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The British Astronomical Association

Variable Star Section Circular

No. 195 March 2023

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Contents

Cover Picture

The field of RW Cephei

Mazin Younis
Quattro 200mm f/4 Newtonian, ASI 294MC-Pro & UV-IR filter
Personal remote telescope, Morocco

From the Director *Jeremy Shears*

Section meeting on 2023 September 2

I am very much looking forward to our Section meeting on Saturday September 2. It will be held at the Humfrey Rooms in Northampton, courtesy of the Northamptonshire Natural History Society.

Gary Poyner and I are putting the speaker programme together. We'd like to have a range of talks from members about their variable star projects, so if you would like to give a talk, please let us know by June 1.

Results published on VSS campaign to observe CG Dra

Many thanks to everyone that has contributed to this observing campaign over the past couple of years. The coverage has been intensive and we have not missed any of its outbursts. As a result, Maxim Usatov and I have published a paper on the ***Outburst Behaviour of the Dwarf Nova CG Draconis*** in *Astronomische Nachrichten* (24 January 2023, https://doi.org/10.1002/asna.20220113). It is also available on ArXiv at: https://arxiv.org/abs/2301.05870. I must admit that Max has done all the heavy lifting on this one, including writing code to analyse the data.

The paper focuses on CG Dra's outburst behaviour in 2022 based on 27436 photometric observations. It includes an updated ephemeris and commentary on the observed eclipse profiles, with P_{orb} = 4h 31m 38s +/- 1s. Two types of quasi-periodic outbursts are identified: normal outbursts, of approximately 1.25 mag amplitude, and bright outbursts of approximately 1.5 mag. The 2022 light curve is shown below.

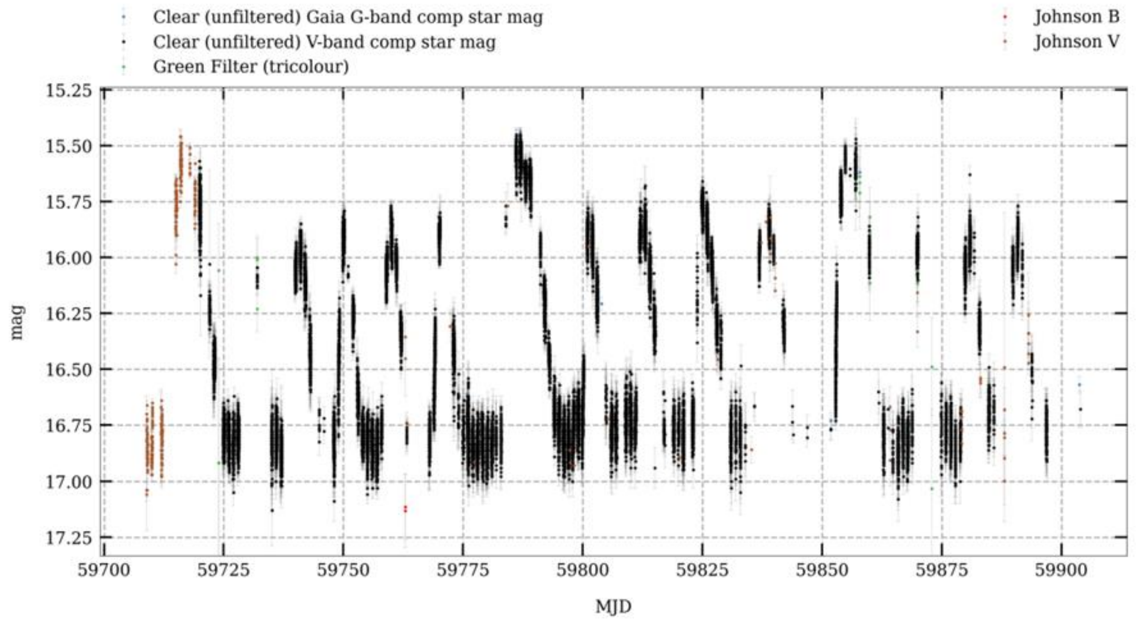

FIGURE 1 The light curve of CG Dra obtained throughout the 2022 BAA VSS observing campaign. Filters are color-coded. The light curve spans JD 2459709.39673 to 2459904.43000 (195 d), containing 27436 observations. BAA observers who have contributed to the light curve above are D. G. Buczynski, D. Shepherd. F. Tabacco, G. Poyner, I. L. Walton, M. Mobberley, M. Usatov, N. D. James, P. Bouchier and R. Sargent.

We intend to continue observing this star during 2023 with the aim of finding out more about its unusual outburst behaviour, so please continue to submit your observations. We would especially like to get good coverage of CG Dra's bright outbursts.

Observing campaign on ER UMa systems

The observing campaign on ER UMa systems continues – many thanks to Stewart Bean for continuing to highlight this. Systems under observation are **ER UMa** itself, **IX Dra**, **RZ LMi**, **V1159 Ori**, **YZ Cnc** and **DI UMa**.

5th European Variable Star meeting

EVS-5 will take place in Barcelona, Spain, on May 27 and 28, 2023. Details at: http://rr-lyr.irap.omp.eu/photometry/EVS5/

I had the pleasure of speaking at EVS-4 in Belgium and found it a most enjoyable conference.

SPRING MIRAS

M = Max, *m* = min.

W And	m=Mar
R Aqr	m=Mar
V Cam	M=May
X Cam	M=Apr
SU Cnc	M=Apr
U CVn	M=Mar
RT CVn	M=Apr
T Cas	M=Apr/May
R Com	m=Mar
S CrB	m=Mar
V CrB	m=Mar/Apr
W CrB	m=May/Jun
T Dra	M=Mar
SS Her	M=Apr/May
	M=Mar
R Hya	m=May
RS Leo	m=May
W Lyn	M=Mar
X Lyn	m=May/Jun
U Ori	M=May
R Ser	M=Apr/May

Source BAA Handbook

Sequence Files – The Future Plan

John Toone

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A plan for overhauling the sequence files in the VSS database is described.

The concept of sequence files was initially conceived during the VSS Officers meeting held at John Isles premises at Covent Garden, London on 12 May 1990. In the meeting the Officers discussed how a database could be constructed that would store all of the estimated two million VSS observations made in the preceding 100 years. A critical aspect of the proposed database was that it had to include the ability to re-reduce data from original light estimates made from multiple sequences. The solution agreed by the Officers was to include sequence files within the proposed database.

The 1990 Officers meeting was also the first time that I met Dave McAdam who was appointed to the position of Computer Secretary 12 months later. [1] Dave announced a plan for database construction in 1991 that included the facility for re-reducing data when sequences were revised. [2] Then throughout the 1990s, Dave worked tirelessly with a team of assistants to get the observations entered into the database. By 2001 the work was substantially complete and the database, including the sequence files, was handed over to John Saxton. [3] Subsequently the sequence files have been updated by various people (Ian Miller, Bob Dryden etc) whenever sequences have been revised.

It cannot be understated the value of the work undertaken by Dave McAdam in the 1990s not only on the database development but also on stitching together the original sequence files within the database. To my knowledge the VSS sequence files are unique and no other variable star database has the ability to re-reduce legacy data to a common magnitude scale. The existing sequence files can be accessed through the VSS webpage via the database portal.

Despite the previous good work done on creating & maintaining the sequence files it is felt that there is a need for a few improvements to eliminate the following:

1. Recalculation of the magnitude can only be done when the light estimate can be linked to comparison stars on the latest sequence. With the evolution of sequences since 1900 many former sequences have been trimmed/altered and as a result only about 50% of the legacy data can be recalculated.

2. Due to changes to the VSS observing programmes some of the latest sequences date back to 1960 so the recalculated values may not be compatible with current photometry and data.

3. The comparison stars have no recognisable ID's and can only be identified by direct reference to the charts which in the case of super-ceded charts is not an easy task.

It is now intended to overhaul the sequence files in the database so that recalculated magnitudes are not restricted to those that can be directly linked to the latest sequence. The plan is to provide recalculated values (largely V) for all comparison stars used and also add unique identifiers (common catalogue ID's) so that in the future any researcher does not need to refer to the charts to identify the comparison stars. Some of the very early sequences prepared by Markwick & others that are currently missing from the files will also be added. Finally, it is intended to include within the sequence files the ASV (from 1899-1922) & AAVSO (from 1920-1980) legacy sequences so that the VSS data can be cross correlated with data derived from using those sequences during the 20th Century.

The task will be undertaken by a small working group formed of Bob Dryden, Andy Wilson & myself and I intend to present further details of the plan at the Section Meeting set for 2 September 2023.

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3 2001 VSSC 109, 4.

The 2022 dimming of RW Cep – A first look.

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Over the past 3 years the visual magnitude of RW Cep has dimmed by ~0.9. Multiband photometry suggests the dimming is less in the IR. At low resolution the spectrum is broadly similar currently compared with historical data. High resolution spectra however show several lines to now be in emission, H alpha in particular. Continued monitoring is recommended as and when RW cep returns to more typical brightness.

Introduction

RW Cep is a semi-regular variable yellow hypergiant (SRD YHG) which for the past 50 years at least, has wandered around within a few tenths of a mean visual magnitude of 7.0 on time scales of a few hundred days. In the last two or three years though it has been becoming appreciably dimmer, this diming superimposed on the usual variations and by the end of 2022 had dropped to magnitude 7.8 visual, 7.5 V (fig 1).

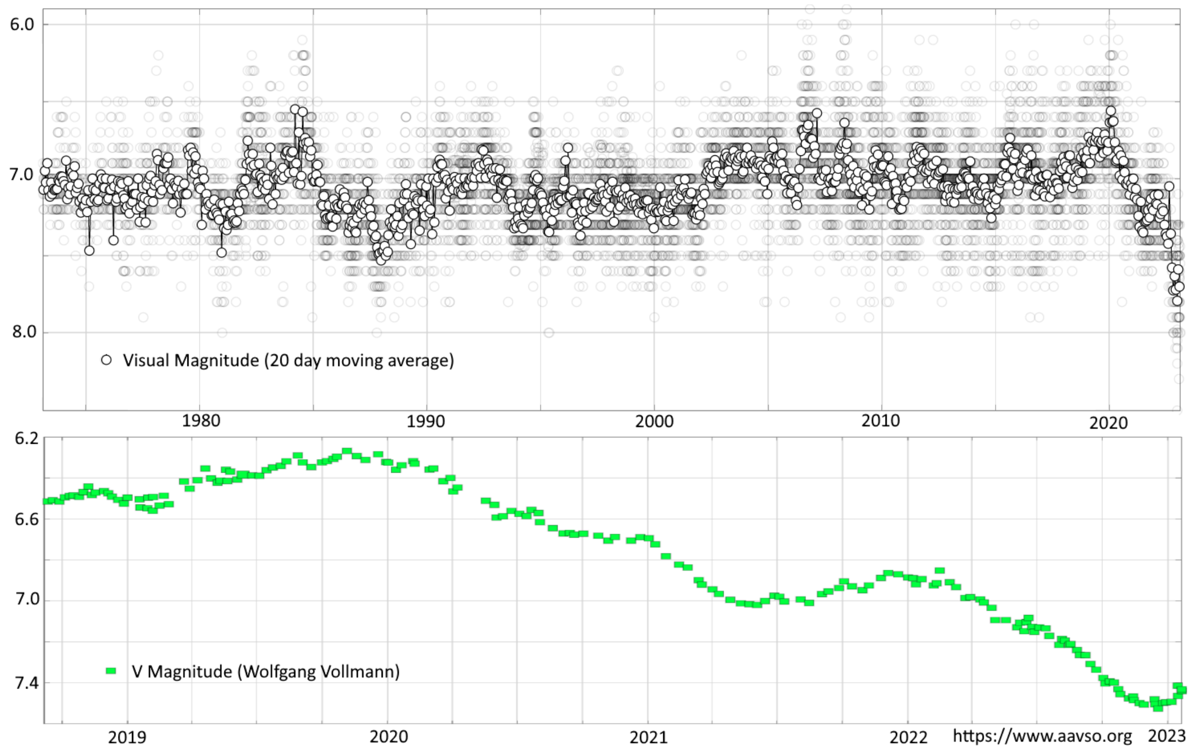

Fig 1. Visual and V magnitude trends from the AAVSO database

In December 2022 Wolfgang Vollmann and Costantino Sigismondi issued ATel 15800 highlighting the dimming and the possible similarity with the 2019 "Great Dimming" of Betelgeuse [1]. As of mid-February 2023, the brightness is currently increasing slightly.

Since mid-December 2022 I have been monitoring RW Cep spectroscopically both at low resolution covering the visual/IR wavelength range and at high resolution covering specific wavelengths. All spectra are available to download from the BAA spectroscopy database [2]. The spectrum has remained essentially unchanged during the monitoring period December 2022-February 2023 so I show just typical examples here.

There are no reliably calibrated amateur spectra pre dimming but there are a number of archived high resolution professional spectra, from the ELODIE spectrograph (Observatoire Haute-Provence) in 1998 and 2003-2005 covering visible wavelengths [3] and one from the ESPaDOnS spectrograph (Canada-France-Hawaii telescope) in 2006 which extends the coverage into the IR [4].

RW Cep is significantly reddened by dust (though to what extent this is interstellar or associated with the star is unclear) so appears much redder than its spectrum would suggest. Spectroscopic classifications of RW Cep from the literature cover a wide range from G8 to M2, however this appears to be due to the differing criteria used for classification rather than any substantial change in the spectrum and in 1980 Keenen set it as a standard for K2 0-Ia in the MK system [5]. A simple match of my dimmed state low resolution spectra to spectra from the Pickles library suggests a classification of K4 I currently, close to the Keenan classification, reddened by E(B-V) = 0.65, (fig 2)

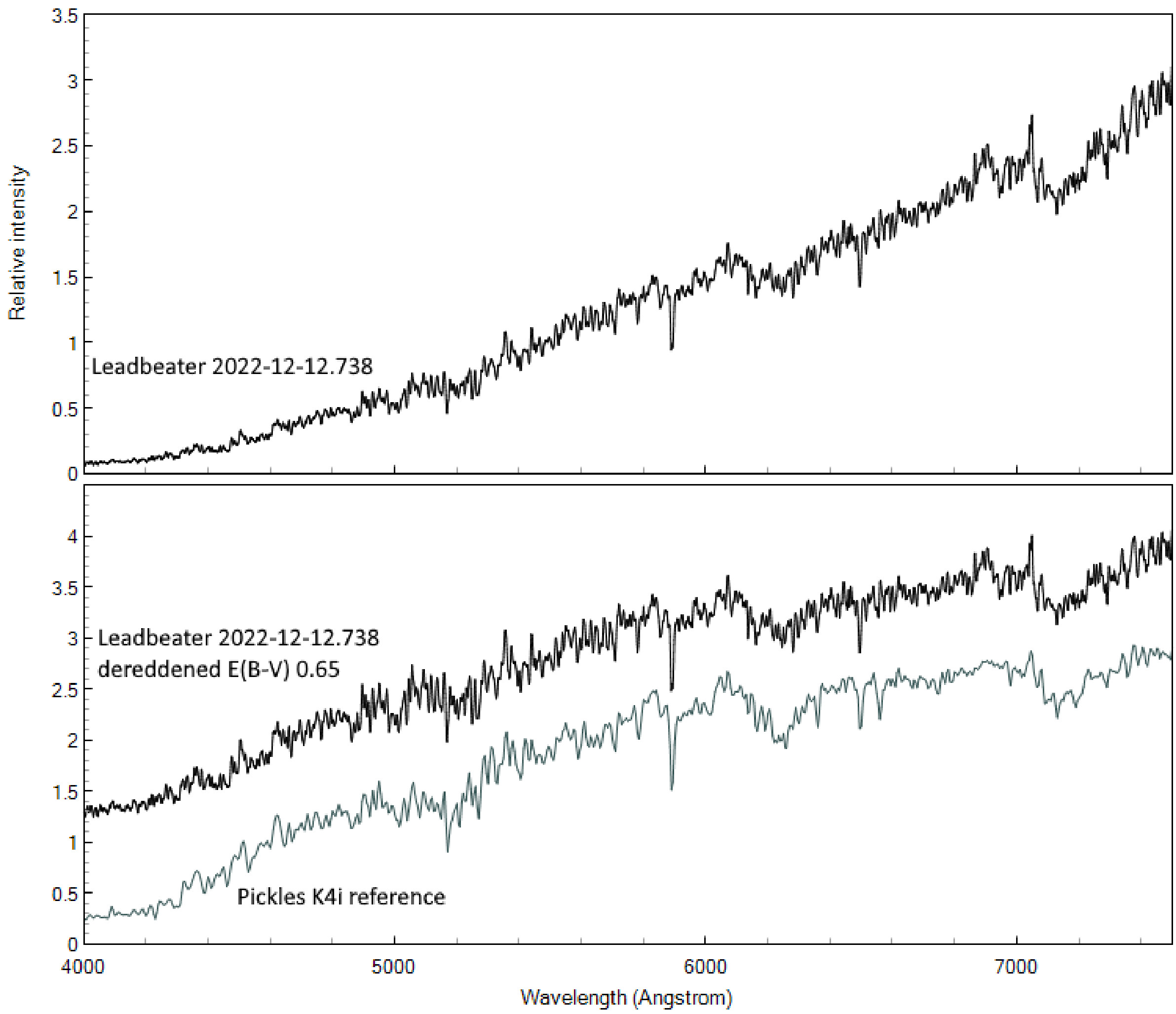

Fig 2. Low resolution (R 500) spectrum, as measured and dereddened, compared with Pickles library reference (normalised in the V band and offset in y for clarity)

Low resolution spectra

Fig 3 shows my typical low resolution (ALPY 600 spectrograph R~500) and very low resolution (ALPY 200 R~130) spectra in the dimmed state compared with typical spectra in the normal state from ELODIE and ESPaDOnS, all spectra normalised in the V band.

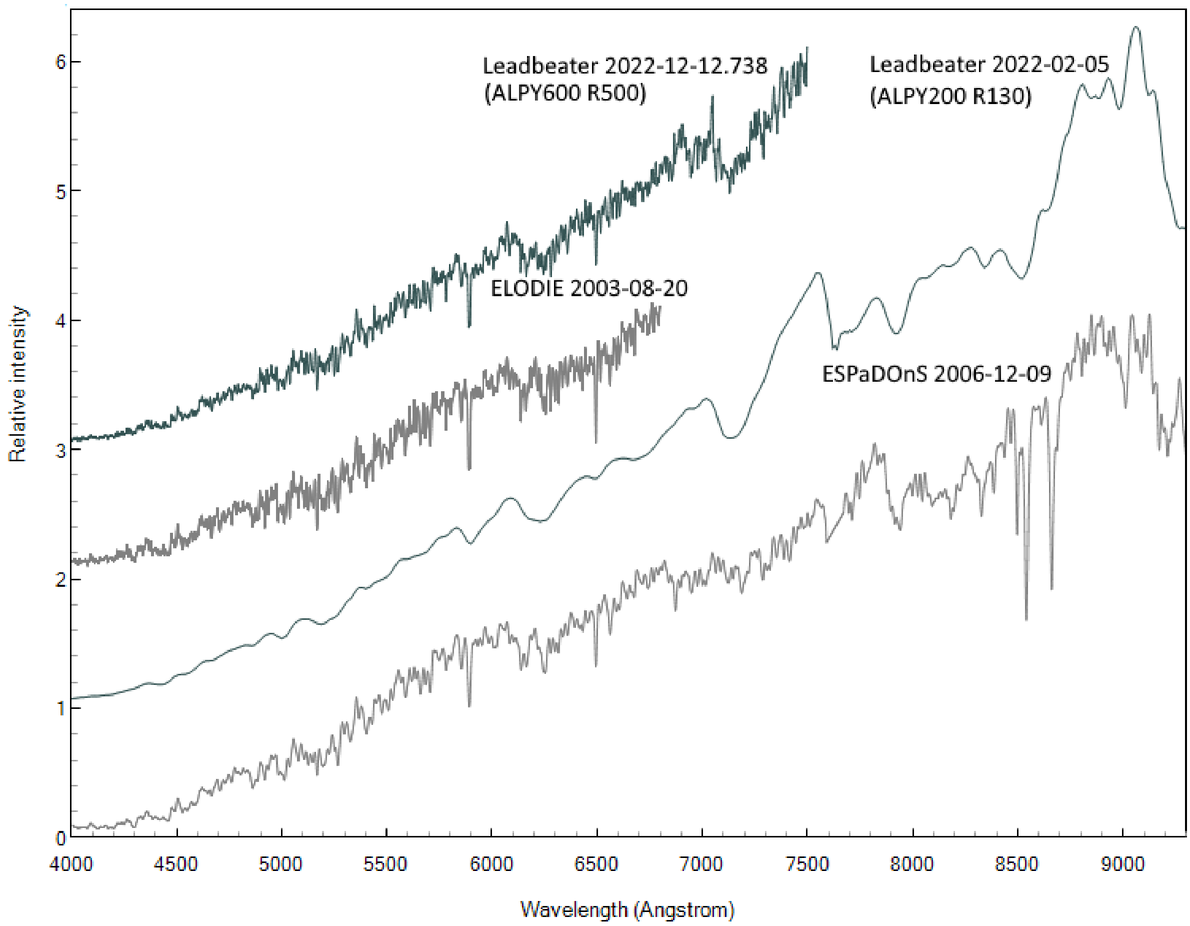

Fig 3. Low resolution spectra during dimming compared with archive spectra (normalised in the V band and offset in y for clarity)

Although the flux in V is currently about half the typical level, the appearance of the spectrum at low resolution has not changed dramatically. Generally, the lines in the ALPY 600 spectrum are perhaps weaker than in the comparisons.

Colour

An important clue in the case of Betelgeuse was the degree to which the dimming was wavelength dependent. (The diming was approximately uniform across the visible range but less into the IR particularly in J,H). Although there are recent multiband photometric data for RW Cep in the AAVSO database there are none pre dimming. There are though some V and Ic data from the Kamogata/ Kiso/Kyoto Wide-Field Survey (KWS) covering the period prior to and including most of the dimming up to mid November 2022 [6]. This shows ~0.2 magnitudes less dimming in I compared with V. Historical values in various catalogues suggest that the current dimming has been the same in B and V but with little or no dimming in J and H, so similar to that seen in Betelgeuse. There are some inconsistencies and scatter however so additional multiband data as RW Cep recovers will be important.

My low resolution spectra are calibrated in relative flux so potentially could be used going forward to estimate the dimming at different wavelengths up to the I band but the pre dimming comparison spectra are "instrumental" i.e. only approximately flux calibrated, excluding atmospheric extinction corrections so are of limited use for accurately estimating colour indexes, particularly at the blue end. A comparison at V and above though suggests V-R has remained constant but V-I has increased by ~0.2, consistent with the KWS data. A complete understanding of the colour change however will likely have to wait until/if RW Cep returns to a more normal state.

High resolution spectra

At high resolution the spectrum of RW Cep is extremely complex with many hundreds of blended lines formed at different depths within the stellar atmosphere, of different widths and moving independently with different radial velocity shifts. This degree of complexity can be seen in a paper by Josselin and Plez which includes an analysis of the ELODIE spectra used here as a comparison [7]. Ignoring these subtleties, the spectra outside the dimming period are broadly similar. There are some significant differences however between these and the spectra in the dimmed state. Fig 4 compares the H alpha region taken in the dimmed state (LHIRES III spectrograph R=15000) with a typical ELODIE (normal state) spectrum.

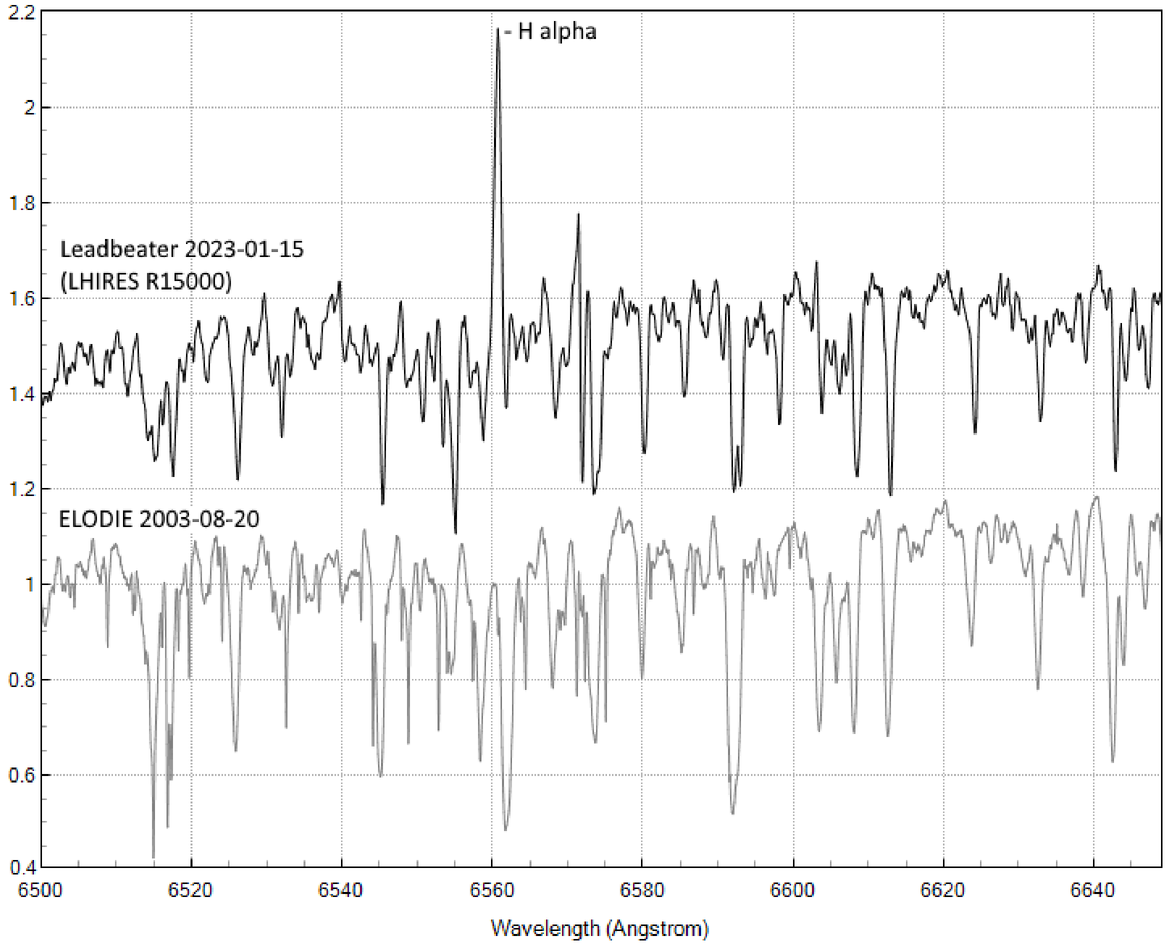

Fig 4. High resolution spectrum covering the H alpha region during dimming compared with archive spectrum (offset in y for clarity)

H alpha is clearly currently in emission. There are also other unidentified lines weakly in emission at 6571 and 6603 Angstrom. None of the ELODIE spectra show H alpha in net emission so this may be associated specifically with this deep dimming episode. The H alpha emission is blue shifted by ~40 km/s relative to the mean radial velocity as measured in the ELODIE spectra, which suggests this emission source is currently expanding outwards. There is also evidence of emission superimposed on many other broad absorption lines which while not strong enough to appear above the continuum, weakens the absorption, confirming the general weakening of the lines seen at low resolution. There appears to have been a red shift of the absorption spectrum of ~20 km/s on average relative to the ELODIE spectra based on cross correlation measurements, though this may be due in part at least to the asymmetric filling of many of the absorption lines by a blue shifted emission component.

Examination of the region in the IR which includes the neutral Potassium lines in at 7665/7699 A reveals them to also be in emission compared with the ESPaDOnS spectrum from 2006, though the analysis of this region is hampered by strong O2 telluric and dust absorption lines. (fig 5)

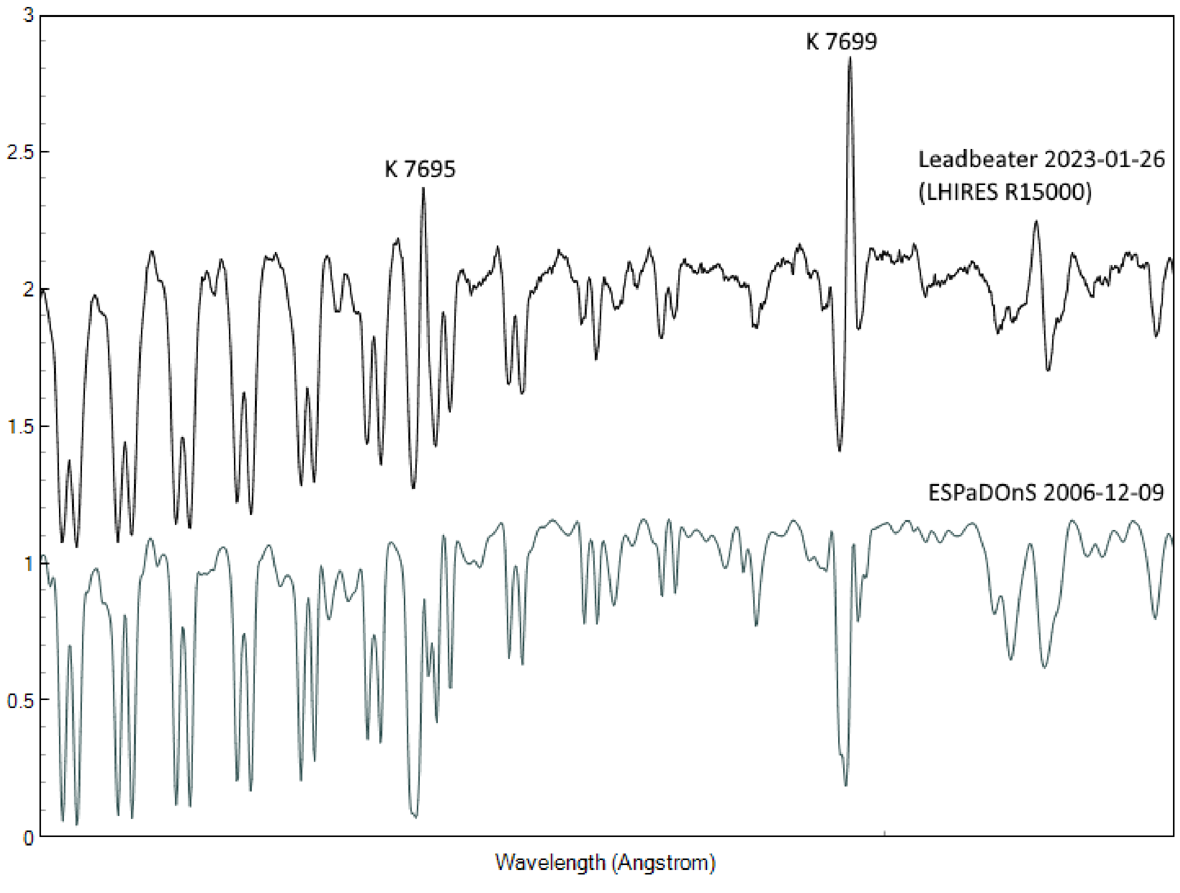

Fig 5. High resolution spectrum covering a region in the IR during dimming compared with archive spectrum (offset in y for clarity)

Further work

Continued monitoring, both spectroscopically and with multiband photometry will be useful to understand what is happening with RW Cep as/if it returns to normal.

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How variable is HD 176981?

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HD 176981 is used as Comparison Star D for the bright Mira-type variable R Aql and has recently been listed in the VSX as a low-amplitude Lb variable. The Hipparcos data are largely constant, with a possible change of a few hundredths of a magnitude during 1990.

HD 176981 is an apparently unspectacular K-type giant, and this is helpful as its main claim to fame is as Comparison Star D for the bright Mira-type variable R Aql, which is currently at an historical maximum. In the previous *Circular* [1] the sequence was revised and the magnitude of HD 176981 adjusted from a *V*-based measurement of 6.3 to a more appropriate visual magnitude of 6.5 on account of its red colour. More details surrounding these changes are given in the baavss-alert posting by John Toone. In the following post Sebastian Otero reported that due to a small variability the star had been added to the AAVSO Variable Star Index (VSX) as a low-amplitude irregular Lb variable. The VSX gives the range as 6.27–6.32 in *V* based on the variation in the photoelectric measurements in the General Catalogue of Photometric Data (GCPD) [2, 3], and the *V* magnitudes transformed from the *Hipparcos* mission. See the posting for more details.

Although HD 176981 is a bright star there has been no particular interest in it and relatively few photoelectric observations have been made. The most detailed listing comes from an early version of the GCPD [4], which shows that eighteen observations were made in four independent sets, mostly during the 1960's, by Johnson et al. [5], Argue [6], Cousins [7], and Moreno [8], where the star was used as a photometric standard. The mean magnitudes listed by the GCPD are *V* =6.297±0.004(sd), *B* − *V* = 1.651 ± 0.025 and *U* − *B* = 1.763 ± 0.045, and there is no suggestion of any variation, although Cousins did note discordant values, but individual measurements were not published.

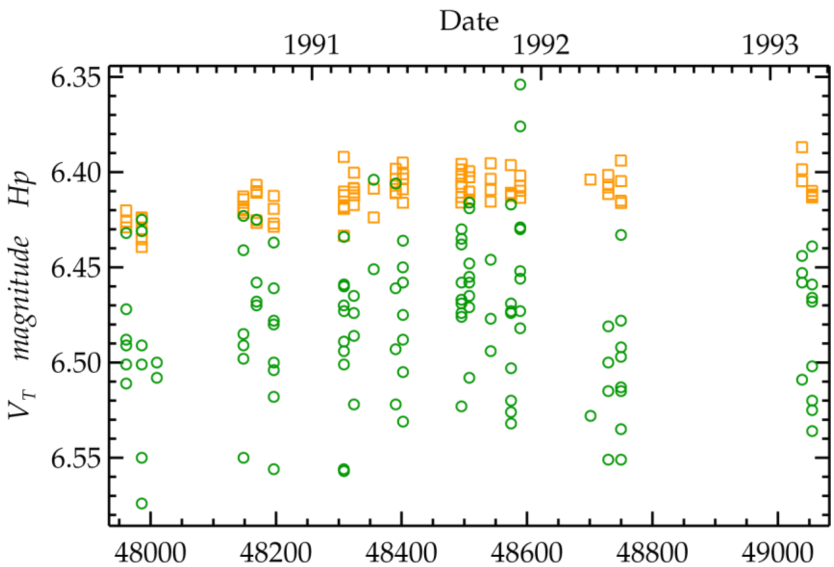

Figure 1. Epoch plot of the untransformed *Hipparcos Hp* (squares) and Tycho V_T magnitudes (circles).

The other data set referred to by the VSX is the *Hipparcos* mission which produced 87 *Hp* measurements from early 1990 to 1993 as shown in Figure 1. The mean is *Hp* = 6.411± 0.010 and the scatter is only marginally larger than the mean internal error of $0^m.007$, as calculated by the mission. However, there is a suggestion that the earliest values, and perhaps all those from 1990, are lower than the mean. The lack of an *Hipparcos* variability flag indicates that the system could not determine if the star was constant or not, and this is presumably why. There is much more *Tycho* photometry but unfortunately this is mostly corrupted with wildly discordant values and large errors. Even for the best data as shown in Figure 1 the internal errors are still typically $0^m.07$ and are consequently unable to show any variability at the $0^m.01$ level.

It should be possible to compare the *Hp* transformed to *V* magnitudes with the earlier photoelectric *V* magnitudes, but there are differing transformations that reflect the different *Hp* passband assumed (see e.g., Figure 10 of Weiler et al. [9]), and the ageing of the *Hp* passband over time [10, 11]. More importantly there is the question of a reliable transformation for very red stars, and HD 176981 has $B - V = 1.651$. The problem is highlighted in Figure 14 of Bessell & Murphy [12] and their calibration extends only to $B - V = 1.10$, so any transformed magnitudes beyond that are questionable.

The star was also used as comparison star for ten nights by Byrne et al. [13] while observing the flare star V1285 Aql, and there is no mention of variation. It also appears in the table of non-variable stars following 3.6 years of near-IR observations by the Diffuse Infrared Background Experiment (*DIRBE*) (see Price et al. [14]) at 1.25, 2.2, 3.5 and 4.9 microns, and cover much the same period as *Hipparcos*. The observations in the DIRBE 1.25- and 2.2-micron bands are shown in Figure 2 with arbitrary zero points. Both have standard deviations of $0^m.072$, so are unlikely to reveal small variations, however, the first set of 1.25-micron data appears to be fainter and this coincides with the fainter *Hipparcos* values.

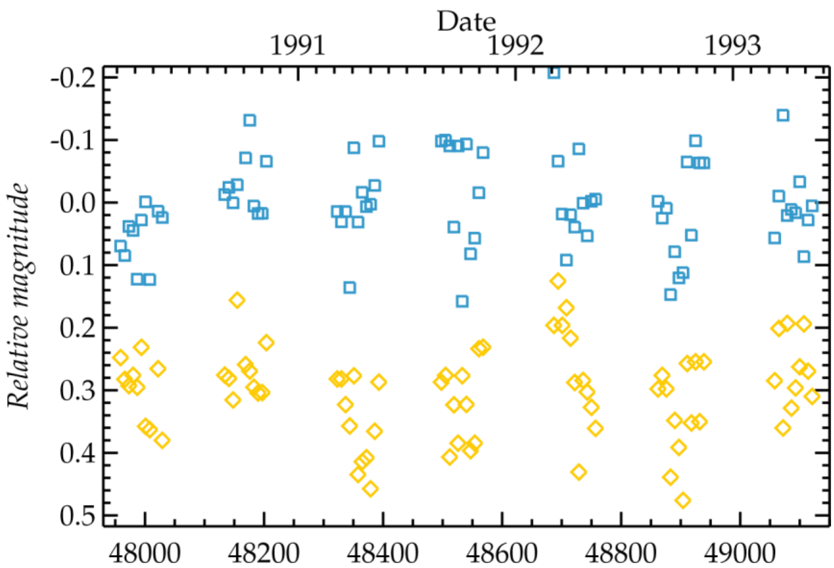

Figure 2. Epoch plot of the DIRBE 1.25- (squares) and 2.2-micron (diamonds) photometry. The rms variation of both bands is $0^m.072$ but there is a suggestion that the earliest set of 1.25-micron data is systematically fainter than the mean.

Kidger & Martın-Luis [15] list two near-IR measurements in the J, H and K bands which show no difference at 6 mmag level. Finally, the star was observed with the Transiting Exoplanet Survey Satellite (*TESS*) in Sector 54 during 2022, and over the 26 days of almost continuous coverage the total range of variation is $0^m.014$, including the high background parts of the light curve. So, on a timescale of days to weeks HD 176981 appears to be very stable to a rms < $0^m.01$, and over years the limit on the average is similar. The only evidence of any significant difference from the mean occurs in the 1990 *Hipparcos* data where there is a possible brightening of $0^m.02$–$0^m.03$ over perhaps two years. Although much less precise, there is the same direction of travel in the 1.25-micron *DIRBE* photometry.

HD 176981 is a single-lined spectroscopic binary and the solution published by Griffin [16] shows a circular orbit with a period of 611 d. Griffin questions the spectral type of the star as K2III, as the star is "...so exceptionally red..." and suggests that it is mid- to late K-type, but not as late as M0III. Unfortunately, the published temperatures available from many catalogues in VizieR range from $T_{\rm eff}$ ~3800 to 4400 K, which cover the range of spectral types from mid-K to early-M [17]. The values from Gaia DR3 are not available yet but should eventually provide some clarification. Griffin suggests that the components have masses of 2 and $\sim 0.3\ M_\odot$, although the nature of the faint secondary is not known. Although unlikely, there is a possibility that an ellipsoidal variation might be produced, however, this is not reflected in the data, so being a binary has no impact on the light curve. The other slightly curious feature of HD 176981 is that the orbit is circular, which as Griffin pointed out is unusual for binaries containing a giant component, with periods longer than 100 days. More recent evidence from systems containing a variety of evolved components supports this distinction [18–20], and the implication is that the orbit has been circularized by mass transfer during later evolution.

The available evidence does suggest that HD 176981 is a low-amplitude, slow, irregular variable with a range of $0^m.02$–$0^m.03$ on a timescale of a year or two, with minimal variation, probably < $0^m.01$ on shorter time-scales. *Gaia* photometry may clarify this, but the star is bright.

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CV & E News

Gary Poyner

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A general update on the CV&E programme during 2022 is included, along with details of the 2022/23 outburst of the old nova GK Per, and the 'prolonged' maximum of the RCB star Z UMi.

A basic report of activities in the CV&E programme appeared in the October 2022 edition of the BAA Journal [1]. Here we delve a little deeper to see what stars have and haven't been observed during 2022.

An inspection of the VSS database statistics reveal that 21,664 *visual* observations of 329 stars falling into the CV&E category were reported to the section in 2022 by 28 observers. The top 20 stars are shown in table 1 below.

Star	Total	Observers	Star	Total	Observers
R CrB	574	15	SU UMa	293	7
SS Cyg	561	10	RU Peg	277	8
Z Cam	560	9	AB Aur	261	8
CH Cyg	513	13	GK Per	261	9
RX And	413	13	U Gem	257	8
T CrB	386	7	SV Sge	243	7
Z UMi	375	6	AH Her	214	4
SS Aur	362	9	TZ Per	213	7
V1405 Cas	359	10	AG Peg	212	7
AB Dra	330	6	AY Lyr	212	6

Table 1. Top 20 visually observed stars in the CV&E programme in 2022

Of the top 20 observed stars of all types, 19 are CV&E stars, with the exception being the SR star Z UMa in 16th place. Stars with over 100 observations reported during 2022 number 44, and 38 stars have 5 or more observers. At the bottom end of the table, 68 stars have less than 20 observations each, and 218 stars (66% of the total number of CV&E stars reported) have a single observer. Fifteen stars which are listed in the CV&E programme on the web page have no observations reported at all (either visual or CCD), and if this situation doesn't improve then it's likely that they will be removed during the next catalogue update. These stars are…

V654 Aur, U Leo, FH Lyn, Lanning-17, Markarian 509, V2110 Oph, V2204 Oph, V2487 Oph, PNV J21581852+2419246, FG Ser, BW Tau, SDSS J103533.03+055158.4, SDSS J172929.47+005404.3, NSV 24587, NSV 25747

The top 5 CCD targets in the CV&E grouping are listed below in table 2. These yielded 80,938 observations – including time series observations. The best observed star in all CCD reports was CG Dra, followed by FL Lyn (9th place), AT Cnc (23), SS Cyg (41) and ER UMa (46).

Star	Total	Observers
CG Dra	28,316	10
FL Lyn	13,953	1
AT Cnc	4,709	3
SS Cyg	3,102	2
ER UMa	2,542	6

Table 2. Top 5 CCD stars in the CV&E programme in 2022

In the DSLR and CMOS categories, table 3 shows the five best observed CV&E stars.

DSLR	Total	Observers		CMOS	Total	Observers
V1405 Cas	17	1		XX Cam	111	1
P Cyg	14	1		DW Cnc	67	1
AT Cnc	12	1		V1405 Cas	58	2
EM Cyg	4	1		RU Peg	44	1
SY Cnc	4	1		U Gem	42	1

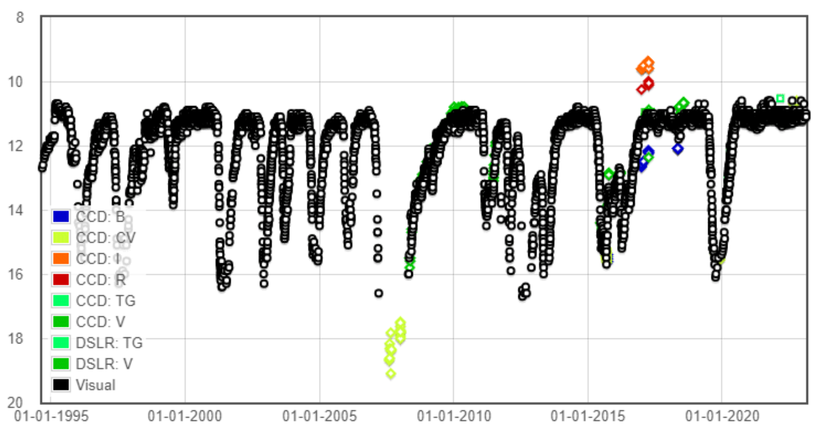
Table 3. Top 5 DSLR & CMOS stars in the CV&E programme in 2022

Database statistics are readily available for inspection from the VSS web page. Simply log-in to the database and click on ‘Database Statistics’ under the general heading. If it’s just variable star data you wish to see, you must choose this from the ‘Object Type’ dropdown menu, after which you need to put in the Julian dates for the period you wish to view.

Compiling a programme of CV’s and Eruptive stars in the modern era, where thousands of new objects are being discovered each year by professional and amateur surveys is an impossible task, and probably a pointless one too. The programme promoted by the VSS for CV’s and Eruptive objects is intended as a guide only. Many of the stars listed are objects which have been under observation by VSS observers for many decades (the so called *legacy* stars), and it’s important that we keep observing these as well as adding new objects to our own observing programmes which are discovered by surveys and announced on the numerous VS email groups which are available.

Z UMi

Z UMi is a popular circumpolar RCB star,(see table 1 above), with a range given as 10.8-19.0V in VSX [2] . Discovered in 1934 by Beljawsky, and (as we now know) misclassified as a pulsating red variable, Z UMi was identified as an RCB star in 1993-94 [3] and has been observed by BAAVSS observers since that time (*see left*). Minima can be very faint (19.1C, 2007), but are generally in the 15.0-16.0 range. Periods at maximum (11.0-11.5 visual) have been generally short (~4 months to one year), but the last three maxima have been longer, and each one.



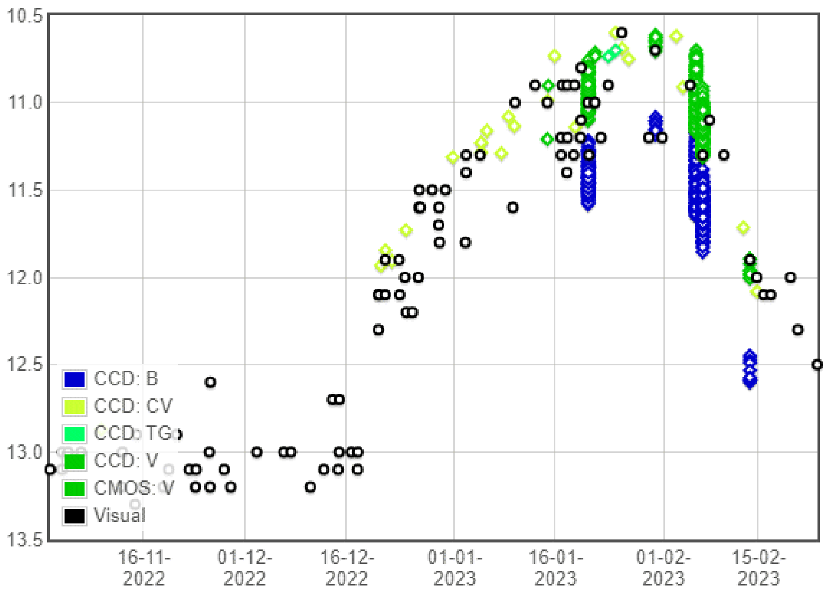
Z UMi 1994-2023. BAAVSS database

longer than the previous – Feb 2014 – May 2015 (453d), Apr 2017 – Jly 2019 (823d) & Jly 2020 – Feb 14 2023 (958d and ongoing). Far be it for me to predict when an RCB fade will occur, but who would bet against one happening this year? If you're not observing Z UMi at the moment and have the means to get below magnitude 11.0-12.0 with your equipment, then perhaps this is a good time to add this star to your programme.

GK Per

A number of observers detected the rise of the current outburst of the old Nova GK Per (Nova Per 1901) during mid December 2022 – the first observed since 2018. The rise to maximum has taken ~45d and peaked at magnitude 10.5 during mid-January. Maximum has appeared to last around 20d before a steeper fade began around Feb 07. At the time of writing (Feb 18), GK Per had faded to 12.1 visual. The previous outburst in 2018 looks very different, with a more symmetric rise and decline, and a shorter period at maximum brightness. The current outburst has spent ~60d brighter then magnitude 12.5, very similar to 2018. Spectroscopic observations have also been obtained by David Boyd, and his report can be seen elsewhere in this circular.

GK Per is an Intermediate Polar classified as type NA/DQ+UG (inner disk truncation due to the white dwarf magnetic field). The first Nova to be discovered in the 20th century (Feb 22nd, 1901 TD Anderson), it began to display dwarf nova outbursts in the mid 1960's, rising to around magnitude 10 every 2-3 years, although this period can vary quite considerably. In the early 1980's the discovery of X-rays from the system enabled astronomers to determine that GK Per is a magnetic CV of the Intermediate Polar type.



GK Per. Nov 1, 2022 – Feb 24, 2023. BAAVSS database. C*ontributing observers; SW Albrighton, D Boyd, LK Brundle, RC Dryden, G Fleming, ML Joslin, PC Leyland, G Poyner, GJ Privett, J Toone, T Vale, IL Walton, PB Withers*

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1. BAAJ Vol. 132, No.5 October 2022
2. AAVSO Variable Star Index
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Serendipitous detection of the white dwarf spin in GK Persei

David Boyd

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GK Persei is an intermediate polar which experienced a nova explosion in 1901 and subsequently small dwarf nova outbursts approximately every 3 years. Spectroscopic and photometric observations during the current outburst which began in 2022 December unexpectedly detected a signal in the B and V band light curves at the spin period of the white dwarf.

Introduction

GK Persei is a cataclysmic variable which experienced a nova explosion in 1901. This was detected at magnitude 2.7 on February 21 by Scottish amateur astronomer Thomas David Anderson [1]). GK Per is an intermediate polar with a K1 IV donor in which the white dwarf (WD) has a moderately strong magnetic field. This means the inner part of its accretion disc is truncated and material in the disc then travels along the magnetic field lines before impacting at high speed onto the polar regions of the WD. This process emits radiation across the electromagnetic spectrum from X-rays to optical that is modulated as the WD spins. GK Per eventually settled into quiescence at 13th magnitude in 1948 then began showing small dwarf nova outbursts approximately every 3 years. The most recent such outburst started around 2022 December 12 and the star gradually brightened reaching a V magnitude of around 10.5 by early February.

Observations

I recorded a spectrum of GK Per on 2023 January 20 with 17 x 300 sec exposures using a LISA spectrograph and 0.28m SCT (Figure 1). I'm concurrently recording B and V magnitudes with another telescope to use for subsequently calibrating the spectrum in absolute flux.

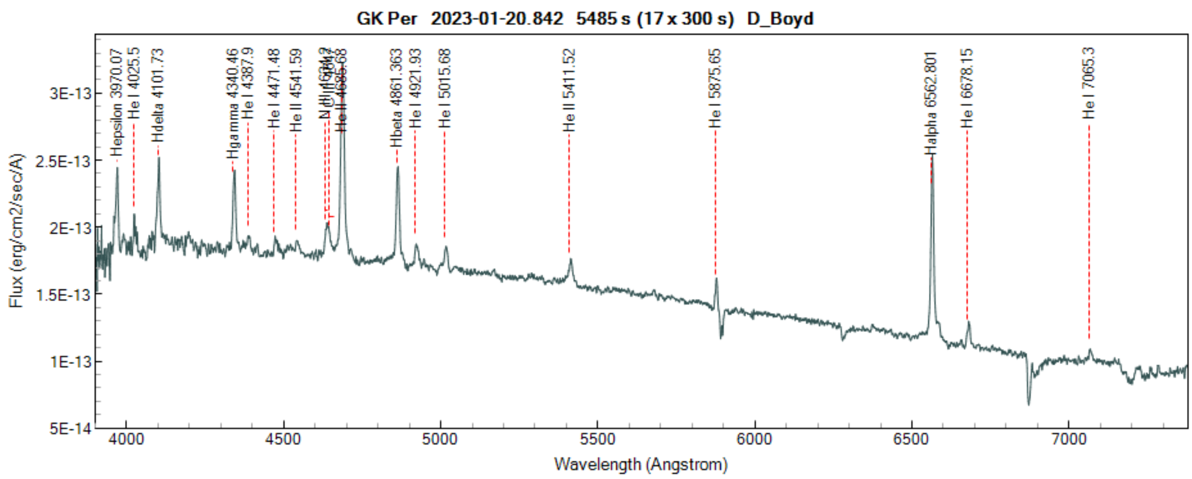

Figure 1. Spectrum of GK Per on 2023 January 20 indicating emission lines mainly of neutral hydrogen and helium.

I would normally only record about 10 minutes in each filter and use an averaged transformed V magnitude to flux calibrate the spectrum. However, I noticed that the magnitude was changing rapidly, probably due to flickering, so I kept recording photometry for 90 mins while I was collecting spectra. Figure 2 shows the resulting B and V magnitudes and B-V colour index.

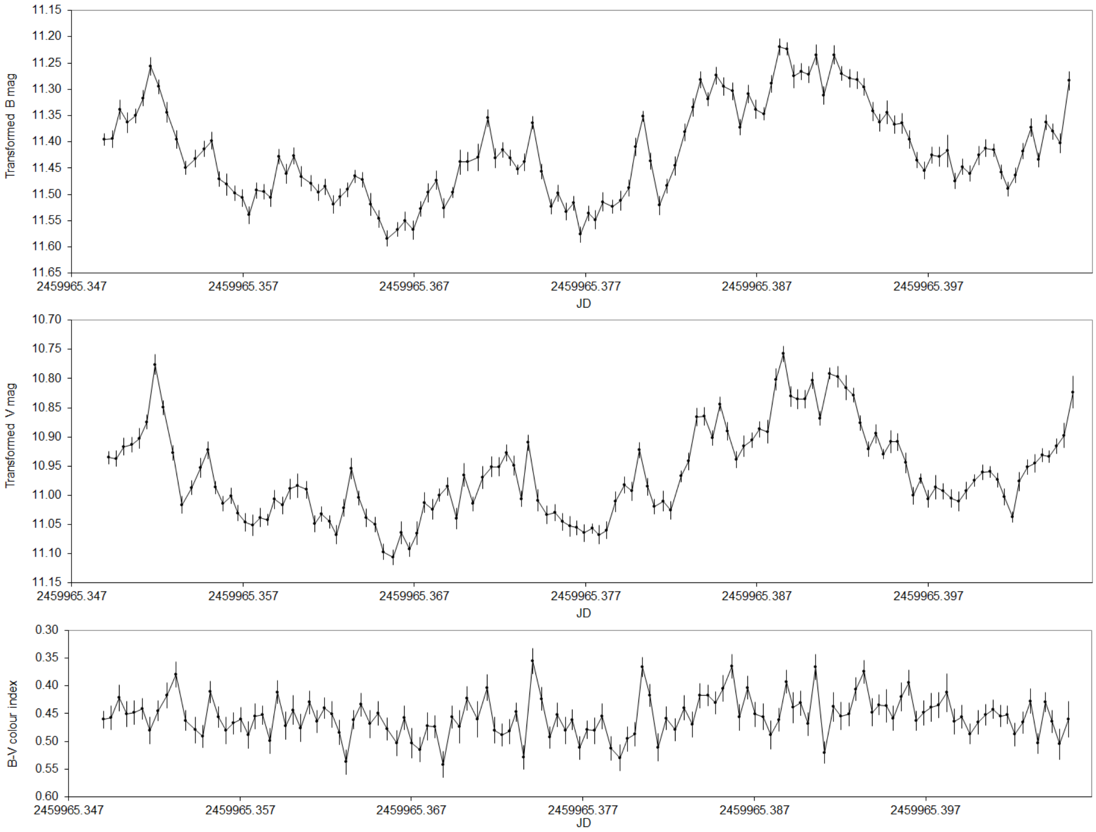

Figure 2. V and B band light curves of GK Per and B-V colour index measured concurrently with the spectrum.

Being curious, I then thought it would be interesting to perform a period analysis of the V band data using Peranso with no expectation of what I would find. I used the PDM method as this assumes no model for the behaviour of the data so is a good choice when you don't know what signals you are looking for. This gave the result shown in Figure 3 with a strong peak at 0.01086 hr = 39.1 sec.

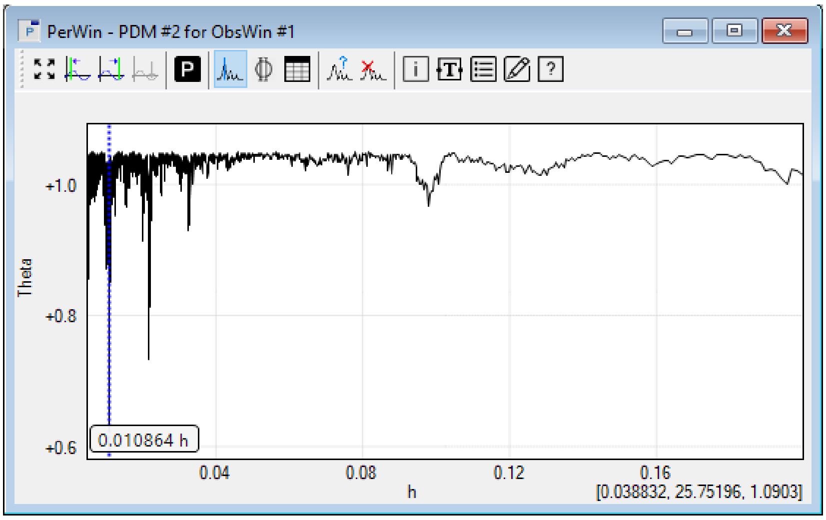

Figure 3. PDM analysis of the V band light curve showing the strongest peak at 0.01086 hr and a small peak around 0.1 hr.

It is often the case that the cadence of measurements can imprint itself in the data so I also computed the spectral window function. This showed a strong peak at the same period. Given that I was imaging for 10 sec in V then 20 sec in B plus time for readout and filter changing, the cadence of my V band measurements was 39 sec. Clearly, I was the cause of this signal. However, there was also a broad weaker signal around 0.1 hr. I analysed that more closely and found a period of 0.09792 hr = 352.5 ± 1.0 sec (Figure 4).

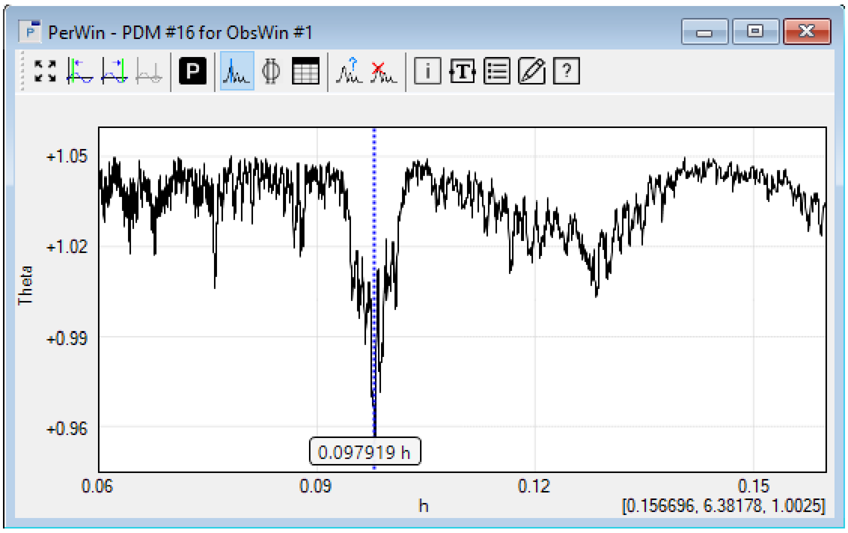

Figure 4. PDM analysis showing the signal at 0.09792 hr.

Curious as to what this might be, I looked through published papers on GK Per and found that in 1985 Watson, King & Osborne detected a signal in hard X-rays at 351 sec which they interpreted as the spin period of the WD [2]. Several subsequent papers repeated this measurement in X-rays, UV and optical wavelengths and Zemko et al. (2017) reported that the WD spin period was slowly decreasing [3]. Extrapolating their results, it was likely to be around 351.23 sec at the present time.

As a reality check, I repeated the period analysis using my B band data and found the signal at 352.6 ± 1.0 sec. As these signals were within 1.5σ of the currently expected WD spin signal, it is likely I detected the WD spin period. I was surprised to find this could be detected with only 90 minutes of photometry.

References

1. Stanley Williams, A. MNRAS, 61, 337, (1901)
2. Watson, M.G., King, A.R., Osborne, J. MNRAS, 212, 917 (1985)
3. Zemko, P. et al. MNRAS, 469, 476 (2017)

The Outburst That Never Was: an OJ287 mystery

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OJ287 is a particularly interesting blazar in Cancer. It appears to be the only known case of an enduring quasar lightcurve periodicity, with large outbursts appearing approximately every twelve years since the late 19th century, quite apart from the many reports of rapid periodicity of 20 to 40 minutes being observed ephemerally. A new outburst was predicted for July 2022, exactly at solar conjunction but, an alternative model suggested that the maximum could be delayed two to three months, into the Autumn observing window. To test this, a major monitoring campaign has been mounted. No outburst has been observed, but a change in mode of variability from slow oscillations of brightness to much faster ones was seen in mid-January 2023.

The blazar OJ287 has been at the heart of many a Ph.D thesis over the decades since it was identified in 1972. One of the few extragalactic objects that a visual observer can see change in brightness in an observing session, many observers have, over the years, published claims of observing transitory fast periodicities, usually around 20 and 40 minutes. What, though, has created a great deal of interest and speculation is the observation that, over now nearly a century and a half, it has shown large outbursts every 11.8 years. The outbursts are not strictly periodic as, every five cycles, there is a small phase shift but, the pattern has continued for long enough that it cannot be ignored. Other quasars, such as 3C273 and 3C345 have shown apparent periods on time scales of years, but they have never lasted more than a few cycles before disappearing: the case of OJ287 is unprecedented in this respect. As stable periodicity demonstrates orbital motion, or oscillation, these periods are a powerful diagnostic of physical processes.

Blazars are a sub-class of quasars in which the relativistic jet expelled from the poles of the central black hole points roughly towards the Earth. This allows us to look down the jet as if we were staring down a lighthouse beam. What makes OJ287 special in this respect is that it has the best-aligned relativistic jet of all known blazars, hence, in many senses, its behaviour is particularly extreme. Unlike many other highly variable quasars – such as BL Lac, AO 0235+164, AP Librae, Mark 501, etc. – the beam of light from the jet is so intense that the underlying giant elliptical galaxy is barely detectable save when the blazar is especially faint.

All this makes OJ287 an extremely rewarding object to study, one of the few in which the observer can watch the equivalent of a trillion Suns switching-on, or switching-off, in an hour or less.

The outbursts of 1994, 2005/6 and 2015 were all predicted with increasing accuracy on the basis of a model developed by Mauri Valtonen at Tuorla Observatory of a binary supermassive singularity in which the secondary, which has a comet-like orbit that precesses extremely rapidly, disrupts the accretion disk of the primary every time that it bursts through it. It is the rapid precession – nearly 30 degrees per orbit – that causes the sequence of outbursts to show a timing jump every 5-6 cycles.

Unfortunately, sometimes the predicted outburst falls in the summer months when OJ287, which is in Cancer, is in solar conjunction and at an elongation below 10 degrees. This was the case in 2015, when the Spitzer Space Telescope was the only instrument able to observe the outburst thanks to its trailing orbit, slightly outside the Earth´s, which allowed it to peer around the limb of the Sun. The outburst duly arrived within three hours of the predicted time and was observed in detail. The situation was even worse in 2022: the predicted outburst was exactly at conjunction and Spitzer had finally been de-commissioned and placed in Safe Mode in January 2020, so was no longer available and no other satellite would be sensitive enough to measure OJ287 reliably. However, there was a possibility of another valid solution (there are sixteen free parameters to fit in the model) that would delay the outburst at least two months, into September, or even October.

In the former case, the outburst would be over when OJ287 was recovered in the morning sky. In the latter, it would be rising to maximum. The only way to find out was to observe and see which model satisfied the observations.

OJ287 was recovered, very low in the morning sky from Japan, on August 28th, around magnitude 16. The first BAA-VSS observations came on September 21st, when Gary Poyner observed it at V=15.47 with SLOOH, in Tenerife. There was initial excitement as the quasar brightened steadily, reaching V=15.10 on October 14/15th (Martin Mobberley with iTel California and Gary Poyner with COAST, Tenerife). Some quick calculations by Mauri Valtonen suggested that, if this was *the* outburst and followed the pattern of a similar event in 2006, OJ287 should start to rise rapidly in the last week of October and peak in the second week of November. Between October 11th and 17th, OJ287 flickered, averaging V=15.12, but seemed to stop rising.

We awaited the rapid climb to V≈14.5 that would indicate that the blazar was entering outburst.

And then, instead of bursting through V=15 to around magnitude 13, it sank like a stone.

By November 3rd, Guy Hurst and Dennis Buczinski were measuring V=15.66. On November 12th, it was below V=16, which is unusually faint and we were wondering just how much lower it would go. On November 18th, Poyner and Hurst were measuring V=16.21.

Historically, magnitudes fainter than V=16 are observed only rarely and are extremely interesting because, at these faint magnitudes, the colour of OJ287 starts to change. Normally, and unusually for blazars, for which the rule is a bluer colour when brightest, the colour index of OJ287 is almost constant (Figure 1):

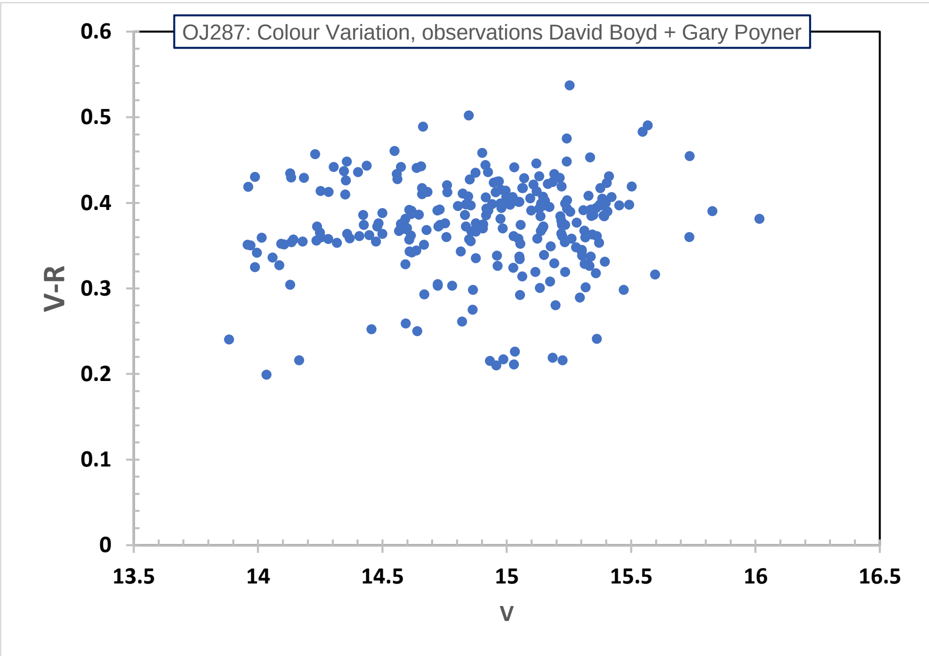

Figure 1: The V-R colour index for OJ287 from observations by David Boyd and Gary Poyner between December 2015 and January 2021. Most blazars are bluer when brighter but, within the dispersion caused by rapid variability, the colour of OJ287 shows no obvious correlation with brightness. The average colour index over the period covered is V-R=0.37.

The colour-magnitude diagram for OJ287 shows a lot of dispersion because magnitudes are never measured truly simultaneously and are subject both to variability and photometric error. However, the average V-R colour index measured by David Boyd and Gary Poyner between 2015 and 2021 was +0.37. In contrast, when the magnitude drops below 16, the underlying giant elliptical galaxy, whose light is normally drowned-out by the blazar, starts to contribute significantly. Giant ellipticals are dominated by old, red stars so, the colour of OJ287 starts to redden as it gets fainter, initially slowly but, if the magnitude gets down below V=16.5, the change in colour starts to be considerable and very obvious. On November 17th, the V-R colour had increased to +0.52, showing that the light of the (invisible) underlying galaxy was shining through clearly and demonstrating that, in the right circumstances, a backyard telescope can reveal a galaxy where the Hubble cannot!

By this point, it was evident that the outburst was not going to happen, but we wondered if we would see an exceptional minimum of OJ287, as had occurred in 1989, when the magnitude dropped below V=17 for a few days. Instead, the quasar started to brighten again and, by mid-December was, again, around V=15.1 and we wondered: could a decimal point have slipped somewhere in Mauri´s calculations? It took only a few days for us to be disillusioned and, again, the brightness fell rapidly, breaking through V=16 once more in mid-January.

What happened afterwards was quite unexpected. The slow up and down cycles stopped, and a series of rapid flares started. A typical flare in OJ287 is generated in the relativistic jet, has an amplitude of 0.5-1.0 magnitudes and takes 5-7 days to rise to maximum and the same to return to quiescence. Instead (Figure 2) we started to see much faster variations of a type that were extremely unusual in this object.

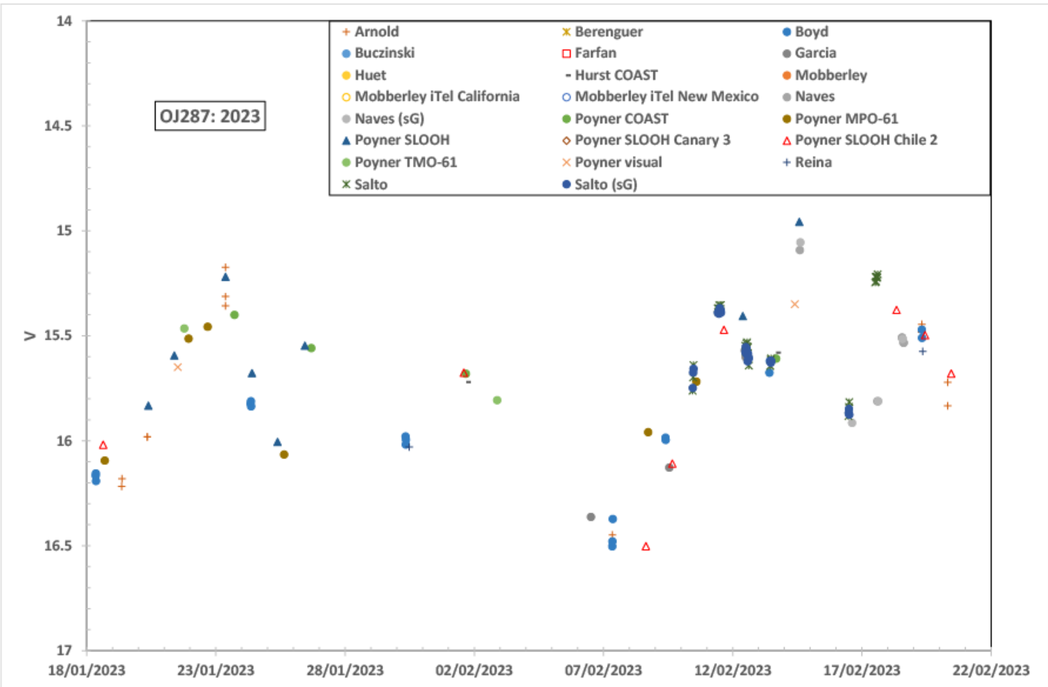

Figure 2: The lightcurve of OJ287 since the minimum of January 17th. We see a series of rapid flares superimposed on slower variations. The lightcurve is heavily undersampled, but there is a strong suggestion that the flares occur approximately every 3 days. The fastest variations are of ≈0.3 magnitudes per hour.

Between February 13/14th and 15/16th the brightness increased from V=15.61 (Josep-Lluis Salto) to V=14.96 (Poyner), dropping back down to V=15.88 the following night. There is a strong indication that these flares are occurring quasi-periodically every 3-4 days, although the lightcurve is too undersampled to be certain of this. Certainly, though, no variations like these have ever been observed during the intensive observing campaign since 2015.

The change in the lightcurve after mid-January 2023 is obvious (Figure 3). In over 35 years of study of OJ287, I can only remember two, very brief episodes of similar behaviour – in 1989 and in 1993 – when we saw the brightness flashing up and down by about a magnitude in an hour or so, but both these episodes lasted for only a few hours. The variations that we are seeing in early 2023 are slower, but longer lasting. On the previous occasions that we saw this type of behaviour, we surmised that a knot of plasma was swirling around inside the relativistic jet and that the quasi-periodic variations of brightness were due to it spiralling in the magnetic field in a sort of pseudo-orbit, giving us a flash of light each time that it aligned more exactly with our line of sight.

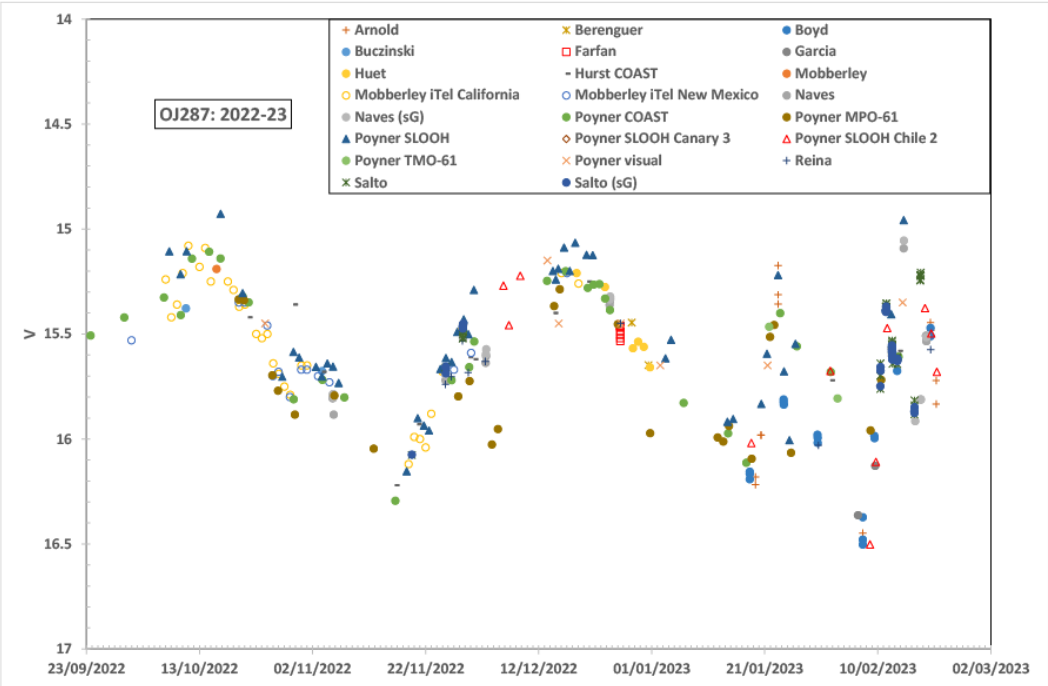

Figure 3: The lightcurve of OJ287 for Autumn and Winter 2022/23. The change of behaviour in mid-January is obvious.

The data in Figure 3 make it obvious that no major outburst took place in 2022. If we look at the lightcurve since 2015 (Figure 4) we see how much it has faded since the peak of the December 2015 outburst that was captured by Faustino Garcia. The trend was reversed briefly in the July 2019 outburst. As can be seen, there was no hint in the observations pre- or post-conjunction in 2019 of any abnormal activity, so it is unsurprising that we see no hint of a similar outburst at conjunction in 2022, although we can be quite confident that it did happen.

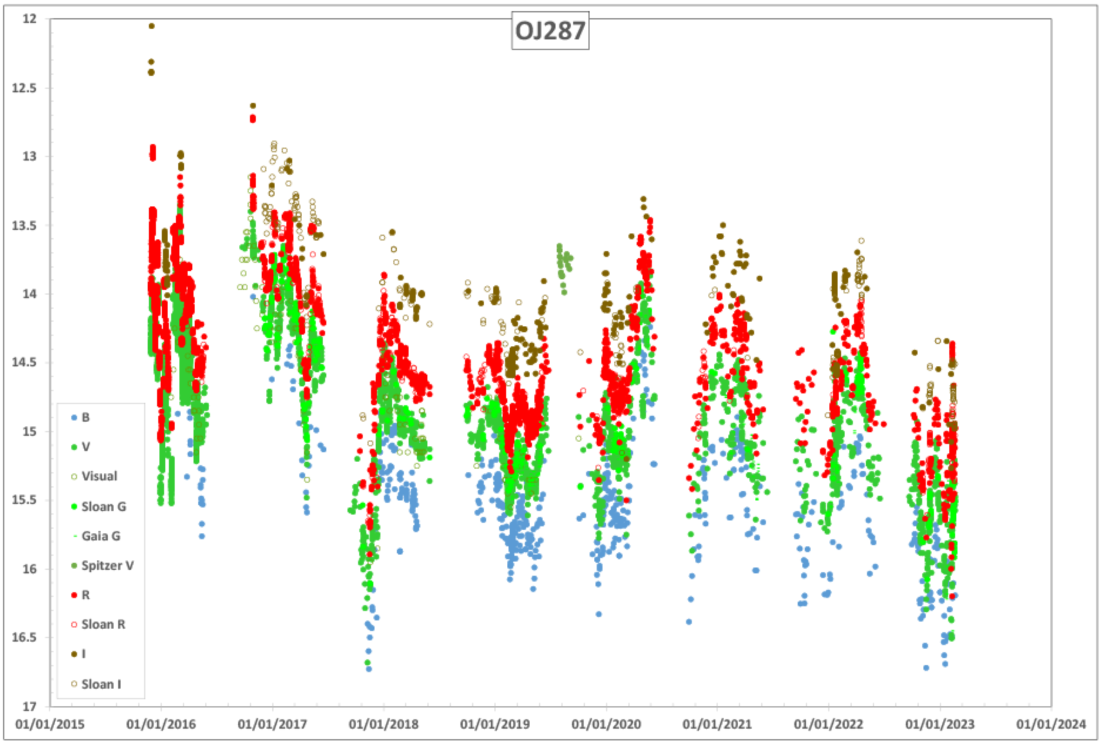

Figure 4: the lightcurve of OJ287 between November 2015 and February 2023. The brightness has trended strongly downwards since the peak in December 2015 apart from the brief, July 2019 outburst. The 2022 outburst would have fallen exactly in the gap at conjunction if it appeared as predicted and, like the one in July 2019, would not reveal itself in pre- or post-conjunction data.

So, OJ287 continues to surprise us. Even if we did not see an outburst in 2022, we have been able to rule out an alternative prediction, which is still valuable. Now, we must wait, patiently, for the next outburst, in 2031, which will be a much more favourable one, to refine the models further. Meanwhile, I wonder how much longer these peculiar, fast oscillations are going to last but, more on that will have to wait for the next BAA-VSS Circular.

Eclipsing Binary News

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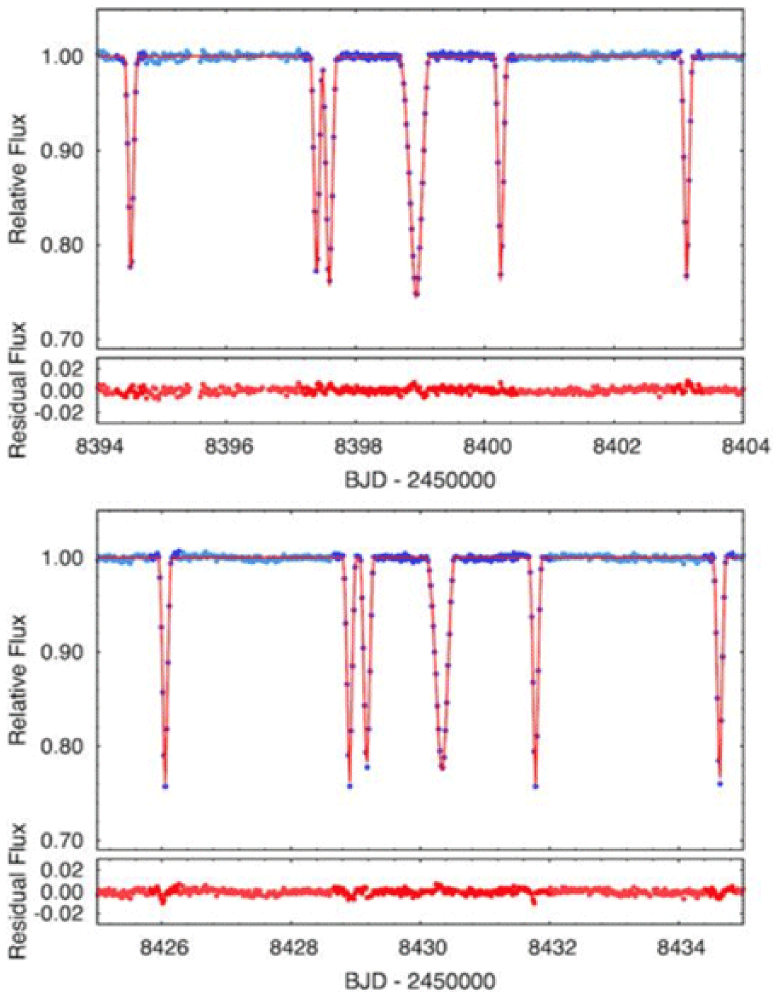
Triply Eclipsing Triple Star Systems

A number of papers have been published in the Monthly Notices of the Royal Astronomical Society of Triply Eclipsing Triple Stars Systems discovered with TESS.

One of these papers is “A Study of Nine Compact Triply Eclipsing Triples” [1]. Another paper is “Six new compact eclipsing triples found with TESS” [2].

An earlier paper is “The compact triply eclipsing triple star TIC 209409435 discovered with TESS” [3]. This paper describes the discovery of a triple system where an inner eclipsing binary has a period of 5.717 days. This system is eclipsed by an outer star with a period of 121.872 days. The paper reports that the TESS data was followed up by archival ground-based observations of the WASP project.

Figure 3.



There was a ground based follow up photometric campaign with the participation of three amateur astronomers operating their own private observatories. The three observatories were located in Perth, Western Australia (PEST Observatory), Raemor Vista Observatory in Arizona, USA, and the ROAD Observatory in the Atacama Desert, Chile. The latter is a remote observatory operated from Belgium.

Figure 3 (*left*) from the 2020 paper, illustrates well the superimposed eclipses of the outer and the inner components of the system.

Figure 7.

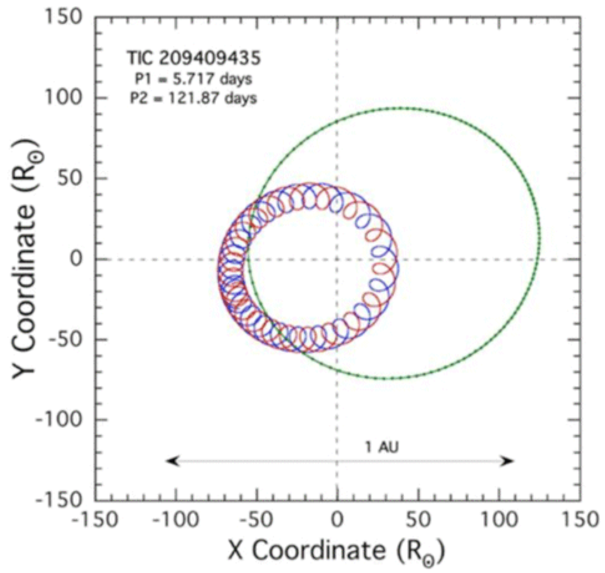
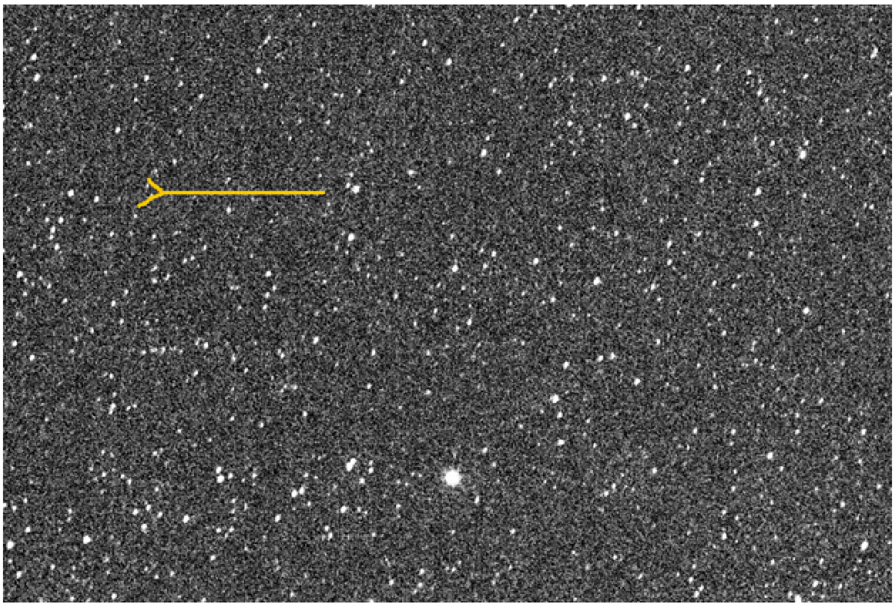


Figure 7 (*above*) from the 2020 paper, illustrates a view of the system from above.

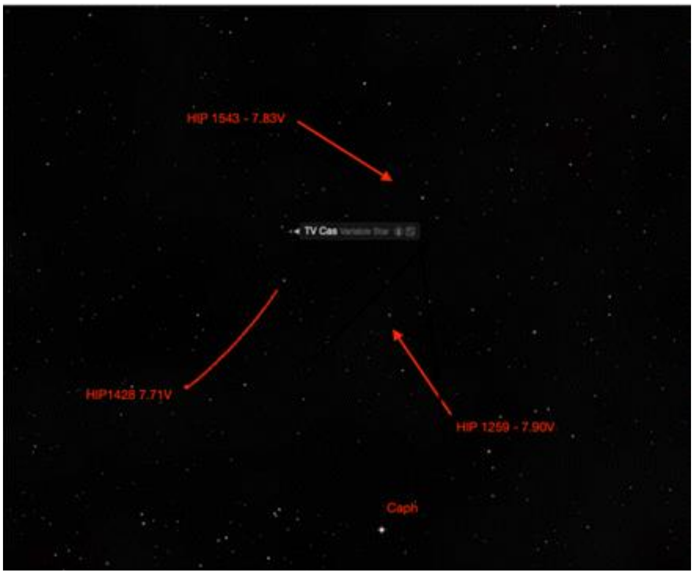
TV Cassiopeiae

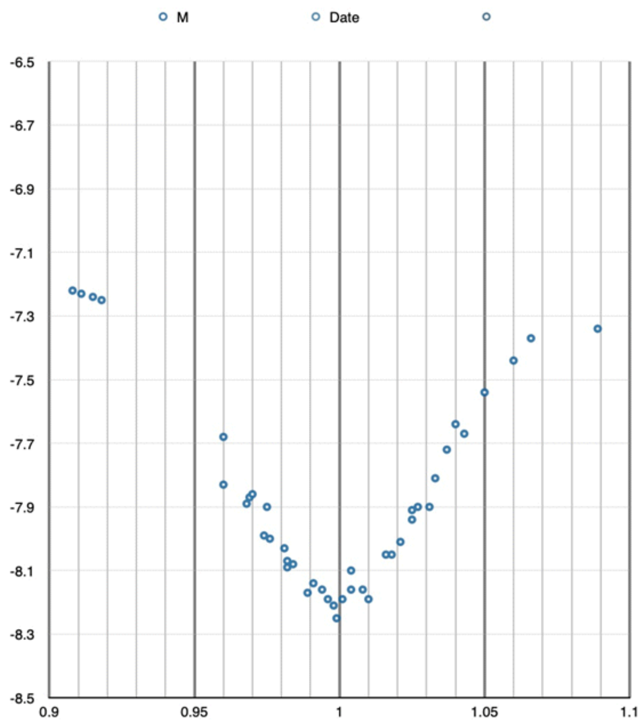
This is a system on our recommended list. It is an Algol type eclipsing binary with a period of 1.81 days. It varies from 7.26V to 8.28V. It is therefore a good target for binocular observers and those who carry out DSLR photometry. The system is easy to find as it is very near the bright star Caph in the constellation of Cassiopeiae. It is visible all the year round from the UK.

The system is worth monitoring because the primary star is of spectral type B9V and is much brighter than the Sun - if the Sun's luminosity is 1 then the primary star of TV Cas has a luminosity of 27.26. The system is said to undergo period changes which is why the system became a BAAVSS target some time ago. The paper chart in my possession is called BAAVSS 1982. As this chart is not suitable for DSLR photometry I have constructed my own chart. Below is my own DSLR image with the arrow pointing at TV Cas. The bright star at the bottom is Caph.



The image *right* shows the comparisons that I have identified from the Hipparcos database. They are all very near TV Cas. V magnitudes can be derived from these comparisons with suitable corrections to the green channel photometry of the DSLR





The plot shown *left* is a record of my DSLR measurements around primary minimum over the last couple of years. The period does not seem to have changed recently and shows the profile of a partial eclipse. The vertical axis is the V (Green Channel) magnitude, and the horizontal axis shows the measurements plotted on a phase diagram based on the current period quoted on the Krakow database. In this diagram one along the bottom axis represents the predicted time of primary minimum.

Each dot represents the analysis of 20 stacked DSLR images with AIP4WIN, using the three comparisons in the above diagram and then corrected to give a V magnitude.

In this type of diagram, a change of period would be suggested by a drift of the measurements around the predicted time of primary minimum to either the right or the left.

References

1 MNRAS <https://doi.org/10.1093/mnras/stad367> Published 02/02/2023.

2 MNRAS Volume 513 Issue 3, July 2022, Pages 4341-4360,

3 MNRAS Volume 496, Issue 4, August 2020, Pages 4624-4636

Long term observations of three variables catalogued as Eclipsing Binaries

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Eclipsing binaries are frequently only observed near their minima in order to determine the times of minima, but these three sets of observations of KU Cyg, V2483 Cyg and V3288 Oph suggest that valuable data can be obtained by observing them at all phases.

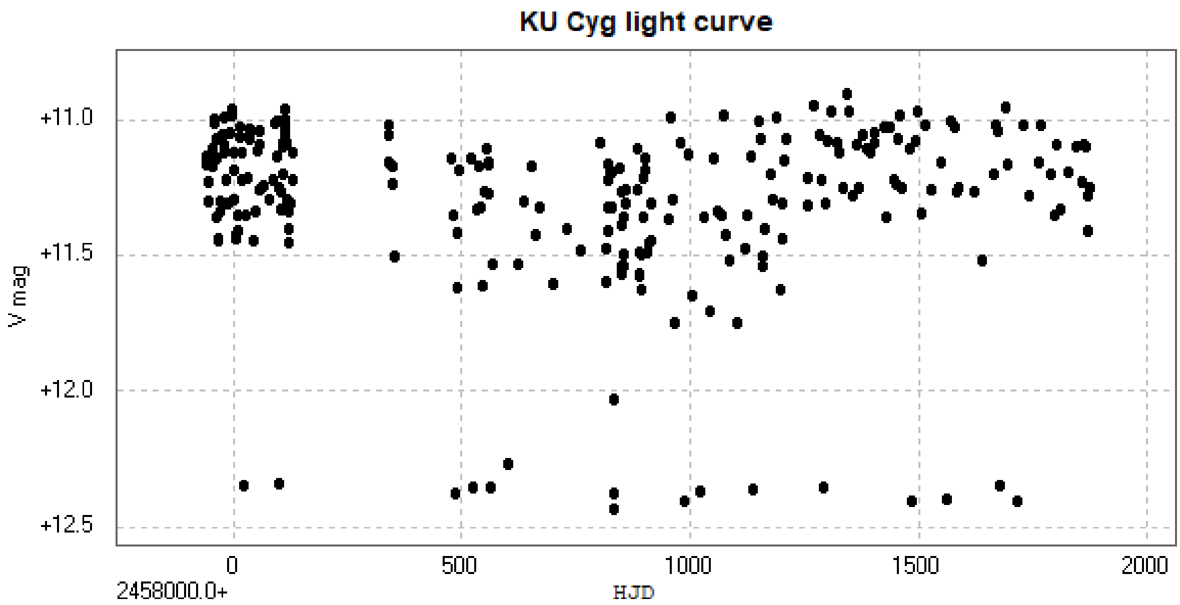
This article discusses three variables catalogued as 'eclipsing binaries' which I have been observing continuously with the Open University COAST telescope for a period of more than five years. All observations were made using a V filter. The catalogue data, in square brackets, was correct as of 2023 February 14.

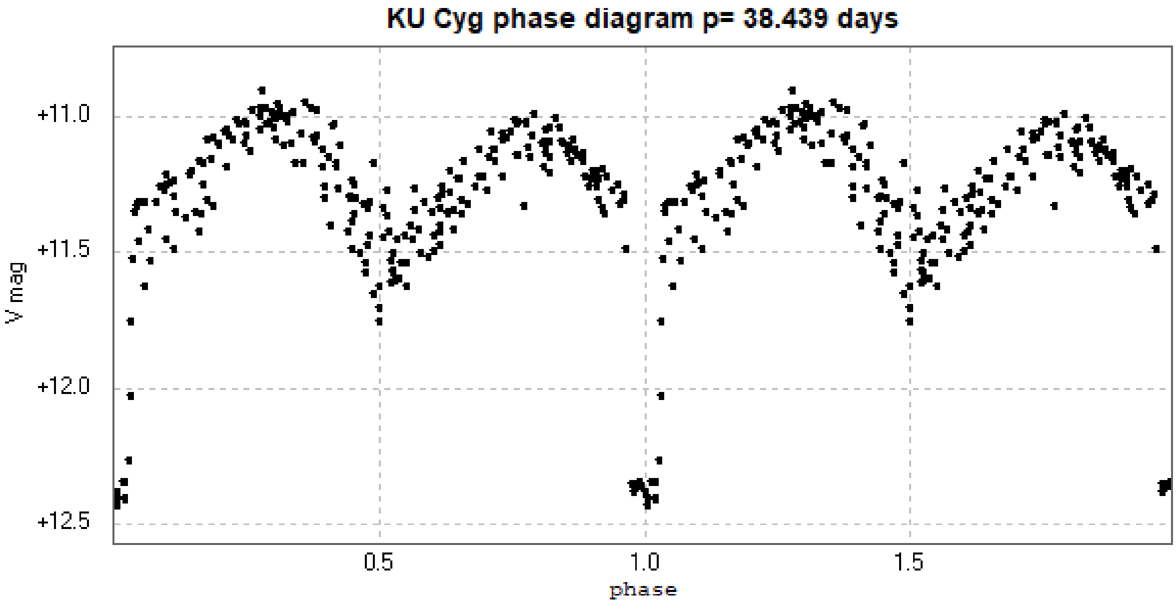
KU Cygni

[GCVS type EA/D:/RS period 38.4393d spectrum F4p+K5eIII

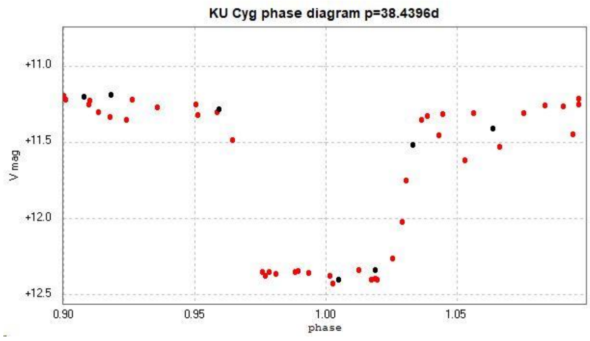
AAVSO VSX type EA/GS period 38.4396d spectrum B7:V+K5IIIe]

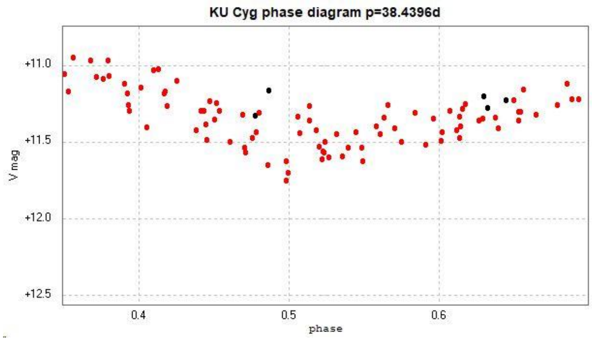
Light curve and phase diagram constructed from 253 observations between 2017 July 7 and 2022 October 23.





Out of eclipse variations are due to an eccentric accretion disk (Otero). Note that the primary minimum is flat while the secondary minimum is less so if at all.



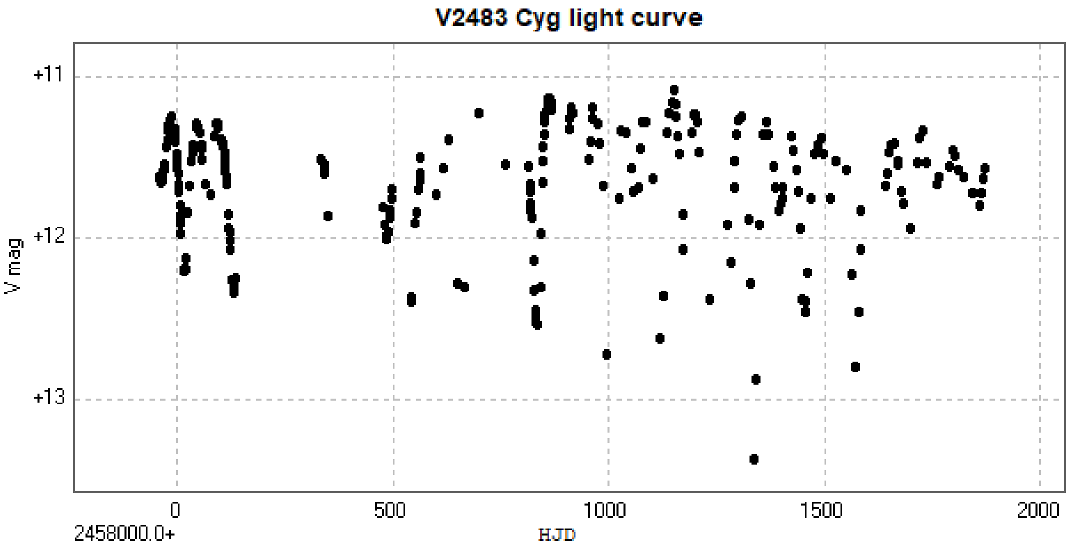


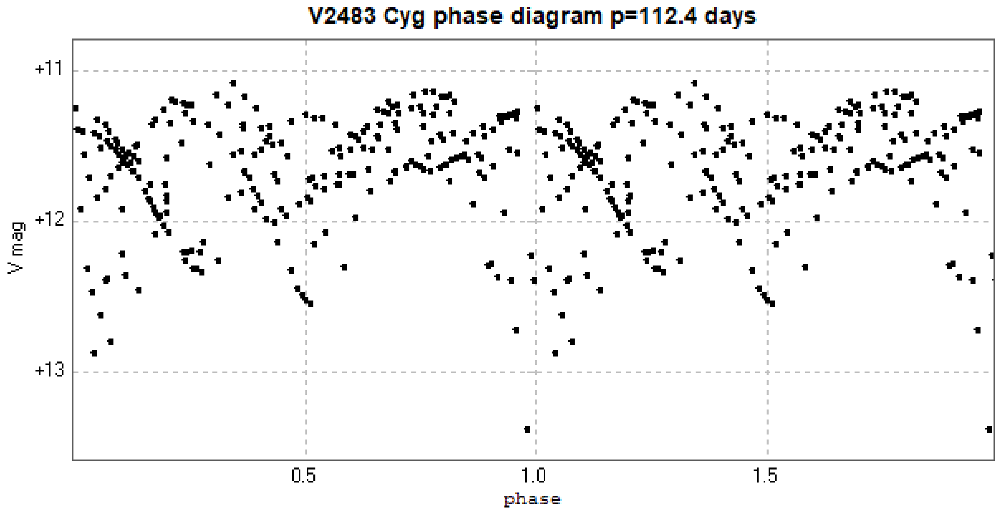
V2483 Cyg

[GCVS type EB period 112.4d   AAVSO VSX type EB/GS period 112.40d]

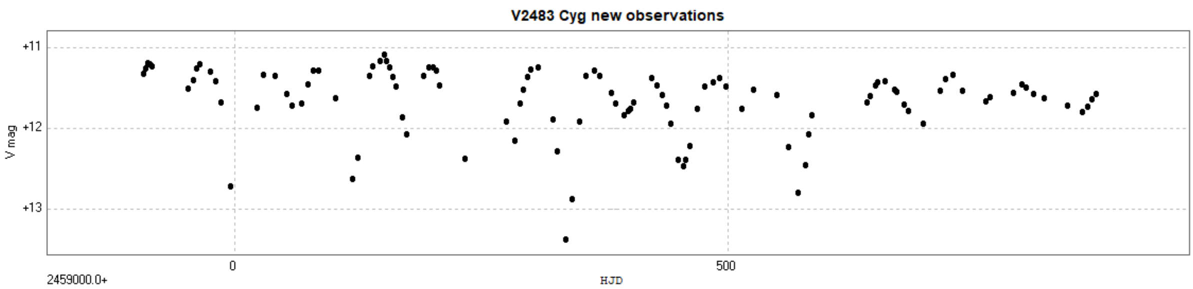
Light curve and phase diagram constructed from 244 observations between 2017 July 23 and 2022 October 20.

These include results published in VSSC 183 (March 2020) in addition to 111 new observations, made between 2020 February 28 and 2022 October 20. The new observations show that the variation in brightness from one cycle to the next is continuing.

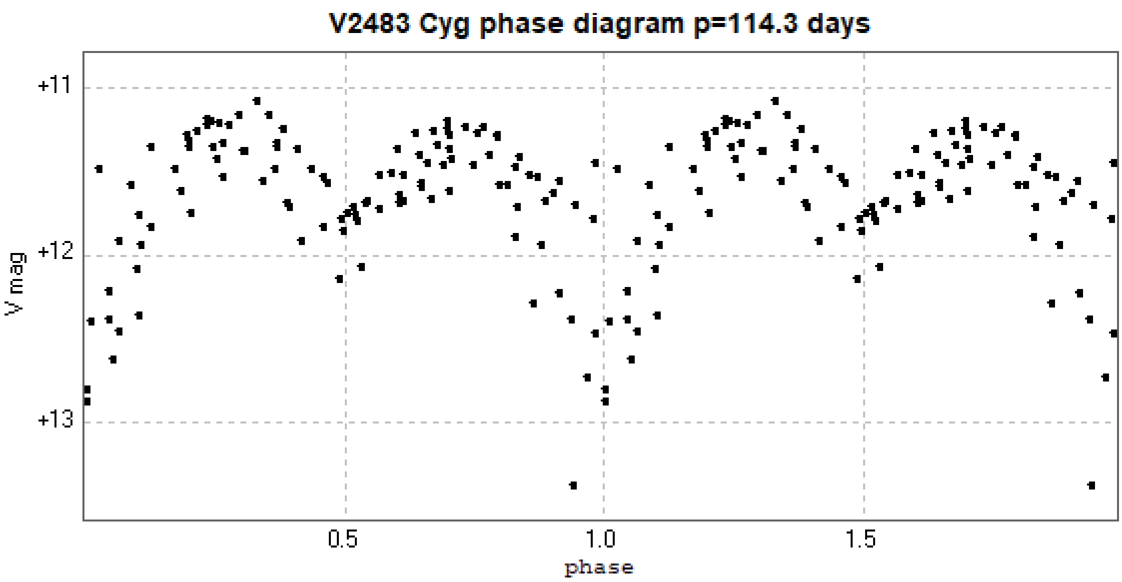




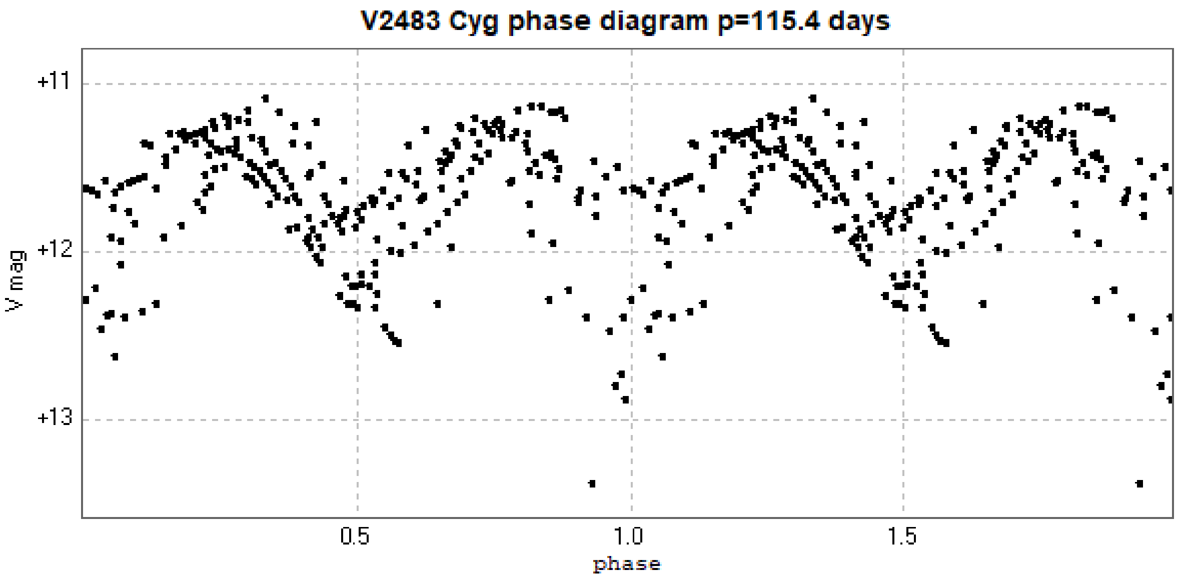
Using the catalogue period of 112.4 days, the phase diagram appears chaotic. To investigate this, the 111 new observations, made between 2020 February 28 and 2022 October 20, are shown on their own below.



For these more recent observations, the best fit period is 114.3 days, the resulting phase diagram is below.



The best fit period for *all* the above observations is 115.4 days, which generates the following phase diagram.

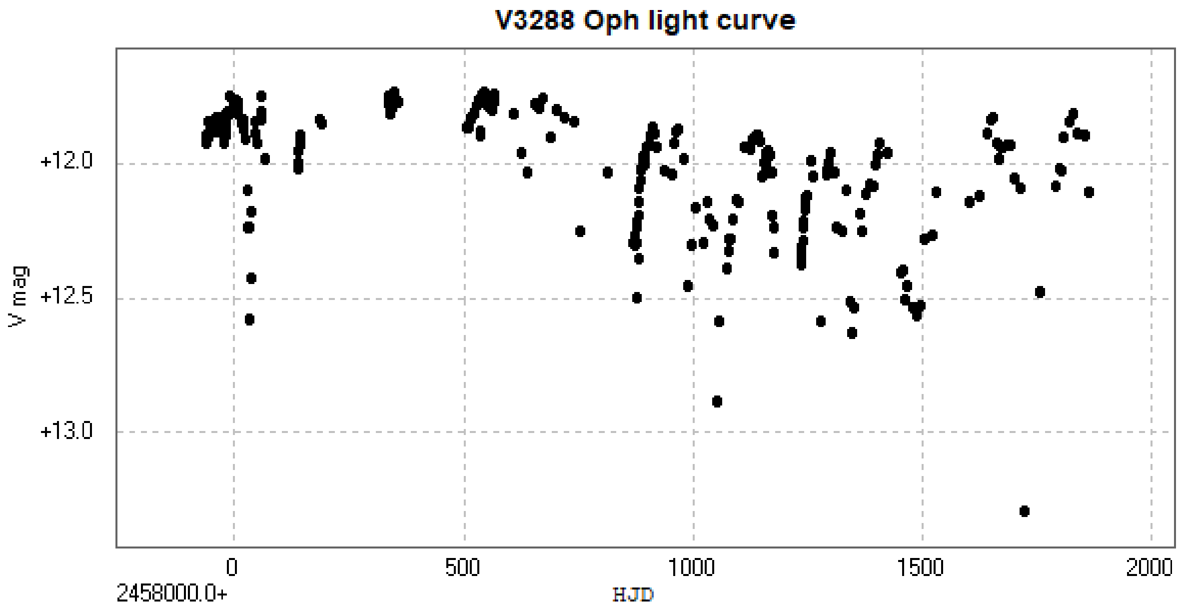


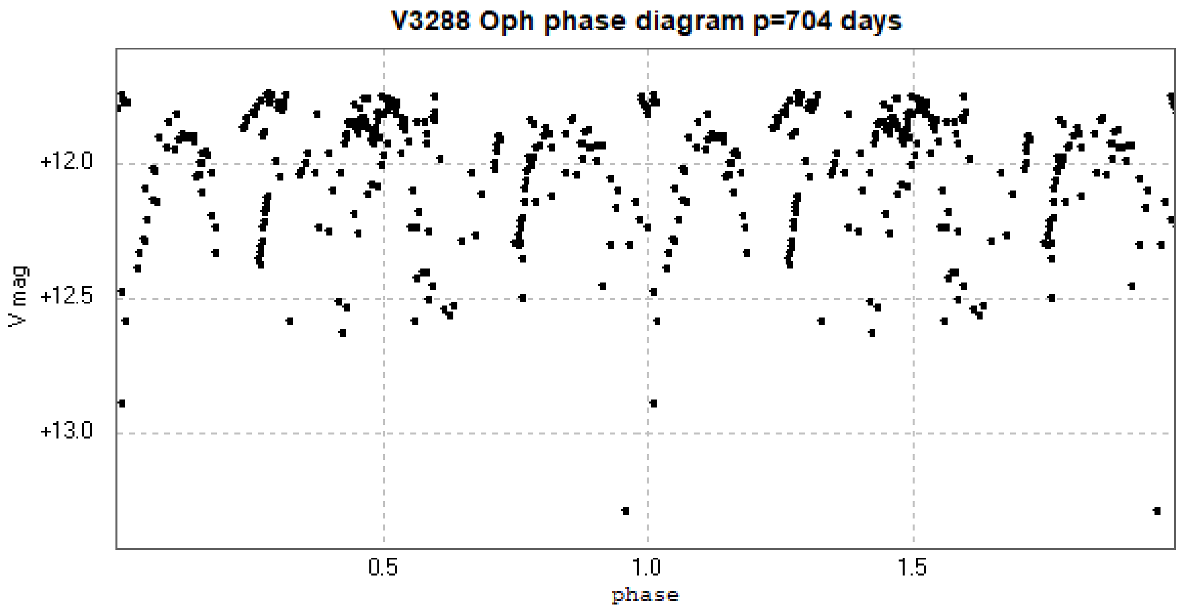
The light curve appears to be *possibly* more consistent with an RV Tauri variable than an EB type. Whatever the type, the period of 112.4 days appears to be in error by 2 or 3 days.

V3288 Ophiuchi

[GCVS type L no period given   AAVSO VSX type EA+ZAND period 704d]

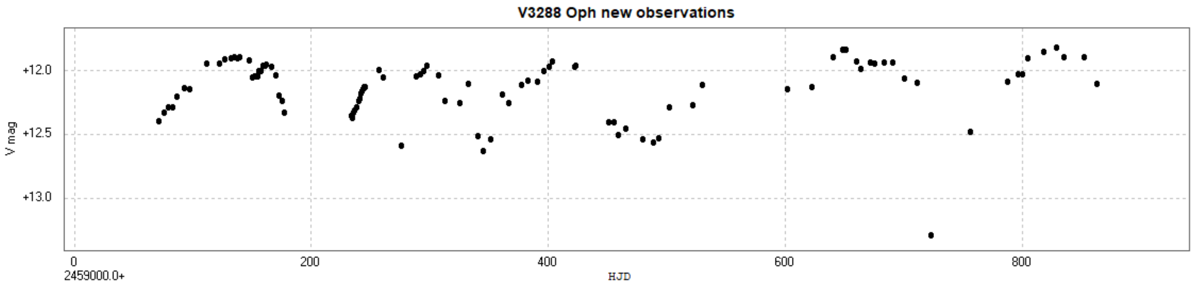
The following light curve and phase diagram were constructed from 265 observations made between 2017 July 5 and 2022 October 10. These include results published in VSSC 185 (September 2020). The new observations show that the variation in brightness from one cycle to the next is continuing.



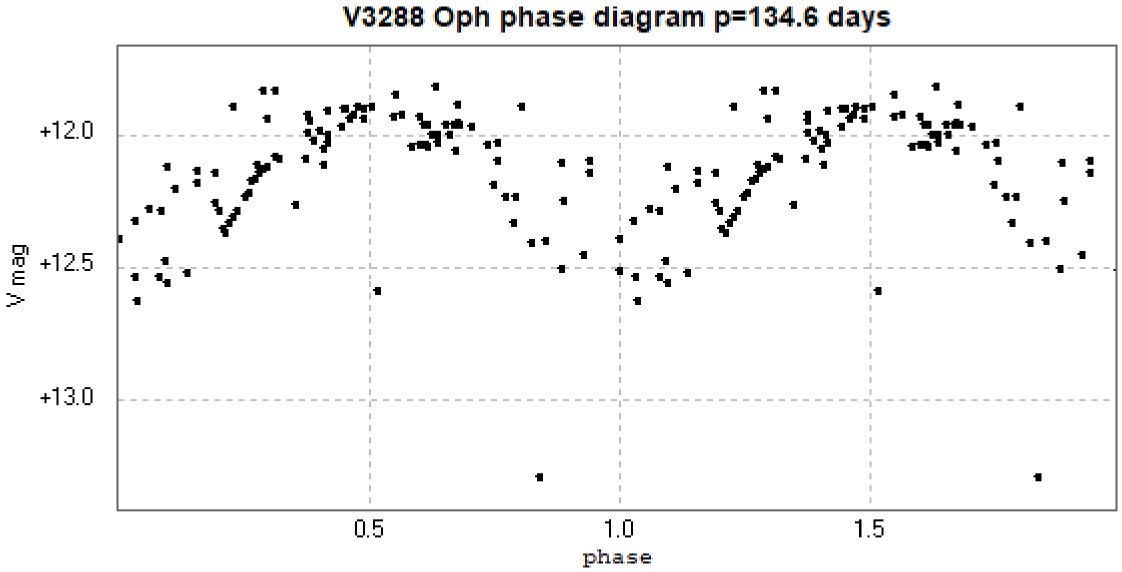


The [AAVSO VSX](#) classifies the system as an EA+ZAND type with a period of 704 days, but the above phase diagram with that period suggests that this period is incorrect.

The 98 new observations, made between 2020 August 9 and 2022 October 10, are shown on their own below.

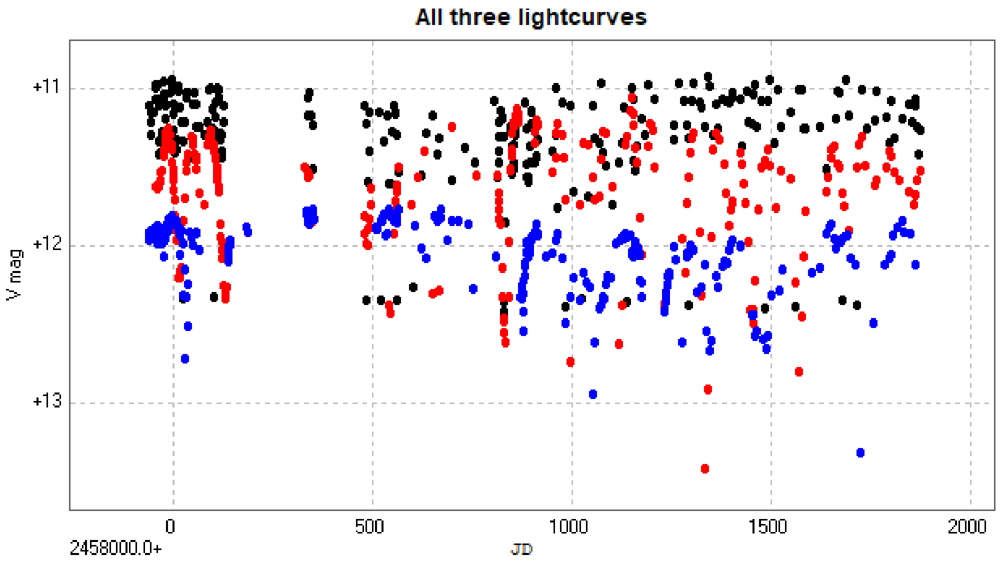


The best fit period for these observations alone is 134.6 days, generating the following phase diagram.



Discussion

All the above light curves show long term variations in their maxima. As a check against some long-term systematic error affecting these results, all three were plotted on the same graph (below); KU Cyg in black, V2483 Cyg in red and V3288 Oph in blue.



Given that there is no apparent consistency between these variations, this would suggest that there is no long-term systematic error affecting them. (At this stage, the near *anti*-phase correlation, particularly between KU Cyg and V3288 Oph, is assumed to be a coincidence and not an effect of the imaging system or photometric methodology. More observations will help check this.)

The above results show the value of observing variables catalogued as eclipsing binaries at all phases when possible. From a visual inspection of the above results.

KU Cyg shows changes over a time of very approximately 1500 days. Variations out of eclipse variations might be due to luminosity changes in an eccentric accretion disc (Otero 2011). This might also explain the flat primary minimum and the continuously variable secondary minimum. Papers about this system include Popper (1964) and Olson, Etzel and Dewey (1995).

V2483 Cyg shows changes over a time of approximately 1000 days. From these observations alone, the light curves and phase diagrams would appear to suggest that V2483 Cyg is an RV Tau type variable rather than an eclipsing binary. These pulsating variables have light curves which can be mistaken for EB type eclipsing binaries, having alternate deep and shallow minima. See e.g., OGLE Atlas of Variable Star Light Curves.

V3288 Oph is more chaotic, but there are some changes over times of anything between 100 and 200 days. The 704 day catalogue period bears no relation to the above observations, that period being the result of only 4(!) observations (Otero). This source also states that variations at maximum, the spectrum and the long period suggest that this is a symbiotic binary system.

All three objects remain in my observing program, and more information can be found on my website. Hopefully, future work might indicate if these changes continue and, if so, whether they have any periodicity to them.

Recent minima of various Eclipsing Binary stars. 5

Tony Vale

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This report lists recent timings of minima of various eclipsing binaries. The observations from which the timings were obtained have all been posted to the BAAVSS photometric database. O-C diagrams for V608 Cas and PV Cas are also included.

Timings:

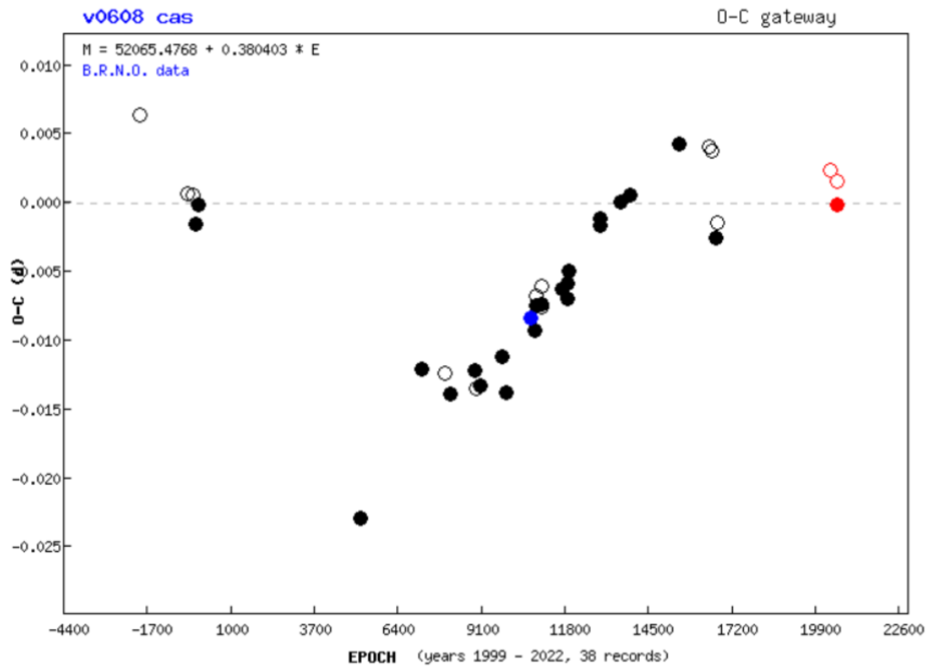
Star	HJD of Min	Filter	Error	Type of Minimum
DL Cep	2459742.51881	V	0.00070	Primary
OO Aql	2459770.45707	V	0.00020	Secondary
SW Lac	2459802.47509	V	0.00060	Secondary
AD And	2459817.51766	V	0.0003	Secondary
V608 Cas	2459833.49798	V	0.0004	Secondary
PV Cas	2459883.39982	V	0.0005	Primary
AD And	2459892.46931	V	0.0004	Primary
CW Cas	2459893.37859	V	0.0003	Primary
DO Cas	2459905.43089	V	0.0004	Primary
CW Cep	2459912.49020	V	0.0007	Secondary
V608 Cas	2459921.37035	V	0.002	Secondary
V608 Cas	2459921.55946	V	0.001	Primary
V765 Cas	2459929.36825	V	0.003	Secondary
AB Cas	2459923.55828	V	0.00064	Primary
PV Cas	2459961.32215	V	0.0005	Secondary
TV Cas	2459962.35154	V	0.0005	Primary
Z Dra	2459965.44010	V	0.0002	Primary

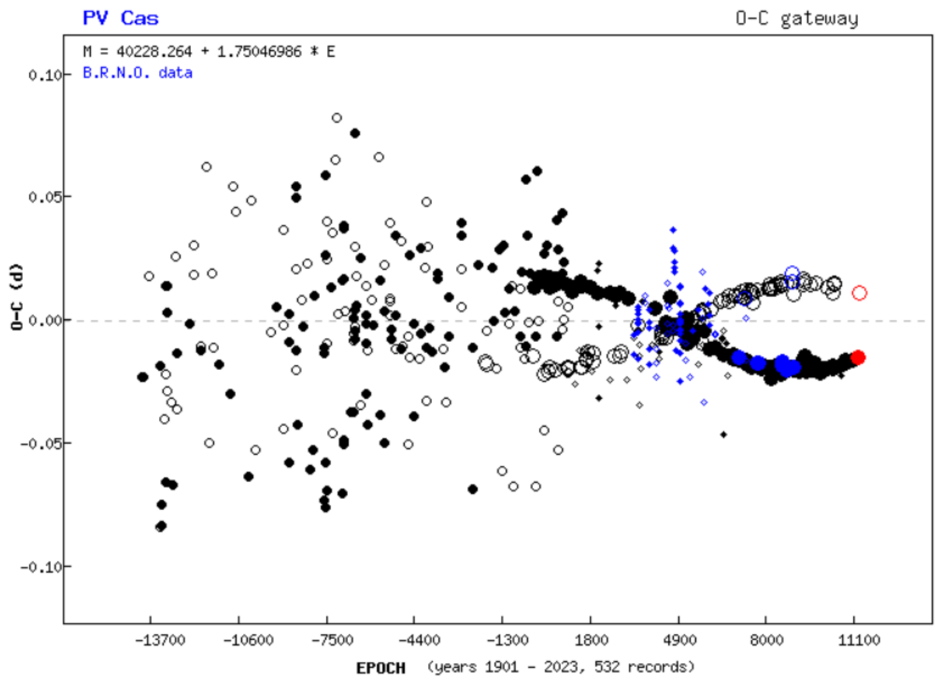
The observations from which these timings were obtained were made from June 2022 to January 2023 using a 102mm refractor and an ASI 183MM-Pro cooled mono CMOS camera and a V band filter. The timings were extracted using Bob Nelson's Minima software.

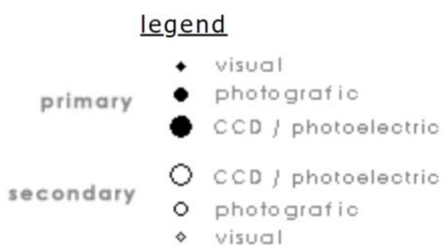
Included above are three observations of V608 Cas which was referenced in an earlier Circular by Des Loughney (Circular 192, p36) and was the subject of a paper by Chris Lloyd (Circular 193, p30). These timings have been plotted on the O-C Gateway of the Czech Astronomical Society (see below) and appear consistent with a sinusoidal solution. Also shown is the O-C diagram of the primary and secondary timings of PV Cas showing interesting apsidal motion. In both diagrams, the primaries are shown as red, filled circles and the secondaries as red open circles.

Editor's Note. This is number 5 in a series of reports from Tony Vale. As this series has only been numbered from this issue, the previous four can be found in the following circulars…

1: VSSC 187, VSSC 188, VSSC 191 & VSSC 193


v0608 cas
O-C gateway
M = 52065.4768 + 0.380403 * E
B.R.N.O. data
O-C (d)
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-4400
-1700
1000
3700
6400
9100
11800
14500
17200
19900
22600
EPOCH (years 1999 - 2022, 38 records)


PV Cas
O-C gateway
M = 40228.264 + 1.75046986 * E
B.R.N.O. data
O-C (d)
0.10
0.05
0.00
-0.05
-0.10
-13700
-10600
-7500
-4400
-1300
1800
4900
8000
11100
EPOCH (years 1901 - 2023, 532 records)


legend
primary
visual
photografic
CCD / photoelectric
secondary
CCD / photoelectric
photografic
visual

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Please make sure of your spelling before submitting to the editor. English (not US English) is used throughout this publication.

Articles can be submitted to the editor as text, RTF or MS Word formats. Light curves, images etc. may be submitted in any of the popular formats. Please make the font size for X & Y axes on light curves large enough to be easily read.

Email addresses will be included in each article unless the author specifically requests otherwise.

Deadlines for contributions are the 15th of the month preceding the month of publication. Contributions received after this date may be held over for future circulars. Circulars will be available for download from the BAA and BAAVSS web pages on the 1st day of March, June, September and December.

Deadline for the next VSSC is May 15th, 2023.

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