Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **419,** 330–335 (2012) doi:10.1111/j.1365-2966.2011.19695.x

Novae in the SuperWASP data base

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Accepted 2011 August 24. Received 2011 August 8; in original form 2011 March 11

ABSTRACT

We present the results of trawling through the SuperWASP data base for classical and recurrent novae. We report light curves for a nova in eruption, and for classical novae and a recurrent nova in quiescence. For five objects in quiescence, we report periodicity, arising in most cases from orbital modulation of the light from the cool secondary star. The stability of the SuperWASP system means that these data have huge potential for the study not only of novae in eruption, but also of the long-term modulations of light during quiescence.

Key words: binaries: eclipsing – stars: individual: HR Del – stars: individual: KT Eri – stars: individual: T CrB – stars: individual: V533 Her– stars: individual: DQ Her – stars: individual: V705 Cas – novae, cataclysmic variables.

1 INTRODUCTION

Cataclysmic variable (CV) stars are binary stars in which mass transfer occurs on to a degenerate object, e.g. a white dwarf, usually from a non-degenerate object. They are generally variable in light output, over time-scales varying from minutes (due to 'flickering'), to hours (due to orbital modulation for main sequence dwarf-white dwarf binaries), to days (due to orbital modulation and eruption) and even years (where the cool component is a giant; see Warner 1995, for a comprehensive review).

These variations have long been monitored visually by the amateur community (giving data over long time-scales, sometimes decades) and photometrically (for shorter time-scales). The former provides long-term light curves of high cadence, but suffer from the disadvantage that they are carried out by a large number of observers with various detectors and instruments, so that photometric consistency can be difficult to attain; the latter tend to be short-lived, intensive campaigns.

The SuperWASP project (Pollacco et al. 2006) delivers high-quality data of high cadence over a timebase that already extends over 6 yr, thus offering the opportunity to study the long-term light curves of CVs. The observing strategy is such that a given field my be observed several times in a night, with cadence ∼10 min, with seasonal and other gaps in the temporal coverage.

2 THE SUPERWASP PROJECT

The SuperWASP project (Pollacco et al. 2006) consists of two separate facilities each of which employs wide angle (f/1.8) telephoto lenses with Andor Technology CCD cameras. The facilities are sited at the Observatorio del Roque de los Muchachos on La Palma in the Northern hemisphere (SuperWASP-N) and at the Sutherland Station of the South African Astronomical Observatory (SuperWASP-S). SuperWASP-N has been carrying out observations since 2004 May, while SuperWASP-S has been observing since 2006 May. A complete description of the SuperWASP facilities and their capabilities is given in Pollacco et al. (2006).

The science driver of the SuperWASP project is the discovery of extra-solar planets using the transit method. While the project is now delivering extra-solar planets at a prolific rate (e.g. Collier Cameron et al. 2007; Anderson et al. 2008; Joshi et al. 2008; Pollacco et al. 2008; Wilson et al. 2008; Christian et al. 2009; Hellier et al. 2009; Maxted et al. 2010; Simpson et al. 2011), the planet-finding strategy means that the SuperWASP data base is a rich mine of information for a wide range of variable stars (e.g. Norton et al. 2007; Maxted et al. 2008) and other objects (Parley et al. 2005).

We present here the result of exploiting the SuperWASP data base (Butters et al. 2010) for observations of classical and recurrent novae, together with a qualitative interpretation of the data. A further paper (McQuillin et al., in preparation) will describe the variations of symbiotic stars in the SuperWASP data base.

3 THE TARGETS

3.1 Classical novae

Classical novae (CNe) are semidetached binary systems in which a white dwarf (WD) primary accretes matter from a cool dwarf secondary via Roche robe overflow (e.g. Bode & Evans 2008, and references therein). The accreted material is degenerate and in time

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Table 1. Classical and recurent novae in the SuperWASP data base.

Object	WASP name	Type	Year(s) of outburst	Orbital period (d)	Period ref.[a]	Inclination	Photometric period (d)[b]
KT Eri	–	CN	2009	?	–	?	–
DQ Her	1SWASP J180730.28+455131.9	CN	1934	0.193621	1	89°.7	0.193 68 ± 0.000 04
HR Del	1SWASP J204220.34+190939.1	CN	1967	0.214165	2	40°	0.214 23 ± 0.000 05
V533 Her	1SWASP J181420.49+415122.3	CN	1963	0.2098	3	43°	0.142 89 ± 0.000 01
				0.1469	4	–	0.142 89 ± 0.000 01
				0.1474	4	–	0.142 89 ± 0.000 01
V705 Cas	1SWASP J234147.23+573100.7	CN	1993	0.2280	5	–	0.204 63 ± 0.000 04
T CrB	1SWASP J155930.15+255512.5	RN	1866, 1946	227.5687	6	–	91 ± 8.3

[a]1. Zhang et al. (1995); 2. Kürster & Barwig (1988); 3. Hutchings (1987); 4. Thorstensen & Taylor (2000); 5. Retter & Leibowitz (1995); 6. Fekel et al. (2000).
[b]This work.

conditions become suitable for thermonuclear runaway in the accreted layer, giving rise to a classical nova eruption. The WD may remain hot for years or decades after the outburst (e.g. Krautter 2008, and references therein), irradiating the secondary and ionizing the material ejected in the nova explosion. In time, mass transfer resumes and the system probably undergoes another nova eruption, typically in $\sim 10^4$–10^5 yr.

A summary of the photometric variations of the stellar remnants of CNe is given by Warner (1995).

3.2 Recurrent novae

Recurrent novae (RNe) form a small heterogeneous group of objects (see Anupama 2008, for a recent review). The secondary star may be a cool giant or a dwarf, and accretion on to the WD may be via Roche lobe overflow or via a wind, but they too undergo nova-like eruptions which are separated by decades rather than millennia.

Photometric variations during quiescence are discussed by Anupama (2008).

3.3 Scope of this work

As the science driver of SuperWASP is the detection of extrasolar planet transits, the prime instrumental requirement is accurate (∼1 mmag) and repeatable photometry over a long time base: colour information is of secondary importance. Since many of the objects in the present study are likely to be emission line objects we might expect that photometric variations might be due to (a) flickering, due to the splash of the interstar stream on to the edge of the accretion disc, (b) orbital modulation, (c) pulsations (in the case of systems having giant secondaries), (d) emission line variations. Prior to 2006 the wavelength response of the SuperWASP system was broad, cutting off at ∼4000 Å at shorter wavelengths and ∼8000 Å at long wavelengths; since 2006 the system has used filters covering 400–700 nm. Therefore there is no straightforward transformation between SuperWASP magnitude (in which the data here are presented) and conventional photometric systems. Furthermore, we can expect that tying down the cause of variations may not be straight-forward but, as flickering is primarily observed at short (∼U) wavelengths, and on time-scales ∼ minutes, we should not expect to observe the effects of this phenomenon in the data.

We also note that the observing strategy for the SuperWASP project (see Pollacco et al. 2006) means that the Galactic plane, in which the objects of interest in this paper are concentrated, is avoided because of the high stellar density and the low spatial resolution (PSF ∼15 arcsec) of the SuperWASP cameras. This strategy clearly restricts the number of CNe and RNe available for the present study (see Warner 2008, for the Galactic distribution of CNe).

In this paper we describe the results of trawling through the SuperWASP data base for CNe and RNe, providing reasonable temporal coverage for 5 CNe and 1 RN for our study. The objects are listed in Table 1, which includes the targets' WASP designation, and other relvant information (note that there is no WASP designation for KT Eri as this object, which erupted in 2009, is not included in any of the input catalogues).

The PERIOD package (Dhillon, Privett & Duffey 2001) was used to investigate the light curves for periodicity. In time, as the SuperWASP data base grows, the number of CNe and RNe amenable to the kind of work described here will increase, as the length of the time-base, the number of objects with data, and the amount of data per object, increase.

4 DATA AND RESULTS

4.1 Classical and recurrent novae

4.1.1 KT Eri

KT Eri (Galactic latitude $b \simeq -32°.2$) was discovered by Itagaki (2009) on 2009 November 25.536 and has been observed as a radio and a soft X-ray source. Hounsell et al. (2010) have presented light curves for this CN as obtained from the Liverpool Telescope and the Solar Mass Ejection Imager (SMEI; Eyles et al. 2003). They find a peak (SMEI) magnitude of 5.42 ± 0.02, a t_2 (t_3) of 6.6 d (13.6 d); maximum light was found to be at JD 245 5149.67 ± 0.04. The WASP light curve is shown in Fig. 1(a). WASP coverage of the eruption started on JD 245 5152.46, with a $m_{\rm WASP} = 6.42$, some 2.8 d after maximum light as identified by SMEI (direct comparison of WASP and SMEI magnitudes is of course not straightforward). From the SuperWASP data the light curve during eruption declined at an average rate of $43.8^{+0.4}_{-0.2}$ mmag d^{-1}. As is commonly the case for fast novae the initial decline (as measured by t_2) is much faster than during later stages of the eruption.

The light variations prior to outburst are shown in Fig. 1(b). The mean WASP magnitude prior to eruption is 15.05 ± 0.05 (shown by the horizontal line in Fig. 1b) but there are clearly ∼0.5 mag variations on either side. Drake et al., (2009) have discussed the pre-outburst variations and they find variations with amplitude ∼1.8 mag and a possible 210 d period.

The combined SMEI and WASP data for the eruption are shown in Fig. 1(c). There seems to be little systematic difference between the WASP and SMEI data, suggesting that the amplitude A of the eruption was $\simeq 8.6$; as noted by Hounsell et al. the low amplitude, coupled with the rate of decline during the early phase, point to a potential RN. A CN with a t_2 value similar to that of KT Eri would be expected to have an amplitude of $\sim$12 mag (see e.g. fig. 2.3 of Warner 2008); we also note that the amplitude of the well-known RN RS Oph, $A \simeq 5.8$ mag, and $t_3 \simeq 10.3$ d.

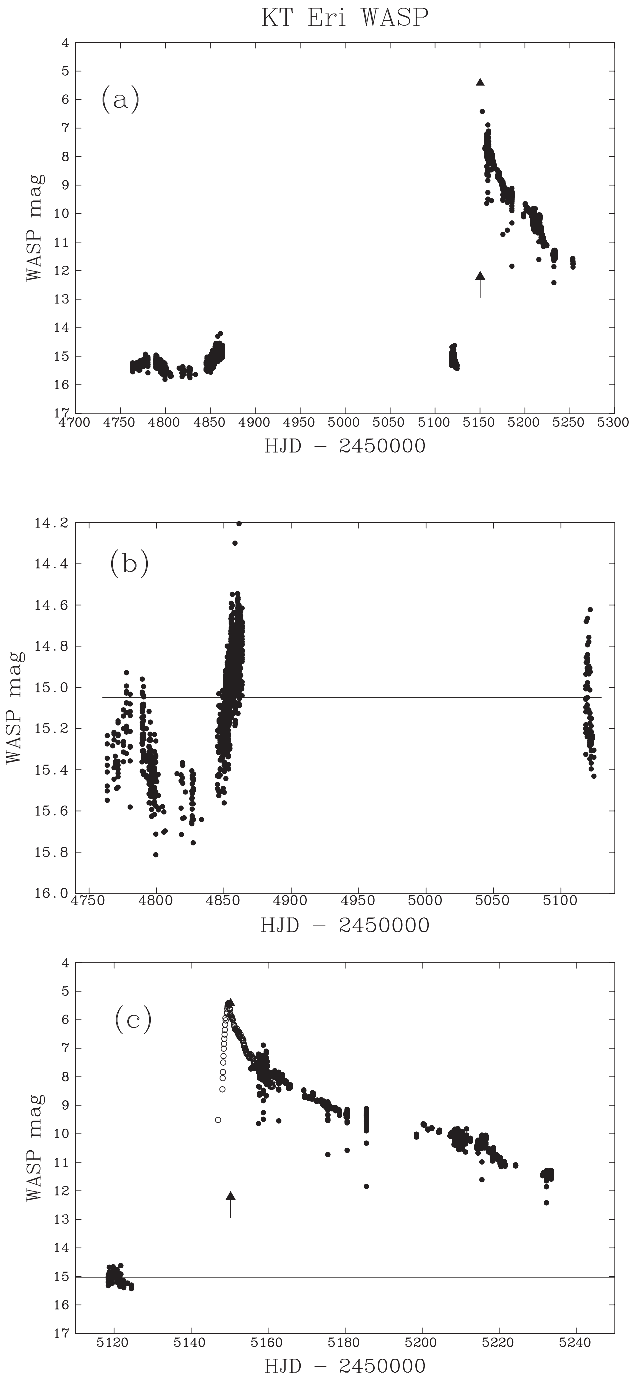

Figure 1. (a) WASP light curve of KT Eri. The arrow and triangle indicate, respectively, the time of maximum and maximum m_{SMEI} from Hounsell et al. (2010). (b) Pre-outburst light curve of KT Eri; the horizontal line is the mean m_{WASP}. (c) Post-eruption light curve of KT Eri, combining SuperWASP (filled circles) and SMEI (open circles) data; the horizontal line is the mean pre-outburst WASP magnitude from (b).

4.1.2 DQ Her

This is a well-known and well-studied eclipsing binary (period 0.193 621 d, Zhang et al. 1995) which erupted in 1934. The eclipse depth in 1990 was $\sim$2.5 mag in *UBV* (Zhang et al. 1995). Our WASP data for this object cover 140 d from JD 245 3140 and the WASP light curve is given in Fig. 2; the eclipses, with depth $\sim$2.5 mag, are clearly visible. The periodogram is shown in Fig. 2; applying PERIOD to the entire WASP data set gives a photometic period of $0.193\,68 \pm 0.000\,04$ d, in good agreement with the known orbital period. The folded WASP light curve is shown in Fig. 2, which shows well the asymmetric primary eclipse of this object (Zhang

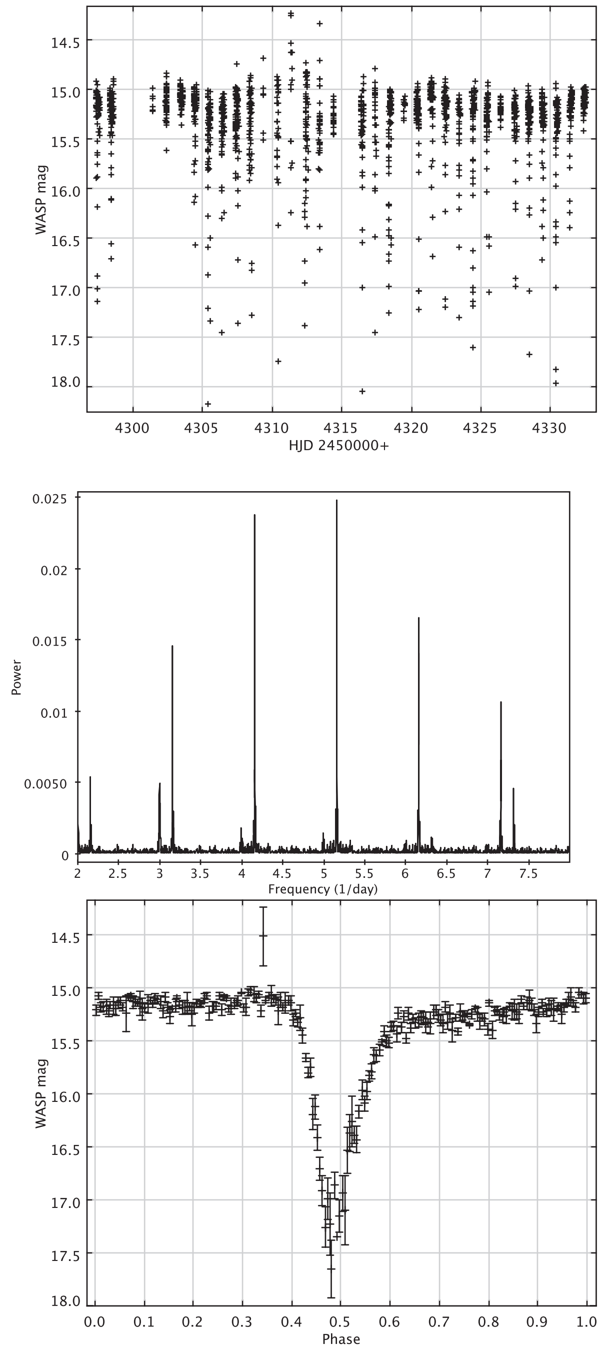

Figure 2. Top: light curve of DQ Her in the SuperWASP data base; centre: periodogram for DQ Her; bottom: light curve binned and folded over 0.193 68 d period.

et al. 1995). It is also evident that the SuperWASP data capture the eclipse minimum, at ∼17 mag, suggesting that the SuperWASP data are reliable at this flux level, at least in cases where the stars are not blended (i.e. separated by at least 1 arcmin from another star). Other than the primary eclipse, there is no evidence for any periodicity in the light curve.

4.1.3 HR Del

HR Del erupted in 1967 and is another well-studied object. Photometric variations with period 0.1775 d were reported by Kohoutek & Pauls (1980), and the orbital period was determined by Kürster & Barwig (1988) to be 0.214 165 ± 0.000 005 d.

Friedjung, Dennefeld & Voloshina (2010) have carried out a photometric study of this object; their observations, in the *UBV* bands, were carried out intermittently over the period 2002–2008. For *B*-band data obtained around 1990 they found a ∼0.1 mag amplitude variation with period at the orbital period, which they attributed to orbital modulation.

Coverage by the WASP project has been extensive, with nearly 350 d of observation in total. Our WASP data cover two intervals, 150 and 300 d from JD 245 3130 (2004) and JD 245 3900 (2006), respectively. The PERIOD package returned a period of 0.214 23 ± 0.000 05 d, in reasonable agreement with the known orbital period (see Fig. 3). The folded light curve (Fig. 3) shows that the amplitude is ∼0.1 mag.

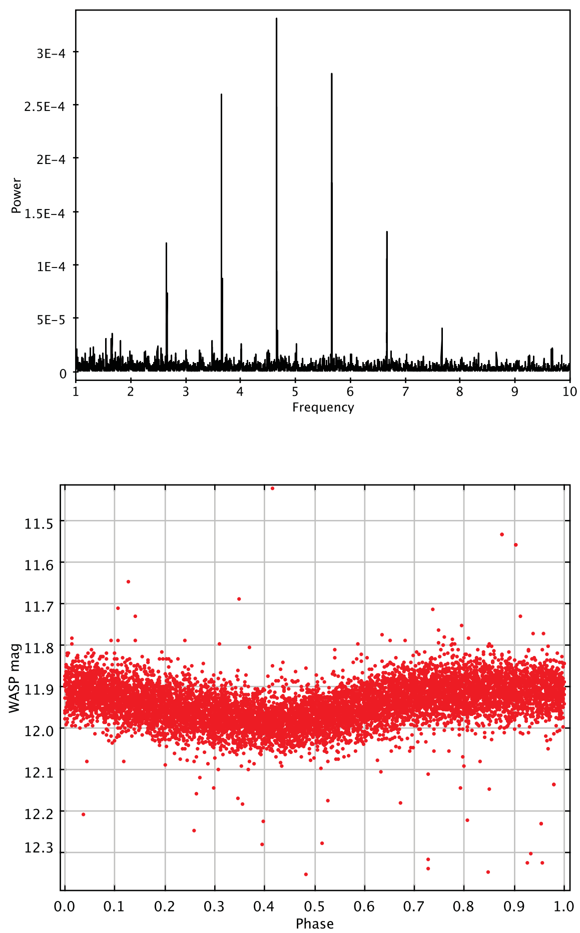

Figure 3. Top: periodogram for HR Del; frequency in d^{-1}. Bottom: light curve of HR Del folded over 0.214 23 d period.

Orbital modulations due to irradiation of the secondary by the still-hot WD are common in old novae (e.g. de Young & Schmidt 1994) and in post common envelope binaries (e.g Somers et al. 1996). As discussed by Friedjung et al. (2010), it is very likely that, in the case of HR Del, the photometric variations in the WASP data are due to irradiation of the cool secondary by the white dwarf.

Friedjung et al. note that there is a hint of a ∼1500- d period in their data but that several years of observation is required to confirm this; the stability of the SuperWASP system is of course well placed to do undertake this study.

4.1.4 V533 Her

V533 Her erupted in 1963 and there has been some uncertainty about its orbital period. Hutchings (1987) found variations in the radial velocity with period 0.209 777 d, and an orbital inclination of 43°. More recently Thorstensen & Taylor (2000), on the basis of a spectroscopic study, reported a much shorter orbital period, with either 0.146 8851 or 0.147 3743 d (uncertainty $\pm 3 \times 10^{-7}$ d in both values) being consistent with their data (Warner 2008, lists both the Hutchings and Thorstensen & Taylor periods in his table 2.5). V533 Her showed rapid (63.6 s period) oscillations; these had ceased by 1982 (Robinson & Nather 1983), and in any case would not show up in the WASP data.

In this case also, the WASP data are split into two intervals with the majority of the data being in the first interval of 140 d from JD 245 3140 (2004; see Fig. 4). PERIOD gave a *photometric* period of 0.142 89 ± 0.000 002 d, close to, but significantly smaller than, the Thorstensen & Taylor *spectroscopically* determined orbital period.

The amplitude is ∼0.2 mag, suggesting that the photometric variations we report here may be due to irradiation of the secondary star by the primary. However the discrepancy between our photometric period and the orbital period reported by Thorstensen & Taylor (2000) indicates that, while such modulations may be occurring, other factors are at work as well.

In some CVs where ‘superoutbursts’ occur, modulations (‘superhumps’) are seen. Where the photometric period is a few per cent *longer* than the orbital period (‘positive superhumps’) they are due to precession of the accretion disc, while ‘negative superhumps’ (such as we might be seeing here) are due to transit of the bright-spot across the face of a tilted disc (Wood & Burke 2007). However, as far as we are aware V533 Her does not undergo superoutburtsts, so it is unlikely that we are seeing this effect in this case.

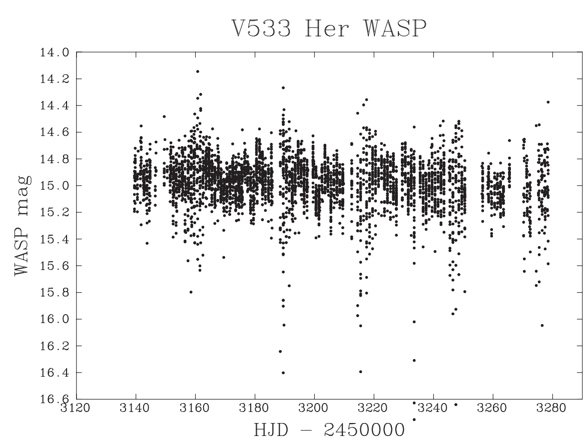

Figure 4. Light curve of V533 Her in the SuperWASP data base for the period JD 245 3120–245 3280.

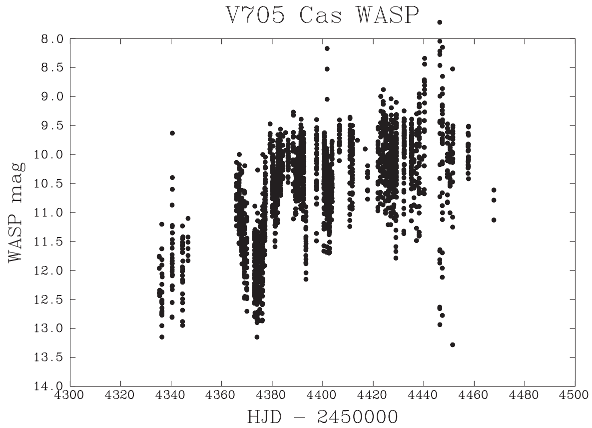

Figure 5. Light curve of V705 Cas in the SuperWASP data base for the period JD 245 4300–245 4500.

Thorstensen & Taylor (2000) conclude that V533 Her is a (non-eclipsing) SW Sex star, one of the defining characteristics of which is high mass transfer rate so that the outer disc in these objects contributes relatively more light than is the case in other CVs (Knigge et al. 2004). In view of the small difference between the spectroscopic Thorstensen & Taylor (2000) and photometric (this paper) periods, and the likely greater contribution of the outer disc to the total light, one possible explanation is that the photometric variations we see in V533 Her arise partially from irradiation of the secondary, but modulated by the precession of an eccentric (or warped) disc.

4.1.5 *V705 Cas*

V705 Cas erupted in 1993 and is an archetypical dust-forming nova (Evans et al., 2005). An orbital period was reported by Retter & Leibowitz (1995), who observed V705 Cas over 10 nights in 1995 August/September. They found periodic oscillations in the *I* band with amplitude 0.05 mag and period 0.2280 ± 0.0005 d; they interpreted this as the orbital period. No other determinations of the orbital period have been reported.

The WASP data for this object cover 130 d, starting JD 245 4300 (2007); the light curve is shown in Fig. 5. PERIOD gives a period of $0.204\,63 \pm 0.000\,04$ d; this is again close to, but significantly smaller than, the previously published orbital period. Despite this discrepancy we are not in a position to draw any conclusions as no detail was given by Retter & Leibowitz (1995).

4.1.6 *T CrB*

T CrB is a RN that has undergone eruptions in 1866 and 1946. The secondary star is a M3 giant (Kenyon & Garcia 1989), and the orbital period is 227.5687 d (Fekel et al. 2000). Yudin & Munari (1993) have presented infrared photometry which shows periodic variation that seem to be phased with the orbital period; they interpret this in terms of the ellipsoidal variations in the giant secondary (see also Belczyński & Mikołajewska 1998; Anupama & Mikołajewska 1999). Based on AAVSO data, the HIPPARCOS catalogue (ESA 1997) gives a photometric period of 112.9 d; this is close to half the orbital period, as would be expected if the variations were ellipsoidal.

The WASP observations were obtained over 150 d from JD 245 3130 (2004). There is clearly a period that is captured in the WASP data, which PERIOD gives as 91 ± 8.3 d (see Fig. 6).

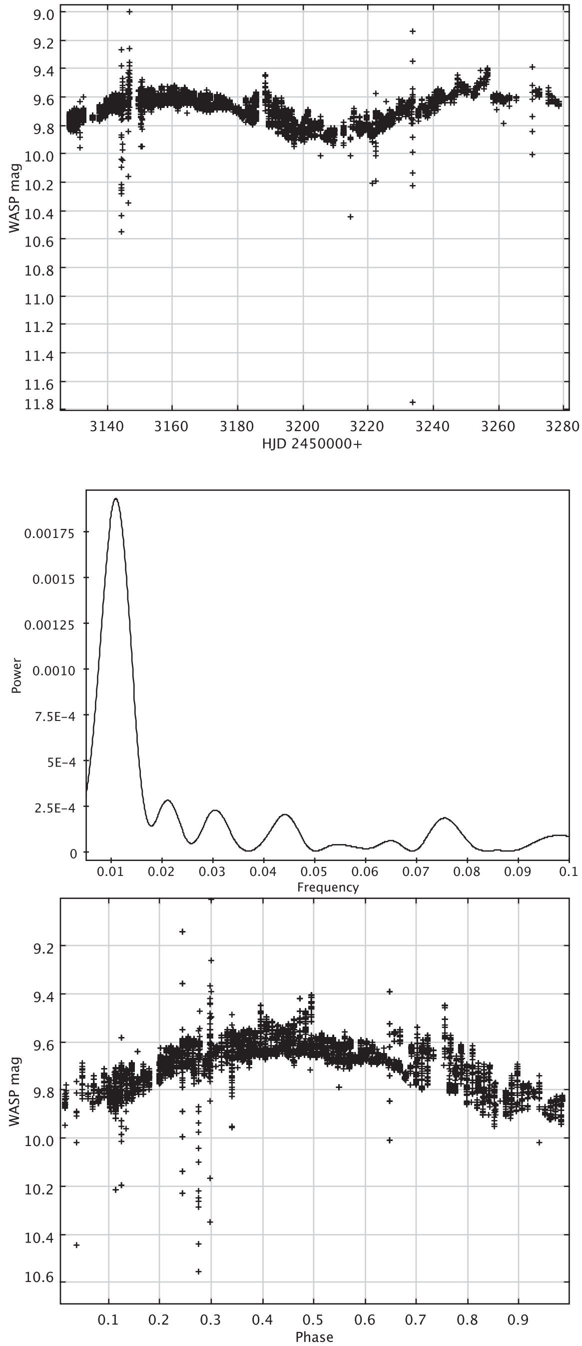

Figure 6. Top, light curve of T CrB in the SuperWASP data base; middle, periodogram for T CrB; bottom, light curve of T CrB folded over 91 d period.

While this seems to be marginally (2.7σ) different from half the orbital period, we should note that the SuperWASP data do not cover an entire orbital period. Any conclusion would therefore be premature and we will revisit the WASP data for T CrB in a future paper.

5 CONCLUSIONS

We have presented a discussion of the light curves of classical and recurrent novae from the WASP archive. The WASP project has covered the 2009 eruption of KT Eri, and in particular its pre-eruption variability. In the case of other classical novae in the WASP data base, the CNe have orbital periods <1 d and the variations evident in the WASP data invariably point to modulations that originate in orbital motion.

The value of the SuperWASP archive for CNe and RNe is that it may potentially contain valuable (indeed unique) data on the poorly observed pre-eruptive variations of classical and recurrent novae. Its value also lies in the increasing time-base over which observations are available; as this becomes longer not only will further objects in these categories become amenable to analysis but more importantly – given the stability of the SuperWASP system – it will become possible to search for period drifts, particularly in those objects displaying mass transfer and mass-loss, and having shorter ($\lesssim$1 d) periods.

ACKNOWLEDGMENTS

RMcQ acknowledges the receipt of a Nuffield undergraduate bursary; RAH is supported by an STFC research studentship. The WASP Consortium consists of representatives from the University of Cambridge (Wide Field Astronomy Unit), Instituto de Astrofisca de Canarias, Isaac Newton Group (La Palma), University of Keele, University of Leicester, The Open University, Queen's University Belfast and University of St. Andrews. The SuperWASP cameras were constructed and operated with funds made available from Consortium Universities and PPARC/STFC. The USAF/NASA SMEI is a joint project of the University of California San Diego, Boston College, the University of Birmingham (UK) and the Air Force Research Laboratory.

We acknowledge with thanks the variable star observations from the AAVSO International Data base, contributed by observers worldwide and used in this research.

We finally thank an anonymous referee for comments that helped to clarify a number of points in this paper.

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