

NEW VARIABLE STARS IN THE FIELD OF OPEN CLUSTER NGC188

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Abstract: A photometric study of variable stars in the field of old open cluster NGC 188 is discussed. Observations were carried out in two bands R and I for 5513 stars up to $R = 17^m$ in the field of $1.5 \times 1.5^\circ$ around the cluster. The photometric data were processed by the console application "Astrokit", which corrects brightness variations associated with the variability of atmospheric transparency and carries out searching for variable stars. We found 18 new variable stars and determined the parameters of one previously known variable. Among discovered stars one is a low-amplitude pulsating variable, one is a EW eclipsing binary, six are eclipsing variables of EA type, five objects are long period variables, and for five stars variability type remains uncertain.

1 Introduction

Study of variable stars makes a major contribution to our knowledge of structure and evolution of stars and stellar systems. Variable stars provide a unique opportunity to determine many important characteristics, either of the stars themselves (size, mass, luminosity) or of the structure of the Galaxy (stellar population analysis). Study of variable stars in clusters is of particular importance because of two main reasons: (1) the information about distance and age of cluster can be improved using some types of variable stars like Cepheids; (2) we can determine age, distance and evolutionary stage of variable stars, which belong to clusters with known distance and age.

NGC 188 (RA2000 = $00^h47^m28^s$, Dec2000 = $+85^\circ15'18''$) is well-studied cluster, what is confirmed by the large number of articles (over 500 in the last 50 years). Fornal et al. (2007) give an adequate review of studies of the cluster fundamental parameters in last 45 years. The median values of these parameters are taken from tab. 1 of Fornal et al. (2007): true distance modulus $11^m.25$, corresponding to the distance 1660 pc, Age= 7 Gyr, reddening $E(B-V) = 0^m.09$ and metallicity $[Fe/H] = 0$. The cluster was studied in a wide range of wavelengths from infrared to X-ray (see e.g. Bonatto et al. (2005), Eggen and Sandage (1969), Janes (1979), Sarajedini et al. (1999), McClure (1974), Twarog et al. (1997), Gondoin (2005)). Platais et al. (2003) compiled a catalogue of positions and proper motions of 7812 stars brighter $V = 21^m$ in the field of 0.72 deg^2 around the cluster center. There are several papers devoted to the search and study of variable stars in the central part of the cluster (Kaluzny and Shara (1987), Zhang et al. (2002, 2004), Kafka and Honeycutt (2003), Mochejska et al. (2008)). In 2004 Stetson et al. published the photometric catalogue for a few thousand of cluster stars. We used this data (Stetson et al. (2004)) as a photometric standard for transformation of instrumental system of our telescope to standard bands. Previously unknown variable stars have been found during the execution of this work. They are discussed in this paper.

2 Observations and Data Reduction

Photometric observations of open cluster NGC 188 were performed in March 2011 in the Astronomical observatory of Ural Federal University. We used MASTER series robotic telescope (Lipunov et al. (2010)). The telescope has two parallel mounted identical tubes of the Hamiltonian system with a diameter of 40 cm and the focal length of 100 cm. Apogee Alta U16M 4096x4096 Peltier-cooled CCD with a pixel size of $9 \times 9 \mu\text{m}$ is installed in the main focus of each tube. Image scale is $1.85 \text{ arcsec pixel}^{-1}$ and field of view is $2 \times 2^\circ$ (see fig. 1). The telescope is equipped with Johnson-Cousins *BVRI* filters. Two tubes allow to observe the same object in two filters simultaneously. The observations were carried out during the period from 11 to 19 March 2011 during 5 nights. Full list of observational nights, used filters and exposure time (TE) are given in the tab. 1. The average seeing was $5''$. Flat field frames were obtained from the twilight sky.

Table 1: Journal of observations

Date	<i>R</i>	<i>I</i>	TE, sec.
11.03.11	53	27	180
14.03.11	37	65	180
17.03.11	45	45	180
18.03.11	21	62	180
19.03.11	51	15	180
Total	207	214	

The obtained data were processed with IRAF V2.14. software package (Tody (1986)). Processing includes the initial photometric reduction, astrometric reduction and aperture photometry. The initial reduction consists of removing overscan, subtraction of dark frames and division by normalized flat frames. Astrometric reduction was made with IRAF/images/imcoords. Tycho-2 catalogue (Hog et al. (2000)) was used as a reference catalogue. To carry out aperture photometry we used list of equatorial coordinates for stars obtained from the best frame. So the same star in all frames in all filters had the same ID and further processing of the photometric data became easier. The aperture photometry was carried out simultaneously for all stars from the list on all frames with the same aperture. The diameter of aperture was equal to 3 pixels ($6''$). Sky background was measured in a ring with width of 5 pixels ($10''$) and inner radius of 7 pixels ($14''$). Photometry for 5513 stars in the range of magnitudes from 11 to 17 with a corresponding accuracy from 0.006 to 0.05 mag (in band *R*) was carried out in field of $90 \times 90'$. Fig. 2 shows the standard deviation of the magnitude versus the magnitude for the bands *R* (left) and *I* (right).

To get and to correct the average magnitudes we used a console application "Astrokit"¹ written by two of us (Krushinsky V. and Burdanov A.) on the basis of modified algorithm of Everett and Howell (2001). This application allows to correct brightness variations associated with the variability of atmospheric transparency and carries out searching for variable stars with the RoMS algorithm of Rose and Hintz (2007). "Astrokit" allows to process a large number of objects simultaneously in an automatic mode. To convert the instrumental magnitudes to the standard ones we took photometric data obtained previously for this area by Stetson et al. (2004). We used linear equations 1 with coefficients

¹The code is available by request to burdanov.art@gmail.com

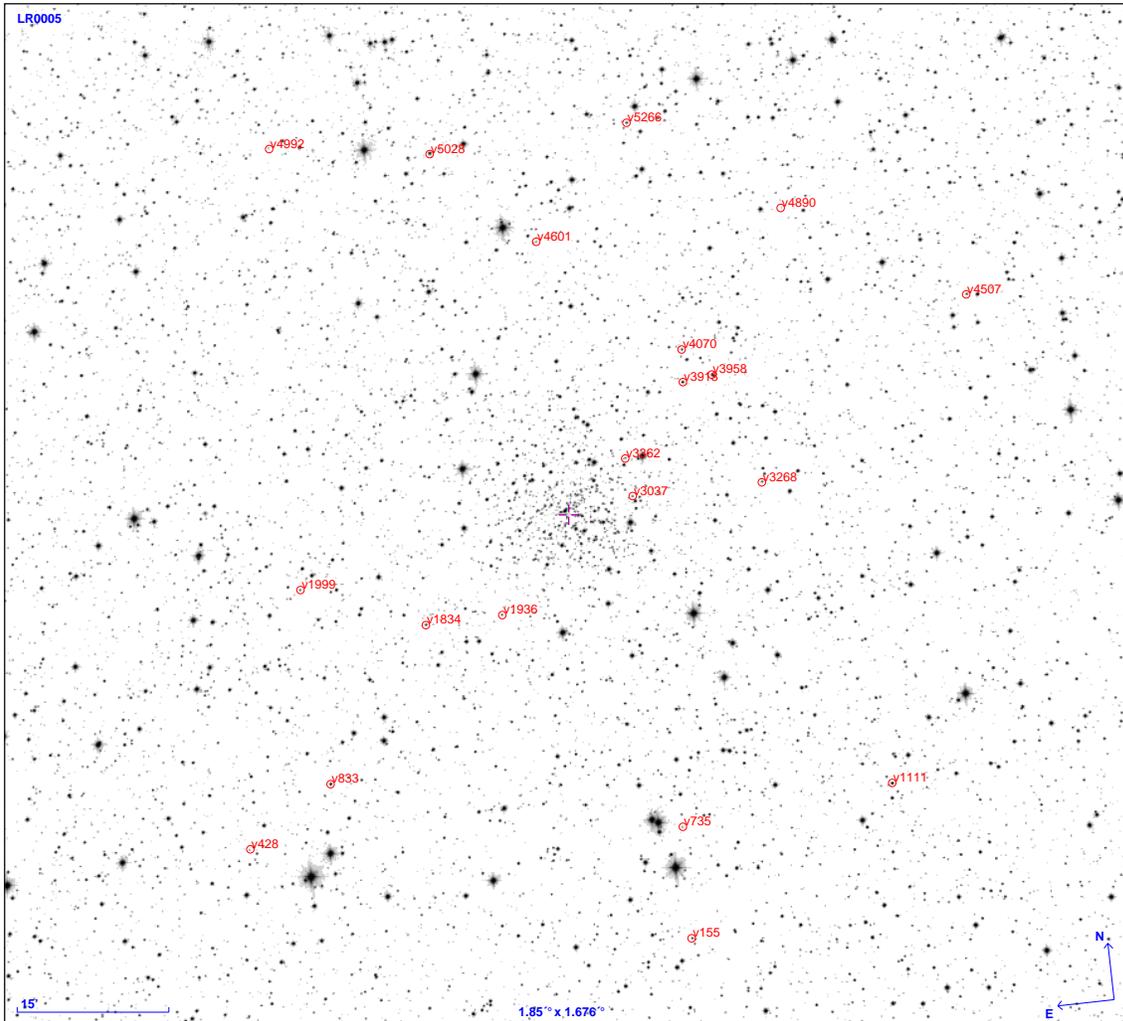


Figure 1: Observed field of open cluster NGC 188. The abscissa is a right ascension, the ordinate is a declination. Red circles denote variable stars studied in this work. This image was made using Aladin software (Bonnarel et al. (2000))

estimated by least squares method for 790 common stars.

$$\begin{aligned} R - I &= 0.832(r - i) + 0.719, & \sigma &= 0.022, \\ R - r &= -0.163(R - I) - 0.252, & \sigma &= 0.036, \end{aligned} \quad (1)$$

where R and I are standard magnitudes, r and i are instrumental magnitudes, σ is standard deviation of conversion. Our photometric data are in good agreement with the results obtained by Sarajedini et al. (1999). The difference between our data and Sarajedini is $\Delta(R - I) = 0^m.009 \pm 0^m.027$, $\Delta R = 0^m.038 \pm 0^m.058$, individual residuals are shown in fig. 3.

3 Variable stars

Kafka and Honeycutt (2003) reported about 51 variable stars in the field of NGC 188, only three of them were previously known. However Mochejska et al. (2008) identified 32

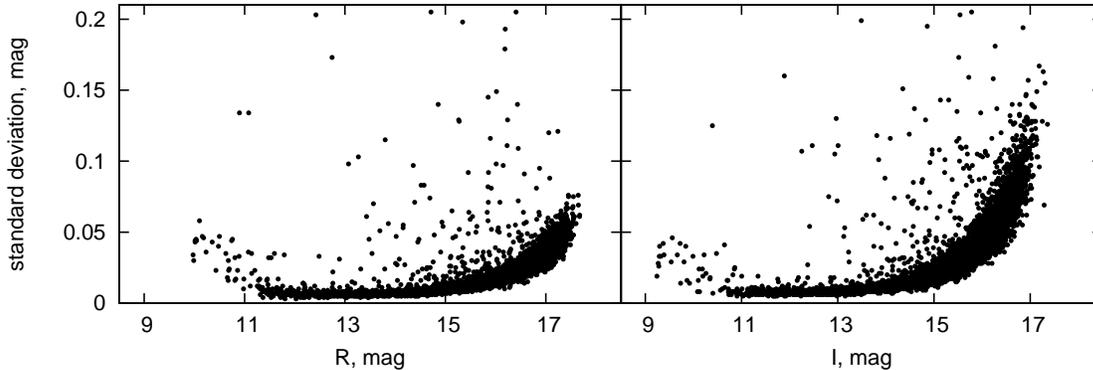


Figure 2: The dependence of the standard deviation of the magnitude for the bands R (left) and I (right)

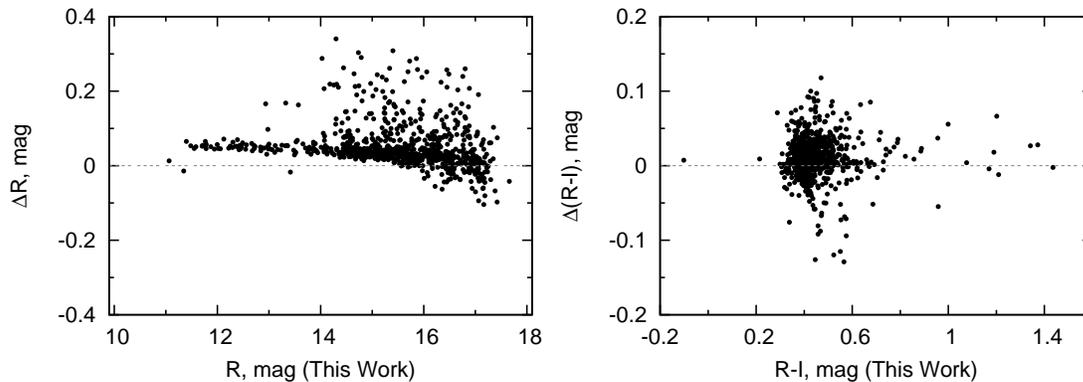


Figure 3: $\Delta R = R_{Sarajedini} - R_{our}$, $\Delta(R-I) = (R-I)_{Sarajedini} - (R-I)_{our}$

stars out of these 48 variables and only for one they found brightness variations.

Today 58 variable stars are known within 2° radius around NGC 188 according to the electronic catalogue of the American Association of Variable Star Observers (AAVSO/VSX). We didn't investigate the known variable stars if our data neither contradict to the previous one nor clarify them. So we refined the parameters for one previously known variable and discovered 18 new ones. Tab. 2 shows the parameters of the studied variable stars. The table contains the identification number (ID) of the star in our list, 2MASS identification number (Skrutskie et al. (2006)), the equatorial coordinates, the observed maximum and minimum magnitudes in the filters R and I (whenever it is possible), the variability type, the ephemeris (if it can be determined from our data) and the probability of membership (MP) in the cluster. The estimates of the membership probability are taken from Platais et al. (2003). Positions in cluster color-magnitude diagram (CMD) of all discovered variables relative to the average NGC 188 sequence of Stetson et al. (2004) are shown in fig. 4. We use this positions for some speculations about membership for our variables hereinafter, because we didn't determine properly which of our stars are really members of NGC 188. Times of minima were obtained with Kwee and van Woerden's (1956) method in "AVE"² software when our data allow such determination. Derived values for one or both filters are listed in tab. 3. To estimate the periods of variable stars

²<http://www.astrogea.org/soft/ave/aveint.htm>

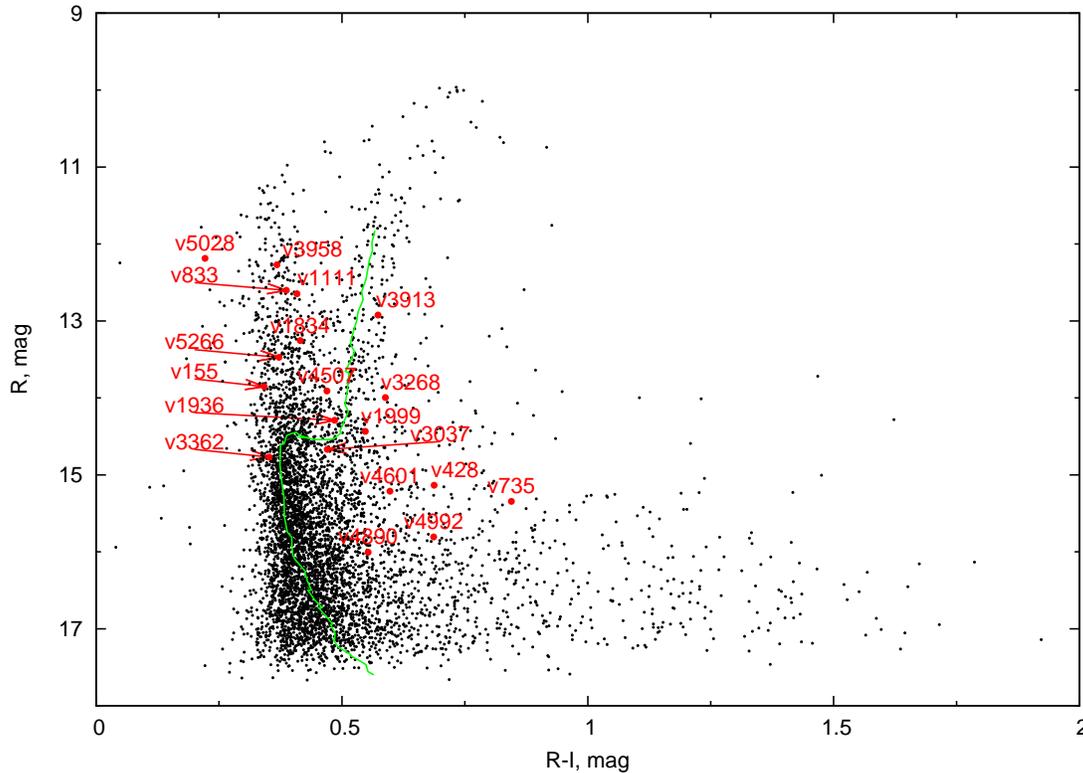


Figure 4: Color-magnitude diagram of NGC 188 based on our photometric data. The red circles denote new variable stars. The solid green line corresponds to an average cluster sequence by Stetson et al. (2004)

we used the "Winefk"³ software which realises the method of periodogram analysis. The software was developed by Goransky V. P. We managed to find periods only for seven variables from our list.

For classification of some discovered variable stars we used the additional photometric data from the 2MASS catalogue, since the infrared interstellar extinction is minimal. Pickles (1998) gives the values of the spectral type and corresponding color indices. We estimated approximate spectral classes for discovered variables using three color indices (R-I)_c, (J-H) and (H-K), which are listed in column 5 of tab. 4. We calculated upper limits of the distances for stars based on their proper motions from the catalogue PPMX (Roeser et al. (2008)) using the equation

$$Dist_{\mu} = Vt/4.74\sqrt{(\mu_{\alpha}^2 + \mu_{\delta}^2)}, \quad (2)$$

where Vt is 200 km/s (mean speed of stars in the Galaxy disk). Derived values are given in column 6 of tab. 4. In accordance with the size of the Galaxy the distance does not exceed 15 kpc.

Lower limit of the distances was obtained under the assumption that all our variables are the main sequence stars. We calculated the distances using the absolute magnitudes in the band J (M_j) for the main sequence stars of different spectral types given by Pickles (1998).

³<http://vgoray.front.ru/software/>

Table 2: Parameters of new variable stars

ID	2MASS	α_{2000}			δ_{2000}			R, mag			I, mag			Type	Ephemeris JD-2455000	MP %
		h	m	s	°	'	''	max	minI	minII	max	minI	minII			
v155	00365525+8433366	00	36	55	+84	33	36	13.853	14.018	13.99	13.436	13.604	13.573	EW	640.2628+0.3518E	
v428	01081272+8438061	01	08	12	+84	38	06	14.971	15.675	15.552	14.382	15.039	14.952	EB	632.2605+0.3077E	
v735	00375107+8444311	00	37	51	+84	44	31	15.294	15.478		14.455	14.554		VAR		
v833	01031463+8445435	01	03	14	+84	45	43	12.669	12.695		12.196	12.219		EA:		
v1111	00224443+8448486	00	22	44	+84	48	48	12.706	12.914		12.130	12.351		VAR		
v1834	00574795+8502290	00	57	47	+85	02	29	13.267	13.346		12.794	12.867		VAR	638.2537+0.8416E	0
v1936	00520870+8504146	00	52	08	+85	04	14	14.357			14.894			EA		0
v1999	01073954+8504072	01	07	39	+85	04	07	14.450	14.616		13.787	13.922		L:		
v3037	00424049+8516494	00	42	40	+85	16	49	14.731	14.851		14.151	14.256		LB		98
v3268	00322120+8518390	00	32	21	+85	18	38	13.914	14.083		13.255	13.409		L:		34
v3362	00432396+8520325	00	43	23	+85	20	32	14.784	14.863		14.365	14.439		VAR	632.3285+0.3102E	93
v3913	00390088+8528154	00	39	00	+85	28	15	12.989	13.052		12.336	12.381		L:		39
v3958	00363416+8529046	00	36	34	+85	29	04	12.336	12.360		11.891	11.920		EA		0
v4507	00145705+8536311	00	14	57	+85	36	31	13.870	13.991		13.359	13.471		LB		
v4601	00521410+8541065	00	52	14	+85	41	06	15.226	15.342		14.558	14.662		VAR	640.5000+2.2555E	0
v4890	00305224+8545368	00	30	52	+85	45	36	15.978	16.363		15.433			EA		
v4992	01164582+8546202	01	16	45	+85	46	20	15.889	16.601		15.111	15.884		EA	635.3397+0.4017E	
v5028	01022872+8548314	01	02	28	+85	48	31	12.245	12.281		11.947	11.975		δ Sct/ β Cep	635.2187+0.0665E	
v5266	00450068+8553285	00	45	00	+85	53	28	13.545			13.093	13.268		EA		

$$Dist_Mj_V = d_0 10^{((J-Mj)/5)}, \tag{3}$$

where d_0 is 10 pc. These values are given in column 7 of table 4.

Comparing the distances computed by two methods we can say that all the studied stars are not closer than 200 pc. Further we suggested that all our stars are subgiants and estimated the new values of distances to the stars Dist_Mj_IV using the eq. 3 again. As a result the distances Dist_Mj_IV to the stars ID v735, v4601 and v4992 appear to be larger than $Dist_\mu$. Therefore we can suggest that variables with ID v735, v4601 and v4992 are the main sequence stars indeed. Additionally in the same way we estimated the distances to the variables in cases they are giants and supergiants. If new value of distance derived for some star is larger than $Dist_\mu$ then this star couldn't be giant or supergiant respectively. The final values of luminosity classes are listed in column 8 of tab. 4.

Such estimation allows us to specify not only spectral types for our variables but roughly determine the location of each variable on the CMD. Moreover estimates of spectral type and distance from photometric data are useful when variability types are defined.

Observations and results for each star are discussed in the next section.

4 Discussion

v155

The light curve of v155 is presented on the left top panel of fig. 5. We derived four times of minima for this variable and were able to determine the period. Because of the shape of the light curve we decided that it is eclipsing binary system of EW type. The depth of the primary minimum equal to about $0^m.17$ for R and I bands. The depth of

Table 3: Times of minima for nine discovered variables

ID	JD(2455...)	Error	Type	Filter
v155	632.3428	0.0006	sec	I
	632.3432	0.0005	sec	R
	635.3362	0.0008	pri	I
	640.2588	0.0015	pri	R
v428	632.2584	0.0005	pri	R
	635.3352	0.0002	pri	I
	638.2593	0.0011	sec	R
	638.2565	0.0009	sec	I
	639.3325	0.0004	pri	I
	640.2480	0.0026	pri	R
v833	635.2535	0.0014	-	R
v1999	635.2622	0.0004	-	R
	635.2891	0.0020	-	I
v3268	635.2581	0.0004	-	I
	365.2546	0.0014	-	R
v3362	632.3324	0.0006	-	I
	632.3301	0.0012	-	R
	638.2674	0.0057	-	I
	638.2534	0.0004	-	R
v4992	635.3384	0.0005	pri	I
	639.3538	0.0087	pri	I
v5028	632.2926	0.0009	-	R
	635.2846	0.0017	-	R
	638.3400	0.0031	-	R
	640.2695	0.0011	-	R
v5266	640.3282	0.0006	-	R
	635.3554	0.0054	-	I

the secondary minimum is about $0^m.14$ in both filters. As can be seen from our light curve the secondary minimum is the total eclipse with the duration of about 0.054P and 0.096P in R and I filters respectively. The precision of our observations is not suitable for the better determination. Nevertheless the almost equal depth of minima, continuous light variations outside the eclipses, short period and spectral type point out to a rather contact or near contact system.

Unfortunately Platais et al. (2003) didn't investigate the area with v155 so we can't say anything about membership in NGC 188 for this system except that its position relative to the average NGC 188 sequence of Stetson et al. (2004) (see fig. 4) points out that it is likely field star.

v428

Star v428 is denoted in the VSX database as suspected variable NSV395 based on the old photographic data (Hoffmeister, 1964). We checked also Simbad database and didn't find any kind of information about this star. So our observations are the first CCD light curve for NSV395 and it is presented on the right top panel of fig. 5. It covers six minima in both filters what is enough for satisfactory determination of period and type of variability.

As one can see the shape of the light curve resembles ones for the eclipsing binary systems denoted usually as EB. As in the case of v155 the secondary eclipse is total with duration is about 0.08P in R filter. The totality of the secondary eclipse in I filter is less obvious. The depth of the primary minimum equals to about $0^m.70$ in R band and to

Table 4: Colors of new variable stars

ID	R-I	J-H	H-K	Sp	Dist μ	Dist_Mj_V	Class
v155	0.342	0.292	0.007	G1	6786	968	V-III
v428	0.687	0.461	0.124	K1	11193	784	V-III
v735	0.845	0.683	0.145	K7	815	349	V
v833	0.387	0.34	0.084	G8	1889	365	V-IV
v1111	0.409	0.42	0.097	K0	18276	288	V-II
v1834	0.415	0.395	0.053	G8	2509	496	V-III
v1936	0.485	0.487	0.074	K2	3771	532	V-III
v1999	0.548	0.572	0.171	K4	8101	360	V-III
v3037	0.47	0.539	0.116	K2	11100	631	V-III
v3268	0.588	0.562	0.216	K4	3127	284	V-IV
v3362	0.352	0.359	0.041	G2	4417	1283	V-IV
v3913	0.573	0.575	0.15	K4	9750	189	V-III
v3958	0.368	0.295	0.079	G1	7487	433	V-III
v4507	0.469	0.385	0.055	K0	2795	525	V-III
v4601	0.598	0.502	0.186	K4	2565	503	V
v4890	0.553	0.377	0.267	K4	47174	839	V-III
v4992	0.687	0.66	0.138	K7	2391	460	V
v5028	0.221	0.163	0.047	F2	5020	657	V-III
v5266	0.372	0.271	0.058	G0	10935	758	V-III

$0^m.66$ in I band. The depth of the secondary minimum is about $0^m.58$ and $0^m.57$ in R and I filters respectively. The difference between values given for R and I bands can be explained by the presence of the small light fluctuations with amplitude of about $0^m.06$ during the both minima on the light curve at least in the R filter.

Based on the position of this star in relation to cluster CMD we assume that v428 is a field star.

v735

The light curve of v735 is shown on the left panel of fig. 6. During our observations we only registered slow increase of brightness from 17 till 19 of March with amplitudes of about $0^m.10$ and $0^m.18$ in the I and R filter respectively. For the first two nights namely March, 11 and 14 brightness of star also increased. We didn't collect any times of minimum or maximum and couldn't determine both period and the character of light variations.

There is no value of membership probability for v735 in the work of Platais et al. (2003) and Geller et al. (2009), but star is far away from average cluster sequence of Stetson et al. (2004) and cluster center so we can assume that it is not the member of NGC 188.

v833

The light curve of this variable is presented on the left top panel of fig. 7. During our observational set only one minimum was detected in R band on March, 14. We tried to determine also time of minimum in I filter for the same night, but observational points were collected some later than minimum occurs. However light variations are obvious from our data: the brightness was almost constant (within the observational accuracy) on March, 11 and March 17-19, while on March, 14 brightness decreased in R band notably. In a less degree this effect is seen on the light curve in I filter. We suppose that such brightness variations indicate an eclipsing binary with EA light curve, but more continuous set of observations is required to confirm or reject our suggestion.

As in the case of v155 and v428 this variable lies far away from cluster CMD and outside the region investigated by Platais et al. (2003) thus we suppose it is rather a field star.

v1111

The light curve of v1111 is shown on the right panel of fig. 6. We registered slow and small increase of brightness during March, 11 and 14 in both R and I filters and small decrease of brightness during March, 19 in the R band only. In the I filter observations on 19 of March were started some later and brightness was almost constant. Neither moments of minima nor maxima had been observed thus we couldn't determine the period and classify this variable.

There is no information about value of membership probability because star was not included to the work of Platais et al. (2003) and Geller et al. (2008). Due to its position relative to the cluster center and CMD we assume that it is a field star.

v1834

Star v1834 shows sinusoidal light variations, its light curve is presented on the left middle panel of fig. 5. We observed slow decrease of brightness on March, 14 from about $12^m.81$ to $12^m.88$ and slow increase of brightness from about $12^m.86$ to $12^m.80$ on March, 17 till March, 19 in I band. The light variations in R filter were similar. We suppose that at least one minimum had to occur between 14 and 17, but we didn't carry out the observations because of the bad weather. As we didn't cover times of minima, the value of period determined with "Winefk" software and given in tab. 2 for this star should be considered only as initial and rough guess.

Spectral type of v1834 derived in this work is G8V–III. Platais et al. (2003) had given zero membership probability for this star, Geller et al. (2008) in their investigation of the stellar radial velocities NGC 188 also couldn't find the MP value for v1834. That is why we could not determine more confidently the position on the CMD based on Stetson et al. (2004) data. So we only believe that it is a star of middle spectral type. In this case its variability can be caused by the presence of fast rotation or/and cool spots. Geller et al. (2008) classified this star as a rapid rotator based on their RV measurements. This fact confirms our hypothesis.

v1936

The light curve of star v1936 is shown on the right top panel of fig. 7. It is obvious that during four nights the brightness of this object was almost constant with small fluctuations around the values listed in tab. 2. However on March, 19 we observed slow increase of the brightness during all night. The light changes in R band were from $14^m.44$ to the maximum level ($14^m.36$). Due to fact that the observation in the I filter started later and lasted shorter we registered smaller increase of brightness from $15^m.04$ to $14^m.94$ only. Decrease of the brightness had to occur between two observational nights, but we didn't observe moment of minimum and thus we can suppose only that depth of the minimum is greater than $0^m.1$. Such fast decreasing and increasing of the light followed by long-time constant brightness can point out to the eclipsing binary of EA type.

As can be seen from fig. 4 v1936 occupies relevant position in cluster CMD close to the subgiant branch, although the MP value given by Platias equals to 0 and Geller et al. (2008) didn't include star in their work.

v1999

Star v1999 shows slow changes in brightness resembling long-period giant variables. Its light curve is presented on the left top panel of fig. 8. We observed only one minimum on March, 14. During three last nights after the brightness of the star slowly increased. We can say nothing about the amplitude of light variations because maximum of brightness wasn't registered.

v1999 lies far away from cluster center and was not included in the study of Platias thus nothing is known about its membership in the NGC 188. However it is close to the red giant branch of cluster CMD. Our preliminary spectral type (see tab. 4) is K4V-III so v1999 can be the late type giant star indeed. Thereby we decide to denote its type variability as 'L:'.

v3037

The light variations of v3037 are similar to ones for previous star v1999. The derived light curve is shown on the top right panel of fig. 8. We had not observe moment of minimum, but it is clearly seen from light curves that it occurred between March, 14 and March, 17. Furthermore the moment of maximum brightness is undetermined too. The registered decrease of light between March,11 and March,14 is about $0^m.1$ in both bands. Then during three nights brightness of the star continuously increased by $0^m.12$. So one can suspect that amplitude of variations is not less than these values.

This star is a X-ray source according to Gondoin (2005), who also determined spectral type as G8III based on (B-V) color index.

The membership probability is known for this star. We listed MP value according to Platias work, while Stetson gives smaller value namely 78% based on average data from Platias and Dinescu et al. (1996). The position of v3037 relative to the cluster sequence (see fig. 4) and our estimate of spectral type (K2V-III) both can be used as evidence that this star is a late-type subgiant or giant with slow light variation caused by pulsations. But X-ray emission can points out to the rapid rotation and magnetic activity of this star (Gondoin, 2005). As we did not determine the period of photometric variations we use type 'LB' as a preliminary.

v3268

The light curve of v3268 we derived is shown on the left middle panel of fig. 8. Our observations cover one moment of minimum in both filters. The amplitude of registered light changes equals to $0^m.16$ in R band and to $0^m.15$ in I band. The shape of the light curve looks like light curve of the pulsating variables.

Geller et al. (2008) classified v3268 (ID 3118 for their study) as double-lined spectroscopic binary and published (see Geller et al., 2009) radial velocity curves for both components. Geller et al. (2009) also determined orbital period $P=11^d.9022$ and masses for both components. We tried to determine period from our data but unsuccessfully. One could

expect the variability caused by eclipses, but orbital period found by Geller et al. (2009) disagrees with photometric brightness variations.

The membership probability for v3268 was determined by several authors. While Platais et al. (2004) gave small value for MP (see tab. 2), Stetson's estimate based on values from Platais et al. (2003) and Dinescu et al. (1996) was higher and equaled to 48%, recently Geller et al. (2008) estimated MP to be 88%. We estimate spectral type of v3268 as K4V-IV, but system lies far from main sequence of NGC 188 so it is rather an evolved star and its photometric variability is caused by pulsations.

v3362

The light curve of v3362 is presented on the middle right panel of fig. 5. Our observations covered two minima in each bands, so we were able to determine the period value. With derived period v3362 shows sinusoidal light variations with amplitude of about $0^m.11$ in both filters.

The value of the membership probability was given for this star by Platais and Stetson, both values are sufficient for v3362 to be a member of NGC 188. Geller et al. (2008) had not determine MP value from their radial velocity study, but classified v3362 as one-lined spectroscopic binary and rapid rotator, but radial velocity curve was not published in their next paper (Geller et al., 2009). Gondoin (2005) included this star to his list of X-ray sources, but obstructed to determine the reason of X-ray emission.

We assumed the G2V–IV spectral type, but because the position of the v3362 is close to the main sequence of NGC 188 it is rather G2V, thus its variability can be caused by rotation or/and chromospherical activity and cool spots.

v3913

The light curve of the v3913 is shown on the middle right panel of fig. 8. As can be seen, we observed slow decreasing of the brightness during all 5 nights with amplitude of about $0^m.1$ in both I and R bands. Without observed moments of minima we did not determine the period of light variations.

We checked the literature and found that membership probability of Stetson is some higher than Platais gave, while neither Dinescu et al. (1996) nor Geller et al. (2008) estimated MP value. However last authors classified v3913 as one-lined spectroscopic binary. We should suppose only that v3913 is a member of NGC 188. In this case from fig. 4 it is clearly seen that star is close to the red giant branch of average sequence of Stetson, so considering our spectral type estimate for v3913 it is rather K4III star with slow variations of light.

3958

The light curve of v3958 is presented on the left middle panel of fig. 7. Twice (March, 11 and 17) during our observations we registered decreasing of brightness up to $0^m.041$ in I filter and up to $0^m.03$ in R filter. But unfortunately on March, 11 set of observations ended before minimum arises, and on March, 17, we were able to register decrease and followed by increase of brightness, but not moment of minimum itself.

The value of membership probability was given by Platais and Stetson, both values are close to zero. Also Geller et al. (2008) denoted v3958 as probably SB2 system, but

didn't determine the MP value. So as this star lies far from average cluster sequence on fig. 4 we can suppose that it is a field star. Based on the shape of light curve and data of Geller we classified v3958 as eclipsing binary of EA type.

v4507

Light curve of the v4507 is shown on the left bottom panel of fig. 8. As can be seen, we observed slow increase for three days and subsequent fast decrease of brightness. We didn't register neither maximum nor minimum definitely.

Also there are no estimates of membership probability for v4507, because it lies far from cluster center, however star occupies relevant position in CMD and can be the possible member of NGC 188. Due to its light curve and derived spectral type we suspect v4507 to be a giant, which variability is caused by the long period pulsations.

v4601

Star v4601 shows sinusoidal light variations with period listed in tab. 2. Its light curve is presented on the left bottom panel of fig. 5. We carried out observations around the minimum brightness twice on March, 17 and March, 19, but didn't register minimum itself. So the value of period we derived with "Winefk" is some preliminary.

Both Platais and Stetson gave 0% for the membership probability of v4601. This star lies far away from average cluster sequence of Stetson et al. (2004) (see fig. 4) and from cluster center (see fig. 1) therefore we suppose v4601 is not a member of the NGC 188.

According to our preliminary value of the spectral type K4V v4601 is a main sequence star thus considering its light curve we suspect that its variability can be caused by the presence of cool spots.

v4890

The light curve of the v4890 is shown on the right middle panel of fig. 7. During the full course of our observations the brightness of star was almost constant except on March, 11 when we registered the increase of brightness from about $16^m.45$ to $15^m.98$ in R filter. However our observations started some later than minimum occurs, so we couldn't determine the period.

Star v4890 is far away from the cluster center and average cluster sequence of Stetson, thus neither Platais, nor Geller et al. (2008) included it to their investigations. We can suppose only, that v4890 is a rather field star. Due to the shape of its light curve we classified v4890 as an eclipsing binary of EA type.

v4992

The light curve of v4992 is presented on the left bottom panel of fig. 5. We had registered moments of minima twice on March, 14 and March, 18 in I filter. The depth of the minimum was about $0^m.84$. Observations in the R filter were shorter on both of these nights thus we didn't cover moments of minima, so our suggestion is preliminary. The brightness was almost constant during other nights. Using derived times of minima we determined the value of period. The shape of the light curve clearly points out to an

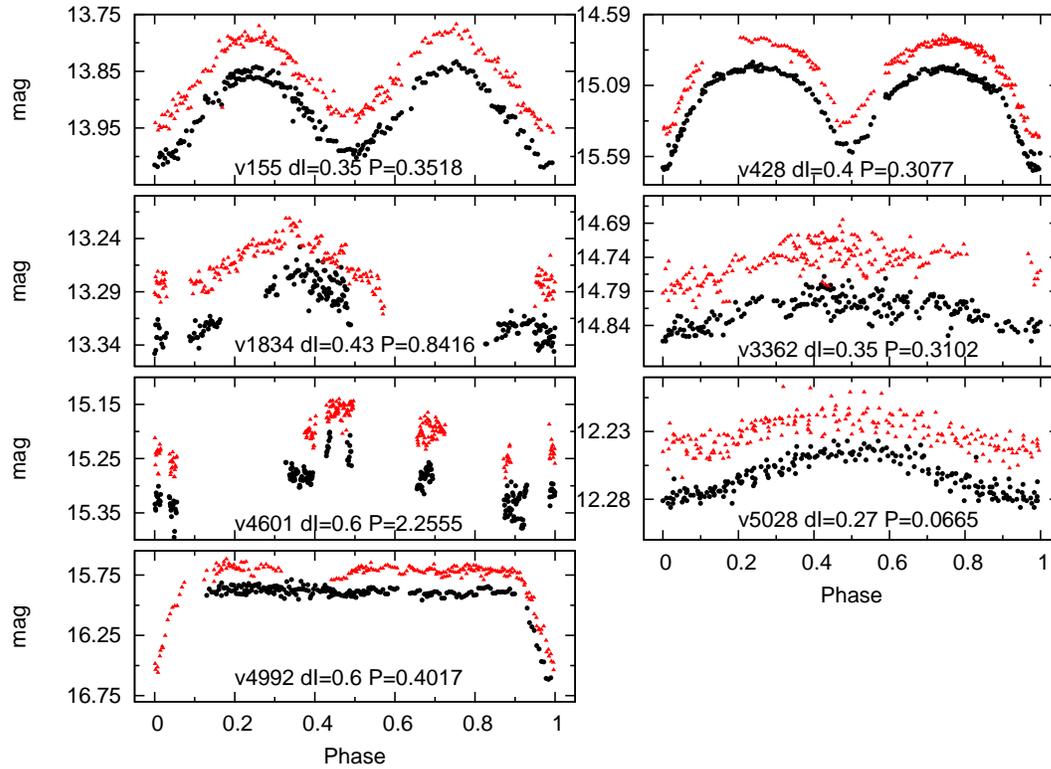


Figure 5: The phase curves of periodic variable stars. Black circles are band R, red triangles are band I. dl indicates a shift of magnitude in band I

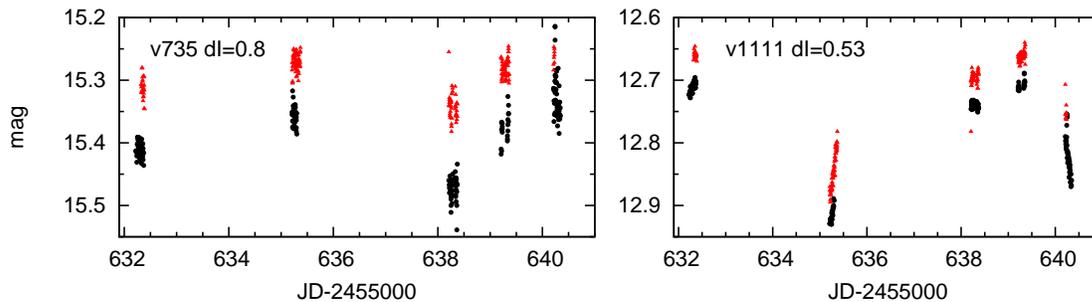


Figure 6: Variable stars with no measurable light curves classification. Black circles are band R, red triangles are band I. dl indicates a shift of magnitude in band I

eclipsing binary of EA type. It should be noted that the depth of the secondary minimum is close to zero, but small shift of moment of secondary eclipse from phase 0.5 is possible.

There is no value of membership probability for this object. Based on the position of the v4992 relative to the cluster center and average cluster sequence of Stetson we suppose that variable is rather a field star.

v5028

The light curve of v5028 is shown on the right bottom panel of the fig. 5. During the course of observations we had registered several fast variations of the brightness with

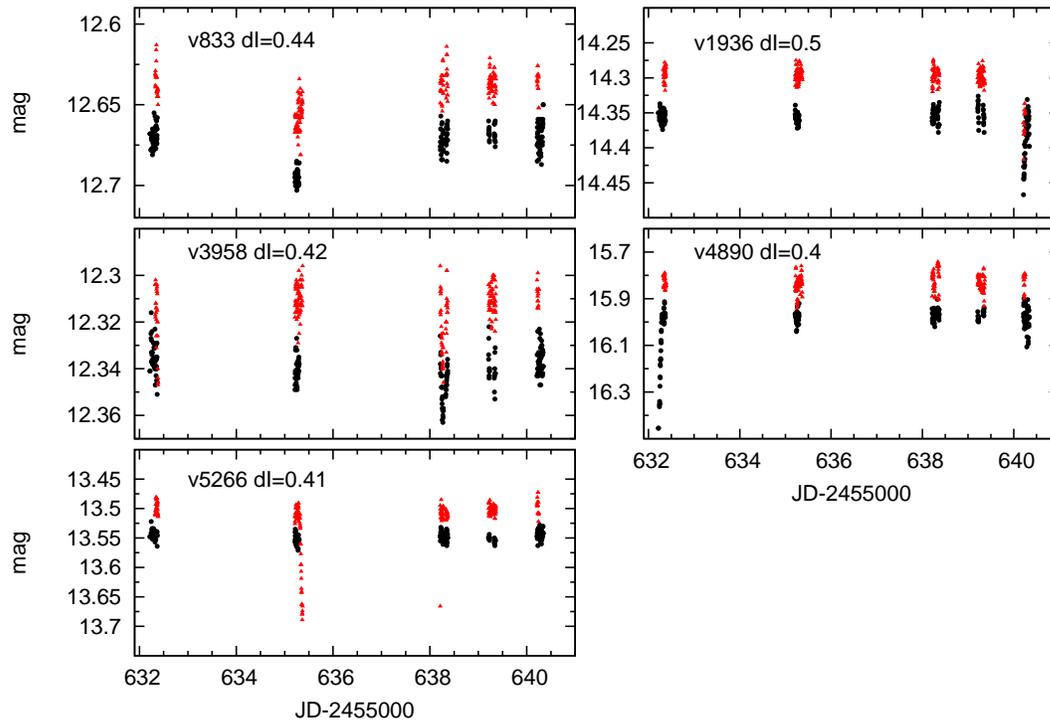


Figure 7: The light curves of eclipsing variable stars type of Algol. Black circles are band R, red triangles are band I. dl indicates a shift of magnitude in band I

amplitude of about $0^m.04$ and $0^m.06$ in the R and I bands respectively.

Nothing is known about membership probability for v5028, because neither Platais nor Geller investigated the area in which star locates.

Such fast changes of brightness together with its short period and our estimate of spectral type (F2V–III) point to the low-amplitude pulsating variable, perhaps a δ Sct type.

v5266

The light curve of variable v5266 is presented on the right bottom panel of fig. 7. We were able to register only one moment of minimum namely on March, 14 in the I band. The observations in the R band ended before minimum arises. The depth of the minimum in the I filter equals to about $0^m.18$. Using only one time of minimum we couldn't determine the value of period, but based on the shape of the light curve we suggest that variation of the brightness are caused by eclipses.

This star lies far away from the cluster center and from average cluster sequence thus we suppose it is rather a field star.

5 Conclusions

In this paper we presented results of searching for variables stars in the field of old open cluster NGC 188. CCD photometry in two bands *R* and *I* was made for 5513 stars up

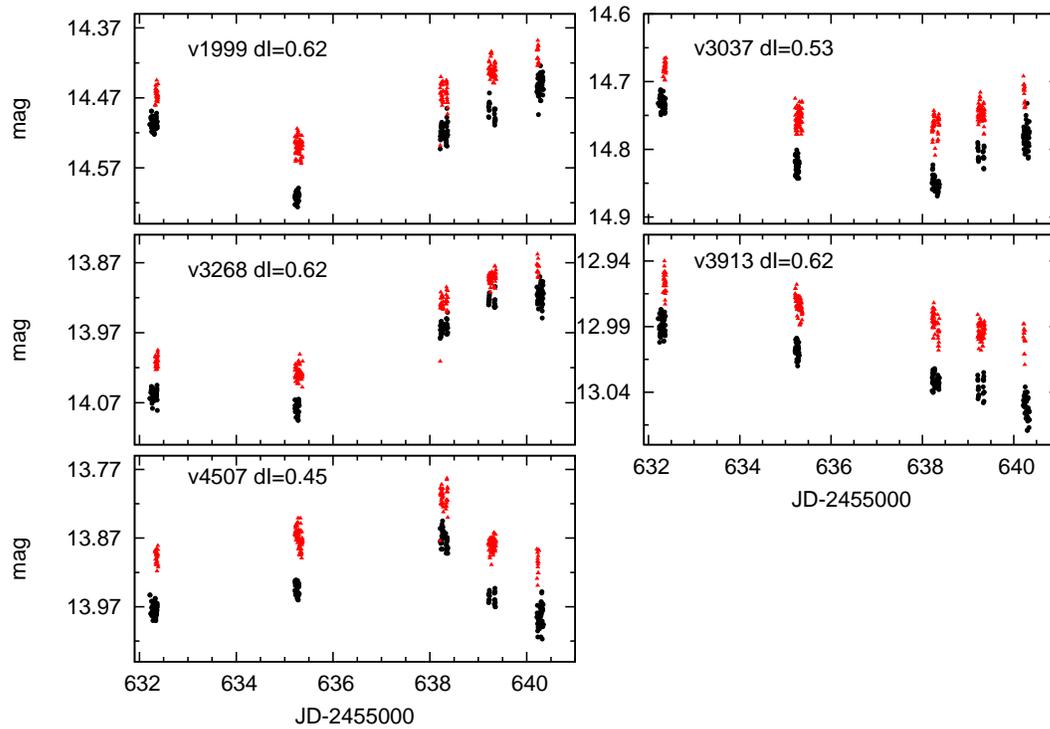


Figure 8: The light curves of slowly pulsating giants. Black circles are band R, red triangles are band I. dl indicates a shift of magnitude in band I

to $R = 17^m$ in the field of $1.5 \times 1.5^\circ$ around the cluster. We discovered 18 new variable stars and determined parameters of one previously known variable star (NSV395). Among discovered variable stars one is of low-amplitude pulsating variable type, one is of W UMA type, six are eclipsing binaries of Algol type, five are long period variables, and for five stars variability type remains uncertain. Seven variables are probably cluster members. The study of open clusters in a wide field of view leads to a more complete selection of variable stars in the cluster.

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