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Search For Variable Stars in the Field of The Young Open Cluster NGC 957

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Abstract: We report on discovery of 10 eclipsing binaries, 3 regular pulsating stars and 1 semi-regular variable in the field of the open cluster NGC 957. Only one of them – a short period semi-detached eclipsing binary – was be a likely cluster member. No short-period pulsating variables were found in the cluster.

The young open cluster NGC 957 (C0230+573) has been a subject of numerous studies to date. Ruprecht (1966) described it as a loose and not rich stellar ensemble of type III2p. Gerasimenko (1991) gathered the photographic *UBV* photometry for 250 bright stars in a region of the cluster and determined the reddening of $E(B - V) = 0.9$ mag, the distance of 2.1 kpc, and the age of about 4 Myr. Dias et al. (2002) give log(*age*) = 7.042, $E(B - V) = 0.842$ mag, and the distance of 1815 pc. More recently, Yadav et. al. (2008) gathered the first *UBVRI* CCD photometry for the cluster. As a result of comprehensive studies they derived $E(B - V) = 0.71 \pm 0.05$ mag, the distances of 2.2 ± 0.2 kpc, and the age of 10 ± 5 Myr (log(*age*)=7.0).

The young open clusters are expected to host pulsating stars which are ideal targets for asteroseismic studies (see e.g. Zwintz at al. 2009). But we do not found pulsating stars in the open cluster NGC 957. In this report we present results of the search for short-period variable stars in the field of NGC 957.

Our observations were gathered in *B* and *V* bands during three observing runs (October, December 2008 and March 2009). We used the 70/172-cm Schmidt Telescope (ST70) of the National Astronomical Observatory (NAO) at Rozhen (Bulgaria), operated by the Institute of Astronomy of the Bulgarian Academy of Sciences. The instrument was equipped with 50-cm correction plate and the SBIG STL-11000 CCD camera (4008 × 2672 pixels × 9μm). The field of view was 72 arcmin in declination and 48 arcmin in right ascention with the scale of 1.08 arcsec per pixel. We used 2 × 2 binning to increase the signal-to-noise ratio. The exposure time was 300 s and 5 s with typical seeing (FWHM) 2 – 3 arcsec. During about 23 hours of observations in total 291 images in the *V* filter and 98 in *B* were secured. About 10000 stars brighter than 19.0 mag in *V* were monitored in total. The accuracy of our photometry for 5-s and 300-s exposures in *V* is plotted in Fig. 1. The collected observations were reduced with the software pipeline developed for the Semi-Automatic Variability Search sky survey (Niedzielski et al. 2003, Maciejewski & Niedzielski 2005). The candidates for new variable stars were selected from the *V*-band database using the analysis of variance method (ANOVA, Schwarzenberg-Czerny 1996).

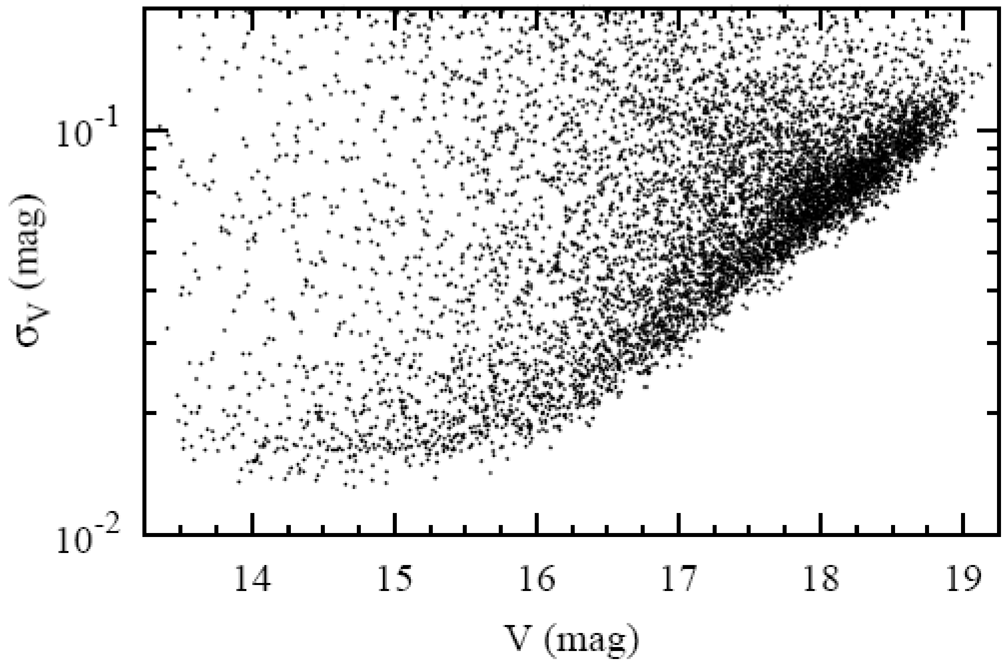

Figure 1. The errors-diagram for average brightness in the *V* filter for 300-s exposures.

New central coordinates of the cluster were redetermined using near-infrared JHK_S photometry extracted from the 2-Micron All Sky Survey (2MASS, Strutskie et al. 2006). We adopted the procedure described in Maciejewski & Niedzielski (2007). Two perpendicular stripes were cut along declination and right ascension starting from the approximate cluster center and a histogram of star counts was built along each stripe. The bin with the maximum value in both coordinates was taken as a new cluster center what resulted in $RA = 02^h33^m32^s$, and $DEC = 57^o35'04''$.

To investigate a structure of the cluster, the radial density profile (RDP) was built by counting stars inside concentric rings of width 1', centered at the redetermined cluster center. The density uncertainty in each ring was estimated assuming Poisson statistics (see Maciejewski & Niedzielski 2007 for details). The RDP is plotted in Fig. 2. To parameterize the density distribution, a two-parameter King (1966) density profile was fitted with the least-squares method in which the uncertainties were used as weights. We derived the core radius (the distance where the stellar density drops to half its maximum value) $r_{core} = 3.35 \pm 0.25$ arcmin, the central density $f_0 = 3.18 \pm 0.14$ stars/arcmin^2, and the density of the background stellar field $f_{bg} = 2.82 \pm 0.05$ stars/arcmin^2. The fitted profile is sketched with a solid line in Fig. 2 while the dashed line marks the level of f_{bg}. The cluster limiting radius r_{lim} was roughly estimated by eye-inspection in the RDP. The stellar density excess is visible up to at least $r_{lim} = 15.4 \pm 1.3$ arcmin.

Collected *BV* photometry allowed us to redetermine cluster's basic parameters. We applied the procedure taken from Maciejewski & Niedzielski (2007). The stellar-background decontaminated colour-magnitude diagram (CMD) was constructed for the central part ($r < 3\ r_{core}$) of the cluster and a set of theoretical Padova isochrones (Giraldi at al. 2002) of the solar metallicity was fitted. As a result the following parameters were derived: log(*age*) = 7.10 ± 0.05, reddening E($B - V$) = 0.81 ± 0.05 mag, the apparent distance modulus of 13.8 ± 0.1 mag, and the distance of 1890 ± 50 pc. The CMD with the best-fit isochrone is plotted in Fig. 3.

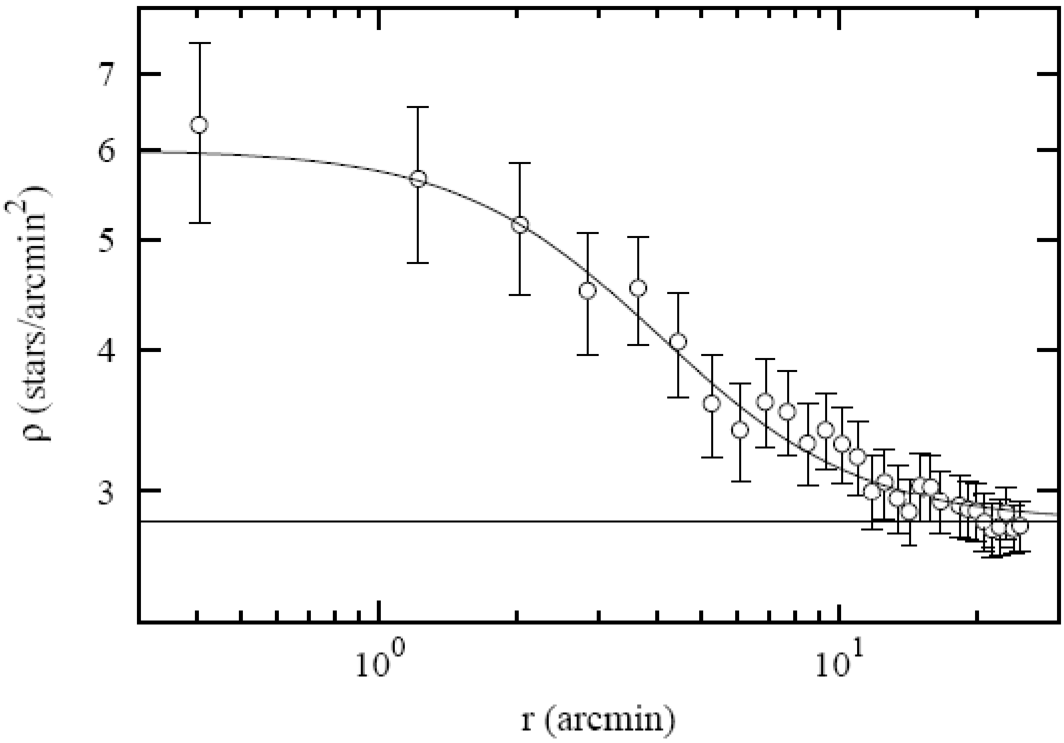

Figure 2. The radial density profile with the best-fit King's formula. The horizontal continuous line marks the background-star-density level.

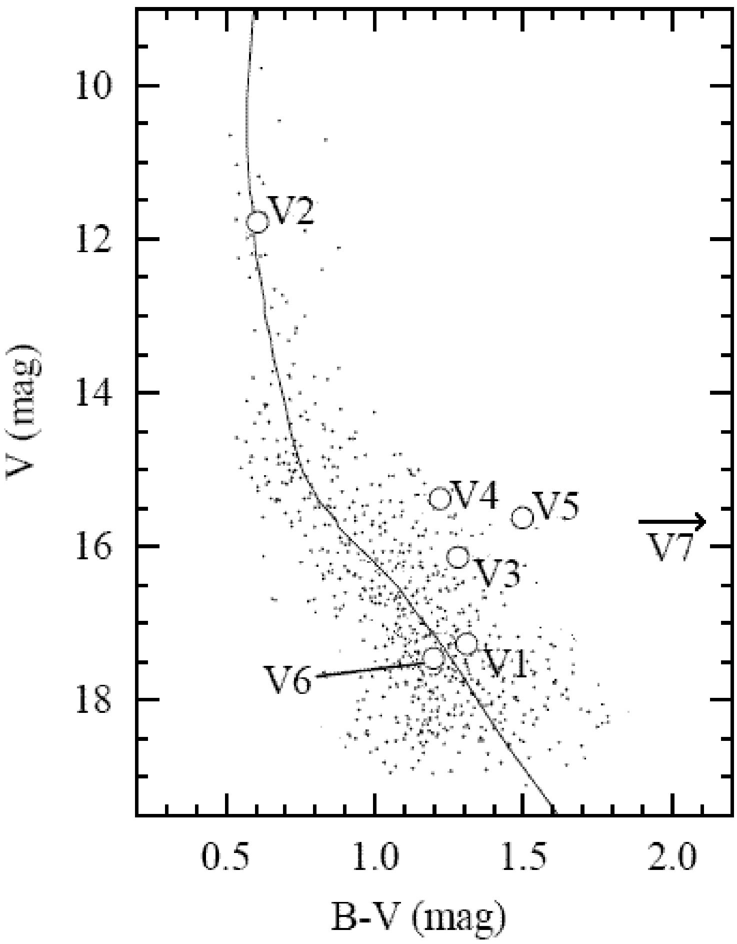

Figure 3. The colour-magnitude diagram for NGC 957 with the best-fit isochrone of solar metallicity. The open symbols denote variable stars located within the cluster's limiting radius. See text for discussion.

The calibration coefficients that transform instrumental magnitudes into standard ones were determined using 20 stars located in the field of the open cluster. Their magnitudes were taken from Hoag at al. (1961). The instrumental coordinates of stars were transformed into equatorial ones based on positions of stars brighter than 17 mag and extracted from the Guide Star Catalog. Transformation exemplars used to calculate coefficients of transformations:

$$V - v = a_1 (b - v) + b_1$$

$$B - V = a_2 (b - v) + b_2$$

Where *b,v* are instrumental brigtness, *B,V* are catalog brightness and a_1, a_2, b_1, b_2 are search coefficients of transformations. Values received we see above pictures in Fig. 4 which are presented linear fit for stars from the filed of the NGC 957.

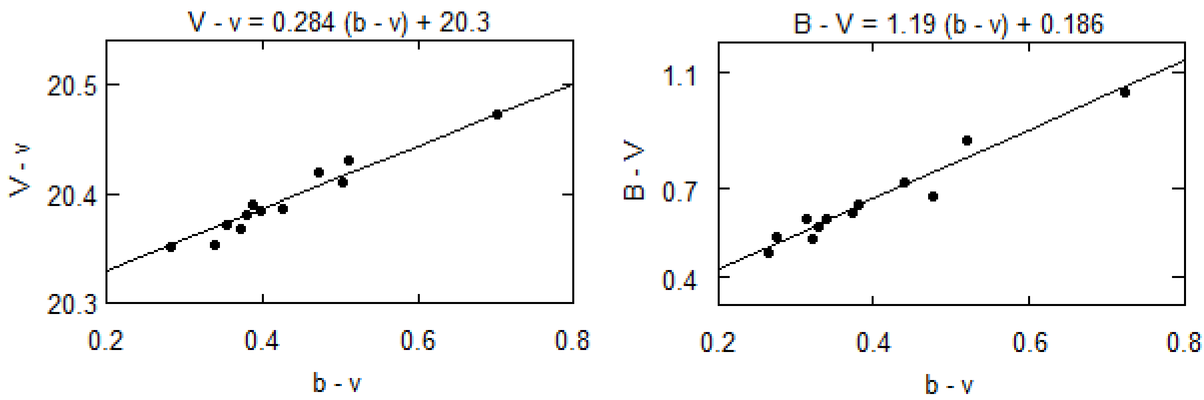

Figure 4. Linear regression method for stars from the field of the open cluster NGC 957.

As a result of our survey 14 variable stars were detected in the field of NGC 957. They are listed in Table 1 and their light curves are presented in Fig. 5 and 6. Seven variables (V1 – V7) are located within the cluster radius and they may be treated as potential cluster members. These variables were plotted in the cluster's CMD (open symbols in Fig. 3) to discuss their membership.

V1 is a contact system (EW) located near the centre of cluster and near the isochrone. Assuming it belongs to the cluster, its absolute magnitude is $M_v = 3.5 \pm 0.1$ mag. The same quantity calculated from the empirical formula $M_V = - 4.44 \log P + 3.02 (B - V)_O + 0.12$ of Ruciński & Duerbeck (1997) is 2.53 ± 0.22 mag what suggests that it can not belong to the cluster.

V2 is a semi-detached system (EB) located in the cluster's center and near the isochrone in the CMD. Therefore we conclude that its membership is likely.

V3 is a contact system located far from the isochrone. However, we may assume that it belongs to the cluster and derive its absolute magnitude $M_v = 2.3 \pm 0.1$ mag. On the other hand, we may calculate system's absolute magnitude using the formula by Ruciński & Duerbeck (1997). We derived $M_v = 3.18 \pm 0.22$ mag what indicates that the system is not a cluster member.

V4 is a short period semi-detached binary which location in the CMD makes its membership unlikely.

V5 is a next contact system discovered in the cluster area. As it is located far from the isochrone, it cannot belong to the cluster for sure.

V6 is a pulsating variable of δ Scuti type (DSCT). Assuming it belongs to the cluster, its absolute magnitude would be 3.6 ± 0.1 mag what is beyond a range of typical values (Duerbeck & Seitter 1982). Our studies indicate that the variable cannot belong to the cluster.

V7 reveals long-term variability. During ~120 days its brightness dropped monotonically by ~0.9 mag. It is extremely red what suggests that it is Mira-like red pulsator. We conclude that this star is not a cluster member for sure.

Remaining variable stars that were detected in the observed area are treated as Galaxy-field stars. Among them we report 2 pulsating variables and 5 eclipsing binaries (see Table 1).

Summarizing, we detected 14 variable stars in the field of NGC 957. Only one variable – a short period semi-detached eclipsing binary – was found to be a likely cluster member. No short-period and any different pulsating variables were found in the cluster. This is contrary to expectation because in that young open cluster (age about 10 Myr) we expected discover few pulsating stars. This non-detection is probably because NGC 957 is not enough numerous cluster, so statistics is worse. Second cause can be observations period, if somebody will be observing in longer period than 6 months maybe discover long-period pulsating stars.

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Table 1. The list of variable stars detected in the field of NGC 957, r_d denotes the distance from the cluster center, V_{max} – the maximal brightness in V band, V_{min} – the minimal brightness in V band, $(B\text{-}V)$ – the color index at the maximum of brightness, P – the period of variation, T_o – the epoch of minimum brightness for eclipsing system or maximum for pulsating stars in HJD based on UTC, types of variability, and cluster membership.

ID	Coordinates J2000.0	r_d (‘)	V_{max} (mag)	V_{min} (mag)	$(B\text{-}V)$ (mag)	P (day)	T_o 2454700+	Type	Member
V1	023307.11+573029.3	5.7	17.27	17.83	1.31	0.628693	74.9212	EW	no
V2	023308.17+572811.8	7.6	11.89	11.99	0.61	0.471920	74.3842	EB	likely
V3	023245.87+574146.7	9.2	16.14	16.47	1.28	0.426930	75.9237	EW	no
V4	023423.11+572546.2	11.6	15.38	15.87	1.22	0.356836	74.9525	EB	unlikely
V5	023226.02+572642.0	12.2	15.59	15.97	1.50	0.305753	75.1037	EW	no
V6	023329.28+574832.1	13.5	17.44	17.79	1.19	0.194234	74.6412	DSCT	no
V7	023345.55+571933.3	15.6	15.74	16.60	>3.5	–	–	MISC	no
V8	023529.33+574455.6	18.4	14.30	14.56	1.00	0.117107	74.5536	DSCT	no
V9	023137.75+574910.7	20.7	15.40	15.51	1.09	0.426741	75.7171	EW	no
V10	023453.85+575625.5	23.9	15.17	16.10	1.08	0.514411	75.4645	EB	no
V11	023440.67+570638.4	29.9	13.91	14.13	1.14	2.757184	80.0627	DCEP	no
V12	023220.65+580419.3	30.8	14.20	14.45	0.75	1.073721	77.2566	EA/EB	no
V13	023448.36+565918.5	37.3	14.76	15.65	0.97	0.658295	75.8633	EB	no
V14	023143.86+565955.7	38.2	16.05	16.56	0.99	0.920321	76.0284	EB/EA	no

References:

Bukowiecki Ł., Maciejewski G. 2008, *IBVS*, 5857
Dias, W. S., Alessi, B. S., Moitinho, A., L´epine, J. R. D. 2002, *A&A*, 389, 871
Duerbeck, H. W., Seitter W. C. 1982, in *Stars and Star Clusters*, ed. K. Schaifers and H. H. Voigt, Springer-Verlag
Gerasimenko, T. P. 1991, *Astron. Zh*, 68, 1103
Gimenez A., Garcia-Pelayo J. 1980, *A&A. Supl.*, 41, 9
Giraldi, L., et al. 2002, *A&A*, 391, 195
Hoag A.A., Johnson H.L., Iriarte B., Mitchell R.I., Hallam K.L., Sharpless S. 1961, *Publ. US. Nav. Obs.* 17, 347
King, I. 1966, *AJ*, 71, 64
Maciejewski G., Bukowiecki Ł., Brożek T., Georgiev TS., Boeva S., Kacharov N., Mihov B., Latev G., Ovcharov E., Valcheva A. 2008, *IBVS*, 5864
Maciejewski, G., Niedzielski, A. 2005, *Balic Astronomy*, 14, 205
Maciejewski, G., Niedzielski, A. 2007, *A&A*, 467, 1065
Niedzielski, A., Maciejewski, G., Czart, K. 2003, *AcA*, 53, 281
Ruciński, S. M., Duerbeck, H. W. 1997, *PASP*, 109, 1340
Ruprecht, J. 1966, *Bull. Astr. Inst. Czechosl.*, 17, 33
Schwarzenberg-Czerny, A. 1996, *ApJ*, 460, L107
Strutskie, M. F., et al. 2006, AJ, 131, 1163
Yadav R.K.S., Kumar B., Subramaniam A., Sagar R., Mathew B. 2008, *MNRAS*, 390, 985
Zwintz, K., at al. 2009, *A&A*, 502, 239

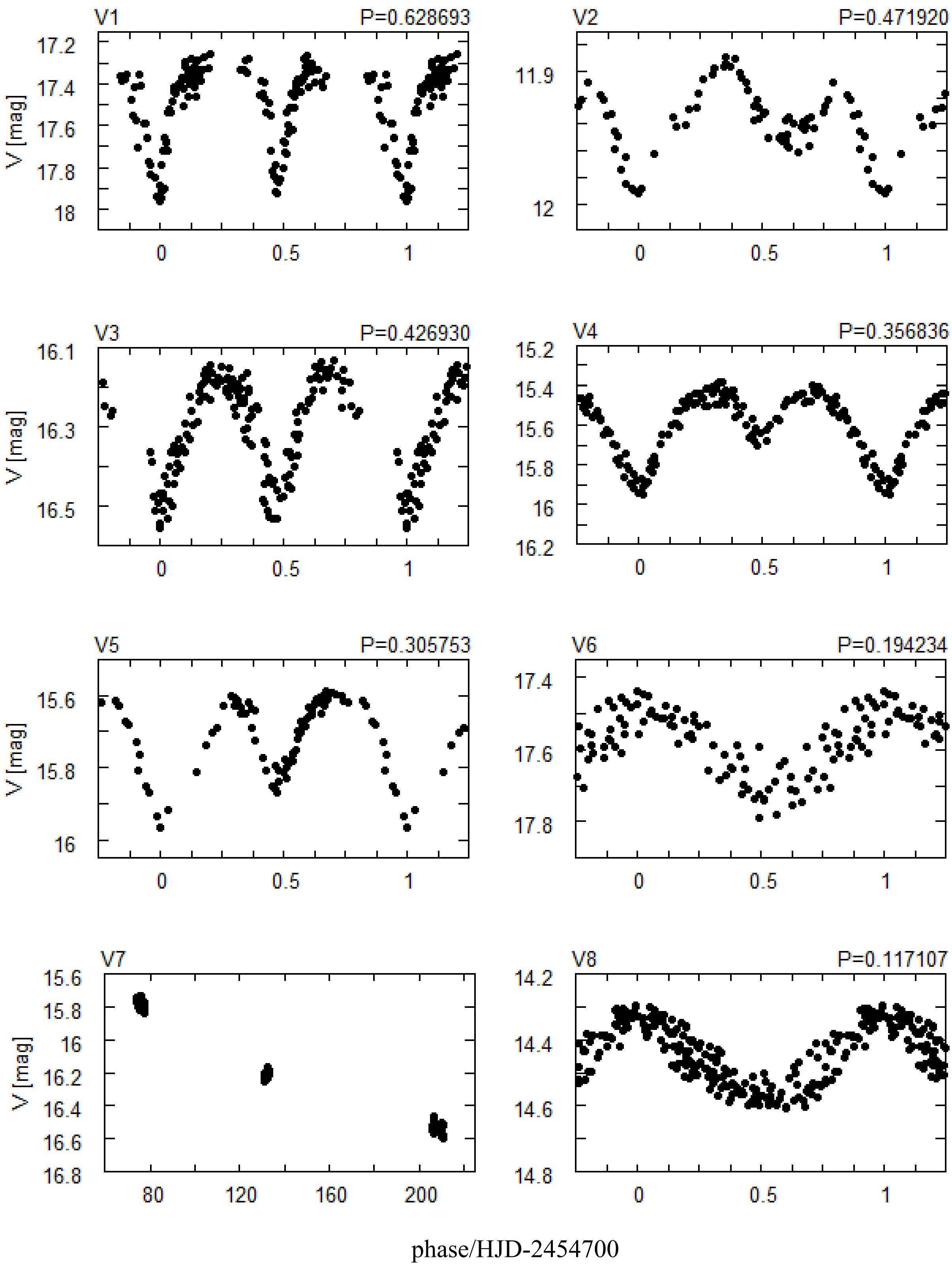

Figure 5. *V*-band light curves of variable stars discovered in the field of NGC 957.

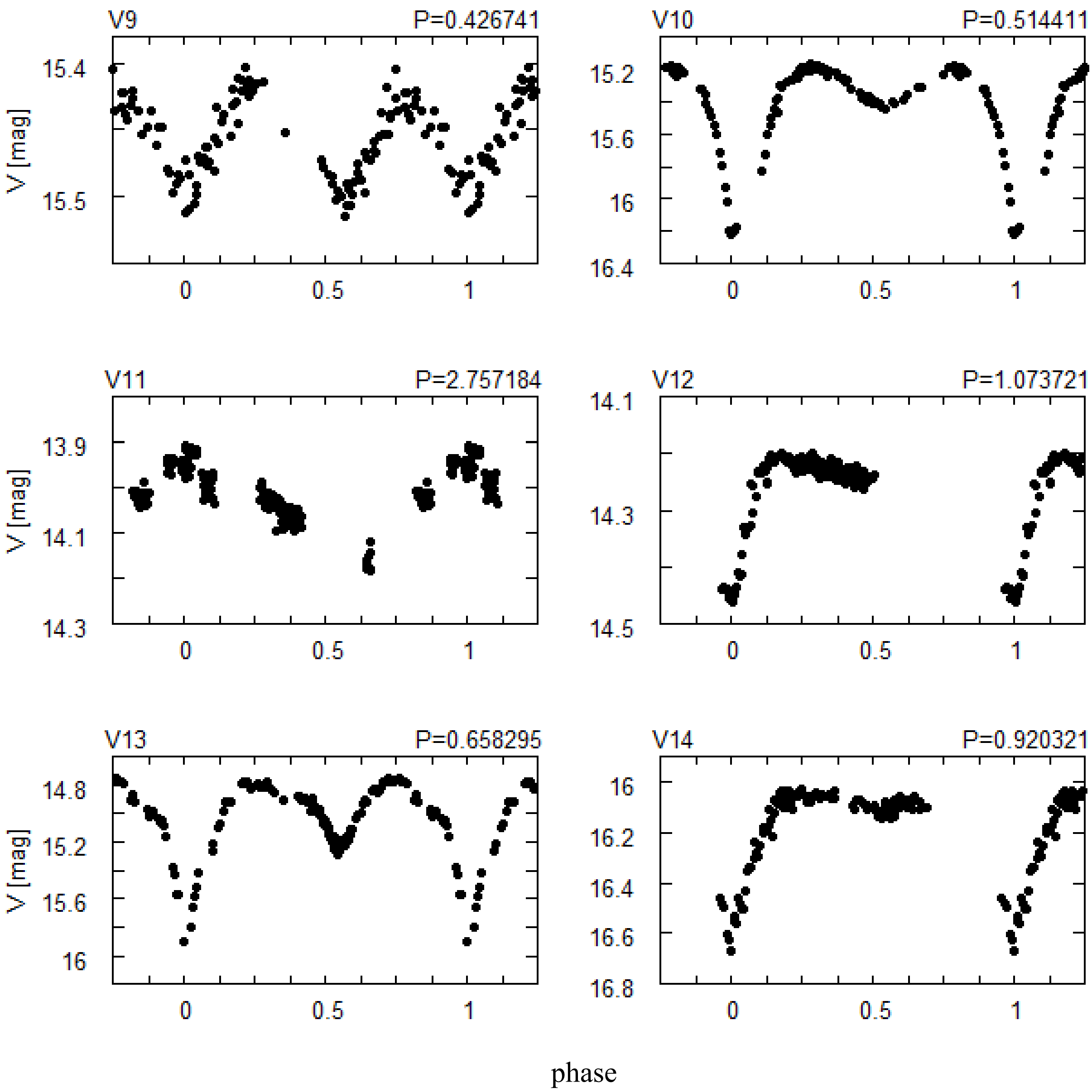

Figure 6. *V*-band light curves of variable stars discovered in the field of NGC 957.