Variable Stars South

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A phased light curve of TESS data for the variable V0701 Cen using period 0.73845030 d and epoch T_i = 2458609.11962 BJD_TDB. See the second installment of Mark Blackford's series on using TESS data for variable star projects on page 6.

Contents

From the director – *Mark Blackford*

Happy New Year everyone, despite the rainy start to 2022 and the continuing pandemic saga I am hopeful things will improve throughout the year.

In this newsletter we have an article by four students at Harper College, Illinois, on a programme analysing multi-colour photometry of three RR Lyrae pulsating stars under the tutelage of Timothy Banks. This is an excellent example of how motivated students with competent guidance can develop a greater understanding of scientific processes and publish in peer reviewed journals. I encourage you to read their paper in JAAVSO (https://app.aavso.org/jaavso/article/3774/).

Former VSS director Tom Richards has decided to step down from his role as co-leader of the Eclipsing Binaries Group and lead author of the annual papers of EB minima. I will take on these roles initially unless someone else has a burning desire. Tom intends to continue observing and contributing to the minima database.

The International Astronomical Union has started a working group on ProAm collaborations. They would like feedback via their survey (https://www.surveymonkey.com/r/IAU_ProAm) from both amateur and professional astronomers interested in ProAm collaborations.

As mentioned in previous newsletters, we were proposing to hold a Variable Stars South Symposium on the Friday before the Easter 2022 NACAA. However, the NACAA committee has determined that holding a normal (physical) meeting is not feasible in the current pandemic environment. Instead they plan to run a couple of one day virtual meetings, with the first being on Easter Saturday and the second (probably) a week later. More details will follow.

The VSS Symposium will now also become a virtual meeting. The format and timing are yet to be determined but it will not be in conjunction NACAA.

Finally, variable star observers and analysts who want their work recorded in the 2021 Variable Stars South Annual Report to RASNZ should send submissions to me by the end of January. The RASNZ Section Reports are published in the March issue of the Southern Stars journal.

Spring and early summer were a wash out for astronomy at Congarinni observatory. Since the October Newsletter only 5 nights have been suitable for photometry. My Paramount MX+ mount is still out of action after more than 4 months but I understand a new electronics board has finally been shipped from the US. Hopefully its arrival will coincide with better weather.

Wishing you all clear skies and good health,

Mark Blackford

Variable stars in the 19ᵗʰ Century - *Mati Morel*

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Summary

An analysis of Chandler's catalogues of variable stars (1888, 1893,and 1896) reveals some interesting findings about the discovery of variable stars in the 19ᵗʰ century.

Introduction

It is well known that the first periodic variable star to be discovered was Omicron Ceti (Mira) in 1596. However its true periodic nature was found by Holwarda in 1638. By the end of 1800 only 15 stars were recognized as variables. Nine of these already possessed Greek or Roman letter names according to Bayer's system, including P Cygni and B Cassiopeiea (SN 1572). To the astronomers of those days, and into the 19ᵗʰ century, a variable star generally meant one that fades and then returns to maximum brightness on a reasonably regular cycle. The occasional nova or supernova which erupted once only just did not fit their narrow definition. In the absence of photographic records visual verification of short-time changes could be be very hard to secure. The tally of discoveries grew very slowly, by chance or as a byproduct of other activities. See Table 1.

A thorough account of variable star astronomy to 1900 is given by Hoffleit (1986).

Naming of variables

In the early days discovery of new variables happened so infrequently that it was thought an intrinsically rare phenomenon. A special naming system was not a pressing concern, and a new star, not hitherto named, would likely be referred to by the discoverer's name, eg. "Pigott's variable in Corona" (= R CrB discovered in 1795, with the letter name conferred much later). This ad-hoc system had severe limitations. In 1844 Argelander at Bonn Observatory in Germany proposed a better system; the first variable in each constellation (other than stars already with Bayer-letter names) would be designated **"R"**, followed by Latin genitive of constellation name, the second discovery would be **"S"** and so on. After **Z,** double letters, **RR, RS** etc would be used. It was expected that this system would be adequate, considering the small number of variables known at that time.

Year	Authority	Variables
1786	Pigott	12
1844	Argelander	18
1866	Schönfeld	119
1888	Chandler	225
1893	Chandler	260
1896	Chandler	393

Table *1. Catalogues of Variable Stars up to 1900.*

In due course variable star observers adopted the system laid down by Argelander in 1844. However there was no central commission or body charged with supervising the naming (or vetting) of new discoveries. This finally happened in 1901, when the *Variable Star Commission* was formed, under the auspices of the Astronomische Gesellschaft in Germany. For all of the 19ᵗʰ century the discoverer of a variable star had the freedom to self-select a name. As the number of known variables in any given constellation was so small, often less than five, it was just a matter of looking up the last named variable from the literature, then choosing the next letter in the series. This was possible when all the discoveries were made visually.

Cataloguing variables in the 19ᵗʰ Century

Prior to the formation of the *Variable Star Commission* in 1901, different individuals undertook the task of compiling and publishing lists of known, named variables. Chandler (1888, 1893, 1896) published

three catalogues. I have looked at the 1888 catalogue, in particular,

I have entered much of Chandler's 1888 catalogue into a spreadsheet, which facilitates extraction of some interesting statistics. This one was almost certainly the last one to consist entirely of <u>visual</u> discoveries. As the 1890s rolled on photography and spectroscopy began to make an impact on variable star research. The 1888 work is useful in that the year of discovery, and the astronomer's name, is recorded in the main table. This information was removed from the main table in the following editions. Chandler applied editorial discretion as to which stars to include. Those which were judged to be constant or erroneous were omitted completely, even though quite a few had been announced and assigned regular variable star names. Particular examples are: -

- U and X Tau – both constant.

- Many stars from Gould, such as R and S Eri, R and T Pup, R Vel, T Car, S Cap, T TrA and others. N Vel was thought variable from 3.4 - 4.4v in 1871. Later study failed to confirm any of these to the degree claimed. All of these have been marked down as "CST". although a few have now, through photoelectric techniques, been found to be microvariables, and could never have been detected visually.

Asteroid hunting and VS discoveries

Nineteenth-century astronomers were fascinated by new solar system objects, such as asteroids and comets. The first four asteroids, "The Big Four", were discovered in fairly quick succession between 1801 and 1807. Thereafter <u>no</u> asteroids were discovered for 38 years, leading many astronomers to abandon the search, believing there were no more to be found. Hencke finally found **5 Astrea** on Dec. 8, 1845, followed by **6 Hebe** on July 1, 1847. Using Chandler's 1888 catalogue and data from the *Minor Planet Centre* it can be shown that a low (or high) rate of VS discoveries correlates with a corresponding rate of asteroid discoveries. See Table 2. Variable star discoveries were a byproduct, frequently, of asteroid hunting. The latter was the main game. Table 2 shows how asteroid and VS discoveries are in a sort of lock-step. I have looked at intervals of 7.5 years each. By 1888.01.01 the number of asteroids stood at 271 compared to 225 variable stars.

Int. #	Year interval	Asteroids/ int.	VS /interval
1.	1.1.1801 - 1.7.1808	4	0
2.	1.7.1808 - 1.1.1816	0	2
3.	1.1.1816 - 1.7.1823	0	1
4.	1.7.1823 - 1.1.1831	0	4
5.	1.1.1831 - 1.7.1838	0	3
6.	1.7.1838 - 1.1.1846	1	1
7.	1.1.1846 - 1.7.1853	22	23
8.	1.7.1853 - 1.1.1861	36	50

Table 2. *Comparison of asteroid and VS discoveries, 1801-1861.*

Active discoverers of variables (and minor planets)

Discovery of variable stars was very spasmodic up till about 1845. This was due in large part to the lack of adequate sky charts. Some observers compiled their own charts along the ecliptic but large sections of sky were hardly covered at all. Andrew Graham compiled the *Markree Catalogue* of 60,000 stars along the ecliptic. These were published in four volumes (1851,1853, 1854 and 1856). The situation improved after about 1860 when the *Bonner Durchmustering* charts of the entire northern hemisphere became available.

The enthusiasm for variable stars was not universal. Some observers leaned heavily towards this line of work, others leaned towards asteroids. Consider two successful asteroid hunters, Hind and de Gasparis:

- J. R. Hind, at London, found 22 variables and 10 asteroids from 1848-1863.

- A. de Gasparis (Naples) discovered 10 asteroids from Aptil 12, 1849 - April 26, 1865, but reported <u>no</u> variable stars.

A list of the major contributing observers for this period is given in Table 3.

Name	VS-tot	Active	MPs	(Yrs active)
Argelande, F.W.A	5	1853-1866		
At Bonn	11	1855-1862		
Baxendell, J	14	1848-1880		
Chacornac, J	4	1853-1856	6	(1853-1860)
Duner	5	1878-1884		
Espin, T.H.C.	6	1886-1888		
Goldschmidt	2	1857-1861	14	(1852-1861)
Gould, B.A.	19	1871-1884		
Harding, K.L.	5	1809-1831	1	(1809)
Hencke, K.L.	5	1851-1860	2	(1845-1847)
Hind, J.R.	22	1848-1863	10	(1847-1854)
Luther, C.T.R.	1	1855	14	(1852-1865)
Peters, N.R.	16	1862-1872	5	(1861-1866)
Pogson, N.R.	14	1852-1866	6	(1856-1866)
Sawyer, Edwin F.	5	1885-1887		
Schmidt, J.F.J.	18	1847-1876		
Schönfeld, E.	8	1856-1883		

Note 1. These 17 observers accounted for 160 variables, or 71% of the known variables

Note 2. 44 other observers contributed the remaining 65 stars in the 1888 catalogue.

Note 3. Between 1871 and 1884 Gould discovered and named at least 10 additional variables (not included above). These were rejected by Chandler.

Table 3. *List of 17 19th Century contributors to variable stars.*

Sky distribution of variables in 1888

As expected the 19th century observers covered the northern hemisphere fairly well. The constellations astride the ecliptic plane were covered even more intensively as that was the favoured hunting ground for asteroids. Almost every northern constellation has at least one variable, according to Chandler. Note the following distribution of variables, from his catalogue.

• Constellations along the ecliptic, including Oph, average 6.1 variables, each.

• Non-ecliptic constellations average only 2.8 variables, each

• The constellation with the greatest number of variables was Cygnus, with 13.

• The second ranking constellation was Virgo, with 10 variables.

• Having reached and exceeded the letter **Z**, both Cygnus and Virgo invoked the double letter (RR) designation, they were the first to reach this threshhold in 1888.

In the southern hemisphere there was only one observer, B.A. Gould at Cordoba Observatory between 1871 and 1884, who actively searched for new variables. When Gould returned to the US in 1885 there were 23 southern constellations with no recognized variables in them. Even two very large constellations barely made the cut. Centaurus had one (**R**), and Eridanus had **R and S,**, but they were both rejected by Chandler. In the north, only two small constellations, Triangulum and Equuleus missed out. Also, Sextans at the equator missed out. .There was much to do, for the coming photographic surveys! The far southern Milky Way (Ara, Lup, Nor, Cen, Cru , Car and Vel) was almost completely untouched.

Classification of variables

It is difficult to compare the classes of variables recognized in 1888 with today, but a few types were well established already. I compare those with what was known by 1948.

- DCEP. 7.1% of total in 1888, vs 5% in 1948 (GCVS)

- EA. 5.3% vs 12% in 1948

- M.   59% vs 36% in 1948

- Novae (all types). 3.6% vs 2% in 1948

With the arrival of deep photography of globular clusters in the 1890s, RR Lyrae-type stars (also known as "cluster Cepheids") were found in considerable numbers. This class was completely unknown in 1888. By 1948 they comprised 18% of all known variables in the GCVS (1st ed. 1948).

References

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Chandler, S.C. 1893 Astron. J 13,89

Chandler, S.C. 1896 Astron. J. 16,148

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Determining ToMs from sparse photometry - V0701 Cen – *Mark Blackford*

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The β Lyrae-type eclipsing binary V0701 Cen was discovered by Strohmeier et al. (1964). AAVSO's Variable Star Index (VSX) lists a V magnitude range of 8.8 to 9.3, period 0.738447 d and zero epoch 2439243.2661 HJD. Despite its relative brightness V0701 Cen has received little attention over the years.

In this article I will use all available primary eclipse times of minimum (ToMs) to refine the orbital period then use archival ASAS and TESS observations to determine additional epochs.

Apart from the VSX epoch, the only published ToMs were by Paschke (2010, 2013) and Neil Butterworth in Richards et al. (2019, 2020). I reanalyzed Neil's primary eclipse light curves and determined slightly different ToMs. I also recorded another primary ToM in 2021. These are listed in Table 1.

HJD of min	error (d)	O-C (d)	Cycle	Eclipse Type	Observer	Date
2439243.2661		0.0000	0	P	VSX	27/04/1966
2455381.3600	0.0050	0.0732	21854	P	Paschke (OEJV 130)	3/07/2010
2456104.3020	0.0050	0.0755	22833	P	Paschke (OEJV 155)	25/06/2012
2458253.9296	0.0010	0.0839	25744	P	Butterworth	15/05/2018
2458609.1262	0.0005	0.0876	26225	P	Butterworth	5/05/2019
2459337.9754	0.0007	0.0895	27212	P	Blackford	3/05/2021

Table 1. *Times of minimum and O-C values calculated using VSX epoch and period.*

Figure 1 is the Observed minus Calculated (O-C) diagram which shows an increasing linear trend indicating the VSX period is slightly too short. The refined period determined by linear regression is 0.73845030(4) d.
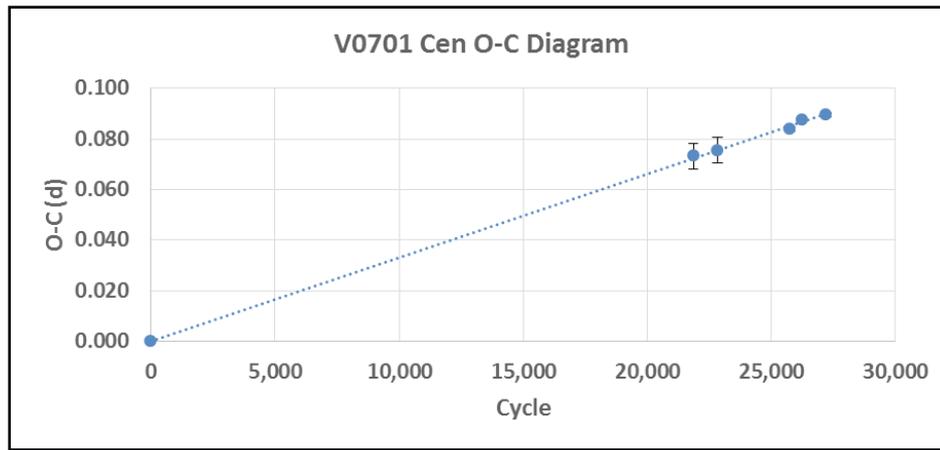
Figure 1. *V0701 Cen Observed minus Calculated diagram using VSX epoch and period.*

Determining Times of Minima from sparse photometry

I will now describe a method for extracting accurate ToMs from sparse light curves using AAVSO's VStar software (Benn, 2012), a simple Excel spreadsheet and Peranso Light Curve and Period Analysis software (Paunzen & Vanmunster, 2016). New epochs will be determined and the V0701 Cen O-C diagram updated using Transiting Exoplanet Survey Satellite (TESS) and All Sky Automated Survey (ASAS) archival photometry.

Example 1 – TESS photometry

TESS observed the V0701 Cen field in 2019 (Sector 11) and the MIT Quick Look Pipeline (QLP) team extracted a 30 minute cadence light curve from full frame images. The QLP data file containing the time and normalized flux of all observations is available from the Mikulski Archive for Space Telescopes (MAST) website (https://archive.stsci.edu/). A VStar plugin allows QLP files to be imported and displayed, with the flux values converted to magnitude.

We could use VStar to create a phase plot of the observations, but I prefer to do that in an Excel spreadsheet. First click on the VStar Observations tab, then select Save from the File menu, enter a name and choose a convenient location to save a .csv format file that contains all the data shown on the Observation tab. Only the first two columns, Time and Magnitude, are required for the Excel spreadsheet which calculates the phase of each observation using a nominated period and epoch. The spreadsheet also plots magnitude as a function of time and phase. Part of the QLP light curve is shown in Figure 2. Each eclipse contains only a few data points, therefore conventional methods of measuring ToM's, such as the Kwee-van Woerden (1956) method and polynomial fitting, are not very accurate.

I will use the entire Sector 11 data set to determine a single accurate epoch. Observations started on April 23rd and ended on May 20th, 2019. The first step is to identify an observation near the bottom of a primary eclipse and close to the middle of the observing run. The selected observation is indicated by the red cross-hair at bottom right of figure 2. This will be used as the initial estimate of the epoch, T_i, in this case T_i = 2458609.11962. It is important to note that the time system of TESS observations is Barycentric Julian Date in Dynamical Time (BJD_TDB). A conversion to Heliocentric Julian Date (HJD) can be made using online tools.
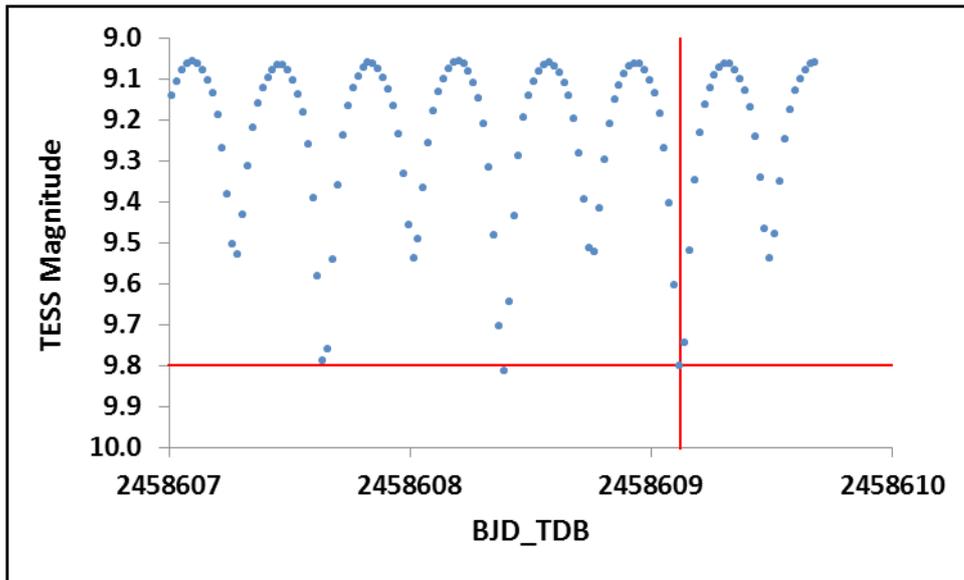
Figure 2. *Section of V0701 Cen QLP light curve showing 3 days near mid-time of TESS Sector 11.*

The next step is to construct a phased light curve using the refined period and initial epoch T_i (Figure 3). The cross hair shows the same observation selected for T_i which is slightly earlier than the actual primary minimum.
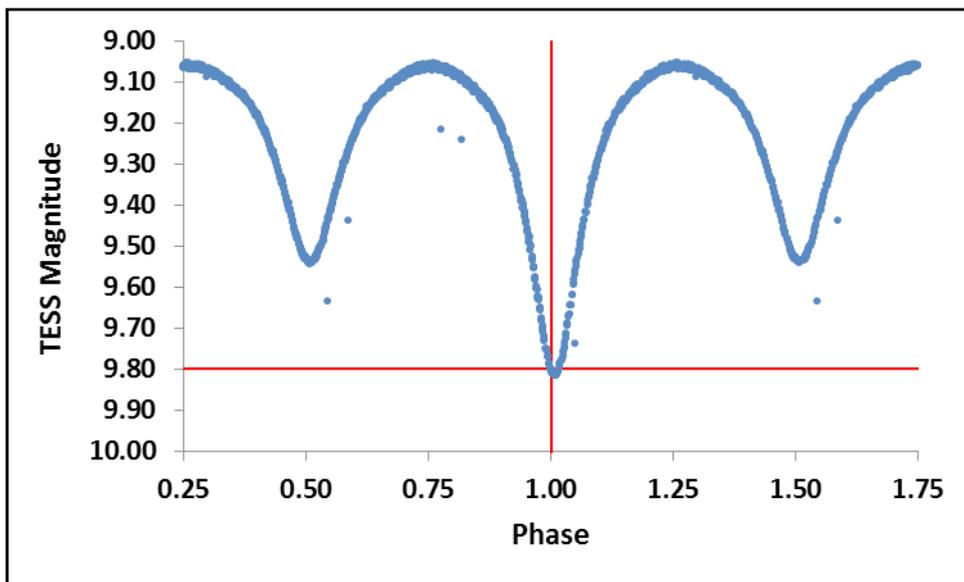

Figure 3. *TESS phased light curve using period 0.73845030 d and epoch T_i = 2458609.11962 BJD_TDB.*

Peranso will be used to determine the offset of T_i from the actual minimum epoch. Save a tab delimited text file containing the phase values in column 1 and magnitude values in column 2. Import this file into a new Peranso Observation Window. Deselect any obvious outliers, place left and right margin cursors either side of the primary minimum, then click on the Find Extremum button (Figure 4). The actual phase of primary minimum is determined using the Kwee-van Woerden method and displayed at the bottom of the plot along with an error estimate.
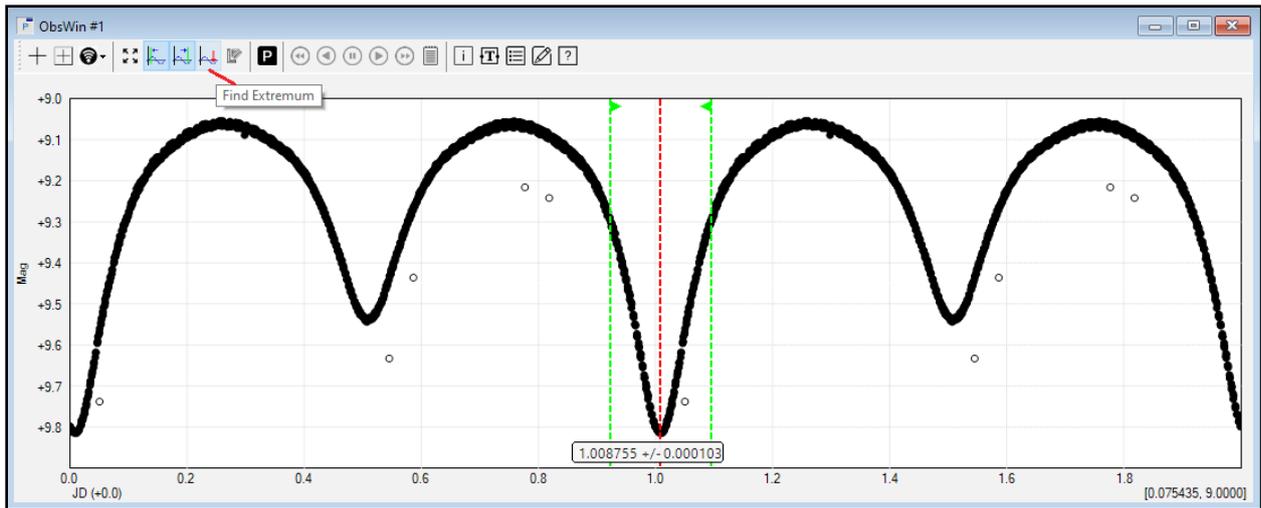
Figure 4. *Peranso Observation Window showing green margin cursors and phase of primary minimum.*

In this example the primary minimum is at phase 1.00876(10) to 5 decimal places, which is 0.00876 phase units after the initial estimate of the epoch, Ti.

To convert to time units simply multiply by the period, i.e. 0.00876 x 0.73845030= 0.00647 d.

The error estimate is converted in the same way, i.e. 0.00010 x 0.73845030= 0.00007 d.

So the accurate epoch for TESS Sector 11 is 2458609.11962 + 0.00647 = 2458609.12609(7) BJD_TDB. The correction to Heliocentric Julian Date is -0.00002 d (1.4 seconds), which is smaller than the error estimate and can safely be ignored.

Example 2 – ASAS photometry

There are numerous photometric archives, such as the All Sky Automatic Survey (Pojmański, 2002), which contain data collected over many years but with very low cadence, typically several days between observations.

The ASAS survey obtained photometry of V0701 Cen between December 9th 2000 and September 14th 2009. These observations were split into 3 roughly equal groups and epochs of primary minimum determined for each. The phase plot of the first group, December 9th 2000 to September 12th 2003, is shown in Figure 5 with the selected initial epoch observation (T_i = 2452248.85429 HJD) indicated.
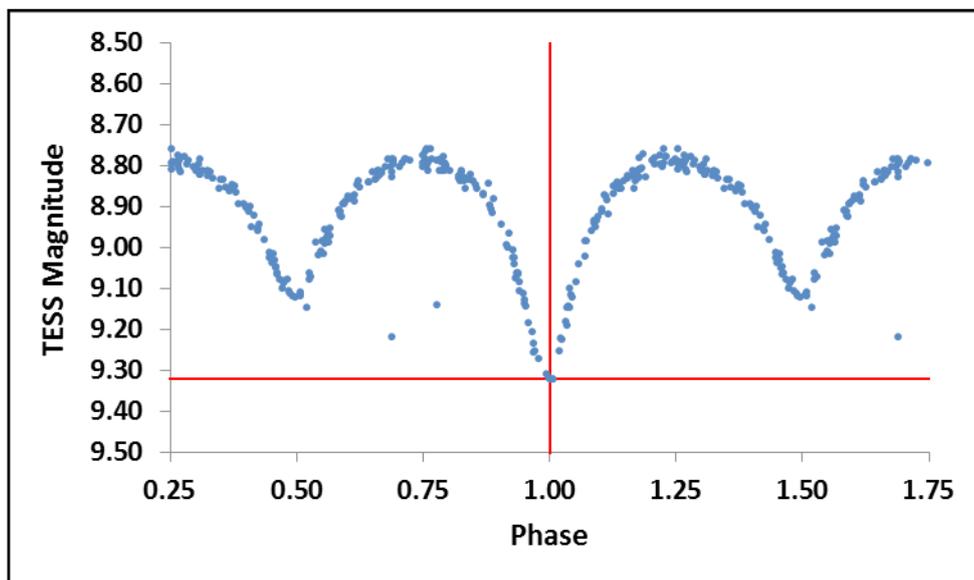

Figure 5. *ASAS phased light curve using period 0.73845030 d and epoch T_i = 2452248.85429 HJD.*

In this example the primary minimum is at phase 0.9967(13) to 4 decimal places, which is 0.0033(13) phase units, or 0.0024(10) days, before the initial estimate of the epoch, Ti. Therefore the accurate epoch for the first group of ASAS observations is 2452248.8519(10) HJD.

The same procedure applied to the second and third sets of ASAS observations yielded the following accurate epochs:

December 2nd 2003 to June 26th 2006	2453471.7258(14) HJD
January 4th 2007 to September 14th 2009	2454595.6472(21) HJD

The ASAS and TESS epochs are shown in Table 2 along with all other known times of minimum. The ASAS and TESS epochs align very well with the other data points in the O-C diagram (Figure 6).

HJD of min	error (d)	O-C (d)	Cycle	Eclipse Type	Observer	Date
2439243.2661		0.0000	0	P	VSX	27/04/1966
2452248.8519	0.0010	-0.0009	17612	P	ASAS	5/12/2001
2453471.7258	0.0014	-0.0007	19268	P	ASAS	11/04/2005
2454595.6472	0.0021	-0.0006	20790	P	ASAS	9/05/2008
2455381.3600	0.0050	0.0010	21854	P	Paschke (OEJV 130)	3/07/2010
2456104.3020	0.0050	0.0002	22833	P	Paschke (OEJV 155)	25/06/2012
2458253.9296	0.0010	-0.0011	25744	P	Butterworth	15/05/2018
2458609.12609	0.00007	0.0009	26225	P	TESS	5/05/2019
2458609.1262	0.0005	0.0010	26225	P	Butterworth	5/05/2019
2459337.9754	0.0007	-0.0003	27212	P	Blackford	3/05/2021

Table 2. *V0701 Cen times of minimum and O-C values calculated using VSX epoch 2439243.2661 HJD and refined period 0.73845030(4) d.*
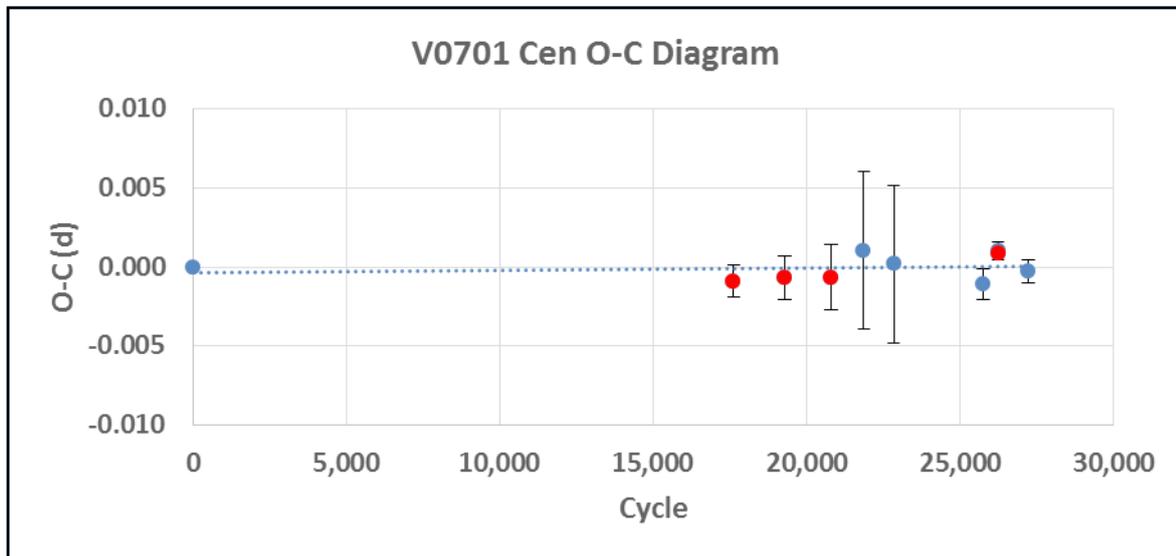

Figure 6. *O-C diagram for V0701 Cen, ASAS and TESS epochs are shown in red.*

Conclusions

The orbital period of the β Lyrae-type eclipsing binary V0701 Cen was refined to 0.73845030(4) d using all previously known times of primary minimum. A method of deriving accurate epochs of minima from sparse light curves was described and used to determine three new epochs from ASAS observations and one from TESS observations, all of which are consistent with the refined period.

Acknowledgements

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Undergraduate project using remote learning and observing

—Liam Parker, Hayden Parker, Ross Parker and Faraz Uddin (Harper College)

One of the most important aspects of the field of science is that of research. Unfortunately, many college students reach the end of their undergraduate degrees without the opportunity to study, document, and publish their own research on a science topic that they are passionate about. This past school year, the four of us, Liam Parker, Hayden Parker, Ross Parker, and Faraz Uddin, were lucky enough to work under the guidance of Timothy Banks (adjunct faculty at Harper College and a data scientist at Nielsen) on a programme analysing multi-colour photometry of three RR Lyrae pulsating stars. We undertook a two-semester class with Dr. Banks, which was built on one of Dr. Mike Fitzgerald's (Edith Cowan University) online "Our Solar Sibling" (OSS) courses (https://www.oursolarsiblings.com/).

This opportunity involved the use of remote telescopes in the Las Cumbres Observatory (LCO) network to study the variability of the RR Lyrae stars UU Ceti, UW Gruis, and W Tucanae in order to calculate the distances to these stars and compare these estimates with the parallax estimates of the Gaia mission.

RR Lyrae stars make good targets for student projects as their periods are short, and so a complete light curve can be collected in a short period. This is important as students need to complete the project within a fixed period, such as a semester or two.

Data were collected on the stars by remotely accessing several telescopes around the world in order to collect images of our respective stars and surrounding stars over several weeks - our favourite for W Tuc were the 0.4 m telescopes at Siding Spring. These images were then processed using a program called Astrosource to reduce the frames (dark subtracting, flat-fielding, and astrometry) and calibrate the photometry.

We applied the distance relations of Catelan et al. (2004) and Caceres & Catalan (2008), together with our observed pulsation periods, to compute estimated distances to the stars. We took metallicity estimates from the literature, making checks of these estimates by completing a Fourier analysis of 22 TESS light curves of RR Lyrae type stars and building a regression model linking metallicity with parameters from these decompositions.

Further details on our reduction process and analysis method can be found in Parker et al. (2021).

Figure 1 shows our final results for UU Cet along with error bars. Our photometric distance estimates (for each of the filters) are in good agreement with the Gaia estimates.
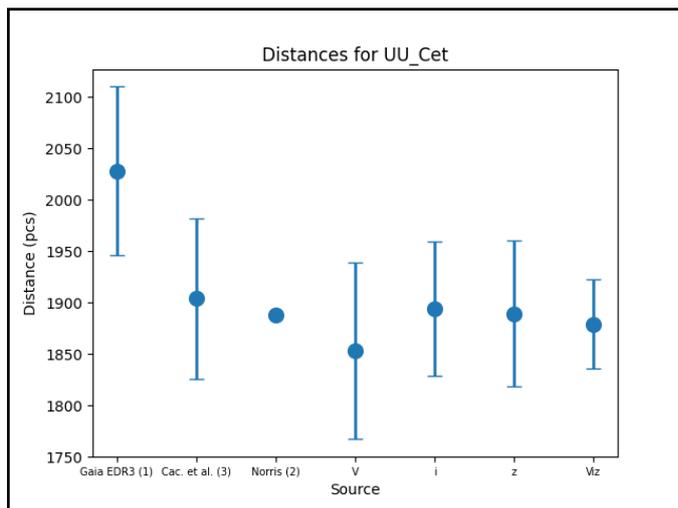
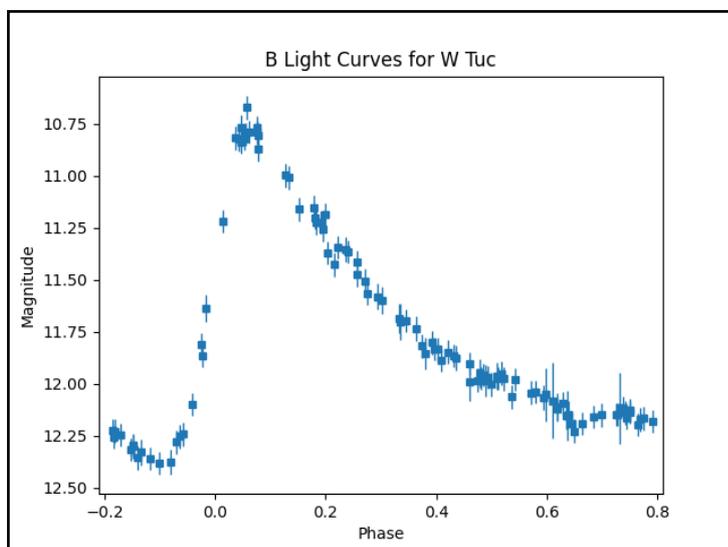**Figure 1.** *Our distance estimates for UU Cet*

Figure2. *B light curve for another of our target stars, W Tuc, phased by our estimated period.*

The pandemic placed strain on traditional methods of learning, with our college campus closed to students and staff pivoting to an online model. While we missed the face-to-face aspect of the course, this pivot was successful. Not only could we schedule observing time on remote telescopes through the internet, we made substantial use of an online learning platform as well as collaboration tools such as Slack and Webex to keep in touch. Even our write-up made use of an online LaTeX tool called Overleaf, where we could work together on the paper and chat with each other to coordinate the work.

The OSS web site is a platform that teachers and students can use to put together studies of stars, galaxies, and astronomy in general. The flexibility of such a web-based course was that we could work through the materials at times convenient for us. The site gives users a step-by-step guide to collecting, analyzing, and presenting evidence gathered using 23 remote telescopes located all across the globe.

Using the OSS platform, we were able to learn about RR Lyrae stars, how to process astronomical data, and to schedule time at these remote telescopes and execute instructions related to pointing the telescopes and setting various telescope parameters tailored to each situation. We are very grateful to Dr. Fitzgerald for making this course platform available for us, and for allocating LCO time for us.

This project was an excellent opportunity for undergraduate students, such as ourselves, to learn about science, astronomy, and to enhance their research and technical writing skills. We acquired a deep understanding of the science behind the calculation of astronomical distances. We learned how to use many software tools that help analyze astronomical images, including manipulations of FITS images. And we learned a great deal about data analysis and visualization, through Python programming to create figures

for our paper and LaTeX to typeset it, to the process of writing a research paper and working through the application and referee process. Overall, we would highly recommend this type of project to anyone interested in the science of astronomy whether on a casual or a career basis, or wanting to engage with students to build their interest in astronomy.

We really encourage astronomers to work with undergraduate students on scientific projects similar to this, building up scientific literacy. And for students we'd say don't hold back if you are offered an opportunity like this - it was a lot of fun and the sense of achievement at the end of the project is priceless.

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The high amplitude delta Scuti star BS Aqr: an updated O-C diagram using TESS data - *Roy Axelsen*

Summary

The O-C diagram of the high amplitude delta Scuti star BS Aqr has been extended with data from TESS (Transiting Exoplanet Survey Satellite) obtained in 2018, 2020 and 2021. Previous data from the literature and previous DSLR photometry by the author indicated that the period of BS Aqr was constant from 1973 to 2013, within the limits of accuracy of the data analysed. The observations from TESS indicate that the period of BS Aqr changed between 2013 and 2018, and that the period from August 2018 to September 2021 was increasing at a slow constant rate of 0.02 ($\pm$ 0.004) s y^{-1}. The period at the time of the last TESS light curve peak plotted in the O-C diagram in this paper, 12th September 2021, was 0.19782214 ($\pm$ 0.00000008) d.

The O-C diagram of BS Aqr

BS Aqr is a 9th magnitude, mono-periodic high amplitude delta Scuti star with a period of approximately 4 hours 45 minutes. It was proposed that the star has a companion, based on a quasi-sinusoidal function fitted by Fu et al (1997) to O-C data obtained between 1936 and 1973. However, DSLR time series photometry obtained in 2013 extended the O-C diagram (Figure. 1) in a pattern that did not continue the previously fitted quasi-sinusoidal function, and thus did not support the proposal that BS Aqr has a companion (Axelsen 2014).
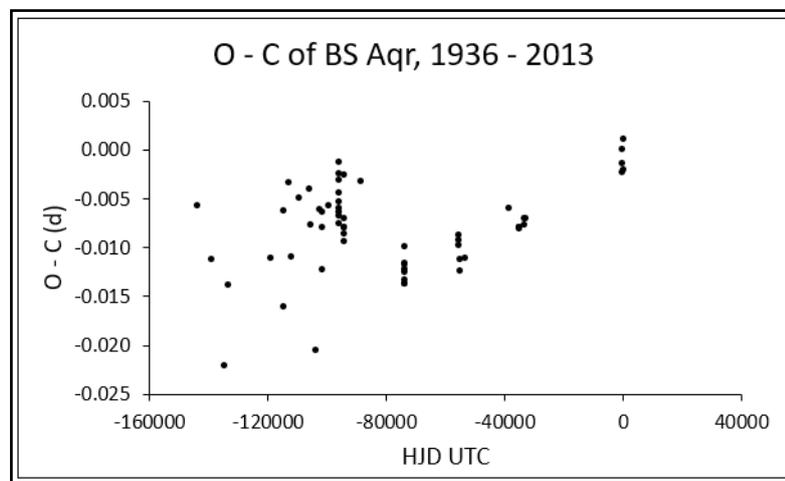

Figure 1. *The O-C diagram of BS Aqr from 1936 to 2013.*

Figure 2 shows the subset of the same data from 1973 and 2013, and a linear function fitted to the data. A linear ephemeris obtained from the times of the peaks of the light curve in this subset showed that the period of the star was 0.197822765 ± 0.000000010 day, which is just under 4 hour 44.9 minutes.
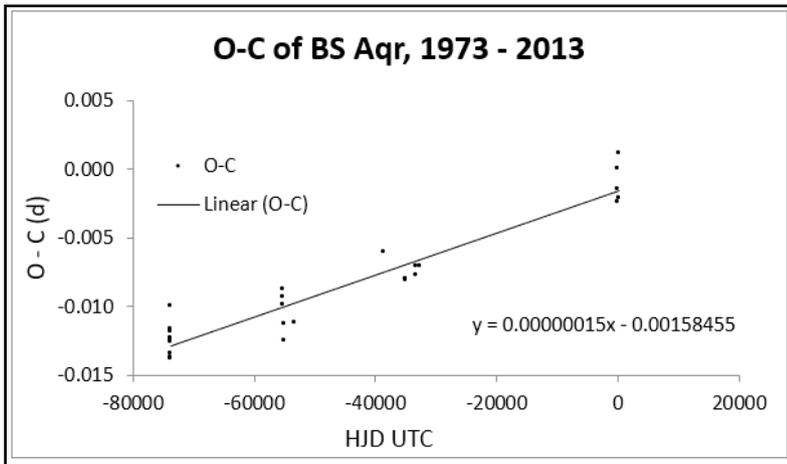

Figure 2. *The O-C diagram of BS Aqr from 1973 to 2013. The data points at the extreme right of the plot are those of Axelsen taken in 2013.*

Further time series photometry of BS Aqr was taken by the author on the nights of the 15th and 16th October, 2021. Images were captured with a ZWO ASI1600MM CMOS camera and a red astrophotography filter through a 120mm f/7.5 refractor. The filter was used as an experiment, as a previous transformation plot of Rc-r against V-Rc (Rc = catalogue magnitude with a Cousins R filter; V = catalogue magnitude with Johnson V filter; r = instrumental magnitude with the red astrophotography filter) was a near-horizontal line, implying that the instrumental magnitudes of stars measured on images taken through the red filter were independent of the colour indices of the stars, at least within the colour index range plotted. Only differential instrumental magnitudes were calculated. True magnitudes were not determined.

TESS (Transiting Exoplanet Survey Satellite) data are available for BS Aqr at the Mikulski Archive for Space Telescopes (https://archive.stsci.edu/) for the months of August and September in 2018, 2020 and 2021. The archive was searched using methods described by Blackford (2021). These data yielded light curves with a large number of peaks for each of the three sets. The times of 4 light curve peaks in each of the 2018, 2020 and 2021 datasets were determined in VStar (Benn, 2012). For each year, the 4 peaks were approximately equally spaced throughout the August-September observing windows, but otherwise randomly chosen. Since TESS data is in BJD (Barycentric Julian Days) in the TDB (Barycentric Dynamic Time) standard, the times of the peaks were converted to HJD (Heliocentric Julian Days) in the UTC (Universal Coordinated Time) standard for the plotting of the O-C diagram.
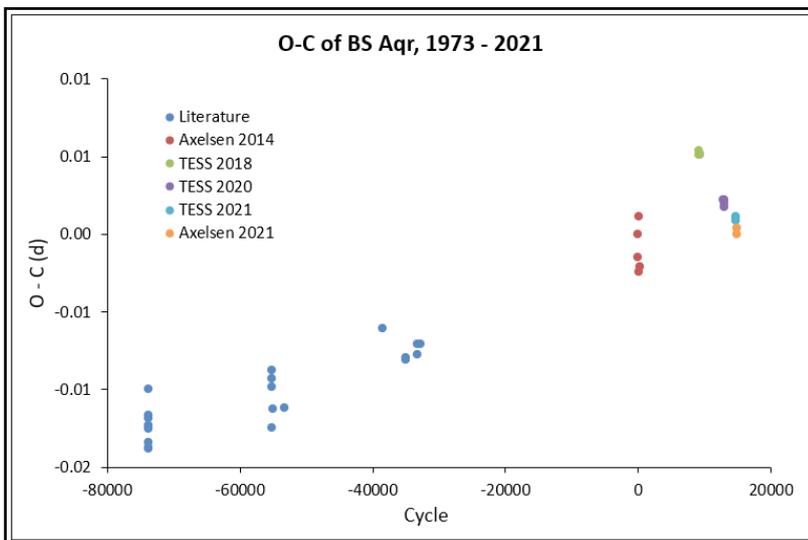

Figure 3. *O-C diagram of BS Aqr from data obtained between 1973 and 2021.*

Figure 3 shows an O-C diagram for BS Aqr from observations obtained between 1973 and 2021 labelled to identify the data obtained by the author, by other authors in previous literature, and data from TESS for 2018, 2020 and 2021. There is a visual impression that the TESS datapoints define a trajectory entirely different from the linear function fitted to data from 1973 to 2013, as shown in Fig. 4. When a fitted function changes direction in an O-C diagram, the implication is that the period of the star has changed. For BS Aqr, such a period change occurred between 2013 and 2018. Not only that, the function fitted to the TESS data is a second order polynomial, concave up, which indicates that the period of BS Aqr between 2018 and 2021 is increasing at a slow constant rate.

The TESS data and the polynomial function fitted to it are shown more clearly in Fig. 5. It is evident from this plot that the TESS data are much more precise that any other observations in the O-C diagram. The first derivative of the second order term indicates that the period is increasing at a constant rate of 0.02 (± 0.004) s y^{-1}. A similar function applied to the ephemeris reveals that the period at the time of the last TESS light curve peak plotted in the O-C diagram was 0.19782214 (± 0.00000008) d.
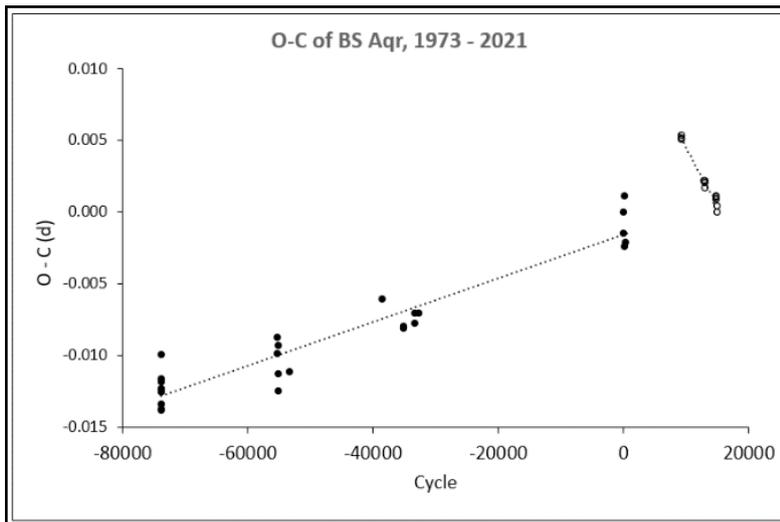

Figure 4. *O-C diagram of BS Aqr plotted from the same data as the diagram shown in Fig. 3, but with a linear function fitted to the 1973 – 2013 data, and a second order polynomial function fitted to the TESS data from 2018, 2020 and 2021.*
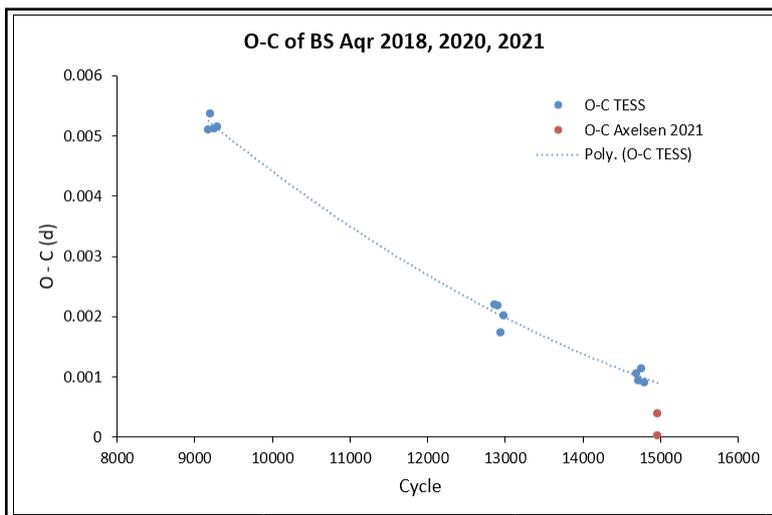

Figure 5. *O-C diagram of BS Aqr from the data obtained by TESS in 2018, 2020 and 2021, and the data obtained by Axelsen (only two points) in October 2021.*

Discussion

If there were any remaining support for the proposal that the O-C data of BS Aqr reflects the light travel time effect from a binary system, it is now dispelled. Clearly, there is no quasi-sinusoidal pattern in the

O-C diagram. However, the most striking element in the O-C observations as shown in this paper is the exquisite precision of the data from TESS, which has yielded a visualization of period change over a short time frame (three years) which may not have been possible from less precise measurements. While the personal observations plotted in Figure 5 show a pleasing result in that the O-C values are relatively close to those from the TESS data, there are only two data points, not enough in the author's opinion to be sure of the actual variance. Observations from TESS are planned to continue into the near future. If TESS observes BS Aqr again in August and September 2022, the data will be added to the O-C diagram and reported.

References

Axelsen, R.A. 2014, JAAVSO 42, 37.

Benn, D. 2012, JAAVSO 40, 852.

Blackford, M. 2021, VSS Newsletter 4, 12.

Fu, J.-N., Jiang, S.-Y., Gu, S.-H., and Qiu, Y.-L. 1997, IBVS 4518.

Software watch

Of interest to those using AstroimageJ (especially for exoplanet transits)

From Karen Collins (lead author of AIJ):

"AIJ version 5 has now been released. It is a a major new release, and requires a fresh install of AIJ. For Mac users that have had to deal with complex installation workarounds, AIJ v5 now installs on a Mac with no special workarounds. This is thanks to a significant contribution by Eric Jensen to develop a process to properly sign and authenticate the code and installation package. The new Windows, Mac, and Linux v5.0.0.00 installation packages are available from the AIJ website here. After installation, go to AIJ_Toolbar > Edit > Options > "Memory and Threads" and update the "Maximum memory" value from the default of 640 or 3000 MB to your preferred AIJ memory upper limit. It is recommended to set the value to ~75% of your computer's physical memory. For example, if you have 8 GB of memory, set the maximum memory value to 6000 MB.

- all previous manual features AIJ workflow continue to be supported, so you can adopt the new features at your own pace

- directly opens TESScut files, TESS postage stamp sequences, TICA FFIs, and SPOC FFIs (drag and drop on AIJ toolbar)

- directly opens zipped fits.fz files as downloaded from the LCOGT archive (no unzipping or FUN-Pack decompression required, just drag and drop the single zip file on the AIJ toolbar)

- automatic aperture size extraction

- automatic comp star selection

- bulk removal of outlier data points

- automatic comp ensemble optimization through RMS minimization

- automatic detrend parameter selection according to BIC

- automatically run the "Add Data" function at the end of the Multi-Aperture run to add new data columns such as BJD_TDB, airmass, etc

- many other detailed enhancements and improvements

- as you can see, the above new features will provide us a platform to provide scripted AIJ data reductions in the future, for users that prefer that mode of operation.

The new Multi-Aperture set-up panel looks like the first image overleaf. The auto radius option will extract a radial profile of the target star and adopt the AIJ suggested aperture radii. You can see the radii

that have been selected by looking at the seeing plot that will pop up.

The auto comp star selection, will do just that. The main thing you will need to set up are the Max and Min comp star brightnesses that you allow, relative to the target star brightness. This will depend on the quality of your detector. The weight of brightness vs. distance (from target star) lets you specify how much you want to emphasize proximity to the target star vs. closeness in brightness to the target star. It seems that 50% works pretty good for LCO images. I think you will find that using the 12 best comp stars is a good max number, since the ensemble optimizer works on that number in just a few seconds.
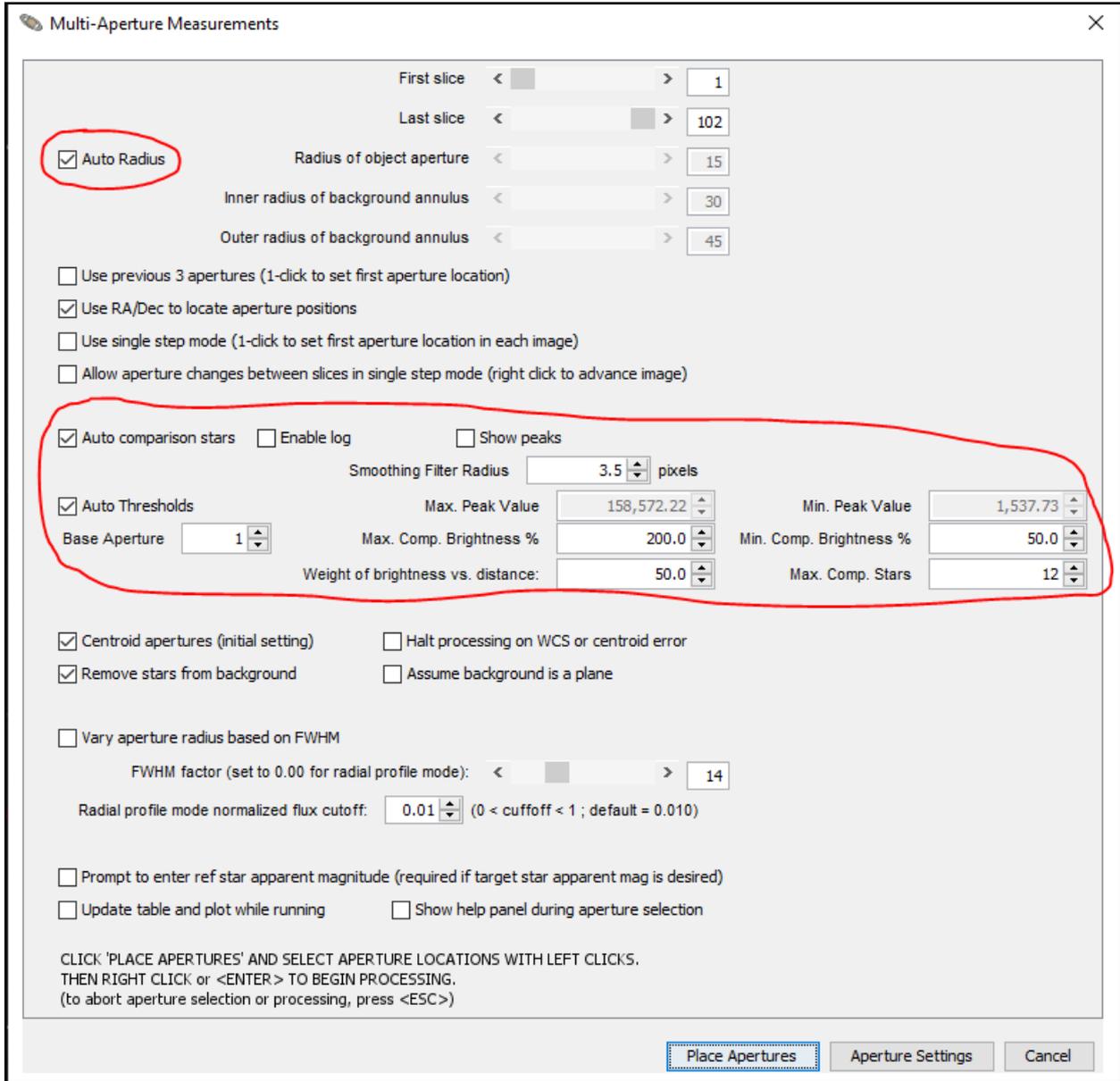
The other three major features are in the Data Fitting panels. To use these, you'll need to set up an approximate transit model fit and include any fixed model parameters that you want from prior knowledge, such as from SPOC or QLP reports for TESS transits. Note that the fit can now be locked to an impact factor b, instead of inclination, if you prefer.

- Click "Clean" to remove any points more than X-sigma from the initial model. X can be set by the user, but 4-5σ seems to work reasonably for many cases.

- In the comp star optimization sub-panel, click start to find the comp star ensemble with the minimum RMS. The comp stars that are considered are the ones set as "C" stars in the Reference Star Settings panel. Note the new "Save" option in the Ref Star panel so that you can save a set of comp stars that you may want to start over with several times. If you need to run optimization again, just select "Recall" to restore the complete comp star set before starting optimize again.
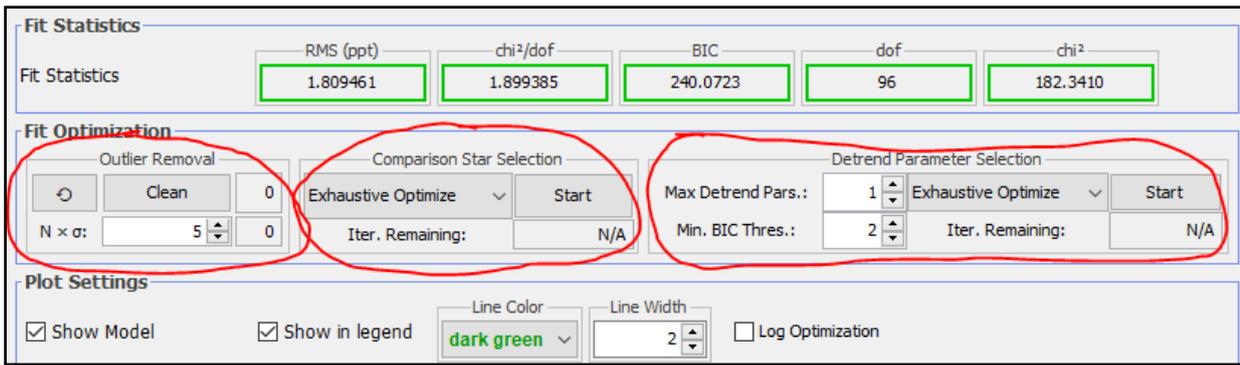
- In the detrend parameter optimization section shown above, click Start to automatically select the best detrending option according to BIC. I recommend using a max of one detrend parameter for full transit light curves (or two parameters if you have a good amount of out-of-transit baseline). I recommend leaving Min BIC Threshold set to the default value of 2 (which means delta-BIC of more than 2 is required per added detrend parameter). The detrend parameters that will be considered are the ones that are displayed in the detrending section above the optimize subpanel (whether the parameter is selected or not). I recommend optimizing against the 7 detrend parameters shown below.

- You may want to iterate between comp star and detrend parameter optimization a couple of times to find the best combination. Be sure to "Recall" the full comp star set that you want to optimize against on each iteration.

- To auto run the New Data function, open the new data panel, set up properly, and then enable "Auto" at the bottom of the panel. The specified values will then be updated at the end of every Multi-Aperture run.

- If you have questions about the new operation, please post them on the AIJ User Forum (http://astroimagej.170.s1.nabble.com/). Again, we will provide more detailed user instructions as time permits.

Enjoy,

Karen

Publication watch

The **SEB team** has published their annual paper on southern eclipsing binary stars.

Richards, T.; Axelsen, R. A.; Blackford, M.; Jenkins, R.; Moriarty, D. J. W., *Southern Eclipsing Binary Minima and Light Elements in 2020*, JAAVSO, vol. 49, no. 2, p. 251

Abstract

We present 246 times of minima of 77 southern hemisphere eclipsing binary stars acquired in 2020. These observations were acquired and analyzed by the authors, who are members of the Southern Eclipsing Binary group of Variable Stars South (VSS) (http://www.variablestarssouth.org), using CCD detectors. For four of the systems we have derived updated light elements and present those as well as O-C values for the VSS minima. This paper is the sixth in a series by Richards et al.

Mark Blackford and **Ed Budding** are co-authors of a new paper on the binary BF Pav

Poro, Atila; Alicavus, Fahri; Fernández-Lajús, Eduardo; Davoudi, Fatemeh; MirshafieKhozani, PegahSadat; Blackford, Mark G.; Budding, Edwin; Jalalabadi, Behjat Zarei; Rahimi, Jabar; Farahani, Farzaneh Ahangarani, *BVRI Photometric Observations, Light Curve Solutions and Orbital Period Analysis of BF Pav*, Research in Astronomy and Astrophysics, Volume 21, Issue 8, id.203.

Abstract

A new ephemeris, period change analysis and light curve modeling of the W UMa-type eclipsing binary BF Pav are presented in this study. Light curves of the system taken in BVRI filters from two observatories, in Australia and Argentina, were modeled using the Wilson-Devinney code. The results of this analysis demonstrate that BF Pav is a contact binary system with a photometric mass ratio $q = 1.460 \pm 0.014$, a fillout factor $f = 12.5\%$, an inclination of 87.97 ± 0.45 deg and a cold spot on the secondary component. By applying the distance modulus formula, the distance of BF Pav was calculated to be $d = 268 \pm 18$ pc which is in good agreement with the Gaia EDR3 distance. We obtain an orbital period increase at a rate of 0.142 s century^{-1} due to a quadratic trend in the O - C diagram. Also, an alternative sudden period jump probably occurred which could be interpreted as a rapid mass transfer from the lower mass star to its companion of about $\Delta M = 2.45 \times 10^{-6}$ M$_\odot$. Furthermore, there is an oscillatory behavior with a period of 18.3 ± 0.3 yr. Since BF Pav does not seem to have significant magnetic activity, this behavior could be interpreted as the light-time effect caused by an undetected third body in this system. In this case, the probability for the third body to be a low mass star with $M \geq 0.075$ M$_\odot$ or a brown dwarf is 5.4% and 94.6% respectively. If we assume $i' = 90°$, $a3 = 8.04 \pm 0.33$ AU. The mass of the secondary component was also determined following two different methods which result close to each other.

Phil Evans is a co-author of a arXiv paper from the ExoClock collaboration

Kokori, A., Tsiaras, A., Edwards, B. et al *ExoClock project II: A large-scale integrated study with 180 updated exoplanet ephemerides.* 2021arXiv211013863K

The ExoClock project is an inclusive, integrated, and interactive platform that was developed to monitor the ephemerides of the Ariel targets to increase the mission efficiency. The project makes the best use of all available resources, i.e., observations from ground telescopes, mid-time values from the literature and finally, observations from space instruments. Currently, the ExoClock network includes 280 participants with telescopes capable of observing 85% of the currently known Ariel candidate targets. This work includes the results of ~1600 observations obtained up to the 31st of December 2020 from the ExoClock network. These data in combination with ~2350 mid-time values collected from the literature are used to update the ephemerides of 180 planets. The analysis shows that 40% of the updated ephemerides will have an impact on future scheduling as either they have a significantly improved precision, or they have revealed biases in the old ephemerides. With the new observations, the observing coverage and rate for

half of the planets in the sample has been doubled or more. Finally, from a population perspective, we identify that the differences in the 2028 predictions between the old and the new ephemerides have an STD that is double what is expected from gaussian uncertainties. These findings have implications for planning future observations, where we will need to account for drifts potentially greater than the prediction uncertainties. The updated ephemerides are open and accessible to the wider exoplanet community both from our Open Science Framework (OSF) repository and our website.

About

Variable Stars South is an international association of astronomers, mainly amateur, interested in researching 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.

Who's who

Director Mark Blackford   **Treasurer/Membership** Bob Evans

Newsletter Editor Phil Evans   **Webmaster** David O'Driscoll

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After you've joined and received your membership certificate, you will be signed up to the VSS-members egroup (see above), and you will also receive a password to access the members' areas of our website.

Newsletter items

These are welcomed and should be sent to the Editor (phil@astrofizz.com). I'd prefer Microsoft Word (or compatible) files with graphics sent separately. Don't use elaborate formatting or fancy fonts and please do not send your contribution as a fully formatted PDF file.

Publication dates are January, April, July and October, nominally on the twentieth day of these months and the copy deadline is the thirteenth of the month though earlier would always be appreciated.

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