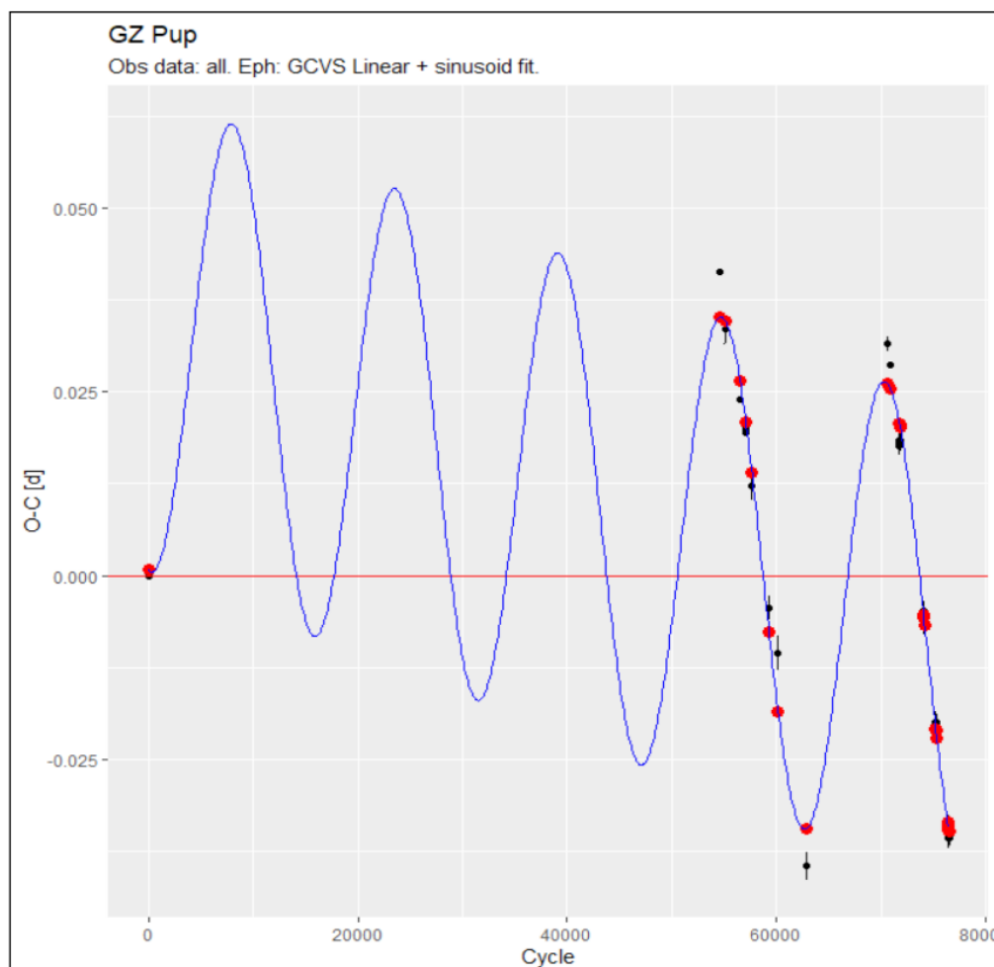




A seemingly compelling sinusoidal fit to an O - C diagram for GZ Pup that may indicate a third body in the system. But all is not as it seems. Read on page 13 how Tom Richards, with the help of Jeff Byron, shows why this scenario just isn't true.

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From the Director – *Mark Blackford*

As I write this column there are some bright spots on the pandemic horizon. Vaccination programmes started slowly but are ramping up across the world and the much anticipated Travel Bubble between Australia and New Zealand is set to open on April 19th, which is good news for those considering attending this year's RASNZ Conference. Wellington Astronomical Society will host the event over the weekend of Friday 9th to Sunday 11th July 2021 at the Wharewaka Events Centre on the Wellington Waterfront.

Congratulations to Andrew Pearce for his April 4th discovery of a classical nova in Sagittarius (designated V6595 Sgr) recorded at magnitude 8.4 on an unfiltered image from a Canon 1100D digital camera + 100mm f/2.8 lens. Andrew's discovery came just 10 days after another, fainter, nova was detected in Sagittarius (designated V6594 Sgr) by the All-Sky Automated Survey for Supernovae (ASAS-SN) and several Japanese amateurs. Then on April 12th yet another nova (designated V1710 Sco) was discovered by ASAS-SN and Paul Camilleri in Katherine, NT. Paul measured it at 9.5 magnitude on an unfiltered image recorded with a Nikon D3200 DSLR and 85mm F/2 Lens. It has certainly been a busy time for nova researchers.



The April/June schedule for AAVSO's free online webinars and how-to hours can be found at <https://www.aavso.org/2021-webinars-april-june> and recordings of previous talks at https://www.youtube.com/playlist?list=PLnZ_rvnR35re3ZxnumCnlesanWvUyy9eB.

The poor run of weather at Congarinni Observatory continues. Since January's newsletter I've managed only 15 observing nights, most of which were partially cloud affected. This has precluded any observations of the long period eclipsing binary V0777 Sagittarii mentioned in the previous newsletter. The upcoming eclipse is predicted to start on April 29th. If conditions allow please make B filter CCD observations once or twice per night in the lead up to and throughout the entire eclipse, then for some days or weeks after the predicted end on June 25th.

Wishing you all clear skies and good health,

Mark Blackford

Greetings to everyone in the Variable Stars South team. I hope you have been safe and well during the Covid-19 challenges. Perhaps it has given you more time to follow your passions. With the possible easing of borders and absence of raised alert level in New Zealand we are looking forward to being able to hold a 'normal' Conference this year. It would be great to see as many of you as possible as we catch up with each other.

The 2021 RASNZ Conference and Annual General Meeting will take place in Wellington this year, 100 years after the first Annual meeting of the Astronomical Society of New Zealand (ASNZ) which was also held in Wellington. Last year's cancelled face to face conference would have celebrated the Centenary of the formation of the ASNZ/RASNZ.



The Wellington Astronomical Society are again hosting this year's conference which will take place over the weekend of 9th to 11th of July 2021. A Dark Sky Workshop is planned for the morning of Monday 12th of July. The Conference will be held in the Wharewaka Function Centre, situated on Wellington's waterfront near Te Papa.

Registration

An on-line registration form is available by following the link to the conference page from <https://www.rasnz.org.nz/groups-news-events/rasnz-conference>. A downloadable registration form is also available at the same link. Final date for registration is the 27th of June 2021

Conference fees are as follows:

\$275 (Members)

\$305 (Non-members)

\$155 (Saturday only)

Dinner: \$100 per person

Dark Sky Symposium \$ 30

Paper submission

The organisers invite and encourage anyone interested in New Zealand astronomy to submit oral or poster papers for the conference programme. Please note that those presenting papers must also register for the conference. An on-line submission form is available by following the link to the conference page from <https://www.rasnz.org.nz/groups-news-events/conf-next>. Titles and abstracts are due by 1 June 2021

The RASNZ Council and Conference Committee and the Local Organising Committee look forward to catching up with you all after a longer than normal break between conferences. We have a lot to celebrate and will have a strong group of Students With A Passion for Astronomy present to help RASNZ move into its second 100 years.

Steve Butler

President, RASNZ

Summary

A study of five old variables reported by Worsell (1919), has been conducted using both archival images and modern photometry, allowing me to reach reasonably conclusive identifications. The stars, **AV**, **BB**, **BD** and **BQ Car**, and **UY Vel** all appear to be constant.

Introduction

The five stars in this study are like orphans - never rediscovered or claimed since 1919. The original discovery reports often provide important clues and when combined with modern photometric data, the likely identification can be pinned down. In the absence of the original Union photographs, taken with the *Franklin -Adams Star Camera* (10" Cooke refractor) with a limit of 15.0-15.5B on a 60min exposure, I have looked at DASCH plates, *mf* series, taken with the Metcalf 10" triplet with a very similar reach to the Union plates. This gave me a sense of what the Union observers would have seen near the target star.

AV Car. 10^h27^m.3 -62°48' (1875), Range 15 - 17p (Innes 1915, Worsell 1919).

Discovery observations from UOC 26 (Innes 1915)

1910 May 7 16 ^m	1914 July 13 16 ^m
1911 Apr 18 16	1915 Apr 17 17 (No defect on this plate)
1914 Apr 27 16	1915 May 5 16

We know the limit of Union plates on the modern B scale; the reported magnitudes (16) indicate a star very close to the limit, but also a skewed magnitude scale. The true magnitude on the modern B scale is closer to ~15+. The reported mag. 17p seems unlikely, as not literally 17B.

The candidate for AV Car is a 15^{mag} star, close to Worsell's approximate position. It lies at :

(J2000) : 10 31 34.97 -63 26 18.7 Gaia DR2 See **Fig. 1**.

From APASS, V = 13.972, B = 15.444. There is a companion 10".2 NW, V = 15.84, and a very close fainter companion (g = 16.41) just E, endfigs 35.633s, 18.90" Other stars, 60" N and 60" S, both red, were looked at, but rejected, being too bright. No variable has been found in this vicinity by recent surveys. ASAS-3 provides a noisy light curve, but it appears to be constant.

BB Car. 10 30.9 -60 17.5 (1875), 14 - 17p "*Is 50" N.f. -60°2014.*" (Innes 1915, Worsell 1919).

Innes (1915) reports seven observations, from 1893 May 10 to 1915 May 5. Three estimates at the 15/16 mag level (Innes' scale) are flagged as doubtful. His estimates are scattered from 14 to 17p and don't favour a particular magnitude. The average is about 15.3. As the variable is so close to the bright star CPD-60°2014 (9.0) estimates may have been hindered by this fact. The position given falls on an empty spot, and is too far (74") from the CPD star, rather than 50". There is a good candidate at (J2000) 10 35 23.39 -60 56 15.0. The offset is 54", a good match. Recent magnitudes from APASS (29) are : V = 14.234 (err 0.055), B-V = 0.643 (err 0.058). See **Fig. 2**.

BD Car. 10 36.8 -59 09 (1875), 13.3-15p "*Is on the centre of a nebulous patch*". (Worsell 1919).

The object is identifiable as a pair of stars on a swath of H II emission. No duplicity was noted; possibly only the brighter, preceding component was clearly seen. Study of modern images shows **no** change in their relative brightness. See **Fig. 3**. Positions and mags. are :

Prec. comp.: (J2000) 10 41 30.704 -59 48 14.01 g = 13.006 Gaia DR2

Foll. comp. : (J2000) 10 41 32.669 -59 48 15.86 g = 13.637 Gaia DR2 Diff.(g) = 0.631

Other astrometric catalogues confirm this offset, with very similar values ASAS-3 records the pair as a blend, V = 12.57 (err 0.078) with no significant variation from 353 observations. Neither star appears to show variability to the degree claimed. The type 'constant' is reasonable.

BQ Car. 10 42.8 -57 53.8 (1875) 15.5 - 17p. No variation found at Harvard. (Worsell 1919)

I set up a reference sequence around BQ Car, using Bruce plate a11987 (1922-05-20). Magnitudes for

seven lettered stars are from APASS. See **Fig. 4**. The Bruce telescope had an aperture of 26"; an exposure of 120min could reach 17.0B. My sequence in V and B is listed here.

	V	B		V	B		V	B
A	14.65	16.30	D	14.21	14.95	G	13.70	14.19
B	13.49	15.22	E	14.60	15.52			
C	13.53	14.20	F	14.62	15.21			

I compared my sequence with plates of 45min exposure and 10" aperture from the DASCH database, namely the *mf* series (Metcalf 10" triplet). The results on 4 plates are::

mf13186 : C and G distinct. Others only suspected; **mf32076** : C and G distinct, E faintly at limit

mf32346 : C and G distinct. E only faintly at limit; **mf33459** : C and G distinct, others suspected.

Worsell's limit of 17p is overstated, by modern standards. In the early 20th century only a very long exposure and a much larger aperture could hope to reach 17^{mag}. On the *mf* plates, assumed to be comparable to the Union Observatory plates, only stars C and G showed up distinctly. Being practically equal in B, neither star was seen to vary. Star C is most likely the candidate star, and likely the star found to be constant at Harvard. Star C is 0.5' from Worsell's position, while G is 2.0' away, and therefore less likely. The data for star C = BQ Car are as follows: :

(J2000) : 10 47 43.99 -58 33 50.8 UCAC3 V = 13.527 (0.083) B-V = 0.677 (0.11) APASS (29)

UY Vel. 10 43.9 -54 05 (1875), 12.5 - 16p. "Is 1.9' S.f. -54 4067". (Worsell 1919).

By offsetting from CPD-54°4067, according to Worsell, I find a good match, a 12th magnitude star at 1.75' sf, in satisfactory agreement with him. Its position is :

(J2000) 10 49 05.78 -54 44 30.8 V = 12.611 B-V = 1.299 APASS (29)

The ASAS-3 light curve gives V= 12.631 (0.073), pretty constant. Finder chart is **Fig. 5**.

Table 1. Summary of results.

GCVS Name	Prelim. Name	Equ. J2000 / Epoch 2015.5	V	B	Class
AV Car	AN 87.1919_	10 31 34.966 -63 26 18.71	13.97	15.44	Constant
BB Car	AN 92.1919	10 35 23.386 -60 56 14.99	14.23	14.88	Constant?
BD Car	AN 94.1919	10 41 30.704 -59 48 14.01	13.05	13.21	Constant
BQ Car	AN 106.1919	10 47 43.989 -58 33 50.80	13.53	14.20	Constant
UY Vel	AN 109.1919	10 49 05.780 -54 44 30.77	12.61	13.91	Constant

Source: Gaia DR2

From APASS.

Conclusion

Subsequent surveys have not recovered these five old variables. These five stars each lie within a circle, $r \sim 3'$ which is devoid of possible variables. I have checked 37 stars from Worsell's work to assess the reliability of his declinations. Within limits his positions are on average pretty close to the mark as 78% of his values are within 30" of the true value, and 51% are within 15". I did **not** find any outliers, i.e. declinations which are off by >80".

References

- APASS 2021 AAVSO Photometric All Sky Survey. <https://www.aavso.org/apass>
DASCH 2021 Digital Access to a Sky Century@Harvard <http://dasch.rc.fas.harvard.edu>
Innes, R. I. 1915 Union Observatory Circular 26.
Worsell, W. M. 1919 Union Observatory Circular 46.

Measuring the effects of master flat frames on the accuracy of DSLR photometry – Roy Axelsen

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Des Loughney used dark frames for calibration, and wrote: “In theory it is advisable also to construct master flat field frames in order to remove the effects of edge distortions of the lens. I have found, however, that the field of view of a DSLR is so wide that a flat field is not required.” (J. Br. Astron. Assoc. 120, 3, 2010).

Current recommendations, exemplified by The AAVSO DSLR Observing Manual, are to use flat fields. So, do they make any difference to the accuracy of DSLR photometric observations? If so, by how much? I decided to try to answer these questions for the equipment and procedures I usually employ. While I was at it, I decided to look also at results from non-calibrated images.

Methods

Overview

The project involved DSLR photometry through a camera lens, with the camera in a fixed position on a tripod. Six stars of 6th and 7th magnitudes in V were selected (Table 1) from E Regions standards (Menzies, J.W. et. al. 1989, S. Afr. Astron. Obs. Circ., 13, 1). Ten images were taken of the field containing these stars, and ensemble photometry was carried out on each star in turn, with the other five stars used as comparison stars. Airmass for all stars in all images fell between 1.04 and 1.05. Atmospheric extinction was therefore ignored. Transformed V magnitudes and B-V colour indices were calculated from aperture photometry in AIP4Win. The final results represent averaged measurements from 10 images. Error was defined as the measured magnitude or colour index minus the corresponding value from the catalogue of E Regions standards.

The measurements were performed on non-calibrated images, on images calibrated with darks only, and on images calibrated with both darks and flats. The aim of the project was to compare the errors in these three situations.

Table 1. *E Region standards used in this study.*

Catalogue No.	V	B-V
E202	7.646	0.174
E226	6.934	0.947
E227	6.836	1.100
E229	6.705	1.482
E231	7.593	1.305
E248	6.599	0.926

Equipment, exposures and calibration frames

The images were captured with a Canon EOS 500D DSLR camera through a Canon EF 200mm f/2.8 L lens, mounted on a sturdy tripod. The instantaneous azimuth and altitude of a star near the centre of the target field were obtained from Stellarium Mobile Plus installed on a smart phone. Pointing of the camera and lens in azimuth was assisted by a magnetic compass of the type used by walkers. Pointing in altitude was assisted by a smart phone clinometer app. The camera was operated using DSLR Controller, also a smart phone app.

Ten consecutive images were taken of the target field. The exposures were each 15 seconds at f/3.5 and ISO 400. Fifteen dark frames were taken immediately thereafter using the same exposure.

Flat fields, on the other hand, were taken indoors at a different time, with the lens set to a focus point as close as possible to that used for the science images. A green electroluminescent (EL) panel was used as the light source. Its intensity could not be varied. The camera was placed on its back on a table, with the

lens aimed at the zenith. A 4mm thick white acrylic plate was placed immediately above the lens itself, and the EL panel was placed over the acrylic plate and in contact with it. Exposures were 1/13 second at f/3.5 and ISO 400. Four sets of 15 frames were taken. After each set of frames was captured the acrylic plate and EL panel were rotated clockwise 90 degrees before taking the next set of 15 images. Thus, a total of 60 flat frames were captured.

A master flat frame was created in AIP4Win, and its 'flatness' tested by plotting ADUs in each pixel against pixel number along the two diagonals. The pixel number occupied the first column of a data table, and the ADU count for each pixel along two diagonals occupied the second and third columns. The graphed data is shown in Figure 1. It is considered that the quality of the flats is acceptable, as most of the ADUs fall within plus or minus 1% of the central value, 1.0.

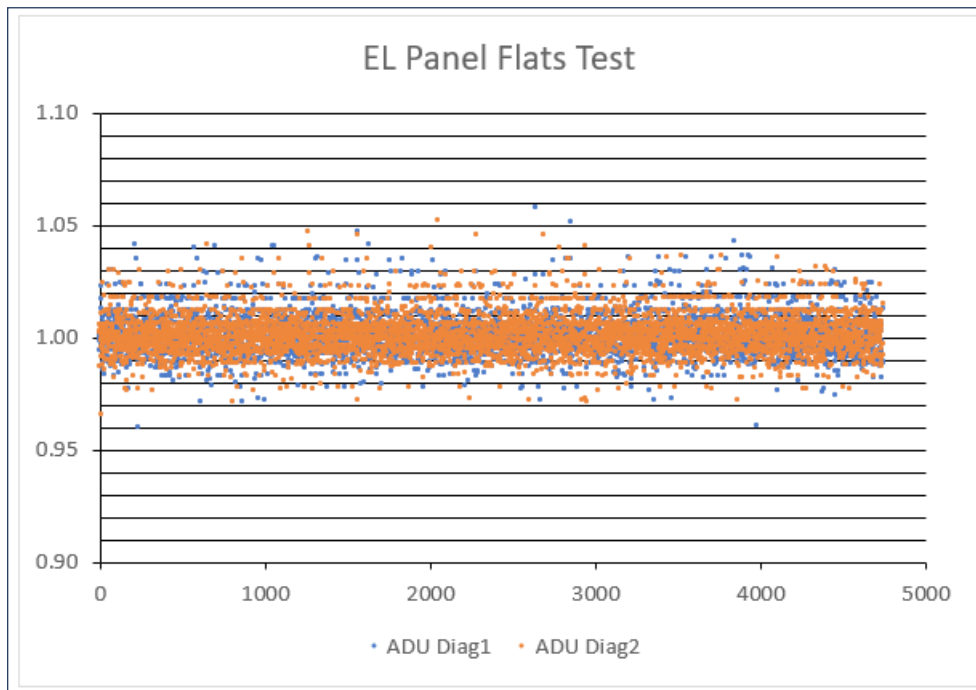


Figure 1. *Diagonals test of master flat frame. The x-axis shows the number of pixels along the diagonals and the y-axis the ADUs in each pixel. The blue and brown points represent data for the two diagonals. See text for further details.*

Photometry

Ensemble photometry was performed in AIP4Win. Transformation coefficients had been determined previously from a different set of E Region Standards. Transformed photometry was run three times: 1. Images not calibrated, 2. Images calibrated with darks only, and 3. Images calibrated with both darks and flats. The results from each photometry run were the averages of the V magnitudes and B-V colour indices from 10 images.

Results

The V magnitude errors and B-V colour index errors for photometry performed with no calibration, calibration with darks only, and calibration with darks and flats are shown in Figures 2 and 3.

For V magnitudes, calibration with dark frames resulted in only a slight improvement in accuracy (in comparison with non-calibrated images) for 4 of the 6 targets, and a slight worsening of the accuracy for the other 2 stars. When calibration was carried out with both darks and flats, however, there was a marked improved in the accuracy of the V magnitudes, with the error for 5 of the 6 targets being less than 0.01 mag.

For B-V colour indices, as for V magnitudes, calibration with dark frames resulted in only a slight improvement in accuracy (in comparison with non-calibrated images) for 4 of the 6 targets. For the other two targets, the accuracy for images calibrated with dark frames was less than for non-calibrated images,

and in one case substantially less. When calibration was carried out with both darks and flats, the accuracy was improved for 3 targets, and was worse for the other three.

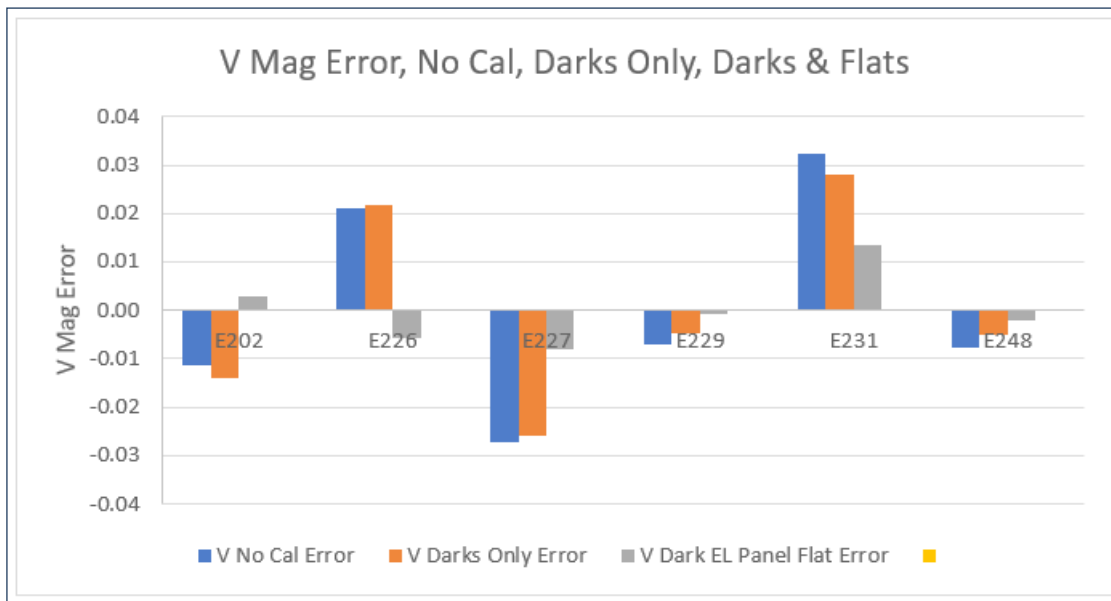


Figure 2. *V* magnitude errors (measured magnitude minus catalogue magnitude) for six target stars from non-calibrated images, images calibrated with dark frames only, and images calibrated with both dark and flat frames.

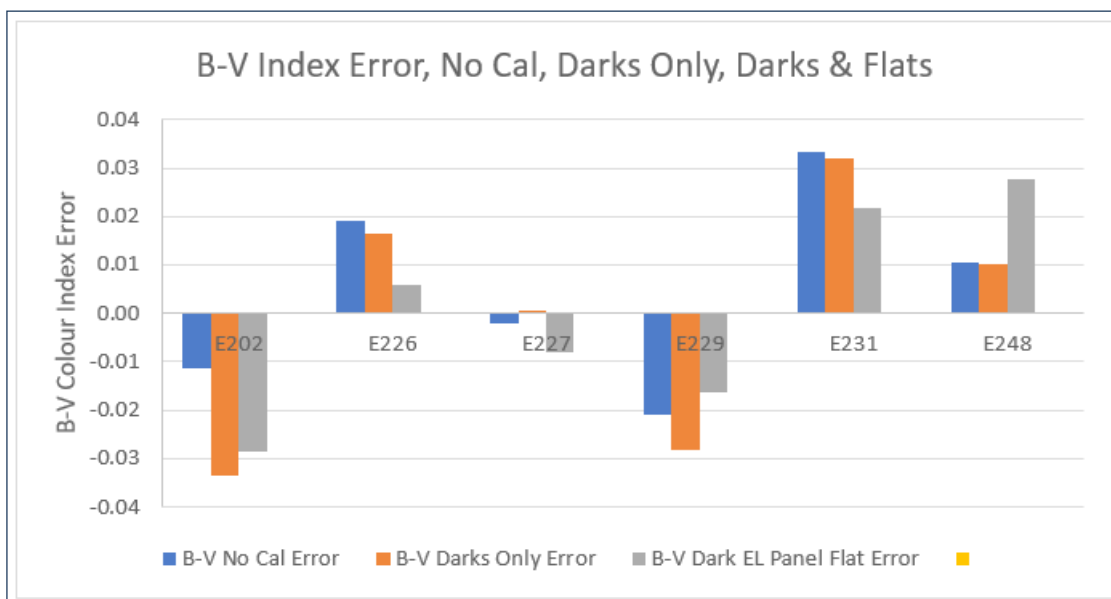


Figure 3. *B-V* colour index errors (measured index minus catalogue index) for six target stars from non-calibrated images, images calibrated with dark frames only, and images calibrated with both dark and flat frames.

Discussion

The results of this trial, and my experience with photometry of other targets, indicate that transformed DSLR photometry in *V* of bright stars using the equipment and procedures described (including, importantly, calibration with darks and flats) is very good. This should come as no surprise, as other observers have also published very accurate results. You may therefore ask - why bother? For me, there are two reasons. First, my curiosity was aroused by Des Loughney's published comment that darks but not flats are required for DSLR photometry. Second, and more importantly, the experience of performing photometry on photometric standard stars is a valuable educational exercise. If the results are not good, analysis of

the reasons for any sub-optimal precision or accuracy can lead to improvement. Good results, on the other hand, lead to confidence in equipment and processes.

In contrast to the accuracy of measured magnitudes in V, it has been my experience and that of others that the determination of B-V colour indices and B magnitudes is less accurate with DSLR photometry. One reason for this, and perhaps the most important, is that the number of blue pixels in a DSLR sensor is of course half that of the number of green pixels, as is the number of captured photons. The signal/noise ratio for the blue channel data will therefore be lower than that for the green channel.

Summary

The accuracy of transformed DSLR photometry in V performed on images captured through a 200mm focal length camera lens from a fixed tripod is very good after calibration using darks and flats, but not as accurate if calibration is performed using darks alone. This outcome does not support Des Loughney's experience that calibration with flats is not needed. The results are reported here because they show how much better DSLR photometry is when flat frames are used, and to emphasize that measuring photometric standard stars is an excellent way to check the accuracy of your equipment and procedures and to give you confidence in them.

Refining the orbital period of KX Velorum – *Mark Blackford*

(markgblackford@outlook.com)

In August 2014 Dr. Pavel Mayer (Astronomical Institute of the Charles University, Czech Republic) contacted me requesting observations of the bright ($V=5.11$) southern eclipsing binary KX Velorum. In a recent paper (Mayer et al., 2014) he and co-authors used radial velocities (RV) measured from archival spectra to determined orbital parameters and masses of the component stars but lamented the fact that no eclipses had been recorded since discovery in 1986 (Balona and Laing, 1986). Eclipse timings would help refine the orbital period and light curve modeling would determine physical parameters of the stars.

According to that paper KX Vel has spectral type B0.5 IV with primary and secondary masses of 16.8(5) and 9.5(3) solar mass, respectively. In the introduction they wrote:

“Massive stars of spectral types O and early B deserve special attention because these extremely rare objects are the main drivers of the chemical and dynamical evolution of galaxies and play an important role as cosmological probes. They are crucial in the comparison to recent refinements of the theory of stellar structure and evolution of massive stars with respect to mass loss, core overshooting, rotation, and metallicity. The still persisting discrepancy between expected and observed masses of very massive stars also needs to be resolved. In particular, binaries offer the opportunity to provide precise absolute stellar quantities (masses, radii, and luminosities) for challenging theoretical predictions.”

Even rarer are eclipsing OB-type systems such as KX Vel.

The photoelectric photometer (PEP) observations of Balona and Laing (1986) showed part of the ingress phase of an eclipse (Figure 1). The period could not be established, although they suspected it might be “quite long”. Mayer et al. (2014) found the period to be 26.30575(13) days from RV analysis. Dr. Mayer provided a list of predicted times of upcoming primary eclipses based on this period. He indicated that secondary eclipses were unlikely to be visible due to the orbital eccentricity of 0.598(6) and 74.6(7) degree inclination.

Primary eclipses are only 0.08 magnitudes deep and were expected to last about 14 hours so an entire eclipse could not be recorded in a single night. Also, the ~26d period meant only a few eclipses could potentially be observed each observing season. So this was quite a difficult target.

After several failed attempts I recorded an eclipse egress on 17 January, 2015 (Figure 2 left panel). The gaps were due to cloud. Nearly 2 years elapsed before I was able to record an ingress and minimum on 27 December, 2016 (Figure 2 right panel). The polynomial fit function in PERANSO (Paunzen and Vanmunster, 2016) was used to estimate ToM of the later eclipse (Figure 3).

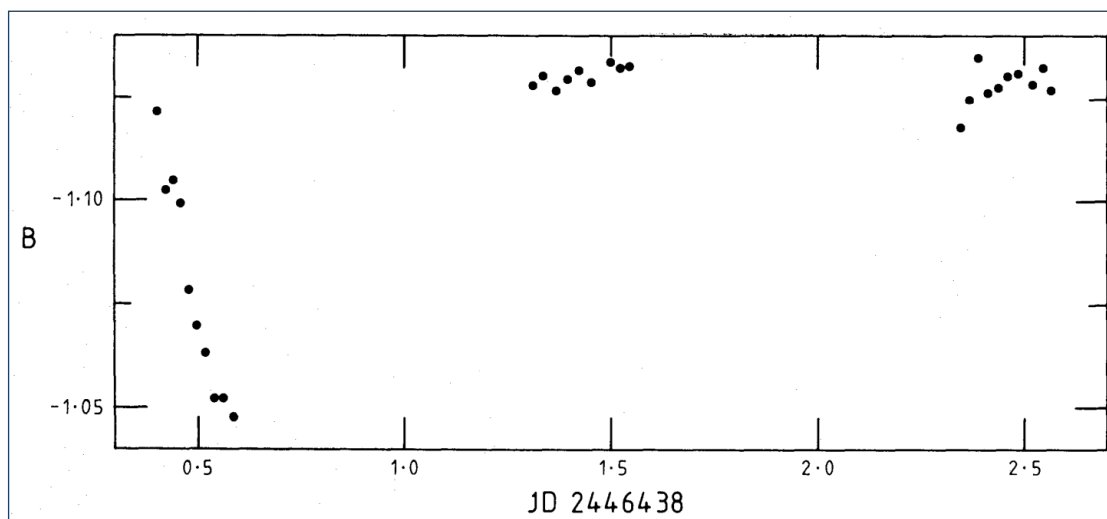


Figure 1. *Stromgren b magnitude light curve from Balona and Laing (1986).*

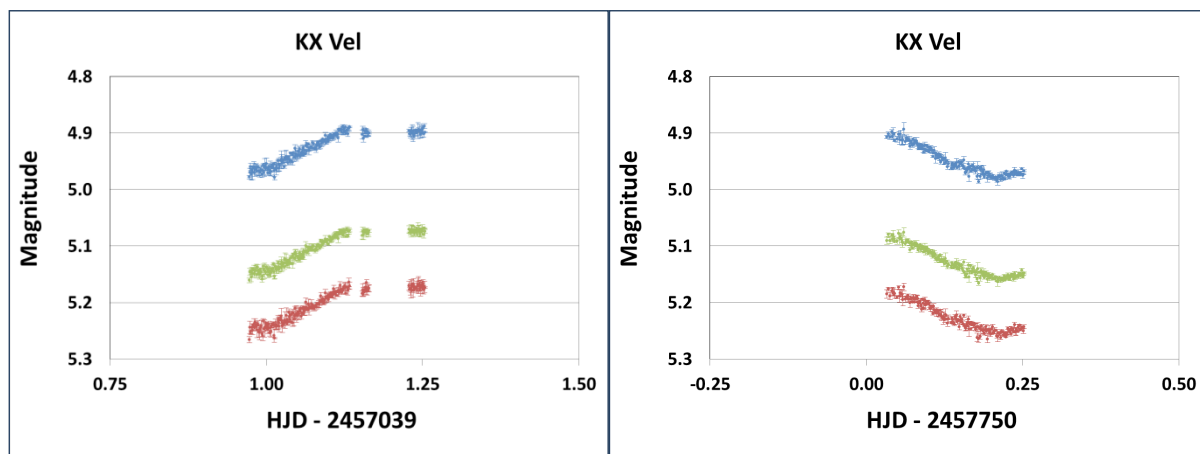


Figure 2. *BVRc light curves recorded with a Canon 1100D DSLR camera and 200mm f2.8 lens on 17 January 2015 (left) and 27 December 2016 (right) .*

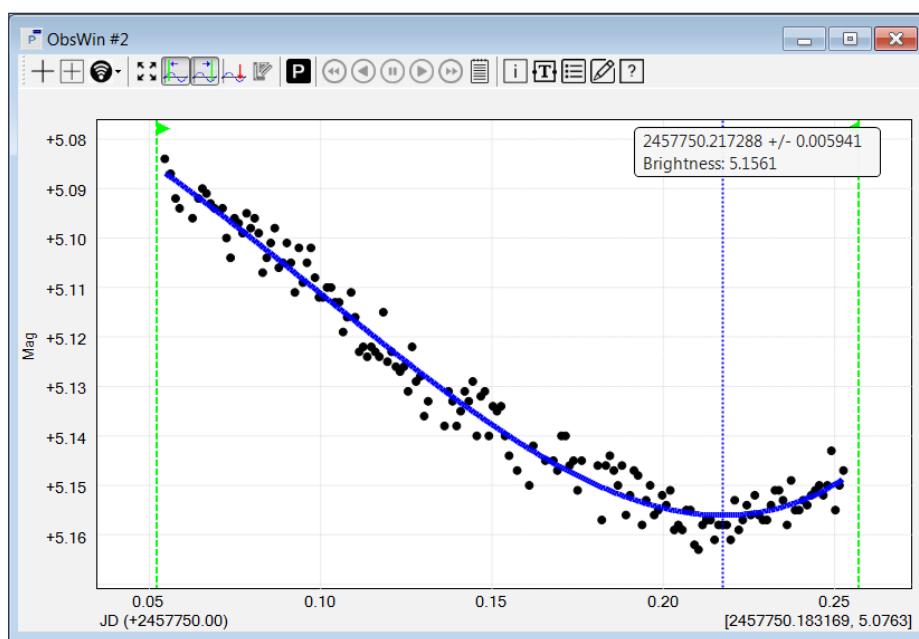


Figure 3. *PERANSO plot of V light curve recorded on 27 December 2016 with Time of Minimum determined by least squares fitting a 4th order polynomial (blue line).*

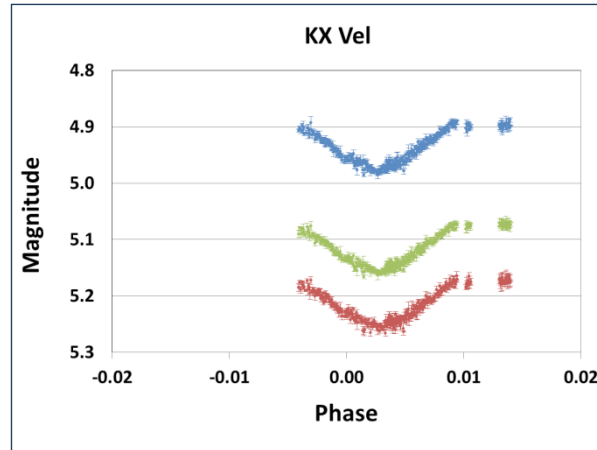


Figure 4. *Phased BVRc light curve using epoch HJD 2449148.16 and period 26.30575d.*

Phased light curves (Figure 4) of these two sets of observations were constructed using the 26.30575 day period and epoch HJD 2449148.16 as recommended by Dr Mayer. I believe that epoch was derived from the same radial velocity data from which the period was calculated. The minimum is offset slightly from phase zero indicating a correction is required to the epoch and/or period, but that would require more minima timings. Unfortunately I was not able to observe any further eclipses after 2016 so work on this had stalled until satellite observations became available recently.

The Transiting Exoplanet Survey Satellite (TESS) imaged the field at 2 minute cadence from 2 February to 25 March, 2019, recording two primary eclipses in exquisite detail. Figure 5 is part of the light curve around the first primary eclipse. The PERANSO plot and Time of Minimum measured by polynomial fit and Kwee-van Woerden (KvW) methods are shown in Figure 6. The polynomial fit error estimates are overly conservative whilst those from KvW are overly optimistic. I opted to use polynomial fit values from both TESS eclipses for this study. All available Times of Minimum are listed in Table 1.

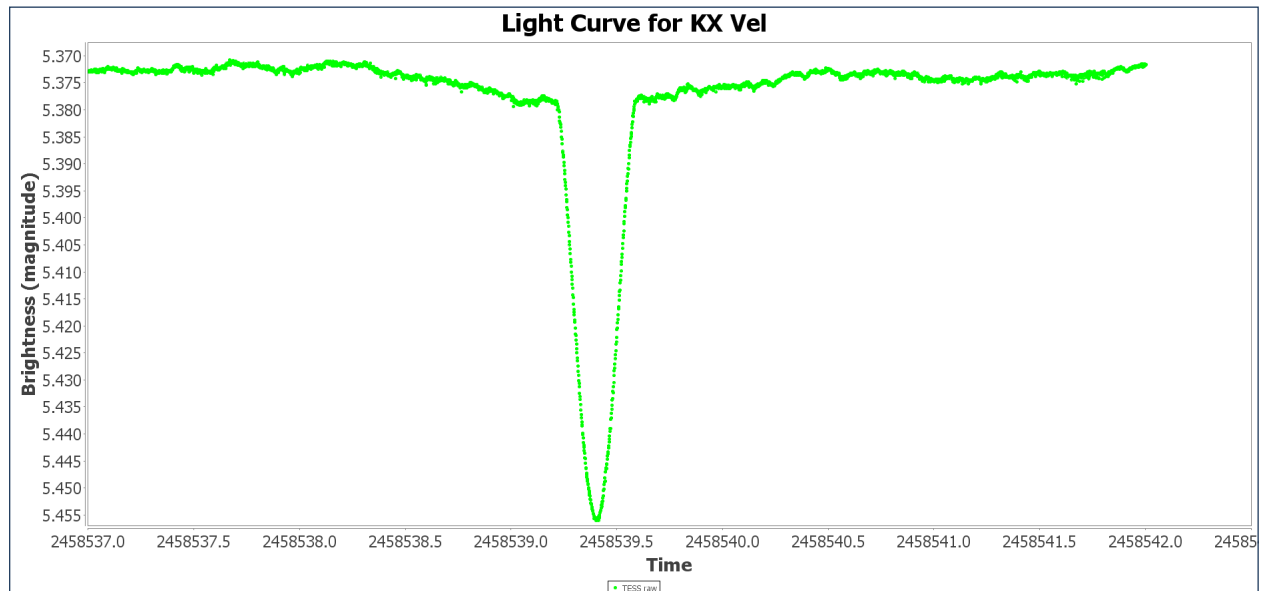


Figure 5. *Part of TESS light curve recorded at 2 minute cadence. Time axis is Heliocentric Julian Date.*

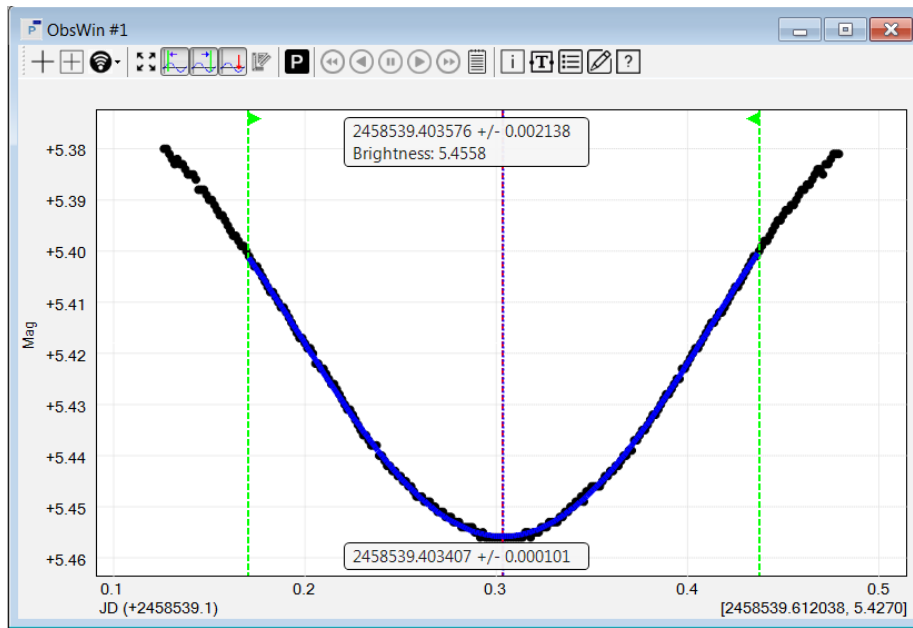


Figure 6. PERANSO plot of first TESS primary eclipse with Time of Minimum estimates from polynomial fit (top) and Kwee-van Woerden (bottom) methods.

HJD	error	Cycle	Source
2446438.62	0.02	0	Estimated from Figure 1, Balona and Laing (1986)
2449148.16	0.02	103	Mayer (private communication)
2457750.2173	0.0059	430	Blackford, this study
2458539.4036	0.0021	460	TESS, this study
2458565.7074	0.0034	461	TESS, this study

Table 1. All available primary eclipse Times of Minimum

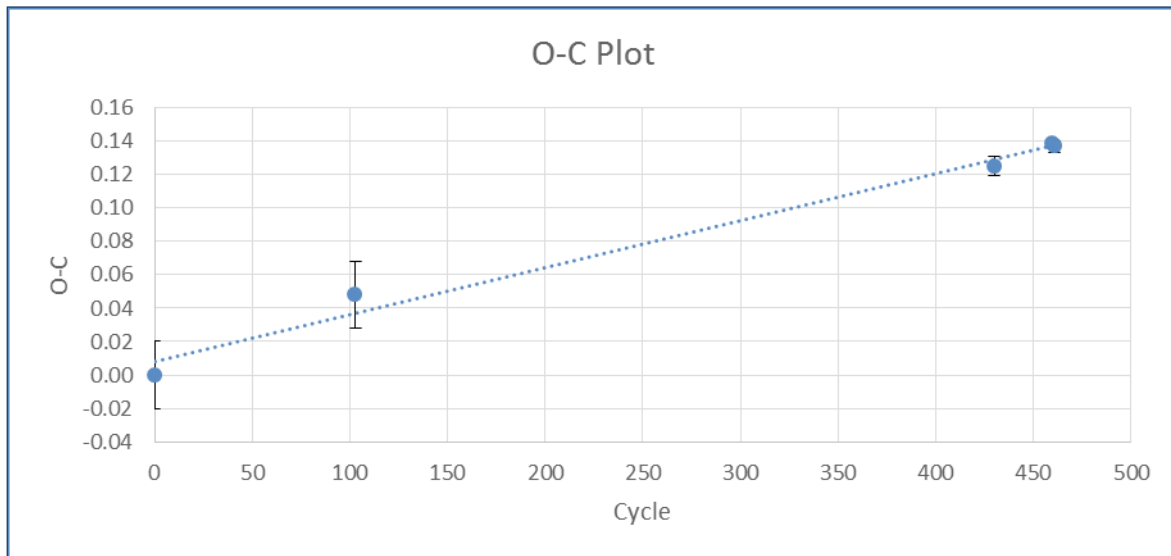


Figure 7. Observed minus calculated diagram of the available Times of Minimum.

The observed minus calculated (O-C) diagram in Figure 7 was constructed using the 26.30575d period and zero epoch HJD 2446438.62 estimated from Figure 1 of Balona and Laing (1986). The upward sloping linear trend indicates the true period is actually slightly longer. Using the LINEST function in Excel to perform linear regression of all 5 data points in Table 1 yielded the following light elements:

$$\text{HJD0} = 2446438.6281(65), \text{ Period} = 26.306030(18)$$

However, the HJD 2449148.16 epoch was derived from spectra collected over a time span of more than a decade and is likely to be less reliable than data points actually measured from observed eclipses. Linear regression of just the 4 eclipse timings yielded the following light elements:

$$\text{HJD0} = 2446438.6198(24), \text{Period} = 26.306047(6)$$

These refined values can be used to constrain a simultaneous modeling of the new TESS light curve and existing radial velocity curves, leading to improved orbital and absolute physical parameters of the binary's component stars. This was exactly the data Dr. Mayer had requested in 2014; sadly he had passed away on November 7, 2018 - the very day of his 86th birthday. Hopefully others can take up the challenge of completing this analysis.

Acknowledgements

This research made use of VStar software (Benn 2012) and Peranso (www.peranso.com), a light curve and period analysis software. This research has made use of the SIMBAD and VIZIER databases, operated at CDS, Strasbourg, France and of NASA Astrophysics Data System Bibliographic Services. This paper includes data collected by the TESS mission, which are publicly available from the Mikulski Archive for Space Telescopes (MAST).

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- Balona, L. A., & Laing, J. D. 1986, MNRAS, 223, 621
Benn, D. 2012, JAAVSO, 40, 852
Mayer, P., Drechsel, H., Irrgang, A., 2014, A&A, 565, 86
Paunzen, E., Vanmunster, T., 2016, Astronomische Nachrichten 337, 239-246.

How a hidden error in period finding leads to false discoveries

In a recent article in this *Newsletter*, I explored the use of software to analyse the period change behaviour of an eclipsing binary with an apparently nonlinear period (Richards 2020). This led to the fitting of a sinusoidal period change model with the resulting “discovery” of a third body in the system.

This is now known to be wrong. This article explains the nature of the (usually hidden) cycle count error that led to that incorrect result, and how in general to detect it.

Introduction

In an article in a previous *Newsletter* (Richards 2020) I discussed the problems of characterizing long-term period change in eclipsing binaries; illustrating some of the issues involved by using a code to find linear, parabolic and/or sinusoidal fits to ephemeris diagrams (Hilditch 2001, p.170), aka O-C diagrams. For terminology data and method see that article. The particular binary used to illustrate the process of estimating period change was GZ Pup.

The best fit derived in that article was a sinusoid. This is illustrated in Figure 1 as an ephemeris diagram with cycle counts as abscissa and residuals from the reference ephemeris (observed – calculated values) as ordinate.

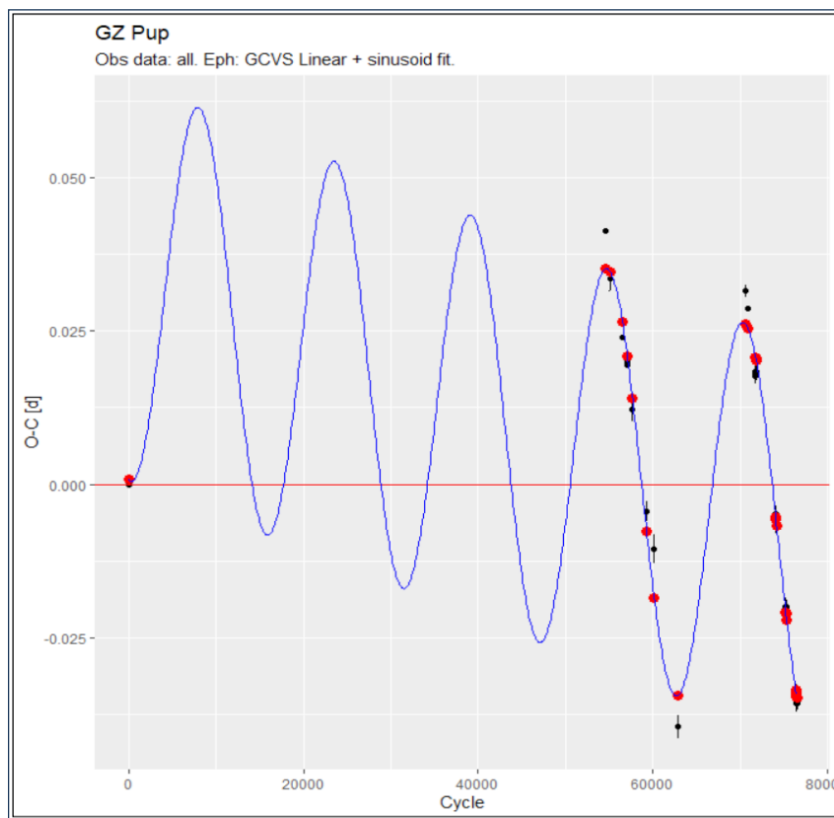


Figure 1. Ephemeris diagram of a sinusoid fit. Observed minima are shown as blue dots. The red dots show their fitted values. The pair of red and blue dots on the left edge are the GCVS epoch and its fit.

In Figure 1 the GCVS epoch was not included in the minima data set for the calculation of the fitted curve, so it is in effect a prediction from the fit to the minima on the right. The GCVS ephemeris (Samus et al, 2017) did however serve as the reference ephemeris for the regression calculation. An initial reference ephemeris (epoch and period) must be used to provide a calculation of the (predicted) cycle count for each minimum in the data set; then the differences between actual observed minimum times and those calculated (O-C) are shown on the Y axis of the plot. (Hilditch 2001, p170; Richards 2020). The problem

to discuss here is the trouble with the necessary assumption of the correctness of the period in the reference ephemeris.

Finding a best linear fit to the observational data.

It is apparent in Figure 1 that a sinusoidal fit is excellent. Figure 2 shows the same data as Figure 1 – plotted with the same reference ephemeris — but showing a linear least-squares fit to the data, which is extremely poor.

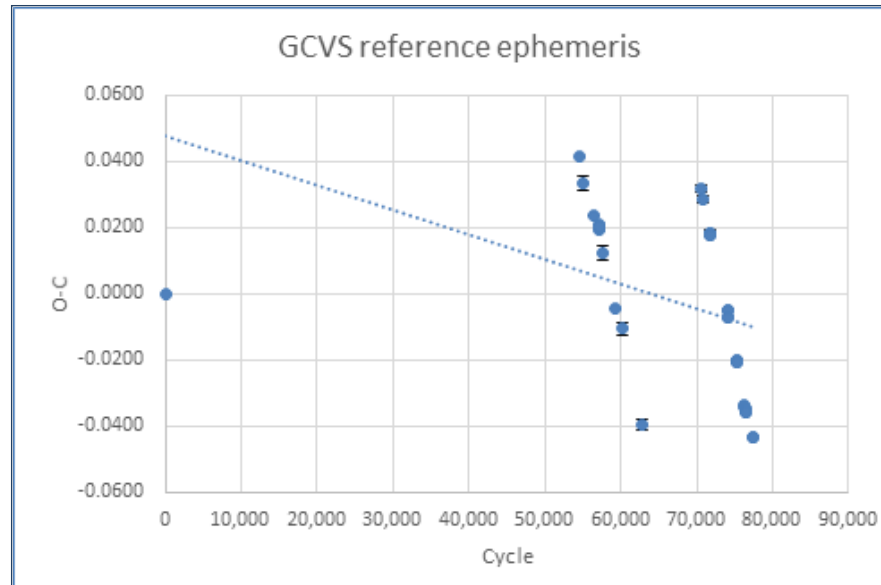


Figure 2. Linear fit to the minima data, using the GCVS as the reference ephemeris. The best fit linear least-squares regression line is dotted.

The inadequacy of the linear fit is obvious – its residual sum of squares (RSS) is 0.02. But importantly the two lines of minima data points are clearly seen, on which the sinusoidal regression of Figure 1 is based.

Recently, Jeff Byron emailed me (Byron 2021) to point out that if the VSX ephemeris (Watson, Henden & Price, 2006) is used as the reference ephemeris, a far better linear fit is obtained, as in Figure 3. This is where my house of cards fell apart. As Byron said “I’m sorry that this is probably not welcome.”

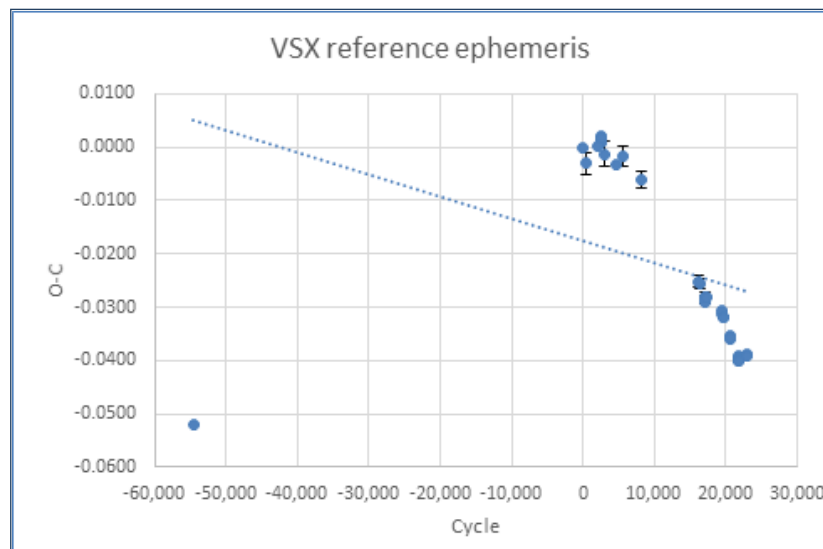


Figure 3. Linear fit to the minima data, using the VSX as the reference ephemeris. The best fit line is dotted.

Here, the double line of minima has disappeared, and with it the need to fit a sinusoidal regression. In this fit, $RSS = 0.00996$, considerably better. A linear fit is still plainly inadequate however. Instead, it looks as if a parabolic fit – much simpler – would suffice, indicating linear period change, not cyclic.

Byron's own calculations derive a best period of 0.3202631 d, sufficiently different from the VSX period of 0.320265 d to yield a rather different residual diagram, Figure 4. In this case, $RSS = 0.00018$, a great improvement. The apparent parabolic trend in Figure 3 has disappeared, replaced by an apparent sinusoidal trend — but very different from that in Figure 1.

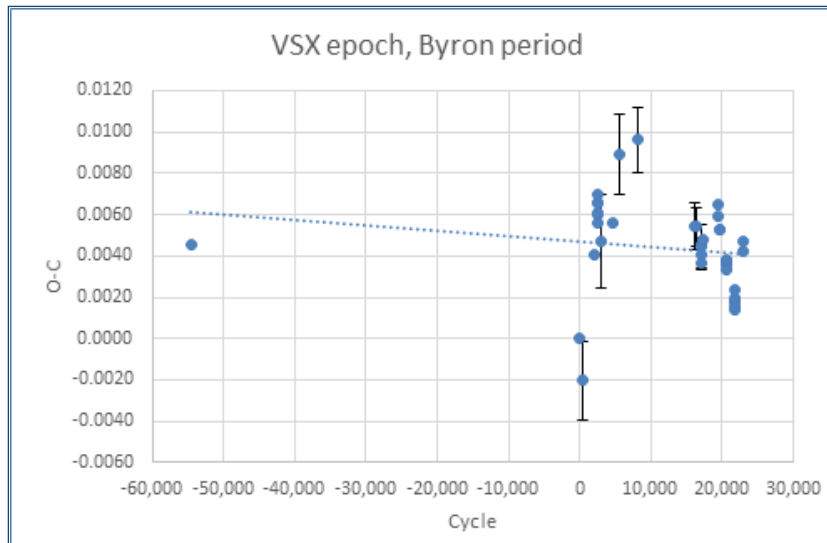


Figure 4. Residual diagram using the same reference epoch as in Figure 3, but Byron's period. The slope of the regression line indicates a better period estimate exists.

It seems surprising that Figures 2, 3 and 4 should show such different patterns of residuals. Moreover, how does one decide which is correct? Minimizing the RSS is certainly one good way; but it might be argued that it is not the linear fit that matters, but the higher-order, parabolic or sinusoidal fit since they indicate period change and actually yield small RSS values. If the RSS of the sinusoid fit in Figure 1 is, for argument's sake, smaller than that of Figure 4, should we not go back to the sinusoid fit and explore for a third body in the system?

The cycle jump problem

Byron's communication answers that (Byron 2021). My analysis in (Richards 2020) has overlooked one issue, the possibility that the cycle count from the GCVS ephemeris over the time interval surveyed is wrong. Byron shows that the GCVS cycle count, and that of VSX, and that of his preferred period (above) all give different cycle counts for the interval from the GCVS epoch to my first minimum estimate. In the present article however I'll explore this not with my first minimum estimate but my first *primary* (i.e. photometrically deeper) minimum estimate at 2457380.19586 (see Figure 5) — hereafter TR-MinI — since my first was of a secondary minimum, creating some confusion.

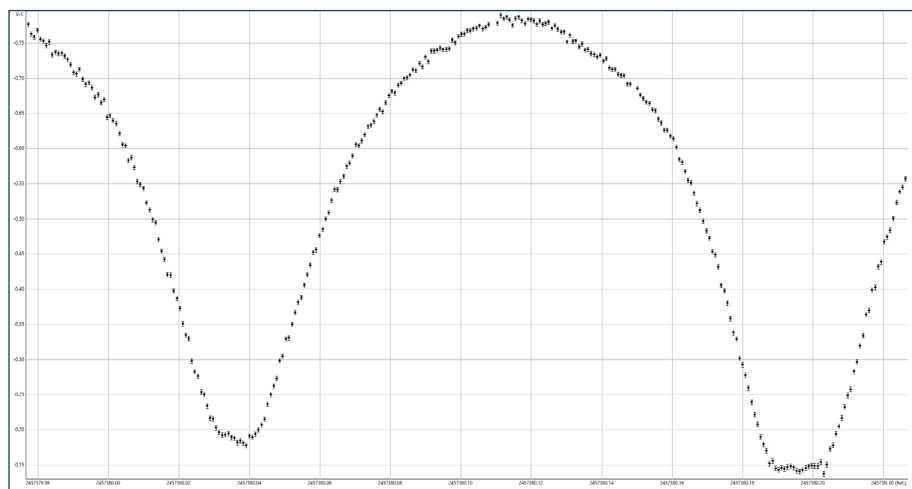


Figure 5. Light curve of GZ Pup from 2015-12-23. (Pretty Hill Observatory) TR-MinI (see text) is the second, deeper minimum.

A regression on that epoch and Byron's period estimate finally gives a best-obtainable linear ephemeris:

$$EO_{\text{best}} = \text{HJD } 2457380.1965(4), P_{\text{best}} = 0.32026307(3) \text{ d} \quad (1)$$

The residual diagram for this reference ephemeris is shown in Figure 6. Note there is at least a zero-slope zero-offset trend line.

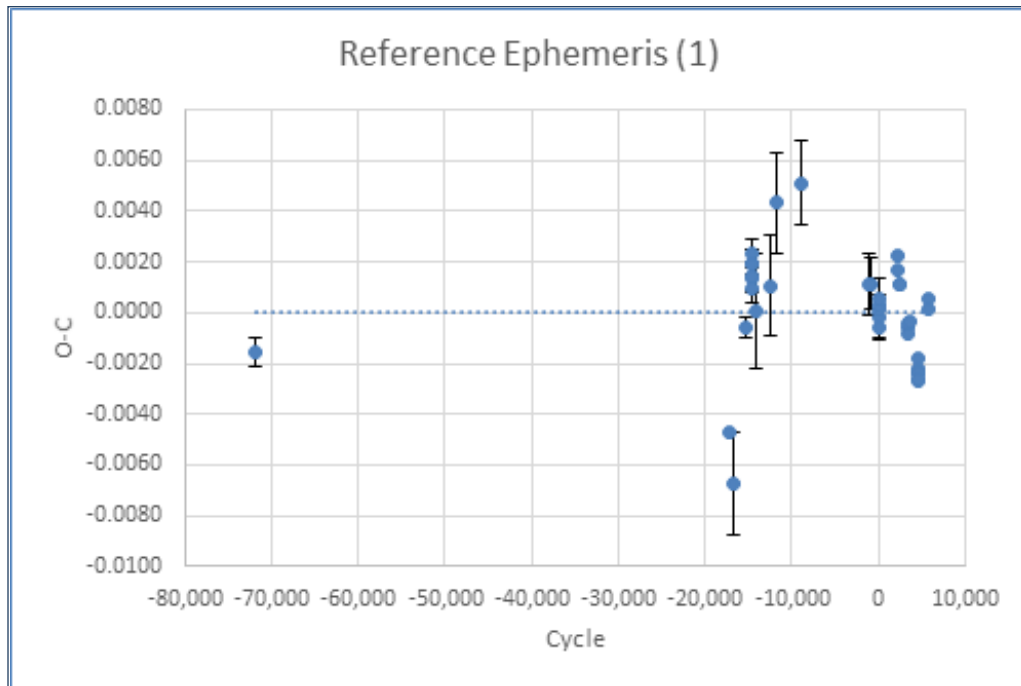


Figure 6. Residual diagram using ephemeris (1) as the reference ephemeris.

Table 1 below compares residuals and cycle counts for that new best epoch compared to the GCVS epoch using these different ephemerides. This is where the ‘cycle count problem’ shows up. In the table, calculations are made as follows:

$$\begin{aligned} \Delta t &= EO_{\text{best}} - \text{GCVS epoch} = 22981.759481 \text{ d} \\ \text{Raw Cycles} &= \Delta t / \text{Period} \\ \text{Rounded Cycles} &= \text{round}(2 \times \text{Cycles})/2 \\ \text{Calculated minimum, C} &= \text{Rounded cycles} \times \text{Period} \\ O-C &= \Delta t - C \end{aligned}$$

The Difference column shows the difference in cycle counts from Ephemeris (1).

Note that the algorithm for calculating C uses the time of the nearest half-cycle to the observed minimum. This allows for the calculation of secondary minima, which for an EW binary like GZ Pup are always at orbital phase 0.5.

Table 1. Cycle counts and O-C values according to different periods.

Ephemeris	Period (d)	Raw Cycles	Rounded Cycles	C (d)	O-C (d)	Difference (cyc)
GCVS	0.32027400	71,756.555	71,756.5	22981.7413	0.0316	2.449
VSX	0.32026500	71,758.571	71,758.5	22981.7360	0.0251	0.432
Eph (1)	0.32026307	71,759.004	71,759.0	22981.7576	0.0054	0.000

What immediately emerges from the O-C column is that TR-MinI will be placed at very different positions in the residuals diagrams based on each ephemeris. The Rounded Cycles column shows that on both GCVS and VSX, TR-MinI will be incorrectly calculated as a secondary minimum, but as a primary minimum on Ephemeris (1). This establishes that both the GCVS and VSX ephemerides are sufficiently wrong to result in an incorrect cycle count for TR-MinI.

P_{best} differs from the GCVS period by 1.1×10^{-5} d, a difference accumulating per orbital cycle, and those cycles are short. Over the time interval used in Table 1 it amounts to 2.5 cycles. A half-cycle error occurs when O-C grows to $P/4 = 0.08$ d, as can be explained with reference to Figure 7.

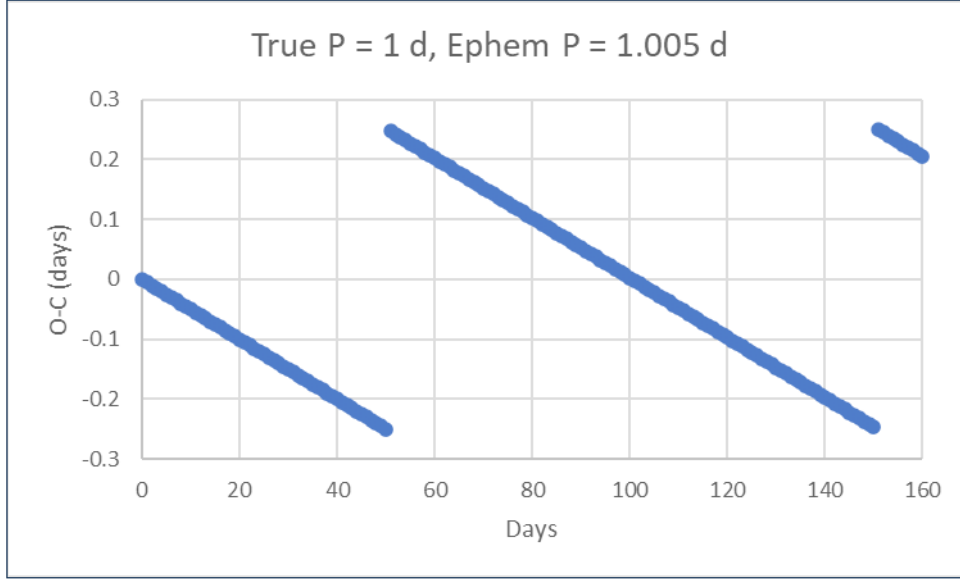


Figure 7. Simulation of cycle count jumps. Model binary has $P_{\text{true}} = 1.0$ d and minima data points every day. Reference ephemeris is $P_{\text{eph}} = 1.005$ d, $E0_{\text{eph}} = 0.0$ d.

In Figure 7 a binary is modelled with a period $P_{\text{true}} = 1.0$ d. To construct the diagram a reference ephemeris is used with $P_{\text{eph}} = 1.005$ d, and the diagram starts at day 0. O-C has a negative slope since $P_{\text{eph}} > P_{\text{true}}$. O-C declines until O-C = -0.25 d at true cycle 50, when the raw cycle count $\text{cyc}_{\text{raw}} = 50 / 1.005 = 49.751$, which rounds *up* correctly to 50; so the calculated minimum is $50 \times 1.005 = 50.25$, and O-C = -0.25 d.

That is where the cycle count makes a jump. At true cycle 51 $\text{cyc}_{\text{raw}} = 51 / 1.005 = 50.746$, which rounds *down* to 50.5, giving a calculated minimum of 50.7525 d and the O-C jumps to 0.2475 d starting the second line of minima in Figure 7.

In general, a cycle count jump occurs at true cycle n when either

- (a) $\text{cyc}_{\text{raw}}(n) > n-1 + 0.75$, but $\text{cyc}_{\text{raw}}(n+1) < n + 0.75$.
- (b) $\text{cyc}_{\text{raw}}(n) > n-1 + 0.25$, but $\text{cyc}_{\text{raw}}(n+1) < n + 0.25$

In both cases the rounded cycle count increases by 0.5 instead of 1.0, making the O-C value increase by $\sim 0.5 \times P_{\text{true}}$ d. Hence the jump from the bottom of one minima line to the top of the next. (When $P_{\text{eph}} < P_{\text{true}}$ corresponding results hold with signs changed; the lines of minima slope upwards, and the jumps are downward.)

The Y-axis height of a minima line is

$$\Delta(\text{O-C}) \sim P_{\text{true}}/2 \text{ [days]} \quad (2)$$

In a line of minima the O-C differences cycle to cycle are $\Delta P = P_{\text{true}} - P_{\text{eph}}$ d/cycle, so the elapsed time for one line is

$$\Delta t = P_{\text{true}} / 2\Delta P. \text{ [cycles]} \quad (3)$$

Compare those two results to the variant of Figure 2 in Figure 8. Assuming $P_{\text{true}} = P_{\text{best}} \sim 0.320$ d, then the two lines in Figure 1 should have $\Delta(\text{O-C}) \sim 0.16$ d, which is the case. Moreover $\Delta P \sim 1.1 \times 10^{-5}$ d/cycle, so $\Delta t \sim 0.320 / (2 \times 1.1 \times 10^{-5}) = 14545$ cycles, agreeing by eye with the spacing of the two lines in Figure 8.

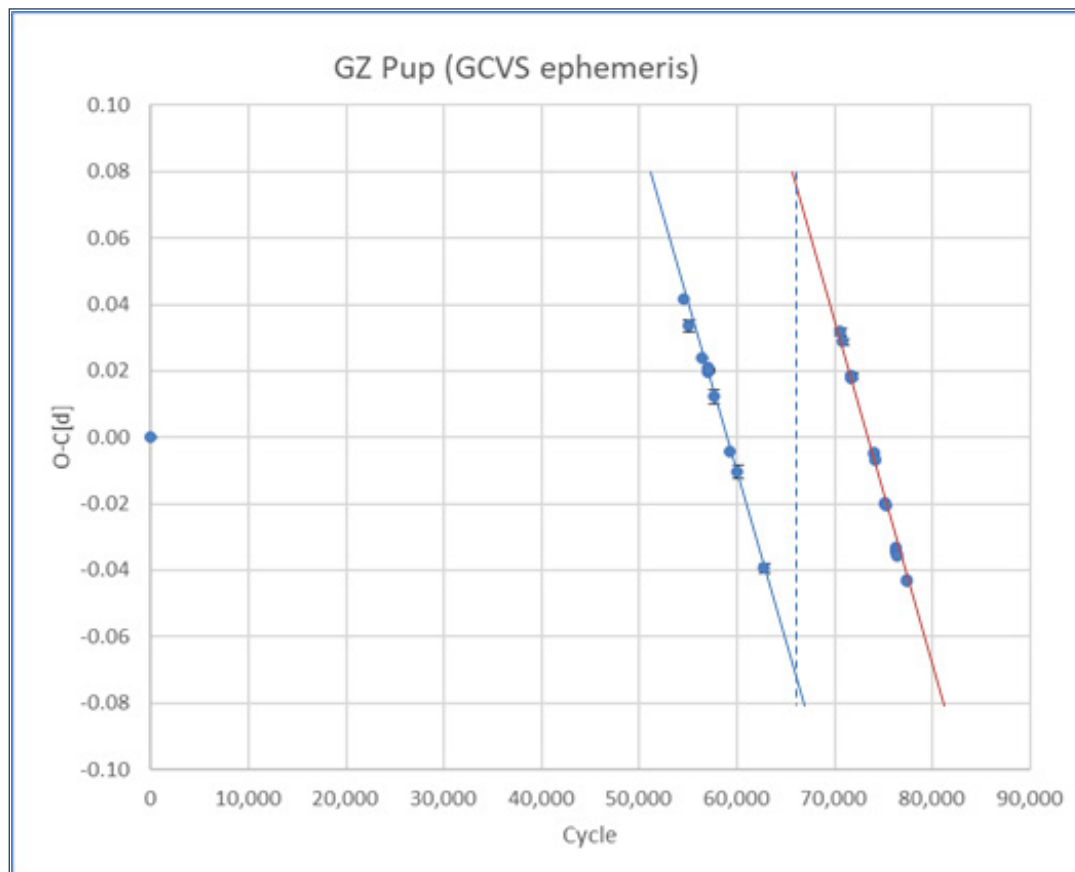


Figure 8. As for Figure 2 but with (approximate) regression lines for the two lines of minima. Note the second line starts at the cycle where the first line stops.

Conclusion

The sinusoidal fit to minima data for GZ Pup (Figure 1) as announced in (Richards 2020), together with the inference to a third body in the system, is wrong, as pointed out in (Byron 2021). However the residuals to a “best” linear fit (Ephemeris (1) and Figure 8) show a possible (but different) sinusoidal trend.

The error is shown to be due to an incorrect cycle count in the reference ephemeris used (GCVS), but (as Byron showed) is also present in the VSX ephemeris. Detecting cycle count errors is not easy, nor definitive, but can easily arise for very short period eclipsing binaries ($P < 1$ d, say) when based on a long-ago discovery ephemeris.

Discovery ephemerides, usually based on analysis of a few photographic plates taken over a year or more, can be sufficiently inaccurate to cause the problem (and are usually not accompanied by precision estimates). There may be no more reliable ephemerides available since then, especially in the south of the sky, until the careful recent work of the Southern Eclipsing Binary Group of Variable Stars South. The data desert in-between can be partially filled in some cases by photometric survey data; but this is also irregular and usually of low precision, meaning the derivation of minima from them is, while possible, quite imprecise. Such data were used for the GZ Pup analysis, occurring in the first line of minima in Figure 8.

The signature of an incorrect cycle count shows up in an ephemeris diagram as parallel sloping lines of (O-C) residuals from a linear reference ephemeris. The characteristics of those lines are expressed in Equations (2) and (3). In the Case of GZ Pup there was sufficient data for those lines to appear, as in Figure 2, but only when the reference ephemeris (GCVS) was sufficiently incorrect to show it. That signature is absent in Figure 3 (VSX reference ephemeris) even though there was a cycle count jump. For the signature to appear there must be sufficient minima data over a sufficiently long time interval to record the jump. For southern eclipsing binaries in particular that is usually not the case.

When the jump signature is absent, a plausible but less definite alternative is to calculate an ephemeris

using only a subset of well-determined minima over a sufficiently small time interval to ensure there can be no cycle count jump within that interval, but sufficiently large to give a small error in the ephemeris period. Its cycle count back to an early ephemeris epoch (ideally the discovery ephemeris) can then be compared with the cycle count of the early ephemeris over the same time interval, as in Table 1. In doing so it is important to see if the period uncertainty in the new ephemeris does not accumulate to anything near a quarter of its period over the time interval, which may cause a jump.

Another indicator of a cycle jump occurs when the ephemeris predicts that a photometric primary minimum is a secondary, or vice versa. But (a) the ephemeris may itself be giving the epoch of a photometrically secondary minimum, and anyway (b) this test fails if there are an even number of cycle jumps.

Plainly these procedures and tests are more heuristic than definitive. They are further weakened if (a) the true but unknown period is non-linear, (b) there are significant or unknown uncertainties in the minima estimates, (c) there are few or no minima estimates over large segments of the time interval surveyed. Consequently it is incumbent on the authors of period analyses to include assessments of all these problems of period determination in their publications. A period determination is of course always hypothetical. But as this article shows, its errors may very well not just be statistical uncertainties but systematic and even unknown.

Acknowledgements

I am deeply grateful to Jeff Byron for pointing out the error in my earlier article, for detecting the cycle jump problem, and for his corrections to the present article. All remaining mistakes in it are entirely mine.

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Publication watch

Mark Blackford has two publications since the last newsletter:

Budding, E.; Love, T.; Blackford, M. G.; Banks, T.; Rhodes, M. J., *Absolute parameters of young stars: V Puppis*, MNRAS, Volume 502, Issue 4, pp.6032-6043 (2021), DOI: 10.1093/mnras/stab381, arXiv: arXiv:2102.00362

Abstract

New spectrometric data on V Pup are combined with satellite photometry [HIPPARCOS and recent Transiting Exoplanet Survey Satellite (TESS)] to allow a revision of the absolute parameters with increased precision. We find: $M_1 = 14.0 \pm 0.5$, $M_2 = 7.3 \pm 0.3$ ($M_\odot$); $R_1 = 5.48 \pm 0.18$, $R_2 = 4.59 \pm 0.15$ ($R_\odot$); $T_1 = 26\,000 \pm 1000$, $T_2 = 24\,000 \pm 1000$ (K), age 5 ± 1 (Myr), photometric distance 320 ± 10 (pc). The TESS photometry reveals low-amplitude (~ 0.002 mag) variations of the β Cep kind, consistent with the deduced evolutionary condition and age of the optical primary. This fact provides independent support to our understanding of the system as in a process of Case A type interactive evolution that can be compared with $\mu 1$ Sco. The $\sim 10 M_\odot$ amount of matter shed by the overluminous present secondary must have been mostly ejected from the system rather than transferred, thus taking angular momentum out of the orbit and keeping the pair in relative close proximity. New times of minima for V Pup have been studied and the results compared with previous analyses. The implied variation of period is consistent with the Case A evolutionary model, though we offer only a tentative sketch of the original arrangement of this massive system. We are not able to confirm the previously reported cyclical variations having a 5.47-yr period with the new data, though a direct comparison between the HIPPARCOS and TESS photometry points to the presence of third light from a star that is cooler than those of the close binary, as mentioned in previous literature.

Borkovits, T.; Rappaport, S. A.; Maxted, P. F. L.; Terentev, I.; Omohundro, M.; Gagliano, R.; Jacobs, T.; Kristiansen, M. H.; LaCourse, D.; Schwengeler, H. M.; Vanderburg, A.; Blackford, M. G., *BG Ind: the nearest doubly eclipsing, compact hierarchical quadruple system*, MNRAS (2021), DOI: 10.1093/mnras/stab621, arXiv: arXiv:2103.00925

Abstract

BG Ind is a well studied, bright, nearby binary consisting of a pair of F stars in a 1.46-day orbit. We have discovered in the TESS lightcurve for TIC 229804573 (aka BG Ind) a second eclipsing binary in the system with a 0.53-day. Our subsequent analyses of the recent TESS and archival ground-based photometric and radial velocity data, reveal that the two binaries are gravitationally bound in a 721-day period, moderately eccentric orbit. We present the results of a joint spectro-photodynamical analysis of the eclipse timing variation curves of both binaries based on TESS and ground-based archival data, the TESS lightcurve, archival radial velocity data and the spectral energy distribution, coupled with the use of PARSEC stellar isochrones. We confirm prior studies of BG Ind which found that the brighter binary A consists of slightly evolved F-type stars with refined masses of 1.32 and 1.43 $M_\odot$, and radii of 1.59 and 2.34 $R_\odot$. The previously unknown binary B has two less massive stars of 0.69 and 0.64 $M_\odot$ and radii of 0.64 and 0.61 $R_\odot$. Based on a number of different arguments which we discuss, we conclude that the three orbital planes are likely aligned to within 17° .

Phil Evans is a co-author of one TESS exoplanet paper published on the arXiv

Dawson, R.I., Huang, C.X., Brahm, R. et al. *Precise Transit and Radial-velocity Characterization of a Resonant Pair: The Warm Jupiter TOI-216c and Eccentric Warm Neptune TOI-216b*. arXiv:2102.06754

Abstract

TOI-216 hosts a pair of warm, large exoplanets discovered by the TESS mission. These planets were found to be in or near the 2:1 resonance, and both of them exhibit transit timing variations (TTVs). Precise characterization of the planets' masses and radii, orbital properties, and resonant behavior can test theories for the origins of planets orbiting close to their stars. Previous characterization of the system using the first six sectors of TESS data suffered from a degeneracy between planet mass and orbital eccentricity. Radial-velocity measurements using HARPS, FEROS, and the Planet Finder Spectrograph break that degeneracy, and an expanded TTV baseline from TESS and an ongoing ground-based transit observing campaign increase the precision of the mass and eccentricity measurements. We determine that TOI-216c is a warm Jupiter, TOI-216b is an eccentric warm Neptune, and that they librate in 2:1 resonance with a moderate libration amplitude of 60^{+2}_{-2} deg, a small but significant free eccentricity of $0.0222^{+0.0005}_{-0.0003}$ for TOI-216b, and a small but significant mutual inclination of $1^{\circ}2\text{--}3^{\circ}9$ (95% confidence interval). The libration amplitude, free eccentricity, and mutual inclination imply a disturbance of TOI-216b before or after resonance capture, perhaps by an undetected third planet.

About

Variable Stars South is an international association of astronomers, mainly amateur, interested in re-searching the rich and under-explored myriad of southern variable stars.

Renamed from the Variable Star Section of the Royal Astronomical Society of New Zealand, it was founded in 1927 by the late Dr Frank Bateson, OBE, and became the recognised centre for Southern Hemisphere variable star research.

VSS covers many areas and techniques of variable star research, organised into projects such as Beginners' Visual Observations and Dual-Maxima Miras. The goal of each project is to obtain scientifically useful data and results. These may be published in recognised journals, or supplied to international specialist data collection organisations.

VSS is entirely an internet based organisation, working through our website <http://www.VariableStars-South.org> and its e-group <http://groups.google.com/group/vss-members>. It also encourages members to work in with major international organisations such as the British Astronomical Association, the Center for Backyard Astrophysics and the American Association for Variable Star Observers.

To find out more, please visit our website, where, incidentally, you will find PDF copies of all our newsletters. Our website has a great deal of information for VSS members, and for anyone interested in southern hemisphere variable star research. All VSS project information and data is kept here too.

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