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The Clusters AgeS Experiment (CASE). Variable Stars in the Field of the Globular Cluster M12*

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ABSTRACT

The field of the globular cluster M12 (NGC 6218) was monitored between 1995 and 2009 in a search for variable stars. *BV* light curves were obtained for thirty-six periodic or likely periodic variable stars. Thirty-four of these are new detections. Among the latter we identified twenty proper-motion members of the cluster: six detached or semi-detached eclipsing binaries, five contact binaries, five SX Phe pulsators, and three yellow stragglers. Two of the eclipsing binaries are located in the turnoff region, one on the lower main sequence and the remaining three among the blue stragglers. Two contact systems are blue stragglers, and the remaining three reside in the turnoff region. In the blue straggler region a total of 103 objects were found, of which 42 are proper motion members of M12, and another four are field stars. 55 of the remaining objects are located within two core radii from the center of the cluster, and as such they are likely genuine blue stragglers. We also report the discoveries of a radial color gradient of M12, and the shortest period among contact systems in globular clusters in general.

Key words: *globular clusters: individual: M12 – Stars: variables: general – blue stragglers – binaries: eclipsing*

1. Introduction

M12 is a nearby ($(m-M)_V = 14.01$ mag) globular cluster located at a high galactic latitude ($b = 26\overset{\circ}{.}3$) in a field of low reddening with $E(B-V) = 0.19$ mag. According to Harris (1996, 2010 edition), its core radius, half-light radius, [Fe/H] index and radial velocity are equal to $0\overset{\prime}{.}79$, $1\overset{\prime}{.}77$, -1.37 and -41.4 ± 0.2 km/s, respectively. Low reddening and relatively low concentration make it an attractive

*Based on data obtained with du Pont and Swope telescopes at Las Campanas Observatory.

target for detailed studies with ground-based telescopes. The photometric survey presented here is a part of the CASE project (Kaluzny *et al.* 2005) conducted with telescopes of the Las Campanas Observatory, Chile.

Early pre-CCD searches for variable stars in the field of M12 were summarized by Clement *et al.* (2001). These studies resulted in the detection of just one variable – a bright, long-period pulsator of W Vir type, which is overexposed in our frames. Based on CCD data, von Braun *et al.* (2002) found another two variables, both of W UMa type (we recovered these, and we retain their original names V1 and V2). To the best of our knowledge, no additional discoveries have been reported.

In this contribution we present results of a long-term photometric survey conducted between 1995 and 2009. Section 2 contains a report on the observations and explains the methods used to calibrate the photometry. The detected variables are presented and discussed in Section 3. The paper is summarized in Section 4.

2. Observations

Our paper is based on two sets of images. The first set was obtained using the 2.5-m du Pont telescope and the 2048×2048 TEK5 CCD camera with a field of view of $8\farcm84$ on a side at a scale of 0.259 arcs/pixel. Observations were conducted on 23 nights from April 26, 1999 to June 29, 2009. The same set of filters was used for all observations. For the analysis, we used 769 *V*-band images with seeing ranging from $0\farcs64$ to $2\farcs07$, and 216 *B*-band images with seeing ranging from $0\farcs71$ to $2\farcs13$. The median value of the seeing was $1\farcs07$ and $1\farcs14$ for *V* and *B*, respectively. Additionally, a few *U*-band frames were taken in April/May 2001 at an average seeing of $1\farcs25$. The second set of images was obtained with the 1.0-m Swope telescope using the 2048×3150 SITE3 camera. The field of view was 14.8×22.8 arcmin^2 at a scale of 0.435 arcsec/pixel. About 50% of the images were taken with a subraster providing a field of view of 14.8×14.8 arcmin^2. Observations were conducted on 57 nights from April 15, 1999 to June 08, 2008. Again, the same filters were used for all observations. For the analysis, we used 978 *V*-band images with seeing ranging from $0\farcs95$ to $2\farcs31$ and 168 *B*-band images with seeing ranging from $1\farcs03$ to $2\farcs15$. The median value of the seeing was $1\farcs37$ and $1\farcs45$ for *V* and *B*, respectively.

The photometry was performed using an image subtraction technique. The du Pont data were reduced with a modified version of the ISIS V2.1 package (Alard 2000), whereas for the frames obtained with the Swope telescope the DIAPL package[†] was used. For each set and each filter, a reference image was constructed by combining several high quality frames. DAOPHOT, ALLSTAR and DAOGROW codes (Stetson 1987, 1990) were used to extract the profile photometry, and to derive aperture corrections for the reference images. Additionally, profile photometry was extracted for individual images from the du Pont telescope. This allowed us to

[†]Available from *http://users.camk.edu.pl/pych/DIAPL/index.html*

obtain useful measurements for stars which were overexposed on the reference images. Also, profile photometry enabled an unambiguous identification of variable stars in crowded fields, which is sometimes problematic when image subtraction only is used. We attempted to resolve numerous blends in the Swope data for the central part of M12 by using star positions from du Pont photometry. In most cases this approach proved to be successful. The accuracy of the du Pont photometry is illustrated in Fig. 1, in which the standard deviation of the photometric measurements is plotted as a function of the average magnitude in *V*.

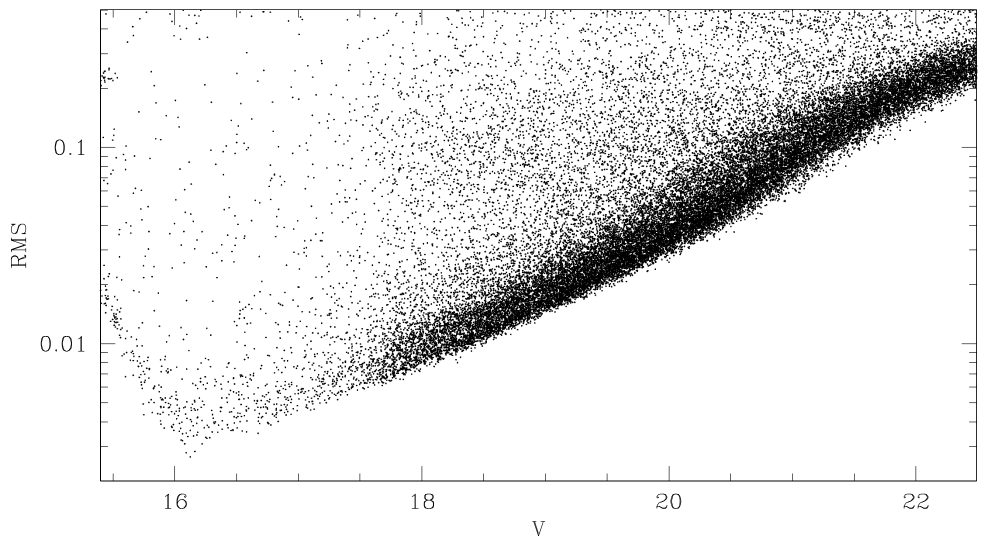

Fig. 1. Standard deviation *vs.* average *V* magnitude for light curves of stars from the M12 field. Light curves are based on images from the du Pont telescope.

2.1. Calibration

The photometry collected with the du Pont telescope was transformed to the standard *UBV* system based on observations of stars from Landolt fields (Landolt 1992). On the night of May 29, 2001 we observed 35 stars from five such fields. These data were used to find the coefficients of linear transformation from the instrumental system to the standard one. Residual differences between the standard and recovered magnitudes and colors amounted to 0.008 mag, 0.007 mag and 0.009 mag for *V*, *B* and $B-V$, respectively. The residuals did not show any systematic dependence on the color index. Transformations for the photometry obtained with the Swope telescope were based on the calibrated data from the du Pont telescope. Linear transformations proved to be entirely adequate. Fig. 2, based on reference images, shows the color–magnitude diagram (CMD) of the observed fields, illustrating the range of stellar population examined for variability (stars with formal error in *V* larger than 0.05 mag and formal error in $B-V$ larger than 0.1 mag are not shown). The contamination of the cluster by field interlopers is rather low, but clearly increases with the larger field of view of the Swope data. Full sets of photometry can be downloaded from the CASE archive.[‡]

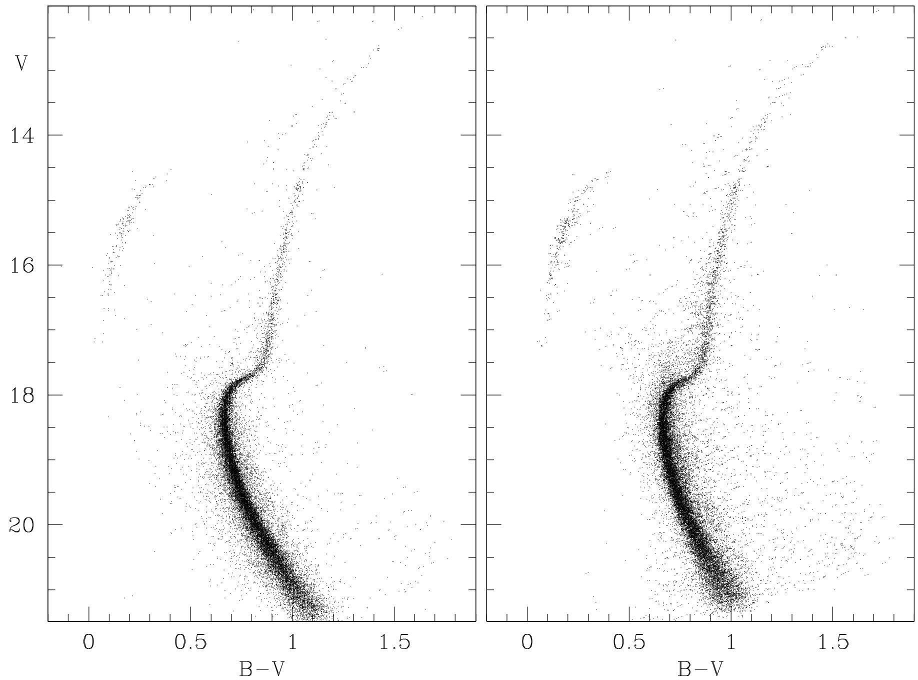

Fig. 2. CMDs of M12 based on the data from the du Pont telescope (*left*) and the Swope telescope (*right*).

2.2. Search for Variables

The search for variable stars was conducted using the AOV and AOVTRANS algorithms implemented in the TATRY code (Schwarzenberg-Czerny 1996, Schwarzenberg-Czerny and Beaulieu 2006). We examined the du Pont light curves of 27 586 stars with $V < 21.5$ mag and the Swope light curves of 23 265 stars with $V < 20$ mag. The limits of detectable variability depended on the accuracy of photometric measurements, which for the du Pont data decreased from 3 mmag at $V = 16$ mag to 30 mmag at $V = 20$ mag and 100 mmag at $V = 21.5$ mag (Fig. 1). For the Swope data the accuracy decreased from 5 mmag at $V = 15$ mag to 50 mmag at $V = 19$ mag and 100 mmag at $V = 20$ mag.

3. The Variable Stars

We detected 33 certain and three suspect variable stars, of which 20 have photometry from both telescopes. Only two of these had been known previously, the two W UMa systems discovered by von Braun *et al.* (2002). Fig. 3 presents finding

[‡]*http://case.camk.edu.pl/*

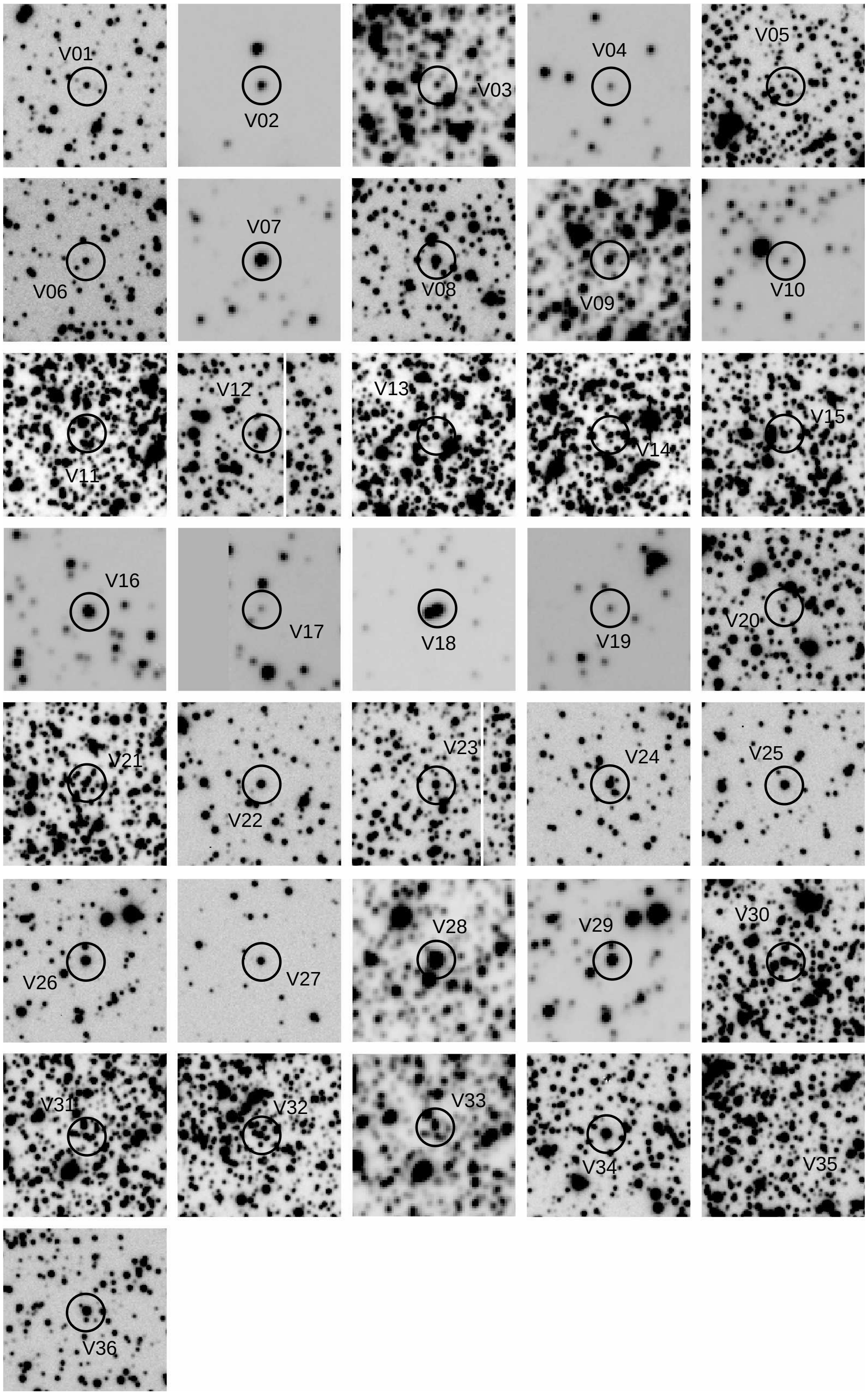

Fig. 3. Finding charts for the variable stars. Each chart is 30″ on a side; North is up and East to the left.

charts for all 36 variables. Basic properties of these variables are listed in Table 1. The equatorial coordinates in Table 1 conform to the UCAC4 system (Zacharias *et al.* 2013), and are accurate to about $0\overset{\prime\prime}{.}2$. We checked that none of our variables coincides with any X-ray source from the list of Lu *et al.* (2009) or with the UV source discovered by Schiavon *et al.* (2012).

The *V*-magnitudes listed in Table 1 correspond to the maximum light in the case of eclipsing binaries, while for the remaining variables average magnitudes are provided. For each variable the $B-V$ color is given, followed by the amplitude in the *V*-band. Periods of variability were found for all stars except two eclipsing binaries, for which parts of single eclipses only were observed. Some light curves show phase shifts and/or change shape from season to season. In these cases we give periods obtained for the indicated season. The last column of Table 1 gives the membership status based on proper motions (PM) taken from Zloczewski *et al.* (2012) and Narloch *et al.* (in preparation). Phased light curves of the variables from Table 1 are presented in Figs. 4–6.

A CMD of the cluster with the locations of the variables is shown in Fig. 7. This diagram is based on the du Pont photometry, and it only includes stars classified by Zloczewski *et al.* (2012) as PM members of M12. Variables that are PM members of M12 are labeled in red, those with PM indicating that they are field objects in blue, and those for which the PM data are missing or ambiguous in black. The exception is V11 for which we have no PM data. We attribute to it a legitimate cluster membership based on our as yet unpublished radial velocity measurements.

3.1. Detached Eclipsing Binaries

We detected 11 detached eclipsing binaries, of which six are proper motion members of the cluster. Systems V10 and V11 are located at the turnoff region. With orbital periods amounting to 4.6 d and 5.2 d, respectively, they are interesting targets for a detailed follow up study aiming at the determination of their absolute parameters, and the age and distance of M12. We are presently conducting such an analysis for V11. The systemic velocity of this binary, equal to -44.4 km/s, differs by less than 10% from the systemic velocity of M12 listed by Harris (1996, 2010 edition). This, together with its location at a distance of $15''$ (*i.e.*, 0.32 core radii) from the center of the cluster leaves little doubt about its membership. It is somewhat surprising that V11 has a markedly eccentric orbit ($\varepsilon \approx 0.1$) despite a relatively short period. At an age above 13 Gyr (Dotter *et al.* 2010), it should have been fully circularized by tidal friction (Mazeh 2008, Mathieu *et al.* 2004). Since we found no indication for a third body in this system, we speculate that the orbit of V11 was distorted during the last few Gyr as a result of a close encounter.

The light curve of V10 shows two partial eclipses of similar depth (≈ 0.35 mag in *V*). As a result, the photometric solution is likely to be degenerate, allowing for a broad range of relative radii. Such a degeneracy may be overcome by the determination of the light ratio from spectra, but this will be difficult given the

Table 1

Basic data of M12 variables identified within the present survey*

Id	RA [deg]	DEC [deg]	V [mag]	$B-V$ [mag]	ΔV [mag]	Period [d]	Remarks[a]	Mem[b]
V01	251.84545	−1.92666	18.93	0.72	0.25	0.243185	EW	Y
V02	251.88581	−2.05289	18.31	1.18	0.12	0.252125	EW	N
V03	251.80287	−1.95726	17.86	0.72	0.08	0.210636	EW	Y
V04	251.90221	−1.91481	19.45	1.18	0.46	0.233990	EW	N
V05	251.79329	−1.93622	18.71	0.67	0.13	0.225502	EW	U
V06	251.83856	−1.91462	18.80	0.74	0.34	0.256196	EW	Y
V07	251.72871	−1.99055	16.65	1.06	0.07	0.257078	EW	N
V08	251.83855	−1.95674	16.48	0.35	0.07	0.435135	EW/Ell,BS	Y
V09	251.82010	−1.94197	17.12	0.77	0.03	0.444540	EW/Ell	U
V10	251.77274	−1.99331	19.06	0.71	0.34	4.595098	EA	Y
V11	251.81257	−1.95160	18.26	0.72	0.36	5.218589	EA	Y
V12	251.82194	−1.92852	16.09	0.37	0.10	1.025114	EA,BS	Y
V13	251.81159	−1.94571	17.07	0.47	0.26	0.734141	EA,BS	Y
V14	251.80630	−1.95057	17.58	0.54	0.62	0.463846	EA/EB,BS	Y
V15	251.80844	−1.94113	17.13	0.38	0.16	0.541709	EA,BS	U
V16	251.86936	−1.92680	17.30	0.83	0.45	2.500325	EA	N
V17	251.83190	−1.86607	20.00	1.30	0.82	2.279741	EA	U
V18	251.71477	−1.95946	16.46	0.90	0.65	17.47090	EA	N
V19	251.73301	−2.00912	19.64	0.83	0.97	–	EA	Y
V20	251.83532	−1.95287	19.72	0.75	0.62	–	EA	U
V21	251.80641	−1.94114	17.11	0.41	0.06	0.019636	SX,BS	Y
V22	251.84708	−1.92796	17.25	0.46	0.05	0.034364	SX,BS	Y
V23	251.82202	−1.96167	16.70	0.41	0.08	0.044294	SX,BS	Y
V24	251.80911	−1.89787	17.20	0.48	0.08	0.045042	SX,BS	Y
V25	251.76203	−1.96051	17.02	0.55	0.17	0.049034	SX,BS	Y
V26	251.80863	−1.99363	16.57	0.83	0.12	1.843644[c]	Sp?	Y
V27	251.84428	−2.01776	17.89	1.12	0.44	11.36074[c]	Sp?,RG?	N
V28	251.81727	−1.93884	13.85	1.00	0.04	0.949850[c]	Sp?	Y
V29	251.80863	−1.99363	16.58	0.75	0.10	1.842144[c]	Sp?	Y
V30	251.81196	−1.93522	16.39	0.50	0.03	0.400692	Ell?,BS	Y
V31	251.81356	−1.95517	17.61	0.44	0.08	0.405218	Ell?,BS	U
V32	251.80431	−1.95410	17.23	0.55	0.07	0.499084	Ell?	U
V33	251.81356	−1.95518	17.53	0.47	0.09	0.682552	Ell?,BS	Y
V34	251.80367	−1.96689	19.55	0.81	0.41	0.352252	Sp?	U
V35	251.80112	−1.95547	17.95	0.63	0.07	0.962294	Ell?	U
V36	251.77580	−1.95956	16.81	0.82	0.02	0.774844	Ell?	Y

*We follow the naming convention of von Braun *et al.* (2002), who are the discoverers of the first two variables listed in the table. Their variable V1 is not the W Vir pulsator referred to as V1 by Clement *et al.* (1988).

[a]EA – detached eclipsing binary, EB – close eclipsing binary, EW – contact eclipsing binary, SX – SX Phe type pulsator, Sp – spotted variable, BS – blue straggler, Ell – ellipsoidal variable, RG – red giant.

[b]Y – member, N – non-member, U – no data or data ambiguous

[c]For the 2001 season.

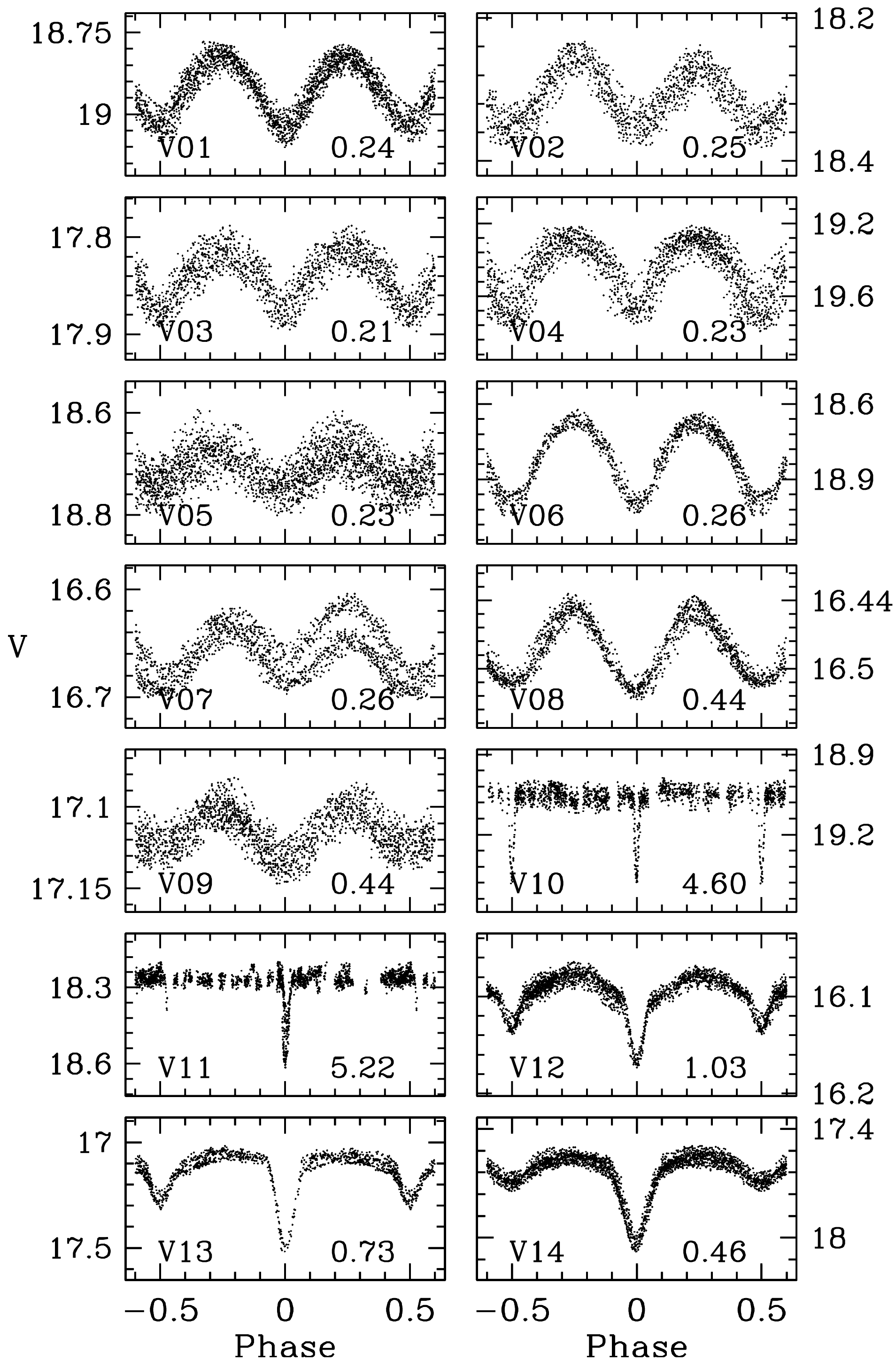

Fig. 4. Phased *V* curves of variables detected in the field of M12. Inserted labels give star ID and period in days.

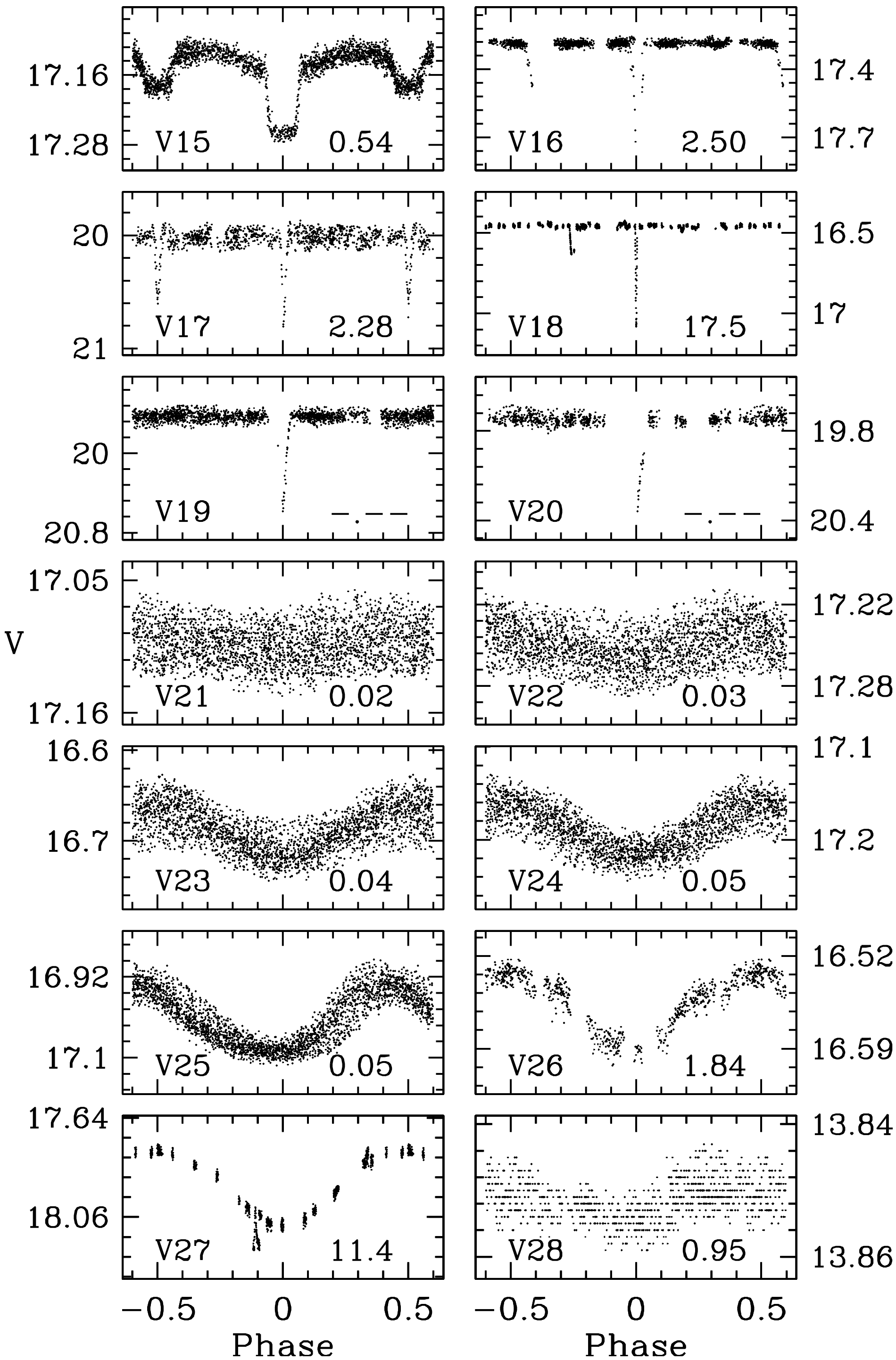

Fig. 5. Same as Fig. 4.

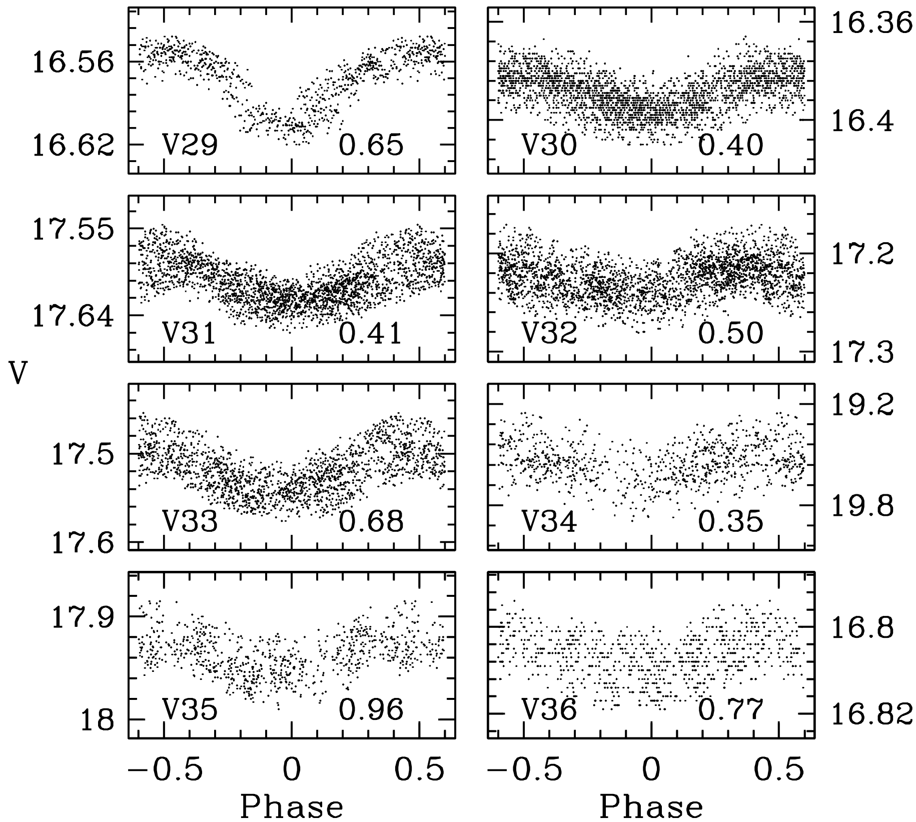

Fig. 6. Same as Fig. 4.

faintness of the system. A much deeper eclipse (≈ 0.95 mag in *V*) was partly observed in V19. As this binary is still fainter than V10, a really large observational effort would be required to collect enough data for an accurate analysis. The same argument concerns V20, for which an eclipse at least 0.6 mag deep in *V* was partly observed. The PM-membership is unclear for this binary, however its location on the main sequence of the cluster and at the edge of the cluster's core ($62''$ from the center) both suggest that it does belong to M12.

A potentially very interesting object is the eclipsing binary V16. We marked it as a non-member in Fig. 7, however it almost meets the membership criterion employed by Zloczewski *et al.* (2012). It is located on the lower red giant branch of M12, $3\farcm8$ (*i.e.*, ≈ 2 half-light radii) away from the center of the cluster. Since we observed only three largely incomplete eclipses, the period of 2.5 d given in Table 1 is a tentative one only, and the eccentricity visible in Fig. 5 may be spurious. If this bright and well-isolated system turns out to be a member of M12, it will provide tight limits for age and distance of the cluster. V18 seems to be even more promising: based on its location on the red giant branch one might expect it to deliver more precise data than V16 which is by ≈ 1 mag fainter. Unfortunately, the

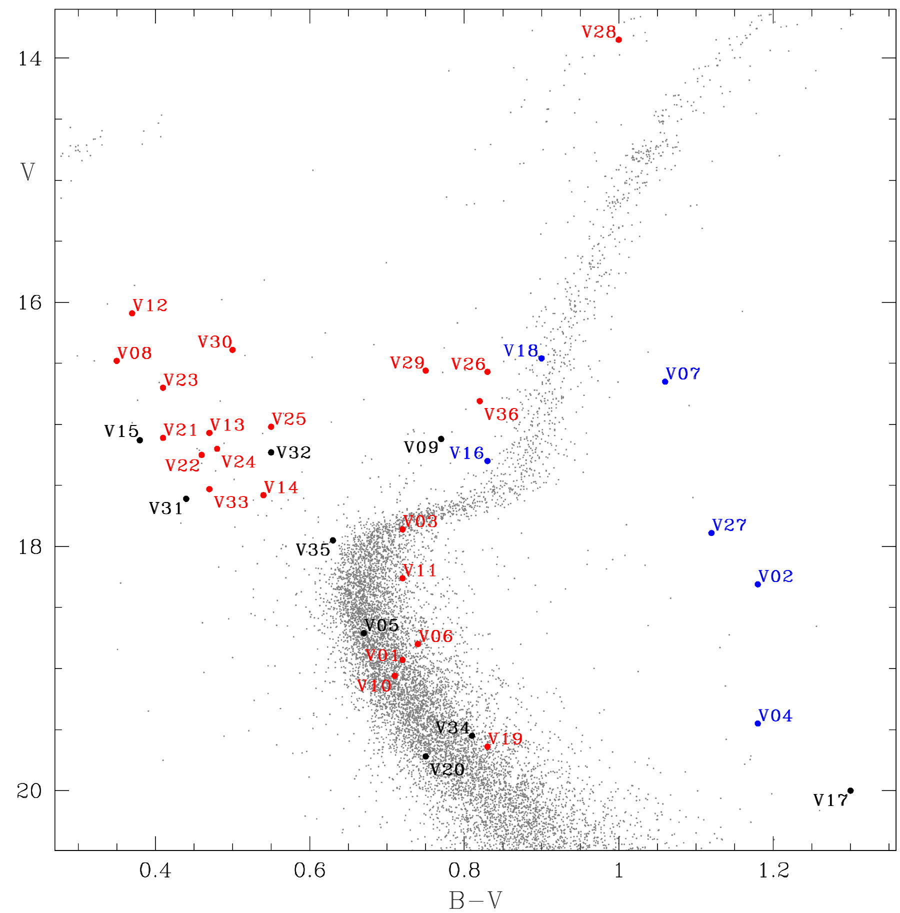

Fig. 7. Color–magnitude diagram for M12 with indicated locations of the variables. Red, blue and black labels denote, respectively, members, non-members and objects for which the membership data are missing or ambiguous.

proper motion of this system proves that we are dealing with a nearby binary which quickly (≈ 14 mas/yr) moves across the M12 field. The PM-membership status of V17 is ambiguous, but its location far to the right of the unevolved main sequence of M12 indicates that it is a field object – probably a pair of nearby red dwarfs.

Variables V12, V13, V14, V15 are located in the blue straggler region between the turnoff and the horizontal branch. The first three of these are cluster members with periods of 1.03 d, 0.73 d and 0.46 d, respectively, and light curves ranging from EA with proximity effect in V12 to EB-like in V14. Well defined moments of contact, together with straight ingress and egress branches of the primary minimum, suggest that they are detached rather than semi-detached. The PM-data for V15 are ambiguous: Zloczewski *et al.* (2012) classify it as a probable member, while Narloch *et al.* (in preparation) as a non-member. However, both its position on the CMD and its location in the field of view ($24''$, *i.e.*, 0.3 core radii from the center of M12) suggest that this system also belongs to the cluster. An additional support for the membership of V15 comes from its nature. Short period (0.54 d), moderate proximity effect and narrow total eclipses with different depths indicate a system with low mass ratio and small secondary which is much hotter than the primary (thus, in the present configuration of the system the main minimum is due to the eclipse of the secondary). Preliminary modeling with the PHOEBE facility (Prša and Zwitter 2005) yields $q \approx 0.1$, $T_p \approx 7500$ K, $T_s \approx 12000$ K, and $R_s/R_p \approx 0.15$. Apparently, the secondary has lost most of its H-rich envelope to the primary, thus conforming to one of the scenarios of the origin of blue straggler stars.

The secondary minima of V12, V13 and V14 are much shallower than the primary minima, likely because of low mass ratios. We suggest that these too have experienced significant mass-transfer episodes. A detailed study of the whole quartet would certainly deliver valuable information concerning the nature and evolution of blue straggler stars.

3.2. Contact Binaries

We identified nine variables with W UMa-type light curves, of which four are PM-members of the cluster, and another three are field interlopers. PM data for the remaining two systems are absent or not accurate enough to evaluate membership probability. Small amplitudes of V08 and V09 suggest that we may deal with elliptical variables rather than genuine contact binaries. Spectroscopical data are needed to resolve this ambiguity. Kaluzny *et al.* (2014) found a general paucity of contact systems on the unevolved main sequences of globular clusters. M12 perfectly conforms to this rule: PM-members V01, V03 and V06 and the suspected PM-member V05 reside in the turnoff region while another PM-member, V08, is a blue straggler. Thus we add to the growing evidence that, at least in globular clusters, the principal factor enabling contact systems to form from close but detached binaries is nuclear evolution: a contact configuration is achieved once the more massive component starts to expand quickly at the turnoff. Apparently, nuclear evolution is more important in this respect than the frequently invoked magnetic breaking; see *e.g.,* Stępień and Gazeas (2012) and references therein.

The binary V09 is a yellow straggler candidate. Based on the available data, its PM-membership cannot be firmly established. The empirical calibration of Rucinski (2000) yields a distance modulus by 0.7 mag smaller than that given by Harris (1996, 2010 edition) for M12. Given the large spread of the calibration, this is also an ambiguous result. However, V09 resides only $42''$ away (0.6 core radii) from the center of M12, and it may well be a cluster member. Since yellow stragglers are rather rare objects, it deserves further study aimed at clarifying its membership and evolutionary status. We note in passing that the periods of all above mentioned W UMa stars except V08 and V09 are shorter than 0.26 d, *i.e.,* they are exceptionally short even for contact systems in globular clusters (Rucinski and Pribulla 2008). Among these, V03 with $P = 0.210636$ d seems to be the new record holder.

3.3. Variable Stars among Blue Stragglers

The CMD based on the du Pont data contains 103 candidate blue stragglers with $16.0 < V < 17.7$ mag and $0.23 < B-V < 0.70$ mag. Of these 42 are proper motion members of M12, four are field stars, and for 57 objects no PM data are available. Of the latter 45 are located within two core radii from the center of the cluster and are likely members. In addition to the five eclipsing binaries described in Sections 3.1 and 3.2, nine variables were found among the stragglers, seven of which are confirmed and another two suspected members of the cluster. Five of these are SX Phe pulsators with periods ranging from 0.019 d to 0.049 d. The star with the longest period, V25, has the largest amplitude (≈ 0.2 mag in *V*) and a light curve characteristic of multimodal pulsations. Unfortunately, the photometry is not good enough to enable a period analysis. Stars V30–V33 exhibit more or less sinusoidal luminosity variations whose nature is difficult to establish. Doubling their periods makes their light curves resemble those of W UMa variables. However in that case the light curves of V30 and V31 become less regular, whereas for V32 and V33 the periods themselves grow too long for contact binaries (Rucinski 2007).

3.4. Remaining Objects

V26, V29 and V36 are members of M12 located in the yellow straggler region, and as such they should be paid particular attention in future studies. V26 exhibits sinusoidal variations with $P = 1.84$ d whose phase and amplitude vary from season to season. Fig. 5 shows data from our best season (2001), in which almost 650 frames were collected during 16 nights. V29 showed clear sinusoidal variation in 2001 only, with two possible periods of 0.647 d and 1.847 d. V36 is a suspected variable with a very noisy light curve and amplitude of only ≈ 0.02 mag. Another M12 member, V28, is located slightly below the asymptotic giant branch. Regular variations, perhaps the due to spots on the surface of a faint companion, were observed in 2001 only. The field object V27 is a flare star exhibiting sinusoidal variations with $P = 11.4$ d whose phase amplitude and average magnitude vary from season to season. Before 2001 the star faded from 17.75 mag to 18.15 mag in *V*. On June 3, 2001 a complete flare was observed: the brightness smoothly increased by 0.2 mag in 1.2 h, and within the next 4 h it returned to the pre-flare level. Five days later regular variations were again dominating, with mean brightness 17.9 mag, amplitude ≈ 0.3 mag, and the same period as before the flare. The flare itself is visible in Fig. 5 as a thin spike at phase 0.4. The nature of the periodic variation is unclear – spectroscopic observations are necessary to discriminate between rotation and orbital motion of V27. The membership of suspected variables V34 and V35 is unclear. Both these objects seem to exhibit roughly sinusoidal variations with $P = 0.35$ d and $P = 0.96$ d, respectively.

4. Summary

We have conducted an extensive photometric survey of the globular cluster M12 in a search for variable stars. A total of 31 variables plus three suspected variables were discovered, and multi seasonal light curves were compiled for another two W UMa type eclipsing binaries that had been known before. For all variables periods accurate to 0.00001–0.001 d were obtained. Seven eclipsing binaries and five pulsating stars (all of them PM-members of the cluster) were found in the blue-straggler region. Four of the binaries are likely to have low mass ratios, most probably due to mass-transfer episodes. Their detailed analysis should deliver very valuable information concerning nature and evolution of blue stragglers. Yellow stragglers are represented in our sample by three PM-members of M12 whose nature is unclear and one W UMa system being a suspected PM-member. Since yellow stragglers are even more rare and interesting than the blue stragglers, these two systems should be paid close attention during future observations. Two detached eclipsing binaries belonging to the cluster were identified in the turnoff region, and another one at the lower main sequence. A potentially very valuable discovery is the detached eclipsing binary V16 residing on the lower red giant branch. If this bright and well isolated object turns out to be a member of M12, it will provide tight limits on the age and distance of the cluster.

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Appendix: Color Gradient

In some GC color gradients have been observed. Roediger *et al.* (2014) listed six such clusters. Since that sample does not include M12, we thought it worthwhile to search for radial variations of the colors in our data. The search was limited to du Pont frames, a few of which were taken in *U*-band. Only PM-members of M12 with $V < 19.5$ mag and color errors smaller than 0.015 mag were included. The field of view was divided into three concentric subfields centered on the center of the cluster, with $0 \le r \le 2\farcm36$, $2\farcm36 < r < 3\farcm74$ and $r \ge 3\farcm74$, respectively. Each subfield contained almost 500 stars. Weighted means of $\overline{B-V}$ and $\overline{U-V}$ colors were calculated separately for giants and HB stars ($V < 17.5$ mag), subgiants ($17.5 \le V < 18.0$ mag), and dwarfs ($V \ge 18$ mag). No clear dependence of $\overline{B-V}$ of r was found in any of the luminosity classes. The same negative result was obtained for $\overline{U-V}$ for giants or subgiants. A clear, albeit weak, dependence emerged only in the case of the $U-V$ color for main sequence stars, with $\overline{U-V}$ increasing from 1.1002 ± 0.0009 mag in the central circle through 1.1142 ± 0.0009 mag in the intermediate ring to 1.1331 ± 0.0008 mag in the outer region. This radial trend is convincingly illustrated by the histograms shown in Fig. 8. We attribute this result at least partly to the relative underabundance of faint red main-sequence stars discovered by De Marchi *et al.* (2006) near the cluster center.

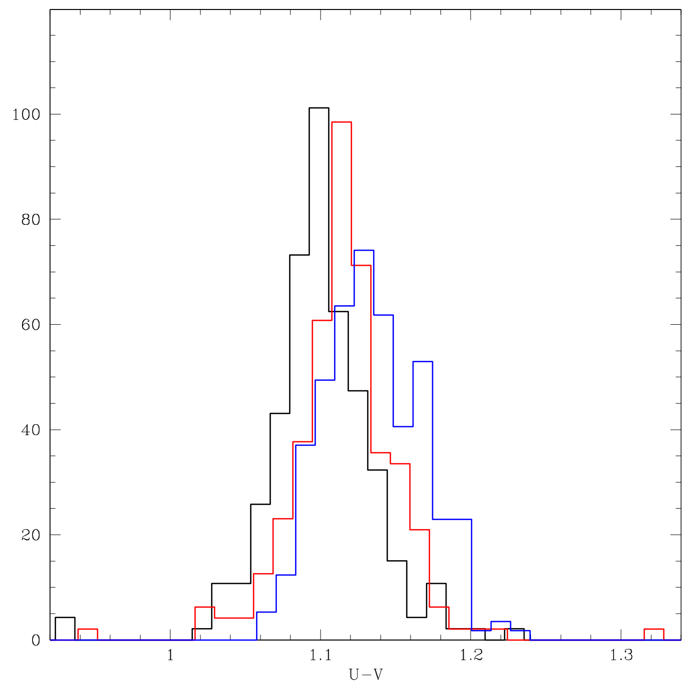

Fig. 8. Histogram of $U-V$ indices of M12 PM-members. Main sequence stars with $18 < V < 19.5$ mag are only shown, and the normalization is arbitrary. Black: central circle $0 \le r \le 2\farcm36$; red: intermediate ring $2\farcm36 < r < 3\farcm74$; blue: outer region $r \ge 3\farcm74$.