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Metal abundances of A-type stars in galactic clusters[⋆]

III. α Persei: new results

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Abstract. We complete our study (Hui-Bon-Hoa et al. 1997) of the abundances of Mg, Ca, Sc, Cr, Fe, and Ni in α Per cluster stars using new spectra of two stars of the previous sample and also adding two more objects. The new spectra of BD +48°894 and HD 21527 show that the former has an almost solar composition whereas the latter is an Am star with the iron peak elements being all enhanced and Ca marginally underabundant. As for the additional stars of this study, HD 19954 has a pattern very close to solar, and HD 20135 is an SB2 system where both components seem to be Am stars: Ca and Sc are strongly deficient; Cr and Ni are overabundant in one component. A more thorough study is needed for confirmation.

Key words: stars: abundances – stars: chemically peculiar – Galaxy: open clusters and associations: individual:

1. Introduction

Diffusion is usually considered as the main physical process that accounts for the abundance anomalies of the Chemically Peculiar stars. According to several theoretical studies (Michaud & Charland 1986; Alecian 1986, 1996), the stratification process is time-dependent and the abundances therefore vary with time. The work of Alecian (1996) is focused on the abundance evolution of Am stars' typically anomalous elements Ca and Sc. Hui-Bon-Hoa et al. (1997, hereafter Paper I) began a series of papers with the purpose of constraining these simulations by observing cluster A stars of the corresponding age range. Paper I dealt with the stars of α Per, Coma Ber, and Praesepe. The Pleiades and Hyades stars along with additional objects of Coma and Praesepe were treated in Hui-Bon-Hoa & Alecian (1998, hereafter Paper II). These studies concluded that the older the cluster, the more often the Am pattern is present and the more the anomalies are pronounced (Hui-Bon-Hoa 1998a, b). Also, atypical patterns with slight *overabundances* of Ca and/or Sc are shown by several stars of the youngest clusters (α Per and Pleiades).

Table 1. Basic data for the programme stars.

Name	HD or BD	Sp. type	V mag.	*S/N*	Remarks
HDK 220	19954	A9IV (1)	9.14	180	
HDK 285	20135	A0p (1)	8.09	270	Am (2), SB2 (this work)
HDK 501	+48°894	F0IV (1)	9.14	200	δ Scuti
HDK 885	21527	A7IV (1)	8.79	250	SB?, Am (2)

References: (1) Morgan et al. (1971); (2) Abt (1978)

This study reexamines the two α Per stars that show these marginal overabundances of Ca and/or Sc with spectra not available when Paper I was published of much higher quality and a more appropriate measurement method for these fast rotators. We also present results for two stars that could not be observed previously because of bad weather.

2. Observations and reductions

2.1. The sample

Am as well as normal A stars are selected for this series of studies since Alecian (1996) predicts possible phases of overabundances of Ca for young peculiar stars. Indeed, the *deficiency* of Ca is a classical criterion for the Am phenomenon and thus young Am stars with *overabundances* of Ca would not be identified as such. The sample stars fulfil the following criteria: (i) a suitable rotational velocity to allow the abundance determination and (ii) the availability of *uvby*β data to estimate the fundamental stellar parameters. The four investigated stars are members of the α Per cluster (Petrie & Heard 1970). Basic data for these objects are gathered in Table 1 (the first column displays the HDK numbers of Heckmann et al. 1956).

2.2. Data collection and reduction

We obtained the spectra in December 1996 with the AURELIE spectrograph (Gillet et al. 1994) attached to the coudé focus of the 152 cm telescope of the Observatoire de Haute-Provence. The settings are the same as in Paper I and yield a spectral resolution of about 34000 (linear dispersion of 5 Å.mm^{-1}) with 5495–5620 Å as spectral interval (typical spectra are shown in

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[⋆] Based on observations collected at the Observatoire de Haute-Provence (France)

Fig. 1 of Paper I). The detector was a linear diode array Thomson TH 7832 with 2036 13 by 750 μm pixels. The integration time was about 3 hours, which yields signal-to-noise ratios (S/N) typically around 230 (see column 5 of Table 1). The S/N reached here is twice the value of Paper I for the two stars in common. Calibration sequences (offset level, exposures of a tungsten lamp and of a thorium-argon hollow cathode lamp) were done between each stellar exposure. The reduction of the spectra made use of codes written by M. Spite (1967, 1996 private communication, details in Paper I).

3. Analysis

3.1. Effective temperature and surface gravity

The estimation of effective temperatures and surface gravities is carried out using *uvby*β photometry (Moon & Dworetsky 1985; Moon 1985). Napiwotski et al. (1993) showed that their calibration is still reliable for single normal stars. The errors come mostly from the uncertainties in the photometric measurements and are ± 200 K for $T_{\rm eff}$ and ± 0.14 for log *g*. The photometric data come from the compilation of Hauck & Mermilliod (1980).

This method for HD 20135, which has been classified as an Ap star (Morgan et al. 1971), is highly suspect. Maitzen & Pavlovski (1987) showed that its Δa-photometry was anomalous, denoting the presence of the 5200 Å flux depression that is typical of magnetic Ap stars. The Strömgren photometry *y* band is affected by this spectral feature (Adelman 1975) as suggested by the abnormally high color excess *E(b-y)* derived by Crawford & Barnes (1974) (the $(b-y)_0$ index is bluer for Ap stars than for normal ones of similar temperature). Therefore, the standard dereddening relations used for the other sample stars (through the code of Moon 1985) may not be valid. Even if its membership may be questionable (see Maitzen & Pavlovski 1987 and references therein), we adopt for HD 20135 the mean reddening of the cluster (Crawford & Barnes 1974), according to its position. The variation of reddening over this cluster has little influence on the fundamental parameters and will be neglected. Since the energy distributions (ED) of Ap stars are different from those of normal stars because of their strong abundance anomalies (Adelman et al. 1995), the use of the Moon & Dworetsky (1985) calibration may not be suitable. A proper calibration for Chemically Peculiar stars with strong abundance anomalies (like magnetic Ap and Hg-Mn stars) should at least consider the effect of these anomalies on the photometric indices. Such a calibration is not available yet and we lack data which could give more direct estimates (spectrophotometry or infrared flux). We can nevertheless obtain rough values of the fundamental parameters by determining them as for a normal star (with the c_0 *vs.* β grids of Moon & Dworetsky 1985) and then correcting them for the changes in the ED (and thus in the photometric indices) induced by enhanced abundances of heavy elements. The last step is performed by comparison between synthetic colours of P00 (solar abundances) and P10 (ten times the solar metal content) ATLAS9 models (Kurucz 1993), also taking the derived abundances of iron peak elements into account. The set of values we obtain is $T_{\rm eff}$ = 8050 K and log *g* = 3.80 with uncertainties of respectively $\pm$350 K and $\pm$0.40. The corresponding errors on the abundances are about $\pm$0.30 dex.

3.2. Abundance determinations

The codes of M. Spite (1967, 1996 private communication) are used for the abundance analyses. The model atmospheres are calculated with the ATLAS9 code (Kurucz 1993) with the options discussed in Paper II. An alternative approach to the classical Mixing Length Theory, which is used in ATLAS9, for the treatment of convection has been proposed by Canuto & Mazzitelli (1991, 1992) and implemented by Kupka (1996a, b, 1998 private communication). By using the two methods for typical stars of this series of papers, we have checked that there were no significant differences (they are of the same order as the rounding errors) in the derived abundances. A discussion about the relevance of these approaches is beyond the scope of this work. The microturbulent velocity is obtained by minimizing the dispersion among the abundance values obtained from the different lines of Fe I.

Data for the lines considered for the abundance determination are the same as in Paper I and II: the “solar” *gf*-values we derived are shown in Table 2, along with the equivalent width measurements. The fitting method of Cayrel et al. (1985) is used mostly with rotational profiles since we have fast rotators (except HD 20135). The use of rotational profiles yields much more stable measurements against the uncertainties of wavelength scale. The smallest equivalent widths used are at least equal to the systematic error made on their measurements for each star, estimated following Cayrel (1988). HD 20135 shows two systems of lines in our spectrum and will be discussed in Sect. 4.

4. Results

The results of the abundance analysis are given in Table 3 along with the fundamental parameters used. The abundance patterns are presented in Fig. 1 (except for the SB2 star HD 20135, see below). The solar abundances are those of Grevesse & Noels (1993), namely: Mg, 7.58; Ca, 6.36; Sc, 3.17; Cr, 5.67; Fe, 7.50; Ni, 6.25. The script [X] for any quantity X means $\log({\rm X})_* - \log({\rm X})_\odot$. The dispersion of the values given by different lines is indicated for Ca and Fe when more than two lines are used for the estimate. The *v* sin *i* values are derived from our equivalent width measurements. The last column of Table 3 indicates the classification we propose for each star from the scheme and criteria of Paper II: abundances within 0.3 dex around the solar value are considered normal (normal stars are denoted nl); the Am star HD 21527 is labelled (c) following the classification of Conti (1970), which means a star with *only* strong metallic lines. The case of HD 20135 deserves a more complete study.

We now discuss each sample star by order of increasing HDK number.

HD 19954 (HDK 220) is almost normal with slight deficiencies of Cr and Fe and a rather strong overabundance of Ni.

Table 2. Equivalent widths in mÅ for the sample stars (HD or BD numbers). The values for HD 20135A and B are not corrected for dilution effects.

λ (Å)	Element	log *gf*	19954	20135A	20135B	+48°894	21527
5501.47	Fe I	−2.95	–	9.3	–	65.5	49.3
5502.09	Cr II	−1.92	25.0	32.9	35.0	28.4	50.0
5506.79	Fe I	−2.80	49.8	20.0	18.7	79.1	52.1
5508.64	Cr II	−1.98	–	29.4	10.0	29.4	–
5512.99	Ca I	−0.29	–	–	–	–	–
5526.82	Sc II	0.08	93.0	<1.0	9.4	99.7	80.0
5528.42	Mg I	−0.62	136.4	17.4	22.4	173.1	113.3
5543.20	Fe I	−1.57	–	–	–	–	–
5543.95	Fe I	−1.09	–	–	–	–	–
5554.90	Fe I	−0.32	34.6	12.4	11.1	53.4	–
5560.22	Fe I	−1.19	–	–	5.2	10.7	–
5569.63	Fe I	−0.54	83.1	33.1	19.9	105.8	86.6
5576.10	Fe I	−0.92	67.7	16.1	13.4	72.4	65.0
5578.73	Ni I	−2.65	24.1	–	–	–	22.7
5581.98	Ca I	−0.71	–	–	–	42.6	10.7
5586.77	Fe I	−0.10	103.6	44.1	42.1	127.0	103.8
5588.77	Ca I	0.21	117.0	11.0	4.0	143.7	83.4
5589.37	Ni I	−1.14	–	3.6	–	8.6	–
5590.13	Ca I	−0.71	–	1.9	1.4	–	19.3
5593.75	Ni I	−0.83	62.5	6.9	–	35.5	25.3
5601.29	Ca I	−0.35	54.6	9.8	1.7	93.7	–

Table 3. Abundances and fundamental parameters for the programme stars. A colon (:) denotes uncertain values (see text for details).

Name	HD	Remarks	*v* sin *i* (km s^{-1})	T_{eff} (K)	log *g*	V_{t} (km s^{-1})	[Mg/H]	[Ca/H]	[Sc/H]	[Cr/H]	[Fe/H]	[Ni/H]	Type
HDK 220	19954		60	7610	4.10	2.5	−0.08	−0.09 (±0.23)	−0.05	−0.16	−0.22 (±0.13)	0.83	nl
HDK 285	20135A	Am (2), SB2 (this work)	14	8050:	3.80:	2.5:	−1.20:	−0.86:	<−2.10:	0.46:	−0.20:	0.43:	–
	20135B		14	8050:	3.80:	2.0:	−1.03:	−1.33:	−1.07:	0.21:	−0.20:	–	–
HDK 501	+48°894	δ Scuti	55	7450	4.20	3.0	0.10	0.00 (±0.19)	−0.10	−0.08	−0.16 (±0.08)	0.32	nl
HDK 885	21527	SB?, Am (2)	52	8210	4.30	2.5	−0.12	−0.24 (±0.19)	0.05	0.43	0.22 (±0.14)	0.89	Am (c)

References: (1) Morgan et al. (1971); (2) Abt (1978)

However, the value for this element is uncertain due to the strong blending of its lines in this fast rotator.

Morgan et al. (1971) classified HD 20135 (HDK 285) as an Ap star, which is confirmed by Maitzen & Pavlovski (1987) by photometric method. It is clearly an SB2 from our spectrum, which explains the radial velocity variations of Petrie & Heard (1970) and the excess of luminosity indicated by Maitzen & Pavlovski (1987), who invoked this argument against the membership of this star. Since it is an SB2, this argument does not hold any longer. According to our spectrum, both components seem to have approximately same luminosity and we therefore adopt a dilution factor of 2. The effective temperatures are also likely to be similar and with all these assumptions, we derive that Cr and Ni are clearly overabundant in component A (that with the most intense metallic lines). Ca and Sc are strongly underabundant in both components, which suggests that we rather have Am stars (see Abt 1978) since these elements are overabundant or marginally deficient in cool Ap stars (Adelman 1973). Mg is also very deficient. The effect of a possible magnetic field on the line formation is neglected. We stress that all the results for this system should be considered very cautiously and a more complete study is needed to draw more definite conclusions.

The two last stars were studied in Paper I. BD +48°894 (HDK 501) has a quasi solar composition as far as our elements are concerned and its pattern looks like that of HD 19954 with much smaller deviations from the solar values. In comparison with the results of Paper I, the present values are smaller for most elements and the slight Ca overabundance is not confirmed. The reduction of the abundance values arises mostly from the equivalent width measurement method since we used here rotational profiles instead of gaussian profiles, the latter leading to overestimates of the wings. There is also a small contribution due to the use of ATLAS9 models calculated without overshooting instead of models interpolated in Kurucz' (1993) grid (see

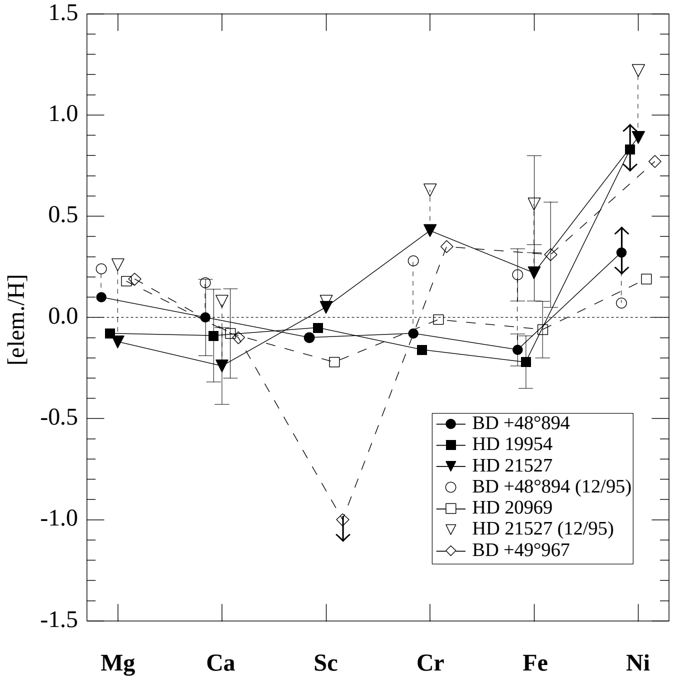

Fig. 1. Abundance patterns for the programme stars (solid lines and filled symbols). An arrow means upper limit and error bars ended by arrows denote very uncertain values. The two sets of results for BD +48°894 and HD 21527 are linked by dotted lines. The other stars of Paper I are represented by dashed lines and open symbols.

Castelli et al. 1997 and Paper II). Hui-Bon-Hoa (1998a) showed that this change alone reduced the abundances by 0.06 dex in mean except for Sc and Ni, which are almost unchanged.

The abundances of HD 21527 (HDK 885) are also reduced in comparison with Paper I and this star is still an Am of type (c) but without the previously found Ca overabundance. Here also the differences arise from the equivalent width measurement method.

5. Discussion

The abundances obtained in the present study are smaller for the two stars in common with Paper I due to the use of a rotational profile in the equivalent width measurements. We are more confident with these new results since the uncertainties related to fast rotators have much less influence on the equivalent widths and therefore on the abundance values. With the present work, there is clearly a lack of Am stars in the α Per cluster: only 2 out of the 5 non-SB2 members we have studied (including stars of Paper I) are Am. Taking into account the bias introduced by the criterion of slow rotational velocity, there should be many more peculiar stars, like in Praesepe (Paper I and II). Moreover, only one object shows obvious deficiency in Sc. In the framework of the diffusion model, this poverty of Am stars can be explained by the time the anomalies take to appear: the stratification process at work could be reflected by the marginal underabundances of Ca (and Sc) we found. Also, time-dependent stratification is consistent with the fact that the two Am stars are the hottest members of our sample since the diffusion time scale is smaller for hotter stars. Besides, anomalies for the iron peak elements seem to appear earlier than those for Ca and Sc since the Am stars of type c are only found in the youngest clusters we studied (α Per, Pleiades, Coma Ber, see Paper I and II) and this is in agreement with the radiative accelerations of Cr, Fe, and Ni computed by Richer et al. (1998). In the view of these new results, the conclusions of Paper I and II with regard to the simulations of Alecian (1996) remain: either our sample stars are too old and have already passed the Ca (Sc) overabundance phase or the extension of the convective zone should be smaller than one pressure scale height and the mass-loss rate around $10^{-14}\,\mathrm{M}_{\odot}.\mathrm{yr}^{-1}$.

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