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CCD photometric search for peculiar stars in open clusters

VI. NGC 1502, NGC 3105, Stock 16, NGC 6268, NGC 7235 and NGC 7510⋆,⋆⋆

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ABSTRACT

In a sample of six young open clusters (NGC 1502, NGC 3105, Stock 16, NGC 6268, NGC 7235, and NGC 7510) we investigated 1753 objects using the narrow band, three filter Δa photometric system resulting in the detection of eleven bona-fide magnetic chemically peculiar (CP) stars and five Be or metal-weak stars. The results for the distant cluster NGC 3105 is most important because of the still unknown influence of the global metallicity gradient of the Milky Way. These findings confirm that CP stars are present in open clusters of very young ages ($\log t \geq 6.90$) at galactocentric distances up to 11.4 kpc. For all programme clusters the age, reddening, and distance modulus were derived using the corresponding isochrones. Some additional variable stars within Stock 16 could be identified by comparing different photometric studies.

Key words. stars: chemically peculiar – stars: early-type – techniques: photometric – Galaxy: globular clusters: general

1. Introduction

We have observed very young objects, including pre-main-sequence (PMS) stars, and distant open clusters in order to detect classical chemically peculiar (CP) stars of the upper main sequence. We applied the Δa photometric system that measures the flux depression at 5200 Å, a typical feature of CP and related objects (Kupka et al. 2004).

The detection of CP stars in young open clusters that are at significantly different galactocentric distances to the Sun will help us understand the evolution and formation of such objects in non-solar environments.

The data were collected at four different observatories and thus with widely different instruments and CCD detectors. Because this and the use of different Johnson V sources, ranging from photographic to CCD observations, the absolute transformation coefficients from our observed y to Johnson V magnitudes vary significantly, but the final color–magnitude-diagrams of all programme clusters are fully compatible. The same holds for the derived normality lines. This is further proof of the intrinsic consistency of the CCD Δa photometric system.

In addition, we applied the isochrones for the Δa photometric system (Claret et al. 2003) that allows us to determine the age, reddening and distance modulus with an appropriate accuracy. The results from our isochrone fitting procedure were compared with published parameters yielding an excellent agreement.

We detected five CP stars in NGC 1502, Stock 16 and NGC 7235 that have ages less than 10 Myr as well as five objects with significant positive Δa values in NGC 6268 (40 Myr). The results for NGC 3105, where one CP star was found, is most important because its distance from the Sun is about 8.5 kpc with a galactocentric distance of 11.4 kpc.

2. Observations, reduction and methods

Observations of the six open clusters were performed at four different sites and telescopes:

- 1.82 m telescope (Cima Ekar, Asiago), AFOSC, TK1024AB 1024 × 1024 pixel CCD, 8′ field-of-view;
- 2 m RCC telescope (BNAO, Rozhen), direct imaging, SITe SI003AB 1024 × 1024 pixel CCD, 5′ field-of-view;

⋆ Based on observations at the Asiago observatory, BNAO Rozhen, CTIO (Proposal 2003A-0057), ESO-La Silla (Proposal 073.C-0144).
⋆⋆ Table with photometric data is only available in electronic form 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/443/157

Table 1. Observing log for the programme clusters. All clusters were observed on one night by Iliev (II), Maitzen (HM), and Netopil (MN).

Cluster	Site	Date	Obs.	$\#_{g_1}$	$\#_{g_2}$	$\#_y$
NGC 1502	Asiago	01.2004	MN	8	8	12
NGC 3105	CTIO	04.2003	HM	6	6	6
Stock 16	ESO	06.2004	MN	10	10	11
NGC 6268	ESO	06.2004	MN	10	10	11
NGC 7235	BNAO	09.2004	II	10	10	10
NGC 7510	BNAO	09.2004	II	12	12	12

- 0.9 m telescope (CTIO), direct imaging, SITe 2084×2046 pixel CCD, 13′ field-of-view;
- 3.6 m telescope (ESO-La Silla), EFOSC2, Loral/Lesser 2048×2048 pixel CCD, 5′ field-of-view.

The observing log with the number of frames in each filter is listed in Table 1. The observations were performed with two different filter sets, both having the following characteristics: g_1 ($\lambda_c = 5007$ Å, $FWHM = 126$ Å, $T_P = 78\%$), g_2 (5199, 95, 68) and y (5466, 108, 70).

The basic CCD reductions and point-spread-function-fitting were carried out with standard IRAF V2.12.2 routines on Personal Computers running under LINUX. For some clusters we also checked these procedures by applying aperture photometry with excellent agreement. The method of calculating the normality line, deriving the errors as well as the calibration of our $(g_1 - y)$ as well as y measurements, is the same as in previous works (Bayer et al. 2000; Paunzen et al. 2003, and references therein) and will not repeated here.

The isochrones shown in Fig. 2 are based on the Δa photometric system and were taken from Claret et al. (2003). The derived ages, reddening and distance moduli together with the errors are listed in Table 2. The fitting procedure takes advantage of the available *UBV* measurements for all programme clusters by comparing our results to those of the color-magnitude-diagrams for the *UBV* photometric system. However, our determination is based on the Δa measurements only, which is another important application of this photometric system.

The tables with all data for the individual cluster stars as well as nonmembers are available in electronic form at the CDS or upon request from the first author. These tables include the cross identification of objects from the literature, the X and Y coordinates of our frames, the observed $(g_1 - y)$ and a values with their corresponding errors, V magnitudes, the $(B - V)$ colors from the literature, Δa-values derived from the normality lines of $(g_1 - y)$, (exclusive nonmembers) and the number of observations, respectively.

The diagnostic diagrams for all six open clusters are shown in Fig. 1. Also, the normality lines and the confidence intervals corresponding to 99.9% are plotted. The detected peculiar objects are marked with asterisks. Only members (filled circles) have been used to derive the normality lines. The selection of these objects are according to their location in the color-magnitude-diagrams as well as the distance from the cluster centers and additional information from the literature (proper motions and radial velocities) taken from WEBDA (`http://www.univie.ac.at/webda/`).

3. Results

In the following we will discuss the results and the comparison with the literature for the individual open clusters in more detail.

NGC 1502: there are several photometric studies of this cluster in the literature (Purgathofer 1961; Reimann & Pfau 1987; Tapia et al. 1991; Delgado et al. 1992; Crawford 1994), but except Purgathofer (1961), all studies are limited to about 12th magnitude. A study of proper motions and the membership probability was carried out by Hopmann (1958). Our age determination for NGC 1502 of $\log t = 6.9$ agrees very well with the values found in the literature ranging from 6.7 (Tapia et al. 1991) to 7.0 (Reiman & Pfau 1987). It is therefore a very young open cluster within the galactic disk. According to Tapia et al. (1991) and Pandey et al. (2003) the reddening law towards NGC 1502 is anomalous with values of R_V between 2.42 and 2.57. Using a value of 2.57 and an $E(B-V) = 0.75$ mag, we obtain a true distance modulus $(m_V - M_V)_0 = 10.17$ and therefore a distance of 1080 pc from the Sun. The apparent distance modulus of 12.1 is in line with the values published by Crawford (1994, 12.02) and Purgathofer (1961, 12.0). Tapia et al. (1991), on the other hand, found a value of 12.7. They report some inconsistencies when calculating the mean absorption towards NGC 1502. This might be the reason for the deviating value. One CP2 candidate was found (#27) with $\Delta a = +88$ mmag which is one of the most extreme values observed yet. This object was also recognized as peculiar within the Geneva photometric system with $\Delta(V1 - G) = +58$ mmag (North & Cramer 1981). This star shows an extreme "blueing" effect which is typical for some magnetic CP objects due to stronger UV absorption than in normal type stars (Adelman 1980). However, its cluster membership is confirmed by the proper motion and the analysis by Tapia et al. (1991) who used *JHK* and *uvbyβ* photometry.

NGC 3105: we have included this open cluster because of the discrepant distances from 5.5(8) to 9.5(1.5) kpc found in the literature (Sagar et al. 2001) and its young age. This implies that NGC 3105 has only a small apparent diameter on the sky (1.5′) and therefore a large number of measured nonmembers. Sagar et al. (2001) list a reddening $E(B-V) = 1.06$ mag and an age of $\log t = 7.40(25)$. We find a slightly lower mean reddening (0.95) but a comparable age (7.30). Figure 2 shows that the coolest red giants cannot be fitted by isochrones in terms of the color also clearly visible in Sagar et al. (2001, Fig. 19 therein). These objects likely show an extended atmosphere with strong stellar winds and mass-loss which severely influences the observed colors (Eigenbrod et al. 2004). However this effect does not influence the fitting of the isochrone itself. There is no doubt that NGC 3105 is a very distant open cluster ($d = 8.53(1.03)$ kpc) that includes at least one CP star (#617, $\Delta a = +31$ mmag). Figure 2 shows that this object is a definite member with an apparent distance of 0.68′ from the clusters center. Unfortunately, it was not measured by Sagar et al. (2001). The finding of one CP star in an open cluster with a distance of 11.4(6) kpc from the galactic center is most important because of the still unknown influence of the global metallicity gradient of the

Table 2. Summary of results; the age, distance modulus, reddening and thus the distance from the Sun was derived by fitting isochrones to the Δa photometry. R_V was set to 3.1, except for NGC 1502, for which Pandey et al. (2003) list 2.57. The distance of the Sun from the galactic center R_0 was set to 8.5 kpc. The errors in the final digits of the corresponding quantity are given in parenthesis.

Name	NGC 1502 C0403+622	NGC 3105 C0959−545	Stock 16 C1315−623	NGC 6268 C1658−396	NGC 7235 C2210+570	NGC 7510 C2309+603
l/b	143.7/+7.7	279.9/+0.3	306.1/+0.1	346.1/+1.2	102.7/+0.8	111.0/+0.0
$E(B-V)$ (±0.02)	0.75	0.95	0.52	0.40	0.90	0.90
$m_V - M_V$ (±0.2)	12.1	17.6	12.9	11.4	15.4	15.5
d [pc]	1080(130)	8530(1030)	1810(220)	1080(130)	3330(400)	3480(420)
R_{GC} [kpc]	9.4(1)	11.4(6)	7.6(1)	7.5(2)	9.8(2)	10.3(2)
$\|z\|$ [pc]	145(17)	45(5)	3(1)	23(2)	46(6)	0(1)
$\log t$ (±0.1)	6.90	7.30	6.90	7.60	6.90	7.35
Tr-type	I 3 m	I 3 p	IV 2 p	II 2 p	III 2 p	II 2 m
n(mem)	34	48	23	34	87	100
n(none)	6	1257	70	28	42	24
CP (No./WEBDA)	1/27	617/−	15/12	15/80 40/39 63/21 70/23 82/−	2/− 96/− 110/− 121/18 123/90 127/92	48/65 121/27
$\Delta a/(B-V)_0/M_V$ [mmag]	+88/−240/+370	+31/+40/−740	+24/−138/+480	+56/−62/+550 +23/−116/+760 +19/−112/−220 +12/−112/+2130 +18/+21/+1500	+56/+119/+1520 +48/+176/+1680 +31/−86/+1070 −41/−53/−1730 −54/+207/−210 −39/+116/+2160	−46/−18/−1020 −27/+209/−3690
n(frames)	28	18	31	31	30	36

Milky Way (Chen et al. 2003) on the formation and evolution of CP stars.

Stock 16: Vazquez et al. (2005) recently identified 27 members on the basis of a deep CCD $UBV(RI)_c$ photometric study. This open cluster is very young with an age of $\log t = 6.9$ derived from our isochrone fitting which is in line with the results from Turner (1985, 6.5–6.7) and Vazquez et al. (2005, 6.7–6.8). There is a significant number of PMS objects identified in the literature (Fig. 2). Most of these PMS stars lie below the normality line (Fig. 1) most certainly caused by the emission of these objects which is a well known phenomenon (Reipurth et al. 1996). The normality line was therefore calculated using only the definite members excluding the possible PMS stars. Vazquez et al. (2005) mentioned photometric discrepancies of some stars compared to the paper by Turner (1985). We found several other stars showing deviations of more than 0.2 mag between the different photometric studies which might be caused by the intrinsic variability of PMS objects on various time scales with amplitudes of the same level as the detected deviations (Zwintz et al. 2005). We compared the available photometry from the literature and searched for objects with at least three significant deviating observations. This resulted in the unambiguous variability for the objects Nos. 1, 10 and 100 (numbering system according to WEBDA). Misidentification in the literature can be excluded because all stars are well separated in the field of Stock 16. A detailed time series analysis of our data will be presented in a separate paper. We discovered one CP candidate (WEBDA #12, $\Delta a = +24$ mmag) in the investigated sample of stars. However, the membership of this object is controversial. Vazquez et al. (2005) defined this star as a probable nonmember, whereas Fenkart et al. (1977) and Turner (1985) classified it as a definite member. From the location of it in various RGU and $UBV(RI)_c$ photometric diagrams, we conclude that this object seems to be a member.

NGC 6268: this is the most poorly investigated cluster in our sample. The only published study, by Seggewiss (1968), is based on photographic plates and shows an excellent agreement for the distance modulus (11.46 versus 11.40) and reddening (0.41 and 0.40) compared to the isochrone fitting procedure presented in this analysis. He stated that there are no evolved members, i.e. giants in this open cluster. We have compared our $(g_1 - y)$ data with the photographic $(B-V)$ and found a large scatter. Lyngå (1987) refers to Moffat & Vogt (1975) and a published age of $\log t = 7.4$ (we have obtained 7.6), but this value could not be retraced, since in the original paper no explicit parameters for NGC 6268 have been given. Because of the very low Δa detection limit, several apparent CP stars were identified. At least three objects show a Δa value of more than +20 mmag with an extreme value of +59 mmag. This situation is similar to the results found for NGC 2516 ($\log t = 7.4$, Pöhnl et al. 2003) which hosts a significant number of CP stars with a large range of peculiarity degrees (Maitzen & Hensberge 1981). Bagnulo et al. (2003) detected a 14.5 kG magnetic field for HD 66318 which is a member of NGC 2516. So further spectroscopic investigations of the bona-fide CP candidates for NGC 6268 are needed.

NGC 7235: Pigulski et al. (1997) presented an extensive study of this very young ($\log t = 6.9$) open cluster on the basis of

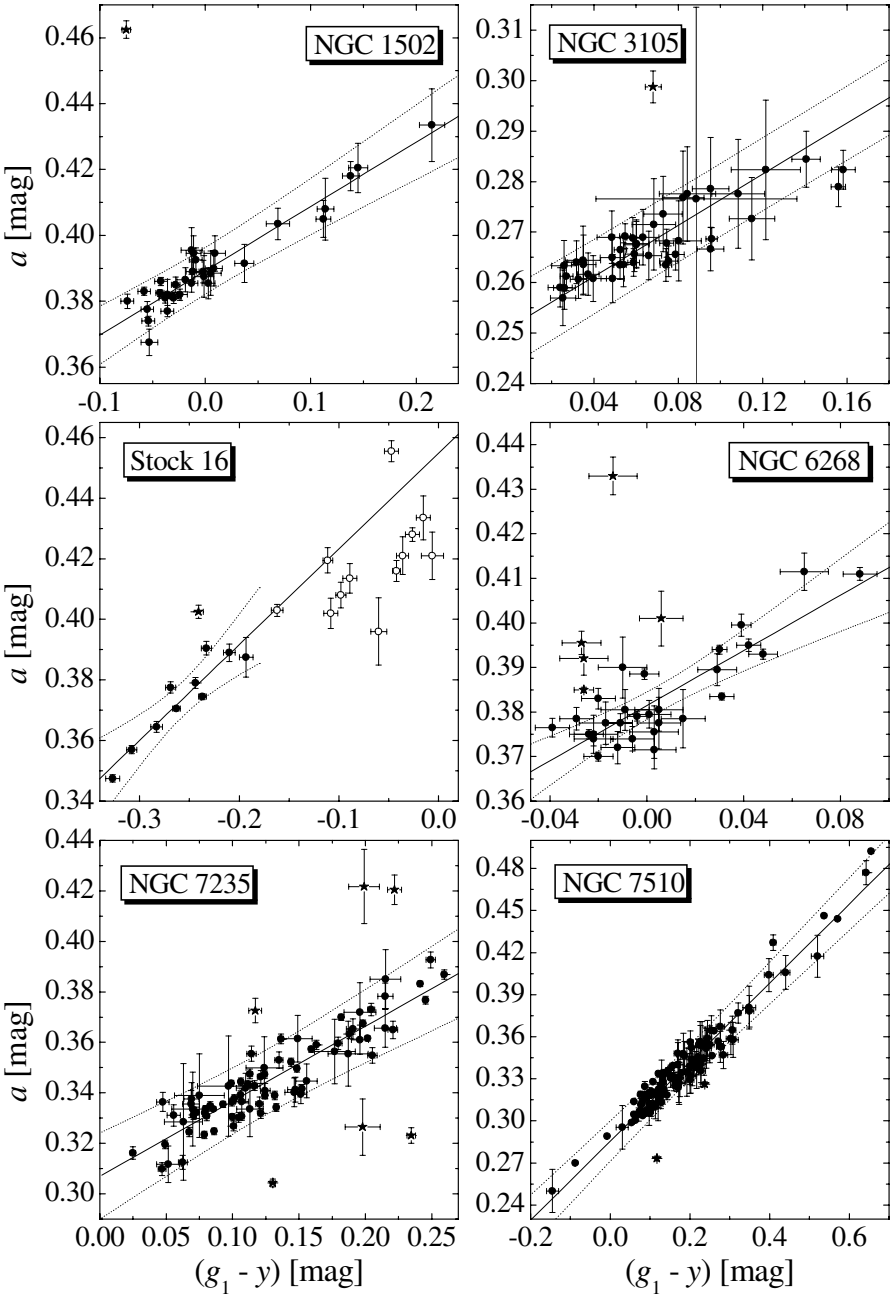

Fig. 1. Observed a versus $(g_1 - y)$ diagrams for our programme clusters. The solid line is the normality line and the dotted lines are the confidence intervals corresponding to 99.9%. The error bars for each individual object are the mean errors. The detected peculiar objects are marked with asterisks. Only members (filled circles) have been used to derive the normality lines. For Stock 16, we also included the PMS objects (open circles) to show the apparent emission (location below the normality line) for these stars. The fitting parameters are listed in Table 3.

$BV(RI)_c$ photometry and additional Hα measurements. They included time series for nine variable stars of all kinds. We are able to confirm the variable stars in common a detailed analysis of those objects will be published elsewhere. Chopinet (1956) classified WEBDA #1 as A1 Ia p, but other sources list B9 Iab (Hiltner 1956), B8 Ia (Sowell 1987) and B8 I (Massey et al. 1995). Because this object has a V magnitude of 8.8, we were not able to measure a Δa index. However, this object is probably not a classical CP star but an evolved supergiant. We found six objects with significant deviating Δa values (three with positive and three with negative). One star (WEBDA #18) seems to be a Be object whereas the other ones (#90 and #92) are good candidates for metal-weak objects because they are too cool to be B-type stars. The three objects with significant Δa-values are most certainly CP stars. All objects seem to be members of NGC 7235.

NGC 7510: no classical CP star was detected in this cluster, but we are able to find significant negative Δa values for the previously known (Sagar & Griffiths 1991; Barbon & Hassan 1996)

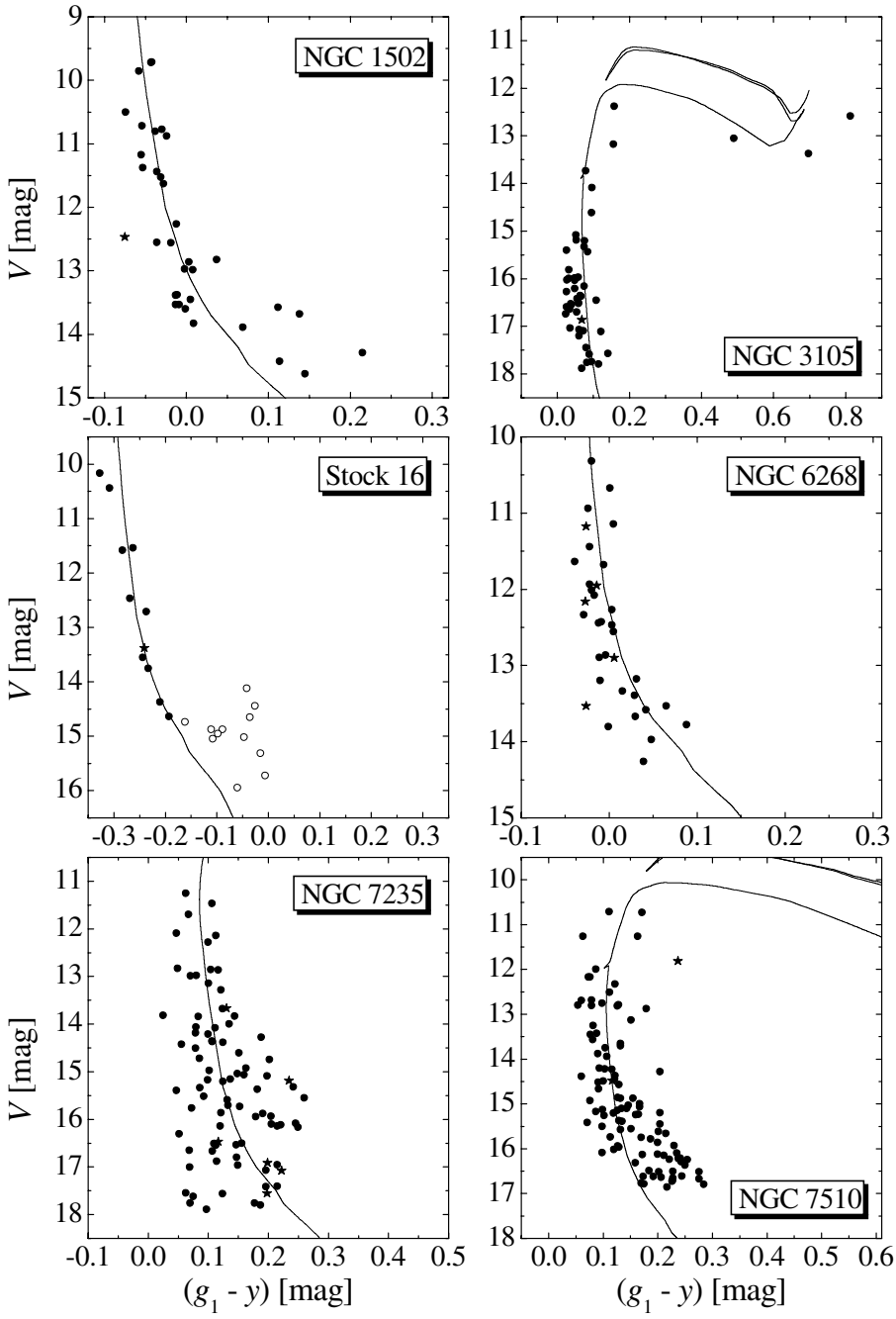

Fig. 2. Observed V versus $(g_1 - y)$ diagrams for our programme clusters. The isochrones are based on the Δa photometric system and were taken from Claret et al. (2003). The derived ages, reddening, and distance moduli are listed in Table 2. The symbols are the same as in Fig. 1.

Be objects WEBDA #27 and #65 which is typical of their emission phase (Fig. 1). Again, this is indication that the Δa photometric system is able to detect Be stars with high efficiency. Our derived age, reddening and distance modulus is comparable to the literature values placing it in the Perseus arm of the Milky Way.

4. Conclusions

We detected eleven bona-fide chemically peculiar stars, five (two previously identified) Be stars as well as metal-weak stars in six young open clusters of the Milky Way. These results are based on photometric Δa measurements of 174 individual frames from four different observatories.

As an important application of the Δa photometric system, isochrones were fitted to the color-magnitude-diagrams (V versus $(g_1 - y)$) of the programme clusters. For this purpose, our measured y magnitudes were directly converted into standard V magnitudes on the basis of already published values. A comparison of our results yields an excellent agreement with the appropriate parameters from the literature.

These findings confirm that CP stars are present in open clusters of very young ages ($\log t \geq 6.90$) at galactocentric distances up 11.4 kpc.

Table 3. The regression coefficients for the transformations and normality lines. The absolute values and errors vary due to the inhomogeneous "standard" observations (photographic, photoelectric, and CCD) found in the literature as well as the dependence on the magnitude range in common, i.e. a broader range guarantees a small error. The offsets are due to the four different telescopes and thus instruments as well as CCD used (Table 1). The errors in the final digits of the corresponding quantity are given in parenthesis.

Cluster	$V = a + b \cdot (y), N$	$a_0 = a + b \cdot (g_1 - y), N$
N 1502	+0.70(10)/0.978(9)/21	0.389(1)/0.195(11)/33
N 3105	−5.52(24)/1.01(1)/115	0.251(1)/0.253(4)/47
Stock 16	−0.07(9)/1.023(8)/8	0.46(1)/0.316(43)/10
N 6268	+0.53(9)/0.937(8)/31	0.381(1)/0.310(37)/29
N 7235	−1.81(22)/0.89(1)/67	0.307(2)/0.297(15)/81
N 7510	−0.07(15)/0.78(1)/122	0.286(1)/0.282(6)/122

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References

Adelman, S. J. 1980, A&A, 89, 149
Bagnulo, S., Landstreet, J. D., Lo Curto, G., Szeifert, T., & Wade, G. A. 2003, A&A, 403, 645
Barbon, R., & Hassan, S. M. 1996, A&AS, 115, 325
Bayer, C., Maitzen, H. M., Paunzen, E., Rode-Paunzen, M., & Sperl, M. 2000, A&AS, 147, 99
Chen, L., Hou, J. L., & Wang, J. J. 2003, AJ, 125, 1397
Chopinet, M. 1956, Journal des Observateurs, 39, 79
Claret, A., Paunzen, E., & Maitzen, H. M. 2003, A&A, 412, 91
Crawford, D. L. 1994, PASP, 106, 397
Delgado, A. J., Alfaro, E. J., Garcia-Pelayo, J. M., & Garrido, R. 1992, AJ, 103, 891
Eigenbrod, A., Mermilliod, J.-C., Clariá, J. J., Andersen, J., & Mayor, M. 2004, A&A, 423, 189
Fenkart, R. P., Binggeli, B., Good, D., et al. 1977, A&AS, 30, 307
Hiltner, W. A. 1956, ApJS, 2, 389
Hopmann, J. 1958, Mitt. Univ. Sternw. Wien, 9, 13
Kupka, F., Paunzen, E., Iliev, I. Kh., & Maitzen, H. M. 2004, MNRAS, 352, 863
Lyngå, G. 1987, Catalogue of Open Cluster Data, 5th edition, CDS, Strasbourg
Maitzen, H. M., & Hensberge, H. 1981, A&A, 96, 151
Massey, P., Johnson, K. E., & DeGioia-Eastwood, K. 1995, ApJ, 454, 151
Moffat, A. F. J., & Vogt, N. 1975, A&A, 39, 477
North, P., & Cramer, N. 1981, in Chemically peculiar stars of the upper main sequence, International Conference on Astrophysics, 23rd, Liège, Belgium, June 23–26, 1981, Reports, Liège, Université de Liège, 55
Pandey, A. K., Upadhyay, K., Nakada, Y., & Ogura, K. 2003, A&A, 397, 191
Paunzen, E., Pintado, O. I., & Maitzen, H. M. 2003, A&A, 412, 721
Pigulski, A., Jerzykiewicz, M., & Kopacki, G. 1997, Acta Astron., 47, 365
Pöhnl, H., Maitzen, H. M., & Paunzen, E. 2003, A&A, 402, 247
Purgathofer, A. 1961, Z. Astrophys., 52, 186
Reimann, H.-G., & Pfau, W. 1987, AN, 308, 111
Reipurth, B., Pedrosa, A., & Lago, M. T. V. T. 1996, A&AS, 120, 229
Sagar, R., & Griffiths, W. K. 1991, MNRAS, 250, 683
Sagar, R., Munari, U., & de Boer, K. S. 2001, MNRAS, 327, 23
Seggewiss, W. 1968, Z. Astrophys., 68, 142
Sowell, J. R. 1987, ApJS, 64, 241
Tapia, M., Costero, R., Echevarria, J., & Roth, M. 1991, MNRAS, 253, 649
Turner, D. G. 1985, ApJ, 292, 148
Vázquez, R. A., Baume, G. L., Feinstein, C., Nuñez, J. A., & Vergne, M. M. 2005, A&A, 430, 471
Zwintz, K., Marconi, M., Reegen, P., & Weiss, W. W. 2005, MNRAS, 357, 345