VARIABLE STARS IN THE OPEN CLUSTER NGC 6738 AND ITS SURROUNDING FIELD

J. Janík[1], T. Hegedüs[2], M. Zejda[1], Z. Mikulášek[1,3], Š. Parimucha[4], M. Csatáryová[5]

1) Department of Theoretical Physics and Astrophysics, Faculty of Science, Masaryk University, Kotlářská 2, 611 37, Brno, Czech Republic honza@physics.muni.cz,mzejda@physics.muni.cz

2) Baja Astronomical Observatory of Bács-Kiskun Country, Baja, Szegedi út, Kt. 766, H-6500 Hungary, e-mail:hege@electra.bajaobs.hu

3) Observatory and Planetarium, Technical University, VŠB, Ostrava, Czech Republic

4) Department of Theoretical Physics and Astrophysics, Faculty of Natural Sciences, P. J. Šafárik University, Jesenná 5, 04 001, Košice, Slovakia stefan.parimucha@upjs.sk

5) Department of Physics, Mathematics and Techniques, Faculty of Humanities and Natural Sciences, University of Prešov in Prešov, Ul. 17 novembra č. 1, 081 16 Prešov, Slovakia

Abstract: New long-term CCD observations of a field including the open cluster NGC 6738 done using a robotic telescope at Baja Observatory bring new photometric data for known variables in the field of studied open cluster as well as unveiling of 14 new variable stars, which classification and parameters of light changes are given.

Keywords: open cluster and associations: individual: NGC 6738 – stars: variables: eclipsing – stars: variables: delta Scuti – stars: variables: RRc Lyrae – stars: individual: V888 Aql, V1515 Aql NSV 11636

1 Introduction

The open cluster NGC 6738 (coordinates of the centre $\alpha_{2000} = 19^{\rm h}01^{\rm m}20^{\rm s}$, $\delta_{2000} = +11^{\circ}36'54"$, $l = 44\overset{\circ}{.}39$, $b = +33\overset{\circ}{.}1$) was first mentioned by John Herschel in 1829. Its apparent dimension of 15 arcmin and the brightness of 8.3 mag make it interesting for stargazers equipped even with a small telescope.

The first potential variable star possibly belonging to this star cluster was described by Sahade & Beron-Davila (1963). They measured the luminosity curve of the eclipsing variable star V888 Aql and estimated its distance from the center of NGC 6738 at approximately one radius of the star cluster. Hintz et al. (2006) studied variable star V1438 Aql found by the Hipparcos mission. They revised the Hipparcos period of 0.1612751 days with a full amplitude of 0.056, however they also mentioned some anomalies which should be studied in detail. The third known variable star in this region, V1515 Aql, discovered in the MISAO project, remained unstudied so far. The star NSV 11636, suspected of RR Lyrae type variability, seems to be an eclipsing variable, but this star has thus far not been studied yet.

We provide new information about above mentioned known variable stars as well as 14 new variables discovered in the open cluster NGC 6738.

2 Observations and data reduction

We observed NGC 6738 on 18 nights between 2008 July 03 and 2009 June 09 (see Tab.1) at Baja Observatory (http://www.bajaobs.hu) using the 0.5-m f/6 Bart Telescope equipped with an Apogee Alta U16 CCD camera without filters and obtained totaly 4316 CCD frames of the studied region[1]. The CCD chip consists of 4096×4096 pixels covering a 42.2 arcmin^2 field of view (see Fig.1) with a resolution of 0.62 arcsec/pixel. The gain and readout noise for the CCD used were taken to be 1.5 e-/ADU and 11.7 e- respectively.

[1]Data are available online on this site http://astro.physics.muni.cz/ocvar

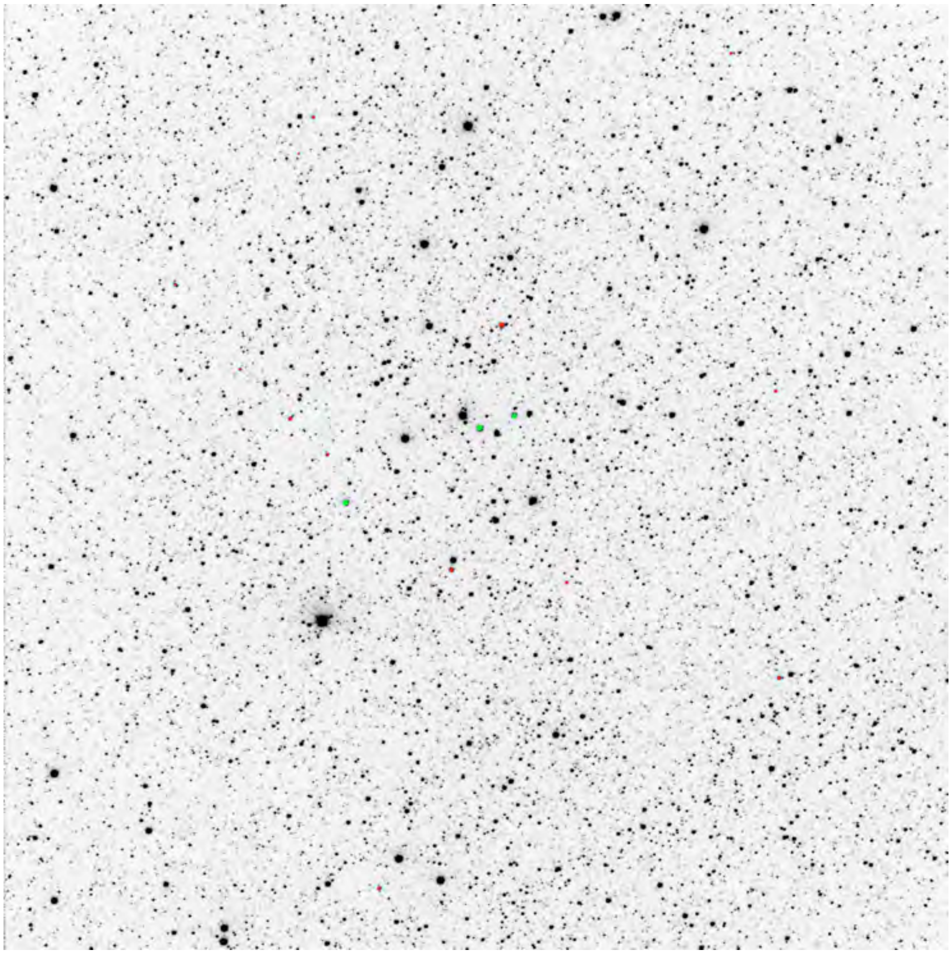

Figure 1: An example 20 s frame showing open cluster NGC 6738 with signed standard stars (green circles) and new variables (red circles) from night 2008 08 11. North is at the top of the image while east is to the left.

The standard reduction of CCD frames (dark frame substraction, flatfielding) and optimal aperture photometry were performed by software package C-Munipack[2]. Instrumental differential magnitudes were computed using the ensemble comparison star method (Kim et al., 2004; Andronov & Baklanov, 2004). The used ensemble comparison star was based on the observations of 3 stars in the center of the cluster numbers: 8 (TYC number 1048 00726 1), 27 (TYC number 1048 00360 1) and 28 (TYC number 1047 01773 1) according to Boeche et al. (2003).

3 Photometry of known variables

There are three known variable stars in the monitored region of NGC 6738 namely V888 Aql, V1438 Aql, V1515 Aql and one suspected variable, stars NSV 11636. However, V1438 Aql is too bright and saturated in the CCD frames. Consequently, we only did photometry on the other three above mentioned, previously known stars.

3.1 V1515 Aql

V1515 Aql = 2MASS J19011493+1132397 was discovered in 2000 by Ken-ichi Kadota and confirmed by Seiichi Yoshida (MisV0534), both from the MISAO projectproject[3], based on 5 measurements. It was initially suspected

[2]http://sourceforge.net/projects/c-munipack/
[3]http://www.aerith.net/misao/data/misv.cgi?en

Table 1: Journal of observations.

Number	Date yymmdd	MJD	No. of frames	Exposure time (s)	Seeing (")
1	080703	54651	351	30	4.5
2	080705	54653	280	20	3.7
3	080718	54666	465	30	2.2
4	080719	54667	505	30	2.0
5	080811	54690	528	20	2.2
6	080812	54691	200	20,60	2.5
7	080814	54693	114	30,40,60	3.8
8	080818	54697	50	60	4.1
9	080909	54719	220	40	3.7
10	080910	54720	117	60	3.7
11	090511	54963	165	30	2.4
12	090514	54966	194	30	4.0
13	090517	54969	88	30	4.1
14	090520	54972	142	120	4.6
15	090521	54973	182	30	3.7
16	090603	54986	100	120	5.0
17	090604	54987	378	30	5.7
18	090609	54992	237	20	3.5

to be a semiregular variable. We found from our 3863 measurements a long-term light change (see Fig. 2) as well as variable nightly oscillations in brightness which are shown in Fig. 3.

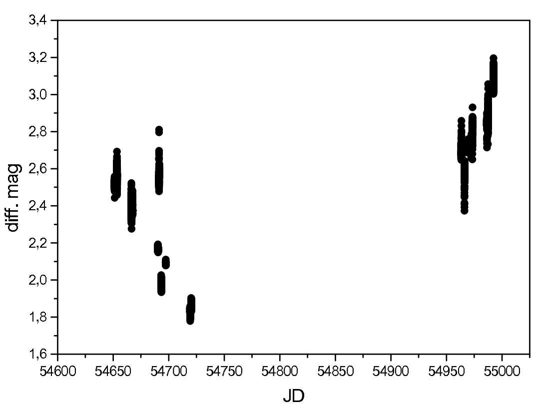

Figure 2: Light curve of V1515 Aql.

3.2 V888 Aql

V888 Aql (= GSC 1048-0362 = 2MASS J19013751+1137599) is an Algol type binary star which is probably a member of the open cluster NGC 6738. Variability of this star was discovered by Hoffmeister (1949) on a photographic plate of the Sonneberg survey with light changes of 13.2 - 14.9 mag. However, the period of light changes has not been estimated so far. From our 3551 measurements of all observational nights we calculated an ephemeris of this system using the following phenomenological model of the one-colour light curve of a well-detached binary revolving in circular orbits. $m(t)$ denotes a magnitude observed at the time t, $\overline{m}$ is the corresponding mean magnitude of the system outside of eclipses:

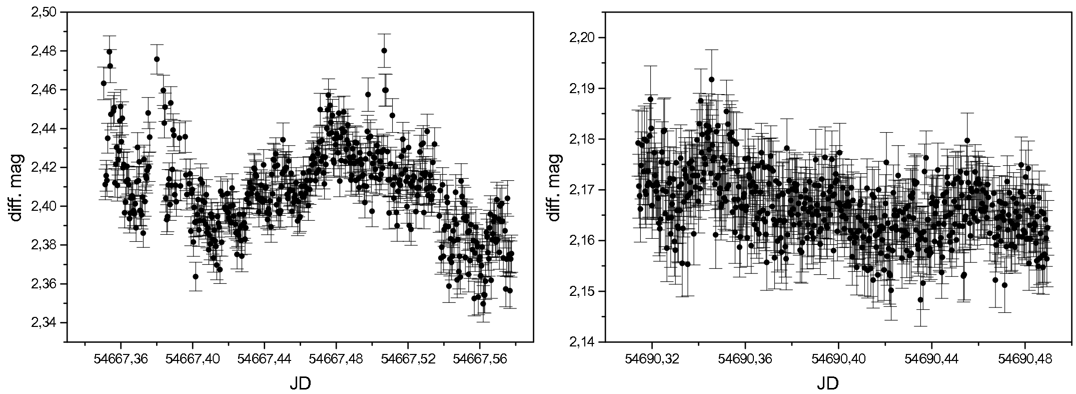

Figure 3: Light curve of two nights showing variability of light changes in V1515 Aql.

Table 2: Times of minima of V888 Aql. The epoch of the minimum E is determined according to linear ephemeris $M_0 = 2454900.6747,\ P = 5.742902\,\mathrm{d}$.

E	HJD-2454000	δ [d]	n	E	HJD-245400	δ [d]	n
-42.0	653.7301	0.0004	273	12.5	972.4608	0.0007	84
12.0	969.5873	0.0005	49	16.0	992.5615	0.0004	184

$$m(t) \simeq \overline{m} + a_1 \left\{1 - \left\{1 - \exp\left[-\left(\varphi_{\mathrm{I}}/d\right)^2\right]\right\}^C\right\} + a_2 \left\{1 - \left\{1 - \exp\left[-(\varphi_{\mathrm{II}}/d)^2\right]\right\}^C\right\} \quad (1)$$

where

$$\vartheta = (t - M_0)/P;\ \varphi_{\mathrm{I}} = \vartheta - \mathrm{round}(\vartheta);\ \varphi_{\mathrm{II}} = \vartheta - \mathrm{floor}(\vartheta) - \tfrac{1}{2}. \quad (2)$$

Free parameters $d = 0.02394(12),\ a_1 = 0.6520(16)\,\mathrm{mag},\ a_2 = 0.2790(17)\mathrm{mag},\ C = 1.252(19)$ found using the standard least square method lead to the following light ephemeris

$$HJD_{\mathrm{prim.min.}} = 2\,454\,900.6747(8) + 5.742902(10) \times E. \quad (3)$$

In this used method we did not need minima timings for period determination, for details see Mikulášek et al. (2012a,b). Nevertheless, for illustration we present times of four observed minima in Tab. 2. The phased light curve is shown in the Fig. 4 left.

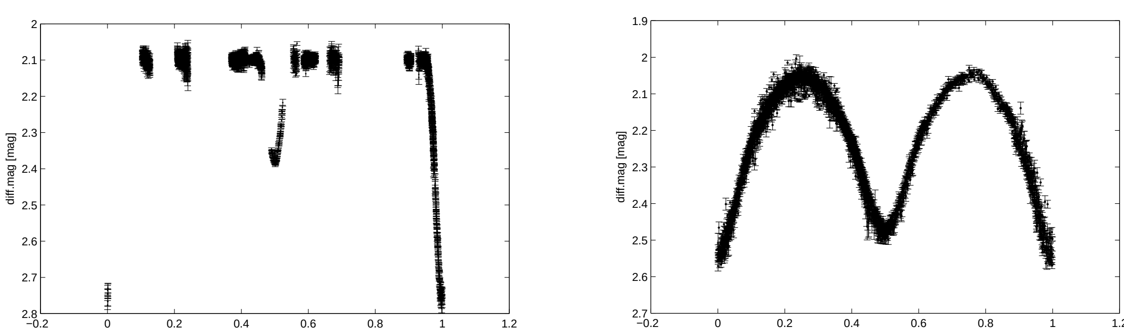

Figure 4: Light curves for stars V888 Aql and NSV 11636 based on parameters from Tab.5.

Table 3: Times of minima of NSV 11636 Aql. The epoch of the minimum E is determined according to linear ephemeris $M_0 = 2\,454\,692.09765$, $P = 0.357\,933\,20$ d.

E	HJD-2454000	δ [d]	n	E	HJD-2454000	δ [d]	n
-113.5	651.47170	0.00012	338	758.5	963.59001	0.00021	126
-108.0	653.44139	0.00018	271	766.5	966.45268	0.00019	120
-69.0	667.40034	0.00013	461	783.5	972.53886	0.00021	81
-5.0	690.30809	0.00007	511	786.0	973.43364	0.00039	110
-2.0	691.38234	0.00025	167	822.5	986.49781	0.00024	55
3.5	693.35109	0.00021	112	825.0	987.39325	0.00018	298
76.0	719.30002	0.00012	211	839.0	992.40245	0.00023	167
79.0	720.37393	0.00019	115				

3.3 NSV 11636

Variability of NSV 11636 was unveiled by Hoffmeister (1967) who considered it as a RR Lyrae type with changes between 14.0 - 14.5 mag. Only recently Diethelm (2010) found that it is an EW type eclipsing binary with a period of $0\overset{\mathrm{d}}{.}357933$. However, our observations provide a longer time-base. Consequently, using our 3236 measurements together with 390 observations from ASAS survey (Pojmanski , 2002), we improved his ephemeris. To do this, we assumed a similar phenomenological model of the one-colour light curve of a binary revolving in circular orbits as in the case V888 Aql, but with a term added to express the first approximation of the apparent proximity effects (ellipticity of components and reflection). $m_j(t)$ denotes a magnitude in the $j-$th observational set observed in the time t, $\overline{m_j}$ is the corresponding mean magnitude of the system outside of eclipses:

$$m_j(t) \simeq \overline{m_j} + a_1 \left\{1 - \left\{1 - \exp\left[-\left(\varphi_{\mathrm{I}}/d\right)^2\right]\right\}^C\right\} + a_2 \left\{1 - \left\{1 - \exp\left[-(\varphi_{\mathrm{II}}/d)^2\right]\right\}^C\right\} + a_3\, \cos(4\pi\vartheta). \tag{4}$$

The free parameters were found using the weighted robust regression outlined in Mikulášek et al. (2008): $d = 0.0681(12)$, $a_1 = 0.234(33)$ mag, $a_2 = 0.1850(31)$ mag, $a_3 = 0.1178(15)$ mag, $\overline{m}_{\mathrm{ASAS}} = 2.184(5)$ mag, $\overline{m}_{\mathrm{own}} = 2.1725(11)$ mag, and $C = 1.066(34)$. The resulting light ephemeris is then

$$HJD_{\mathrm{prim.min.}} = 2\,454\,692.09765(5) + 0.35793320(11) \times E \tag{5}$$

and the phased light curve is shown in the Fig. 4 right. During our monitoring we registered the brightness minima given in Tab. 3.

4 Photometry of new variables

The field of NGC 6738 is crowded by many stars.To identify real variable stars among them all sources of false variability must first be excluded. These include saturation, blending, close presence of a dead column and so on. We took into account only stars measured in at least 60 per cent of frames. We made only differential photometry with regard to three standard stars in the center of cluster (described before), because we observed without filters.

We used the variability index method (Welch & Stetson 1993) to search for new variables in our field of view for all nights and separately for each star.

All new variable stars (see Tab. 4) are pulsating variables with the exception of BAJA-6738-009 which which is a W UMa type eclipsing variable. The classification of pulsating stars (DSTC and RRc type stars) is based on the program PerSea 2.6 (Maciejewski & Niedzielski, 2005). Period analysis was done using the program Period04 version 1.2.0 (Lenz & Breger, 2005) but without error estimates which this program cannot calculate.

Discovered δ Scuti type stars have periods between 0.0178 – 0.1831 days with amplitudes of 0.008 – 0.025 mag. One of the new variables is a RRc type star with a period of 0.319 days and an amplitude of 0.246 mag (see Tab.5 and Fig.5 left).

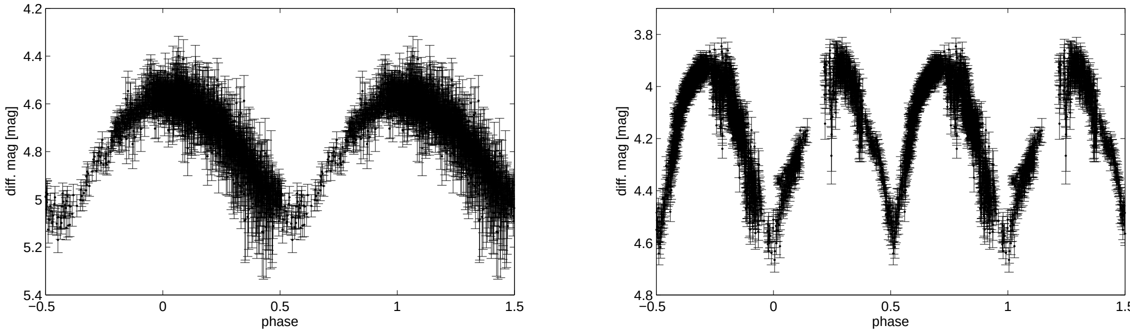

Figure 5: Light curves of RRc variable BAJA-6738-0012 and EW BAJA-6738-0009 based on parameters from Tab.5. Larger scatter in the left figure is caused due to lower brightness of variable star.

Table 4: New variable stars: identifiers, coordinates and types

name	USNO B1.0 ID	2MASS	α(2000)	δ(2000)	type
BAJA-6738-0002	1014-0418843	19012474+1129381	$19^h01^m24.74^s$	+11 29' 38.1"	DSCT
BAJA-6738-0003	1016-0430069	19015394+1136146	$19^h01^m53.94^s$	+11 36' 14.6"	DSCT
BAJA-6738-0004	1014-0414801	19002573+1124582	$19^h00^m25.73^s$	+11 24' 58.2"	DSCT
BAJA-6738-0005	1016-0427782	19011599+1140254	$19^h01^m15.99^s$	+11 40' 25.4"	DSCT
BAJA-6738-0009	1018-0453867	19003515+1152267	$19^h00^m35.15^s$	+11 52' 26.7"	EW
BAJA-6738-0012	1017-0447486	19015272+1147549	$19^h01^m52.72^s$	+11 47' 54.9"	RRc
BAJA-6738-0013	1012-0417257	19013724+1115358	$19^h01^m37.24^s$	+11 15' 35.8"	DSCT
BAJA-6738-0014	1018-0457799	19014300+1149013	$19^h01^m43.00^s$	+11 49' 01.3"	DSCT
BAJA-6738-0015	1018-0458307	19015026+1149319	$19^h01^m50.26^s$	+11 49' 31.9"	DSCT
BAJA-6738-0016	1015-0418928	19014728+1134402	$19^h01^m47.28^s$	+11 34' 40.2"	DSCT
BAJA-6738-0018	1017-0448903	19021494+1142073	$19^h02^m14.94^s$	+11 42' 07.3"	DSCT
BAJA-6738-0020	1016-0424429	19002670+1137355	$19^h00^m26.70^s$	+11 37' 35.5"	DSCT
BAJA-6738-0021	1016-0430598	19020308+1138243	$19^h02^m03.08^s$	+11 38' 24.3"	DSCT
BAJA-6738-0023	1014-0417481	19010405+1129067	$19^h01^m04.05^s$	+11 29' 06.7"	DSCT

5 Conclusion

We unveiled 14 new variable stars using our wide-field survey of NGC 6738. We classified them as δ Scuti type (12), RR Lyrae c type (1) and one eclipsing binary. We did not find any rotational variable stars even they are common in open clusters. The periods of found variable stars seems to be too short for rotational variable stars. Improved light ephemeris and timings of minima were obtained using new phenomenological approach to all collected data.

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Table 5: New variable stars: R2 brightness from USNO B1.0, times of maxima (excluding BAJA-6738-0009), periods and amplitudes

name	type	R2 [mag]	T_0 [HJD-2400000]	Period [d]	Ampl. [mag]	No. of points
BAJA-6738-0002	DSCT	11.04	54651.592925	0.076425	0.0120	3859
BAJA-6738-0003	DSCT	12.91	54651.397973	0.017825	0.0095	2994
BAJA-6738-0004	DSCT	12.21	54651.625830	0.115962	0.0245	3292
BAJA-6738-0005	DSCT	11.01	54651.918480	0.177358	0.0160	3854
BAJA-6738-0009	EW	14.10	54651.425161	1.158811	0.3035	2256
BAJA-6738-0012	RRc	14.97	54652.028163	0.319163	0.2470	1743
BAJA-6738-0013	DSCT	11.90	54651.569667	0.052927	0.0100	2413
BAJA-6738-0014	DSCT	13.23	54651.731703	0.183118	0.0210	3703
BAJA-6738-0015	DSCT	12.16	54651.557455	0.087489	0.0065	3520
BAJA-6738-0016	DSCT	13.98	54651.545251	0.072262	0.0060	3384
BAJA-6738-0018	DSCT	12.50	54651.423900	0.030717	0.0080	2475
BAJA-6738-0020	DSCT	13.53	54651.529952	0.096413	0.0130	3191
BAJA-6738-0021	DSCT	14.08	54651.543767	0.078218	0.0150	3464
BAJA-6738-0023	DSCT	13.37	54651.660585	0.096259	0.0115	3330

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