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CP2 stars as viewed by the $uvby\,H_\beta$ system*

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Abstract. The aim of this work is to study the capacity of the $uvbyH_\beta$ system for detecting the chemically peculiar (CP) stars based on the effect that peculiar features in the flux distribution have on all the Strömgren-Crawford indices.

Our study focuses on the classical magnetic peculiar stars (CP2), though Am stars (CP1) are also included for comparison with cool CP2 stars. Satisfactory results were obtained for hot CP2 stars: the definition of a new index p, which is a linear combination of $uvbyH_\beta$ colours, allowed us to separate a high percentage of hot CP2 stars from normal stars. According to this new index, 60 new CP2 candidates are proposed.

The working sample was extracted from *The General Catalogue of Ap and Am stars* by Renson et al. (1991). Photometric observations to enlarge the sample of CP2 stars with complete $uvbyH_\beta$ photometry were carried out. These observations are also reported in the present paper.

The new index p is also used to correct the reddening of early CP2 stars computed as if they were normal stars.

Key words: stars: chemically peculiar — stars: fundamental parameters — stars: early type

1. Introduction

A star is classified as chemically peculiar (CP) if its spectrum shows abnormal line strengths of one or several elements. The chemically peculiar stars were divided by Preston (1974) into four subgroups according to their peculiar spectral features: CP1 (Am stars), CP2 (classical magnetic Ap stars), CP3 (HgMn stars) and CP4 (He-weak stars). Subsequently, it was shown that some CP4 stars were related with the CP3 stars, while others were related with the CP2 stars and new groups were identified: the He-rich and the λ-Boo stars.

The distribution of degrees of peculiarity does not show any gap between normal and CP2 stars, instead the smooth transition between normal and peculiar stars forces CP-investigators to set a threshold value (e.g. 3 s.d. of normal stars) for all of the related peculiarity parameters in order to distinguish peculiar stars.

The range of temperatures for CP phenomenon is about 7000−15000 K (Lanz 1993) where the stellar atmospheres are stable: the lower limit corresponding to temperatures where convection is not yet relevant whereas at the upper limit radiatively driven stellar winds start to cause significant mass loss.

CP2 stars, including both Bp and Ap, differ from other peculiar stars in that they possess strong global magnetic fields (Lanz 1993). These stars are main-sequence objects and, as pointed out by North (1993), they do not undergo great changes during their life on the main sequence. Mechanisms involving diffusion produce anomalies in non-evolved stars yielding a separation of chemical elements in different layers at the surface of magnetic stars (Cowley 1993). As a result, CP2 stars exhibit three main broad band flux depression features centered on λ4100 Å, λ5200 Å and λ6300 Å (Kodaira 1969). The depression at λ5200 Å, with a two component structure, extends over 1000 Å according to Adelman (1980). This depression is at its maximum at temperatures of about 12000−13000 K (Hauck & North 1982). The feature at λ4100 Å is also characteristic of CP2 stars but it is not present in all of them. Finally, a still smaller number of CP2 stars present the λ6300 Å flux depression. Adelman & Pyper (1993) described a feature at λ3509 Å probably due to abnormally strong line absorption in the Balmer continuum.

Although generally yielding much less diversity of astrophysical information than spectroscopic techniques, photometry has been increasingly used for the identification of CP stars since one can obtain data on a much larger number of stars than is possible through spectroscopy. Moreover, with photometry a much fainter limiting

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* Tables 2, 3 and 7 are also available in electronic form from CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

magnitude is attainable and the photometric indices are free from personal judgment, unlike the spectroscopic classification. While broad band photometric systems, like the UBV system, are ineffective in detecting the features of CP2 stars, the photometric indices of intermediate and narrow band systems are perceptibly modified by the peculiarities. The most effective detection is obtained with filters specifically designed to measure the characteristic features in the spectrum, such as the Δa-system (Maitzen 1976). The Geneva system, in spite of being designed for more general purposes, has proved its capability to identify CP2 stars (North & Cramer 1981).

In the $uvbyH_\beta$ system, usually only the m_1 index is used to discriminate CP stars, although several earlier studies (Cameron 1967; Hauck 1975) have shown that the peculiar features in the flux distribution alter all the Strömgren-Crawford indices. The aim of this paper is to harness this to optimally separate CP2 stars from normal stars, finding the best combination of colour indices through the *Multiple Discriminant Analysis.* We consider different temperature regions for which individual definitions of our peculiarity parameter are provided.

The determination of physical stellar parameters, such as effective temperature, surface gravity, absolute magnitude or age, needs a previous criterion of classification of stars, since the calibrations are different for normal and CP2 stars. The peculiarity parameter defined in this work provides this classification and is especially useful for those stars with only $uvbyH_\beta$ measurements. Moreover, it provides a list of CP2 candidates among those stars with already measured $uvbyH_\beta$ indices.

We also compare the colour excesses computed for early CP2 stars from Johnson and Strömgren-Crawford photometries and give a correction to the reddening computed assuming these CP2 stars to be normal.

2. The sample

2.1. CP2 in Renson et al. (1991) Catalogue

We extracted a sample of 2089 CP2 stars from *The General Catalogue of Ap and Am stars* by Renson et al. (1991). Stars marked there as of "doubtful nature" or as "improperly considered Ap" were not included. Only 184 stars (9% of our total sample) appear in that catalogue as "well-known Ap".

The Renson et al. catalogue also quotes $uvbyH_\beta$ photometry. The main source is *The $uvbyH_\beta$ catalogue* by Hauck & Mermilliod (1990; hereafter referred to as HM). There is complete photometry for 452 CP2 stars, only Strömgren colours for 294 stars and only β index for 47 stars.

In order to enlarge the sample with complete photometry, we performed photometric observations for 208 stars. So, in total there are now 660 CP2 stars with complete $uvbyH_\beta$ photometry, 177 of which are "well-known Ap" stars (96% of "well-known Ap" stars and 27% of the stars with complete photometry). 571 stars (87%) are included in the Hipparcos Input Catalogue (Turon et al. 1992; hereinafter HIC).

Table 1 shows the distribution of CP2 stars over 4 groups (defined by the main spectral peculiarity given by Renson et al. 1991) according to their absolute and relative numbers for both total sample and the subsample with the complete $uvbyH_\beta$ photometry, as well as the completeness (in %) of the subsample and the numbers of the subsample stars present in the HIC. In all cases, the photometric completeness is in the order of 30%. So, all main peculiarities are represented in the sample with complete photometry as in the total sample.

Table 1. Distribution of CP2 stars in our sample

Main pecul.	Total sample		Complete photometry		% Completeness	HIC	
Si	1258	60%	392	59%	31%	336	86%
Eu	125	6%	33	5%	26%	30	91%
Cr	189	9%	66	10%	35%	57	86%
Sr	517	25%	169	26%	33%	148	88%
Total	2089	100%	660	100%	32%	571	87%

2.2. Observations

The observations were carried out during February and September 1995 during 4 nights of good photometric quality. The instrument used in February was the 50 cm Danish telescope in the European Southern Observatory (ESO) at La Silla (Chile) equipped with an automatic six channel $uvbyH_\beta$ spectrograph photometer for simultaneous measurements in the four $uvby$ Strömgren filters and in the narrow and wide H_β bands of the Crawford system (Grønbech et al. 1976; Grønbech & Olsen 1977; Florentin Nielsen 1983). In September, the observations were carried out at Calar Alto (Almería, Spain) with the 1.52 m telescope of the Observatorio Astronómico Nacional, equipped with a one channel photometer with a dry-ice cooled RCA 31034 photomultiplier. Several stars observed in February were reobserved in September in order to improve the accuracy of their previous measurements.

The standard stars were taken from the lists of Knude (1992); Perry et al. (1987); Crawford et al. (1972, 1973) and Olsen (1983). They were observed every hour and at the beginning and the end of each night, with a total of 15−20 standard stars being observed per night.

The reduction procedure was fully described in Figueras et al. (1991). Residuals of all transformations were checked against colour, magnitude and air mass, and no systematic trend was found. Linear time dependent corrections to the visual magnitude were not required. No systematic trends were found between northern and southern observations.

Tables 2 and 3 list the *uvby* and H_β photometric data for the programme stars. The first one lists magnitude, colours and β index for 46 stars and the second one gives β index for 162 stars. The individual error quoted is the standard deviation of the average obtained following Rosselló et al. (1985). When only one observation could be made, the individual quoted error is the rms residual of standard stars of the night of the observation. In this case, the error for the stars HD 180058 and HD 273763, which are fainter than the standard stars (visual magnitude ranging from 5.5 to 9.5), has to be considered as a lower limit to the actual error. Mean values of the individual errors are $\sigma(V) = 0.012 \pm 0.010$, $\sigma(b-y) = 0.005 \pm 0.004$, $\sigma(m_1) = 0.006 \pm 0.004$, $\sigma(c_1) = 0.011 \pm 0.011$ and $\sigma(\beta) = 0.009 \pm 0.007$. The columns labeled N and N_β give the number of observations performed for each star. The spectral types quoted are from the Renson et al. (1991) catalogue.

External comparison for the stars in Tables 2 and 3 having either *uvby* or H_β photometry in Renson et al. catalogue was performed. The V magnitude was compared with the values quoted in the Renson et al. (1991), HIC catalogue and General Catalogue of Photometric Data (GCPD, Hauck et al. 1990). Two stars (HD 50143 and HD 50304) present much larger differences than the average when compared with Renson et al. and HIC's V magnitude. On the other hand, Renson et al. and HIC's V magnitude for HD 50304 are also in disagreement. Our photometry agrees with that quoted in the GCPD compilation. Table 4 shows the results obtained without including these two stars in the V comparison. We conclude that there were no systematic differences.

Table 4. External errors with Renson et al. (1991), HIC and GCPD compilations, expressed as our values minus catalogued values

	mean	s.d.	N
$\Delta(V)$: Renson et al.	−0.02	0.13	44
$\Delta(V)$: HIC	0.014	0.038	42
$\Delta(V)$: GCPD	0.015	0.036	44
$\Delta(b-y)$	0.004	0.009	7
$\Delta(m_1)$	−0.008	0.014	7
$\Delta(c_1)$	−0.001	0.035	7
$\Delta(\beta)$	0.002	0.030	22

2.3. Normal stars

We used the sample of single normal stars of Jordi et al. (1997). They are stars with known spectral type and luminosity class, non-metallic or peculiar and without quoted emission lines or doubtful spectrum. Variable stars were also removed. All the stars in the sample have complete $uvbyH_\beta$ photometry taken from HM or the BDA data base (Mermilliod 1992).

Table 5. Size of the samples: stars classified by the algorithm described in Figueras et al. (1991) and Jordi et al. (1997)

Region	Early	Intermediate	Late	Total
Normal stars	1301	565	939	2805
CP2 stars	472	99	78	649

2.4. Photometric classification

The stars in both samples (normal and peculiar) were classified into "photometric regions", following the algorithm described in Figueras et al. (1991) and Jordi et al. (1997). The stars not classified by the algorithm (about 15%) were assigned on an individual decision basis to a photometric region, mainly taking into account their spectral type. Normal stars classified as supergiants were not considered. Four early CP2 stars with β and $[u-b]$ indices at the limit of being considered supergiants, were treated as main-sequence stars.

There are only three peculiar stars in our sample with $[u-b] < 0.5$ and very few with spectral type later than F0 ($\beta < 2.72$). In order to ensure the same colour range for normal and peculiar stars, both samples were restricted to these limits. This corresponds approximately to spectral types B5-A9. The final number of stars in each photometric region is shown in Table 5.

3. Separation of CP2 from normal stars

The peculiar features in the spectral flux distribution of CP2 stars cause deviations from the values of photometric indices of normal stars. As previous authors have already mentioned, the blanketing is increased in CP2 stars, so the m_1 index is larger than for normal stars (Strömgren 1963, 1967; Cameron 1967) and the hottest stars do not satisfy the $[u-b]$ vs. m_1 relation although they satisfy the $[u-b]$ vs. β relation (Strömgren 1966). On the other hand, the Balmer jump decreases, so c_1 decreases as well (Preston 1975; Gerbaldi et al. 1974). The hottest CP2 stars look bluer than normal stars and the coolest are too red (Wildey et al. 1962). The β index also decreases (Hauck 1975). Henry (1969) showed that the peculiar A0-A3 stars are below the relation for normal stars in the Strömgren $(b-y)$ vs. a diagram.

Most of the authors used m_1 vs. c_1 or m_1 vs. $(b-y)$ diagrams (Cameron 1967; Maitzen 1976; Hauck 1975; Adelman et al. 1995, among others) to separate peculiar from normal stars. However, since all Strömgren-Crawford indices are altered by the peculiarities, we make use of the whole photometric information concerning peculiarity for the sake of the discrimination.

The method used was the *Multiple Discriminant Analysis* also called the *Canonical Discriminant Analysis* (hereinafter MDA; see for example Murtagh & Heck 1985). This method analyzes g populations, formed by n_g individuals, described by q variables. The g populations are represented along canonical orthogonal axes maximizing the spread of the means of the populations and restraining their compactness. The MDA is invariant under linear transformations of the variables and it takes into account the correlation between them. In our case, there are two populations (the normal stars and the peculiar stars) and the observed variables are the Strömgren-Crawford photometric indices. One axis is enough to represent two populations. We denote p the coordinate associated with this axis.

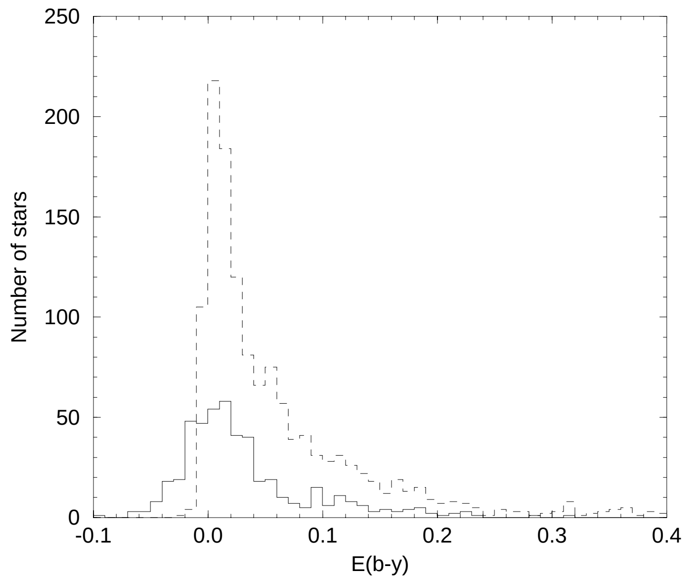

Fig. 1. Histogram of colour excess for normal (dashed line) and CP2 (solid line) stars classified into the early region

4. Results

The analysis was performed separately for each photometric region. The method was applied several times using as variables the observed Strömgren-Crawford indices ($(b-y)$, m_1, c_1 and β) and the bracket, reddening free, indices ($[m_1]$, $[c_1]$ and β). So, each analysis yielded different definitions of the p coordinate.

4.1. Early region

From a photometric point of view, a star belonging to the early region is a star located in a specific zone of the diagrams $[u-b]-\beta$ and $[m_1]-\beta$ (Strömgren 1966). For normal stars this corresponds approximately to spectral types B0-B9. However, since peculiar stars are bluer than normal stars, some A0-A2 peculiar stars are also classified into the early region.

In general, a linear combination of the $uvbyH_\beta$ colours will not be reddening free. Although standard calibrations to compute reddening are not suitable for CP2 stars, we dereddened them as if they were normal stars since the uncertainties are of about 0.010 mag (Maitzen 1980) and we will come back to this problem in Sect. 6. The number of stars as a function of the computed reddening is shown in Fig. 1. 59 (13%) CP2 stars and 277 (21%) normal stars have a colour excess greater than 0.10 mag. To avoid the effect of the reddening, we built a subsample of almost unreddened stars, removing all those with $E(b-y) > 0.10$ mag, and we performed the discriminant analysis.

The MDA yielded the following value for p:

$$p = 47.628 + 12.595(b-y) + 52.514\,m_1 + 0.118\,c_1 - 19.289\,\beta \quad (1)$$

the zero point being introduced in order that $\overline{p} = 0.0$ for normal stars. To estimate the order of the errors of the coefficients, we built different subsamples of normal and CP2 stars by randomly reducing the whole samples in 10% of stars. The MDA applied to these subsamples shows that the coefficients vary by about 2−3%.

A polynomial was fitted to the normal stars:

$$p_0 = -\ 3.540 + 15.875\,[u-b] - 20.985\,[u-b]^2 + 8.398\,[u-b]^3 \quad (2)$$

and a $\Delta p = p - p_0$ was defined. So, p_0 gives a standard relation for normal stars ($\sigma = 0.57$) and Δp, for a given star, is the difference between its p coordinate and the p coordinate of a normal star with the same $[u-b]$. The polynomial was fitted as a function of $[u-b]$, in order to avoid the reddening in the x-axis, following Maitzen & Vogt (1983). Figure 2 shows the p coordinate for the normal and CP2 samples and the standard relation of normal stars.

As a threshold value for peculiarity, we defined Δp_0 above which 50% of the CP2 stars are located. The percentage of normal stars with respect to the total number of stars with $\Delta p > \Delta p_0$ shows the associated "contamination". This contamination is an indicator of the capability of Δp to separate CP2 from normal stars. In the present case, a threshold of $\Delta p_0 = 1.50$ yields a contamination of about 2%. The percentage of contamination increases quickly as the threshold decreases.

Table 6 shows the efficiency of Δp as a function of the $[u-b]$ (i.e. temperature). The best segregation is obtained

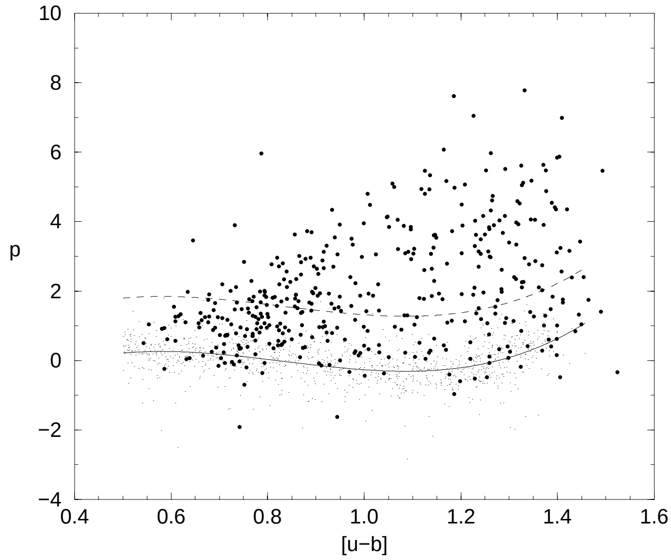

Fig. 2. p vs. $[u-b]$ for the stars of the early region with $E(b-y) \leq 0.10$ mag. The ordinate p resulted from the application of the *Multiple Discriminant Analysis* using $(b-y)$, m_1, c_1 and β as variables describing the behaviour of both populations: peculiar and normal stars. Dots represent normal stars and full circles CP2 stars. The solid line is the adopted standard relation for normal stars and the dashed line indicates the threshold above which 50% of the CP2 stars are placed

for high values of $[u-b]$, whereas for the hottest stars ($[u-b] < 0.7$) it is poor. This is due to the decreasing sensitivity of the v-band to indicate higher opacities among hotter B-type stars.

A fraction of the contamination can be explained by the presence of undetected binaries. The binary nature can increase the value of p of the primary component up to 0.1 for a B5-type star and by up to 0.6 for an A0-type star. The maximum increase is obtained when the secondary is an A3-A5 type star. So, in some combinations of spectral types, normal binary stars could be misclassified as CP2 stars. On the other hand, p is not reddening free: following Eq. (1) and applying the common extinction curve we obtain $E(p) = -4.7E(b-y)$, so reddening decreases p and Δp, and we cannot differentiate a very reddened peculiar star from an unreddened normal star.

For the total sample, including reddened stars, the value of the contamination is about 3%, while the detection remains around 50%.

In order to analyze the effect of the peculiarity in each filter, it is useful to rewrite the Eq. (1) as follows:

$$p = 47.628 - 92.315\,b + 39.919\,y + 0.118\,u + 52.278\,v - 19.289\,\beta. \quad (3)$$

The contribution of y-band to p is due to the feature at λ5200 Å, whereas v is modified by the 4100 Å feature. The coefficient of u shows that this band does not play any significant role in p. The negative sign of the β coefficient is due to the fact that the β index for CP2 stars is lower than for normal stars. The contribution of b, in spite of its coefficient, is small, because it lies in a region only slightly affected by the peculiarity.

The use of bracket, reddening free, indices to characterize the populations in the MDA yielded to a contamination of 13%. The effectiveness is smaller than with observed indices, probably because we are removing part of the information contained in the $(b-y)$ colour.

As mentioned above and since the peculiar stars are bluer than the normal stars, some CP2 stars with spectral types A0-A2 are photometrically classified into the early region. We also carried out a discriminant analysis with a sample limited by spectral type from B0 to B9, i.e. instead of classifying the stars into the early region by their photometry we classified the stars by their spectral type. The contamination indicator is higher than before (15%), very probably because we excluded stars (see Fig. 2) which exhibit the largest p values from our sample.

Since Δp inferred from Eqs. (1) and (2) yield the lowest level of contamination, this peculiarity parameter is the one adopted from now on.

Table 6. Detection and contamination for $\Delta p_0 = 1.50$

$[u-b]$ range	CP2 stars	normal stars	% detection	% contamination
0.5−0.7	35	232	9	0
0.7−0.9	129	217	49	2
0.9−1.1	87	204	52	4
1.1−1.3	92	267	62	0
1.3−1.5	70	104	41	2
0.5−1.5	413	1024	50	2

The Δp parameter defined by Eqs. (1) and (2) is only able to detect CP2 stars. A sample of 71 CP3 stars extracted from Renson et al. catalogue showed a mean value of Δp equal to 0.16 (s.d. 0.41). This is because Δp is mainly sensitive to the λ5200 Å depression, not present in the CP3 stars.

Table 7 lists 60 stars extracted from HM catalogue that we consider likely to be peculiar (i.e. with $\Delta p > 1.50$). To build the table we considered all early stars with complete photometry in the HM catalogue and removed the stars belonging to Renson et al. catalogue, all those having Δa or Geneva photometry (which are more effective to detect CP2 stars than $uvbyH_\beta$ system, see Sect. 5) and the stars having a quoted peculiar spectra in SIMBAD data base.

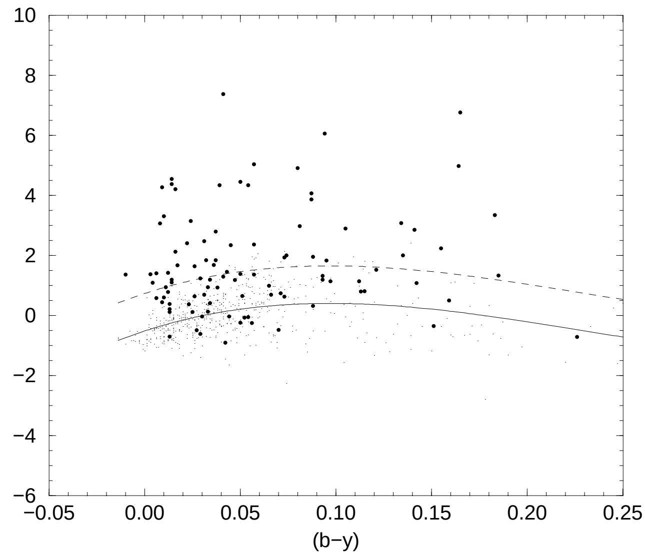

Fig. 3. The same as Fig. 2, but for the intermediate region

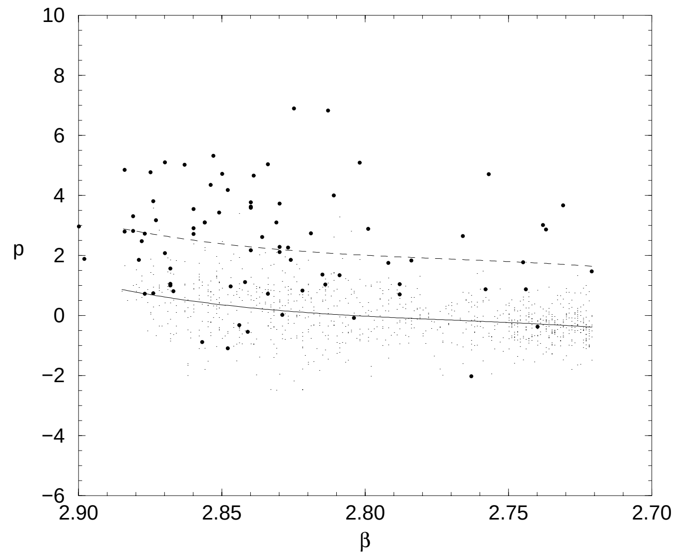

Fig. 4. The same as Fig. 2, but for the late region

4.2. Intermediate and late regions

A similar analysis was applied to the intermediate and late regions, with subsamples of stars with $E(b-y) \leq 0.10$ mag. Unfortunately, the Δp's obtained are less efficient (Figs. 3 and 4) than in the early region.

The calculated values of p and the standard relation for normal stars are, for the intermediate region:

$$\begin{aligned} p &= 71.545 + 3.047(b-y) + 34.463\,m_1 - 2.214 c_1 \\ &\quad -26.003\,\beta \\ p_0 &= -0.600 + 32.160(b-y) - 389.936(b-y)^2 \\ &\quad +1423.289(b-y)^3 \end{aligned} \tag{4}$$

and for the late region:

$$\begin{aligned} p &= -51.273 + 11.254(b-y) + 38.126\,m_1 - 2.188\,c_1 \\ &\quad +15.978\,\beta \\ p_0 &= -6463.727 + 6993.984\,\beta - 2524.369\,\beta^2 + 303.920\,\beta^3 \end{aligned} \tag{5}$$

50% of detection is at $\Delta p_0 = 1.25$ and 2.00 mag, with contamination levels of 29% and 17%, for intermediate and late regions, respectively. Due to the small size of the samples, the errors of the coefficients are larger than for the early region: around 6% for the intermediate region and 4% for the late region.

Several authors have pointed out the similarity between cool CP2 stars, mainly Sr stars, and metallic stars, also named CP1 stars. To test this point, we applied the MDA to a sample of metallic stars extracted from *The General Catalogue of Ap and Am stars* by Renson et al. (1991). The sample contains 494 stars classified into the late photometric region according to the same algorithm used above. Considering two populations, normal stars and metallic stars, the MDA yielded:

$$\begin{aligned} p = &- 22.517 + 10.765(b-y) + 44.363\,m_1 + 1.198\,c_1 \\ &+ 4.250\,\beta. \end{aligned} \tag{6}$$

The efficiency of this p is shown in Fig. 5. With $\Delta p_0 = 1.82$ the contamination is equal to 1.1%. The dependence of p on each colour does not differ excessively from the p obtained for cool CP2 stars. So, the MDA confirms the mentioned similarity between CP1 and cool CP2 stars. Cameron (1967) already noticed that cool CP2 stars are placed on a c_1 vs. m_1 diagram at the same location as Am stars. All attempts at separating both types using these indices were unsuccessful.

5. Comparison with other peculiarity criteria

This section compares the efficiency of Δp with the criteria introduced by former authors when using the $uvbyH_\beta$ system or other photometric systems.

The lower efficiency of p in the intermediate and late regions is paralleled by previous authors. Maitzen (1975) showed using spectrophotometry how the depth of the λ5200 Å feature decreases towards the cooler, i.e. Sr stars. Δa and $\Delta m_1(b-y)$ were found to be correlated except for the Sr stars. Maitzen & Vogt (1983) also found that the correlation between the Geneva's parameter $\Delta(V_1-G)$ and the Δa index was lower for the Sr stars than for the Si and Cr stars. In particular, the criterion of

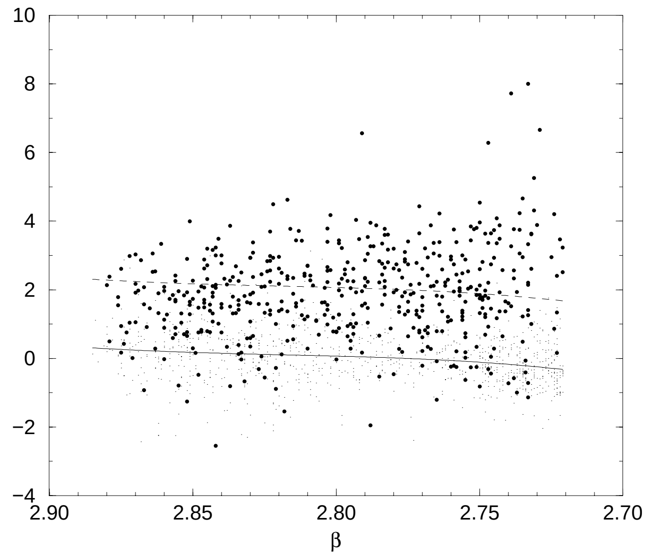

Fig. 5. The same as Fig. 2, but for Am stars

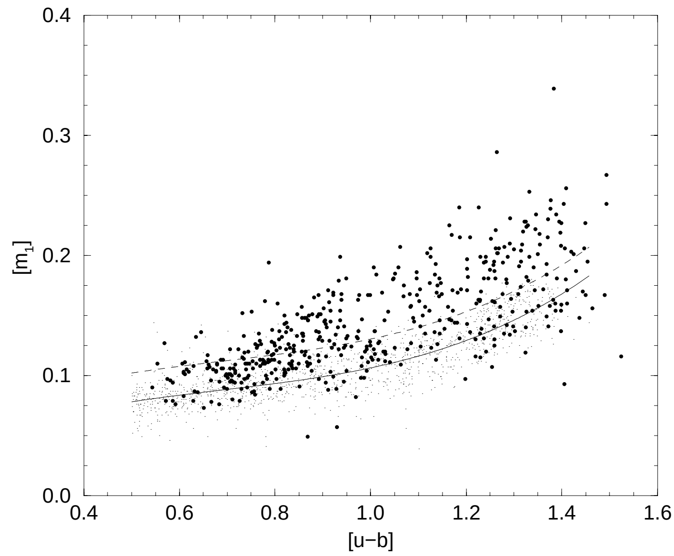

Fig. 6. $[m_1]-[u-b]$ diagram for the stars in the early region. Dots represent normal stars and full circles CP2 stars. The solid line is the adopted standard relation for normal stars and the dashed line indicates the threshold above which 50% of the CP2 stars are placed

$\Delta(V_1-G)\geq 0.010$ mag in detecting CP2 stars is only able to classify 36% of the Sr stars sample used by the authors. In our case, the smaller size of CP2 samples (only 93 and 70 CP2 stars for the intermediate and late regions, respectively), hindered the analysis.

So, the following comparison is restricted to the stars in the early region.

5.1. The $uvbyH_\beta$ system

A study of the location of CP2 stars in a colour-colour diagram was carried out by Cameron (1967). On a c_1-m_1 diagram, certain regions corresponding to high m_1 values are mainly occupied by Ap stars. Maitzen (1976) and Adelman et al. (1995) showed that there is a relation between Δm_1, using $(b-y)$ as free parameter, and the strength of the λ5200 Å feature. Figures 6 and 7 show our samples on the $[m_1]-[u-b]$ and $[c_1]-[u-b]$ diagrams. In the same way as with the p coordinate, we fitted standard relations to normal stars in each diagram, we considered peculiarity thresholds for which 50% of CP2 stars are separated and we computed the percentage of contamination of normal stars. The contamination ratios are of 16% and 17%. So, these diagrams are less effective than the $p-[u-b]$ diagram.

On the other hand, a star with an $E(b–y)\leq -0.04$ mag, computed by using the calibrations for normal stars (Crawford 1978), was considered as peculiar by Philip et al. (1976). In our CP2 sample, there are only 16 stars (3%) with such a colour excess, while all normal stars have a reddening higher than this. These 16 stars have a $\Delta p>3.2$ so they are also classified as peculiar with our peculiarity level of $\Delta p_0=1.50$.

5.2. Δa photometry

Maitzen (1976) introduced a photometric index (the a index) to measure the intensity of the depression at λ5200 Å, by comparison of the flux at the center with the mean of the flux at each side of the depression. The Δa index is the difference between the measured a index for a given star and the a index of the normality line for the same temperature. For the CP2 stars this Δa index is significantly positive and all the stars with $\Delta a\geq 0.010$ mag are considered as peculiar stars.

We compiled the published a photometry in the literature: Maitzen 1976; Maitzen & Vogt 1983; and the series of papers *Photometric Search for CP2 Stars in Open Clusters* (Maitzen 1993; Maitzen et al. 1988 and references therein) and built a sample of 1703 stars with measured Δa, 930 having complete $uvbyH_\beta$ photometry, too. The stars were treated with the same classification algorithm and their colour excess was computed. There are 577 stars belonging to the early region and 453 of them have $E(b-y)\leq 0.10$ mag.

Comparison of the Δp defined by the Eqs. (1) and (2) with the measured Δa shows a high correlation between both indices (Fig. 8a). The Δp_0 threshold is able to detect 60% of the stars with $\Delta a\geq 0.010$ mag with a contamination of about 5% of stars with $\Delta a<0.010$ mag. Although the Δa index is more efficient than the Δp index, the correlation between them demonstrates that Δp is also a good indicator of peculiarity.

On the other hand, the correlation between Δa and Δp is better than the correlation between Δa and $\Delta[m_1]$ or $\Delta[c_1]$, (Figs. 8b and 8c). The contaminations in these cases are three times higher.

5.3. The Geneva system

The Geneva photometric system is capable of detecting CP2 stars through the λ5200 Å depression (North & Cramer 1981). Two indices, $\Delta(V_1 - G)$ and ΔZ, were defined with this purpose. $\Delta(V_1 - G)$ is defined as the measured $(V_1 - G)$ for a given star less the $(V_1 - G)$ for a normal star with the same $(B_2 - V_1)$ colour. ΔZ is a combination of the filters U, B_1, B_2, V_1 and G (Cramer & Maeder 1979, 1980) and has the advantage of being reddening free, although it seems that it is slightly sensitive to certain systematic effects which are not clearly understood (North & Cramer 1981).

Figure 9 shows the comparison between the $\Delta(V_1 - G)$ and the Δp. The photometric data in the Geneva system were extracted from Rufener (1988). There are 1235 normal stars and 396 CP2 stars with measurements in both the Geneva and the $uvbyH_\beta$ photometric systems. The stars with $\Delta(V_1 - G) \geq 0.010$ mag are considered peculiar stars. This criterion recognizes 71% of CP2 stars with a contamination of only 1%. So, the Geneva system is more efficient than the Strömgren-Crawford system, since it gives a direct measurement of the flux depression at λ5200 Å. $\Delta(V_1 - G)$ is not a reddening free index either and the very reddened CP2 stars are not detected (Hauck & North 1982).

For an analysis of the correlation between Δa and $\Delta(V_1 - G)$ peculiarity indices see Maitzen & Vogt (1983).

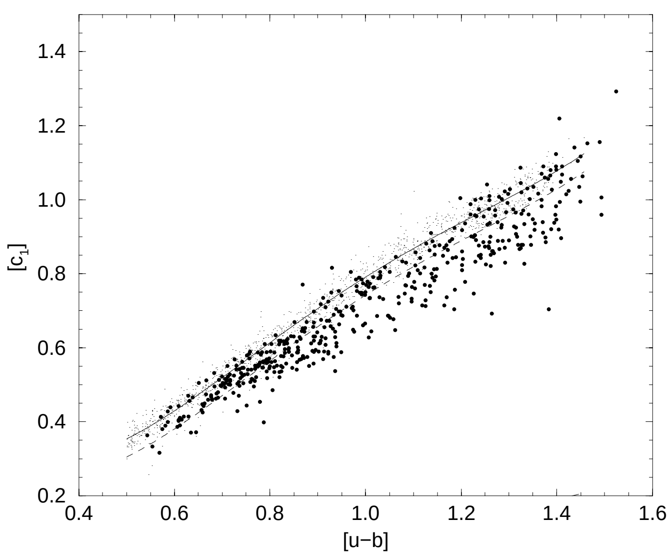

Fig. 7. The same as Fig. 6 but for the $[c_1] - [u - b]$ diagram

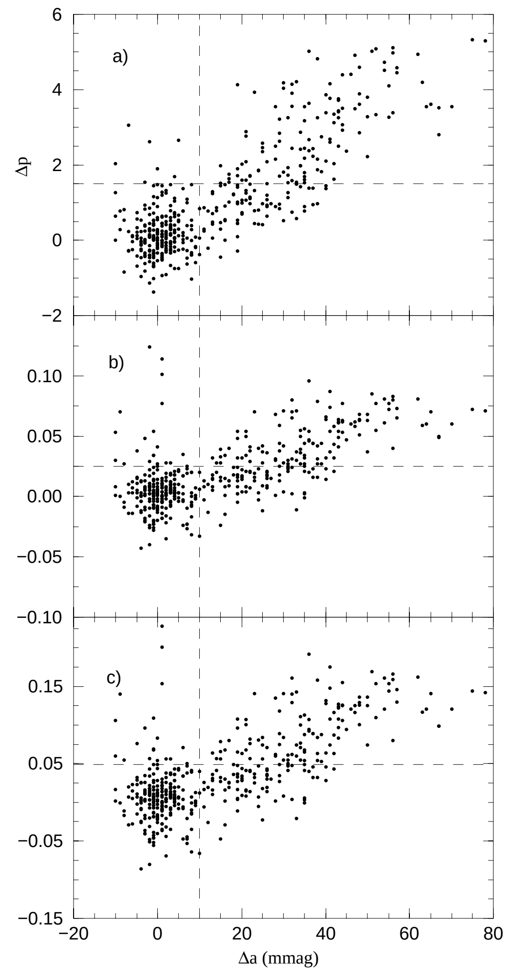

Fig. 8. a) Correlation between Δa and Δp defined by Eqs. (1) and (2). **b)** Correlation between Δa and $\Delta[m_1]$. **c)** Correlation between Δa and $\Delta[c_1]$. Horizontal and vertical dashed lines correspond to the threshold values of either index for the detection of CP2 stars

6. Reddening

The $(b - y)$ and c_1 indices are smaller for a peculiar than for a normal star. So in the c_1 vs. $(b - y)$ diagram used by Crawford (1978) to establish the standard relation for early normal stars, the peculiar stars are often below this standard relation and yield negative reddenings. The criterion by Philip et al. (1976) to separate peculiar stars is based on such negative reddenings. So, the excess is often underestimated if the peculiar stars are treated as normal stars.

Since Johnson filters are wider than $uvbyH_\beta$ filters, the Johnson colour indices are not greatly affected by the peculiarity. So, when treating the peculiar stars as if they were normal stars, the colour excess computed from Johnson photometry is more realistic than when computing from Strömgren-Crawford photometry. We compared

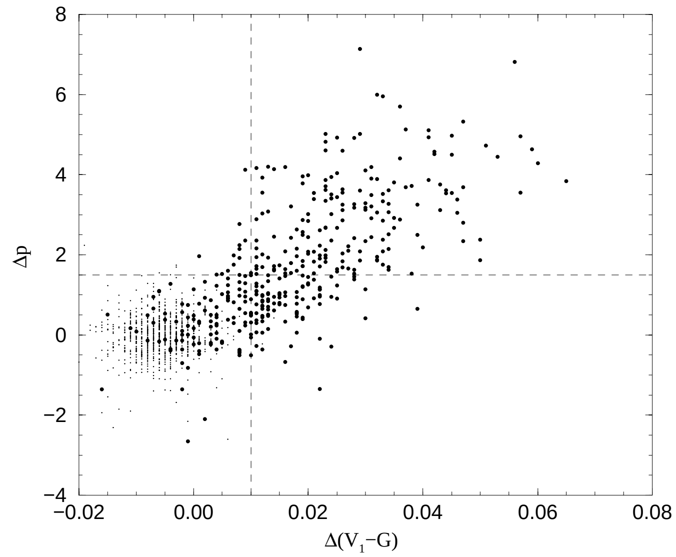

Fig. 9. Correlation between Δp defined by Eqs. (1) and (2) and $\Delta(V_1 - G)$. Dots are normal stars and full circles are CP2 stars from Renson et al. (1991) catalogue. Horizontal and vertical dashed lines correspond to the threshold values of both indices to recognize CP2 stars

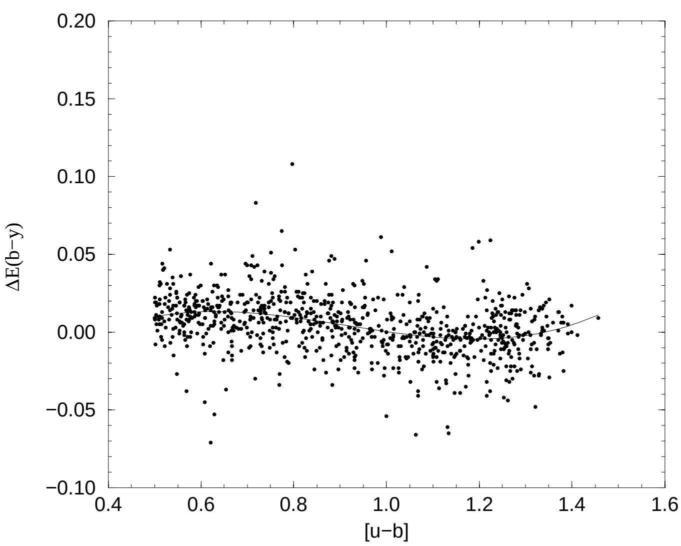

Fig. 10. Difference in colour excess computed from Johnson photometry by the Q-method and from $uvbyH_\beta$ photometry for normal stars belonging to the early region

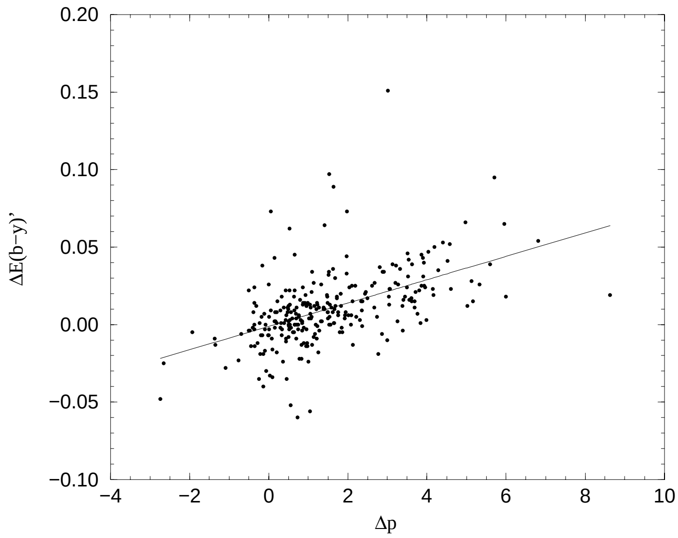

Fig. 11. Correlation between the difference of colour excess due to peculiarity for CP2 stars belonging to the early region

the colour excesses computed from both photometries for CP2 (284) and normal (844) stars of the early region.

To compute $E(B-V)$, we applied the Q-method using $E(U-B)/E(B-V) = 0.72$ (Crawford & Mandwewala 1976) and the luminosity class V calibration by Schmidt-Kaler (1982) for the relation $(U-B)$ vs. $(B-V)$. The $E(B-V)$ was converted to $E(b-y)_Q$ by the factor 3/4.27. The $E(b-y)$ was computed from Crawford's (1978) calibration for normal main-sequence stars. Differences $\Delta E(b-y)$ in the sense $E(b-y)_Q - E(b-y)$ are plotted vs. $[u-b]$ index in Fig. 10 for the normal stars. This $\Delta E(b-y)$ reflects the intrinsic differences of the two methods when computing reddening, i.e. the differences between the standard calibrations used. However, the $\Delta E(b-y)$ of the CP2 stars includes the difference due to the calibrations and the difference induced by the peculiarity.

For normal stars $\Delta E(b-y)$ can be fitted by:

$$\Delta E(b-y) = -0.124 + 0.526[u-b] - 0.633[u-b]^2 + 0.232[u-b]^3.$$

Subtracting this difference from the $\Delta E(b-y)$ of CP2 stars, the new $\Delta E(b-y)$ will only be due to the peculiarity of the star. The correlation with Δp is shown in Fig. 11 and is fitted by:

$$\Delta E(b-y)' = (-0.001 \pm 0.002) + (0.008 \pm 0.001)\Delta p. \quad (7)$$

Maitzen & Vogt (1983) performed an analysis of the colour excess, computed from Crawford's calibration, of CP2 stars located in an almost reddening-free sky region. They deduced a moderate correlation between the negative reddening values and the peculiarity index Δa. Our correlation is stronger than theirs. With this $\Delta E(b-y)'$ the number of negative excesses in our sample is reduced considerably.

Since without a spectrum we cannot know a priori if a star is peculiar, the best solution is to use the Δp parameter given by Eqs. (1) and (2) and to correct the excess a posteriori with the preceding expression if the star is classified as CP2.

7. Conclusions

We built two samples of stars: one of them made up of CP2 stars and the other of normal stars. The application of the *Multiple Discriminant Analysis* gave a combination of the Strömgren-Crawford photometric indices which was able to optimally distinguish both samples. The analysis was conducted separately for the early, intermediate and late photometric regions defined by Strömgren. We used both observed and reddening free indices. The best result was obtained, for the early region, using the observed indices as variables to characterize the unreddened populations (Eqs. (1) and (2)). For these stars, a peculiarity level of $\Delta p_0 = 1.50$ detects 50% of the CP2 stars with a contamination of around 2%. Furthermore, Δp presented a high correlation with peculiarity indices in other photometric systems, such as Δa and $\Delta(V_1 - G)$.

The ability of Δp to detect peculiar stars is smaller than that of the Δa or $\Delta(V_1 - G)$ indices. This was not unexpected, because they specifically measure the depression at λ5200 Å. However, the efficiency of Δp was higher than that of $\Delta[m_1]$ or $\Delta[c_1]$ used elsewhere.

For the intermediate and late regions, even though a small separation between peculiar and normal stars was present, the correlation of Δp index with Δa was very poor. New observations enlarging the sample of cool peculiar stars with available $uvbyH_\beta$ photometry are needed in order to carry out a more accurate study of these stars. On the other hand, Δp cannot discriminate between cool CP2 stars and Am stars.

A list of 60 new early CP2 candidates among those stars with only $uvbyH_\beta$ measurements was proposed.

Finally, the difference between the $E(b-y)$ of CP2 stars computed from the calibrations suitable for normal stars and the actual $E(b-y)$ was shown to correlate with the peculiarity index Δp (Eq. (7)).

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