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CCD photometric search for peculiar stars in open clusters

II. NGC 2489, NGC 2567, NGC 2658, NGC 5281 and NGC 6208⋆,⋆⋆,⋆⋆⋆

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Abstract. High accurate photometric data in the three filter, narrow-band Δa-system for five open clusters (NGC 2489, NGC 2567, NGC 2658, NGC 5281 and NGC 6208) are presented permitting one to detect apparent chemically peculiar stars. The ages and distances are wide spread to improve the statistics of peculiar stars in our Milky Way. A total of 235 stars within these clusters have been observed. We have detected ten apparent peculiar objects (six with significant positive and four with negative Δa-values) in four open clusters. Although three of them within the boundaries of NGC 2567 are probably not members of this cluster. Since no Strömgren $uvby\beta$ data are available from the literature, Johnson UBV photometry was used to test and calibrate our photometric data. The results from a comparison of both systems are excellent.

Key words. stars: chemically peculiar – stars: early-type – techniques: photometric – open clusters and associations: general

1. Introduction

We continue our search for chemically peculiar objects of the upper Main Sequence using the three filter Δa-system (Maitzen 1976) and applying the CCD technique. The first paper of this series (Bayer et al. 2000, Paper I hereafter) presented the characteristics of the telescopes, instrumentation, filters and the reduction processes which were used.

Another five open clusters (NGC 2489, NGC 2567, NGC 2658, NGC 5281 and NGC 6208) with distances from 1000 to 3800 pc and ages from 0.01 to 1 Gyr have been investigated. A broad variety of distances and ages brings us closer to find a possible correlation of the apparent number of chemically peculiar depending on these parameters.

In addition to $(g_1 - y)$ measurements, Johnson $(B-V)$ values from the literature were used to derive Δa-values. Color-magnitude diagrams are shown for all five open clusters in Fig. 2.

In total, we detected six objects with significant positive Δa-values and four with negative ones. Three of the latter found in NGC 2567 are most probably not members of the cluster but background stars.

2. Observations and reduction

Observations of the five open clusters were performed with the Bochum 61 cm (ESO-La Silla) as well as the Helen-Sawyer-Hogg 61 cm telescope (UTSO-Las Campanas Observatory) in 1995. The instrumentation and filters used are described in Paper I. The observing log is listed in Table 1.

The basic reductions (bias-subtraction, dark-correction, flat-fielding) were carried out within standard IRAF routines. For all frames we have applied a point-spread-function-fitting within the IRAF task DAOPHOT (Stetson 1987). Photometry of each frame was performed separately and the measurements were then averaged and weighted by their individual photometric error.

3. Results

In Paper I, we compared our photometric indices with results from published Strömgren $uvby\beta$ photometry. The situation for the five open clusters presented here is different. None of them has yet been investigated, to our knowledge, via Strömgren $uvby\beta$ photometry. However, Johnson UBV photometry is available for all of them and has been used to test and calibrate our photometric data.

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⋆ Based on observations at ESO-La Silla and UTSO-Las Campanas.

⋆⋆ Tables 4 to 8 are only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/373/153

⋆⋆⋆ Figure 1 is only available in electronic form at http://www.edpsciences.org

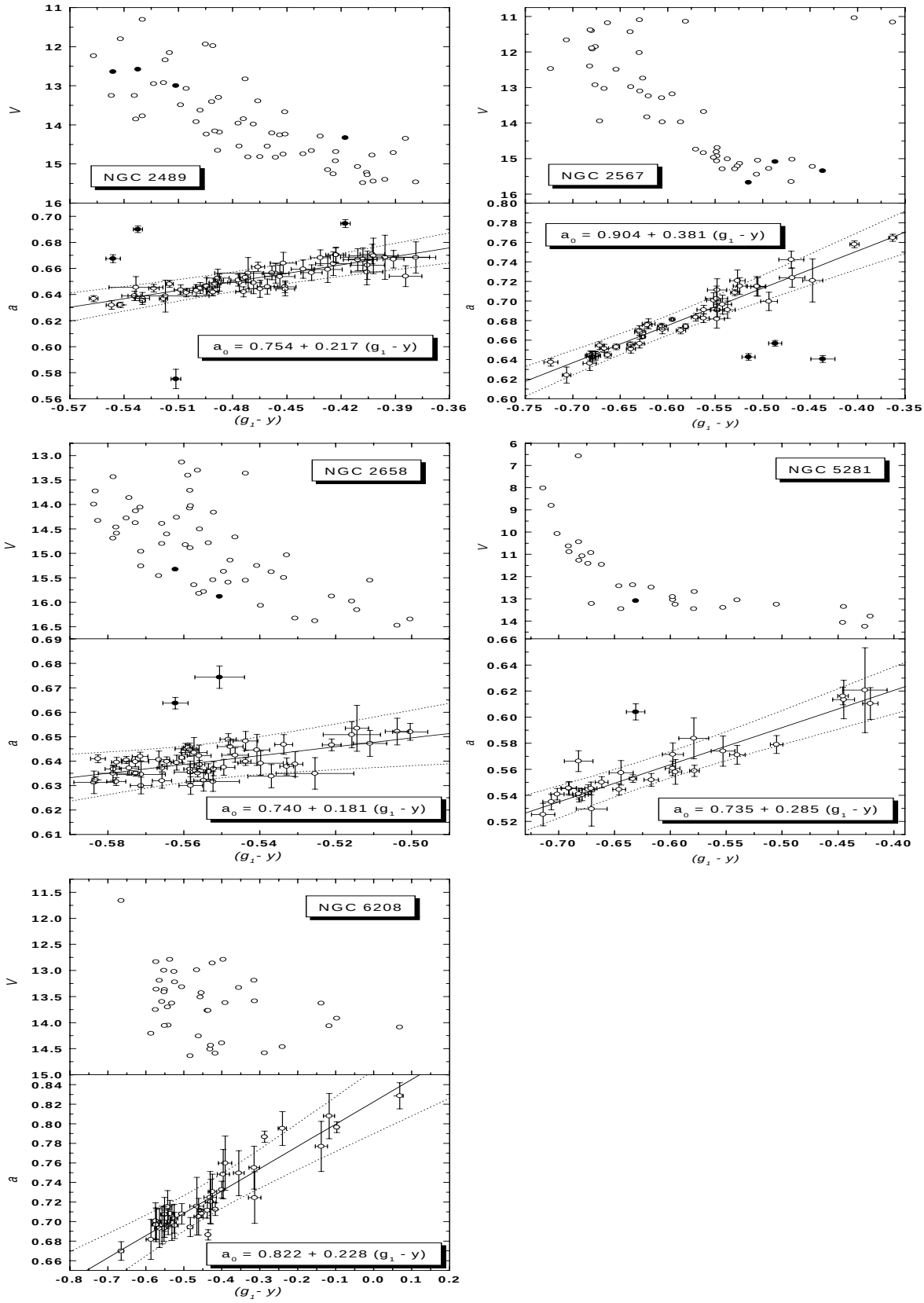

Fig. 2. V versus $(g_1 - y)$ and a versus $(g_1 - y)$ for NGC 2489 (left upper panel), NGC 2567 (right upper panel), NGC 2658 (left middle panel), NGC 5281 (right middle panel), NGC 6208 (left lower panel). Filled circles indicate apparent peculiar stars whereas open circles are non−peculiar objects. The solid line is the normality line whereas the dotted lines are the confidence intervals corresponding to 99.9 %. The error bars for each individual objects are the mean errors. The measurement errors of V are much smaller than the symbols and have been omitted.

Table 1. Observing log.

Cluster	Site	Nights	$\#_{g_1}$	$\#_{g_2}$	$\#_y$
NGC 2489	ESO	3	3	4	3
	UTSO	1	1	1	1
NGC 2567	ESO	4	5	7	5
NGC 2658	ESO	3	4	5	3
	UTSO	1	1	1	1
NGC 5281	ESO	4	10	13	9
NGC 6208	ESO	2	3	4	5

The normality lines were, therefore, independently derived for $(g_1 - y)$ and $(B - V)$, respectively. We have only taken published $(B - V)$ values for this analysis and not tried to transform $(g_1 - y)$ values in the corresponding system. There are several reasons for this. Firstly, most of the data are based on photographic plates resulting in larger uncertainties. An unknown error is introduced by unresolved visual binaries not taken into account by the photometry. From a statistical point of view, the "mixture" of different data sets will give misleading results. A comparison of the Δa-values for both systems results in an excellent agreement. There are only a few exceptions which are discussed in the relevant sections.

However, for the peculiar objects reported in this paper without $(B - V)$ values from the literature, a heuristic transformation of measured $(g_1 - y)$ values was applied. Starting with a list of all stars observed in both systems, objects which deviate more than $5\,\sigma$ from a preliminary linear least square fit were rejected. A final least square fit gives a correlation of $(g_1 - y)$ with respect to $(B - V)$. These "calibrated" values were only used to have an estimate of the temperature range for the apparent peculiar objects (Table 2) found. No other attempt to use these values was done.

For the calibration of our y measurements we have used published V observations. A linear fit always resulted in an excellent correlation with a negligible regression coefficient. The only exception are the data for NGC 6208. This is probable caused by our larger errors as well as those in the measurements of Lindoff (1972).

Candidate peculiar stars in all five clusters were selected if their mean Δa-values are 3σ (taking the standard deviation of the photometry) outside the corresponding confidence intervals of the normality line. If available, we have also checked the apparent peculiarity of Δa using $(B - V)$ from the literature. In overall, the Δa-values for both systems are in excellent agreement shows confidence for the detected apparent peculiar stars.

Table 2 lists our observed open clusters and their characteristics from the literature (Lyngå 1987 and the references listed in the corresponding sections). Further, the number of observed stars, the number of individual frames (Table 1) the regression coefficients for all relevant transformations and normality lines are listed. In addition, the described peculiar objects with their Δa-values and apparent $(B - V)_0$ values as well as the 3σ detection limit are given.

The finding charts of our open clusters are shown in Fig. 1. The size of the symbols are inversely proportional to the apparent visual magnitudes of the objects in the sense that larger symbols denote brighter objects.

The complete tables with all data for the individual cluster stars are available both from SIMBAD (via anonymous ftp) or upon request from the first author. These tables include the cross identification of objects from the literature, the observed $(g_1 - y)$ and a values with their corresponding errors, V magnitudes, the $(B - V)$ values from the literature and Δa-values derived from the normality lines of $(g_1 - y)$ and $(B - V)$, respectively.

Table 3 lists the apparent peculiar stars found within our investigation. The individual objects are discussed in more detail in the following subsections.

The V versus $(g_1 - y)$ and a versus $(g_1 - y)$ diagrams for all five open clusters are shown in Fig. 2. Furthermore, the normality lines and the confidence intervals corresponding to 99.9% are plotted. Filled circles indicate the apparent peculiar objects.

3.1. NGC 2489

Lindoff & Johansson (1968) used photographic plates to investigate this rather rich open cluster at a distance of about 1450 pc from the Sun. The earliest members found have spectral types of about B8. The Johnson UBV measurements of Ramsay & Pollacco (1992) were also used for our analysis. Figure 2 shows a well defined Main Sequence with objects down to 15.5 mag.

The normality lines based on both $(B - V)$ and $(g_1 - y)$, respectively, are given as:

$$a_0 = 0.618 + 0.056 \cdot (B - V)$$

and

$$a_0 = 0.754 + 0.217 \cdot (g_1 - y).$$

We find four objects (Nos. 24, 39, 54 and 57) which deviate from the normality line by more than 3σ. These stars are all members of NGC 2489 according to Lindoff & Johansson (1968). Ramsay & Pollacco (1992) have only one star among their sample (No. 24). They also list this star as being a member of this open cluster. The stars with positive Δa-values have approximate spectral types of B8, A0 and F3, respectively, whereas the negative one is around A2. These types are well in the range of classical chemically peculiar stars.

3.2. NGC 2567

NGC 2567 was the subject of a detailed investigation by Clariá & Lapasset (1986). They presented photoelectric Johnson UBV photometry for 164 objects brighter than 14.6 mag. Further photometry was published by Lindoff (1968) and Ramsay & Pollacco (1992). This open cluster is the most extensively investigated of our five targets.

Table 2. Summary of results.

Name	NGC 2489	NGC 2567	NGC 2658	NGC 5281	NGC 6208
Name	C0754−299	C0816−304	C0841−324	C1343−626	C1645−537
l/b	247/−1	250/+3	255/+6	309/−1	334/−6
$E(B-V)$	0.40	0.13	0.40	0.26	0.18
d [pc]	1450	1600	3800	1300	1000
$\log t$	8.45	8.43	8.50	7.04	9.00
Tr-type	I 2 m	II 2 m	I 2 r	I 3 m	III 2 r
n(obj)	59	50	55	30	41
$\Delta a/(B-V)_0$	+0.032/−0.18	−0.065/+0.41	+0.043/+0.01	+0.049/+0.00	
	+0.052/−0.11	−0.062/+0.55	+0.026/+0.03		
	−0.061/+0.04	−0.097/+0.70			
	+0.031/+0.46				
$V = a + b \cdot (y)$	−8.16/0.997	−8.34/1.005	−8.17/0.995	−8.56/1.013	−6.67/0.916
$a_0 = a + b \cdot (g_1 - y)$	0.754/0.217	0.904/0.381	0.740/0.181	0.735/0.285	0.822/0.228
$a_0 = a + b \cdot (B-V)$	0.618/0.056	0.627/0.130	0.640/0.093	0.532/0.096	0.674/0.054
$3\,\sigma$ [mag]	0.013	0.021	0.010	0.006	0.018
n(frames)	13	17	15	32	12

Several red giants have been found to be members of NGC 2567. Two of them were also observed by us (Fig. 2). Furthermore, the turn off point for this cluster is nicely visible (earliest spectral type of about B8). The Main Sequence consists of late-type B, A and F stars. Clariá & Lapasset (1986) found no evidence for differential reddening across the cluster. They derived a distance of 1620 pc from the Sun as well as 420 pc above the Galactic plane. The latter is probably incorrect because a Galactic latitude of +3° and the given distance from the Sun, a distance of only 85 pc above the Galactic plane has been calculated. The metallicity was found to be nearly solar.

The normality lines based on both $(B-V)$ and (g_1-y), respectively, are given as:

$$a_0 = 0.627 + 0.130 \cdot (B-V)$$

and

$$a_0 = 0.904 + 0.381 \cdot (g_1 - y).$$

From Fig. 2 it is evident that three stars lie significantly below the normality line (Nos. 2, 4 and 16). Unfortunately, none of these objects was observed by Clariá & Lapasset (1986). However, No. 16 was addressed as non-member according to Ramsay & Pollacco (1992; No. 3 therein). Using the classical Q-method, they derived an interstellar reddening of about 2.1 mag for this star whereas the mean value for this cluster is about 0.8 mag. We also tend to believe that the other two stars are probable background stars.

3.3. NGC 2658

With a distance of about 3800 pc, NGC 2658 is the most distant open cluster investigated in the Δa-system so far. Johnson UBV colors were taken from Ramsay & Pollacco (1992). Note that they mixed up Nos. 70 and 119 in their finding chart. No other appropriate publication was found in the literature.

However, the apparent reddening and, hence, the resulting distance and age of this cluster from Ramsay & Pollacco (1992) are controversial. Lyngå (1987) lists $E(B-V) = +0.04$ mag, $r = 2000$ pc, $\log t = 9.15$ and an earliest spectral type of about F8. Since Ramsay & Pollacco (1992) derived $E(B-V) = +0.40$ mag, the distance and age as given in Table 2 are implied. We are confident that the latter values are correct because of the results from the Q-method (Golay 1974). Ramsay & Pollacco (1992) list 38 members of this cluster together with their $(B-V)$ and $(U-B)$ colors based on CCD observations. These objects have spectral types from late B to mid A type (according to the Q-method) making the values given in Lyngå (1987) highly improbable. Furthermore, the results from the Δa-photometry support these findings. Taking a distance of 3800 pc, we derive a distance of about 400 pc above the Galactic plane.

The color-magnitude diagram (Fig. 2) shows a well defined Main Sequence with objects going down to $V \approx 16.5$ mag. No significant differential reddening was found for this cluster. The normality lines based on both $(B-V)$ and (g_1-y), respectively, are given as:

$$a_0 = 0.640 + 0.093 \cdot (B-V)$$

and

$$a_0 = 0.740 + 0.181 \cdot (g_1 - y).$$

Two peculiar objects were detected with a high significance: No. 26 ($\Delta a = +0.026$ mag; No. 33 according to Ramsay & Pollacco 1992) and 53 (+0.034 mag; No. 80). Both stars are members according to Ramsay & Pollacco (1992). They listed absolute magnitudes of 1.13 ($(B-V)_0 = +0.02$ mag) and 1.80 mag ($(B-V)_0 = +0.00$ mag), respectively. This matches very well with a spectral type of A0 suggesting that both objects are A0 Si stars.

The detection of two chemically peculiar objects in such a distant open cluster lends confidence to

Table 3. Stars of the investigated open clusters with peculiar Δa-values.

Cluster	No_1	No_2	X	Y	V	a	$\sigma(a)$	(g_1-y)	$\sigma(g_1-y)$	Δa	$(B-V)$	Δa
NGC 2489												
	24	2	225.5	241.8	13.00	0.575	0.003	−0.511	0.007	−0.068	0.44	−0.066
	39	58	267.5	521.3	12.58	0.690	0.002	−0.532	0.003	+0.052	0.29	+0.056
	54	40	380.9	349.9	12.64	0.667	0.004	−0.546	0.003	+0.032	0.22	+0.037
	57	43	422.3	49.1	14.33	0.694	0.003	−0.418	0.003	+0.031	0.86	+0.028
NGC 2567												
	2		20.5	441.8	15.34	0.641	0.003	−0.437	0.013	−0.097		
	4		38.8	283.0	15.08	0.657	0.003	−0.487	0.007	−0.062		
	16	3	129.0	215.4	15.67	0.643	0.003	−0.515	0.007	−0.065	0.56	−0.057
NGC 2658												
	26	33	165.5	236.0	15.31	0.664	0.002	−0.562	0.004	+0.026	0.43	+0.020
	53	80	342.3	310.8	15.98	0.674	0.005	−0.551	0.004	+0.034	0.41	+0.032
NGC 5281												
	24		322.2	179.0	13.09	0.604	0.006	−0.631	0.008	+0.049		

Col. 1: Cluster name.
Col. 2: Notation sorted after X and Y, respectively (Fig. 1).
Col. 3: Notation according to Lindoff & Johansson (1968; NGC 2489), Ramsay & Pollacco (1992; NGC 2567, NGC 2658).
Cols. 4, 5: X and Y coordinates in the finding charts (Fig. 1).
Col. 6: Visual magnitude.
Cols. 7, 8: mean a-index and its standard deviation.
Cols. 9, 10: mean (g_1-y) value and its standard deviation.
Col. 11: Deviation from cluster line $a_0 = a + b \cdot (g_1-y)$ using the corresponding constants as listed in Table 2.
Col. 12: $(B-V)$ from the literature.
Col. 13: Deviation from cluster line $a_0 = a + b \cdot (B-V)$ using the corresponding constants as listed in Table 2.

investigate the incidence of such objects depending on different metallicities in our Milky Way in the near future.

3.4. NGC 5281

A sequence of 11 B-type stars of this open cluster was observed by Moffat & Vogt (1973). The earliest bright star found has a spectral type of about B5. We have used their photoelectric measurements to derive the normality lines based on $(B-V)$. Together with the one of (g_1-y), they are given as:

$$a_0 = 0.532 + 0.096 \cdot (B-V)$$

and

$$a_0 = 0.735 + 0.285 \cdot (g_1-y).$$

Only one star shows clearly a significant, positive Δa-value: No. 24. Its position in the color-magnitude diagram suggests that it is a member of this open cluster with a spectral type of about A0. Unfortunately, it was not measured by Moffat & Vogt (1973). Very recently, Sanner et al. (2001) presented proper motions for NGC 5281. Their result for our photometric peculiar object does by no means contradict the membership to this cluster. NGC 5281 contains also a well known supergiant (No. 21 in our sample) which exhibits a slightly enhanced Δa-value (+0.026 mag). However, within the error limits, this value is not significant according to our peculiarity criterion. Using the Δa-value derived from the Johnson photometric system, it is even less significant: +0.017 mag. The well known emission line star No. 10, shows only a slight negative value (−0.006 mag), whereas the corresponding value from the Johnson photometric system is −0.019 mag. However, it proves that the Δa photometric system is able to detect emission line stars.

3.5. NGC 6208

Lindoff (1972) already pointed out that this old open cluster lies in a dense region, 100 pc above the Galactic plane. This makes it rather difficult to investigate its membership and astrophysical properties. He finds that only half of the objects in the innermost 12′ are true members of NGC 6208.

The color-magnitude diagram shown in Fig. 2 coincides very well with the one given by Lindoff (1972). It already shows the rather broad and poorly defined Main Sequence of this cluster.

The normality lines based on both $(B-V)$ and (g_1-y), respectively, are given as:

$$a_0 = 0.674 + 0.054 \cdot (B-V)$$

and

$$a_0 = 0.822 + 0.228 \cdot (g_1-y).$$

Within the detection limit (0.018 mag), no apparent peculiar object was found. Taking the rather old age of NGC 6208 ($\log t = 9.0$) this is well in line with prior investigations (Maitzen 1993).

4. Conclusions

In the second paper of our series on CCD Δa photometry of open clusters, we presented high accurate data of five open clusters (NGC 2489, NGC 2567, NGC 2658, NGC 5281 and NGC 6208) for more than 230 objects. For none of these clusters differential reddening was found to play an important role. Overall we have detected ten apparent peculiar objects. But three are probably not members of the corresponding cluster. The results of the individual clusters follow:

- NGC 2489: Three stars with positive (spectral types B8, A0 and F3) and one negative (A2) Δa-values were detected. These objects are true members of this cluster according to the literature;
- NGC 2567: The three objects with significant negative Δa-values are most probably not members of this cluster but background stars. Otherwise no peculiar object was found;
- NGC 2658: This far distant open cluster ($r = 3800$ pc) exhibits two members with positive Δa-values (both around A0). The membership of both objects is confirmed by the literature;
- NGC 5281: Only one apparent peculiar star was found ($\Delta a = +0.049$ mag). A known supergiant within this cluster shows a slightly enhanced Δa-value whereas an emission type star behaves only as a marginally peculiar star just below the detection limit;
- NGC 6208: This rather poorly defined open cluster seems to contain no peculiar object.

The newly discovered apparent peculiar stars should now be observed spectroscopically to shed more light on their nature and to unambiguously establish their peculiarity type. The determination of chemically peculiar stars at larger distances than 1000 pc from the Sun will allow us to analyze a possible correlation of different metallicities in our Milky Way with respect to the apparent number of chemically peculiar stars.

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