

THREE NEW VARIABLE STARS NEAR TT ARI

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Abstract: Three new variable stars in Aries were discovered using the remotely controlled astrophysical refractor AP-180 of the Tzec Maun Observatory (USA) in 87.5' x 58.3' field of the cataclysmic variable star TT Ari. These stars : USNO-B1.0 1047-0021596, USNO-B1.0 1049-0021745 and USNO-B1.0 1048-0022462 have been preliminary registered in VSX (Variable Stars Index, AAVSO) and got names VSX J020534.8+144630, VSX J020730.1+145623 and VSX J020617.2+145213, respectively.

The first two stars are eclipsing binaries and have been classified as EW-type. The third star has a low amplitude and sinusoidal curve, and may be classified as DSCT or a low-inclination binary system without eclipses – Ell-type.

1. Introduction

We observed the field of the cataclysmic variable star TT Ari during the period from JD 2455146 to JD 2455226. All observations were obtained using the remotely controlled astrophysical refractor AP-180 (D=180mm, F=1317mm) of the Tzec Maun Observatory (Mayhill, New Mexico, USA), which was equipped with the CCD camera SBIG STL-11K. The field of view was 87.5' x 58.3'. All observations were obtained with clear filter. The maximum quantum efficiency of the camera sensor is close to the standard R-band. Thus we have used the calibration in R.

Among about 1500 point sources, which had been matched on our frames, we have discovered 3 new variable stars.

2. Field research

To search for the new variable stars, we have examined twice the best frames of the field and analyzed the dependence of the standard deviation of the brightness estimates for a given star on its mean brightness, using the software package C-Munipack (Motl, 2007). The first stage was an examining the longest series (7 hours), which had been obtained on JD 2455156, to search for short-periodic variables. The second stage was to examine the frames of the whole observation period, choosing several images per night – for long-periodic variables.

The results of the first stage were 3 new variable stars: USNO-B1.0 1047-0021596, USNO-B1.0 1049-0021745 and USNO-B1.0 1048-0022462. Unfortunately, no long-periodic variables were found.

The VizieR service had been used for checking if these variable stars are still unknown.

The positions of new variable stars are shown in Figures 1, 2, 3.

We chose 3 comparison stars: USNO-B1.0 1052-0022726, USNO-B1.0 1052-0022777 and USNO-B1.0 1051-0022166. Their magnitudes in R-band and V-R color indexes, according to Henden (2007), are given in Table 1, and their positions are marked in Figure 4.

To determine the color transformation coefficients, we have used the mean magnitudes of 39 stars from our data and the corresponding Henden's (2007) calibration. The relation between the instrumental system and that of Henden (2007) was computed using the computer program "O" (Andronov, 2001):

$$CR - R = -0.04(\pm 0.011) + 0.083(\pm 0.024) \cdot (V - R),$$

where CR – our magnitudes, R and V – magnitudes in standard R- and V-bands. The values of the transformation coefficients are close to zero, thus we use the R magnitudes for calibration of photometry.

Table 1. Comparison stars.

	USNO-B1.0	RA (2000.0)	Dec	R	V-R
Comp 1	1052-0022726	02 ^h 06 ^m 49.038 ^s	+15 ^d 16 ^m 59.58 ^s	14.231	0.402
Comp 2	1052-0022777	02 ^h 07 ^m 02.172 ^s	+15 ^d 12 ^m 39.65 ^s	14.341	0.475
Comp 3	1051-0022166	02 ^h 07 ^m 13.311 ^s	+15 ^d 11 ^m 12.62 ^s	13.428	0.433

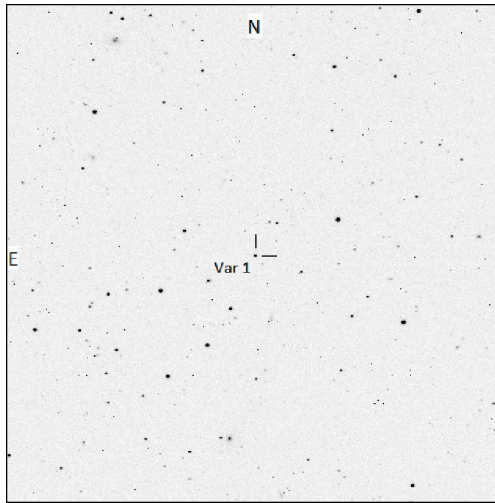


Figure 1. The 20' vicinity of the variable star USNO-B1.0 1047-0021596

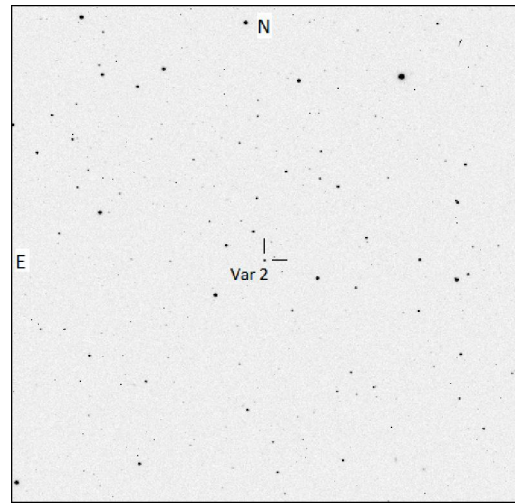


Figure 2. The 20' vicinity of the variable star USNO-B1.0 1049-0021745

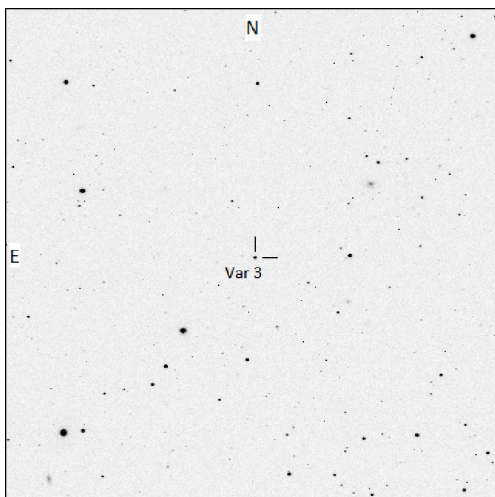


Figure 3. The 20' vicinity of the variable star USNO-B1.0 1048-0022462.

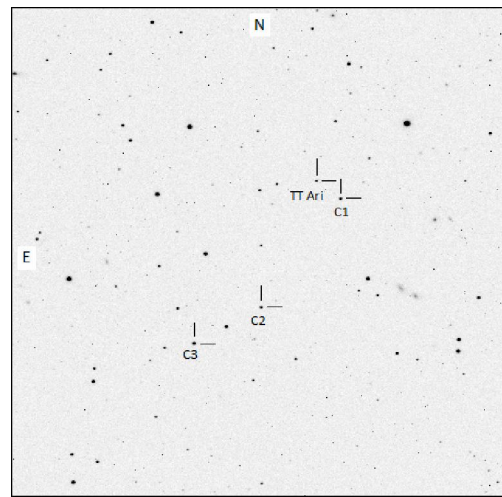


Figure 4. TT Ari and three comparison stars. The field of view is 20'x20'.

3. Data analysis

The approximate values of the photometric periods of new variable stars have been preliminary determined using the computer program “WinEffect” (Goransky, 2005). For the periodogram analysis, we have used the Kholopov’s (1969) 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).

The types of variability were determined as EW (W UMa) for both USNO-B1.0 1047-0021596 and USNO-B1.0 1049-0021745, and DSCT (δ Sct) for USNO-B1.0 1048-0022462. Then the computer program FDCN (Andronov, 1994, 2003) was used, which computes the coefficients of the statistically optimal trigonometric polynomials using the least squares method routine and differential corrections for the period. All the parameters needed for the General Catalog of Variable Stars (GCVS, Samus’ et al. 2010) have been determined with corresponding error estimates. After classifying and calculation of the most important parameters, we have registered our newly discovered variable stars in the Variable Stars Index – VSX, operated by the AAVSO.

USNO-B1.0 1047-0021596 is an eclipsing binary with nearly identical minima: $\min_I = 14.419 \pm 0.003$, $\min_{II} = 14.363 \pm 0.003$. The maximum is $\max = 14.219 \pm 0.004$, the period $P = 0.569332 \pm 0.000015$ d, the initial epoch $E_0 = \text{HJD } 2455181.3717 \pm 0.0008$. We used the trigonometrical polynomial of the statistically optimal degree $s = 6$. The phase curve is shown in Figure 5. Except an ellipsoidal effect, this system shows a slight reflection effect. The star got the VSX name J020534.8+144630.

USNO-B1.0 1049-0021745 is an eclipsing binary too, with an unusually large amplitude $A = 0.88$ mag, $\max = 15.344 \pm 0.009$, $\min_I = 16.231 \pm 0.011$, $\min_{II} = 16.094 \pm 0.012$. This binary also has a rather short period $P = 0.223445 \pm 0.000001$ days, which indicates that the system is very close. The initial epoch $E_0 = \text{HJD } 2455181.1713 \pm 0.0003$. The phase curve is shown in Figure 6. The VSX name is J020730.1+145623.

The depth of the primary and secondary minima is 0.887 mag and 0.750 mag, respectively. These values are rather high. Let's introduce a parameter Y :

$$Y = \left(1 - 10^{-0.4\Delta m_1}\right) + \left(1 - 10^{-0.4\Delta m_2}\right)$$

corresponding to a ratio of the sum of deficiencies of flux at the primary and secondary minimum to the maximal brightness of the system. This parameter is equal to unity, if assuming that both stars are spherically symmetric, of equal radii and both eclipses are total (i.e. the inclination angle $i=90^\circ$). For spherical stars, this parameter will decrease (for other equal parameters) either with deviation of i from 90° , or difference in radii, as at least one eclipse will become partial. In the case of the star VSX J020730.1+145623, the parameter $Y=0.558+0.499=1.057$, which is impossible for spherically symmetrical stars. This argues for a necessity of taking into account the ellipticity of stars and a possible reflection effect. For this purpose, we have modeled the out-of-eclipse part of the light curve by a symmetric expression:

$$m(\phi) = C_0 + C_1 \cos(2\pi\phi) + C_2 \cos(4\pi\phi), \quad (1)$$

where C_0 corresponds to a period-averaged mean value, C_1 is a semi-amplitude of the reflection effect, and C_2 is a semi-amplitude of the effect of the ellipticity. Strictly saying, if

the reflection effect is comparable for both stars, it has a contribution not only at an orbital frequency, but also at a double orbital frequency (cf. Kopal 1959, Tsessevich 1971).

An examination of the trigonometric polynomial fit of statistically optimal order $s=8$, which was used for the determination of the parameters, shows that the eclipse has a half-width of 0.10. So the out-of-eclipse phases are 0.2 .. 0.4 and 0.6 .. 0.9. At these phase intervals, there are 434 points out of 671. The coefficients were computed using the MCV program (Andronov and Baklanov 2004) and are equal to

$$\begin{aligned}C_0 &= 15.511 \pm 0.004; \\C_1 &= 0.017 \pm 0.005; \\C_2 &= 0.162 \pm 0.006.\end{aligned}$$

Although the coefficient C_2 is ~ 10 times larger than C_1 , C_1 is also statistically significant. For these coefficients, the resulting smoothing curve has a maximum of 15.350 ± 0.008 , main minimum of 15.691 ± 0.009 and a secondary minimum of 15.656 ± 0.011 . Computing the depth of the minima as a difference between the smoothing value and that of the "out-of-eclipse" fit instead of the "maximum", we get $\Delta m_1 = 0.540 \pm 0.014$ and $\Delta m_2 = 0.438 \pm 0.016$ and a corresponding parameter $Y = 0.392 + 0.332 = 0.724$. This value is significantly smaller than unity, in an agreement with theoretical expectations for partial eclipses.

Thus we conclude that the system has a strong effect of ellipticity, much smaller reflection effect, and at least one partial eclipse. The small difference between the depth of two minima is typical for the W UMa - type stars, as one may see e.g. from the observed parameters listed in the GCVS.

USNO-B1.0 1048-0022462 has a nearly sinusoidal symmetric curve, so the statistically optimal degree of the polynomial is $s=1$. This star has a small amplitude of 0.087 ± 0.003 mag and a short period: max = 13.590 ± 0.002 mag, min = 13.677 ± 0.002 mag, $P = 0.180929 \pm 0.000005$ days. This is similar to the Delta Sct - type stars. In this case the initial epoch is $E_0 = \text{HJD } 2455181.7054 \pm 0.0008$. The phase curve is shown on the Fig.7.

Another possible explanation of a small amplitude and a sinusoidal shape is a low inclination non-eclipsing binary system with a strong effect of ellipticity. The phase curve is shown on the Fig.8. At such assumption, the statistically optimal degree of the polynomial is $s=2$, the period $P = 0.361849 \pm 0.000011$ days (which coincides with a double of the period mentioned above within error estimates), the initial epoch is $E_0 = \text{HJD } 2455181.6141 \pm 0.0009$. For this star, we have again used Eq.(1). The corresponding coefficients are:

$$\begin{aligned}C_0 &= 13.632225 \pm 0.00055 \\C_1 &= 0.00452 \pm 0.00079 \\C_2 &= 0.04263 \pm 0.00078\end{aligned}$$

The r.m.s. deviation of observations from the fit is 0.020 mag. The ratio of the values of the coefficients to their error estimates are 5.7 and 54.3 for C_1 and C_2 , respectively. Although the coefficient C_1 is much smaller than C_2 , formally it may be assumed as a statistically significant one. Thus one may not rule out a possibility that the object is a non-eclipsing close binary system with very similar components and some possible evidence for a reflection effect and/or deviations of the form (if nearly filling the Roche lobe) from ellipsoids.

From a pure photometry, it is not possible to distinguish between these two classifications. Future multi-color photometry or spectral studies may solve the problem.

This star got the VSX name J020617.2+145213.

The final results are summarized and tabulated 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), and a single chart where all 3 new variable stars, TT Ari and the comparison stars are marked, are attached and available from the OEJV web-site.

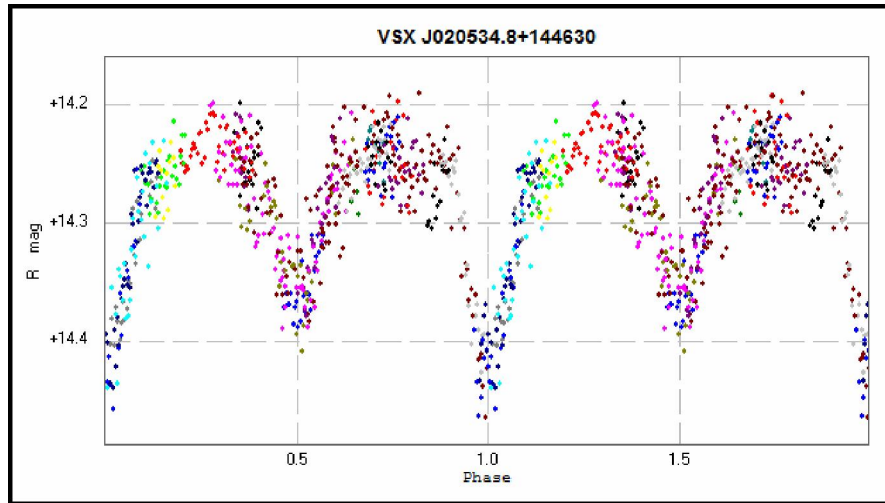


Figure 5. The phase curve of USNO-B1.0 1047-0021596. Each color means another night.

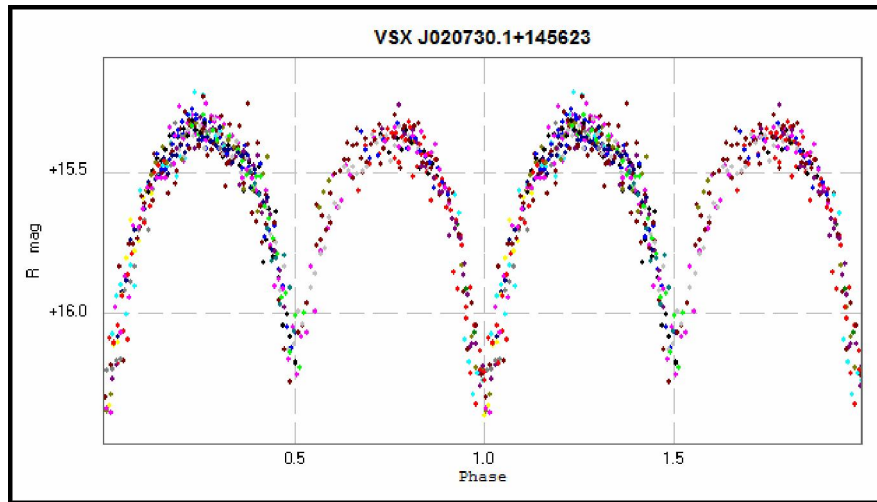


Figure 6. The phase curve of USNO-B1.0 1049-0021745. Each color means another night.

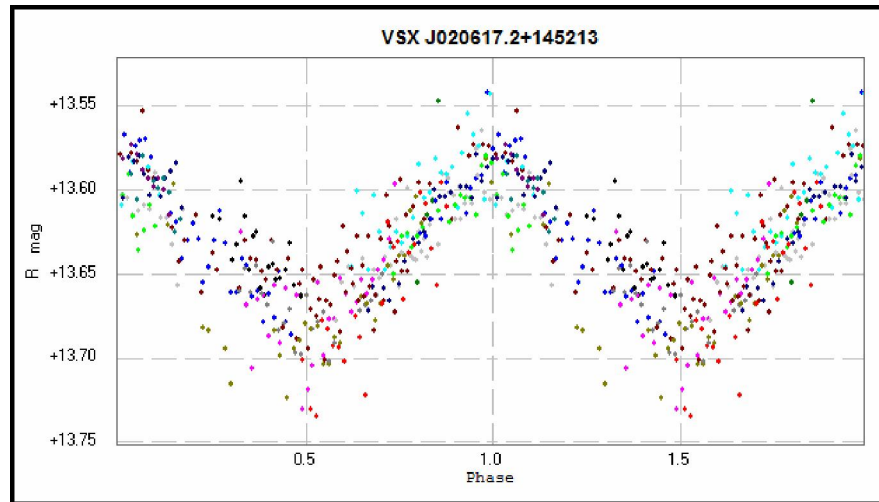


Fig. 7. The phase curve of USNO-B1.0 1048-0022462 in a case of DSCT solution.

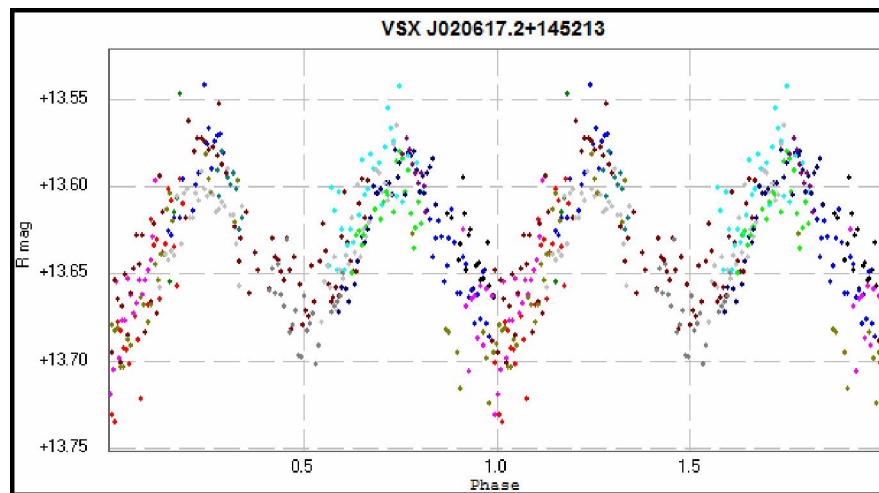


Fig. 8. The phase curve of USNO-B1.0 1048-0022462 in a case of binary system solution.

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

#	USNO-B1.0	RA	Dec	VSX
1	USNO-B1.0 1047-0021596	02 ^h 05 ^m 34.791 ^s	+14 ^d 46 ^m 30.34 ^s	VSX J020534.8+144630
2	USNO-B1.0 1049-0021745	02 ^h 07 ^m 30.181 ^s	+14 ^d 56 ^m 23.07 ^s	VSX J020730.1+145623
3	USNO-B1.0 1048-0022462	02 ^h 06 ^m 17.209 ^s	+14 ^d 52 ^m 13.56 ^s	VSX J020617.2+145213

Table 3. Characteristics of the discovered stars

#	Type	Period, d	max	min (min _I)	min _{II}	Initial epoch, HJD
1	EW	0.569332±0.000015	14.219±0.004	14.419±0.003	14.363±0.003	2455181.3717±0.0008
2	EW	0.223445±0.000001	15.344±0.009	16.231±0.011	16.094±0.012	2455181.1713±0.0003
3	DSCT	0.180929±0.000005	13.590±0.002	13.677±0.002		2455181.7054 ±0.0008
	EII	0.361849±0.000011	13.587±0.002	13.679±0.002	13.670±0.002	2455181.6141 ±0.0009

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