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BVI_c light curves of type II Cepheids and RV Tau type stars

L.N. Berdnikov[1,*], A.Y. Kniazev[1,2,3], A.K. Dambis[1], V.V. Kravtsov[1], E.N. Pastukhova[4]

[1]*Sternberg Astronomical Institute of the Moscow State University, 13 Universitetskii Pr., Moscow, 119992 Russia*
[2]*South African Astronomical Observatory, P.O. Box 9, Observatory, Cape Town, 7935 South Africa*
[3]*Southern African Large Telescope, P.O. Box 9, Observatory, Cape Town, 7935 South Africa*
[4]*Institute of Astronomy, Russian Academy of Sciences, 48 Pyatnitskaya Str., Moscow, 119017 Russia*

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A total of 16568 measurements in the BVI_c photometric system were acquired in 2005–2014 for 64 type II Cepheids and 54 RV Tau type stars. Observations were made with the 76-cm telescope of the South African Astronomical Observatory (SAAO, South Africa) and the 40-cm telescope of the Cerro Armazones Observatory (OCA) of the Universidad Catolica del Norte in Chile. We report light-curve plots and suitable ephemeris. We found six type-II Cepheids with periods shorter than 2 days to be likely anomalous Cepheids.

Keywords: Stars: variables: Cepheids, Stars: Population II, RV Tau type stars, Techniques: photometric

1 Introduction

Type II Cepheids – classified as CW type variables in the General Catalogue of Variable Stars (GCVS)(Samus et al. 2012) – are old stars with ages greater than 10^9 yr, which concentrate to the Galactic center. Like RR Lyrae type stars, they are good distance indicators that can be used to study the structure of the Milky-Way thick disk and halo.

An analysis of Cepheid data acquired in microlensing projects in the Magellanic clouds and the Galactic bulge (see, e.g., (Soszynski et al. 2008, 2011) showed that CW type Cepheids and RV Tau type stars outline the same period-luminosity relation

*Email: leonid.berdnikov@gmail.com

if half the period is adopted for RV Tau type stars. Hence RV Tau type stars can also serve as bona fide distance indicators for the studies of the structure of the Galactic halo and thick disk.

In this paper we report BVI_c photoelectric and CCD observations of 64 CW type Cepheids and 54 RV Tau type variables, with 90% of these stars so far lacking such kind of photometry.

2 Observations

CCD observations were performed during 11 observing seasons from April 2005 through May 2014 with the 76-cm telescope of South African Astronomical Observatory (SAAO) in South Africa and with the 40-cm telescope of Cerro Armazones Observatory (OCA) of the Universidad Catolica del Norte in Chile. We used SBIG CCD ST-10XME camera equipped with filters of the Kron–Cousins BVI_c system (Cousins 1976).

We first reduced only observations acquired using "all sky" technique and only on photometric nights to produce the catalog of positions and magnitudes for all objects on the best CCD frames. We selected from this catalog constant stars, which we then used as comparison stars to acquire differential photometry for all stars in all CCD frames, including those taken on non-photometric nights. For a complete description of the observation and reduction technique see (Berdnikov et al. 2011).

Photoelectric photometry was performed from December 2006 through January 2008 with the 76-cm telescope of South African Astronomical Observatory (SAAO) in South Africa. We used a single-channel pulse-counting photoelectric photometer equipped with a Hamamatsu R943-02 photomultiplier and BVI_c filters of the Kron–Cousins system (Cousins 1976). We described the technique of observations, reduction for atmospheric extinction, and transformation of instrumental magnitudes into the standard photometric system in our earlier paper (Berdnikov, Turner 2004).

3 Results

We acquired a total of 10384 photometric measurements for 64 type II Cepheids and 6184 photometric measurements for 54 RV Tau type variables. The results of observations can be found in electronic form in (Berdnikov et al. 2023).

Small period changes in pulsating variables, which have practically no effect on the inferred distances, are often apparent even on several-years long time intervals (see, e.g., Berdnikov, Pastukhova (1994a, 1994b, 1995)); as a result, for most of variable stars the actual times of maxima (for CW Cepheids) or minima (for RV Tau stars) deviate appreciably from the ephemerides published by 2014 (GCVS (Samus et al. 2012) and ASAS-3 catalog of variable stars (Pojmanski 2002)). For this reason, we plot our light curves with the ephemerides from Tables 1–4 [in Tables 2 and 4 we provide Gaia DR3 J2000 coordinates for the epoch of J2016.0 (Gaia Collaboration et al. 2016, 2023) along with ASAS names of the stars], which we improved based on the times of maxima (for Cepheids) and minima (for RV Tau type stars) computed

using the Hertzsprung method (Hertzsprung 1919) whose computer implementation is described in (Berdnikov 1992). We determined the ephemerides based on V-band observations reported in Berdnikov et al. (2023) and CCD observations from the ASAS-3 catalog (Pojmanski 2002); all ephemerides in Tables 1–4 refer to the V band.

Table 1 Ephemerides for CW type Cepheids listed in the GCVS.

Cepheid	Epoch, JD hel	Period, days
V475 Ara	2436721.6336	1.50120000
GK Cen	2455412.1963	1.949833
IU Cen	2453336.0704	3.3192516
V415 Cen	2454236.79	26.6603
V445 Cen	2455470.70	14.2172
BV Cha	2454161.9961	1.23803885
XY Hyi	2455907.484	22.1587
DF Hyi	2454267.0129	1.1225989
VX Ind	2453590.2859	1.4619446
UX Lup	2454740.410	16.25356
II Nor	2450207.66	23.5333
CE Oph	2454407.253	15.88766
V2137 Oph	2456777.5075	1.18202240
V2628 Oph	2454487.34	13.3088
GK Sgr	2455555.692	14.86662
V1821 Sgr	2456784.6324	9.51627060
V1822 Sgr	2454863.00	7.52557
V1828 Sgr	2456783.50	12.99325
V1882 Sgr	2454908.3355	2.71119248
V2284 Sgr	2454688.573	1.938658
V2511 Sgr	2456767.0966	1.72475700
V2546 Sgr	2454580.82	14.3905
V2793 Sgr	2454641.989	16.22011
V2944 Sgr	2454649.727	12.22564
V3820 Sgr	2450804.12	13.13825
V507 Sco	2455021.85	11.79856
V516 Sco	2455296.726	15.65785
V517 Sco	2455209.189	1.176306
V532 Sco	2455131.2527	24.14939308
V533 Sco	2456745.8888	15.52900000
V542 Sco	2454546.653	15.23567
V706 Sco	2455253.224	12.63584
V708 Sco	2455182.329	27.1700
V742 Sco	2455005.93	14.51770
DD Vel	2455045.72	13.2075
YZ Vir	2454790.187	14.47271

Figures 1–7 show the three-color light curves of CW type Cepheids. The circles and dots show photoelectric and CCD observations, respectively. For 61 stars such light curves were obtained for the first time. The scatter of data points in the plots indicates that observational errors are close to 0.01^m. Observations of three Cepheids – ASAS

Table 2 Ephemerides for CW type Cepheids listed in the ASAS-3 catalog.

Cepheid	Right ascension, (J2000)	Declination, (J2000)	Epoch,	Period,
	h m s	° ′ ″	JD hel	days
ASAS 003041-4416.4	00 30 41.38	-44 16 22.6	2454205.2546	1.9006898
ASAS 014049-6729.7	01 40 49.20	-67 29 42.0	2454302.9288	1.1225970
ASAS 044546-1748.7	04 45 46.09	-17 48 44.7	2455164.4719	0.9195727
ASAS 050514+2145.8	05 05 14.26	+21 45 48.9	2453824.124	13.9410
ASAS 070747-2455.2	07 07 46.78	-24 55 10.3	2454154.920	11.18265
ASAS 072845-4428.3	07 28 44.78	-44 28 16.6	2454526.8885	1.4377536
ASAS 092701+1412.1	09 27 00.91	+14 12 10.2	2455566.9273	1.3212185
ASAS 094844-3921.4	09 48 43.82	-39 21 29.4	2454667.2918	1.2017308
ASAS 104440-6003.6	10 44 40.49	-60 03 33.2	2454349.02	105.833
ASAS 115302-2313.0	11 53 01.96	-23 12 59.2	2453855.360	15.5727
ASAS 133028-3812.5	13 30 28.20	-38 12 30.0	2453593.49	15.2940
ASAS 140434-4532.4	14 04 33.93	-45 32 31.8	2455623.797	16.99892
ASAS 142357-0100.1	14 23 57.88	-01 00 10.3	2455579.8951	1.3067458
ASAS 144155-1938.1	14 41 55.62	-19 37 58.0	2455259.9049	1.0118964
ASAS 160723-2957.2	16 07 22.77	-29 57 11.8	2455424.186	37.3283
ASAS 161115-1651.6	16 11 14.89	-16 51 40.2	2454941.23	13.2261
ASAS 164328-2122.6	16 43 28.20	-21 22 39.3	2453655.88	37.439
ASAS 165857-4312.3	16 58 57.07	-43 12 19.2	2455085.865	10.99158
ASAS 171022-0403.6	17 10 22.06	-04 03 36.2	2454780.795	15.1863
ASAS 173443-1741.8	17 34 42.87	-17 41 51.1	2454974.20	18.1107
ASAS 174134-4854.6	17 41 34.45	-48 54 36.4	2455456.358	10.54989
ASAS 185152-1333.6	18 51 51.58	-13 33 32.3	2455500.7640	1.268903
ASAS 190418-3142.2	19 04 17.65	-31 42 13.0	2454136.70	39.328
ASAS 190649+2300.6	19 06 48.59	+23 00 32.1	2454738.974	4.839092
ASAS 190744-5950.7	19 07 44.41	-59 50 43.9	2454812.2021	1.790798
ASAS 193606-2538.3	19 36 05.69	-25 38 13.2	2455434.182	9.51917
ASAS 193907-2049.2	19 39 06.56	-20 49 14.1	2455442.829	14.2869
ASAS 211406+0019.2	21 14 06.02	+00 19 12.1	2455168.146	15.2634
ASAS 231839-6752.5	23 18 38.74	-67 52 27.5	2455362.3226	2.5515796

115302-2313.0, ASAS 174134-4854.6, and ASAS 185152-1333.6 – do not fit into a single light curve because of abrupt changes of their periods; in Figure 8 we repeat these light curves taking into account the shifts of seasonal light curves for these Cepheids.

A comparison of the light curves of type II Cepheids in our Galaxy (Figures 1–8) with the light curves for the corresponding LMC stars (Soszynski et al. 2008) shows that Cepheids with periods shorter than 2 days, large amplitudes and highly asymmetric light curves – V475 Ara, DF Hyi, ASAS 003041-4416.4, ASAS 014049-6729.7, ASAS 094844-3921.4, and ASAS 142357-0100.1 – are most likely anomalous Cepheids (BLBOO type in the GCVS classification), which in the period-luminosity diagram for LMC Cepheids lie almost halfway between classical and type II Cepheids.

Three-color light curves for RV Tau type stars in Figures 9–15 are shown by circles. For 43 stars such observations were made for the first time.

Table 3 Ephemerides for RV Tau type stars listed in the GCVS.

Star	Epoch, JD hel	Period, days
DY Aql	2455149.47	131.86
EZ Aql	2455148.87	38.69
V590 Aql	2455186.41	117.38
RT Ara	2455117.38	76.43
UY Ara	2455107.99	56.91
V686 Ara	2455111.62	36.21
KO Cnc	2455129.78	66.23
RX Cap	2455163.93	67.83
GK Car	2455197.39	55.30
RU Cen	2455112.28	64.66
SX Cen	2455165.19	32.96
CN Cen	2455145.43	50.60
GP Cha	2455181.69	100.07
SY Cir	2455094.23	46.25
V385 CrA	2455137.00	78.97
V338 Lib	2455100.66	311.61
AS Mus	2455125.04	52.92
EP Mus	2455075.43	42.65
PX Mus	2455028.92	58.91
V338 Mus	2454929.83	206.41
V404 Nor	2455100.52	53.64
TT Oph	2455089.32	60.95
TX Oph	2454980.78	133.59
UZ Oph	2455090.23	87.40
V453 Oph	2455070.00	81.02
AR Pup	2455254.36	76.72
V594 Pup	2455132.62	57.93
V558 Sgr	2455102.80	63.36
V760 Sgr	2455164.45	45.16
V1864 Sgr	2455130.53	80.80
V411 Sco	2455142.85	133.06
V423 Sco	2455115.17	59.60
AN Sct	2455217.62	65.41
HI Tel	2455207.04	66.28
NW Tel	2455218.33	68.99
CY Vel	2455193.97	39.07
V517 Vel	2455088.95	161.15

The periods of most of RV Tau type stars are significantly longer than the duration of observational seasons, making it impossible to achieve complete light-curve coverage. We therefore show for comparison ASAS-3 (Pojmanski 2002) observations (small points), which, unfortunately, were made only in one, V-band filter and are indicative of the shape of the light curves and their variation.

The large scatter of data points on the light curves of DY Aql, SX Cen, GP Cha, PX Mus, UZ Oph, and AR Pup can be explained by the fact that according to

Table 4 Ephemerides for RV Tau type stars listed in the ASAS-3 catalog.

Star	Right ascension, (J2000)	Declination, (J2000)	Epoch,	Period,
	h m s	° ′ ″	JD hel	days
ASAS 093507-4534.8	09 35 06.96	-45 34 48.0	2455352.13	122.36
ASAS 121159-5847.0	12 11 59.15	-58 47 00.7	2455427.81	198.60
ASAS 135914-5210.7	13 59 14.50	-52 10 42.2	2455049.04	75.81
ASAS 154200-2046.7	15 42 00.05	-20 46 45.9	2455119.34	49.87
ASAS 170042-3300.4	17 00 42.17	-33 00 25.7	2455108.36	46.23
ASAS 170320-2428.9	17 03 19.64	-24 28 56.8	2454868.31	90.02
ASAS 171139-2328.0	17 11 39.18	-23 28 00.4	2454850.62	53.07
ASAS 171413-1320.7	17 14 13.61	-13 20 40.0	2455060.13	56.02
ASAS 172055-2129.3	17 20 54.98	-21 29 20.4	2455186.22	68.78
ASAS 174955-4019.9	17 49 54.93	-40 19 53.2	2455150.58	60.85
ASAS 175310-1519.6	17 53 09.88	-15 19 33.6	2455180.44	58.98
ASAS 175846+2428.4	17 58 46.52	+24 28 25.0	2454803.51	94.74
ASAS 175934-3935.1	17 59 34.48	-39 35 07.0	2455194.35	61.80
ASAS 181811-3533.7	18 18 11.84	-35 33 43.4	2455117.27	70.97
ASAS 193648-3425.8	19 36 48.07	-34 25 49.6	2455097.67	106.37
ASAS 194411-1119.5	19 44 11.12	-11 19 27.3	2455149.13	58.65
ASAS 202412-2457.0	20 24 11.74	-24 57 01.4	2455179.57	51.35

the GCVS classification these are RVB-subtype variables, which are characterized by large periodic variations of the mean magnitude. The remaining RV Tau type stars belong to RVA type and the mean magnitude of these variables remains constant [1].

The new data obtained in this study will be used to investigate the structure and kinematics of the old disk and Galactic halo and also to study the properties of Cepheids and RV Tau type stars and, particular, to search for evolutionary changes in their periods.

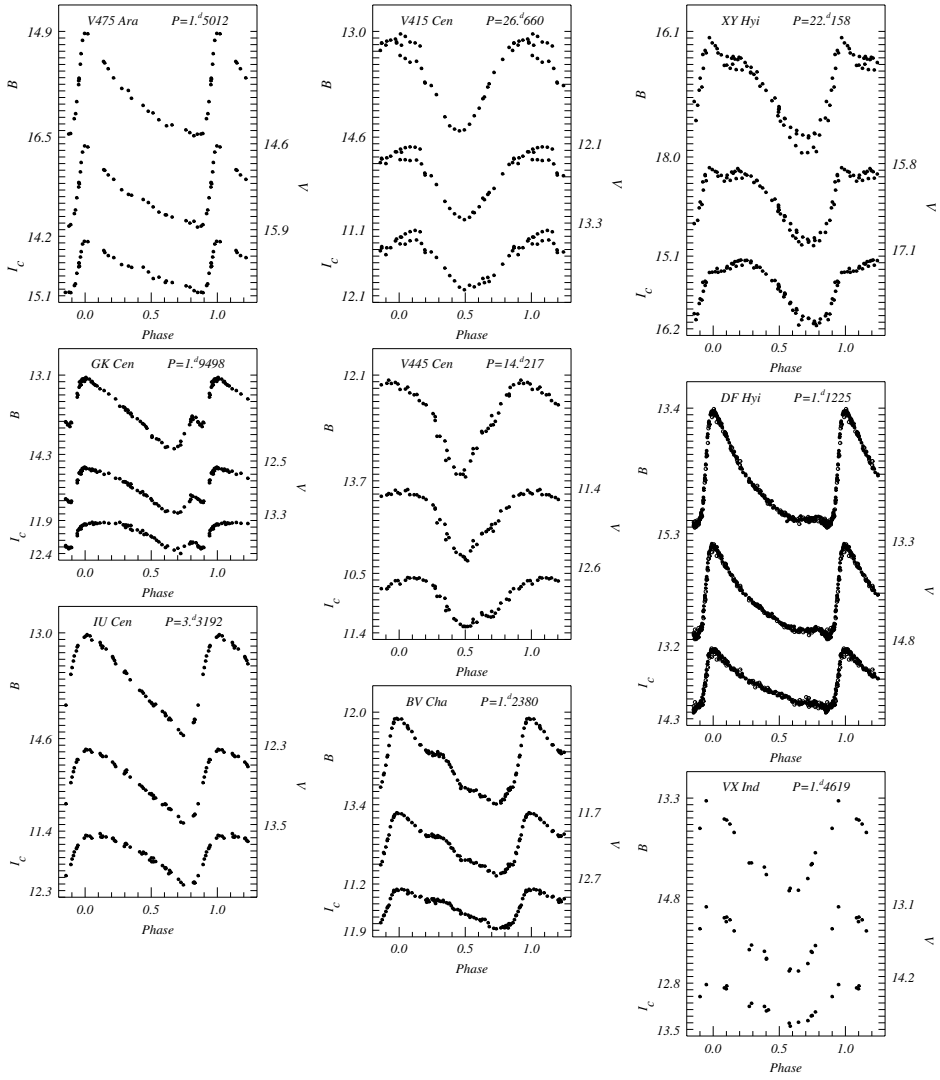


Figure 1 Light curves of type II Cepheids: V475 Ara, GK Cen, IU Cen, V415 Cen, V445 Cen, BV Cha, XY Hyi, DF Hyi and VX Ind. The circles and dots show photoelectric and CCD observations, respectively.

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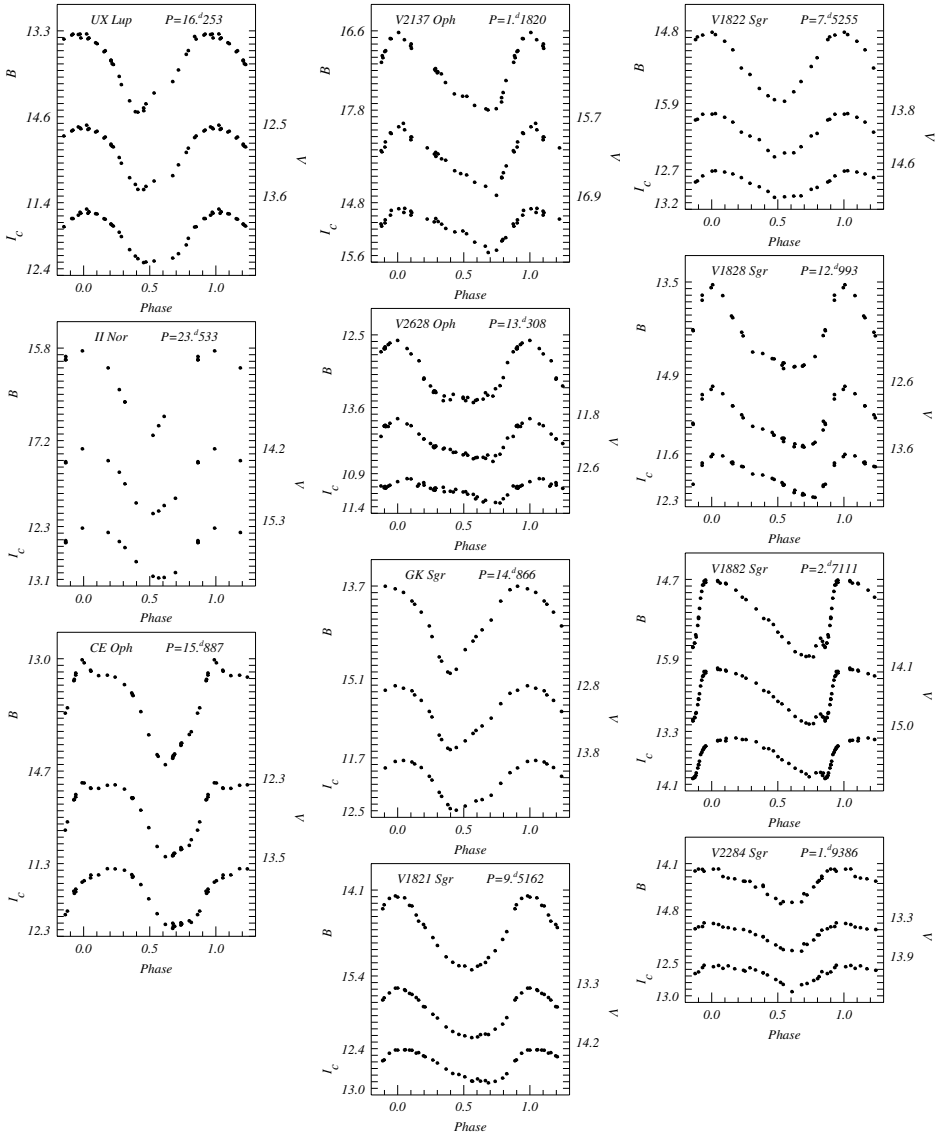


Figure 2 The same as in Figure 1 but for UX Lup, II Nor, CE Oph, V2137 Oph, V2628 Oph, GK Sgr, V1821 Sgr, V1822 Sgr, V1828 Sgr, V1882 Sgr and V2284 Sgr.

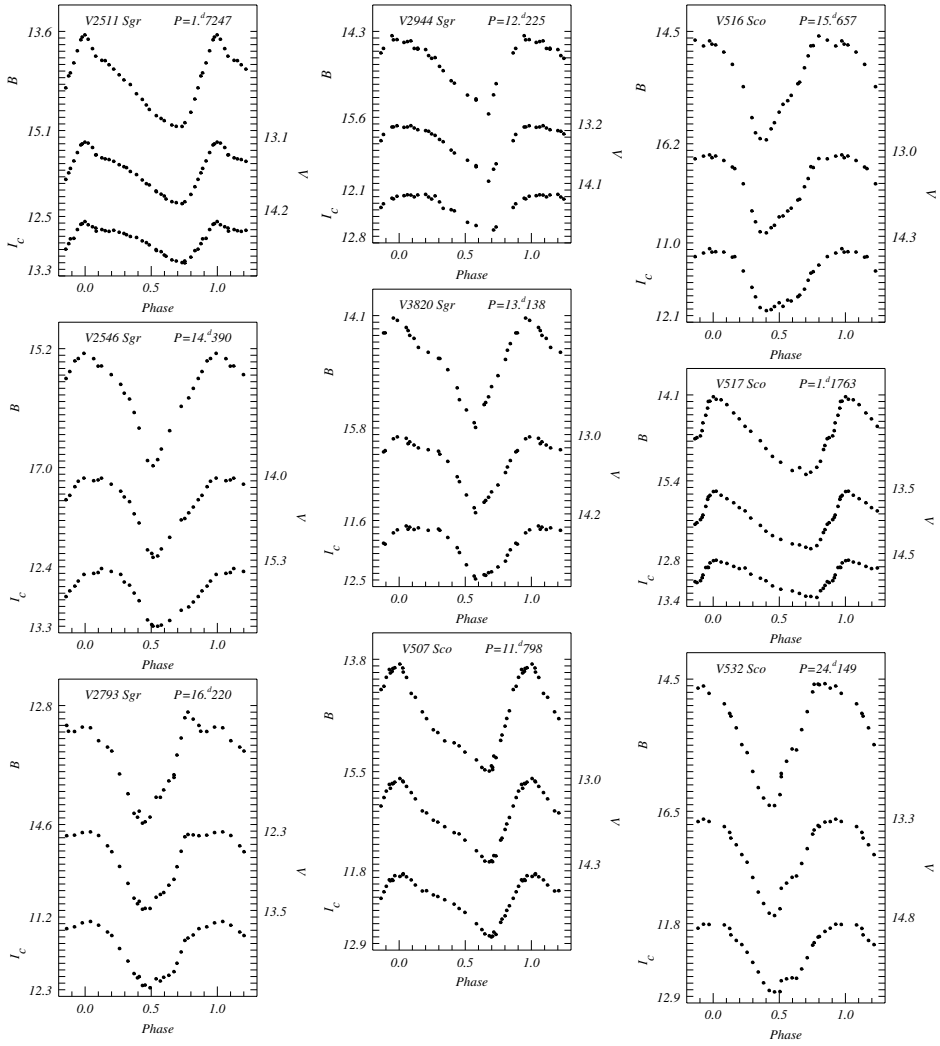


Figure 3 The same as in Figure 1 but for V2511 Sgr, V2546 Sgr, V2793 Sgr, V2944 Sgr, V3820 Sgr, V507 Sco, V516 Sco, V517 Sco and V532 Sco.

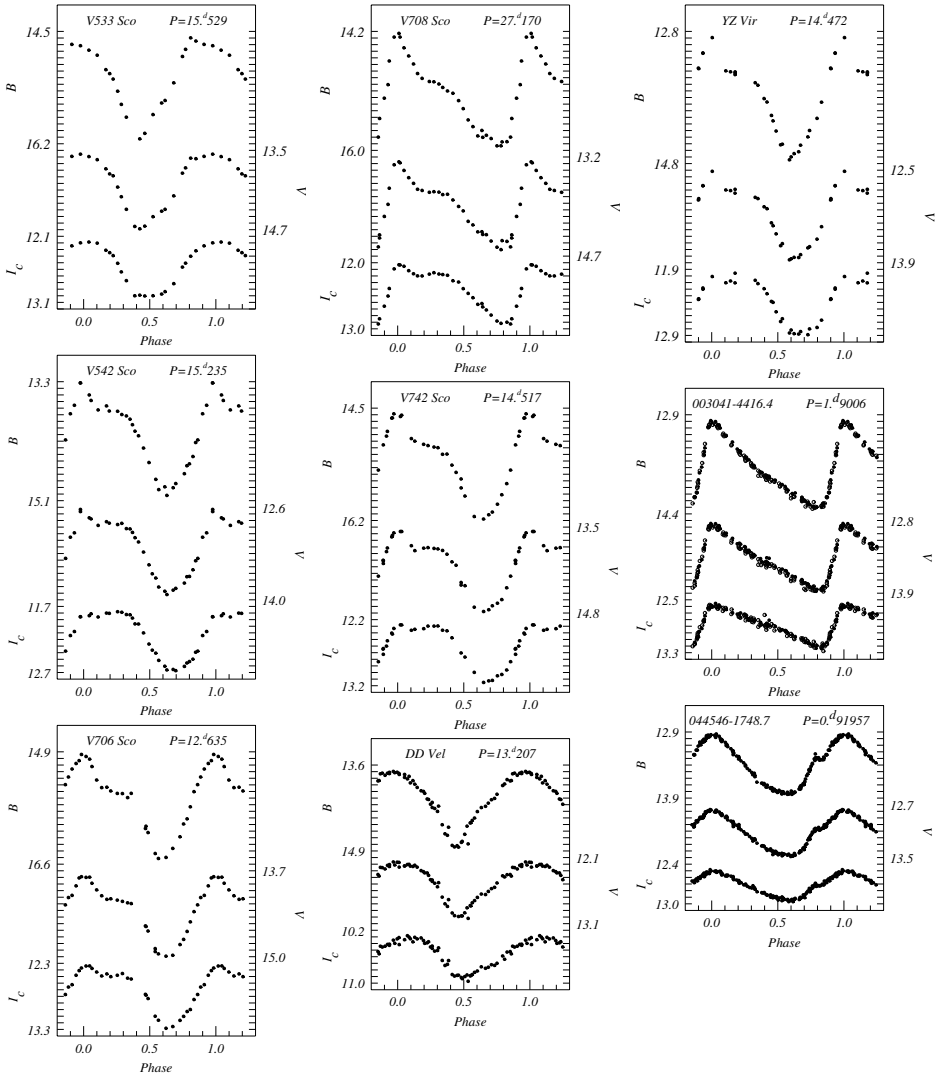


Figure 4 The same as in Figure 1 but for V533 Sco, V542 Sco, V706 Sco, V708 Sco, V742 Sco, DD Vel, YZ Vir, ASAS 003041-4416.4 and ASAS 044546-1748.7.

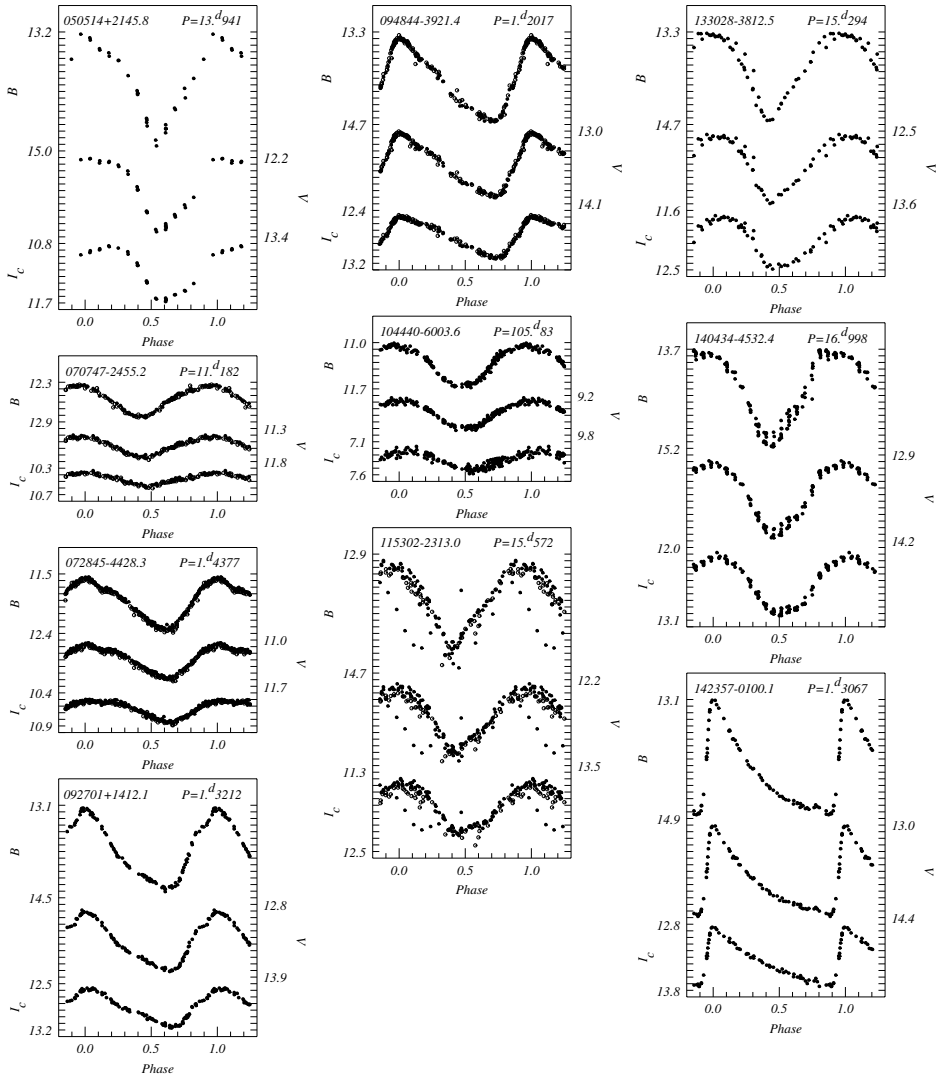


Figure 5 The same as in Figure 1 but for ASAS 050514+2145.8, ASAS 070747-2455.2, ASAS 072845-4428.3, ASAS 092701+1412.1, ASAS 094844-3921.4, ASAS 104440-6003.6, ASAS 115302-2313.0, ASAS 133028-3812.5, 140434-4532.4 and ASAS 142357-0100.1

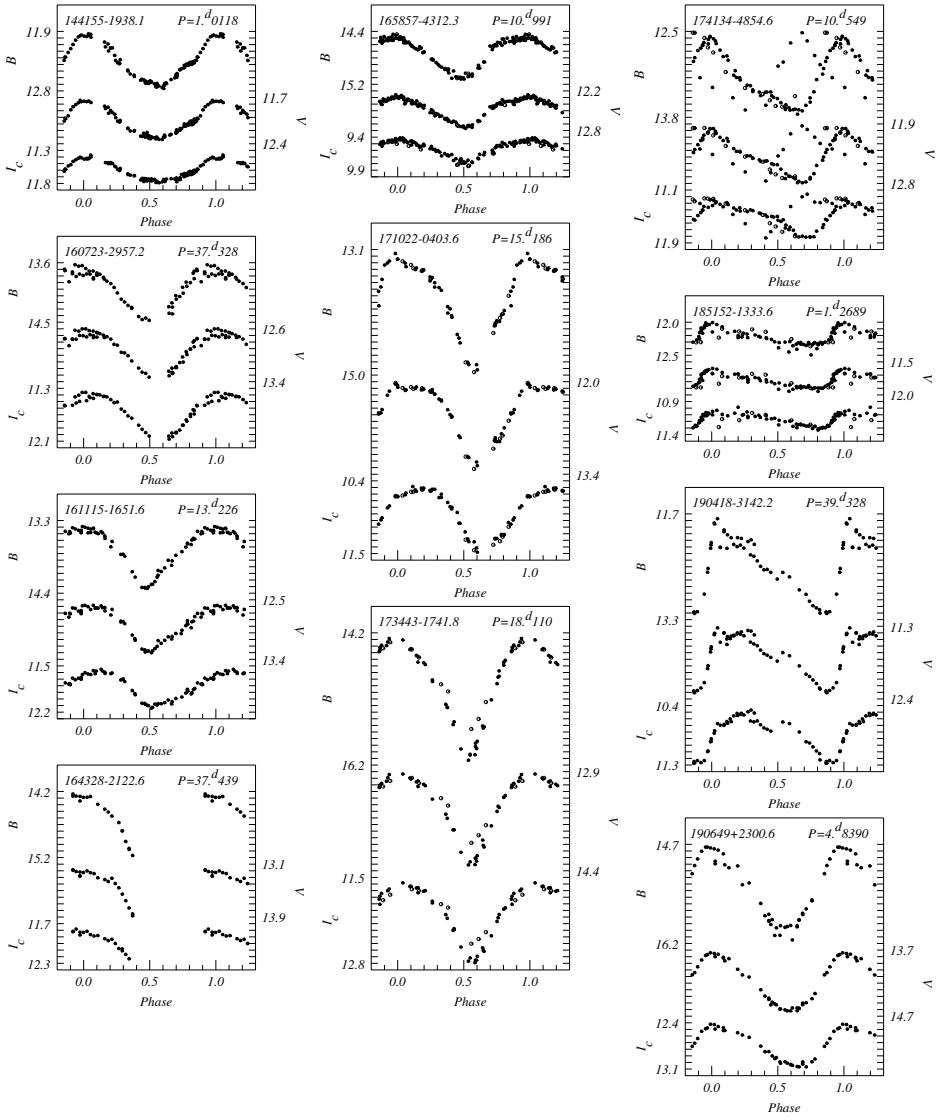


Figure 6 The same as in Figure 1 but for ASAS 144155-1938.1, ASAS 160723-2957.2, ASAS 161115-1651.6, ASAS 164328-2122.6, ASAS 165857-4312.3, ASAS 171022-0403.6, ASAS 173443-1741.8, ASAS 174134-4854.6, ASAS 185152-1333.6, ASAS 190418-3142.2, and ASAS 190649+2300.6.

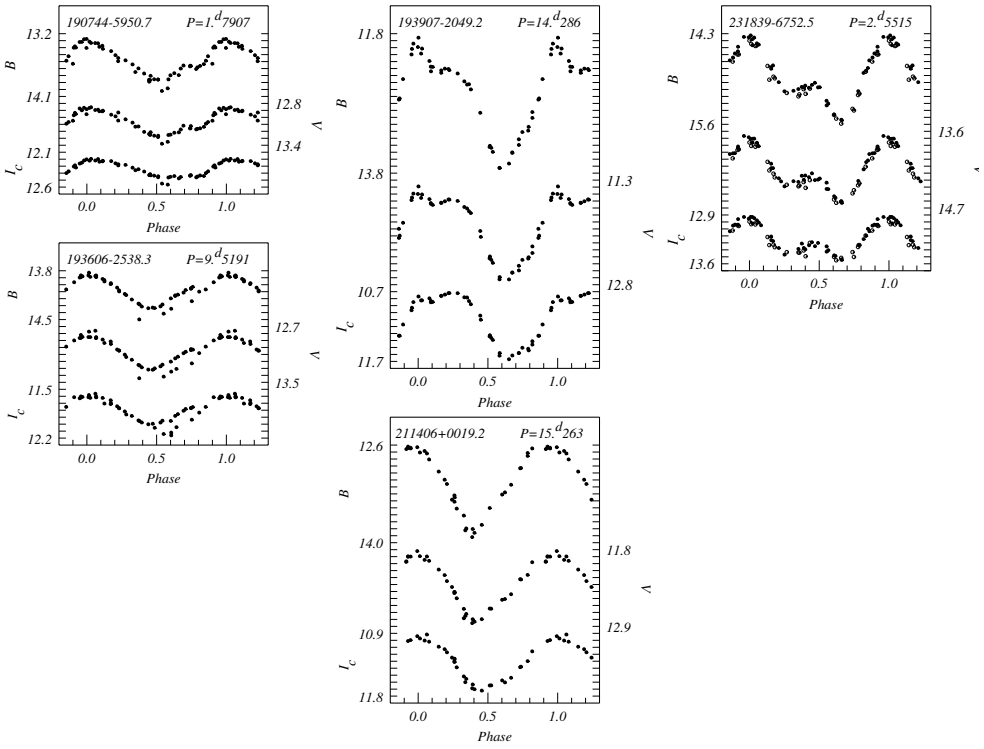


Figure 7 The same as in Figure 1 but for ASAS 190744-5950.7, ASAS 193606-2538.3, ASAS 193907-2049.2, ASAS 211406+0019.2 and ASAS 231839-6752.5.

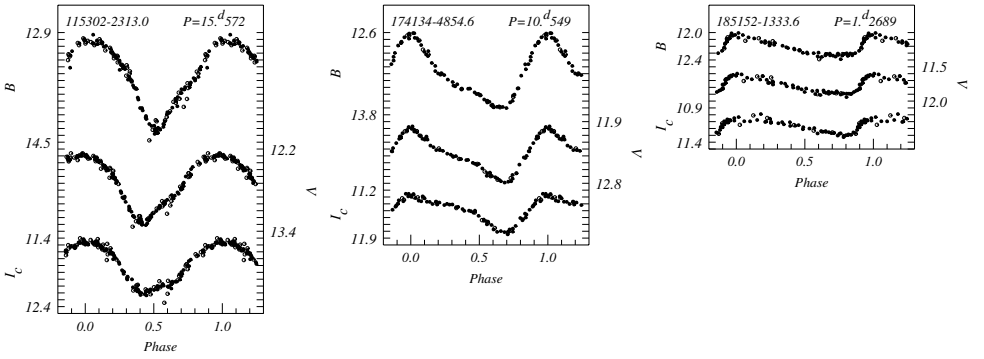


Figure 8 The same as in Figure 1 but for ASAS 115302-2313.0, ASAS 174134-4854.6 and ASAS 185152-1333.6 with seasonal light-curve shifts taken into account.

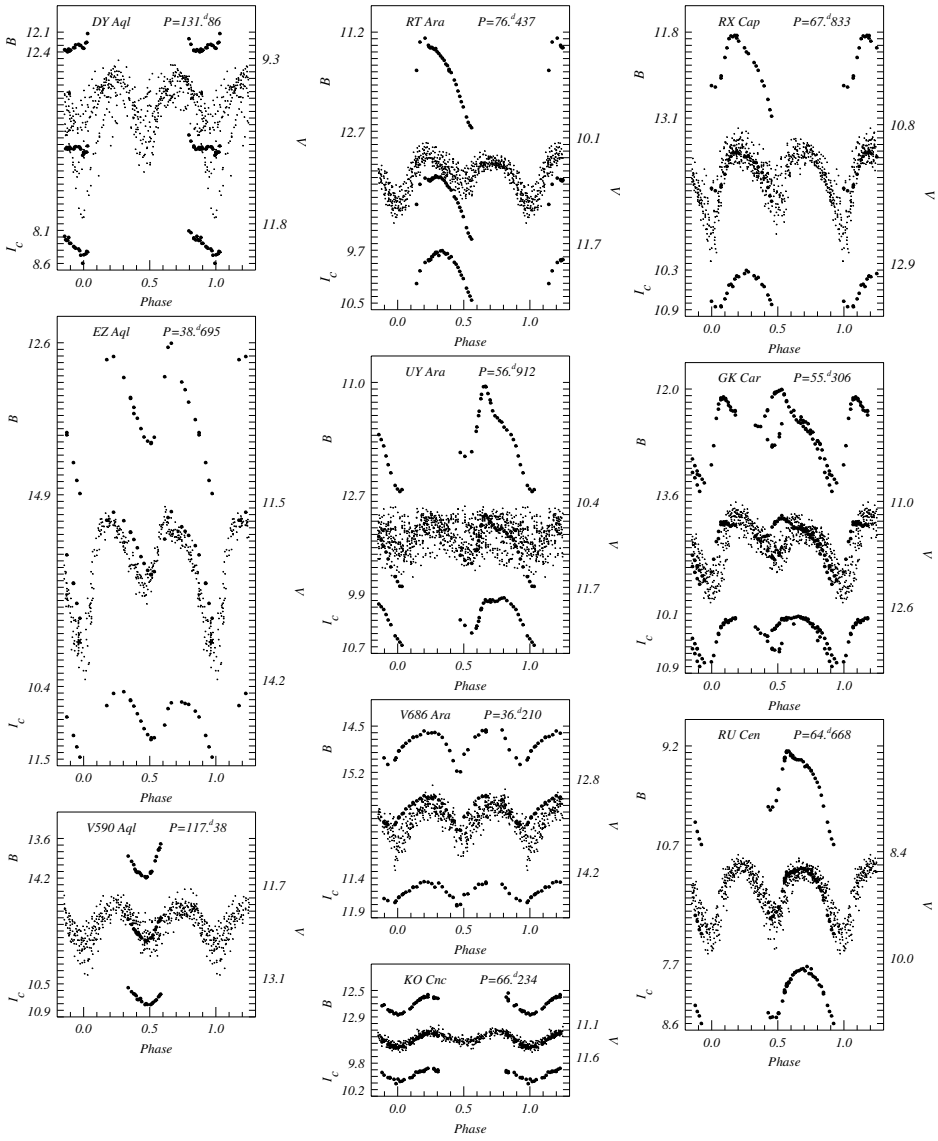


Figure 9 Light curves of RV Tau type stars: DY Aql, EZ Aql, V590 Aql, RT Ara, UY Ara, V686 Ara, KO Cnc, RX Cap, GK Car, RU Cen. Small points - observations from ASAS-3 catalog.

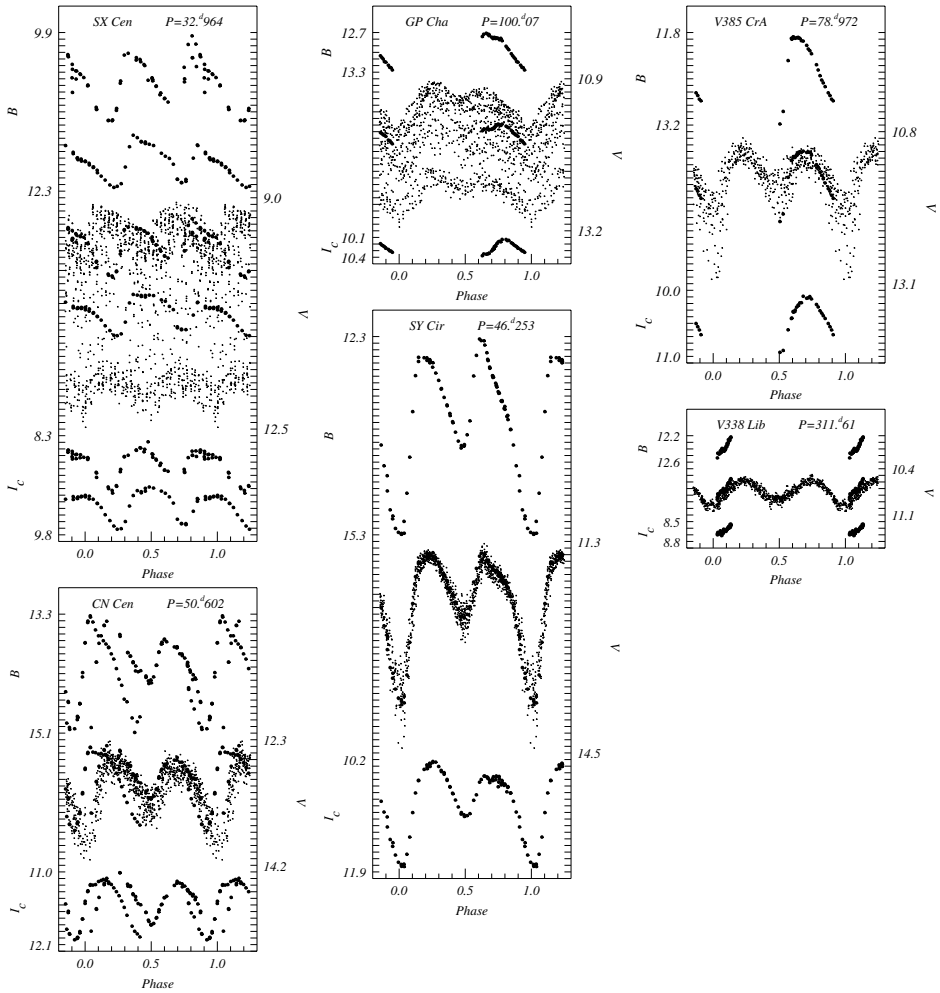


Figure 10 The same as in Figure 9 but for SX Cen, CN Cen, GP Cha, SY Cir, V385 CrA, and V338 Lib.

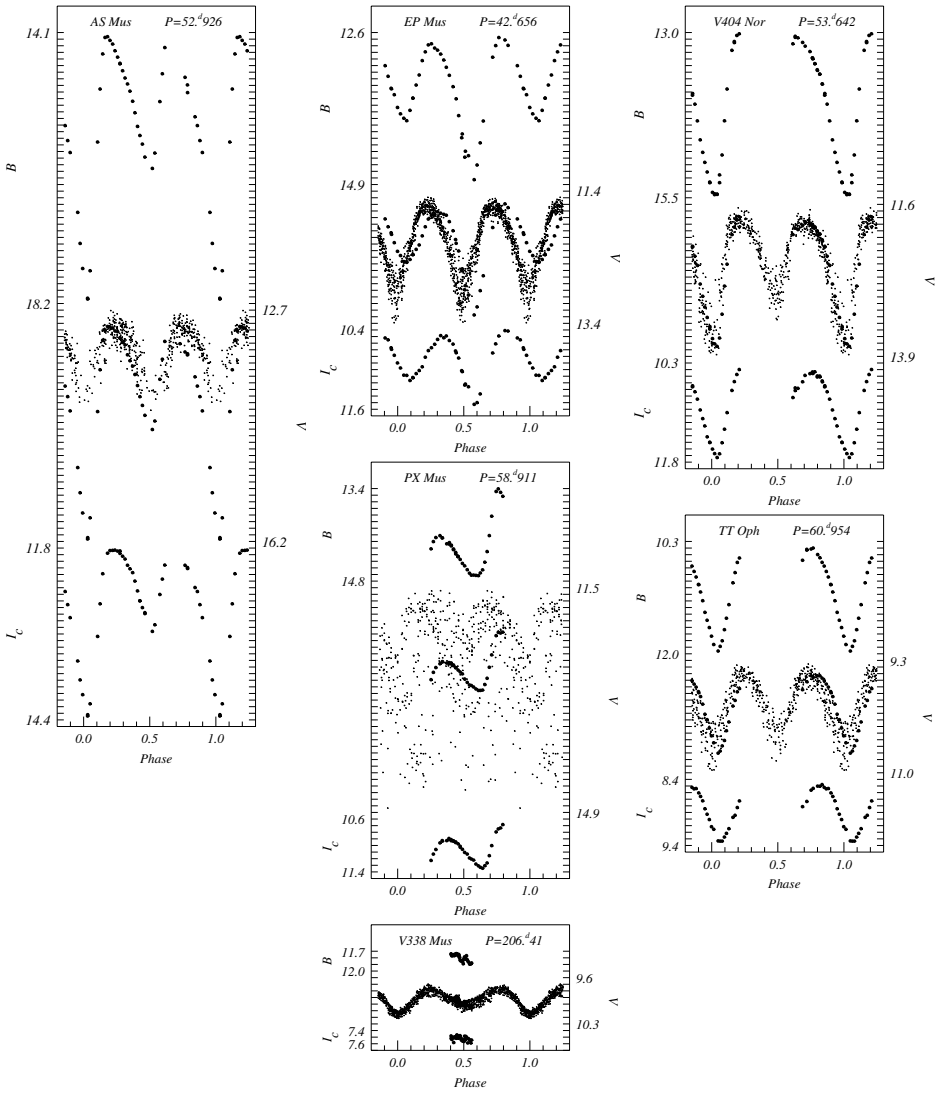


Figure 11 The same as in Figure 9 but for V453 AS Mus, EP Mus, PX Mus, V338 Mus, V404 Nor, and TT Oph.

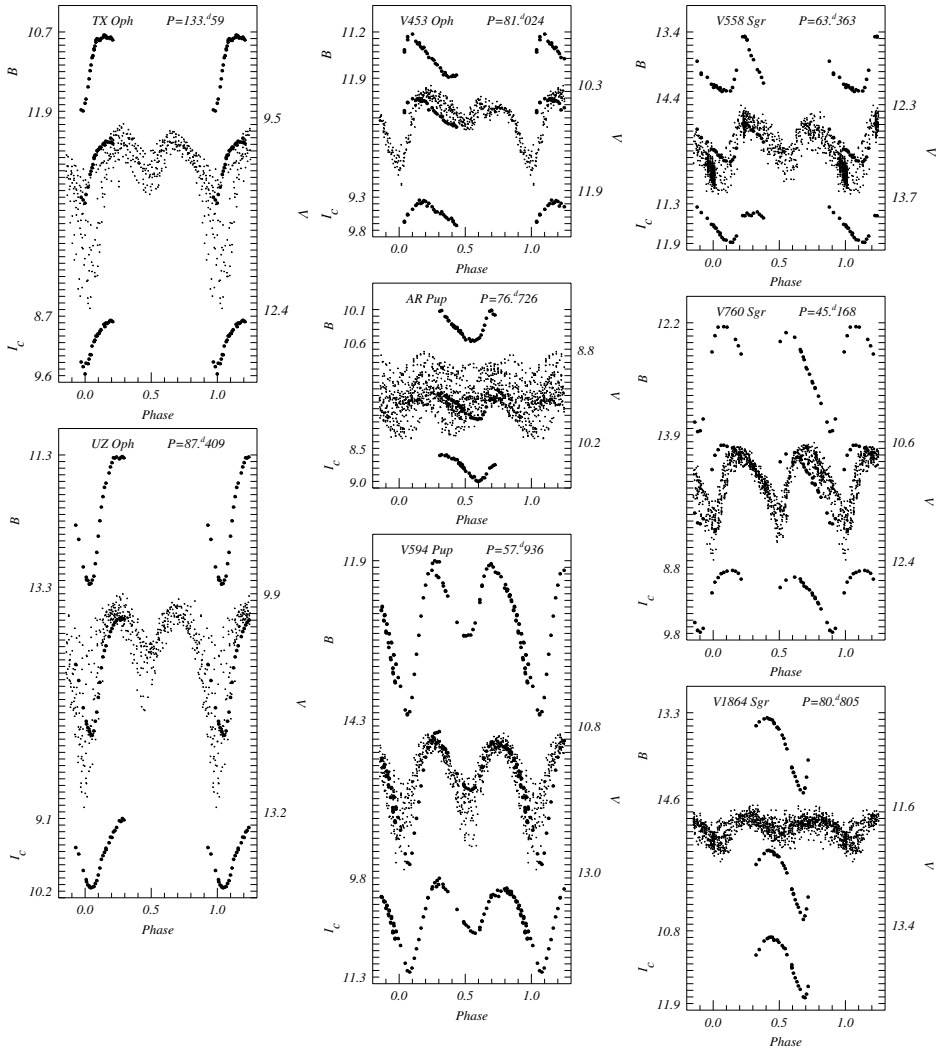


Figure 12 The same as in Figure 9 but for TX Oph, UZ Oph, V453 Oph, AR Pup, V594 Pup, V558 Sgr, V760 Sgr, and V1864 Sgr.

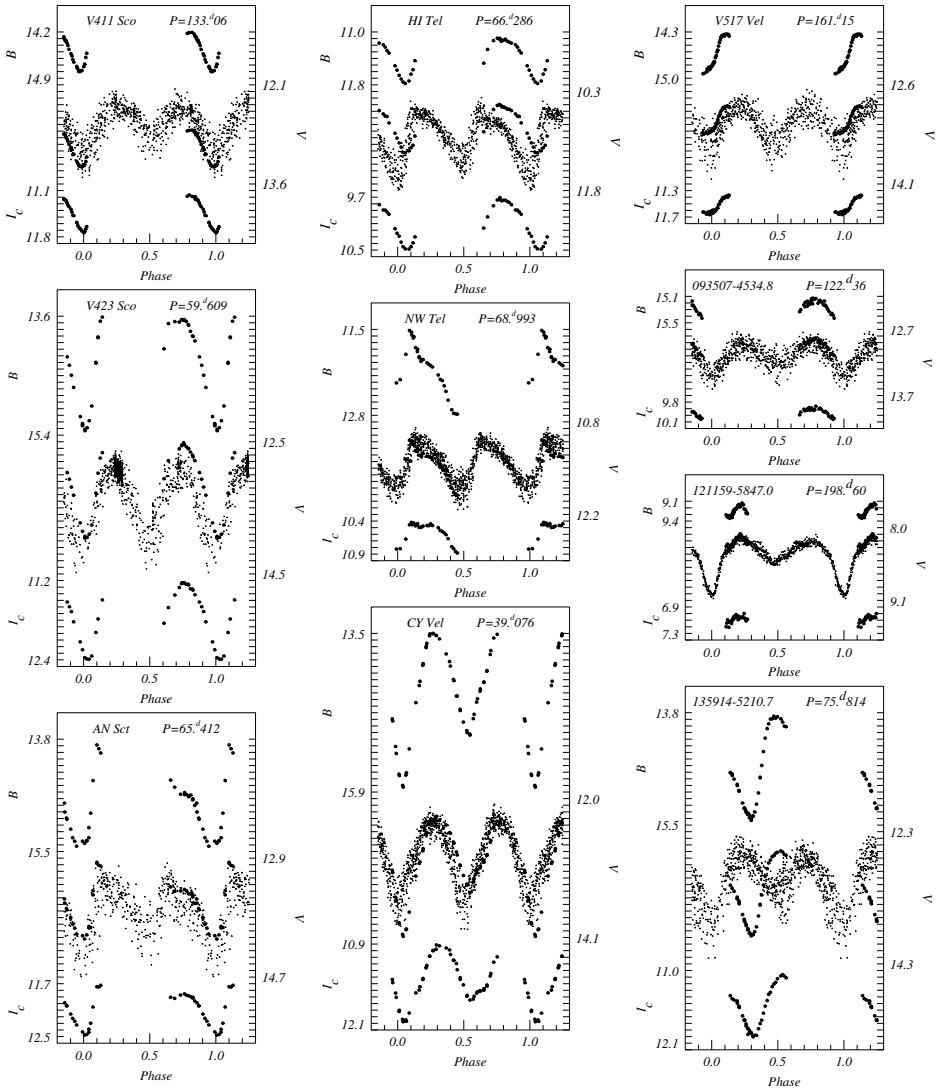


Figure 13 The same as in Figure 9 but for V411 Sco, V423 Sco, AN Sct, HI Tel, NW Tel, CY Vel, V517 Vel, ASAS 093507-4534.8, ASAS 121159-5847.0, and ASAS 135914-5210.7.

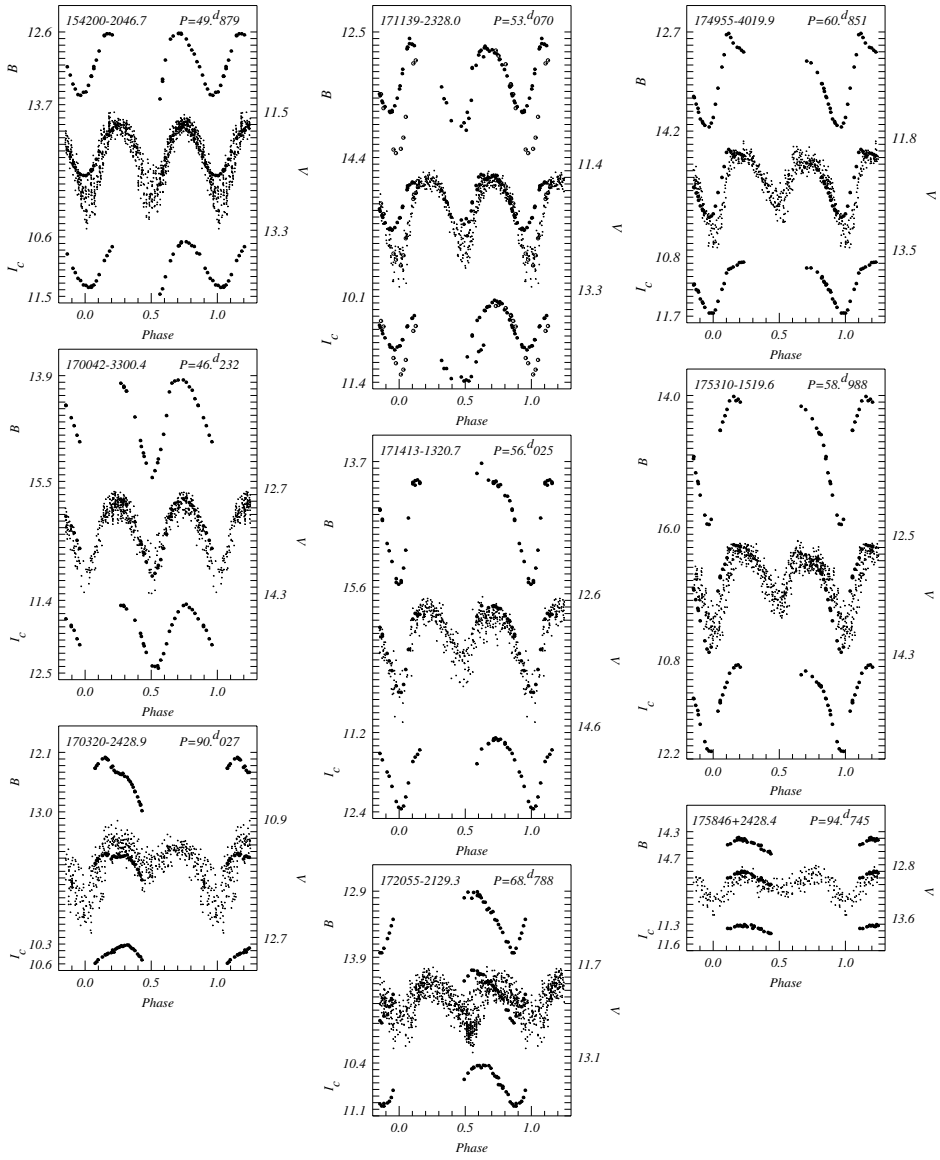


Figure 14 The same as in Figure 9 but for ASAS 154200-2046.7, ASAS 170042-3300.4, ASAS 170320-2428.9, ASAS 171139-2328.0, ASAS 171413-1320.7, ASAS 172055-2129.3, ASAS 174955-4019.9, ASAS 175310-1519.6, and ASAS 175846+2428.4.

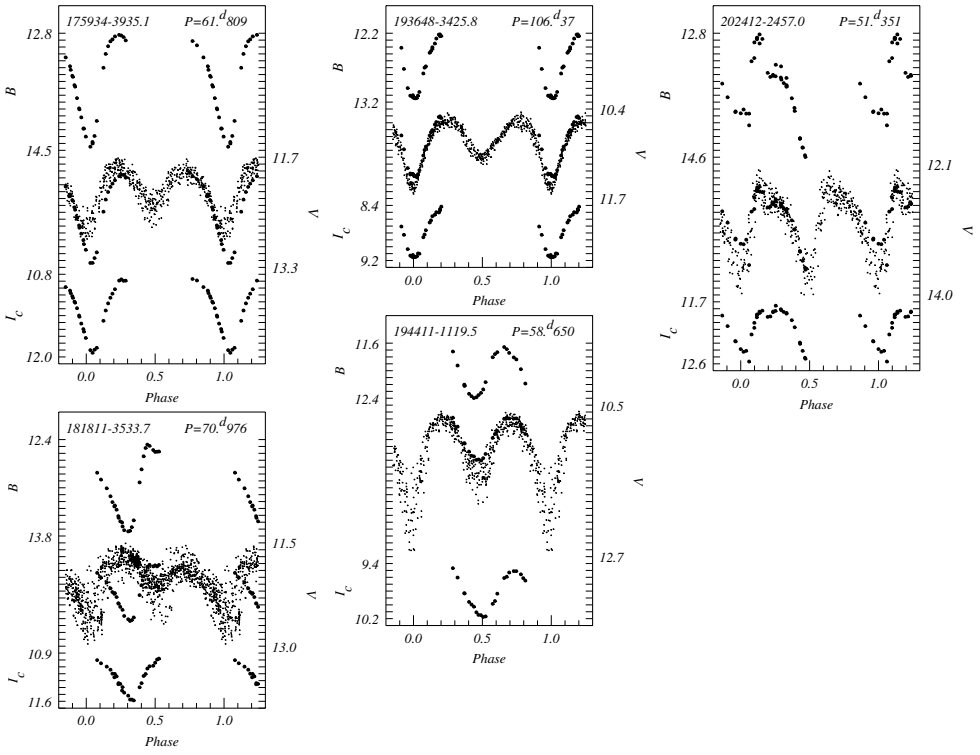


Figure 15 The same as in Figure 9 but for ASAS 175934-3935.1, ASAS 181811-3533.7, ASAS 193648-3425.8, ASAS 194411-1119.5, and ASAS 202412-2457.0.

4 Conclusions

The following results were obtained in this study:

(1) For 64 type II Cepheids 10384 measurements were made in the B-, V-, and I_c-band filters. Such observations have been obtained for the first time for 61 stars.

(2) For 54 RV Tau type stars 6184 measurements were made in the B-, V-, and I_c-band filters. Such observations have been obtained for the first time for 43 stars.

(3) Our observations combined with ASAS-3 catalog data [11] allowed us to derive the ephemerides for all the 118 stars observed.

(4) Six variables classified as type-II Cepheids with periods shorter than 2 days, large amplitudes and highly asymmetric light curves in our sample – V475 Ara, DF Hyi, ASAS 003041-4416.4, ASAS 014049-6729.7, ASAS 094844-3921.4, and ASAS 142357-0100.1 – are most likely anomalous Cepheids.

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