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Variable Star Section Circular

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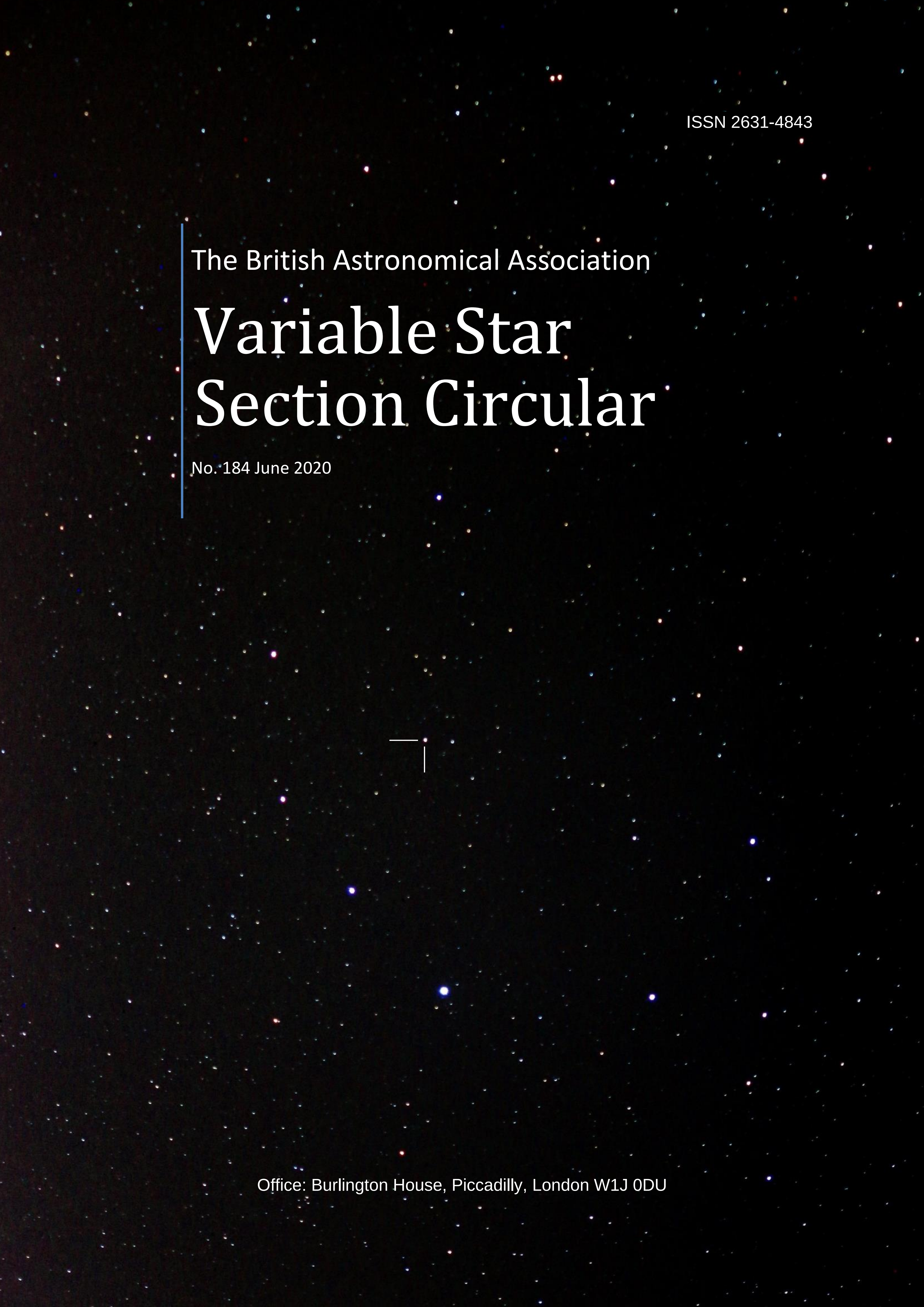

Office: Burlington House, Piccadilly, London W1J 0DU

Contents

Cover Picture

Corona Borealis and R CrB
April 21, 2020. Canon 650D 55mm 6x60s

From the Director *Jeremy Shears*

Little did I know when I wrote this column for the last VSSC that I'd be preparing the next in the midst of a coronavirus lockdown. This has prevented gatherings across the country including, of course, our Section meeting which should have taken place on May 9. I am sure you were as disappointed as me that we could not meet. Apologies in particular to the speakers. We will reschedule for next year and make an announcement in due course.

SUMMER MIRAS

M = Max, m = min.

R Aqr	M=Jly
R Aql	m=Jly/Aug
V Cam	M=Jun/Jly
X Cam	M=Jun/Jly
	m=Aug/Sep
SU Cnc	M=Aug/Sep
	m=Jun
U CVn	M=Jun
RT CVn	M=Jun/Jly
o Cet	m=May/Jun
R Com	M=Jly/Aug
S CrB	M=Jly/Aug
W CrB	M=Jun
R Cyg	m=May/Jun
V Cyg	M=Aug/Sep
T Dra	m=May/Jun
SS Her	M=Jun
	M=Jly/Aug
SU Lac	M=Jun/Jly
RS Leo	m=Jly/Aug
W Lyn	m=May/Jun
X Oph	m=May/Jun
R Ser	M=May/Jun
T UMa	m=Aug/Sep

Source BAA Handbook

I was actually in India on a work assignment for the first 3 months of this year, when the pandemic started. I had to return a few days earlier than planned on the last British Airways flight out of Bangalore before India stopped air travel completely. At the time of writing, my airfreight consignment is stuck there, including a few of my astronomy books, telescope tripod and mount – and much of my summer clothing. It was collected from my residence, but was impounded at the airport when the restrictions came in. Whilst in Bangalore, I was able to connect with Professor G. C. Anupama who is Dean of the Indian Institute of Astrophysics and Professor-in-Charge of the Indian Astronomical Observatory. She is also currently President of the Astronomical Society of India. Her research interests include supernovae and cataclysmic variables, such as novae and dwarf novae. I have suggested the VSS could help with any relevant projects she might have in the future. Remarkably, the weather has been generally excellent up and down the country since my return and I know many people have been making the most of the clear skies, with hardly any contrails, to get on with observing. One of the benefits of being locked down at home, although I recognise for many it will have been a struggle. I know that quite a few people are using the time to analyse data and to write articles.

Astronomy webinars in the time of corona

Naturally, all BAA meetings have been cancelled or postponed in the meantime. To help maintain a sense of community at a time when many of us are unable to leave home, the BAA has been organising a series of weekly webinars at 7pm on Wednesdays. The presentations typically last for 15-30 minutes followed by questions from those attending. These are free to watch by everyone, whether a BAA Member or not. If you want to catch up on a webinar which has already been broadcast, recordings can be viewed on the BAA YouTube channel. Details of past and forthcoming webinars are available on the BAA website. I presented a webinar on "Two variable stars in the Northern Crown", which was a general introduction to VS astronomy, with a focus on **R CrB** and **T CrB**. Tantalisingly, but very much on cue, R faded slightly a couple of days before transmission, but it subsequently brightened again. This occurrence did help to illustrate the point that stars **do** vary! You can watch the webinar here: https://www.youtube.com/watch?v=O4N9ewfnAKk. I was gratified to receive some enquiries about

observing variables afterwards, with new observations following shortly after that. There is a lovely image of CrB on the cover of this circular, showing R, courtesy of Nick Hewitt.
I highly commend to you the webinar "From Kitchens to Comets - Hunting for molecules with a spectroscope", by Hugh Allen, Chairman of the Wells & Mendip Astronomers. This includes a panel discussion/Q&A with Hugh, David Boyd, Robin Leadbeater and Andy Wilson. See: https://www.youtube.com/watch?v=y6x1wuwKK20. I was also surprised to learn from John Mason's webinar on Patrick Moore during the war years, just how many variable star observations Patrick made whilst on active service, even while flying in bombers!
Note also that the Society for Astronomical Sciences is organising an online symposium jointly with AAVSO. The first session is on May 30, which is free, and there are 4 further session in June for which there is a fee. Details and programme here: https://socastrosci.z2systems.com/np/clients/socastrosci/event.jsp?event=27&

More variables in the news

Although lost from view for the season now, **Betelgeuse** has continued to receive much attention. In the last VSSC, Dr Mark Kidger wrote a fascinating piece about the recent fade of the star, which was read enthusiastically by many BAA Members, many of whom are not committed VS'ers. I am delighted that Mark continues his discussion on the star in the current circular, and we are treated to a further article by Chris Lloyd. Following the BBC News coverage of Betelgeuse and **V Sge** in the last few months, another variable object to receive attention on the BBC website was the blazar **OJ 287**. This fascinating system contains a binary black hole (BH): a supermassive BH of 18 billion solar masses being orbited by a 'smaller' BH of a mere 150 solar masses. It's usually seen shining as a point source of light around magnitude 14.0-15.0. The reason why it hit the news is a publication in the *Astrophysical Journal Letters* on the Eddington flare caused by the impact of the secondary BH onto the accretion disk of the primary observed by Spitzer in July 2019. Gary Poyner has coordinated amateur observations of OJ 287 for many years and his summary of the latest findings can be read on the BAA website: https://britastro.org/node/21817

VSS campaigns on U Leo and HR Lyr

A reminder that the campaign to observe the old nova **U Leo** continues: see the 2019 December BAA *Journal* and VSSC 182 for more details. Our band of observers has been expanding and I'd like to thank Stephen Arnold, Graham Darlington, Sjoerd Dufoer, Carlo Gualdoni, Paul Leyland, Michael Linnolt, Ken Menzies, Ian Miller, Roger Pickard, Jose Ripero, Richard Sabo, Dave Smith; also thanks to Boris Gänsicke who obtained spectroscopy on U Leo during March 2020 using the Isaac Newton Telescope.

I presented an update on the VSS **HR Lyr** campaign which took place during the 2019/20 observing season in VSSC 183. A more detailed paper has now been submitted to the BAA *Journal*. Although the campaign is officially over, I hope observers will keep this star on their observing programme. It's a good target to follow through the summer, autumn and well into next winter.

John Toone clocks up 200,000!

Hearty congratulations to John for making his 200,000th variable star observation. In John's own words: "Last night (12th May) at 23:56 GMT I recorded my 200,000th visual magnitude estimate. In accordance with the VSS Director's strict instruction it was of T CrB at mag 9.8. It was my 3,506th observation of T CrB since 2nd May 1981 which represents 25% coverage of all nights during that period. Shame that T CrB couldn't manage an outburst last night, that really would have been something to celebrate!!" This is quite a milestone, John – and an impressive record on T CrB to boot. Here's to your next 200k!

STOP PRESS: BAA medals for Roger Pickard and Gary Poyner

I am delighted to announce that at its meeting on May 27, BAA Council agreed to award medals to Roger Pickard and Gary Poyner in recognition of their services to variable star astronomy and to the VSS. Please join me in congratulating Roger and Gary! The following are excerpts from their award citations.

Merlin Medal and Gift: Roger Pickard

This award shall be made in recognition of a notable contribution to the advancement of astronomy.

Roger Pickard has made a lifetime contribution to variable star research, both as an observer and as VSS Director. As the longest serving Director he has seen many changes in variable star astronomy, including the advent of CCD photometry by amateurs and the emergence of large astronomical surveys, and has ensured that the Section remains relevant to today's variable star enthusiasts, both visual and CCD. He has promoted the VSS far and wide and encouraged people to take up VS observing. He has also forged links with the professional research community, which rightfully holds the work of our observers in high regard. Other developments which he has overseen include the computerisation of the Section's historical and handwritten observations, as well as the updating of the VSS photometry database.

Walter Goodacre Medal and Gift: Gary Poyner

The award shall be given in recognition of the recipient's contribution to the progress of astronomy over many years, special regard being had to his or her work communicated to the Association.

Gary Poyner has made significant contributions to variable star astronomy over a period of 45 years. He has made over 300,000 visual variable star observation (in addition to over 45,000 CCD measures), making him one of the most prolific visual variable star observers ever to have lived. He has coordinated many pro-am observational campaigns which have led to new astrophysical insights, notably the international OJ287 observing campaign. Gary's main VS interest is in Cataclysmic Variables (CV's), especially Dwarf Novae. He is internationally recognised for his observational work on CV's and has ~ 500 variables on his observing programme, of which some 90% are CV's. He served as VSS Director 1995-1999. Gary has written, or contributed to, well over 100 papers, many of which have appeared in the BAA Journal.

STOP PRESS 2: PQ And

The dwarf nova PQ And has been reported to be in outburst at mag 10.5 on May 28.776 by Kenji Hirosawa, Aichi, Japan). This means that it is some 9 magnitudes above its usual quiescence of 19.2. PQ And has only been seen in outburst once before when Dave McAdam discovered it as Nova And 1988. So, this is its first appearance for 32 years.

PQ And is located in Andromeda at RA 02 29 29.55 Dec +40 02 40.0 (J2000.0). A finder chart is available from the AAVSO website: https://www.aavso.org/apps/vsp/chart/?star=PQ%20AND&fov=60&maglimit=14.5&resolution=150&north=up&east=left

Do try to observe this very rare event. At 10th mag it is visible in a small telescope. You might have to wait another 32 years for the next one!

Missing Data from 1980-1985

John Toone

I am aware from my observational logbooks that I have a significant number of visual observations not currently included within the BAA VSS database. In 2015 I estimated that approximately 47,000 observations made prior to 2007 were missing either due to not being submitted or the paper report forms that had been submitted had gone astray. The BAA VSS database is very good for pinpointing missing observations by listing individual observer's monthly totals and it seemed in my case more than 50% of my earliest observations in 1975-1985 were missing so I felt that was a good place to start fixing the issue.

I joined the BAA in 1981 so many of my earliest observations were not made with BAA VSS sequences and my first task was to prepare sequence files that correlated the sequences used by the BAA VSS. Where this was not possible (when different comp stars were used for example) I included within the sequence file modern photometry that aligned all comp stars used with the latest BAA VSS sequences. Fortunately, I had retained all the old charts & sequences used and had (apart from some of the very earliest data in 1975) recorded the light estimate so the bulk of the observations could be re-reduced.

The first part of the task was completed in July 2017 when I submitted my re-reduced data for 1975-1979. This consisted of 2,045 observations made at a time when I was learning and ramping up undertaking visual photometry.

The next task was to re-reduce the data from 1980-1985 which represents the first period that I was in full production averaging approximately 4,000 observations per annum from 1981. This is also the time when I started to adopt BAA VSS sequences having taken on the duty of producing the telescopic programme charts in 1982. The work of re-reducing the 1980-1985 data was completed in April 2020 and has resulted in the following positive impact on the database:

Year	Database Total	Re-reduced Observations 2020	Database Impact
1980	475	2144	+1669
1981	730	3918	+3188
1982	1208	4017	+2809
1983	2108	4178	+2070
1984	2783	4307	+1524
1985	1937	3817	+1880
Totals	9241	22381	+13140

In addition to observations of variable stars I also undertook 390 light estimates of planets, asteroids & comets during this period. These were recorded in exactly the same way as the variable star observations and those for asteroids are retained in the BAA VSS database.

Further to the above I estimate that I still have 33,000 observations missing from the database within the years 1986-2006. Going forward I intend to continue focusing on the earliest missing data in case I never complete the task because the oldest data requires the greatest interpretation prior to re-reduction. Having said that I do hope to get the time to fully complete the work once I reach retirement.

Pulsating Star Programme

Shaun Albrighton

The Variable Star Section of the BAA has changed considerably, as have the thoughts and theories of its Directors. Here we take a look back to a 1903 Memoir for an insight into those ideas.

Many observers have favourite stars, however often nearby variables are ignored. Observers are encouraged to include additional stars, with examples in Perseus and Ursae Major being highlighted.

To begin this report, I thought I would start by looking back to some interesting comments in an old BAA Memoir, namely the 'Fifth Report of the Section for the Observation of Variable Stars'. This report by the then Director, Col. E. E. Markwick, F.R.A.S, covers observations made between 1900-1902 and was published in December 1903 at a cost of one shilling to members.

At this time, the BAAVSS grouped stars into one of four categories, Algol Type, Short Period, Long Period and Irregular. Whilst both Algol and Long Period variables appeared to be correctly defined (LPVs being mainly Mira type variables, with two SR stars, Eta Gem and W Cyg), the other two categories seem less well defined.

Short Period - Of the nine stars listed most are delta Cepheid variables, but also included were beta Lyr (aware that this star was a close binary system) and R Lyr. The latter star is now listed in VSX as SRb, range 3.81-4.44, period 46 days.

Irregular – With the exception of R CrB the remaining stars are semi regular variables and one RV Tauri star, R Sct. No doubt the lack of both time frame and pure number of observations meant that analysis at this time was not practical.

Perhaps the most interesting section of the report is the Director's comments and ideas on long period variables. I reproduce these in full.

LONG PERIOD VARIABLES

We now come to the long period variables, Class II. Of Pickering. They are, of course, a very interesting study on account of the deficiency of our knowledge as to what may be the vera causa of the phenomena they exhibit. A star of this type may sometimes be really invisible in a telescope of very considerable power. Then, a tiny point of light shows itself where nothing was seen before, and the light emanating from this point goes on increasing in an enormous geometrical ratio, till at maximum the star can be seen by the naked eye.

However, as it were, at its consummation of light, it begins to gradually fade and soon becomes again the merest point, before finally disappearing. And this, on the average period of about one year. What theory will fit in with these changes? What would happen to us (or the "Martians") if similar fluctuations in the light and heat radiations of our sun were to come about? It is quite safe to say none of us would be left to read the results.

And yet to the Director there has always seemed to exist an analogy between the curve of sun-spot variation and the curve of a long period variable, although no variable is known which has anything like so long a period as the 11 year one of sun-spots.

Plea to observers – If you observe A why not observe B

On investigating the database to analyse observations received, it has struck me that in certain cases there are charts, (in particular binocular variables) which have sequences for several variables, however the totals for each star can vary, sometimes considerably. In addition, there are often nearby variables on different charts which can be either ignored or observed more frequently. What follows is the first batch of suggestions for observers to **plan smart**, as it were, increasing their number of estimates, for little additional time.

The totals for observations are for the three years 2017-2019.

Variables, in or near the Double Cluster in Perseus

This beautiful region of the sky is home to a number of pulsating variables. First up are four stars originally on the Binocular Programme, SU Per, AD Per, KK Per and PR Per. Whilst SU Per and PR Per have attracted some 150 estimates, for AD Per and KK Per the total is closer to 100. Please note that these stars benefit from the use of larger binoculars or indeed a smaller telescope (I regularly use a 130mm reflector at x21). Whilst not binocular stars, RS Per and BU Per (both stars received approx. 120 estimates) are also ideal candidates for smaller scopes. Marked on the chart for RS and BU Per is a further variable FZ Per. VSX lists this as type SRc, range 9.8-10.77B, period 184d. Visually the star seems to vary either side of mag 8.5. Finally, S Per (187) is a fascinating SRc variable displaying multiple periodicities. Perhaps observers of the nearby cataclysmic variable TZ Per, could star hop across to make a weekly estimate, thereby improving coverage of this star?

Variables near Delta Ursae Majoris

Now we move in to Ursae Major and the popular variable Z UMa. This star received some 914 estimates during the three-year period, compared to 582 for RY UMa, which is part of the same chart. Whilst in the area why not pick up a recently added star, Y UMa, which is again perfect for 70mm+ binoculars or a smaller telescope. In addition, there are two Mira variables in the same area, T UMa (327) which as of mid-May appears to be fading from a max of approx. 8, and S UMa (125) which is fading towards minimum? Perhaps observers of T UMa could be encouraged to pick up S UMa, which is in the same low powered field. As a final note, the wide field chart for T UMa also depicts a third Mira variable RS UMa, one that I have recently added to my personal programme (chart via AAVSO VS plotter). RS UMa is currently 9th magnitude rising towards max.

I do hope that observers will consider adding or expanding their programme to improve coverage of some of the stars mentioned.

Back to contents

Report on the Long Period Variable Z Ursæ Majoris Using BAAVSS Archival Data

John Greaves
cpmjg@tutanota.com

The red giant long period variable star Z Ursæ Majoris is analysed utilising data from the BAAVSS photometry database revealing that in the last decade and a half this former multiperiodic semiregular variable (SRb subtype) has become a monoperiodic semiregular variable (SRa subtype) which in tandem with an even more recent trend in amplitude increase could mean the star is currently technically a Mira variable.

METHODOLOGY

The British Astronomical Association's Variable Star Section (BAAVSS) kindly provided the BAAVSS' observation archive for the red giant Long Period Variable (LPV) Z Ursæ Majoris (Z UMa) from the BAA Photometry Database (https://www.britastro.org/photdb/). From this were selected the positive visual observations which were then binned into ten day means from the date JD 2440000, this date was selected as this is approximately the point where fully contiguous observations commence. The means were then analysed utilising the AMPSCAN procedure of BAA member John J Howarth (eg Howarth and Greaves 2001) in order to follow the evolution of any periodicities within the data. Plots of phase variation over time and amplitude over time are generated and the results examined for details and/or pattern. Phase variation is in many ways analogous to traditional O-C methods (observed minus calculated, for LPVs the observed are traditionally times of maxima) except trends in periodicity variation act in the opposite direction upon a plot. The advantage of the AMPSCAN procedure is that it follows a larger part of the lightcurve over time, not just the maxima, and also provides directly quantified magnitude variation in the form of the semiamplitude (basically, the half amplitude), over the same time span and at the same time resolution as for the phase.

RESULTS

The ten-day binned mean visual lightcurve from JD 2440000 to date is presented in Figure 1. At JD 2450000 onwards the symbols are plotted as open for readier comparison with later presented Figure 3, and also highlights the recent trend in amplitude increase for this LPV.

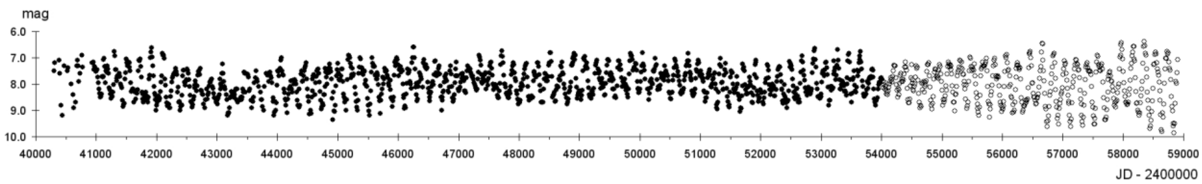

Figure 1: The BAAVSS visual lightcurve from JD 2440000 to around JD 2459000 plotted as ten day means of magnitude against Julian Date. Later symbols are plotted as open to allow ready comparison of that time range with other Figures presented.

The results in phase and amplitude shift over time for the entire lightcurve in Figure 1 are presented in Figure 2 based on a main period of 188.9 days as derived from the full lightcurve. The phase in degrees is represented by filled circles relative to the left y axis and for illustrative purposes instead of plotting a 'wrap-around' at 360 degrees the phase has 360 degrees added to it when it would have otherwise wrapped around to smaller values. The actual value for phase has no direct significance, it is the variation over time in phase that is of interest, that is it is a relative measure. The phase is such that when it is linear and horizontal, or alternatively because LPV periodicities exhibit an amount of jitter of ten or so days between consecutive cycles, when the overall mean trend in phase is linear and horizontal the test period used in the AMPSCAN procedure is representative. When the phase declines monotonically and linearly then that part of the phase plot is better represented by a longer period, when it increases in a similar manner then it is better represented by a shorter period. A curved overall trend would be indicative of declining or increasing period dependent upon direction. In Figure 2 it can be seen that the period derived from the full lightcurve of 188.9 days fits the time interval following roughly JD 2450000 well enough (jitter allowing) but prior to that a linear slanted line suggests a longer, albeit mostly stable, period prevailed. Meanwhile the plot of amplitude over time shows its own story.

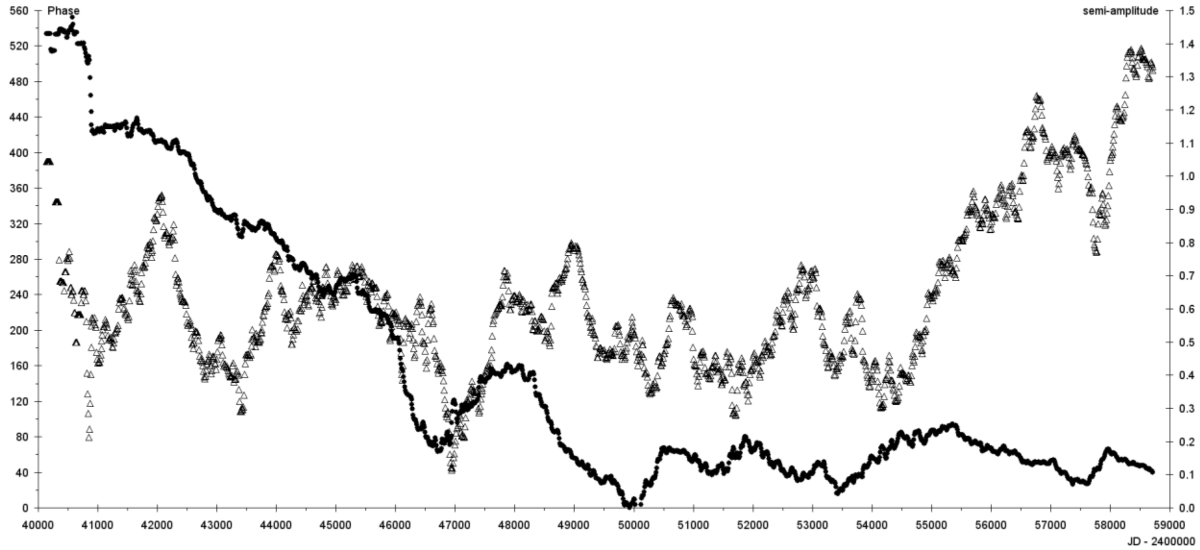

Figure 2: The phase in degrees is plotted as filled circles relative to the left hand y axis, whilst the semiamplitude in magnitudes is plotted as open triangles to avoid confusion with the phase and is keyed to the right hand y axis, with the x axis being the Julian date after removing 2400000.

Semiamplitude, especially for long period variables, has a wide range of scatter over time, reflecting as it does the real variation in the lightcurve. These can be periodic, or completely stochastic. At times waxing and waning of lightcurves over longer time scales in Semiregular multiperiodic variables can be due to beat effects between the two to more periods involved. However, visually another factor comes into play. The optimal black body wavelength for red giant LPV stars is not in the visual but the near infrared, where the amplitude of variation is far lower. This in itself would not be a problem if it wasn't for another factor, as oxygen rich red giant LPVs (as opposed to Carbon star red giant LPVs which are not considered here) reach the cooler parts of their pulsation cycle metallic oxides condense out of the stellar atmosphere, primarily Titanium and Vanadium Oxides (TiO and VO). These are optically opaque molecules and thus artificially reduce the visual magnitude of these stars, that is increase their amplitude, irrespective of pulsation. This can lead to an exaggeration in the amplitude of a visual cycle that is far more marked than similar purely pulsational variational shifts in the near infrared, where these molecules are not particularly opaque. This is a likely contributory factor in the marked scatter in minimum magnitude across a red giant LPV's lightcurve often to a greater range than mere beat modulations would display. Therefore the amplitude of visual lightcurves for Semiregular variables can include all of the combination of beating of harmonics, optical opacity and real variations in amplitude due to pulsation whilst displaying amplitude changes that can appear to affect only the maximum or minimum or leave the main amplitude the same whilst the mean magnitude shifts the range of maximum or minimum or any other combination of all these, including none of them at all, from cycle to cycle.

Nevertheless, trends within this scatter can still at times appear if the change is profound enough in comparison to the random shifts and Figure 2, where semiamplitude is denoted by open triangles and is relative to the right hand side y axis, shows that from JD 2454000 onwards a steady increasing trend in overall semiamplitude occurred. This may or may not be slowing down in recent times, only time and further observations will show if recent trends are real or just temporary jitter, this being a constant problem of interpretation for short term variation in red giant LPVs. Plotting both phase and semiamplitude over time for the full lightcurve on the same graph also demonstrates that the change in periodicity is apparently unconnected to the change in semiamplitude, there being a lag of roughly 4000 days between the two events, which being a lag of over 20 cycles appears to show a simple physical connection between the two phenomena is unlikely. That is, there is no reason to expect the two occurrences to be anything but independent of each other.

Utilising JD 2450000 as a breakpoint the full dataset was split into two separate datasets, consisting of all observations prior to JD 2450000 and all observations posterior to JD 2450000 respectively. Each dataset was then searched for periodicities and AMPSCAN phase and semiamplitude plots for said generated. This is one of the benefits of the AMPSCAN procedure over more traditional methods, it can reveal juncture points at times where data can be split and retested separately. Further testing of each derived dataset will easily show if the split was objective enough as if it is a false assumption that any particular point is a point of change then that subset of data, after re-examination, will show noise and/or meaningless results, whereas if real the results will demonstrate the point.

Examining the dataset stretching from JD 2440000 to JD 2450000 as expected revealed a different main period of 194.0, also the power spectrum revealed a much lower semiamplitude but evident broader peak centred upon 204.8 days, as would be expected for a broadly doubly periodic Semiregular variable. There were no other significant peaks but the broader profile of the 204.8 day peak suggests either a small range of periodicity around this value or some drift over time for this value, however the frequency of observation within the visual dataset is not large enough to breakdown this complex of periodicities further.

Meanwhile examining the dataset from JD 2450000 to nearly JD 2459000 gave a period of 189.0 days, not much different from the period derived from the overall lightcurve. Note this has not been called the main period of 189.0 days. That is because the second 204.8-day period has now disappeared. From JD 2450000 there is no other significant peak but the main period. In fact, even what small peaks do appear are simply the half period and double period aliases of that period (aliases are harmonic artefacts of fouriergrams, or combinations thereof). In fact, annual aliases appeared neither in these two separate datasets nor the full dataset, which given that the period is not far from half a year (~183 days) was fortunate for the analysis. Likely the circumpolar nature of this object from the UK probably assisted here although observations are likely fewer when the star lies low below the North Celestial Pole and opposite the Midnight Meridian.

The pre JD 2450000 and post JD 2450000 datasets were processed via AMPSCAN on their respective 194.0 and 189.0 day main periods and the results are plotted in Figure 3, where the filled circles are phase in degrees relative to the left y axis and the semiamplitude in magnitudes is represented by filled triangles relative to the right hand y axis for the 194.0 day period pre JD 2450000 dataset whilst the open circles and open triangles are for the post JD 2450000 dataset relative to the left hand and right hand axes respectively. That is, open symbols are for data after JD 2450000 tested at the 189.0 day period, closed symbols are for data prior to JD 2450000 at the 194.0 day period, with phase in degrees as circles relative to the left hand axis throughout and triangles are semiamplitude in magnitudes relative to the right hand axis throughout.

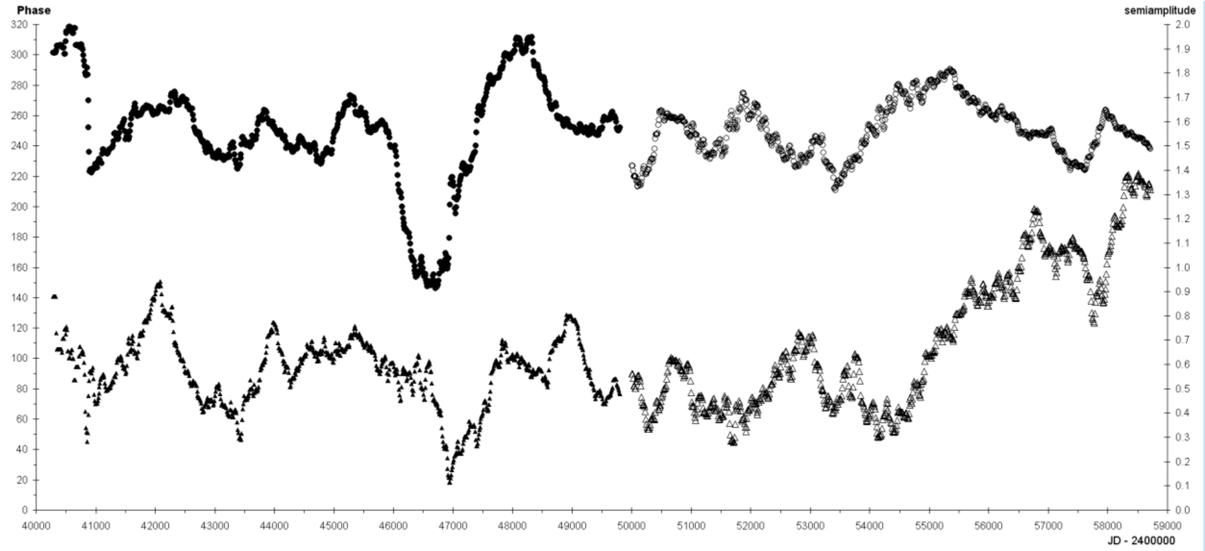

Figure 3: The phase and semiamplitude in degrees is plotted as filled symbols for data from JD 2440000 to JD 2450000 with phase as circles relative to the left hand y axis and semiamplitude as triangles relative to the right hand y axis. The open circles are the same again but for the data from JD 2450000 onwards. The phase values for the latter range have all been shifted by the same constant amount, thus maintaining their variation, to remove an arbitrary processing offset for visualisation purposes as the relative variation in phase is what matters whilst the absolute value is arbitrary.

Figure 3 demonstrates that prior to JD 2440000 mean phase is relatively flat showing the 194-day period is representative throughout whilst those posterior to that date are well represented by a 189-day period throughout. Having said that separate analysis of the data just from JD 2454000 onwards gave a period of 189.9 days with a completely flat least squares fit. However, due to the jitter and temporary drifts in periodicity displayed by red giant LPVs it is easy to be fooled into seeing a trend in what may only be a temporary glitch, and the smaller the timespan of any particular dataset the more problematic it is to be assured of seeing real trend instead of local noise. Nevertheless during a timescale approaching 9000 days from JD 2450000 a single sole steady periodicity of around 189 days average has held constant for Z UMa as would be expected for an SRa subtype of red giant LPV, whilst before that a steady periodicity of around 194 days held sway with little significant drift in that value either inherently or due to interference from the smaller amplitude roughly 205 day periodicity, with multiperiodicity being characteristic of an SRb red giant LPV.

The BAAVSS Photometry Database allowed an independent check of the single periodicity nature since at least JD 2454000 due to the inclusion of many DSLR measurements provided by one Des Loughney. This data gave a single periodicity of around 190.6 days for that duration, not an exact agreement with the visual data (exact period can be passband dependent) but the main point is no other periods appeared in that DSLR dataset. Similarly, the main trend in amplitude increase was also confirmed, albeit with some slight offsets in variation but echoing the pattern nevertheless.

The single periodicity of around 189 days can also be demonstrated by Figure 4 which is a phase plot of the visual data posterior to JD 2450000 folded on that period and reveals a phase plot that would be expected from a singly periodic variable of stable period during its dataset duration. The y axis is in magnitudes and the x axis is the phase, usually represented as 0 to 1 but two cycles are shown here for illustrative purposes. Basically, a clean lightcurve is easier to visualise when plotted for two cycles.

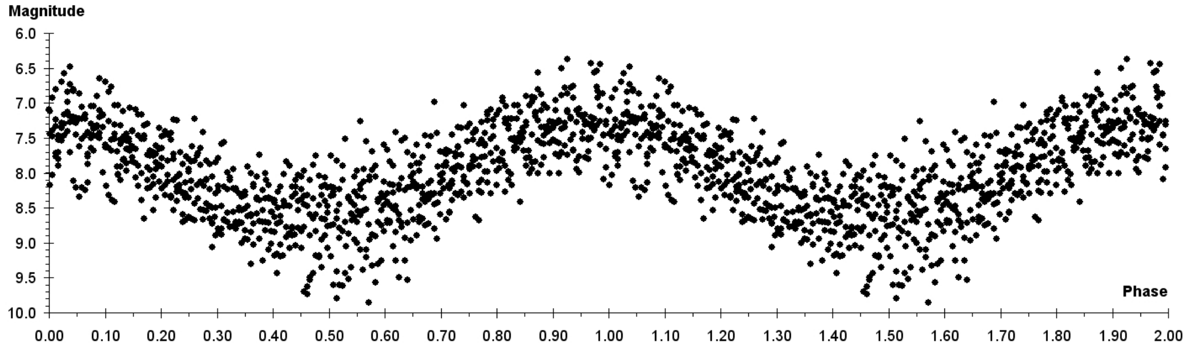

Figure 4: Phase plot of the BAAVSS visual data from JD 245000 onwards when plotted folded upon a 189 day period with two cycles shown for clarity

Yet semiamplitude remained the same after JD 2450000 with the albeit largely scattered variations in semiamplitude keeping pretty much the same near flat trend. The period jump was not attended by any change in semiamplitude behaviour with respect to the main trend. Yet Figure 3 also demonstrates that semiamplitude did begin to change at JD 2454000, increasing mostly monotonically albeit with a recent dip that only time will tell if the increase in semiamplitude is over or whether this recent dip is merely random scatter. In fact, near the end of the data the semiamplitude approaches 1.4 magnitudes, which doubles to a full amplitude of 2.8 magnitudes, which is over the admittedly arbitrary 2.5 magnitude threshold where red giant LPVs are instead classified as Mira variables.

CONCLUSION

BAAVSS Visual data during the approximate time interval JD 2440000 to JD 2450000 reveal that the red giant long period variable Z UMa was at least a doubly periodic SRb variable, whilst after approximately JD 2450000 it became a singly periodic SRa variable and further, that after around JD 2454000 the amplitude of this object increased sufficiently until, at least presently, if can be considered a Mira variable of roughly 2.8 magnitude mean range and roughly 190 day period.

Acknowledgements

The BAA Photometry Database is acknowledged as the source for the data on which this article is based. It is also necessary to acknowledge the visual observers providing the data to this database as without their hard work and reporting of said hard work none of this analysis would be even remotely possible. The full list of observers can be found by interrogating https://www.britastro.org/photdb

References:

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Betelgeuse: the expected recovery happens

Mark Kidger

European Space Agency European Space Astronomy Centre

Betelgeuse has been the focus of considerable attention due to its recent, deep minimum to the extent that 10% of all the light curve data on the star in the AAVSO archive, extending 126 years, has been obtained in just the last six months. Speculation that Betelgeuse was in imminent danger of becoming a supernova has been based mainly on a series of misunderstandings. Investigation of the lightcurve record shows that

- ***(i) the star has brightened significantly over the last sixty years***
- ***(ii) the evidence for similarly deep minima in 1946, 1947 and 1984 relies on fragmentary data and single observers, and***
- ***(iii) the entire extreme historical range of Betelgeuse from magnitude 0.1-1.6 appears to have occurred in the last three years.***

While the dominant period in the historical record is one of 6.1 years, a 430 day cycle has started to dominate the light curve in the last few years and was the cause of the recent minimum, the depth was exacerbated by what appears to have been a major release of opaque dust in our line of sight. If the 430-day period is stable enough to have predictive power, a new minimum, probably of considerably smaller depth, is expected in mid-April 2021.

Introduction

The recent, almost unprecedented dimming of Betelgeuse has caused huge interest. Many people who would never normally look at a variable star have been tempted to make estimates to the extent that almost 10% of the data in the AAVSO archive for this star, which extends back to 1894, has been obtained in the last six months [as a point of comparison, for χ Cyg, which is one of the most heavily observed stars in the AAVSO archive, the figure is that just 0.3% of the data has been in the same period, which includes a light curve maximum].

As an M2Iab star, Betelgeuse is a massive red supergiant, with a mass generally accepted to be in the range 10-20$M_\odot$, although both larger and smaller values have been suggested and a lifetime of around 10 million years. We know that Betelgeuse must be smaller than 40 $M_\odot$, because such stars never become red giants, but rather strip their outer layers and become blue supergiants such as Sunduleak -69 202, precursor of Sn1987a. As a red supergiant, we know that Betelgeuse is at least in the helium-burning phase of its lifetime, but we have no way of knowing how far along it is. Given that the hydrogen-burning stage of a 20 $M_\odot$ star lasts about 8-10 million years, the helium-burning phase about 500-600 thousand years, carbon-burning, only about 1000 years, and oxygen-burning, less than a year, it is far more probable that Betelgeuse is still in the helium-burning phase than one of the later ones. The best estimate is that the star is 80-90% through this helium-burning phase but, if the lower mass estimates are correct, it could be that Betelgeuse is even further from being supernova.

The stories of imminent explosion seem to be due to the 2009 study that measured the diameter of Betelgeuse in the infrared to be about 43 milliarcseconds (mas), quite a lot smaller than the previously accepted values of around 56mas. This led to a popular belief that the star is shrinking rapidly, which would be the prelude to a supernova explosion. In fact, it is pulsating and so the diameter changes with time. Similarly, there is no well-defined edge to the star and the size varies according to the wavelength at which it is observed and, any large structures on the surface will also modify diameter estimates, as will the presence of recently expelled, warm dust shells.

The historical light curve

The total of 39740 visual estimates or V-band photometry measures looks impressive, although there is a 12-year gap from 1906-1918 with almost no data, while the earliest estimates in the AAVSO database are BAA-VSS data from 1894 on. Over 126 years of light curve record, the average is 315 observations per year, but 78% of that data was obtained after 1970, 42% since the start of the year 2000, and 10%, just in the last six months, so the lightcurve sampling is, by no stretch of the imagination, even. Lack of homogeneity greatly complicates its analysis.

Previous deep minima of Betelgeuse have occurred, apparently, in 1946/1947 and 1984 according to widely shared plots published in social media, based on 10-day means. These plots suggested that the 2020 minimum was not the deepest one observed in the historical record. However, poor sampling means that which point or points enter in a particular bin due the selection of the starting date, can change completely the light curve (**Figure 1**).

As always, it is interesting to go back to the source data and investigate. What the database shows is that the 1946 minimum, nominally on 26th July 1946, may have been as deep as the recent one, although this conclusion depends on around ten estimates made shortly before conjunction and just two, very faint estimates made immediately after conjunction. That of 1947, which may have been around 13th October 1947, is also based on post-conjunction data in the morning sky that shows a great deal of dispersion. If we take the 1947 data at face value, Betelgeuse *may* have brightened from about magnitude 1.6 to 0.2 in just three months. The data from 1984 is even worse, with a dispersion of a magnitude in the estimates at the time of the potential minimum and most of the very faintest points coming from a single observer.

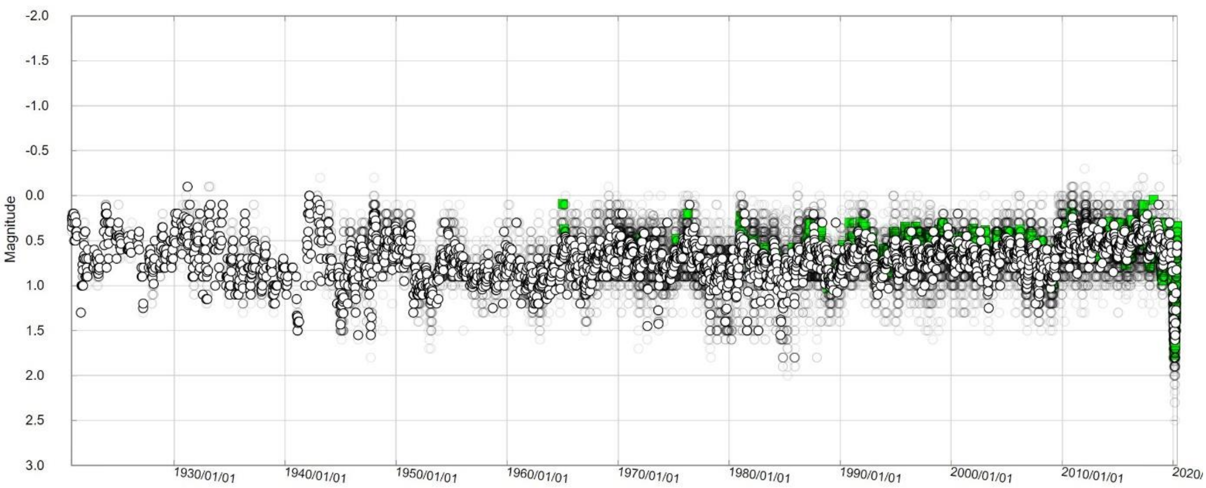


Figure 1: Ten days means of Betelgeuse for the 100 years from January 1st1920, to the present. On many occasions the mean is based on a single point: changing the starting point for the 10-day means by a few days can change radically the aspect of the light at poorly sampled epochs. *Credit*: AAVSO database.

In contrast, an interesting phenomenon in the 2020 minimum is the relatively small dispersion of the data compared to previous minima. Most of the estimates fall within a range of ±0.25 magnitudes. Although a small fraction of the data is very much more discrepant, the global trends are clear and few observers deviate much from them. Given the wide availability of recent light curve data it is tempting to wonder how much observers were influenced in their estimates by prior knowledge.

Another interesting phenomenon is that, if we look at the data over just the last one hundred years, we see that, up until about 1963, the "typical" average magnitude of Betelgeuse was in the range 0.8-0.9. Since then, though, there has been a steady rise in average level until, over the last decade, Betelgeuse has averaged magnitude 0.5. A corollary of this is that, in recent years, Betelgeuse has reached exceptionally bright maxima. In 2017, Betelgeuse was, just before conjunction, as bright as Rigel, at magnitude +0.1, a datum confirmed by photoelectric photometry. Only once in the entire AAVSO record, in early 1942, was Betelgeuse as bright as this (excluding outliers).

Betelgeuse is, along with such stars as Megrez (δ UMa), an anomaly in the Bayer classification of stars (Bayer, 1603, Uranometria) which, in general, does follow quite well the relative brightness of stars in a constellation. Here, Bayer assigned *Alpha* to a star that is clearly not the brightest in the constellation, ranking both Betelgeuse and Rigel as "luminis primi" (first magnitude), with Betelgeuse ahead of Rigel. We know that, on some occasions (Chi Cygni, Omicron Ceti, …) variability influenced his choices [others (Sagittarius) were simply bizarre, but unlikely to be his own choices[1]]. There has been some speculation that possibly Betelgeuse had a particularly bright maximum at the time that Bayer assigned his letters. However, Bayer does not explain his choice of ranking Betelgeuse ahead of Rigel, limiting his discussion to a description of the relative positions of the stars in the figure of Orion, so we will never know with certainty. However, Sigismondi (2019, arXiv:1912.12539 [astro-ph.SR]) notes that, in 1852, Betelgeuse "became the brightest star in the northern hemisphere", suggesting that a maximum in that year must have reached negative magnitude, brighter than any maximum in the last century and that particularly bright historical maxima may have occurred.

The 2020 minimum

The AAVSO lightcurve for the winter 2019/2020 observing season is shown in **Figure 2**. Early post-conjunction observations show Betelgeuse stable around magnitude 0.6, about 0.2 magnitudes down on its pre-conjunction level. The fade started around October 10th, initially slowly, before accelerating at the end of the month to almost exactly 0.01 magnitudes/day.

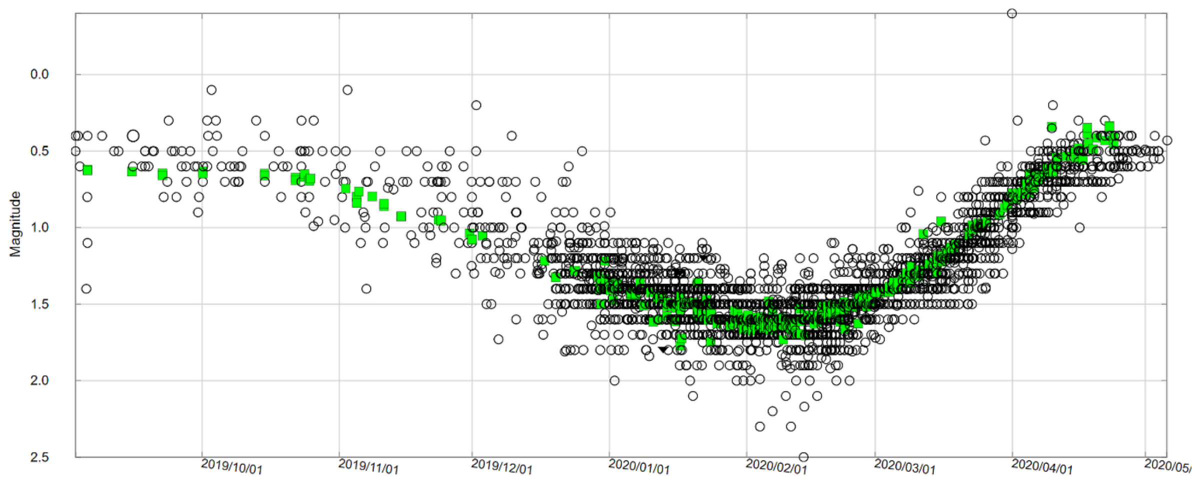


Figure 2: The AAVSO database for Betelgeuse from September 2019 to the present. The extraordinary increase in number of observations from mid-December 2019, when knowledge of the deep minimum was extensively publicised (e.g. Guinan et al., 2019, ATel #13341) , is evident. Credit: AAVSO database.

Two-day means show a minimum of magnitude 1.64±0.02 on February 3rd, although the minimum is essentially flat at magnitude 1.61, without statistically significant deviations, from January 25th to February 17th, indicating a mean date of minimum of February 6th. Since then, the rise has been more rapid than the decline, reaching 0.5 by mid-April, at which point the magnitude has stabilised.

There has been a considerable increase in the amount of high-precision photoelectric photometry in the last 10 years (**Figure 3**). The photoelectric light curve shows that, from 2010 to 2014 the annual amplitude was 0.3-0.4 magnitudes: at the limit of what is detectable visually, even by experienced observers. Since 2015, the amplitude has increased steadily and quasi-periodic oscillations have become increasingly evident, culminating in the deep 2020 minimum.

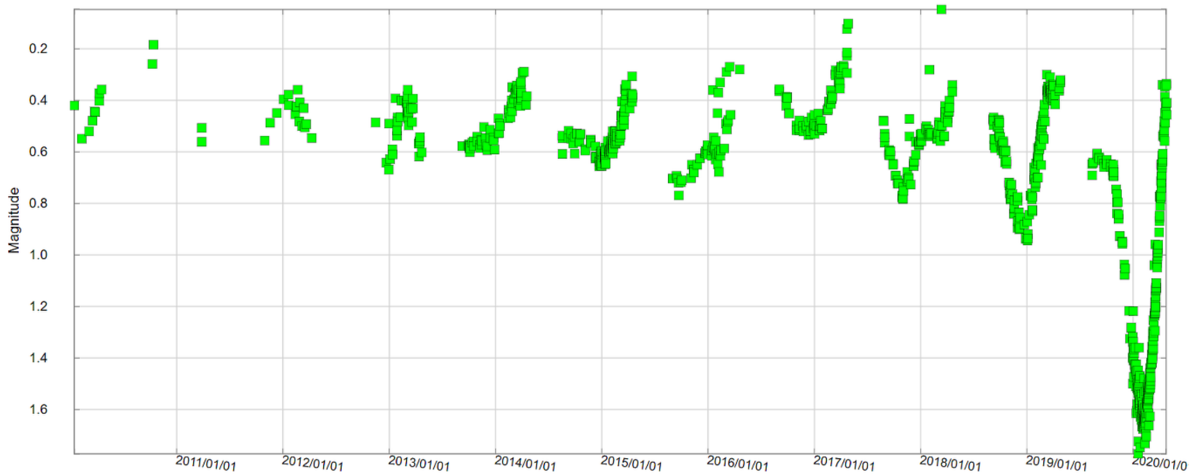


Figure 3: The photoelectric V lightcurve of Betelgeuse from 2010 to date. From 2010-2014 the typical amplitude was just 0.3-0.4 magnitudes. Since 2015, there is a clear increase year-on-year in the amplitude of the annual maxima and minima. Credit: AAVSO database.

Why did Betelgeuse fade?

Even a cursory glance at **Figure 3** suggests that there is a oscillation of a little more than a year. Fourier analysis of the light curve (**Figure 4**) shows a strong signal at a period of 430±10 days (Guinan et al., 2019, ATel #13365). The broadness of this peak, even after 20 cycles have been covered, suggests that the light curve is not purely periodic, but rather that this is the *characteristic period* in the light curve.

Extrapolation of this 430 day period led to a predicted date of minimum of February 21st 2020, with an uncertainty of ±7 days (Guinan & Wasatonic, 2020, ATel #13439), in reasonable agreement with the observed date of February 6th. How stable this period will be in the future though, is not guaranteed.

Why was the 2020 minimum so deep?

This is an excellent question. The average amplitude of the 430 day cycle over the last 20 years has been only about 0.4 magnitudes, insufficient to give such a deep minimum. One possibility, that is supported by the increasing depth of the minima in the last few years, is that the amplitude of the 430 day period is modulated by the 2200 day period and that the two minima coincided in 2020. While the timing of the supermaximum of 2017 would be fairly consistent with this model, the absence of any clear previous supermaxima and superminima in the light curve argues against it.

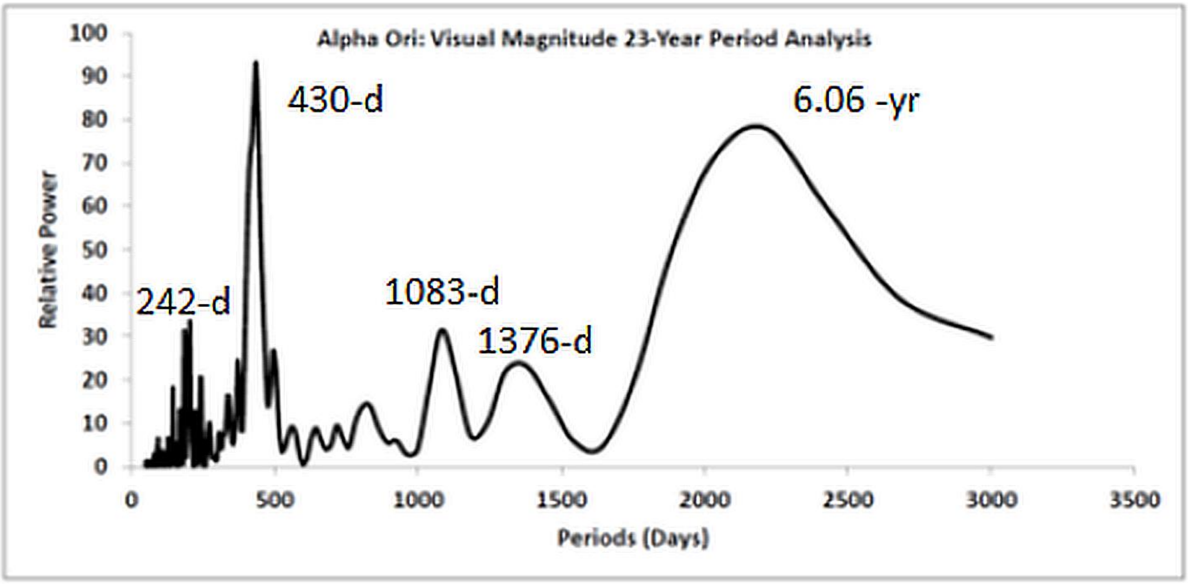


Figure 4: Fourier spectrogram of the lightcurve of Betelgeuse (1997-2020). The predominant period is 430 days, with a broad peak at 6.06 years (2200 days). The periods at 242 and 1376 days appear to be harmonics of the main periods. Credit: Peranso.

Another possibility is that, for inscrutable reasons of its own, the 430 period, which has only been detected relatively recently, has simply become stronger, or more stable in recent years and is now the dominant mode of variation. Sigismondi (2019, arXiv:1912.12539 [astro-ph.SR]), analysed eight years of CCD differential photometry, from late 2011 to early 2020, pointing out that the 430 day period has only been present strongly in the light curve for the last three cycles. This suggests that we may, unknowingly, be seeing some previously unknown aspect of stellar physics playing out before our very eyes. Evidence for this is provided by the fact that an analysis of 60 years of AAVSO data (Karoska, 1987, Lecture Notes in Physics, Volume 274) finds a rather different set of periodicities at 20.5, 8.8, 6.5, 5.7 and 1.05 years. While the mean of the 6.5 and 5.7 years periods is in good agreement with the 6.08 year period seen in Figure 4, the 1.05 year period, which is barely significant in the Karoska analysis, corresponds to 385 days, in some disagreement with the 430±10 days found by Guinan et al. (2019, ATel #13365). Thus the 430-day period may be both recent and likely to be only temporary.

What happened to Betelgeuse?

Betelgeuse shows strong metal oxide lines towards the red end of the spectrum, with titanium oxide [TiO] particularly strong (see Kaler, 1989, "The stars and their spectra", Cambridge University Press, p.70). The strength of the TiO lines is strongly temperature sensitive. We see this in the fact that Betelgeuse is an M2Iab star, while Mira Ceti, an M7IIIe, or Rho Persei, an M4II star, which are thus cooler than Betelgeuse, have much stronger TiO lines.

This means that photometry with narrow-band filters centred on the strongest TiO band at 7190Å relative to the nearby reference continuum at 7520Å is sensitive to the temperature of the star, while a third, relatively line-free window at 1024Å (these are known as the Wing Bands A, B & C respectively) is a good indicator of the bolometric (total) luminosity of the star. Photometry in these bands revealed that the mean photospheric temperature dropped from 3650K in September 2019, to 3565K at the end of January 2020 (Guinan & Wasatonic, 2020, ATel #13439). As a star cools, more of its light gets emitted in the infrared compared to the visible, so to know the true luminosity, we need to calculate the bolometric luminosity, which adds up the total emission, visible and invisible of a star (or a galaxy), compensating for the fact that some visible emission has just been shifted into the infrared.

What the Wing Band photometry revealed is that, while the visible brightness dropped by 1 magnitude (i.e. to 40% of its pre-fade level), the bolometric luminosity, as estimated from Wing Band C, only dropped to 77% of the pre-fade value. From these various measures, if one assumes that the whole surface of the star has the same temperature and brightness, like a spotless Sun at solar minimum, you can use the ratio of temperature and total luminosity to estimate the change in the radius of the star[2].

It is well known that pulsating stars change diameter and temperature simultaneously (**Figure 5**).

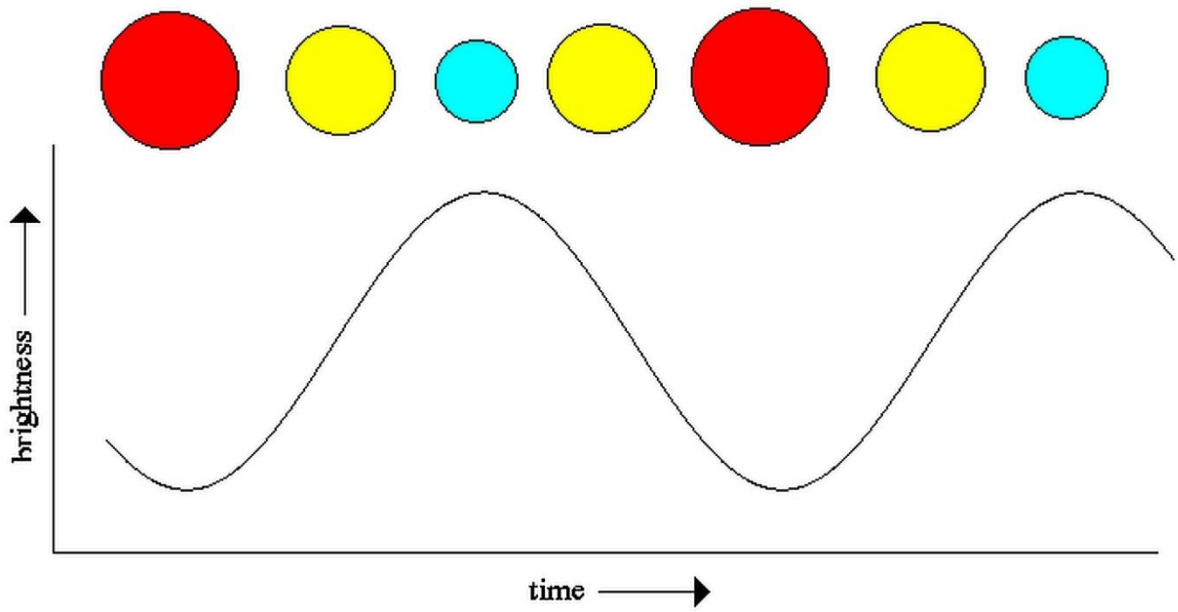


Figure 5: the classical temperature/brightness relationship for a pulsating star over its lightcurve cycle. The increasing temperature as it contracts leads to the star being brightest when smallest. Image: University of Oregon.

Intuitively, one would expect a decrease in temperature and a decrease in brightness to indicate an increase in diameter. Interestingly, the results for Betelgeuse though showed a small *decrease* in effective radius. The calculated effective diameter is 8% *smaller* than it was, pre-fade, in September 2019 (Guinan & Wasatonic, 2020, ATel #14349). However, the authors add an important caveat to their conclusions: the calculation assumes that the whole photosphere has the same brightness (i.e. it is spherically symmetrical). This is a very large assumption and, as we will see, has been proved to be invalid.

Imaging with the SPHERE, the high-resolution, adaptive optics, optical/near-infrared imager on ESO's Very Large Telescope has shown (**Figure 6**) that the assumption of spherical symmetry does not hold. Images of Betelgeuse that resolve the disk were taken in the H-alpha filter in January 2019 and again in December 2019; the former close to the previous minimum (magnitude 0.9), the latter, during the decline to the February 2020 minimum (magnitude 1.2).

The images show that, not only was Betelgeuse not spherically symmetrical when approaching minimum, apparently the visible photosphere was not even approximately spherical, thus the assumptions made by Guinan & Wasatonic (2020, ATel #14349) break down badly. The shape of the star is irregular and there is a something that could be a dark cloud in front of the star, or a much cooler area in the lower right-hand quadrant.

Infrared photometry shows that the infrared brightness did not fade when the visible brightness did. Infrared light penetrates dust efficiently, which is why we use infrared images to investigate star formation inside nebulae that may have 100 magnitudes of visible extinction. However, it also explains why the brightness measured in the Wing C filter showed a much smaller drop: the wavelength of this filter is far enough into the infrared for it to penetrate the dust much better than the shorter wavelength of the TiO band, so it could still see Betelgeuse shining relatively clearly through the dust cloud.

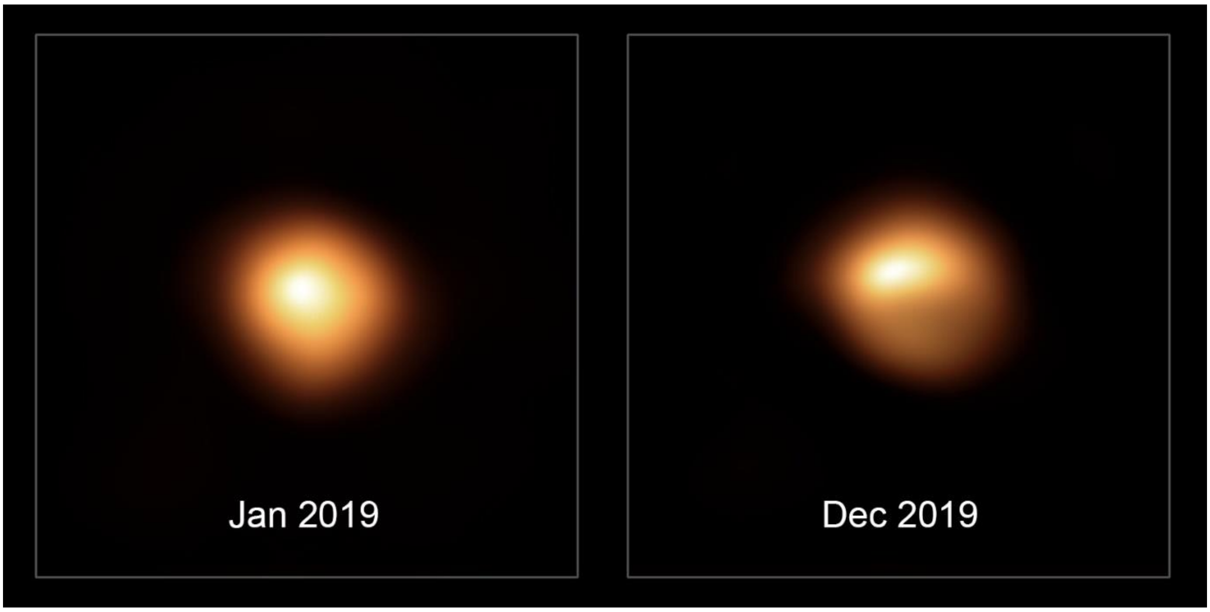


Figure 6: This comparison image shows the star Betelgeuse before and after its unprecedented dimming. The observations, taken with the SPHERE instrument on ESO's Very Large Telescope in January and December 2019, show how much the star has faded and how its apparent shape has changed. Credit: ESO/M. Montargès et al.

Other ESO infrared images show huge plumes of dust around Betelgeuse that have been ejected in previous episodes, while the far-infrared images with Herschel suggest that violent dust ejection has been going on for at least 30000 years – the large dust shell observed by Herschel is expanding at 30km/s.

Together, the evidence indicates that the fade was due to a massive dust ejection of "large" (about micron-sized) dust particles that partly hid the star, temporarily blocking the visible light, but not the infrared. In other words, Betelgeuse is, or maybe *is becoming*, somewhat analogous to R Coronae Borealis[3]. Intriguingly though, the recent, increasingly deep minima, seem to be quasi-periodic, something that is certainly not a characteristic of episodic dust producers.

Conclusions

Observations suggest that minimum was reached around February 7th 2020, in reasonable agreement with the recent 430 day period in the light curve and that the unusual depth was due to a combination of the minima of the 6.1 and 430 day periods and the ejection of a massive cloud of opaque dust, obscuring the visible disk. How stable and enduring the 430-day period is remains uncertain but, if it continues to be present in the lightcurve, we would expect a new minimum to around magnitude 1.0 to occur around April 12th 2021.

[1] In his Table 30, Bayer assigned Alpha and Beta to two, fourth magnitude stars, too far south to be observed from his observing location in Germany while, at the same time, classing them as of second magnitude. His star chart also shows these two stars as the most brilliant, above Epsilon and Sigma, which are by some distance the brightest stars in the constellation. It seems that, in this case, Bayer based his choices on bad information from an unknown party, although he may well have been guided in such discrepant cases by the classification of Ptolemy in the Almagest. Evidence for this is that Bayer follows Ptolemy in various widely-discussed cases of discrepancy in the Bayer classification, such as Megrez and Denebola. Ptolemy describes Betelgeuse solely as “The bright, reddish star on the right shoulder” and assigns it magnitude 1.

[2] This is the famous Stefan-Boltzmann Law: $L=A.\sigma T^4$, in which L is the total luminosity emitted, A is the surface area and T the temperature, with σ the Stefan-Boltzmann Constant.

[3] To be clear, R CrB and Betelgeuse are very different types of star. R CrB is a hydrogen-depleted G0Iep yellow supergiant star, although of slightly less than solar mass, so we cannot take this analogy too far.

Betelgeuse – A Century and more of Variation

Christopher Lloyd

The mean light curve of Betelgeuse is constructed from the visual data in BAA VSS and AAVSO archives. Period analysis reveals clusters of periods around 2000 and 400 days but these are swamped by the long-term trends. No identifiable periods emerge but the feature near 400 days is the most persistent and survives even when the range of variation is low. Herschel's data from 1836-40 and early data from the BAA VSS ~ 1900 show a range of V ~ 0 – 1 ,so the star was brighter and more active than recently. Historically it shows a wide range of behaviour.

On a good day Betelgeuse is one of the brightest stars in the night sky, brighter that Procyon, Rigel and Capella, even Vega and possibly even brighter than Arcturus, leaving only Rigel Kent, Canopus and Sirius outshining it. But these days are rare, and there are also bad days as witnessed recently when Betelgeuse underwent an unusually deep and rapid fade down to the relegation zone of magnitude 1.6. Betelgeuse spends most of its time at magnitude 0.5-0.8 in the realm between Procyon and Aldebaran, but it does undergo slow excursions of half a magnitude with brief runs up to magnitude zero and occasional rapid fades. Its spectral type is M1-2 1a-ab so it is a very luminous early M-type supergiant, which accounts for its pronounced orange colour as opposed to the deeper red of most Mira-type variables. Betelgeuse itself is classified as an SRc variable due to its small range of variation and lack of clear periodic variation. The AAVSO VSX gives a main period of 423 days, with a secondary at ~2100 days, but the GCVS gives the period as 2335 days. A trawl through the literature will turn up many others.

Betelgeuse is such a bright star in a prominent constellation that its variability must have been known to the ancients. Wilk (1999, J.AAVSO) continues the theme that the variability of bright stars, including Betelgeuse, was known to the pre-Classical Greeks and is reflected in their mythology. Myths of the Australian Aboriginals lead to an even more direct description of its variability with the star becoming periodically brighter and fainter (Leaman & Hamacher, 2014).

When it comes to more modern times it seems most likely that the variation was discovered or rediscovered, in the western world at least, by Sir John Herschel as reported to the RAS in 1840. Herschel started making naked-eye observations of some dozens of stars at the Cape, including Betelgeuse during 1836, and continued these the following years, including on the ship during the trip back to the UK in 1838, until early 1840. The results are presented in a *Monthly Notices* paper and in much more detail in the *Memoirs*. Herschel was following his own advice in making observations of variable stars, which he thought showed "*a sure promise of rich discovery*", and this is as true today as it was when he wrote his *Treatise on Astronomy* in 1833.

The discovery can probably be pinpointed to the 26th November 1839 when he was "*surprised, and I may almost say startled by the extraordinary splendour of α Orionis*", which at that time he placed between Capella and Rigel. Both have V ~ 0.1. He was then prompted to review his observations of the previous years and came to the realization that Betelgeuse was variable with a likely period of about one year. Herschel's method of observation was at the same time obvious and original, as no one else seemed to be doing this. In the early observations he simply recorded which two stars bracketed the variable and recorded this in the undeniably magnificent, "*Order of Lustre*", so there would be a sequence like, α Crucis – Betelgeuse – Regulus, and no magnitudes were involved. As time progressed he inserted "*imaginary stars*" at equal intervals of lustre between what could be called the comparisons, and so the fractional method was born. Herschel's measurements are given in Table 1 and plotted in Figure 1. His estimates are given with the imaginary stars as he indicated “|” and the magnitudes calculated using modern values of the *V* magnitudes, with additional guidance from the notes that accompanied each estimate. The general order of lustre that he used is, Capella (0.1), Rigel (0.1), Procyon (0.4), Achernar (0.5), Aldebaran (0.9), α Crucis (0.8), Pollux (1.2) and Regulus (1.4), but it is clear that some small inconsistencies exist. However, given the wide range in colour of these stars and their dispersal over the sky this is not unexpected, and has no material effect on the results. Some of the apparently inconsistent results in Table 1 can be explained by extinction effects on either the variable or the primary comparisons.

Table 1. Herschel’s observations of Betelgeuse from 1836 to 1840. The bracketing stars only are given for the early observations but the “*imaginary stars*” indicated “|” are included for the later data. The derived magnitudes are based on modern V measurements and additional notes to the observations. There will be some small rounding issues.

<table>
<tr><th>Date</th><th>JD</th><th>Measure</th><th>Mag.</th></tr>
<tr><td>1836 Mar. 22</td><td>2391726</td><td>α Crucis – Betelgeuse – Regulus</td><td>1.1</td></tr>
<tr><td>1836 Nov. 12</td><td>2391961</td><td>Betelgeuse} – Procyon
Rigel}</td><td>0.0</td></tr>
<tr><td>1836 Nov. 13</td><td>2391962</td><td>Betelgeuse = Rigel</td><td>0.1</td></tr>
<tr><td>1836 Nov. 26</td><td>2391975</td><td>Procyon – Betelgeuse – Achernar</td><td>0.4</td></tr>
<tr><td>1837 Oct. 24</td><td>2392307
2392307</td><td>Betelgeuse – Achernar (high in the sky)
Betelgeuse – Rigel – Aldebaran (low)</td><td>0.3
-0.1</td></tr>
<tr><td>1837 Dec. 3</td><td>2392347</td><td>Rigel very much larger than Betelgeuse</td><td>(0.8)</td></tr>
<tr><td>1837 Dec. 16</td><td>2392360</td><td>Rigel – Achernar – Betelgeuse</td><td>0.7</td></tr>
<tr><td>1837 Dec. 29</td><td>2392373</td><td>Procyon – Betelgeuse – Aldebaran</td><td>0.6</td></tr>
<tr><td>1838 Jan. 2</td><td>2392377</td><td>Achernar – Betelgeuse – Pollux</td><td>0.8</td></tr>
<tr><td>1838 Jan. 6</td><td>2392381</td><td>Achernar – Betelgeuse – Aldebaran</td><td>0.7</td></tr>
<tr><td>1838 Jan. 13</td><td>2392388</td><td>Achernar – Betelgeuse – Aldebaran</td><td>0.8</td></tr>
<tr><td>1838 Feb. 25</td><td>2392431</td><td>Procyon – Betelgeuse – α Crucis</td><td>0.6</td></tr>
<tr><td>1838 Apr. 14</td><td>2392479</td><td>Rigel – Betelgeuse – Aldebaran</td><td>0.5</td></tr>
<tr><td>1839 Jan. 16</td><td>2392756</td><td>Aldebaran is greater than Betelgeuse</td><td>(1.1)</td></tr>
<tr><td>1839 Jan. 17</td><td>2392757</td><td>Aldebaran – Betelgeuse – Pollux</td><td>1.0</td></tr>
<tr><td>1839 Jan. 22</td><td>2392762</td><td>Aldebaran – Betelgeuse – Pollux</td><td>1.0</td></tr>
<tr><td>1839 Nov. 26</td><td>2393070</td><td>Capella || Betelgeuse | Rigel</td><td>0.1</td></tr>
<tr><td>1839 Nov. 30</td><td>2393074</td><td>Rigel | Procyon, Betelgeuse || Aldebaran</td><td>0.4</td></tr>
<tr><td>1839 Dec. 11</td><td>2393085</td><td>Rigel | Procyon | Betelgeuse || Aldebaran</td><td>0.6</td></tr>
<tr><td>1839 Dec. 29</td><td>2393103</td><td>Rigel, Procyon, Betelgeuse, Aldebaran</td><td>0.7</td></tr>
<tr><td>1840 Jan. 2</td><td>2393107</td><td>Rigel || Procyon | Betelgeuse || Aldebaran</td><td>0.6</td></tr>
<tr><td>1840 Jan. 5</td><td>2393110</td><td>Rigel || Procyon | Betelgeuse || Aldebaran</td><td>0.6</td></tr>
<tr><td>1840 Jan. 6</td><td>2393111</td><td>Rigel || Procyon || Betelgeuse || Aldebaran</td><td>0.7</td></tr>
<tr><td>1840 Jan. 7</td><td>2393112</td><td>Procyon | Betelgeuse | Aldebaran</td><td>0.7</td></tr>
<tr><td>1840 Feb. 25</td><td>2393161</td><td>Procyon || Betelgeuse | Aldebaran</td><td>0.7</td></tr>
<tr><td>1840 Apr. 18</td><td>2393214</td><td>Procyon | Betelgeuse || Aldebaran</td><td>0.6</td></tr>
</table>

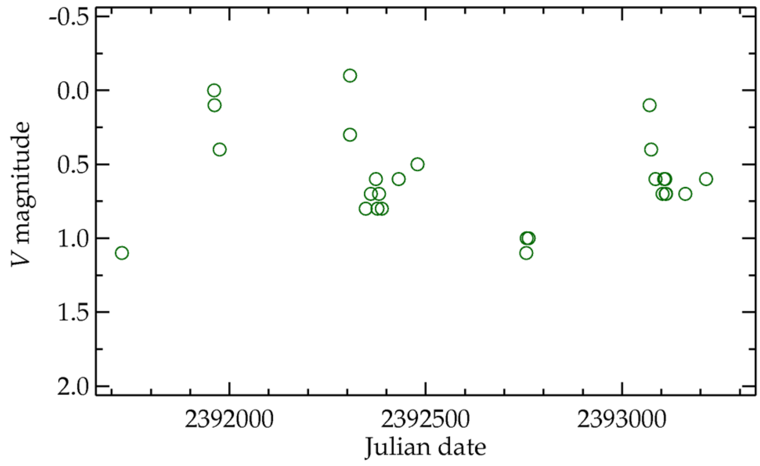


Figure 1: Herschel's light curve of Betelgeuse from 1836 to 1840

Herschel's short run of observations span the range *V* = 0 – 1.1, which is much larger than its normal range and reaches the bright limit, so during this time the star was bright and active. From Figure 1 it can be seen that if the uncertainties are small, and if you're Herschel they probably are, then a vaguely seasonal, periodic variation could fit the data, and this is what Herschel reported. The only other observation from around this time is a report by R.H. Allen and cited by Wilk that on 5th December 1852, Betelgeuse was reported to be "*the largest (brightest) star in the northern hemisphere*".

Despite Herschel's efforts to kick-start variable star astronomy both through his manifesto in 1833 and his practical efforts in 1840 and after, there was little response from the community. Argelander started doing similar work in Bonn in the 1840s and the modern basis of the magnitude scale was established by Pogson by 1856 (see Jones 1968 for example). Over the next 30 or so years various variable star organisations came and went in the UK as thoroughly detailed by Toone (2010, J.BAA 120, 135) before the BAA VSS finally emerged in 1890.

The earliest VSS observations of Betelgeuse were made by Prof. Joao De Morae Pereira, one of only 19 members of the VSS at this time, who made a series of observations in the winter of 1893/4 and the following two years. Unfortunately, neither the comparison stars nor the step values he used were recorded but the die was cast and a few years later E.E. Markwick and several other early pioneers of variable star astronomy were making observations. For these also no sequences are available, but the step values have been recorded so it is possible to see the obvious comparison stars Procyon and Aldebaran being adopted, and with the same magnitudes as used today.

The complete light curve from the combined BAA VSS and AAVSO archives is shown in Figure 2. The plot shows 10-day means with a single observation as a small dot, up to 10 observations as an open circle and above 10 as a filled circle. Care must be taken when interpreting specific features as the alignment of the 10-day bins can make a large difference to the number of observations that are included in each bin. Not surprisingly the early data are relatively sparse and there is a large gap from 1910 to 1920. Following that the record is a largely complete, but it is thin in places. Even from the start the seasonal trends noted by Herschel can be seen and the range of variation from *V* ~ 0 – 1 is also similar to what he reported. There are also signs of longer time-scale features with the star cycling over ~ 2000 days. From JD ~ 2427000 the star begins to have significant excursions below

Back to contents

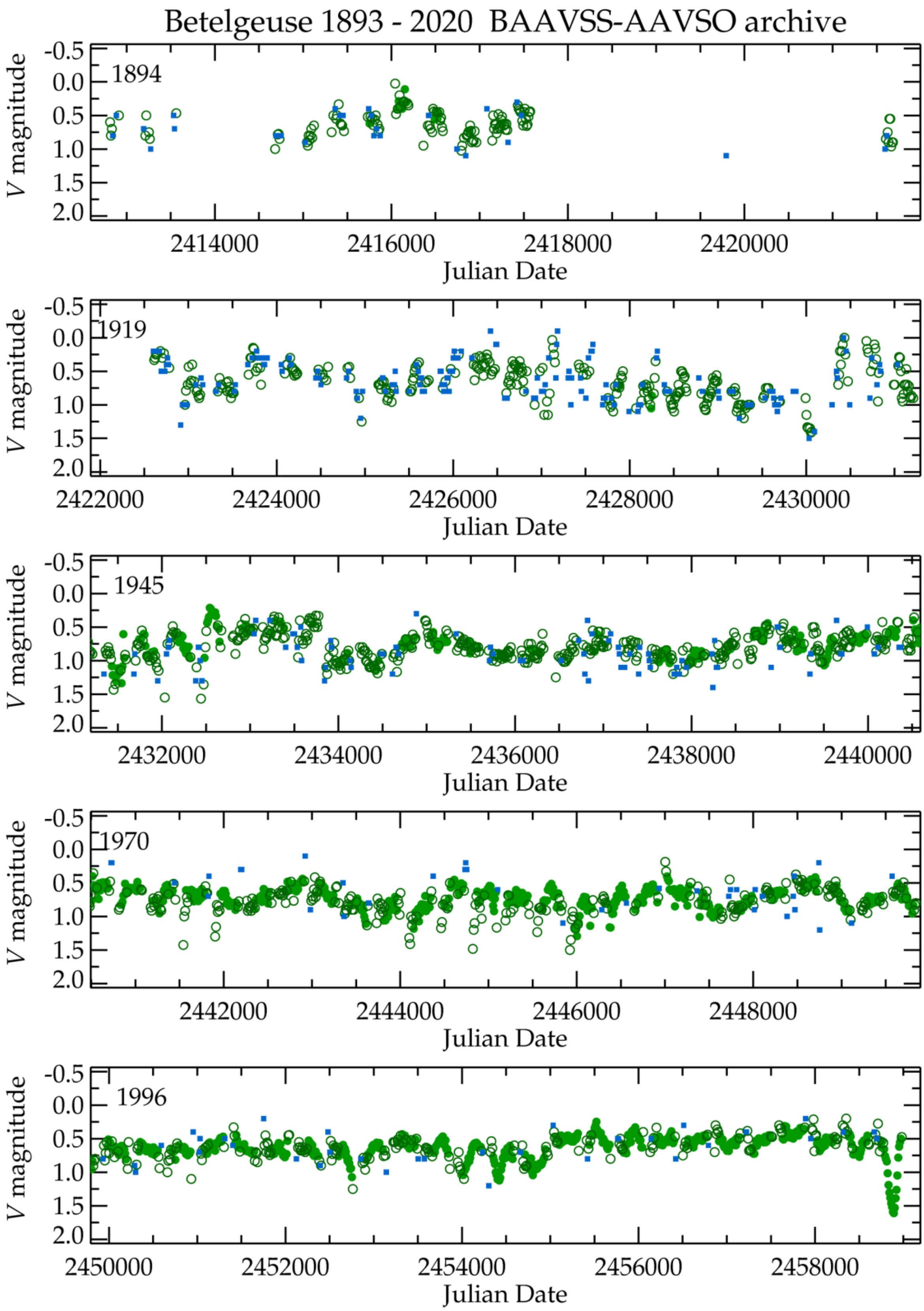


Figure 2: The combined BAA VSS – AAVSO light curve of Betelgeuse from 1893 to the present. The points are 10-day bins with single points shown as dots, up to 10 points as open circles, and more than 10 as filled circles. The year is shown at the start of each panel which cover ~25 years.

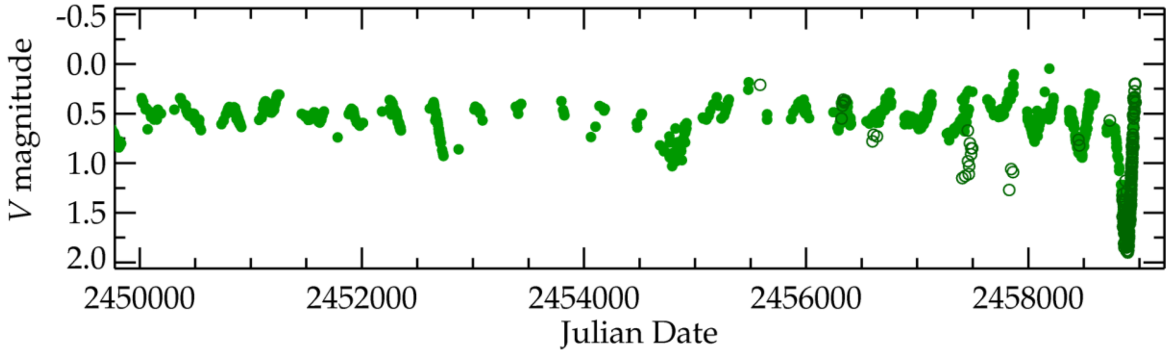


Figure 3: The recent *V* (filled circles) and TG data of Betelgeuse covering the same range as the bottom panel of Figure 2.

magnitude 1, with a few deeper fades to *V* ~ 1.5, and consistent brightenings to magnitude 0. Over this period the seasonal trends become a clearer, saw-tooth pattern as more observations are made. Around JD = 2431000 the star undergoes a substantial fade from V ~ 0.3 to 1.4 and this was followed ~ 500 and 1000 days later by two other deep fades which coincide with the minima of the saw-tooth pattern. These are the most consistent and faintest magnitudes in the record – up until the present – but they are not particularly well observed. There is then a long section up to JD ~ 2450000 where the saw-tooth pattern becomes less visible and the light curve is largely dominated by small variations on long time scales. For the last 25 years the range of variation has been at a minimum and a weak saw-tooth pattern has re-emerged. Also, there has been a distinct change in level at JD ~ 2455000 with mean V = 0.67 before and V = 0.56 after, despite the recent deep fade. Mean *V* magnitude for 4000-day sections of the 10-day mean light curve are given in Table 2.

Julian Date range	Mean	Standard deviation
2412000 – 2416000	0.67	0.16
2416000 – 2420000	0.58	0.22
2420000 – 2424000	0.59	0.26
2424000 – 2428000	0.59	0.24
2428000 – 2432000	0.82	0.29
2432000 – 2436000	0.75	0.23
2436000 – 2440000	0.82	0.17
2440000 – 2444000	0.71	0.17
2444000 – 2448000	0.78	0.20
2448000 – 2452000	0.67	0.13
2452000 – 2456000	0.67	0.17
2456000 – 2460000	0.56	0.21

Table 2. Mean magnitudes and dispersions for 4000-day intervals of the 10-day means

That is why Betelgeuse is an SRc variable. There is no clear periodicity but some features of the light curve do emerge, 1) the long-term changes in level, 2) the ~2000+ day variation which comes and goes, and 3) the saw-tooth pattern which is sometimes equally invisible. In recent years an increasing number of photoelectric and CCD V-band measurements have been made together with some DSLR TG values. These data from JD ~ 2450000 are shown in Figure 3 and cover the same range as the bottom panel of Figure 2. With less scatter the seasonal runs are much more clearly visible and surprisingly small details in the visual record can be confirmed. Generally, the comparison is remarkably good. Curiously though, the small change of level in the visual data cannot be seen but the latter half of the *V* data do have a slightly brighter limit. The other important point to emerge from the *V* data is that the variations are almost entirely linear, which is saying something about the processes involved.

There are various tools that can be used to find periodic variations, even if they are buried in the noise, but the interpretation is often the problem. The most widely used technique is probably the Discrete Fourier Transform (DFT) periodogram which measures the power – that is the semi-amplitude[2] – at a particular frequency. The DFT of the 10-day means is shown in the upper panel of Figure 4 with the periods associated with the major peaks identified. The first point to notice is the power range. The peak corresponds to an amplitude of ±0.1 magnitudes so no periods here are going to account to anything but the smallest variation in the light curve. The longest period is longer than the run of data and is driven by the small changes of level identified in Table 2, and the two other long periods are a response to other long-term trends, which are invisible to the eye. The first period that can be clearly related to variations in the light curve is at 2081 days, but this is close to two other prominent periods and a cluster of weaker ones between 1000 and 3000 days. All of these are related to the continuum of variations on this time scale in the data, but the specific periods that appear dependent on the vagaries of that particular data set. Similarly for the features near 380 days. These correspond to the saw-tooth pattern and cover a range of 300 – 500 days. While this is not periodic it is probably the most persistent and diagnostic feature of the light curve. The shortest period identified is a harmonic of this one.

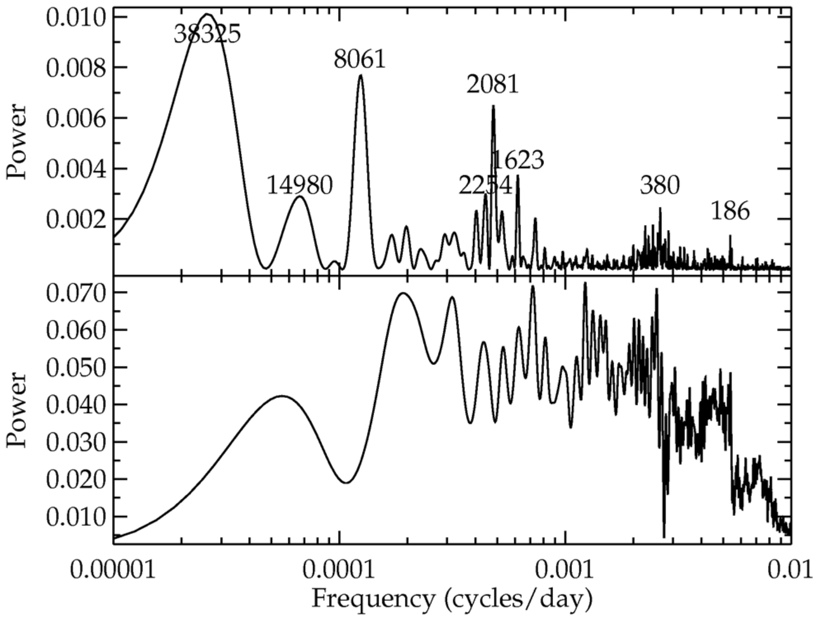


Figure 4: Upper panel: The DFT periodogram of the 10-day means with the dominant periods identified. Lower panel: The DFT periodogram of the *V* data, mostly from the last 30 years.

The DFT of the *V* data is shown in the lower panel of Figure 4 and immediate differences can be seen. The power is much larger, and accounts for most of the variation seen in the data, and the only really persistent feature is the one near 400 days. The 2000+ day cluster has gone because the recent light curve has been essentially flat, and there is little power at the longest periods because there are no data there.

There is clearly no single period near 2000 or 400 days but both could be representative of real periods in the data that meander between 1000 – 3000 and 300 – 500 days. The cluster of features in the periodogram just gives a snapshot of this for the past 100 years, that would eventually become filled in over great tracts of time. The alternative is that there is no periodicity at all and that the processes at work in the star recognize no clock, just a loose time scale – sometimes. The difference in interpretation leads to very different visions of how the atmosphere of the star operates.

The recent deep fade has led to a renewed interest in Betelgeuse and an explosion in the number of observations made, if not the star itself (see Figure 2 of the accompanying paper). The fade was first noticed by Guinan et al. (2019, ATel#13341) who also pointed out that it appeared to be a deep minimum of the 400 day cycle. In a later update (ATel#13365) they also suggested that the fade might be due to the coincidence of the minima from both cycles, not in an additive sense as the amplitudes are too low, but presumably as some sort of resonance. However, even this seems unlikely as the ephemeris of the long cycle must be unknown; they put an uncertainty of 180 days on the period, and it has been effectively absent for the past 25 years.

Obviously, there is great interest in what is likely to happen next year. The recent minimum was in early February so the next one might reasonably be in March 2021; periodic or not there is still a preferred time scale. Betelgeuse is on average as bright as it's ever been and in the past this has usually been accompanied by greater activity. Maybe unprecedented bright magnitudes will be seen. Looking back at the previous double deep minima around 1945 raises the tantalizing prospect of further deep minima disappearing into the twilight. Were they real – will it do it again?

In view of recent events this comment by Herschel is equally apt today.

"*It may be easily supposed … that the confirmation or disappointment of this expectation is awaited with no small interest.*"

Indeed. All eyes will be on Betelgeuse next year.

CV & E News

Gary Poyner

Latest on the continuing anomalous behavior of the UG star SS Aur, the April 2020 outburst of the UGSU star QZ Vir and a low state in the symbiotic variable YY Her are covered.

SS Aur

In VSSC 175 (March 2018) I wrote about the unusual outburst behaviour occurring with SS Aur since early 2014. Now over two years later, we see this anomalous outburst activity continuing, with a brighter than 'normal' minimum, reduced amplitude, and a higher frequency of outbursts (Fig. 1).

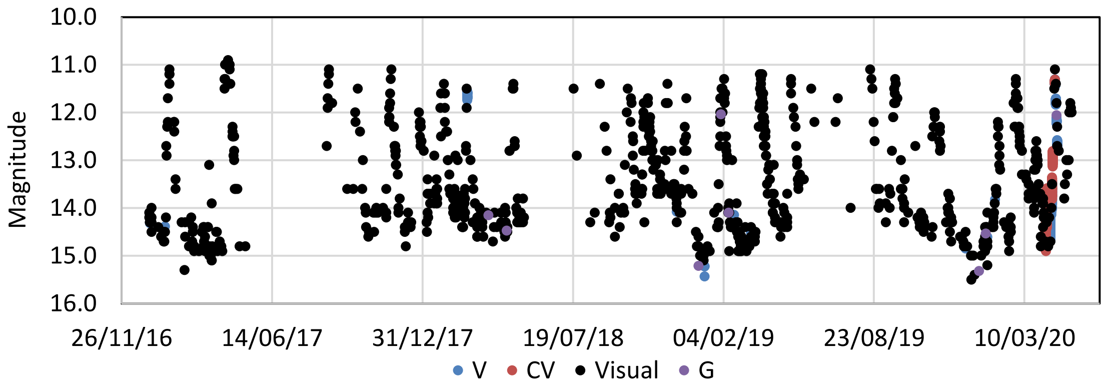


Figure 1: 2,756 observations from BAAVSS database. Jan 01, 2017 – May 12, 2020

CCD observers Roger Pickard (V) and Steve Johnstone (CV) undertook a 1h 53m simultaneous time series run on 2020 April 15 whilst SS Aur was slowly rising to outburst which peaked 5 days later. The resulting light curve (Fig. 2) shows hump like features declining towards the end of the run. The duration of the two prominent and well-defined humps in the centre of the light curve are 23 and 24 minutes respectively, with the amplitude being 0.4mag. The Porb for SS Aur is 0.1828d (4.39h). These are the first concentrated time series observations made of SS Aur and reported to the BAAVSS DB since CCD's were introduced to the amateur community well over two decades ago.

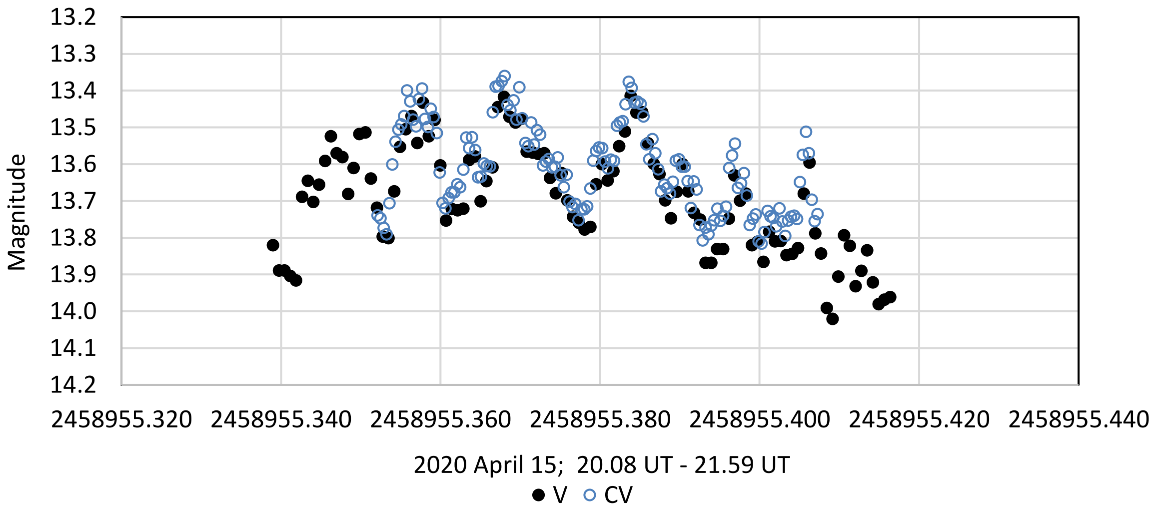


Figure 2: Time series obtained by Roger Pickard (V) and Steve Johnstone (CV) April 15, 2020

QZ Vir

The UGSU star QZ Vir entered its first outburst since May 2019 on April 3 at magnitude 10.5 M_{vis}. By April 6 it had faded by over a magnitude to 11.9 vis, suggesting a normal outburst. However, two days later the brightness had increased to 10.7 vis and continued in superoutburst to April 15 when it had faded to 11.4 mean M_{vis}. The expected rapid decline occurred and by April 21 had faded to 15.5 M_{vis}. A small post outburst brightening then occurred on April 23 when QZ Vir reached 14.5 vis and quickly faded to 15.2 by April 25 when over the next two weeks it varied slightly as it slowly faded to minimum 16.0CV (Fig. 1)

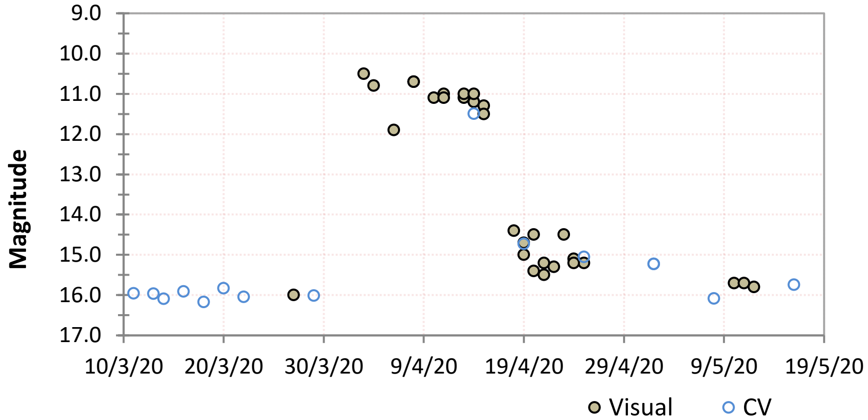


Figure 1: 54 observations from J. Toone and G. Poyner. BAAVSS DB

The outburst episode was notable in that the precursor outburst on April 3 was actually brighter than the following superoutburst, which is quite unusual. The short post outburst brightening is also uncommon in this system, with just three well defined brightenings in the last 20 years – the 2015 outburst being the best covered which included a 3 magnitude outburst following the superoutburst.

YY Her

A classical symbiotic star, YY Her was first identified as a variable star by Wolf in 1919, although it was Herbig who first did a spectroscopic study in 1950 and established YY Her as a symbiotic star. The historic light curve (1890 onwards) displays bright outbursts to magnitude 11 from a quiescence of 13.0-14.0 vis, and occasional low states to below magnitude 14.0. Analysis of the historic light curve can be found in Formiggini & Leibowitz.

The BAAVSS has 1680 observations in the database dating back to 1988. Several 'outbursts' exceeding one magnitude can be seen in the light curve (Fig. 2), along with an obvious variation at minimum and even short duration dips approaching magnitude 14.0. Since the star was picked up in the morning sky in March, YY Her has slowly faded by nearly a magnitude to its current brightness of 13.8 M_{vis}, the faintest it has been seen since July 2015 and only the sixth time it has been seen approaching magnitude 14.0 in 32 years. Observer numbers have dwindled to just three in the past 12 months, so a request is now being made for more observers to join in and follow YY Her this observing season and hopefully beyond.

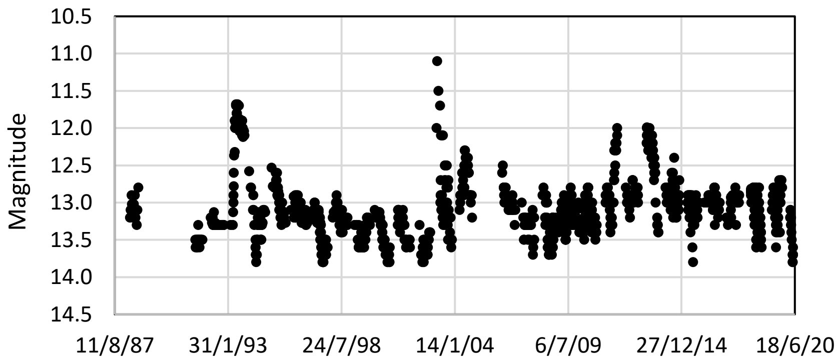


Figure 2: Combined BAAVSS Visual and V light curve for the period May 1988-Apr 2020

Supernova 2020ue in NGC 4636

Guy Hurst

A report and light curve by the UK Nova/Supernova patrol on SN 2020ue.

Koichi Itagaki, Japan relayed on TNS Astronomical Transient Report No. 58616 discovery of a new transient SN 2020ue in NGC 4636. The location (fig 1) is in the constellation of Virgo at:
RA = 12:42:46.780 DEC = +02:39:34.20 (2000)

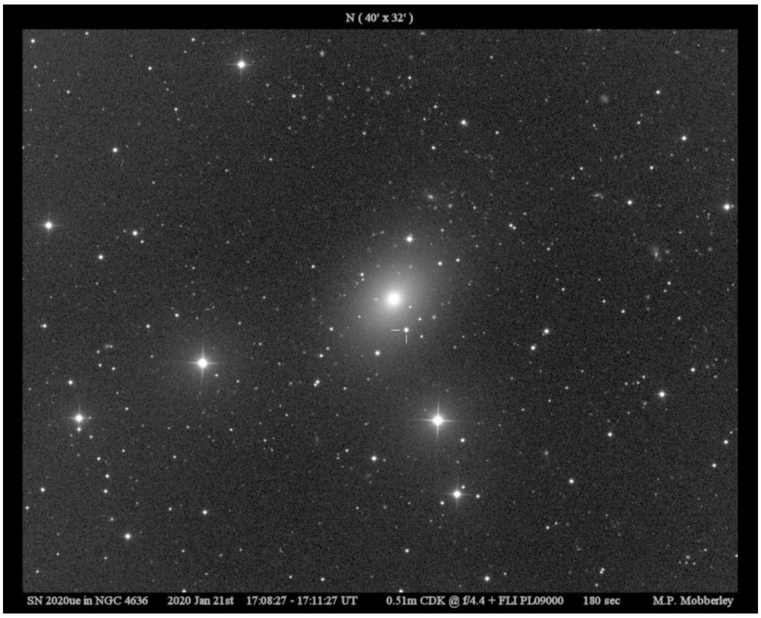


Figure 1: Image by Martin Mobberley of SN 2020ue, 2020 Jan 21

NGC 4636 is an elliptical galaxy located at a distance of about 55 million light years.
Its apparent dimensions are about 105,000 light years across, similar in size to our Milky Way galaxy. It was discovered by William Herschel on 1784 February 23, and lies one and a half degrees southwest of delta Virginis.

SN 2020ue was discovered by Itagaki on 2020-Jan-12 at 17h 20mUT using: 0.5-m F/6.0 reflector + CCD (KAF-1001). When found it was magnitude 15 in a clear filter.

An independent detection was made by the ATLAS group on:2020 Jan 18 15h25m55s mag 12.74. The object therefore was found on the rise Jan 12 mag 15 but gained about three magnitudes by Jan 18. Miho Kawabata analysed the spectrum of the supernova and classified it as type Ia.

Amateurs were encouraged to monitor and most used the AAVSO chart (Fig 2) which initially recorded a maximum of about magnitude 12.2V on January 26.

The light curve (Fig 3) logged by the coordinator of the UK Nova/Supernova Patrol (BAA and TA) yielded 103 estimates/measures showing a fairly smooth linear decline to about magnitude 16.1 by May 7. Major contributions by Gary Poyner and Martin Mobberley as well as the coordinator ensures detailed coverage used in enquiries from professional astronomers.

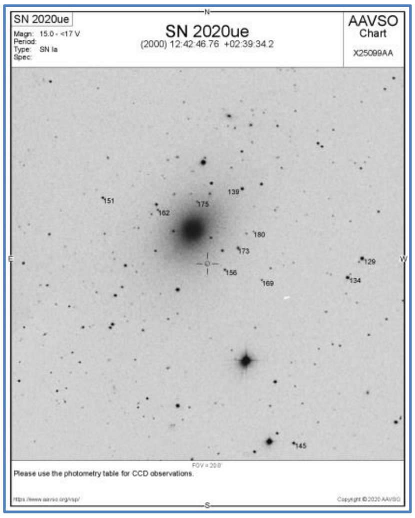


Figure 2: AAVSO Chart

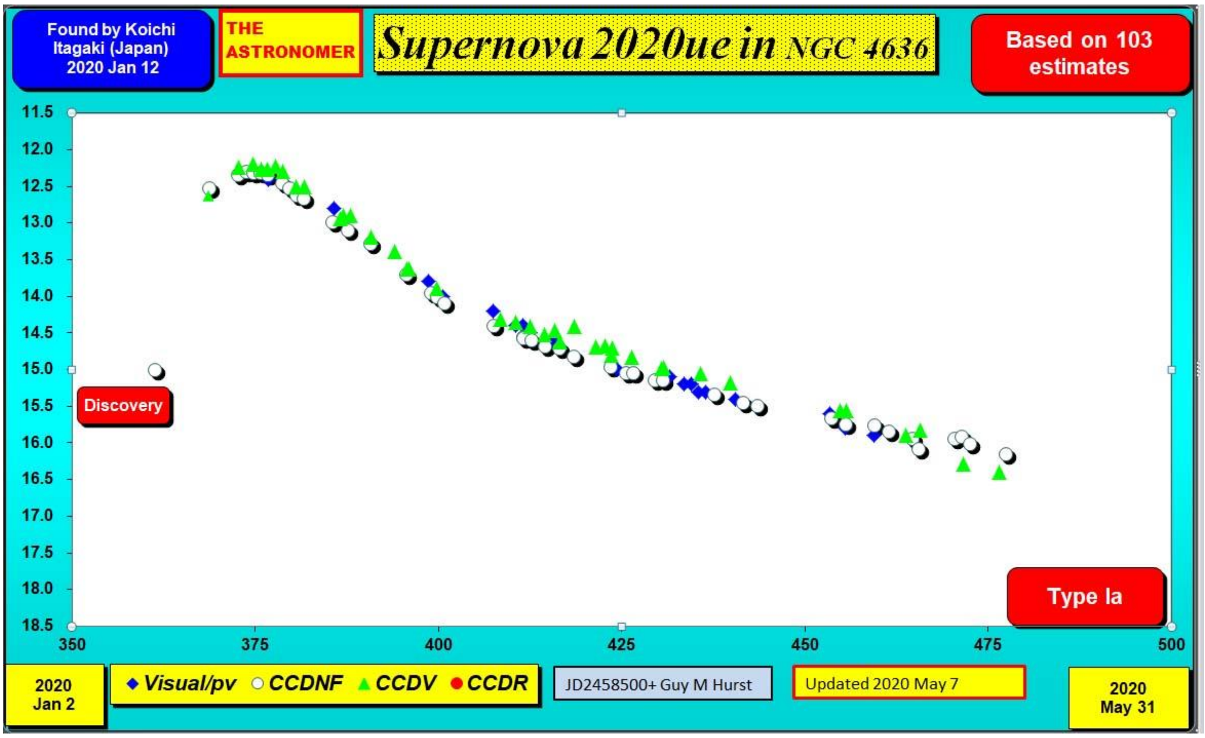
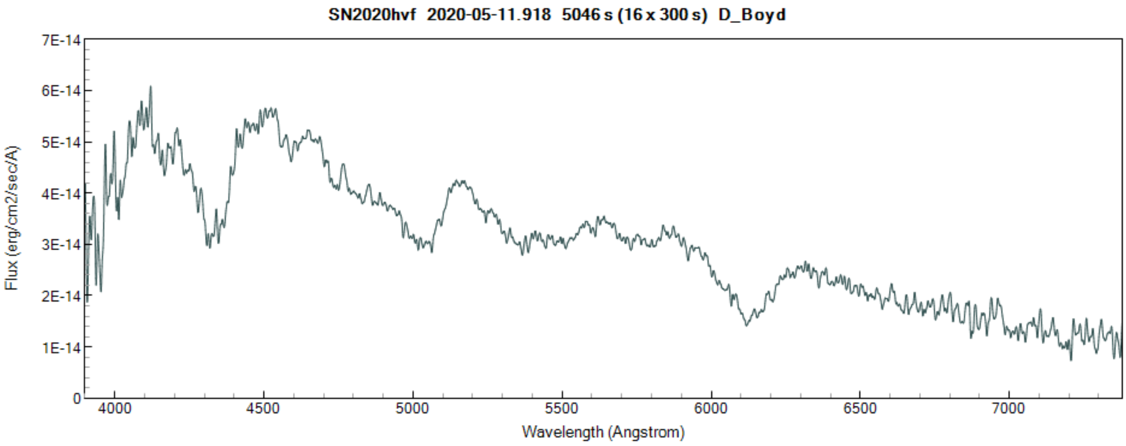


Figure 3: UN Nova/Supernova patrol light curve for SN 2020ue

Details of the new object by IAU can be viewed here:
https://wis-tns.weizmann.ac.il/object/2020ue

And whilst were on the subject of Supernovae, David Boyd reports the following spectrum of SN 2020hvf….Ed.



This spectrum of type 1a supernova SN 2020hvf was taken on 11 May with a LISA spectrograph (R~1100) on a C11 and has been calibrated in absolute flux using a V magnitude of V=12.67 measured concurrently with the spectrum using another scope. It is now close to maximum light. The spectrum has been smoothed with a Gaussian factor 2.5. The blue-shifted location at 6118A of the prominent Si II 6355A absorption feature indicates an expansion velocity of ~11,200 km/s.

David Boyd

Back to contents

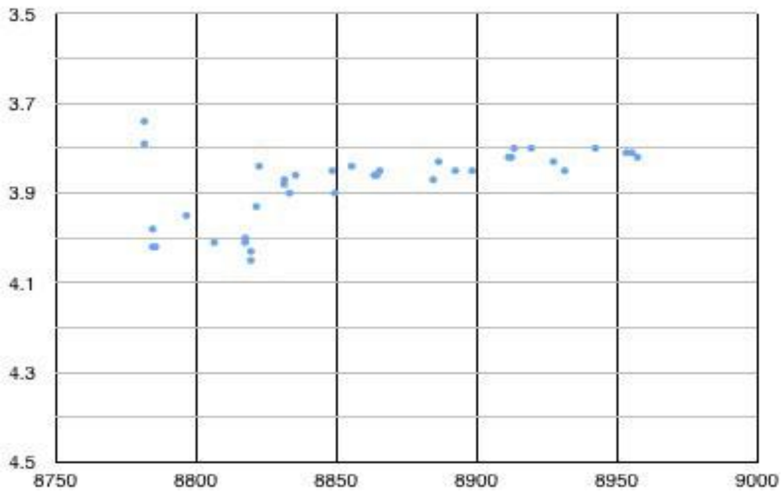
Eclipsing Binary News

Des Loughney

News on zeta Aur, beta Lyr, SZ Psc and U Cep.

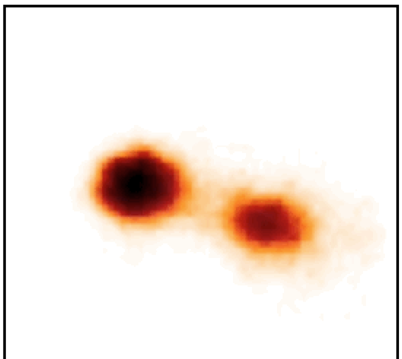
zeta Aurigae

In VSSC 183 it was reported that the zeta Aurigae system did not return to its normal brightness following the eclipse in October/November 2019. The normal brightness would have been 3.75V. As the diagram to the right (taken from personal measurements) illustrates measurements of the system were extended until 17th April 2020. The system has still not recovered to the normal out of eclipse brightness. The system seems to be now varying between 3.80V and 3.90V. A lot more measurements need to be done but they now suggest that zeta Aurigae is not just an eclipsing binary but has another mode of variation with an amplitude of 0.1V and a period of around 30 days.



beta Lyrae

According to Wikipedia the CHARA array, for the first time, obtained actual images of the eclipsing binary beta Lyrae in 2008. The CHARA (Centre for High Angular Resolution Astronomy) array is an optical interferometer. The array consists of six 1 metre telescopes. Wikipedia presents a movie of one period using the actual images. Below is one of the images.


Interacting Binary Beta Lyrae

According to the paper that published the images (1): “The images show clearly the mass donor and the thick disk surrounding the mass gainer… The donor is brighter and generally appears elongated in the images, the first direct detection of photospheric tidal distortion due to Roche lobe filling.”

SZ Pisces

I have been asked some questions about the SZ Psc system. While it is not on our recommended list it is still an interesting system and worth observing. There isn't a BAAVSS chart, but I would be happy to recommend three comparisons that would be useful for DSLR photometry. While it is an eclipsing binary of the Algol class which can be observed visually, it illustrates other features which DSLR photometry can pick up. Its classification is EA/DS/RS. Its period is about 3.966 days and the GCVS states that it's out of eclipse magnitude is 7.18V. The depth of the primary eclipse is 7.72V and the secondary eclipse is 7.38V. The secondary eclipse could be measured with DSLR photometry. The system can be observed favourably in the autumn.

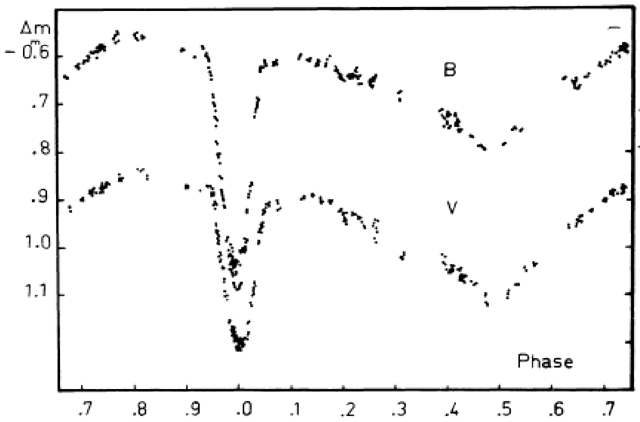


Fig. 1. The blue and yellow light curves of SZ Psc.

It is an RS Canum Venticorum system which means that its light curve exhibits distortion waves which are believed to be produced by starspots on the cooler component (2). Sometimes the eclipses are total and sometimes partial. Shown here is a light curve that is reproduced in (2) showing a partial eclipse. The distortions of the light curve above are evident. If similar distortions are present currently then they could be picked up with CCD or DSLR photometry.

U Cephei

U Cep is one of the 'Beginner Eclipsing Binaries' listed in our Eclipsing Binary Handbook. It was also our Variable Star of the Year in 2006. The statement about the system can be viewed on the BAAVSS website. It is judged to be a good beginner's system because the whole Algol class of eclipse can be viewed with binoculars (6.9 to 9.4 magnitude). It is thought to be a good example of a flat bottomed total eclipse which lasts about two hours. The system has been of professional interest because it shows a lot variation on the traditionally portrayed light curve. There can be sudden changes in the shape of the light curve and the depth of the eclipse due to variations in the rate of mass transfer and the resulting accretion disk.

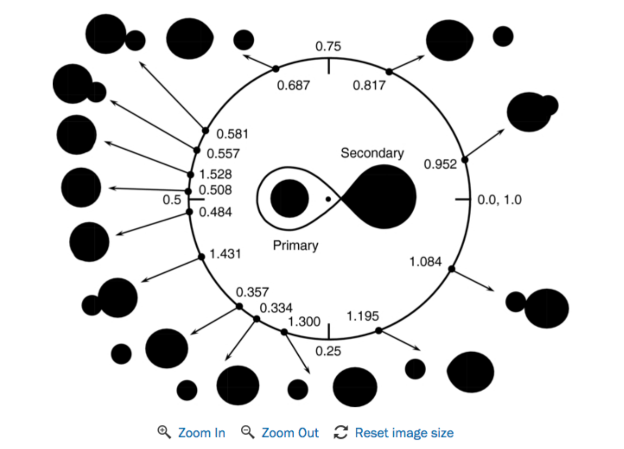
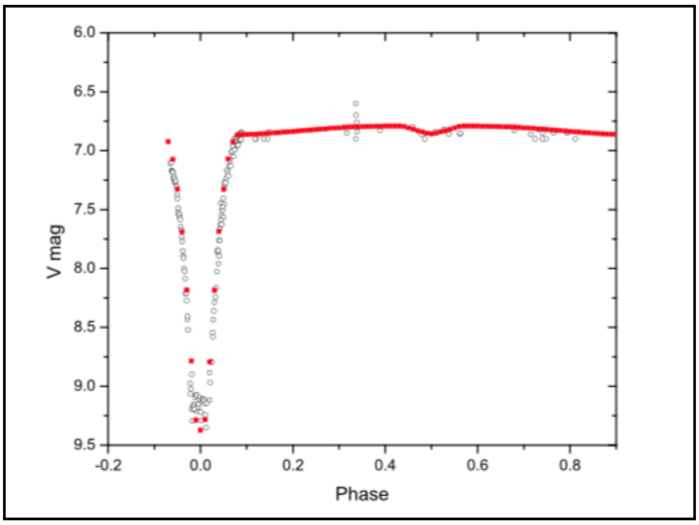


Figure 1. U Cep orbital orientations for SWP images. Based on Binary Maker 3.0 plot.

This is a system that has been imaged (3) showing the inclination of the components of the system through one period.

The Krakow predictions are not necessarily reliable in a system where the period is changing quite quickly. The current predictions are based on elements that were established 18 years ago. It has been estimated that the period is lengthening by about 15 seconds from one eclipse to the next. This may not seem very much but over 18 years it can mean that predictions could be out by over a day if the rate of change of the period is constant. It would be a worthwhile endeavour to establish the current time of mid primary eclipse. It may turn out that the period has changed significantly over the past 18 years.



1. ‘First Resolved Images of the Eclipsing and Interacting Binary Beta Lyrae, M.Zhao et al, 2008, the Astrophysical Journal Letters, Volume 684, Number 2.
2. ‘Two colour photoelectric investigation of SZ Pisces’ Z Tunca, 1984, Astrophysics and Space Science, Vol 105, No 1, pp 23 -31.
3. ‘Ultraviolet Spectroscopic Analysis of Transient Mass Flow Outburst in U Cephei’ P R Tupa et al, 2013, The Astrophysical Journal, Volume 775, No 1.
4. ‘The O-C curve analysis and simultaneous light curve solutions of classical Algol system U Cephei’ D Manzoori, 2008, Astrophysics and Space Science, Vol 318, pp 57-67

Algol type eclipsing binary TX UMa.
Can all sources have the correct period?

James Screech

TX UMa is an EA type eclipsing variable star with a range of 7.06V-8.8V and a catalogued period of 3.063295d. However, observations carried out in March 2020 may cast some doubt on the accuracy of this period.

Can all internet sources have the incorrect period for the Algol type eclipsing binary TX UMa? Is it possible that one period measurement was incorrect and then everyone else assumed that it was correct and so refinements over the years have just been based on measurements on this period?

Online sources give a period of just over 3 days 1 hour 31 minutes for TX UMa, as listed in table 1 below.

Source	Period(d)	D:hh:mm:ss
GCVS	3.0632382000	3d 1h 31m 4s
SIMBAD	3.063292	3d 1h 31m 8s
VSX	3.063295	3d 1h 31m 9s
Krakow	3.0633391	3d 1h 31m 12s

Table 1

However, I performed time series photometry of this star five times over a short period (22nd, 23rd, 26th, 27th & 31st March 2020) and plotted the results on a phase diagram based on the VSX period (3.063295) figure 1. This shows three distinct eclipse clusters at different phases approximately .33 phase apart.

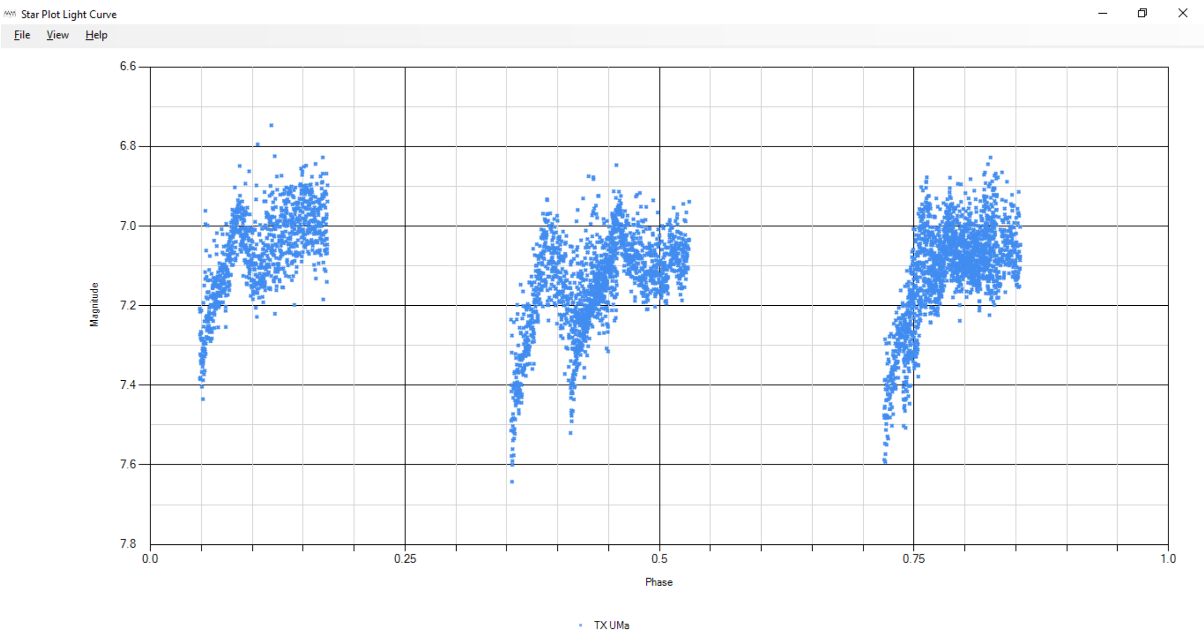


Figure 1:

It is unfortunate that during the period of observations the eclipse minima were all before it was dark enough to make photometric measurements and so only part of the rise from minimum is shown for each. The clusters are made up from, first minima (27th), second (23rd & 31st) and the third (22nd & 26th). As the second and third minimum clusters clearly show, the rises do not align exactly, implying that the quoted period is not exactly three times the actual period. In fact, it would appear that the actual period is very close to 1 day as shown in figure 2 which is a phase plot with the period set to 1 day. A better estimate of the actual period was obtained by running the data from 22nd and 31st (the first and last datasets) through a running average algorithm and producing graphs of the results, measuring the difference in time of the peak following the eclipse and dividing this by nine (the number of periods between the data peaks). This gives a period of 0.997(4). It is unfortunate that timings of minima were not possible to better define the period.

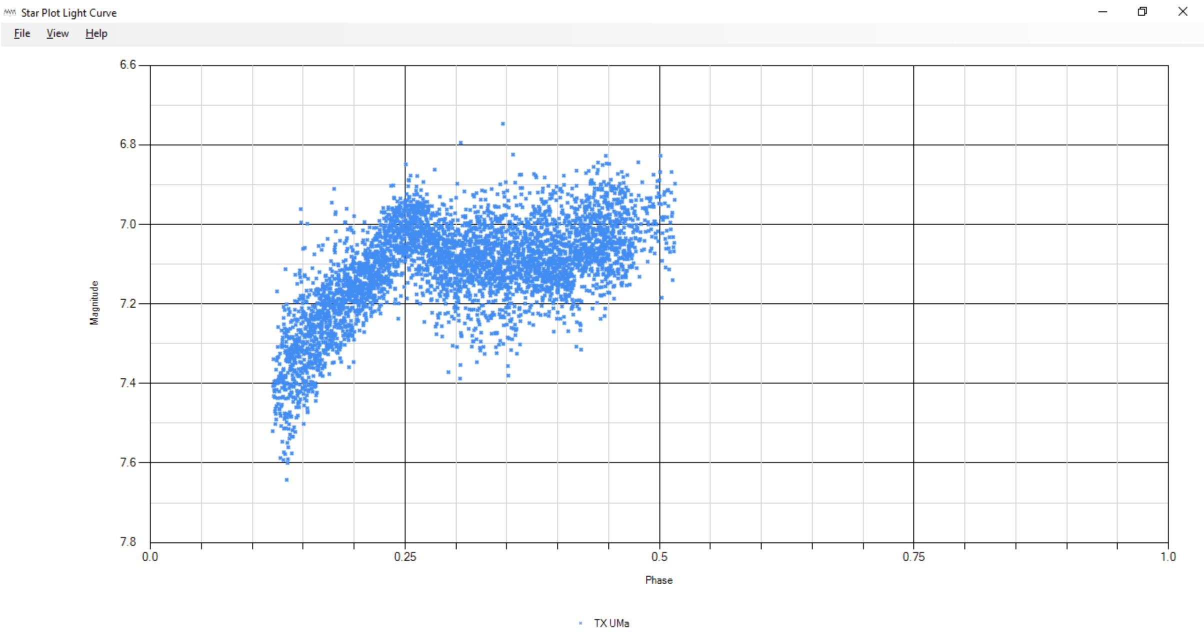


Figure 2:

So, what could be wrong with the catalogued period? Speculating (I have no further evidence to back this up) I suspect that when this variable was first discovered it was observed every three days and not more frequently and so a period of near three days was assumed. Everyone then assumed the period was three days and so only looked for minima at this interval. Also, as my measured period is actually slightly less than a third of the quoted period, I suspect that there has been a period change over time due to either mass transfer between the components or the gravitational influence of a third body. Period changes have been noted in this system previously - 40 years ago by Kreiner & Tremko (1)

Further time series photometry is required of this system to confirm the period, based on my observations I predict eclipses will occur in dark skies next winter (2020-2021).

All photometric measurements in this article were from images taken with a Canon 500D and Canon 200mm f2.8 lens using ISO400 and 20 second exposures, they were dark subtracted and flat framed. Photometry was performed with Muniwin 2.1.

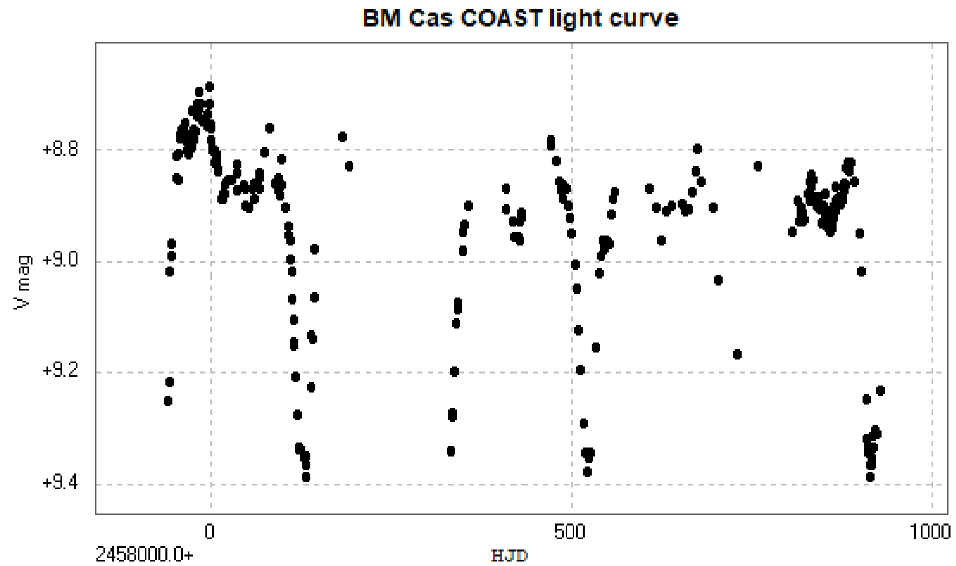
1: Kreiner & Tremko: 1980, Analysis of the Change of Period and the Photometry of the Minima of the Eclipsing Binary System TX Ursae Maioris

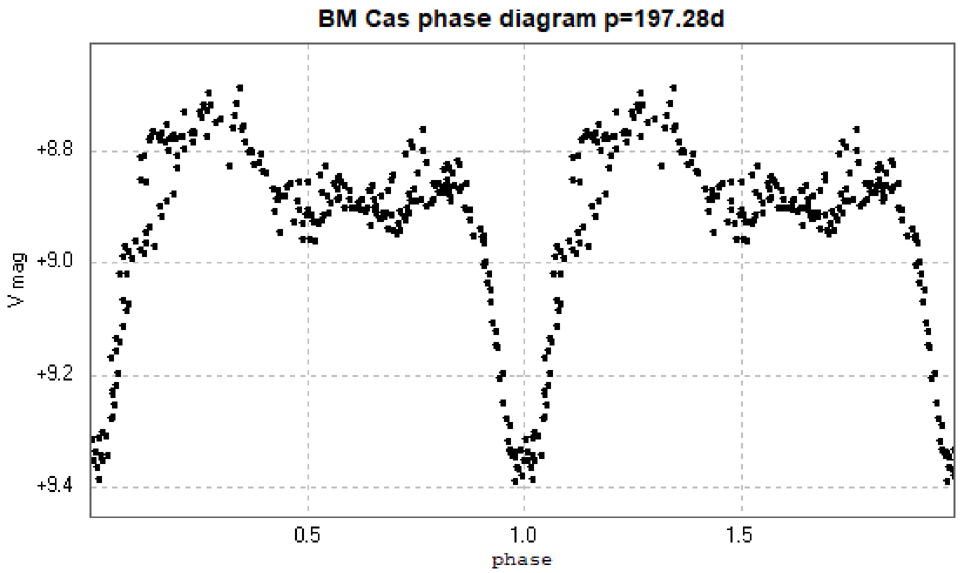
More observations of eclipsing binaries using the Open University COAST telescope.

David Conner

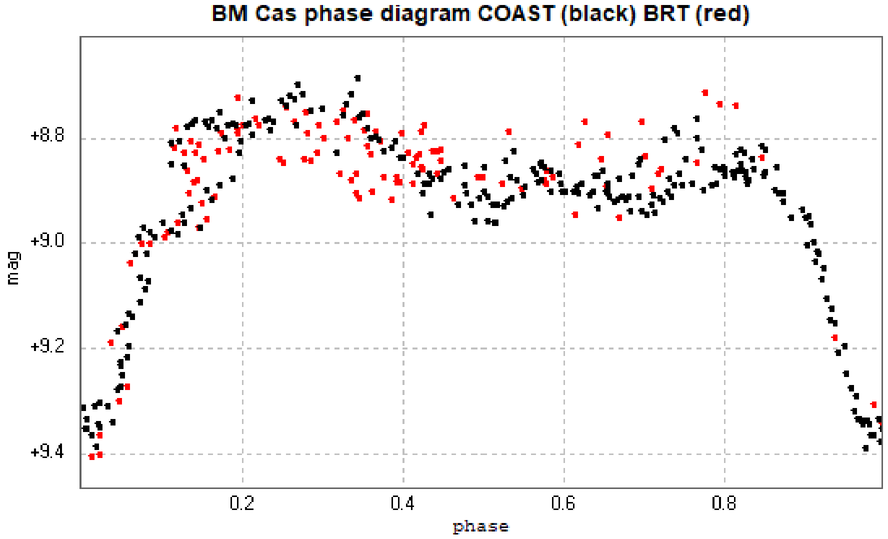
More results from an ongoing project to observe eclipsing binaries with the Open University COAST telescope, a 14 inch / 35 cm Schmidt-Cassegrain telescope located on Mt Teide in Tenerife. Details of the system types and periods are from the AAVSO VSX, accessed 2020 May 13.

BM Cas (EB/GS p=197.28d)

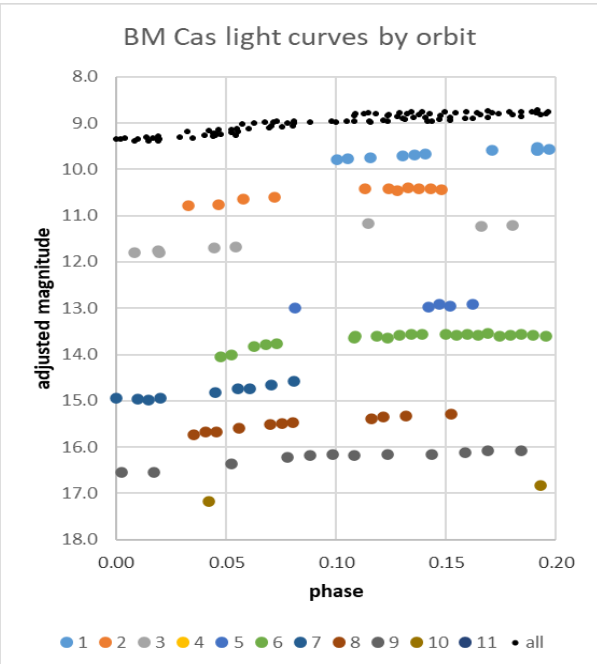


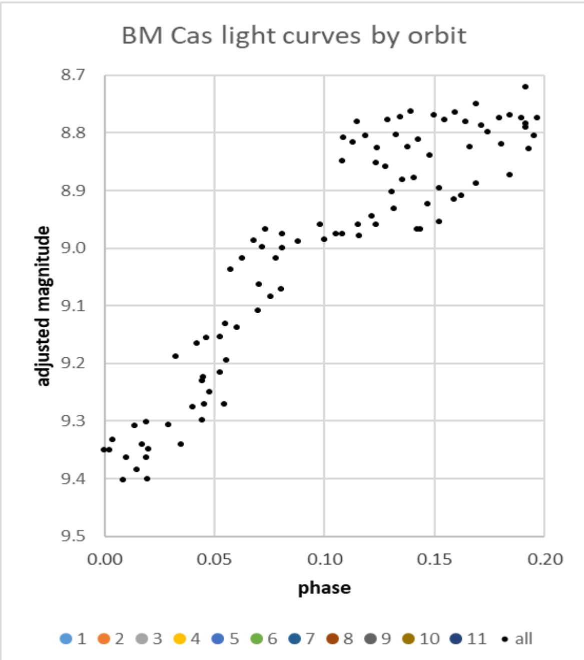


There is an apparent concave 'glitch' at around phase 0.1 where the phase diagram doubles back on itself. I had some previous observations made with the now obsolete Bradford Robotic Telescope (BRT), and the 116 data points obtained between 2012 September 4 and 2016 October 3 have been added to the COAST data in the single phase diagram below.



It will be seen that this concave feature is present in the BRT data as well. Separating out the sections of the light curve corresponding to individual cycles of the star and adjusting their plotted magnitudes so that they were separated vertically generated the following diagrams (below). The left-hand diagram shows the individual cycles (excluding orbit 4, which has no relevant data points) together with the complete light curve at the top, while the right-hand diagram shows the complete light curve in detail. It is evident that the light curves for each individual orbit do not show this feature (they are increasing monotonically) which suggests that it is an artefact of plotting a phase diagram of a star with such an irregular, although fundamentally periodic, light curve.

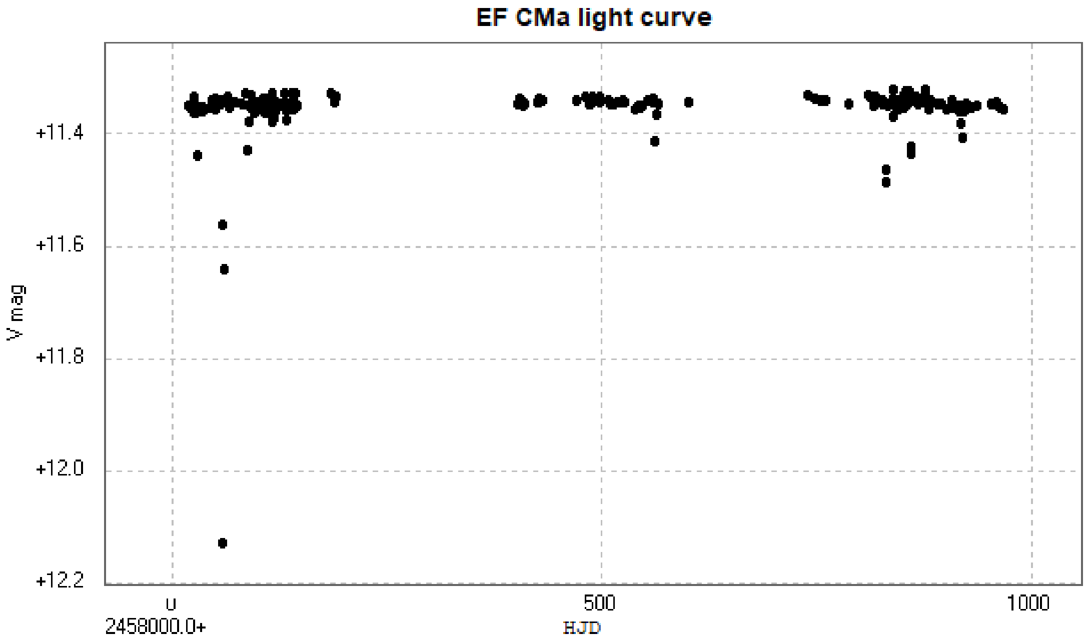


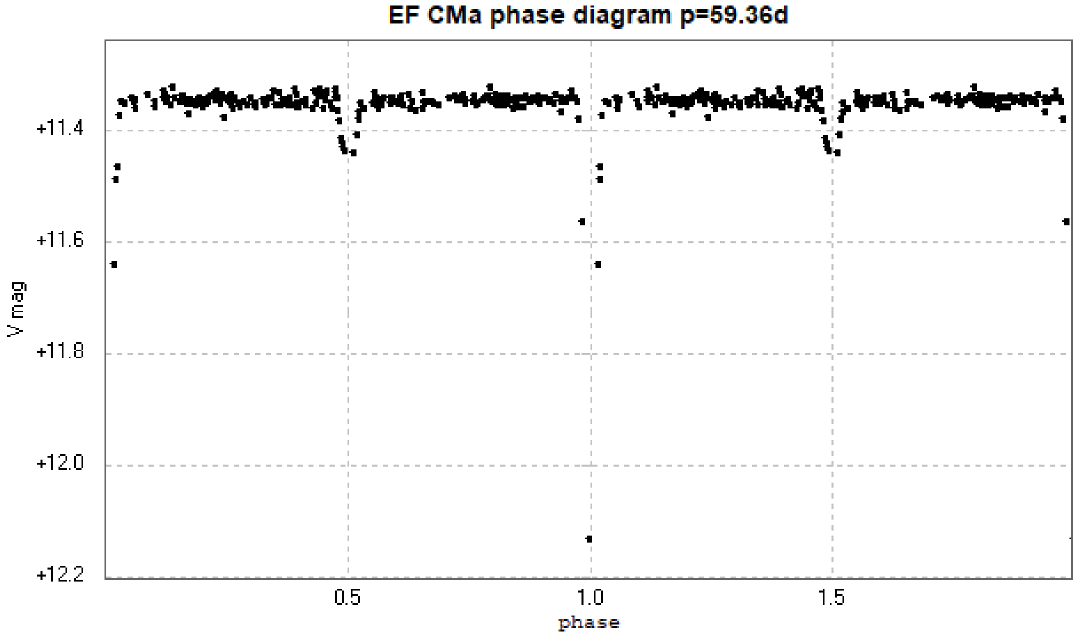


These irregular(?) variations might be due to some as yet undetermined type of variations in the hotter component (Fernie 1997) or a ‘hot region’ located between the two components Kalv *et al* 2004).

EF CMa (EA/DS p=59.36d)

Light curve and phase diagram constructed from photometry of 227 images taken with a V filter between 2017 September 22 and 2020 April 27.

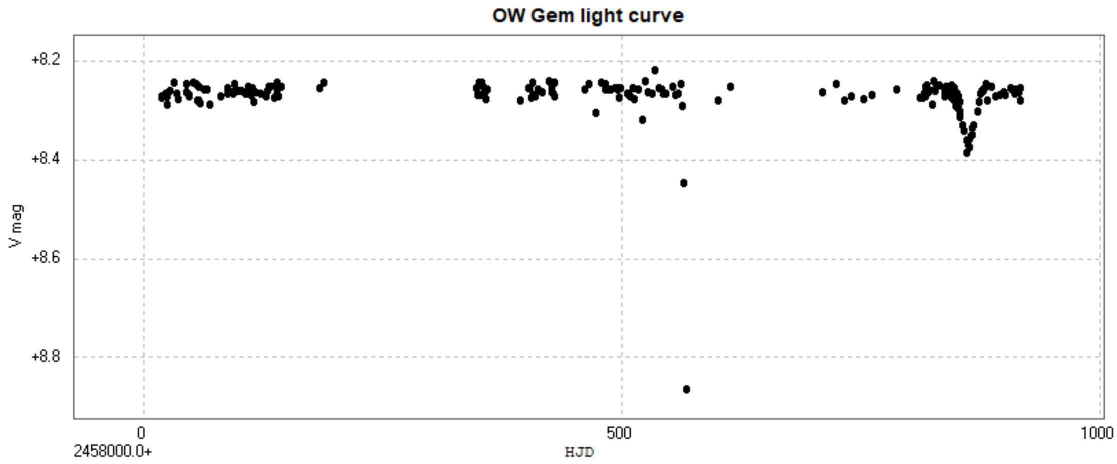


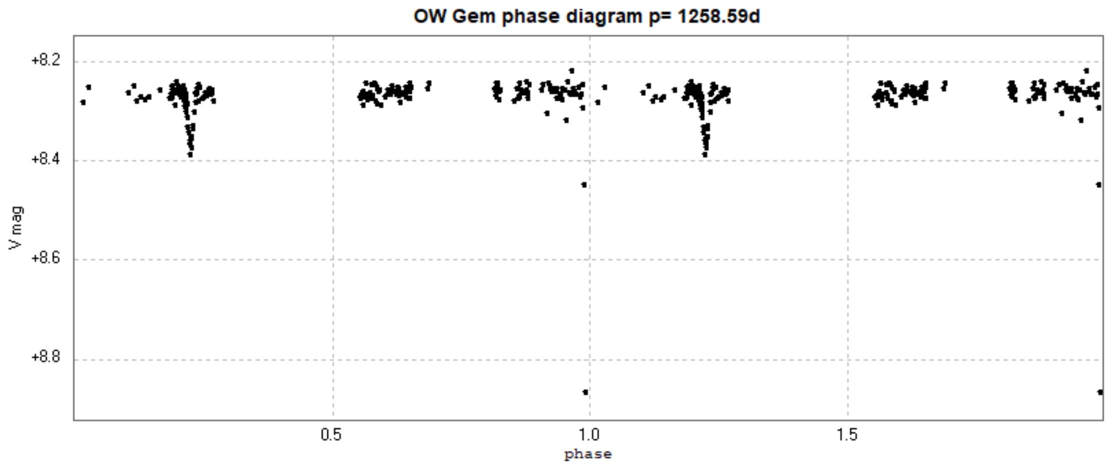


The primary eclipse in particular is not well covered. A classic case of more observations needed

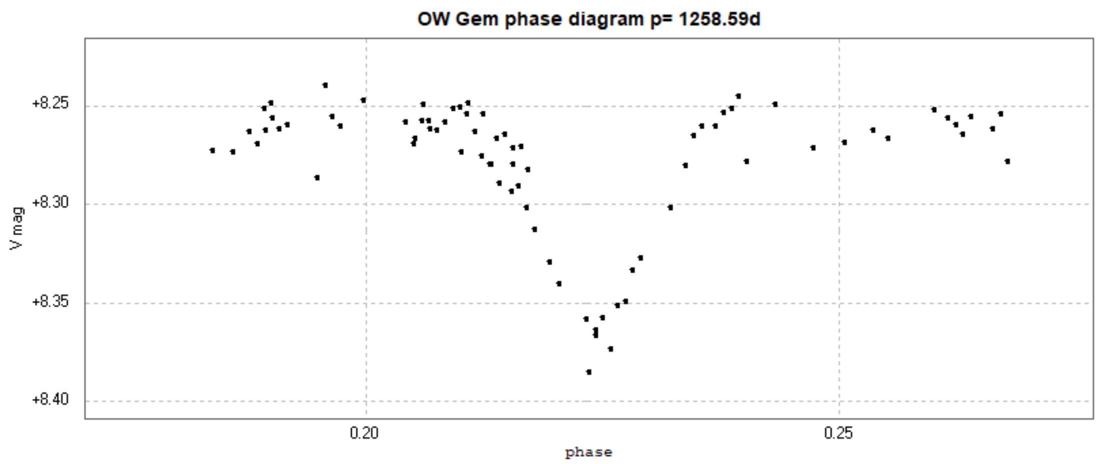
OW Gem (EA/GS p=1258.59d)

Light curve and phase diagram constructed from photometry of 210 images taken between 2017 September 22 and 2020 March 8, using a V filter.





Note that the period of this system is about 1259 days, so the phase diagram does not cover one complete orbit. Due to poor weather in Tenerife there are only 2 observations of the primary minimum, but the secondary minimum is better covered and appears to occur between phases 0.21 to 0.24 – see below (it's not possible to be more precise due to the lack of observations around phase 0.). Again, more observations needed.



Back to contents

Future work

Observations of these and other variables is ongoing with COAST, although a reduction in available time on the telescope, together with focussing issues and poor weather, has led to a significant reduction in the number of useful images returned from the observatory. The next stage of this project will be to start modelling some of the more simple systems using Binary Maker 3. Further information about these and other eclipsing binaries in this project can be found on my website.

The evolution of the Hα double emission line during the total eclipse of the binary star system VV Cephei from 2017-19

Jack Martin

VV Cep is binary star system consisting of an M2 1ab type supergiant orbited by a smaller hot main sequence B 0-2V type dwarf companion. Every 20.36 years an eclipse occurs. Although I took spectroscopic observations from 2015-08-26 to 2020-03-02 over 135 nights, I present a sample of 6 cropped spectra centred on the red Hα region, obtained around the eclipse period approximately 2017-08-24 to 2019-11-18. The purpose of this short paper is to show my results, demonstrate the advantage of high-cadence long-term monitoring of one object in one spectral line, in order to study and understand the changes in its behaviour; the astrophysical processes involved; to obtain detailed higher resolution and scientifically useful data in collaboration with other amateurs/professionals.

Introduction

VV Cep is a 5th magnitude binary star system in the constellation of Cepheus

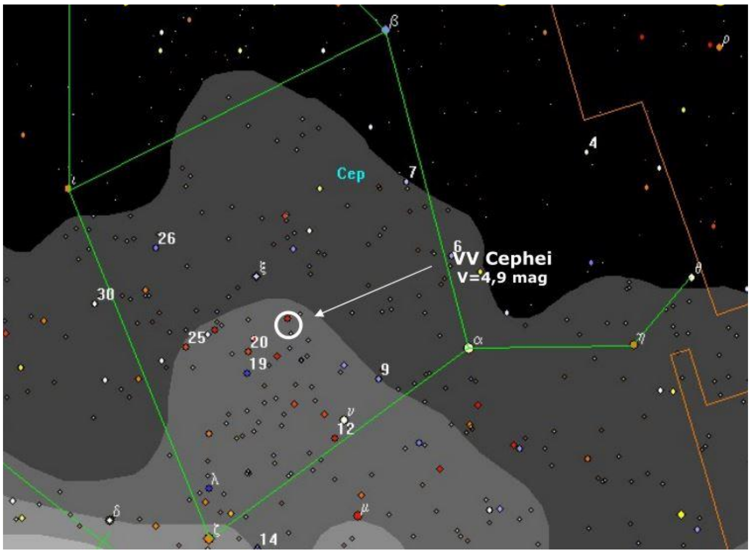


Figure 1: Star map of the Constellation of Cepheus indicating the position of VV Cep. E. Pollmann

There is a mass exchange at periastron between the two stellar components, in which the larger brighter supergiant with its extended atmosphere is orbited by a much smaller, hotter main sequence star.

The smaller B-type main sequence companion star, with a radius of approximately 13 $R_\odot$ orbits the M-type supergiant primary radius approximately 100 $R_\odot$ at an average distance of about 19-20 AU over a period of 20.36 years, with an orbital eccentricity *e* = 0.35 (Wright 1970) and an orbital inclination of 76-77°, where it is itself surrounded by an extended hydrogen gas disk (Fig 2).

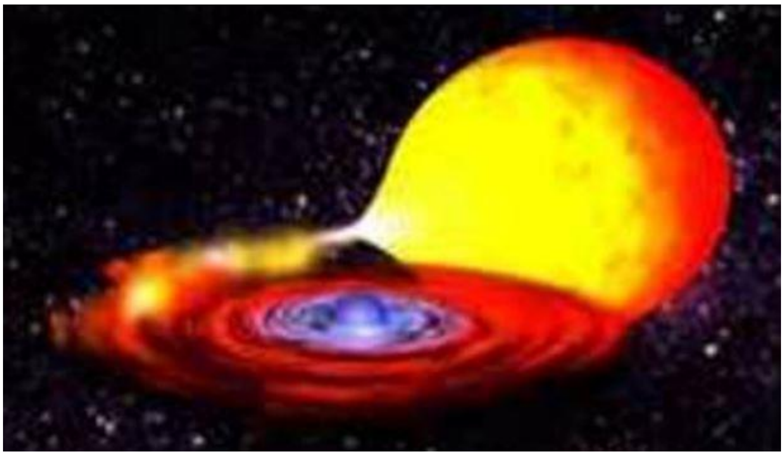


Figure 2: Artists impression of VV Cep binary star system. E. Pollmann

However, since the entire binary star system is surrounded by a large-scale cloud of neutral hydrogen, the stellar wind of the supergiant, an absorption is created in the observer's line of sight that splits the intrinsic single emission into two components, a (blue) V component and a (red) R component (Fig 3a).

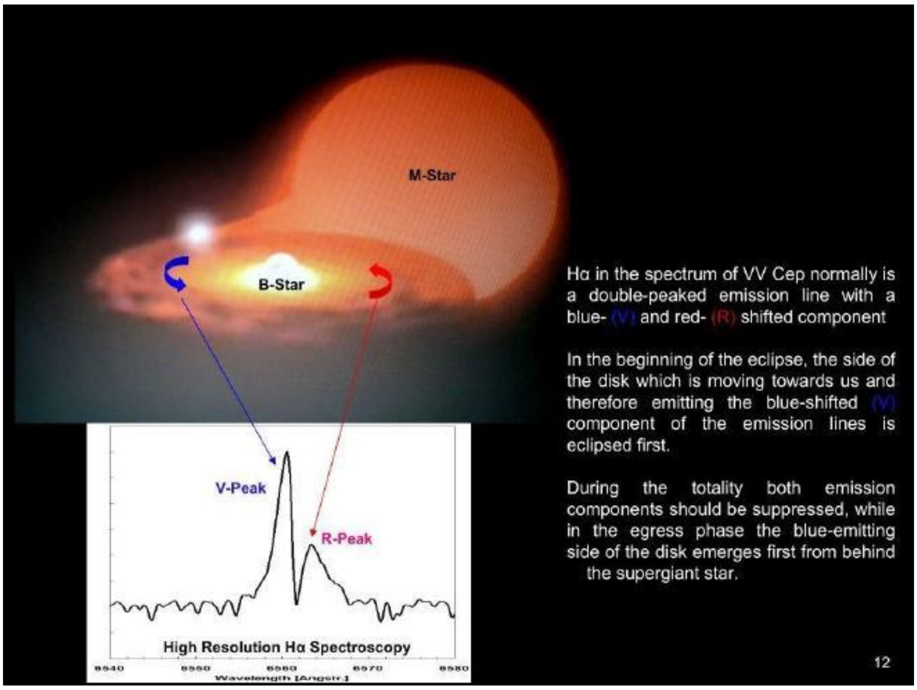


Figure 3a: Artists impression of eclipse passage and effect on the Hα double emission line.
E. Pollmann

In 2015 a combined photometric/spectroscopic campaign was organized by P. Bennett (Canada) J. Hopkins (USA) and E. Pollmann (Germany) to monitor the eclipse which began around the beginning of 2017 August and lasted approximately 650 days. Using high resolution spectrographs, such as the LHires III, we studied the dynamics of the accretion region around the B-type companion star, which are responsible for the recombination spectrum of the Hα double emission spectral line at 656.3 nm (Fig 3b). The continuance of high-cadence observations allowed the time-variation of the Hα blue (V) and red (R) emission components to be analysed in detail.

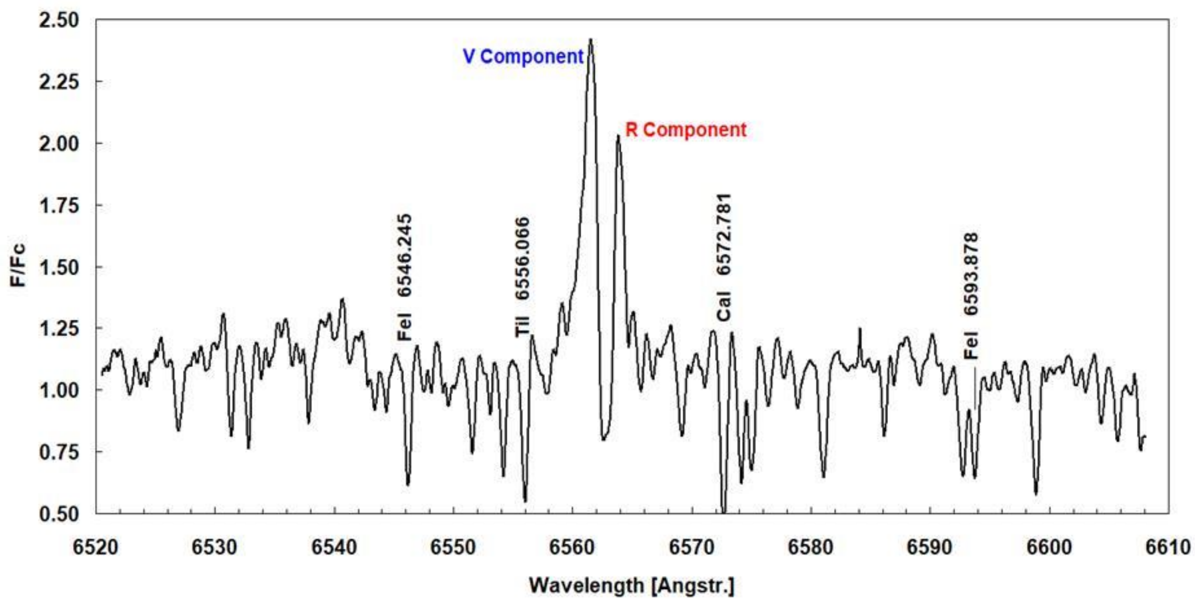


Figure 3b: Emission of the Hα double peak profiles V & R components has different origins. E. Pollmann

Method

Spectra were obtained using the following setup; Paramount MX, Celestron C14, Atik 460 monochrome CCD science camera, Lodestar monochrome CCD guide camera, LHires III spectrograph, 2400 l/mm grating, 23 μm slit, resolution (R~18000), integration time 300-600s (Fig 4). Data reduction was carried out using BASS (Basic Astronomical Spectroscopy Software) created by John Paraskeva.

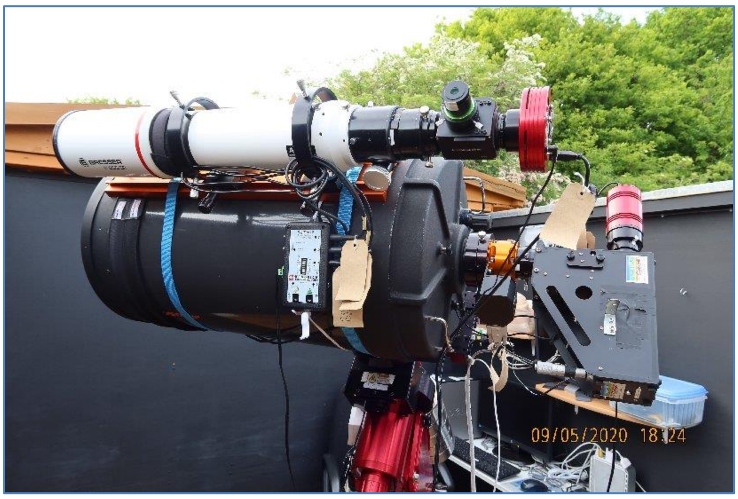


Figure 4: The authors Spectroscopic imaging setup

Results

The spectra were not continuum or instrument response corrected, as this was not a requirement of submission to the eclipse monitoring project. The data obtained from the Hα line is important, as it explains the dynamics of the eclipse. Over this eclipse period, with approximately 810 days of coverage either side, significant changes in the blue and red wings of the Hα double-peaked emission line profile can be seen, in the series of spectra, indicated by the region in (Fig 5).

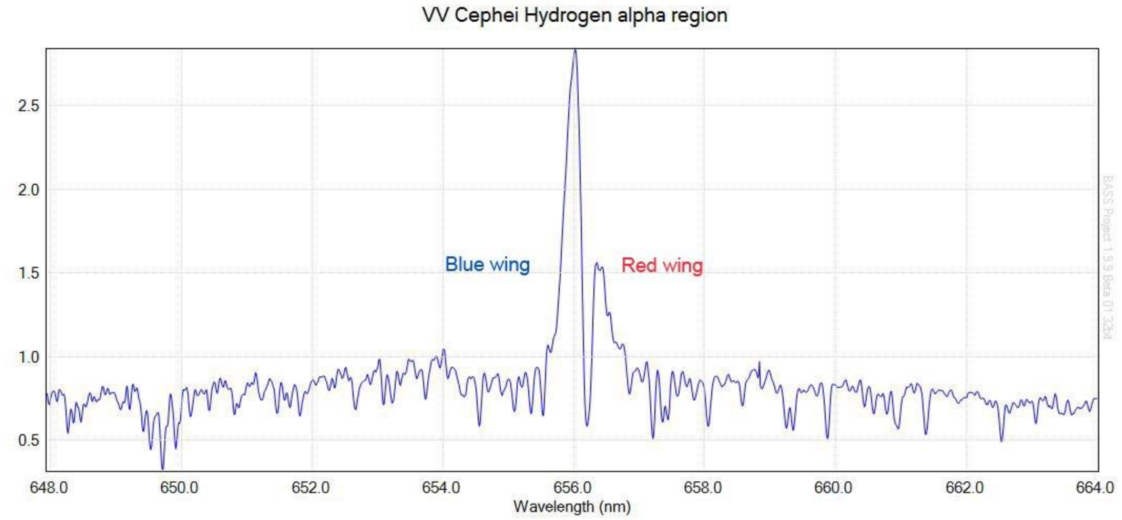
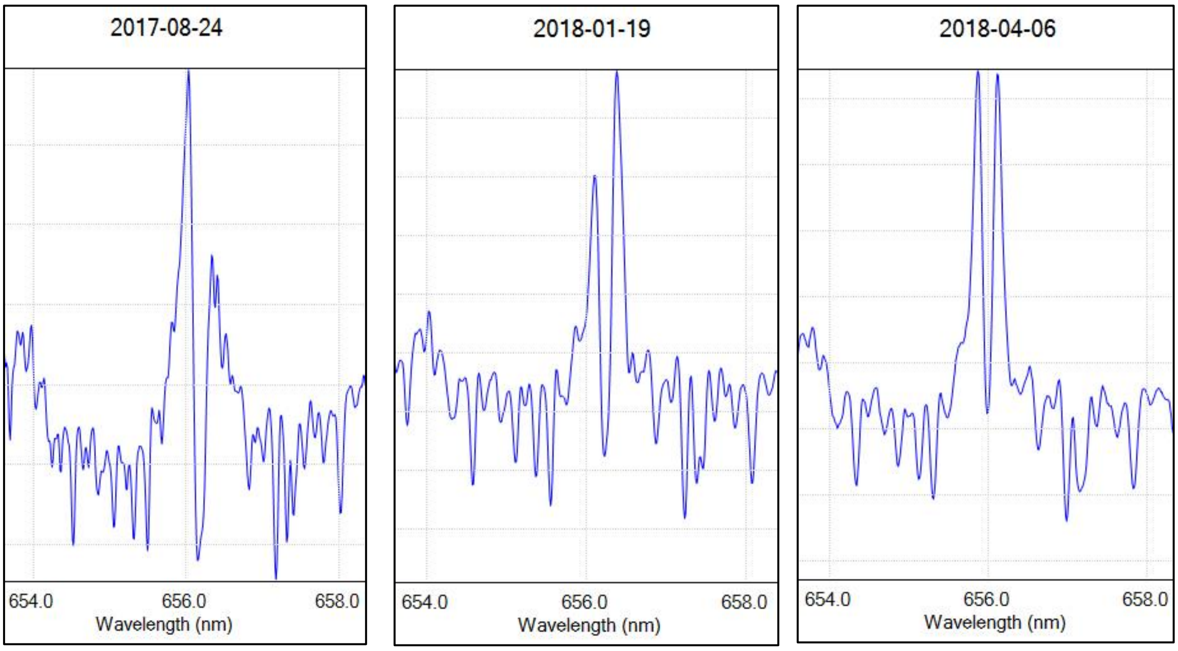
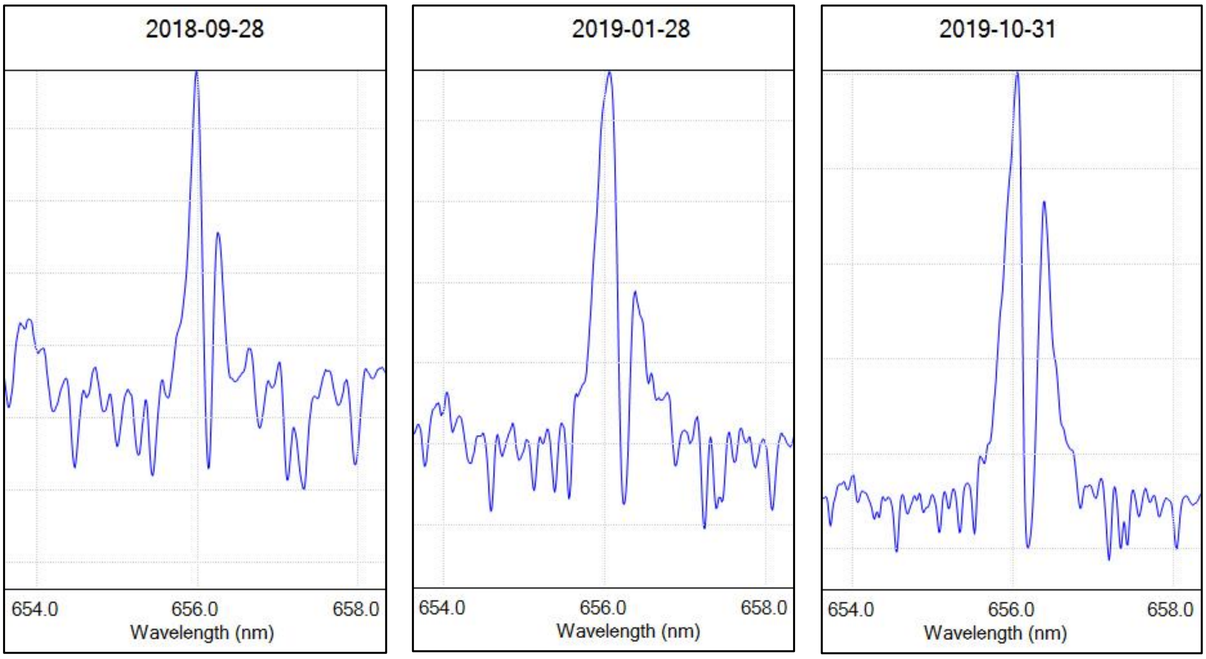


Figure 5: VV Cep Hα region. Jack Martin



Back to contents



Conclusions

Coverage of the 1997/99 eclipse was very limited. However, the 2017/19 eclipse presented amateurs with a golden opportunity, to get more accurate data. This became the first amateur spectroscopic study of a binary star system eclipse of its kind. Long term monitoring with such a high cadence produced unprecedented detail.

Results were sent to E. Pollman, Principal investigator of the VV Cephei eclipse campaign, for inclusion into a larger Hα profile dataset consisting of data contributed by 38 amateur observers. We now have the most comprehensive record of this eclipse event to date.

For a more detailed account and understanding of the astrophysics, analysis and newly discovered 42-day period variability in the equivalent width of the Hα emission of VV Cep, I would refer the reader to the E. Pollmann and P. Bennet paper in the references section

Acknowledgements

Thanks to E. Pollman for guidance throughout the campaign, and S. Needham for help with grammar corrections.

Pollmann, E., Bennett, P. *Spectroscopic monitoring of the 2017-19 eclipse of VV Cephei* AAVSO BASS, https://groups.io/g/BassSpectro

$R_{\odot}$ Solar radius = 6.955 x 10^8 m ~109 Earth radii.
μm = micron, e.g. 10 - 55 μm width of wool fibre.

I have included these examples to give a sense of scale.

[jackmartin781@gmail.com]

Back to contents

Observations of the 2020 eclipse of the enigmatic binary EE Cephei

David Boyd

Photometry of the 2020 eclipse of EE Cephei reveals a complex light curve which poses further challenges for those trying to model the behaviour of this enigmatic binary.

EE Cephei is an unusual binary consisting of an 11th magnitude Be type star with a low mass companion which may be surrounded by a dark, dusty disc. In this respect it has similarities to the long period eclipsing binary ε Aurigae. The disc causes eclipses of the Be star every 5.6 years but the profile of these eclipses changes every orbit and it has proved difficult to construct a model of the system which will predict reliably what the next eclipse will look like. Predications made before the last eclipse in 2014 that it would be 2 magnitudes deep proved to be wrong as I reported in an article in the Journal in 2015 (1). Subsequent analysis of the 2014 eclipse has prompted the suggestion that both the Be star and the disc may be precessing (2). I have continued to observe EE Cep using V and Ic band filters since 2014 as shown in Figure 1. It is clear there was no secondary eclipse.

The 2020 eclipse was predicted to start around 7th March (3, 4) but, although conditions in the UK were poor early in 2020, observations showed that ingress clearly began in February as shown in Figure 2. Conditions improved in March and a long spell of clear nights in April enabled me to follow the second half of the eclipse in great detail. Mid-eclipse appears to have occurred earlier than the predicted time of 4th April, although this is difficult to tell given the complex profile of the eclipse. This eclipse has proved to be even shallower and more complex than the 2014 eclipse. The (V-Ic) colour index of EE Cep increased by 0.1 magnitudes during the eclipse, similar to my observations in 2014.The structure in the eclipse profile may support the suggestion that the disc could have a multi-ring structure. Work continues to try to explain this eclipse and all previous eclipses of EE Cep with one coherent model.

Professional astronomers studying this system have encouraged amateur observations and in recent weeks, when many professional observatories have been shut down because of coronavirus, it has been amateurs around the world who have helped to maintain continuity of observation.

About 13 months after the 2014 eclipse I observed a noticeable, and so far unexplained, increase in the V and Ic light curves (Figure 1). Observations of EE Cep around May 2021 are encouraged to see if this behaviour is repeated.

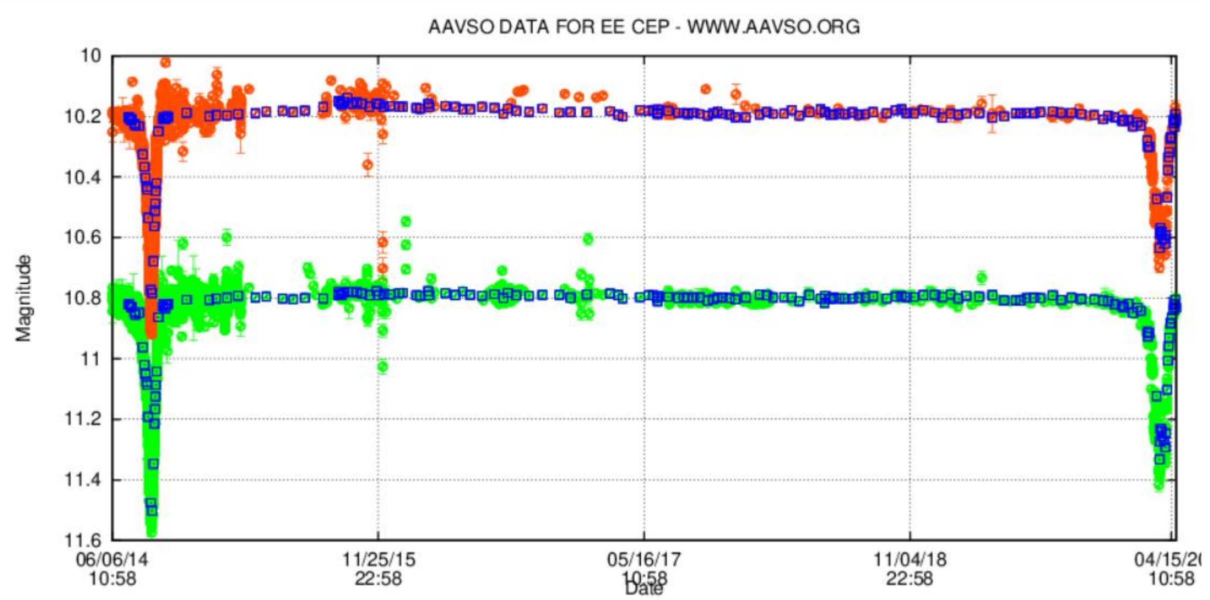


Figure 1. AAVSO V and Ic band light curves for EE Cep from 2014 to 2020. My observations are marked in blue

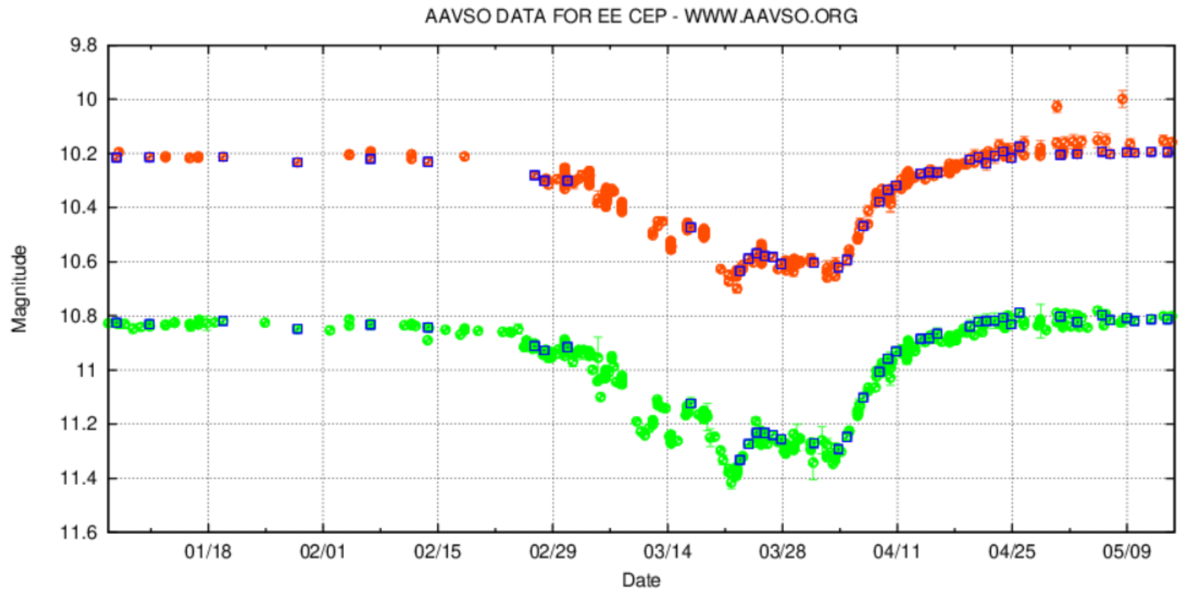


Figure 2. AAVSO V and Ic band light curves for EE Cep during the 2020 eclipse. My observations are marked in blue.

(1) Boyd, D. Journal of the British Astronomical Association, 125, 2, 94 (2015), http://articles.adsabs.harvard.edu/pdf/2015JBAA..125...94B

(2) Pieńkowski, D. et al., submitted to Astronomy & Astrophysics (2020), https://arxiv.org/abs/2001.05891v1

(3) VSS Circular 183, pg 29, https://www.britastro.org/vss/VSSC183.pdf

(4) AAVSO Alert Notice 700, https://www.aavso.org/aavso-alert-notice-700

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Back to contents