Peremennye Zvezdy (*Variable Stars*) **31**, No. 1, 2011

Received 7 January; accepted 19 January.

GSC 2576–02071 and GSC 2576–01248: two Algol-type eclipsing binaries studied using CCD observations and historical photographic data

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An initial investigation of two poorly studied eclipsing binaries separated by $\sim 3'$ in the sky is presented. The first star (GSC 2576–01248) was discovered by the TrES exoplanet search project. The second one (GSC 2576–02071) was identified by the authors during CCD observations of GSC 2576–01248. We combine our dedicated CCD photometry with the archival TrES observations and data from the digitized photographic plates of the Moscow collection to determine periods of the two variable stars with high precision. For GSC 2576–01248, addition of historical photographic data provides a major improvement in accuracy of period determination. No evidence for period change in these binary systems was found. The lightcurve of GSC 2576–01248 is characterized by a prominent variable O'Connell effect suggesting the presence of a dark starspot and asynchronous rotation of a binary component. GSC 2576–02071 shows a shift of the secondary minimum from the phase = 0.5 indicating a significant orbit eccentricity.

1 GSC 2576–01248: a short-period Algol-type binary with O'Connell effect

GSC 2576–01248 = T-CrB0-04444 = 2MASS 16113251+3306054 ($16^{\rm h}11^{\rm m}32\overset{\rm s}{.}51$ $+33^\circ06'05\overset{''}{.}4$, J2000; Skrutskie et al. 2006) was discovered as an eclipsing binary by Devor et al. (2008) during the Trans-atlantic Exoplanet Survey (TrES; Alonso et al. 2004). It was also independently detected by the authors using archival photographic data during initial tests of our digitized photographic plate analysis pipeline (e.g., Sokolovsky 2006; Kolesnikova et al. 2010). The digitized photographic plates were originally obtained in 1973–1975 with the 40-cm astrograph of the Crimean Laboratory of Sternberg Astronomical Institute (series "A" of the Moscow plate collection, field ξ CrB). To assess the quality of the photographic photometry obtained with our pipeline, in 2006 we have conducted V-band CCD observations of the binary using the 50-cm Maksutov telescope (AZT-5) of the Crimean Laboratory. The CCD observations were reduced in the standard way involving dark-frame and flat-field corrections and aperture photometry of the target star, the comparison (TYC 2576–2051–1, V=10.76, Høg et al. 2000) and check stars in the field of view. A typical accuracy of individual CCD photometric measurements is $\sigma_{\rm CCD} \approx 0\overset{\rm m}{.}02$ while the typical accuracy of our photographic photometry for a $13^{\rm m}$–$14^{\rm m}$ star was found to be $\sigma_{\rm phot} \approx 0\overset{\rm m}{.}07$.

Our series of CCD frames was checked for presence of other variable objects in the field using the VaST software (Sokolovsky and Lebedev 2005), which resulted in the discovery of another eclipsing binary, GSC 2576–02071, just $3'$ away (see the following section). The effort to determine the period of the newly discovered binary using observations with a number of telescopes (Table 1) in 2006–2007 has resulted in a high-quality lightcurve also for GSC 2576–01248 since both stars fit in the same field of view for all the instruments used (Fig. 1).

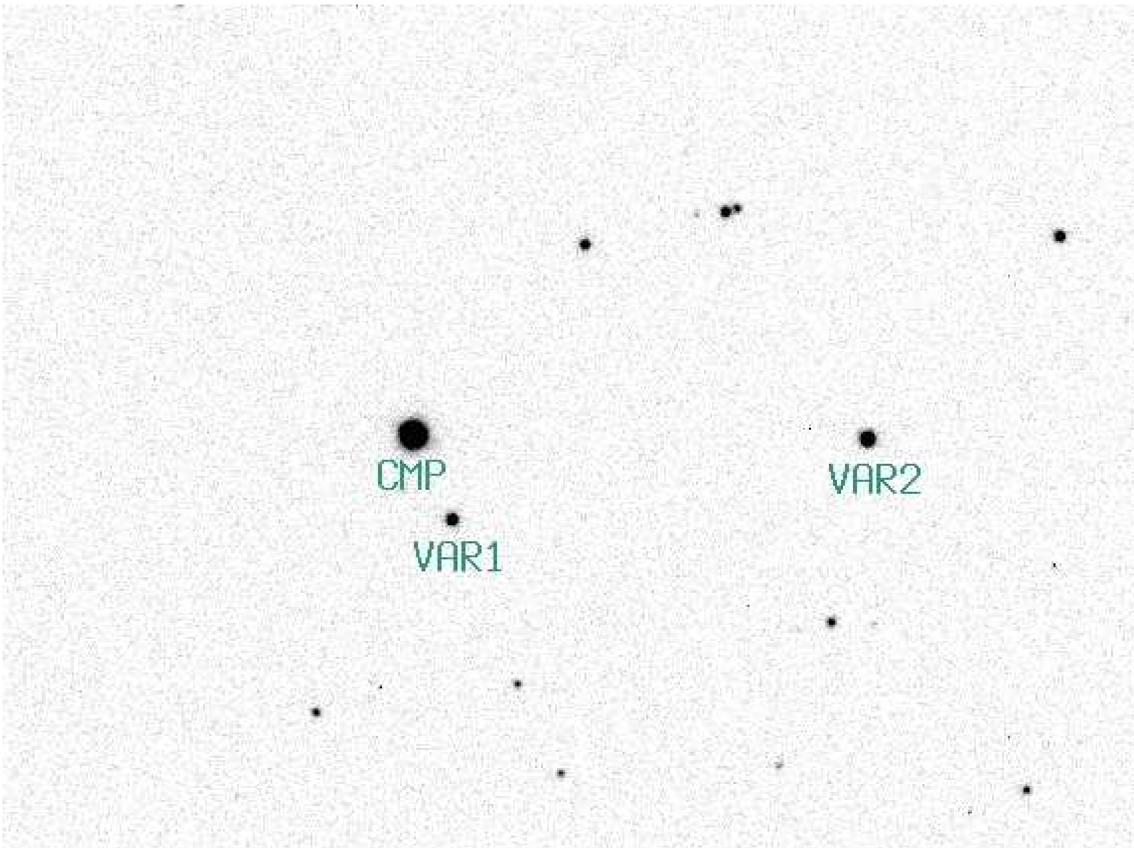

Figure 1. Finding chart for the variable stars GSC 2576–01248 (marked VAR1), GSC 2576–02071 (VAR2), and the comparison star TYC 2576–2051–1 (CMP) made from a V-band frame obtained with AZT-5. The field is $8\overset{'}{.}7 \times 6\overset{'}{.}5$ wide, centered at $16^{\rm h}11^{\rm m}28\overset{\rm s}{.}8$, $+33°06'55\overset{''}{.}8$ (J2000). North is up, east is to the left.

Observations obtained with different instruments were combined into a single lightcurve by shifting individual lightcurves to match the average out-of-eclipse brightness to that observed with AZT-5. The eclipse depth is the same for both V-band and unfiltered lightcurves (Fig. 2) thanks to the spectral response curve of the blue-sensitive KAI-2020M CCD chip used in the ST2000XM camera, which reaches its peak quantum efficiency in the 410–550 nm range around the V band.

The combined lightcurve of GSC 2576–01248 was analyzed with the Lafler & Kinman (1965) method, which is well-suited for eclipsing binaries of the Algol type, such as the two variable stars presented in this paper. Figure 3 shows the fine structure of the most significant peak on the Lafler & Kinman periodogram with and without the archival photographic data included in the analysis. Thanks to the large time baseline (photographic observations were obtained in 1973–1975 while the CCD observations were obtained in 2005–2007), the addition of less-precise photographic data to the high-accuracy CCD observations provides a significant improvement in the periodogram peak localization resulting in the following light elements:

$$\mathrm{HJD(TT)}_{\mathrm{min\ I}} = \begin{matrix} 2454255.4056 \\ \pm 0.0002 \end{matrix} + \begin{matrix} 0\overset{\mathrm{d}}{.}524016 \\ \pm 0.000002 \end{matrix} \times E.$$

The phased lightcurves folded with the above period are presented in Fig. 4. The eclipses are partial and last for about 2 hours. The primary eclipse is $0\overset{\mathrm{m}}{.}66$ deep and the secondary eclipse is $0\overset{\mathrm{m}}{.}47$ deep in the V band.

Figure 5 shows the phased lightcurve for the two consecutive observing seasons, 2006 and 2007. The presence of a prominent ($|\Delta m| \approx 0\overset{\mathrm{m}}{.}03$) time-variable O'Connell effect (O'Connell 1951, Davidge & Milone 1984) is evident from the plot. The difference in maxima brightness (and eclipse depth) seems to be caused by a wide dip, slowly travelling backwards through the phased lightcurve. The effect may be explained by the presence of a dark starspot on one of the binary system components that rotates asynchronously (slightly slower) with respect to the orbital motion.

Times of individual minima were measured from the CCD lightcurves by applying the standard Kwee & van Woerden (1956) method. A relatively large number of minima observed over the long time baseline (Table 2) provides an opportunity to search for possible period changes. From the $O-C$ plot (Figure 6) it is evident that the long-term behavior of the system is consistent with the orbital period being the same in 1973–1975 and 2005–2007. The estimated (also following Kwee & van Woerden 1956) errors of minima time determination cannot account for the observed scatter of measurements around $O-C=0$; however, we note that these error estimations should be treated with caution since they do not account for any systematic difference in the shape of the descending and ascending branches of the eclipse lightcurve (real or caused by uncorrected systematic effects in photometry) or for the sensitivity of the method to the exact choice of eclipse boundaries, which needs to be set manually for the time of minimum determination. For photographic observations, no time series were recorded during eclipses. The few faintest data points on the photographic lightcurve were taken as the best available minima time estimates in that era. The total uncertainty of the photographic times of minima determination was set to a typical exposure time used for the plates (~ 40 min).

Table 1: Instruments used to observe GSC 2576–01248 and GSC 2576–02071

Observatory	Telescope	Aperture, cm	Filter	Detector
Crimea (SAI)	astrograph	40	none	photographic plate
	AZT-5	50	V	CCD Pictor 416XTE
	Zeiss-2	60	V	CCD ST2000XM
			V	CCD Apogee 47P
Crimea (CrAO)		24	none	CCD ST2000XM
Ka-Dar	Meade LX200-14″	35	none	CCD ST2000XM
	Vixen	10	none	CCD ST2000XM
TrES	see Alonso et al. 2004			CCD

SAI stands for the Sternberg Astronomical Institute's Crimean Laboratory, CrAO is the Crimean Astrophysical Observatory (Ukraine).

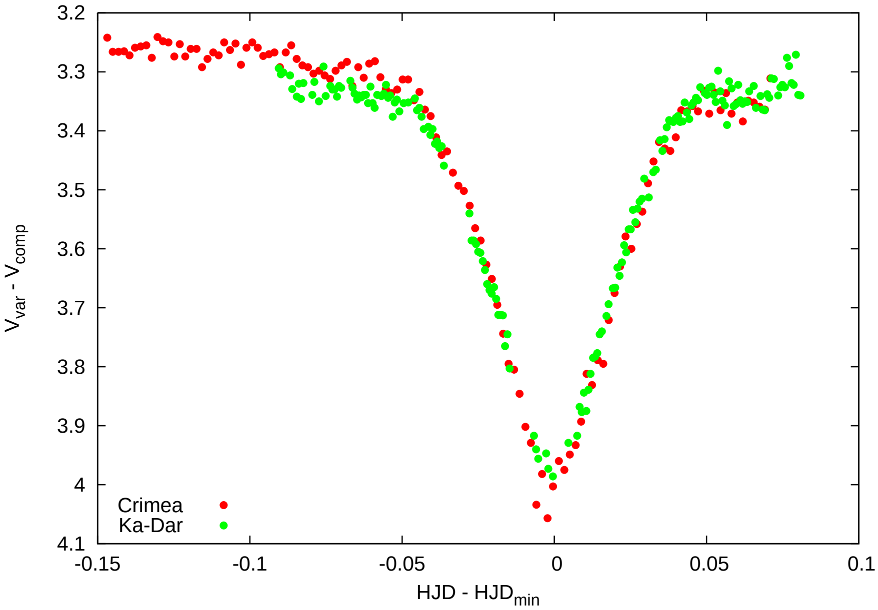

Figure 2. Two primary minima of GSC 2576–01248 observed in Crimea (red) with AZT-5 in V band on JD2453928.4 and in the Ka-Dar observatory using Meade LX200-14″ (green) without filter on JD2454255.3. The depth of the minima is virtually the same for V-band and unfiltered observations, meaning that by shifting the zero-point of the unfiltered lightcurve, these observations may be combined into a single lightcurve for period analysis.

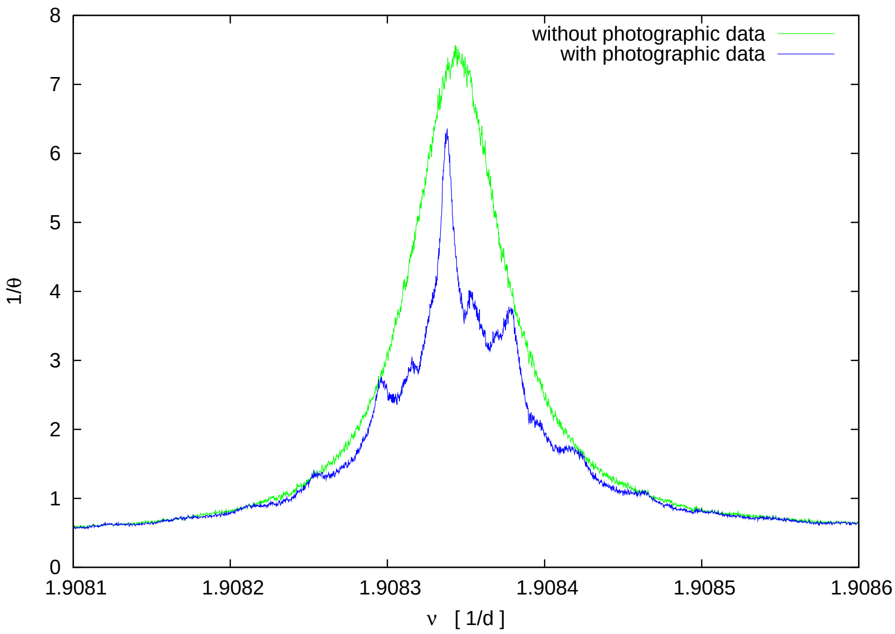

Figure 3. Periodogram of GSC 2576–01248 computed using the Lafler & Kinman (1965) method in a narrow frequency range around the most significant peak. ν is the trial frequency in cycles per day; θ is the normalized sum of squared magnitude differences between each two subsequent points of the lightcurve phased with the trial frequency ν (Goranskij et al. 2010). The green curve shows the periodogram for the CCD-only dataset which includes TrES and our dedicated CCD photometry. The blue curve represents the dataset that additionally includes archival photographic measurements, resulting in a much narrower peak in the periodogram.

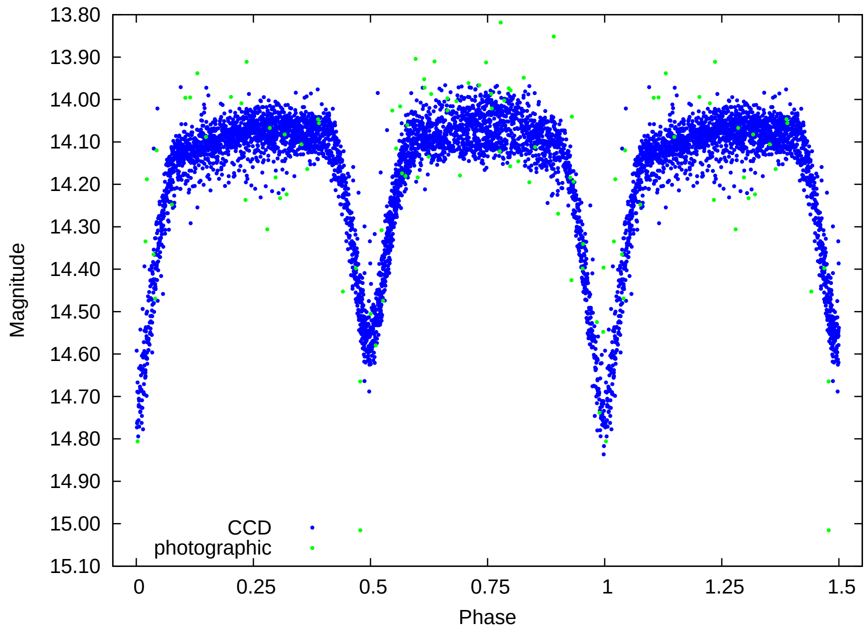

Figure 4. Lightcurve of GSC 2576–01248 combining CCD (blue) and photographic (green) data phased with the following light elements: HJD(TT)$_{\rm min\ I}$ = 2454255.4056 + $0^{\rm d}\!.524016 \times$ E.

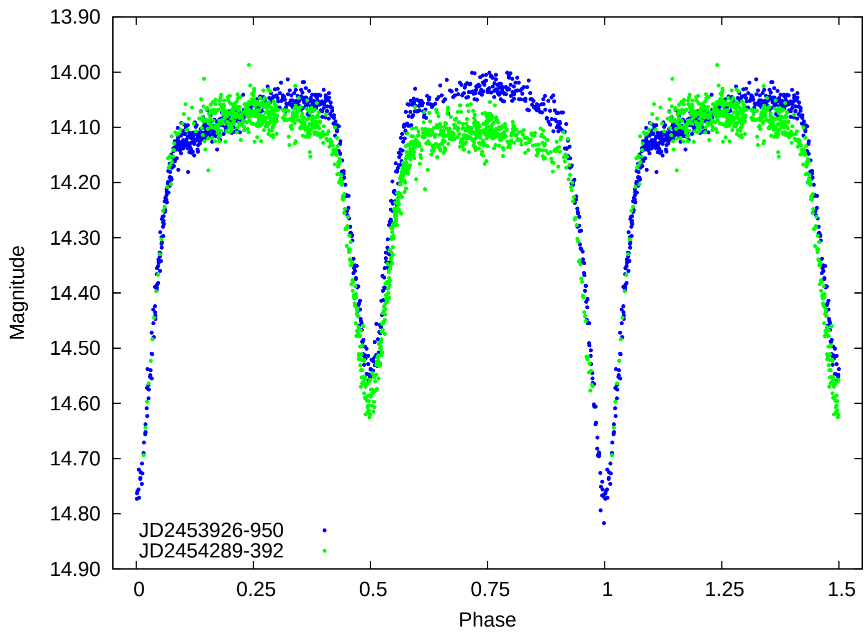

Figure 5. Lightcurve of GSC 2576–01248 for the observing seasons 2006 (blue) and 2007 (green) folded with the light elements HJD(TT)$_{\rm min\ I}$ = 2454255.4056 + $0^{\rm d}\!.524016 \times$ E. The time-variable O'Connell effect is clearly visible.

Table 2: Observed minima times of GSC 2576-01248

HJD(TT)	Error (d)	Type	Telescope
2441868.4437	0.0150	II	40-cm ($m_{\mathrm{pg}} = 15.56$)
2441925.3015	0.0150	I	40-cm ($m_{\mathrm{pg}} = 15.28$)
2442127.5787	0.0150	I	40-cm ($m_{\mathrm{pg}} = 15.09$)
2442269.3137	0.0150	II	40-cm ($m_{\mathrm{pg}} = 15.21$)
2442301.2939	0.0150	II	40-cm ($m_{\mathrm{pg}} = 15.12$)
2442487.5805	0.0150	I	40-cm ($m_{\mathrm{pg}} = 15.35$)
2442507.4844	0.0150	I	40-cm ($m_{\mathrm{pg}} = 15.07$)
2453501.8726	0.0006	I	TrES
2453502.9180	0.0003	I	TrES
2453503.7031	0.0009	II	TrES
2453503.9686	0.0004	I	TrES
2453505.7983	0.0008	II	TrES
2453506.8454	0.0007	II	TrES
2453509.7310	0.0010	I	TrES
2453510.7770	0.0010	I	TrES
2453511.8259	0.0003	I	TrES
2453512.8997	0.0078	I	TrES
2453515.7563	0.0013	II	TrES
2453518.9025	0.0006	II	TrES
2453519.9480	0.0008	II	TrES
2453520.7357	0.0010	I	TrES
2453523.8815	0.0019	I	TrES
2453527.8083	0.0011	II	TrES
2453528.8539	0.0015	II	TrES
2453529.9059	0.0005	II	TrES
2453530.6903	0.0002	I	TrES
2453532.7891	0.0013	I	TrES
2453533.8342	0.0006	I	TrES
2453534.8807	0.0006	I	TrES
2453535.9306	0.0012	I	TrES
2453536.7175	0.0005	II	TrES
2453928.4226	0.0004	I	AZT-5
2453932.3507	0.0010	II	AZT-5
2453938.3775	0.0008	I	AZT-5
2453939.4259	0.0004	I	AZT-5
2453944.4031	0.0005	II	AZT-5
2454255.4058	0.0002	I	LX200-14″
2454305.4496	0.0004	II	Zeiss-2

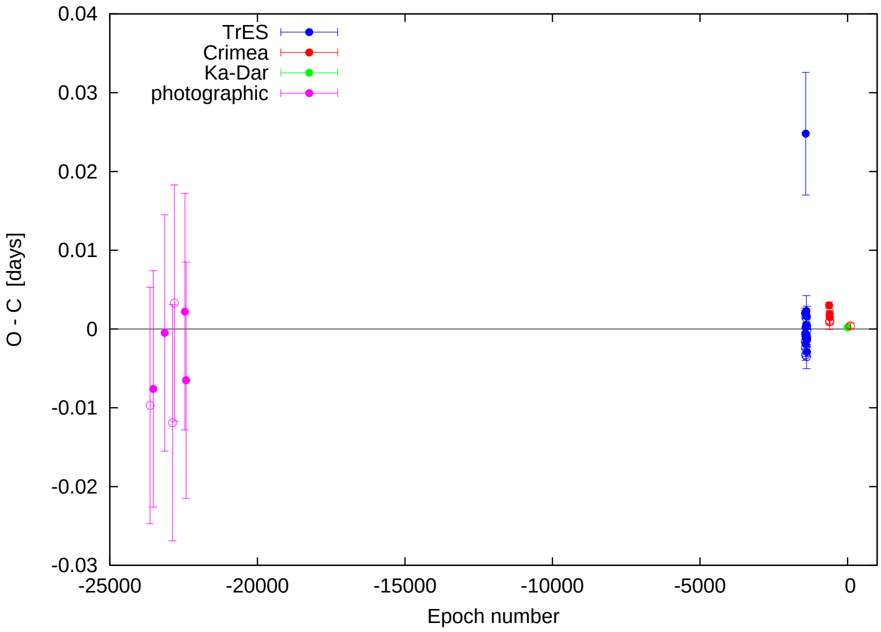

Figure 6. $O-C$ plot for GSC 2576–01248 constructed using the following light elements: $\mathrm{HJD(TT)}_{\mathrm{min\ I}} = 2454255.4056 + 0\overset{\mathrm{d}}{.}524016 \times \mathrm{E}$. Primary minima are filled circles and secondary minima (shifted in phase by 0.5), open circles.

2 GSC 2576–02071: a long-period Algol-type binary with an eccentric orbit

GSC 2576–02071 = T-CrB0-03105 = 2MASS 16111795+3307131 ($16^{\mathrm{h}}11^{\mathrm{m}}17\overset{\mathrm{s}}{.}96$ $+33^{\circ}07'\!.13''\!.2$, J2000; Skrutskie et al. 2006) was discovered as an Algol-type eclipsing binary during our CCD observations of GSC 2576–01248. After the initial detection of an eclipse in summer 2006, it took a significant amount of observing time with a number of telescopes (Table 1) and the addition of the TrES archival data to accurately determine the binary's orbital period:

$$\mathrm{HJD(TT)}_{\mathrm{min\ I}} = \underset{\pm 0.0007}{2453505.8159} + \underset{\pm 0.00025}{8\overset{\mathrm{d}}{.}28376} \times E.$$

The archival photographic data provide no additional constrains on the period because of their low accuracy, small variability amplitude of GSC 2576–02071, and lacking photographic data around the primary eclipse. Therefore, only CCD data were used for the period determination. We have employed the same data analysis and period search technique as for GSC 2576–01248 (described in the previous section). The times of minima observed for GSC 2576–02071 are listed in Table 3.

Figure 7 presents the phased lightcurve of GSC 2576–02071. The secondary eclipse phase is 0.5193 ± 0.0001, indicating a significant orbital eccentricity. Additional observations are desirable to search for signs of an apsidal motion or period change in this system. The eclipses are partial and last for about 6 hours (Fig. 8). The primary eclipse is $0\overset{\mathrm{m}}{.}35$ deep while the secondary eclipse is $0\overset{\mathrm{m}}{.}25$ deep. The scatter of the out-of-eclipse lightcurve (excluding the photographic data) is characterized by $\sigma = 0\overset{\mathrm{m}}{.}016$, which is consistent with the expected accuracy of the combined multi-instrument CCD dataset.

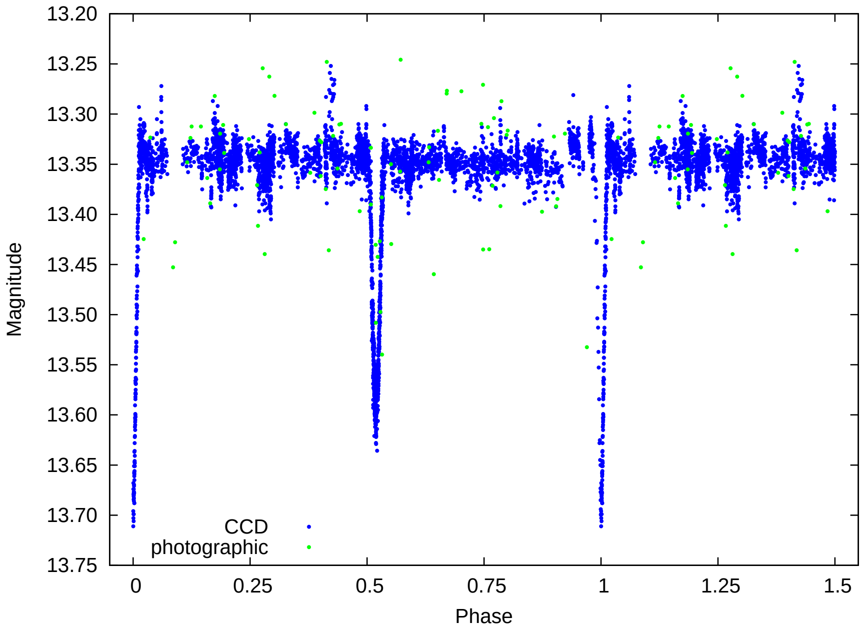

Figure 7. Lightcurve of GSC 2576–02071 combining all available CCD (blue) and photographic (green) photometry phased with the light elements determined solely from the CCD data: $HJD(TT)_{min\ I} = 2453505.8152 + 8\overset{d}{.}28376 \times E$.

Table 3: Observed minima times of GSC 2576-02071

HJD(TT)	Error (d)	Type	Telescope
2453501.8338	0.0008	II	TrES
2453505.8159	0.0007	I	TrES
2454247.3690	0.0007	II	LX200-14″
2454305.3557	0.0007	II	Zeiss-2

3 Conclusions

An initial investigation of two poorly studied eclipsing binary stars, GSC 2576–02071 (previously unknown) and GSC 2576–01248 (discovered by Devor et al. 2008), based on the archival photographic and modern CCD data is presented. In the case of GSC 2576–01248, the addition of photographic observations from 1973–1975 provides a significant improvement in the accuracy of period determination over the CCD-only dataset obtained in 2005–2007 thanks to the long time baseline between the observation epochs. Comparison of the archival photographic data with modern-day CCD photometry also provides an opportunity to search for possible long-term period changes, which, however, were not detected for the two binaries described here. The secondary minimum of GSC 2576–02071 is shifted from the phase = 0.5. This binary system is a promising apsidal-motion candidate.

Acknowledgments: We are deeply grateful to Jonathan Devor, Francis O'Donovan, Georgi Mandushev, and David Charbonneau of the TrES team for providing their observations of GSC 2576–02071 and GSC 2576–01248. We would like to thank S. V. Nazarov for the opportunity to use CrAO's 24-cm telescope and V. P. Goranskij for providing his lightcurve analysis software. This publication makes use of data products from the Two

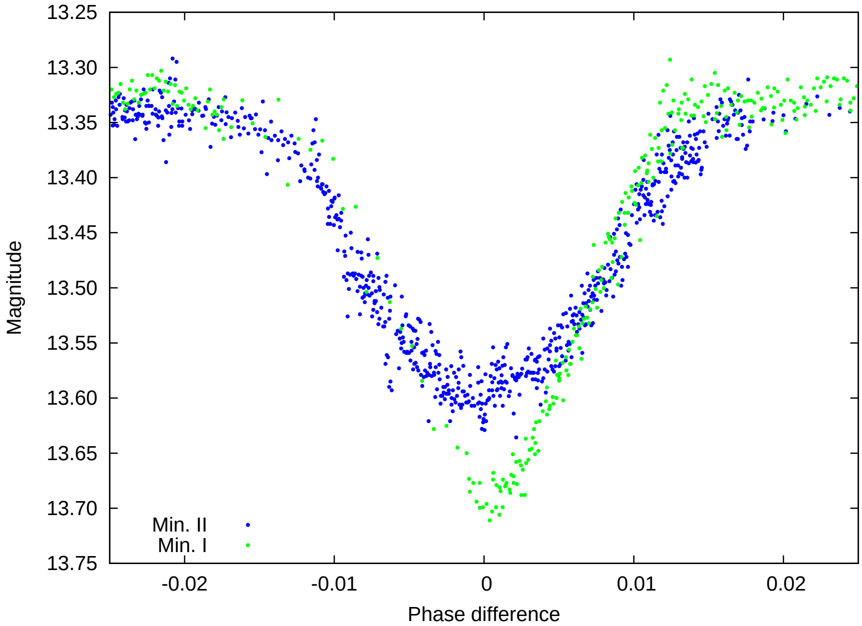

Figure 8. Primary (green) and secondary (blue) minima of GSC 2576–02071 compared. The secondary minimum appears to be about 40 minutes longer then the primary one and is slightly asymmetric with the ascending branch longer then descending.

Micron All Sky Survey, which is a joint project of the UMass/IPAC-Caltech, funded by the NASA and the NSF. This work has made use of the Aladin interactive sky atlas, operated at CDS, Strasbourg, France, the International Variable Star Index (VSX) operated by the AAVSO, and NASA's Astrophysics Data System. K.S. is supported by the International Max-Planck Research School (IMPRS) for Astronomy and Astrophysics at the universities of Bonn and Cologne.

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