SDSS J161033.64–010223.3: A second Cataclysmic Variable with a Non-radially Pulsating Primary

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ABSTRACT

We find from high speed photometry of the Sloan Digital Survey cataclysmic variable candidate SDSS J161033.64–010223.3 that it has a double humped modulation, which is probably orbital, with a period of 80.52 minutes, and shows strong ZZ Cet type pulsations. The largest amplitude oscillations have periods near 607, 345, 304 and 221 s. The amplitudes of some of the oscillations are seen to vary on time scales of hours, indicating modes with unresolved multiplets in which the splittings are $\sim 1$ d$^{-1}$. This is only the second dwarf nova found to have non-radial pulsations of its white dwarf primary.

Key words: techniques: photometric – binaries: close – stars: individual: SDSS J161033.64–010223.3, cataclysmic variables

1 INTRODUCTION

The white dwarf accretors in cataclysmic variable (CV) stars have outer layers that differ from those of isolated white dwarfs. Not only is there an accumulation of hydrogen-rich material, leading ultimately to a nova explosion, the accretion process itself results in heating, mixing and compression which change the thermal structure and composition profile (Townley & Bildsten 2003). Observations that contribute towards probing these structures are not easy to interpret – the chemical compositions of the outer layers of the primaries of CVs are complicated by the rapid settling rate of the heavier elements (Sion 1999), the chemical abundances in nova ejecta are the end product of a mixture of dredge-up from the core and nuclear reactions during the explosion, embedded in shock-driven hydrodynamic processes. It would be of greater value to probe the outer layers by more direct means, as is possible through the application of asteroseismology to single white dwarfs (e.g., Clemens 1993).

A start in this direction was made by the discovery of the first CV to show non-radial pulsations (i.e. a CV whose primary is a ZZ Cet star) – namely the dwarf nova GW Lib (Warner & van Zyl 1998). GW Lib is a low mass transfer ($M$) system that has only had one observed outburst (in 1983) of very large amplitude. Its oscillation spectrum is complicated and has yet to be fully unravelled (van Zyl et al. 2000), and as such it remains to make a quantitative contribution to the determination of outer structure of an accreting white dwarf. Its predominant oscillation modes have periods that lie near 236, 376 and 650 s, with amplitudes in the range 5 – 15 mmag, and evidence for other modes, including sum and difference frequencies, and some possible periods around 1000 s and 5000 s. As with large amplitude ZZ Cet stars, the oscillation spectra are not stationary, individual modes (which may in many cases be unresolved multiplets) varying greatly in amplitude on time scales of days, months and years.

Nevertheless, the discovery of further examples of this class of CV will surely be welcomed, and that is what we present here – a second CV in which large amplitude non-radial oscillations of the primary can be studied by the brightness modulations that they cause. In Section 2 we describe what was previously known about the star, in Section 3 we present our photometric observations and their Fourier transforms and in Section 4 we add some general comments.

2 THE STAR SDSS J161033.64–010223.3

The Sloan Digital Sky Survey has released an initial tranche of newly discovered CVs, found as candidates from their colours and then selected on the basis of spectroscopic appearance (Szkody et al. 2002). Among the multitude of spectra one in particular caught our attention. The nineteenth magnitude SDSS J161033.64–010223.3 (which we will abbreviate to SDSS1610) shows a blue continuum with broad hydrogen absorption lines containing narrow emission cores, and He I 5876 Å weakly in emission. It is typical of a dwarf nova in quiescence. The depth of the Hβ absorption, when compared with that for isolated white dwarfs (Wesemael et
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Figure 1. The light curves of SDSS1610 on 2003 June 7 and 9. Run S7000 has been displaced downwards by 0.3 mag for display purposes only.

Table 1. Observing log.

| Run No. | Date of obs. (start of night) | HJD of first obs. (+2452000.0) | Length (h) | $t_{in}$ (s) | Tel. | V (mag) |
|---------|------------------------------|--------------------------------|------------|-------------|------|--------|
| S6998   | 2003 Jun 03                  | 794.29592                      | 1.92       | 60          | 74-in | 18.9   |
| S6991   | 2003 Jun 06                  | 797.26242                      | 6.32       | 45          | 74-in | 18.9   |
| S6994   | 2003 Jun 07                  | 798.23303                      | 7.00       | 45          | 74-in | 19.0   |
| S6998   | 2003 Jun 08                  | 799.47233                      | 1.08       | 60          | 74-in | 19.0   |
| S7000   | 2003 Jun 09                  | 800.28837                      | 5.75       | 60          | 74-in | 19.0   |

Note: $t_{in}$ is the integration time.

al. 1993), shows that there can be little overlying emission continuum from an accretion disc. The system is therefore in a very low state of mass transfer, a requirement if the heating effect of accretion is not to move the white dwarf out of the ZZ Cet instability strip (which for isolated DA white dwarfs is $\sim 11000 – 12000$ K (Bergeron et al. 1995)).

3 PHOTOMETRIC OBSERVATIONS

We have carried out high speed photometric observations of SDSS1610 with the 74-inch Radcliffe reflector at the Sutherland site of the South African Astronomical Observatory, using the University of Cape Town CCD Photometer (O’Donoghue 1995) with no photometric filter (i.e., in ‘white light’). Our observing log is given in Table 1.

Variations of brightness on time scales $\sim 100$s of seconds were evident even on the first night of observation, which was of poor photometric quality. In Fig. 1 we show the light curves obtained on later nights, of better quality. The slow variation is caused by differential extinction relative to the (redder) comparison star. The presence of continuous oscillations with a range $\sim 0.10$ mag is obvious. Fourier transforms (FTs) of the three long runs (S6991, S6994 and S7000) with first and second order trends removed, are shown separately in Fig. 2. The dominant regions of oscillation power, in order of decreasing amplitude, are at $\sim 607$ s, $2488$ s (or its alias at $2419$ s), $304$ s (the first harmonic of $607$ s), $220$ s and $345$ s, with amplitudes in the range $5 – 25$ mmag. The frequencies are listed in Table 2. The fact that these periods bear no simple relationship to each other (as could be the case if the star was an intermediate polar in a low state) and their time scales show that SDSS1610 is a second example of a CV with a non-radially oscillating primary. The absence of much overlying emission from the accretion disc implies that the observed amplitudes are not greatly reduced from those originating in the primary.

There are low frequency peaks in the FTs of individual nights in the vicinity of $200$ $\mu$Hz and its first and second harmonics. In the FT of the three long runs combined (Fig. 3) there is a choice of aliases, the best-fitting being $207.0$ ($\pm 0.4$), $413.7$ ($\pm 0.2$) and $625.1$ ($\pm 0.6$) $\mu$Hz. This is equivalent to a period of $80.52$ min and its harmonics. The alternate choice is equivalent to $85.08$ min. We suggest that these features are produced by orbital modulation. As has been pointed out by Thorstensen et al. (2002), the dwarf novae with orbital periods in the vicinity of $80$ mins are a particularly interesting group, of which GW Lib ($P_{orb} = 76.78$ min from spectroscopic observations) is a member. The orbital signal is strongest in run S6994. We have prewhitened the light curve at the principal oscillation frequencies and produced a light curve folded on the $80.52$ period, which is shown in Fig. 4. It is a double humped light curve, very similar to that of WZ Sge (Patterson 1980) and WX Cet (Rogoziecki & Schwarzenberg-Czerny 2001), both of which are very low $\dot{M}$ dwarf novae where it is proposed that the bright spot on the disc is visible from behind through the low optical thickness disc (Robinson, Nather & Patterson 1978a).

The FTs of SDSS1610 bear a strong resemblance to that of the ZZ Cet star VY Hor (O’Donoghue, Warner & Crammer 1992), where the principal frequency is $1626$ $\mu$Hz at an amplitude of $60$ mmag. In VY Hor and GD 154 (Robinson et al. 1978b), the eigenfrequencies are completely described by the sequences $pf$ and $(q + \frac{1}{2} + \epsilon)f$, where $p = 1, 2, \ldots$ and $q = 0, 1, 2, \ldots$. For VY Hor $\epsilon = 0.037$ and for GD 154 $\epsilon = -0.03$. A similar situation obtains in PG 1351+489, where $\epsilon = -0.03$ (Winget, Nather & Hill 1987).

In the case of SDSS1610, where the amount of observa-
Table 2. The suite of frequencies observed in SDSS J161033.64–010223.3.

| ID          | Frequency (µHz) | Period (s) | Ampl. (mmag) | Frequency (µHz) | Period (s) | Ampl. (mmag) | Frequency (µHz) | Period (s) | Ampl. (mmag) |
|-------------|-----------------|------------|--------------|-----------------|------------|--------------|-----------------|------------|--------------|
| f₁          | 1648.9 ± 2.1    | 606.5 ± 0.8| 23.4         | 1646.3 ± 1.2    | 607.4 ± 0.4| 25.9         | 1651.0 ± 1.3    | 605.7 ± 0.5| 30.0         |
| 2f₁         | 3286.4 ± 9.1    | 304.3 ± 0.8| 6.3          | 3292.3 ± 2.9    | 303.7 ± 0.3| 10.0         | 3290.6 ± 3.9    | 303.9 ± 0.4| 9.7          |
| f₂          | 2889.0 ± 7.7    | 344.0 ± 0.9| 7.5          | 2896.0 ± 7.5    | 345.3 ± 0.9| 4.0          | 2907.3 ± 6.8    | 344.0 ± 0.8| 6.3          |
| f₁ + f₂     | 4530.7 ± 6.1    | 220.7 ± 0.3| 9.4          | 4540.0 ± 4.1    | 220.3 ± 0.2| 7.2          | 4547.3 ± 4.6    | 219.9 ± 0.2| 8.2          |
| 2f₁ + f₂    | 5834.7 ± 9.3    | 171.4 ± 0.3| 6.2          | 5771.6 ± 8.0    | 173.3 ± 0.2| 3.7          | 5775.2 ± 8.6    | 164.6 ± 0.2| 5.0          |
| Ω           | 190.5 ± 4.0     | 5249 ± 110 | 11.0         | 198.7 ± 11.0    | 5033 ± 279 | 10.1         | 5033 ± 279      | 198.7 ± 11.0| 10.1         |
| 2Ω          | 406.9 ± 6.1     | 2458 ± 37  | 7.5          | 410.2 ± 2.2     | 2437 ± 13  | 11.9         |                 |             |              |

Note: ‘:’ indicates an uncertain identification.

Figure 2. The Fourier transform of SDSS1610 for run S6991 (upper panel), run S7000 (middle panel) and run S6994 (lower panel). The frequencies listed in Table 2 are marked here by label and dotted vertical bars.

Figure 3. The Fourier transform of the three long runs combined, showing the low frequency range.

Figure 4. The average light curve of SDSS1610 (run S6994) folded on the 80.52 min period, after the light curve had been prewhitened at f₁, 2f₁ and f₁ + f₂.

from one run to the next. For this reason, we have not given frequencies determined from the FT of the combined runs, which in addition introduces the problem of aliasing. If the proximity to values of (q + 1/2)f in GD 154, VY Hor and PG 1351+489 is a sign of non-linear resonant coupling between modes (O’Donoghue et al. 1992), it would appear that in SDSS1610 we are seeing resonances close to another commensurability, viz (q + 3/4)f. In GW Lib, a similar structure is seen in the FT with the presence of q = 0, 1 and 2 peaks, and p = 1 peaks, where f = 1545 µHz and (q + 1/2 + ε)f with ε ≈ −0.03.
night to night and even within a run. In Fig. 5 we show FTs of the first and second halves of run S6994 which illustrate that the first harmonic of the principal eigenfrequency is varying in strength. As with other ZZ Cet stars, this simply means that there is unresolved multiplet structure in these FTs.

A few unidentified low amplitude peaks (∼ 4 – 5 mmag) present in the FTs are not listed in Table 2; they occur in individual runs only. These are: 3860.1 µHz in run S6991; 8731.1 µHz and 9712.3 µHz in run S6994; 6893.6 µHz and 8225.4 µHz in run S7000.

4 DISCUSSION

Clemens (1993) partitioned ZZ Cetis into a 'hot' group and a 'cool' group and shows that the distribution and range of periods is different in the two groups. A decade later, with far more ZZ Cet stars known, this division is less convincing; there are many stars that combine oscillation modes from both groups, as do GW Lib and SDSS1610. Clemens also pointed out that similarities in the ZZ Cetis, at least among the hotter ones, probably arise because all have a similar amount of hydrogen, ∼ 10^{-4} M_☉ in their envelopes. The primary of a CV could have any amount of hydrogen, from zero to ∼ 10^{-4} M_☉, depending on when it last had a nova eruption.

SDSS1610 probably has rare dwarf nova outbursts of amplitude similar to WZ Sge and would therefore reach \( m_V \sim 11 \) at maximum. A search through archived sky patrol plates is therefore recommended, and a watch should be kept for future outbursts. The value of following the heating effects of an outburst on the eigenfrequencies of the primary has already been pointed out (Warner & van Zyl 1998).

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