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# Spectroscopic analyses of six suspected chemically peculiar stars

Giovanni Catanzaro★

*INAF – Catania Astrophysical Observatory, Via S. Sofia 78, I–95123, Catania, Italy*

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**ABSTRACT**

The abundance pattern of six stars classified as suspected chemically peculiar in the *General Catalogue of Ap and Am stars* by Renson has been derived to ascertain the real nature of these objects. Spectroscopic observations in the range $\lambda\lambda$4800–5600 Å have been carried out at the stellar station of the INAF – Catania Astrophysical Observatory.

Among the studied stars, for only three of them we confirmed their peculiarity, HD 155102 being a silicon star, HD 159082 a mercury–manganese star and HD 162132 a moderate metallic A-type star.

The other three objects have chemical abundances not so different from the standard values derived in the literature for A-type stars and, furthermore, they do not show light variability. Hence, we suggest that they could be ruled out from Renson's catalogue.

**Key words:** stars: abundances – stars: chemically peculiar – stars: individual: HD 155102 – stars: individual: HD 159082 – stars: individual: HD 162132.

## 1 INTRODUCTION

Chemically peculiar (hereafter CP) stars are main-sequence objects whose spectral types are between B and F and for which abundances are not consistent with their effective temperatures.

CP stars are characterized by spectral, photometric and magnetic variations with a common period. In the oblique rotator model, proposed by Stibbs (1950), chemical elements are not homogeneously distributed over the stellar surface and the observed variations are due to the stellar rotation. It is commonly accepted that anomalous abundances are caused by diffusion processes (Michaud 1970). Magnetic fields are suspected of influencing the diffusion suppressing the mass motions and changing the path of ionized species (Michaud, Megessier & Charland 1981). Therefore, diffusion in CP stars results in a non-homogeneous distribution of elements on the stellar surface.

In the *General Catalogue of Ap and Am stars* compiled by Renson (Renson 1991), 6684 stars are listed. Among those, for only 325 objects has the peculiar nature been well ascertained, while for 1725 of them their classification is still doubtful.

Leone & Catanzaro (1998) studied a sample of suspected CP stars and concluded that only two out of 10 are really peculiar, the others being normal in their chemical composition.

In this paper, with the aim of understanding their actual nature, we present elemental abundance analyses for six other stars classified as suspected CP in Renson's catalogue.

## 2 OBSERVATIONS AND DATA REDUCTION

Spectroscopic observations were carried out at the 91-cm telescope of the INAF – Catania Astrophysical Observatory. The telescope is linked with a REOSC spectrograph through an ultraviolet (UV)–near-infrared fibre of 200-μm core diameter. The observations were obtained using the echelle cross-dispersion configuration based on a 900 grooves mm$^{-1}$ echellette grating and the echelle grating with 79 grooves mm$^{-1}$ blazed at 63°.443. Spectra were recorded on a thinned, back-illuminated (SITE) CCD with 1024 × 1024 pixels of 24-μm size, typical readout noise of 6.5 e$^{-}$ and photon gain of 2.5 photons per ADU. This configuration results in a spectral range from approximately $\lambda$4800 to $\lambda$5600 Å (seven orders) with the resolving power, as deducted from the emission lines of the Th–Ar calibration lamp, of about $R = 15\,000$.

The stellar spectra, calibrated in wavelength and with the continuum normalized to unity, were obtained using standard data reduction procedures for spectroscopic observations within the NOAO/IRAF package, i.e. bias frame subtraction, trimming, flat-fielding, scattered light correction, fitting traces and orders extraction and, finally, wavelength calibration. The amount of scattered light correction was about 10 ADU. After the division by the flat-field image, the residual shape of each single spectral order has been removed dividing by a Legendre function of order 3.

As the apparent magnitudes of our targets are different, the exposure times were adjusted in order to obtain signal-to-noise ratios (S/N) as much as possible similar for all the spectra. Thus, the achieved S/N ratios were dependent only on the wavelengths such that at $\lambda$4800 Å S/N $\approx$ 100 increasing up to 200 at $\lambda$5500 Å.

For each star, we computed the heliocentric Julian Date and the heliocentric radial velocity, derived via the classical Doppler shift formula. To account for systematic errors, we observed three stars with constant and well-known radial velocity, namely HD 136202, HD 161096 and HD 204867 extracted from the list of CORAVEL standard stars (Udry, Mayor & Queloz 1999). The velocities reported in Table 1 are the corrected values.

★E-mail: gca@oact.inaf.it

**Table 1.** Journal of observations. For each star, we report adopted effective temperature and gravity, rotational velocity from Royer et al. (2002), with the exception of HD 155125 and HD 159082 for which velocities have been estimated in this study, microturbulent velocity, heliocentric Julian day of the observation and heliocentric radial velocity.

| Star | $T_{\rm eff}$ (K) | $\log g$ | $v \sin i$ (km s$^{-1}$) | $\xi$ (km s$^{-1}$) | HJD (240 0000.+) | $V_{\rm R}^{\rm helio}$ (km s$^{-1}$) |
|---|---|---|---|---|---|---|
| HD 155102 | $9000 \pm 160$ | $3.60 \pm 0.10$ | 38 | 3.4 | 52834.391 78 | $-6.58 \pm 2.10$ |
| HD 155125 | $9200 \pm 240$ | $4.10 \pm 0.10$ | 10 | 2.1 | 52796.525 94 | $2.09 \pm 1.51$ |
| HD 157740 | $8800 \pm 220$ | $3.50 \pm 0.15$ | 33 | 3.3 | 52796.528 98 | $13.95 \pm 2.50$ |
| | | | | | 52836.425 28 | $15.84 \pm 0.96$ |
| HD 158261 | $9900 \pm 220$ | $4.00 \pm 0.10$ | 17 | 2.3 | 52825.997 50 | $-6.94 \pm 1.45$ |
| HD 159082 | $11300 \pm 300$ | $4.10 \pm 0.12$ | 10 | 1.8 | 52834.418 35 | $-17.98 \pm 1.75$ |
| HD 162132 | $8800 \pm 300$ | $4.30 \pm 0.17$ | 39 | 2.6 | 52811.471 68 | $18.06 \pm 3.96$ |

For each line, equivalent width and central wavelength have been measured with a Gaussian fit using standard IRAF routines. According to Leone, Lanzafame & Pasquini (1995), the S/N of our spectra and the rotational velocities of our targets lead to an upper limit for the error on the measured equivalent widths of ≈10 mÅ.

## 3 DETERMINATION OF ATMOSPHERIC PARAMETERS

The approach we used in this paper to determine effective temperature ($T_{\rm eff}$) and surface gravity ($\log g$) was to compare the observed and theoretical profiles of a Balmer line. In practice, the procedure used for our targets was to minimize the difference among observed and synthetic H$\beta$ profiles, using as goodness-of-fit parameter the $\chi^2$ defined as

$$\chi^2 = \frac{1}{N} \sum \left( \frac{I_{\rm obs} - I_{\rm th}}{\delta I_{\rm obs}} \right)^2,$$

where $N$ is the total number of points, $I_{\rm obs}$ and $I_{\rm th}$ are the intensities of the observed and computed profiles, respectively, and $\delta I_{\rm obs}$ is the photon noise. Errors have been estimated as the variation in the parameters that increases the $\chi^2$ by a unit.

As starting values of $T_{\rm eff}$ and $\log g$, we have determined the effective temperature and gravity from Strömgren photometry according to the grid of Moon & Dworetsky (1985). The photometric colours have been dereddened with the Moon (1985) algorithm. The source of the Strömgren photometric data was Hauck & Mermilliod (1998). Results of our calculations are reported in Table 1 and in Fig. 1.

As a check for the goodness of our $T_{\rm eff}$ and $\log g$ determination, we could consider the consistency of the abundances derived from spectral lines of iron and chromium in the first two stages of ionization (see Table 2 for details).

The observed spectra have been analysed using ATLAS9 (Kurucz 1993) to compute the local thermodynamic equilibrium atmospheric models, SYNTHE (Kurucz & Avrett 1981) to identify spectral lines and WIDTH9 (Kurucz & Avrett 1981) to derive abundances from single lines; all these codes have been used in the linux version implemented by Sbordone et al. (2004). For all the spectral lines, the adopted $\log gf$ were taken from the NIST data base or, when not available there, from Kurucz & Bell (1995).[1] The derived abundances have been compared with those given for the Sun (Grevesse & Sauval 1998) and with those typical for A-type stars (Erspamer & North 2003).

[1] A complete list of spectral lines used, measured equivalent widths, adopted $\log gf$ and individual abundances, with their references, is reported in Appendix A in the online version of the article on *Synergy*.

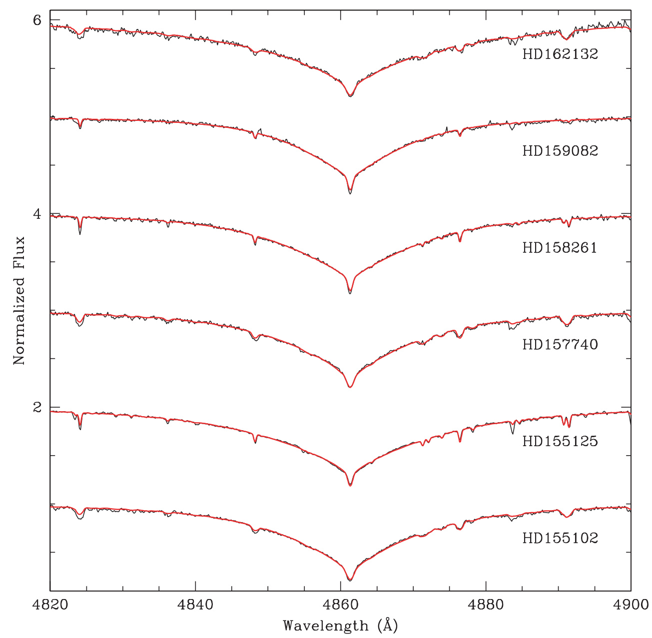


**Figure 1.** Comparison between the observed and synthetic H$\beta$ line profiles for our targets.

Errors on abundances were generally derived from the standard deviation of abundances computed for each line. In cases where only one line was available, we translated the errors on the atmospheric parameters and on the equivalent widths into an abundance uncertainty.

The microturbulent velocities ($\xi$), reported in Table 1, have been estimated demanding that abundances from all unblended iron lines are independent of their equivalent widths. Errors on $T_{\rm eff}$, $\log g$ and equivalent width reflect a ~0.1 km s$^{-1}$ error on $\xi$.

## 4 RESULTS

All our stars have been observed by the *Hipparcos* satellite. Using the Phase Dispersion Method (Stellingwerf 1978) as coded in the NOAO/IRAF package, we searched for light variability. No periodic variations have been found for our targets.

Adelman (1994) pointed out that abundances for A-type stars are different from the solar values, in particular the discrepancies increase towards the heaviest elements (see Fig. 2). Thus, in

**Table 2.** Derived abundances and errors for the suspected CP stars of our sample. For comparison, we report both the solar values (Grevesse & Sauval 1998) and the mean abundances derived for A-type stars (Erspamer & North 2003). All the abundances are reported in the form log $N_{\rm el}/N_{\rm tot}$.

| Ion | HD 155102 | HD 155125 | HD 157740 | HD 158261 | HD 159082 | HD 162132 | Sun | A-type |
|---|---|---|---|---|---|---|---|---|
| Mg I | −4.61 ± 0.16 | −4.74 ± 0.11 | −4.44 ± 0.17 | −4.13 ± 0.16 | −4.45 ± 0.20 | −4.13 ± 0.12 | −4.45 | −4.25 ± 0.17 |
| Si II | −3.93 ± 0.05 | −4.25 ± 0.07 | −4.02 ± 0.07 | −4.12 ± 0.16 | −4.63 ± 0.18 | −3.74 ± 0.14 | −4.48 | −4.33 ± 0.16 |
| Ca I | −5.61 ± 0.07 | −5.51 ± 0.20 | −5.67 ± 0.09 | – | – | – | −5.67 | −5.46 ± 0.22 |
| Ti II | −7.01 ± 0.19 | −6.94 ± 0.14 | −6.98 ± 0.14 | −6.77 ± 0.16 | −6.16 ± 0.05 | −6.78 ± 0.20 | −7.01 | −6.81 ± 0.21 |
| Cr I | −6.00 ± 0.14 | −6.02 ± 0.10 | −6.32 ± 0.18 | – | – | −5.37 ± 0.15 | −6.36 | −6.04 ± 0.22 |
| Cr II | −6.12 ± 0.22 | −6.13 ± 0.19 | −6.19 ± 0.13 | −6.05 ± 0.23 | −6.01 ± 0.04 | – | – | −6.04 ± 0.22 |
| Mn II | – | – | – | – | −4.58 ± 0.33 | – | −6.64 | −6.24 ± 0.20 |
| Fe I | −4.32 ± 0.11 | −4.28 ± 0.20 | −4.28 ± 0.20 | −4.03 ± 0.13 | – | −3.59 ± 0.06 | −4.53 | −4.22 ± 0.19 |
| Fe II | −4.37 ± 0.34 | −4.30 ± 0.30 | −4.36 ± 0.25 | −4.24 ± 0.24 | −4.35 ± 0.31 | −3.61 ± 0.25 | – | −4.22 ± 0.19 |
| Ni I | – | −5.00 ± 0.16 | – | – | – | – | −5.78 | −5.36 ± 0.29 |
| Zn I | – | −6.73 ± 0.10 | – | −6.46 ± 0.11 | – | – | −7.43 | −6.95 ± 0.29 |
| Y II | – | −8.53 ± 0.23 | −8.73 ± 0.21 | – | – | – | −9.79 | −8.92 ± 0.25 |
| Ba II | −9.13 ± 0.17 | −8.37 ± 0.25 | −9.05 ± 0.26 | −8.44 ± 0.18 | – | −8.53 ± 0.28 | −9.90 | −8.85 ± 0.45 |

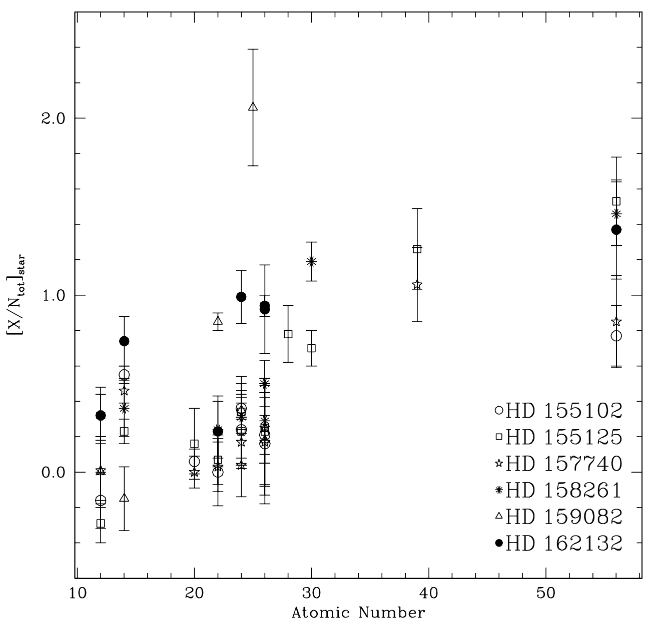


**Figure 2.** The abundance anomalies of our target stars relative to solar values as a function of atomic number $Z$. Increase of the discrepancies towards the heaviest elements confirms the result found by Adelman (1994) for normal A-type stars.

order to highlight possible chemical anomalies, we compared each abundance with the corresponding value for standard A-type stars given by Erspamer & North (2003). This comparison is shown in Fig. 3.

In the following sections we will describe the results obtained for each single star.

### 4.1 HD 155102 = HR 6376 = HIP 83816

Since the first observation by Cowley et al. (1969), HD 155102 has been classified as an Ap star due to the enhanced silicon abundance measured in its spectrum. Floquet (1975) noted that the Si II blend λλ4128–31 appears to be stronger than that for the normal stars of the same spectral type and he classified this object as A2IV Si. Nevertheless, Cucchiaro et al. (1978), analysing UV spectra obtained with the spectrograph on board the *TD1* satellite, found this object normal.

With the adopted effective temperature and gravity, we derived the chemical abundances reported in Table 2. As a general result, we found that they are close to the values given for normal A-type stars, with the exception of silicon which is about 0.4 dex over the normal value and magnesium which is 0.4-dex underabundant.

In conclusion, we confirm the enhanced silicon abundance inferred previously by quoted authors.

### 4.2 HD 155125 = HR 6378 = HIP 84012 = $\eta$ Oph

HD 155125 is a double visual binary (ADS 10374) the orbit of which has been recently computed by Soederhjelm (1999) using *Hipparcos* data.

Cowley et al. (1982) found an anomalous ratio between Sc II λ4246 and Sr II λ4215 Å, in particular this star shows a barely perceptible scandium line but an enhanced strontium line. According to these authors, normal abundances of those elements are expected when their ratio is close to unity.

Gerbaldi et al. (1989), in a study concerning the oxygen abundance in a sample of Ap stars, used HD 155125 as a standard star. The same conclusion is shared by Cucchiaro et al. (1978).

Chemical abundances inferred by us do not show any appreciable discrepancy from normal; only nickel and yttrium are slightly over the normal limit. Moreover, as this star has been classified as strontium enhanced by Cowley et al. (1982), we searched for Sr lines in our spectrum. In particular, there are a number of lines[2] that would appear in our spectral region if the abundance typically measured in Ap stars (López-García, Adelman & Pintado 2001) occurs in this star. Not one of these lines has been observed in our spectrum.

Then, taking into account also the null light variability, we conclude that it could be ruled out from the list of suspected CP stars.

### 4.3 HD 157740 = HR 6481 = HIP 85185

The only hint of a possible peculiar nature of HD 157740 is reported in Hauck & North (1982). These authors, quoting a private communication by C. Jaschek, stated that the star belongs to the subgroup

[2] Sr I: λλ4962.259, 5480.859 Å; Sr II: λλ5363.114, 5379.130, 5385.447 Å.

 

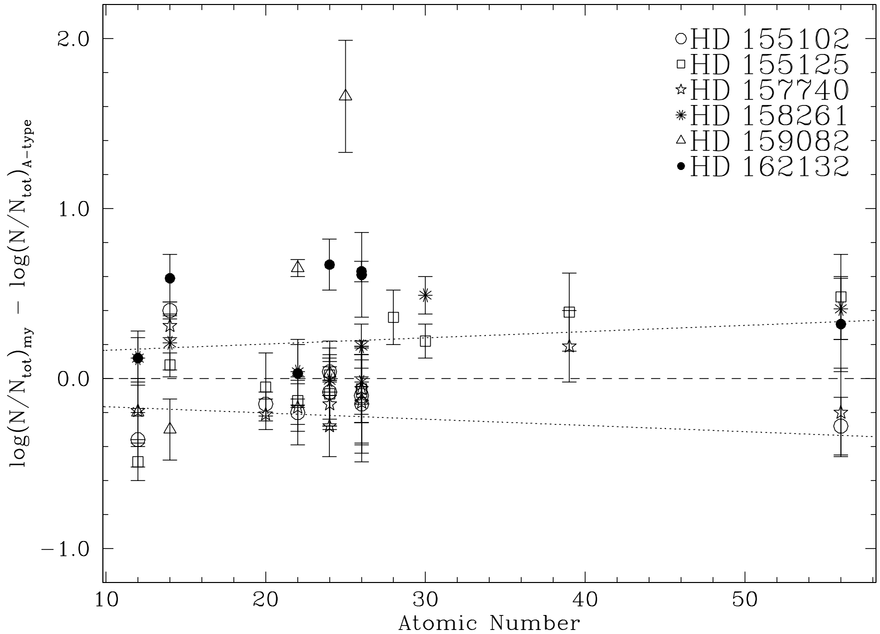


**Figure 3.** Abundance pattern derived by the comparison from our stars' abundances and the corresponding values for normal A-type stars. The normality strip is represented by dotted lines plotted $1\sigma$ above and $1\sigma$ below the zero value.

of Cr Eu Sr. As for the previous two objects, HD 157740 is considered normal in the work by Cucchiaro et al. (1978). Moreover, this star is a spectroscopic binary (Carrier et al. 2002).

In our spectral range, we observed a number of chromium lines, both neutral and once ionized, from which we derived an abundance absolutely consistent with the A-type value reported in the last column of Table 2. Concerning Sr and Eu,[3] no lines have been observed in our spectrum. Other chemical elements have been found normal in their abundances, with the exception of silicon for which a moderate overabundance of about 0.3 dex has been derived.

Moreover, comparing our two spectra, we did not observe any appreciable variability in the line strength and, from *Hipparcos* data, no periodic variability has been found. Then, taking into account all this evidence, we conclude that HD 157740 is a normal A-type star.

### 4.4 HD 158261 = HR 6506 = HIP 85832

The peculiar nature of this star has been supposed by Osawa (1959) on the basis of his low-resolution (125 Å mm$^{-1}$) spectroscopic observations carried out at the 40-inch refractor telescope of the Yerkes observatory. The author noted a rather strong complex of spectral lines around λλ3944 and 4137 Å, but without referring to any element in particular. HD 158261 is a spectroscopic binary with the primary component classified as normal A0V in Abt & Bidelman (1969).

The abundances inferred in this study for this object showed normal values for the abundances of the iron peak elements, i.e. titanium, chromium and iron, as well for magnesium, silicon and barium. Only zinc is slightly over the upper limit of the normal region, i.e. about 0.4 dex.

Based on these results and taking into account also the null light variability, we confirm the Abt & Bidelman (1969) conclusion.

[3] Eu I lines in our spectral range: λλ4962.545 and 5303.860 Å.

### 4.5 HD 159082 = HR 6532 = HIP 85826

HD 159082 is a well-known SB1 star since Campbell's (1922) observations. This object has been classified as a λ Boo star by Abt & Morrell (1995) in their paper on rotational velocity of A-type stars. Gerbaldi, Faraggiana & Lai (2003) found that the UV flux computed from *TD1* magnitudes is inconsistent with the hypothesis that the star is λ Boo and they stated the possibility that this inconsistency is due to its binarity. HD 159082 is also listed in the catalogue of HgMn stars compiled by Schneider (1981). Stickland & Weatherby (1984) using their own and Campbell's radial velocity measurements determined an orbital period of 6.797 53 d.

An abundance study of this star is due to Woolf & Lambert (1999). By using atmospheric parameters ($T_{\rm eff} = 11\,100$ K, $\log g = 3.97$ and $\xi = 1.3$ km s$^{-1}$) in agreement, within the experimental errors, with those we adopted they found $\log N_x/N_{\rm H} = -6.33$, $-4.50$ and $-6.41$ for chromium, iron and mercury abundances, respectively. These results lead to solar abundance for chromium and iron, but about 4.5-dex overabundance of mercury.

While iron abundance determined in our study is in agreement with the value found by Woolf & Lambert (1999), we found chromium abundance 0.3 dex greater than the one derived by the previous authors. This difference could be ascribed to possible stratification of chromium with height in the upper atmosphere of HD 159082, as has already been observed in several HgMn stars by Savanov & Hubrig (2003). However, it is impossible to say anything in this case since the spectral line (Cr I λ3983.896 Å) used by Woolf & Lambert (1999) is generated at the same optical depth as the lines used by us. Probably the difference is due to some indetermination in the atomic parameter of the lines involved. Finally, we can say nothing about mercury, as no Hg lines fall in our spectral region.

According to our analysis, titanium is 0.6 dex over the typical value for A stars; silicon is slightly underabundant, about 0.3 dex under the normal value that is typical for HgMn stars (see e.g.

Catanzaro, Leone & Leto 2003 and references therein). For manganese, a number of unblended single ionized lines fall in the spectral range of our interest. From those lines, we estimated an abundance of $\log N_{\rm Mn}/N_{\rm tot} = -4.58 \pm 0.33$, that is about 1.6 dex over the standard value.

Considering these results, together with those inferred in the literature, we confirm that HD 159082 belongs to the subgroup of HgMn stars.

### 4.6 HD 162132 = HR 6641 = HIP 87045

Abt & Bidelman (1969) classified HD 162132 as a probable metallic line star (Am). This conclusion was confirmed later by Bidelman (1988), who stated that it is a moderate Am star belonging to a SB1 system with an orbital period of 2.82 d.

Moderate overabundances of Si, Cr and Fe (about 0.6 dex) have been derived from our analysis. The other identified elements in our spectrum, magnesium, titanium and barium, do not show any appreciable discrepancy with the standard abundance. Furthermore, in agreement with the general results obtained by Adelman (1998) regarding the luminosity constancy in the Am group, we did not found any hint of light variability in the *Hipparcos* data.

We confirm the Am classification of HD 162132.

## 5 CONCLUSIONS

In this paper, we analysed spectra for six stars which have been classified as suspected CP stars in the literature (Renson 1991), with the aim of ascertaining if they really present chemical anomalies when compared with the normal main-sequence stars of the same spectral type.

For all the stars of our sample, we derived effective temperatures and gravities by fitting the observed H$\beta$ profiles with synthetic models computed using the linux version of the ATLAS9 and SYNTHE codes. The results of our analysis confirm the peculiar nature of three objects, namely HD 155102 (Si star), HD 159082 (HgMn) and HD 162132 (Am). In contrast, we did not find any particular anomaly in the chemical pattern of the other three targets: HD 155125, HD 157740 and HD 158261. Thus, for the latter objects we suggest ruling out their membership of the group of CP stars of the main sequence.

## ACKNOWLEDGMENTS

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## APPENDIX A: LIST OF SPECTRAL LINES

In this section (Tables A1–A6, available in the online version of the article on *Synergy*), we report the complete list of spectral lines used in our analysis. The letters denoting the references for each line have the following meaning: (a) Blackwell, Petford & Willis (1979); (b) Blackwell, Menon & Petford (1984); (c) Bridges & Kornblith (1974); (d) Bridges (1973); (e) Fuhr & Wiese (1998); (f) Klose (1971); (g) Kostyk & Orlova (1982); (h) Kostyk & Orlova (1983); (i) Kostyk (1982); (j) Kurucz & Bell (1995); (k) Lennard et al. (1975); (l) May, Ritcher & Wichelmann (1974); (m) Roberts, Andersen & Sorensen (1973); (n) Tozzi, Brunner & Huber (1985); (o) Wolnik, Berthel & Wares (1970); (p) Wolnik, Berthel & Wares (1971); (q) Wujec & Weniger (1981). For the Si II lines marked with an asterisk, according to the NIST data base, the transition probabilities were calculated from the multiplet value assuming a pure LS-coupling.

## SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online.

**Table A1.** Spectral lines identified in the spectrum of HD 155102. For each line we report the laboratory central wavelength, the measured equivalent width, the adopted $\log gf$ and the derived abundance expressed in the form $\log N_{\rm el}/N_{\rm tot}$. References for $\log gf$ are in the last column.

**Table A2.** As Table A1 but for HD 155125.

**Table A3.** As Table A1 but for HD 157740.

**Table A4.** As Table A1 but for HD 158261.

**Table A5.** As Table A1 but for HD 159082.

**Table A6.** As Table A1 but for HD 162132.

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