Variable star photometry with a DSLR camera

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Introduction

In recent years it has been found that a digital single lens reflex (DSLR) camera is capable of accurate unfiltered photometry as well as V-filter photometry.[1] Undriven cameras, with appropriate quality lenses, can do photometry down to magnitude 10. Driven cameras, using exposures of up to 30 seconds, can allow photometry to mag 12.

The cameras are not as sensitive or as accurate as CCD cameras primarily because they are not cooled. They do, however, share some of the advantages of a CCD as they have a linear response over a large portion of their range[1] and their digital data can be accepted by software programmes such as *AIP4WIN*.[2] They also have their own advantages as their fields of view are relatively large. This makes variable stars easy to find and an image can sometimes incorporate several stars of interest. The cameras can easily be used to analyse bright stars.

A V magnitude estimate can be made in fifteen minutes. V is the apparent magnitude of a star, determined by photometry, in a standard wavelength band in the yellow-green region, chosen to correspond with that to which the human eye is most sensitive. In the widely used Johnson photometry system, the filter used to measure V magnitude has a central wavelength of 5450Å and a bandwidth of 880Å. The fifteen minutes includes taking twenty 5-second images and analysing the images on a computer. An unfiltered estimate can be done in under ten minutes.

With care and in good conditions photometry using a DSLR can be done to an accuracy of 0.02 mag. This can be achieved by studying images with the photometric tools of *AIP4WIN* and working out the camera settings to achieve the best possible signal to noise ratio (SNR). When the *AIP4WIN* Single Image Photometry tool is used to make an instrumental magnitude estimate of a star it will state the SNR in the pop-up box. For good quality photometry the reported SNR should be over 100.

Eclipsing binaries are observed in order to make estimates of mid-eclipse, which then enable a calculation of the current period of the system. Changes in period can be studied. The greater accuracy of DSLR photometry compared with visual methods enables improved determinations of the time of mid-eclipse. Another advantage of the DSLR approach compared with the visual is that the images can be archived.

DSLR photometry opens a new world of observation to amateur astronomers in the sense that a large number of bright variable stars with variations under 0.5 magnitude can now be studied. I have used the method to create lightcurves of stars with an amplitude of under 0.2 magnitudes.

Equipment

Canon 350D/450D DSLR cameras are suitable for photometry. My experiments suggest that the cameras should be used with quality lenses of at least 50mm aperture. This allows sufficient light to be gathered over the range of exposures that are possible with an undriven camera. For bright stars (over mag 3) lenses of smaller aperture can be used. I use two excellent Canon lenses of fixed focal length. One is the 85mm f1.8 lens which has an aperture of 52mm. This allows undriven photometry down to mag 8. The second is the 200mm f2.8 lens with an aperture of 72mm, which allows undriven photometry to about mag 10. The camera and lens are mounted on a sturdy tripod. A remote switch (Canon RS60-E3) should be used to prevent camera shake. It is possible for the camera to be remotely controlled from a PC via the connecting cable and the EOS utility software supplied by Canon with the DSLR. The camera mirror can also be set in the locked up position which helps to reduce vibration.

Christian Buil provides useful information on DSLR cameras on his website 'Observations and Tips,'[7] though some of his articles remain to be translated into English. A translation of his article 'DSLR High Precision Photometry' can be found on the Citizen Sky website.[8] It will be noted that Buil's article was written in 2005.

The images of the target variable star and comparison are interpreted on a PC using the software package *AIP4WIN* version 2.[2] This program opens the RAW images produced by a Canon camera which can then be analysed using the program's multi image/deep sky stacking facilities and its photometric tools.

Methods

Through experience it has been found that accuracy is severely affected by windy conditions which vibrate the camera and tripod, and by atmospheric turbulence and light pollution when the target stars are less than 30° above the

horizon. Ideally, if it is a practical option, images are made when the target star is above 40°. With these qualifications reasonably accurate measurements can be made from a suburban setting. A dark sky site is not a necessity. If observations are made from a dark sky site then good estimates can be made when the target star is above 20° altitude but a correction for atmospheric extinction is then required.

Better images result if the camera and lens can reach thermal equilibrium with the outside environment. The camera should be put out for 20 or 30 minutes before imaging. This is more important when using larger lenses (such as a 200 or 400mm) and on a Scottish winter night when the difference in temperature between inside and outside can be over 20°C.

Accompanying the *AIP4WIN* software is *The Handbook of Astronomical Image Processing* by Richard Berry & James Burnell.[2] A study of this book suggests the right way to go about acquiring quality images. The suggestions have been well confirmed by experiments. The images have to be in RAW format as the JPG format does not retain enough photon information. A reasonable estimate needs at least the average of ten images. If precision is very important then up to 50 images may be necessary.

A master dark frame must be constructed to be subtracted from each image to reduce thermal noise. A master dark frame is made from ten dark images. These are images taken with the camera capped, downloaded to the PC and stacked with *AIP4WIN* to produce the master dark frame. A separate master dark frame is required for each camera exposure time used. I use sets of dark frames for a week or two and then change them as the outside environment either warms or cools.

In theory it is advisable also to construct master flat field frames in order to remove the effects of the edge distortions of the lens. I have found, however, that the field of view of a DSLR is so wide that a flat field is not required, if you are using high quality lenses, provided the target star and comparison are in or near the centre of the field of view. Stopping down the lens (as part of the process to get the right amount of light) also minimises lens distortion around the edges of the image.

A lot of thought has to go into the selection of a suitable comparison star(s) as only one or two are required. The comparison stars may already be suggested by a standard chart for visual observations. I always check the possible comparisons with the *Hipparcos* catalogue[5] to ensure that it really is non-variable or has just a very small variation. It is assumed that the correct magnitude of the comparison is the V magnitude quoted in the catalogue to one hundredth of a magnitude.

In many studies the comparisons listed on BAAVSS charts can be used with the magnitude listed on the chart. This is because the information required is the change in magnitude rather than the V magnitude. This is usually the case when observing eclipsing binaries.

Camera settings

For satisfactory results it is vital to get a signal to noise ratio (SNR) of over a hundred in the images of the target star and the comparison.[1] This is achieved by adjusting the camera settings. For studying a star such as ρ (rho) Cas (magnitude variation 4.1 to 6.2) I used, with an 85mm lens, the settings of ISO 800, f3.5 and an exposure of 5 seconds. These settings result in an SNR of around 220 when the star is mag 4.8, dropping to 100 if the star fades to mag 6. For ε (epsilon) Aur (mag 3 to 3.8) I used, with an 85mm lens, settings of ISO 200, f4.5 and an exposure of 5 seconds. These result in an SNR of 140. I changed the ISO for ε as otherwise *AIP4WIN*'s photometry tool recorded the image as being oversaturated at ISO 800. In my experience a higher ISO results in higher SNRs (and saturation if it is too high).

For the eclipsing binary U Cep, which fades to a magnitude of around 9.1, I used, with a 200mm lens, the settings of ISO 800, f2.8 and an exposure of 3.2 seconds. Each setting is usually good over a range of 2.5 magnitudes.

The maximum exposure possible with an undriven camera (to avoid unacceptable blurring), using the 85mm lens, is 6 seconds unless you are working relatively near to the celestial pole, when longer exposures are possible. As a general rule it is best to go for the longest possible exposure since this markedly improves the results by reducing the effect of scintillation. The usual maximum exposure with an undriven 200mm lens is 2.5 seconds.

If one is following the fade of an eclipsing binary over a range of more than 2½ magnitudes, it will be necessary to change the settings to catch more or less light as appropriate by altering the aperture stop of the lens. In particular, it is essential to avoid saturating any of the pixels in the stellar images. As a general rule of thumb it is best to keep pixel values to less than 50% saturation.

Slightly defocusing the image enables a better photometric analysis of stars. This ensures that light from the star is not modulated by the sensor structure within the camera. Special care has to be taken to achieve the right amount of
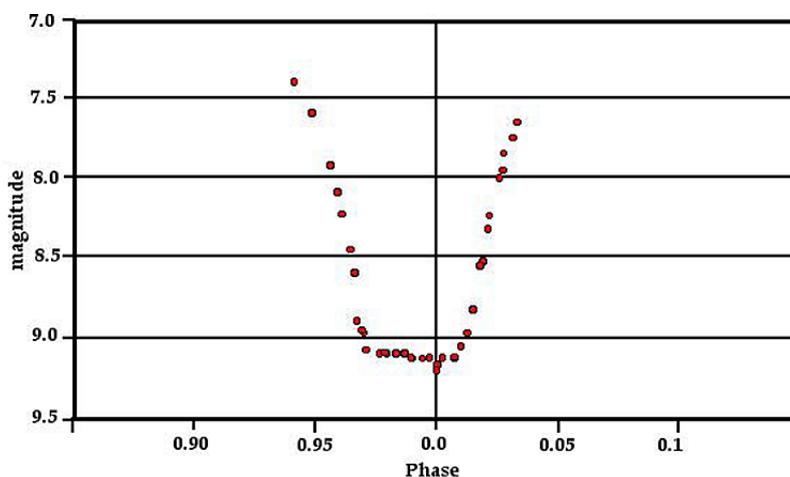

Figure 1. **Observations of U Cep by the author in 2009 January–February. The 0.0 point of the phase axis (the predicted time of mid-eclipse) is based on the latest Krakow period of 2.493121 days.**

defocusing. One cannot completely rely on the infinity setting of a camera to judge the amount of defocusing. The point of infinity setting will vary slightly as the lens expands and contracts in response to the ambient temperature. The variation is greater with a larger lens.

Finding the target star

One drawback with these camera models is the viewfinders, which were not designed with astronomy in mind and are not very good for finding the target star. Only bright stars can be seen. The target star and comparison(s) will usually be invisible. When first imaging a target one usually has to take several images of the general area and examine them on the computer to work out how much the camera needs to be adjusted in order to centre the target star. For cameras possessing the LiveView facility, it is very much easier to see and focus on the brighter stars. A description of the LiveView facility for the Canon 40D, which is similar to the 450D, is given on Christian Buil's website.[6]

Once the target has been imaged several times one soon learns how, by eye, to offset the camera correctly from a bright star. Similarly one learns the right movement of the camera between image sets to compensate for the rotation of the Earth.

The field of view of the 85mm lens is so large that little adjustment is necessary. Two or three sets of images can be taken ten or fifteen minutes apart. The field of view of the 200mm is significantly smaller and more care has to be taken particularly near the celestial equator.

Experience suggests that never more than three sets of ten images should be taken without checking on your PC to ensure that the target stars are centred. It is too easy to make errors as the night draws on.

Results

U Cep

Figure 1 shows recent observations (2009 January) of the eclipsing binary U Cep using DSLR photometry. The figure presents a light curve of estimates collected on three different nights. The estimates have been combined in a phase diagram. Each point on the figure represents the average magnitude after an analysis of ten images. Each estimate is unfiltered and is not a V estimate. There is no need to use a V filter when the main objective is to time the midpoint of an eclipse, since the shape of the light curve will be similar with and without a filter.

The current stated period of U Cep, which varies in eclipse from mag 6.7 to 9.2, is 2.493121 days. If this period is correct then the midpoint of the eclipse should have coin-
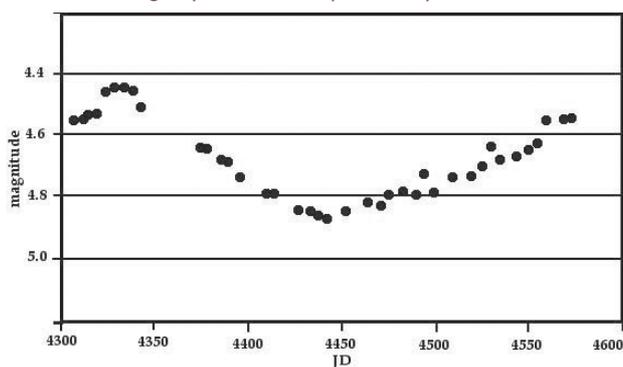

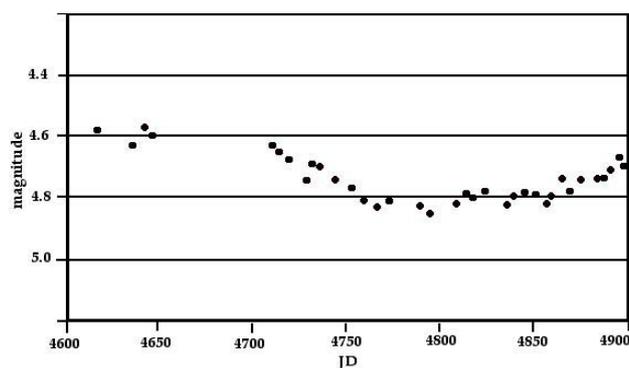**Figure 2.** Observations of ρ Cas over a 300-day period in 2007/2008.

Figure 3. Observations of ρ Cas over a 300-day period in 2008/2009.

cided with the vertical line. It can be seen that the midpoint is earlier than the predicted time. After a correction to take account of heliocentric time it worked out that the eclipse was about 30 minutes early, which corresponds to a new period of 2.493087 days. This period has now been accepted by the Krakow website[4] which provides information on eclipsing binaries.

ρ Cas

The approach described here is a useful backyard method suitable for amateur astronomers wishing to carry out V photometry, which provides improvements in accuracy compared to visual estimates. It can be used on brighter stars as well as on stars down to mag 10 without having to resort to a telescope with a drive. The set up is robust and easily transported. With experience the time spent in acquiring 10 images and producing a measurement of the magnitude can be less than 10 minutes.

I find the method particularly useful for constructing good lightcurves of eclipsing binaries, Cepheids and irregular variables. The increased accuracy can make a surprising difference to the quality of a lightcurve.

Figures 2 and 3 provide a record of unfiltered observations of the well known variable ρ Cas over a 600-day period between 2007−2009. Each point on the figures represent the average of ten images. It can be seen that there seems to be a period that approximates to the 320-day period stated in the GCVS.

V photometry

Hoot[1] describes how V photometry is possible with a DSLR. The light-sensitive chip within the DSLR is composed of an array of pixels which are individually covered by green, blue and red filters. This is necessary for high quality colour photography. Luckily the software that comes with the camera combined with *AIP4WIN* enables one to access the data recorded by every individual pixel. An image is produced from data that solely arrive through the green filters. The software produces what is called a 'green-channel image'. This can be stacked with other green-channel images and the stacked image analysed with *AIP4WIN*'s photometric tools.

The standard green filter used in Canon cameras is approximately equivalent to the Johnson V filter. To convert the estimates from green channel analysis to professional level V estimates one has to use a transformation coefficient (TC). The value of the TC has been worked out for my Canon 450D by comparing measurements of non-variable stars, taking into account the difference in their colour expressed as the (B−V) index. I used an ensemble of suitable stars near to lambda Aurigae to calculate the TC. A value of 0.15 was obtained for this particular camera.

V photometry of ε Aur, using green channel analysis, was carried out as part of an international campaign to monitor this unusual eclipsing variable. Five measurements of the star were obtained, each based on 20 images taken on the night of 2009 March 28 with the 85mm lens at an aperture of f4.5 using 5 second exposures at ISO 200.

The results were as follows:

20:36 UT	V= 3.095
21:09 UT	V= 3.097
21:57 UT	V= 3.106
22:03 UT	V= 3.081
22:30 UT	V= 3.097

The average of these five estimates is 3.095 with a standard error of 0.004.

Figure 4 shows observations of ε Aur between 2009 January−April. All the points represent the average of 20 images. The overall picture can be compared with CCD estimates on the website of the International Campaign to study the 2009−2011 eclipse of ε Aur.[3] From page 20 of Newsletter 11, which can be downloaded from the website, we see that the estimates record well a pulsation in the target star.

Conclusion

This article demonstrates that photometry of variable stars can be carried out successfully using a DSLR camera, yielding results 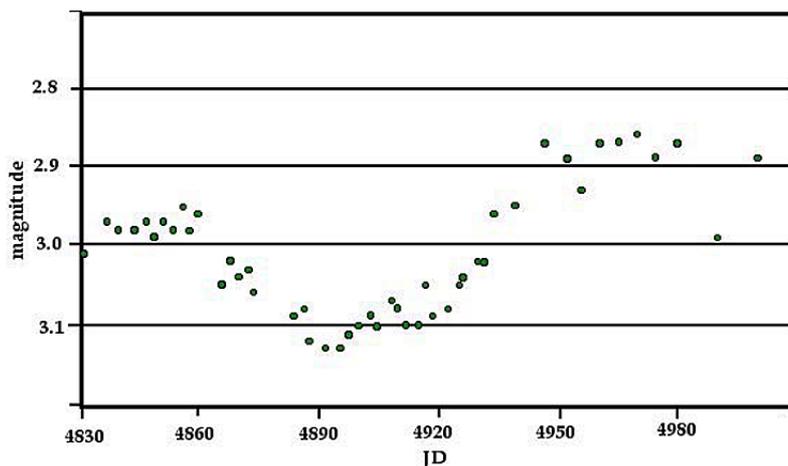which are significantly more accurate than visual estimates. The methodology permits the amateur to make accurate observations of a wide range of variables down to mag 10 without the need for a telescope or a drive. It has also been shown that accurate V photometry can be performed using the green channel image produced by the camera. More widespread use of DSLR cameras for photometry should permit more observers to study the variability of relatively bright stars, which until now have not attracted much attention amongst the amateur community mainly because their amplitude of variation, at less than 0.4 magnitudes, is too small to be followed visually.

Figure 4. Observations of ε Aur over a six-month period between 2009 January−June, showing out-of-eclipse variation.

Acknowledgments

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References

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4 **http://www.as.up.krakow.pl/o-c/data**>
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