OBTAINING SUCCESSFUL CCD LIGHT CURVES OF FAINT CATACLYSMIC VARIABLES

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Abstract

There are advantages and disadvantages to using CCDs for producing light curves of variables that were previously too faint to observe with photometers. With the availability of more data on fainter sources comes increased effort in data handling and reduction. Examples of light curves of 16th-20th magnitude cataclysmic variables obtained with a 36-inch telescope are shown. Some techniques that have proven helpful for maximizing the results on the short time scale variability of cataclysmic variables are discussed.

1. Introduction

As active mass-transferring close binaries, cataclysmic variables (CVs) provide an interesting array of variability to tantalize observers who are intent on pursuing their behavior at ever decreasing levels of brightness. With the better quantum efficiency of CCDs, hundreds of CVs are now accessible to moderate size telescopes (the 14- to 30-inch aperture range). The dilemma facing CV observers is how much to sacrifice the accuracy in the resulting magnitudes in order to observe the faintest objects. The decision for each night depends on the specifics of the project. For the case of the determination of the outburst state of a dwarf nova, which varies with an amplitude of several magnitudes on time scales of weeks to months, the magnitude need only be accurate to a few tenths of a magnitude on any night, so one long integration per object provides the necessary data. However, in pursuing the orbital variations of CVs, or the spin time scales of CVs with magnetic white dwarfs, which can involve repetition time scales as short as 15 minutes (spin) and 85 minutes (orbital), and amplitudes as small as a tenth of a magnitude, more care must be exercised to obtain a good combination of signal to noise and time resolution.

2. CCD Advantages

CCD arrays provide several unique advantages over photometers in obtaining magnitudes for CVs. A major advantage is that an observer does not have to wait for "photometric" sky conditions in order to obtain data. Relative photometry with respect to constant stars obtained on the same frames can produce a highly accurate differential light curve even when several magnitudes of clouds are present. Figure 1 shows published data on BY Cam (Szkody, Downes, and Mateo 1990) obtained under cloudy conditions. In these cases, the only constraint is that there are sufficient photons remaining to produce the desired accuracy. This generally means that the bright end of an observing program can be accomplished. If the surrounding stars have been calibrated during photometric conditions, the relative photometry on a cloudy night can be converted to absolute photometry. Efforts are now underway by several groups to obtain calibrated CCD fields for most CVs.

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A second advantage of CCDs is the possibility of observing much fainter objects, due to the better quantum efficiency (especially at visual to red wavelengths) and the fact that no aperture centering is required to obtain a measurement. If a telescope points well, the observer merely has to go to the correct coordinates and take a long exposure. Under dark sky conditions, a 36-inch telescope can accomplish orbital time resolution work on 20th magnitude objects, while a 14-inch telescope can work to 18th magnitude.

A third advantage of the CCD is the benefit to the observer. With no need to re-center or do sky measurements periodically, a long series of measurements can be started and the observer can go away (even sleep!) for 4-8 hours, if there is no rain in sight and if the telescope tracks well.

2. CCD Disadvantages

Since this is not a perfect world, there are some drawbacks to CCD use. As arrays become larger, the readout times become longer (over a minute for 1024 arrays) and the dead time between exposures may increase as images pile up on the disk. The net result of this problem is that it is not efficient to work on bright systems with large arrays, as the readout time is much longer than the integration time.

A second potential problem is that disks fill up quickly with large images obtained in a rapid integration mode over several hours. Large disk capacity is a necessity for light curve work.

Despite coatings and thinning of arrays, the UV response is still much lower than the visual and red. This is especially unfortunate for CVs, which have important phenomena (flickering, hot spots) occurring in the short wavelength part of the spectrum.

A problem that affects the efficient use of an observer's time is that it is not easy to determine how the source is varying in real time. There is no automatic comparable number to the total count rate provided by photometers. Thus, it is necessary to write or have access to software that selects an aperture and extracts a magnitude while a time series is progressing.

Lastly, the calculation of the accuracy of the data being obtained is not as straightforward as for a photometer (1 / square root N), since the read noise and the gain of the chip must be taken into account in order to convert the observed analog-to-digital unit (ADU) counts into an appropriate sigma. See Howell, Mitchell, and Warnock (1988) for a determination of errors in relative CCD photometry, and Newberry's review of signal-to-noise ratio in this volume.

3. Solutions

In order to maximize the use of CCDs for observations of rapid variability in faint CVs, certain strategies may be employed. For stellar sources, the large format is not necessary, so the array size may be reduced by binning the chip or by reading out only a portion of the array. A 150 x 150 array can be read out in only a few seconds. The small pictures also save disk space. The only constraint is to have an area large enough to contain at least 2 comparison stars in addition to the variable. There are also some software programs which extract and save only small areas around a few stars of interest, rather than the whole field.

In order to estimate quickly the correct balance between the source faintness and the time resolution for seeing conditions that extend over more than a pixel, a good rule of thumb is to use an integration time that gives a peak count rate of about 200 over the sky background. This usually results in a total count rate of a couple thousand and a resulting statistical error of a few percent. These levels easily allow the determination of variability of a few tenths of a magnitude on time scales of a few minutes. Some examples of the types of light curves that can be produced with the KPNO and CTIO 36-inch telescopes under these constraints are shown in Figures 2-5. Figures 2, 3, and 4 show orbital variations of dwarf novae and novalike variables, while Figure 5 shows the spin modulation detected for a magnetic CV.

References

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Howell, S. B., and Szkody, P. 1988, *Pub. Astron. Soc. Pacific,* 100, 224.
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Szkody, P., Howell, S. B., Mateo, M., and Kreidl, T. J. 1989, *Pub. Astron. Soc. Pacific,* 101, 899.

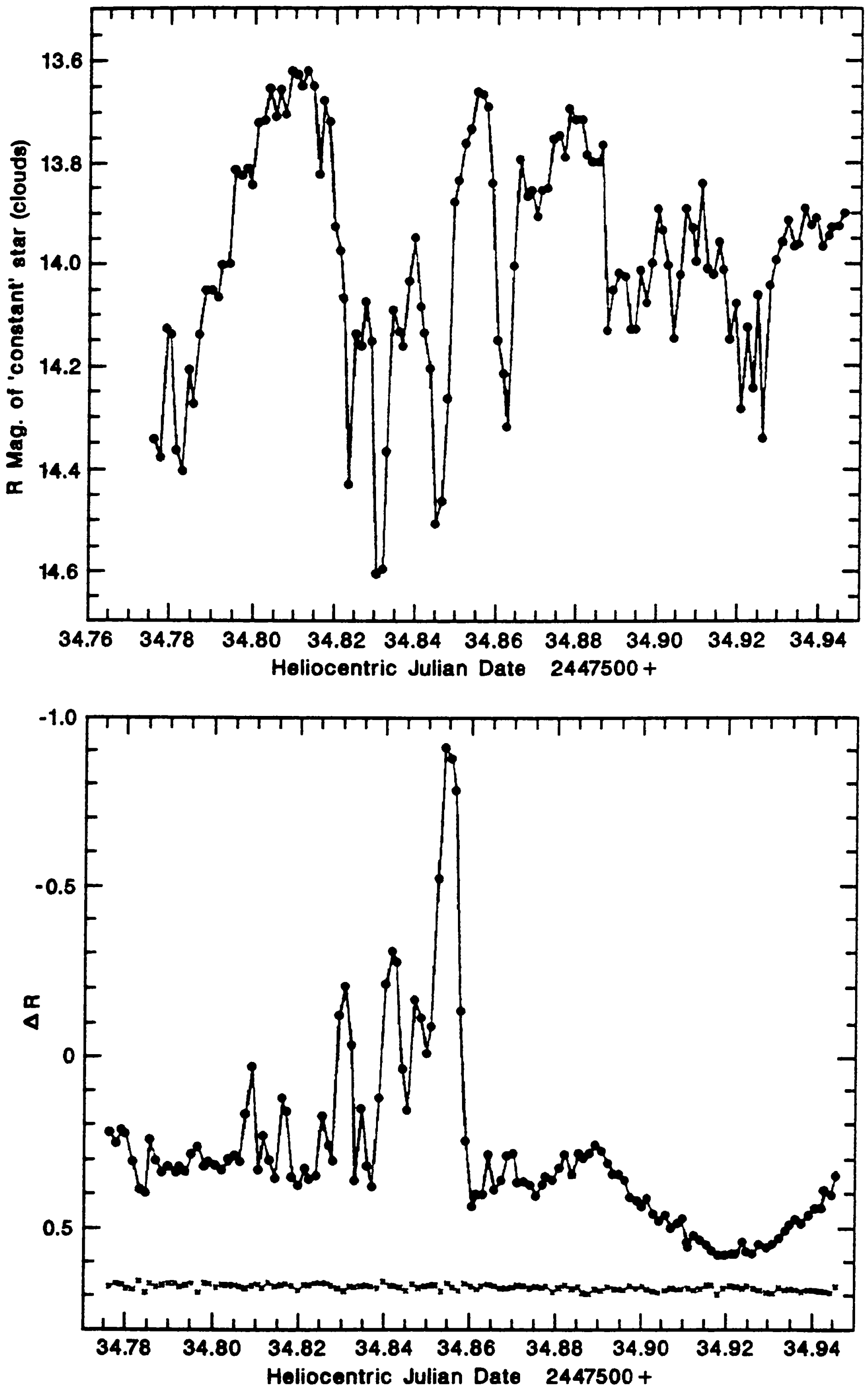

Figure 1. The top light curve shows the magnitude of a constant star during the course of observations, showing that up to one magnitude of variation from passing clouds was present. The bottom figure shows the differential magnitudes between two comparison stars (crosses) on the same frames, implying that the cloud removal is good to better than 1%. The resulting differential light curve of the 17.5 magnitude variable BY Cam shows a real light variation over its 3.3 hour orbit of over a magnitude. Taken from Szkody, Downes, and Mateo 1990.

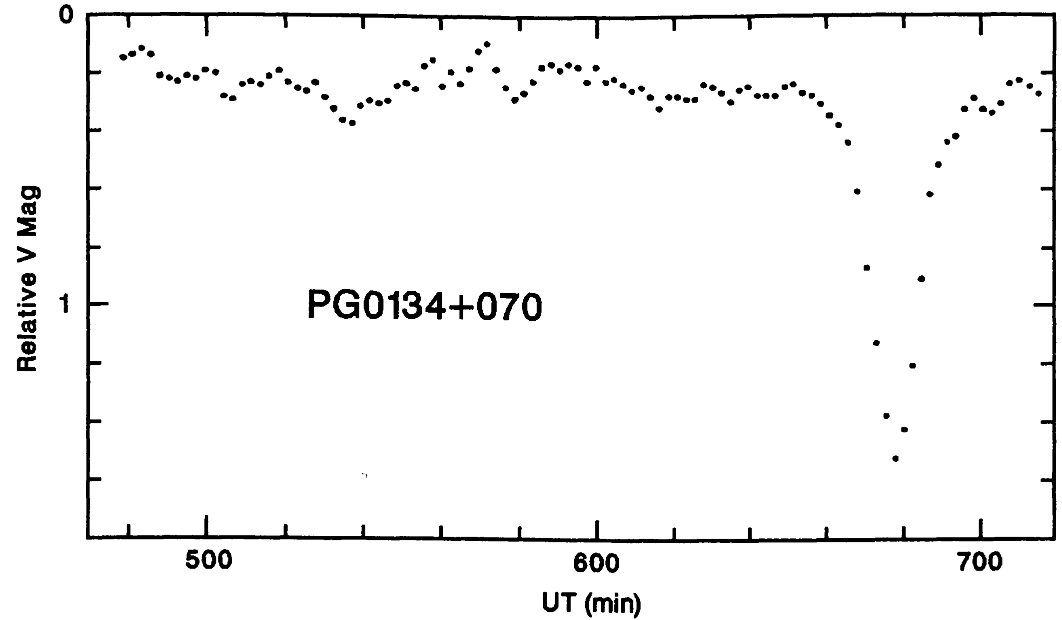

Figure 2. The differential V light curve of the V = 15.8 novalike variable PG0134+070 (= AY Psc), obtained with the KPNO 36-inch telescope using 2 minute integrations resulting in an accuracy of 0.01 magnitude. The light curve shows eclipses with a period of 5.2 hours. Taken from Szkody *et al.* 1989.

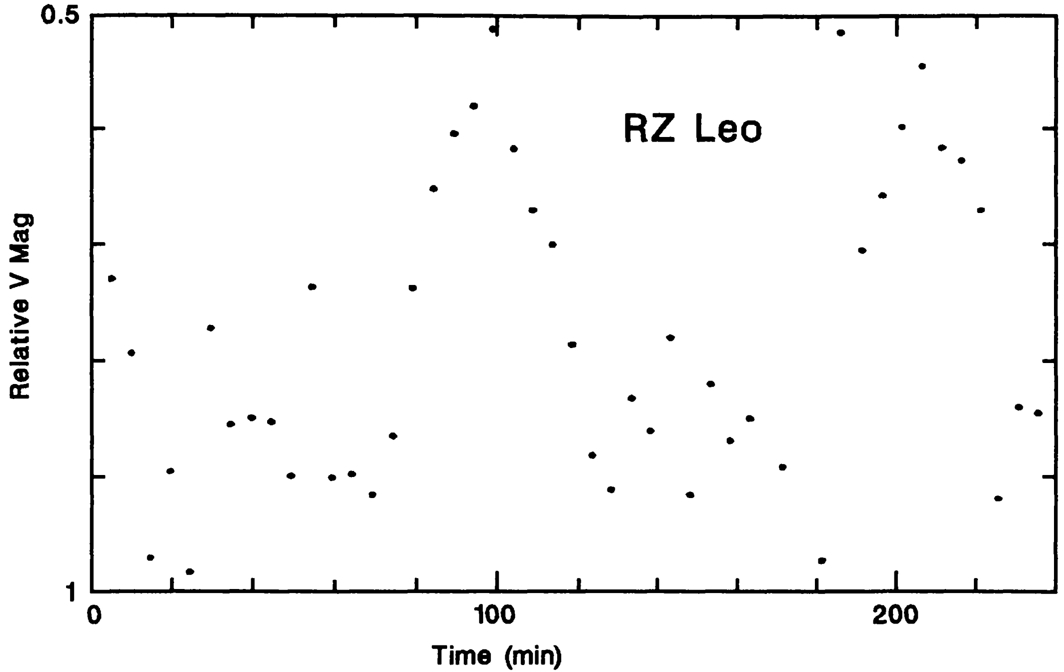

Figure 3. The differential light curve of the V = 19.1 magnitude dwarf nova RZ Leo, obtained at KPNO with 270 second integrations and a sigma of 0.04. The light curves show a 0.5 magnitude variation on an orbital time scale of 1.7 hours. Taken from Howell and Szkody 1988.

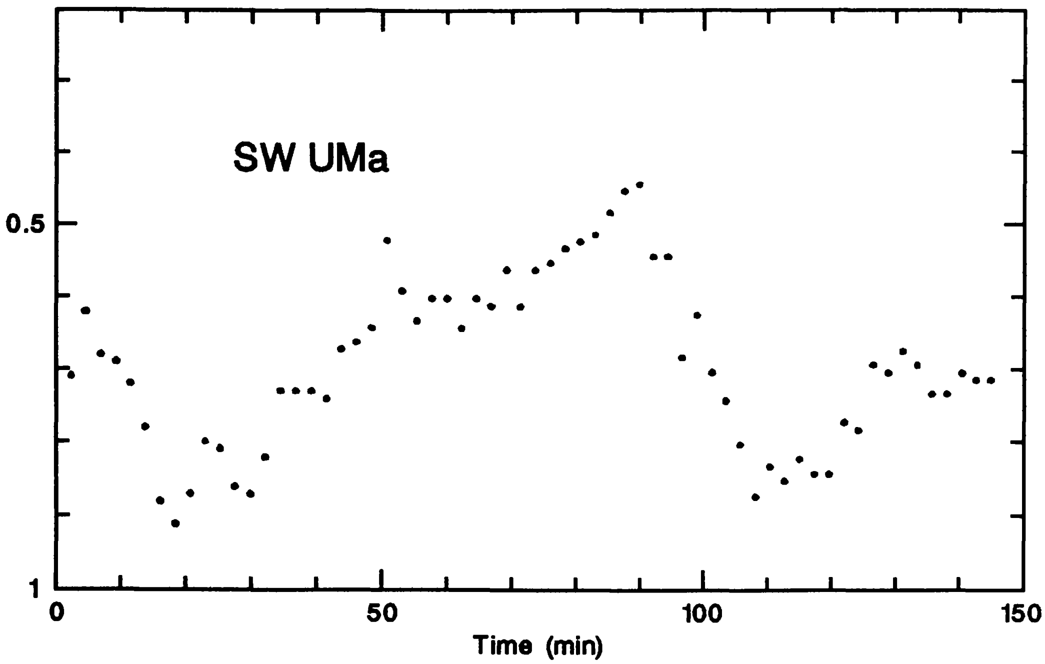

Figure 4. The differential light curve of the B = 17.0 dwarf nova SW UMa, with 2 minute integrations and a sigma of 0.05, revealing the 0.3 magnitude amplitude variability on the orbital time scale of 81.8 minutes. From Howell and Szkody 1988.

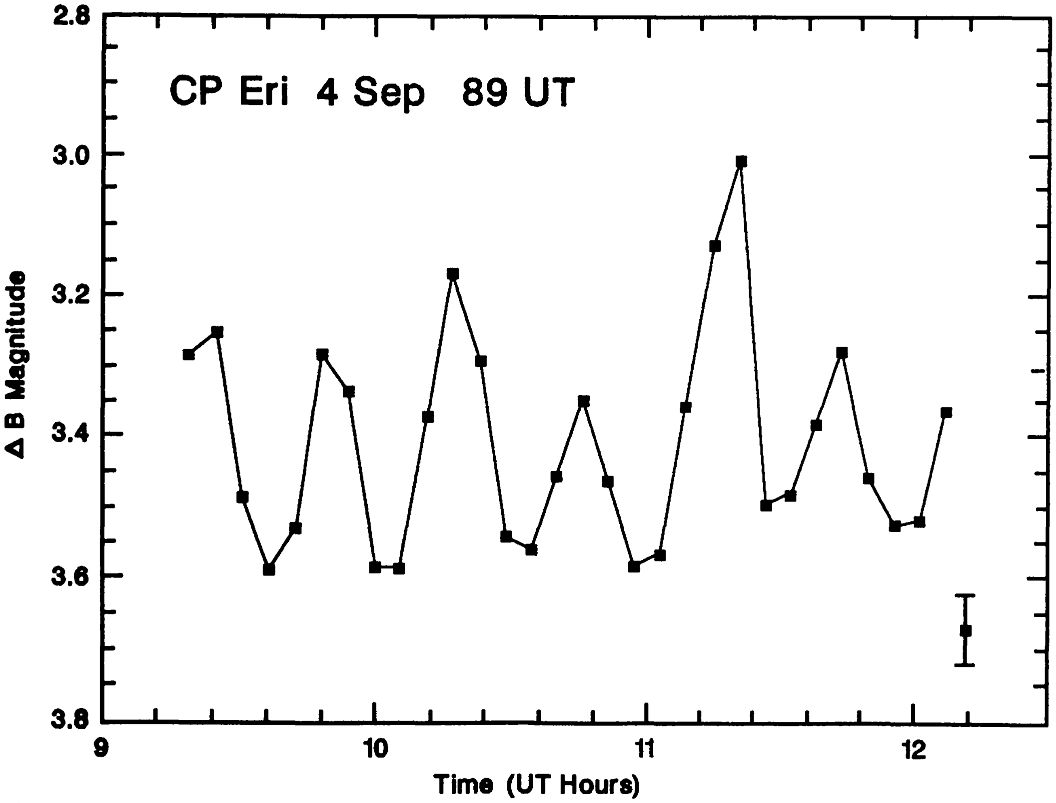

Figure 5. The differential light curve of the magnetic variable CP Eri. Integrations of 320 seconds with a sigma of 0.05 clearly reveal a 29 minute periodicity in this B = 19.3 variable. From Howell *et al.* 1991.