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VARIABLE STARS IN THE FIELD OF THE OPEN CLUSTER NGC 457

MACIEJEWSKI, G.[1]; BUKOWIECKI, Ł.[1]; BROŻEK, T.[1]; GEORGIEV, TS.[2]; BOEVA, S.[2]; KACHAROV, N.[3]; MIHOV, B.[2]; LATEV, G.[3]; OVCHAROV, E.[3]; VALCHEVA, A.[3]

[1] Centrum Astronomii Uniwersytetu Mikołaja Kopernika, Gagarina 11, Pl-87100 Toruń, Poland; e-mail: gm@astri.uni.torun.pl

[2] Institute of Astronomy, Bulgarian Academy of Sciences, 72 Tsarigradsko Chausse Blvd., 1784 Sofia, Bulgaria; e-mail: tsgeorg@astro.bas.bg

[3] Department of Astronomy, University of Sofia, 5 James Baurchier Str., 1164 Sofia, Bulgaria

According to the WEBDA[1] data base (Mermilliod 1996), the open cluster NGC 457 is known as a relatively young stellar system of $\log(age) = 7.324$, the reddening $E(B-V) = 0.472$ mag, and the distance of 2.43 kpc. Its apparent diameter was estimated to be 20' (Dias et al. 2002). No search for variable stars in the cluster has been performed to date.

The field of NGC 457 was searched for variable stars in B and V bands with two Schmidt telescopes. The first campaign was performed between 2007 November and 2008 April with the 90/180 cm Schmidt-Cassegrain Telescope (TSC90) of the Nicolaus Copernicus University Astronomical Observatory in Piwnice near Toruń, Poland (see Bukowiecki & Maciejewski 2008 for details). In total 478 images in V and 142 in B were obtained during about 56 hours of observations. The second campaign was performed between 2007 December and 2008 March with 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 (see Maciejewski et al. 2008 for details). During almost 19 hours of monitoring 218 images in V were acquired. About 14900 stars brighter than 19.0 mag in V band were monitored in total.

One of the detected bright variables (V3 = V765 Cas) was also observed with the TSC90 in the Cassegrain mode with the Richardson spectrograph and Wright CCD camera. We obtained spectra between 3500 and 5500 Å with 2 Å/pix reciprocal dispersion with 600 gr/mm grating for spectral classification.

Both data sets were reduced and analysed in the way described in Bukowiecki & Maciejewski (2008). The transformation of instrumental magnitudes into standard ones based on over 800 cluster stars which photometry was taken from Phelps & Janes (1994). The $(B-V)$ coverage was in range between 0.25 and 2.0 mag. The residuals in observed and literature $(B-V)$ are shown in Fig. 1.

As a result of the analysis the following parameters were derived: the central coordinates $RA = 01^{\rm h}19^{\rm m}38^{\rm s}$, $DEC = 58^\circ16'48''$, the limiting radius of 14.7 ± 1.3 arcmin, $\log(age) = 7.40 \pm 0.05$, $E(B-V) = 0.48 \pm 0.05$ mag, the apparent distance modulus $m - M = 13.55 \pm 0.10$ mag, and the distance of 2.6 ± 0.3 kpc. The radial density

[1] http://www.univie.ac.at/webda/

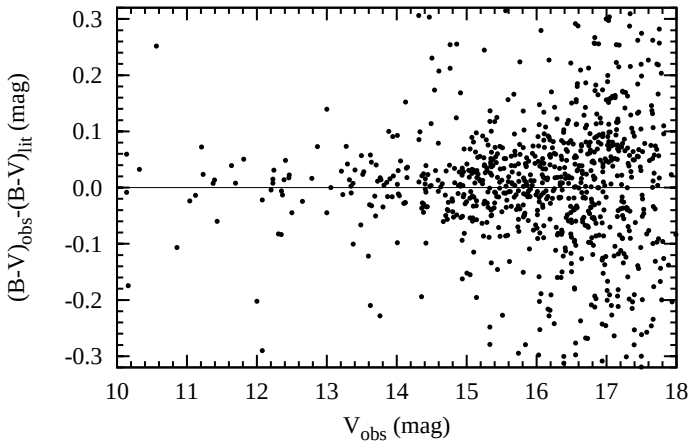

Figure 1. The comparison of the observed photometry with the literature one.

profile, plotted in Fig. 2, can be approximated with the King's formula (King 1966) with the following best-fit parameters: the central density $f_0 = 5.34 \pm 0.17$ stars/arcmin^2, the core radius $r_{\rm core} = 2.43 \pm 0.13$ arcmin, and the density of the background stellar field $f_{\rm bg} = 1.87 \pm 0.05$ stars/arcmin^2. The colour-magnitude diagram (CMD) constructed for NGC 457 with the best-fit isochrone of solar metallicity is presented in Fig. 3.

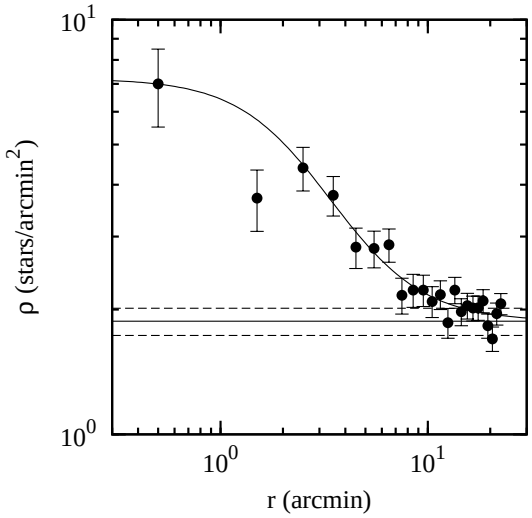

Figure 2. The radial density profile with the best-fit King's formula. The horizontal continuous line marks the background-star-density level and the dashed ones its 3-sigma error.

As a result of our survey 29 new and 2 known variable stars were detected in the field of NGC 457. They are listed in Table 1 and their light curves are presented in Figs. 4 and 5. Twelve variables (V1–V12) are located within the cluster limiting radius. They were marked with open symbols in cluster's CMD to discuss their membership. It is clear that 4 of them, i.e. V6, V7, V9, and V10 cannot belong to the cluster for sure because they are located far from the isochrone.

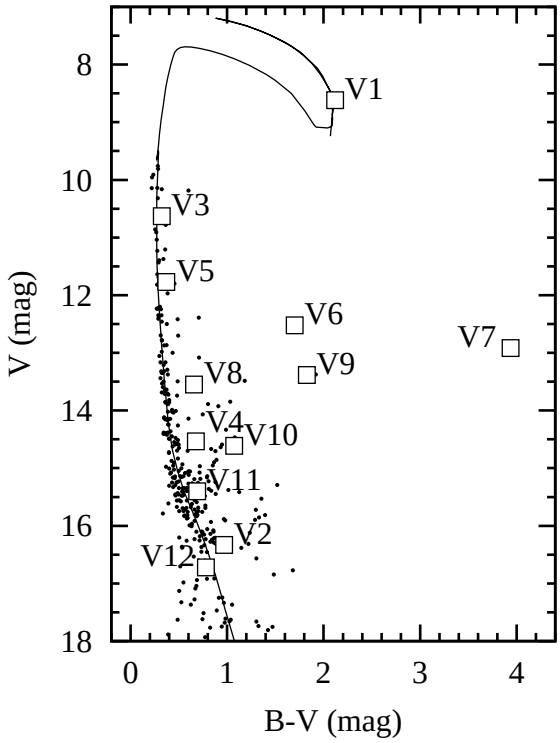

Figure 3. The colour-magnitude diagram for NGC 457 with best-fit isochrone of solar metallicity. The open symbols denote variable stars located within the cluster's limiting radius. See text for discussion.

V1 is a red and bright evolved star known as V466 Cas – an irregular pulsating variable. The star was found to be saturated in our short V band exposures, however its light curve was recorded in the B band database and plotted in Fig. 4. Its V magnitude and the $(B-V)$ colour index were taken from the SIMBAD database. The star and NGC 457 share the common proper motions (Perryman et al. 1997, Loktin & Beshenov 2003) what allows to conclude that V1 (V466 Cas) is cluster's member.

V2 is a faint contact system located near the isochrone. Assuming it belongs to the cluster, its absolute magnitude is $M_{\rm V} = 2.7$ mag. The same quantity calculated from the empirical formula of Ruciński & Duerbeck (1997) is 3.8 mag. Therefore, we conclude that V2 is a background star.

V3 is known as V765 Cas – an eclipsing system of EB type of spectral type B5. Our photometry clearly indicates that the variable is de facto a short period Algol-type system with a typical shape of minima and unequal brightness near the maxima. The variable is situated near the isochrone thus it can be treated as cluster's member. Additionally, the star was observed spectroscopically with the TSC90 in the Cassegrain mode to redetermine its spectral type. The spectrum is plotted in Fig. 6 where spectral lines that were used for classification are marked with arrows. The ratios of HeI[λ4026]/HI[λ4340] and HeI[λ4471]/HI[λ4340] were considered. As a result the spectral type of V3 (V765 Cas) was found to be slightly earlier, i.e. B2.5.

The light-curve variability of V4 indicates that it is a contact system. Assuming it belongs to the cluster, its absolute magnitude is $M_{\rm V} = 0.9$ mag. The same quantity calculated from the empirical formula of Ruciński & Duerbeck (1997) is much greater, i.e., 1.7 mag. Therefore, we conclude that the membership of V4 is unlikely.

Table 1. The list of variable stars detected in the field of NGC 457. $r_{\rm d}$ denotes the distance from the cluster center, $V_{\rm max}$ – the maximal brightness in V band, ΔV – the amplitude of variation in V, $(B-V)$ – the color index at the maximum of brightness, P – the period of variation, T_0 – the epoch of minimum brightness for eclipsing systems or maximum for pulsating stars in HJD, types of variability, and cluster membership.

ID	Coordinates J2000.0	$r_{\rm d}$ (')	$V_{\rm max}$ (mag)	ΔV (mag)	$B-V$ (mag)	P (day)	T_0 2454400+	Type	Member.
V1	011953+581830	2.7	–	–	–	–	–	MISC	Yes
V2	011929+581340	3.4	16.33	0.21	0.97	0.297507	15.7227	EW	No
V3	011909+581725	3.9	10.63	0.41	0.32	1.716280	15.6925	EA	Yes
V4	012014+581435	5.2	14.54	0.29	0.68	0.554334	15.8838	EW	No
V5	011902+581920	5.4	11.77	0.17	0.37	–	–	MISC	Likely
V6	011901+581009	8.3	12.52	0.21	1.70	–	–	MISC	No
V7	011852+580930	9.5	12.92	0.15	3.94	–	–	MISC	No
V8	011849+582353	9.6	13.55	0.44	0.66	1.720430	39.2008	EA	Likely
V9	011841+580756	11.6	13.39	0.23	1.83	–	–	MISC	No
V10	011908+580418	13.1	14.61	0.26	1.07	1.824432	18.6319	DCEP	No
V11	011751+581523	14.1	15.40	0.07	0.69	0.048419	15.3794	DSCT	Likely
V12	012043+582821	14.3	16.72	0.17	0.78	1.58797	18.0380	EA	Likely
V13	011848+583138	16.2	13.97	0.16	0.85	4.078303	28.0865	DCEP	–
V14	011749+582430	16.2	14.73	0.85	1.09	0.260823	16.0161	EW	–
V15	012048+583112	17.1	15.27	0.20	1.27	14.44783	42.7258	DCEP:	–
V16	011757+582749	17.2	15.83	0.16	0.98	0.283611	15.8081	EB	–
V17	011811+583200	19.0	16.71	0.36	1.06	0.374246	16.0459	EW	–
V18	011733+580922	19.2	15.68	0.29	0.84	0.381185	16.0145	EW	–
V19	012038+583438	19.5	14.95	0.72	0.88	0.552955	16.8896	EB	–
V20	012023+575726	20.3	15.15	0.62	0.72	0.602602	16.7453	RRAB	–
V21	012155+580611	21.0	13.79	0.14	0.64	1.168862	39.5650	CWB	–
V22	011805+575752	22.6	14.10	0.48	0.68	2.571928	19.8162	EA	–
V23	011708+582827	22.8	16.54	0.13	0.66	0.171418	15.6109	DSCT	–
V24	012223+582408	22.8	14.76	0.07	0.67	0.063837	15.4797	DSCT	–
V25	012145+580121	22.8	16.21	0.44	0.91	0.320205	15.8258	EW	–
V26	011952+584457	28.2	15.34	0.11	0.68	0.888248	17.4587	RR:	–
V27	012204+583811	28.6	13.86	0.52	0.83	3.953425:	18.7548	EA	–
V28	012038+574911	28.8	13.54	0.26	1.80	–	–	MISC	–
V29	011702+575631	29.0	15.71	0.12	1.09	7.845039	42.1188	DCEP:	–
V30	011917+574559	30.9	15.70	0.13	0.77	0.194762	15.6996	DSCT	–
V31	011712+584958	38.2	13.57	0.25	1.15	–	–	MISC	–

Remarks: V1 = V466 Cas, V3 = V765 Cas

V5 was found to be a blue pulsating variable of unresolved type, revealing brightness changes on long-time scale. It is situated in the bright part of cluster's CMD in the area of SPB variables, thus its membership is likely.

V8 is a detached eclipsing system. Its location in the CMD suggests that it can belong to the cluster.

V11 is a short-period pulsating variable of δ Scuti type. Assuming it belongs to the cluster, its absolute magnitude is $M_{\rm V} = 1.8$ mag – a typical value for variables of that type. This suggests that membership of V11 is likely.

V12 was classified as a faint detached eclipsing system. It is located near the isochrone, thus the variable can be treated as cluster's member.

Concluding, 6 variables detected in the field of NGC 457 are unquestionable or likely cluster members. The cluster is found to be rich in eclipsing systems represented by 3 detached binaries. More interestingly, brightness of the systems decreases with distance

from the cluster centre. Assuming an eclipsing binary belonging to the cluster, its maximum brightness can be interpreted as a rough approximation of its total mass. As a result of the mass segregation, more massive (i.e. brighter) systems are expected to occupy the central part of a cluster while the less massive (i.e. fainter) ones – the outer region (e.g. Lamers et al. 2006 and references therein).

The original photometric data are available on the survey's web site:
`http://www.astri.uni.torun.pl/~gm/OCS`.

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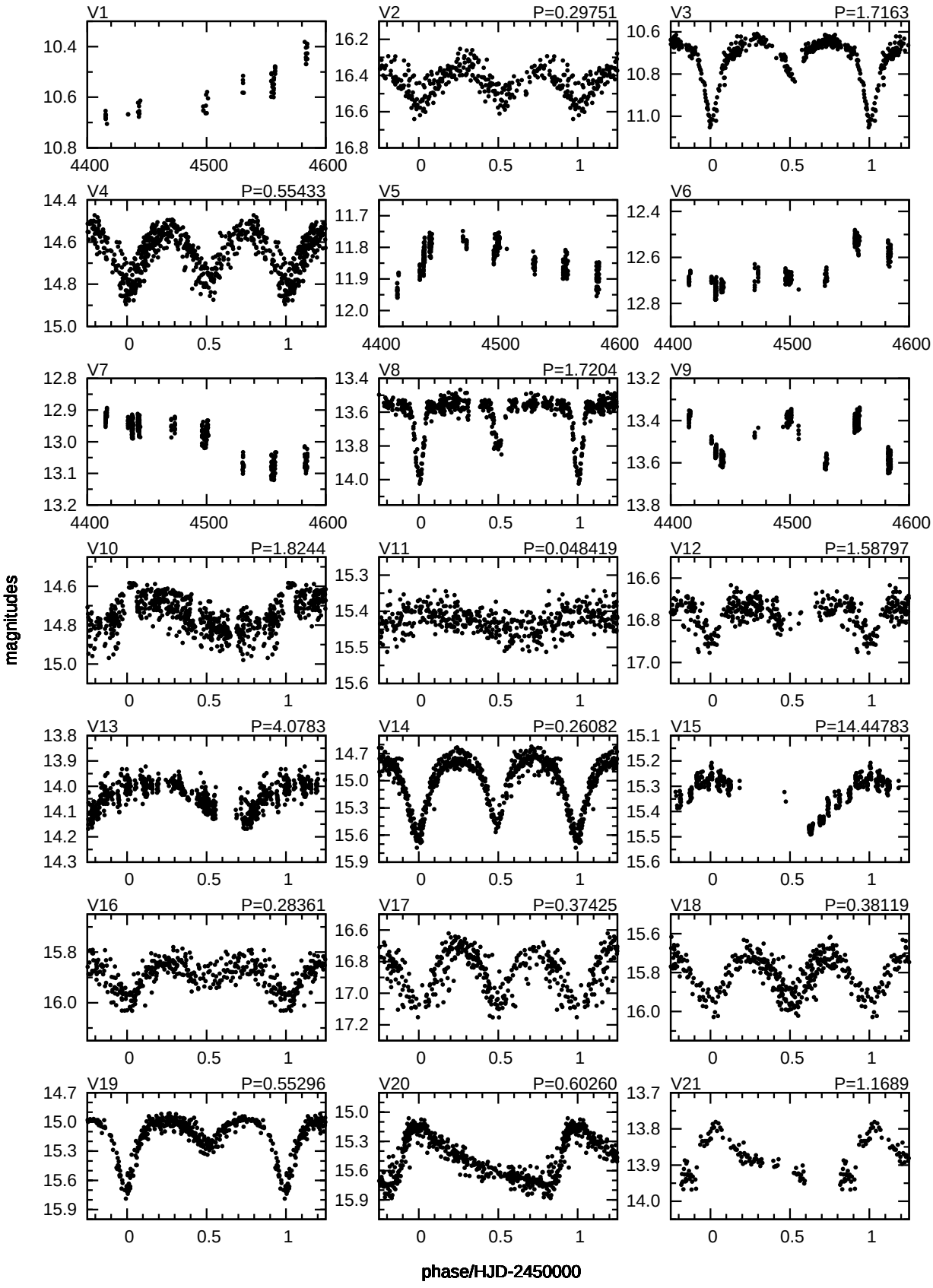

Figure 4. Light curves of variable stars discovered in the field of NGC 457.

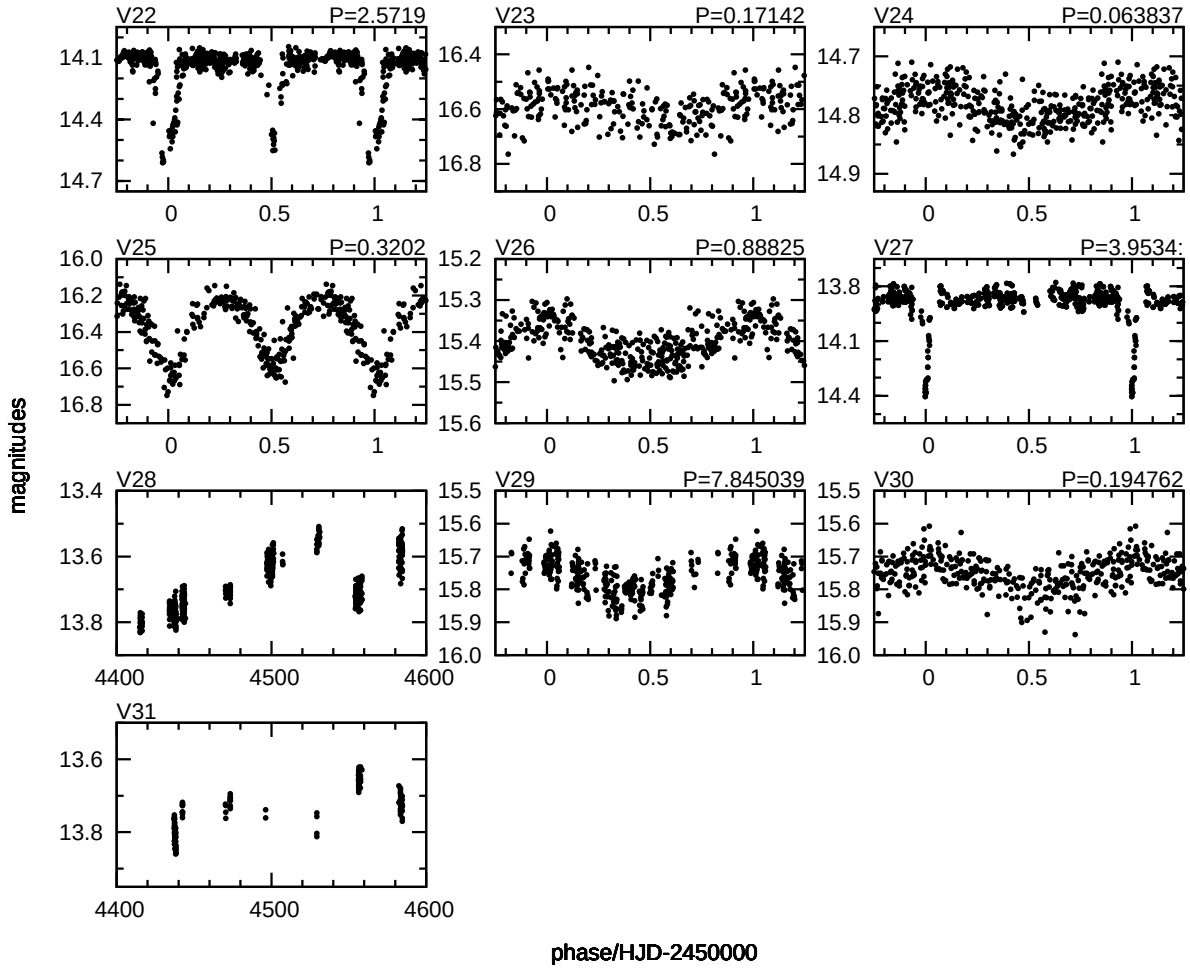

Figure 5. Light curves of variable stars discovered in the field of NGC 457.

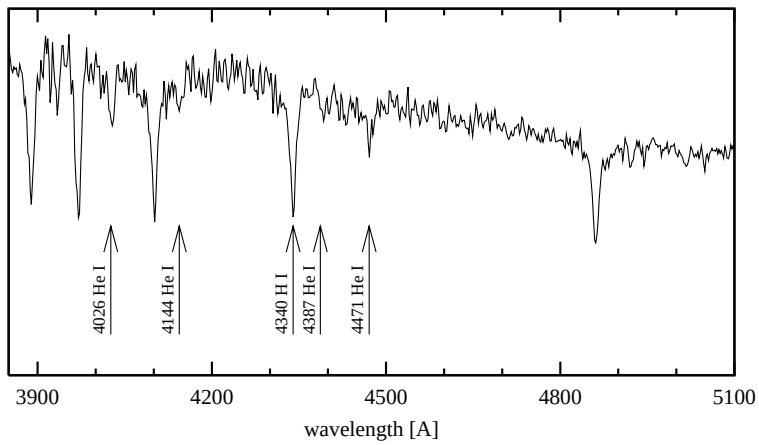

Figure 6. The optical spectrum obtained for V3 (V765 Cas) in the blue. Spectral lines that were used for classification are marked with arrows.