High speed photometry of faint Cataclysmic Variables: III. V842 Cen, BY Cir, DD Cir, TV Crv, V655 CrA, CP Cru, V794 Oph, V992 Sco, EU Sct and V373 Sct

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ABSTRACT
We present further results from a high speed photometric survey of faint cataclysmic variables. We find that V842 Cen (Nova Cen 1986 No. 2) is highly active, but with no evident orbital modulation. BY Cir (Nova Cir 1995) is an eclipsing system with an orbital period ($P_{\text{orb}}$) of 6.76 h. TV Crv, an SU UMa type dwarf nova, is found to have $P_{\text{orb}} = 1.509$ h from photometry at quiescence. DD Cir (Nova Cir 1999) is an eclipsing system with $P_{\text{orb}} = 2.339$ h, a possible secondary eclipse, and a $\sim 670$ s photometric modulation. V655 CrA is highly active but shows no orbital modulation. The identification of V794 Oph is probably incorrect as we find no photometric variability. CP Cru (Nova Cru 1996) is an eclipsing system with $P_{\text{orb}} = 22.7$ h. V992 Sco has $P_{\text{orb}} = 3.686$ h from its periodic modulation. The supposed identification of EU Sct is probably incorrect. And finally, during one run V373 Sct (Nova Sct 1975) had a 258.3 s coherent periodicity, making it a candidate DQ Herculis star.

Key words: techniques: photometric – binaries: eclipsing – close – novae, cataclysmic variables

1 INTRODUCTION
In continuation of this series (Woudt & Warner 2001, 2002) we present the results of high speed photometry of a further 10 cataclysmic variable stars (CVs). These are mostly quite faint and in crowded fields, requiring the use of the University of Cape Town’s CCD photometer (O’Donoghue 1995) in frame transfer mode and with no optical filter (i.e. the observations were made in ‘white light’). All of our observations were made at the Sutherland site of the South African Astronomical Observatory, using the 1.9-m (74-in) and 1.0-m (40-in) reflectors. The photometry was calibrated by observing hot white dwarf standards, but is not considered of high quality because CVs have non-standard flux distributions, so transformations to a standard photometric system (and, indeed, choice of the correct atmospheric extinction coefficient) are not possible. We leave our magnitudes on our own non-standard system.

As in the previous papers, we have concentrated on faint nova remnants. These have proved to be rewarding (e.g. for discovery of magnetic associated phenomena) and are in any case in most need of increased knowledge of orbital periods and of the discovery of eclipsing systems. Our observational philosophy is to consider this work as a survey, spending only sufficient time on each star to establish its essential properties. For the faintest objects where no certain identification has hitherto been given, we are usually satisfied merely to discover which of the candidates in the field shows rapid brightness variations. Often such a demonstration requires several attempts before the seeing conditions are good enough to isolate candidates from their neighbours.

We use psf fitting, aperture photometry and image subtraction techniques in this quest. In the survey we are frequently pushing the telescopes to their magnitude limits and adjust the integration time according to seeing or faintness. We only observe brighter objects if the seeing is poor, or there is intermittent cloud, or there is a proximate moon.

In Section 2 we give the results of our observations; Table 1 contains the list of runs and the details for all the observed stars. Section 3 contains a summary of the results obtained from these new observations.

2 OBSERVATIONS

2.1 V842 Centauri
V842 Cen was Nova Centauri 1986 No. 2, discovered at magnitude 5.6 but subsequently assigned a maximum magnitude of $V = 4.6$ (Duerbeck 1987). It was a moderately fast nova,
Table 1. Observing log.

| Object | Type | Run No. | Date of obs. (start of night) | HJD of first obs. (+2451000.0) | Length (h) | $t_{in}$ (s) | Tel. | V (mag) |
|--------|------|---------|-------------------------------|-------------------------------|------------|------------|------|--------|
| V842 Cen | NR | S6096 | 2000 Jun 03 | 699.24431 | 10.23 | 5 | 74-in | 15.8 |
|        |     | S6097 | 2000 Jun 04 | 700.20473 | 11.14 | 5, 10 | 74-in | 15.8 |
|        |     | S6321 | 2002 Mar 21 | 1355.33839 | 1.68 | 6 | 40-in | 15.9 |
| BY Cir  | NR | S6298 | 2002 Mar 13 | 1347.56636 | 1.93 | 15 | 74-in | 17.8 |
|        |     | S6301 | 2002 Mar 14 | 1348.43030 | 5.29 | 15 | 74-in | 17.8 |
|        |     | S6302 | 2002 Mar 15 | 1349.26660 | 9.15 | 20 | 74-in | 17.7 |
|        |     | S6306 | 2002 Mar 18 | 1352.48120 | 1.25 | 15 | 74-in | 17.7 |
|        |     | S6308 | 2002 Mar 18 | 1352.60138 | 1.39 | 20 | 74-in | 17.7 |
| DD Cir  | NR | S6399 | 2002 May 31 | 1426.21021 | 2.99 | 60 | 74-in | 20.1 |
|        |     | S6404 | 2002 Jun 02 | 1428.22039 | 5.83 | 60 | 74-in | 20.1 |
|        |     | S6408 | 2002 Jun 03 | 1429.21094 | 1.02 | 60 | 74-in | 20.2 |
|        |     | S6416 | 2002 Jun 05 | 1431.20365 | 2.38 | 60 | 74-in | 20.2 |
|        |     | S6421 | 2002 Jun 08 | 1434.20882 | 3.01 | 60, 120 | 74-in | 20.1 |
|        |     | S6425 | 2002 Jun 09 | 1435.19953 | 4.87 | 90 | 74-in | 20.0 |
| TV Crv  | DN | S6355 | 2002 Apr 07 | 1372.32645 | 2.88 | 30 | 74-in | 18.8 |
|        |     | S6359 | 2002 Apr 08 | 1373.23083 | 1.58 | 30 | 74-in | 18.9 |
| V655 CrA | NR | S6505 | 2002 Aug 28 | 1515.33190 | 2.71 | 10 | 74-in | 17.6 |
|        |     | S6512 | 2002 Aug 29 | 1516.25599 | 1.45 | 15 | 74-in | 17.4 |
|        |     | S6517 | 2002 Aug 31 | 1518.22488 | 5.59 | 15 | 74-in | 17.6 |
|        |     | S6521 | 2002 Sep 01 | 1519.21711 | 3.21 | 15 | 74-in | 17.6 |
| CP Cru  | NR | S6294 | 2002 Mar 12 | 1346.32945 | 7.59 | 45, 60 | 74-in | 19.6 |
|        |     | S6303 | 2002 Mar 16 | 1350.30020 | 8.08 | 45 | 74-in | 19.7 |
|        |     | S6304 | 2002 Mar 18 | 1352.24923 | 2.02 | 45 | 74-in | 19.7 |
|        |     | S6314 | 2002 Mar 19 | 1353.45168 | 1.61 | 60 | 40-in | 19.6 |
|        |     | S6325 | 2002 Mar 22 | 1356.47462 | 1.53 | 60 | 40-in | 19.7 |
|        |     | S6332 | 2002 Mar 23 | 1357.46866 | 0.88 | 60 | 40-in | 19.6 |
| V794 Oph | NR | S6419 | 2002 Jun 06 | 1342.33235 | 2.06 | 6 | 74-in | 17.2 |
|        |     | S6429 | 2002 Jun 10 | 1346.29756 | 1.26 | 15 | 74-in | 17.1 |
| V992 Sco | NR | S6322 | 2002 Mar 21 | 1355.41396 | 5.76 | 20 | 40-in | 17.2 |
|        |     | S6326 | 2002 Mar 22 | 1356.54380 | 2.69 | 10 | 40-in | 17.0 |
|        |     | S6339 | 2002 Mar 24 | 1358.49867 | 3.51 | 15 | 40-in | 17.0 |
|        |     | S6398 | 2002 May 30 | 1425.28958 | 9.71 | 6 | 74-in | 17.1 |
|        |     | S6400 | 2002 May 31 | 1426.34201 | 2.81 | 10 | 74-in | 17.0 |
|        |     | S6402 | 2002 Jun 01 | 1427.28741 | 1.08 | 10 | 74-in | 17.1 |
|        |     | S6405 | 2002 Jun 02 | 1428.47032 | 3.16 | 10 | 74-in | 17.1 |
| EU Sct  | NR | S6500 | 2002 Aug 27 | 1514.44263 | 0.62 | 5 | 74-in | - |
|        |     | S6523 | 2002 Sep 01 | 1519.40923 | 0.83 | 5, 15 | 74-in | - |
| V373 Sct | NR | S6358 | 2002 Apr 07 | 1372.57518 | 2.28 | 30 | 74-in | 18.7 |
|        |     | S6361 | 2002 Apr 08 | 1373.48768 | 4.31 | 30 | 74-in | 18.6 |
|        |     | S6497 | 2002 Aug 27 | 1514.24270 | 2.90 | 30 | 74-in | 18.5 |

Notes: NR = Nova Remnant; DN = Dwarf Nova; $t_{in}$ is the integration time; `:' denotes an uncertain value; * mean magnitude out of eclipse.

with $t_{3} = 48$ d, which developed an obscuring dust shell. De Freitas Pacheco et al. (1989) determined $E$(B-V) = 0.54 mag, and Downes & Duerbeck (2000) measured $V = 15.82$ in 1998 and detected a 6" diameter ejecta shell around the nova remnant. An IUE spectrum has been published (Gonzalez-Riestra, Orio & Gallagher 1998), obtained in 1991, showing the strong emission lines of CII, SiIV, NIV, HeII and CIII characteristic of a post nova with a white dwarf primary that is still very hot.

We have made two long runs on V842 Cen, listed in Table 1 and shown in Fig. 1. It is evident that V842 Cen is continuously flaring with rises of up to 0.25 mag on a characteristic time scale of $\sim 5$ mins. This is one of the most active nova remnants we have seen. Although the light curves are both $\sim 10.5$ h long, we see no clear indication of any orbital modulation and conclude that V842 Cen is probably of low inclination. We have made Fourier transforms (FTs) of the runs, and subsections of them, and find that there are no short period (tens of seconds) modulations that would be classified as dwarf nova oscillations (DNOs). However, occasionally there appear to be strong quasi-periodic oscillations (QPOs) present with time scales $\sim 750$ s and $\sim 1300$ s on the first night and $\sim 950$ s on the second night. These QPOs will be analysed and discussed elsewhere, together with results from other CVs. We point out, however, the striking similarity...
Figure 1. The light curves of V842 Cen, obtained in June 2000. The light curve of run S6097 has been displaced vertically downwards by 0.3 mag for display purposes only.

Figure 2. The light curves of BY Cir, obtained in March 2002. All light curves, except the upper one, have been displaced downwards by 0.5, 1.0, and 1.5 mag, respectively, for display purposes. The light curves have been phased according to ephemeris given in Eq. 1.

larity of the light curve of V842 Cen to that of the nova-like TT Ari (see Figure 9 of Patterson 1994).

2.2 BY Circini

BY Cir was Nova Circini 1995, discovered at V ~ 7.2 on 27 January 1995 (Liller 1995) and reported to be at V = 15.9 on 23 March 1998 (Downes & Duerbeck 2000). The light curve is illustrated by Bateson & McIntosh (1998); it shows that BY Cir was a slow nova, falling smoothly with $t_3 = 157$ d.

We observed BY Cir on four nights (Table 1), finding on the first night that it is an eclipsing system with eclipses ~0.9 mag deep. The following two nights we made longer runs to determine the orbital period, and subsequently another short run to improve the accuracy of the period. BY
show that DD Cir has a mean magnitude of 12.5 mag. Therefore may fade out of sight in the next few years. The light curves of DD Cir are displayed in Fig. 4 and the mean curve (Fig. 5), is HJDmin = 2452347.5790 + 0d.2816(±2) E. (1)

The depth of eclipse is seen to vary by about 0.3 mag and there is variable asymmetry in the eclipse profile. Flickering is present on a number of time scales, and the profile of the final eclipse has clusters of points showing that the flickering continues during at least the falling and rising portions.

An FT of the combined light curves (with the eclipses removed) shows no evidence for any persistent coherent periodicities other than P orb and its harmonics; on individual nights there are no dwarf nova oscillations (DNOs: periodicities ∼10–50 s) detected.

2.3 DD Circinus

DD Cir was discovered as Nova Cir on 23 August 1999 at an apparent magnitude of 7.7 (Liller 1999). It proved to be a very fast nova, with a pre-eruption brightness V > 21 (Downes et al. 2001) and t2 ∼ 4.5 d. There are no recent estimates of its brightness. The chart published by Downes et al. does not identify DD Cir, so we reproduce one of our CCD frames in Fig. 3.

Our photometric observations are listed in Table 1 and show that DD Cir has a mean magnitude of ∼ 20.1. Maximum brightness during eruption may have been missed, and it is not certain that it has yet reached its quiescent magnitude, so we can only deduce that the range is ≥ 12.5 mag. With the inclination ∼ 79° deduced below, DD Cir should have a range ∼ 15 mag (see Figure 5.4 of Warner 1995) and therefore may fade out of sight in the next few years.

The light curves of DD Cir are displayed in Fig. 4 and show that it is an eclipsing system with an eclipse depth ∼ 0.6 mag and an orbital period of 2.339 h. A period of that value is of particular significance because it lies within the ‘period gap’ shown by dwarf novae and nova-like variables (Warner 1995), further reducing the case for such an orbital period gap in the classical novae (e.g. Warner 2002). The ephemeris for time of mid-eclipse, deduced from our light curves, is

\[ HJD_{\text{min}} = 2452426.2102 + 0d.00746(±1) E. \]  

The upward convexity and variability of the light curve between eclipses encouraged us to look for a superhump signal, but removing the eclipses from the light curves, or prewhitening at the orbital period and its harmonics, leaves no indication of any signal near to P orb in the FTs. Therefore we interpret the convexity as a reflection effect, resulting from the fact that DD Cir was a nova less than three years ago and the primary may still be quite hot. The high inclination favours such a reflection effect.

A sinusoidal fit to the mean light curve outside of eclipses gives a peak-to-peak range of 0.30 mag for the reflection signal – see Fig. 5. (For this mean light curve we have omitted the final run, S6425, which shows deep dips and asymmetry.) Reflection effects in post-novae are expected to be large only when a high mass transfer rate (high M), high luminosity accretion disc does not dominate the system. A relatively short period and high inclination system such as DD Cir is optimal for a strong reflection effect. Alternatively, if the system is strongly magnetic (as in a polar) then no disc exists and reflection luminosity can also dominate, as in the nova V1500 Cyg (Kalużny & Chlebowski 1988). In DD Cir, however, there is clear evidence of an accretion disc: the eclipse profile is that of partial eclipse of an extended disc.

This can be made more quantitative as follows. The total width of eclipse is 2φd = 0.19 and the total width at half depth is 2φp = 0.074. Inserted into Equation (2.65) of Warner (1995) (which is correct for deep eclipses: because part of the reflected light remains at mid-eclipse, the eclipse is actually a little deeper than measured) this gives a disc radius r d/a ≥ 0.47, where a is the separation of components. At P orb = 2.34 h we expect the mass of the secondary to be 0.19 M⊙ (Equation (2.100) of Warner 1995), and adopting a primary mass of 1.1 M⊙ (in accordance with the typically high masses for the primaries of novae) we have a mass ratio q = 0.17. Harrop-Allin and Warner (1996) find from analysis of many CV eclipses that high M-discs have radii comparable to the tidal truncation radius r t/a = 0.60(1 + q), which is r t/a = 0.51 for q = 0.17. It is clear, therefore, that DD Cir contains a high M disc.

The individual light curves, and the mean curve (Fig. 5), show that the brightness at phase 0.5 falls below what would be expected of a sinusoidal reflection effect. It is possible that this is the effect of a secondary eclipse. That such might be detectable in special circumstances is shown by the following analysis.

With the parameters for DD Cir deduced above, and using the graphs of the relationships between q, inclination i, and φp given by Horne (1985), we find i = 79° for DD Cir. Ignoring the vertical thickness of the disc, the disc seen in projection at orbital phase 0.5 obscures the irradiated secondary from its pole down towards lower latitudes when cos i = (R d/a)(1 + r d/a)−1, where R d is the radius of the secondary. For q = 0.17 we find R d/a = 0.24 (Warner 1995), which gives i = 80.5°. It happens, therefore, that in DD Cir...
the inclination is such that a large fraction of one hemisphere of the irradiated secondary is obscured by the optically thick accretion disc. With the above parameters we find that the disc obscures the primary from its pole down to a latitude $l \sim 20^\circ$ (see Fig. 6), and that as a result $\sim 30\%$ of the surface area of the secondary is obscured at orbital phase 0.5. Such obscuration is of course the case for all high inclination CVs, but in general the secondary contributes such a small fraction of the total luminosity that the effect is not detectable. In DD Cir, however, we have a unique CV with high inclination and substantial luminosity of one side of the secondary, so we may hope to see secondary eclipses in the light curve.

DD Cir has one more property of interest. In runs S6416, S6421 and S6425 the FTs show distinct periodic signals at 662 s, 665 s and at 673 s respectively, all with amplitudes $\sim 0.025$ mag. Note that for the analysis of this $\sim 670$ s signal in the various runs, we have removed the eclipses in each of the runs. The differences in period are within the uncertainties due to noise and data length. Furthermore, in S6399 there is a signal with amplitude 0.011 mag at 668 s, which is only at the level of the noise, but supports the possible existence of a persistent periodicity. In S6404 the amplitudes near 670 s are $< 0.01$ mag, but a small amount of noise in antiphase with the signal could cause cancellation. The mean light curve for S6421, which has the clearest signal, is shown in Fig. 7, where the amplitude is 0.026 mag. The FT for the entire data set, excluding S6404, naturally has an alias problem; the two highest peaks are at 666.08 s and its one day alias 671.28 s, both with amplitudes of 0.017 mag.

The $\sim 670$ s signal is indicative of the rotation period of the primary or its orbital sideband. It would be valuable to extend observations of DD Cir, with larger telescopes, before it fades further.
2.4 TV Corvi

TV Crv is an SU UMa type dwarf nova with a quiescent magnitude $V \sim 19$ and superoutbursts spaced about a year apart (Levy et al. 1990). During the superoutburst in June 1994 superhumps were observed with a period $P_{sh}$ of $1.56 \pm 0.02$ h (Howell et al. 1996). Superhumps usually have periods a few percent longer than the orbital periods (Warner 1995), so a $P_{\text{orb}} \sim 1.50$ h is expected. No spectroscopic or photometric periods in quiescence have hitherto been obtained.

We observed TV Crv at minimum light in the hope of detecting an orbital modulation. Our observations are listed in Table 1. Having found a clear orbital modulation on the first night, we observed on the second night for just sufficient time to include another orbital hump. The double humped profile of the light curve puts a great deal of power into the first harmonic, which has three aliases in the FT; we use these to find three possibilities for the fundamental period: $1.414, 1.461$ and $1.512$ h. In addition, there are three aliases at the fundamental itself, at $1.506, 1.617$ and $1.747$ h. Knowing the superhump period enables unambiguous selection of $P_{\text{orb}} = 1.509$ h from this suite. The ephemeris for times of maxima is given by

$$HJD_{\text{max}} = 2452372.3371 + 0^d06288(\pm 13) \ E. \quad (3)$$

In Fig. 8 we show the mean light curve, co-added at the orbital period. The range of the orbital modulation is 0.2 mag. The superhump excess $(P_{sh} - P_{\text{orb}})/P_{\text{orb}} = 0.034$, and the beat period $P_b = (P_{sh}^{-1} - P_{\text{orb}}^{-1})^{-1} = 1.9$ d. These values are similar to those of other SU UMa stars with orbital periods near 1.5 h (Warner 1995).

2.5 V655 Coronae Austrinae

Nova Coronae Austrinae was discovered on objective prism plates in June 1967 and was very poorly observed. Downes et al. (2001) give a magnitude of 17.6 at quiescence, measured on a J plate. No observations of V655 CrA at quiescence have previously been reported; our photometric runs are listed in Table 1. A CCD frame of the vicinity of V655 CrA is illustrated in Fig. 9; this shows that the nova remnant is a member of a close triplet of stars. The star that we have found to be variable is marked.

In Fig. 8 we show the mean light curve, co-added at the orbital period. The range of the orbital modulation is 0.2 mag. The superhump excess $(P_{sh} - P_{\text{orb}})/P_{\text{orb}} = 0.034$, and the beat period $P_b = (P_{sh}^{-1} - P_{\text{orb}}^{-1})^{-1} = 1.9$ d. These values are similar to those of other SU UMa stars with orbital periods near 1.5 h (Warner 1995).

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The light curves of V655 CrA are displayed in Fig. 10. There are large variations around a mean magnitude of 17.6. Although there are clearly preferred time scales associated with the variations, we find nothing in the FTs indicative of repetitive modulations – as we added more data, the FT changed in character and in the positions of the principal peaks.

2.6 CP Crucis

CP Cru was Nova Crucis 1996, discovered by Liller at \( V = 9.2 \) (Liller 1996) and observed at \( V = 19.48 \) in March 1998 (Downes & Duerbeck 2000). It was a very fast nova \( (t_2 \sim 4 \text{ d}) \) and is seen in an HST image to have a \( 0.6'' \times 0.6'' \) shell (Downes & Duerbeck 2000). True maximum light was probably missed.

Our observations are listed in Table 1 and show that the nova was at \( V \sim 19.6 \) in March 2002, and therefore is now probably near to its quiescent level. Such a fast nova, seen at the relatively high inclination that we deduce below, should have an eruption range \( \sim 14.4 \text{ mag} \) (Figure 5.4 of Warner 1995) and therefore could have reached \( V \sim 5.2 \) at maximum. This is in agreement with Downes & Duerbeck, who deduce an absolute magnitude \( M_V \sim -5.3 \) which is about 3.7 mag too faint for the speed of the nova.

The light curves of CP Cru are shown in Fig. 11 and reveal that it has shallow eclipses, about 0.25 mag deep, giving it an inclination \( \sim 70^\circ \). We observed CP Cru just sufficiently to determine its orbital period unambiguously (the initial observations gave several possible aliases; we chose our subsequent observing times to eliminate or confirm these). The orbital period is \( 22.7 \text{ h}^\dagger \), which is the third longest period known for a classical nova. The secondary in CP Cru must be considerably evolved. The ephemeris for mid-eclipse is

\[
HJD_{\text{min}} = 2452346.620 + 0.0040944(\pm 1) \text{ E.}
\]  

2.7 V794 Ophiuchi

V794 Oph was discovered by Burwell & Hoffleit (1943) on an objective prism plate taken in July 1939 and became a slow nova with \( t_3 = 220 \text{ d} \), resembling HR Del in its light curve (Duerbeck 1987). Szkody (1994) gave \( V = 17.70 \) and \( (B-V) = 1.5 \), measured in 1989, and Hoard et al. (2002) gave \( J, H, \) and \( K \) magnitudes of the same star, identified on Duerbeck’s (1987) finding chart. Ringwald, Naylor & Mukai (1996) obtained a spectrum of the star, showing a featureless continuum increasing strongly to long wavelengths.

At maximum, V794 Oph was \( m_{pg} = 11.7 \). The range of such a slow nova would be expected to be \( 8-11 \text{ mag} \), depending on its orbital inclination (Figure 5.4 of Warner 1995). The candidate star at \( V \sim 17.7 \) would therefore seem rather too bright to be the nova remnant, and this conclusion is supported by the spectrum.

We have obtained high speed photometry of the candidate, see Table 1, and find no variability in it. We have not found rapid variability of any other stars in the field, either of the candidate, or of stars near the position given by Burwell & Hoffleit, which differs from Duerbeck’s candidate by nearly 1°. It is not clear by how much maximum brightness was missed, but we suggest that the true nova remnant is likely to be considerably fainter than the candidate’s 17.7. Our magnitude estimate for the V794 Oph candidate is somewhat uncertain due to its red colours.

2.8 V992 Scorpii

Nova Scorpii 1992 was discovered at \( V \sim 8.2 \) by Camilleri (1992) and brightened to \( V = 7.26 \) four days after discovery (Kilmartin 1992). It was a slow nova, the light curve of which is shown by Smith et al. (1995).

Our photometric observations of V992 Sco are listed in Table 1 and show the nova to have faded to \( V \sim 17.1 \) by early 2002, giving an eruption range of at least 9.8 mag. The light curve of the longest run in the May 2002 set of runs (S6398) is shown in Fig. 12. An FT of this data set, followed by a non-linear least squares fit to the fundamental and first harmonic, delivers a fundamental period of 3.686 h with an amplitude of 0.044 mag and a first harmonic with an amplitude of 0.018 mag. Similar treatment of the March 2002 runs gives the independent estimates 3.685 h at 0.070 mag and the harmonic at 0.015 mag. Fig. 13 shows the mean light curves of the March and May runs, co-added at the 3.686 h period, which we interpret as \( P_{\text{orb}} \) for V992 Sco. The low amplitude of the orbital modulation suggests an intermediate orbital inclination, probably \( \sim 40^\circ \).

The FTs show no other coherent periodicities in the light curves.

2.9 EU Scuti

EU Sct was Nova Scuti 1949, discovered on 31 July of that year and reaching a photographic magnitude of 8.4 at max-
imum brightness 5 days later. It was a moderately fast nova with $t_3 = 42$ d. Szkody (1994) measured $V = 17.37$ and (B–V) = 2.66 in 1988 for the candidate star indicated in Deurbeck’s (1987) finding chart. Szkody pointed out the extreme redness of this star, as also did Weight et al (1994), who proposed (by comparison with the recurrent novae RS Oph and T CrB which have red giant companions) that EU Sct might be a recurrent nova. There has been no detailed spectroscopic study of EU Sct in quiescence.

Our observations of EU Sct are listed in Table 1. The photometric calibration that we normally apply is not appropriate for an object with such red colours. We therefore do not list the mean magnitude of EU Sct in Table 1. We find no rapid variation in the candidate star – which, being very red, appears much brighter on our CCD frames than on the photographic finding chart and is easy to measure accurately. However, there is a 19.1 mag companion 4″ south of the candidate, which is difficult to observe but in the first of our runs has possible photometric variations. If this is the true candidate then the eruption range was 10.7 mag, which is compatible with a nova having $t_3 = 42$ d if it has low orbital inclination (Fig. 5.4 of Warner 1995). Spectra of the two objects are required to test our suspicions.

### 2.10 V373 Scuti

V373 Sct was discovered as a nova on 15 Jun 1975, but it was subsequently found that maximum light, at $V = 7.1$, had occurred just over a month earlier (Duerbeck 1987). It was a moderately fast nova with $t_3 = 85$ d. The spectrum obtained by Ringwald et al. (1996) in 1991 showed strong Balmer emission on a blue continuum, and very strong HeII $4686\AA$ and the CIII/NIII blend at 4650Å, which is often indicative of a magnetic system. Their photometry gave a $V$ magnitude of 18.7.

Our observations are listed in Table 1. We also find a mean magnitude near 18.7, showing that V373 Sct has settled down at minimum light. The eruption range of 11.6 mag and value of $t_3$ combine to suggest a high inclination orbit. However, the light curves, seen in Fig. 14, show great activity but no hint of any orbital modulation.
Figure 15. The Fourier transform of V373 Sct (run S6361). The peak at 258.3 s is marked by the diagonal bar.

The large amplitude flickering, as with the strong ionic emission lines, is also often a signature of a magnetic system. In V373 Sct we have found that a third magnetic diagnostic is present – a coherent luminosity modulation of the kind seen in non-synchronous rotators such as DQ Herculis stars and intermediate polaris. The only significant feature in the FTs of the three light curves is a narrow spike at a period of 258.3 s in run S6361 – see Fig. 15. There is no significant power at this period in the FTs of the other two runs – but there is considerable noise in this region due to the flickering. There is no significant amplitude at the first harmonic of the signal.

Fig. 16 shows the O–C diagram and amplitude plot for run S6361. Five cycles of the signal, with 50% overlap, have been fitted to a sinusoid with a period of 258.3 s. There is an increase in the length of the error bars on the amplitude points where steep slopes occur in the light curve. It is difficult to filter the large amplitude rapid variations out of the light curve without removing part of the coherent signal, which is of similar time scale, so we have merely analysed the raw light curve. The O–C phase variations are consistent with a signal of constant period, the mean amplitude of which is $\sim 0.02$ mag.

A modulation at 258 s is considerably longer than any DNOs observed in CVs (which usually have periods much less than 100 s). However, the three old novae V533 Her, DQ Her and GK Per show (or have shown, in the case of V533 Her, where the signal is no longer visible) highly stable modulations at 63.63, 71.07 and 351.34 s respectively (see, e.g., the review in Warner 1995). If the 258 s periodicity proves to be persistent and coherent then V373 Sct will join this group of rapid rotators.

3 SUMMARY

The most important result from our survey is that we have detected eclipses in three old novae: BY Cir with $P_{\text{orb}} = 6.76$ h, DD Cir with $P_{\text{orb}} = 2.339$ h (placing it squarely in the “orbital period gap”), and CP Cru with $P_{\text{orb}} = 22.7$ h, which is the third longest period known for a classical nova. We also find a fourth orbital period, from the presence of a modulation at 3.686 h in the old nova V992 Sco. In addition, DD Cir has a $\sim 670$ s low amplitude photometric modulation and the old nova V373 Sct has a 258.3 s modulation; these are signatures of magnetic primaries with these as their spin period, or orbital side bands. There is some evidence that DD Cir has a 0.3 mag reflection effect that is partly obscured at phase 0.5, producing a secondary eclipse caused by the optically thick accretion disc.

The old novae V842 Cen and V655 CrA are highly active photometrically but show no clear periodic modulation, indicating that they are low inclination systems.

We have also measured $P_{\text{orb}} = 1.509$ h for the SU UMa star TV Crv from an orbital modulation seen during quiescence. Only the superhump period, observed during superoutburst, was previously known for this star.

Our observations of V794 Oph and EU Sct throw doubt on the currently proposed identification of these old novae.

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