The Challenge of Observing the ζ Aurigae Binary Stars

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Abstract Observations of the ζ Aurigae binary stars ζ Aur, 31 Cyg, and 32 Cyg were made in V and B during their most recent eclipses. All three stars were measured photometrically mainly in the blue light that traces the hot companion star being eclipsed. The light curves of all three stars show precise timing during the entire recent eclipses. The magnitude and the duration of the eclipses in V and B are described here and predictions are made for the future.

1. Objective

The purpose of monitoring the ζ Aur stars ζ Aur, 31 Cyg, and 32 Cyg was to detect entire eclipses in both (Visual) and (Blue), determining both brightness and amplitude. Each of the three star systems consists of a supergiant class K star and a small hot class B star which revolve around one another, causing the light to be eclipsed as seen from Earth. When the B star was near the limb of the supergiant K star, the atmosphere of the K star was monitored. Information was obtained to measure the intensity of the K star's atmosphere when the B star shone through it (an atmospheric eclipse).

More information was monitored during the partial phases, especially in B light when the B star went behind the K star's limb during totality. How long the B star stayed behind the K star determined the length of the total eclipse. According to Stencel (2013), K supergiants are typically five magnitudes brighter than B stars. Therefore, the magnitudes are mentioned together in the text.

2. Method

Photoelectric photometry was used to monitor the eclipses of ζ Aur, 31 Cyg, and 32 Cyg in V and B. The Johnson filters have a peak spectral response at 4500 Å (blue) and 5400 Å (Visual), respectively.

The readings were taken using an SSP3 OPTEC photometer coupled on a 10-inch f/10 MEADE telescope. For each set of observations on each variable, four readings were taken at 10-second intervals of the variable, sky, and then the comparison stars. This author sometimes monitored three to four sets, depending on the weather conditions and time. To reduce the data, the photometric readings of the variable, sky, and comparison stars were averaged. Then, the sky was subtracted from the star's readings. That left the ratio brightness between the variable and the comparison stars. Once the ratio was calculated, the variable's brightness could be determined using the known magnitude of the comparison stars. Also, the standard deviation (SD) was calculated to analyze how much error was in the readings. Most of the time, the error ranged from 0.012 magnitude to as much as 0.043 when all the readings were calculated. The altitude was also calculated to determine the air mass during the time of the observations. During the observing run, the higher the stars and the smaller the airmass, the better the chance of getting the accurate readings from the photometer. However, the airmass and extinction corrections were not applied to the reported magnitudes. The measurements are raw photometry, uncorrected for differential extinction between variable and comparison star and not transformed to the Johnson system, which limits their accuracy and application (Table 1).

Many factors that can affect the readings must also be considered: seeing conditions, winds, periodic clock drive error, polar alignment, and the stability of the photometer. During most nights, the seeing conditions were above average with no winds, and the periodic clock drive error was noticeable at times. Being that a portable observatory was used, the polar axis was aligned as close as possible to the celestial north pole. Therefore, in spite of the small drift, the star still stayed inside the reticle circle during the observation. For the SSP-3 OPTEC photometer itself, the unit was turned on at least an hour before the start of the first counts. This warm-up routine continued until the photometer dark count was stable enough for accurate readings; the colder the outside air temperature was, the more time the photometer needed to warm up. The unit was running on a nine-volt battery to avoid a power cord tangle-up during the night's run. In the photoelectric photometry method, the precision can be as little as 0.01 magnitude. The observations were accurate enough to generate the true shape of the light curve.

3. The ζ Aur stars

3.1. ζ Aur

ζ Aur is a supergiant K4II star orbited by a hot B7V star and has a combined magnitude of +3.75 (Hopkins 2013). The prototype of its class, ζ Aur is one of the "Three Kids" stars located near α Aur (Capella). Spectroscopically, it is seen as two stars (supergiant K and small hot B) that eclipse one another.

Every 2.66 years or 972 days, the smaller B star is completely eclipsed by the larger K supergiant. While the stars are of different sizes, only the K star that passes in front of the hot B star can be detected. The B star is approximately magnitude 8, so it dominates the light in the B wavelengths (Stencel 2013). Jeffrey Hopkins (2013) predicted the total eclipse from October 31, 2011, to December 9, 2011, based on his measurements from the 1982, 1985, and

Table 1. Differential photometry of ζ Aur.

UT Date	JD 2450000+	λ Aur +4.71 V comparison star, V filter: Magnitude	Standard Deviation	λ Aur +5.34 B comparison star, B filter: Magnitude	Standard Deviation	B–V
9/3/2011	5807.77	3.72	0.05050	4.87	0.02760	1.15
9/13/2011	5817.72	3.70	0.03381	4.85	0.05600	1.15
9/19/2011	5823.71	3.72	0.02134	—	—	—
9/30/2011	5834.70	3.75	0.03024	4.88	0.01885	1.13
10/8/2011	5842.76	3.77	0.02204	4.97	0.01165	1.20
10/16/2011	5850.71	3.76	0.01126	4.92	0.01581	1.16
10/22/2011	5856.73	3.77	0.01642	4.94	0.01676	1.17
10/24/2011	5858.71	3.78	0.02375	4.94	0.02387	1.16
10/31/2011	5864.68	3.79	0.02387	5.01	0.01371	1.22
11/2/2011	5867.67	3.94	0.03450	5.39	0.01706	1.45
11/3/2011	5868.71	3.95	0.01246	5.38	0.01389	1.43
11/6/2011	5871.76	3.95	0.01408	5.41	0.01188	1.46
11/13/2011	5878.77	3.91	0.01773	5.44	0.01669	1.53
11/19/2011	5884.71	3.94	0.02605	5.41	0.01414	1.47
11/25/2011	5890.70	3.96	0.02828	5.43	0.01753	1.47
12/2/2011	5897.72	3.94	0.00926	5.42	0.00518	1.48
12/11/2011	5906.73	3.80	0.01963	4.96	0.01587	1.16
12/12/2011	5907.71	3.81	0.01874	4.96	0.01879	1.15
12/25/2011	5920.76	3.80	0.02147	4.96	0.01985	1.16
1/1/2012	5927.73	3.79	0.02014	4.98	0.01978	1.19

2009 eclipses. λ Aur was the comparison star (+4.71 V, +5.34 B). Also, the partial eclipse is known to be very steep. During the partial phases, Contacts I and II and Contacts III and IV may each be a little as one-and-a-half days apart.

The eclipse of ζ Aur was successfully observed during 2011. Twenty nights were monitored in V and nineteen in B (Table 1). Observations started on September 3, 2011 (JD 2455807.77) to establish the light curve baseline. Hopkins calculated the first contact to begin October 29, 2011, and November 19, 2011, time of mid-eclipse. Unfortunately, the author was clouded out for the first contact prediction. Observations on October 31, 2011, at 4:30 UT showed no change in brightness in V. But in B, the brightness may have dipped slightly. On November 2, 2011, at 4:30 UT, it seemed that the eclipse was already in total. Both Contacts I and II were missed due to the weather, but the partial may have lasted less than two days. Totality was predicted to last for thirty-seven days (until December 9, 2011, JD 2455904), but observations showed the eclipse was already over on December 11 at 5:20 UT (JD 2455906.73). Contacts III and IV during egress were also missed because of the cloudy weather. ζ Aur

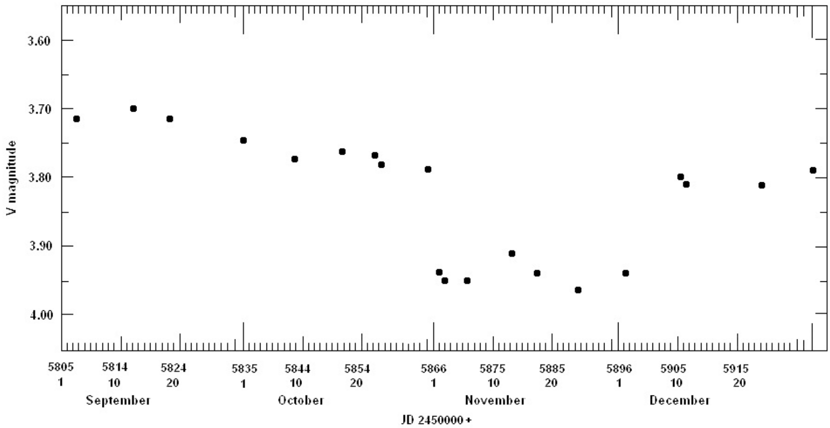

Figure 1. Light curve of ζ Aur, September 1, 2011–December 31, 2011. ζ Aur V magnitude with respect to λ Aur +4.71 magnitude.

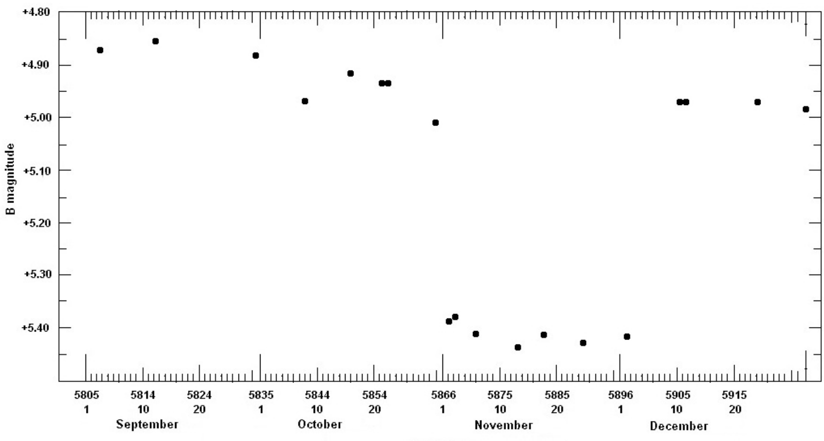

Figure 2. Light curve of ζ Aur, September 1, 2011–December 31, 2011. ζ Aur B magnitude with respect to λ Aur +5.34 magnitude.

was monitored until January 1, 2012 (JD 2455927.73), to make sure the eclipse was truly over. During the eclipse, the brightness dipped about 0.20 magnitude in V and about 0.45 magnitude in B (Figures 1 and 2).

3.2. 32 Cyg

32 Cyg is a supergiant class K3 with a small hot class B3 star and a total magnitude of +4.03 (Hopkins 2013). This binary system was recognized to be one of the ζ Aur group. The eclipse occurs every 1,147.6 days (3.15 years). Every 3.15 years, the smaller B star is partially eclipsed by the larger K star.

The eclipse was predicted to occur between August 26, 2012, and September 11, 2012. The comparison star was 30 Cyg (+4.83 V, +4.92 B). The partial eclipse is known to be very shallow and partial phases may last five to six days.

The eclipse was successfully monitored in V and B on 22 nights (Table 2). The brightness dipped a mere 0.03 magnitude in V and about 0.12 magnitude in B, where the eclipse was clearly evident. Observations were started on August 7, 2012 (JD 2456146.66), to establish a baseline for the light curve. The partial phase began before August 27, 2012 (JD 2456166.54). A total eclipse may have started before September 1, 2012 (JD 2456167.73). The light curve showed that the partial phase between Contacts I and II lasted for six days. Totality may have been over on September 12, 2012 (JD 2456182.67); it is not clear how long totality lasted. Totality may have been very brief during the first half and perhaps was grazing during the second half. Also, Contacts III and IV

Table 2. Differential photometry of 32 Cyg.

		32 Cyg +4.83 V comparison star		*32 Cyg +4.92 B comparison star*		
		V filter		*B filter*		
UT Date	*JD 2450000+*	*Magnitude*	*Standard Deviation*	*Magnitude*	*Standard Deviation*	*B–V*
8/7/2012	6146.66	4.04	0.011	5.33	0.013	1.29
8/13/2012	6152.66	4.01	0.024	5.32	0.017	1.31
8/17/2012	6162.76	4.02	0.011	5.34	0.014	1.32
8/23/2012	6162.73	4.04	0.017	5.33	0.007	1.29
8/24/2012	6163.71	4.04	0.029	5.33	0.010	1.29
8/27/2012	6166.54	4.05	0.019	5.36	0.018	1.31
8/29/2012	6168.67	4.06	0.019	5.41	0.024	1.35
8/30/2012	6169.70	4.05	0.024	5.44	0.025	1.39
8/31/2012	6170.71	4.05	0.033	5.46	0.010	1.41
9/1/2012	6171.73	4.03	0.012	5.40	0.018	1.37
9/3/2012	6173.66	4.05	0.024	5.32	0.019	1.27
9/6/2012	6176.69	4.07	0.016	5.36	0.011	1.29
9/7/2012	6177.73	4.03	0.009	5.34	0.022	1.31
9/8/2012	6178.76	4.03	0.033	5.38	0.030	1.35
9/10/2012	6180.65	4.02	0.028	5.33	0.009	1.31
9/11/2012	6181.71	4.05	0.028	5.35	0.021	1.30
9/12/2012	6182.67	4.05	0.028	5.32	0.013	1.27
9/13/2012	6183.66	4.01	0.015	5.32	0.019	1.31
9/14/2012	6184.70	4.03	0.025	5.32	0.014	1.29
9/17/2012	6187.73	4.03	0.012	5.32	0.015	1.29
9/20/2012	6190.66	4.03	0.011	5.33	0.011	1.30
9/24/2012	6193.69	4.05	0.019	5.34	0.019	1.29

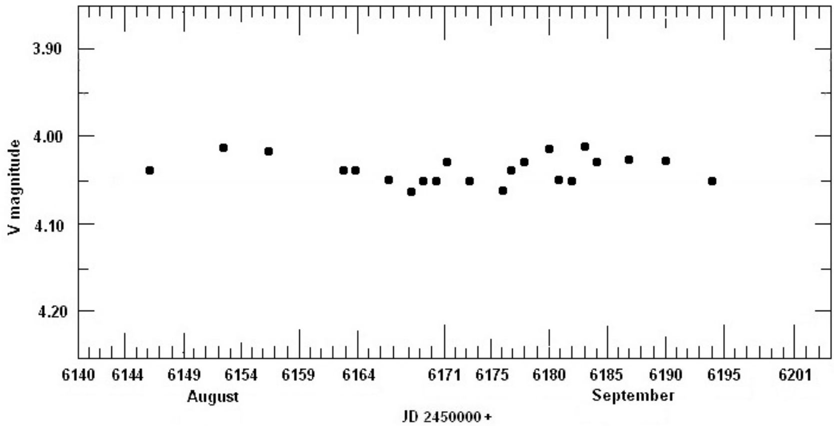

Figure 3. Light curve of 32 Cyg, August 1, 2011–September 18, 2011. 32 Cyg V magnitude with respect to 30 Cyg +4.83 V magnitude.

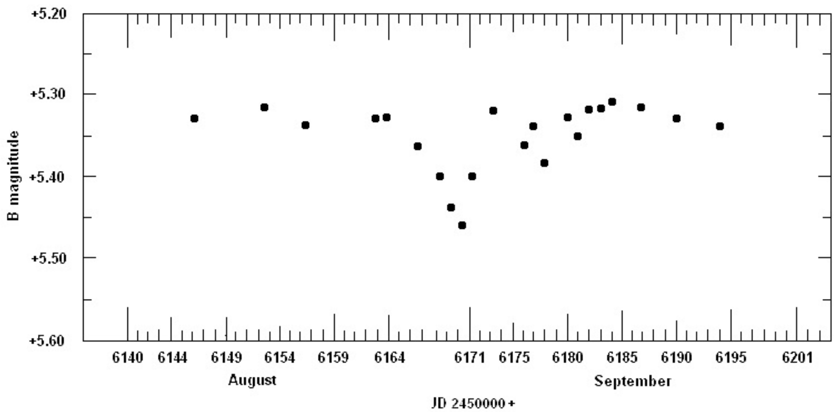

Figure 4. Light curve of 32 Cyg, August 1, 2011–September 18, 2011. 32 Cyg B magnitude with respect to 30 Cyg +4.92 B magnitude.

weren't clear. In addition to a possible grazing eclipse, 32 Cyg may have had an extended atmosphere on one side during the second half of totality. The much larger eclipse amplitude in B (Figures 3 and 4) occurred because the B3 star contributes more of the B light to the system, while the K3 star contributes more of the V light.

3.3. 31 Cyg

31 Cyg is a supergiant class K2 with a small hot class B3 star and has a total magnitude of +3.79. This binary system is also recognized to be one of the ζ Aur star group. The eclipse occurs every 3,784.3 days (10.4 years), making 31 Cyg one of the longest periodic eclipsing binaries. While it is a 10.4 year eclipse,

the author took every opportunity to monitor this star. The eclipse was predicted to begin on October 8, 2013 (JD 2456573), and last nearly 62 days (Stencil 2013) through December 11, 2013 (JD 2456637). The comparison star was 30 Cyg (+4.83 V, +4.92 B). The partial eclipse is known to be very steep and it can be as little as two days between Contacts I and II and Contacts III and IV.

31 Cyg was monitored nineteen nights in V and B (Table 3). The observations started about five weeks before the ingress-predicted date, so the baseline of the light curve could be established. The light curves in both V and B showed normal brightness during the atmospheric eclipse. The last observation before ingress was made on October 3, 2013 (JD 2456568.63). The next observation, on October 14, 2013 (JD 2456579.63), shows the B star already in totality with the supergiant K star. Therefore Contacts I and II were missed due to the cloudy weather. The total eclipse was observed until the predicted date for egress on December 11, 2013 (JD 2456637). Luckily, the egress (Contacts III and IV) was caught. In fact, note that the last six readings, including the time of egress, were made at the same time. Measurements were made right at the start of darkness due to 31 Cyg's low altitude in the NW.

The system was observed for two more weeks to be sure that the eclipse was over.

Stencel *et al.* (1984) carried out a full coverage of the 1982 eclipse. Their photometric study enabled prediction of the 2013 timetable of the eclipse. Throughout the eclipse, the V light curve showed a dip of 0.12 magnitude. The B light curve showed a deeper eclipse of 0.32 magnitude. It was obvious that the B star was being eclipsed and just the supergiant K star was shining alone. The light curves in V and B are a little different from each other during egress, which was caught. It took one day after totality ended for V to return to pre-eclipse brightness, while B took two to three days. The most reasonable explanation for this phenomenon is the fuzziness of the supergiant K star. The K star atmosphere is more opaque at shorter wavelengths, causing the B magnitude to fade and recover more slowly than the V. In V, the supergiant K star's limb is much sharper, with the B star shinning with less contrast (Figures 5 and 6).

4. Discussion

All three ζ Aur binary stars (ζ Aur itself, and 31 and 32 Cyg) were monitored photoelectrically in B and V from Holtsville, Long Island, New York. The eclipses were observed successfully and the results are comparable with eclipses of the past.

More observations are needed for 32 Cyg. It is not clear whether the eclipse was total, grazing, or a combination of both (Griffin 2013). During 2012, the eclipse was seen but totality may have been very brief at the start, followed by sporadic brightness or surges during the second half. Once it reached the pre-

Table 3. Differential photometry of 31 Cyg.

UT Date	*JD 2450000+*	*31 Cyg +4.83 V comparison star* *V filter* *Magnitude*	*Standard Deviation*	*31 Cyg +4.92 B comparison star* *B filter* *Magnitude*	*Standard Deviation*	*B–V*
09/05/2013	6540.63	3.80	0.010	4.86	0.016	1.06
09/07/2013	6542.62	3.80	0.019	4.89	0.008	1.09
09/09/2013	6544.71	3.80	0.025	4.89	0.011	1.09
09/15/2013	6550.71	3.82	0.008	4.88	0.014	1.06
09/20/2013	6555.72	3.79	0.013	4.89	0.018	1.10
09/26/2013	6561.64	3.80	0.013	4.88	0.008	1.08
09/29/2013	6564.74	3.76	0.021	4.86	0.029	1.10
10/03/2013	6568.63	3.81	0.018	4.88	0.011	1.07
10/14/2013	6579.63	3.91	0.011	5.21	0.005	1.30
10/21/2013	6586.62	3.91	0.006	5.20	0.013	1.29
10/28/2013	6593.70	3.90	0.008	5.22	0.009	1.32
11/09/2013	6605.52	3.91	0.005	5.22	0.013	1.31
11/20/2013	6616.54	3.90	0.013	5.20	0.011	1.30
11/30/2013	6626.50	3.90	0.016	5.21	0.011	1.31
12/11/2013	6637.50	3.93	0.011	5.19	0.009	1.26
12/12/2013	6638.50	3.79	0.018	5.00	0.019	1.21
12/13/2013	6639.50	3.82	0.013	4.92	0.011	1.10
12/17/2013	6643.50	3.82	0.013	4.87	0.018	1.05
12/28/2013	6654.50	3.79	0.008	4.87	0.017	1.08

eclipse brightness after the eclipse ended, its behavior was normal. It seemed to last 11 days. The fluctuation was not seen well in V band but perhaps only in partial. It was much more pronounced in B band where the eclipse was just total and the chromophere of the K star extended farther out. Unfortunately, there were no check stars to further analyze the data to see whether or not the scattering in the light curve was real during the second half of totality. As far as the author can tell, the conditions appeared to be stable.

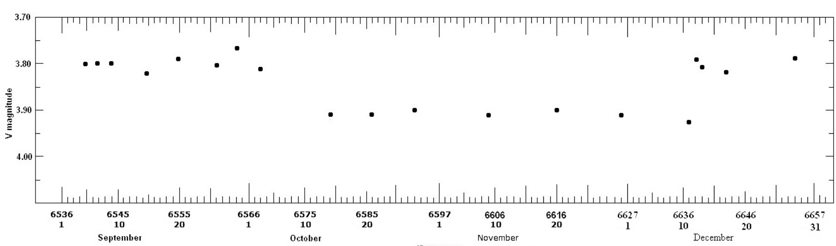

Figure 5. Light curve of 31 Cyg, September 1, 2011–December 31, 2011. 31 Cyg V magnitude with respect to 30 Cyg +4.83 V magnitude.

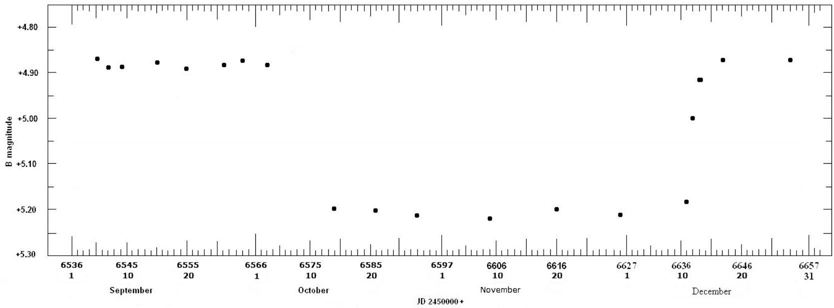

Figure 6. Light curve of 31 Cyg, September 1, 2011–December 31, 2011. 31 Cyg B magnitude with respect to 30 Cyg +4.92 B magnitude.

The next eclipse of 32 Cyg is scheduled for October 18, 2015 (JD 2457314), at mid-eclipse after 1,147 days, or 3.15 years, assuming the predicted date (Hopkins 2013) of September 6, 2012 (JD 2456167) was correct. Anyone who might be interested to observe the next 32 Cygni eclipse should contact the author for a possible observing campaign. Photometric observations are needed. Hopefully, the contact points and the totality/grazing observations eclipse can be solved.

For ζ Aur and 31 Cyg, the light curves may show the eclipse lasting a day or two longer in B than in V. This might be due to the extended atmosphere of the supergiant K star and the result of more absorption involved near the supergiant's limb. But the ingress and egress must be caught to further analyze the contact points.

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