CP2 stars as viewed by the $uvbyH_\beta$ 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 $\lambda$-Boo 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 $\lambda4100$ Å, $\lambda5200$ Å and $\lambda6300$ Å (Kodaira 1969). The depression at $\lambda5200$ 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 $\lambda4100$ 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 $\lambda6300$ Å flux depression. Adelman & Pyper (1993) described a feature at $\lambda3509$ 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
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 $\Delta$a-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 $uvbyH$ 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 $uvbyH$ measurements. Moreover, it provides a list of CP2 candidates among those stars with already measured $uvbyH$ 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 “improperly considered Ap” were not included. Only 184 by Renson et al. General Catalogue of Ap and Am stars.

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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.

<table>
<thead>
<tr>
<th>Main</th>
<th>Total</th>
<th>Complete</th>
<th>% Complete</th>
<th>pecul.</th>
<th>sample</th>
<th>photometry</th>
<th>peculiarity</th>
<th>HIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr</td>
<td>517</td>
<td>25%</td>
<td>169</td>
<td>26%</td>
<td>86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eu</td>
<td>125</td>
<td>6%</td>
<td>33</td>
<td>5%</td>
<td>91%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>189</td>
<td>9%</td>
<td>66</td>
<td>10%</td>
<td>86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr</td>
<td>517</td>
<td>25%</td>
<td>169</td>
<td>26%</td>
<td>86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2089</td>
<td>100%</td>
<td>660</td>
<td>100%</td>
<td>571</td>
<td>87%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 $uvbyH$ spectrograph photometer for simultaneous measurements in the four $uvby$ Strömgren filters and in the narrow and wide $H$ bands of the Crawford system (Gronbech et al. 1976; Gronbech & 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
Table 4. External errors with Renson et al. (1991), HIC and GCPD compilations, expressed as our values minus catalogued values.

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

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)

<table>
<thead>
<tr>
<th>Region</th>
<th>Early</th>
<th>Intermediate</th>
<th>Late</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal stars</td>
<td>1301</td>
<td>565</td>
<td>939</td>
<td>2805</td>
</tr>
<tr>
<td>CP2 stars</td>
<td>472</td>
<td>99</td>
<td>78</td>
<td>649</td>
</tr>
</tbody>
</table>

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 $\beta$ 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. $\beta$ 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 (Wilkey et al. 1962). The $\beta$ 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. $\alpha$ 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 \( n_q \) 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.

### 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 \( \beta \) and the bracket, reddening free, indices \([m_1], [c_1] \) and \( \beta \). 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 \( p \):

\[
p = 47.628 + 12.595(b-y) + 52.514 m_1 + 0.118 c_1 -19.289 \beta
\] (1)

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

the zero point being introduced in order that \( \varpi = 0.0 \) 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:

\[
\] (2)

and a \( \Delta p = p - p_0 \) was defined. So, \( p_0 \) gives a standard relation for normal stars (\( \sigma = 0.57 \)) and \( \Delta p \), 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 \( \Delta p_0 \) 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 \( \Delta p \) 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 \( \Delta p \) as a function of the \([u-b]\) (i.e. temperature). The best segregation is obtained
The coefficient of \( u \) shows that this band does not play any significant role in \( p \). The negative sign of the \( \beta \) coefficient is due to the fact that the \( \beta \) 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 \( \Delta p \) 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 \( \Delta p_0 = 1.50 \)**

<table>
<thead>
<tr>
<th>( [u - b] ) range</th>
<th>CP2 stars</th>
<th>normal stars</th>
<th>% detection</th>
<th>% contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5–0.7</td>
<td>35</td>
<td>232</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>0.7–0.9</td>
<td>129</td>
<td>217</td>
<td>49</td>
<td>2</td>
</tr>
<tr>
<td>0.9–1.1</td>
<td>87</td>
<td>204</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td>1.1–1.3</td>
<td>92</td>
<td>267</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>1.3–1.5</td>
<td>70</td>
<td>104</td>
<td>41</td>
<td>2</td>
</tr>
<tr>
<td>0.5–1.5</td>
<td>413</td>
<td>1024</td>
<td>50</td>
<td>2</td>
</tr>
</tbody>
</table>

The \( \Delta p \) 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 \( \Delta p \) equal to 0.16 (s.d. 0.41). This is because \( \Delta p \) is mainly sensitive to the \( \lambda 5200 \) 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 \( \Delta \alpha \) or Geneva photometry (which are more effective to detect CP2 stars than \( uvby \) system, see Sect. 5) and the stars having a quoted peculiar spectra in SIMBAD data base.
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 $\Delta p$'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:

$$p = 71.545 + 3.047(b - y) + 34.463m_1 - 2.214c_1 - 26.003 \beta$$
$$p_0 = -0.600 + 32.160(b - y) - 389.936(b - y)^2 + 1423.289(b - y)^3$$  \hspace{1cm} (4)

and for the late region:

$$p = -51.273 + 11.254(b - y) + 38.126m_1 - 2.188c_1 + 15.978 \beta$$
$$p_0 = -6463.727 + 6993.984\beta - 2524.369\beta^2 + 303.920 \beta^3$$  \hspace{1cm} (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:

$$p = -22.517 + 10.765(b - y) + 44.363m_1 + 1.198c_1 + 4.250 \beta.$$  \hspace{1cm} (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 $\Delta p$ with the criteria introduced by former authors when using the $uvbyH_β$ 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 $\lambda 5200$ Å feature decreases towards the cooler, i.e. Sr stars. $\Delta a$ 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 $\Delta a$ index was lower for the Sr stars than for the Si and Cr stars. In particular, the criterion of
$\Delta(V_1 - G) \geq 0.010$ 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 $\Delta m_1$, using $(b - y)$ as free parameter, and the strength of the $\lambda 5200$ 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. \(\Delta a\) photometry

Maitzen (1976) introduced a photometric index (the \(a\) index) to measure the intensity of the depression at $\lambda 5200$ Å, by comparison of the flux at the center with the mean of the flux at each side of the depression. The \(\Delta a\) 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 \(\Delta a\) 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 $\Delta a$, 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 $\Delta p$ defined by the Eqs. (1) and (2) with the measured $\Delta a$ shows a high correlation between both indices (Fig. 8a). The $\Delta p_0$ 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 $\Delta a$ index is more efficient than the $\Delta p$ index, the correlation between them demonstrates that $\Delta p$ is also a good indicator of peculiarity.
On the other hand, the correlation between $\Delta a$ and $\Delta p$ is better than the correlation between $\Delta a$ 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 $\lambda 5200$ Å depression (North & Cramer 1981). Two indices, $\Delta (V_1 - G)$ and $\Delta Z$, 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. $\Delta Z$ 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 $\Delta p$. 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 $\lambda 5200$ 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 $\Delta a$ and $\Delta (V_1 - G)$ peculiarity indices see Maitzen & Vogt (1983).

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 $\Delta p$ 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 $uvbyH_β$ 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 & Mandewewala 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 $\Delta p$ is shown in Fig. 11 and is fitted by:

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

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 $\Delta a$. 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 $\Delta p$ para-
meter 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 
on 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 contam-
ination of around 2%. Furthermore, $\Delta p$ presented a high 
correlation with peculiarity indices in other photometric 
systems, such as $\Delta a$ and $\Delta (V_1 - G)$.

The ability of $\Delta p$ to detect peculiar stars is smaller 
than that of the $\Delta a$ or $\Delta (V_1 - G)$ indices. This was not 
unexpected, because they specifically measure the depres-
sion at $\lambda 5200$ Å. However, the efficiency of $\Delta p$ 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 $\Delta p$ parameter was very 
poor. New observations enlarging the sample of cool pe-
culiar stars with available $uvbyH_\beta$ photometry are needed 
in order to carry out a more accurate study of these stars. 
On the other hand, $\Delta p$ 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 $\Delta p$ (Eq. (7)).

References

A&A 467, 296
Cameron R.C., 1967, in R.C. Cameron (ed.) The Magnetic and 
Related Stars. Mono Book Corp., Baltimore, p. 471
Cowley C.R., 1993, in Dworetsky M.M, Castelli F., Faraggiana 
R. (eds.) Peculiar versus Normal Phenomena in A-type and 
Related Stars. ASP Conf. Ser. 44, 18
Crawford D.L., Barnes J.V., Gibson J., et al., 1972, A&AS 5, 
109
Crawford D.L., Mandlwewala N., 1976, PASP 88, 917
Report No. 50, p. 141
Hauck B., 1975, in Weiss W.W., Jenkner H., Wood H.J. (eds.) 
No. 32, Vienna, p. 365
Hauck B., Nitschelm C., Mermilliod M., Mermilliod J.-C., 
1990, A&AS 85, 989 (GCPD)
Jordi C., Masana E., Figueras F., Torra J., 1997, A&AS 123, 
83
Lanz T., 1993, in Dworetsky M.M, Castelli F., Faraggiana R. 
(eds.) Peculiar versus Normal Phenomena in A-type and 
Related Stars. ASP Conf. Ser. 44, 60
Maitzen H.M., 1975, in Weiss W.W., Jenkner H., Wood 
Colloquium No. 32, Vienna, p. 233
Maitzen H.M., 1993, A&AS 102, 1
Mermilliod J.-C., 1992, Bull. Inform. CDS 40, 115
Murtagh F., Heck A., 1985, Multivariate Data Analysis D. 
Reidel Publishing Company, p. 113
North P., 1993, in Dworetsky M.M, Castelli F., Faraggiana R. 
(eds.) Peculiar versus Normal Phenomena in A-type and 
Related Stars. ASP Conf. Ser. 44, 577
23rd Liège Astrophys. Coll. Université de Liège, p. 55
Preston G.W., 1974, ARA&A 12, 257
Schmidt-Kaler Th., 1982, in Landolt-Börnstein VI. Vol. 2b.
Springer-Verlag, Berlin
Strömgren B., 1963, QJRAS 4, 8
Strömgren B., 1966, ARA&A 4, 433
Turon C., Crézé M., Egret D., et al., 1992, ESA SP-1136 (HIC)