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# Newly discovered binary system VSX J052807.9+725606 – the only "twin" of V361 Lyr

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During more than 20 years the well studied short periodic binary system V361 Lyr with an extremely asymmetric light curve figured in many papers as a unique system with a direct impact of matter which caused a rather large steady hot region. According to the classical model of this star, due to the hot spot, the phase curve exhibits a strong asymmetry (Andronov et al. 1987; Hilditch et al. 1997).

However, another star VSX J052807.9+725606 was discovered, which shows similar features of the light curves: very strong asymmetry of maxima, wavelength dependence of amplitude and the shift of the secondary minimum from the phase 0.5. We also present the results of further multi-color *B, V, R* photometric study of this exotic star, obtained with the 1.25-m telescope of the Crimean Astrophysical Observatory. The variability of color indices yields the corresponding changes of color temperature. We also compare both stars and analyze the first models of VSX J052807.9+725606, based on pure photometry computed using the Binary Maker 3.

*Keywords*: Binary star; Hot spot; V361 Lyr; VSX J052807.9+725606

## 1 Introduction

A new variable star VSX J052807.9 + 725606 = USNO-B1.0 1629-0064825 ($05^h28^m$ $07.975^s$, + $72°56'06.05''$) was discovered in 2010 by Virnina and Andronov (Virnina and Andronov 2011), using the remotely controlled refractor AP180 ($D$ = 180 mm, $f/7.32$) of Tzec Maun Observatory (USA). This telescope was equipped with an unfiltered monochrome CCD camera SBIG STL-11K. The field of view was $87.5' \times 58.3'$. The maximum quantum efficiency of the camera sensor is close to the standard $R$-band. The phase curve of this star is shown in Fig. 1. The authors also obtained the photometric ephemerides of VSX J052807.9+725606: $T_{\min}(HJD) = 2455261.8484(16) + E \times 0.41179(5)$. Virnina and Andronov (2011) noticed a huge difference between the magnitudes in maxima, and indicated that the value of this effect is $0^m.289 \pm 0^m.026$. Besides, the secondary minimum appeared to be shifted from the phase $\phi = 0.5$, the phase of the secondary minimum is $\phi = 0.543 \pm 0.007$. The most likely explanation of such an asymmetric light curve is the presence of a hot region in the atmosphere of one of the stars.

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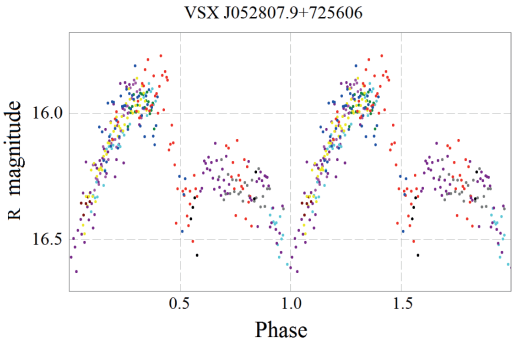



**Figure 1** The first phase curve. Different colors mean different nights of observations.

The only known binary system which shows similar photometrical features of the light curve was V361 Lyr. The $BVR_c$ phase curves of this star, which we obtained on a 16″ Ritchey–Chretien, are shown in Fig. 2. The direct impact model of this star, which had been proposed by Andronov and Richter in 1987 (Andronov et al. 1987), was later confirmed by spectral observations and eclipse-mapping of this star by Hilditch et al. (1997). The cause of a steady hot region supposed to be the accretion stream of matter, which does not form the accretion disk, but, deviated by the Coriolis force from the line of centers, impacts into the photosphere of the accretor component with a shift towards the orbital motion.

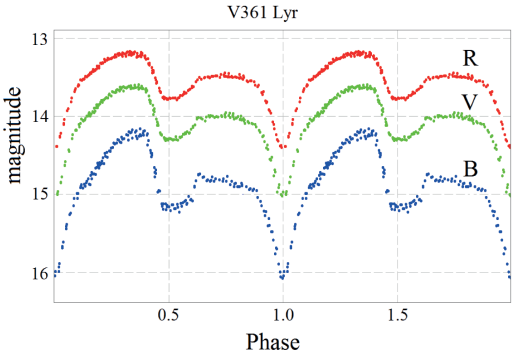



**Figure 2** *BVR* phase curves of V361 Lyr.

However, V361 Lyr remained the only known binary system with these features, until VSX J052807.9+725606 was discovered.

## 2 Photometric study

After its discovery, further studies of VSX J052807.9+725606 were performed on the 1.25-m AZT-11 telescope of the Crimean Astrophysical Observatory (Virnina et al. 2011), using filters with the following effective wavelengths: $B = 466$ nm, $V = 548$ nm, $Rc = 640$ nm. The field of view of this telescope is $7.85' \times 7.85'$. In this field

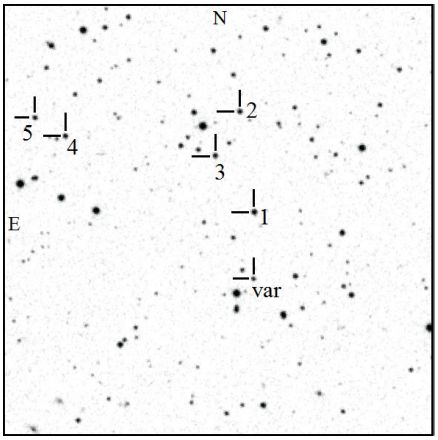



**Figure 3** Comparison stars for VSX J052807.9+725606. Coordinates of the center $RA = 05^h28^m19^s$, $Dec = +72°57''30'$.

**Table 1** Magnitudes of comparison stars in the standard system.

| No | USNO-B1.0 | $B$ | $V$ | $Rc$ |
|---|---|---|---|---|
| 1 | 1629-0064823 | $15.580 \pm 0.039$ | $14.909 \pm 0.041$ | $14.433 \pm 0.014$ |
| 2 | 1629-0064833 | $16.047 \pm 0.043$ | $15.419 \pm 0.041$ | $14.940 \pm 0.015$ |
| 3 | 1629-0064852 | $16.585 \pm 0.045$ | $15.703 \pm 0.043$ | $15.088 \pm 0.013$ |
| 4 | 1629-0064957 | $15.948 \pm 0.041$ | $15.399 \pm 0.041$ | $14.977 \pm 0.017$ |
| 5 | 1629-0064975 | $16.158 \pm 0.048$ | $15.630 \pm 0.040$ | $15.231 \pm 0.015$ |

there are no comparison stars with known magnitudes. Thus we used three stars in the vicinity of SU Cam as the reference ones to determine the magnitudes of comparison stars near VSX J052807.9+725606 using Pogson's formula as it was described in Virnina et al. (2011). According to AAVSO database their USNO-B1.0 numbers and magnitudes are: 1639-0055745 ($B = 14^m.890$, $V = 14^m.159$ $R = 13^m.728$), 1638-0055544 ($B = 15^m.260$, $V = 14^m.617$, $R = 14^m.249$), 1639-0055718 ($B = 15^m.831$, $V = 15^m.081$, $R = 14^m.620$). Five stars of the vicinity of VSX J052807.9+725606 were chosen as the comparison stars. They are marked in Fig. 3 together with the variable star itself. Information on the comparison stars is given in Table 1. The phase light curves in the $B, V, R$ bands in the instrumental system are shown in Fig. 4.

Apart from the observational $BVR$ light curves, we obtained the smoothed curves and smoothed color indices. Using these curves, we determined the phases of maxima and minima and confirmed the phase shifting of the secondary minimum. We noticed that, like in the case of V361 Lyr, there is a wavelength dependence of the amplitude and asymmetry: the longer the wavelength the smaller the difference.

The amplitudes $A$ and the differences of magnitudes at maxima $\Delta$max are given in Table 2. From the color indices the color temperatures of 4965($\pm$74) K and 4686($\pm$82) K in the primary and secondary minima were obtained in Virnina et al. (2011). We also calculated new ephemeris:

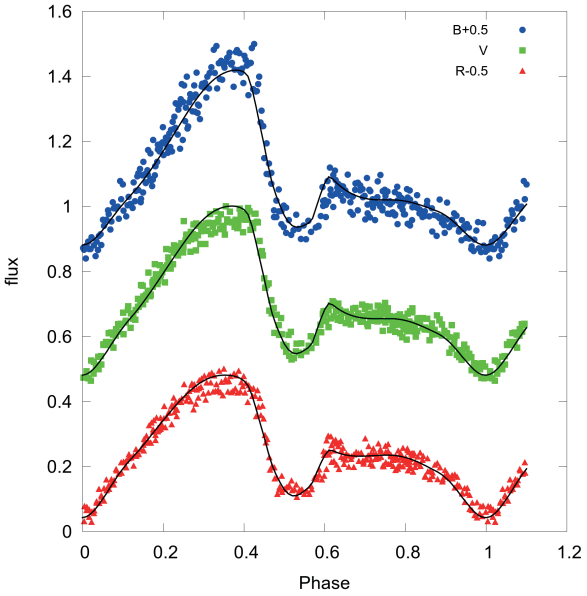



**Figure 4** The *BVR* phase light curves of VSX J052807.9+725606.

$$T_{\min}(HJD) = 2455549.6252(8) + E \times 0.41172(1).$$

**Table 2** Parameters of the phase curves.

| Parameter | $B$ | $V$ | $Rc$ |
|---|---|---|---|
| $\mathrm{Min_I}\ \phi = 0.00$ | $17.667 \pm 0.021$ | $16.799 \pm 0.015$ | $16.187 \pm 0.007$ |
| $\mathrm{Min_{II}}\ \phi = 0.53$ | $17.630 \pm 0.025$ | $16.668 \pm 0.018$ | $16.089 \pm 0.008$ |
| $\mathrm{Max_I}\ \phi = 0.38$ | $16.553 \pm 0.021$ | $16.046 \pm 0.015$ | $15.582 \pm 0.007$ |
| $\mathrm{Max_{II}}\ \phi = 0.64$ | $17.248 \pm 0.019$ | $16.446 \pm 0.013$ | $15.867 \pm 0.006$ |
| $A$ | $1.113 \pm 0.030$ | $0.751 \pm 0.021$ | $0.605 \pm 0.011$ |
| $\Delta$max | $0.694 \pm 0.028$ | $0.399 \pm 0.020$ | $0.286 \pm 0.010$ |

## 3 System parameters

Using Binary Maker 3 (Bradstreet and Steelman 2004), the preliminary physical parameters of VSX J052807.9+725606 were computed. The color temperature in the primary minimum, calculated in Virnina et al. (2011), was chosen as an initial temperature of the secondary component. In the absence of radial velocities, the mass ratio was preliminary determined from pure photometry. As in the case of V361 Lyr, the primary component is more massive and hotter than the secondary one. The primary component slightly fills its Roche lobe ($f_1$), and the secondary component fills ≈70% of its inner volume. The "hot spot" appeared to be an extended region (∼120°) elongated on the equator of the secondary component. This region was imitated by adding 5 hot spots with slightly different radii and temperature factors.

According to Hilditch et al. (1997), V361 Lyr has similar features – the length of the hot region is ∼100°. The theoretical curves in $B, V, R$ bands are shown in Fig. 4 by solid lines. The spots parameters of VSX J052807.9+725606 are presented in Table 3, and the physical parameters of the system are compared with the ones of V361 Lyr, determined by Hilditch (1997), in Table 4. The positions of the spots are illustrated in Fig. 5, where the model of the system is shown at the phases 0.30 and 0.63.

**Table 3** Parameters of the spots.

| Spot No | Co-latitude | Longitude | Spot radius | Temp. factor |
|---|---|---|---|---|
| 1 | 90 | 8.5 | 12 | 2.4 |
| 2 | 90 | 34 | 14 | 2.0 |
| 3 | 90 | 61 | 16 | 1.65 |
| 4 | 90 | 80 | 16 | 1.57 |
| 5 | 90 | 98 | 13 | 1.3 |

**Table 4** Physical parameters of V361 Lyr and VSX J052807.9+725606.

| Parameter | V361 Lyr | VSX J052807.9+725606 |
|---|---|---|
| Gravity darkening $g_1 = g_2$ | 0.32 | 0.32 |
| Albedo $A_1 = A_2$ | 0.5 | 0.5 |
| Inclination $i$ | 85.7 | 66.0 |
| Eccentricity $e$ | 0 | 0 |
| Temperature $T_1$, K | 6200 | 5830 |
| Temperature $T_2$, K | 4500 | 5010 |
| Mass ratio $q = m_2/m_1$ | 0.694 | 0.793 |
| Potential $\Omega_1$ | | 3.4045 |
| Potential $\Omega_2$ | | 3.6539 |
| Fillout $f_1$ | 0.0 | 0.0 |
| Fillout $f_2$ | –0.1 | –0.065 |
| $r_1$ (pole) | 0.387 | 0.375 |
| $r_1$ (side) | | 0.396 |
| $r_1$ (back) | | 0.426 |
| $r_2$ (pole) | 0.280 | 0.306 |
| $r_2$ (side) | | 0.316 |
| $r_2$ (back) | | 0.335 |

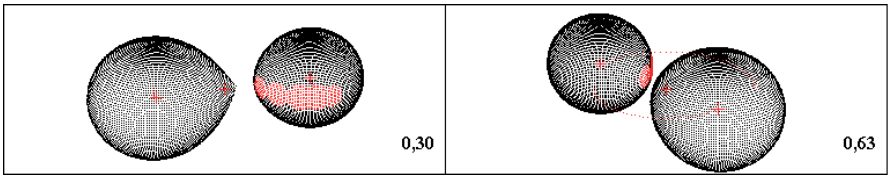



**Figure 5** The model of the system at the phases 0.30 and 0.63.

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