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PERIOD ANALYSIS OF A BLAZHKO STAR V0346 DRACONIS

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Abstract: Period analysis of an RRab star V0346 Dra based on photometric measurements from NSVS and DASCH projects is presented. We confirm light curve modulation known from literature and estimate modulation period for the first time. NSVS measurements spanning one year allowed us to determine the length of the Blazhko cycle as 101(2) d. This value is close to 103.65(2)-day period estimated from photographic measurements from the DASCH project which have a lower quality but 92-year long timebase. Blazhko effect causes well apparent phase and amplitude modulation easily visible in $O-C$ diagram and in maximum–$O-C$ dependency.

1 Introduction

V0346 Dra = GSC 04189-00342 = 2MASS J16082123+6229545 = NSVS 2844577[1] was discovered as a variable star by Wils et al. (2006) based on ROTSE measurements (NSVS project, Woźniak et al., 2004). They determined brightness range of 13.80 − 14.72 mag (C-clear close to R-band) and pulsation period $P_{\rm puls} = 0.53451$ d. They identified V0346 Dra as RRab Lyrae subtype star pulsating in the fundamental pulsation mode. At the same time, based on the same data, similar period $P_{\rm puls} = 0.53452$ d was obtained by Kinemuchi et al. (2006) who calibrated brightness variation in ROTSE magnitudes (C) to the standard Johnson-V system and determined mean V-brightness as 14.32 mag and V-amplitude as 1.20 mag.

Three years later, Kim et al. (2009) independently identified variability of the object using their own observations with 15.5cm telescope from Bohyunsan Optical Astronomy Observatory which were primarily focused on contact eclipsing binary BX Dra. They determined slightly different parameters than previous authors (period of $P_{\rm puls} = 0.5344(5)$ d and amplitude of light variations of 0.75 mag in V[2]). Their light curves in B and V bands show evident signs of modulation (see their Fig. 2, variable 1) which they explained as the Blazhko effect (without period estimation). The object was included in the 80-th name-list of variable stars and named as V0346 Dra recently (Kazarovets et al., 2013). The purpose of our study is the determination of the Blazhko period which has not been determined yet.

[1] RA:$16^{\rm h}08^{\rm m}21\overset{\rm s}{.}23$ DEC:$+62^\circ29'54\overset{''}{.}5$

[2] We note that their measurements show amplitude of about 1.45 mag in V at maximum Blazhko phase.

2 Photometric data and their analysis

For our period analysis we used three datasets. First data were adopted from Kim et al. (2009). Their 379 measurements in V-band (differential magnitudes) cover 123-day period in 2008 (17 nights, JD 2454575.0 – 2454698.1). Unfortunately, these high quality measurements with mean uncertainty of 0.016 mag are splitted into two subsets by a 70-day gap. Their B-band dataset has the same distribution, but is less numerous (336 points) and has larger scatter (0.027 mag). Therefore we analysed only their V measurements.

The second dataset we analysed is from the NSVS project (Woźniak et al., 2004) and contains 245 measurements covering almost one year during 1999 and 2000 (359 days, JD 2451274.7 – 2451633.7). The quality of these measurements (0.12 mag) is much lower than for Kim et al. (2009) data. The third dataset that we investigated consists of photographic measurements from digitalized Harvard plates (realised by the project DASCH[3], Grindlay et al., 2009, 2012). This very sparse dataset contains 194 usable measurements with very low quality and with mean uncertainty of 0.23 mag. These plates were obtained during almost 92 years in 1897 – 1989 (JD 2414182.5 – 2447675.7).

The period analysis was performed using PERIOD04 software (Lenz & Breger, 2005). We searched for the main pulsation frequency and its harmonics, or other significant peaks in subsequently prewhitened frequency spectra. The list of the strongest detected frequencies probably connected with pulsation, or modulation is presented in Table 1. In V-band data from Kim et al. (2009) we identified only the main pulsation frequency $f_0 = 1.87068(6)\,\mathrm{c\,d^{-1}}$ ($P_{\mathrm{puls}} = 0.53456(2)\,\mathrm{d}$) and its harmonics up to $7f_0$[4]. Unfortunately, this inhomogeneous dataset did not allow us to estimate period of the well-visible Blazhko modulation.

Table 1: Frequencies probably connected with pulsation and modulation identified in the datasets from Kim et al. (2009), NSVS and DASCH. The uncertainties ($1\,\sigma$) in the final digits are given in parentheses and were determined via least-squares method.

ID	Kim et al. (2009) (V)		NSVS (C)		DASCH (pg)	
	Frequency $[\mathrm{c\,d^{-1}}]$	Amplitude [mmag]	Frequency $[\mathrm{c\,d^{-1}}]$	Amplitude [mmag]	Frequency $[\mathrm{c\,d^{-1}}]$	Amplitude [mmag]
f_0	1.87068(6)	433(5)	1.87082(10)	211(14)	1.8708369(10)	352(22)
f_0+f_{Bl}	–	–	1.88074(16)	133(14)	1.8804851(19)	192(22)
$2f_0$	3.75127(14)	171(5)	3.74162(23)	92(14)	3.6839104(26)?	141(22)
$2f_0+f_{\mathrm{Bl}}$	–	–	3.75225(28)	76(14)	–	–
$3f_0$	5.62226(16)	151(5)	–	–	–	–
$4f_0$	7.48370(25)	99(5)	–	–	–	–
$5f_0$	9.37382(28)	88(5)	–	–	–	–
$6f_0$	11.23493(61)	40(5)	–	–	–	–
$7f_0$	13.12448(49)	50(5)	–	–	–	–

Analysis of NSVS data revealed the main pulsation frequency ($f_0 = 1.87082(10)\,\mathrm{c\,d^{-1}}$, $P_{\mathrm{puls}} = 0.53452(3)\,\mathrm{d}$), its second harmonic $2f_0$ and side peaks near both frequencies (see

[3]All data used for analysis are available on request.
[4]Peak at $6f_0$ has signal-to-noise ratio lower than 4.

Fig. 1). According to mathematical description of the Blazhko effect this should be manifestation of modulation (Benkő et al., 2011). From the frequency f_0 and its close peak the Blazhko period is $P_{\rm Bl} = 101(2)$ d, from $2f_0$ and $2f_0 + f_{\rm Bl}$ the modulation cycle is a bit shorter (94(3) d). The last strong peak in the frequency spectrum (signal-to-noise ratio larger than $4\,\sigma$) has a very suspicious value close to 0.5 c d^{-1} and it is probably connected with one-day observing period.

Although frequency spectra are dominated by daily aliases the basic pulsation frequency is well defined and it was identified in all studied datasets. Therefore, misclassification with daily alias can be excluded. Regarding the the Blazhko period we suppose that it is real and also well estimated because no apparent peak is visible around 0.01 c d^{-1} (Blazhko frequency) in the spectral window (bottom part of Fig. 1).

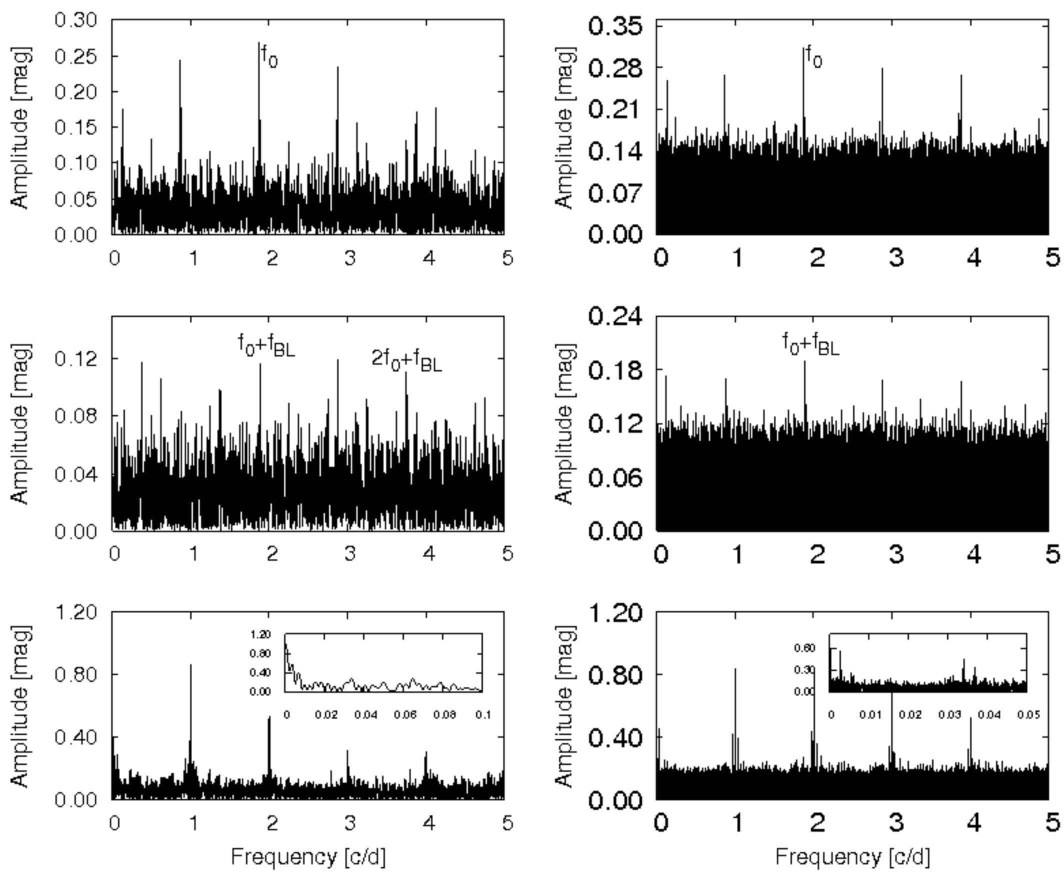

Figure 1: Frequency spectra and spectral window of NSVS data (the left panels) and DASCH data (the right panels). Middle panels show the spectra after removing basic pulsation component(s). Spectral windows (the bottom panels) show no apparent peak around 0.01 c d^{-1}.

Low-quality photographic measurements from DASCH project allow to identify only the main frequency ($f_0 = 1.8708369(10)$ c d^{-1}, $P_{\rm puls} = 0.5345201(3)$ d) and one side peak (Fig. 1). From these peaks we calculated the Blazhko period as $P_{\rm Bl} = 103.65(2)$ d which well corresponds with the NSVS value. Residual spectrum contains possible $2f_0$ peak, but the detected frequency differs from the expected value significantly. Similarly as in NSVS data, frequency spectra are dominated by daily aliases, but no apparent peak around supposed Blazhko period is detectable in spectral window (right bottom panel of Fig. 1). In addition, in DASCH frequency spectra also monthly and yearly aliases are well distinguishable.

Results from frequency spectra analysis are strengthened by the look of the light curves folded with both pulsation (Fig. 2) and the Blazhko period (Fig. 3). The modulation is well apparent in both figures causing blurring in Fig. 2 and sinusoidal envelope in Fig. 3[5]. We present also measurements from Kim et al. (2009) phased with pulsation and Blazhko periods (Fig. 4). Since the data from DASCH span the largest interval we adopt as default values of the Blazhko period $P_{\mathrm{Bl}} = 103.65(2)\,\mathrm{d}$ and the time of zero epoch the first observed time of maximum (JD 2454575.0355, see below.)

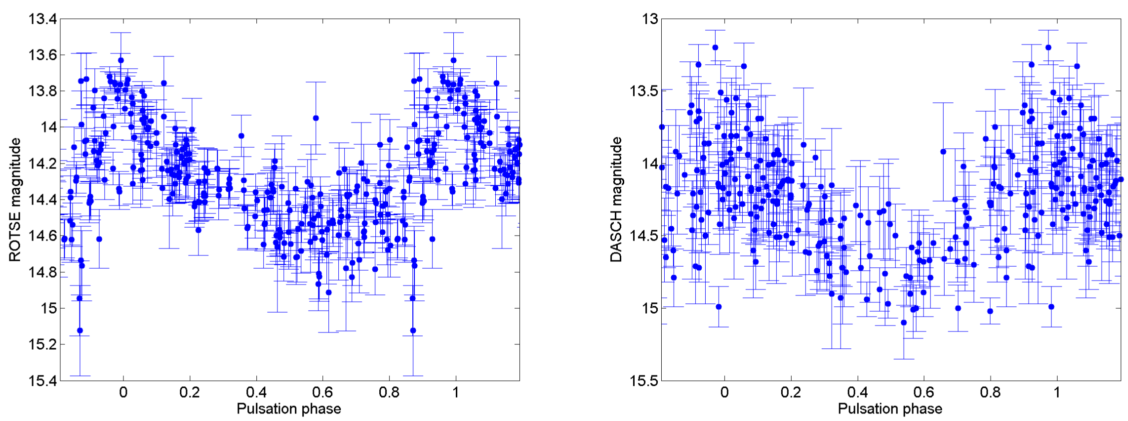

Figure 2: Data of V0346 Dra phased with pulsation period of 0.53452(3) d from the NSVS project (ROTSE, the left panel) and 0.5345201(3) d from DASCH (the right panel).

Subsequently we determined maxima timings and corresponding maximal brightness for the test of phase and amplitude modulation (Tab. 2). Only data from Kim et al. (2009) has sufficient time resolution (6 well-covered maxima in each colour band). NSVS and DASCH data are for this purpose inappropriate due to sparse sampling. The shape of light curve in a vicinity of maximal brightness was fitted with algebraic polynomials using least-squares method. For a better estimation of the parameter uncertainties we used statistical method (bootstrap-resampling of the original light curves, see Skarka et al., 2015, in prep.). Final values were used for reconstruction of variation in $O-C$ diagram and for displaying maximum–$O-C$ dependency (see Fig. 5). We estimated semi-amplitude of $O-C$ variation close to 0.015 d (the best found cosinusoidal fit, as the most simple approximation, gives even 0.025 d) and total amplitude of variation in maximal brightness of at least 0.5 mag (the right panel of Fig. 5). Although there is a large gap in $O-C$ diagram, the changes in amplitude correlated with changes in period clearly shows the presence of the Blazhko effect.

[5] JD 2451318.730 was used as the zero epoch of pulsation cycle for NSVS data and 2440898.177 for DASCH measurements. Concerning Blazhko phase curves JD 2451302 was used as the zero epoch for NSVS data and 2440892 for DASCH measurements.

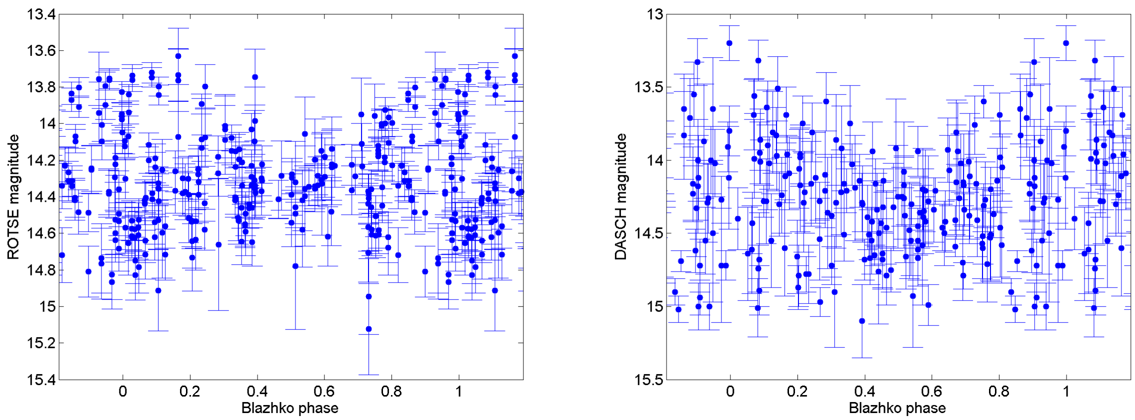

Figure 3: NSVS data of V0346 Dra phased with 101(2)-day Blazhko period (left) and DASCH measurements phased with 103.65(2)-day period (right).

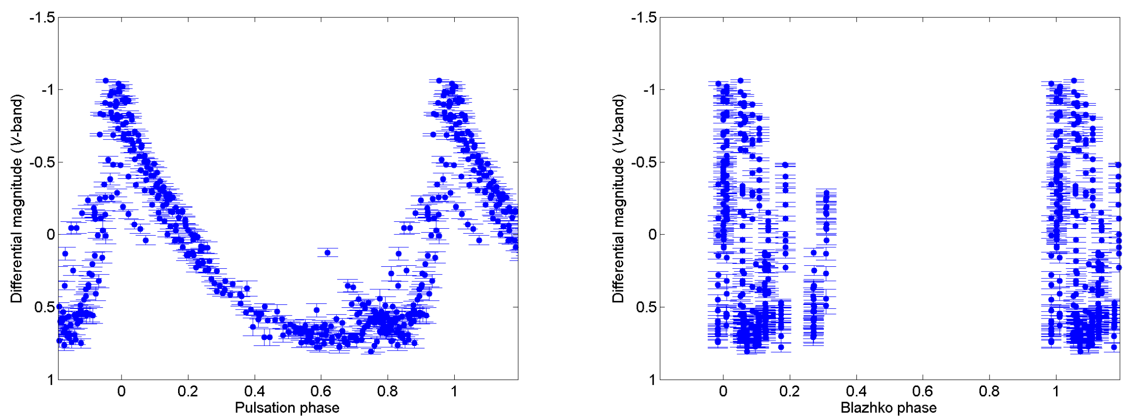

Figure 4: Data from Kim et al. (2009) phased with pulsation period of 0.53456(2) d (the left panel) and Blazhko period of 103.65(2) d. See details in text.

Table 2: Maxima timings and maximal differential magnitudes determined from Kim et al. (2009) data.

Kim et al. (2009) (V)			
$T_{\rm max}$	$\delta T_{\rm max}$	$m_{\rm max}$	$\delta m_{\rm max}$
2454575.0355	0.0019	−0.400	0.025
2454576.1082	0.0021	−0.400	0.031
2454584.1134	0.0005	−0.295	0.007
2454607.0818	0.0035	0.178	0.013
2454684.0691	0.0109	−0.409	0.178
2454685.1441	0.0013	−0.332	0.069

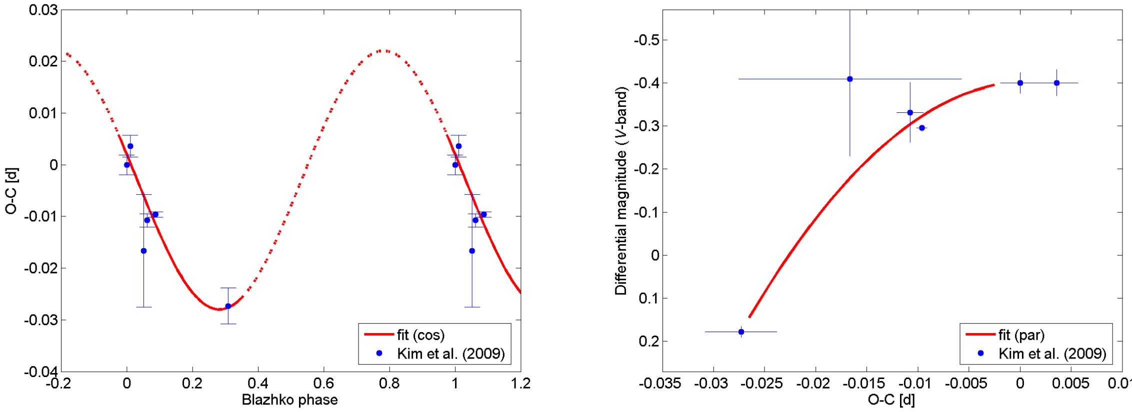

Figure 5: $O-C$ diagram of V0346 Dra based on maxima determined from V-measurements of Kim et al. (2009) together with the best cosinusoidal fit (left panel) and dependence between differential maximal magnitude and $O-C$ values together with parabolic fit (right panel).

3 Results and Summary

Our period analysis of NSVS data for V0346 Dra resulted in the identification of Blazhko modulation with 101(2)-d period. It is quite surprising, because at least two studies which were focused on RR Lyrae stars, and were based on the same data, did not mention the Blazhko effect (Kinemuchi et al., 2006; Wils et al., 2006). The Blazhko period close to 100 day was independently confirmed using photographic measurements from DASCH project. The advantage of lower uncertainty of measurements from NSVS is compensated by two-order longer timebase of the DASCH data set. This allowed us to precisely estimate the value of the Blazhko period ($P_{\rm Bl}$ = 103.65(2) d). High-quality measurements from Kim et al. (2009) were insufficient for determination of Blazhko period using frequency analysis (range of timebase is comparable with the Blazhko period, data contains 70-day gap). We used them for determination of maxima timings and verification of both kinds of modulation – in amplitude and phase.

Our estimated pulsation periods of 0.53456(2) d (Kim et al., 2009), 0.53452(3) d (NSVS), and 0.5345201(3) d (DASCH) differ a bit for each analysed datasets. Therefore data points from each project were displayed with corresponding period and zero epoch. Close values of mean pulsation period based on different datasets suggest that the pulsation period is probably constant, or very slowly variable. Although the Blazhko effect is unambiguously present in V0346 Dra, the value of the modulation is still not well determined and needs additional refinement.

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References

Benkő, J. M., Szabó, R., & Paparó, M. 2011, *MNRAS*, **417**, 974, 2011MNRAS.417..974B

Grindlay, J., Tang, S., Simcoe, R., et al. 2009, *Preserving Astronomy's Photographic Legacy: Current State and the Future of North American Astronomical Plates*, **410**, 101, 2009ASPC..410..101G

Grindlay, J., Tang, S., Los, E., & Servillat, M. 2012, *IAU Symposium*, **285**, 29, 2012IAUS..285...29G

Kazarovets, E. V., Samus, N. N., Durlevich, O. V., Kireeva, N. N., & Pastukhova, E. N. 2013, *Information Bulletin on Variable Stars*, **6052**, 1, 2013IBVS.6052....1K

Kim, D., Jeon, Y.-B., Lee, U., et al. 2009, *Information Bulletin on Variable Stars*, **5872**, 1, 2009IBVS.5872....1K

Kinemuchi, K., Smith, H. A., Woźniak, P. R., McKay, T. A., & ROTSE Collaboration 2006, *AJ*, **132**, 1202, 2006AJ....132.1202K

Lenz, P. & Breger, M., 2005, *CoAst*, **146**, 53, 2005CoAst.146...53L

Skarka, M., Dřevěný, R., Auer, R. F. et al. 2015, in prep.

Wils, P., Lloyd, C., & Bernhard, K. 2006, *MNRAS*, **368**, 1757, 2006MNRAS.368.1757W

Woźniak, P. R., Vestrand, W. T., Akerlof, C. W., et al., 2004, *AJ*, **127**, 2436, 2004AJ....127.2436W