35
HIP 39409	7.538	0.093	144	7.416	0.143	37	3.826	0.129	31
HIP 44817	7.741	0.105	66	7.614	0.206	33	4.227	0.124	30
HIP 49520	7.292	0.084	156	7.181	0.115	37	3.565	0.123	22
HIP 51266	7.528	0.118	121	7.504	0.128	28	4.021	0.197	34
HIP 55288	7.583	0.144	130	7.542	0.129	31	4.036	0.166	27
HIP 56280	7.531	0.121	147	7.419	0.135	32	3.848	0.144	17
HIP 58298	6.963	0.114	143	6.910	0.145	38	3.382	0.161	13
HIP 58813	7.588	0.094	146	7.460	0.130	37	3.883	0.063	22
HIP 58864	7.158	0.123	157	7.112	0.149	39	3.598	0.179	17
HIP 59743	7.525	0.095	137	7.485	0.188	33	3.973	0.122	31
HIP 62596	7.566	0.107	143	7.486	0.128	32	3.900	0.193	23
HIP 64030	6.904	0.194	138	6.868	0.122	41	3.463	0.305	11
HIP 65176	7.622	0.091	146	7.528	0.131	35	3.918	0.180	25
HIP 65352	7.087	0.097	155	7.075	0.127	24	3.579	0.076	30
HIP 69328	7.215	0.103	157	7.097	0.149	36	3.492	0.132	22
HIP 70269	7.229	0.098	153	7.141	0.141	39	3.566	0.133	21
HIP 70386	7.485	0.106	142	7.387	0.178	34	3.801	0.156	18
HIP 73674	7.191	0.095	159	7.106	0.116	34	3.533	0.136	26
HIP 74432	7.546	0.096	148	7.484	0.139	36	3.948	0.151	33
HIP 76446	7.427	0.080	121	7.343	0.117	35	3.777	0.157	30
HIP 76602	7.271	0.126	160	7.205	0.121	37	3.642	0.193	19
HIP 78024	7.576	0.090	131	7.483	0.128	35	3.895	0.149	24
HIP 79818	7.081	0.122	139	7.033	0.121	37	3.541	0.213	11
HIP 80399	7.601	0.080	117	7.497	0.145	35	3.940	0.097	26
HIP 84405	7.195	0.082	131	7.163	0.218	28	3.651	0.136	35
HIP 101292	7.559	0.098	144	7.463	0.149	35	3.891	0.158	36
HIP 103438	7.519	0.104	111	7.426	0.134	32	3.870	0.146	29
HIP 104687	7.569	0.111	150	7.500	0.141	38	3.953	0.150	31
HIP 114914	7.577	0.100	151	7.465	0.139	39	3.893	0.085	26

Table 6. Temperature difference using different methods. The weighted average between the temperature difference based on the ionization equilibrium of iron and vanadium was adopted because of its higher accuracy.

Object	Ion. Eq. mean	Ion. Eq. Fe	Ion. Eq. V	Exc. Eq.	ΔV	$B - V$	$V - I$	$b - y$	$V - K$	$J - K$	$J - H$
HIP 3290	143 ± 11	155 ± 14	127 ± 16	65 ± 41	≤577	165	169		-31	65	191
HIP 10175	299 ± 8	264 ± 13	319 ± 10	238 ± 21	≤261	186			176	487	273
HIP 20552	253 ± 9	210 ± 14	288 ± 12	214 ± 16	≤227	250			-98	-388	252
HIP 37923	66 ± 10	63 ± 15	69 ± 13	17 ± 49	≤57	-16		0	123	121	40
HIP 39409	25 ± 11	8 ± 19	34 ± 14	-1 ± 18	≤32	-252			97	434	-416
HIP 44817	267 ± 9	243 ± 14	283 ± 11	271 ± 47	≤178	43	140	118	180	-10	169
HIP 49520	50 ± 6	43 ± 8	61 ± 10	30 ± 14	≤85	-64	136		188	305	149
HIP 51266	148 ± 10	112 ± 18	166 ± 12	79 ± 34	≤133	-33			303	76	198
HIP 55288	579 ± 10	578 ± 12	583 ± 20	501 ± 60	≤427	754			755	887	576
HIP 56280	73 ± 10	53 ± 14	95 ± 15	168 ± 27	≤53	-40		71	-133	-95	-88
HIP 58298	34 ± 5	36 ± 5	25 ± 11	63 ± 12	≤63	144					
HIP 58813	376 ± 9	312 ± 17	400 ± 10	363 ± 22	≤384	307	190	309	-547	-215	1605
HIP 58864	277 ± 11	280 ± 13	271 ± 20	274 ± 25	≤367	677	701		198	439	223
HIP 59743	164 ± 9	120 ± 14	195 ± 11	136 ± 17	≤151	105			207	90	175
HIP 62596	-29 ± 8	-21 ± 11	-37 ± 11	-55 ± 21	≥-22	-23	-76	-155	-358	-387	-59
HIP 64030	439 ± 14	448 ± 14	323 ± 53	408 ± 30	≤316	400			470	493	470
HIP 65176	391 ± 8	355 ± 11	426 ± 11	414 ± 25	≤452	515	432		839	669	699
HIP 65352	202 ± 8	172 ± 14	216 ± 10	237 ± 16	≤166		106	131	104	117	-1
HIP 69328	163 ± 8	161 ± 10	166 ± 15	149 ± 22	≤240	224	170		255	18	214
HIP 70269	4 ± 7	12 ± 8	-20 ± 15	9 ± 14	≤9				-69	-167	-121
HIP 70386	193 ± 18	202 ± 23	181 ± 28	324 ± 32	≤119	250		40	170	309	76
HIP 73674	5 ± 7	10 ± 11	0 ± 10	20 ± 12	≤5	-8		26	10	-146	32
HIP 74432	167 ± 8	130 ± 13	190 ± 10	61 ± 24	≤470	185	152	163	124	-23	134
HIP 76446	720 ± 18	631 ± 31	771 ± 23	638 ± 60	≤674	812			651	883	575
HIP 76602	-3 ± 8	1 ± 9	-19 ± 18	-19 ± 18	≤45	131	40	0	230	158	428
HIP 78024	855 ± 24	794 ± 33	918 ± 34	594 ± 50	≤917	902			571	368	946
HIP 79818	223 ± 7	226 ± 7	189 ± 29	184 ± 26	≤337	377			180	135	447
HIP 80399	-16 ± 4	-16 ± 8	-16 ± 5	-32 ± 17	≤426						419
HIP 84405	-4 ± 5	-9 ± 10	-3 ± 6	25 ± 10	≤-9						
HIP 101292	-8 ± 5	-13 ± 9	-6 ± 6	1 ± 12	≤11				-114	-72	-13
HIP 103438	639 ± 21	515 ± 36	704 ± 26	490 ± 62	≤325	526	547		598	398	706
HIP 104687	40 ± 5	40 ± 7	41 ± 8	32 ± 16	≤24	254			-162	242	5
HIP 114914	151 ± 7	127 ± 10	175 ± 10	117 ± 15	≤214	242	224		23	219	232

Table 8. Sensitivity to abundance and temperature difference when changing of atmospheric parameters for a few selected pairs.

Changes	$\Delta \text{Fe I}$	$\Delta \text{Fe II}$	ΔVI	ΔT_{eff} (Fe)	ΔT_{eff} (V)	ΔT_{eff} mean
HIP 114914						
Reference	-0.013	-0.033	-0.068	21	-23	-1
$\Delta T_{\text{eff}} + 30 \text{ K}$	-0.029	-0.022	-0.107	-8	-56	-31
$\Delta T_{\text{eff}} - 30 \text{ K}$	+0.008	-0.044	-0.034	+57	+6	31
$\Delta \log g + 0.05 \text{ dex}$	-0.009	-0.053	-0.067	+49	-9	21
$\Delta \log g - 0.05 \text{ dex}$	-0.015	-0.012	-0.068	-2	-37	-20
$\Delta [\text{A/H}] + 0.05 \text{ dex}$	-0.017	-0.048	-0.068	35	+9	12
$\Delta [\text{A/H}] - 0.05 \text{ dex}$	-0.007	-0.018	-0.067	11	-32	-10
$\Delta \xi + 0.20 \text{ km s}^{-1}$	+0.019	+0.013	-0.051	6	-42	-17
$\Delta \xi - 0.20 \text{ km s}^{-1}$	-0.041	-0.074	-0.091	+36	-11	11
HIP 73674						
Reference	0.033	0.037	0.045	-4	5	0
$\Delta T_{\text{eff}} + 30 \text{ K}$	0.011	0.043	0.013	-36	-20	-27
$\Delta T_{\text{eff}} - 30 \text{ K}$	+0.053	0.029	0.077	+26	+31	29
$\Delta \log g + 0.05 \text{ dex}$	+0.034	0.017	0.045	+19	18	19
$\Delta \log g - 0.05 \text{ dex}$	0.028	0.057	0.045	-32	-8	-18
$\Delta [\text{A/H}] + 0.05 \text{ dex}$	0.030	0.025	0.044	5	+12	9
$\Delta [\text{A/H}] - 0.05 \text{ dex}$	0.034	0.049	0.045	-15	-2	-8
$\Delta \xi + 0.20 \text{ km s}^{-1}$	0.052	+0.066	0.074	-15	5	-6
$\Delta \xi - 0.20 \text{ km s}^{-1}$	0.008	0.009	0.050	-1	27	14
HIP 84405						
Reference	0.001	-0.004	-0.005	5	0	0
$\Delta T_{\text{eff}} + 30 \text{ K}$	-0.011	0.022	-0.045	-36	-44	-42
$\Delta T_{\text{eff}} - 30 \text{ K}$	+0.011	-0.026	0.032	+41	+38	39
$\Delta \log g + 0.06 \text{ dex}$	+0.003	-0.023	-0.002	+28	+14	18
$\Delta \log g - 0.05 \text{ dex}$	-0.001	0.017	-0.009	-19	-17	-17
$\Delta [\text{A/H}] + 0.05 \text{ dex}$	-0.012	-0.026	-0.008	15	11	12
$\Delta [\text{A/H}] - 0.06 \text{ dex}$	0.017	0.028	-0.001	-12	-19	-17
$\Delta \xi + 0.20 \text{ km s}^{-1}$	0.008	0.010	0.007	-3	-2	-2
$\Delta \xi - 0.12 \text{ km s}^{-1}$	0.000	-0.005	-0.007	6	-1	0
HIP 56280						
Reference	-0.006	-0.025	-0.057	20	-21	0
$\Delta T_{\text{eff}} + 30 \text{ K}$	-0.025	-0.022	-0.085	-4	-42	-22
$\Delta T_{\text{eff}} - 30 \text{ K}$	+0.013	-0.030	-0.029	+47	0	24
$\Delta \log g + 0.05 \text{ dex}$	-0.005	-0.045	-0.057	+44	-7	19
$\Delta \log g - 0.05 \text{ dex}$	-0.008	-0.006	-0.057	-2	-34	-17
$\Delta [\text{A/H}] + 0.05 \text{ dex}$	-0.008	-0.035	-0.059	30	-16	8
$\Delta [\text{A/H}] - 0.05 \text{ dex}$	-0.006	-0.018	-0.056	13	-25	-4
$\Delta \xi + 0.20 \text{ km s}^{-1}$	0.023	0.013	-0.050	10	-42	-15
$\Delta \xi - 0.20 \text{ km s}^{-1}$	-0.034	-0.071	-0.065	41	3	21

Table 9. Mean slopes of the variations in abundance difference and temperature difference between the components due to changes in the atmospheric parameters of the secondary.

Parameter	Change	$\Delta(\Delta[\text{Fe/H}](A - B))$	$\Delta(\Delta T_{\text{eff}}(A - B))$
ΔT_{eff}	10 K	0.0058 ± 0.0008	10.2 ± 1.4
$\Delta \log g$	0.01 dex	0.0005 ± 0.0002	3.64 ± 0.22
$\Delta [\text{A/H}]$	0.01 dex	0.0011 ± 0.0006	1.93 ± 0.36
$\Delta \xi$	0.1 km s ⁻¹	0.0107 ± 0.0033	5.41 ± 2.07

Table 10. Comparison of our analysis of HIP 76603/2 with that by Fuhrmann (2004).

	T_{eff}	$\log g$	[Fe/H]	ξ
HIP 76603: US	6162	4.27	-0.25	1.57
HIP 76603: F04	6250	4.26	-0.18	1.17
HIP 76602: US	6165	4.31	-0.16	1.57
HIP 76602: F04	6236	4.32	-0.12	1.16
$\Delta(A - B)$: US	-3	-0.04	-0.09	0.00
$\Delta(A - B)$: F04	+14	-0.06	-0.06	+0.01