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TWO NEW ECLIPSING VARIABLE STARS IN BOOTES

NATALIA A. VIRNINA

Department "High and Applied Mathematics"
Odessa National Maritime University, Odessa, Ukraine, virnina@gmail.com

Abstract: We report the discovery of two new variable stars, USNO-B1.0 1238-0228470 and USNO-B1.0 1229-0276915, in Bootes using the remotely controlled astrophysical refractor AP-180 of the Tzec Maun Observatory (USA) in 87.5' x 58.3' field centered on $14^h15^m27.40^s$ $+33^d31^m32.5^s$. We have already preliminary registered these stars in VSX (Variable Stars Index, AAVSO) and these stars have got names VSX J141509.2+335222 and VSX J141340.5+325648, respectively.

Both stars are eclipsing binary systems. USNO-B1.0 1238-0228470 has been classified as EB or EA/SD. It is rather bright – it shows low-amplitude variations in a range of 12.833 – 13.080 (R), the period is short relatively to the classic EB-type stars: P=0.47813±0.00004 d, the initial epoch is T_0=HJD2455268.5270±0.0007. USNO-B1.0 1229-0276915 has been classified as EA/SD-type. This star is rather faint for the 180mm telescope: 16.821 – 17.593 (R), the period is P=0.46908±0.00004 d, the initial epoch is T_0=HJD2455268.8822±0.0011.

We've observed the field without known variable stars. The center was on $14^h15^m27.40^s$ $+33^d31^m32.5^s$, the field of view was 87.5' x 58.3'. All observations were unfiltered, obtained using the remotely controlled astrophysical refractor AP-180 (D=180mm, F=1317mm) of the Tzec Maun Observatory (Mayhill, New Mexico, USA). This telescope was equipped with the CCD camera SBIG STL-11K. The maximum quantum efficiency of the camera sensor lies between 600nm and 625nm, which is close to the standard R-band. Although the "unfiltered" photometric system has a wider spectral band then the R one, the color transformation coefficients between the instrumental system and that of Henden (2007) are close to zero (Virnina 2010). Thus we have used the calibration in R. The time used is UTC.

We have discovered the variability of USNO-B1.0 1238-0228470 and USNO-B1.0 1229-0276915 using the software package C-Munipack (Motl, 2007) by analyzing the dependence of the standard deviation of the brightness estimates for a given star on its mean brightness.

We've preliminary registered these new variable stars in the VSX catalog, operated by AAVSO: USNO-B1.0 1238-0228470 = VSX J141509.2+335222 and USNO-B1.0 1229-0276915 = VSX J141340.5+325648. The finding charts of these new variable and comparison stars are shown in the Figures 1, 2. The overall field used is available from the OEJV page.

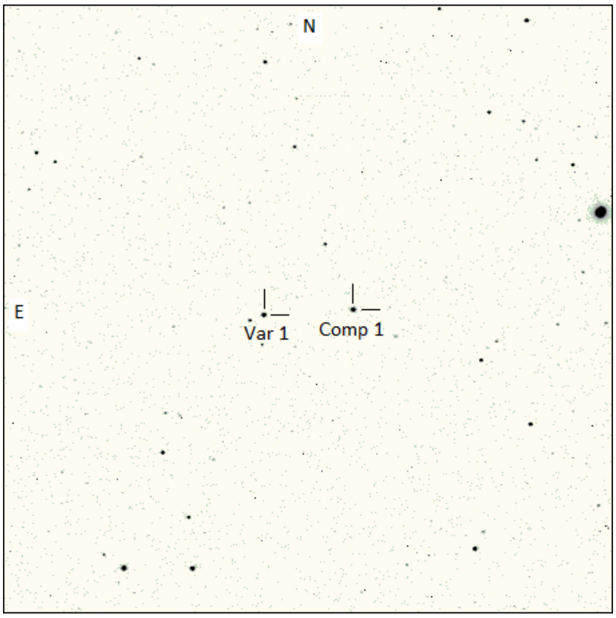

Fig.1. 20'x20' finding chart for VSX J141509.2+335222

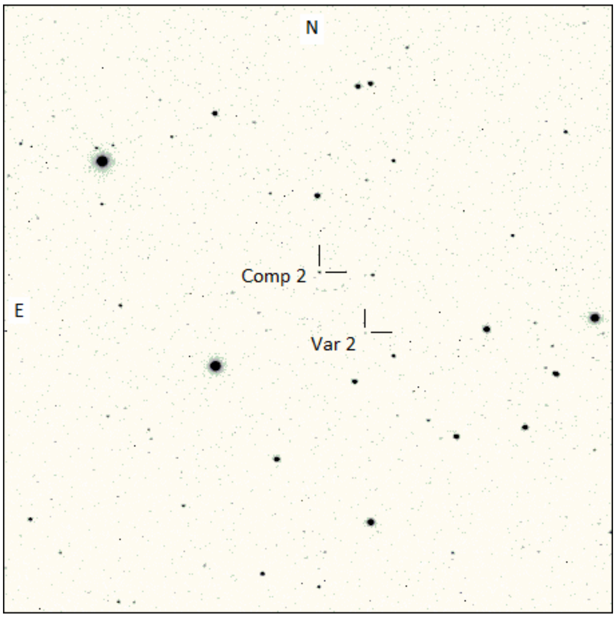

Fig.2. 20'x20' finding chart for VSX J141340.5+325648

We used different comparison stars for calibration photometry because of a big difference between the mean brightness' of new variable stars. Comp 1 = USNO-B1.0 1238-0228430 had been used as a comparison star for the first variable star USNO-B1.0 1238-0228470, and Comp 2 = USNO-B1.0 1229-0276945 – for the second one USNO-B1.0 1229-0276915. We used the photometric catalog SDSS and the transformation formulae (Lupton, 2005) to transform the u, g, r, i, z photometry into the B, V, R, I system. The information about the comparison stars is presented in Table.1.

Table 1. Comparison stars.

	USNO-B1.0	RA (2000.0)	Dec (2000.0)	R
Comp 1	1238-0228430	$14^h14^m55.200^s$	$+33^d52^m32.31^s$	12.622
Comp 2	1229-0276945	$14^h13^m47.715^s$	$+32^d58^m46.71^s$	15.621

To determine the approximate values of the periods of new variable stars, the software "WinEffect" (Goransky, 2005) was used. The periods have been determined from the periodogram analysis using the Kholopov's (1971) improvement of the method by Lafler and Kinman (1965). Statistical properties of the non-parametric methods of the periodogram analysis were reviewed by Andronov and Chinarova (1997).

Then the FDCN software (Andronov, 1994, 2003) was used, which allows to determine the coefficients of the statistically optimal trigonometric polynomials using the least squares method routine with differential corrections for the period. Other parameters of the light curve and their error estimates are determined using this approximation.

According to the GCVS (Samus' et al. 2009), the EA-type systems differ from the EB and EW types: "It is possible to specify, for their light curves, the moments of the beginning and end of the eclipses".

The phase curve for the first variable star, USNO-B1.0 1238-0228470 = VSX J141509.2+335222 is shown in the Fig. 3. Assuming that the light curve is smooth, it may be classified as a binary system EB-type because of a rather large difference between the depths of the primary and the secondary minima: min_I=13.080±0.003, min_{II}=12.916±0.002, the maximum max=12.833±0.002. The period of this system is unusually short for the EB type:

P=0.47813±0.00004 d. The initial epoch is T_0=HJD2455268.5270±0.0007. We used the trigonometrically polynomial of the statistically optimal degree $s = 4$.

The second star, USNO-B1.0 1229-0276915 = VSX J141340.5+325648, shows a smaller difference between the depth of two minima, min_I=17.593±0.018, min_{II}=17.494±0.022, max=16.821±0.026 thus, assuming smooth variations, we classified it as EW-type. The statistically optimal degree of the trigonometrically polynomial was $s = 4$ too. The period and the initial epoch were calculated with corresponding error estimates: P=0.46908±0.00004 d, the initial epoch is T_0=HJD2455268.8822±0.0011. The phase curve for this star is shown in the Fig. 4.

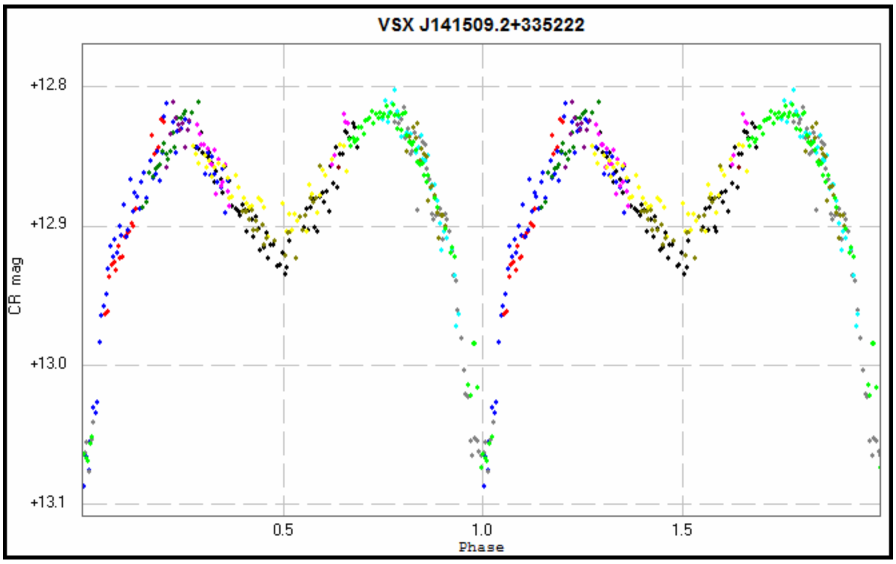

Fig.3. The phase curve for USNO-B1.0 1238-0228470 = VSX J141509.2+335222
Each color means another night.

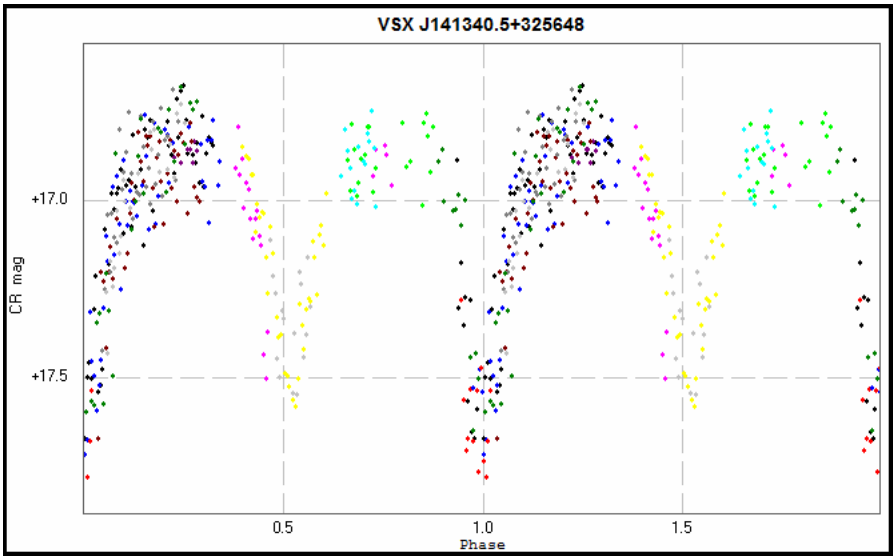

Fig.4. The phase curve for USNO-B1.0 1229-0276915 = VSX J141340.5+325648
Each color means another night.

All the parameters needed for the General Catalog of Variable Stars (GCVS, Samus' et al. 2010) have been determined with corresponding error estimates and summarized in Tab.2, where the coordinates, USNO-B1.0 and VSX names are given, and in Tab.3, where all parameters with corresponding error estimates are shown. The original HJD photometry files (HJD-2400000, CR magnitude), are attached and available from the OEJV web-site.

Additionally, to check an EA classification of these stars, we have used the new program "NAV" ("New Algol Variable") recently developed by Andronov (2010, in preparation), which allows to fit relatively narrow minima by using a 5-parameter low-order trigonometric polynomial (TP) fit plus a compact function to fit two eclipses of different amplitudes C_6 (primary eclipse) and C_7 (secondary eclipse):

$$x(\phi) = C_1 + C_2\cos(2\pi\phi) + C_3\cos(4\pi\phi) + C_4\sin(2\pi\phi) + C_5\sin(4\pi\phi) + \\ + C_6 H(\phi, C_8, \alpha_1) + C_7 H(\phi + 0.5, C_8, \alpha_2) \qquad (1)$$

Here it is assumed that the orbit is circular, thus the semi-durations of both eclipses C_8 are the same. The function

$$H(\phi, C_8, \alpha_1) = \begin{cases} ((1-(\phi/C_8)^{\alpha_1})^{3/2}, & \text{if } 0 \le \phi \le C_8 \\ 0, & \text{if } C_8 \le \phi \le 1 - C_8 \\ ((1-((1-\phi)/C_8)^{\alpha_1})^{3/2}, & \text{if } 1 - C_8 \le \phi \le 1 \end{cases}$$

is dependent on a free parameter α_1, which describes the profile of the minimum: for the partial eclipse with a nearly parabolic shape near its center, a good estimate is α_1=2, whereas for full eclipses, one should expect larger values of α_1, which increase with an increasing arbitrary duration of the full eclipse (see Andronov 2010, in preparation, for details). The phase ϕ is defined from zero to unity, as an usual convention for phases. Other parameters are ususlly interpreted as: C_1 – mean brightness neglecting both eclipses; C_2 is semi-amplitude of the reflection effect; C_3 is semi-amplitude of the ellipticity effect; C_4 and C_5 characterize asymmetry of the curves. Similarly to the program name, the fit (1) is called "NAV".

Obviously, the TP and NAV fits generally differ only at the intervals of the primary ($0 \le \phi \le C_8$, $1 - C_8 \le \phi \le 1$) and secondary ($0.5 - C_8 \le \phi \le 0.5 + C_8$) minima, being identical for the phases out of eclipse.

As no horizontal parts of the light curve are seen in both eclipses for both stars, there are no full eclipses and we used α_1=α_2=2, so the only free parameter is C_8=D/2, where D is a parameter listed in the GCVS, which is defined as "full duration of eclipse". The test function $\sigma(C_8)$ is the unbiased r.m.s. estimate of the observations from the best fit. From its minimum, the parameters C_1—C_8 were determined for the first and second variable stars. They are listed in the Table 4. The corresponding smoothing light curves are shown in Fig. 4,5.

Apparently, both stars show similar values of the eclipse duration D=2C_8 of 0.162±0.006 and 0.158±0.006. Thus parameter is dependent on relative dimensions of stars and inclination, and thus varies from system to system. Many other systems listed in the GCVS have smaller values of D. However, the values determined for our new variables are not outstandingly large - e.g. for the first EA/SD variable listed in the GCVS - RT And - D=0.17. The significant ellipticity effect, which is characteristic for SD systems, is important for both stars. However, a small reflection effect is statistically significant only for the first star. The secondary eclipse is negligible in amplitude as compared to the ellipticity effect. This indicates that the secondary has a significantly smaller brightness, and so the temperature.

One may note a r.m.s. deviation of the points from the fit of 0.014 mag for the first star (12.8-13.1) and 0.120 for the second faint star (16.8-17.6).

Table 2. Coordinates and cross-identifications of the discovered stars

#	USNO-B1.0	RA	Dec	VSX
1	USNO-B1.0 1238-0228470	$14^h15^m09.282^s$	$+33^d52^m22.12^s$	VSX J141509.2+335222
2	USNO-B1.0 1229-0276915	$14^h13^m40.556^s$	$+33^d56^m48.16^s$	VSX J141340.5+325648

Table. 3. Characteristics of the discovered stars from the trigonometric polynomial (up) and "NAV" fits (bottom)

#	Type	Period, d	Max	min_I	min_{II}	Initial epoch, HJD
1	EB EA	0.47813±0.00004	12.833±0.002 12.825±0.001	13.080±0.003 13.072±0.002	12.916±0.002 12.910±0.002	2455268.5270±0.0007
2	EW EA	0.46908±0.00004	16.821±0.026 16.828±0.009	17.593±0.018 17.653±0.013	17.494±0.022 17.502±0.018	2455268.8822±0.0011

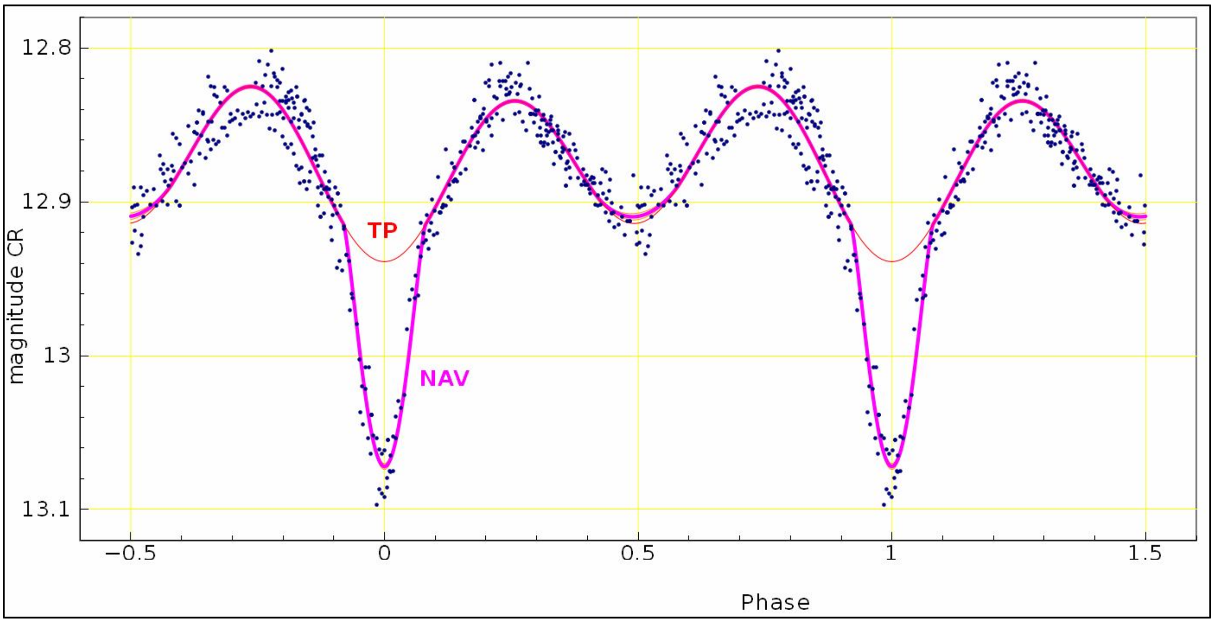

Fig.5. The phase curve for USNO-B1.0 1238-0228470 = VSX J141509.2+335222 and the .TP (red) and NAV (magenta) fits with "1σ" corridor (dark yellow). The TP and NAV fits are identical outside eclipses. Because the error estimates for the smoothing curve are small, the "1σ" corridor is smaller than the line thickness and not visible for this star.

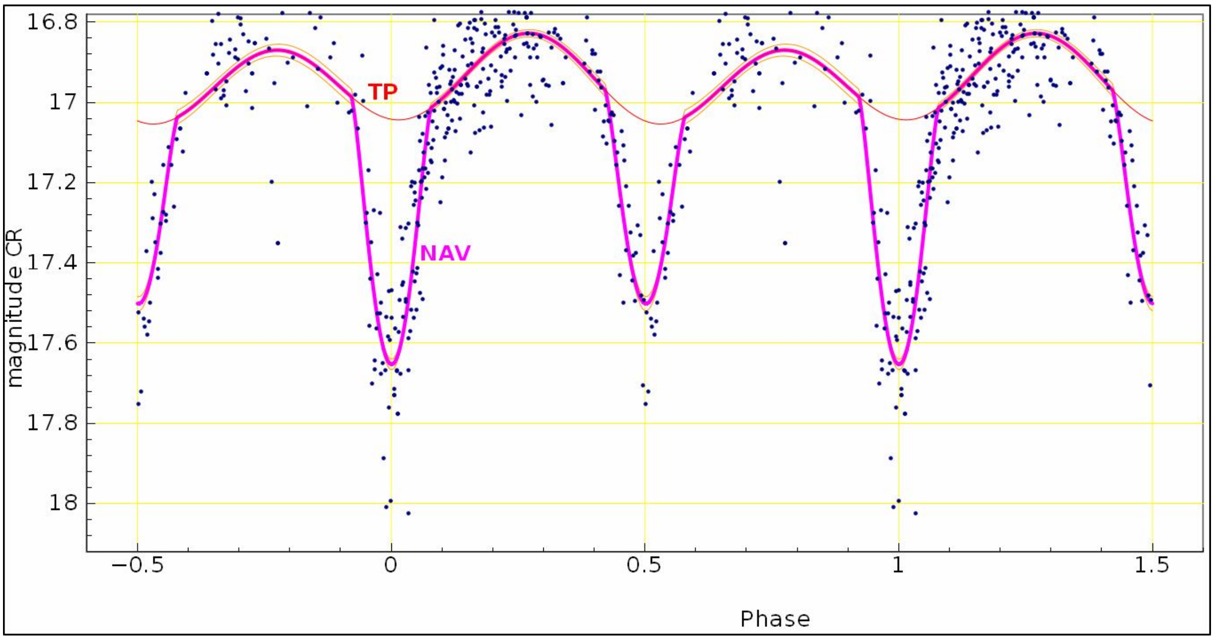

Fig.6. The phase curve for USNO-B1.0 1229-0276915 = VSX J141340.5+325648 and the .TP (red) and NAV (magenta) fits with "1σ" corridor.

Table. 4. Parameters the "NAV" fits. The statistically significant coefficients are shown with a normal font, the statistically insignificant (at 4σ level) ones are shown in *italics*.

#	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	σ
1	12.878 ±0.001	0.013 ±0.001	0.048 ±0.001	*0.004 ±0.001*	*-0.002 ±0.001*	0.133 ±0.003	*-0.004 ±0.003*	0.081 ±0.003	0.014
2	16.949 ±0.007	*-0.002 ±0.011*	0.095 ±0.009	*-0.022 ±0.007*	*0.028 ±0.008*	0.611 ±0.023	0.455 ±0.029	0.079 ±0.003	0.120

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