

The Clusters AgeS Experiment (CASE). Variable Stars in the Field of the Open Cluster NGC 6253*

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ABSTRACT

The field of the metal-rich open cluster NGC 6253 has been surveyed in a search for variable stars. A total of 25 new variables were detected, 14 of which are bright stars with $13 < V < 15$ mag. This domain was not covered in an earlier work by de Marchi *et al.* (2010). Four variables, including three short-period eclipsing binaries, are candidate blue straggler stars. Two new detached eclipsing binaries at the turnoff of the cluster and another one on the subgiant branch were identified. These three systems deserve a detailed follow-up study aimed at a determination of the age and distance of NGC 6253. New photometry for 132 stars from the sample of de Marchi *et al.* (2010) is provided.

Key words: *open clusters and associations: individual: NGC 6253 – Stars: variables: general – blue stragglers – binaries: eclipsing*

1. Introduction

NGC 6253 ($l = 335.4$, $b = -6.3$) is an old open cluster projected against the central part of the Galactic disk. A first study based on *UBVRI* CCD photometry was presented by Bragaglia *et al.* (1997). An important result of this seminal paper was strong evidence that the metallicity of the cluster is about twice the solar value. Subsequent photometric studies were published by Piatti *et al.* (1998, *BVI*), Sagar *et al.* (2001, *UBVRI*), Twarog *et al.* (2003, *uvbyH β*), and Montalto *et al.* (2009, *BVRIJHK*). The latter paper includes proper motion (PM) data and membership probabilities for brighter stars in the cluster field. Montalto *et al.* (2009) also discuss the age of NGC 6253, quoting 3.5 Gyr as the most likely value.

Based on spectra of four red-clump giants, Carretta *et al.* (2007) determined the metallicity of NGC 6253 to be $[\text{Fe}/\text{H}] = +0.46 \pm 0.03 \pm 0.08$ (*rms* + systematic

*Based on data obtained at Las Campanas Observatory.

error). The same value of $[\text{Fe}/\text{H}] = +0.46_{-0.03}^{+0.02}$ was derived from high resolution spectra of 65 stars by Anthony-Twarog *et al.* (2010). Spectra of seven stars obtained by Sestito *et al.* (2007) yielded $[\text{Fe}/\text{H}] = +0.37 \pm +0.07$ – a value slightly lower, but consistent within error limits with the previous two measurements. An even lower value was more recently reported by Montalto *et al.* (2012), who measured $[\text{Fe}/\text{H}] = +0.26 \pm 0.11$ and $[\text{Fe}/\text{H}] = +0.19 \pm 0.13$ from VLT/UVES high-resolution spectra of a main-sequence star and two red clump stars, respectively.

The first and so far the only search for variable stars in NGC 6253 field was conducted by de Marchi *et al.* (2010). They used ESO-MPI 2.2-m telescope plus wide field CCD WFI camera to monitor a 32×32 arcmin region centered on the cluster. A total of 45.3 hours of observations in *R*-filter were collected over 10 consecutive nights in 2004. Light curves were extracted for about 250 000 stars of which 595 were classified as variables. The sample of variables located within 8 arcmin from the cluster center and considered possible members includes 13 contact binaries, 9 detached or semi-detached systems, 16 “rotational” variables, 16 long-period objects and one dwarf nova. In our opinion none of the detached binaries listed by de Marchi *et al.* (2010) deserves a detailed follow-up study.

We obtained an independent photometry of NGC 6253 within the CASE project (Kaluzny *et al.* 2005) with the aim to detect detached eclipsing binaries which could be used for the determination of age and distance of the cluster, as proposed by (Paczynski 1997). Before we reduced our data, Montalto *et al.* (2011) discovered that their star #45368 – a proper-motion and radial-velocity member of NGC 6253 located at the turnoff of the cluster – is an eclipsing binary. This star was not included among variable stars of de Marchi *et al.* (2010). We decided to focus on this object in order to obtain complete light and velocity curves (which will be analyzed in a separate contribution). Here we present light curves of 25 new variable stars detected in the cluster field. We have also identified 132 stars from the list of variables compiled by de Marchi *et al.* (2010). Their light curves and periods are available from the CASE archive[†].

While searching the literature for reliable photometric data that would enable a transformation from our instrumental system to the standard one, we found large discrepancies between published sets of *BV* photometry of NGC 6253. We discuss these discrepancies and argue in favor of a transformation to the standard *BV* system based on the photometry of Sagar *et al.* (2001).

2. Observations

The data were collected at Las Campanas Observatory on 78 nights between August 2007 and October 2010. We used the 1.0-m Swope telescope and the SITE3 CCD camera which has a scale of 0.445 arcsec/pixel. Time-series observations were conducted with *BV* filters. We obtained a total of 1016 useful images in *V* and

[†]<http://case.camk.edu.pl/>

275 in *B*. The median exposure time was 90 s for *V* and 150 s for *B*. The actual exposure time varied according to observing conditions, longer for nights with clouds or poor seeing. The median seeing was equal to 1."5 and 1."6 for *V* and *B* frames, respectively. Images were taken with the camera subrastered to 2048×2150 pixels, resulting in a field of view of 14.8×15.6 arcmin. The monitored region was centered at $RA(2000) = 254.8053$ deg and $Dec(2000) = -52.7200$ deg. These coordinates correspond approximately to the center of NGC6253. Our field is included entirely within the region surveyed by de Marchi *et al.* (2010), covering 21% of its area. The angular diameter of NGC 6253 does not exceed 16' (Bragaglia *et al.* 1997), what implies that we surveyed nearly the whole area of the cluster.

3. Photometric Reductions

The full field of 2048×2150 pixels was divided into a mosaic of 5×5 overlapping subfields. These subfields were analyzed independently, thereby reducing the effects of PSF variations across the frame. Each subfield had a size of 570×590 pixels and the overlap between fields amounted to 160 pixels in *X* and *Y*. The time-series photometry was derived with an image subtraction technique using the DIAPL code[‡]. Template images were obtained by averaging several frames taken with good sky conditions and good seeing. For the templates, profile photometry with DAOPHOT and ALLSTAR codes (Stetson 1987) was extracted. Aperture corrections necessary for the proper transformation of light curves from differential counts to instrumental magnitudes were derived for each subfield separately using the DAOGROW code (Stetson 1990).

We were planning to transform the instrumental system to the standard one using results from existing photometric studies of NGC 6253. Unfortunately, as noted already by Anthony-Twarog *et al.* (2010), the four available sets of *BV* photometry mentioned in Section 1 show significant discrepancies. We compared these using data from the WEBDA base[§] to find that the differences are not only large, but also color-dependent (Fig. 1). A detailed comparison indicates that no two of the four data sets agreed with each other. Photometry of Piatti *et al.* (1998) was calibrated based on 12 standard stars from Landolt (1992). Bragaglia *et al.* (1997) used data for 18 stars from four Landolt fields. Montalto *et al.* (2009) observed one Landolt field, but they based their calibration on Stetson's photometry[¶]. The calibration of Sagar *et al.* (2001) is based on 40 standard stars from E and F regions (Menzies *et al.* 1989).

Within the CASE project we have always taken a great care to accurately transform our photometry from the instrumental system to the standard one. Specifi-

[‡]Freely accessible at <http://users.camk.edu.pl/psych/DIAPL/index.html>

[§]<http://www.univie.ac.at/webda/navigation.html>

[¶]<http://cadwww.dao.nrc.ca/standards/>

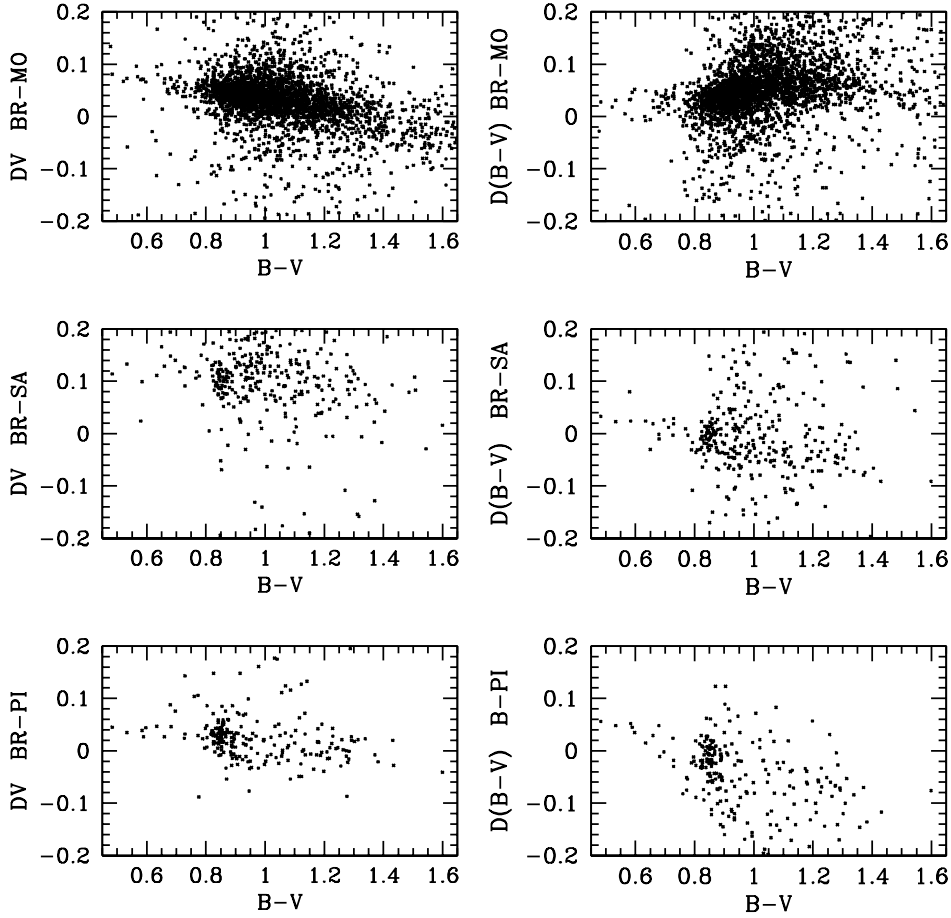


Fig. 1. Differences between NGC 6253 photometries of Montalto *et al.* (2010), Sagar *et al.* (2001) and Piatti *et al.* (1998) with respect to the photometry of Bragaglia *et al.* (1997) are shown in *top*, *middle* and *bottom* rows, respectively, as a function of the $B - V$ color. The *left panel* of each row shows differences in V , while the *right one* – differences in $B - V$. All differences are clearly color-dependent.

cally, we have used equations

$$v = a_1 + V + a_2 \times (B - V) + X \times k_v \quad (1)$$

$$b = a_3 + V + a_4 \times (B - V) + X \times k_b \quad (2)$$

$$b - v = a_5 + a_6 \times (B - V) + X \times k_b v \quad (3)$$

where v and b are instrumental magnitudes, X is the air mass, and all coefficients are to be found from observations of photometric standards. During most of the CASE observing seasons the same CCD camera with the same set of filters was used, and in several photometric nights observations of Landolt standards were taken. We found that over the years the color terms in Eqs.(1)–(3) remained constant. Facing serious discrepancies in the published photometry of NGC 6253, we

decided to adopt as secondary standards the data set which would lead to a transformation with color terms most consistent with ours. This was done by substituting in Eq.(1), Eq.(2) and Eq.(3) our instrumental bv magnitudes together with the corresponding published magnitudes and calculating the coefficients. As it turned out, only the photometry of Sagar *et al.* (2001) reproduced a_2 , a_4 and a_6 in a consistent fashion, yielding

$$v = V - 1.679(7) - 0.008(7)(B - V) \quad (4)$$

$$b = B - 2.090(9) - 0.046(9)(B - V) \quad (5)$$

$$(b - v) = -0.413(7) + 0.964(7)(B - V) \quad (6)$$

with the terms Xk from Eqs.(1)–(3) included in additive constants. The transformations (4)–(6) are based on 122 stars with $11.6 < V < 18$ mag and $0.27 < B - V < 1.79$ mag. The *rms* values of residuals for these stars amount to 0.019 mag, 0.022 mag and 0.018 mag for V , B and $B - V$, respectively. We therefore transformed all our instrumental data to the system of Sagar *et al.* (2001). We are unable to verify the correctness of zero points of this transformation, but we hope that it is free from systematic color-dependent errors. However, it is clear that new observations are needed to clarify the calibration problems discussed above.

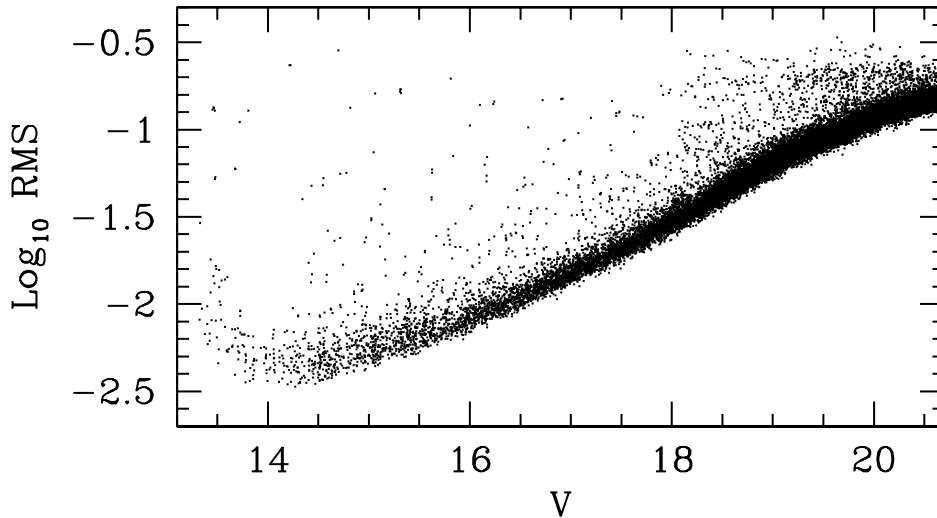


Fig. 2. Accuracy of the photometry of the observed field. *RMS* values of individual measurements in the V -band are plotted vs. the average V -magnitude.

As shown in Fig. 2, the accuracy of our photometry decreases from 3 mmag at $V = 14$ mag to 25 mmag at $V = 18$ mag and 100 mmag at $V = 20$ mag. Fig. 3 shows the color–magnitude diagram (CMD) of the observed field. The right panel only includes objects which are PM-members of the cluster according to Montalto *et al.* (2009), with the membership probability limit decreasing linearly from 90% at $V = 12.5$ mag to 50% at $V = 18.0$ mag. The PM data were only available for $\approx 37\%$ of the observed field.

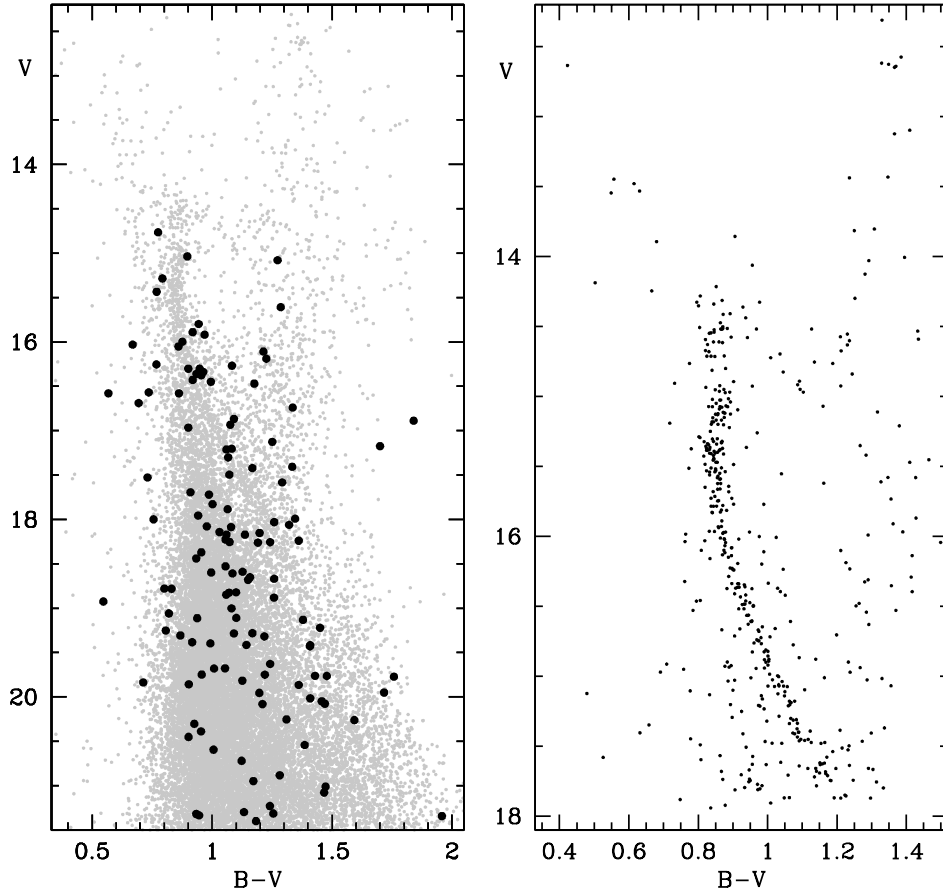


Fig. 3. Color–magnitude diagram of the observed field. *Left*: all stars (variable stars discovered by de Marchi *et al.* (2010) are marked with thick black dots). *Right*: proper motion members of NGC 6253 (note the change of the vertical scale).

The astrometric solution for the V -band reference image was determined from the positions of 1400 UCAC4 stars (Zacharias *et al.* 2013). The average residuals in RA and DEC between the cataloged and recovered coordinates amount to 0.000 ± 0.077 and 0.000 ± 0.125 arcsec, respectively.

4. Variable Stars

We derived V -band light curves of 21 871 stars with $V < 20.5$ mag, each of these containing at least 500 measurements with a magnitude error ≤ 0.1 mag. We began by using our equatorial coordinates to identify variables already reported by de Marchi *et al.* (2010). In the case of doubtful identification, light curves of the best matching objects were examined to see which is the actual variable. We identified 132 objects in this way. The light curves of the remaining stars from our sample were examined for periodic variability with the AOV and AOVTRANS algorithms

(Schwarzenberg-Czerny 1996, Schwarzenberg-Czerny and Beaulieu 2006) as implemented in the TATRY code^{||}. Twenty-six variables not listed in de Marchi *et al.* (2010) were identified. One of these is the eclipsing binary reported as star #45368 by Montalto *et al.* (2011).

Table 1

Basic data of NGC 6253 variables identified within the present survey

ID	RA [deg]	DEC [deg]	MP ^a [%]	V _{max}	$\langle B \rangle - \langle V \rangle$	DV	Period [d]	Type ^b
00	254.78927	-52.83545	-	12.860	0.372	0.07	0.0304328(1)	δ Sct, BS
01	254.63200	-52.77554	-	17.935	0.947	0.14	0.2856667(1)	EW
02	254.87423	-52.68190	-	19.442	1.098	0.51	0.3201930(1)	EW
03	254.63978	-52.61062	-	18.914	1.168	0.36	0.3414981(1)	EW
04	254.64443	-52.75881	-	20.051	0.986	0.70	0.3440106(4)	EW
05	254.87089	-52.66645	-	14.450	0.843	0.07	0.35801236(1)	EW
06	254.79032	-52.83517	-	16.717	0.853	0.20	0.39768833(1)	EW
07	254.63988	-52.82878	-	16.587	0.616	0.43	0.41130522(1)	RRc
08	254.67979	-52.66643	0	14.619	0.788	0.035	0.47518561(8)	Sp, Ell?
09	254.63440	-52.61026	-	15.648	0.626	0.023	0.47911411(1)	EW
10	254.67110	-52.82267	-	17.999	0.895	0.31	0.53285385(2)	EW
11	254.88926	-52.65563	-	13.716	0.664	0.38	0.57914361(1)	EW, BS
12	254.83146	-52.64999	-	15.104	0.878	0.12	0.6542998(6)	Sp
13	254.81845	-52.71808	96	13.653	0.665	0.36	0.88644025(1)	EB, BS
14	254.75385	-52.71431	95	13.472	0.612	0.18	1.15518598(1)	EA, BS
15	254.82151	-52.71217	95	14.709	0.839	0.27	2.572391(2)	EA
16	254.77604	-52.70025	97	14.544	0.832	0.20	4.580597(2)	EA
17	254.62174	-52.61255	-	14.669	0.998	1.01	5.11162(3)	EA
18	254.67926	-52.65474	56	15.106	1.822	0.18	25.501(3)	Sp
19	254.63715	-52.60220	-	14.643	1.104	0.10	27.4762(7)	Sp
20	254.75563	-52.70552	95	13.649	1.292	0.17	28.2517(3)	Sp
21	254.85541	-52.79515	91	13.363	1.754	0.43	39.491(1)	Sp
22	254.96731	-52.83655	-	18.179	2.623	> 2.0	-	P?
23	254.79213	-52.72136	94	15.198	0.869	0.13	-	EA
24	254.68618	-52.66308	98	14.101	1.679	> 0.73	-	P
25	254.97043	-52.67775	-	14.825	1.785	> 0.64	-	P

^a membership probability from Montalto *et al.* (2009)

^b type: EW – contact binary, EB – close eclipsing binary, EA – detached eclipsing binary, BS – blue straggler candidate, Sp – spotted, Ell – elliptical, RRc – RR Lyr c-type, P – pulsating (long period)

The basic properties of the newly discovered variables are listed in Table 1 together with their equatorial coordinates. Magnitudes at maximum at minimum light are, respectively, medians from the brightest 10% and the dimmest 5% of

^{||}<http://users.camk.edu.pl/alex/#software>

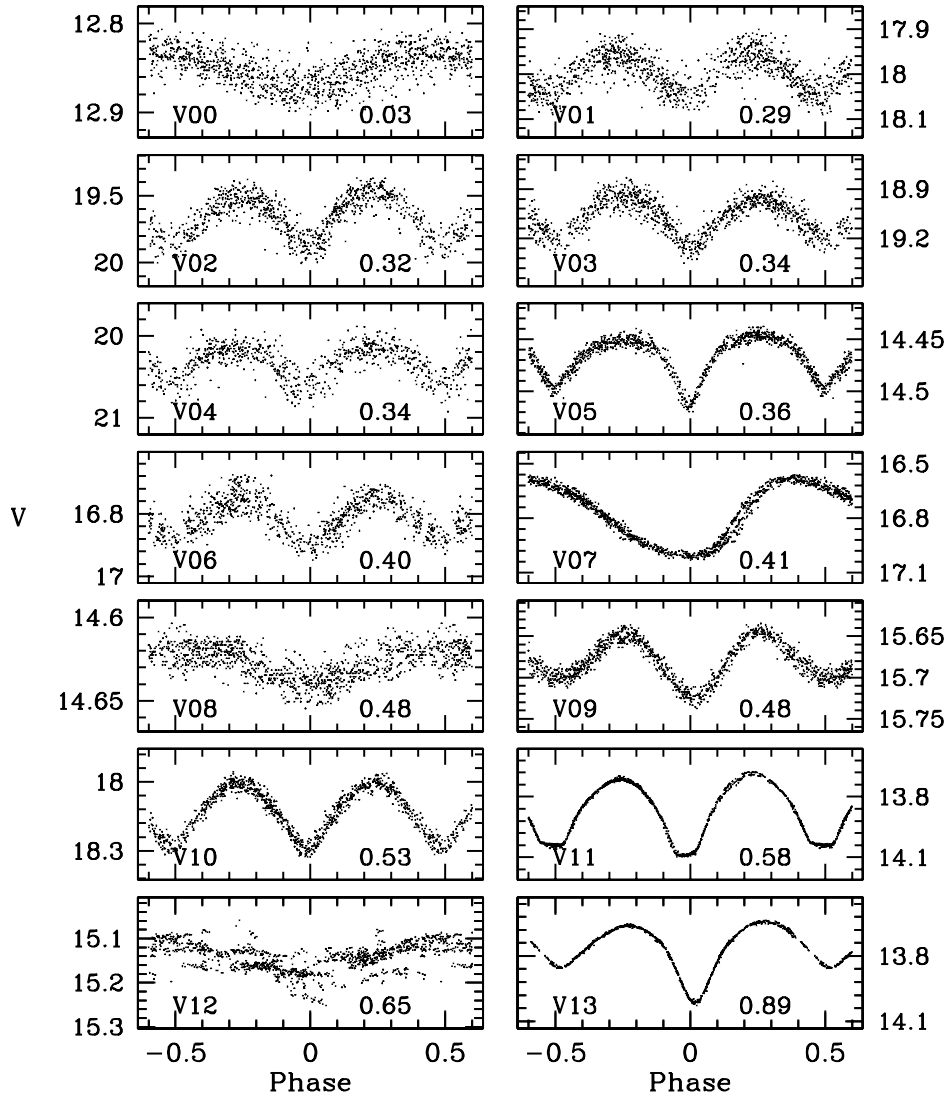


Fig. 4. Phased V -light curves of new variables from the observed field (continued in Fig. 5).

light curve points. Periods and period errors have been derived with the help of the TATRY code. The photometry of the new variables can be downloaded from the CASE archive at <http://case.camk.edu.pl>. The archive also contains the reference frame of the surveyed field taken in V -band, and rectangular coordinates of all objects for which the V -magnitude was obtained. This enables interested observers to make tailored finding charts for the new variables.

Phased light curves of 22 objects are presented in Figs. 4 and 5. Periods of the remaining four variables could not have been determined, and the corresponding light curves are shown in Fig. 6 as functions of time. The CMD of the cluster with the variables marked is shown in Fig. 7, divided into two panels to facilitate

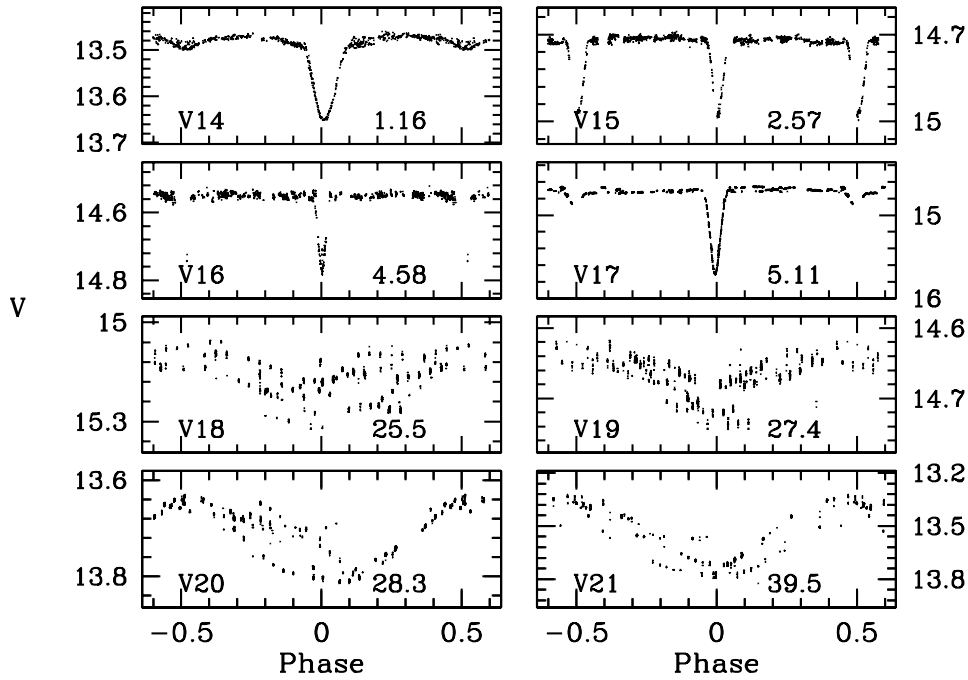


Fig. 5. Phased V-light curves of new variables from the observed field (continuation of Fig. 4). Included is the detached eclipsing binary V15 discovered by Montalto *et al.* (2011, their star #45368), which we analyze in detail in a separate contribution.

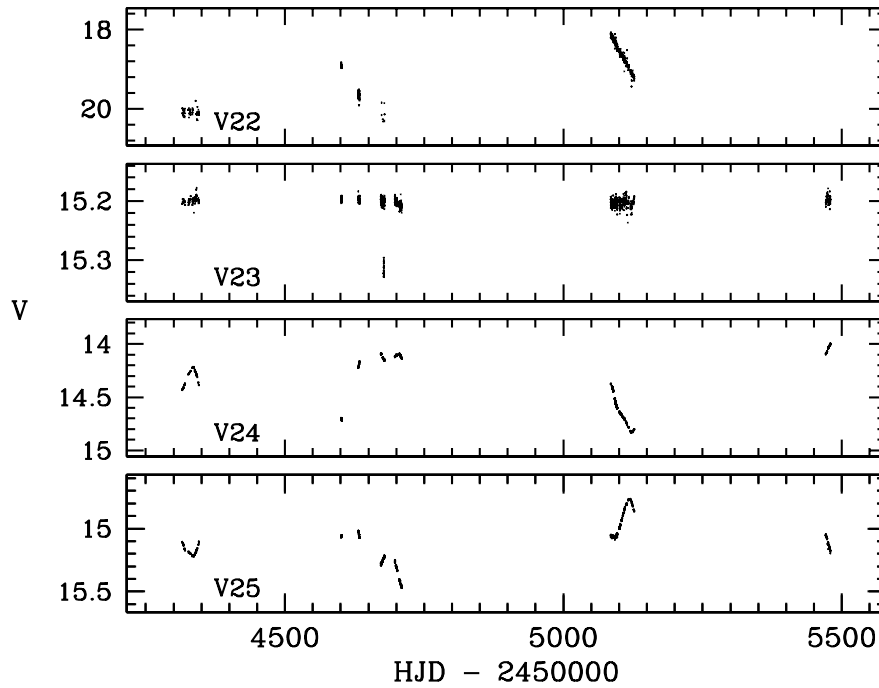


Fig. 6. V-light curves of new long-period variables from the observed field.

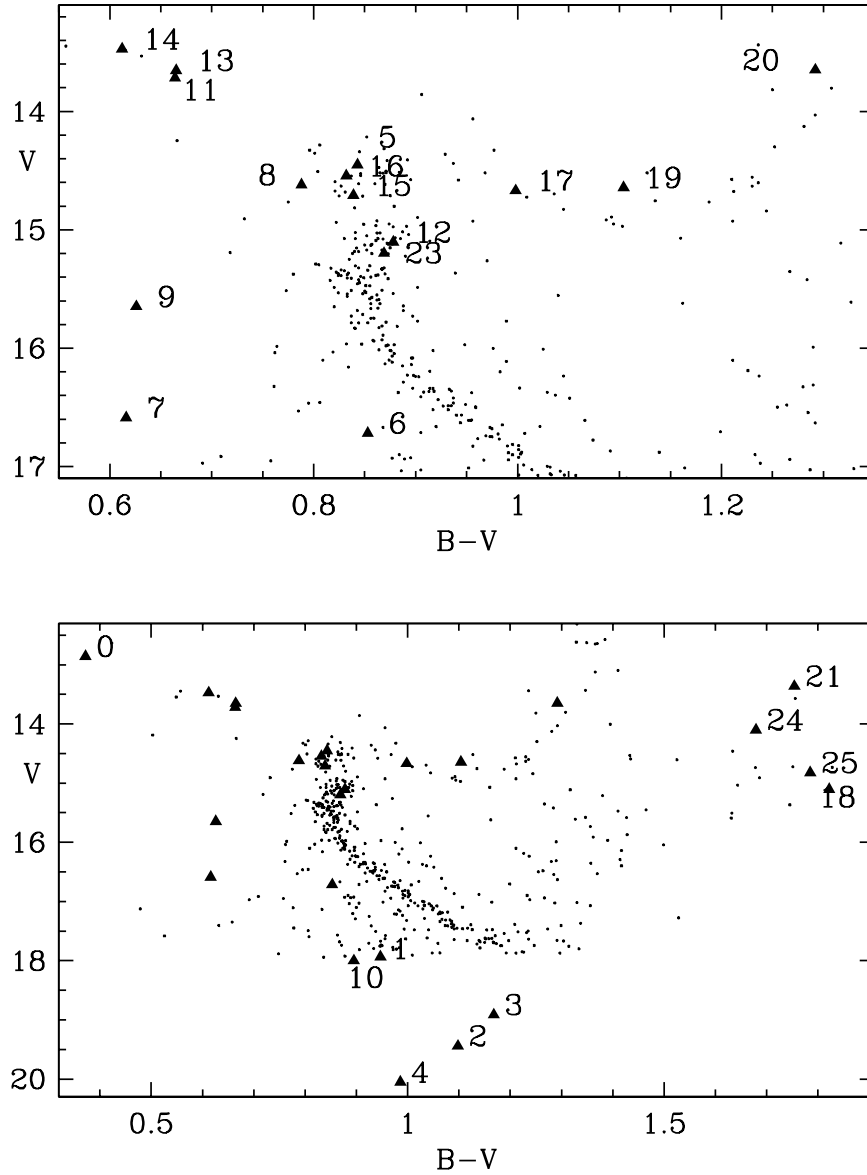


Fig. 7. Color-magnitude diagram for proper motion members of NGC 6252. Positions of stars with light curves shown in Figs. 4 and 5 are marked with triangles and labeled. The red pulsating star V22 with $B - V = 2.6$ mag is not shown. Magnitudes at maximum light and average colors from Table 1 are plotted.

the identification. For clarity, only stars classified by Montalto *et al.* (2009) as members of NGC 6253 are plotted as the background, but it is evident that the CMD is still contaminated by numerous field objects. This is due to a lack of clear separation of cluster and field stars on the vector-point diagram (Montalto *et al.* 2009). A new PM survey with longer time-baseline would improve this situation.

Most of the new variables are bright stars with $V \lesssim 15$ mag. This is a natural consequence of the fact that the survey of de Marchi *et al.* (2010) was limited to stars fainter than $V \approx 15$ mag (see Fig. 3). Our sample includes four possible blue stragglers (BS) of which two, V13 and V14, are PM members of the cluster. The membership status of the remaining two is unknown. Three BSs, V11, V13 and V14 are eclipsing binaries. All three show shallow eclipses, indicating low mass ratios. Because the secondary eclipse of V11 is total, the mass ratio of this binary can be uniquely determined, and using Phoebe package (Prša and Zwitter 2005) we obtained $q = 0.16$ from the analysis of the V -band light curve. The brightest of the variable BS candidates is the multiperiodic δ Sct-type pulsator V00 with a dominant periodicity of 0.030 d. The object is located about 0.5 mag above the extension of the unevolved main-sequence of the cluster. If it really belongs to NGC 6253, then the cluster apparent distance modulus of 11.8 ± 0.3 (Twarog *et al.* 2003) implies an absolute magnitude $M_V = 1.1$ mag for V00, well within the limits of the absolute magnitudes of δ Sct stars (Handler 2005).

The contact binary V5 is located at the turnoff of the cluster together with detached binaries V15 and V16. Another detached system, V23, resides in the vicinity of the turnoff. V15, V16 and V23 are PM-members of NGC 6253. As mentioned above, an analysis of V15 will be presented in a separate contribution. For V16 we partly covered five eclipses. This turned out to be insufficient for a unique determination of the period, so that the 4.58 d quoted in Table 2 should be regarded as a preliminary value. For V23 only one eclipse was observed, with a depth of about 0.12 mag.

By far the most interesting of our eclipsing binaries is V17, located on the subgiant branch of the cluster. The secondary eclipse is shallow with $\delta V \approx 0.15$ mag, but this does not exclude the possibility that the system is of SB2 type. The deep primary eclipse ($\delta V \approx 1$ mag) and different temperatures of the components should result in a unique solution of the light curves. More observations are needed to refine the shape of the secondary eclipse, but these should be relatively easy given the known ephemeris. Two other variables located on the subgiant branch are V19 and V20, the latter being a PM member of the cluster. Unstable sine-like light curves with low amplitudes indicate that these stars are spotted variables. Several variables located off the main sequence and subgiant branch of the cluster are likely field objects. This group includes the RRc star V07. As it was noted by the referee, the light curve of this star shows in fact two closely spaced periodicities bracketing the period listed in Table 1.

As a by-product of the present survey we obtained light curves of 132 variables from the list compiled by de Marchi *et al.* (2010) and analyzed these in search for periodicity. For most of them we confirmed the periods obtained by de Marchi *et al.* (2010), however in some cases alternative periods were found or no periodicity was detected. These results are available from the CASE archive at <http://case.camk.edu.pl/>.

5. Summary

We have conducted an extensive photometric survey of the metal rich open cluster NGC 6253 in a search for variable stars. Twenty five new variables were detected. The sample includes 15 stars with $13 < V < 15$ mag, thus extending an earlier investigation by de Marchi *et al.* (2010) to brighter objects. Three eclipsing binaries and one pulsating star were found in the blue-straggler region. Three new detached eclipsing binaries were discovered in the turnoff region, and another one on the subgiant branch. These systems are promising candidates for spectroscopic and photometric follow-up to determine age and distance modulus of the cluster. Light curves and revised periods were obtained for 132 variables from the sample of de Marchi *et al.* (2010). These are available from the CASE electronic archive together with our photometric data for NGC 6253.

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