CP2 stars in clusters: deep Δa-photometry

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Abstract. The search for chemically peculiar (CP) stars in open clusters using photoelectric photometry sampling the presence of the characteristic flux depression feature at 5200Å via the Δa-system (Maitzen 1976) has so far delivered data for objects usually no more distant than 1000 pc from the Sun. If one intends to study the presence of CP stars at larger distances from the Sun, classical photometry has to be replaced by CCD photometry.

For the first time, our investigation presents the results of CCD-photometry in the Δa-system for a rich open cluster which is at a distance clearly beyond hitherto studied objects, Melotte 105 (2 kpc, log age = 8.5).

Comparison with published *uvby*-photometry yields the calibration of the colour index $g_1 - y$ of our system, which is necessary for deriving the peculiarity index Δa. For this we achieve an average accuracy of 0.007 mag.

Six objects with only marginally peculiar Δa-values were found, but spectroscopic and additional photometric evidence is needed to substantiate their peculiarity.

1. Introduction

Chemically peculiar (CP) stars of the upper main sequence have been targets for astrophysical studies for exactly 100 years. Starting with the pioneering work of Maury (1897), most of this interval was devoted to the detection of peculiar features in their spectra and photometric behaviour, leading to the post World War II discovery of magnetic fields and the Oblique Rotator concept of slowly rotating stars with non-coincidence of magnetic and rotational axes. Since spectroscopic work required high resolution to accomplish magnetic field measurements, the determination of small Doppler shifts and the identification of the highly crowded narrow lines, investigations of CP-stars tended rather to the study of exotic individual behaviour than to the extraction of features common to this special group of main sequence stars.

Only 30 years ago a statistical study using the Strömgren system paved the way to a period of work aimed at shaping our concept towards questions on the origin of CP-stars, their evolution on the main sequence and their dependence on other parameters like metallicity, location in the galactic plane etc.

The prerequisite for investigating larger samples of CP-stars (including the generally fainter open cluster members) is unambiguous detection. Looking into catalogues of CP-stars, especially of the magnetic ones, it immediately becomes

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obvious that there are many discrepancies at classification dispersion. Even the short list of peculiar stars identified by Maury (1897) contains one object which is classified as erroneous entry in the catalogue of Renson (1991).

The reasons for discrepant peculiarity assessments are to be found in the differences of personal pattern recognition among different classifiers, differences of (mainly photographic) observing material (density of spectrograms, widening of spectra, dispersion, focussing), seeing conditions (for objective prism spectra), but also intrinsic variability of peculiar spectral features (e.g. silicon lines).

Photometry has shown a way out of this dilemma, especially through the discovery of characteristic broad band absorption features, the most suitable of them located around 520 nm. Two decades ago Maitzen (1976) introduced a 3 filter photometric system which samples the depth of this green flux depression by comparing the flux in the center (522 nm, g_2), with the adjacent regions (500, g_1, and 550 nm, y) using a band-width of 13 nm. The respective index was introduced as:

$$a = g_2 - (g_1 + y)/2$$

Since this quantity is slightly dependent on temperature (increasing towards lower temperatures), the intrinsic peculiarity index had to be defined as

$$\Delta a = a - a_o[b - y]$$

i.e. the difference between the individual a-value and the a-value of non-peculiar stars of the same colour (the locus of a_o-values has been called *normality line*).

Maitzen (1976) showed that virtually all peculiar stars with magnetic fields, the CP2-group according to the definition of Preston (1974), have positive Δa values larger than 0.012 mag up to 0.075 mag.

This result was corroborated by Maitzen & Vogt (1983) for a significantly larger sample. In a series of papers (first: Maitzen & Hensberge 1981; last: Maitzen 1993) 38 open clusters have been surveyed for the presence of magnetic peculiar stars using Δa-photometry with the conventional photomultiplier technique. The advantage of this approach is both a relatively high accuracy of the detection index Δa (external scatter for normal stars 3-5 mmags) and its immediate availability, hence detection of CP2-stars right at the telescope (provided that the data acquisition system is able to display linear combinations of on-line magnitudes).

On the other hand the magnitude limit is about 12 for work with a 1m telescope. This limit corresponds to a vicinity of only about 1 kpc around the Sun. Even in this area we can reach in some cases only the hotter domain of CP2-stars.

If one considers to study the behaviour and appearance of peculiar stars over a significant range of galactocentric distances - speculating about the possible influence of different degrees of metallicity and/or galactic magnetic field strengths - then it is imperative to increase the actual magnitude limit by at least 2-3 magnitudes. Discarding the use of 4m telescopes as highly unrealistic for this purpose we are left with employing the CCD-technique. Maitzen et al. (1997) have prepared the ground by showing that for field stars in the range 8<V<10, Δa values obtained with CCD-photometry at a 60cm telescope exhibit essentially the same error level as conventional photoelectric photometry.

Aside from the basic advantage of CCD-photometry - i.e. simultaneous recording of many individual objects not only saving time but also increasing precision - the second benefit becomes more and more obvious when we observe clusters at larger distances with decreasing angular separations of their members, and this is the determination of stellar magnitudes by fitting of point spread functions.

The primary goal of the present study is to evaluate the accuracy performance of CCD-photometry, i.e. to which limiting magnitude the peculiarity index a viz. Δa can be determined in an open cluster with a precision comparable to classical photoelectric photometry within reasonable amounts of observing time.

Here we present the results for our first open cluster, Melotte 105, measured in the Δa system with the Bochum 61cm telescope during a campaign in April/May 1995 at ESO La Silla, during which 3 dozens of other open clusters were observed.

Mel 105 is at a distance of 2000 pc in the 4th galactic quadrant and has a reddening of $E(B-V)=0.38$. Therefore, it is at a larger distance than all other open clusters surveyed so far by photoelectric photometry in Δa and a good starter for studying remote clusters in this system.

2. Observations and Reduction

Observations were performed with the 61 cm Bochum telescope at ESO-La Silla on 4 photometric nights (April 8, 9, 13, 16, 1995). The telescope was equipped with a liquid nitrogen cooled Thompson 7882 CCD (384x576 pixels) resulting in a field of view of about 3' by 4'. Three Schott interference filters (diameter of 50mm) were used. Two frames per filter were obtained on each of the aforementioned nights; the integration time was always 600 seconds per frame.

The basic CCD-reduction steps (bias-subtracting and flat-fielding) were performed using standard IRAF-routines. Contrary to our introductory paper on CCD-Δa photometry (Maitzen et al. 1997), we had to resign about aperture photometry, and used the package DAOPHOT fitting point spread function profiles to the stellar images.

Our sample contains 71 stars brighter than $V=15$ which exhibit an average scatter of 0.0040 mags around their mean a-values. The remaining 43 stars up to the magnitude limit 16 in V scatter by 0.0073 mags around their a-averages.

In order to establish the line of normality for deriving the deviations Δa , we have chosen *reference stars* according to the following criteria:
They had to exhibit an average behaviour both in the m_1 vs. $b-y$ and c_1 vs.

$b-y$ diagrams based on the CCD-photometric study of Balona & Laney (1995). This way 16 objects have been obtained spanning an interval in $b-y$ from 0.28 to 0.50 corresponding to B9 - A8 stars after subtraction of the cluster reddening.

As abscissae in the a vs. colour diagrams we were able to choose among 3 types of temperature indices:
photographic $B-V$ values from Sher (1965), $b-y$ just mentioned and g_1-y of our own photometric system. From the correlation of our index with either $B-V$ and $b-y$, we immediately conclude that we should resign about using the photographic $B-V$ data for deriving Δa-values. On the other hand it is very comforting to notice the very good correlation of CCD-based $b-y$ and g_1-y.

Therefore we decided to derive Δa-values from normality lines based on both $b-y$ and g_1-y:

$$a_0 = 0.603 + 0.139\,(b-y)$$

and

$$a_0 = 0.753 + 0.197\,(g_1-y)$$

The Δa-values scatter around their lines by 0.0028 and 0.0034 mags, respectively. Assuming that the Δa values of the reference stars follow a normal distribution, we have calculated confidence intervals (Rees 1987) of 99 percent, respectively.

The average scatter of the Δa values derived from the $b-y$ normality line is 0.0073 if we regard only those 45 stars which are brighter than $V=15$. With the g_1-y normality line we get a scatter of 0.0079 for the 68 stars of the same brightness interval. Had we taken all objects in both cases we would have arrived at mean scatter values of 0.0088 and 0.0104 for $b-y$ and g_1-y , resp. The reason for the larger difference in the second case is the lower number of stars fainter than $V=15$ measured by Balona & Laney (1995). Fainter stars do not only increase the scatter in Δa because of photon statistics, but also because of the higher reddening usually related to background stars which moves them to the right and away from the normality line.

The opposite case - foreground stars with lesser reddening - will also increase the Δa scatter, shifting the points systematically to the left, even leading to the possibility of mimicking a peculiar star.

We conclude that the assignment of peculiarity is less straightforward in the case of clusters more distant than those so far observed with conventional photoelectric Δa photometry.

Six objects could be considered as mild photometric CP2-candidates which ought to be verified by spectroscopy. But none of them could be called an outstanding photometric peculiar object, since the positive deviations from the normality line hardly reach 0.020 mag.

3. Results

Melotte 105, a rather rich open cluster with more than 100 stars measured in our programme does not possess any pronounced photometrically peculiar star of type CP2, although it has many stars around A0 where the relative frequency of those stars reaches its maximum. The probability to identify a mild peculiar star from 6 candidates by spectroscopy does not seem very high. Our sample shares 68 stars in common with that observed in CCD-photometry by Balona & Laney and the high degree of correlation between their $b-y$ values and our g_1-y values justifies the use of the latter ones for the purpose of deriving Δa-values. The larger negative deviations for the fainter stars of our sample (which are significantly less present in the Strömgren study) can, therefore, be easily ascribed to the effect of larger interstellar reddening of background stars.

As a result of this investigation, we state that for the observing time invested (240 minutes of net integration time) for this cluster, we achieve a threshold value for peculiarity slightly above 0.020 mags for stars brighter than $V=15$. Therefore we conclude that about twice the amount of integration time would be sufficient to lower the threshold to values obtained with classical photoelectric photometry (with $V=11$ as the limit for the same telescope size!).

The big step forward in saving telescope time becomes visible if one considers that for a cluster with the same amount of stars, but at the $V=11$ level we would have needed 50 hours of photoelectric observing at the same telescope!

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References

Balona, L.A., Laney, C.D.: 1995, *Mon. Not. R. Astron. Soc.* **277**, 250
Maitzen, H.M.: 1976, *Astron. Astrophys.* **52**, 223
Maitzen, H.M.: 1993, *Astron. Astrophys., Suppl. Ser.* **199**, 1
Maitzen, H.M., Hensberge, H.: 1981, *Astron. Astrophys.* **96**, 151
Maitzen, H.M., Vogt, N.: 1983, *Astron. Astrophys.* **123**, 48
Maitzen, H.M., Paunzen, E., Rode M.: 1997, *Astron. Astrophys.* **327**, 636
Maury, A.C.: 1897, *Ann. Astron. Obs. Harvard* **Vol. 28**, Part 1
Preston G.W.: 1974, *Ann. Rev. Astron. Astrophys.* **12**, 257
Rees, D.G.: 1987, *Foundations of Statistics*, Chapman & Hall, London
Renson, P.: 1991, *Catalogue Général des Etoiles Ap et Am*, Institut d'Astrophysique, Université de Liège
Sher, D.: 1965, *Mon. Not. R. Astron. Soc.* **129**, 237