# Variable Star Photometry at West Challow Observatory

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**Abstract**

This paper describes the facilities and observing programme of a small personal observatory set up in the UK for CCD photometry of variable stars. Its development has been driven by the belief that committed amateurs can make a valuable scientific contribution to the study of variable stars. Observing projects carried out at WCO are described including examples of Pro-Am collaboration and contributions to the observing programmes of the BAAVSS, AAVSO and CBA.

## 1. Introduction

As someone with a scientific background, I have always been interested in the potential of amateur astronomers to make scientifically useful contributions to the subject. The availability of affordable CCD cameras coupled with computer controlled telescopes offered me the opportunity I had been looking for. After investigating various possible areas I finally settled on measuring variable stars.

I live in the centre of southern England in a region called the Vale of the White Horse. It is named after a Bronze Age stylised representation of a horse, about 375 feet long, carved into the chalk on a nearby hillside some 3000 years ago, no one really knows why. The countryside is a shallow basin formed over millennia by the River Thames which flows through the Vale. The climate is generally mild, it rarely goes below –5C, and the weather is consistently variable. My observing log shows that during 2005 I recorded usable images on 115 nights, while in 2006 the figure was 96 nights.

## 2. Equipment

West Challow Observatory, named after my small village of about 50 houses which is listed in the Doomsday Book of 1086AD, was originally established in 1998 after many years of using portable telescopes for purely visual observing. It has been equipped in turn with a 0.06-m refractor, 0.1-m and 0.25-m Newtonian reflectors and now a 0.35-m SCT, all on pier-mounted GEMs and housed in a simple run-off shed. The 0.35-m is equipped with a JMI remote-controlled focuser, an Optec 2x focal reducer, a True Technology filter wheel with Schuler BVI and Clear filters, and a dew heater (Figure 1).

**Figure 1: 0.35-m SCT with SXV-H9 CCD camera**

I use Starlight Xpress cameras, originally a HX 516 and now a SXV-H9. They have the useful characteristic of extremely low and virtually exposure-independent dark current. The SXV-H9 camera is normally used in 2x2 binned mode which gives a field of about 16x12 arcmin and a pixel size of 1.4 arcsec/pixel. Seeing at the site is typically in the range 3-5 arcsec FWHM. All cables run underground into a small hut which is the observatory ‘control room’ containing power supplies, computer, etc. The mount is controlled using Guide and the camera and filter wheel with AstroArt. Focusing is controlled manually and regularly monitored during a long run to correct for thermally induced changes in the position of the focal point. Flat fielding is carried out using a white screen illuminated with a fluorescent lamp and imaged through a translucent sheet. Comparisons with sky flats indicate that the differences are acceptably small (resulting magnitude differences are <0.005).

## 3. Data analysis

When I started I found analysing time-series of images manually a real chore. A conversation with Richard Berry at the British Astronomical Association (BAA) Winchester conference in 2000 brought relief, AIP4WIN was about to be launched. It would be hard to underestimate the empowerment this software has brought to amateur CCD photometrists at modest cost. However it also created another problem: how to use the output files of measurements which it produced. I started developing an Excel spreadsheet for this which eventually grew into a family of tools for analysing both filtered and unfiltered observations, including transformations where appropriate, and for calculating differential magnitudes with as realistic an estimate of the error as possible. This was later extended by Andy Wilson, an experienced VB programmer, to include macros which made it more user friendly. It has been widely distributed and used within the BAA Variable Star Section (BAAVSS) [2].

With the advent of AIP4WIN v2 [1], and the possibility of easily measuring multiple comparison stars, I re-engineered the spreadsheets to implement a version of weighted ensemble photometry. The methodology for doing this is the subject of a poster paper at the symposium. This revised spreadsheet has also been enhanced by Andy and distributed to users running AIP4WIN v2.

Besides calculating magnitudes and errors, the spreadsheet produces several plots (Figure 2). These show the derived magnitudes and errors for the variable and each of the comparison stars and also the behaviour of the mean image zero point and its error during the run, a good way of spotting changing conditions and problem images. Variation of a comparison star by only a few hundredths of a magnitude is usually apparent enabling it to be eliminated from the ensemble. The spreadsheet also generates the output formats required by the BAAVSS, the American Association of Variable Star Observers (AAVSO) [3] and the Centre for Backyard Astrophysics (CBA) [4].

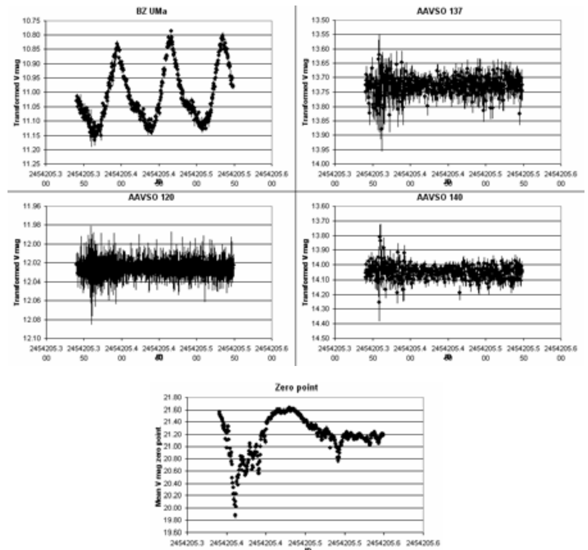


**Figure 2: Variable and comparison light curves and image zero point plot**

As a general rule, I carry out at least a preliminary analysis of all my observing runs as they progress to ensure that everything is working properly, that focus is being maintained, and to check what the variable is doing. It is quite exciting to think you might be the first person ever to see superhumps in the light curve of a particular dwarf nova. For a few minutes, until you email your discovery to others in the community, you are the only person in the world who knows the true nature of that star.

## 4. The Learning Curve

Developing the necessary skills in CCD photometry has been a gradual learning process. Understanding calibration and filter transformations, and developing consistency in operating equipment and analysing data, eventually builds confidence that the variations you see are intrinsic to the object being observed, subject of course to the inherent limitations of your equipment, the observing conditions and statistical uncertainty. Under reasonable conditions with an unfiltered 60 sec exposure I find I can measure mag 14.5 stars with SNR ~100, mag 16 with SNR ~50 and mag 17 with SNR ~20. A V-filter reduces these figures by around 1 to 1.5 mags. I have tried to capture my experiences in climbing this learning curve in a Beginners' Guide to Measuring Variable Stars which is published by the BAAVSS [5].

Once you are regularly submitting observations to one of the international variable star databases, the logical next step is to consider publishing an analysis of your results. This is a good way to teach yourself about the current state of variable star research since you have to present your results within the context of existing knowledge and previous published work. I have also found it a good way of developing working relationships with other observers since combining the results of several observers will almost always produce a better and more complete analysis.

## 5. Observing Programme

The observing programmes of the BAAVSS, AAVSO and CBA offer a wide variety of observing challenges sufficient to exercise the skills of any observer. Like all beginners I dabbled in various ventures but have gradually migrated towards generating time-series light curves for various purposes including planned collaborative research programmes and observing targets of opportunity. The ability to switch immediately to observing a new target such as a just-announced outbursting CV without reference to a telescope allocation panel is one of the benefits of being an amateur astronomer.

In the remainder of this paper I will briefly mention five areas in which I have been active recently:

1) monitoring ephemerides of eclipsing SW Sex stars;
2) measuring periods in outbursting dwarf novae;
3) following the decline of novae;
4) discovering new variable stars;
5) developing comparison star sequences.

## 6. Monitoring Ephemerides of Eclipsing SW Sex Stars

Among the CVs found by the Hamburg Quasar Survey team are several SW Sex variables, some of which are eclipsing [6]. It is now some time since the ephemerides of these stars were first measured. In the course of writing a new paper on them, the team wanted to check whether the original ephemerides were still accurate. At the request of Dr Boris Gaensicke at Warwick University, I measured eclipse timings and compared them with predictions to see whether there was a discrepancy. These observations were made unfiltered to maximise signal-to-noise in the light curve.

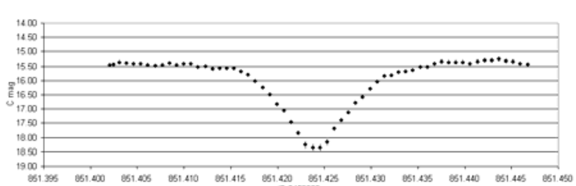


**Figure 3: Eclipse light curve for HS 0728+6738**

Figure 3 shows a typical eclipse light curve from which the time of minimum is extracted by a quadratic analysis, if necessary corrected for asymmetry in the shape of the eclipse. A heliocentric correction is then applied to the observed time. In most cases the time of minimum could be determined with a precision better than 20 sec.

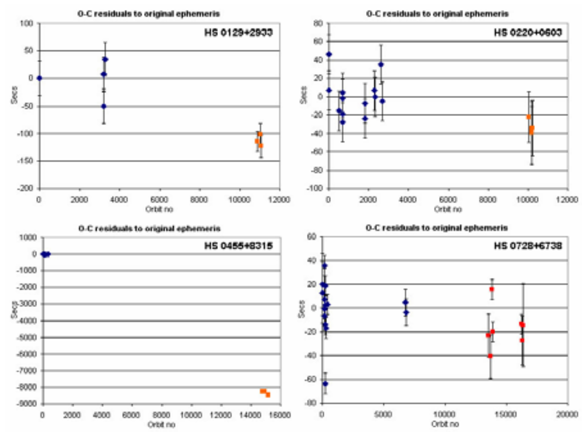


**Figure 4: O-C diagrams for 4 eclipsing SW Sex stars**

Figure 4 shows O-C (observed minus calculated) diagrams of the difference between the observed and predicted times of eclipse for four of these variables. The data points to the left of centre are those used to determine the original ephemerides, those to the right are my measurements. It was clear that in all these cases the published ephemeris needed to be revised, in most cases by a small amount but in one case substantially. The updated values are included in a paper currently being published [7]. This project is continuing and being expanded to check the ephemerides of a larger set of eclipsing SW Sex variables. It appears that many of those will need to be updated. In the longer term, we will also be looking for any departure from a linear ephemeris in these stars, as has been seen for example in OY Car.

## 7. Measuring Periods in Outbursting UGSU Dwarf Novae

The Sloan Digital Sky Survey has also been a fruitful source of new CVs. Many of these are faint in quiescence (~18$^{th}$ mag) but outbursts of eclipsing systems, when they occur, provide an opportunity to refine their orbital periods. An example of this is SDSS J170213.26+322954.1, for which the first photometry was obtained by Arne Henden at the USNO Flagstaff Station in 2003. At that time the orbital period was determined to be ~2.5 hrs. During its first observed outburst in 2005, by measuring the times of 13 eclipses and combining these with

Henden's original observations, Arto Oksanen and I were able to refine the orbital period to a precision of about 1 msec. We also detected superhumps and measured their period and so were able to calculate ε, the superhump period excess for this system [8]. There are various published empirical relationships between ε and q, the mass ratio of the binary, which then enable q to be estimated.

It is always exciting to make the first observation of superhumps in the light curve of a CV in outburst as this confirms its UGSU classification. During the past year I have been fortunate to observe superhumps for the first time in V1316 Cyg, V337 Cyg, Var Cam 06 and SDSSp J082409.73+493124.4. The June 2006 superoutburst of V1316 Cyg was particularly well observed by the CBA community and a comprehensive report on this will shortly be published. Figure 5 shows the first observation of superhumps in V1316 Cyg.

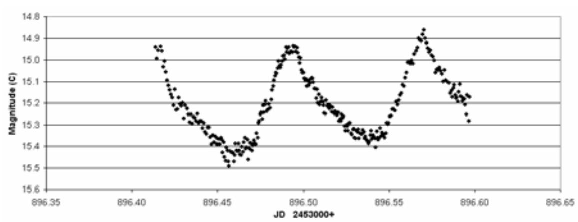


**Figure 5: Superhumps in V1316 Cyg on 2006 June 9**

By combining data from several observers it may be possible to measure the periods of both common superhumps, which occur in the early stage of an outburst, and late superhumps, which have a slightly shorter period and usually follow a change in phase of the superhump signal. Tonny Vanmunster's period analysis software Peranso [9] has been invaluable in enabling these analyses. It is the accessibility of software such as this, previously only available in professional astronomical software suites, which has empowered today's amateur astronomers to be able to make scientifically useful contributions.

An interesting recent observation was obtained during the first and long-awaited superoutburst of the dwarf nova BZ UMa in April 2007. At the peak of the outburst on 14 April, when the superhump amplitude was greatest at ~0.3 mag, the V–Ic colour index apparently varied in phase with the superhumps in V and Ic with amplitude ~0.02 mag becoming bluer at the superhump peaks and redder in the troughs. The superhump period in V on that day was 0.0702+/-0.0008d. Figure 6 shows light curves in V, Ic and V–Ic. At the time of writing, analysis of the data from this superoutburst continues.

An additional benefit of performing long time-series runs is the ability to use them to analyse the flickering behaviour of CVs. This stochastic process is believed to be associated with irregularity in the transfer of material either into or out of the accretion disc. The scalegram analysis technique described by Fritz and Bruch [10] has been applied to my data for several CVs by Chris Lloyd of the Open University. The slope and height parameters α and Σ which characterise the flickering behaviour of a CV can be determined from the scalegram. When plotted in α – Σ space, different types of CV tend to fall into distinct clusters, thus providing an additional clue to the nature of an unclassified CV. Figure 7 shows a scalegram containing several time-series runs on V1363 Cyg (sloping lines) together with a comparison star from the same images (horizontal lines). The positive slope of the lines for V1363 Cyg indicates that it generates more flickering power at longer rather than shorter timescales.

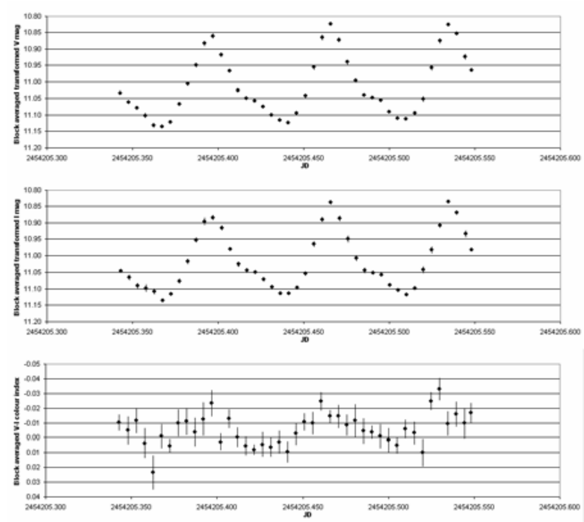

**Figure 6: Light curves in V, Ic and V–Ic for BZ UMa on 2007 April 14 (each data point is an average of 10 measurements, 2 cycles are shown)**

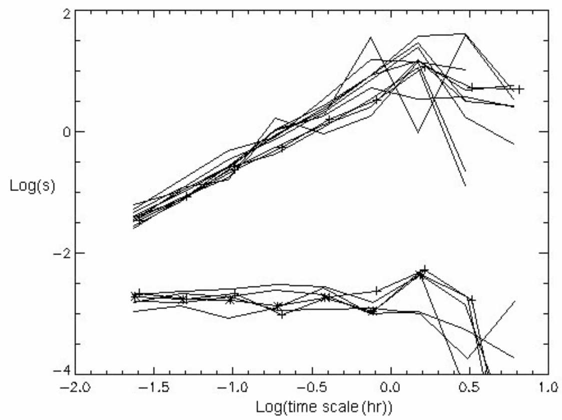


**Figure 7: Scalegram for V1363 Cyg (upper lines) and a comparison star (lower lines)**

## 8. Following the Decline of Novae

It is both interesting and useful to follow the decline of novae as every one is different and often they do unexpected things. A recent example is V2362 Cyg which peaked around mag 8 in April 2006 then declined rapidly for 3 months before rising and declining again. 12 months later, it remains 5 magnitudes brighter than its expected quiescent level. Nova experts are still debating what might be going on in this system. Using filters to observe at more than one wavelength, it is possible to detect colour changes which indicate physical processes such as the emission of dust.

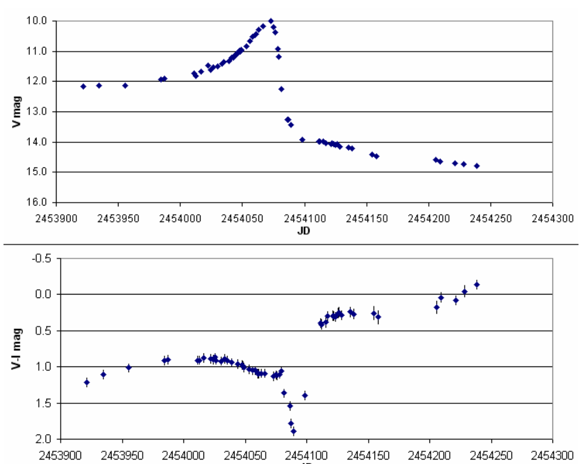


**Figure 8: V light curve and V–Ic colour index for V2362 Cyg**

Figure 8 shows my measurements of the V magnitude and V–Ic colour index of the nova since June 2006. Magnitudes have been corrected to account for the nearby mag 15 star which is also included within the photometry aperture. There was an emission of dust in early December (JD ~2454075) which produced a rapid fading and a temporary reddening in the colour index.

## 9. Discovering New Variable Stars

It is not unusual to find that comparison stars in a variable chart originally developed for visual use are actually variable at the level of a few hundredths of a magnitude. One advantage of using several comparison stars is that this low level variation may be recognised and the variable comparison star not used if high accuracy is required.

One example I found in 2005 was GSC 3132-1448 in Lyra (RA 19h 06m 46.60s, Dec +44° 01′ 46.30″, J2000) which is the star marked 131 in the AAVSO chart for MV Lyr. This appears to be an eclipsing binary of magnitude 13.1V with a primary eclipse depth of ~0.2 mag and the intriguing (and rather frustrating) period of 7 days +/- 1 min (Figure 9). Tom Krajci and Bart Staels have helped me put this light curve together. Efforts to confirm its nature by getting observations of the secondary eclipse continue.

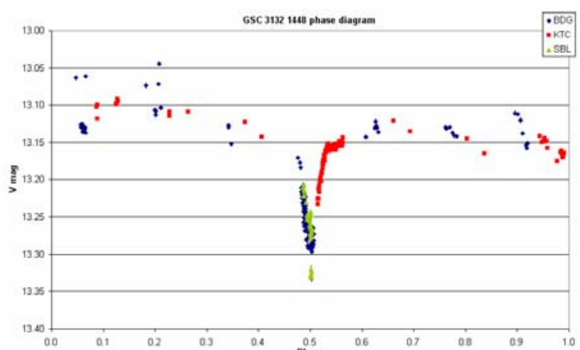


**Figure 9: Phase diagram for GSC 3132-1448**

Another is the star TYC 3181-1907 in Cygnus (RA 21h 11m 44.99s, Dec +44° 45’ 30.4”, J2000) which has been marked as a comparison star in some charts for the nova V2362 Cyg. I obtained several long runs on this star over a 6 month period while looking (unsuccessfully) for periodicity in the nova. Its mean magnitude is 11.63V and its V-Ic colour index is 0.46. Arne Henden had also collected about 250 measurements of the same star which he kindly gave me. Period analysis of all of this data shows that it has a full amplitude of ~0.08 mag and a likely period of 2.92 days. Figure 10 shows a phase diagram assuming this period.

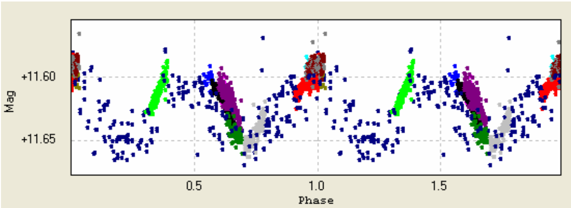


**Figure 10: Phase diagram for TYC 3181-1907**

## 10. Developing Comparison Star Sequences

Improving existing charts and developing comparison star sequences for new variables is an important and ongoing task. Observers with filters who are able to transform their results to the standard Johnson-Cousins photometric system can contribute to this work. As conditions in the UK are rarely suitable for all-sky photometry, I have used Hipparcos stars whose derived Johnson V magnitudes are accurate to around 0.01 mag to define zero-points in V [11]. This is good enough to produce charts for visual use. As this activity usually involves comparing measurements with other experienced observers, it is a good way to build confidence in your observing technique and to fine tune your analysis procedures.

## 11. Conclusion

Developing the necessary skills and observing procedures to measure variable stars using CCD photometry is a very enjoyable but quite demanding challenge. The more you learn, the more you realise there is to learn. However, well motivated amateurs prepared to invest the effort can contribute much to the science of variable stars and derive great satisfaction in the process.

## 12. Acknowledgements

I gratefully acknowledge the support and encouragement of many colleagues, too numerous to mention individually, in all of the organisations mentioned in the paper. Without their willingness to share their experience, I would have taken much longer to climb the learning curve. My thanks are due also to several professional astronomers including Boris Gaensicke, Chris Lloyd and Arne Henden who have taken time to point me in useful directions and provide invaluable advice.

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## 13. References

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