Light Curve of the Eccentric Eclipsing Binary GSC 3152-1202

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Abstract A complete light curve of this eccentric (~2.094d) eclipsing binary system has been determined, in *B*, *V*, and *R* bands. The primary and secondary minima are slightly different in depth, and the color index does not change during either primary or secondary eclipse. Newly-determined times of minimum confirm the previously-suspected rapid change in the orbital phase of the secondary minimum, implying significant apsidal motion.

1. Background

The star GSC 3152-1202 (J2000 coordinates: R.A. $20^h\ 27^m\ 17.3^s$, Dec. +37° 56' 26") is identified as an eccentric-orbit eclipsing binary in the catalogue of Bulut and Demircan (2007) on the basis of observations reported by Otero *et al.* (2006).

Kozyreva *et al.* (2009) reported *V*-band differential photometry light curves of the primary and secondary eclipses and times of both primary and secondary minima. They concluded that: the two stars must be nearly identical in terms of temperature and size; as inferred from the displacement of the secondary eclipse from the 0.5 phase, the orbit is eccentric; and their $T_{min,II}$ timings provide evidence for rapid change in the orbital phase of the secondary eclipse in the intervening decade between their observations and Otero's.

Broadband SuperWASP photometry (Pollaco *et al.* 2006) captured eclipses of this system, but no analysis of their times of minimum light has been reported.

Shortly before the preparation of this paper, Bloomer *et al.* (2011) published several recent times of minimum (including one that was also observed for this study).

Considering the rapid apsidal motion and the lack of absolute photometry, it seemed worthwhile to record the complete light curve in three bands (*B*, *V*, and *R*), and to make additional measurements of the times of minima to support future modeling of this system. To that end, nineteen nights during July–September 2010 were devoted to photometry of this target at the author's Altimira Observatory.

2. Observations

All observations were made at Altimira Observatory, Coto de Caza, California, using a 28-cm (=11-in) Schmidt-Cassegrain telescope operating at *f*/6.3, an SBIG ST-8XE CCD imager (non-anti-blooming), and photometric *B*-, *V*-, and *R*-band filters from Custom Scientific. The image scale is 1.1 arcsec/pixel, and typical seeing was between 2 to 3 arcsec. For each observing session, the filter wheel was cycled to provide an imaging sequence of R-R-V-V-B-B for four to eight hours per night. Exposure durations were one minute in *R*-band, two minutes in *V*-band, and five minutes in *B*- band. These provided typical signal-to-noise ratio (SNR) on the target of about 125:1 in *V*- and *R*- bands, and 50:1 in *B*-band. Comparison stars were all somewhat brighter than the target, hence presented higher SNR.

All images were examined for problems such as poor tracking, poor focus, cosmic ray hits, or aircraft trails affecting the stars of interest, and problematic images were not used in the photometric analysis. Also, any images exposed at high air mass ($X \geq 2$) were removed from the analysis. Many nights were "non-photometric," but the overall consistency of the results demonstrates that modest light pollution and high (or variable) extinction did not adversely affect the resulting differential photometry. The target field, identifying the comparison stars used, is shown in Figure 1.

Comparison star colors and standard magnitudes were assessed in two ways: 1) On two clear and stable nights at Altimira Observatory, the target field-of-view, one or two Landolt fields, and the AAVSO field of M-27 (at essentially the same air mass as the target) were imaged. Using the known transforms for Altimira Observatory, the standard magnitudes of the comparison stars were determined. 2) The "Big Mak" telescope at Tzec Maun Observatory, New Mexico Skies, near Mayhill, New Mexico, was used to image the target field and two Landolt fields, to calibrate the comparison stars. The resulting comparison star properties are given in Table 1.

Differential photometry (using the ensemble of comparison stars) was done with the software package MPO CANOPUS/PHOTORED using a circular measuring aperture of 13 pixels diameter (≈ 14 arc-sec), and sky annulus surrounding the measuring aperture. The stability of the comparison stars was checked by intercomparing them throughout the observing season. Comparison stars 1, 2, 3, and 5 showed no evidence of variability throughout the duration of this project.

Instrumental-band photometry ("var-comp") was translated into standard *B*-, *V*-, and *R*-band magnitudes by use of the calibrated comparison star magnitudes and colors, and the known transformation coefficients of the Altimira Observatory equipment (previously determined by reference to Landolt standard star fields).

3. Times of Minimum

In the course of this observing campaign, three primary minima and one secondary minimum were recorded. The times of minimum based on the method of Kwee and vanWoerden (1956) are given in Table 2.

Light curve data for this star were extracted from the recently-released SuperWASP database (Butters *et al.* 2010) for three nights that contain eclipses (two primary and one secondary eclipse). From these data, the times of minimum light were determined using the Kwee-vanWoerden method, and are given in Table 3.

4. O–C evidence

Otero *et al.* (2006) reported P_{Otero} = 2.09372 d, HJD_{0min} I = 2451478.596 (UT date = 1999-10-27), and indicated that the orbital phase of the secondary minimum was $\varphi_{sec} \approx 0.489$; however, they also noted that their reported HJD_0 might refer to the secondary minimum. Based on Kozyreva's data and the data presented here, it appears that Otero's $HJD_{0min\ I}$ was, indeed, the primary minimum. From these data a reference time was establishedfor secondary minima as $HJD_{0min\ II} = HJD_{0min\ I} + 0.489\ P_{Otero} = 2451479.6198$.

Kozyreva *et al.* (2009) reported one primary and one secondary eclipse, whose times of minimum are given in Table 4; they observed that $\varphi_{sec} \approx 0.5475$, based on their recommended period P = 2.093731.

To display the changing orbit, all of these times of minima were compared to an ephemeris based on the Otero times of minimum and the period determined by Kozyreva.

The resulting O–C curve is shown in Figure 2. It confirms Kozyreva's key result, that the phase of secondary minimum is changing quite rapidly. Kozyreva *et al.* explain this by rapid apsidal motion in the system. Times of minimum that were taken within a couple of months of the times determined in this study were recently reported by Bloomer *et al.* (2011), and are also included in Figure 2.

5. Light curve

Using the calibrated colors and magnitudes of the comparison stars and the known photometric transforms of Altimira Observatory, the ensemble differential photometry was transformed to standard *B*, *V*, and *R* magnitudes, and phased to the orbital period. The resulting light curves are shown in Figure 3. Note that the eclipse depths are essentially the same in all bands. The primary eclipse depth is 0.6 magnitude, and the secondary eclipse depth is ~ 0.5 magnitude in all bands (±0.05).

To determine the color index vs. phase, these light curves were binned into bins of 0.02 phase (e.g. 0.00 to 0.02, 0.02 to 0.04, and so on), and the brightness averaged in each bin. From this, the averaged [*B–V*] and [*V–R*] colors were determined for each phase bin. The results are shown in Figure 4. There is no sensible change in color during the eclipses: the colors are constant at [*B–V*] = 1.36 ± 0.06 and [*V–R*] = 0.83 ± 0.02.

(These are colors on the standard Johnson-Cousins system, but "as measured"—no correction has been made for interstellar reddening. Considering the star's position in the heart of the Cygnus Milky Way, it seems reasonable to suspect that it may be subject to significant interstellar extinction and reddening, which will have to be taken into account in any modeling of the system).

6. Conclusions

GSC 3152:1202 is an eclipsing binary composed of two stars of nearly-equal temperature and nearly-equal radii in an eccentric orbit. The times of secondary minimum display a large rate of change (i.e., changing orbital phase, relative to the primary minimum). This might make it an interesting test system to validate models of stellar parameters and orbital apsidal motion.

7. Acknowledgements

I am pleased to acknowledge the assistance of the Tzec Maun Foundation Observatory, which provided telescope time for calibration of the comparison stars.

This work made use of the following on-line databases: VizieR (http://vizier.u-strasbg.fr/viz-bin/VizieR) (Ochsenbein *et al.* 2000); TASS (The Amateur Sky Survey) http://sallman.tass-survey.org/servlet/markiv/template/Welcome.vm (Droege *et al.* 2006); Super WASP http://www.wasp.le.ac.uk/public/, the WASP consortium which comprises the University of Cambridge, Keele University, University of Leicester, The Open University, The Queen's University Belfast, St. Andrews University and the Isaac Newton Group. Funding for WASP comes from the consortium universities and from the UK's Science and Technology Facilities Council.

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Table 1. Comparison stars (photometry from Altimira Observatory).

Star	*B* ±0.05	*V* ±0.02	*R* ±0.01	*B–V* ±0.05	*V–R* ±0.02
comp 1 = GSC 3152:376	13.84	12.68	11.95	1.16	0.73
comp 2 = GSC 3152:1192	12.58	11.75	11.23	0.83	0.51
comp 3 = GSC 3152:1020	13.00	12.42	12.04	0.58	0.38
comp 5 = GSC 3152:474	12.41	11.96	11.63	0.45	0.33

Table 2. Times of minimum of GSC 3152:1202 measured at Altimira Observatory (this study).

	Primary Eclipse Times of minimum (HJD)				
UT date	*V band*	*B band*	*R band*	*average*	*±*
2010-07-14	2455391.78289	0.77598	0.78217	2455391.7803	0.005
2010-08-04	2455412.71940	0.71915	0.71829	2455412.7189	0.001
2010-08-27	2455435.75103	0.75345	0.75074	2455435.7517	0.002
	Secondary Eclipse Time of minimum (HJD)				
2010-09-16	2455455.74945	0.74868	0.74895	2455455.7490	0.001

Table 3. WASP times of minimum (star = 1SWASP J202717.24+375626.8).

UT Date	*HJD per WASP TMID*	*±*	*min*
2007-07-11	2454292.561	0.002	I
2007-08-21	2454334.437	0.002	I
2007-10-24	2454398.371	0.002	II

Table 4. Kozyreva times of minimum.

UT Date	*HJD Tmin*	*±*
2009-06-21	2455004.4386	0.0002
2009-08-22	2455066.3026	0.0003

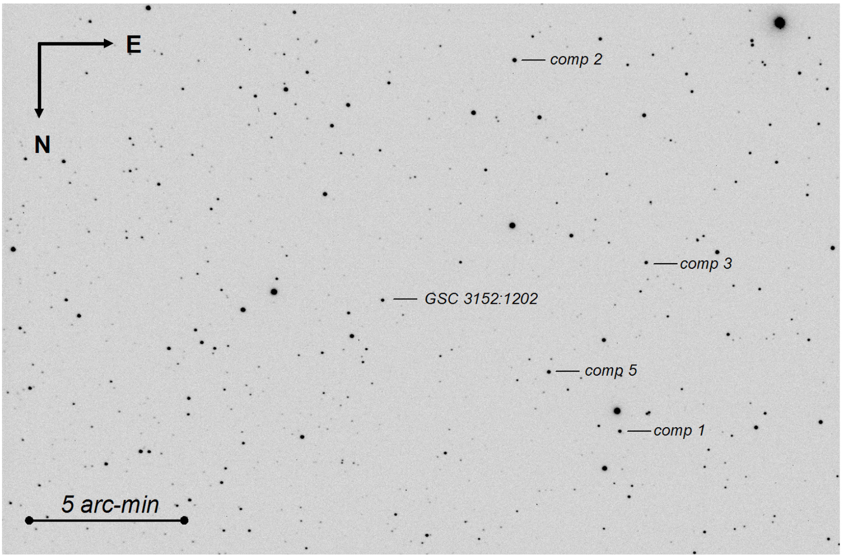

Figure 1. Field of view of GSC 3152:1202 showing comparison stars used.

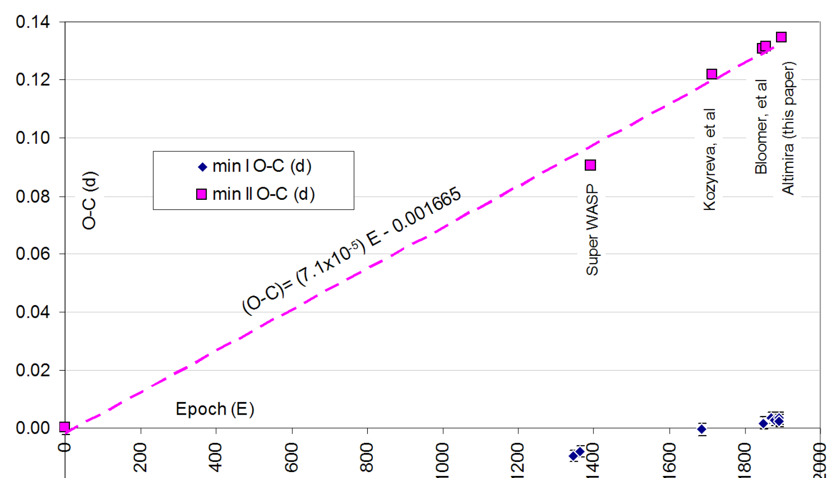

Figure 2. O–C diagram of GSC 3152:1202 showing significant rate of change of the times of secondary minimum. (Based on $HJD_{0min,I} = 2451478.596 + 2.093731E$ and $HJD_{min,II} = 2451479.6198 + 2.093731E$).

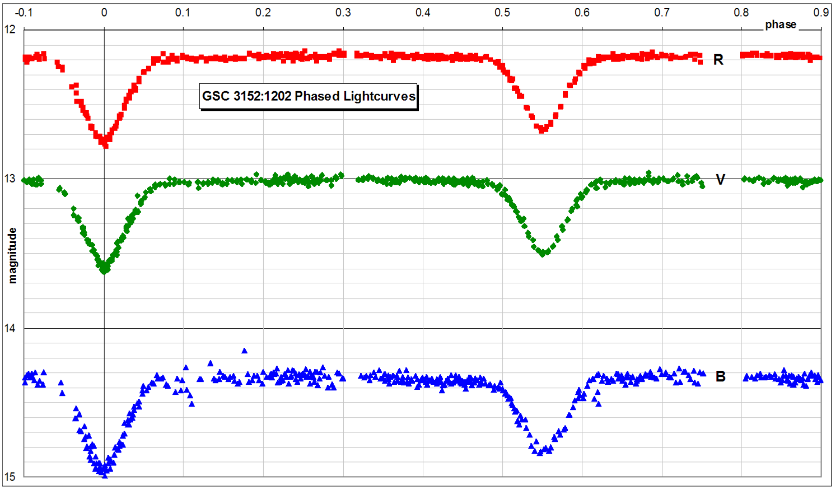

Figure 3. Light curve of GSC 3152:1202 in *B*-, *V*-, and *R*-bands.

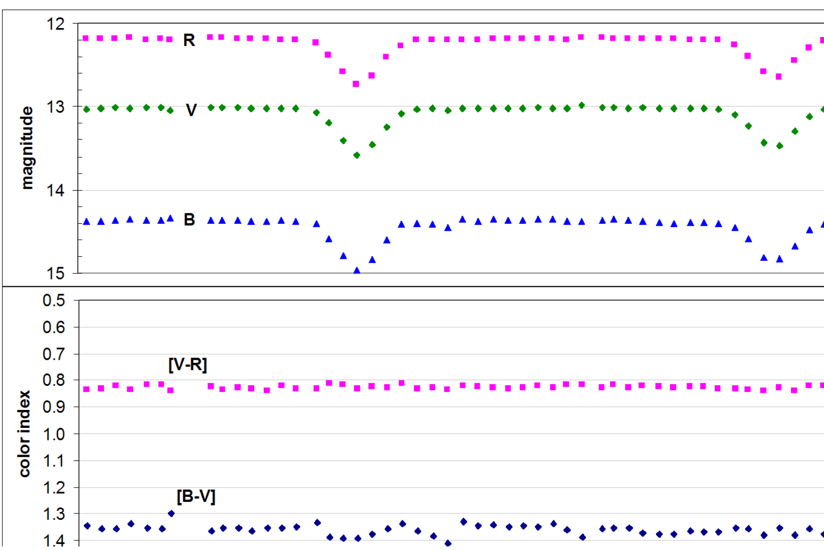

Figure 4. Color index as a function of phase, showing that there is no change in color during eclipses.