Newsletter 2020-2

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www.variablestarssouth.org

It was a clear and almost moonless (8%) night at Cerro Tololo in Chile but none of the domes were open. Many such professional observatories around the world have been shut due to the unavailability of staff who are required by their governments to practice social distancing or isolation due to the COVID-19 pandemic. [Image taken from CTIO webcam at http://www.ctio.noao.edu/soar/content/cerro-tololo-outside-webcam-0]

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From the Director - *Mark Blackford*

What a world we now live in! I hope you are all well and finding ways to keep sane while practicing your social distancing. When I wrote this column for the January Newsletter it was with great anticipation of the upcoming VSS Symposium and NACAA conference over the Easter weekend and the RASNZ Centenary Conference in May. Unfortunately COVID-19 put an end to these and most other events around the globe and forced severe restrictions on all our lives. Hopefully by the time the next Newsletter is published we'll be able to see the light at the end of the pandemic tunnel.

No decision had been made as to when and where the NACAA conference will be rescheduled, similarly for the VSS Symposium. Several presentations intended for the symposium will instead be adapted into newsletter articles.

In this issue Roy Axelsen presents results of further testing of his ZWO ASI1600MM Pro Camera for photometry, Tom Richards describes a program he wrote for period change analysis, and Stan Walker discusses long period variables.

We are actively exploring a suggestion by David O'Driscoll to hold one or more short webinars in the coming months using the Zoom video conferencing software.

Despite social distancing restrictions we can still observe variable stars. Unfortunately, at Congarinni Observatory conditions have continued to be very unfavourable. Bushfires over summer gave way to extended periods of rain and cloud on the east coast of Australia. I managed only 15 nights of observing in the last 11 weeks. On the bright side, at least the dams are all full.

I use a 10" Dobsonian for deep sky observing while my photometry telescopes do their thing automatically. After more than a decade of faithful service the laminated particleboard mount finally gave up the ghost so I made a new mount from 19 mm marine ply. To improve the azimuth movement I used a vinyl record between the Teflon pads on the base plate and rocker box base. This is a technique I've used on several previous Dobsonian scopes, usually a record from one of my favourite bands. This time, I broke with tradition and chose "Heavy Weather" by Weather Report, seemed appropriate given conditions in recent months.

Wishing you all clear skies and good health,

Mark Blackford

Zoom into VSS? - *David O'Driscoll*

With the cancellation of NACAA due to the COVID-19 crisis, VSS Symposium 6 was also cancelled. Many of the speakers will be publishing articles in the newsletter based upon their planned presentations. However I have suggested to Mark Blackford that we look at running one or more short seminars via Zoom conferencing over the next couple of months, as I have the technical capability to arrange this. I will post more details to the VSS discussion forum in coming weeks, but can I ask any presenters who planned to be at VSSS6 (and indeed anybody else who was unable to attend) to consider whether they would like to present if such a concept gets off the ground. Stay tuned for more details.

A script to study minima timing variations in EBs - *Tom Richards*

tomprettyhill@gmail.com

Abstract

This paper explores issues of determining and explaining long-term period change (or more accurately minima timing variations, since the latter aren't necessarily brought about by the former) in eclipsing binaries. To do this I have used a code I have written in the statistical scripting language R.

The form of the paper is a narrative of successive issues and problems encountered in developing a minima timing analysis for the eclipsing variable GZ Puppis. This was chosen over the standard scientific report format in order to illustrate and discuss the steps and pitfalls reaching an acceptable result. A report would basically just present the final result, not the journey. (The final result belongs in another paper.)

A PowerPoint presentation accompanies this paper, available on the Variable Stars South website, www.variablestarssouth.org.

Introduction

The aim of this paper is to set out and discuss problems in long-term minima timing analysis, in particular for eclipsing binary stars. Variations in a series of eclipse timings for a binary are revealed by computing the difference between the observed time of minimum eclipse against that calculated from a base linear ephemeris, which defines a fixed orbital period P for the system and one zero epoch (aka time of minimum) E_0. These data are conveniently presented in an *ephemeris diagram*, sometimes called an eclipse timing diagram or (O-C) (Observed – Calculated) diagram. Several examples are displayed in this paper. These diagrams are constructed by calculating the cycle number n of an observed epoch O_n occurring at orbital cycle n using the defining ephemeris (where $n = 0 \equiv E_0$). For that cycle count n the calculated epoch (time of minimum) is $E_n = E_0 + nP$. The ephemeris diagram is then a plot of $(O_n - E_n)$ against n, briefly (O-C). Such diagrams are extremely sensitive to eclipse timing anomalies, many of which are brought about by a change in the period of the eclipsing binary.

Many eclipsers exhibit more or less complex changes in orbital period over a timescale of decades or even shorter. These changes can be due to many processes; some are angular momentum and mass exchange between the stars, loss of mass from the system entirely, and magnetic activity cycles analogous to the sunspot cycle. Other anomalies visible in an ephemeris diagram may not be caused by period change, such as the effect of elliptical orbits exhibiting a rotating major axis; and the presence of other gravitationally bound bodies which may not be bright enough for a photometric signature but change the distance and hence light arrival time of the binary.

To exemplify the issues involved in determining causes of epoch timing anomalies, the binary system GZ Pup was selected; as I had good observational data of mine on it, complex epoch anomalies were evident, and there are sufficient minima data on it in the literature to explore the problem of obtaining a robust characterization of long-term changes in the system.

To assist in exploring these issues, I developed a code in the statistically oriented programming language R (Ihaka & Gentleman, 1996). Essentially GZ Pup was a test-bed for the code, which I am now applying to other systems I'm studying. It is possible, with some difficulty, to carry out many of the same analyses in Microsoft Excel or Libre Office Sheets; but the process is tedious, inelegant, and error-prone. It also lacks the easy application to other binary systems that a program provides.

GZ Pup is described in VSX (Watson et al. 2014) as an EW/KW system (briefly, an eclipsing binary with a late-type spectrum, and the stars in contact or nearly so, with a common photosphere). The 1953 discovery ephemeris in the GCVS (Samus et al. 2017), which is used as the base ephemeris for the present study, is

$$P = 0.320274 \text{ d}$$
$$E_0 = \text{HJD } 2434398.437$$

Figure 1 shows the phased V-band light curve for the system, obtained in the 2019-20 observing season as described below. The primary (deeper) minimum is on the left of the curve.

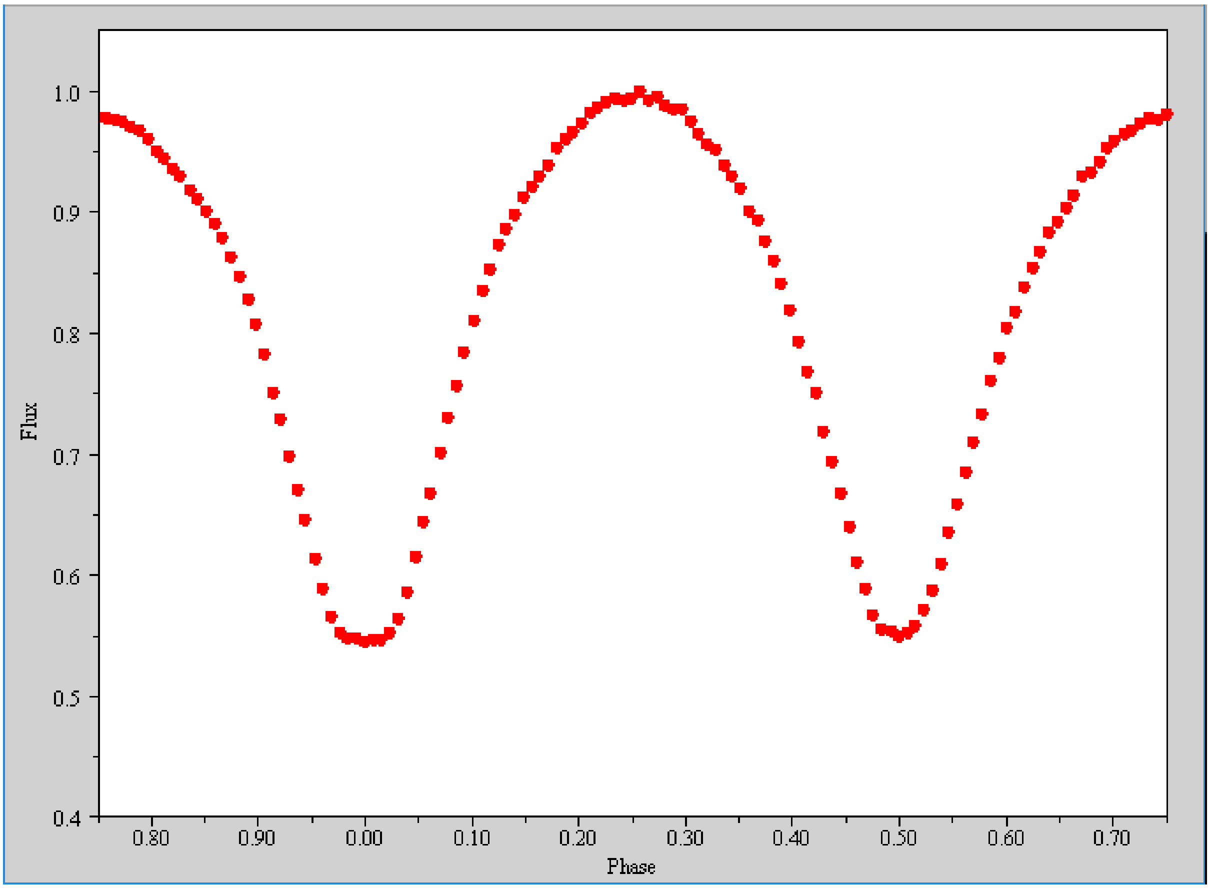

Figure 1. *Differential V flux curve of GZ Pup phased on P = 0.320239 d, showing binned data from the 2019-20 season. The primary minimum is at phase 0.0. (Pretty Hill Observatory)*

Observations and minima timing — a linear fit

I obtained twenty minima timings over five observing seasons, shown in the first three columns of Table 1. The observed minima (first column in Table 1) were compared with the calculated minima as described above to derive O-C estimates (last three columns of Table 1) from which ephemeris anomalies can be studied.

Table 1. *Minima estimates (Pretty Hill Observatory, 2014-2020)*

HJD of min	HJD error (d)	Eclipse Type	Cycle	O-C (d)	O-C error (d)
2457019.100988	0.0009	P	70629	0.03164	0.0009
2457374.111304	0.0011	S	71737.5	0.01823	0.0011
2457380.036532	0.0008	P	71756	0.01839	0.0008
2457380.195861	0.0011	S	71756.5	0.01758	0.0011
2457386.121639	0.0010	P	71775	0.01829	0.0010
2457403.095828	0.0010	P	71828	0.01796	0.0010
2458113.120206	0.0007	P	74045	-0.00512	0.0007
2458119.045680	0.0012	S	74063.5	-0.00472	0.0012
2458146.106706	0.0009	P	74148	-0.00685	0.0009
2458147.067502	0.0009	P	74151	-0.00687	0.0009
2458484.142730	0.0015	S	75203.5	-0.02003	0.0015
2458487.024818	0.0016	S	75212.5	-0.02041	0.0016
2458487.185398	0.0011	P	75213	-0.01996	0.0011

2458513.126734	0.0011	P	75294	-0.02082	0.0011
2458842.035467	0.0008	P	76321	-0.03349	0.0008
2458850.041663	0.00082	P	76346	-0.03414	0.0008
2458861.090585	0.00115	S	76380.5	-0.03467	0.0012
2458879.024945	0.00127	S	76436.5	-0.03566	0.0013
2458883.989423	0.00097	P	76452	-0.03543	0.0010
2458884.149254	0.0010	S	76452.5	-0.03573	0.0010

The O-C data were then plotted using the R script against cycle number (Figure 2). These yield a sensibly linear regression line, giving confidence they indicate a constant period over this time interval.

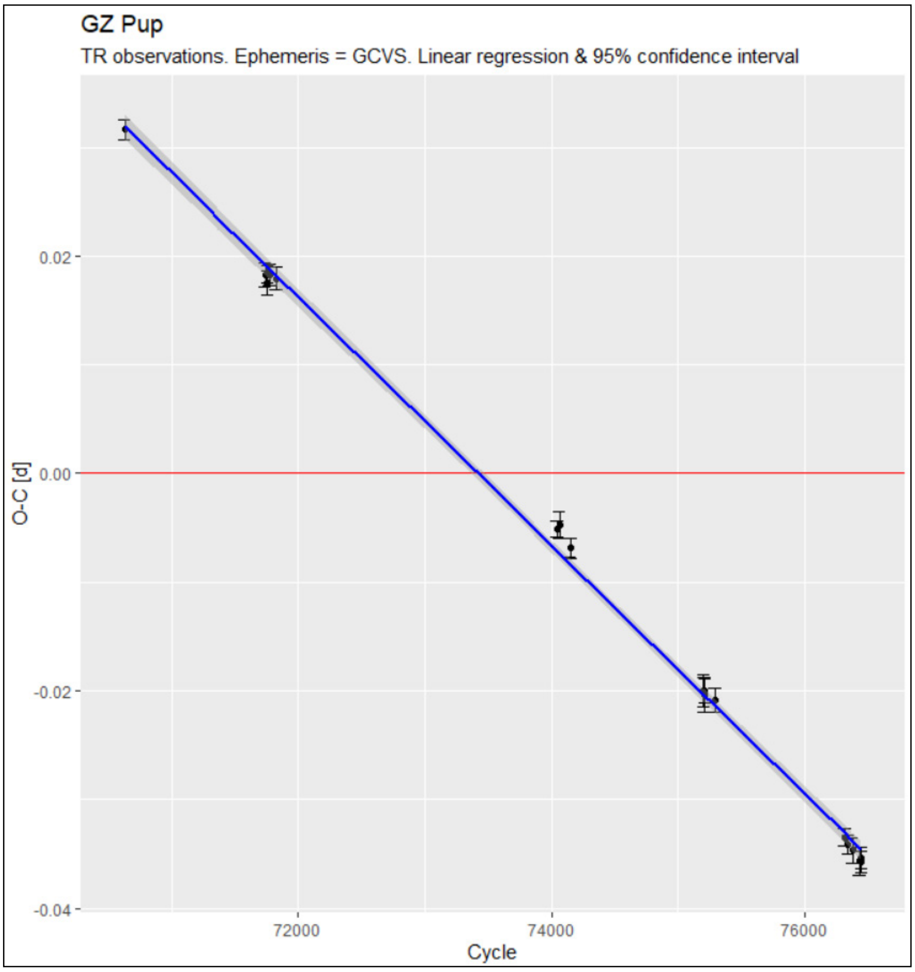

Figure 2. *Eclipse timing diagram of the O-C data in Table 1.*

The linear ephemeris from this fit (blue line) gives a high degree of confidence in the fit. Here's some of the summary output from the script:

E = HJD 2434399.275970 +/- 0.00996054

P = 0.3202626 +/- 1.340847e-07 d

Residual standard error: 0.001165 on 18 degrees of freedom

Multiple R-squared: 0.9975, Adjusted R-squared: 0.9974

The low errors on the best-fit epoch and period, and the low residuals in the fit, show that fit is an excellent model of the period behavior of the system. Moreover the coefficient of determination R^2 is effectively at the perfect value of 1.0.

The downwards slope of the regression line shows that the period derived from the Table 1 data differs from that given in GCVS, whose predictions lie along the red line at O-C = 0.

So it seems a correction to the GCVS period is in order. However, just to show that the statistics on a sample may not generalize well, Figure 3 shows what happens if we add the GCVS E_0 to the minima data used in Figure 2.

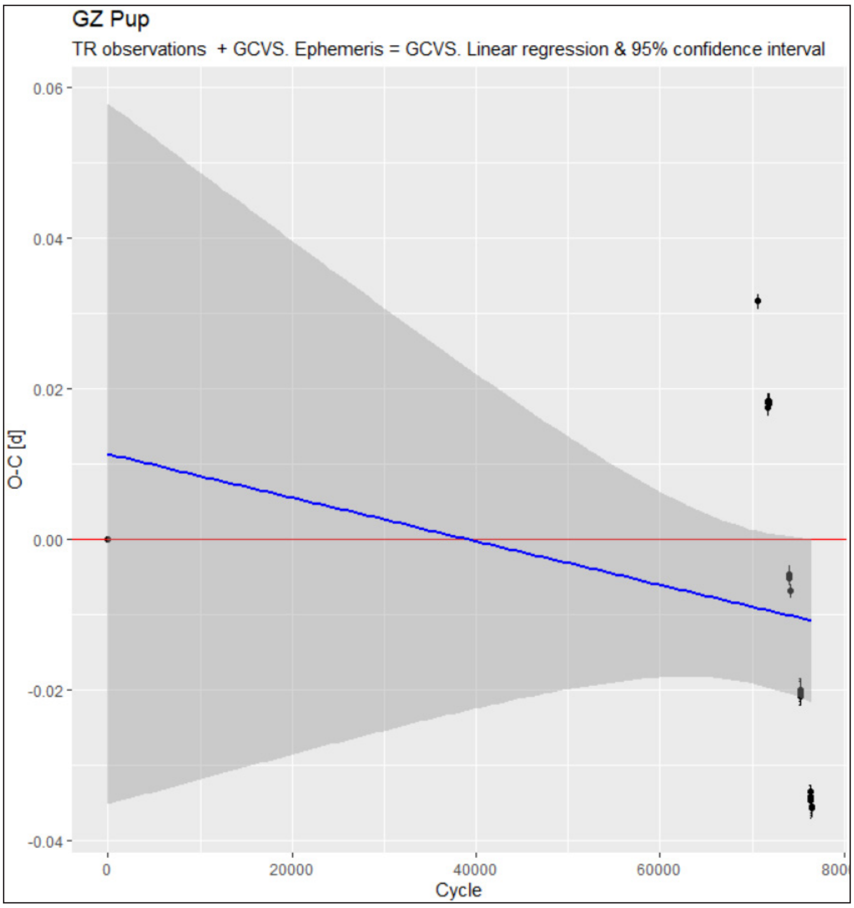

Figure 3. *Ephemeris diagram using the O-C data in Table 1 plus the GCVS mimimum. The grey band shows the 95% confidence interval.*

This time, the results are awful. The Pretty Hill data lie way off the regression line, as does the GCVS data point at cycle 0. The 95% confidence band is ~0.1 d wide at the GCVS data point, an error that is simply not believable. The 95% confidence band in Figure 2 by comparison is scarcely visible. And the Adjusted R^2 drops to 0.005 – so London to a brick the alternative hypothesis of the GCVS red line remains acceptable. But we can't leave it at that: the Pretty Hill data still needs explaining.

Constant period change — parabolic fit

So how to accommodate the Pretty Hill data? Maybe the answer is there's been a constant level of period change over this whole time period. So, in the script, a search was made on top of that poor linear fit for a quadratic fit – which represents a constant period change. The result is in Figure 4.

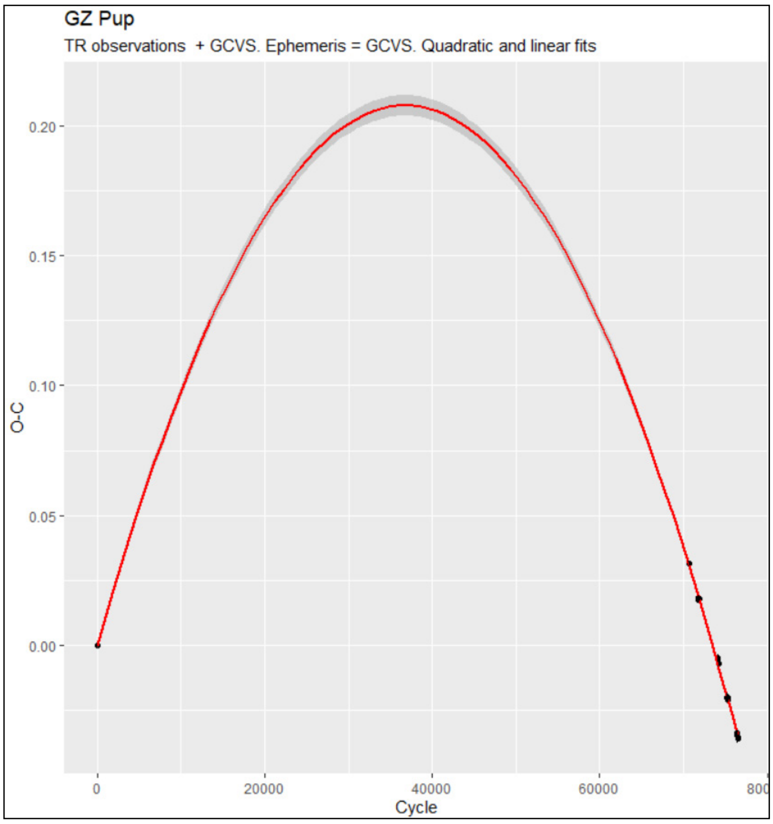

Figure 4. *Quadratic fit on the Pretty Hill and GCVS data.*

This looks excellent, and the script's summary output agrees:

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-4.479e-06	8.550e-04	-0.005	0.996
Cycle	1.132e-05	1.024e-07	110.494	<2e-16 ***
cycle_sq	-1.540e-10	1.350e-12	-114.067	<2e-16 ***

Residual standard error: 0.000855 on 18 degrees of freedom

Multiple R-squared: 0.9987, Adjusted R-squared: 0.9985

Astrophysical summary

E = HJD 2434398.436996 +/- 0.000855

P0 = 0.3202853 +/- 1.02e-07 [d] at E

Period change:

delta_P = -3.08e-10 d/cycle

Pdot = -9.62e-10

Pdot' = -4.07e-12 sec/yr

On the minima data used, the period change represented by the parabola is the best hypothesis. But like any hypothesis it is subject to testing by further data. In this case we need some other epoch data in the interval between the GCVS point in 1953 and the Pretty Hill data from 2014 onwards. Or, a few more years of minima data in future. Are there such data in this case, or must we wait?

The problem facing southern-hemisphere research in this field is that most eclipsing binaries listed in the GCVS south of say -30° have *no* minima timing data since the original discovery report, which may be 50-100 years old. A binary can have gone through considerable evolutionary non-evolutionary changes in that time. But in such cases the best that observers and analysts can do in the Southern Eclipsing Binary project of Variable Stars South is to record minima times year by year in the hope of developing a pattern. That pattern may simply confirm the original discovery ephemeris — or often not, as here.

Third-party data and a third body

In the case of GZ Pup there are some intervening epoch data, from (Pilecki et al 2007) which is used as the VSX ephemeris, (Kreiner 2004), (Pavlov et al, 2016) and (Sobotka 2007).

In addition ASAS3 (Pojmanski 2002) provides a resource of photometric data for the years 2001-2009. ASAS3 data can be problematic because it is not only very noisy but also of low and irregular cadence (usually 3 days when in season, at best). Consequently a phased light curve derived from such photometry will itself have considerable period error. The final problem is to extract a reliable low-error epoch from such data. In the case of eclipsing binaries, which can be expected to be undergoing period change, an overall ASAS3 ephemeris, however it is derived from the photometric data, will mask any period change over that time. At best it will result in larger ephemeris error terms. The data shown below however include ASAS3 epochs derived (by a procedure that I may report on in future) from four time-separated groups of data as well as from the entire dataset.

To inspect the data from these third-party sources, go to the referenced literature. Also they are not shown by distinctive symbols in the plots below, since the aim is to show how *any* data are handled in the software process and their consequences for minima timing analysis.

Figure 5 shows the addition of these other minima data to the Figure 4 plot. They plainly don't fit it at all, nor could a different parabola be made to include them in a plausible fit.

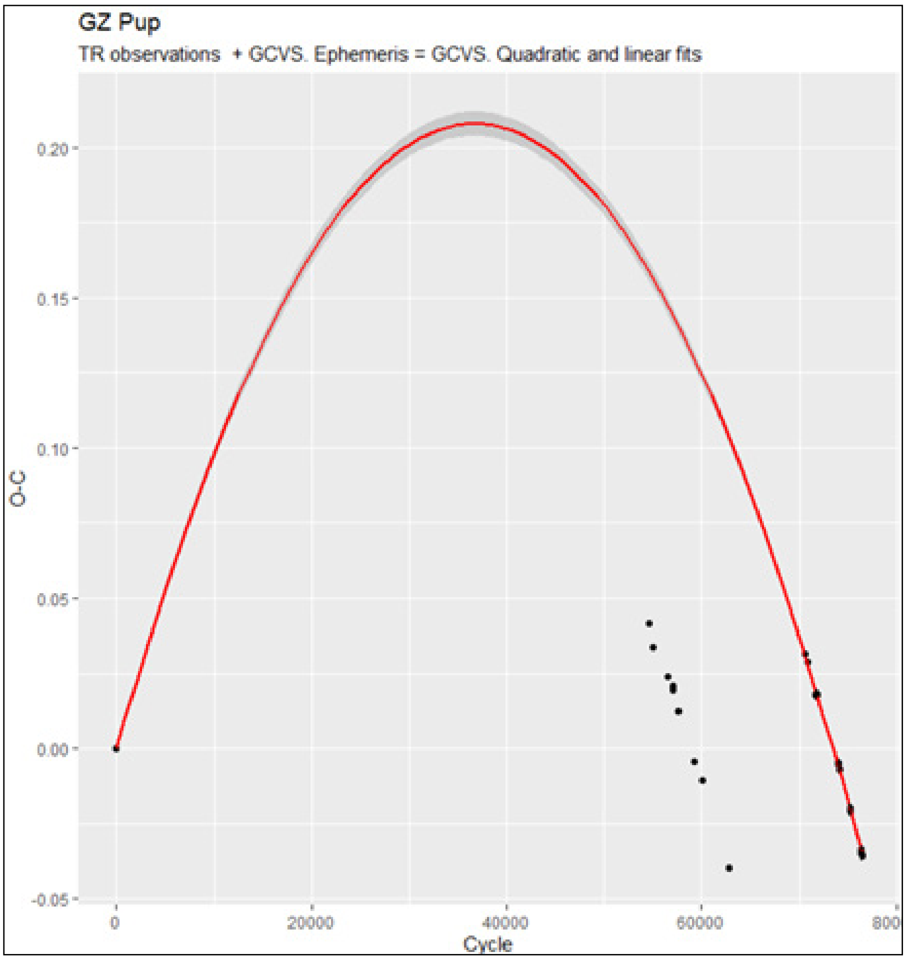

Figure 5. *The parabolic fit diagram from Figure 4 with the other epoch data (see text).*

The lineup of the new data, roughly parallel to the Pretty Hill data, suggests there may be a period oscillation. However fitting a sinusoid to the data introduces a computational problem. So far the two fits (straight-line and parabolic) are examples of linear regression: the fitting of an equation that's linear in its coefficients to the data, i.e. an equation of the form

$$y = \beta_0 + \beta_1 f_1(x) + \beta_2 f_2(x) + \cdots + \beta_n f_n(x)$$

with the coefficients β as the only coefficients in the equation. The regression method then finds the best model for the data – i.e. the values for the coefficients. The goodness of the model is then measured by the coefficient of determination.

However to fit a sinusoid we need terms of the form $\beta\ sin2\pi x/P$ and $\beta\ cos2\pi x/P$ with the additional coefficient P giving the period of the sinusoid, whose value also has to be found. To handle this the code inserts finely spaced range of values for the coefficient P serially into the following equation,

$$y = \beta_0 + \beta_1 x + \beta_2 sin2\pi x/P + \beta_3 cos2\pi x/P$$

For each such value the linear regression procedure is then applied to the equation to find the regression fit and its coefficient of determination recorded . The value of P for which the coefficient of determination is a maximum, and the values of the βs for that fit are then returned as the model. The procedure is surprisingly fast.

For the data displayed in Figure 5 (but with the GCVS data point removed from the calculation) this process delivers the fit illustrated in Figure 6.

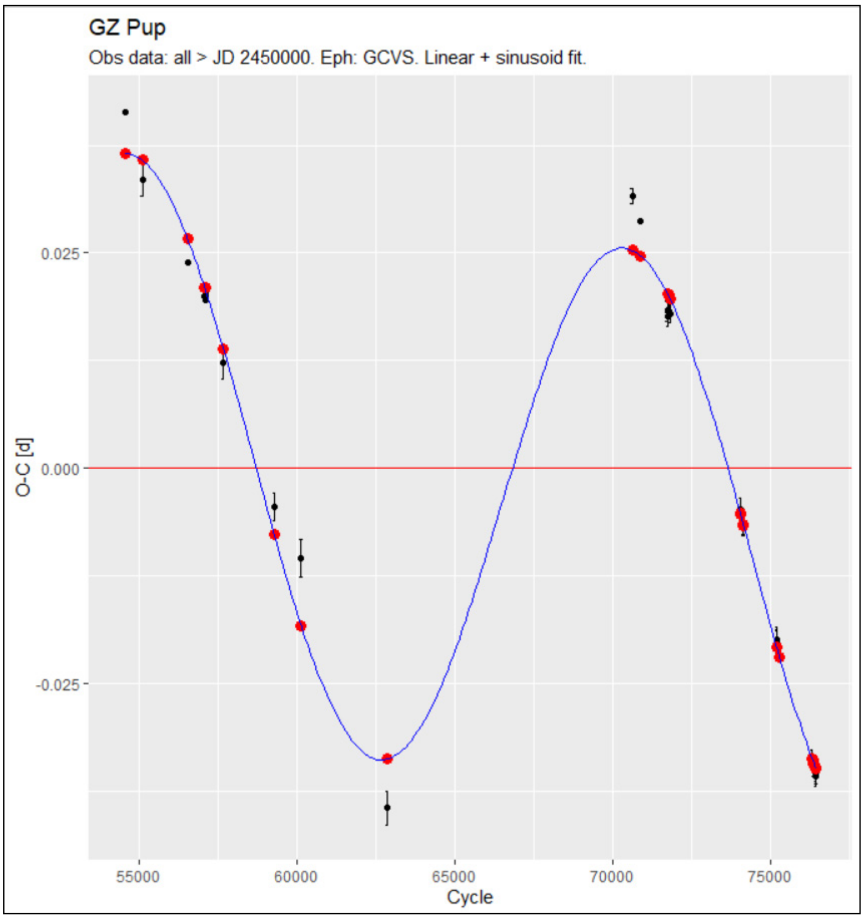

Figure 6. *Sinusoid fit to all the data in Figure 5, but showing only the data points with cycle > 55000 on the GCVS ephemeris. Red dots are fitted values of the same cycle value as the black observation dots*

Note the curve trends downwards with time indicating the GCVS period is too great. That is captured by the β_1 coefficient.

The next question is, how well does this curve fit the GCVS epoch? This is a blind prediction since that point was not in the regression data. If the fit to the GCVS data point is good (which is on the other side of a very large time gap) we can have much confidence in the regression curve. Figure 7 illustrates. (O-C) on the GCVS point is only 0.011 day. Moreover, incorporating the GCVS data point into the regression data makes almost no difference to the equation of the fitted curve.

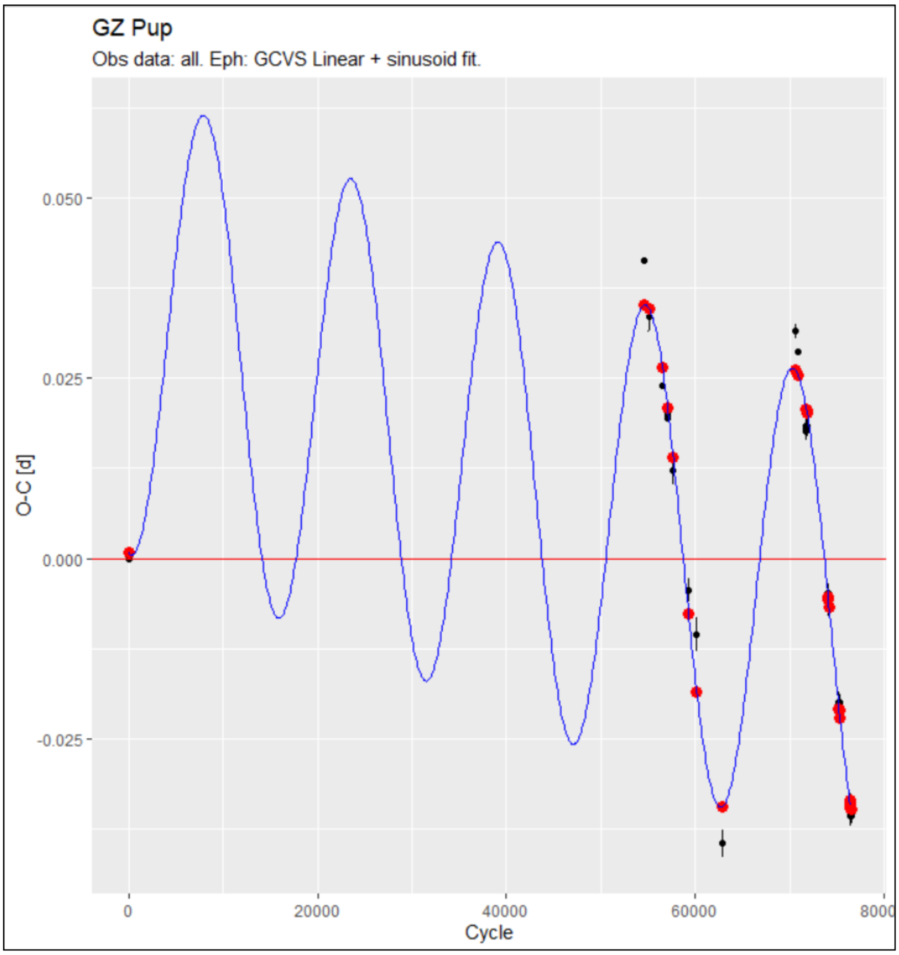

Figure 7. *The sinusoid fit of Figure 6 extended to the GCVS data point, which was not in the fitted data.*

A regular sinusoid like that indicates the presence of the third body in the system, with the binary orbiting the system's barycentre. The code's summary output from the sinusoid fit includes the following (i is the inclination of the orbital axis to line-of-light):

Sinusoid parameters

Period = 15583.89 cycles, Amplitude = 0.0326 d

New ephemeris: E_n = 2434398.470178 + n * -5.597e-07 +

-3.159e-03 * sin(4.032e-04 * n) + -3.245e-02 * cos(4.032e-04 * n)

Astrophysical parameters

Orbital radius, a1 sin i = 5.6442e+00 AU

Orbital period, P = 13.66493 yr

From the photometric data we cannot determine the orbital radii a_1 of the eclipsing pair or a_2 of the third body. However Figure 1 shows the primary eclipse is total, so i is close to 90°. (Subsequent modelling puts it at 84°.) If we assume the three-body system is flat, i.e. take the plane of the system as the plane of the binary, then a_1 = 5.613 AU. That's about as far as one can take the system's parameters. Without double-lined spectroscopic data the system's masses or even mass ratios cannot be determined. (Subsequent modelling in Binary Maker 3 (Bradstreet & Steelman, 2002) shows no evidence of a third light, so at present all that can be said is the third body is either a very faint star (~< 5% of the binary's flux) or a planet.

The code's summary output from the fit in Figures 6 and 7 includes a correction to the GCVS linear period. It shows no sign of linear period change, or apsidal motion (orbital eccentricity in the total system or in the binary). Nor is there any indication of a fourth body. The code can test for all of those, but those tests are not included in this article. The residuals from the Figure 7 fit, which are very small, show no obvious structure (Figure 8) supporting those null conclusions. The five data points with the largest error bars are from the grouped-data and all-data epochs derived from ASAS3 data, as discussed earlier.

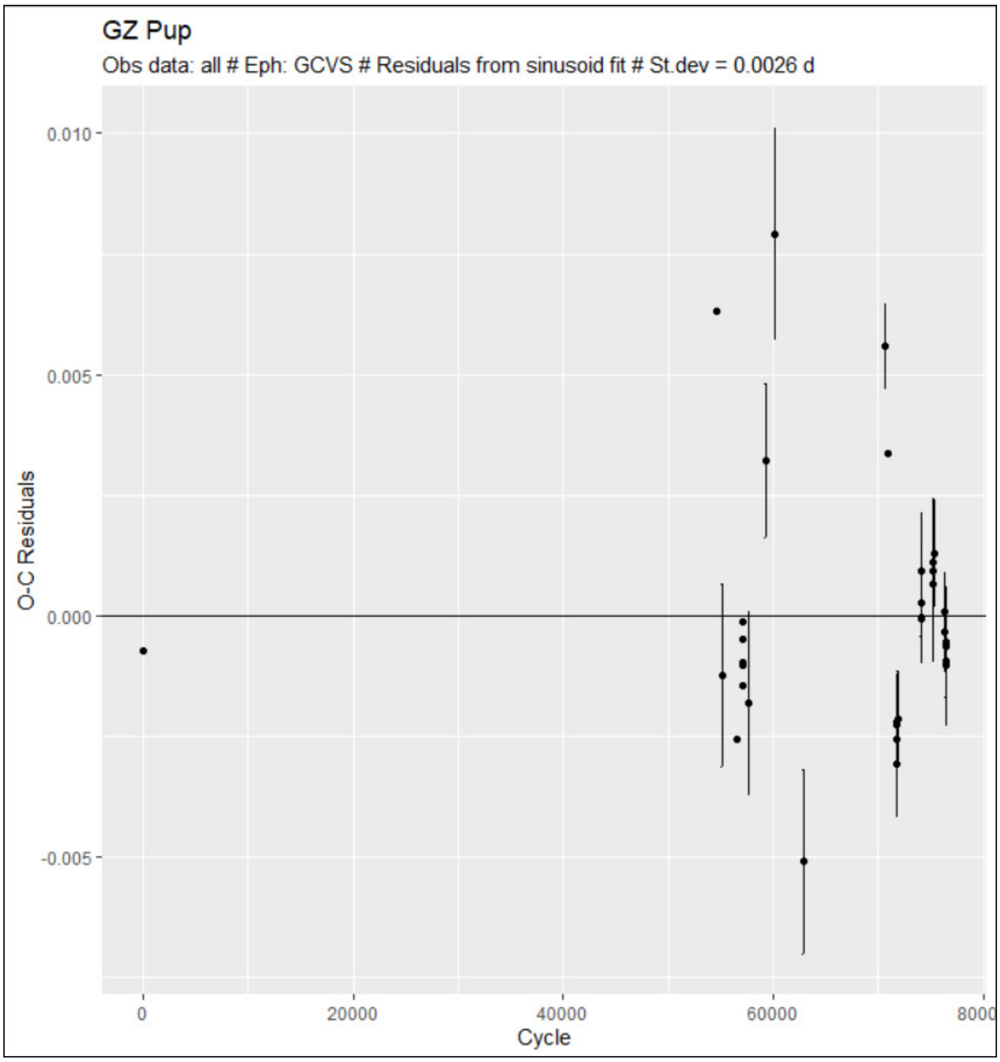

Figure 8. *Residuals from the Figure 7 fit, also showing error bars where known.*

Conclusion

An R code has been used to investigate minima timing anomalies in the GZ Pup system. The process demonstrated that a plausible model for linear period change (visualized as a parabola) had to be rejected when other available minima data were introduced. A sinusoidal model was found that fitted closely all available data including the original (1953) discovery epoch. That model also produced a linear period different from the discovery period, but did not show any period change.

The model also showed that the period of the sinusoid could be attributed to a third body gravitationally bound with the binary. The period and orbital radii (*a* sin *i*) of the three-body system were derived.

Investigations with the code did not provide evidence of a fourth body or orbital eccentricity. The code can be used to investigate those features of the system however.

This study does not make use of error-bar weighting, because too many data points are supplied without uncertainties – a pervasive problem in minima analysis, It is also possible to use the code to assess the quality of minima data from one source — the ASAS3 data above are a case in point.

Any such model fit as the ones shown above, no matter how good its coefficient of determination, is always subject to testing by further epoch data (as was illustrated in Figure 5). A high coefficient of determination is a necessary, but far from sufficient, condition for an acceptable model.

The problem of obtaining adequate epoch data is more acute for stars with little or no minima data since discovery. More will be gathered at Pretty Hill Observatory in the next two or three seasons which should show if the minimum of the fitted curve is reached and turning.

The progress of this study, as narrated though this article, shows clearly how the best model one can make of minima timing data is always hypothetical, as are the astrophysical deductions from the model. The currently best model stands to be confirmed, rejected or modified by further data. That is simply something one must live with in this field — all one can do is demonstrate the hypothesis is the best available *so far*.

Acknowledgements

This study, and the development of the R code that made it possible, was inspired by Grant Foster's excellent book *Analyzing Light Curves – A Practical Guide.*(Lulu, 2010, see www.lulu.com). The book investigates the statistical issues involved in analysis of light curves of most types of variables, using R to show how it's done.

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Eta Carinae photometric campaign: 2019+2021: the first year – *Mark Blackford*

(markgblackford@outlook.com)

This project was introduced in the April 2019 VSS newsletter so I thought it appropriate to summarise the first year of observations. A small group of dedicated photometrists have contributed valuable data in the lead up to periastron of the binary's 2023 day orbit on February 17th 2020 and in the following weeks.

Steve Kerr (observing from near Rockhampton, Qld) used a Meade DSI Pro II and a Johnson V filter on a Meade 12" SCT with an f/6.3 focal reducer (Figure 1). A two-hole aperture mask allowed exposures of a few seconds. Steve captured 60 images then produced 4 average stacks (each of 15 images) which he emailed to me to do the photometry.

Figure 1. *Steve Kerr's photometry setup.*

During 2019 I used an Atik One 6.0 CCD camera and Johnson V filter on an 80 mm f6 refractor stopped down to either 50 mm or 33 mm. Like Steve, I recorded 60 images then made 4 average stacks. Unfortunately the mount became unreliable late in the year so in 2020 I started using an SBIG STT-3200ME CCD camera and Johnson V filter on a 14" f8 Ritchey Chretien telescope with a two-hole aperture mask. With this setup I recorded 120 images each session from which 4 average stacks were made.

Giorgio Di Scala was also monitoring eta Car up until May 26th 2019 however I have not seen any later observations in the AAVSO International Database. I have not included Giorgio's observations in this summary.

Dave Blane (Henley on Klip, Gauteng, South Africa) used a Canon 1300D DSLR camera on a 150 mm f5 refractor stopped down to 100 mm. Exposures were 6 seconds at ISO100 with ten images recorded for each observation. Dave determined the magnitude of eta Car from the green channels of the DSLR RAW images and submitted these as TG (tri-colour green) magnitudes to the AAVSO's International Database. These are not directly comparable with Johnson V magnitudes due to the different spectral response of the DSLR sensor. His TG light curve does show the same general features as the V light curves from Steve and I (Figure 2). However there were significant zero point offsets between each observer's data sets. We shouldn't be surprised by this as no attempt was made to transform measured magnitudes to a standard system.

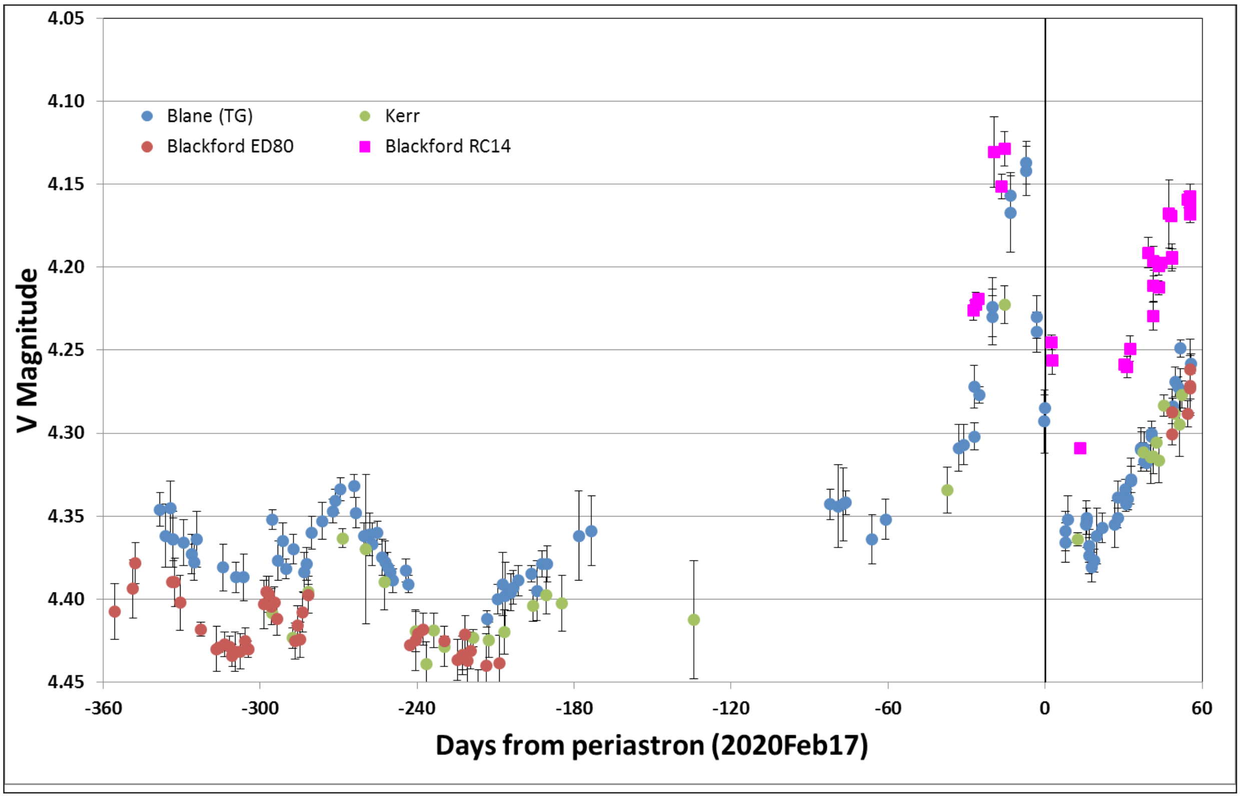

Figure 2. *Observations of eta Carinae recorded between February 26th, 2019 and April 12th 2020. Periastron is indicated by the vertical line at day zero on the x-axis.*

The La Plata Observatory in Argentina conducted a long term monitoring programme from January 2003 through to September 2014 and then resumed again from January through May 2017. The very old 80 cm telescope developed problems and the eta Car campaign started in 2003 was discontinued. This was the reason Augusto Damineli reached out to Variable Stars South to continue monitoring eta Car in the lead up to the 2020 periastron passage and beyond.

Zero point corrections were applied to align our new observations with the La Plata system and the resulting combined light curve is shown in Figure 3. Steve's observations were adjusted by -0.060 mag, my ED80 observations by -0.070 mag and my RC14 observations by +0.036 mag.

Augusto pointed out that zero point correction of Dave's TG magnitudes could not be completely reliable because of the mismatch between the DSLR G and Johnson V filter passbands. However, as you can see in Figure 3, after a -0.040 mag zero point correction, the TG magnitudes agree with the others to within a few milli-magnitudes.

In a recent email Augusto wrote: "You guys are doing a terrific job! Despite of the covid-19 pandemia, the lightcurve is much better than in the 2014 periastron."

This campaign will continue through until February 2021. If you wish to participate please contact the author and visit the project webpage: https://www.variablestarssouth.org/eta-carinae-photometric-campaign-20192021/.

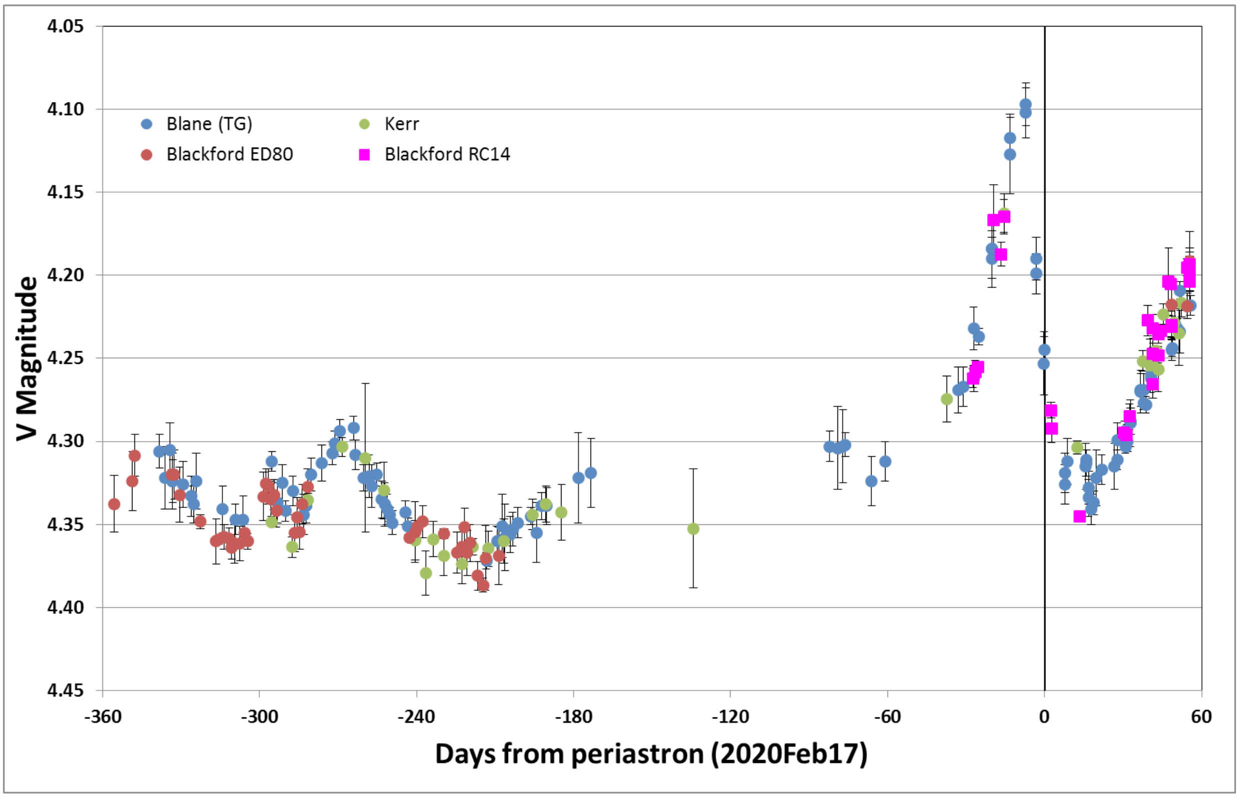

Figure 3. *Combined light curve with zero point corrections applied to align with the La Plata system.*

Photometry with the ZWO ASI1600MM Pro – *Roy Axelsen*

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A short report on the linearity and precision of this camera was published by the author in the VSS newsletter 2019-4 of October last year, which described and illustrated that the camera's response is linear until close to saturation, and that photometric precision for appropriate targets is very good. A more detailed paper was on the programme for VSSS6 associated with NACAA in April 2020, but those meetings were cancelled due to regulations in response to the COVID-19 pandemic. This article contains material that would have been presented at VSSS6.

The ZWO ASI1600MM Pro is a cooled monochromatic astronomical camera which has a 17.6 x 13.3 mm sensor with 4656 x 3520 pixels, each 3.8 µm square. In high resolution mode it has 12 bit ADC, which does impose some limitations for photometry in comparison with 16 bit cameras. However, as will be shown below, it is capable of impressive precision when used with small refracting telescopes and bright targets down to 10th magnitude. There is good precision for 11th magnitude targets when multiple magnitude measurements can be averaged. There is very good accuracy for transformed photometry of bright targets.

The ZWO camera has been used by the author with an 80 mm refractor, focal length 600 mm and a 120 mm refractor, focal length of 900 mm, giving a focal ratio of 7.5 for both. The fields of view are 100 x 76 arc min and 67 x 50 arc min, respectively.

The author's personal preferences when imaging for photometry with this camera are:

1. Defocus the images.
2. Use long single exposures.
3. Optimise precision by tuning the length of exposure and the degree of defocus
    a) For frames which are only minimally defocused, the ADUs in the images of brighter stars may be close to or above the top of the linear range of the camera even with short exposures. In this setting precision may be suboptimal within the linear range, even though ADUs may be close to its upper limit.
    b) Therefore, defocus the image further. This allows longer exposures, the capture of more photons, a lower signal/noise ratio and higher precision.
4. Use unity gain (1 e-/ADU) when possible, corresponding to a gain setting of 139 dB units for this camera. Each unit is 0.1 dB.
5. For bright stars, decreasing the gain may be beneficial or necessary (>1 e-/ADU up to the limit for the camera of 5 e-/ADU).

During discussion on the AAVSO Photometry Forum 'CMOS Cameras for Photometry', it was apparent that some experienced CCD photometrists were averse to defocusing images. Photometry of well-focussed images of brighter stars would therefore require the stacking of multiple short exposures or taking averages of the measurements on multiple consecutive images. These are not currently viable options for me, since almost all of my work involves time series photometry on stars with short periods (e.g., delta Scuti variables with periods of only a few hours).

The following describes the various tests performed.

Adjusting the gain to expand dynamic range (longer exposures) for bright stars

The targets were the enigmatic variable FR Cet and a check star. FR Cet varies between 6th and 7th magnitudes and the chosen check star is magnitude 8.8 in V. Three sets of 10 images were taken binned 2x2, with the following settings. For the first set, exposures were 15 seconds, and the gain 1 e-/ADU; second set, exposure 45, gain 2.75 e-/ADU; third set, exposure 120 seconds, gain 5 e-/ADU. In Figure 1, concentrate on the check star light curves, which clearly show progressively improved precision from the first set to the third set of images (upper left panel, upper right panel, bottom panel in that order). In upper left and right panels improvement in the precision of the FR Cet light curve is also evident. In the upper right panel, the dip in the brightness of the variable prior to the meridian flip is an artefact due to saturation.

Slightly more defocus after the meridian flip removed the artefact.

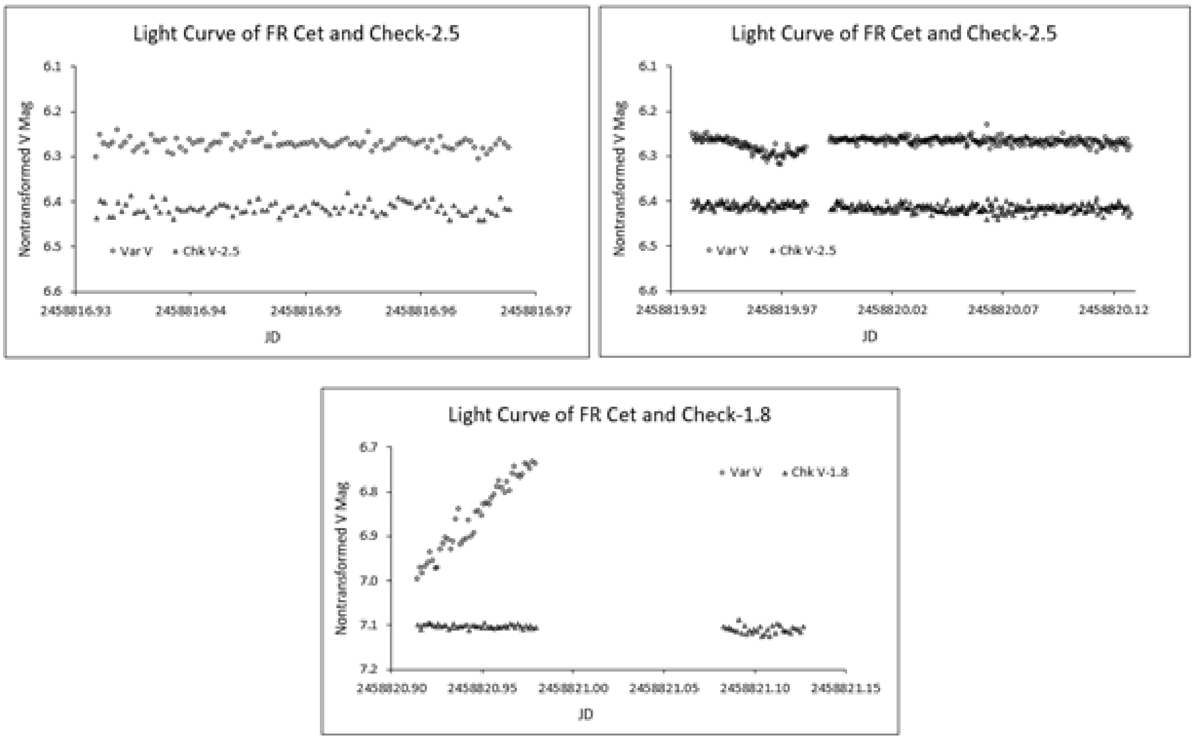

Figure 1. *Light curves of FR Cet and check star on three consecutive nights, showing increased precision for the check star progressing through the following settings: 15 sec exposure, gain 1 e-/ADU (upper left panel); 45 sec exposure, gain 2.75 e-/ADU (upper right panel); 120 sec exposure, gain 5 e-/ADU (lower panel). Precision for the variable is better in the right upper panel than in the left upper panel.*

Thus, for brighter stars, changing the gain from 1 e-/ADU to <1 e-/ADU up to 5 e-/ADU allows longer exposure times, and better precision.

Precision in photometry of 11th magnitude Landolt stars

Four 11th magnitude Landolt stars in one field were imaged through a 120 mm refractor. A series of 10 consecutive unbinned defocused images was taken with an exposure of 180 seconds at unity gain (1 e-/ADU). Differential v (instrumental) magnitudes were calculated for pairs of stars. The results are graphed in Figure 2, and listed in Table 1.

It is clear from the graph that the precision would not be optimal for time series photometry but would be acceptable for calculating averages of multiple magnitude determinations.

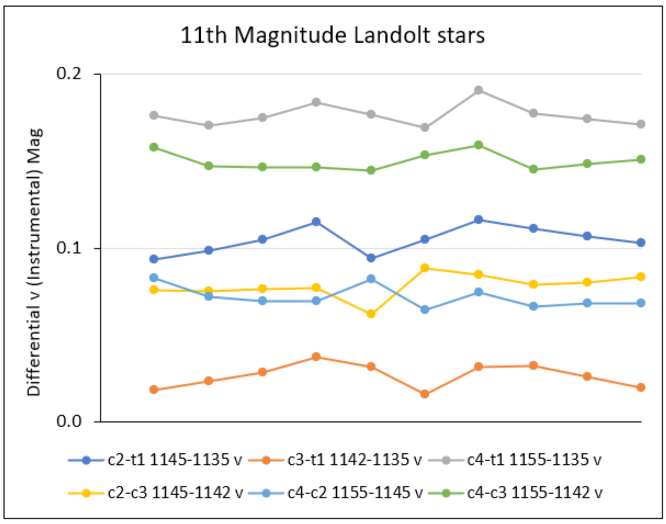

Figure 2. *Differential magnitudes of pairs of 11th magnitude Landolt stars. The labels in the legend (t1, c2, c3 etc.) are those assigned by AstroimageJ, the software used for aperture photometry. The other numbers (1145, 1135 etc.) designate catalogue magnitudes of the stars in V. For example 1145 means 11.45.*

	c2-t1 1145-1135 v	c3-t1 1142-1135 v	c4-t1 1155-1135 v	c2-c3 1145-1142 v	c4-c2 1155-1145 v	c4-c3 1155-1142 v
	0.094	0.018	0.176	0.075	0.082	0.158
	0.098	0.023	0.171	0.075	0.072	0.147
	0.105	0.029	0.175	0.076	0.070	0.146
	0.115	0.037	0.184	0.077	0.069	0.147
	0.094	0.032	0.176	0.062	0.082	0.144
	0.105	0.016	0.169	0.089	0.065	0.153
	0.116	0.032	0.191	0.084	0.075	0.159
	0.111	0.032	0.177	0.079	0.067	0.145
	0.106	0.026	0.174	0.080	0.068	0.148
	0.103	0.020	0.171	0.083	0.068	0.151
SD	**0.008**	**0.007**	**0.007**	**0.007**	**0.006**	**0.005**

Table 1. *This table lists the differential magnitudes from which Figure 2 were drawn, and the standard deviations.*

Precision in photometry of 10th magnitude Tycho stars

Four 10th magnitude stars in one field were imaged through a 120 mm refractor. A series of 10 consecutive unbinned defocused images was taken with an exposure of 180 seconds at unity gain (1 e-/ADU). Differential v (instrumental) magnitudes were calculated for pairs of stars. The results are graphed in Figure 3 and the statistics are shown in Table 2.

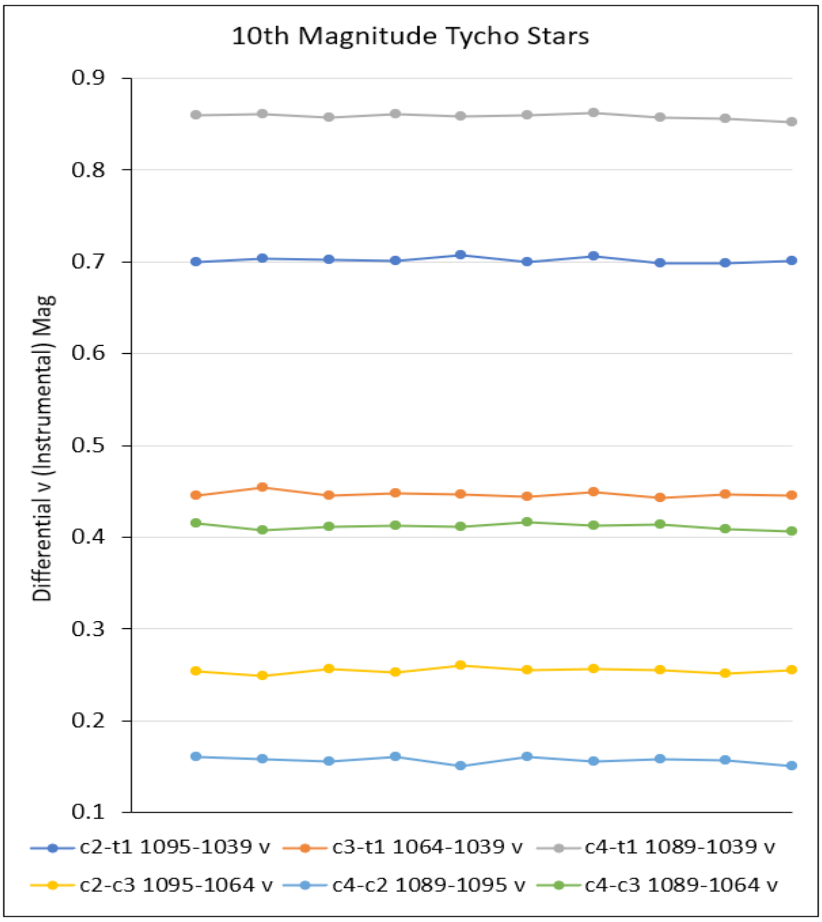

Figure 3. *Differential photometry of pairs of 10th magnitude stars. The labels and the numbers at the bottom of the figure are explained in the legend to Figure 2.*

	c2-t1 1095-1039 v	c3-t1 1064-1039 v	c4-t1 1089-1039 v	c2-c3 1095-1064 v	c4-c2 1089-1095 v	c4-c3 1089-1064 v
	0.699	0.445	0.860	0.254	0.161	0.415
	0.703	0.454	0.861	0.249	0.158	0.408
	0.702	0.446	0.857	0.256	0.155	0.412
	0.701	0.448	0.861	0.253	0.160	0.413
	0.707	0.447	0.858	0.260	0.151	0.411
	0.700	0.444	0.860	0.256	0.160	0.416
	0.706	0.449	0.862	0.257	0.156	0.413
	0.699	0.443	0.858	0.256	0.158	0.414
	0.699	0.447	0.856	0.252	0.157	0.409
	0.702	0.446	0.853	0.256	0.151	0.407
SD	**0.0028**	**0.0029**	**0.0029**	**0.0031**	**0.0035**	**0.0032**

Table 2. *Statistics from the differential photometry of 10th magnitude stars. These are the data from which the graphs in Figure 3 were drawn.*

It is clear from both Figure 3 and Table 2, particularly the standard deviations in the latter, that the photometric precision for 10th magnitude stars is very good.

Accuracy in photometry of 8th and 9th magnitude E Region standard stars

BV transformation coefficients were determined for the ZWO camera and a 120 mm refractor from images of two sets of E Region standard stars, at 4H and 6H RA respectively. Exposures were 75 seconds at unity gain (1 e-/ADU) and binned 2x2. Pairs of stars were selected. One star of each pair was designated the target and the other the comparison star. Transformed V magnitudes and B-V colour indices were determined for each target star. When the target and comparison stars were from the 6H RA E Region standards, the 4H RA transformation coefficients were used, and vice versa. The standard stars are listed in Table 3.

Catalog #	Catalog V	Catalog B-V
E201	8.811	0.122
E204	8.198	0.128
E207	8.947	0.340
E209	8.567	0.316
E217	8.345	0.570
E221	9.680	0.571
E223	8.698	0.850
E234	8.755	1.018
E236	8.022	1.598
E238	9.667	1.436

Catalog #	Catalog V	Catalog B-V
E302	8.277	-0.074
E305	8.050	0.124
E306	8.168	0.184
E316	8.656	0.266
E319	8.986	0.258
E320	8.278	0.408
E339	8.584	1.017
E341	8.678	1.138

Table 3. *E Region standards from 4H RA (left panel) and 6H RA (right panel).*

Transformation plots for the 4H RA standards are shown in Figure 4, and those for the 6H RA standards in Figure 5. The results of the photometry are shown in Tables 4 and 5.

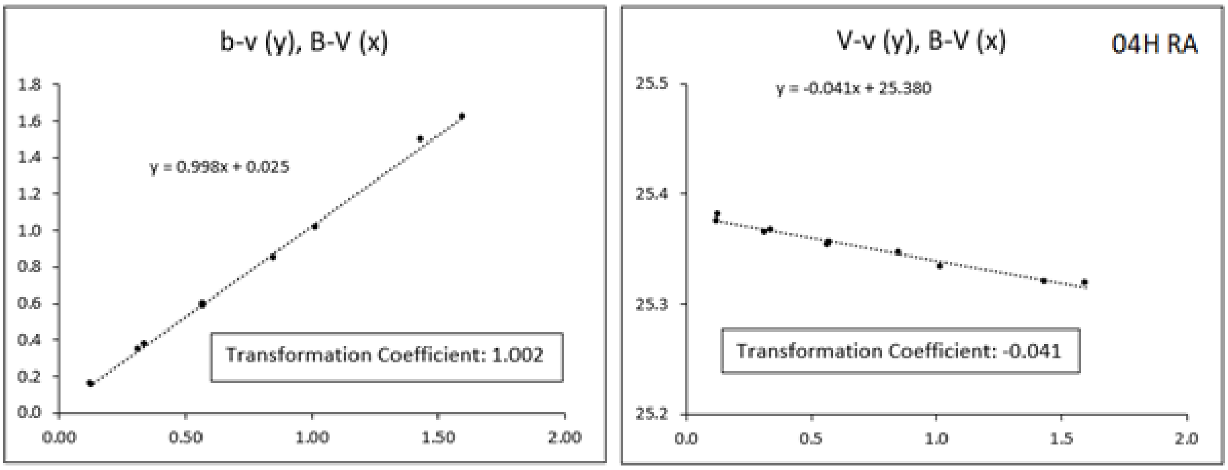

Figure 4. *Transformation coefficient plots from 4H RA E Region standards.*

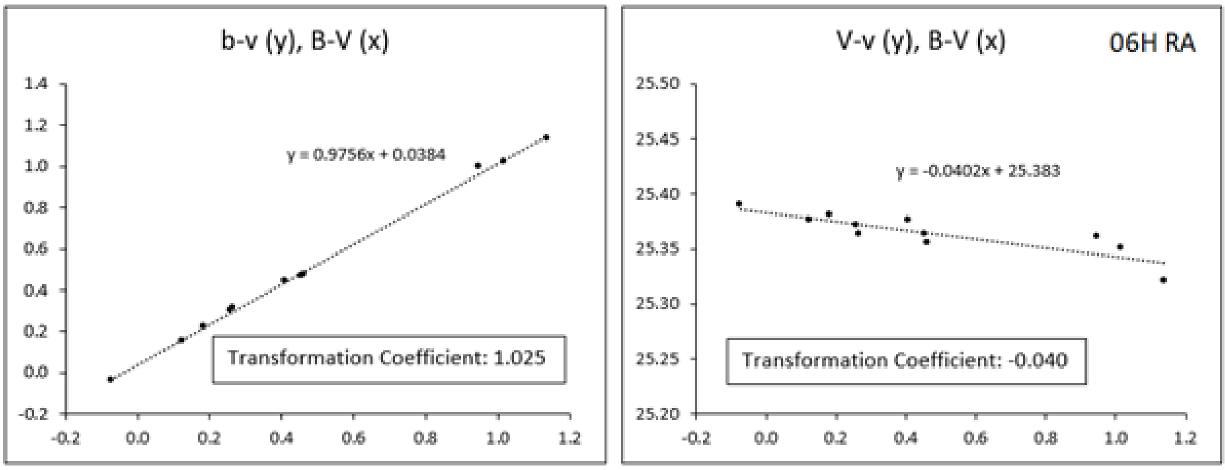

Figure 5. *Transformation coefficient plots from 6H RA E Region standards.*

Target Catalog #	Comp Catalog #	ΔB-V (Target - Comp)	ΔB-V (Target Calc-Catalog)	ΔB (Target Calc-Catalog)	ΔV (Target Calc-Catalog)
E223	E238	-0.586	-0.076	-0.077	0.000
E236	E234	0.580	0.036	0.026	-0.010
E236	E201	1.476	0.019	0.016	-0.003
E236	E204	1.470	0.030	0.031	0.002
E234	E201	0.896	-0.017	-0.010	0.007
E234	E204	0.890	-0.006	0.005	0.011
E201	E204	-0.006	0.011	0.015	0.005
E207	E217	-0.230	0.020	0.016	-0.005
E209	E221	-0.255	-0.003	-0.002	0.000

Table 4. *Results for photometry from E Region standards from 4H RA (using transformation coefficients from 6H RA standards). Each row shows the results from one target star/comparison star pair. The first two columns identify the stars, and the third column shows the difference between the B-V values for each target and comparison star pair. The fourth, fifth and sixth columns show the differences between the calculated and catalogue results for each parameter, as shown in the column headings. The greyed cells in the first results row show the largest differences between the calculated and catalogue values. These are the worst results. All others were substantially better.*

Target Catalog #	Comp Catalog #	ΔB-V (Target - Comp)	ΔB-V (Target Calc-Catalog)	ΔB (Target Calc-Catalog)	ΔV (Target Calc-Catalog)
E305	E341	1.014	0.032	0.017	-0.015
E339	E306	0.833	-0.033	-0.036	-0.003
E339	E320	0.609	-0.029	-0.027	0.001
E339	E302	1.091	-0.027	-0.031	-0.004
E306	E320	-0.224	0.004	0.008	0.004
E306	E302	0.258	0.006	0.005	-0.001
E320	E302	0.482	0.002	-0.004	-0.005
E319	E316	-0.008	-0.003	-0.011	-0.007

Table 5. *Results for photometry from E Region standards from 6H RA (using transformation coefficients from 4H RA standards). For a description of the contents of the columns, see the legend for Table 4.*

The above results show impressive accuracy, particularly for V magnitudes, with 14 of 17 calculated values differing by less than 0.01 from catalogue. The other 3 calculated magnitudes differed from catalogue by 0.01, 0.011 and 0.015. The results for B-V colour indices and B magnitudes are still good (apart from those in the greyed cells in the top results row of Table 4), as seen by scanning down the numbers in the fourth and fifth columns of Tables 4 and 5, but not quite as good as the values for V magnitudes.

Summary

The performance of the ZWO ASI1600MM Pro camera is linear until close to saturation. With appropriate targets (i.e., not too faint) photometric precision and accuracy are very good. It must be emphasized that this is a 12 bit camera, and in the author's opinion it is necessary to defocus the images to optimize precision and accuracy, particular for time series photometry.

Final Comment

As noted earlier in this paper, during discussion of the camera on the AAVSO Forum 'CMOS Cameras for Photometry', the opinion was expressed by experienced CCD photometrists that images should be well focused. One of the reasons given was that a procedure that required tuning the degree of defocus to the brightness of the target would introduce a complexity that novice observers may find intimidating. Another reason was that the procedure for public access robotic systems needed to be as 'algorithmic' as possible, and adding a procedure for variable degrees of defocusing would complicate the setup prior to imaging each target. I am sympathetic to these concerns. They arise only because the camera under discussion has 12 bit ADC. For cameras having greater bit depths, well-focused images could be taken under most circumstances, and the issue of defocusing may therefore not arise.

Miras from an astrophysical viewpoint – Stan Walker

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Abstract

One hundred and fifty years of intensive time series photometry (TSP) of long period variables such as Mira stars have found less than a dozen stars with true long term changes – thus interest seems to be falling. But amateurs now have access to equipment capable of measuring other aspects of these stars: filters and detectors which allow UBVRI colour photometry, with extensions to J, H and K passbands; spectroscopic equipment capable of measuring radial velocities accurately; all of which can be combined with satellite measures of distance and other things.

This review is largely based upon the known attributes of two Mira stars which have shown two maxima per cycle. There are similar stars where detailed study of the astrophysical aspects would be valuable. When successful results are obtained these can be used as a template for observing the full range of long period cool stars – Miras, SR stars and similar objects. This provides a raison d'ệtre for amateur measures of these stars for the next century, even though the increasing number of surveys may relegate TSP to a role comprising data-mining of these surveys.

Introduction

If we wish to study evolutionary or other changes in stars which take thousands or millions of years to evolve we must seek targets among the stars which seem different. The Dual Maxima Mira stars are one group of these. They comprise a small number of objects in the southern hemisphere centred on a region including and surrounding the Southern Cross.

In the 1960s only two, R Centauri and R Normae, were known and it was not clear whether the period was over 500 days or whether the stars had a period of half that with alternate deep and shallow minima.

Since then four others with the classic, almost symmetric light curves have been found. There are a dozen or more others which at times show two maxima but mostly of unequal brightness. These include two in the north, U Canis Minoris and T Cassiopeia. Light curves of the six southern DM Miras are presented.

Two of these stars have shown notable period and light curve shape changes, as well as changes in other features. I will examine these in detail

Welch's red variable in Crux

This all began on 11 October, 1969, when Brian Marino and I first measured Ron Welch's newly discovered variable star in UBV using the Auckland Observatory's new photometer. Figure 1 below shows parts of the first 6 cycles – the V light curve below, B-V above, both to the same scale. This was the third known double maximum Mira, notable for its very red colour and large B-V, or temperature, changes. The same year he discovered a fifth magnitude nova in Sagittarius but few people remember that!

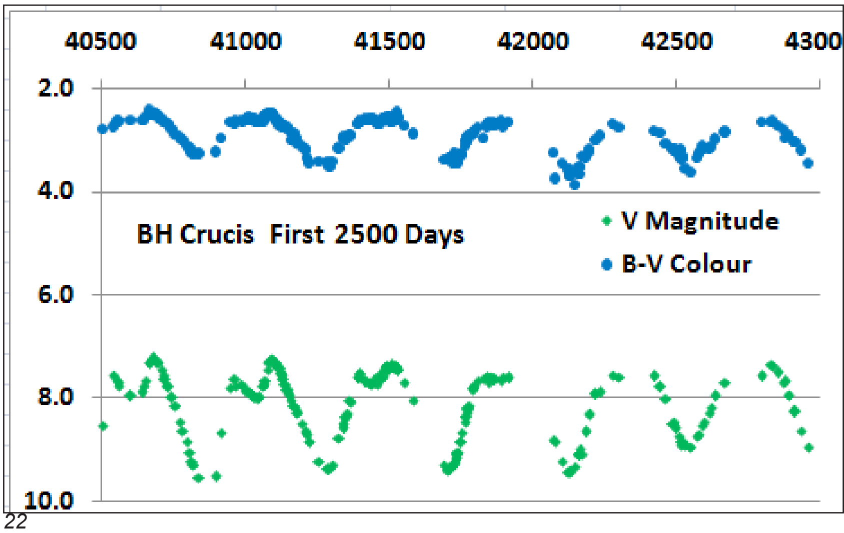


Figure 1. *A portion of the first six cycles of the light curve of BH Crucis as measured by Brian Marino and the author.*

Pulsating Stars

Here we mean stars with radial pulsations which appear to be caused by shock waves resulting from the cyclic ionisation and recombination of one of two elements – helium in the case of the regular Cepheids and other variables in the well known instability strip; hydrogen in the much cooler stars of the AGB.

There is a critical difference. Although the ionisation/recombination takes place in a region of all stars where energy transfer is by radiative processes the shocks must travel through the star's envelope which is radiative for most Cepheids but becomes convective in the cooler stars such as Miras, semi-regular and other long period pulsating objects. This produces turbulence, star spots and other disturbances.

Thus the light curves of the cooler stars are less regular and show more forms of variation. One of these variations, Miras with dual peaks of brightness, is shown on the following two graphics. These additional types of variation provide information about the envelope through which they travel.

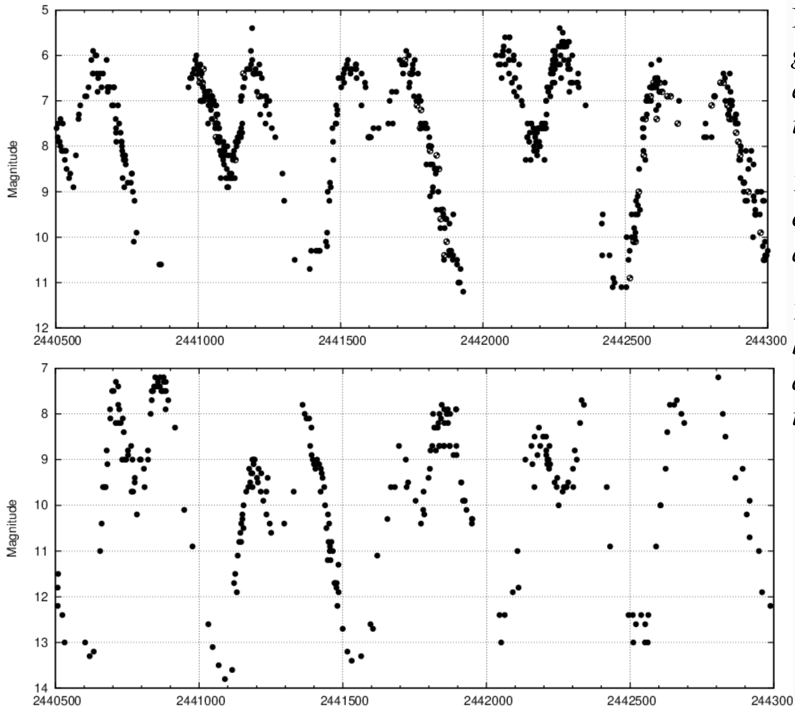
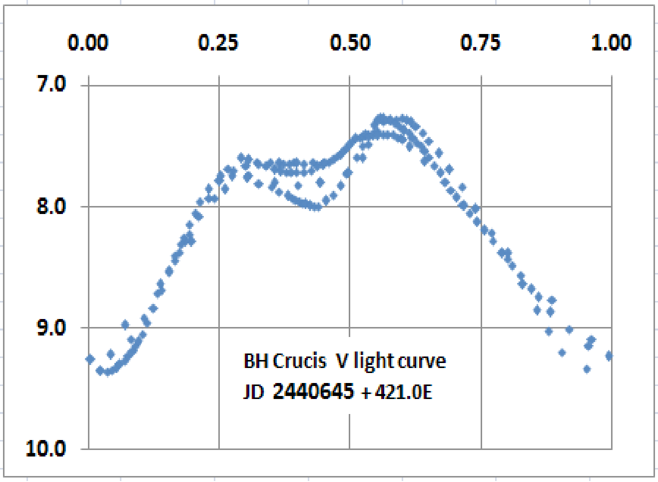


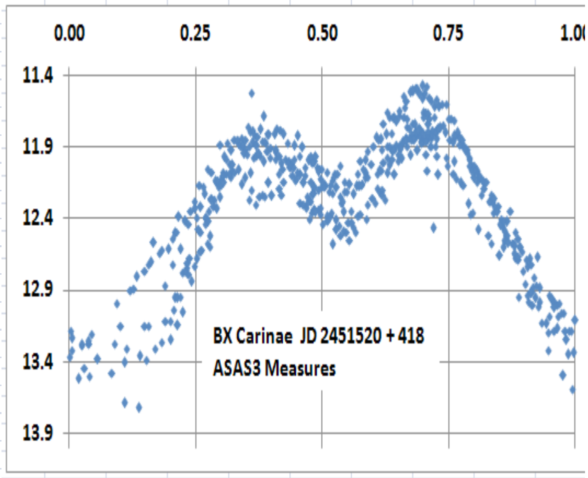
Figure 2. *R Centauri in the upper graph is the brighter so is accepted as the prototype. R Normae, below, is much less well studied.*

These graphs of visual measures cover the same interval of 2500 days as the BH Crucis graph.

The two maxima are similar in brightness but with DMMs it's often difficult to decide which is the more important.

More Double Maxima Miras





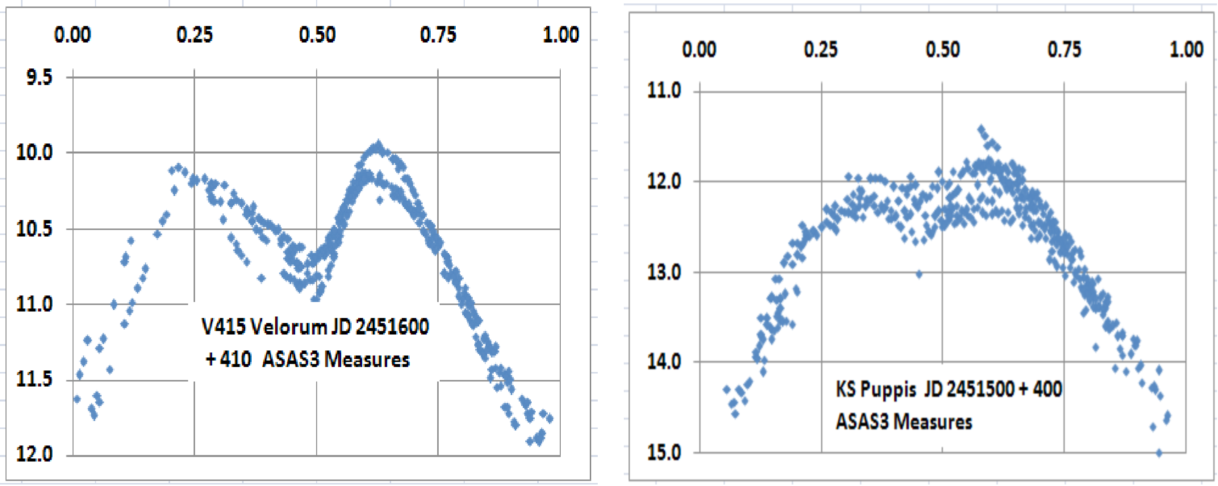


Figure 3. *These four additional stars show symmetric light curves and are all low amplitude. Except for BH Crucis spectral classes are not available. The phased light curves are from ASAS3.*

Which other stars are worth investigating over the long term?

The simple answer is LPVs which are different - evidenced by the shape of the light curve or period or amplitude variations. The following six graphs show some stars similar to DM Miras but with more irregular light curve shapes amplitudes and periods.

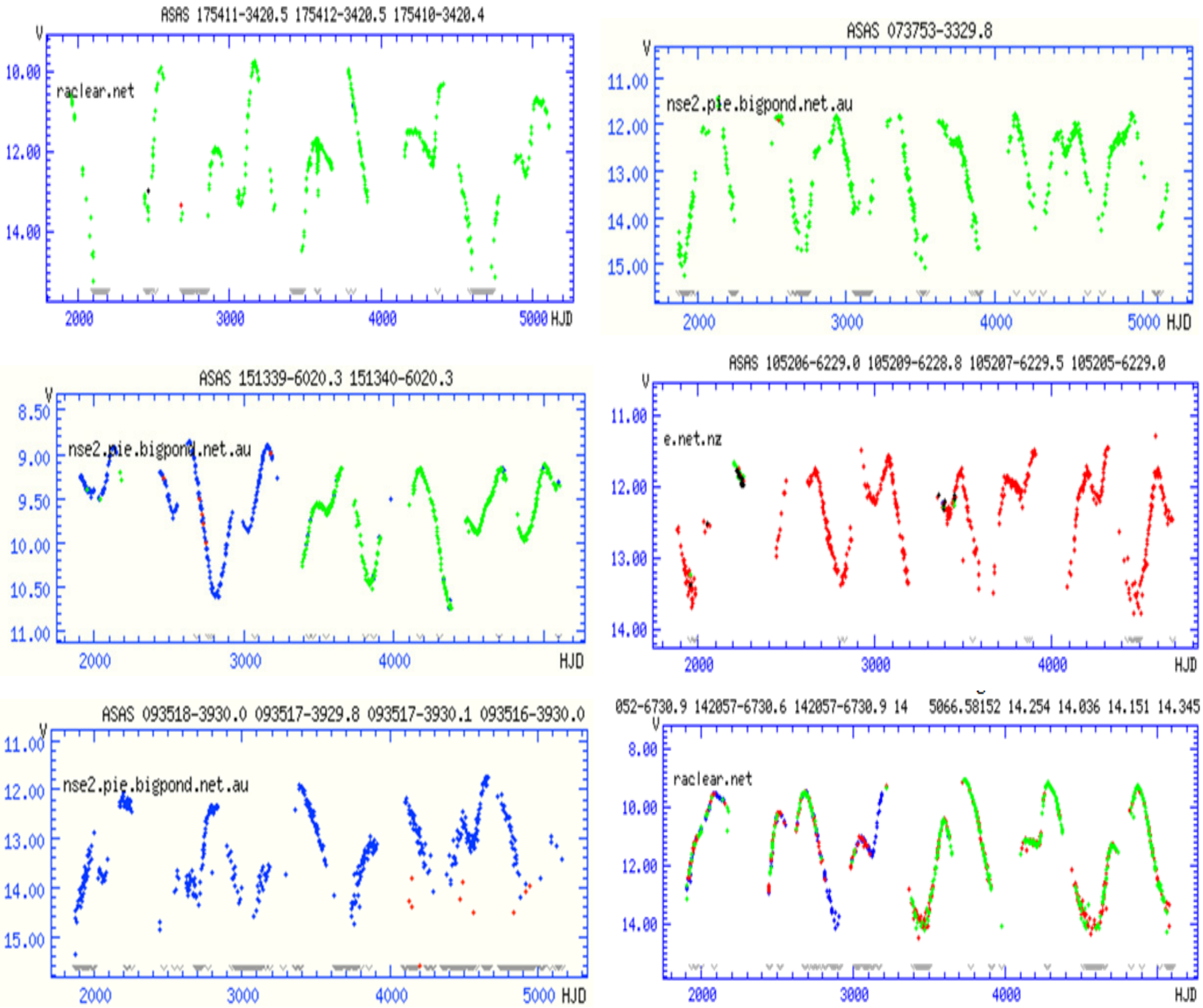


Figure 4. *Some examples of stars with light curves similar to Dual Maximum Miras*

Where or how do we find these different stars? Some indicators might be:

- Periods of over 400 days seem to be less stable - these stars are very large
- Spectral classes C and S or CS indicate highly evolved objects
- All these have low surface gravity – ejection of mass, often at high rates

Stars with changing periods

- The latter come in different categories:
- Slow reduction of period – helium flashes – probably neither start nor end seen in any of these
- Fast increase in period – some aspect of helium flash – or something else
- Abrupt changes like Mira – no ideas

There are other changes such as overall brightness increases or decreases. L^2 Puppis has shown a number of these and recently even Betelgeuse has undergone such an event, apparently mainly at visual wavelengths.

These interesting changes of behaviour are usually found by visual observers or others monitoring these stars with an uncalibrated V filter in a CCD camera.

A selection of changing periods

The most well known is apparently due to a helium 'flash' in Mira stars which we see as a long duration fading in the brightness of these objects. R Hydrae may well have entered this phase 250 years ago and its period, after being fairly stable from 1946 to 2007, now seems to be decreasing again. R Aquilae is another such object in the southern sky.

LX Cygni has an interesting SC3e spectrum, similar to BH Crucis, and showed a reverse period change - from ~470 to ~580 days over 20 cycles or ~30 years. Like BH Crucis it's not yet clear whether the period has become stable again.

Mira's period has been observed for ~425 years and in 1930 showed an abrupt change. This is clearly shown in the O-C diagram.

Many other Miras (and also some SR stars with periods near 150 days) show alternations of period over a time scale of decades. One of the more striking is RU Scorpii which showed a period of 371.1 days for 52 years from 1928 to 1980 then changed to a period of 350 days over 26 years to 2006. Similar periods existed prior to 1928 but the coverage was not adequate to determine enough epochs of maximum for certainty. Almost all Miras seem to show this type of behaviour. One confusing issue is that with the popular wavelet type software which samples over average periods those with frequent alternations give the impression of constant period changes, not the abrupt changes which are probably more real.

Examples of each type of change are shown below. The vertical scale is in days, horizontal is cycles.

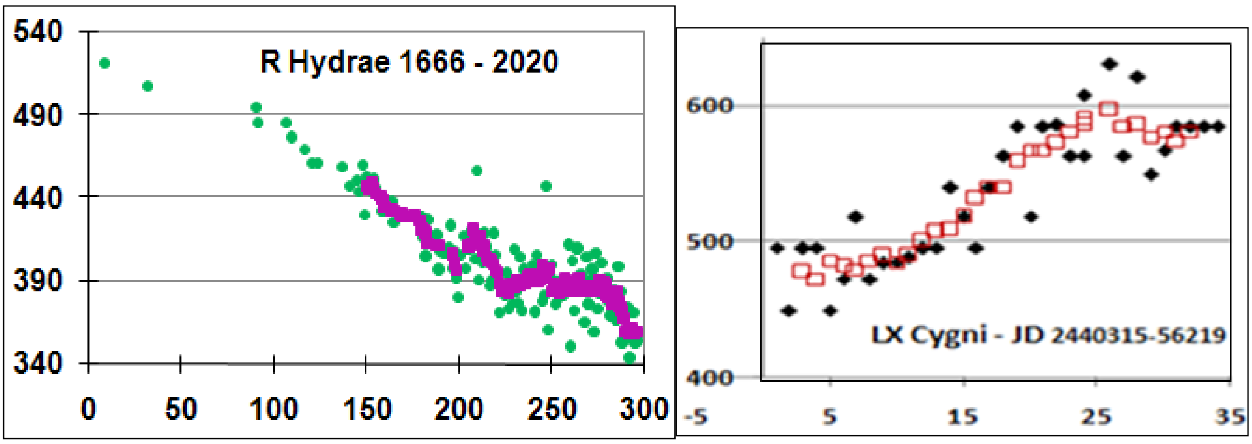


Figure 5. *Left, the light curve of R Hydrae which is likely undergoing a helium flash and right, the light curve of LX Cygni whose period appears to be lengthening.*

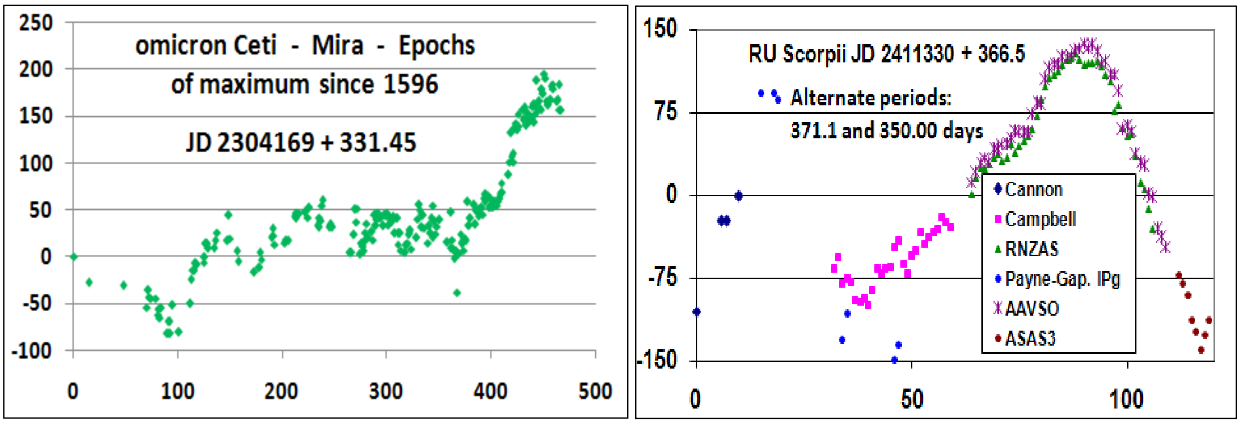


Figure 6. *Two examples of Miras that have undergone abrupt period changes.*

Other examples of unusual behaviour

Spectral and V-I measures show evidence of mass ejection by LPV stars. A good example of this is L^2 Puppis which has undergone a number of these events over the last century. The present event has seen the star dim to well below naked eye level. The vertical scale is in intensity units, the horizontal in JD -2400000.

Less unusual are the Mira stars which show humps, usually on the rising branch of the light curve. A well observed star of this type is R Telescopii. Note that the V magnitude of R Telescopii in the graph has been offset by -4 magnitudes. Maximum is normally around V = 8.

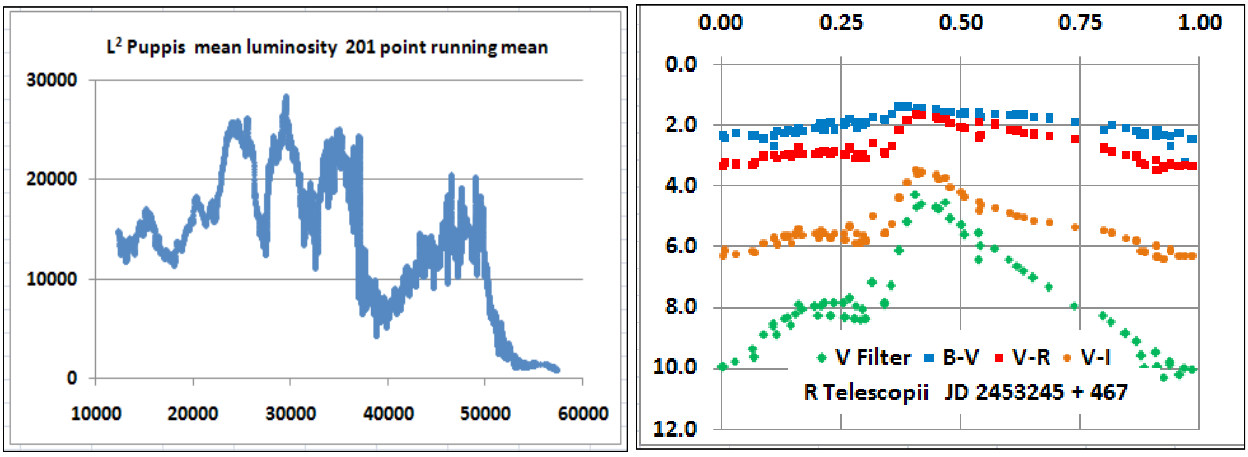


Figure 7. *Left the light curve of L^2 Puppis showing evidence of mass ejection and right, V Telescopii showing humps on the rising branch.*

The visual 'finds' - an example

KL Cygni satisfies some of the criteria for stars which may be undergoing evolutionary changes. The GCVS quotes two periods – 536.8 days until 1962 and 526 days up to 1985 – but since 2001 it has hardly been observed. The GCVS gives a spectral class of Ce and Guide 9 a J-K of 2.58, so it's a red carbon star. There has been some discussion on the internet about a possible dramatic change in amplitude. Some BVRI measures might be rewarding as it reappears in the north morning sky. The only measures in the IDB are shown in Figure 8 opposite. A target for northern observers.

Aspects of filters - Johnson or Sloan?

If the amateur measures of LPVs are to be a valuable resource over the next century we must make them as good as possible using the filters which provide the most useful information. So the question then arises - which or both? The question would be best asked in a century's time. But let's do our best

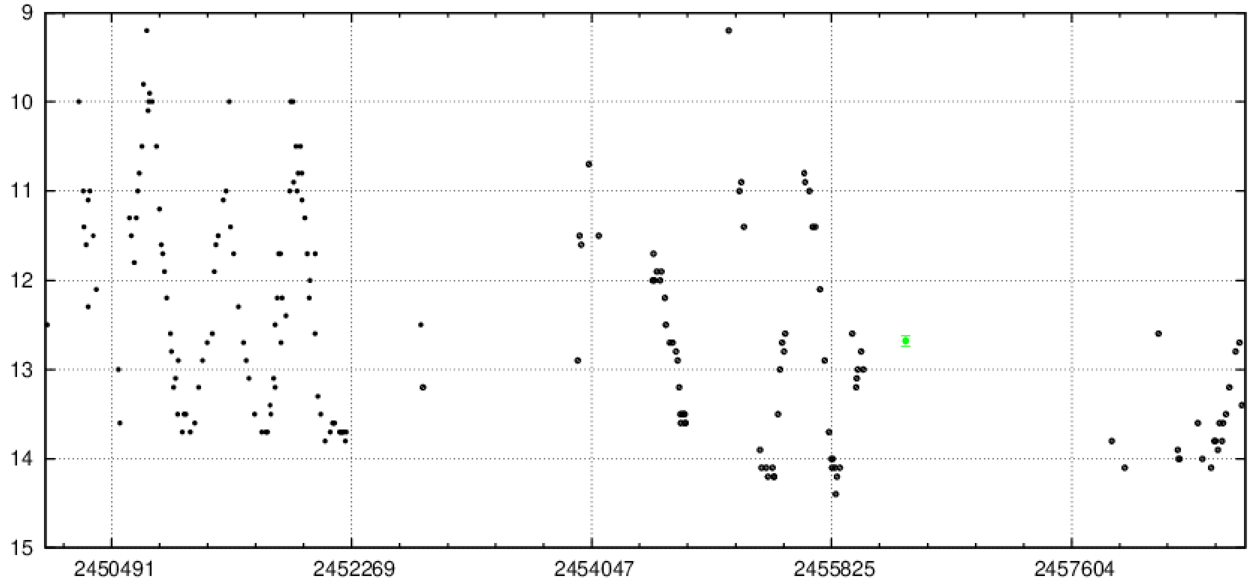


Figure 8. *KL Cygni is an example of a red carbon star undergoing evolutionary changes.*

- Neither system is all that suitable for cool red stars.
- Historical measures of these stars are mainly visual with some V and B from the 1950s
- Current measures include some R and I but the accuracy may be doubtful
- B-V provides a good colour-temperature relationship
- Sloan has more precise boundaries but conversion is difficult

The Sloan u filter is completely on the short wavelength side of the Balmer decrement which makes it more reliable for hot, blue stars. But most common CCD and similar detectors are almost useless in this area. The z filter also has advantages with very red stars.

Probably most of the original work in the LPV field will continue to be done by amateurs with professionals following up with more detailed theoretical and physical explanations. So we should continue with the Johnson system at this stage. But there are questions.

- Will UBVRI filters still be made?
- What are the markets for these filters - if there are none they will disappear
- Visual observations are adequate for most TSP of periodicities but are declining in number
- Colour photometry is inefficient for tracking normal periodic behaviour - standard TSP is better
- Increase of satellite and other surveys will produce masses of data
- How does one access these measures?

The filter wavelength comparisons are shown in Table 1 below.

Johnson	**Eff W'length**	**Sloan**	**Eff W'length**
U	**365.6**	**u′**	**358**
B	**435.3**		
		g′	**475.4**
V	**547.7**		
R	**634.9**	**r′**	**620.4**
		i′	**769.8**
I	**879.7**		
		z′	**966.5**

Table 1. *There is no V filter but this can be overcome by using (g′ + r′)/2 but the H alpha emission of these stars in the r′ filter distorts this to some extent. Johnson I can also be compared to (i′+ z′)/2 but once again prominent spectral lines are a problem.*

Radial velocity measures

The development of low cost, efficient, spectrographic equipment sees amateurs becoming strongly involved in this area. Whilst spectral classes and maximum-minimum variations of almost all Miras are available from the GCVS little is readily available in most cases about RV changes during pulsation cycles. The exception is that it is clear that the star is smallest near maximum brightness and largest at minimum. The low surface gravity at minimum allows material to escape, hence the strong emission signatures.

- Hydrogen alpha and beta in emission most prominent – but these emanate from a gas shell – not the stellar surface
- Surface RVs need to be measured using other spectral lines
- What is available?
- Let's look at some interesting possibilities
- BH Crucis as it is now – a brighter star than 50 years ago
- R Centauri – the prototype Dual Maxima Mira – period becoming shorter

There are a few LPVs with RV curves but these seem mostly aimed at measuring the amplitude. This seems to be about 15 to 20 km/s for normal Miras with a few like R Horologii and VZ Velorum at ~25 km/s. R Centauri has a low 7 km/s amplitude but R Normae is easier to measure at 15 km/s. There appear to be no complete light curves of any of the DM stars but many detailed observations are unpublished or difficult to find.

This background has set the scene to consider our two main stars

Let's now consider two DM Maxima Miras, R Centauri and BH Crucis. Particular interest is in the colours at maximum although all are important. The following two graphs portray the V, B-V and U-B during several cycles in the 1970s.

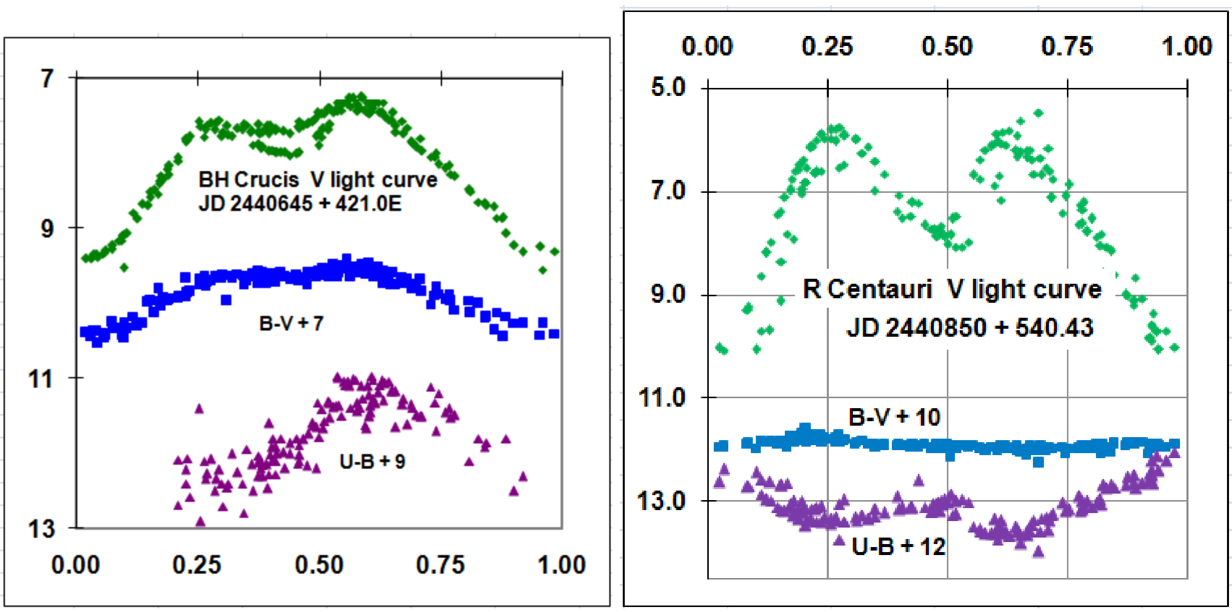


Figure 9. *Graphs showing the colours at maximum light for two DM Miras - BH Cru and R Cen.*

BH Crucis, as a carbon rich Mira, barely makes the 2.5 magnitude amplitude requirement. More important – the second maxima of BH Crucis is the brighter in B-V, thus the hotter in contrast to R Centauri where the reverse is found. ***Why*** is an unanswered question.

Changes in BH Crucis 1970 to 2008

BH Crucis showed dramatic changes over an interval of about 28 years. These are shown in the following four graphs.

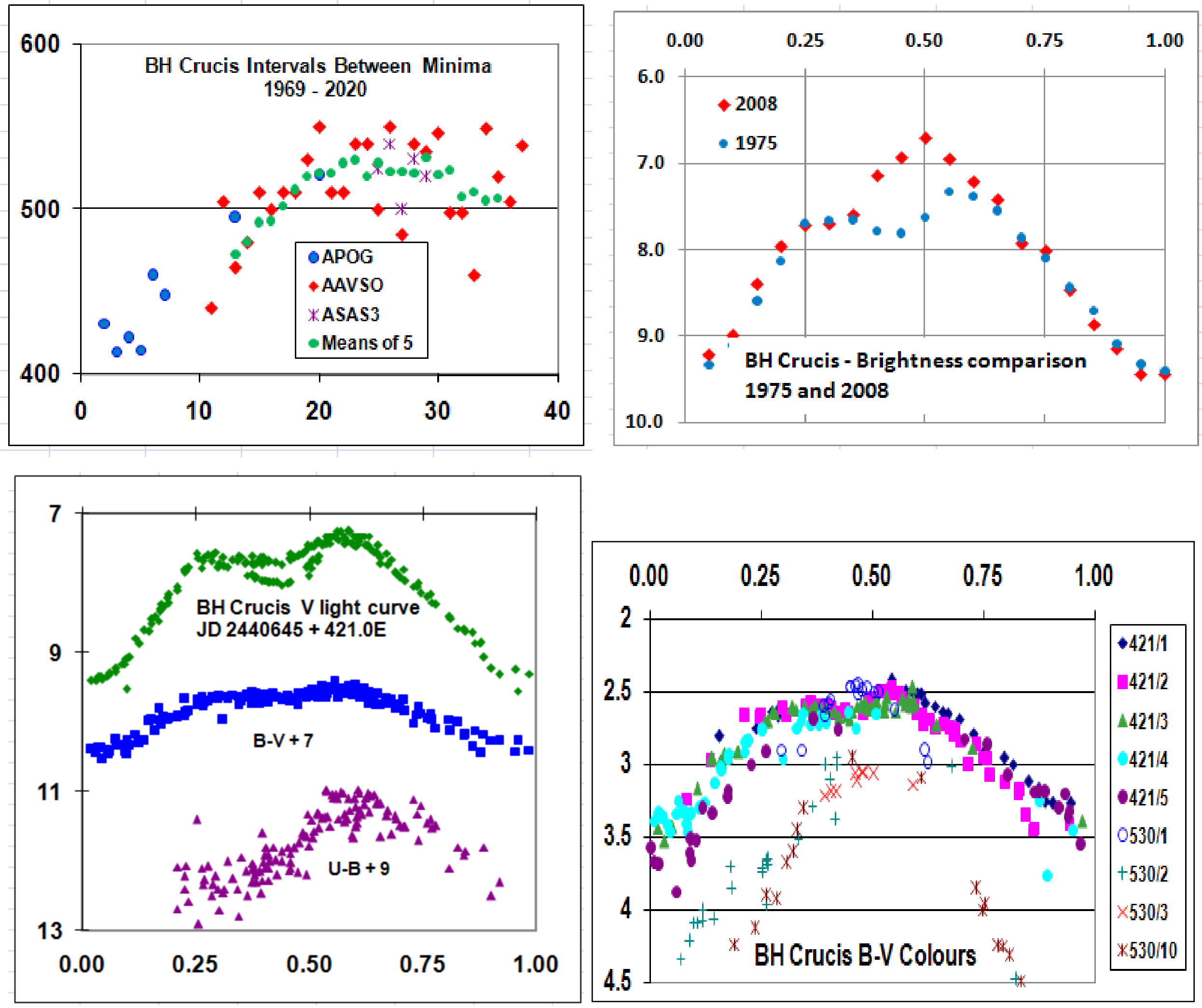


Figure 10. *The upper left graph is a periodogram showing the dramatic period increase over about 20 cycles. The upper right shows the light curve at the start of the increase in blue, the light curve at the end in red. In this case the change in magnitude is a clear indicator of a brightness increase without the need to change these into intensities. It also shows the change from a DM Mira to a Mira with a pronounced hump on the rise. This is significant in that it suggests a link between these two types of star.*

The lower left graph shows phased measures during the 1970s. The second maximum is the brighter and hotter as shown by the B-V. The U-B light curve is interesting, showing a significant increase during the second maxima. Whilst not shown here, the U-B light curve of most Miras shows the reverse as the stellar luminosity increases whilst the emission shell's luminosity remains much the same.

The lower right graph shows changes in the B-V during nine cycles These are five at the shorter period, three at the beginning of the longer 530 day period and one by Giorgio di Scala using a CCD detector which matches the earlier 530 day period curve well. There is a large change in colour, indicating a temperature drop which seems to have occurred a little after the longer period became established. The code on the right shows period and cycle number at that period. A dozen or so intervening cycles are not shown.

Coupled with the increase in brightness the lower temperature indicates a very large change in radius over the 30 years. This would have been clearly shown with RV measures but none are available.

R Centauri - possibly a unique star?

This star is both a DM Mira and a star presumed to have experienced the onset of reducing period due to a helium flash.

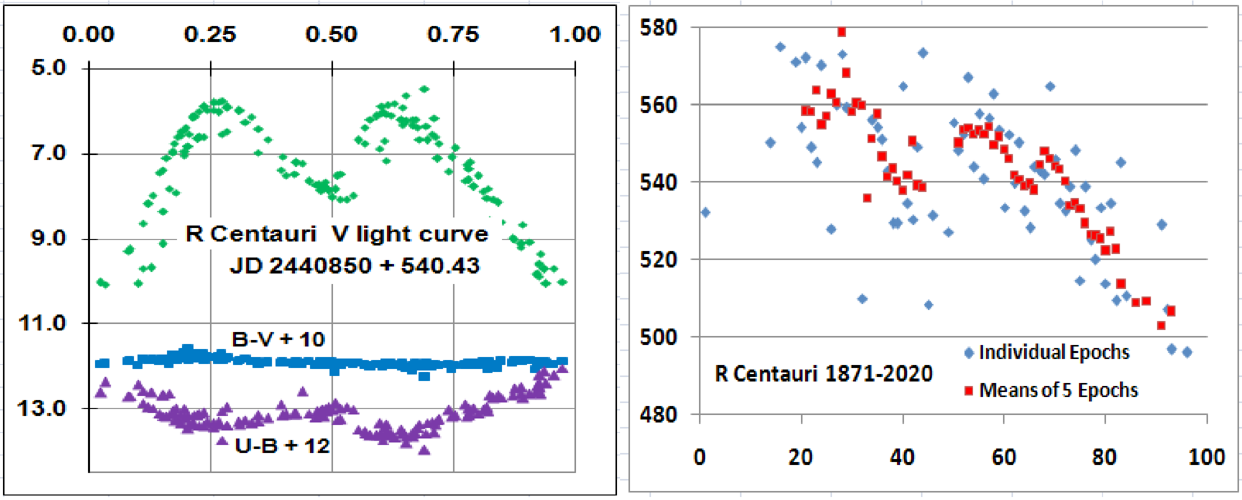


Figure 11. *The left graph shows phased V, B-V and U-B measures during the 1970s. The star is at its hottest and brightest at phase 0.25 but reaches a similar brightness at phase 0.62, probably due to a larger radius. The date of the graph centre is centred on epoch 70 of the adjacent periodogram.*

The right hand graph presents a periodogram from 1871 to 2020. The presence of two maxima seems to make epochs of maxima a little more uncertain. The first two scattered epochs are so doubtful that it's not possible to state when the decrease began. The blue points are single epochs, the red squares indicate means of 5 measures. The 560 day period of the 1890s is now 494 days.

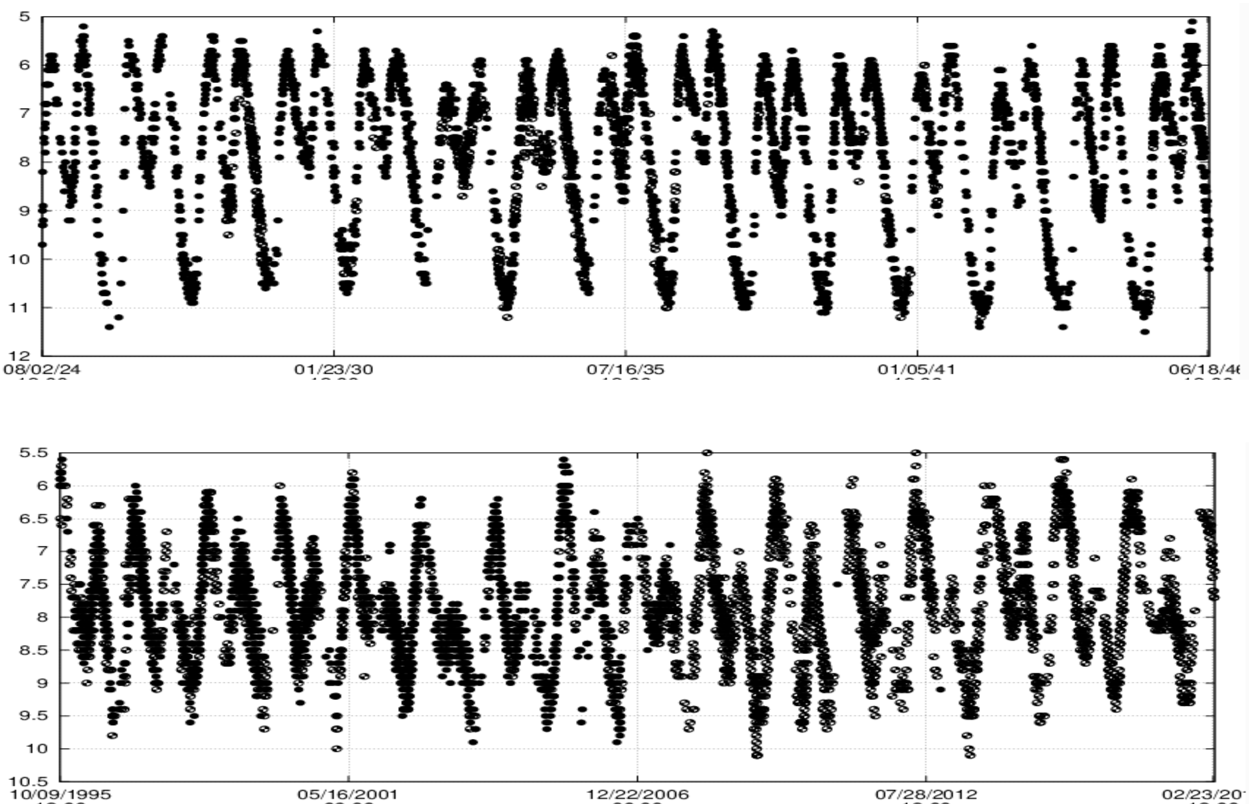


Figure 12. *The above two graphs show overall changes in the light curve 1924-1946 compared to 1995-2018. The amplitude seems to have decreased slightly but this may be merely sequence changes. The lack of stability in the second maximum is clearly shown.*

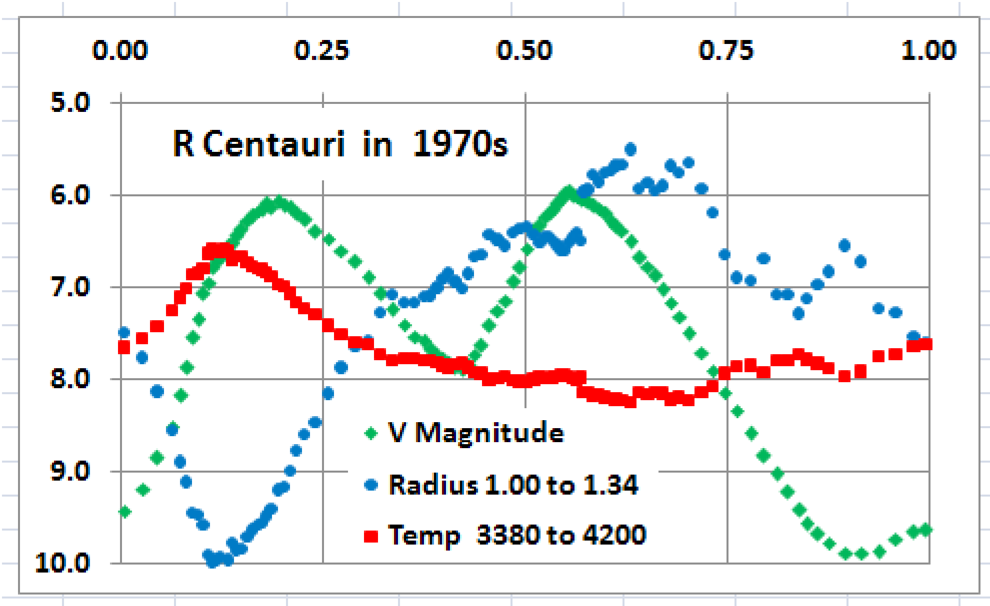


Figure 13. T*his graph is a very crude adaption of the Stefan/Boltzsman relationship as it relates to luminosity, temperature and radius.*

At these cool (by stellar standards) temperatures the bolometric corrections are very high and temperatures uncertain. Only radial velocity measures will allow accurate radius change values to be found. The vertical scale refers to the V magnitude - the radius and temperature both reach maximum values at the top of the curve.

A bolometric correction would see the second maximum much brighter than is shown here with a consequent increase in the radius It seems to confirm that the first maximum is associated with temperature, the second with a much larger radius at a slightly lower temperature. It's clear from this that RV measures are essential.

Target stars for the project

Six stars have been selected based on the light curve shape. The initial goals are set out below. Periods vary a few percent either side of those given. The dates of opposition are only within a few days. Two other possible DMMs are at the bottom of the list.

Star	R.A.	Dec.	Max	Min	Period	Spectrum	Type	Opposition
R Centauri	14 16 34	-59 54.8	5.8	9.0	500:	M4e 8e II	Mira	26 Apr
R Normae	15 35 57	-49 30.5	6.4	12.0	507		Mira	16 May
BH Crucis	12 16 17	-56 17.2	6.5	9.8	530:	SC4.5/8e 7/8e	Mira	26 Mar
BX Carinae	10 52 06	-62 29.0	11.7	13.8	427	--	SRa	5 Mar
V415 Velorum	10 03 30	-46 49.2	9.6	11.8	410~		Mira	23 Feb
KS Puppis	07 37 53	-33 29.8	12.3	14.5	427		Mira	16 Jan
UZ Circini	14 20 52	-67 30.8	9.0	14.0	538	--	Mira	27 Apr
TT Centauri	13 19 35	-60 46.7	9.0	13.4	462	CSe	Mira	11 Apr

Table 2. *Selected stars for observers embarking on the LPV project.*

The goals initially will be:

- Obtain V and B-V of both maxima

- Measure V, B-V of the light curve in the upper half of the range – V-R, V-I optional
- Radial velocity measures of the brighter objects across dual maxima region

Note that BH Crucis now is a 'hump' Mira but the area from phase 0.25 to 0.75 is interesting and worthy of attention.

Predictions for the next cycle are set out in each case. For ease of planning these use calendar dates. Most of the major goals will be achieved if the top half of the light curve is observed in reasonable detail.

Star	Minimum	Mag	Max I	Mag	Min Sec	Mag	Max II	Mag
R Centauri	25.8.2021	9.3	24.8.2020	6.0	13.1.2021	8.0	4.4.2021	7.5
R Normae	5.6.2020	13.5	10.9.2020	6.8	26.11.2020	7.7	14.2.2021	7.0
BH Crucis	23.1.2021	10.5	2.6.2021	9.0	4.7.3021	9.0	7.4.2020 1.9.2021	7.0 7.0
BX Carinae	23.9.2020	13.5	17.1.2021	11.3	22.2.2020 19.4.2021	12.3	2.3.2020 29.6.2021	11.6
V415 Velorum	27.8.2020	12.0	25.10.2020	10..	13.3.2021	10.5-8	28.3.2020 21.5.2021	10.00 10.00
KS Puppis	17.9.2020	14.5	5.1.2021	12.3	1.2.2020 6.3.2021	12.6	20.4.2020	11.8
UZ Circini	10.2.2020 6.8.2021	14.0	13.7.2020	9.0	4.9.2020	11.5	25.12.2020	11.0
TT Centauri	4.3.2021	14.0	27.2.2020 3.6.2021	10.0	13.5.2020	10.5	13.7.2020	9.5

Table 3. *Approximate observing dates for the various minima and maxima for the project stars.*

Observing the target stars

Accuracy is essential. This is best obtained by using one reliable comparison star and two or three checks. The amplitude of most of these targets is relatively low so one set of Comp/Check stars is adequate. The lower part of the light curve is not as critical.

Details of the selected comp/checks are given in the accompanying article. Do not use any other stars as their magnitudes are not as accurately known.

Since all of the periods are in excess of 400 days a measure each 10-15 days is adequate with, perhaps, every 7 days around the two maxima and the intervening minimum.

Predictions of the various phases are shown above but may be a few weeks in error as some stars are poorly observed.

What affects measures

To convert your derived magnitudes to the standard system consider:

- The scale factor (transformation) to ensure your filters match the wavelengths of the standard UBVRI system. This needs pairs of filters
- Removing primary extinction if stars are measured at a significant air mass difference from each other. This should only happen at low altitudes
- Adjusting for secondary extinction if stars are of different B-V and other colours

In the southern hemisphere the E and F Region standards should be used for deriving transformations. At fainter levels the Landolt standards may be used.

Primary extinction is highly variable but is largely negated by ensuring all stars are close together.

Secondary extinction is usually fairly constant and is always present when stars are of different colours.

The project takes these factors into account in selecting comparisons.

Recording of measures

I do not think Variable Stars South should set up a database but the problem is that the International Database maintained by the AAVSO records colour photometry in a manner unhelpful to analysis. Most recording and presentations to date use the more conventional V, B-V, U-B, V-R and V-I layout. This also has the advantage of showing errors more readily as these colour curves vary only slowly and faulty measures stand out clearly.

For TSP measures of periods these must always be measured through the same filter as epochs of maximum are wavelength dependent - maximum in B occurs almost 2 days earlier than in I with a Mira of a 400 day period. So there is no advantage - but a clear disadvantage - in using anything other than V magnitudes for period checks.

Until the database question can be resolved you should maintain your own records in Excel or whatever. The suggested format is JDH, V, B-V, V-R, V-I, with similar V plus colours for each check star, air mass. If you care to send me a copy every so often I will record these as well. Check the accuracy by averaging the catalogue/observed differences without sign.

If RV measures can be obtained they should be recorded as to the object and JDH.

Summary

There are several important things about these stars which can be determined in a year or two of observing. These include:

- Whether there is a B-V colour difference between the two maxima.
- A full B-V light curve providing a more detailed view of temperature changes
- Radial velocity measures will provide a measure of radius variations during a cycle

On a longer time scale:

- V-R and V-I colours will be useful to future analysis
- In the wider Mira field do period alternations show colour differences?
- Have the stars with period changes reverted to non-changing periods?
- Can we establish before and after colours for stars where periods change?

Other questions and answers will arise as more observational material is gathered.

Conclusions

This project conforms to the Variable Stars South goals of making observations which have lasting value but which also allow the discovery of important and publishable information about particular stars in a reasonable period.

One of the goals is to establish whether R Centauri is an unusual Mira apart from its dual maxima nature. In the determination of this the colours of the respective maxima are important as illustrated by the contrast between R Centauri and BH Crucis.

This presentation is, in effect attempting to rationalise what is now to some extent happening in the amateur LPV observing field. I have discussed some aspects of this with Mark Blackford and we had hoped for a discussing with Stella Kafka at Parkes - but the situation is now dramatically different.

Dual Maxima Mira comparisons – *Stan Walker*

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Introduction

Help is needed in setting up a more detailed investigation of the six most prominent stars of this type, along with two other stars which may be related. Observations will need a comparison star and three check stars linked to southern standards, preferably E Regions. Values are needed in V, B-V,V-R and V-I. Until good values are available the values in the table for each star should be used but the 'errors' will only reflect what corrections need to be made to the tables.

Why not use APASS?

The colour variations of the target stars are small and observations need to be accurate to 10 millimags or better. Most APASS values appear to be accurate only to ~25 millimags from about magnitude 10-11 and fainter. There seem to be other problems as discussed in the analysis of S Orionis discussed in the January Variable Stars South newsletter, 2020/1. In pursuing the reasons for this I was recommended to a paper by Tonry et al. ApJ, 2018, ***The ATLAS All-Sky Stellar Reference Catalog*** which detailed a re-analysis of a large number of APASS images and discussed the accuracy of these. Tonry et al. consider standards with an accuracy of 10 millimags or more unsuited to their requirements and the same applies to the DMM project. One other problem is that APASS does not provide R or I values and many amateurs are observing with these filters.

Do not think this is a criticism of APASS. It has served well to provide reliable visual comparisons for Miras and other LPVs in the region fainter than V = 10. This has been the traditional role for amateur variable star observers for 150 years and it is ideal for time series photometry of periods and changes in them, as well as multiple periods. But it was not designed to have the accuracy required in many areas of astrophysics. So here we must turn to the methods used by PEP from the 1950s.

The classical approach

This was built up over many years using the equipment then available. It needed to be based on measures of stars and their colours which did not really become available until the advent of PEP and Johnson's definition of a usable system of filters. An early catalogue of the UBVRI measures of many of the brightest stars was published by the Tonantzintla Observatory (Mexico). Perhaps the best of the early catalogues were the Yale Bright Star Catalogue and the Royal Observatory Bulletin 64. In Auckland we used the latter for a source of comparisons near the target star and established a main comparison star and two or three check objects, all non variable, in each target star field. In published papers it was deemed good practice to provide details of all of these and the adopted magnitudes. This method seems to be falling into disuse but it is still probably the most accurate method and is used in this project.

Comparisons and checks

For each of the target stars there is one main comparison and three check stars. At present we can provide only approximate values for these, largely based on Guide 9 for V, B-V, and calculated values for V-R and V-I derived from applying average relationships to B-V based on the Cape E Region standards. These relationships are V-R = 0.546 x B-V and V-I = 1.073 x B-V.

Help is requested in improving these values to make them internally consistent in each star field and as close to the overall standard system as possible. Four stars are not adequate for ensemble photometry. But as many observers are using different ensembles the comparison plus three check stars system will improve the accuracy.

Let's look at the proposed comparisons for the first star, the prototype DMM star, R Centauri. This varies in V from 5.8 to 10.0, a range of 4.2 magnitudes. This comparison star has been selected as it is mid-range of the variation so that the extreme intensities of the variable will be within +/- 8 times that of the comparison. This concept is followed with the other target stars. A table follows. Red figures denote values derived using the formulae described above.

R Centauri

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	HD 125117	A0	7.966	0.076	0.041	0.082		
Check 2	Tyc 8690 1120	---	9.750	1.035	0.565	1.111		
Check 3	Tyc 8690 1104	A0	9.666	0.078	0.426	0.084		
Check 4	Tyc 8690 2402		10.275	0.663	0.362	0.711		

Sequential photometry

This introduces one of the needs of this type of observing, particularly with the brighter variables - there are no comparisons of suitable magnitude and colour in the field of the variable. So measures of a nearby field and the target star must be in the form of - comps, R Cen, comps, R Cen, comps. All classical PEP was done in this manner as only one star at a time could be measured. One example to show the accuracy attainable is the eclipsing binary V777 Sagittarii where the standard deviations in V, B-V, U-B were: Uneclipsed 0.008, 0.012, 0.073 and eclipsed 0.007, 0.011, 0.093. The U-B signal was at U = 13 which was near the limiting magnitude in that filter. V was at 8.5.

With the added advantage of all the stars and sky being measured at the one time it should be possible to achieve an accuracy of +/- 5 millimags with CCDs. Another advantage is that in V-R and V-I the effects of primary extinction are much less than in B. Accuracy in this context is true accuracy, not the misleading value of precision which is quoted by most software packages.

R Normae

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	HD 138845	B9	9.474	-0.019	-0.010	-0.020		
Check 2	HD 138960	A0	9.093	0.070	0.038	0.075		
Check 3	HD 138976	F5	9.432	0.515	0.281	0.553		
Check 4	Tyc 8804 517		10.884	0.513	0.280			

BH Crucis

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	HD 105857	A2	7.332	0.117	0.064	0.126		
Check 2	HD 105817	A0	8.465	0.026	0.014	0.135		
Check 3	HD 106066	F5	9.133	0.417	0.228	0.447		
Check 4	Tyc 8640 909		9.977	0.029	0.016	0.031		

BX Carinae

	Catalogue	Spec	V	B-V	V-R	V-I	Comments	
Comp 1	Tyc 8961 566		10.856	0.519	0.283	0.557		
Check 2	10 57 41 -62 29 20		11.980	N.A.			Catalog is Coordinates	

Check 3	Tyc 8962 834		11.785	0.274	0.150	0.294		
Check 4	Tyc 891 17		11.838	0.835	0.456	0.896		

V415 Velorum

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	HD 297129		9.436	0.912	0.492	0.979		
Check 2	HD 297131	A3	9.572	0.346	0.189	0.371		
Check 3	Tyc 8186 132	A0	9.956	0.128	0.070	0.137		
Check 4	Tyc 8182 100		10.326	0.790	0.431	0.848		

KS Puppis

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	Tyc 7109 661		10.664	0.820	0.448	0.880		
Check 2	Tyc 7109 247		10.988	0.613	0.335	0.658		
Check 3	Tyc 7109 1049		11.516	0.085	0.046	0.091		
Check 4	Tyc 7108 595		11.285	0.562	0.307	0.603		

UZ Circini

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	Tyc 9244 1594	B9	9.164	0.015	0.008	0.016		
Check 2	Tyc 9244 75	F8	93674	0.571	0.312	0.613		
Check 3	Tyc 9244 464		11.310	0.714	0.390	0.766		
Check 4	Tyc 9244 667		11.143	0.504	0.275	0.541		

TT Centauri

	Catalogue	Spectrum	V	B-V	V-R	V-I	Comments	
Comp 1	Tyc 8990 123		10.719	0.295	0.161	0.317		
Check 2	Tyc 8990 696		9.408	0.085	0.046	0.091		
Check 3	Tyc 8990 411		10.132	0.513	0.280	0.550		
Check 4	Tyc 8990 807		10.968	0.527	0.288	0.565		

SS Crucis – reflections on a forgotten Mira variable – *Peter Williams*

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[Editor's note: A version of this article has appeared on the Long Period Variables Facebook pages and also as the AAVSO's LPV of the month]

Most of us who are members of and contribute observations to the AAVSO would receive the weekly Data Usage Report, an email that lists the stars for which your observations have been downloaded from the AAVSO International Database with a general indicator of the intended purpose that the data is to be used. A quick look through these reports is interesting as they show the wide variety of stars in which researchers, educators and students are interested and it provides a sense of satisfaction that our observations, when reported, are indeed of value.

Most often the data downloaded is in groups of a particular variable star class: - the novae, RCB stars, Cepheids or Mira stars and occasionally, for whatever reason, one star in particular stands out. A star that recently caught my eye is SS Cru and this prompted me to look back at my visual data.

SS Cru is one of a number of southern Mira stars that was listed in the GCVS as "not studied" or for which there was no known type, period or epoch for determining the date of maximum brightness. Back in the mid-1990s I had selected around two dozen or so of these "not studied" Miras and added them to my regular working list with the aim of, firstly, detecting and identifying them as their positions were often poorly measured or simply in error, then following up by making regular observations to determine the basic parameters of their variations. This is hardly earth shattering research and was merely aimed at filling in a few of the missing gaps in the catalogue data.

The problem with any such programme on Mira stars is, of course, that as these stars have cycles close to a year and often longer, it can take a decade or so to accumulate enough observations to adequately determine the star's behaviour and much longer to investigate any trends or changes that may occur. First results for this unofficial programme were published in 2000, appearing in Publications 24 of the then VSS RASNZ on NSV4189 Hydrae and which subsequently received the official GCVS designation V371 Hya.

SS Cru was discovered on the Sydney Observatory Plates and reported by Harley Wood (who would later to become NSW Government Astronomer at the Sydney Observatory) in the Circulars of the Union Observatory, Johannesburg, May 1920 as a star of photographic range 12.8 to fainter than 15 but with no type, period or epoch for maximum and there was apparently no follow up during the subsequent 80 years.

SS Cru was added to my working list in March 2000 and the first positive sighting was not until 4 months later on July 19 and at a position somewhat different to the catalogue position. This detection was reported through the VSNET of Kyoto University (vsnet-chat 4695, 2001 Aug 05).

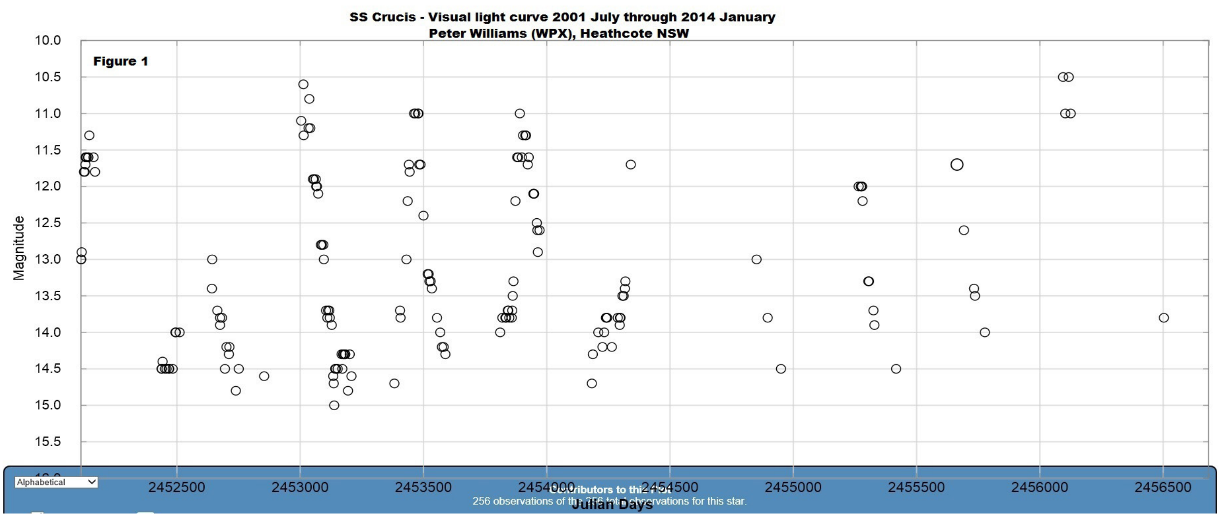

Figure 1. *Visual light curve of SS Cru, obtained at Heathcote NSW, on which is shown only the positive observations.*

During the following 7 years through to 2014 January a total of 249 observations were made and reported to the AAVSO. For clarity only the positive data points of those 249 observations have been plotted here as the light curve in Figure 1 from which a mean cycle of 443.6 days is evident, with the usual cycle to cycle variations typical for long period Mira stars.

Figure 2 also displays the upper limits (negative or fainter-than observations) and these exclude the possibility of a shorter mean cycle that could occur due to a seasonal gap in the data. The visual range of 10.5 to fainter than 15 is evident.

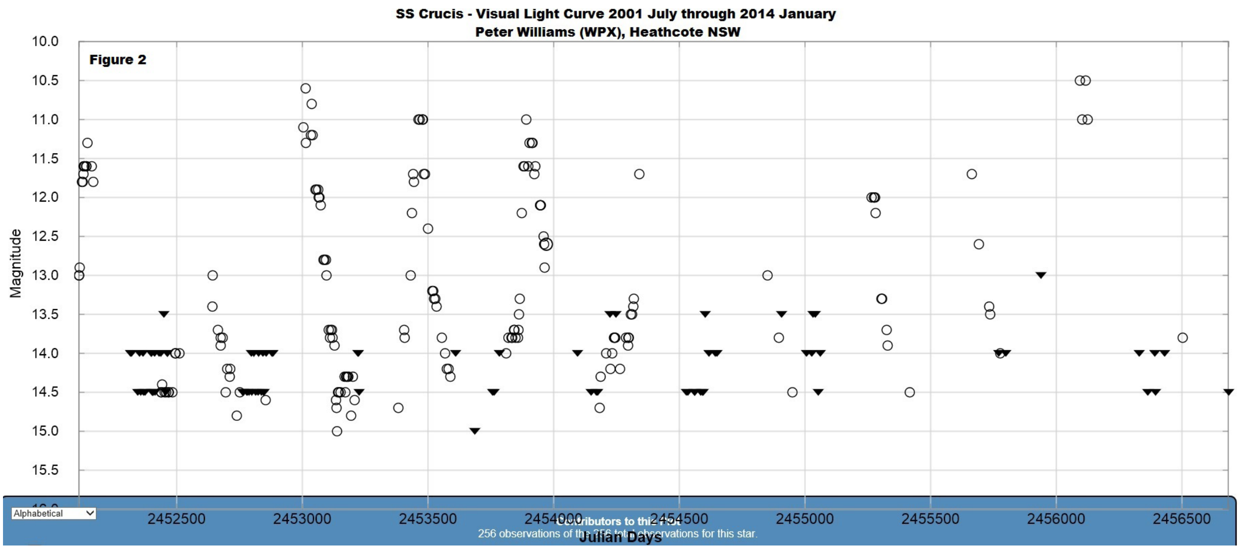

Figure 2. *Visual light curve of SS Cru, obtained at Heathcote NSW, showing both positive magnitude measurements and upper limits where the star was invisible and fainter than the value shown*

V-magnitudes for the lettered comparison stars were kindly measured by Colin Bembrick at his Mount Tarana Observatory, Napoleon Reef, NSW and have been added to the AAVSO chart shown here as shown in Figure 3.

The intention was to publish the results for SS Cru and other similar 'unloved' southern Miras through either the Variable Stars South of the RASNZ or the AAVSO, thus continuing the series of results for stars previously published.

However, by the time sufficient visual data had become available for these stars there were a number of automatic sky surveys, both professional and amateur, in full swing with data mining quickly filling in the missing catalogue detail and, unfortunately, causing enthusiasm to quickly wane and the observation focus change to other stars. But looking back, stars from this programme for which results had been earlier published include Cd-62 466 Car, DI Car, IY Car, V600 Car, YY & NSV19431 Cen, T CMa, EO Eri, SW Hor, V371 Hya, X Mus and V407 Sco, so the effort put into this modest programme has certainly not been without achievement.

And just quickly eyeballing several of the other dozen or so unloved southern Miras from that long ago programme it is apparent that some may not be behaving as expected from the current VSX detail. So perhaps there is still more to be done with these visual observations as we keep in mind that the catalogue data is only as good as the updates and observations available at any given time.

In the case of SS Cru, it is both interesting and satisfying to note the above mean visual period and magnitude range are in good agreement with the 441 days and 10.2 to fainter than 14V currently listed for SS Cru in the VSX of the AAVSO, and to also wonder what the student who downloaded the observations is planning or hoping to achieve when analysing the data.

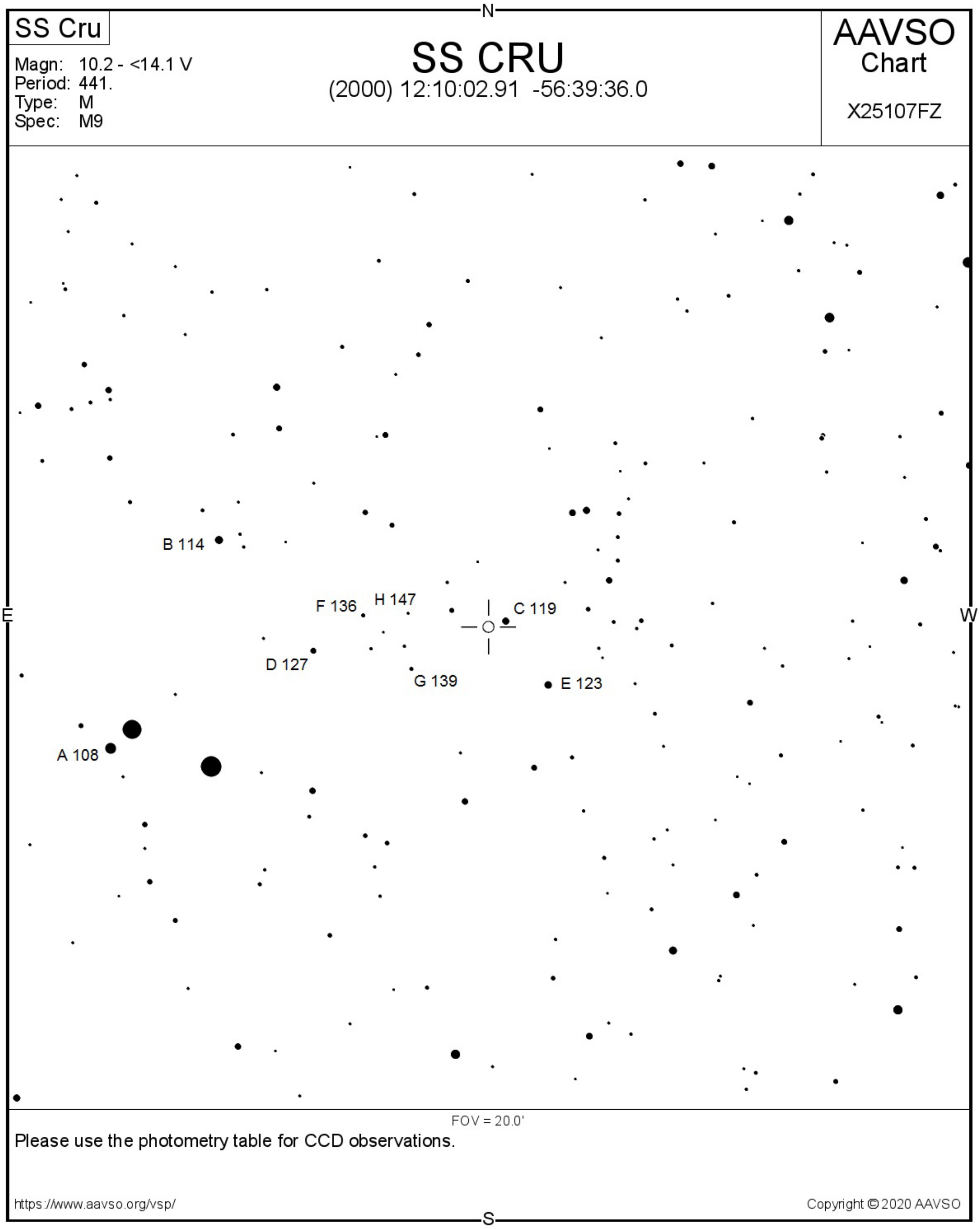

Figure 3. *AAVSO finding chart with comparison star V-magnitudes as supplied by Clin Benbrick.*

Publications watch

Carl Knight and Phil Evans are both co-authors on a new paper accepted for publication in Monthly Notices of the Royal Astronomical Society.

Baluev, R.V. et al. "*WASP-4 transit timing variation from a comprehensive set of 129 transits.* arXiv:2004.09109.

Abstract

We homogeneously re-analyse 124 transit light curves for the WASP-4 b hot Jupiter. This set involved new observations secured in 2019 and nearly all observations mentioned in the literature, including high-accuracy GEMINI/GMOS transmission spectroscopy of 2011-2014 and TESS observations of 2018. The analysis confirmed a nonlinear TTV trend with $P/|\dot{P}| \sim (17-30)$ Myr (1-sigma range), implying only half of the initial decay rate estimation. The trend significance is at least 3.4-sigma in the agressively conservative treatment. Possible radial acceleration due to unseen companions is not revealed in Doppler data covering seven years 2007-2014, and radial acceleration of -15 m $s^{-1}yr^{-1}$ reported in a recent preprint by another team is not confirmed. If present, it is a very nonlinear RV variation. Assuming that the entire TTV is tidal in nature, the tidal quality factor $Q'_* \sim (4.5-8.5) \cdot 10^4$ does not reveal a convincing disagreement with available theory predictions.

About

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

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

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

VSS is entirely an internet based organisation, working through our website http://www.VariableStarsSouth.org and its e-group http://groups.google.com/group/vss-members. It also encourages members to work in with major international organisations such as the British Astronomical Association, the Center for Backyard Astrophysics and the American Association for Variable Star Observers.

To find out more, please visit our website, where, incidentally, you will find PDF copies of all our newsletters. Our website has a great deal of information for VSS members, and for anyone interested in southern hemisphere variable star research. All VSS project information and data is kept here too.

Who's who

Director Mark Blackford

Treasurer/Membership Bob Evans

Newsletter Editor Phil Evans

Webmaster David O'Driscoll

Visit our website to see a list of our area advisers, and to find out about our projects and how to contact their leaders

Membership

New members are welcome. There is no annual subscription but donations would be gratefully received. Find out how to join by visiting the VSS website. There you will find out how to join by post, email, or directly online. If you join by email or online and wish to make a donation you will get a link to pay by PayPal's secure online payment system, from your credit card or bank account.

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

Newsletter items

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

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

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