



The 64 metre diameter Parkes radio telescope. Parkes will be the venue for the 6th VariableStarsSouth Symposium to be held on 10 April in conjunction with NACAA 2020. For a list of talks see Mark's article on page 3 of this newsletter.

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From the Director – *Mark Blackford*

Another year slips by and a new one starts. I hope you all enjoyed the Christmas/New Year period without indulging too much in the food and celebrations typical of the season.

NACAA 2020 and the Sixth Variable Stars South Symposium are fast approaching. The VSSS6 programme of talks is rapidly filling up. A few more oral presentations can be accommodated but don't wait too long to submit your abstract. See details elsewhere in this Newsletter.

The Royal Astronomical Society of New Zealand will be celebrating their centenary at the RASNZ 2020 conference, May 8th to 10th, Wellington, NZ. I've booked my accommodation already and hope to catch up with many VSS members over the weekend.

In August Sydney will host the [43rd COSPAR Scientific Assembly](#), a large international conference bringing together astronomers, space scientists and engineers, and administrators from around the world. A quick glance through the [Scientific Program Overview](#) reveals the very broad range of topics to be discussed, a great many of which would be of interest to VSS members. A public lecture "Where and How Did Life Evolve on Earth and What Are the Implications for Mars Exploration" will be presented by Abigail Allwood (Jet Propulsion Laboratory, Pasadena, CA, USA) at 8pm Thursday, 20 August.

You may have noticed that the semi-regular variable Betelgeuse has been fading dramatically recently, giving Orion a rather unbalanced appearance. It will be interesting to watch over the next few months to see just how faint it gets before, presumably, starting to brighten again.

The component stars in the 5.5yr period binary Eta Carinae are approaching perihelion on February 17th, 2020. Frequent monitoring over coming months is needed to record details of the light curve for analysis by professional astronomers. See the "[Eta Carinae Photometric Campaign: 2019+2021](#)" project page for details. My own observations have been hampered by events described in the following paragraph, but I hope to be able to contribute again soon.

At Congarinni Observatory conditions over the last couple of months were very unfavourable for variable star observing. Bushfires in the Nambucca Valley and surrounding areas resulted in almost continuous thick smoke haze which obscured all but the brightest stars. There were very few opportunities to observe between October 22nd and December 28th. At one stage the fires approached within metres of my southern fence line but neighbours, local RFS volunteers and two water bombing helicopters managed to keep it contained.

However this was a small inconvenience compared with other people's losses. My thoughts are with those who lost property, homes and loved ones in the recent fires all around Australia.

Wishing you all clear night time skies and rain during daylight hours,

Mark Blackford



Sixth Variable Stars South Symposium – *Mark Blackford*

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VSSS6 will be held on Friday, April 10th, 2020 in Parkes NSW, just prior to the NACAA meeting. The symposium will have a single stream of oral presentations. There will also be a poster display for those who prefer to present their work in that manner. These will be on display for the entire weekend giving delegates to the NACAA conference and other satellite meetings the opportunity to view them.

We are delighted to announce that Dr Stella Kafka, AAVSO Executive Director, will be presenting two talks at VSSS6. Stella is looking forward to meeting everyone and is more than happy to chat if you have any questions or suggestions regarding variable star matters. There will be plenty of opportunities to catch up with her over the weekend.

The VSSS6 programme is coming together nicely with ten talks already submitted (see list below). There's room for 2 or 3 more so please act quickly to secure your spot. The standard duration is 30 minutes. We may be able to accommodate shorter or longer talks, but that will depend on the number of submissions we receive. The NACAA Welcome Reception on the Friday evening will limit how late our symposium can run. We anticipate including a short question and answer session where delegates can pose questions or suggestions regarding our hobby or Variable Stars South.

Paper submission and registration for the Symposium are through the NACAA 2020 website. The VSSS6 Call for Presentations webpage (<https://nacaa.org.au/2020/vsss6/cfp>) is live and the registration page will be online by the time you read this notice.

The deadline is **January 31st, 2020**. Late proposals may be accepted, depending on venue restrictions, scheduling, etc. But please submit your proposals as soon as possible to allow us to start putting the programme together. It will also help with planning our resource requirements for the venue, etc.

On the Thursday evening before the symposium we'll have an informal VSS gathering at a local pub or restaurant, like we did before the Sydney 2016 symposium. I was in Parkes in July and scoped out a couple of options that aren't too far from the NACAA venue.

Preliminary list of oral presentations:

Presenter	Title
Roy Axelsen	Photometry of Variable Stars with the ZWO ASI1600MM Cooled Monochromatic CMOS Astronomical Camera
Roy Axelsen	HD 121191 and HD 121620: Two Previously Unreported Variable Stars
Mark Blackford	O-C Diagram analysis of eclipsing binaries
Ed Budding	Progress report on Southern Binaries Programme
Stella Kafka	Spectroscopy with small telescopes
Stella Kafka	Citizen Science with the AAVSO
David Moriarty	Photometric and spectroscopic monitoring, radial velocities and evolutionary status of the chromospherically active, close eclipsing binaries ST Centauri and V0775 Centauri
David O'Driscoll	Portal to research? The future of the VSS website
Tom Richards	The Error of their Ways A study of uncertainty problems in light curve analysis
Stan Walker	Long Period Variables - from TSP to Astrophysics

Abstract

The author has undertaken a project to update the coordinates of 4801 LMC variables as listed by *Samus et al (2002)*. Improved positions from Gaia DR2 (2018) yield a highly accurate and uniform data-set, with respect to instrument used, reference frame and epoch. This first tranche deals with 2180 LMC stars with Harvard Variable (HV) names.

Background

The well-known atlas of the LMC (Hodge & Wright, 1967) has been a standard for anyone wishing to identify, with certainty, variable stars in the Cloud. The LMC charts at my disposal are not originals, and are near the end of their useful life. While the H & W atlas of the LMC is long out of print it seemed that the best way of making the VS data available to researchers into the future is to create an electronically readable database. This could be best achieved by identifying each star accurately by retrieving its coordinates from Gaia (Cat I/345) via VizieR. This covers the entire expected magnitude range, 10 - 19p.

Method

File **EVS CAT.DAT** (CDS II/214A, 2002) was downloaded from VizieR to my PC and parsed into a spreadsheet. With 4801 lines in the file, it simplified editing positional details while preserving other bits. VizieR made the necessary adjustment for precession from epoch B1950.0 to J2000. I then compared published positions with existing charts. Any disagreement required further investigation to determine the **true** position. When the basic (true) position had been verified better coordinates were retrieved from Gaia DR2. All Gaia positions are for Epoch 2015.5, Equinox J2000.0, with no adjustment for precession. True members of the LMC show minimal **pm**, and they account for more than 99% of LMC HV stars.

Results

The first tranche of this project covers only those variables plotted on the H & W atlas; about 2180 HV stars. I actually include some high-numbered HV stars (above HV 13000) which do not appear in their atlas but can often be found in SIMBAD. It is hoped that the presentation of better coordinates will assist the identification of variables in the absence of the H & W Atlas. However, it is well understood that many parts of the LMC are extremely crowded. I have found that Gaia is able to pick out individual variables in the most crowded situations, such as star clusters. Nevertheless companion stars are very common and I had to proceed very carefully, paying close attention to the remarks of H & W. Their charts do not always resolve them. The main sources of direct imagery are ESO and UKS plates, which tend to go **too** deep. It is still recommended to consult charts for identification, as the different filters used in photography can change the aspect of a field quite significantly.

The final file of LMC HV stars is too long for inclusion in the newsletter but will be placed on the VSS website as a plain text file, **LMC_HV_VARS.DAT**. The columns are:

- Col. 1: The running number, as assigned by the GCVS team, in format LMC Vxxxx.
- Col. 2: Reserved to flag non-members of the LMC, by “n”.
- Col. 3: Approx. visual magnitude, near max, (Very approx., for internal use only).
- Col. 4-6: Right Ascension for J2000, Epoch 2015.5, from Gaia DR2.
- Col. 7-9: Declination, J2000, Ep. 2015.5 from Gaia DR2.
- Col. 8: Source. G = Gaia DR2.
- Col. 9: Max. magnitude.
- Col. 10: Min. magnitude.
- Col. 11: Filter
- Col. 12: Published epoch JD 24...+
- Col. 13: Period (d)

Col. 14: M-m or D
Col. 15: Spect.
Col. 16: HV number
Col. 17: Other ID.
Col. 18: GCVS / NSV name
Col. 19: Remark

Note that two columns have been omitted, both have 3-digit codes in the GCVS file, enumerated as **(1) Reference to a published study**, and **(2) Chart reference**

The total of references is at least 560 papers, and it would be impractical to reproduce them. These can all be found on the GCVS website. The *Chart ref.* is redundant. All HV stars have been charted by Hodge & Wright (1967).

My file preserves the *content* of **EVS CAT.DAT** from VizieR, with minimal change - some extra identities. However the **arrangement** has been changed, especially the identifiers.

Table 1. Summary of errors and corrections

This table lists the most significant typos, errors, etc I detected during the course of this research. (This table is shown on the next page).

Acknowledgement

This research would not have been possible without the use of the VizieR service of CDS, Strasbourg, and the SIMBAD database.

References

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- URL: <http://www.sai.msu.su/gcvs/gcvs/v/>

TABLE 1 SUMMARY OF ERRORS AND CORRECTIONS FOR HV STARS IN LMC

LMC Var	HV#	J2000.00		Correction
.....	12710	04 40 06.276	-63 43 57.73	ASAS J044006-6344.0 13.11G. Not in GCVS
V0016	12717	04 43 20.847	-69 13 47.81	ID. as shown on H&W chart 21B is correct; they allude to a "close comp. to E" (remark p91). B-V = 0.613, consistent with a Cepheid. Another star follows 3.47s, but is blue, B-V = 0.151, and is known as ASAS J044324-6913.7. VSX has conflated the two stars. Latter ID. is wrong.
V0639	2269	05 01 00.71	-69 17 27.0	DecDeg is -69 not -66.
V0640	12506	05 01 26.86	-66 16 34.3	DecDeg is -66 not -69.
V0736	13019	05 02 32.54	-68 44 39.5	LMV1693 (Gaposchkin (1970)). Corrected position.
V0826	12242	05 04 38.76	-65 48 17.8	GCVS posn. error. Too far west by 32s.
V1054	2318	05 06 27.90	-68 52 18.3	GCVS poition offset to E by 1.30s.
V1080	2319	05 06 52.97	-68 39 35.6	SIMBAD error, as it really refers to HV 2315.
V1165	5609	05 08 03.32	-68 37 32.6	As described by H&W; has close comp. ~5" to S.
V1271	12984	05 09 42.78	-67 24 43.1	GCVS posn. off by 4.4s.
V1282	11988	05 09 32.17	-69 06 37.1	GCVS posn. off by 5.9s
V1380	2341	05 11 26.01	-66 30 07.7	Older published coordinates refer to V1382=V6. See Glass (1985) MNRAS 214,405.
V1421	13053	05 11 55.27	-68 26 20.7	GCVS posn. off by 8.9s.
V1709	5698	05 14 57.82	-69 35 32.0	GCVS posn. off by 22.6s.
V1721	12207	05 15 38.48	-65 38 09.8	GCVS posn. off by 8.25s.
V1729	5704	05 15 06.89	-70 01 49.6	SIMBAD positional error. GCVS correct.
V1883	927	05 16 54.91	-69 19 50.4	GCVS posn. erroneous. Corrected.
.....	12989	05 18 27.393	-69 03 02.51	15.7p. Gaia DR2 posn. Not in SIMBAD or GCVS.
V1962	12009	05 18 41.88	-69 38 23.0	GCVS posn. off by 38.3s.
V2034	13030	05 18 58.20	-69 16 46.2	GCVS posn. off by 6s.
V2368	13032	05 23 09.02	-70 06 37.6	GCVS posn. off by 8.2s.
V2375	5796	05 23 38.52	-68 36 19.2	= LMV1772. Corrected position.
V2457	12798	05 25 03.21	-66 08 07.1	SIMBAD error; refers to star 3.2s foll, 28.6" N.
V2613	12805	05 26 56.38	-65 08 36.8	SIMBAD error, refer to note by H & W (1967). The H & W chart 41B shows the correct position.
V2677	5842	05 27 27.50	-66 43 07.5	SIMBAD cites a different star (endfigs 25.1596s, 25.77", m = 16.64, J-K = 0.66 (2MASS)). The star plotted on chart 43B is LMV949 Irr range 0.60. "Radcliffe Memorandum No. 1" agrees. Adopted.
V2992	5883	05 30 09.45	-68 59 45.3	SIMBAD position incorrect.
V3159	5910	05 31 38.68	-70 07 36.1	SIMBAD and GCVS both off. My adopted position is from chart 45cB; is midway between the formers.
V3173	2625	05 31 30.67	-71 44 48.1	GCVS typo. which shows HV 5625.
V3889	13001	05 39 33.90	-70 04 39.5	Corrected HV. Actual HV 13001 lies just 6" NE of TYC 9167 333 (11m), missed by Gaposchkin (1970). V3933 (=LMV1680, 10s E) is not HV 13001, which is really HV 13003. See H&W chart 53B.
V3922	2756	05 39 47.34	-70 01 16.7	HV no. omitted in GCVS-EVS.
V3933	13003	05 39 52.86	-70 04 50.6	HV number corrected. See note for V3889.
V4565	12070	05 52 27.84	-69 14 10.1	The position plotted on chart 61B falls on an empty spot, with no variable. H&W surmise the true var. lies 15.8s W, matching WOH S 515, SR, V=15.5, B-V 1.17. Later authors all agree.
V4588	12680	05 53 55.44	-70 17 05.4	Northern star of 6" pair.

This table has three different numbering systems for LMC variables, each with standard 2 or 3-letter prefixes. The numbering systems require attention to avoid confusion! "LMC Vxxxx": From GCVS, Vol. 5 "EXTRAGALACTIC VARIABLES" 1995,2002. CDS Cat II/214A. "HV" Harvard Variable as plotted in "Atlas of LMC", Hodge & Wright (1967). "LMV" Numbered LMC variables studied by S. Gaposchkin (1970), SAO Special Rep. 310. "A Topographic Study of 1830 LMC Variables". 1970SAOSR.310....1G.

Abstract

This paper discusses the outcomes of a 3 year visual observational programme of selected symbiotic stars that was conducted between 2016 and 2019 as part of the Edward Corbould Research Fund (ECRF) grant obtained from the AAQ in 2016. It presents a general discussion on symbiotic stars, selection of the stars to be observed and the outcomes from the observations. 731 visual observations on 7 candidate stars was performed.

Symbiotic stars – background

Symbiotic stars were first so named by Merrill (1941) upon discovery as they had unusual spectra showing both the spectral properties of a hot star and of a cool one. Symbiotic stars are binary systems in which a hot compact star, usually a white dwarf, accretes material from its giant companion, usually a red giant. Some symbiotics may instead have a yellow G-K giant companion, or may have a neutron star as the compact component (Mikołajewska 2007).

Accretion in symbiotics occurs predominantly through capture of the red giant wind, or through some form of Roche lobe overflow (Podsiadlowski & Mohamed 2007; Mikołajewska 2007). Symbiotics are, by necessity from the presence of the giant star, wider binary systems than cataclysmic variables (CVs). Symbiotic binaries typically have orbital periods of between a few hundred to greater than 900 days (Mikołajewska 2007), with some that have periods of over 20 years (Kenyon 1986).

Symbiotics may undergo periods of brightening or outbursts for a variety of reasons. While some symbiotics have been found to produce nova eruptions, for example the X-ray producing V407 Cyg (Abdo et al, 2010; Cheung et al, 2014), the vast majority of eruptions are not the result of a thermonuclear runaway. Instead, they are accretion driven or powered by quasi-steady nuclear burning on the surface of the white dwarf. It is these non-nova outbursts that are referred to as symbiotic eruptions.

In general, symbiotics can be thought of as cousins to novae — the evolution of the ejecta from a symbiotic eruption from the surface of the white dwarf has many similarities to the ejecta from nova eruptions. The eruptions during these active phases can brighten the star by several magnitudes and leave resolvable remnants (Hack & Paresce 1993; Eyres et al, 1995; Richards et al, 1999).

Symbiotic eruptions can also produce bipolar jets (Sokoloski & Kenyon 2003) and asymmetric nebulae like those of many planetary nebulae (PNe) (Munari & Patat 1993); additionally they are considered possible hosts for the formation of second-generation planets (Perets & Kenyon 2013) and are candidates for progenitors of type Ia supernovae (SNIa) (Dilday et al. 2012).

Symbiotic stars are a class of objects with a wide variety of properties and parameters. Some have quasi-steady nuclear burning on the surface of the white dwarf, and others do not. It is unknown what fraction of symbiotic binaries have shell-burning on the surface of the white dwarf, as opposed to being purely powered by accretion.

The mass transfer rates in symbiotics are not well constrained, since optical emission tends to be dominated by the red giant or reprocessed emission from a shell burning white dwarf. While accretion disks do form around some symbiotics, they are not a universal feature, and it is difficult to get direct evidence for the presence of an accretion disk in symbiotic systems, much less their disk size or accretion rate. It is therefore unclear if symbiotic outflows are anchored in an accretion disk in the same way that jets are anchored in the disks in X-ray binaries and quasars. While jets have been seen in about 5% of symbiotics, in truth most have not been observed or imaged with the resolution necessary to detect a transient jet. Symbiotics can therefore provide a diverse sample of systems which can lead to a better understanding of accretion powered systems, the formation of collimated jets and the shaping of ejected nebulae.

Symbiotic stars are not as well understood as cataclysmic variables (CVs) in part because of their longer variability time scales mean that observations over many years are required to cover different outburst states and orbital phases. Optical monitoring by amateurs can identify systems in outburst and also help

to build a comprehensive database of outburst and quiescent light curves. Long term optical light curves will improve understanding of symbiotic outbursts, jet production and the connection between outbursts, jets and accretion disks in symbiotic stars (Sokoloski, 2003).

Observing programme

The ECRF project entailed the systematic visual observation and subsequent analysis of approximately 6-8 unstudied fainter symbiotic stars. The targets were a selection of these stars with no reported observations in the AAVSO International Database and with brightnesses that are generally too faint for the automated surveys to follow in any great detail (approximately 13-14th magnitude and fainter). Also some of the stars are located in dense star fields or form close pairs to other stars which again make it difficult for the automated surveys to follow these accurately.

Due to the limitation of my observatory only those stars located between declinations -10 deg and -60 deg can be followed. I worked with the AAVSO Variable Star Index (VSX) administrator, Sebastian Otero, to identify suitable candidates and chose stars that have been neglected both due to their faintness and their southern declination. The fainter stars on the list are generally below 14th magnitude. There are some brighter candidates around 11th magnitude and these ones form close pairs to existing stars and therefore difficult to observe in smaller telescopes.

The stars that were selected and some background information on them are listed below:

AS 201 in Pyxis

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=235345>

It is in a crowded area and little is known about it. There are some observations in the AAVSO database but no period or large amplitude variations are seen.

Hen 3-905 in Centaurus

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=241019>

No observations in the AID. It has also contaminated data in ASAS-3 and it looks like it undergoes outbursts.

ESO 454-30 in Ophiuchus

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=241039>

Another one with no period, sparse data and no observations in the AID.

PN Sa 3-43 in Ophiuchus

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=241035>

No observations in the AID. A couple of Mira-like peaks in ASAS-3 data and that's all.

[ALS88] 2 in Sagittarius

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=249633>

This one seems to have undergone a nova-like outburst in ASAS-3 data but it is faint for the survey.

V1044 Cen

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=8341>

Has a close companion which makes it difficult for wide field surveys

AS276 in Corona Australia

<https://www.aavso.org/vsx/index.php?view=detail.top&oid=241077>

Prior to commencing the programme, I worked with the AAVSO chart team and was able to have comparison star sequences generated for each of these variables.

The intention of the project was therefore to visually monitor this selection of stars at a frequency of approximately 1 visual observation every 5-10 days (similar to the existing long period variable monitor-

ing programme I'm currently running) during their observing season. The observations were to look for the following:

- Evidence of periodicity in the light curve that could be related to or indicative of the orbital period of the symbiotic system. Obviously any periodicity will only become apparent if the system orientation is close to edge on with respect to our line of sight
- Evidence of any brightening or outbursts

All data was submitted to the AAVSO on a monthly basis.

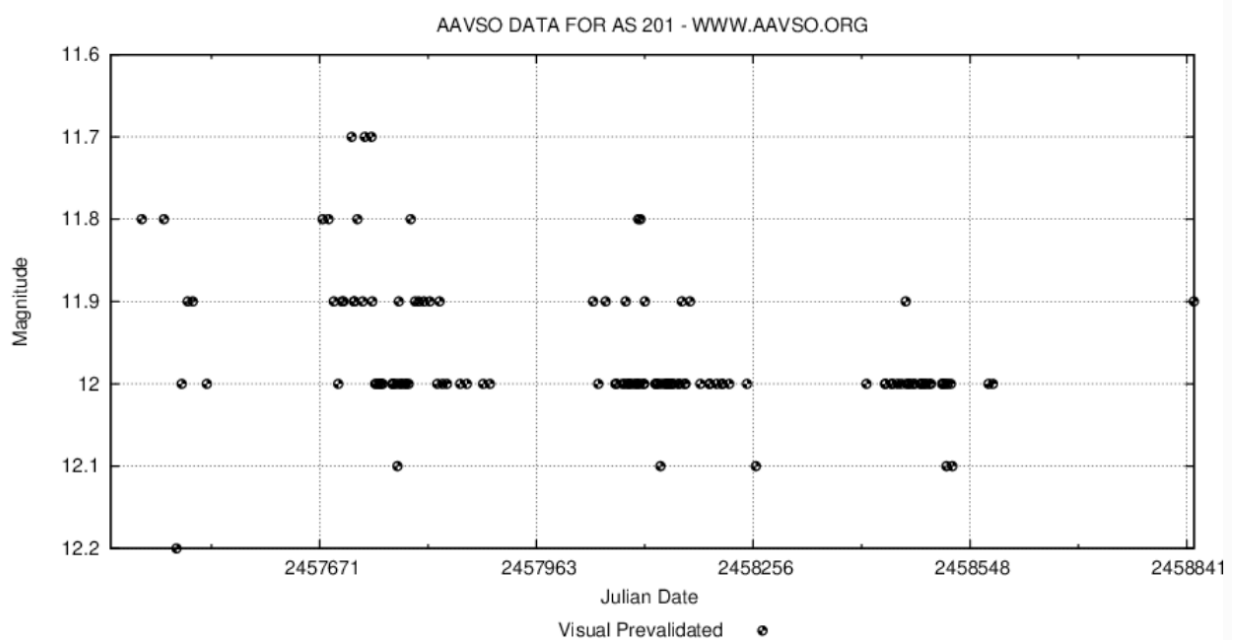
In order for me to get the best out of the project, I needed to re-aluminise the mirror in my existing 16" reflector. The mirror is approximately 27 years old and needed to be recoated in order to be able to fully utilize it to try and follow these stars down to 15th magnitude or better. Funds received from the Edward Corbould Research Fund were used to re-aluminise the primary mirror which was completed in Q3 2016.

Observation results

AS 201 in Pyxis

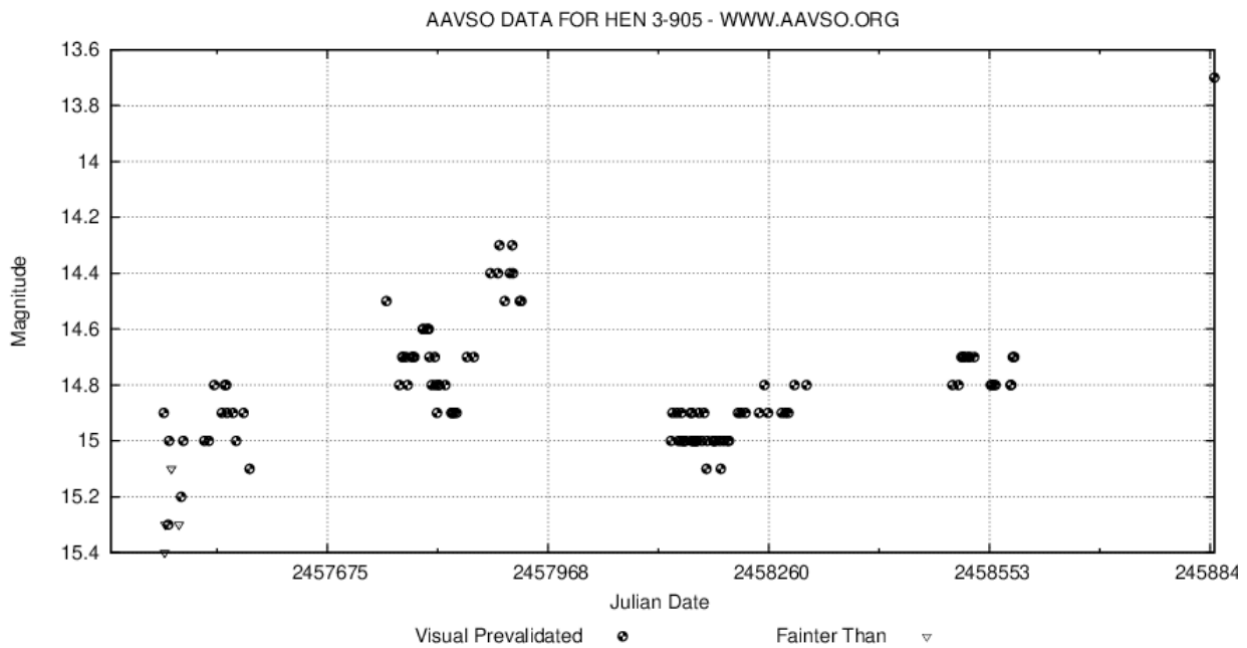
It is in a crowded area and little is known about it. There were some observations in the AAVSO database before I started but no period or large amplitude variations are seen.

A light curve for 2016-2019 based on my observations (open circle) is shown below. I made a total of 131 observations. The star remained relatively constant at around 12th magnitude throughout the 3 year period



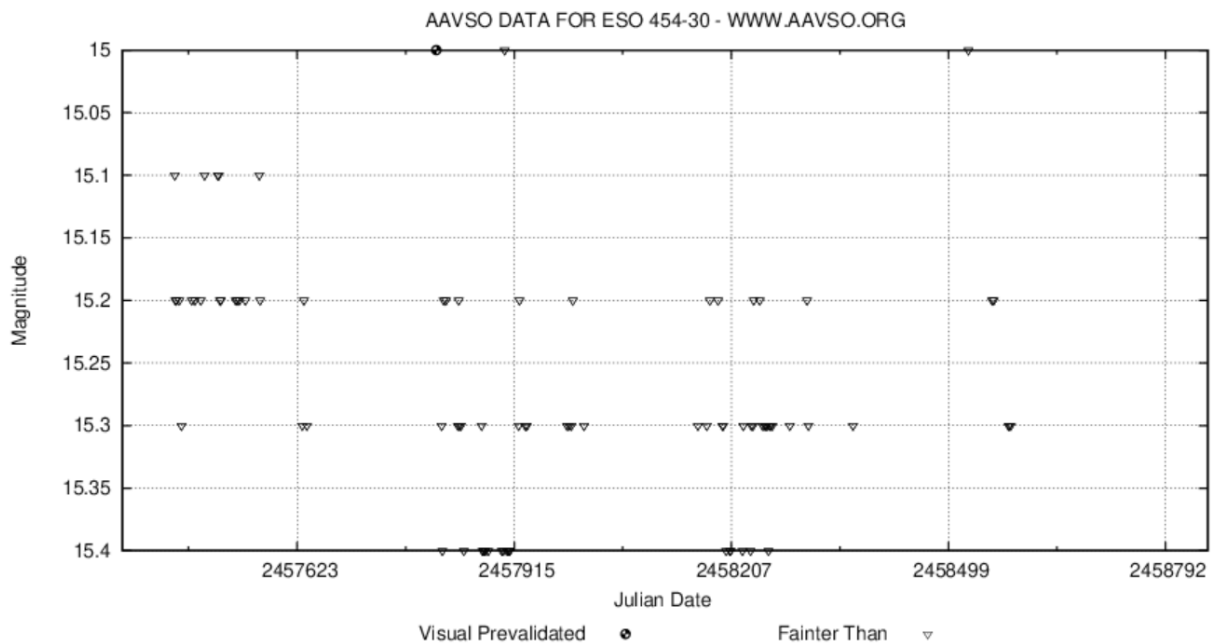
Hen 3-905 in Centaurus

A light curve for 2016-2019 based on my observations (open circle, positive observation and open triangle, negative observation) is shown below. I made a total 121 observations. The star appears to show a gradual increase in brightness from magnitude 15 to around 14.5 by mid 2017 and then a decrease back to around 15th magnitude by mid 2018. However an observation right at the end of 2019 shows a significant increase in brightness by about 1 magnitude. It's unclear as to the rate of increase of brightness it experienced as well as it's future behavior.



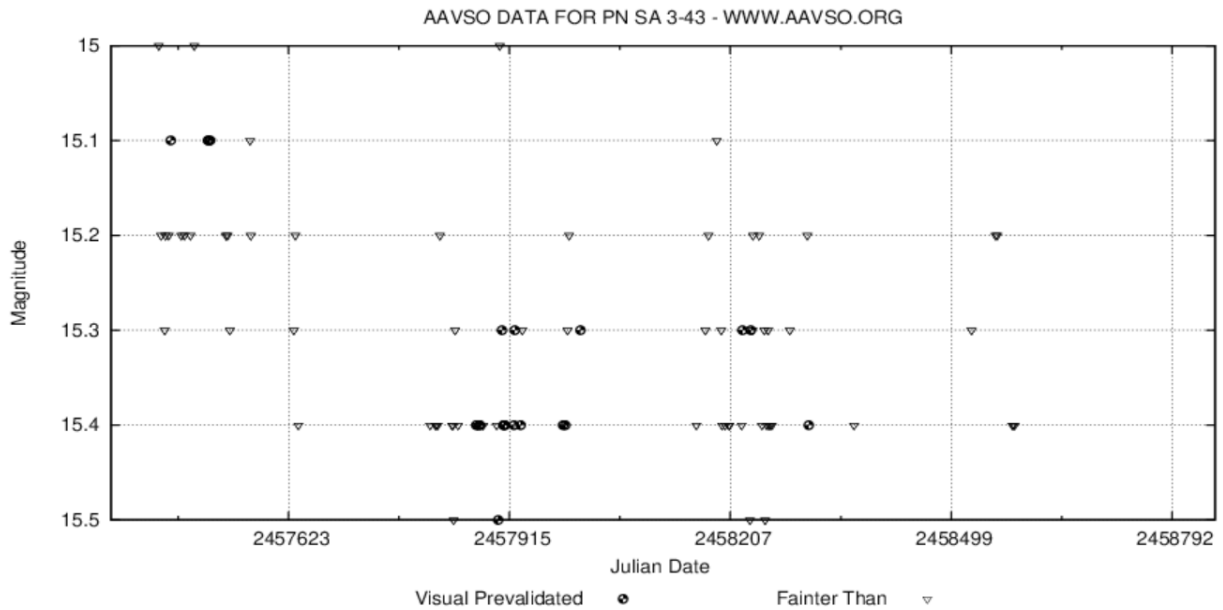
ESO 454-30 in Ophiuchus

A light curve for 2016-2019 based on my observations (open circle, positive observation and open triangle, negative observation) is shown below. I made a total of 88 observations. The star has not been visible during this period with a single positive observation of mag 15.0.



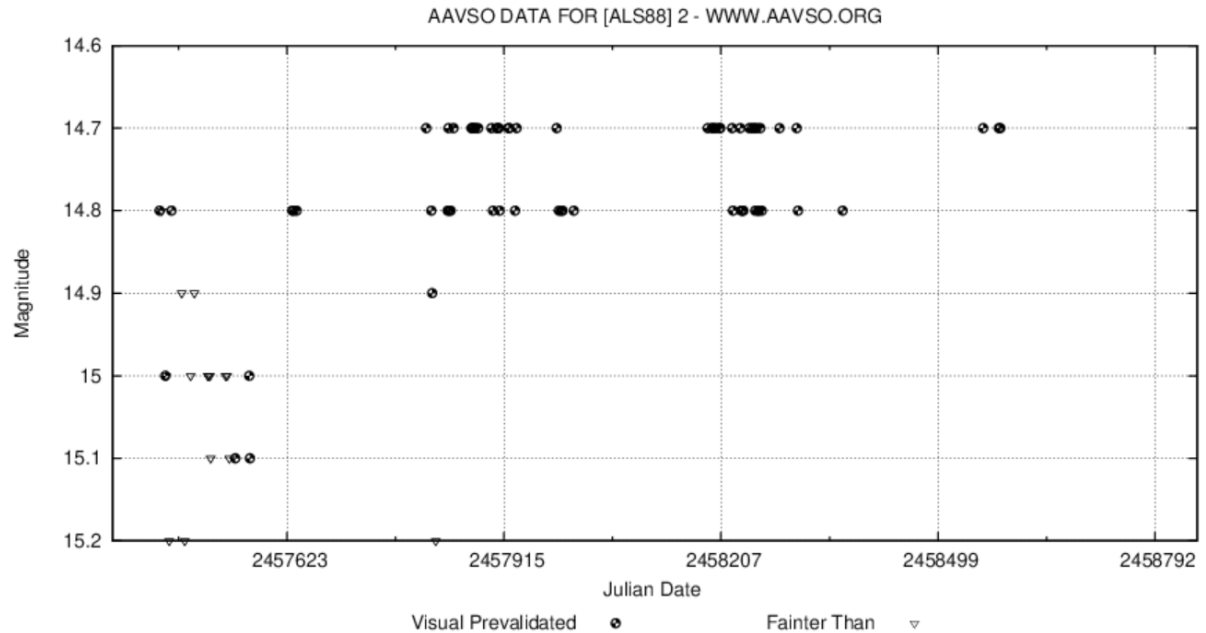
PN Sa 3-43 in Ophiuchus

A light curve for 2016-2019 based on my observations (open circle, positive observation and open triangle, negative observation) is shown below. I made a total of 88 observations. The star has remained faint during this period with some positive detections between magnitude 15.0 and 15.5.



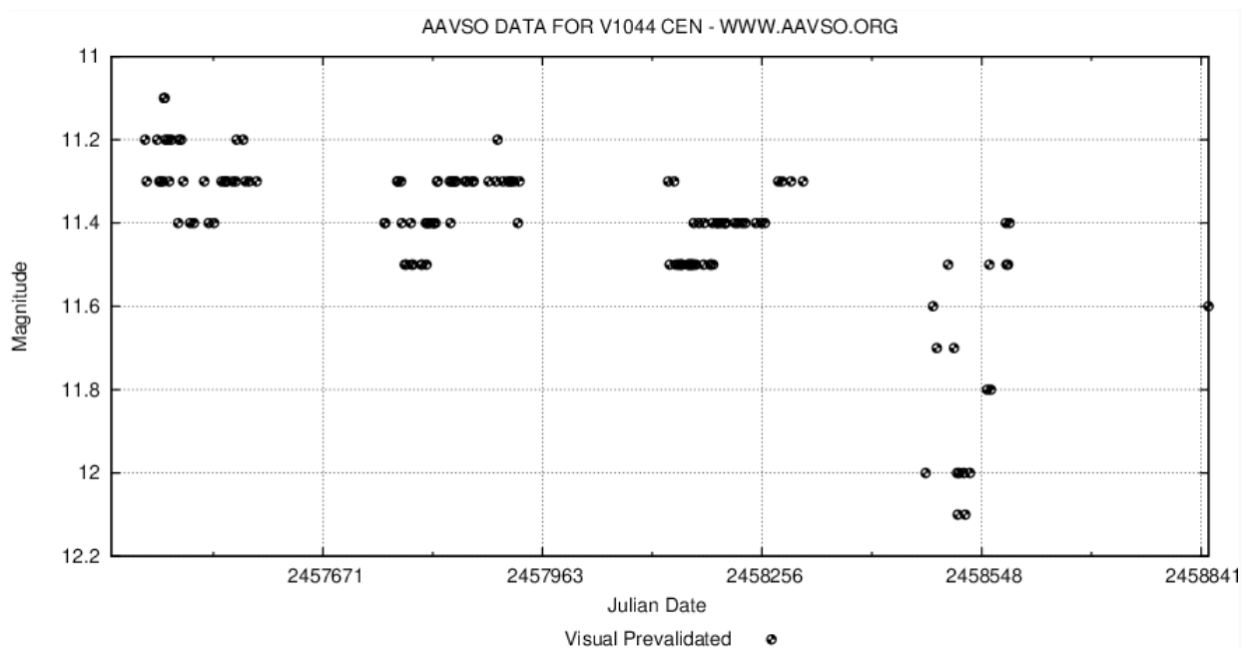
[ALS88] 2 in Sagittarius

A light curve for 2016-2019 based on my observations (open circle, positive observation and open triangle, negative observation) is shown below. I made a total of 81 observations. The star has remained relatively constant in brightness varying between magnitude 15.1 and 14.7 with a possible gradual increase in brightness up to about mid 2017 and then relatively stable since then.



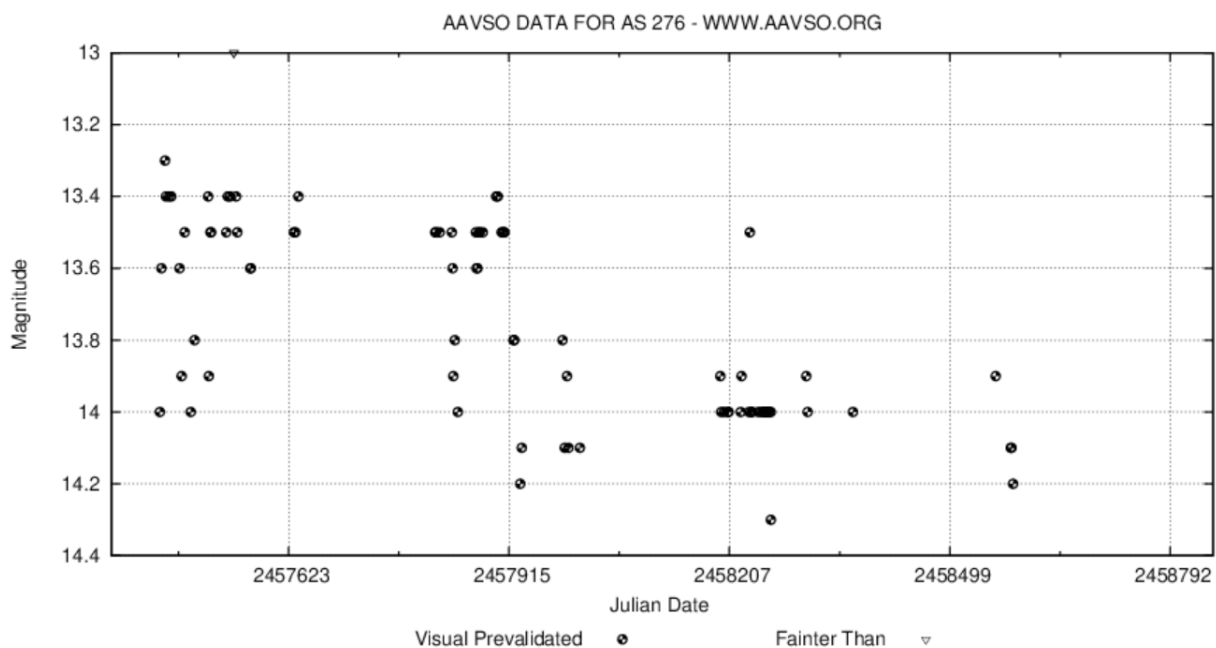
V1044 Cen

A light curve for 2016-2019 based on my observations (open circle) is shown below. I made a total 139 observations. The star remained relatively constant in brightness varying between magnitude 11.1 and 11.5 up until the end of 2018. It then sustained a brief dip in brightness down to 12th magnitude before recovering by April 2019.



AS276 in Corona Australia

A light curve for 2016-2019 based on my observations (open circle, positive observation and open triangle, negative observation) is shown below. I made a total of 83 observations. The star has generally remained around magnitude 13.5 with some dips down to magnitude 14 on several occasions. However it does seem to be have been consistently fainter from early 2018 onwards.



Discussion of results

None of the stars showed any drastic increases in brightness indicating a symbiotic eruption over the 3 year period. This is understandable and seems to support the much longer activity timescale of symbiotic stars compared to other cataclysmic variable types.

A preliminary assessment was conducted to ascertain whether any of the stars displayed periodicity in their brightness variations. There is no conclusive evidence of any periodicity with noisy signals seen in the DFT analysis.

Even though the formal ECRF program has been completed, I do intend to keep monitoring these stars over the longer term.

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A new software tool for O-C diagram analysis – *Mark Blackford*

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The Observed-minus-Calculated diagram is a valuable tool for studying changes in periodic behavior of many astronomical targets, including transiting exoplanets, pulsating stars and eclipsing binary (EB) stars. There are many excellent references in the literature, see for example Sterken (2005) and Axelsen (2014).

My interest in O-C diagram analysis stems from observations I made of the eclipsing binary GG Lup starting in 2011 for Ed Budding's Southern Eclipsing Binaries programme (Budding 2015). When compared with earlier published light curves it was clear that the phase of secondary eclipses relative to primary eclipses was changing slowly in a cyclic manner. This turned out to be due to apsidal motion of the eccentric orbit of the two stars in the system.

Figure 1 shows an O-C diagram of published times of minimum derived from photoelectric, CCD and DSLR observations since 1985. All except two eclipse timings since 2011 are from my observations.

As far as I could determine, the most recent published O-C diagram analysis of GG Lup was Wolf and Zejda (2005) which only included data up until 2004. The more recent data will allow orbital parameters derived by Wolf and Zejda to be further refined. I'll report results of this analysis in a talk at the 6th Variable Stars South Symposium (VSSS6) and eventually in a future VSS Newsletter.

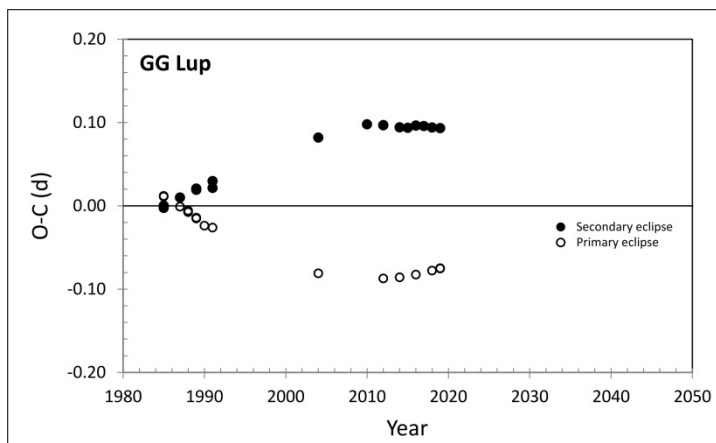


Figure 1. O-C Diagram of GG Lup primary (filled circle) and secondary (empty circles) eclipse timings.

Apsidal motion is one possible cause of apparent or real period change in eclipsing binary systems. Others include mass transfer between the two stars, momentum transfer via magnetic breaking and the gravitational influence of additional stars in the system.

Detailed mathematical models for analysing O-C diagrams have been developed over the years but until recently have not been implemented in easily used and readily available software. In 2014 I provided GG Lup eclipse timing data to Dr Petr Zasche (Charles University, Prague, Czech Republic) who kindly analysed them using his programs. Although freely available, these programs required the rather expensive MatLab software which I did not have access to.

Now Pavol Gajdos (Pavol Jozef Safarik University, Kosice, Slovakia) has provided, free of charge, his OCFit software which allows researchers to construct and analyse O-C diagrams to determine various physical parameters. These include mass transfer rates, orbital periods and ellipticity, mass functions, etc. OCFit is described in Gajdos and Parimucha (2019) so I won't repeat that here. Rather, I'll present my experiences with installing and using the program on my Windows10 tablet computer. It can be run under different operating systems but I have not tried to do that.

OCFit is a stand-alone package written in python, most functions of which can be operated through a fairly intuitive graphical user interface. Not being very software savvy, the GUI option was the obvious choice for me. Pavol provides a compiled GUI version for Windows operating systems that does not require python to be pre-installed on your computer. Simply download the compressed "ocfit-gui-win.zip" file from GitHub¹, extract the contents to a new folder (which I cleverly named OCFit GUI). Two files are extracted, "ocfit-bg.exe" and "ocfit-gui.exe".

Also available are several PDF documents² that you should download and read. The first is "gui-paper.pdf" which is the Gajdos and Parimucha (2019) reference mentioned above. The "gui.pdf" document is a PowerPoint presentation which I found invaluable for working out how to prepare data files and operate the program, and "manual.pdf" is just that, a detailed description of the OCFit program. I found the manu-

al more than a little overwhelming, but those who are more python savvy may wish to delve into the inner workings of the software.

To launch the program double click on the “ocfit-gui.exe” file. A text box opens, followed several seconds later by the OCFit GUI window (Figure 2). Most buttons on the GUI window are greyed out initially, only becoming active after completing the required steps.

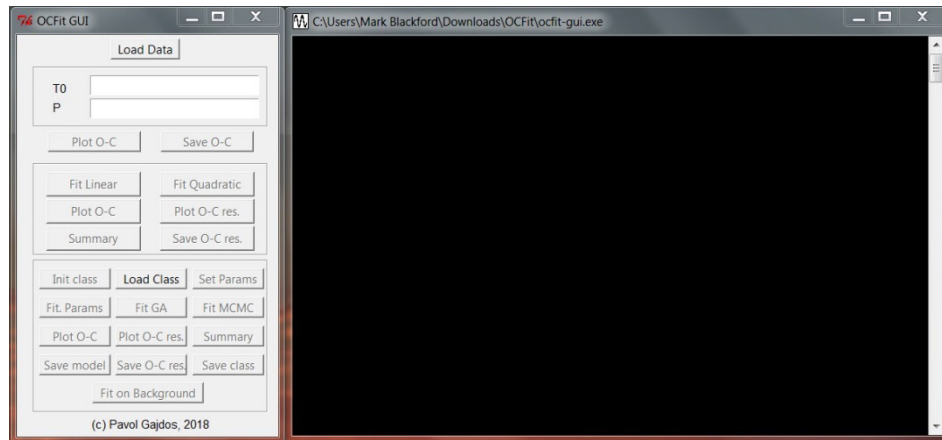


Figure 2. Opening screen when OCFit is first launched.

The first step is to create a data file containing information necessary for constructing an O-C diagram for the particular star you are interested in. This is a text file with extension “.dat” consisting of 1 or more columns delimited by a special character of your choosing (I use “,” comma). See Section 5.1 of Gajdos and Parimucha (2019) for an explanation of what can be included in a data file.

I’ll use eclipse timing data for XY Leo from the Lichtenknecker Database³ to illustrate key points. Only data derived from electronic observations will be used, not visual or photographic which are much less accurate. XY Leo is a well-studied quadruple system composed of a ~0.284 day period eclipsing pair and a ~0.805 day period non-eclipsing pair (Djurasevic, et al. 2006). The two pairs are in an elliptical orbit about each other with a period of 19.59 years (Yakut, et al. 2003).

A simple data file for XY Leo is shown in the left panel of Figure 3 where the first row is the header and subsequent rows contain heliocentric Julian date of observed times of minimum (the O part of O-C) and a weighting factor. Columns are delimited by a comma. I create data files in Microsoft Excel and save them as comma separated variable (.csv) files, then change the extension to .dat in Windows Explorer.

The specific layout of the data file (right panel Figure 3) needs to be defined before it can be loaded into OCFit. For the XY Leo data.dat file the fields are Delimiter = “,” Header = 1 row, Obs time = column 0, Weight = column 1. Tick boxes to the right of the last two fields need to be activated.

Next we need to input a zero epoch date and period into the T0 and P fields, respectively. These are used to calculate the expected time of minimum (the C part of O-C). Yakut, et al. (2003) reported values of T0 = 2435484.0239 (HJD) and P = 0.28410229 (d) which produce the O-C diagram in the left panel of Figure 4. The discontinuity at the end of the curve is due to O-C values becoming too large compared with the orbital period of the eclipsing binary.

A continuous O-C curve (right panel Figure 4) is produced when T0 = 2455953.9161 (HJD) which is a measured primary eclipse minimum by Diethelm (2012). Filled and empty circles are primary and secondary eclipses, respectively.

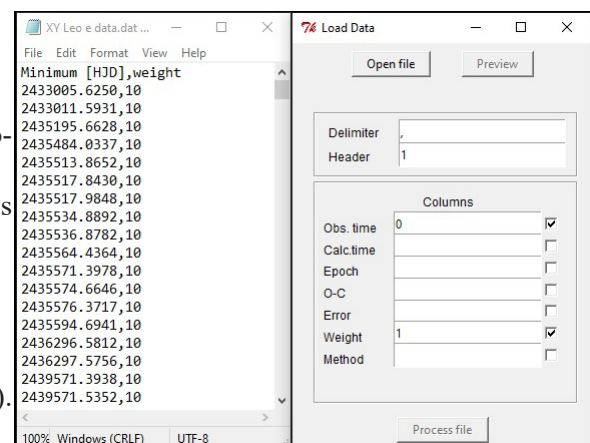


Figure 3. Left: XY Leo data file containing observed eclipse timings. Right: Load Data window configured to import the data file.

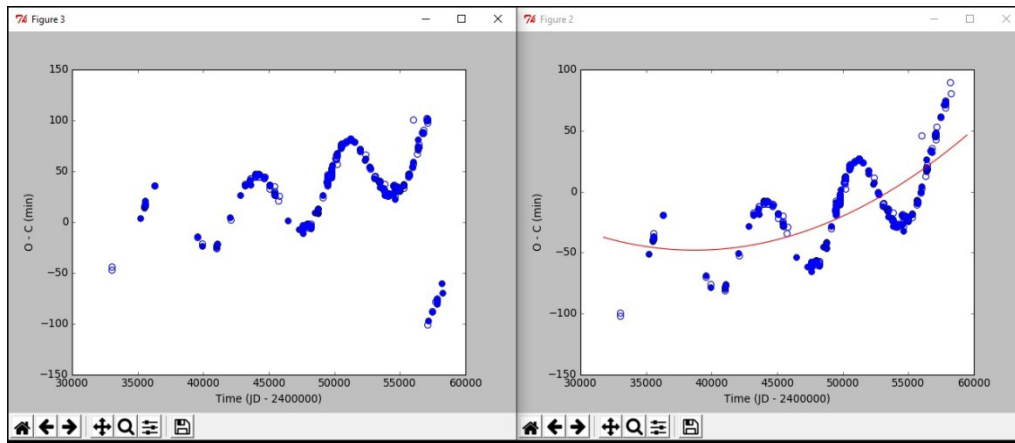


Figure 4. Left: XY Leo O-C diagram using $T_0 = 2435484.0239$ (HJD) and $P = 0.28410229$ (d). **Right:** O-C diagram using $T_0 = 2455953.9161$ (HJD) and $P = 0.28410229$ (d).

The sine wave is due to the eclipsing pair moving closer toward then further away from the observer as they orbit the distant pair. This is called the Light Time Effect (LiTE).

In addition to the sinewave there is a longer term parabolic curve which may be due to a changing orbital period of the eclipsing pair or the LiTE from yet another star in the system in an even wider orbit. For this article I'll assume the former situation.

The model fitting functions of OCFit are used to refine the orbital period (and rate of period change) of the eclipsing binary, determine the period and ellipticity of the wide orbit of the non-eclipsing pair about the eclipsing pair, and estimate the mass ratio of the two pairs. This is a multi-step process starting with a quadratic fit to model the parabolic component. The quadratic model (red line) is shown in the right panel of Figure 4.

In the Model Parameters window (Figure 5) we select the type of analysis we wish to perform. OCFit currently includes nine common models of periodic O-C changes. For XY Leo we want LiTE3Quad which models the LiTE for a 3rd body plus a quadratic term. All relevant parameters are listed in the lower section of the window. Greyed out parameters are used in other model options. See Gajdos and Parimucha (2019) for definitions of these parameters.

The T_0 and P fields are pre-populated with the initial refined values determined above. OCFit does not require initial values for the other parameters. However we do need to input reasonable Min and Max values and step sizes to constrain the fit. Tick boxes to the right of each line need to be selected to include those parameters in the least squares fit. Figure 5 shows the values I chose to use for XY Leo.

The next step is to do a relatively crude, but fast, fitting of the LiTE3Quad model to determine approximate values for all parameters. This is done in two parts. As explained in Gajdos and Parimucha (2019), OCFit uses Genetic Algorithms (GA) to determine starting parameter values which are used as initial values for a Markov Chain Monte Carlo (MCMC) routine to get final values together with their statistically significant uncertainties.

We then take these parameter values and perform MCMC again with much finer step sizes. On my tablet computer this took ~30 minutes for the XY Leo analysis. Further iterations of MCMC, with restricted ranges and finer step sizes, may produce improved results. Figure 7 shows my final O-C diagram and model as well as the value and error of the fitted parameters. A

param.	value	min.	max.	step	fit
t0	2455953.92794	2455953	2455954	0.001	☒
P	0.284103778657	0.25	0.30	0.0001	☒
Q		-1e-11	1e-11	1e-14	☒
a_sin_i3		1	4	0.01	☒
e3		0	1	0.01	☒
w3		0	6.28	0.01	☒
t03		2450000	2460000	10	☒
P3		5000	10000	10	☒
a_sin_i4				0.01	☐
e4		0	1	0.01	☐
w4		0	6.28	0.01	☐
t04				10	☐
P4				10	☐

Figure 5. Model Parameters window with initial settings appropriate for XY Leo.

comparison of my results with those reported by Yakut, et al. (2003) is shown in Table 1. Our data sets were not identical so some divergence is to be expected. Never-the-less, there is reasonable agreement for most parameters.

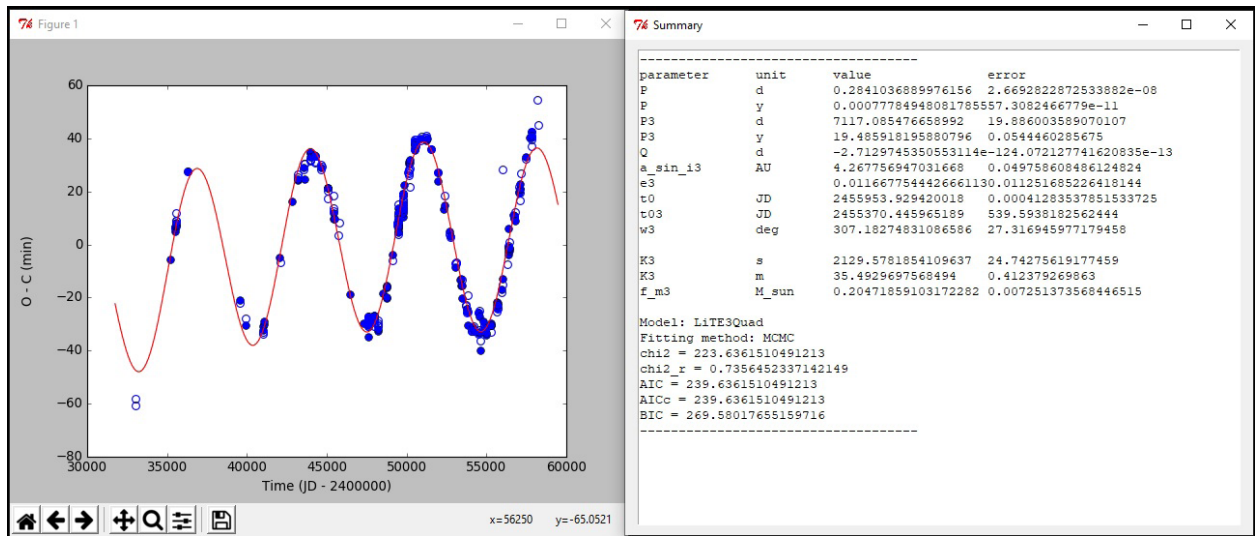


Figure 6. Final O-C diagram with LiTE3Quad model (red line) and derived parameters with errors.

Table 1. Comparison of parameters derived for XY Leo from O-C diagram analysis.

Parameter	Yakut et al. (2003)	This study
$P1$ (day) - period of eclipsing pair	0.28410229(1)	0.28410369 (3)
$P3$ (day) - period wide orbit	7156(49)	7117 (19)
e - wide orbit eccentricity	0.12(1)	0.012 (11)
$A \sin I$ (AU) – wide orbit radius	4.083(5)	4.27 (5)
$f(m)$ (solar mass) – 3 rd body mass function	0.177(2)	0.205(7)

Since I am no expert in using OCFit the process described above may not be the most appropriate, however the results are encouraging. I found the process of installing OCFit very simple and the GUI layout fairly intuitive. Documentation was adequate for me to get started using the program without too much problem. However, a beginner's guide to best practices when using OCFit to analyse O-C diagrams would be useful.

My VSSS6 talk will focus on several interesting southern eclipsing binaries that I've been observing, illustrating how the shape of each O-C diagram is influenced by the specific configuration of the system.

¹ <https://github.com/pavolgaj/OCFit/releases/tag/0.1.2-alpha>

² <https://github.com/pavolgaj/OCFit/tree/master/manuals>

³ <https://www.bav-astro.eu/index.php/veroeffentlichungen/service-for-scientists/lkdb-engl>

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Lessons from the field of FR Ceti

Introduction

FR Ceti is a 6th magnitude A0III variable star at RA 02 24 58.4 DEC -02 46 48, with a listed amplitude of 6.31 to 6.65 magnitude in V. It is included in the seventh and last category of the General Catalogue of Variable Stars (GCVS), named ‘Other Symbols’, which are: BLLAC, DST, GAL, L:, QSO, S, *, +, and :

Ninety three stars, including FR Ceti, are listed under the * symbol. They are described as:

‘Unique variable stars outside the range of the classifications described above. These probably represent either short stages of transition from one variability type to another or the earliest and latest evolutionary stages of these type, or they are insufficiently studied members of future new types of variables.’

When I noticed FR Ceti in late 2019 while browsing this part of the GCVS, it was reasonably placed for observing, and I was able to take images on five nights from late November to early December 2019. Bushfires were prevalent in New South Wales and Queensland at this time. Smoke haze was often present, varied in density, and affected the results.

Methods

Images of the field of FR Ceti binned 2x2 were taken through a V filter with a ZWO ASI1600MM monochromatic CMOS astronomical camera cooled to -10 deg C. Observing nights were the 29th November, and the 2nd to the 5th December, with the last images captured in the early hours of the 6th December.

The telescope was a SkyWatcher BD ED120 refractor at f/7.5, and the equatorial mount was autoguided throughout. Flat fields were taken every night, and dark frames were taken when appropriate, as the exposures changed during the first three nights. On the first night, exposures of 15 seconds at unity gain (1e-/ADU) were short enough to avoid saturation, but photometric precision for the variable and the check star was poor. The gain settings of the camera were therefore changed, with the aim of increasing the lengths of exposures and hopefully improving the precision. On the second night, the gain was set to 2.75e-/ADU and the exposures were 45 seconds.

On the third and subsequent nights the gain was set to the ‘maximum’ of 5e-/ADU and the exposures were 120 second. Images were defocused, and the aim was to defocus enough to prevent saturation of an image of a 6th magnitude star, but still to keep the counts for that star in the high part of the linear range of the sensor. However, an error made in the pre-meridian flip settings on the night of the 2nd of December, resulted in saturated pixels in images of FR Ceti in many of the frames taken.

Figure 1 shows the field of view of FR Ceti. The comparison and check stars are labelled, with magnitudes of about 8.2 and 8.8 respectively in V. A brighter 7th magnitude star in the field (just below the ‘Check Mag 88’ label in Figure 1) was not used as a comparison star, as it is listed as a spectroscopic binary in SIMBAD.

Table 1 lists data from SIMBAD for the variable, comparison and check stars. There is a large colour index difference between the variable and comparison star. However, this was accepted so that the brighter of the standard stars could be used as the comparison.

Star	Star Name	RA	DEC	V	V Err	B	B Err	B-V
Var	FR Ceti	02 24 58.4	-02 46 48.1	6.335	0.010	6.322	0.015	-0.013
Comp	HD15032	02 25 13.1	-03 13 03.0	8.19	0.01	9.62	0.03	1.43
Check	HD14905	02 24 13.3	-03 14 16.6	8.83	0.02	9.37	0.03	0.54

Table 1. Data from SIMBAD for the variable, comparison and check stars in the FR Ceti field of view.

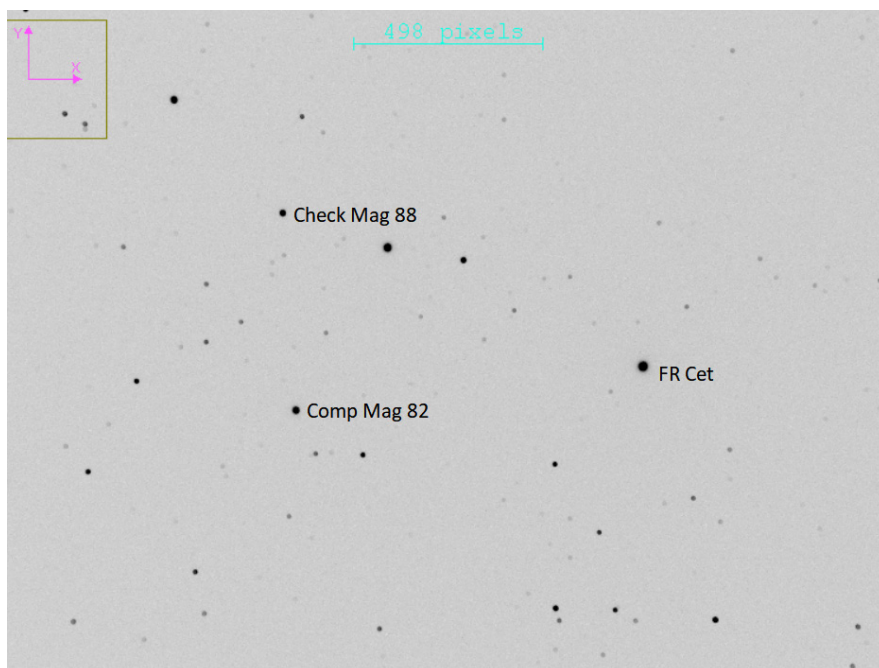


Figure 1. *The field of FR Ceti with the variable, comparison and check stars labelled. North is right, east is up. This is a screen shot of a defocused image binned 2x2 taken with the ZWO ASI camera and displayed in AstroimageJ.*

Results

Figure 2 shows the light curves of the variable and the check star for each of the 5 nights. Note that the scales of the Y-axes differ among the panels in order to show the light curves optimally. The panels are described in turn.

Panel A, exposure 15 sec, gain $1e^-$ /ADU, 29 November. FR Ceti does not appear to vary, but photometric precision is poor, even though the degree of defocus was set so that the counts were toward the upper part of the linear range of the sensor. The exposure and gain were therefore both reset before the next night's observations. See panel B.

Panel B, exposure 45 sec, gain $2.75e^-$ /ADU, 2-3 December. Photometric precision is improved. The variation in the magnitude of FR Ceti prior to the meridian flip is spurious, because the degree of defocus of the images was not enough to prevent saturation of some pixels. This was corrected during the meridian flip, after which FR Ceti appears to be constant. The exposure and gain were again reset before the next night's observations. See panel C.

Panel C, exposure 120 sec, gain $5e^-$ /ADU, 3-4 December. There is a dramatic change in the variable star, which faded to 7th magnitude before these observations commenced, then brightened through the night. The gap in the data occurred because images were accidentally deleted. The precision for the check star appears to be good, but the Y-axis scale is different from that of panels A and B in order to accommodate the variable star light curve. See panel D, showing the data plotted with a different scale on the Y-axis.

Panel D, exposure 120 sec, gain $5e^-$ /ADU, 3-4 December. Same night as for panel C, but with the Y-axis scale adjusted to have the same range as panels A and B. Precision for the check star has improved even further. The latter part of the check star light curve shows deterioration in the precision.

Panel E, exposure 120 sec, gain $5e^-$ /ADU, 4-5 December. FR Ceti shows irregular but more or less progressive brightening during the hours of observation. The early part of the check star light curve is not optimal.

Panel F, exposure 120 sec, gain $5e^-$ /ADU, 5-6 December. Smoke haze affects the early parts of the variable and check star light curves. The variable brightens progressively for most of the hours of obser-

vation. The early part of the check star light curve is not optimal.

Saturation of pixels occurred only for the variable star, and only during the pre-meridian flip observations on the night of the 2-3 December. No saturated pixels were identified on any other night.

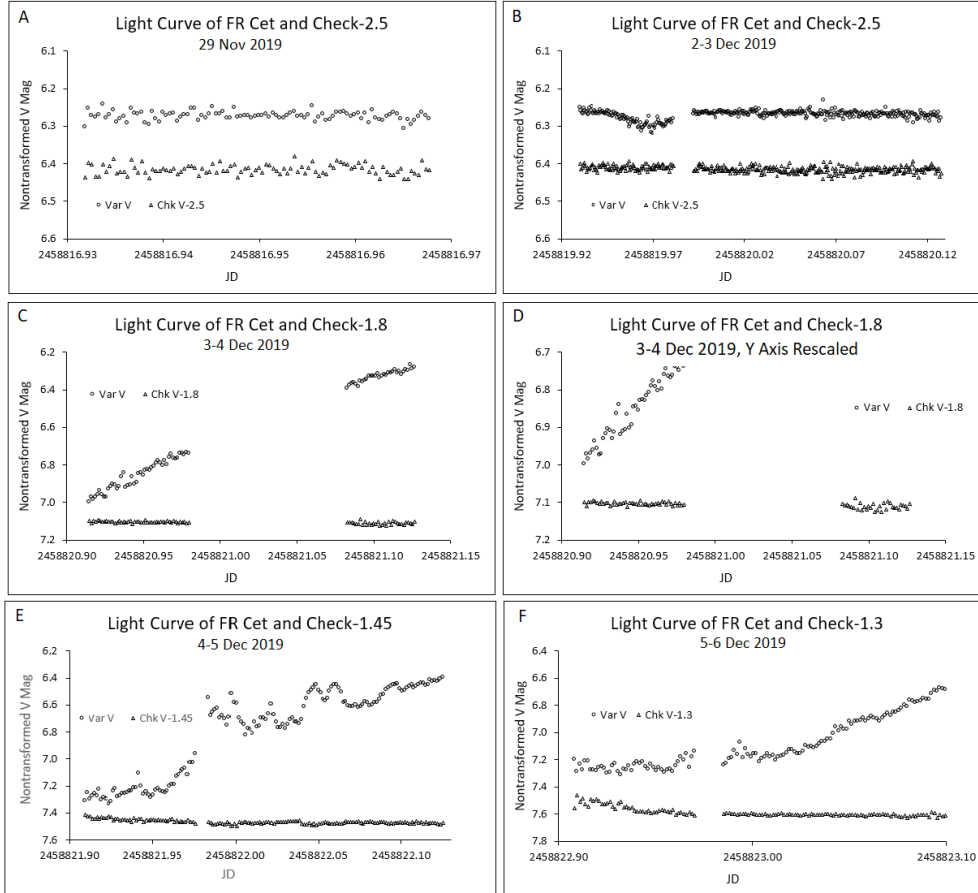
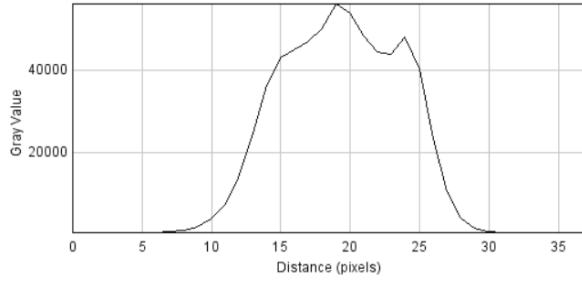


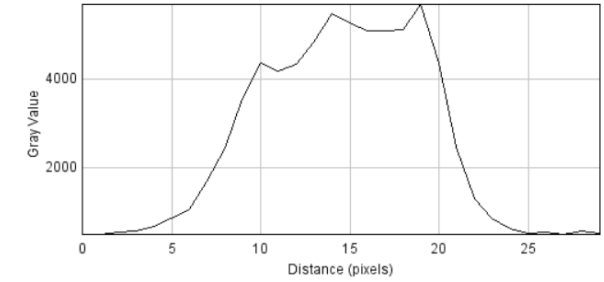
Figure 2. Light curves of FR Ceti and the Check star for all 5 observing nights. Note that the scales of the Y-axes differ among the panels and the check star magnitudes are scaled differently in the upper, mid and lower panels so that the check star light curves can be seen near the light curves of the variable. Panels A to C, E and F are the complete light curves from all observations taken on each night. In Panel D, the range of the Y-axis has been rescaled to match panels A and B, so that the precision of the measurements of the check star can be compared visually.

Figure 3 illustrates line profiles of the variable star (panels on the left) and the check star (panels on the right) in representative images from each of the first three nights. The upper panels thus show the line profiles at a gain of $1e^-/ADU$ and exposure of 15 seconds; the mid panels a gain of $2.75e^-/ADU$ and exposure of 45 seconds; and the lower panels a gain of $5e^-/ADU$ and exposure of 120 seconds. The maximum counts per pixel for the variable star in the upper and lower panels are close to the upper region of the linear range of the sensor, found in previous testing to be 62,132. The maximum count for the variable in the mid panel, approximately 62,800, indicates that pixels were saturated. Many images taken before the meridian flip on this night (2nd and 3rd December) had saturated pixels, resulting in spurious variation in the FR Ceti light curve. After the meridian flip, the degree of defocus was increased, there were no saturated pixels, and no variation occurred in the magnitude of FR Ceti.

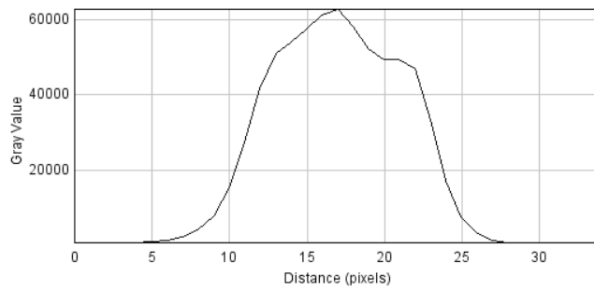
FR Cet Line Profile, gain 1e/ADU, 15 seconds
Maximum count ~ 56,000/pixel



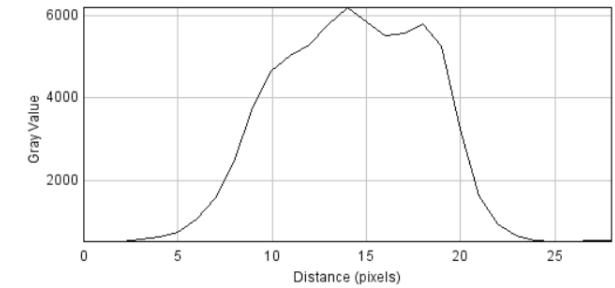
Check Star Line Profile, gain 1e/ADU, 15 seconds
Maximum count ~ 5,600/pixel



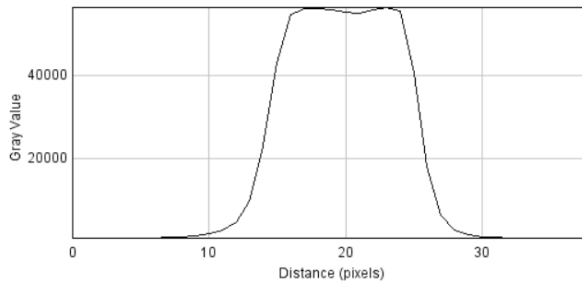
FR Cet Line Profile, gain 2.75e/ADU, 45 seconds
Maximum count ~ 62,800/pixel



Check Star Line Profile, gain 2.75e/ADU, 45 seconds
Maximum count ~ 6,400/pixel



FR Cet Line Profile, gain 5e/ADU, 120 seconds
Maximum count ~ 56,000/pixel



Check Star Line Profile, gain 5e/ADU, 120 seconds
Maximum count ~ 15,800/pixel

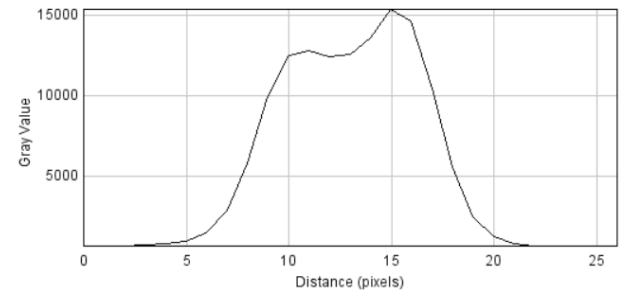


Figure 3. Line profiles of representative images of the variable star and the check star from each of the three observing nights.

How much, then, did the precision of the check star measurements improve as the camera settings were adjusted? Table 2 shows the mean and standard deviation for the check star magnitudes for each of the first three nights (9th November, 2nd-3rd December, and 3rd-4th December). Only measurements taken prior to meridian passage of the star are included. There is clearly a progressive improvement in the precision of the photometry as the exposures and the camera settings are changed.

Table 2. Means and standard deviations of the check star magnitudes prior to meridian passage on each of the first three nights of observation.

Date	Mean of Check Star Magnitudes	Standard Deviation of Check Star Magnitudes
29 November	8.915	0.013
2 December	8.910	0.007
3 December	8.902	0.004

Figure 4 (left panel) shows approximately 100 days of data for FR Ceti captured by the All-Sky Automated Survey for Supernovae (ASAS-SN) in the Sloan g passband. Light curves of FR Ceti from the author's data in V from all five observing nights are in the right panel of the same figure. The range of magnitudes appears to be consistent between the two panels, given that the passband of the Sloan g filter is roughly equivalent to the combined Johnson V and B passbands.

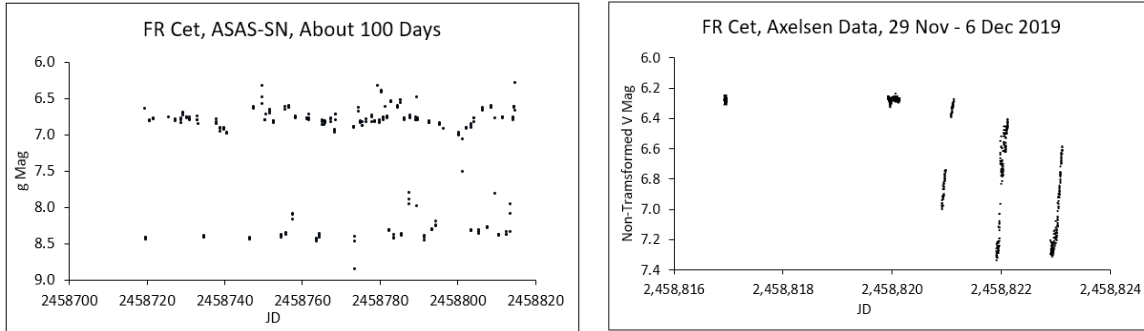


Figure 4. *Light curves of FR Ceti. The panel on the left is from ASAS-SN g, over a time of about 100 days. The panel on the right is from the author's data.*

Discussion

There are two parts to this study. The first is the reporting of observations of the enigmatic variable star FR Ceti, which do not show light curves of any recognizable type of variable, but reveal a time frame of about one day, with approximately parallel light curves on successive observing nights (right panel in Figure 4, author's data). No further conclusions can be drawn at this time from these preliminary observations.

The second part is the reporting of the effects of the adjustments to the settings of the ZWO ASI camera to optimise the photometric precision for both the variable and check star. If precision in time series photometry is not optimal, adjustments that may improve it, individually or in combination, are:

- Increasing the exposure
- Further defocusing the image
- Resetting the gain (increasing the number of e^- /ADU)

Experience has shown that, whatever the settings, the best precision is achieved with this camera when the counts per pixel for the brightest star measured are in the upper part of the linear range of the sensor. Increasing the exposure too much will, of course, saturate pixels. Further defocusing the image, spreading the signal from the star over more pixels, allows the exposure to be lengthened further without saturating the image.

Resetting the gain in the manner noted above (by increasing the number of e^- /ADU) will also decrease the counts per pixel. However, quantization errors can occur, since more than one electron released by incident photons on one pixel is needed to increase the count by one. But when used in appropriate circumstances, the effects are favourable, particularly in the presence of a high dynamic range, which applies to the field of FR Ceti studied and reported herein. The variable was brightest at magnitude 6.25, whereas the check star magnitude as measured was 8.9.

Conclusion

In a previous paper (VSS Newsletter, October 2019), it was shown that the ZWO ASI1600MM camera has a linear range to near full well capacity, and is capable of precision photometry. The present preliminary work shows how careful tuning of exposure length, degree of defocus of the images and gain setting can optimise the camera's performance.

The art and frustrations of estimating eclipsing binary minima

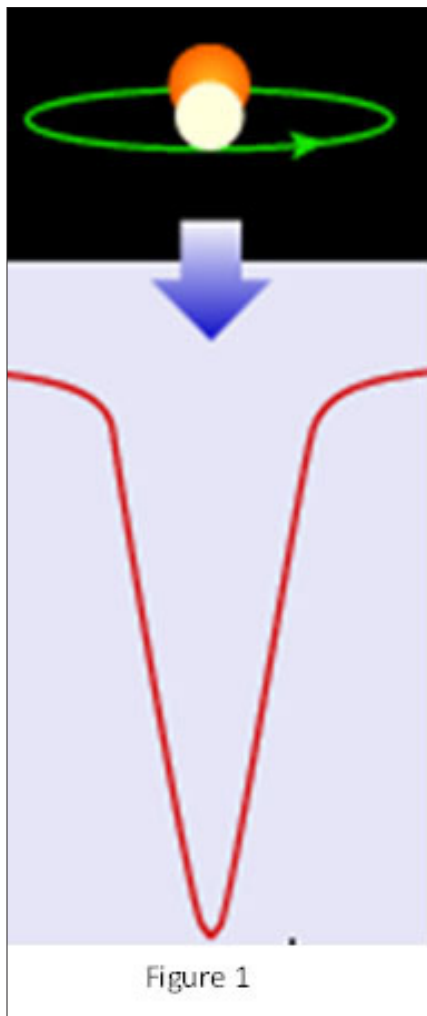
Abstract

Estimating the minimum of an eclipse light curve has practical and theoretical difficulties. The two common methods - Kwee & van Woerden and polynomial fitting - can disagree significantly. This talk will discuss various methods, their good and weak points, and when and how best used.

What are we measuring?

The aim for most purposes is to obtain the time of mid-eclipse (epoch). Why? By itself one eclipse timing is not of great interest; but when a series of eclipse times are available, two very important quantities can be obtained, the period, and period change. Bear in mind that the time of mid-eclipse (epoch) may differ from the time of minimum (ToM), but the latter is all you can measure.

The period can be obtained from a series of ToMs by applying the least squares linear regression method (LSM) to them. This only works if the period is already well enough established for us to obtain a series of pairs of values <orbital cycle number, ToM>. The *VSS minima form* is an Excel template that will calculate this.



Alternatively, measuring individual minima can be avoided entirely by folding a set of light curves of eclipses obtained on different nights. Again a roughly established period is needed so the folding algorithm can find the best fit near that value. The result is a period value which, as with the LSM, finds the best fold for all the curves in the dataset – but it does assume P is constant over the duration of the dataset.

This method can be applied to data acquired by patrol telescopes, eg ASAS3, which may last for years. Its downside however is that it does not supply any actual ToMs. At least one such needs to be known with as much accuracy as possible – and used as the *zero epoch*, E_0 . Together with a period determination P as described above, we can predict any past or future epoch:

$$E_n = E_0 + n \times P \quad (1)$$

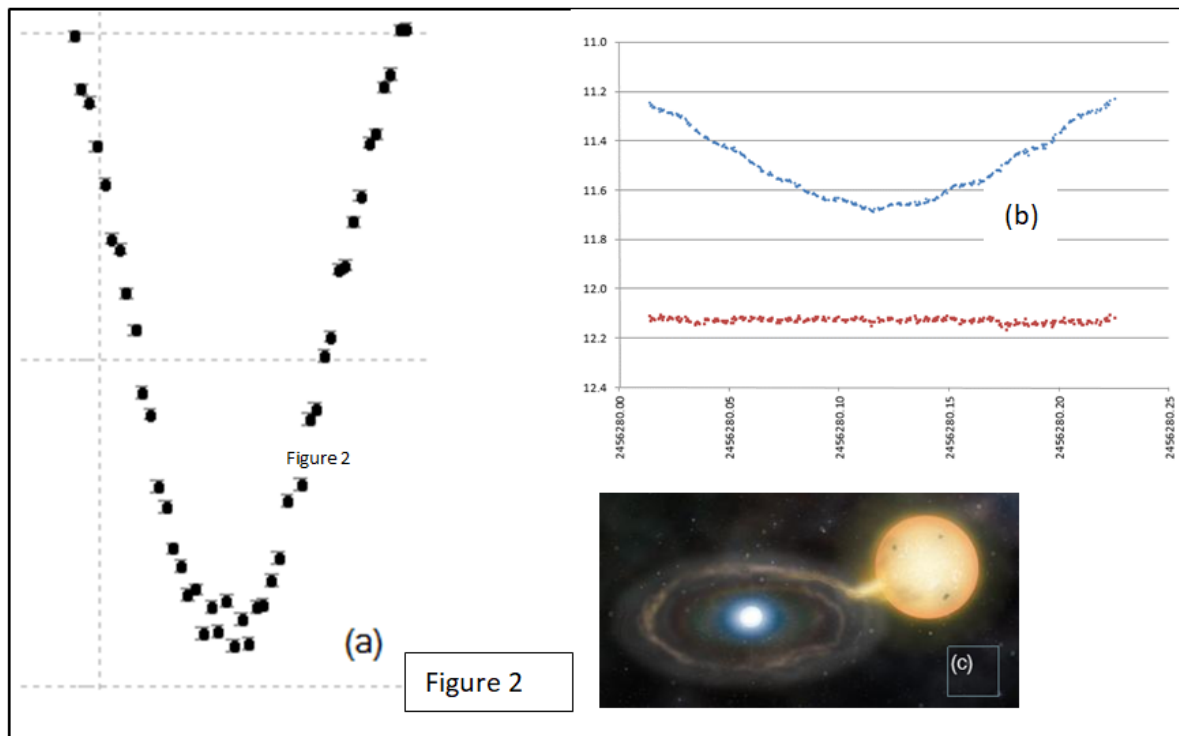
where n is the number of orbital cycles since E_0 .

So much for finding individual minima times and the period. Inspection of observed times over several years may reveal a systematic discrepancy from the times predicted by equation (1). A study of these may point to such important features as a long-term period increase or decrease, or even a cyclic change in period. This is a powerful probe into astrophysical processes such as mass loss or transfer between the two stars, or the presence of a third body orbiting in the system. But it relies on knowing as accurately as possible many ToMs.

How do we obtain the time of mid-eclipse? It may seem that the obvious answer is that minimum light must occur at mid-transit as in the rather idealized Figure 1. But using the minimum point as indicating mid-eclipse isn't that simple. In Figure 2, the typically

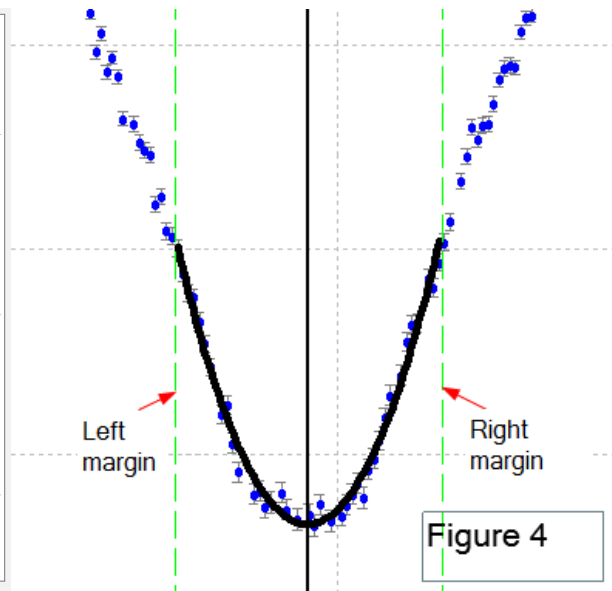
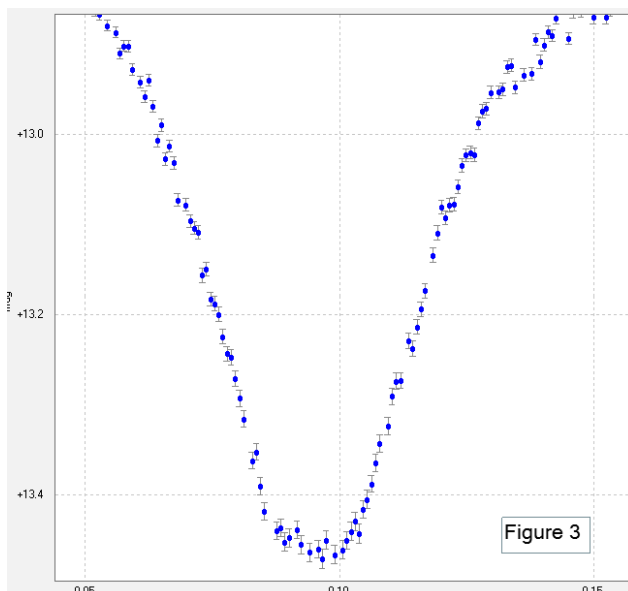
ragged distribution of data points around the minimum in (a) shows the difficulty of pinpointing the lowest point. (b) shows what happens if the transiting star is pulsating. And (c) shows how irregular photospheres, discs, bright spots streams and starspots could offset minimum light from mid-eclipse. So finding

the minimum point does have its problems. For most purposes however it's the best we can do.



Polynomial Fitting

The depths of an eclipse curve, as in **Figure 2a**, look very much like a parabola. This gives some hope that the eclipse curve might be well matched by a polynomial, whose minimum is the point of central eclipse. In fact an entire eclipse curve — usually bell-shaped — does not look like a parabola (**Figure 3**). That suggests you should be chasing higher-order polynomials — which have nothing to do with the geometry of the transit — to get a good fit.



PERANSO (www.peranso.com) has a curve-fitting routine that will make polynomial fits of arbitrary order. It will find the polynomial (of the order you specify) that fits the curve best between a left and right margin you specify, as in **Figure 4**. The best fit is found by a statistical fitting routine that finds polynomial coefficients that yield the smallest residuals — another least-squares fitting routine. Note it does not follow that the minimum of the polynomial curve sits at the minimum of the data curve — residuals might be minimized if it is considerably off to one side in an asymmetrical data curve (and most are asymmetrical

to some extent). Let us look at some examples, all from PERANSO.

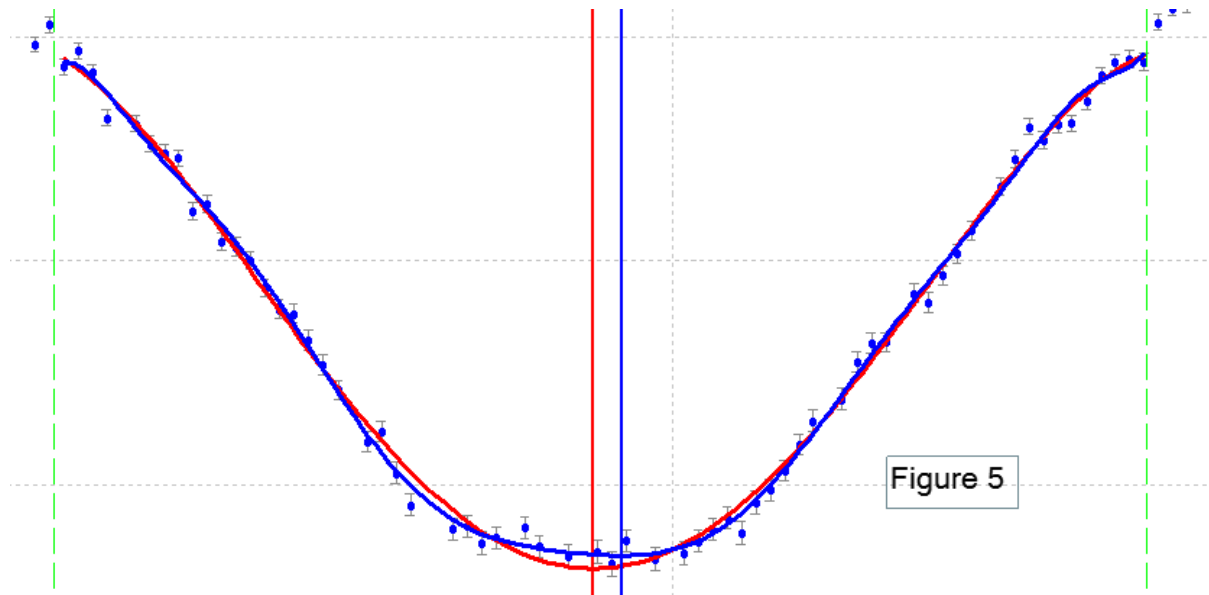


Figure 5 shows in red a 5th-order polynomial fit that seems to find a reasonable minimum, marked by the vertical red line. However it's a poor fit to many of the data points, so the analyst here fitted a 13th-order polynomial, which follows the data far better. That included the data points around minimum which as usual show some scatter due to noise. The result is a polynomial minimum (marked by the blue vertical line) offset from the red minimum by 138 seconds – well outside the time-stamp errors. The lower order minimum (red) is plainly far better. One problem is that by chasing the vagaries of the data curve (“over-fitting”), the more flexible high-order polynomial departed a long way from a theoretical curve that would be generated by the geometry of the eclipse. The red curve represents the geometry better. Another problem is that the data points mark out a decidedly asymmetric floor which is not due to noise (as other datasets of this particular binary attest). The higher-order (blue) polynomial looks for the low point in the floor; whereas the 5th-order one doesn't have the freedom to follow such asymmetries very well, so finds a minimum that is more due to the symmetry in the sides of the curve.

So how should we use polynomial fitting to represent the underlying eclipse geometry rather than the vagaries of noisy data, starspots, pulsations and the like? In my experience it is useful to start with a second-order polynomial (plain old parabola) and fit it to the lower part of the curve where it's convex outwards. You adjust the margins till you get a parabola that fits the whole region well, as in **Figure 6(a) and (b)**, where the black curve on narrower margins (right) is a better fit than the red on wider margins (left).

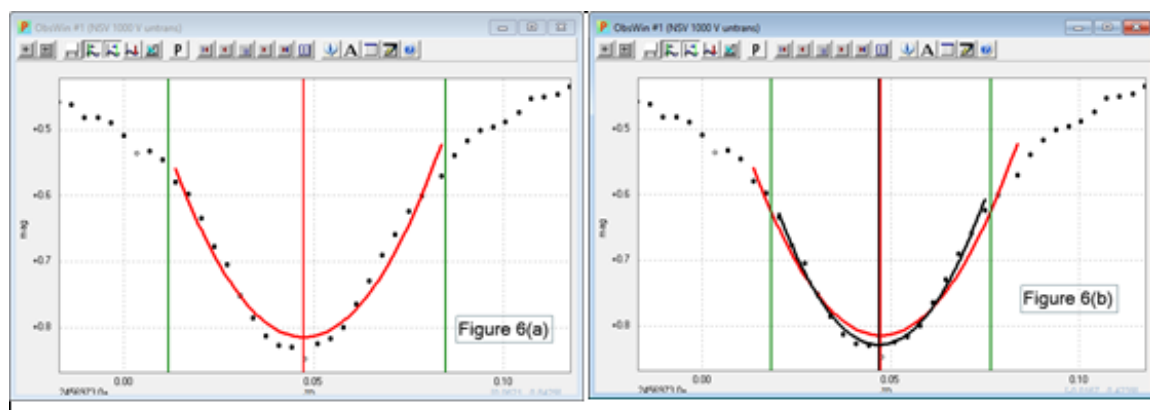


Figure 7 is a closeup of the minima measurements made from those two parabolas, plus for good measure a 5th and a 9th order polynomial. The data points (small black squares) are 1 minute apart. As usual the 9th order polynomial (green), trying to fit all the data points, yields a distorted minimum measure. The 5th-order (light blue) yields a good minimum measurement, but doesn't come as close to fitting the dots. In my opinion the black parabola is the fit of choice. True, it lies above the three data points left of minimum, but only the unacceptable 9th order reaches them.

Results are set out in **Table 1**. The minima are given in minutes difference from the mean of the four minima. It's worth noting that the two higher-order polynomials have smaller errors, but that's only because they join the dots better.

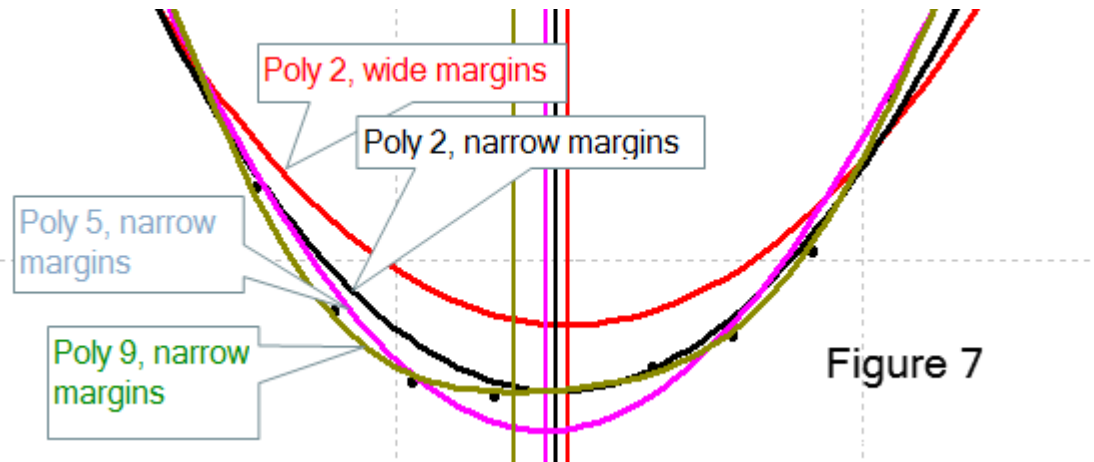
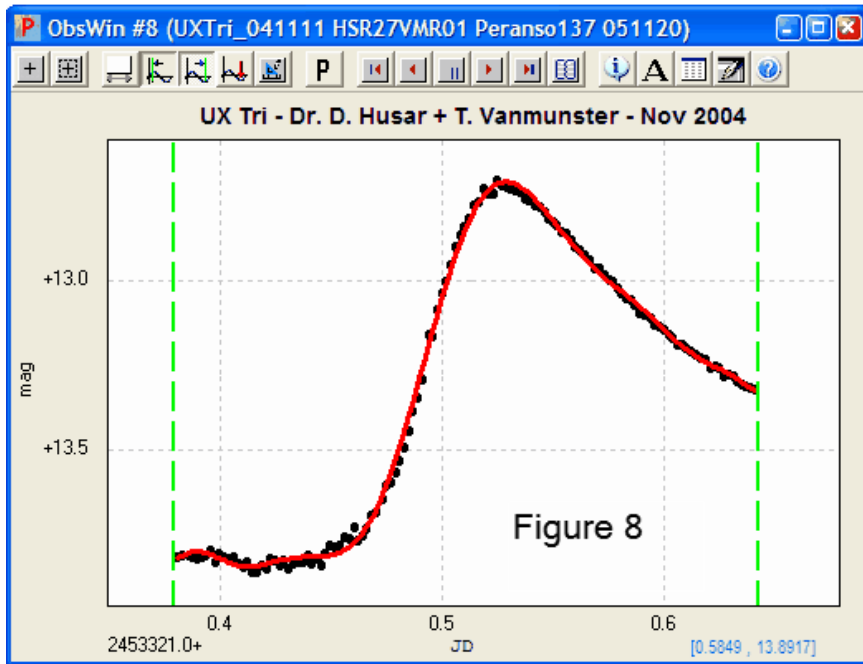


Table 1. Minima of polynomials in Figure 7.

Measure	Min (minutes)	Error(minutes)	Colour in Fig. 7
Poly 2, wide margins	1.3111	5.27	red
Poly 2, narrow margins	0.6176	3.27	black
Poly 5, narrow margins	0.0180	2.10	light blue
Poly 9, narrow margins	-2.0008	2.61	green

Polynomial fitting has uses other than trying to find minima of fairly symmetrical eclipsing binary light curves. Figure 8, from the PERANSO manual, shows what can be achieved with highly asymmetrical light curves.



Conclusion: polynomial fitting is a bit of an art, tempered by experience and experimentation. But for symmetrical eclipsing binary light curves, a parabolic fit on the convex-out lower part of the curve is a good benchmark.

Kwee and van Woerden

The Kwee-van Woerden Method (KWM) is undoubtedly the most widely used routine for finding minima (Kwee & Van Woerden 1956). Unlike the polynomial method, KWM works only for roughly symmetrical light curves, which effectively means eclipsing binaries. Nor does it show a fit to the data points.

Here's a rough indication of how it works. By reflecting the data points on one side of a (vertical) trial minimum line to the other side — rather like the 'tracing paper method' of Minima 25 (see Figure 12 below) — we get two magnitudes at every time position (actually we only consider the magnitude pairs at a range of equal time steps). As we shift the trial minimum stepwise along the time axis, the sum of those magnitude differences will decrease as we get close to the "true" minimum (try it using Minima 25). Then the true minimum can be found analytically from a simple analysis of the way those sums increase or decrease as we step the trial minimum along.

Doubts have been raised about the KWM, e.g. (Mikulasek 2013) and (Byron 2014). Mikulasek after extensive simulations, concludes that KWM gives very good estimates of minimum, but the uncertainty times in KWM are underestimated by 1.4 times. Nevertheless he advocates abandoning the method. Byron (2014) carried out simulations using the PERANSO implementation. I have been unable to confirm his conclusion that it works best on real data when no interpolation is used (though Byron did suspect it might not work well). I have found, using real observing data that it agrees extremely well with low-order polynomial fitting.

The following experiments are all from PERANSO representations of data of mine.

Table 2 shows the minima found when margins were successively widened.

Table 2. Four KWM measures on the Figure 10 data.

KWM	Min (d)	error
1 (narrowest)	0.045689	0.000346
2	0.045797	0.00027
3	0.046694	0.000093
4 (widest)	0.048642	0.00036
mean	0.046706	0.000267
sd	0.001367	
POLY 2	0.046682	0.00195

Note the standard deviation of the KWM measures is nearly an order of magnitude greater than the individual errors calculated by KWM. A parabolic fit (Poly 2 in the table) on the widest margins that gave a good fit (as described above) gives a minimum that agrees with the mean KWM measure within all error limits — in fact they differ by only 0.03 minutes — is close to the standard deviation from the mean of the KWM estimates, and nearly an order of magnitude greater than the individual KWM error estimates.

This, and many other comparisons I've carried out on real observational data, may suggest that the KWM is, contrary to its detractors, as good as polynomial fitting (at least, the parabolic method recommended here). However I find that the parabolic method is more immune to noise, no doubt because a parabola doesn't tolerate excursions to outliers. To illustrate, in the data in **Figure 9**, there is a very low data point that experience suggests is an outlier (hollow in the left curve, filled in the right).

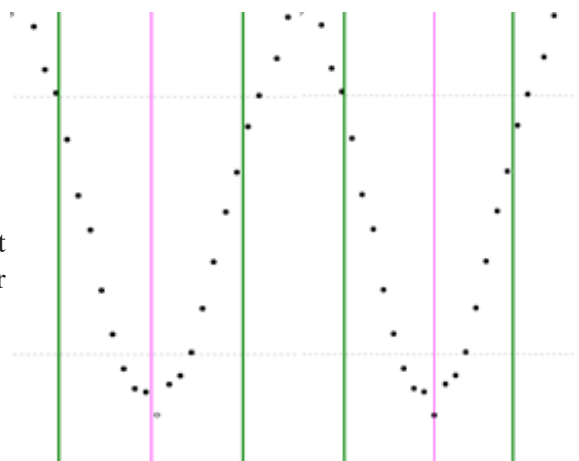


Figure 9

This sort of annoying thing happens all the time, and is always particularly noticeable around minimum, creating problems for the data analyst. KWM handles this poorly, as Figure 9 shows. The difference in minima measurement is 0.0017 d or 2.5 minutes, too much to tolerate. However the presence or absence of the rogue data point made only 0.000002 d (0.003 minutes) difference to the parabolic minima (not shown here).

The problem of flat minima

If eclipsing binaries execute a total eclipse, for a while only the light of the bigger star is visible and the eclipse minimum will be flat. Half an orbit later the smaller star executes a total transit, obscuring the same amount of the larger star for a while. This may yield a minimum that's slightly curved, due to limb darkening on the larger star. **Figure 10** illustrates.

Data for totalities are typically ragged, so how do KWM and polynomial fitting handle them? Figure 11 superimposes a parabolic fit and a KWM fit around the same margins. In this case their lines of minimum are indistinguishable.

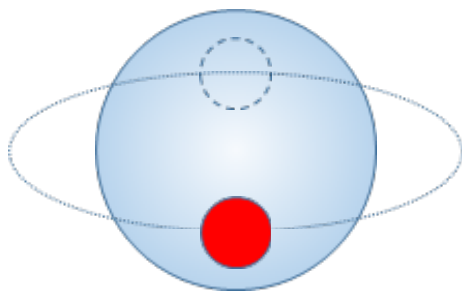


Figure 10

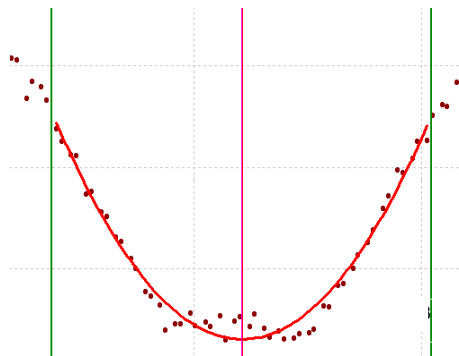


Figure 11

However in many cases of flat minima KWM can get confused whereas the parabola takes its fitting cue mainly from the arms and effectively ignores the mess on the floor. So for flat minima, I trust the parabola more.

Other methods – Bob Nelson’s Minima 25

Bob Nelson offers an intriguing suite of minimum-finding techniques called Minima 25 (<https://www.variablestarssouth.org/resources/bob-nelson/>). They can all be brought to bear on the same light curve, and you the analyst can take the weighted mean of their results. The beauty of it is that if one or two methods yield outlier results you can ignore them and take the improved mean and standard deviation of the rest.

Figure 12 shows four of the methods. **Figure 13** shows a table of the results. Note the chord bisection method provides (of necessity) inner left and right margins allowing one to exclude an arbitrary range of data points around the minimum.

Conclusion

Have we got anywhere? Not if you wanted a single authoritative answer of what to use for minima finding. I have tried to illustrate strengths and weaknesses, some useful techniques, and problems to look for; but in the end it's your experience and willingness to experiment on a light curve of yours, that will guide you. Issues to watch for while experimenting are:

- how wide can you set the margins (to get more data) or should you narrow them (to get a better fit)?
- can you estimate which order of polynomial fits best without over-fitting, and what does that do for the vital polynomial curve-fit to minimum?
- what difference is made by excluding flat floors?

- and are you getting a reasonable error figure? On this point I would be suspicious of any estimate error less than 0.0001 day (as for KWM and standard error of weighted mean in **Figure 13**).

One overall issue is to make sure to use just one method when measuring a suite of minima on the one binary. If there are systematic problems induced by the light curve shape, eg a sloping floor to totality, that will at least make any offset of estimates from the true minimum more consistent. It also helps ensure the errors in the minima estimates are more uniform, which matters when carrying out O-C analysis. A mix of the KWM estimates and polynomial fit estimates (with error figures typically a magnitude larger) can yield poor O-C results – but that is the subject of another paper.

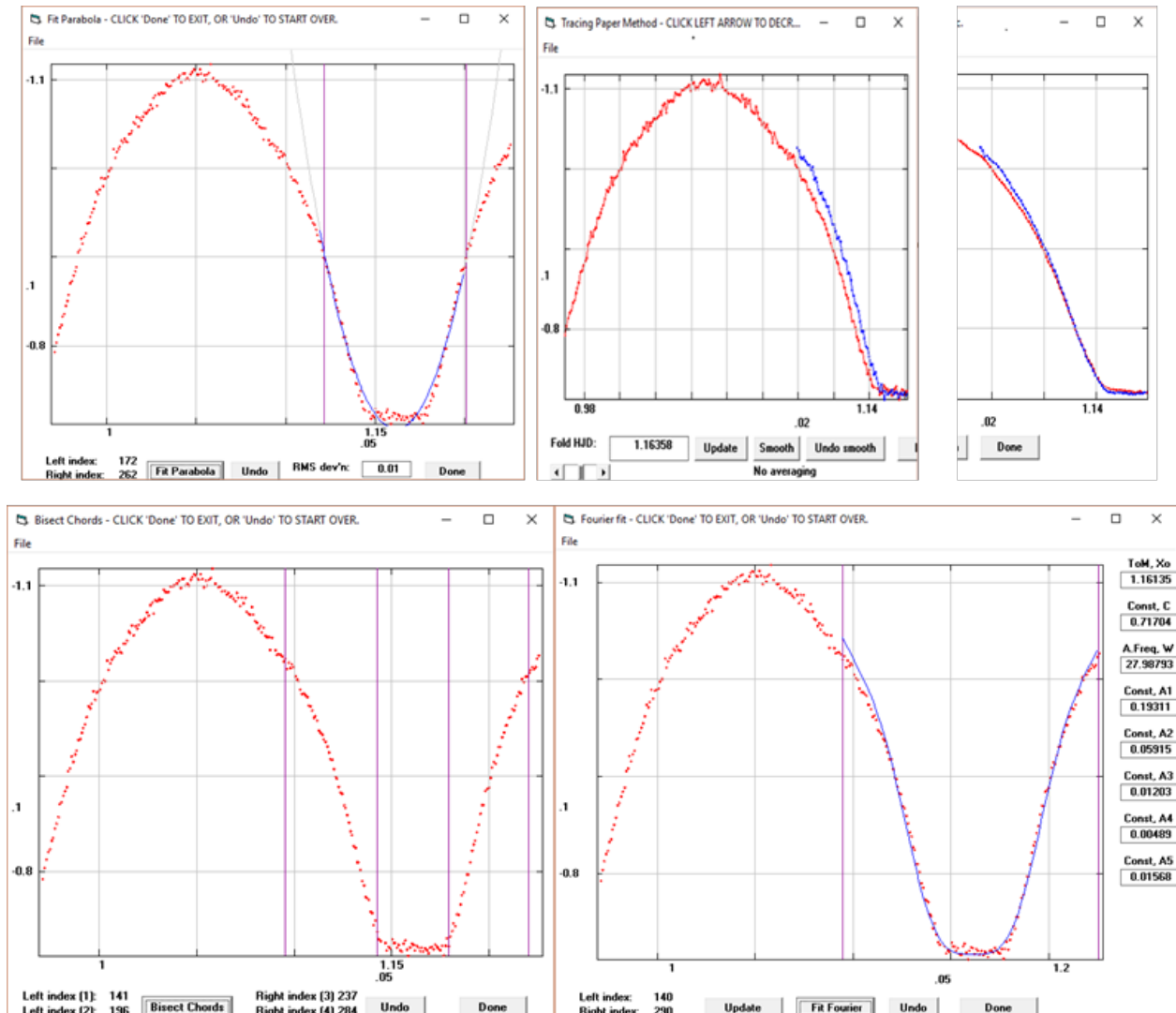


Figure 12, clockwise from top left: parabolic fit, tracing paper before and after adjusting, Fourier fit, chord bisection (with flat floor excluded).

Minima - Pup HI 2015-12-28 V untrans TJR for Minima-25c.csv

File Help

Minima v2.3

		Time of Minimum	Est'd Error	Use in Mean?
1. Parabolic Fit	Go	2457385.16162	0.00029	☒ In
2. Tracing Paper	Go	2457385.16158	0.0001	☒ In
3. Bisectors of Chords	Go	2457385.16184	0.02588	☒ In
4. Kwee and van Woerden	Go	2457385.16145	0.00008	☒ In
5. Fourier Fit	Go	2457385.16135	0.00014	☒ In
6. Sliding Integrations	Go	2457385.16161	0.00053	☒ In

Simple Mean	2457385.16157	☒ +Mags ☐ -Mags (inverted)
Weighted Mean	2457385.16148	Original # data points 291
Std. Error of Weighted Mean	0.00006	Edited # data points 291
Std. Deviation of Means	0.00017	Plot/Edit Data
		Calc. Means

Figure 13. Results table for Minima 25.

References

- Byron, Jeff (2014). "Measuring Times of Minima with Peranso". Unpublished.
- Kwee, K.K. & H van Woerden (1956). "A method for computing accurately the epoch of minimum of an eclipsing variable." BAN 12:464, 327.
- Mallama, A. D.: "A FORTRAN Subroutine for Determining Times of Minimum Light"; International Amateur-Professional Photoelectric Photometry Communication, No. 7, p.14
- Mikulasek,Z.; Chrastina,M.; Liska,J.; Zejda,M.; Janík,J.; Zhu,L.-Y.; Qian,S.-B.: "Kwee-van Woerden method: To use or not to use?"; Astronomy & Astrophysics, November 4 2013

Introduction

Studies of dual maxima Miras such as R Centauri and BH Crucis suggest that there is a link between these stars and other Miras which show pronounced humps, usually on the rise. I have been using the International Database, maintained by the AAVSO but including observations from almost all amateurs, in order to study some of the most interesting objects. S Orionis, reasonably bright and accessible from both hemispheres, seemed an ideal object.

What might one expect to find which is different? Analysis of the V and B-V of BH Crucis and R Centauri over nearly half a century indicates that factors other than periods and period changes must be considered. In both cases the B-V colours indicate different temperatures at each of the two peaks of the dual maxima even though the brightness is (or in the 1970s was) the same. Thus, in order to obey the Stefan-Boltzman law we must accept that the radius and temperature differ between these two maxima. Why?

Since BH Crucis has in this interval changed from a dual maxima Mira to a single maximum Mira with a well-defined hump on the rise this appears to confirm the connection between the behaviour of both these Mira types. The changing periods are probably unrelated to this similarity.

This led to an analysis of observations of a number of brighter Miras with well-defined humps at times. Most of these appear to have periods in excess of 400 days. As S Orionis is easily observed from both north and south hemispheres and well observed it seemed an ideal candidate.

Here we are moving from classical amateur studies of periods and period changes - which have produced less than ten examples in well over a century of measures - into the modern field of astrophysics. This involves a change from *'what is happening'* to *'why it is happening'*.

Astrophysics - a future role for amateur observers

For well over a century amateurs have made observations which allow periods and changes in periods of stars to be studied. The area of greatest success has been long period variables - Miras, semi-regular stars and others where amplitudes and periods are both suited to measures without specialised equipment.

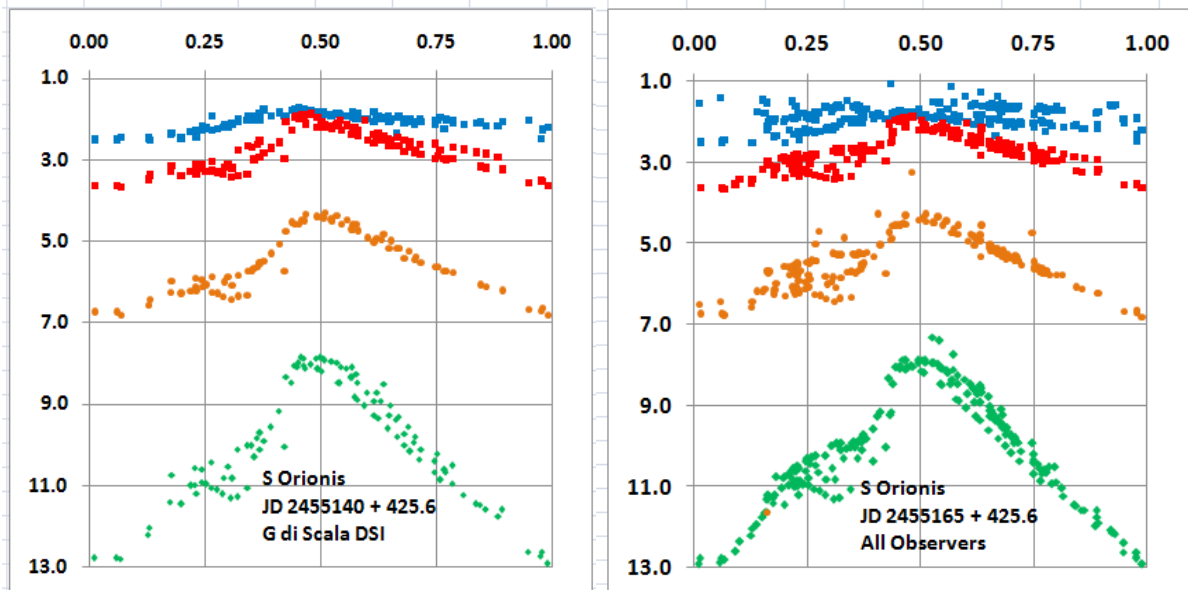
Recently, however, there has been a major change in observational astronomy. The complex photo-electric photometry systems of the mid-twentieth century have been largely replaced by simple CCD detectors and computer recording. Rather than sequential measures of a single star at a time it's now simple to measure whole fields of stars on a single image. The best users of this advance have been amateurs specialising in cataclysmic variable stars and eclipsing binaries. But in these areas single filter photometry is usually adequate. The only need of two filter photometry using B and V filters is in cases where high accuracy is needed. This need for accuracy requires the use of B and V to measure transformation corrections and atmospheric extinction.

The area we see most use of the BVRI filters is in LPV observers, where these measures are quite common. Provided they are carefully transformed and accurate, future generations will owe a great debt to today's observers, the local and national societies who encourage these observations and the AAVSO which maintains the International Database. But here a question arises - how good are they? Let's consider the example of S Orionis.

B-V colours and temperature

Giorgio di Scala of NSW has made very good measures of quite a number of Mira stars. S Orionis is one of these and Figure 1a shows measures from JD 2453631 to JD 2457426, a little less than 9 cycles. The most important curves are V, which shows some variation in brightness in different cycles and B-V which varies from 1.74 at maximum to 2.51 at minimum. The GCVS gives a spectral class of M6.5e to M9.5e, indicating that it is one of the cooler Mira stars. Thus these values are close to expectations. There

are a few outlying points. The V-R and V-I colours show a larger amplitude. There is little historical information about R and I filter measures but this will build up over future years.



Figures 1a, 1b. *Giorgio di Scala's measures are in the left graph, measures by all observers in the right. Both show, from the top, the colours B-V, V-R and V-I, and V at the bottom.*

The colours indicate a little reddening but perhaps less than expected in the Orion region. In order to follow the R and I light curves which reach apparent magnitudes of 5.70 and 3.37 respectively at maximum some defocusing was required by di Scala but it's not clear how the northern observers coped with this problem.

The di Scala B-V colour curve shows a smooth rise in temperature as the star brightens and a similar cooling as it fades. But one would expect a dip from phase 0.25 to 0.35 where the hump occurs. There is no such corresponding dip. This indicates that something other than temperature causes this.

The right hand illustration is quite messy. It comprises all the multi-colour measures of S Orionis over the interval JD 2453631 to JD 2457854. The main interest is in V and B-V which have a better historical coverage and are better understood. Clearly there are two differences between the two datasets.

This is shown more clearly in the enhanced plot of B-V in Figure 2. Series 1 points are measures by di Scala, series 2 and 3 are by two other experienced observers who can be relied upon to make the correct transformations and extinction corrections and series 4 comprises scattered measures from others.

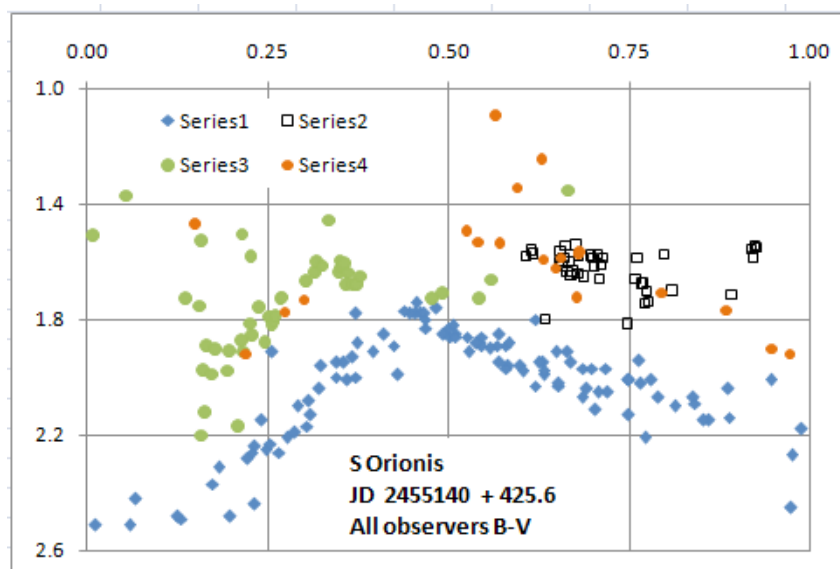


Figure 2. *The B-V curve of Figure 1b is shown on a better scale with a division into selected observers as described in the text.*

A little of the scatter is attributable to the differences between cycles. The di Scala measures show this - but the major differences must arise from faulty comparison star values and changing to different comparison stars as the S Orionis' brightness rises and falls.

Firstly, in the B-V there is an offset to the blue of about 0.4 magnitudes in the measures other (mainly northern hemisphere) compared with di Scala's and secondly a high scatter reaching over 0.5 magnitudes at times. There is little consistency. Allen's Astrophysical Quantities provides B-V values of 1.63 and 1.80 respectively for M5 giants and supergiants at maximum, given a little reddening, so the di Scala values are much as expected. Why is the other data blue-shifted and so noisy?

There are other examples of this problem. It would be valuable to encourage more observers from both hemispheres to join in the Variable Stars South Dual Maxima Mira project. But we need consistency of measures. Are the northern comparison star values correct or are the transformations and extinction corrections inadequate?

Comparison stars for observers:

The photometry table for S Orionis lists 22 stars from four different sources covering the range $V = 7.5$ to $V = 14.3$. The good thing is that the B-V range is from 0.139 to 0.757 with only the two faintest stars at 1.101 and 1.154. Thus small amplitude variability is unlikely. However, the quoted errors in V range from 0.018 to 0.100 with the largest errors at magnitudes between 7.5 and 9.5. B-V errors range from 0.028 to 0.173 in a similar pattern. This may explain some of the noise and perhaps the general offset but not the 0.5 range which is about 70% in intensity.

The greatest divergence in B-V is when the star is faint - below $V = 10$ to 11. Toward the top of the rise to maximum the northern B-V curve begins to become redder and similar to the southern values. This suggests that there has been a change in the comparison stars used and that the brighter ones are more similar in B-V to the Cape E Region standards. But the fainter comparisons have a systematic offset in B-V. Why, and what is the remedy?

In the early days of PEP it was customary to indicate the comparison stars used and their adopted magnitudes. Thus all observers were working with similar values. Errors were also published in a more reasonable manner based on the differences between the check star observations and the adopted values - not the very optimistic figures produced by the commercial software packages in wide use today. The internal accuracy of the values of the stars in use was also checked frequently. It is very clear that this has not been done for the S Orionis photometry table.

This brings up the question of the accuracy of published magnitudes which provide some of the brighter comparisons - how accurate are they? One of the early attempts to list all UBVR measures was a USNO catalogue and the disparities between published data were alarming - from memory up to 0.250 in V on some of the brighter stars. Mermillod attempted something similar but finally abandoned it at the end of the 20th century with the comment that extinction seemed to be too difficult to remove from measures. Perhaps this was merely a polite way of saying that too many observers were not removing these effects, perhaps even not using adequate transformation values? So how do we achieve high accuracy?

The area is not very rich in stars but at -20 degrees from the galactic plane that's not surprising. Since the star can be as bright as $V = 7.5$ or so (GCVS gives 7.2) a ninth magnitude star seems best suited to the brighter, more interesting parts of the cycle. But within 20 arcminutes of S Orionis the brightest stars are 7.496, a 9.560 G5 star not in the photometry table, and three tenth magnitude stars only one of which is in the table. So what have the observers been using? In spite of the statements that the complexity of the IDB would allow us to identify the comparisons used almost all observers quote 'STD' which is unhelpful.

This photometry table needs to be scrapped and replaced in the manner described below under conclusions.

NSV 2014 and its effect

The nearest star to the variable, at a distance of ~38", seems to be NSV 2014. Guide 9 quotes two spectra, M and G5. It is listed as the fifth entry in the photometry table with values of $V = 10.233$ and $B-V =$

0.500 derived from APASS. Plotting the light curve from ASAS3 the variations closely match those of S Ori which clearly indicates contamination due to the low resolution. Does this occur in the reverse direction?

Hipparcos gives an error of 0.032 for this star which also indicates variability - a stable star by comparison usually reflects the Hipparcos internal accuracy of ~ 0.007 magnitudes. But are these measures affected by the proximity of S Orionis? Perhaps this star is stable, with a spectral class of G5 which matches the APASS B-V of 0.500 reasonably well.

The Dual Maxima Mira Project and other LPVs

Before any observer becomes involved seriously in observing these a sound idea is to read an article about transformations in the November, 2010, VSS Newsletter 'High precision UBVR transformation to the Standard UBVR colour system - Stan Walker' or the original paper by Robert H Hardie in 1962 in the 'Stars & Stellar Systems' series - *Astronomical Techniques*, Univ Chicago Press, 178 or another explanation by Brian F Marino in 1970 in *RASNZ Southern Stars*, 24 No 3, 47.

Selection of comparisons is another important step. We should adopt the method used in the early days of photometry - select stars close by the target star to nullify primary extinction and always indicate what values have been assigned to these stars. Since AAVSO charts have become the standard they need to be correct and here the chart team must work with experienced photometrists to ensure the most appropriate stars with reliable magnitudes are selected.

Conclusions

The divergence of ~ 0.3 in the B-V colour equates to almost a whole spectral class - from late M to late K - and a difference in effective temperature of $\sim 800\text{K}$. Quite clearly this makes the data useless for astrophysical purposes. In this case the differences seem consistent indicating a difference between northern and southern comparison stars, although this difference reduces as the star brightens.

The problem is not confined to S Orionis, although there is little overlap between observers in the north and south so it has not been widely explored. Stars within 20 degrees of the equator seem unpopular. R Centauri is another where one observer's B measures are far too bright, as they are for several other stars. The star T Cassiopeia is also of interest in the context of dual maxima Miras. This star at times has a long maximum - up to about half the period of ~ 445 days - and in many ways resembles R Centauri but here I note stretches of V measures differing by ~ 0.4 magnitudes.

With the AAVSO now being the sole provider of charts for many of these stars there is a responsibility to see that both the visual and photoelectric magnitudes of comparison stars are correct and the selections sensible. Thus for a star like S Orionis there are three ideal comparisons within 15 arcminutes of the variable as well as a similar number of usable but fainter stars. These should all have been measured in BVRI filters using appropriate stars from Landolt's equatorial standards. The latter tend to be on the faint side but there are suitable groups at 3 hr 53 RA, Dec 00 00, 5hr 57, -00 10 and 4hr 52, 00 00. The internal accuracy within the S Orionis field of the adopted comparisons is critical.

If PEP with its reliance on sequential measures of each star involved, plus the sky background could achieve measures with standard deviations of $V = 0.008$ at magnitude 8.5 and $B-V = 0.012$ at 10.5 in B why cannot CCDs do even better given that, in most cases, all the stars and sky involved are on one image?

There might be a thought to write the problem of S Orionis off as due to contamination from NSV 2014. But in Auckland we measured the eclipsing binary KZ Pavonis at the request of Ed Budding. This has a companion star at a distance of about 6 arcseconds. Using our normal focal plane aperture of 31" we usually included both stars on the basis that Ed's software would remove the third light problems. But on good nights - and at OneTree Hill in those days they were very good - we measured each star individually, close to the aperture edge. When we added the total intensities in this manner they were $\sim 10\%$ higher than with both in the aperture. This indicated a very low contamination level. So, given the $\sim 38''$ separation of S Orionis and NSV 2014, contamination is not a believable answer.

We hope to discuss these problems and usable solutions at the forthcoming VSSS6 and NACAA meetings in Australia.

Publication watch

David Moriarty has a paper published in *Astrophysics and Space Science* on his work with two eclipsing binaries.

D. J. W. Moriarty, A. Liakos, M. J. Drinkwater, A. Mohit, S. M. Sweet J. F. West

Photometric and spectroscopic monitoring, radial velocities and evolutionary status of the chromospherically active, close eclipsing binaries ST Centauri and V0775 Centauri. *Astrophys Space Sci* 365, 1 (2020) doi:10.1007/s10509-019-3709-7

Abstract

We have combined photometric and spectroscopic observations of two very close eclipsing binary systems, ST Centauri and V775 Centauri, to determine their evolutionary state from calculations of masses and radii and other properties. Spectral types were determined and radial velocities calculated from spectra obtained with the Australian National University's 2.3 m telescope and Wide Field Spectrograph. The spectral type of the ST Cen primary component is F8 IV and the secondary is F8 – 8.5 IV. The ST Cen mean masses and radii of $1.40 \pm 0.05 M_{\odot}$ and $1.38 \pm 0.10 M_{\odot}$ and $2.2 \pm 0.1 R_{\odot}$ and $2.13 \pm 0.08 R_{\odot}$ for the primary and secondary components respectively, indicate that they are close to terminal age on the Main Sequence. Although the spectra of V775 Cen appeared to be single lined, the broadening function method enabled us to determine the radial velocities of the faint secondary component as well as those of the primary star. The mean masses and radii of the V775 Cen components are $1.66 \pm 0.31 M_{\odot}$ and $0.72 \pm 0.29 M_{\odot}$ and $1.68 \pm 0.11 R_{\odot}$ and $1.24 \pm 0.08 R_{\odot}$ for components 1 and 2 respectively. Our data show that V775 Cen is a close Algol binary system, with a secondary component that has evolved beyond terminal age Main Sequence, has filled its inner critical equipotential surface and is transferring mass to the primary star. The masses and radii of both components of V775 Cen are smaller than those of other Algol binary systems. Although the primary component of V775 Cen is on the Main Sequence, its spectral type is F0/F1 class IV. Both systems displayed episodes of photospheric and chromospheric activity. This was evident in the H α lines of ST Cen and the Na I D lines of the components in both systems. Narrow Na I D lines between those of the binary components suggest that circumbinary gas is present.

Phil Evans is a co-author in two exoplanet papers published on the arXiv.

Romy Rodríguez Martínez et al, KELT-25b and KELT-26b: *A Hot Jupiter and a Substellar Companion Transiting Young A-stars Observed by TESS.* arXiv:1912.01017.

Abstract

We present the discoveries of KELT-25b (TIC 65412605, TOI-626.01) and KELT-26b (TIC 160708862, TOI-1337.01), two transiting companions orbiting relatively bright, early A-stars. The transit signals were initially detected by the KELT survey, and subsequently confirmed by TESS photometry. KELT-25b is on a 4.40-day orbit around the V = 9.66 star CD-24 5016 ($T_{\text{eff}}=8280^{+440}_{-180}$ K, $M_{*}=2.18^{+0.12}_{-0.11} M_{\odot}$), while KELT-26b is on a 3.34-day orbit around the V = 9.95 star HD 134004 ($T_{\text{eff}}=8640^{+500}_{-240}$ K, $M_{*}=1.93^{+0.14}_{-0.16} M_{\odot}$), which is likely an Am star. We have confirmed the sub-stellar nature of both companions through detailed characterization of each system using ground-based and TESS photometry, radial velocity measurements, Doppler Tomography, and high-resolution imaging. For KELT-25, we determine a companion radius of $R_p = 1.64^{+0.039}_{-0.043} R_J$, and a 3-sigma upper limit on the companion's mass of $\sim 64 M_J$. For KELT-26b, we infer a planetary mass and radius of $M_p = 1.41^{+0.43}_{-0.51} M_J$ and $R_p = 1.940^{+0.060}_{-0.058} R_J$. From Doppler Tomographic observations, we find KELT-26b to reside in a highly misaligned orbit. This conclusion is weakly corroborated by a subtle asymmetry in the

transit light curve from the TESS data. KELT-25b appears to be in a well-aligned, prograde orbit, and the system is likely a member of a cluster or moving group.

Allen B Davis et al. *TOI 564 b and TOI 905 b: Grazing and Fully Transiting Hot Jupiters Discovered by TESS.* arXiv:1912.10186.

Abstract

We report the discovery and confirmation of two new hot Jupiters discovered by the Transiting Exoplanet Survey Satellite (TESS): TOI 564 b and TOI 905 b. The transits of these two planets were initially observed by TESS with orbital periods of 1.651 d and 3.739 d, respectively. We conducted follow-up observations of each system from the ground, including photometry in multiple filters, speckle interferometry, and radial velocity measurements. For TOI 564 b, our global fitting revealed a classical hot Jupiter with a mass of $1.463^{+0.10}_{-0.096} M_J$ and a radius of $1.02^{+0.71}_{-0.29} R_J$. TOI 905 b is a classical hot Jupiter as well, with a mass of $0.667^{+0.042}_{-0.041} M_J$ and radius of $1.171^{+0.053}_{-0.051} R_J$. Both planets orbit Sun-like, moderately bright, mid-G dwarf stars with $V \sim 11$. While TOI 905 b fully transits its star, we found that TOI 564 b has a very high transit impact parameter of $0.994^{+0.083}_{-0.049}$, making it one of only ~ 20 known systems to exhibit a grazing transit and one of the brightest host stars among them. TOI 564 b is therefore one of the most attractive systems to search for additional non-transiting, smaller planets by exploiting the sensitivity of grazing transits to small changes in inclination and transit duration over the time scale of several years.

About

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

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

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

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