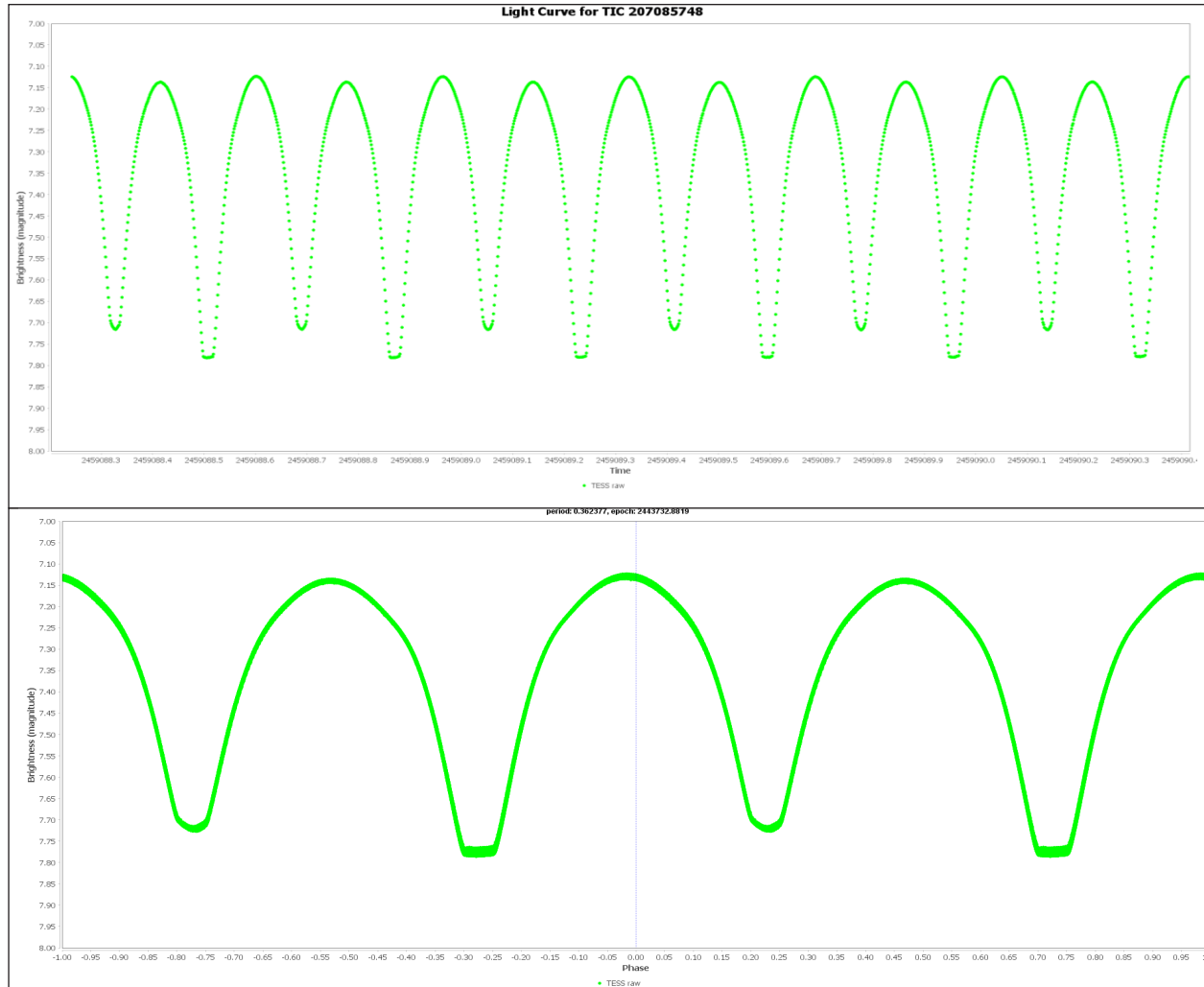




Using TESS to mine variable star data. *Top panel* VStar plot showing part of AE Phe light curve obtained from TESS. *Bottom panel* phased light curve using period 0.362377 d and epoch HJD 2443732.8819 from the AAVSO Variable Star Index (VSX). See Mark Blackman's article on page 12

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From the Director – *Mark Blackford*

As I write this column thunderstorms light up surrounding hills and a micro bat swoops on insects outside my study window. I won't be observing variables tonight but nature is putting on a pretty awesome show anyway.

Congratulations to Rod Stubbings and Peter Williams on achieving significant milestones earlier this year. Peter made his 200,000th visual observation on 2021 July 4 and Rod made his 350,000th on 2021 June 28. Only 12 observers in history have achieved 200,000 or more visual observations, to have two Australians in that number is remarkable. Rod's first 200,000 observations took 18 years 8 months at an average of almost 30 observations per day. His next 150,000 observations took only another 9 years - so much for slowing down as you get older!



An article in the February 2012 VSS newsletter, in the form of an interview, celebrates Rod's 200,000th observation and career up until then. In this newsletter we reproduce an article commemorating Peter's 200,000th observation, originally published in the British Astronomical Association Variable Star Section Circular Number 189 September 2021.

On a more sombre note, I was saddened to hear of the passing of Mike Simonsen in July. Mike was a driving force in AAVSO when I was getting started in variable star observing about a decade ago. We corresponded on a number of issues and his passion for all things astronomy was infectious. In 2013 I attended AAVSO Headquarters in Boston for a workshop to start writing the DSLR Photometry manual. Meeting Mike in person was one of the highlights of that trip for me.

I extend my heartfelt condolences also to former VSS director Stan Walker on the passing of his wife Joan in May.

Congarinni Observatory continued to enjoy good astronomy conditions in recent months. On one night, however, a light shower of rain passed over while the observatory was opened. I managed to close the roof fairly quickly, but not before my Paramount MX+ mount lost communication with the controlling PC. It turns out that the electronics board in the mount had failed and needed to be replaced. So I'll be operating with just my smaller photometry rig for quite a while until the replacement board arrives.

Wishing you all better luck, clear skies and good health,

Mark Blackford

Summary

I have re-examined basic data for two suspected variables, NSV 18748 and 18749, close to RY Car (M), using GAIA EDR3, and also historical observations by VSS, RASNZ.

Introduction

Johnson and Liller (1975) carried out a photographic study of the light curve of the Mira variable RY Carinae. They found that the light curve had a flat bottom at about 14.3 p_g. A closer examination at higher resolution using Bruce and Metcalf plates from the Harvard collection showed that RY Car had two companions - one of 14.3p, 13.5" SSE and another of 16p, 17" ESE, called "x" by them. When RY Car was at minimum phase the 14^m.3 star had been estimated by mistake. A third companion was observed on an archival plate (April 1, 1908), but never seen again. They called this mystery star "z", and is now designated NSV 18748, 16.0 - (17.0p.

Star "x", mentioned above, was reported to be variable by the same authors. Its range is 15.7 -17.0p and is now known as NSV 18749. See **Figure 1**, an extract of UKST blue plate, which identifies all of the stars mentioned here. I have examined the surroundings of RY Car in the Gaia EDR3 to see what can be gleaned.

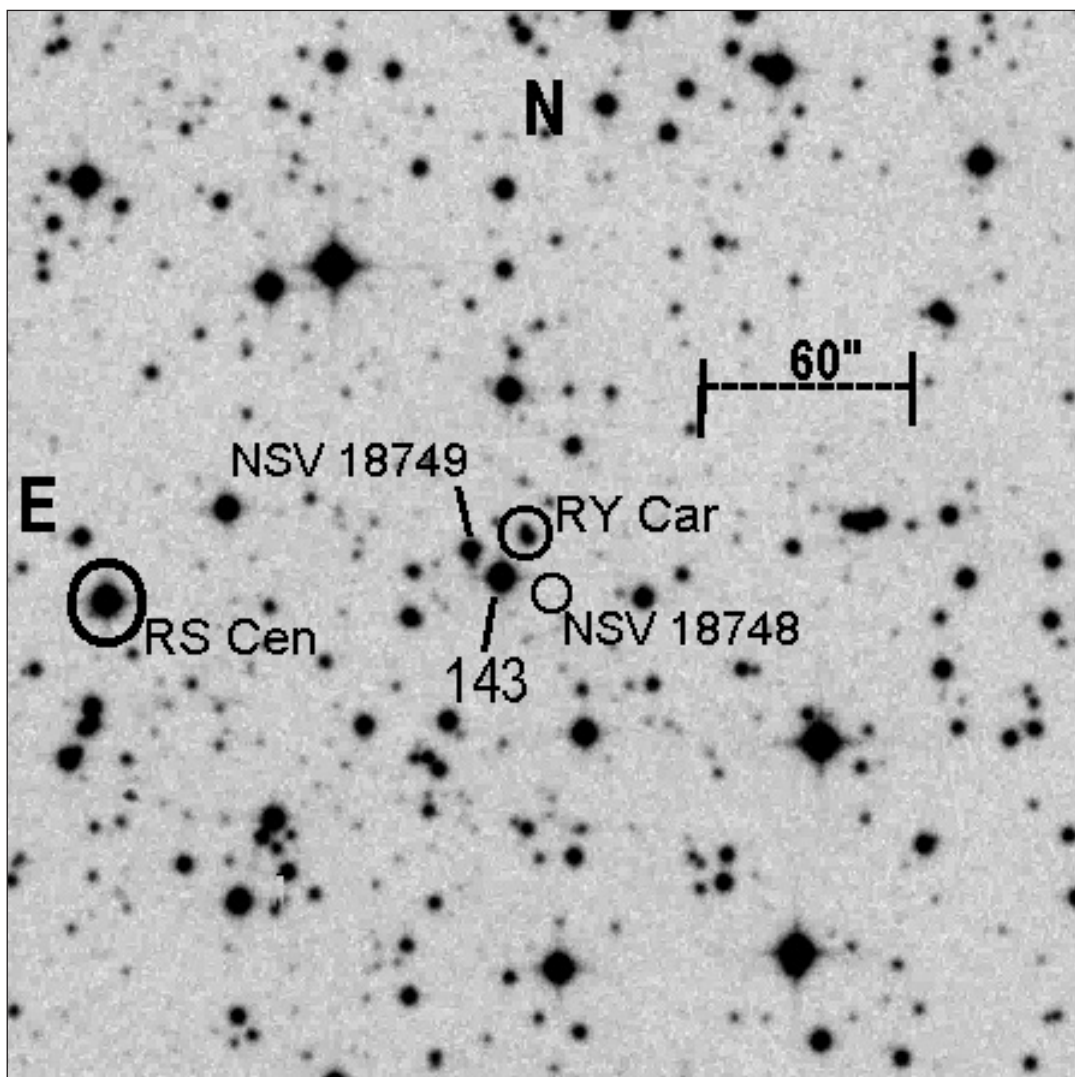


Figure 1. An extract of the UKST blue plate

NSV 18748

Observed on one Harvard plate. April 1, 1908, at 16 mag. According to GCVS its position is (J2000) **11 20 10.8 -61 52 33**. Johnson and Liller (1975) published a finder chart, but the quality is poor, and not suitable for reproduction here. I have measured the position, as best as one can, with reference to nearby EDR3 stars. My estimated position is determined as:

(J2000) **11 20 10.50 -61 52 32.4**. None of the reference stars showed significant proper motion.

My position agrees well with the GCVS, considering the inherent uncertainty.. I have attempted to recover the original plate, using *DASCH*, but with no success. It is interesting that NSV 18748 lies in the midst of an elongated ring (dia. ~30") of about 10 or 11 faint (limit $G=21.0$) Gaia stars, but the variable is rather isolated and does not match any Gaia star. A possible plate defect?

They were not uncommon in the early 20th century.

NSV 18749 = “x”

Reported by Johnson and Liller (1975). This object appears in Gaia EDR3 as follows:

(J2000) **11 20 13.672 -61 52 20.94** $G = 15.79$

From *SkyMapper* I retrieved the following Sloan data: $g = 16.176$ $r = 15.692$. From this one derives, from a conversion, $V = 15.881$ $B-V = 0.693$. Assuming it is a main-sequence star, we can infer a spectral type between G5 and G8.

Observations by VSS, RASNZ

The standard chart and visual sequence for RS Cen/RY Car issued by AAVSO in 1951 was also used by the VSS for many years. The sequence is shown on VSS chart 175, published in 1968. Neither the AAVSO nor the VSS charts indicated the close companions to RY Car, and the observers were probably unaware of them. The faintest designated comparison star was 13.1v, on the old Harvard scale, which is now obsolete. On the modern scale this star is $V=12.46$. I have looked up lists of visual observations of RY Car made between 1958 and 1965 (VSS Circulars 92 to 117), and the overwhelming majority of estimates were negative, <13.1 or <13.6 (Harvard scale). Positive estimates above 13.1 clearly record RY Car near maximum, and therefore misidentification did not become an issue, visually. It is possible that, on some occasions, a faint (13.9 - 14.0) positive estimate of RY Car may actually refer to the 14.3 companion, but these are extremely rare.

Conclusion

The precise positions of NSV 18748 and 18749 are both secure. The actual nature of NSV 18748 (whether real or not) may be questioned until further data turns up. I have addressed the matter of whether VSS estimates of RY Car had been skewed by close companions. The VSS records show that, historically, visual observers never got down to 14^m.0 on a consistent basis.

References

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Johnson, Caryn and Liller, Martha H. 1975 JAAVSO 4, No.1, 31
VSS, RASNZ Circulars 1959 - 1965.
Circs. 92, 93, 95 (1959)
Circs 109, 110 (1961)
Circs 111,112,113 (1963)
Circs 115 (1964)
Circs 116, 117 (1965)

Transformation coefficients with R, G and B astrophotography filters – *Roy Axelsen*

royaxelsen7@gmail.com

On 1st September 2020, an item was posted in the AAVSO ‘Instrumentation and Equipment’ forum under the topic ‘Photometric Filter Selections’, which contained the results of transformation relationships for R, G and B astrophotography filters. The ‘linear regression slopes’ were listed as: blue vs Johnson B, 0.991 ± 0.004 ; green vs Johnson V, 0.991 ± 0.003 ; blue minus green vs Johnson B-V, 0.588 ± 0.014 ; green minus red vs Johnson V-Ic, 0.584 ± 0.010 . Note that these numbers do not represent transformation coefficients.

I was curious to see what the transformation relationships were for astrophotography filters with my camera. It turns out that the linearity of the usual transforms is very good, and that an unexpected result with the red filter could be useful for non-transformed time series photometry. The results are reported herein.

Methods

Autoguided images of two adjacent fields of E Region standards (Menzies et al 1989) at 20H RA were obtained on the night of 6th August 2021. There were 7 target stars in the first field and 2 in the second. A ZWO ASI1600MM CMOS monochromatic camera imaged through ZWO R, G and B astrophotography filters ZWO (<https://astronomy-imaging-camera.com/>) and an 80mm f/7.5 refractor. The target stars, listed in Table 1, ranged in V magnitude from 7.324 to 8.338, and the B-V range was -0.042 to 1.416. Five images were taken of each field through each of the R, G and B filters. The images were calibrated with darks and filter-specific flats, and aperture photometry performed in AstroimageJ. Instrumental magnitudes for each of the three filters were averaged across the five images for the transformation plots and calculations.

Star	V	B-V	V-Rc
E802	7.915	-0.042	-0.014
E806	8.322	0.192	0.110
E835	8.338	1.083	0.552
E809	7.821	0.296	0.171
E833	7.867	1.125	0.564
E840	8.104	1.416	0.756
E815	8.063	0.468	0.266
E831	7.551	0.962	0.517
E814	7.324	0.509	0.298

Table 1. Target stars from E Region Standards, at 20H RA.

Results

Table 2 overleaf shows the results from the photometry and the parameters needed for the plots of the transformation relationships. The latter are displayed in Figure 1. The transformation coefficients are listed in Table 3.

Discussion

The transformation plots in Figure 1 show small residuals and would therefore be likely to result in accurate photometry provided that the spectra of target stars resemble those of a black body, and provided the V-Rc values of target stars are within (or close to) the range studied herein. The RGB filters used in this study show transmission curves with rectangular profiles (Figure 2), which are very different from those of the red, green and blue filters of DSLR cameras and of the corresponding Johnson-Cousins filters. As always, when filters for photometry have transmission curves which do not resemble those of filters that define accepted photometric systems, photometry of stars with ‘peculiar’ spectra may not be

accurate. For example, accurate magnitudes cannot be determined with non-scientific filters for stars with emission lines or absorption bands outside the transmission curves of those of scientific filters. However, the H alpha emission line at 656nm, which appears in the spectra of classical novae, would be easily recorded in images taken through the R filter used herein.

Transform	Slope	Formulation for Transformation Coefficient (TC)	TC
B-V / b-g	0.612	1 / Slope	1.633
V-Rc / g-r	1.272	1 / Slope	0.786
B-V / B-b	0.243	Slope	0.243
B-V / V-g	-0.145	Slope	-0.145
V-Rc / Rc-r	-0.010	Slope	-0.010

Table 3. Transformation coefficients.

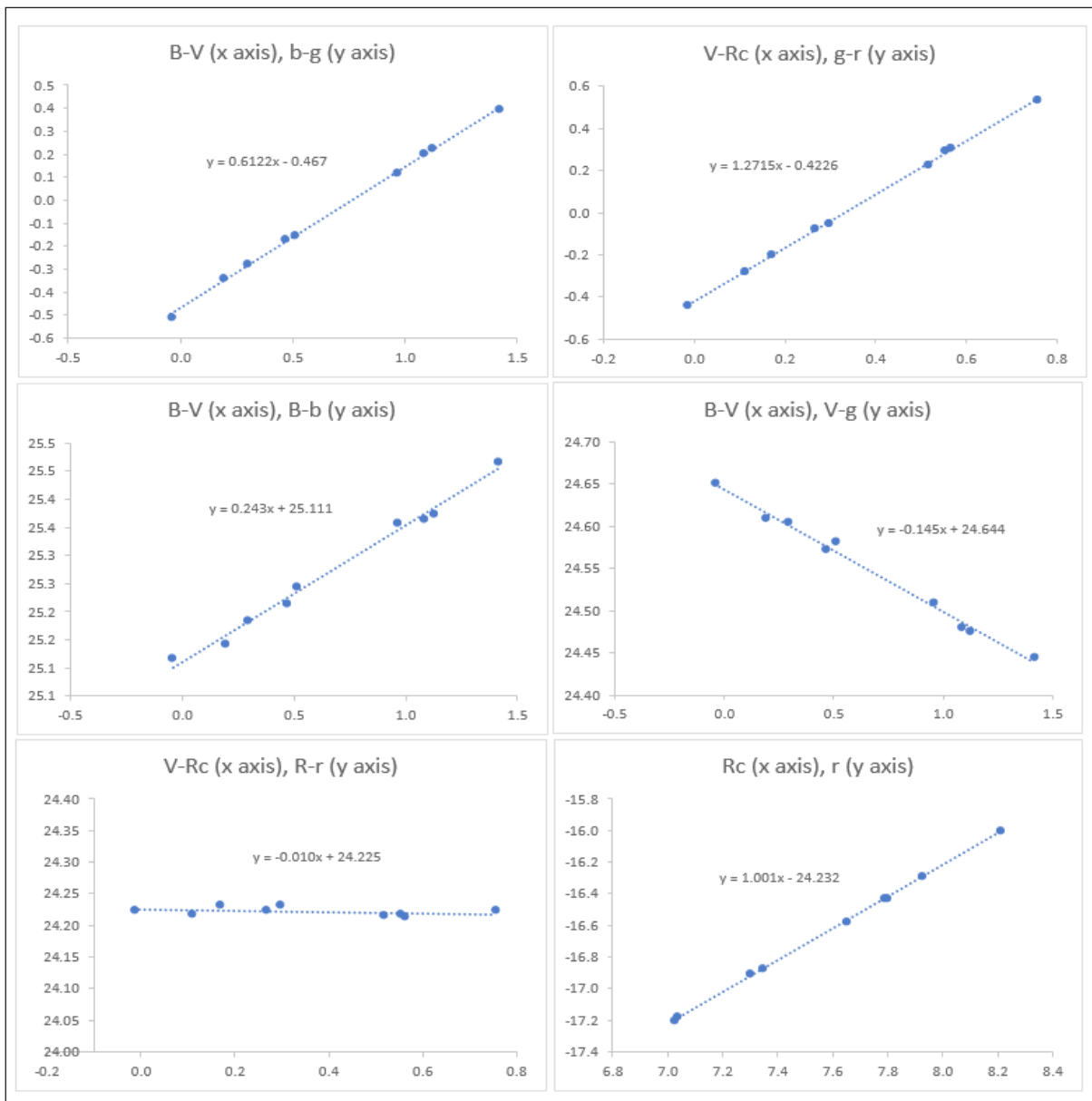


Figure 1. The various transformation plots are shown in the top and middle panels, and the bottom left panel. An additional relationship, the instrumental magnitude r versus Rc , is shown in the bottom right panel.

The other point of interest is the plot in the bottom left panel of Figure 1, V-Rc / Rc-r, which is close

Star	b	g	r	b-g	g-r	V-g	B-b	Rc-r
E802	-17.243	-16.735	-16.294	-0.508	-0.442	24.650	25.116	24.223
E806	-16.628	-16.286	-16.005	-0.342	-0.281	24.608	25.142	24.217
E835	-15.943	-16.142	-16.430	0.200	0.288	24.480	25.364	24.216
E809	-17.065	-16.784	-16.582	-0.280	-0.203	24.605	25.182	24.232
E833	-16.382	-16.607	-16.910	0.225	0.302	24.474	25.374	24.213
E840	-15.946	-16.341	-16.876	0.395	0.535	24.445	25.466	24.224
E815	-16.683	-16.509	-16.428	-0.174	-0.081	24.572	25.214	24.225
E831	-16.845	-16.958	-17.181	0.113	0.224	24.509	25.358	24.215
E814	-17.410	-17.257	-17.205	-0.153	-0.052	24.581	25.243	24.231

Table 2. Instrumental magnitudes (b , g , r) and the parameters calculated from them for the transformation plots. V , B and Rc represent catalogue magnitudes with Johnson V and B and Cousins R filters.

to being a horizontal line. The implication is that $Rc-r$ is hardly influenced at all by the colour of the star within the range of $V-Rc$ values studied. This point can be looked at another way by examining the bottom right panel of Figure 1, which shows that the plot of r against Rc has a slope very close to unity.

These relationships imply that, for stars with spectra that resemble those of a black body, and with $V-Rc$ values within or close to the range studied herein, Rc magnitudes can be calculated directly from the formula that describes the linear function in the bottom right panel of Figure 1. They also have implications for differential photometry performed with observations through the R filter alone used for time series photometry where the objective is the timing of events such as the minima of eclipsing binary light curves and the maxima of light curves of pulsating variable stars. For these types of studies using the red astrophotography filter and camera described in this paper, transformation to a standard system can be ignored. This conclusion will be strictly true only if the timings of light curve events are not materially different between light curves obtained through filters of different colours. This point has not been tested by the author.

It is emphasized that the above results cannot be generalized to other monochromatic cameras and other red astrophotography filters. Their characteristics would need to be determined separately.

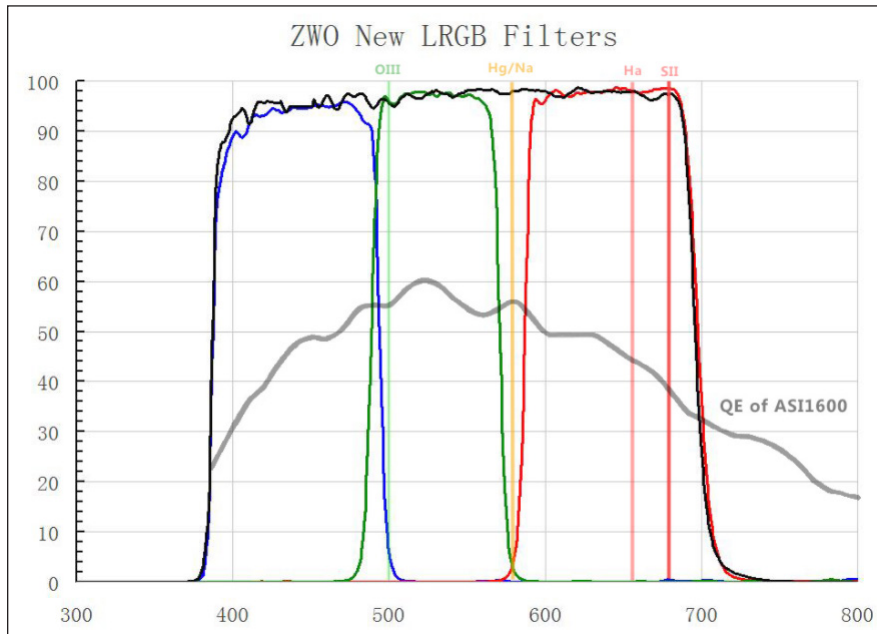


Figure 2. Transmission curves of ZWO L-RGB astronomical filters from the ZWO website (downloaded 10 September, 2021).

Conclusion

Transformation plots determined from images obtained with a ZWO ASI1600MM (monochromatic) CMOS camera through RGB astrophotography filters from ZWO yielded good, linear relationships for the usual parameters. These filters could therefore be used for transformed photometry, provided that the stars studied had spectra resembling those of a black body, and had colour indices within or close to the range of standard stars used in this study. Transformed magnitudes for stars with peculiar spectra, particularly emission lines or absorption bands outside the transmission curves of the filters studied in this paper, but within the transmission curves of standard scientific filters, would not be accurate. The H alpha line at 656nm would be picked up by the R filter. An unexpected finding was that Rc-r was almost constant across the entire range of colour indices of the stars studied, implying that photometry through the red filter alone could be used for determining Rc magnitudes of stars with spectra resembling black bodies within or close to the colour index range studied.

Bibliography

Menzies, J.W., Cousing, A.W.J., Banfiel, R.M., and Laing, J.D. 1989, S. Afr. Astron. Obs. Circ., 13, 1.

Simple differential ensemble photometry – *Roy Axelsen*

The following article complements the one titled “Transformation coefficients with R, G and B astrophotography filters” which appears elsewhere in this edition, and which concluded that photometry with the ZWO ASI1600MM camera and ZWO red astrophotography filter would allow photometric measurements unaffected by the colour indices of the stars studied. It is proposed that this camera-filter combination would therefore be useful for the timing of light curve events with differential photometry alone. Of course a similar procedure could be applied to photometric data obtained through any other filters, but target-comparison star colour differences and changing airmass over time would affect the results differently.

Simple differential photometry yields a value defined by the expression:

$$m_x - m_c \quad (1)$$

where m_x is the instrumental magnitude of the target (variable or check) star and m_c the instrumental magnitude of a comparison star. For a study of a variable star and its several comparison stars, such a formula will yield values that vary, because the magnitudes of the comparison stars will vary. How, then, can ensemble photometry be performed using such values?

Ensemble photometry is often used in the study of variable stars. In its most basic form, the process is to calculate the magnitude of the variable star for each of several comparison stars, then average the results to obtain a final magnitude value. This is fine when true magnitude values are calculated, because each member of the comparison star ensemble will (or should) yield a magnitude for the variable star which will be close to the true magnitude. For simple differential photometry, however, the values resulting from the differences between the instrumental magnitudes of the variable and comparison stars will vary widely, because the magnitudes of the comparison stars will of course vary. This paper describes one way to perform ensemble photometry in this situation, using Johnson V data on the eclipsing binary BC Gru.

Methods

Time series photometry of the EW eclipsing binary star BC Gru was taken during four nights in July and August 2021. The data reported here were obtained on the night of 30 July. Autoguided images from exposures of 180 seconds were captured with a ZWO ASI1600MM CMOS astronomical camera through a Johnson V filter and an 80mm f/7.5 refracting telescope. Calibration with darks and flats and aperture photometry were performed in AstroimageJ. The variable star, three comparison stars and one check star were measured. The comparison and check star data are listed in Table 1.

Star	Cat	V	B-V
Comp 1	TYC 8450 444	10.15	0.658
Comp 2	TYC 8450 495	10.69	0.960
Comp 3	TYC 8450 289	9.96	0.640
Check	TYC 8450 346	9.90	1.070

Table 1. List of comparison and check stars for photometry of BC Gru.

For the purposes of this paper, differential magnitudes were calculated using expression (1) above. True magnitudes were not calculated. Atmospheric extinction was ignored.

Results

Differential magnitudes of the variable and check stars were calculated using each of the three comparison stars in turn. The results are plotted against JD in Figure 1, which shows data obtained across one night. There was a problem with image capture, which caused the large gap in the data. The differential magnitudes span a range of values.

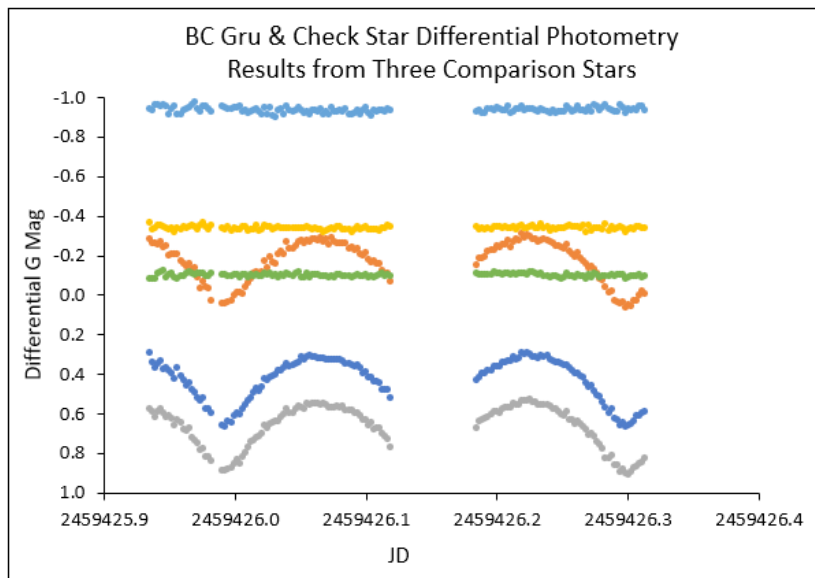


Figure 1. Differential *G* magnitudes calculated for the variable and check stars using instrumental magnitudes for each of the three comparison stars.

Since ensemble photometry is the objective, the results were normalized, using the average differential magnitude for each of the three sets of variable star data and each of the three sets of check star data. It was arbitrarily decided to normalize the variable star differential magnitudes to an average of 5 magnitude units. The average differential magnitude for each set of variable star data was therefore subtracted from 5, and the result added to every differential magnitude calculated across the entire night. For the check star, the magnitude was normalized to 5.3 magnitude units, to allow clarity in the plotting of the normalized light curves. The results of the normalization are shown in Figure 2.

The final calculation was to take the average of the three normalized differential magnitudes for the variable star and the check star from every image taken through the night. The results are plotted in Figure 3, which represents the results of ensemble photometry for the variable and check stars.

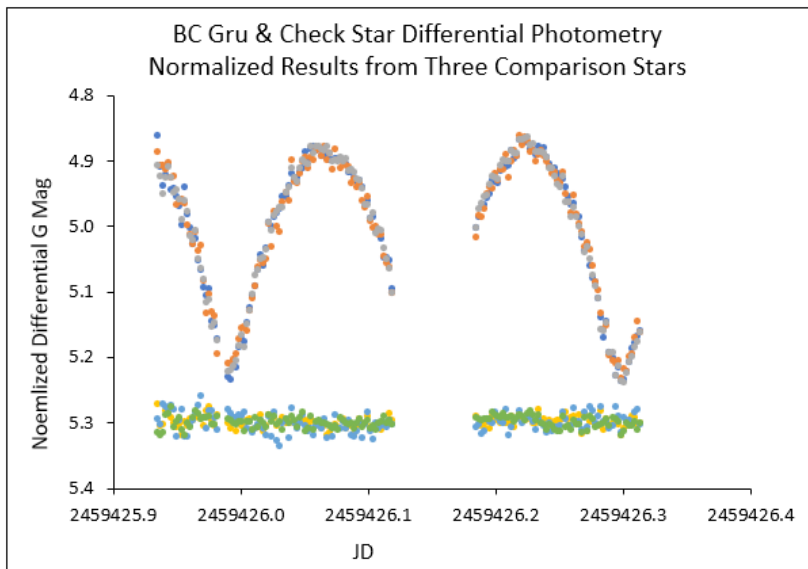


Figure 2. *Differential magnitudes calculated for the variable and check stars normalized to 5 magnitude units (for the variable) and 5.3 magnitude units (for the check star).*

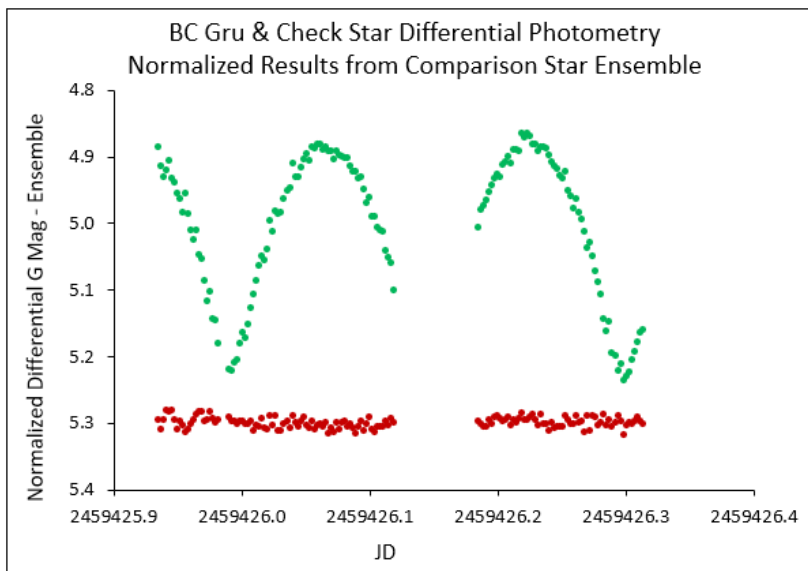


Figure 3. *Ensemble photometry results obtained by averaging the normalized differential photometry data.*

Discussion

Many amateur photometrists derive standardized magnitudes from their measurements, given by the formula:

$$M_x = (m_x - m_c) + M_c \quad (2)$$

where M_x is the standardized magnitude of the target (variable or check) star, m_x and m_c are the instrumental magnitudes of the target and comparison stars, respectively, and M_c is the catalogue magnitude of the comparison star. For most imaging systems (camera plus filter) the value of M_x is accurate only when the colour indices of the target and comparison stars are similar. Therefore a more stringent procedure will include transformation coefficients, and, for observations taken at higher airmasses, atmospheric extinction coefficients.

Simple differential photometry is therefore more rudimentary than the measures described in the above paragraph. I often use it to plot a light curve quickly to do a rapid check on a night's observations. New

recruits to the discipline of photometry may find it appealing.

It is important to stress that the values read off from the y axes in Figures 1 to 3, and particularly for Figures 2 and 3, are not true magnitudes, a fact obvious when realizing that BC Gru is a 10th magnitude star.

Finally, why bother to do this, when standardized magnitudes are so easy to obtain? The answer arises from the paper describing photometry with a red astrophotography filter and the ZWO ASI1600MM camera elsewhere in this newsletter. If an Rc (Cousins R) catalogue magnitude can be obtained or calculated for a comparison star, then it can be used to determine a standardized magnitude for a target star. If, however, only (say) Johnson B and V magnitudes are available, then use of the red astrophotography filter for time series work could only be done with simple differential magnitudes.

Conclusion

A method for performing differential photometry from an ensemble of comparison stars is described. In this context, differential photometry means a value in magnitude units obtained from the expression (mx – mc), where ‘mx’ is the instrumental magnitude of a target (variable or check) star, and ‘mc’ the instrumental magnitude of a comparison star. The method can be used for time series photometry without the necessity of determining standardized or transformed magnitudes.

This article is intended only as an introduction to the TESS Mission and how its photometric data is proving to be a boon to professional and amateur variable star researchers alike. The reader is referred to the excellent mission website (<https://tess.mit.edu/>) for engineering and science details. I freely acknowledge shamelessly plagiarizing material from this site.

Transiting Exoplanet Survey Satellite (TESS)

TESS is an MIT-led NASA mission to discover exoplanets by looking for transits in an all-sky photometry survey. The satellite was launched in April 2018 and completed its two year prime mission in July of 2020. It has now entered into its extended mission lasting approximately two years and will continue to scan the sky for exoplanets and transient events.

TESS' 13.7 day highly stable eccentric orbit maximizes sky coverage and gives a mostly unobstructed view of the cosmos, all from a low-radiation, thermally benign environment. The cameras image a strip of sky continuously for two orbits before the spacecraft is re-oriented to an adjacent strip and the process repeated. Each strip is called a sector and 13 sectors are covered each year. Sectors 1 to 13 (year 1) and sectors 27 to 39 (year 3) covered the southern hemisphere. Regions near the ecliptic were covered in only one sector per year whereas the ecliptic poles were imaged continuously for the year. Figure 1 shows the sky coverage in the first two years. The extended mission will essentially repeat the coverage.

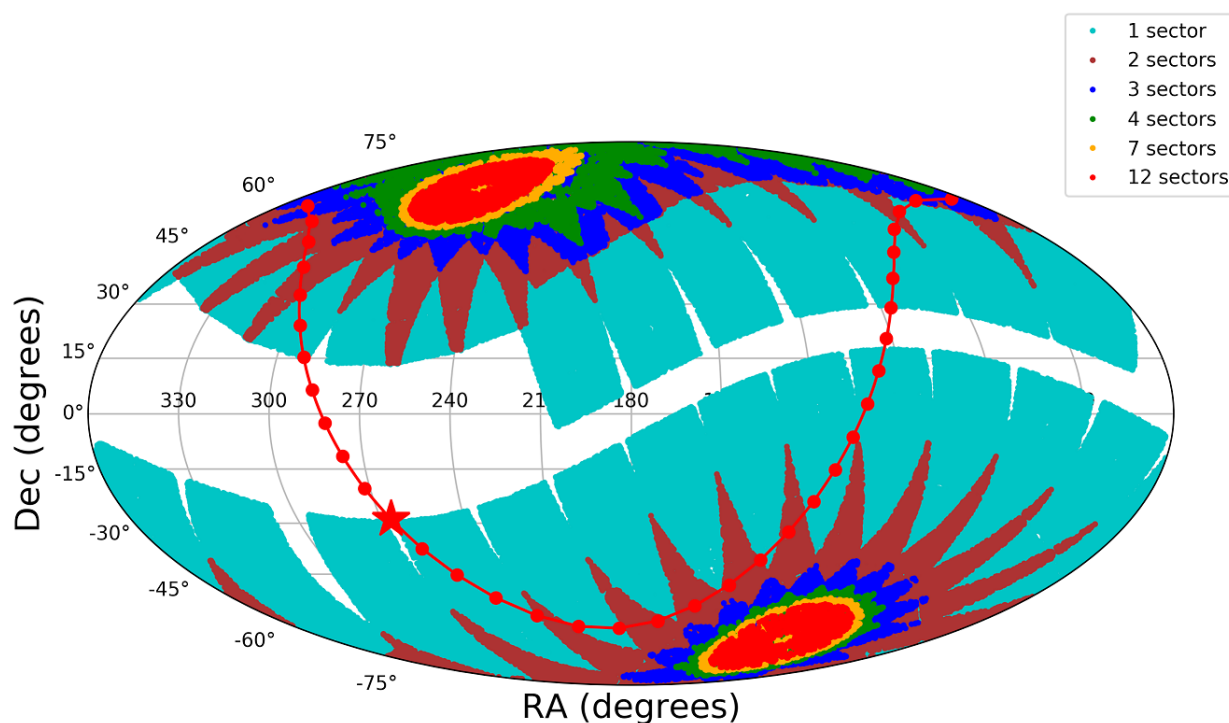


Figure 1. *TESS sky coverage of two year prime mission.*

As of August 8th, 2021 a total of 4471 TOIs (TESS Objects of Interest - i.e. exoplanet candidates) had been identified, 154 of which had so far been confirmed as exoplanets and 922 confirmed as false positives. Follow-up studies are required to confirm the true nature of the remaining candidates. Some will be background eclipsing binaries or other phenomena, but many are expected to be real exoplanets. The brightness of the stars they orbit should allow ground and space based telescopes to probe some of these planets' atmospheres for water, oxygen, and other molecules that might make them hospitable to life.

However, as exciting as these discoveries are they are not the topic of this article. A by-product of the exoplanet search is a wealth of high precision 2 minute cadence light curves of hundreds of thousands of stars, and millions more at 30 minute cadence, that are publicly available to anyone who might be interested.

Cameras

TESS has four identical cameras each equipped with custom f/1.4 lenses with an effective aperture of 10cm, providing a 24×24 degree field of view. They are aligned to cover 24×90 degree strips of the sky called sectors. Each camera has four 2k x 2k CCDs with a pixel scale of 21 arcseconds per pixel. The CCDs read out continuously at 2-second intervals.

TESS uses a red-optical bandpass covering the wavelength range from about 600 to 1000 nm. Figure 2 shows the TESS bandpass relative to the Johnson-Cousins VRI_C and SDSS z bandpasses. A star's apparent magnitude in the TESS bandpass is called its TESS magnitude.

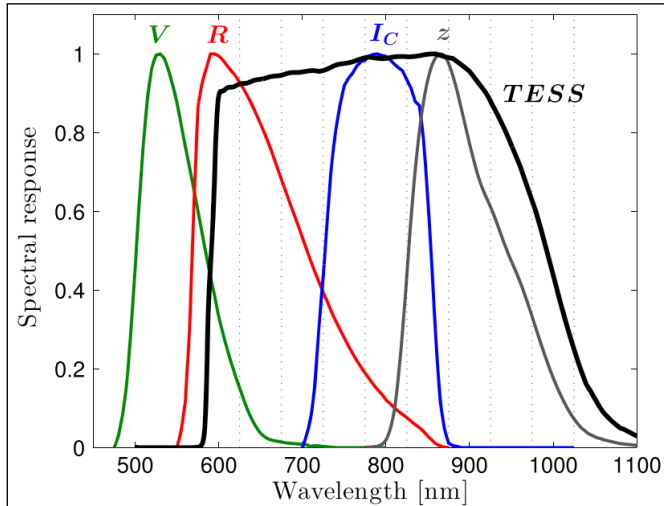


Figure 2. *TESS spectral bandpass (Sullivan, 2015).*

Types of images

The 2 second data is used for spacecraft guiding, but they are not downloaded to the ground. They are processed on the spacecraft into stacked 2 minute and 30 minute cadence images. To reduce data storage and transfer requirements 10×10 pixel postage stamps are extracted from the 2 minute images. The postage stamps are centered on stars in the Candidate Target List (CTL) compiled prior to the mission. The CTL covers the entire sky, with each TESS observing sector containing $\sim 20,000$ stars selected for 2-minute observations. The CTL is a subset of a much larger catalog called the TESS Input Catalog (TIC) which includes $\sim 473 \times 10^6$ objects. See Stassun (2018) and Fausnaugh (2021) for details of target selection.

Postage stamps for a few very bright asteroseismology targets are downloaded at 20 second cadence. This maximizes sensitivity to detecting short-period oscillations.

The postage stamps and 30 minute full frame images are compressed and stored in solid-state buffers. Data from the buffers are returned to Earth when the spacecraft reaches perigee, every 13.7 days.

Light curve data sources

NASA's TESS Science Processing Operations Center (SPOC) pipeline generates light curves from each 2 minute cadenced target. Light Curve Files contain flux time series data using Simple Aperture Photometry (SAP). These are FITS format files that contain the output of the photometric extraction and subsequent systematics removal performed by the SPOC algorithms.

A single Light Curve File contains the data for one target for one observing sector. If a target was observed in more than one TESS sector, multiple Light Curve Files are created. These can be downloaded from the Mikulski Archive for Space Telescopes (MAST) website. I will describe the procedure later.

NASA does not produce light curves from the 30 minute full frame images. However several groups are producing light curves for the community at large. Each uses their own photometry extraction and systematics removal routines.

- **Eleanor:** Open access PSF-fitting pipeline led by University of Chicago (Feinstein et al. 2019)
- **Filtergraph:** Open access difference imaging pipeline led by Vanderbilt University (Oelkers & Stassun (2018 & 2019)
- **LightKurve:** A package for Kepler & TESS time-series analysis (Barentsen et al. 2019)
- **TASOC Pipeline:** PSF photometry data reduction pipeline led by the TESS Asteroseismic Consortium
- **Quick-Look Pipeline (QLP):** Aperture photometry pipeline led by MIT (Huang et al. 2020)
- **LcTools:** Windows based set of applications for finding and recording signals in light curves (Schmitt et al. 2020)

There may be others I am not aware of. Eleanor, TASOC and QLP data are available from the MAST website; however to date I have only accessed QLP data. LcTools is a comprehensive set of Windows programs for generating and analysing light curves from the TESS and Kepler satellites. I won't be discussing LcTools in this article but may write another article in the future.

Downloading TESS SPOC light curve files

As mentioned above, TESS SPOC 2 minute cadence light curves are available from the MAST website (<https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html>). Clicking on the link will open the MAST Portal webpage. Figure 3 shows the top part with parameters set to search for data on any objects within 3 arcsec of the eclipsing binary AE Phe. This target was imaged at 2 minute cadence in sectors 2, 3 and 29.

Figure 3. MAST Portal search parameter entry fields.

Clicking on the Search button produces a table listing 23 data sets from the TESS, GALEX and IUE space missions. I am not concerned with GALEX and IUE data. Under the “Provenance Name” filter on the left of the page select the SPOC check box to display only the 7 data sets produced by the NASA TESS Science Processing Operations Center (Figure 4).

Filters

Clear Filters Edit Filters... Help...

Keyword/Text Filter

Filter All Columns

Mission

SPOC

(7 of 7)

ELEANOR

(0 of 6)

TESS-SPOC

(0 of 3)

AIS

(0 of 2)

TASOC

(0 of 2)

QLP

(0 of 2)

Provenance Name

Quantity

List View

Album View

Edit Columns... Table Display: All

	Actions	Observation Type	Mission	Provenance Name	Instrument	Project	Filters	Waveband	Target Name	
	1		science	TESS	SPOC	Photometer	TESS	TESS	Optical	TESS FFI
	2		science	TESS	SPOC	Photometer	TESS	TESS	Optical	TESS FFI
	3		science	TESS	SPOC	Photometer	TESS	TESS	Optical	TESS FFI
	4		science	TESS	SPOC	Photometer	TESS	TESS	Optical	207085748
	5		science	TESS	SPOC	Photometer	TESS	TESS	Optical	207085748
	6		science	TESS	SPOC	Photometer	TESS	TESS	Optical	207085748
☒	7		science	TESS	SPOC	Photometer	TESS	TESS	Optical	207085748

Figure 4. Search results for TESS SPOC data sets for AE Phe. Only the first 9 columns are shown.

The first 3 entries are Full Frame Images (as identified in the “Target Name” column), one from each of the sectors in which AE Phe was imaged. These are FITS format files however they are extremely large and I have not tried to download any. I’m not sure if my astronomy software is capable of opening them.

We are interested in the entries with  icons signifying light curve files. Clicking on that icon should bring up a plot of the measured flux (not magnitude) as a function of time. Occasionally, e.g. entry 7 in

Figure 4, an error message pops up indicating there were no time series data available for that dataset. Figure 5 shows the light curve of AE Phe from sector 29 (entry 6).

The legend at right has check boxes to select either an uncorrected or corrected light curve. The TESS mission website defines these as:

- 1) Simple Aperture Photometry (SAP): The act of summing all pixel values in a pre-defined aperture as a function of time.
- 2) Pre-search Data Conditioning SAP flux (PDCSAP) flux: SAP flux from which long term trends have been removed using so-called Co-trending Basis Vectors (CBVs). PDCSAP flux is usually cleaner data than the SAP flux and will have fewer systematic trends.

Although in my experience the uncorrected SAP light curves are often better than the corrected version.

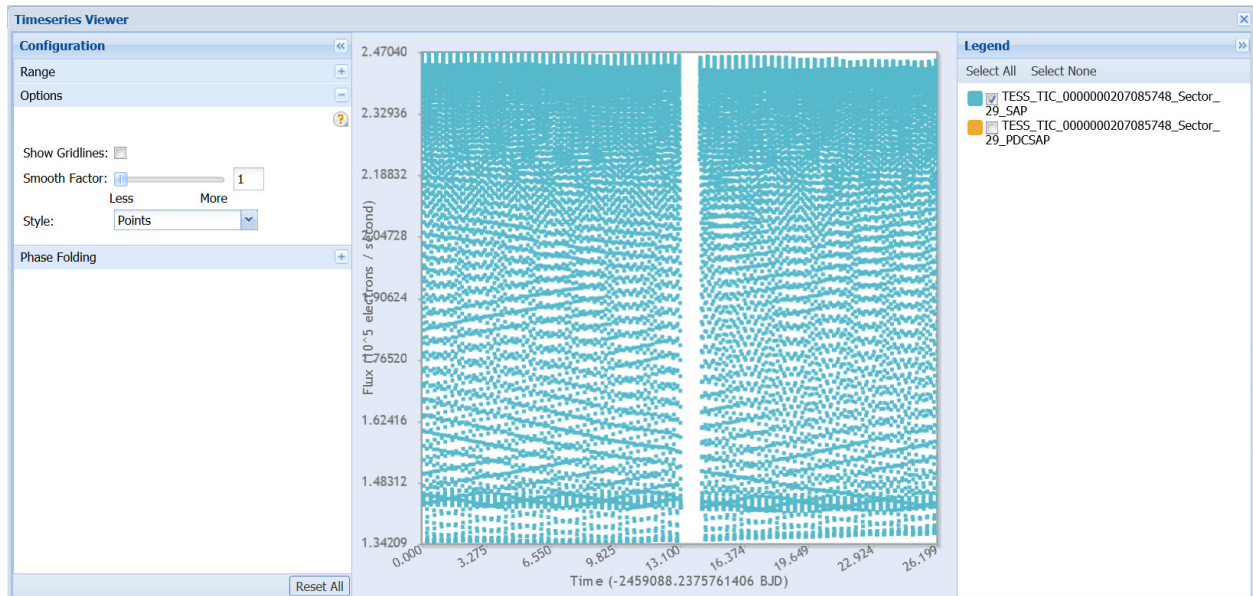


Figure 5. *AE Phe sector 29 Simple Aperture Photometry (SAP) light curve.*

Data download from the satellite occurs once per orbit and results in a gap in the middle of the light curve. Other small gaps can be caused by spacecraft glitches. The Time and Flux axes can be adjusted under the Range tab on the Configuration panel, or by clicking and dragging within the plot panel.

Displaying TESS light curves in VStar

A more convenient way to view and analyse a light curve is to use David Benn's free VStar program available from the AAVSO website. I won't get into the details of installing and using VStar, I'll leave that to the interested reader.

Click on the floppy disc icon in the MAST search result list to download a Zipped folder containing the light curve file. Unzip the folder to a convenient location on your computer. Launch VStar and select "New Star from Kepler/TESS FITS File v2.2..." under the File menu. Navigate to the unzipped folder, dig down through several sub-folders and double click on the file ending in "s_lc.fits". Select the Raw (SAP_FLUX) option then click OK. The light curve displayed in the VStar Plot window will be very similar to the MAST Timeseries Viewer plot except that flux has been converted to magnitude.

The top panel of Figure 6 shows part of the sector 29 light curve of AE Phe (TESS Input Catalog number 207085748). The bottom panel is the light curve phased using period 0.362377 d and epoch HJD 2443732.8819 from the AAVSO Variable Star Index (VSX). The VSX period appears to be slightly too long as primary eclipses are occurring earlier than expected. The 3 sectors of TESS data for AE Phe show significant variation in the light curves over time. I plan to write another article for a future Newsletter.

It is important to note that the time system of TESS observations is Barycentric Julian Date in Dynamical Time (HJD_TDB). VStar does not attempt to convert that to Julian Date or Heliocentric Julian date.

The user must be aware of that fact and make any necessary conversions when making comparisons with other sources of observations.

Version 3 of the light curve and period analysis software Peranso (www.peranso.com) can import TESS SPOC 2 minute cadence light curves directly from the internet. I have only a little experience with this feature, but it looks very promising for those prepared to pay the license fee.

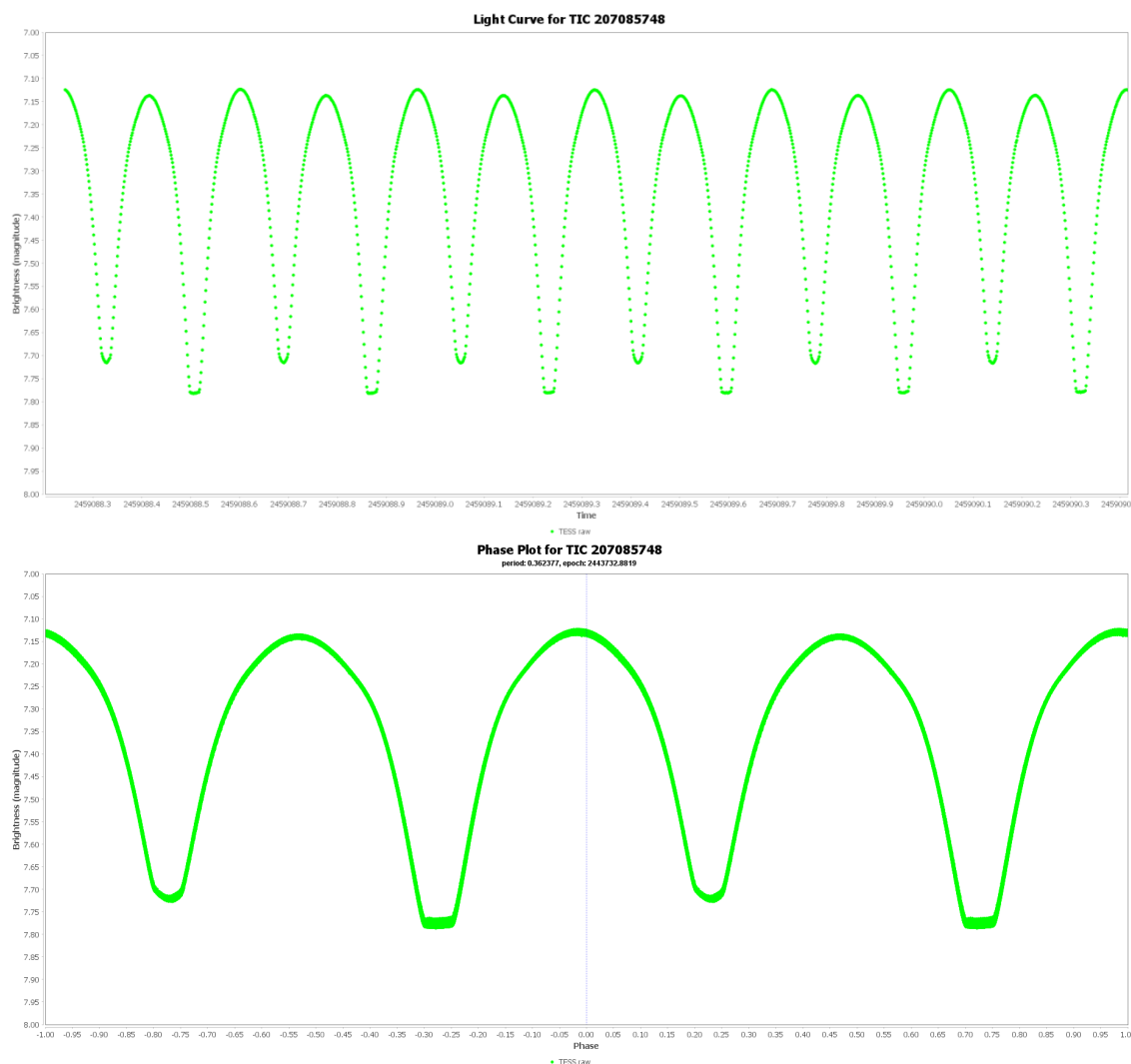


Figure 6. Top panel VStar plot showing part of AE Phe light curve. **Bottom panel** phased light curve using period 0.362377 d and epoch HJD 2443732.8819 from the AAVSO Variable Star Index (VSX).

Downloading and viewing QLP light curve files

QLP light curves are very useful for targets that were not selected for 2 minute cadence monitoring. I'll use the classical Cepheid VW Cru as an example. On the MAST Portal web page (Figure 3) enter "VW Cru, r=3s". Under the "Provenance Name" filter on the left of the search result page select the QLP check box to display the single data set produced by the Quick-Look Pipeline team.

For a QLP data set clicking the  icon does not display a light curve, however, clicking the floppy disc icon will download a Zipped folder. As before, unzip the folder to a convenient location, launch VStar and select "New Star from QLP FITS File v0.2..." under the File menu. Navigate to the unzipped folder, dig down through several sub-folders and double click on the file ending in "_llc.fits". Select the Raw (SAP_FLUX) option then click OK. Figure 7 is the light curve of VW Cru (TIC 179721969), in this case a 30 minute cadence is perfectly adequate.

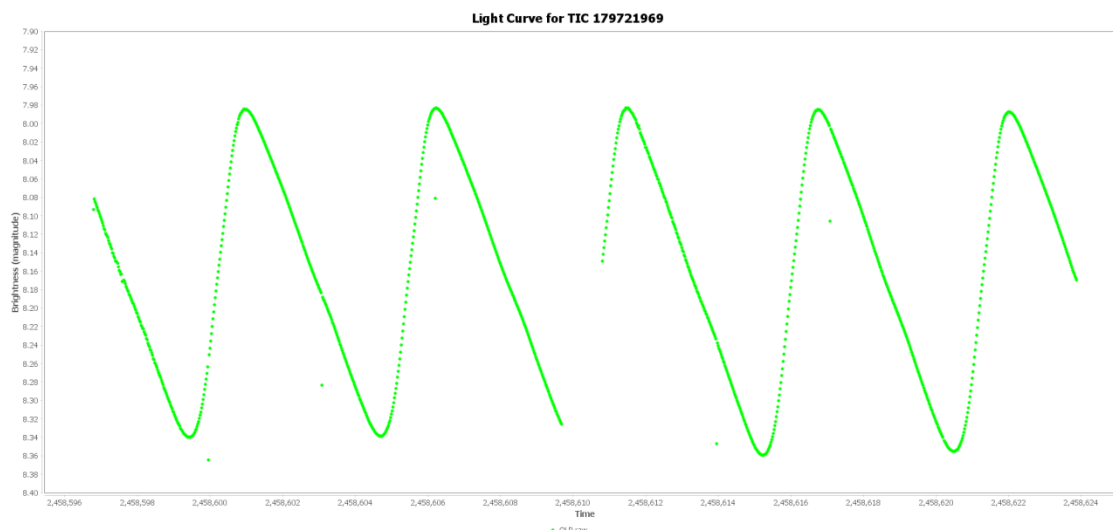


Figure 7. *VW Cru 30 minute cadence QLP light curve.*

Noise and systematic effects

As the examples above demonstrate, TESS data are of very high quality. However there are several sources of noise and systematic effects. Some of these can be partially corrected for within the data processing pipeline, but residual effects may still be present.

A key source of systematic noise comes from random pointing variations i.e., spacecraft jitter. This causes changes in the measured brightness as stars move across CCD pixels.

Saturation of bright star images in the 2 second exposures is expected at I_c magnitude 7.5; however this does not represent the bright limit for precise photometry. Excess charge from saturated pixels is spread across adjacent pixels. Precision photometry can still be achieved by creating a photometric aperture that is large enough to encompass all excess charge. The TESS bright limit is around $I_c=4$.

The TESS point spread function varies significantly across the focal plane due primarily to the optics. Photometry of an object is typically obtained through the summation of all pixels within a given region. This region is referred to as an “aperture mask” determined through the processing pipeline. Unlike typical apertures, TESS apertures are not circular and vary across the CCD.

TESS photometry for many targets will be contaminated by nearby objects due to the large 21 arcsec per pixel image scale. Background eclipsing binaries, for instance, can lead to transit-like features in light curves. Higher resolution observations by ground based telescopes are needed to weed out false positives. The AAVSO Exoplanet Section is one group coordinating these follow-up observations.

Each camera has a lens hood to reduce scattered light from the Earth and Moon. Due to TESS’s wide field of view and the physical restrictions of the Sun shade the lens hood is not 100% efficient. Typically scattered light causes patchy brightness 2-6 times that of the nominal sky background and covers approximately 10-15% of the field of view. The position and intensity of scattered light in images varies depending on position and phase of the Earth and Moon relative to the camera pointing.

Cosmic-ray hits on the TESS CCD’s are a significant source of noise. For full frame images this is especially true and nearly half of the pixels are affected. To help mitigate the effect of cosmic-rays, images are stacked and pixels are examined in small groups. The highest and lowest values are removed, and those remaining are summed to create the final stack. Although this reduces contamination by a factor of 100, some low level outliers still exist and can be seen within the data.

I will present one example of a false signal, in this case due to contamination from a nearby bright eclipsing binary. The naked eye star eta Muscae is in fact a multiple system composed of at least 5 stars. The light is dominated by eta Mus A ($V \sim 4.8-4.9$), a close partially eclipsing binary with a 2.396318d period. A 7.3 magnitude visual companion eta Mus C appears about 58” NW of the close binary, while a 10th mag (J) closer companion eta Mus B is $\sim 3''$ SE of the main pair. Finally an even closer companion

eta Mus D orbits the eclipsing pair in a ~ 2090 d eccentric orbit (Blackford, Butland & Budding, 2016). The nomenclature of eta Mus B and eta Mus C are reversed in that reference compared with the SIMBAD Astronomical Database.

Figure 8 shows the, supposedly, corrected PDCSAP 2 minute light curve of eta Mus C displaying eclipse-like dips superimposed on a ~ 2.28 d Cepheid-like pulsation. The dips are not correlated with the pulsation period but have the exact same 2.396318d period as the eclipsing eta Mus A pair. Clearly there is residual contamination from the brighter nearby pair. However, the Cepheid-like pulsations may actually be real which would represent an interesting new finding.

Despite possible residual artefacts, in general TESS light curves are far superior to any derived from ground based observations but care must be taken to identify false signals.

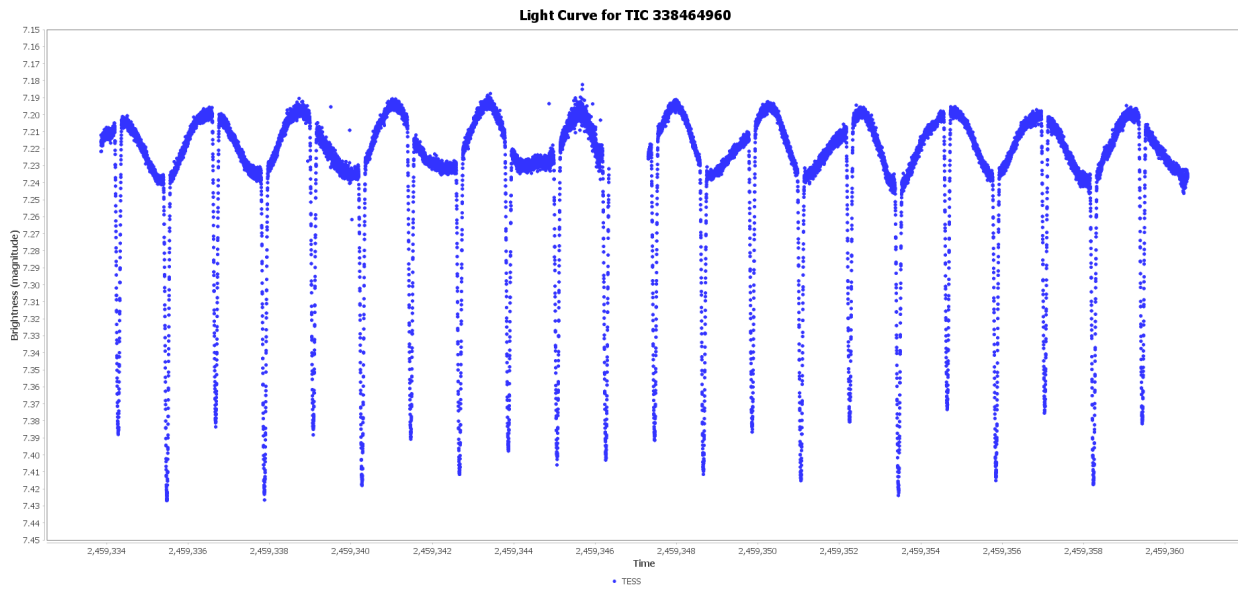


Figure 8. “Corrected” PDCSAP light curve of eta Mus C showing residual contamination.

Conclusions

A valuable by-product of the TESS mission is a database of high precision photometry of millions of bright stars. Apart from the mission’s prime objective of discovering exoplanets, professional and amateur astronomers are using the database to investigate a wide range of stellar behavior, as evidenced by hundreds of papers published in astronomy journals so far. These include, but are not limited to, period analysis of various types of pulsating stars, Times of Minimum determinations and light curve modelling of eclipsing binary stars and asteroseismology.

There are limitations to TESS photometry so ground-based photometry has not been rendered redundant. TESS employs only a single red-optical bandpass filter, the mission will be limited to about 4 years total and most parts of the sky will only be imaged for a small part of that time, false signals do compromise some light curves due to contamination from nearby stars or other sources of noise and systematic effects.

This article only scratches the surface of how to access and use TESS photometry. I encourage you to explore its potential.

Acknowledgements

This research made use of the AAVSO VSX database and 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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Reflections on a personal milestone or two* – Peter Williams

On the evening of Feb 2, 2021 there was a small window of clear sky after the end of twilight before the clouds rolled in, as is all too typical during summer here in Heathcote on the southern outskirts of Sydney, NSW. I tried to put that short amount of time to good use and managed to observe about 20 variable stars with the 10x50mm binoculars. It was a race against time as I moved from one field to the next, keeping just ahead of the clouds until the sky was eventually clouded out.

During that quick run of variable stars I managed to record the brightness of Theta Apodis, a semi regular red variable star in the somewhat obscure constellation Apus lying to the south of the box-shaped asterism of Musca, itself located at the foot on the Southern Cross. Theta Aps was at that time well within its normal brightness range and shining at magnitude 6.4 – pretty unremarkable.

It dawned on me a short time later when the sky was totally clouded out that I had observed Theta Aps earlier, on Feb 2, 1971 when it was at magnitude 5.5, again within its normal brightness range and also pretty unremarkable. That most recent observation of Theta Aps is, however, somewhat remarkable for being exactly 50 years to the day when I made my very first variable star observation – that earlier observation of Theta Apodis! Wow! 50 years of variable star observing makes me think these variable stars may be more than just a passing fad.

Yet I had been observing the night sky for several years prior to that observation of Theta Aps, since about 1966 when I borrowed my grandfather's pair of binoculars, and then in more detail after receiving a small 60mm refracting telescope for Christmas 1968 from my parents. If only they knew what they had started those 55 years ago! But even before all this I had a childhood fascination with the night sky and



*This article originally appeared in the BAA Variable Star Section Circular 189, September 2021.

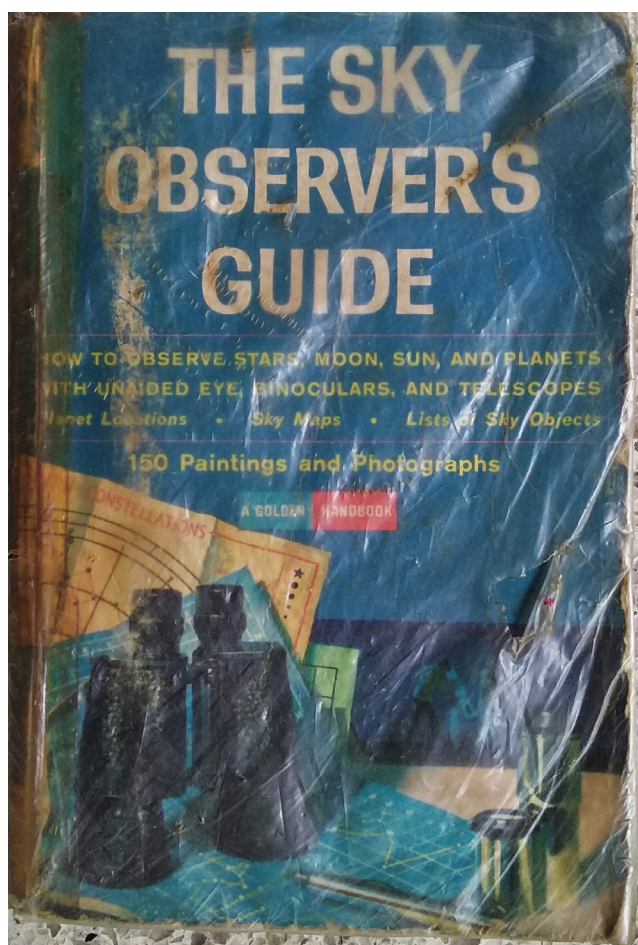
recall as a youngster noting the two naked eye double stars Mu Sco and Alpha Cap returning over several successive years, long before I knew any of the constellations.

My interest in variable stars had a rather unglamorous beginning and stems from having received a small soft cover book, "The Sky Observers Guide", also at Christmas in 1968. This included a rather brief section describing variable stars but, wow, the light curve shown for the star Mira Ceti made me think how fascinating it would be to see with my own eyes a star go through such a dramatic change in brightness.

Then, just a few years later I noticed Theta Aps included in a list of variable stars within Norton's Star Atlas (1966 15th edition, reprinted 1969). Using a hand drawn chart traced from the Becvar's Atlas Coeli with comparison star magnitudes from the Yale Bright Star Catalogue in the library of the Sutherland Astronomical Society (formally James Cook Astronomers Club) in southern Sydney I followed Theta Aps for the 8 months February through September 1971 and, despite Norton's listing it as an irregular variable, there was a clear semi regular period near 119 days.

And I still use that same copy of Norton's to this day as the convenient charts cover the whole sky in large sections to naked eye visibility and are just so convenient to quickly orient myself and identify an area of sky that contains an object of interest. Those charts have the usual assortment of deep sky and multiple stars circled to denote a successful observation and also have a good many additional variable stars and novae plotted to aid in their initial location.

During those 50 years of variable star observing I have certainly clocked up a few hours under the night sky and have seen some very interesting and unusual stellar behaviour, some regular happenings and some unexpected & unpredictable behaviour, plus a discovery or three. There have been many cooperative programs organised through the Variable Star Section of the Royal Astronomical Society of New Zealand (VSS, RASNZ) and the American Association of Variable Star Observers (AAVSO), the Variable



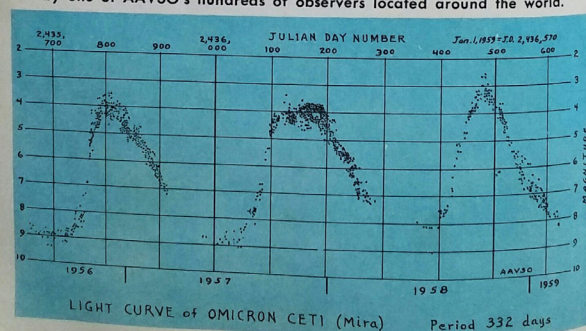
brighter than they are. Any variable that is extremely close to a much brighter star can be deceptive. Some variables are members of pairs that are hard to separate even with high power. The greater the difficulty, some observers say, the greater is the sport.

Continued observation of variables by amateurs for over 50 years has helped professional astronomers toward knowledge of the structure, composition, and evolution of the universe. Data provided by the AAVSO are continually used in astronomical research.

Novas are a special class of variables. They usually rise swiftly from obscurity, then slowly fade—sometimes beyond the limits of the greatest telescopes. Some flare up again later, but most become faint variables or disappear from view entirely. They are undoubtedly manifestations of explosions of vast proportions.

One nova that "rose again" was RS Ophiuchi. It burst forth in 1898 and again in 1933. Then, in July 1958, it burst forth again and rose to a magnitude of about 5.5. An alert amateur in Maine, Cyrus Fernald, noted this new outburst and reported it promptly. Ob-

Changing light output: In this chart, each dot represents an observation by one of AAVSO's hundreds of observers located around the world.



Star Network (VSNET) of the Kyoto University in Japan and the Variable Star Section of the British Astronomical Association in the UK (BAA VSS), in support of professional astronomers using either ground based telescopes or orbiting satellite observatories.

The 60mm refractor was eventually replaced by a 15cm F8 Newtonian and that in turn superseded with a 30cm F6 Newtonian, supplemented by 10x50 and 20x80mm binoculars.

But it has not only been variable stars that have taken my interest. During the early years there were descriptive notes of over 2,000 deep sky objects through the humble 15cm Newtonian reflector, total magnitude and central condensation estimates of comets (including Halley's Comet 1985/86), total and grazing lunar occultations, recording sunspot numbers, transit timings of structures in Jupiter's cloud belts and timing the eclipse disappearance & re-appearance of the Jovian Galilean satellites, plus the occasional eclipse and many beautiful planetary & lunar conjunctions just asking to be photographed.

There has also been showing the night sky to thousands of visitors at the Green Point Observatory of the Sutherland Astronomical Society right from the early days of the school Star Night programme, SAS Practical Astronomy Course (SASPAC) and the Public Open Nights, and writing about these adventures and more in the Sutherland Astronomical Society newsletter "Southern Observer" and for some years penning a regular column on variable stars in the Sky & Space magazine.

Following on from this, I more recently achieved another small personal astronomical milestone. On the evening of July 04, 2021 (local time) I reached and passed the 200,000 visual variable star observation mark.

To add a little background to this story, it was during a recent holiday to the UK (2019 in the pre-Covid era!) this approaching milestone was discussed over pizza and a few beers with John Toone of the British Astronomical Association Variable Star Section. Both John and I were approaching the 200K at that time.

I have known John for many years, since our first meeting during the ASNSW South Pacific Star Party at Ilford NSW in 1999, and we have since met up on several occasions both here in Oz and in London for either "Pizza on The Rocks" or "Pizza beside The Thames" depending upon which side of the globe we found ourselves.

At John's suggestion, I juggled my usual routine list of stars on that all-important night so the 200K observation was of the bright semi regular red variable Theta Apodis. This was, of course, rather symbolic remembering that Theta Aps was the star of which I had made my very first variable star observation 50 years and 5 months earlier. It just seemed rather fitting in some way!

By reaching the 200K mark it seems I have joined a somewhat exclusive club of just 11 other visual observers world-wide who have achieved this number, including John Toone. I am indeed therefore in good company.

While the number of observations is certainly a great personal achievement and has involved some considerable time and a consistent effort over the long term, I would like to think the data has been accurate and therefore useful to the variable star research community, rather than just numerous. I have also witnessed a good deal of interesting and some unexpected stellar activity along the way but it also has been a lot of fun both observing the night sky and sharing an enthusiasm for these things with others, while doing a little bit of science along the way.

Publication watch

Mark Blackford has two publications in the last quarter.

Poro, A., Blackford, M.G., Davoudi, F., Mohandes, A., Madani, M., Rezaei, S., Bozorgzadeh, E., *The New Ephemeris and Light Curve Analysis of V870 Ara by the Ground-Based and TESS Data*, arXiv:2105.11194

Abstract. New CCD photometric observations and their investigation of the W UMa-type binary, V870 Ara, are presented. Light curves of the system were taken through BVI filters from the Congarinni Observatory in Australia. The new ephemeris is calculated based on seven new determined minimum times, together with the TESS data and others compiled from the literature. Photometric solutions determined by the Wilson-Devinney (W-D) code are combined with the Monte Carlo simulation to determine the adjustable parameters' uncertainties. These solutions suggest that V870 Ara is a contact binary system with a mass ratio of 0.082, a fillout factor of 96 ± 4 percent, and an inclination of 73.60 ± 0.64 degrees. The absolute parameters of V870 Ara were determined by combining the Gaia EDR3 parallax and photometric elements.

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, Volume 503, Issue 3, pp.3759-3774, DOI:10.1093/mnras/stab621, arXiv:2103.00925

Abstract. BG Ind is a well-studied, bright, nearby binary consisting of a pair of F stars in a 1.46-d orbit. We have discovered in the TESS light curve for TIC 229804573 (aka BG Ind), a second eclipsing binary in the system with a 0.53-d period. Our subsequent analyses of the recent TESS and archival ground-based photometric and radial velocity (RV) data reveal that the two binaries are gravitationally bound in a 721-d 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 light curve, archival RV data, and the spectral energy distribution, coupled with the use of PARSEC stellar isochrones. We confirm prior studies of BG Ind that 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 that we discuss, we conclude that the three orbital planes are likely aligned to within 17° .

Phil Evans has one TESS exoplanet publication:

Gan, Tianjun, Lin Zitao, Xuesong, Wang, et al. *TOI-530b: A giant planet transiting an M dwarf detected by TESS*. 2021arXiv211004220G

Abstract. We report the discovery of TOI-530b, a transiting giant planet around an M0.5V dwarf, delivered by the Transiting Exoplanet Survey Satellite (TESS). The host star is located at a distance of 147.7 ± 0.6 pc with a radius of $R_{*} = 0.54 \pm 0.03 R_{\odot}$ and a mass of $M_{*} = 0.53 \pm 0.02 M_{\odot}$. We verify the planetary nature of the transit signals by combining ground-based multi-wavelength photometry, high resolution spectroscopy from SPIRou as well as high-angular-resolution imaging. With $V=15.4$ mag, TOI-530b is orbiting one of the faintest stars accessible by ground-based spectroscopy. Our model reveals that TOI-530b has a radius of $0.83 \pm 0.05 R_{J}$ and a mass of $0.4 \pm 0.1 M_{J}$ on a 6.39-d orbit. TOI-530b is the sixth transiting giant planet hosted by an M-type star, which is predicted to be infrequent according to core accretion theory, making it a valuable object to further study the formation and migration history of similar planets. We discuss the potential formation channel of such systems.

Roy Axelsen has a revised paper in the latest JAAVSO.

Retraction of and Re-analysis of the Data from HD 121620: A Previously Unreported Variable Star with Unusual Properties". JAAVSO, Vol. 49, No. 2, 2021.

Abstract. The original paper (published in JAAVSO, Vol. 48, No. 1, 2020) is retracted, because the photometric data and conclusions in it are erroneous due to varying degrees of saturation of the images of the target star. This paper describes the results of a study of the original data aimed at determining why the erroneous light curves were highly complex

Letter to the editor

Minima 2020

Reviewing the preprint of our JAAVSO article on our minima in 2020, which will appear online shortly and in the electronic/print journal in the December issue, I realise the staggering amount of observational and analysis work that is summarised in the article. Thank you all for your time and care. Now on to finalising 2021 on a high note, with much to report in the next paper in the series!

Our work is extremely important, because it is effectively the only short-cadence photometry being done on southern eclipsers. With our minima data now spanning up to 7 years we are reaching the time span needed to obtain significant information on periodicity and period change - with much astrophysical spinoff as you all know. This is hinted at in the O-C diagrams in the paper, and each of those binaries could have a paper of its own based on the epoch data we have gathered (together with the poorer quality epoch data that can be extracted from low-cadence surveys such as ASAS3).

One general conclusion we can reach from our work is that the “discovery” ephemerides as catalogued in GCVS and VSX are generally poor, at best a guide. This is partly due to the methods often used (low-cadence photographic work - imagine trying to measure the density of a dot on a photographic plate) and partly to possible period changes. The trouble is that, because of lack of epoch data between discovery and our work, you can’t always disentangle those two problems. Much to be done!

Additionally there is of course shape modelling of these binaries. We do not collect full photometric data, only minima estimates based on that data, but I hope everyone is uploading theirs to the AAVSO. Col Bembrick is always keen to do shape modelling, so if you have good clean full light curves - possibly obtained by period folding from multiple partial light curves - contact me and I’ll put you in touch with Col.

Tom Richards

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

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Treasurer/Membership Bob Evans

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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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