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SS Cygni Revisited

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Abstract

New spectroscopic and photometric observations of SS Cygni, the brightest dwarf nova system, have been obtained, with the aim of mapping starspots on the surface of the secondary star. Four nights of echelle spectroscopy in quiescence have been obtained using the 2.2-m telescope at San Pedro Martir (Mexico) in August 2012 and another two nights at the 3.5-m telescope at Apache Point Observatory, USA, in September 2012, but these data are still being reduced. Simultaneous CCD photometry was also obtained at the two sites, and the Mexican photometry was extended into the subsequent long outburst. This presentation reveals some interesting photometric behaviour in that outburst, but further data will be necessary before the nature of the behaviour can be determined.

Keywords: cataclysmic variables - dwarf novae - optical - spectroscopy - photometry - individual: SS Cyg.

1 Introduction

The canonical model of cataclysmic variable (CV) evolution requires secondaries to be magnetic, to allow magnetic braking to keep the star in contact with its Roche lobe. Magnetic activity should produce starspots, as shown by observations of rapidly rotating single stars. Detection of starspots on CV secondaries provides evidence for magnetic fields, and Roche tomography has been used to reveal spots on four systems: AE Aqr (Watson et al. 2006), BV Cen, V426 Oph (Watson et al. 2007a, 2007b) and RU Peg (Dunford et al. 2012). The unusual nova-like system AE Aqr is the brightest of these, and the others are at least two magnitudes fainter.

SS Cygni is the brightest dwarf nova, and in quiescence is only half a magnitude fainter than AE Aqr. It is therefore an obvious candidate for study and high-resolution echelle data were obtained in 2012 August (in Mexico) and September (in the USA), with simultaneous photometry. The Mexican echelle data were taken with the 2.2-m telescope at the San Pedro Martir (SPM) observatory in Baja California; the V photometry was taken with the SPM 0.84-m telescope. The US echelle spectra were taken with the 3.5-m telescope at the Apache Point Observatory (APO); simultaneous photometry was also obtained, using the NMSU 1-m telescope at APO (V) and the UW 0.76-m at Manastash Ridge Observatory (g, r, i).

2 Spectra

The US spectra were taken on two nights with the APO 3.5-m and have been fully reduced but not yet analysed. In Figure 1 we show part of the average spectrum from the first night; the region shortward of 6750 Å makes it clear that there are many absorption lines that can be used for Roche tomography. Four nights of data were taken with the SPM 2.2-m; these spectra are still being reduced.

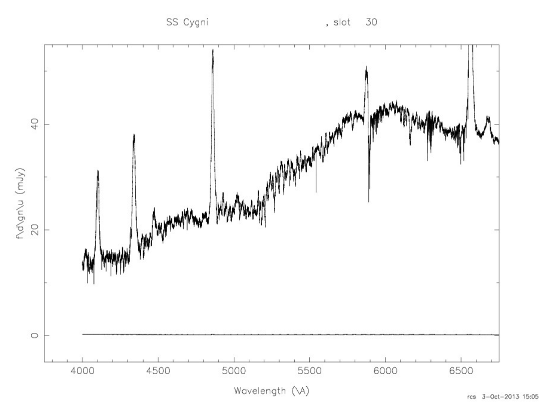

Figure 1: A portion of the average of 29 spectra of SS Cygni taken with the echelle spectrograph on the 3.5-m APO on 20/21 September 2012. In addition to strong emission lines, there are many absorption lines suitable for Roche tomography of the secondary.

3 Photometry

All the photometry has been fully reduced; here we just discuss the analysis of the Mexican data.

At the San Pedro Martir (SPM) observatory in Mexico, simultaneous V photometry with the 0.84-m telescope was taken to enable flux calibration of the echelle spectra being taken with the 2.2-m telescope. By good fortune, SS Cygni went into outburst one day after the spectra had been taken, and our Mexican colleagues kindly allowed us to continue photometric observing; the complete coverage is shown in Figure 2. Unfortunately, no useful data were obtained on the fifth night in outburst, which was clouded out; however, the mean level on that night does appear to be higher than on the previous nights, possibly lending support to the prediction of Cannizzo (2013; see also Cannizzo 2012) that long outbursts should have a precursor outburst at the beginning. Subsequent AAVSO data confirmed that this was a long outburst.

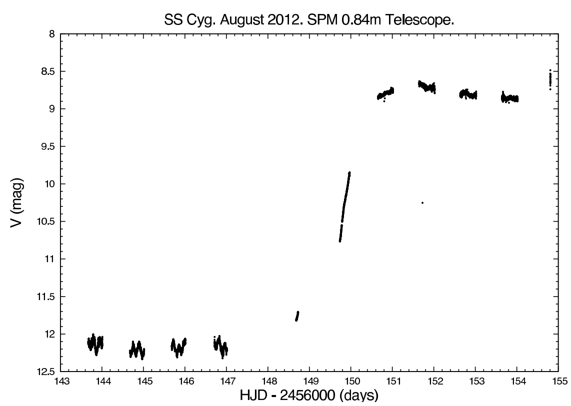

Figure 2: V photometry of SS Cygni in quiescence, rise and outburst, August 2012.

We first analysed the quiescent data, looking for the dominant period. As expected, the only significant period to be found was the orbital period; a light curve folded on that period showed the characteristic double hump arising from ellipsoidal variation.

There were four nights of useable outburst data. The data were first detrended, by removing linear trends from each individual night and then adding or subtracting suitable constants to bring all the nights to the same average magnitude. The *Starlink* package PERIOD was used to search for the dominant period, using five different methods: String-length, Minimum chi-squared, Lomb-Scargle, Fourier Transform and Clean. Some of these methods produced no very useful results, and the clearest and most consistent results were obtained with the Minimum chi-squared and Lomb-Scargle methods. The results below quote only the results from those two methods.

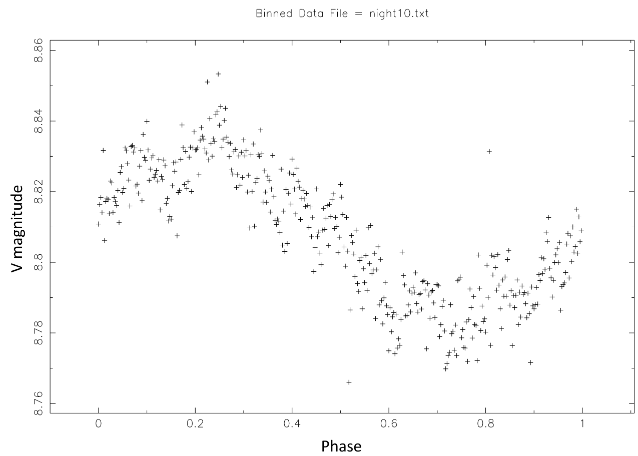

Figure 3: Night 3 outburst data folded on a period of 0.35273 days and binned into 400 bins. Note that the magnitude scale has brightness increasing downwards.

Analysing the entire data-set gave a best-fit period that was about 1.5% smaller than the orbital period, but the signal was not strong and this result is not thought to be significant. However, when the different nights were analysed separately a very different pattern emerged: each night had a different dominant period. The clearest result was for the 3rd night in outburst, where the two methods agreed on a period of 0.353 days. This is approaching the length of the data stream on that night (0.384 days), but is significantly shorter, and there is no sign of the data length in the period analysis. This period is also significantly longer than the orbital period of 0.27513 days. Figure 3 shows the night 3 data binned and folded on a period of 0.35273 d.

The best period on night 2 was close to the orbital period, with minimum chi-squared giving 0.2715 d and Lomb-Scargle giving 0.2769 d. However, the other two nights both gave significantly shorter best periods: 0.1433 d on night 1 and 0.1963 d on night 4. The Lomb-Scargle plots for all the nights are shown in Figure 4 – note that the maximum power varies from night to night.

Thus, apart from night 2, the outburst data are **not** consistent with the orbital period, with two shorter periods and one longer one. There is a temptation to consider the night 3 data as evidence for a positive superhump – Boneva et al. (2009) suggested that in outburst SS Cyg has an elliptical disc. If so, SS Cyg is not impossibly far off the standard $P_{\rm sh}, P_{\rm orb}$ relation, and the orbital period of 6.6 h would be the longest on that relation. However, with a well-determined mass ratio q of 0.683 (Bitner at al. 2007), it strongly violates the normal resonance criterion of $q < 0.33$.

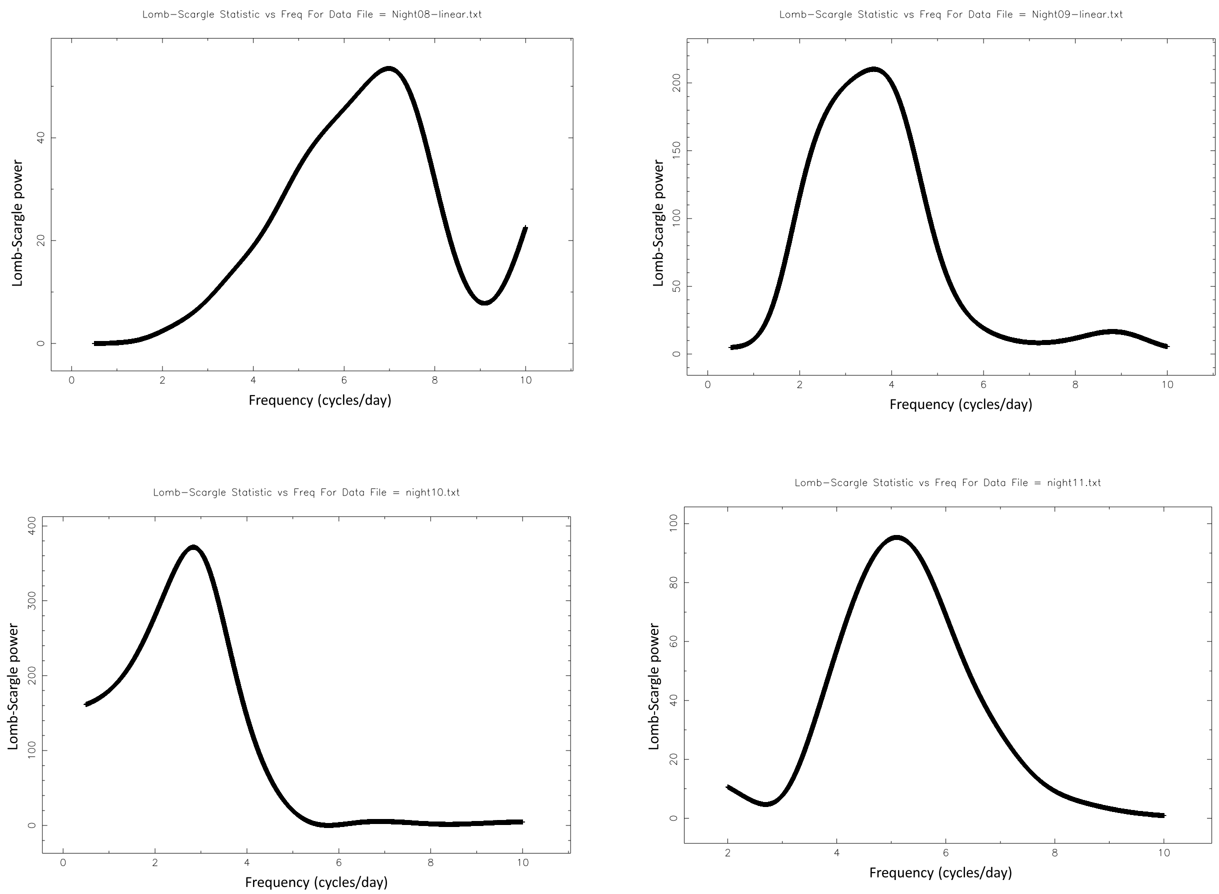

Figure 4: Lomb-Scargle power plots for the four outburst nights. By far the strongest signal is on night 3, with a maximum power of ∼350. The maximum power on the other nights are: ∼50 (night 1), ∼200 (night 2) and ∼100 (night 4). The dominant periods on nights 1 to 4 are 0.1433 d, 0.27-0.28 d, 0.35273 d and 0.1963 d respectively. The horizontal axis is frequency, in cycles/day.

Furthermore, the amplitude is low (∼0.08 mag), the superhump excess (28%) is rather large, and two of the other nights suggest *negative* superhumps (although these have even larger differences from the orbital period, at 48% and 29% smaller, and have similarly small amplitudes).

Is there a better explanation? One possibility was raised by Bisikalo (2013; see also Zhilkin & Bisikalo 2010), who showed models where fluctuations in the accretion rate onto the white dwarf, caused by variations in the generation of magnetic field in the disc, produced brightness variations on various timescales. Perhaps we are seeing evidence in our data for similar brightness variations, which might be stochastic in nature.

4 Conclusions

The spectral data we have obtained for SS Cygni appear to be good enough for us to be able to map starspots on the surface of the secondary component.

The photometric data in quiescence appear to show ellipsoidal variations on the orbital period.

However, the photometric data in early outburst are generally **not** consistent with the orbital period. The data from the 1st and 4th nights have shorter periods (negative superhumps?) while the data from the 3rd night show a longer period (a positive superhump in the longest-period system so far?).

Alternatively, we may have found evidence for variations in the accretion rate onto the white dwarf, caused by magnetic effects in the disc. Whatever the explanation, it would be worth monitoring SS Cygni intensively during its long outbursts, to see whether this peculiar behaviour is repeated.

It turns out that the kind of photometric data we obtained during the long outburst in August 2012 is rare: not many people have carried out time-resolved observations of the long outbursts in dwarf novae and so the nature of the behaviour during these outbursts is still quite uncertain (cf. Cannizzo 2012, 2013). In order to test whether any changes are periodic or stochastic, it will be necessary in future to monitor as many of these long outbursts as possible, in SS Cygni and in similar dwarf novae. It is hoped to do this by organising an international campaign involving both the amateur community and the many robotic telescopes scattered around the world.

By the time these data are available, it is hoped that predictions of the magnetic effects in the disc, by Bisikalo and others (e.g. Bisikalo 2013), will have reached the stage where they may be compared in detail with the data to discover whether the model is compatible with observations.

Acknowledgement

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DISCUSSION

DAVID BUCKLEY: I am puzzled by the superhump excess ϵ for TX Col. Is there a reference for the superhump period?

ROBERT SMITH: I took the superhump period and excess for TX Col from Montgomery (2009, ApJ, 705, 603), who quoted Retter et al. (2005, ASSL, 332, 251). The Retter et al. conference paper is suggestive but not definitive.

CHRISTIAN KNIGGE: Since you typically see only about one cycle of your periods in each epoch, is it not possible that the variability is stochastic rather than periodic?

ROBERT SMITH: In some cases we have two cycles. But more generally, yes, to call them periodic changes is a bit speculative. However, there *is* a clear single peak in the Lomb-Scargle power spectrum on each night, and they are certainly at different frequencies on different nights. The night-to-night changes may be stochastic, as you suggest, but there is definitely something interesting happening.