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ORIGINAL ARTICLE

ASAS 160125-5150.3—the second galactic classical Cepheid with strong Blazhko effect

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Abstract In 2005–2014 we acquired a total of 135, 137 and 134 measurements in B-, V- and I_c-filters, respectively, for the 5-days Cepheid ASAS 160125-5150.3. Our observations showed variations of light amplitude, which allowed us to suspect the presence of the Blazhko effect. Combining our measurements with ASAS-3 data allowed us to determine the period of the Blazhko effect $P_{Bl} = 1242^d \pm 10^d$, and now ASAS 160125-5150.3 is the second Galactic Cepheid (after V473 Lyr) with strong Blazhko effect pulsating in the first overtone.

Keywords Variable stars · Photometry · Cepheids · Blazhko effect

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1 Introduction

Variations of light curves, known as the Blazhko effect (Blazhko 1907), were found in many RR Lyrae variables since 1907, whereas V473 Lyr (Burki and Mayor 1980; Molnar and Szabados 2014) has been the only Galactic Cepheid known to exhibit the Blazhko effect with amplitude variations between $0^{\rm m}_{.}05$ and $0^{\rm m}_{.}4$ in V. Recently, amplitude variations in several Galactic and Magellanic Clouds Cepheids were detected (Moskalik and Kolaczkowski 2009; Anderson 2014; Derekas et al. 2016; Smolec et al. 2016; Smolec 2017), but these variations were tens times smaller than in V473 Lyr, which remains the only Galactic Cepheid with strong Blazhko effect.

Our observations of the 5-days Cepheid ASAS 160125-5150.3 (Pojmanski 2002) conducted in 2005 and 2007 showed different light amplitudes, $0^{\rm m}_{.}1$ and $0^{\rm m}_{.}2$ respectively, and we suspected the presence of the Blazhko effect. Inspection of the data from ASAS-3 catalog confirmed our suspicion.

The main goal of this study was to acquire further observations of ASAS 160125-5150.3 and to determine the period of the Blazhko effect.

2 Observational data

We performed photoelectric and CCD observations of ASAS 160125-5150.3 during seven observing seasons from April 2005 until May 2014 (JD 2453483-2456790) with the 76-cm telescope of the South African Astronomical Observatory (SAAO) in South Africa and with the 40-cm telescope of the Cerro Armazones Observatory (OCA) of the Universidad Catolica del Norte in Chile using the SBIG ST-10XME CCD camera equipped with BVI_c filters (Cousins

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Table 1 Observations of ASAS 160125-5150.3

HJD 2400000	Filter	Magnitude	HJD 2400000	Filter	Magnitude	HJD 2400000	Filter	Magnitude
53483.7606	V	12.285	53483.7606	I_c	9.794	53487.7534	B	14.357
53487.7534	V	12.321	53487.7534	I_c	9.807	53488.7305	B	14.318
53488.7305	V	12.276	53488.7305	I_c	9.784	53489.7220	B	14.492
53489.7220	V	12.351	53489.7220	I_c	9.842	53490.6652	B	14.493
53490.6652	V	12.430	53490.6652	I_c	9.876	53491.6468	B	14.526
53491.6468	V	12.440	53491.6468	I_c	9.908	53492.7059	B	14.440
53492.7059	V	12.382	53492.7059	I_c	9.865	53495.6677	B	14.541
53495.6677	V	12.379	53495.6677	I_c	9.882	53496.6775	B	14.499
53496.6775	V	12.415	53496.6775	I_c	9.896	53497.6718	B	14.420
53497.6718	V	12.372	53497.6718	I_c	9.854	53498.7102	B	14.379
53498.7102	V	12.309	53498.7102	I_c	9.818	53499.6961	B	14.498
53499.6961	V	12.373	53499.6961	I_c	9.845	53501.6077	B	14.528
53501.6077	V	12.403	53501.6077	I_c	9.868	53502.6375	B	14.425
53502.6375	V	12.374	53502.6375	I_c	9.853	53503.6051	B	14.349
53503.6051	V	12.301	53503.6051	I_c	9.796	53504.6104	B	14.418
53504.6104	V	12.362	53504.6104	I_c	9.835	54111.5808	B	14.317
54111.5808	V	12.275	54111.5808	I_c	9.799	54118.5873	B	14.712
54118.5873	V	12.544	54118.5873	I_c	9.970	54119.5820	B	14.610
54119.5820	V	12.466	54119.5820	I_c	9.972	54120.5845	B	14.220
54120.5845	V	12.198	54120.5845	I_c	9.750	54122.5902	B	14.620

1976). In SAAO we also used a single-channel pulse-counting photoelectric photometer equipped with a Hamamatsu R943 02 photomultiplier tube. The technique of photoelectric and CCD observations and their reduction is described in Berdnikov and Turner (2004) and Berdnikov et al. (2011), respectively.

We acquired a total of 135, 137 and 134 measurements in B-, V- and I_c-filters, respectively, (see Table 1 whose complete version is available in electronic form) with photometric errors close to $0\overset{m}{.}01$.

For this study we also used V-band observations from ASAS-3 catalog (Pojmanski 2002).

3 Blazhko effect

Figure 1 shows the V-band light curve, and Fig. 2, the corresponding phased light curve computed using the following light elements (ephemeris):

$$\begin{aligned}\text{MaxHJD} &= 2454392.079(\pm 0.022)\\ &\quad + 5\overset{d}{.}020132(\pm 0.000074)E. \qquad (1)\end{aligned}$$

It is clearly evident that the light amplitude is variable, however, the small number of our observations and big gaps in the light curve (Fig. 1) make it impossible to determine the exact period of these variations using frequencies spectra or the method developed by Goranskij (1976). Supplementing

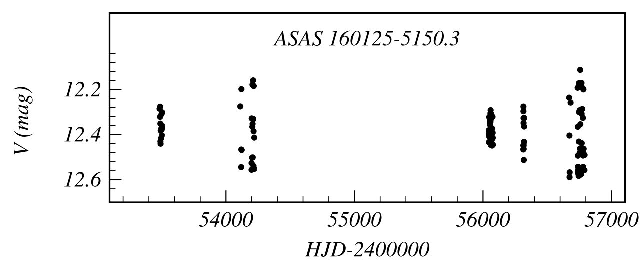

Fig. 1 Light curve of ASAS 160125-5150.3 based on our V-band observations

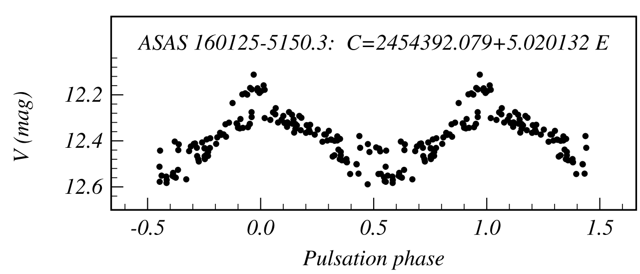

Fig. 2 Phased light curve of ASAS 160125-5150.3 based on our observations

our measurements with ASAS-3 data also does not allow us to determine P_{Bl}.

We then used the ephemeris from the ASAS-3 catalog to construct the mean light curve based on ASAS-3 obser-

Table 2 Results of O–C calculations of V-band observations of the Cepheid ASAS 160125-5150.3

Max HJD	Error	E	O–C	A_V	ε	N	Reference	Number	Phase$_{Bl}$
2452022.5644	0.0940	−472	−0.0123	0.2826	0.02363	65	ASAS-3	1	0.2609
2452489.4952	0.1205	−379	0.0463	0.1976	0.02218	49	ASAS-3	2	0.6368
2452780.4770	0.0549	−321	−0.1396	0.2846	0.01382	103	ASAS-3	3	0.8710
2453111.8785	0.0718	−255	−0.0667	0.3847	0.02314	45	ASAS-3	4	0.1377
2453493.5538	0.0841	−179	0.0785	0.1295	0.01040	16	This paper	5	0.4450
2453508.5462	0.1109	−176	0.0105	0.1566	0.01524	116	ASAS-3	6	0.4570
2453834.8235	0.0582	−111	−0.0207	0.2957	0.01678	73	ASAS-3	7	0.7197
2454186.2143	0.0207	−41	−0.0392	0.3765	0.00742	21	This paper	8	0.0025
2454266.5833	0.0388	−25	0.0077	0.3639	0.01295	131	ASAS-3	9	0.0672
2454623.0889	0.0836	46	0.0840	0.1779	0.01314	150	ASAS-3	10	0.3542
2454989.6390	0.0805	119	0.1644	0.2159	0.01563	110	ASAS-3	11	0.6492
2456058.8355	0.0321	332	0.0728	0.1334	0.00417	40	This paper	12	0.5098
2456314.7920	0.0559	383	0.0027	0.2094	0.01042	14	This paper	13	0.7159
2456676.1130	0.0954	455	−0.1259	0.4173	0.03729	5	This paper	14	0.0067
2456761.5193	0.0239	472	−0.0618	0.3911	0.00733	41	This paper	15	0.0755

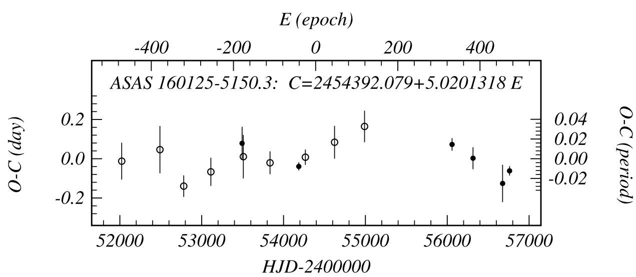

Fig. 3 O–C diagram of ASAS 160125-5150.3. The *points* and *open circles* show our measurements and ASAS-3 data, respectively

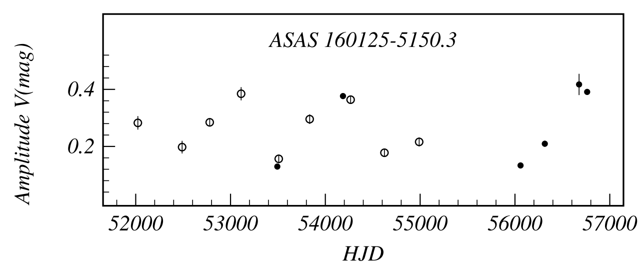

Fig. 4 V-band amplitude variations of ASAS 160125-5150.3. The *points* and *open circles* show our measurements and ASAS-3 data, respectively

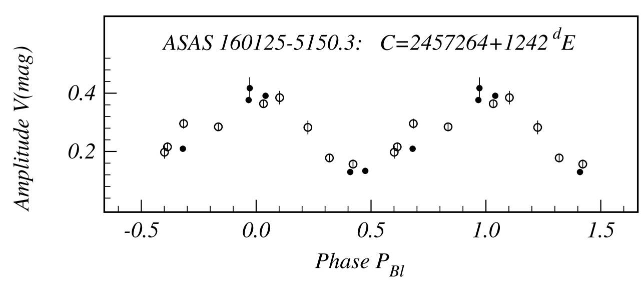

Fig. 5 V-band amplitude variations of ASAS 160125-5150.3 folded with P_{Bl}. The *points* and *open circles* show our measurements and ASAS-3 data, respectively

vations and used this template to reduce all V-band observations from both Table 1 and ASAS-3 catalog with the Hertzsprung (1919) method (whose computer implementation is described by Berdnikov (1992)). The results of the O–C calculation of seasonal light curves of ASAS 160125-5150.3 are given in Table 2. The first and second columns give the inferred time of maximum brightness and its standard error, respectively; the third and forth columns give the number of epoch, E, and the O–C residual (in days); the fifth and sixth columns give the amplitude, A_V, and its standard error, ε, respectively; seventh to ninth columns give the number of observations, N, the data source, and number of maximum respectively; and the tenth column gives the phase of the Blazhko period.

The plots in Figs. 3–7 are based on Table 2.

The least square analysis of O–C residuals allowed us to obtain refined ephemeris (1), which we used to plot the O–C diagram shown in Fig. 3.

Figure 4 shows the dependence of amplitude A_V on JD. A periodogram analysis (Lafler and Kinman 1965) of the A_V series yields the Blazhko period of $P_{Bl} = 1242 \pm 10$ days, implying the following ephemeris for the Blazhko effect:

$$\mathrm{MaxHJD} = 2457264 + 1242^d E. \tag{2}$$

Figures 5 and 6 show the amplitudes and pulsation phases (O–C residuals expressed in fractions of pulsation

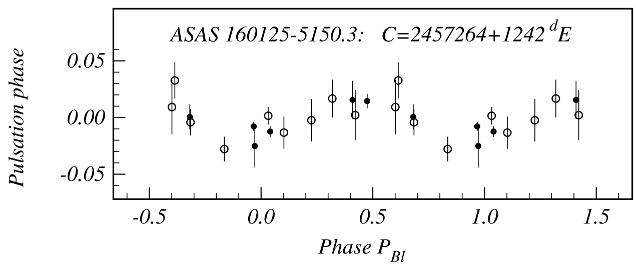

Fig. 6 Pulsation phases (O–C residuals expressed in fractions of the pulsation period) of ASAS 160125-5150.3 folded with P_{Bl}. The *points* and *open circles* show our measurements and ASAS-3 data, respectively

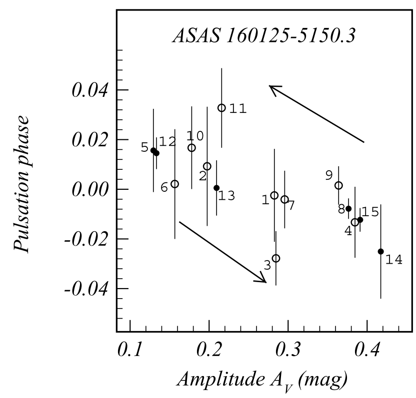

Fig. 7 Loop diagram showing the amplitude and the pulsation phase (O–C residuals expressed in fractions of pulsation period) relations during the modulation cycle. The *points* and *open circles* show our measurements and ASAS-3 data, respectively. The digits indicate the numbers of light maxima in Table 2

period) folded with these elements, respectively. The loop diagram—the amplitude–pulsation phase relation over the modulation cycles (digits from 1 to 15)—shows counterclockwise rotation.

Figures 8 and 9 show the light curves phased with ephemeris (1) for our BVI_c observations and for ASAS-3 observations, respectively, constructed in small phase bins of the Blazhko period P_{Bl} corresponding to the maximum and minimum amplitudes.

4 Discussion

Photometric behavior of ASAS 160125-5150.3 is the same as that of V473 Lyr, which is a classical Cepheid pulsating in the second overtone with a period of $1^{d}.4909$ and modulated with a period of 1205^{d} (Molnar and Szabados 2014).

The light curve of ASAS 160125-5150.3 looks rather symmetric, making it unlikely to be a fundamental mode pulsator. The most commonly used method of determining the mode of pulsation for a Cepheid is based on the Fourier decomposition of the photometric phased curve. However

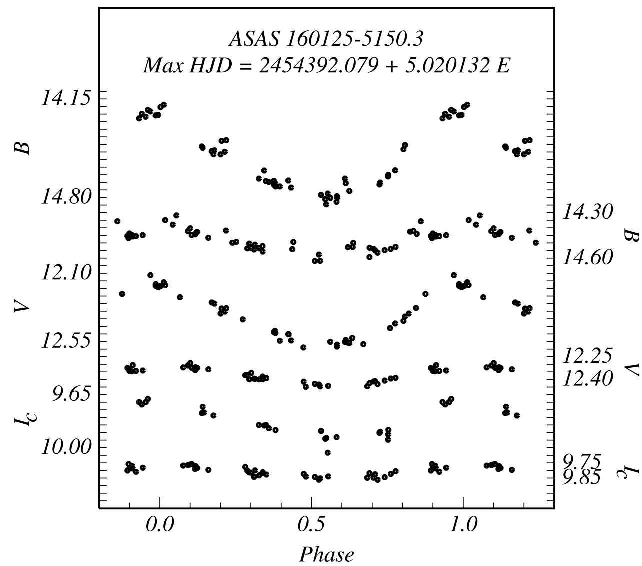

Fig. 8 B-, V- and I_c-band phased light curves (based on the data from Table 1) of ASAS 160125-5150.3 in narrow Blazhko phase bins corresponding to the maximum and minimum amplitude

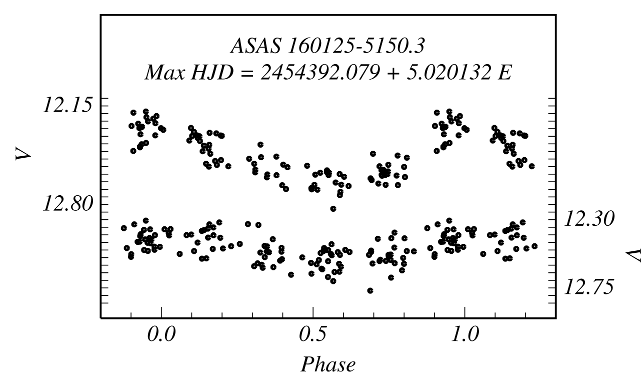

Fig. 9 V-band phased light curve of ASAS 160125-5150.3 (based on the data from ASAS-3 catalog) in narrow Blazhko phase bins corresponding to the maximum and minimum amplitude

the shape of the light curve of ASAS 160125-5150.3 varies over modulated period, hence the Fourier parameters vary as well, and therefore this method is not completely correct.

We nevertheless performed cosine-based Fourier decomposition of the mean light curve, which was used as template in the O–C calculations, and determined the amplitude parameters $R_{21} = 0.1273 \pm 0.0004$ and $R_{31} = 0.0506 \pm 0.0004$, and phase parameters $\phi_{21} = 3.8307 \pm 0.0030$ and $\phi_{31} = 1.4106 \pm 0.0075$. The location of these parameters in the Fourier parameter vs. pulsation period diagrams (Mantegazza and Poretti 1992; Soszynski et al. 2008, 2010) suggests the first-overtone pulsation mode. Further evidence for the first-overtone classification is provided by the fact that all periods of the second overtone Cepheids found in the Galaxy and Magellanic Clouds are shorter than $1^{d}.5$ (Molnar and Szabados 2014; Soszynski et al. 2008, 2010)

5 Conclusions

In 2005–2014 we acquired 135, 137 and 134 measurements in B-, V- and I_c-filters, respectively, for the 5 days period Cepheid ASAS 160125-5150.3. Combining our observations with ASAS-3 data allowed us to discover the Blazhko effect and determine its period, which is equal to $1242^d \pm 10^d$.

Fourier coefficients of the phased light curve suggest the first overtone pulsation mode. Further evidence for classifying the star as a first overtone pulsator is provided by the fact that all periods of the second overtone Cepheids found in the Calaxy and Magellanic Clouds are shorter than $1\overset{d}{.}5$ (Molnar and Szabados 2014; Soszynski et al. 2008, 2010).

Photometric behavior of ASAS 160125-5150.3 is the same as that of V473 Lyr, and we conclude that ASAS 160125-5150.3 is now the second known Galactic classical Cepheid with the strong Blazhko effect.

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