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TIME-SERIES PHOTOMETRY OF GW LIBRAE ONE YEAR AFTER OUTBURST

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ABSTRACT

We present preliminary results from a total of 212.1 hours of data from multi-site observations of GW Lib. Our results reveal a signal near the 2.1-hr period previously detected by Woudt & Warner in quiescense, but of slightly shorter period, and also a modulation at ∼4-hr. Both the 2 and 4-hr modulations appear to vary in period and/or phase. The 4-hr period may be the fundamental period and the 2-hr period a harmonic. Fourier analysis also shows a transient ∼20-min modulation that is anti-correlated in amplitude with the ∼2-hr periodicity. Using a smaller data set, we investigate higher frequency pulsations and compare to those found by previous authors before outburst.

Subject headings: stars: binaries: photometric—stars: dwarf novae, cataclysmic variables—stars: individual (GW Lib)

1. INTRODUCTION

Cataclysmic variables (CVs) are close binary systems, usually consisting of a white dwarf (WD) primary and a cool main-sequence companion. The secondary star fills its Roche lobe, causing mass-transfer to the primary via the inner Lagrangian point. However, the angular momentum of the infalling matter and the small size of the primary typically prevent material from becoming directly accreted. Instead, an accretion disk is formed around the white dwarf. Angular momentum in transported outwards in the disk through viscous interactions between material at different radii. This process allows the bulk of the matter present in the disk to lose angular momentum and migrate towards the primary. Many of the photometric features of CV systems can be traced to interactions within the disk (Hellier 2001; Warner 1995).

Dwarf Novae (DNe) are a class of CV that show periodic outburst events, where a brightening of a varying range of magnitudes may be observed. SU UMa-type dwarf novae display two types of outbursts: regular DN outbursts and superoutbursts, which are greater in amplitude and typically longer in duration. During superoutburst, an SU UMa-type dwarf nova displays a modulation of its lightcurve with a period slightly greater than its orbital period, known as superhumps. The fractional difference between the period of the superhumps and the orbital period is known as the period excess $\epsilon = (P_{\rm sh} - P_{\rm orb})/P_{\rm orb}$. For the observational properties of SU UMa-type dwarf novae, see Warner (1995b). For an explanation of the tidal and thermal instabilities in the accretion disk which originate superoutbursts and superhumps in SU UMa-type dwarf novae, see Osaki (1996).

WZ Sge-type dwarf novae are considered a subclass of SU UMa-type dwarf novae, undergoing large-amplitude superoutbursts (usually ∼8 mag) with very long reccurance times (∼10 yr or more). It is in this subclass where GW Lib resides. GW Lib was first found to be in outburst in 1983 as a ninth magnitude star (González 1983), later fading to magnitude 18.5 in quiescence. Once classified as a classical nova (CN), later spectroscopic observations during quiescence showed the emission line characteristics of a dwarf novae with a low rate of mass transfer (Duerbeck & Seitter 1987; Ringwald, Naylor, & Makai 1996; Szkody, Desai, & Hoard 2000). Recently, GW Lib was seen in outburst for the second time in April 2007 displaying superhumps with a 1.1% period excess (Kato 2007), solidifying its classification as a WZ Sge-type dwarf nova.

GW Lib contains the first non-radially pulsating white dwarf (DAV or ZZ Ceti-type) discovered in a CV system (Warner & van Zyl 1998; van Zyl et al. 2000). Analysis of the Fourier transforms from several observations in 1997 and 1998 showed three principal structures in the regions near 650, 370, and 230 s (van Zyl et al. 2000, 2004). Curiously, later observations in May 2001 (Woudt & Warner 2002) showed, in addition to the previously uncovered oscillations, a ∼2.1 hr photometric period not present in the 1997 or 1998 data. The presence of this signal, in addition to the recent outburst of GW Lib, has made it an intriguing target for a large-scale photometric campaign.

In none of the above observations was GW Lib's spectroscopically determined 76.78-minute period

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TABLE 1
Observing Log (HJD 2454615-30)

Telescope(s)	Observer(s)	Nights/Hours
CBA-Nelson 35 cm	R. Rea	13/115
CBA-Pretoria 30 cm	B. Monard	8/62
CBA-New Mexico 28 cm	T. Krajci	8/36
SARA Observatory 0.9 m	WSPM[a]	3/12
CBA-Perth 25 cm	G. Bolt	6/42
CBA-Utah 61 cm	J. Foote	2/8
?	G. Roberts	2/6
CBA-Pakuranga 25 cm	J. McCormick	1/6

[a] M. Wood, E. Schwieterman, D. Piwowar, and E. May

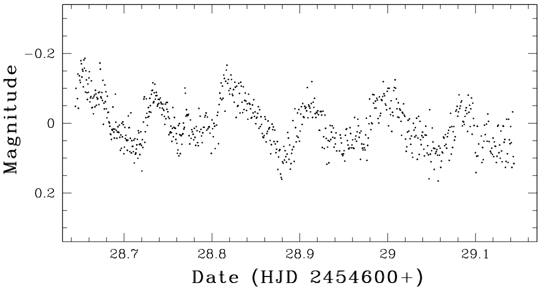

Fig. 1.— Combined data from the SARA Observatory and Robert D. Rea.

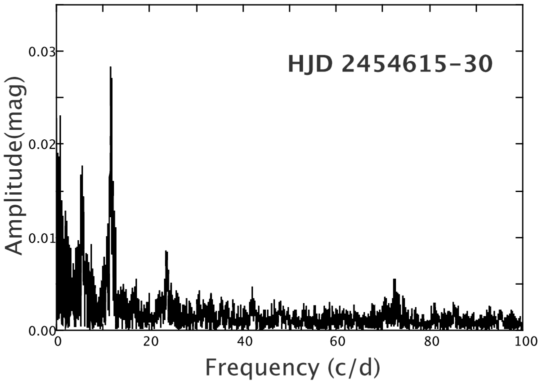

Fig. 2.— Fourier transform of data range HJD 2454615-30.

(Thorstensen et al. 2002) detected photometrically. GW Lib's short orbital period, which puts it near or beyond the ~76-78 minute orbital period minimum for cataclysmic variables, makes it of additional interest.

This paper presents the results of a multi-site photometric campaign of GW Lib. In section 2, we discuss our observations. In section 3, we present our data reduction and analysis, and in section 4 we discuss our results.

2. OBSERVATIONS

Our journal of observations is provided in Table 1. The observations using the SARA 0.9-m telescope at Kitt Peak National Observatory were conducted on the nights of 2008 June 11 UT (HJD 2454628) through 2008 June 13 UT (HJD 2454630) with an Apogee U42 CCD and a Custom Scientific infrared-blocking (IRB) filter. We used 2×2 binning, yielding an effective pixel width of 27μm. The CCD was cooled to -20 °C on all three nights. The remaining data from other sites were obtained with a variety of CCD systems and were reduced before being sent to the Center for Backyard Astrophysics (CBA) archives.

3. DATA REDUCTION AND ANALYSIS

IRAF[1] routines were used for the processing of the raw CCD images and the photometry of the FIT data – other CBA observers used different software packages. The raw images were bias, dark, and flat-field corrected. The routines were modified to calculate and include airmass in the output file. Data were corrected for extinction using airmass values where available, and we used differential photometry to obtain magnitudes. We obtained a total of 212.1 hours of data.

3.1. *Low Frequency ($\lesssim$ 100 c/d) Modulations in GW Lib*

Figure 1 shows a sample data set from our observations of GW Lib. A ~4 hr period seems visually evident. The frequency analysis was carried out using the *Period04* package (Lenz & Breger 2005), which utilizes the Discrete Fourier Transform method. A Fourier transform of our entire set of observations (HJD 2454615–2454630) revealed peaks in the regions of ~5-6 c/d, ~11-12 c/d, ~24 c/d , and ~70-75 c/d (Figure 2). The ~24 c/d frequency appears to be a harmonic of the 12 c/d frequency. The 12 c/d (~2 hr) frequency is in rough agreement with the 2.1 hr photometric period originally reported by Woudt and Warner (2002) and confirmed by subsequent authors before the 2007 outburst (Hilton et al. 2007). However, the ~5-6 c/d frequency may be the true modulation of the signal. This is apparent when viewing the characteristics of the light curve in Figure 1.

The pulsation we detect at ~70-75 cycles per day is most likely the ~75 cycle/day modulation reported by Copperwheat et al. (2008) from observations obtained 2008 March 30 to April 29 (74.86 ± 0.68 c/d best-fit on 2008 March 31). The pulsation was not apparent in Copperwheat's May/June data.

Copperwheat et al. also found the 2 hr period was measurably shorter after outburst than before, disappearing during outburst (although they do not mention the 4-hr periodicity). This is consistent with our results.

A constant/phase period model cannot fit our entire May/June data set, leading us to believe the above modulations are quasi-periodic in nature. In order to demonstrate this, Fourier transforms of sets of two UT days of data (to obtain a very modest baseline) were taken and are displayed in series in Figure 3. It appears that the ~2 and ~4 hr signals wander in phase and period. Intriguingly, it seems that the ~70-75 c/d pulsation is anti-correlated with the ~11-12 c/d modulation.

Table 2 presents the frequencies for each amplitude spectrum. Mean trends were subtracted from the light curve before the Fourier transform. The amplitiude spectrum was then calculated, and each successive residual prewhitened until the data were consistent with noise. The frequencies were then fitted to the individual data sets by a non-linear least squares fit. Errors were calculated in the *Period04* package using a Monte Carlo

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[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation

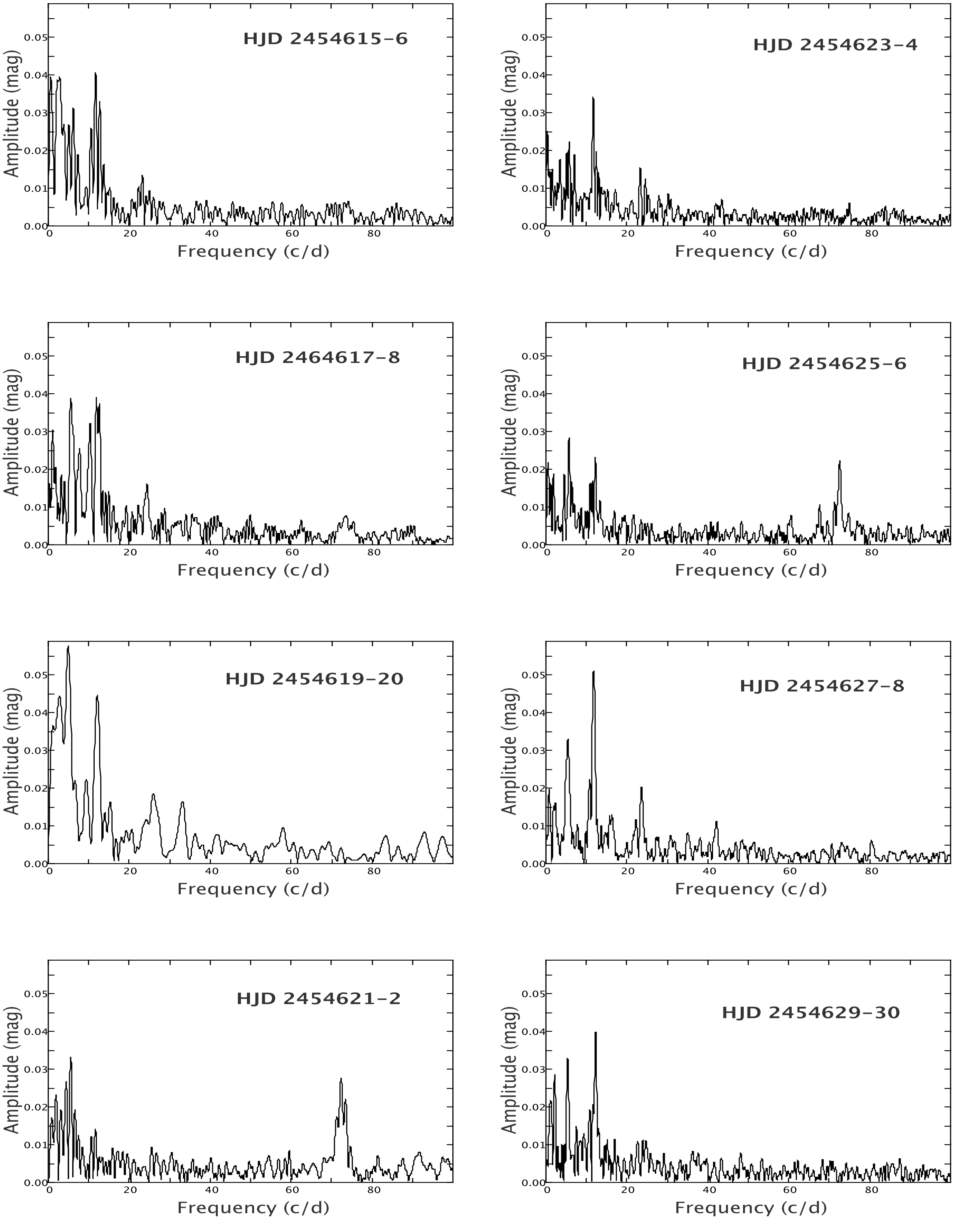

FIG. 3.— A series of Fourier transforms using two day blocks of our HJD 2454615-30 data set. Note the transient 70-75 c/d pulsation and changing amplitude of the 11-12 c/d signal.

TABLE 2
Frequencies and Amplitudes

Date (2454+)	Frequency (cycles/day)	Amplitude (mmag)
HJD 615-6	6.3±5.1	38±1.2
	11.678±.023	42.96±.30
	22.3±1.1	10.7±2.3
HJD 617-8	5.5229±0.0023	34.9±1.2
	6.2430±0.0076	17.19±0.95
	11.0591±0.0037	34.1±1.2
	11.8717±0.0023	59.0±1.4
	13.5±2.2	15.5±1.4
	24.40±0.36	21.5±1.4
	26.5±2.3	13.4±2.1
	73.265±0.018	8.56±1.3
HJD 619-20	4.941±0.048	56.9±3.7
	12.066±0.068	46.1±4.0
	26.1±3.2	20.0±6.4
HJD 621-2	5.57±0.24	32.6±3.9
	72.360±0.049	27.2±2.9
HJD 623-4	5.852±0.027	22.3±2.1
	11.720±0.017	33.6±2.0
HJD 625-6	5.712±0.022	27.6±2.4
	12.204±0.027	23.1±2.5
	72.59±0.029	22.4±2.2
HJD 627-8	5.461±0.028	32.4±2.1
	11.7982±0.0072	49.2±1.3
	23.643±0.024	17.6±1.3
HJD 629-30	2.2±1.1	28.8±6.2
	5.379±0.024	30.3±2.1
	12.293±0.016	39.2±2.1

simulation. Obvious aliases and frequencies just above noise level were left out. Due to the low sampling rate and short baseline of each two-day data set, the data presented in Figure 3 and Table 2 are intended to represent the qualitative nature of the evolution of the amplitude spectra, rather than provide a precise quantative description.

3.2. *High Frequency ($\gtrsim$ 100 c/d) Pulsations in GW Lib*

In order to locate pulsations in GW Lib with frequencies greater than 100 c/d, we utilized the three nights days of SARA data (HJD 2454628-30) due to these data containing the shortest integration times (20 s). The Fourier transform of this data set is shown in Figure 4.

Initial data reduction was performed as described at the beginning of section 3. Additionally, lower frequency trends were removed by dividing each of the three nights by a boxcar smoothed curve. The frequencies, amplitudes, and errors were calculated with the same procedure described in § 3.1. Unfortunately, the noise level is too high to definitively report any pulsations. There is power in the regions of 640 and 231 s, which correspond within error to the 650 and 230 s pulsations modes reported by van Zyl et al. (2000, 2004). However, if we had not known *a priori* that pulsations in these regions had been reported before, we would not report them here. The largest amplitudes we detect in our higher frequency spectrum are smaller than the lowest value pulsations reported in van Zyl et al. (2004). Our marginal detections are listed in Table 3.

TABLE 3
Marginal Detections

Frequency (c/d)	Period (s)	Amplitude (mmag)
134.9±7.5	640.±34.	2.93±0.68
374.±13	231.±8.	2.55±0.8
686.6±2.9	125.80±0.49	2.54±0.72
959.8±6.2	90.02±0.58	2.58±0.76

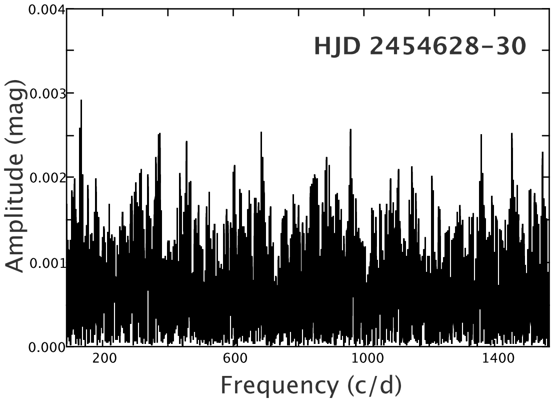

Fig. 4.— Fourier transform using frequency range 100 c/d to Nyquist frequency. Data from the SARA 2008 June 11 to 13 UT data set.

We display our results in Table 3. The periodicities we located near 640 s and 231 s correspond within error to the 650 and 230 s pulsation modes reported by van Zyl et al. (2000, 2004); however the 370 s pulsation is not apparent in these data. Additionally, the 125.8 and 90.02 s pulsations appear to have 5:1 and 7:1 resonances with the 650 s pulsation, respectively. The 59.43 and 63.5 s signals are suspect and may be artefacts, as they are ∼3 times the photometric integration time. There may be additional pulsations present in the WD of GW Lib, but they are not significantly above noise level. Even those pulsations we have reported here should be considered marginal detections.

4. DISCUSSION AND CONCLUSIONS

Utilizing data from the SARA Observatory and the Center for Backyard Astrophysics, were were able to determine several periodicities in GW Librae. We strongly suspect the ∼4-hr periodicity detected is the true modulation of the ∼2-hr photometric period reported by previous authors. Additionally, examination of the light curve strongly suggests a ∼4 hr period. We also report a transient ∼20-min periodicity that may be anti-correlated with the 2-hr signal. All three of these modulations were found to wander in period/phase significantly over the course of days. Observations reported by other authors corroborates the existence of the ∼20-min pulsation, the somewhat shorter period of the ∼2-hr modulation after the 2007 outburst, and the poor clocks of these two signals (Copperwheat et. al. 2008).

We examined high frequency signals using a smaller data set and were unable to confirm or rule out pulsations due to noise. However, they could have been no greater than 3 mmag, our highest marginal detection.

None of the periodicities we reported correspond to the

76.78-min orbital period determined by Thorstensen et al. (2002). GW Lib's orbital period puts it at or near the period minimum for CVs. The mass ratio of this system is extremely low. We calculate a mass ratio of q =0.056 using ϵ =0.011 (Kato 2007) and an empirical formula for determining the mass ratio q based on the period excess of superhumps (Patterson 2001; Patterson et al. 2005):

$$\epsilon = 0.18q + 0.29q^2 \tag{1}$$

With such a small mass ratio, it is likely the WD and disk contribute almost all of the light from the CV system. Additionally, it is likely the secondary is tidally locked with the WD. This reduces the number of clocks present in the system. It seems unlikely that the rotation rate of the WD would be the source of the 2 and 4-hr modulations, though Szkody et al. (2002) put forward a dual-temperature model of the WD in GW Lib. Coupled with a slow rotation rate not atypical for WDs in CV systems, this could conceivably explain the anomalous photometric period, though it does beg the question of what causes a dual-temperature WD. It is also possible that these modulations are caused by an unknown accretion process, an interaction between the rotational and orbital periods, or extraordinarily long pulsations modes in the WD.

With the recent outburst of GW Lib, and the attention given to it after becoming known to contain the first nonradially pulsating WD discovered in a CV system, there exist many data sources to study its amplitude spectra before, during, and after outburst. A compilation and analysis of this entire data set may yield additional clues to uncovering the origin of GW Lib's mysterious periodicities. Such an analysis would of course supercede these preliminary results.

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