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A Study of 13 Classical Cepheids

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We present our detection of 6 new Classical Cepheids and a photometric study of 7 known Classical Cepheids. We used all observations available for these stars in the ASAS-SN, 1SWASP, ASAS-3, and NSVS online public archives, our photographic estimates (for 6 stars) and our CCD observations (for 2 stars). We analyzed all data using the period-search software developed by Dr. V.P. Goranskij for Windows environment. Light elements and parameters of the light curves were obtained.

1 Introduction

In this paper, we present a study of 13 Classical Cepheids, sub-types DCEP and DCEPS according to the GCVS classifications system (Samus et al., 2017). We used all observations available for these stars in the All-Sky Automated Survey for Supernovae (ASAS-SN[1]; Shappe et al., 2014; Kochanek et al., 2017), the Wide Angle Search for Planets (1SWASP [2]; Butters et al., 2010), The All Sky Automated Survey (ASAS-3[3]; Pojmanski, 2002), and the Northern Sky Variability Survey (ROTSE-I/NSVS[4], Wozniak et al., 2004) online public archives. The 1SWASP observations are available as FITS tables, which were converted into ASCII tables using the OMC2ASCII program as described by Sokolovsky (2007); we also used the SuperWASP FITS to ASCII lightcurve conversion service[5]. Two stars were studied using our multicolor CCD observations. Our CCD observations in the Johnson B, V, and R bands were performed at the Tien Shan Astronomical Observatory of the V.G. Fesenkov Astrophysical Institute, at the altitude of 2750 m above the sea level. The observatory has two Zeiss 1000-mm telescopes. Most of our observations were performed with the eastern Zeiss 1000-mm reflector; the detector was an Apogee U9000 D9 CCD camera. The time interval of the observations was from JD 2456771 to JD 2458816. Reductions were performed using the MaxIm DL aperture photometry package. Magnitudes of the comparison stars (in Johnson's B and V bands) were taken from the AAVSO Photometric All-Sky Survey (APASS[6]) catalog. The R-band observations could be presented only as magnitude differences with respect to the comparison star. For the R band, the total variability amplitude is given. For 6 stars,

[1] https://asas-sn.osu.edu
[2] http://wasp.cerit-sc.cz/form
[3] http://www.astrouw.edu.pl/asas/?page=aasc
[4] http://skydot.lanl.gov/nsvs/nsvs.php
[5] http://scan.sai.msu.ru/swasp_converter/
[6] http://www.aavso.org/download-apass-data

we estimated photographic plates of the Moscow stacks. The photographic plates were originally obtained in the time interval from JD 2433485 to JD 2450156 with the 40-cm astrograph of the Crimean Laboratory of Sternberg Astronomical Institute (series "A" of the Moscow plate collection). Magnitudes of the comparison stars ($B_{\rm pg}$ band) were taken from the USNO-B1.0 catalog (Monet et al., 2003). The stars were identified in the USNO-B1.0 and GSC (Morrison et al. 2001) catalogs. The tabulated coordinates of the variables were drawn from the Gaia DR2 catalog (Gaia Collaboration, Brown et al., 2018). Many of the studied stars were not detected as variables in the Gaia DR2 project. The light curves for all photometric data, finding charts, and photometric data we used are available online in the html version of this paper as a zip-archive. In this archive, the following notation is used in file names. "dt" means a data file; "lc", a light curve; and "ch" means a finding chart. Numbers correspond to Tables 1, 2, and Section 4. Symbols after star numbers in the names of data files correspond to the photometric system: B, V, R are our B, V, and R CCD observations; "p" stands for photographic data; "n", for NSVS data; "a', for ASAS-SN V-band data; "a3", for ASAS-3 observations; and "w" designates data from the 1SWASP survey.

2 New Classical Cepheids

In this section, we present our detection of six new Classical Cepheids. The variability of the stars 1–4 was detected in the GDS catalog (Hackstein et al., 2015). Later, these variables were included in the ASAS-SN Catalog of Variable Stars (II, Jayasinghe et al., 2018) and classified as semiregular stars, given their wrong periods. The variability of the stars 5 and 6 was suspected in 2008 by J. S. Shaw and coauthors in their electronic publication[7] according to NSVS data. One part of this work included over 70000 suspected variables detected according to statistical properties of the photometric data; types of variability were not determined. This data is available electronically as the untyped.cat file[8] (second list of variables). Our study of the stars 1–5 was based on ASAS-SN data. To improve the light elements, we additionally used, for stars 1, 2 and 4, ASAS-3 data; for star 5, we used NSVS and 1SWASP data. For star 6, we used NSVS data and our CCD observations (photometry in Johnson's V and R bands). The NSVS data are for a blend, so the variable was identified according to our CCD observations, and our CCD V magnitudes are given in Table 1b. Information on these stars is presented in Tables 1a and 1b. The light curves for two of the stars are displayed in Fig. 1. Table 1a contains star numbers from the GSC or USNO-B1.0 catalogs; equatorial coordinates (J2000); galactic latitude b; color indices $J-K$ and $B-V$ according to 2MASS (Skrutskie et al., 2006) and APASS catalogs, respectively. Table 1b contains type of variability; magnitudes at maximum and minimum in the V band; period and epoch of maximum of variability; $M-m$ asymmetry parameter of the phased light curve.

[7] http://www.physast.uga.edu/~jss/nsvs/
[8] http://www.physast.uga.edu/~jss/nsvs/untyped.cat.Z

Table 1a. New Cepheids – basic data

No.	Name		RA (J2000)	Dec (J2000)	b, deg	$J-K$	$B-V$
1		USNO-B1.0 0385-0155151	$09^{\rm h}30^{\rm m}45\overset{\rm s}{.}69$	$-51°28'54\overset{''}{.}9$	-0.1	0.90	–
2	GSC 08979-00459,	USNO-B1.0 0274-0451865	12 17 19.40	–62 30 18.3	+0.1	0.96	1.72
3	GSC 08983-02017,	USNO-B1.0 0253-0271835	12 20 24.49	–64 39 42.9	-2.0	0.73	1.49
4	GSC 08330-05432,	USNO-B1.0 0413-0521664	16 46 21.00	–48 39 23.8	-2.1	0.82	1.73
5	GSC 03164-00705,	USNO-B1.0 1339-0375939	20 22 57.15	+43 59 40.9	+3.9	1.22	2.34
6		USNO-B1.0 1295-0410006	20 25 20.47	+39 35 17.6	+1.0	2.17	–

Table 1b. New Cepheids – parameters

No.	Type	V, mag	P, days	Max, HJD	$M-m$
1	DCEP	13.37 – 14.01	4.4491	2457903.62	$0\overset{\rm p}{.}25$
2	DCEPS	13.17 – 13.45	3.9466	2457901.30	0.47
3	DCEPS	12.13 – 12.46	2.26815	2457901.50	0.40
4	DCEPS	12.21 – 12.55	4.3678	2457890.42	0.47
5	DCEPS:	13.78 – 13.90	2.67824	2457600.81	0.48
6	DCEP	16.84 – 17.58	10.2865	2451404.0	0.47:

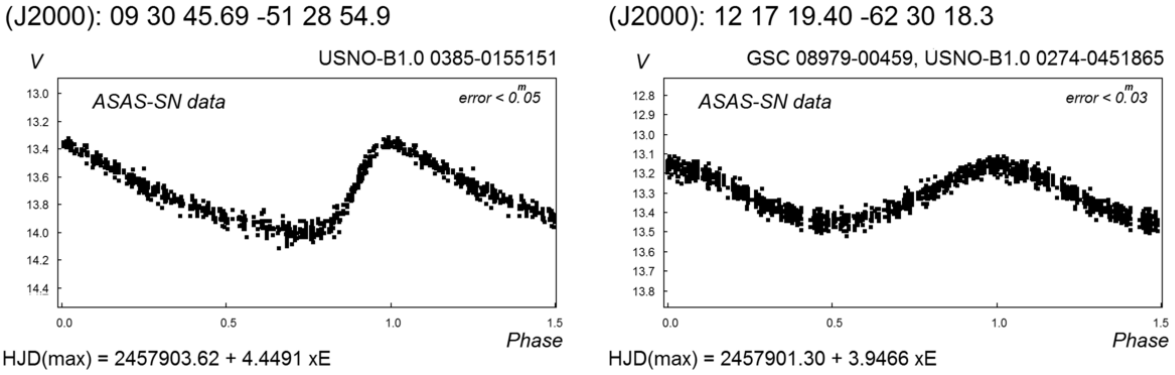

Figure 1. The phased light curves of two new classical Cepheids: USNO-B1.0 0385-0155151 (No. 1, type DCEP) and GSC 08979-00459 (No. 2, type DCEPS), ASAS-SN data.

3 Photographic photometry of known Cepheids

The results of our eye brightness estimates using photographic plates of the Moscow stacks and photometric survey study of six known Cepheids are presented in Tables 2a, 2b and, 2c. The photographic light curves for all studied stars are displayed in Fig. 2. The contents of Table 2a is similar to that of Table 1a. For one star (No. 5), its GCVS name, without GSC or USNO-B1.0 numbers, is given. Table 2b contains: type of variability; magnitudes at maximum and minimum in the photographic $B_{\rm pg}$ band and in the V band according to ASAS-SN data; period and epoch of maximum (for the ASAS-SN time interval); $M-m$ asymmetry parameter of the phased light curve. Asterisks mark ASAS-SN magnitudes for blends with close companions. Table 2c contains additional epochs of maxima, based on our photometric estimates, NSVS and 1SWASP data. For most stars, besides photographic data, we used observations from NSVS, 1SWASP, and ASAS-SN surveys. For the study of star 4, 1SWASP data is not available; we additionally used ASAS-3 data.

Table 2a. Known Cepheids – basic data

No.	Name		RA (J2000)	Dec (J2000)	b, deg.	$J-K$	$B-V$
7	GSC 03329-02310,	USNO-B1.0 1355-0116588	$04^h29^m22^s.62$	$+45°34'03''.2$	-2.1	0.84	1.59
8		USNO-B1.0 1405-0120933	04 30 20.61	+50 34 20.0	+1.5	0.87	1.58
9	GSC 03350-00271,	USNO-B1.0 1401-0122174	04 31 11.34	+50 09 03.6	+1.3	0.87	1.61
10		USNO-B1.0 1077-0123407	06 18 22.92	+17 47 54.6	+1.0	0.80	1.65
11	V1090 Cyg		21 45 18.41	+54 29 47.0	+0.9	0.86	1.34
12		USNO-B1.0 1430-0461182	21 48 28.96	+53 01 42.5	–0.5	0.87	1.86

Table 2b. Known Cepheids among known variables – parameters

No.	Type	V, mag	B_{pg}, mag	P, days	Max, HJD	$M-m$
7	DCEPS	13.15 – 13.36*	14.68 – 14.96	2.278273	2457601.03	$0^p.41$
8	DCEPS:	14.62 – 14.90	16.15 – 16.35	2.01448	2457600.30	0.42
9	DCEPS	14.20 – 14.57	15.75 – 16.15	2.983525	2457601.14	0.46
10	DCEP	14.24 – 14.72*	15.7 – 16.8	2.52180	2457601.95	0.27
11	DCEP	11.84 – 12.44	13.6 – 14.3	7.22992	2457602.90	0.27
12	DCEP	13.21 – 13.77	15.1 – 15.9	5.31882	2457604.17	0.28

Table 2c. Known Cepheids – additional maxima

No.	Photographic, JD	NSVS, HJD	1SWASP, HJD
7	2448248.72	2451506.65	2454400.05
8	2448301.46	2451500.46:	2454411.38
9	2448200.05	2451481.93	–
10	2444211.19	2451537.02	–
11	2436845.80	2451450.24	2454342.21
12	2436844.82	2451450.36	2454343.80

Comments for individual stars contain the history of variability discoveries, information concerning studies of the stars by other authors and photometric surveys. The variability of stars 1–4 was suspected by J. S. Shaw from NSVS data, untyped.cat[9]; thetype of variability was not determined. First of all, we give the NSVS number and two possible periods according to this publication. The stars No. 1–3, 5, and 6 are included in the ASAS-SN Catalogs of Variable Stars (Jayasinghe et al., 2018; Jayasinghe et al., 2019); the stars No. 1–5 are included in the ZTF catalog (Chen et al., 2020). In the Comments, we give the numbers in these catalogs, types, and periods. For the ASASSN-V stars, the number of the corresponding ASAS-SN catalog is given in brackets. For ZTF stars, the source ID number is in brackets.

Comments for individual stars:

7. NSVS 4267817, $P_1 = 4^d.55706824$, $P_2 = 2^d.27862279$. ASASSN-V J042922.58+453404.2 (VI), DCEPS, $P = 12^d.4183422$ (the detected period is wrong). ZTFJ042922.62+453403.2 (ID 91206), CEP, $P = 2^d.2781231$ d.

8. NSVS 4265264, $P_1 = 6^d.06138774$, $P_2 = 2^d.01851385$. ASASSN-V J043020.57+503419.1 (VI), type DCEPS, $P = 2^d.0146172$. ZTFJ043020.61+503420.0 (ID 91628), CEP, $P = 2^d.0145808$.

9. NSVS 4266268, $P_1 = 26^d.91220893$, $P_2 = 2^d.98422638$. ASASSN-V J043111.33+500903.8 (I), type DCEPS, $P = 2^d.98385$. ZTFJ043111.34+500903.7 (ID 91974), CEP, $P = 2^d.9837163$.

10. NSVS 9747467, $P_1 = 3^d.3135174$, $P_2 = 2^d.52006821$. ZTFJ061822.91+174754.7 (ID 150754), CEP, $P = 2^d.5227304$. Included in the catalog of the OGLE Collection of Galactic Cepheids (Udalski et al., 2018) as OGLE-GD-CEP-0030, type DCEP, light

[9] http://www.physast.uga.edu/~jss/nsvs/untyped.cat.Z

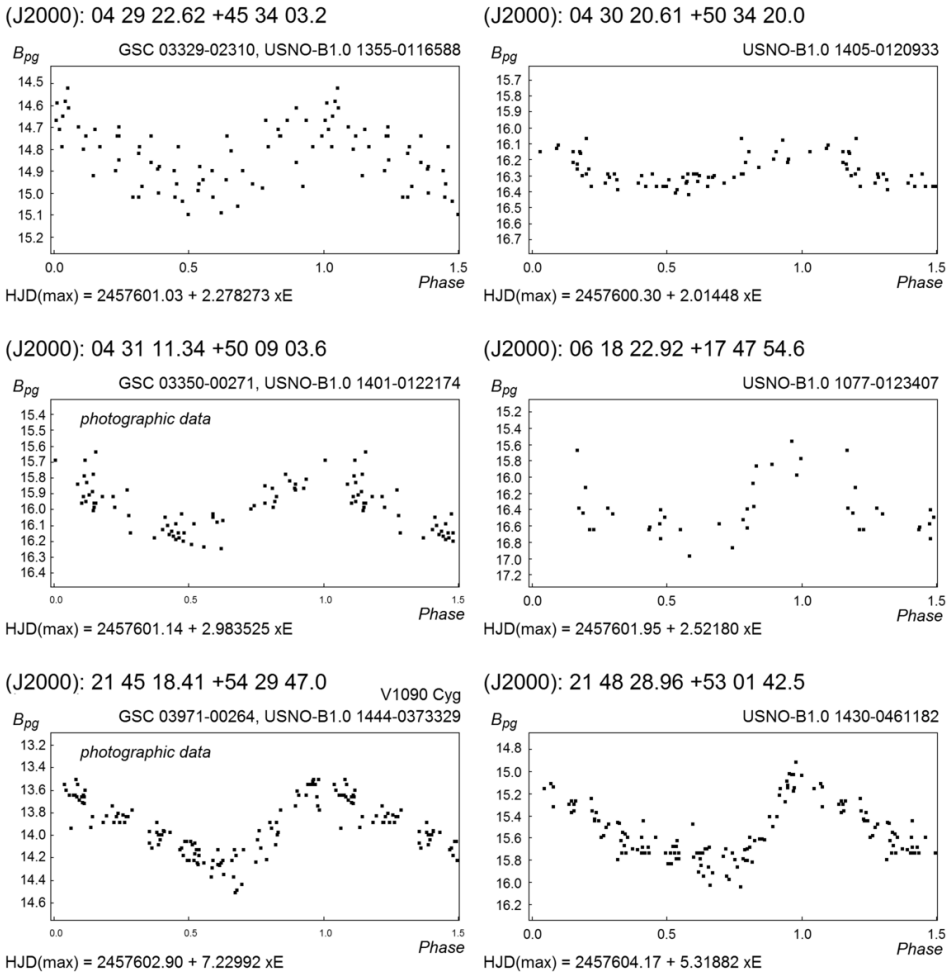

Figure 2. Photographic photometry light curves of six known Classical Cepheids.

elements HJD(max) = 2457001.7382 + $2^{\rm d}.521838 \times E$.

11. The variability was discovered by Romano (1964), the variable was characterized as a possible irregular variable (type I), magnitude range 12.6 – 13.9 (pg). This author noted that the star showed rapid oscillations and not excluded regular variability with the cycle of 12–14 days. Later, the GCVS gave type IS: according to this publication. ASASSN-V J214518.38+542946.8 (II), DCEP, $P = 7^{\rm d}.2309469$. ZTFJ214518.41+542947.0 (ID 699099), CEP, $P = 7^{\rm d}.2293001$. Included in the Gaia DR2 catalog of variables (Gaia Collaboration, Brown et al., 2018), type DCEP, $P = 7^{\rm d}.23098814$. The AAVSO data base includes 179 observations, observers T. Krzyt, R. Sabo, and E. Schwendeman. These data confirm our light elements.

12. The variability was detected by Hoffman et al. (2009) from NSVS data, NSVS 3412804. The variable was classified as a CEP star, with the period $P = 1^{\rm d}.23002$ (this period is wrong). ASASSN-V J214828.90+530142.3 (II), DCEP, $P = 1^{\rm d}.2274276$ (this period is also wrong). Included in the Gaia DR2 catalog of variables with a wrong type, MIRA_SR (long period-variable stars, including omicron Ceti and semiregular variables). Sebastian Otero, in his communication to VSX AAVSO (2018-12-22), gives the new light elements, HJD(max) = 2457886.14 + 5.31900 × E, based on ASAS-SN data.

4 Study of USNO-B1.0 1425-0436360

The variability of USNO-B1.0 1425-0436360 (No. 13 in the present study), RA(J2000) = $21^{\rm h}12^{\rm m}41\overset{\rm s}{.}86$, Dec(J2000) = $+52°30'07\overset{''}{.}2$, was suspected in 2008 by J.S. Shaw on the base of NSVS data (NSVS 5850436, type not determined, $P_1 = 4\overset{\rm d}{.}62325707$, $P_2 = 4\overset{\rm d}{.}63503822$). We studied all data available at the time, those from NSVS and 1SWASP. This data measured combined light of two stars (a photometrical blend). We suspected the classical Cepheid type because of its galactic latitude ($b = +2\overset{\circ}{.}8$). To identify the variable, we started multicolor Johnson B, V, and R-band CCD observation of its field. Our observations were performed in the JD 2456771–2457971 time interval. We obtained the light elements, light curve parameters of the variable. Our assumption was confirmed: USNO-B1.0 1425-0436360 is a classical Cepheid (type DCEP). Later, the light elements were improved using ASAS-SN data (the variable is not included in the ASAS-SN Catalogs of Variable Stars). In 2020, the variable was listed in the ZTF catalog, ZTFJ211241.86+523007.2 (ID 666800), $P = 4\overset{\rm d}{.}618581$. The magnitude range from the ASAS-SN data is $15.4 - 16.1$ (V). The color index from the 2MASS catalog is $J - K = 1.44$. Using all available data, we obtained the following light elements (the epoch is for the time range of the CCD observations): HJD(max) = $2457095.50 + 4\overset{\rm d}{.}61816 \times E$. Other times of maxima, according to data from photometric archives, are (HJD): 2451452.11 (NSVS), 2454343.08 (1SWASP), 2457603.62: (ASAS-SN). The magnitude range from CCD observations is $18.27 - 19.27$ (B), $15.32 - 16.06$ (V), the full R-band amplitude is $0\overset{\rm m}{.}57$. The $B - V$ color index varies from 2.95 (maximum) to 3.21 (minimum). The light curve asymmetry parameter is $M - m = 0\overset{\rm p}{.}24$. The variable is located in the field of the open cluster Kronberger 80 (at the angular distance of $10'.7$); the cluster membership is not excluded. The light curves of USNO B1.0 1425-0436360 for our CCD data, ASAS-SN, 1SWASP, and NSVS are displayed in Fig. 3.

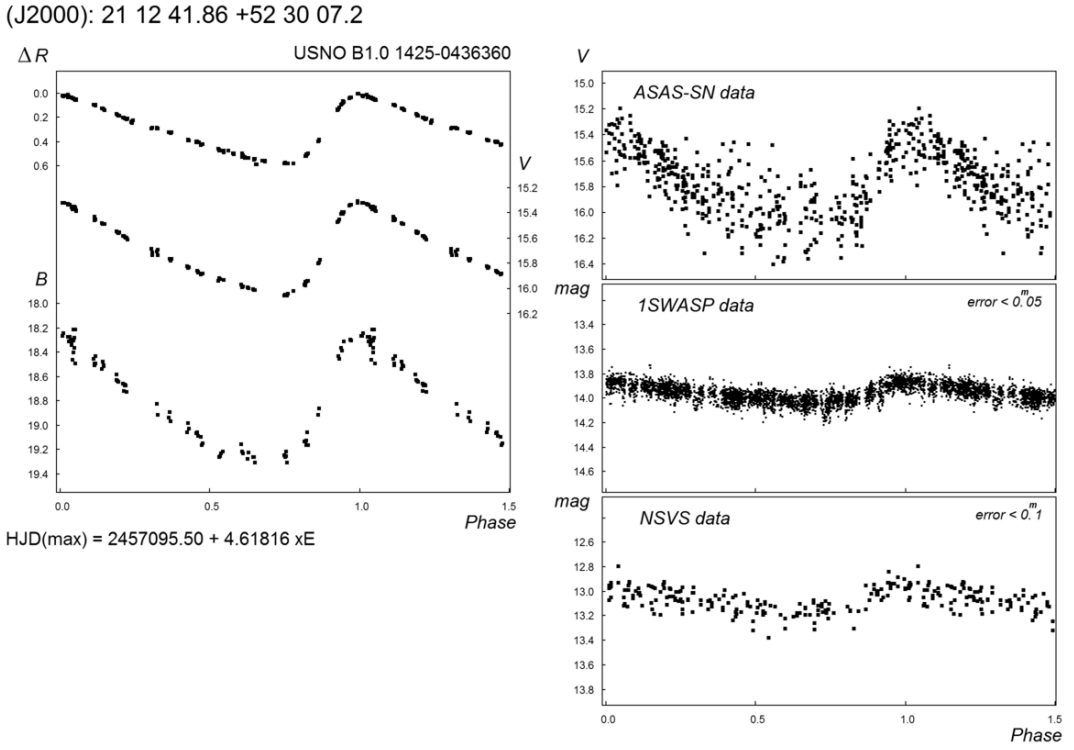

Figure 3. The phased light curves of USNO-B1.0 1425-0436360.

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