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Following the Pulsations in the Long-term Cooling of GW Librae and V386 Serpentis

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Abstract

GW Lib and V386 Ser are dwarf novae systems containing pulsating white dwarfs that underwent large 8–9 mag amplitude outbursts in 2007 and 2019, respectively. Following the pulsation periods in these systems after the outburst provides a means to view the heating and cooling effects of mass accretion on the instability region of the white dwarf. Follow-up optical observations during 2021–2023 for these two systems are reported, resulting in a time span coverage of 16 yr for GW Lib and 4 yr for V386 Ser after their outbursts that reveal large differences in behavior as their white dwarfs returned to quiescence. GW Lib showed intermittent longer periods at 19 minutes, 1.4, 2, and 4 hr during the first 16 yr after the outburst, before finally showing, at 14 yr post-outburst, two of the three short-period modes apparent during preoutburst quiescence. In contrast, V386 Ser appeared to follow theoretical expectations, showing a shorter-period pulsation soon after the outburst, and progressively longer periods as it cooled to its quiescent state. While the optical light returns to quiescent value within 2 yr, it is apparent that the white dwarf takes much longer to recover to its quiescent state. Theoretical work is needed to explain the large differences in otherwise similar systems.

Unified Astronomy Thesaurus concepts: White dwarf stars (1799)

1. Introduction

The pulsating white dwarfs that are in close binaries and accreting matter from a companion star provide a unique opportunity to study the effects of accretion heating and cooling on observable timescales (Szkody 2021). Whereas evolutionary cooling of white dwarfs takes millions of years, the binary accretion results in dwarf nova outbursts that last for weeks, during which the increased accretion of the disk material onto the white dwarf results in compressional heating that increases its temperature (Godon & Sion 2003). The systems in this study have short periods and extreme mass ratios that lead to very large amplitude (8–9 mag) super-outbursts with maximal heating. As the white dwarf subsequently cools back to its quiescent level, the pulsations can be followed to determine the conditions at the base of the convection zone that drive the pulsations (Townsley et al. 2004). The theoretical expectation is for the pulsations to stop during the outburst if the heating eliminates the outer convection zone, moving the white dwarf out of the ZZ Ceti instability strip. As the white dwarf cools, it reestablishes an outer convection zone that can drive pulsations, first at short periods when the convection zone is shallow, then gradually in longer-period modes as the convection zone deepens toward the quiescent state (Goldreich & Wu 1999).

The accreting pulsators in this study have the advantage of having low secular mass transfer rates and thus low quiescent mass accretion rates, so consequently they have long timescales between outbursts (decades instead of the usual months for most dwarf novae). The low accretion rate also means that the disk contribution to the total light is less than for most dwarf novae. Past data have shown that the white dwarf contributes 75%–89% of the ultraviolet light and 42%–75% of the optical light for these low accretion rate systems (Szkody et al. 2010).

Thus, in order to determine the best determination of the temperature of the evolving white dwarf, ultraviolet spectra are needed. The increased amplitude (factor of 6–10) of the pulsations in the UV over the optical is also a benefit of observing in the UV (Szkody et al. 2010). However, optical observations are necessary to follow the evolution of the pulsations over long periods of time as Hubble Space Telescope (HST) observations are short and difficult to obtain. Since the outbursts cannot be predicted and there are only 18 accreting pulsators known at this time, there are only a few that have been followed with HST and optical observations for any length of time after outburst. In this paper, we summarize the results that we have obtained in the last three years in continuing to follow the outbursts of GW Lib and V386 Ser.

GW Lib underwent a 9 mag optical outburst in 2007 after a previous outburst in 1983. It was followed optically and with Galaxy Evolution Explorer for the first few years (Bullock et al. 2011) and then by HST and optical until 2017. Prior to its outburst, it showed consistent pulsation periods in both optical (van Zyl et al. 2004) and UV at 650, 370, and 237 s (Szkody et al. 2002). The optical sometimes showed a 2 hr variation as well (Woudt & Warner 2002). Following the outburst, a surprising 19 minutes pulse was viewed along with 275 s, 83 minutes, and 4 hr periods that intermittently came and went throughout the years (see the most recent summary in Chote et al. 2021). A long 88 days K2 observation took place in 2017 along with several HST orbits that tied together the short, 19 minutes, and 4 hr periods as all part of the pulsation modes (Gaensicke et al. 2019). Table 1 summarizes the past data on

Table 1
GW Lib Postoutburst Period Summary

Year	Observatory	Month	Periods	References
2008	APO	Mar 29	19.1 m	Bullock et al. (2011)
2008	LT	Mar–Jun	296 s, 19.2 m, 2.1 hr	Copperwheat et al. (2009)
2008	GALEX	May–Jun	4 hr	Bullock et al. (2011)
2008	SARA	May–Jun	19.8 m, 4 hr	Schwieterman et al. (2010)
2008	CBA	May–Jul	19 m	Vican et al. (2011)
2009	GALEX	May 16	4 hr	Bullock et al. (2011)
2010	GALEX	Apr 25	4 hr	Bullock et al. (2011)
2010	HST	Mar 11	266–292 s	Szkody et al. (2012)
2010	McO	Mar 11	284 s	Szkody et al. (2012)
2011	HST	Apr 9	293 s	Szkody et al. (2012)
2011	APO	Apr 4, 8	276, 298 s, 85 m	Szkody et al. (2012)
2011	KPNO	May–Jun	291–329 s	Szkody et al. (2012)
2011	MJO	Jul–Aug	276–323 s, 83 m	Szkody et al. (2012)
2012	MJO	Mar 25	83 m	Chote & Sullivan (2016)
2012	MJO	Apr–May	277–281 s, 19 m	Chote & Sullivan (2016)
2013	MJO	Mar 13	82 m	Chote & Sullivan (2016)
2013	APO	May 4	83 m	Chote et al. (2021)
2013	HST	May 30	270–290 s, 4.4 hr	Toloza et al. (2016)
2014	APO	Mar 25	83 m	Chote et al. (2021)
2015	HST	Apr 22	373 s	Szkody et al. (2016)
2015	APO	Apr 21, 22	364, 372 s, 2.1 hr	Szkody et al. (2016)
2015	MJO, CTIO	Apr–May	312–370 s, 2 hr	Chote et al. (2017)
2016	La Palma	May–Jun	19 m	Chote et al. (2017)
2017	APO	Mar 4	19 m	Chote et al. (2021)
2017	HST	Aug 31, Sep 6	275–319 s, 4 hr	Chote et al. (2021)
2017	NGTS	Jan–Sep	19 m, 83 m, 2 hr, 4 hr	Chote et al. (2021)
2017	K2	Aug–Nov	19 m, 4 hr	Gaensicke et al. (2019)
2021	TESS	Apr 29–May 26	2 hr	This work
2021	Pal	Jun 11	384 s, 666 s, 19 m	This work
2022	APO	Jul 29	498 s, 19 m	This work
2023	NTT	Apr 4	370 s, 640 s, 19 m	This work
2023	APO	Jun 23	372, 653 s, 88 m	This work

GW Lib. Following this time, there was a lack of observations due to the inability to secure HST time, bad weather at the Apache Point Observatory (APO), and the COVID-19 pandemic. Optical ground data commenced in 2021–2023, while observations with the Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2014) occurred in 2019 and 2021.

V386 Ser had its only known outburst (8 mag) in 2019. HST coverage was accomplished during the first 2 yr following the outburst along with optical observations (Szkody et al. 2021). Ground-based coverage prior to its outburst, including an 11 days international campaign (Mukadam et al. 2010), revealed a consistent large amplitude pulsation at 609 s. Following the outburst, the cooling appeared to follow theory at first, showing a short period at 104 s and subsequent lengthening to 194 s in 2020 (Szkody et al. 2021). Table 2 summarizes the past data on V386 Ser. Our latest optical data were obtained in 2021–2023.

Table 2
V386 Ser Postoutburst Period Summary

Year	Observatory	Month	Periods	References
2019	McO	Jul 3, 24, 25	104 s	Szkody et al. (2021)
2019	HST	Aug 15	104 s	Szkody et al. (2021)
2020	HST	Feb 28	175, 187 s	Szkody et al. (2021)
2020	McO	Jun 22	190 s	Szkody et al. (2021)
2021	APO	May 12	658 s	This work
2021	Pal	Jun 11	643 s	This work
2022	APO	May 28	653 s	This work
2022	APO	Jul 29	651 s	This work
2023	APO	Jun 23	628 s	This work

2. Observations

Over the years, optical observations took place at a variety of observatories (Tables 1 and 2) with frame-transfer CCDs and BG-40 filters at the APO 3.5 m telescope, McDonald Observatory (McO) 2.1 m and 0.9 m telescopes, and Mt. John 1 m telescope (MJO). Additional data were acquired with standard CCDs on the KPNO 2.1 m telescope, the NGTS and CTIO robotic telescopes, the Center for Backyard Astronomy (CBA), and Southeastern Astronomy Research networks. Our latest data from 2019 to 2023 include the instruments at APO and McO as well as the CHIMERA (Harding et al. 2016) camera with g and r filters on the Palomar 200 in telescope, and ULTRACAM (Dhillon et al. 2007) with u, g, r filters on the 3.5 m New Technology Telescope (NTT).

The dates for these observations are listed in Tables 1 and 2. Observations of GW Lib were also accomplished by TESS (Ricker et al. 2014) between 2019 April 23 and May 20 (Sector 11) and 2021 April 28 and May 26 (Sector 38)[7]. Sector 11 was observed at 30 minutes cadence while Sector 38 had both 2 minute and 20 s observations. Lomb–Scargle periodograms were computed using a variety of implementations, including

[7] doi:10.17909/da3r-xr10.

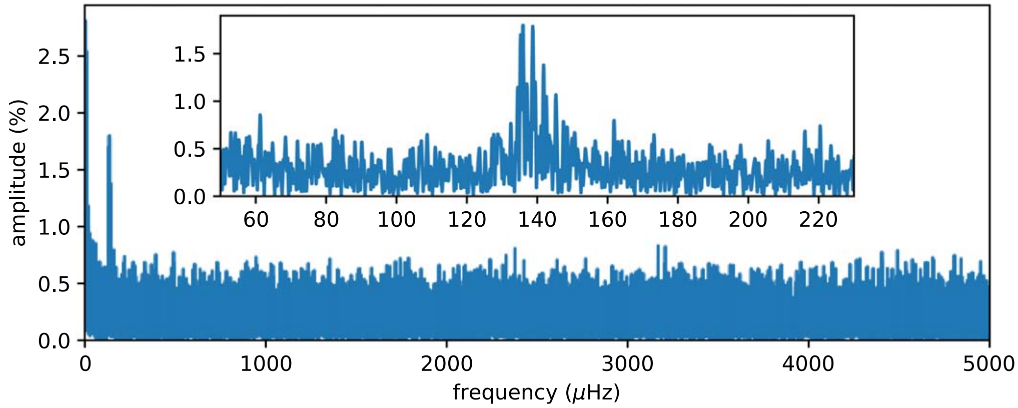

Figure 1. Periodogram of TESS sector 38 data on GW Lib 2021 April–May. The inset plot zooms in on the broad 2 hr (140 μHz) signal.

with the GATSPY package (VanderPlas 2016), with lightkurve (Lightkurve Collaboration et al. 2018), and with the pdm program within IRAF (Tody 1986). Some periods were measured with the interactive prewhitening package PYRIOD.[8]

3. Results

Figures 1–4 show periodograms and light curves for all the new data. Since these data were obtained with different size telescopes, cadences, and lengths of data sets, the noise levels and detection of faint signals varies. While the longer periods of hours and 83 and 20 minutes are usually of high enough amplitude to be evident by eye in the light curves (see Figures 2–3) and occur at the 3%–5% level in periodograms (Chote et al. 2021), the shorter pulsation periods can be buried in the noise. In GW Lib, the three quiescent pulsation periods are present in periodograms at less than 1.5% amplitude (van Zyl et al. 2004), while the quiescent pulsation at 609 s in V386 Ser is typically near 3% amplitude (Mukadam et al. 2010).

3.1. GW Lib

While the TESS Sector 11 data set did not reveal any significant period, the Sector 38 data set had adequate time resolution to search for all the past periods shown by GW Lib. However, the only feature evident in the periodogram is a broad peak at 2 hr (Figure 1) with an amplitude near 2%. While the month-long observation length with TESS is superior to the few short hours of ground data for detecting the 2–4 hr periods in GW Lib, the 0.5% noise level is comparable to the Chimera data on a larger telescope, so it should have been able to pick up at least the 20 minutes if it was present (compare Figures 1 and 2).

At the time our postpandemic ground data recommenced in 2021, GW Lib was already at a similar timeframe prior to its next expected outburst in 2031 (if the outburst period is 24 yr as calculated from the difference between the 1983 and 2007 outbursts) compared with the preoutburst data listed in van Zyl et al. (2004). Thus, we expected to see the three quiescent periods of 237, 370, and 650 s. Figure 2 shows the periodograms and light curves for our observations with Chimera in 2021 (simultaneous *r* and *g* photometry), and from APO in 2022 and 2023, with the dominant periods observed during quiescence marked with vertical dotted lines. The periodograms displayed in black represent light curves that were detrended with a 30 minutes median filter with WOTAN (Hippke et al. 2019) to isolate variations on pulsation timescales, and the periodograms of the nondetrended data are shown in gray. The durations of these light curves (1.3–2.3 hr) are too short to precisely measure the 2 hr variation that was dominant in the 2021 TESS data, though all light curves show some power consistent with variations near that timescale in the nondetrended light curves. The dominant pulsational variability detected during the 2021 Chimera and 2023 APO runs have timescales consistent with the modes observed near 650 s and 370 s in quiescence, along with the 19 minutes period that was frequently evident during the postoutburst years (Chote et al. 2021). Different signals are observed in our 2022 data, where the 19 minutes period is dominant, with a second signal at 500 s.

Additional ULTRACAM data in 2023 April on the NTT was obtained with simultaneous *u*, *g* , *r* filters. The periodograms in Figure 3 also show 2 of the 3 quiescent pulsation periods at 370 and 650 s, as well as a timescale near 19 minutes. The light curve shows a large hump feature that lasts as long as 86 minutes in the blue filter (right side of Figure 3). The hump changes shape in the redder filters, and is more reminiscent of the variation near 83 minutes that is sometimes apparent (Chote et al. 2021). The 2023 June 23 light curve (bottom panel of Figure 2) visually shows a variation near this timescale as well.

In summary, the high amplitude outburst in GW Lib has had a long-term effect, lasting almost 16 yr. The two main quiescent pulsation modes have been present for the last 2 yr, although intermittent periods near 20 and 83 minutes, which were not so prominent prior to the outburst, still appear.

3.2. V386 Ser

The early measurements of the white dwarf temperature and pulsation spectra in V386 Ser showed a theoretically expected cooling curve, exhibiting progressively longer pulsation periods back toward the quiescent mode at 609 s during the first 1.5 yr after its 2019 outburst (Szkody et al. 2021). However, during the next two observing seasons (2021 and 2022), the period jumped to a value near 650 s, 7% longer than its quiescent period of 609 s. The data obtained in 2023 reveal a gradual move back toward this quiescent period as the periodogram shows a prominent period at 628 s. This evolution of the variability of V386 Ser is shown in a series of periodograms in Figure 4. The dominant period during each night of observation is shown in Figure 5.

Each jump in pulsation period is expected to be caused by the convection zone driving progressively longer-period

[8] https://github.com/keatonb/Pyriod

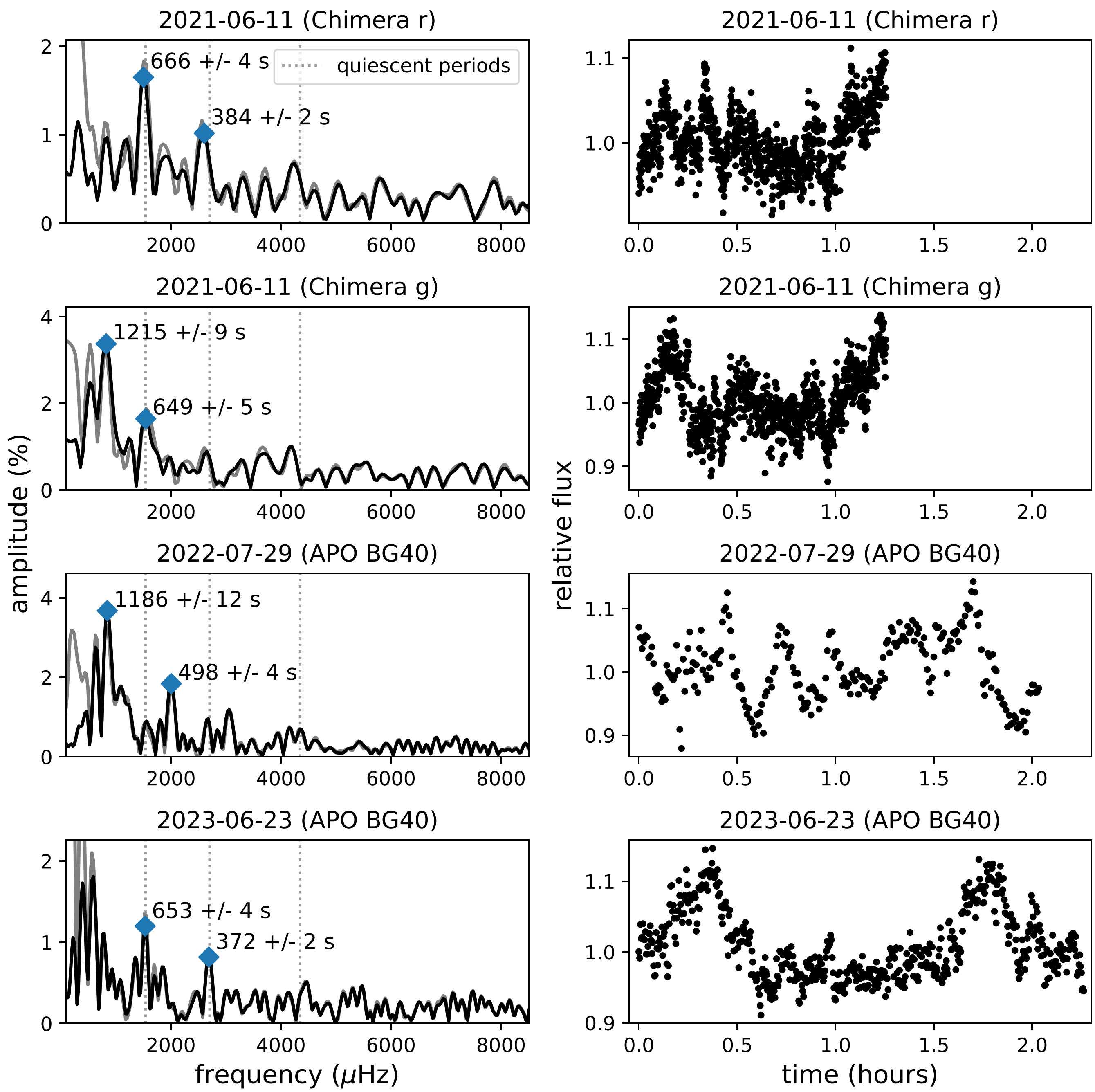

Figure 2. Periodograms (left) and light curves (right) of GW Lib obtained with Chimera *g* and *r* in 2021 and at APO with BG40 in 2022 and 2023. Periodograms in black were computed for light curves were smoothed with a 30 minute median filter to remove long-timescale variations before computing these periodograms for detecting pulsation signals. The displayed light curves have not been detrended. The periodograms in gray show the low-frequency content of the nondetrended light curves. Dominant periods detected in quiescence are marked with dotted vertical lines.

pulsations as it deepens after outburst (Goldreich & Wu 1999). The pulsations with periods longer than the quiescent period that were observed between 2021 and 2023 likely represent a different mode of oscillation of the star than observed in quiescence, since the pulsational eigenfrequencies are expected to increase (move to shorter period) in response to the nova outburst (as modeled in Szkody et al. 2021).

4. Discussion

It is apparent from following the long-term cooling of these two systems that there is no uniform path to the preoutburst state after a large accretion event and that the return to the quiescent state can take more than a decade. The behavior of GW Lib was especially unexpected in showing a long period of 19 minutes after outburst instead of the short periods. The UV observations confirmed the temperature of the white dwarf remained elevated compared to its preoutburst value for at least 10 yr, and its convective layers did not return to their normal state for at least 16 yr. On the other hand, V386 Ser began a normal cooling sequence both in its UV temperature decline and in the observed short period change in its pulsation, but then abruptly switched to a longer period than quiescence for 2 yr before gradually starting to shorten toward its quiescent value after 4 yr past outburst. These behaviors are apparent

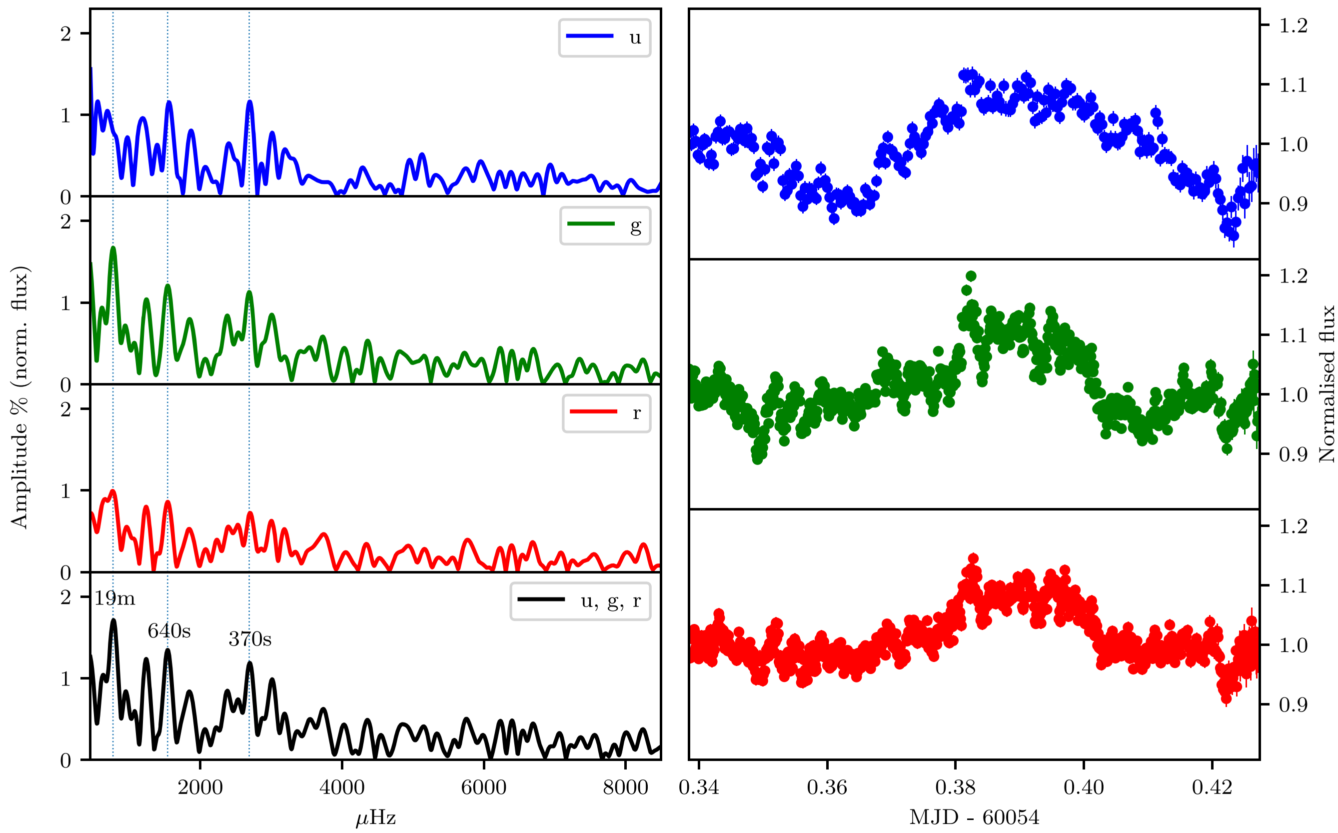

Figure 3. ULTRACAM 2023 April light curves (right) and periodograms (left) of GW LIb in *u*, *g*, *r* filters. The light curves show a prominent hump lasting 86 minutes in the *u* filter while the periodograms show the 3 shorter periods.

only in the pulsation spectrum, as the optical magnitudes in both cases returned to quiescent values within two years after outburst. Observationally, GW Lib and V386 Ser are very similar in most aspects. They have similar orbital periods (76.8 and 80.5 minutes respectively), white dwarf masses (0.8 ± 0.1 and 0.7 ± 0.2 solar), white dwarf temperatures (14,700 and 14,500 K), outburst amplitudes (9 and 8 mag), and superoutburst plateau durations (1 month), so the cause of their different pulsation behaviors remains to be determined.

Besides these unusual paths to quiescence, there are other puzzling aspects that have emerged from the long-term study of GW Lib. One is the unusual switch to a period near 20 minutes in the optical and its intermittent disappearance. This period is mentioned as apparent at a low level during a few nights in 1997 before the outburst (van Zyl et al. 2004) and is weakly (<2% amplitude) detected in the UV data of 2017 (Chote et al. 2021) while the shorter periods are dominant in both the optical at quiescence and in the UV after outburst. Besides this 20 minute period, there are also intermittent periods near 83 minutes and 2 or 4 hr and all the periods appear to have some connection to each other. The 7.5 month optical monitoring by Chote et al. (2021) showed that the 83 minutes and 2/4 hr periods switch on timescales of a week, while the HST short period pulse becomes apparent only during the large 4 hr variation of the UV flux, tying together the shortest and longest periods. The 83 minutes timescale is close to, but longer than, a typical superhump period, which is thought to arise from a resonance in the disk that is present when the disk is enlarged after outburst. But the optical magnitude is at the quiescent value when this period is present, and there is no change in brightness when the period switches to the 83 minutes from the 20 minutes dominance.

A similar switch from a 20 minute pulsation to an 86 minute period, with no outburst and no change in optical brightness is also apparent in the accreting pulsator EQ Lyn (Mukadam et al. 2013). BW Scl is a third accreting pulsator that also shows similar periods of 20 and 87 minutes in its power spectra (Uthas et al. 2012; Neustroev & Mäntynen 2023). Along with GW Lib, all three systems have orbital periods under 80 minutes. All three have hot white dwarfs (near 15,000 K) so should have short, not long pulsation periods. Thus, there may be some connection between low-frequency pulsations and tidal or disk phenomena. Among the 18 known accreting pulsators (Szkody 2021), there is one additional system with an orbital period under 80 minutes and a known 20 minute pulsation: SDSS1457+51 (Uthas et al. 2012). This object does not have a white dwarf temperature determined from HST ultraviolet spectra nor any record of an 83–87 minute period.

An intriguing result connecting pulsations with the orbit was mentioned in Mukadam et al. (2010). Their 11 day observing campaign on V386 Ser during quiescence showed periods at 806, 347 and 221 s in addition to harmonics of the primary pulsation period of 609 s. These additional periods are linear combinations between harmonics of the pulsation signal and the second orbital harmonic. Since accreting white dwarfs are so close to the donor star, this could be a consequence of tidal distortion in the white dwarf. Alternatively, there could be some irradiation of structures in the binary system caused by the white dwarf temperature variations, or the disk could modulate observability of the white dwarf pulsations. Further work on an explanation for these periods is needed.

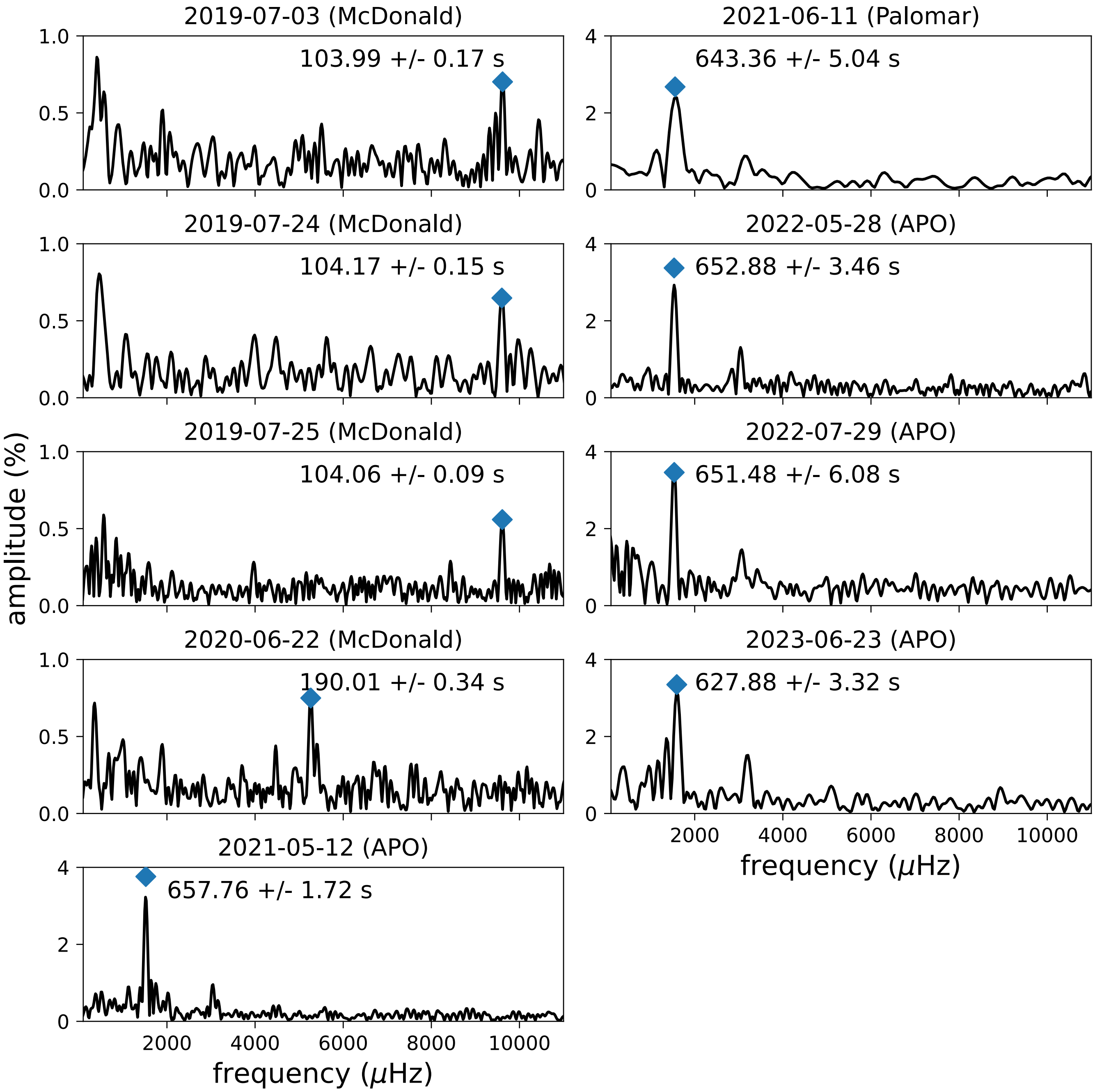

Figure 4. Early (left) periodograms of V386 Ser in 2019–2020 and recent ones in 2021–2023. Light curves were smoothed with a 30 minutes median filter to remove long-timescale variations before computing these periodograms for detecting pulsation signals.

5. Conclusions

Following the pulsation spectra in two accreting pulsating white dwarfs after a large amplitude dwarf nova outburst has revealed several interesting properties as well as a large difference in behavior. While the optical magnitudes returned to quiescence within 2 yr, the white dwarfs did not return to their quiescent pulsation modes for long periods of time (up to 16 yr for GW Lib and more than 4 yr for V386 Ser). GW Lib showed a long-period mode at 19 minutes in its first year past outburst, which intermittently became the prominent period throughout the years. Even longer periods of 1.4, 2, and 4 hr also played a role. In contrast, V386 Ser appeared to follow theory in showing a shorter period pulsation within months of its outburst, which gradually lengthened in the following year, but suddenly jumped to a longer period than quiescence in years 2–3, followed by a shortening in year 4. All these data imply that the white dwarf does not monotonically cool following an outburst. This is supported by the ultraviolet data obtained for GW Lib for 10 yr following its outburst (Szkody et al. 2016; Toloza et al. 2016).

It is intriguing that there are now three accreting pulsators containing hot white dwarfs with orbital periods below 80 minutes that undergo switching between periods near 20 and 83 minutes in their optical light curves. The modeling of the large UV changes during the 4 hr variation of GW Lib by Toloza et al. (2016) was consistent with a temperature increase

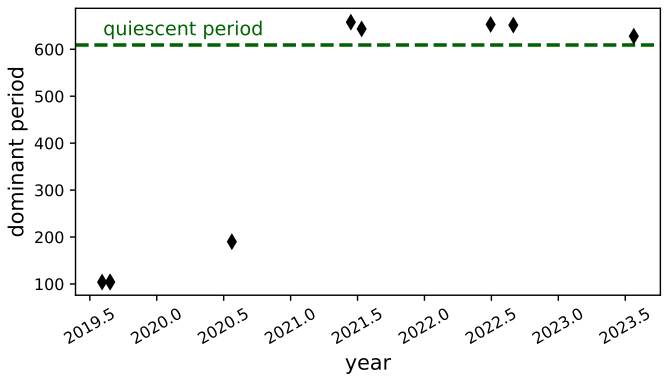

Figure 5. Evolution of the dominant variability period observed from V386 Ser over 4 yr of observations. V386 Ser shows short period pulsations following its outburst, then gradually longer periods as it approaches and then slightly overshoots its quiescent period.

on large regions of the white dwarf surface that are due to low-order modes on a rapidly rotating white dwarf. It would be helpful for theorists to consider further low-order modes as well as the impact of these temperature changes on the surrounding disk of the white dwarf.

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References

Bullock, E., Szkody, P., Mukadam, A. S., et al. 2011, AJ, 141, 84
Chote, P., Gänsicke, B. T., McCormac, J., et al. 2021, MNRAS, 502, 581
Chote, P., Mukadam, A. S., Aungwerojwit, A., et al. 2017, in ASP Conf. Ser. 509, 20th European White Dwarf Workshop, ed. P.-E. Tremblay, B. Gänsicke, & T. Marsh (San Francisco, CA: ASP), 335
Chote, P., & Sullivan, D. J. 2016, MNRAS, 458, 1393
Copperwheat, C. M., Marsh, T. R., Dhillon, V. S., et al. 2009, MNRAS, 393, 157
Dhillon, V. S., Marsh, T. R., Stevenson, M. J., et al. 2007, MNRAS, 378, 825
Gaensicke, B., Toloza, O., Hermes, J. J., & Szkody, P. 2019, in Compact White Dwarf Binaries, ed. G. H. Tovmassian & B. T. Gansicke (New York: AIP Publishing), 51
Godon, P., & Sion, E. M. 2003, ApJ, 586, 427
Goldreich, P., & Wu, Y. 1999, ApJ, 511, 904
Harding, L. K., Hallinan, G., Milburn, J., et al. 2016, MNRAS, 457, 3036
Hippke, M., David, T. J., Mulders, G. D., & Heller, R. 2019, AJ, 158, 143
Lightkurve Collaboration, Cardoso, J. V. d. M., Hedges, C., et al. 2018, Lightkurve: Kepler and TESS Time Series Analysis in Python, Astrophysics Source Code Library, ascl:1812.013
Mukadam, A. S., Townsley, D. M., Gänsicke, B. T., et al. 2010, ApJ, 714, 1702
Mukadam, A. S., Townsley, D. M., Szkody, P., et al. 2013, AJ, 146, 54
Neustroev, V. V., & Mäntynen, I. 2023, MNRAS, 523, 6114
Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, JATIS, 1, 1
Schwieterman, E. W., Wood, M. A., Piwowar, D., et al. 2010, JSARA, 3, 6
Szkody, P. 2021, FrASS, 8, 184
Szkody, P., Gänsicke, B. T., Howell, S. B., & Sion, E. M. 2002, ApJL, 575, L79
Szkody, P., Godon, P., Gänsicke, B. T., et al. 2021, ApJ, 914, 40
Szkody, P., Mukadam, A., Gänsicke, B. T., et al. 2010, ApJ, 710, 64
Szkody, P., Mukadam, A. S., Gänsicke, B. T., et al. 2012, ApJ, 753, 158
Szkody, P., Mukadam, A. S., Gänsicke, B. T., et al. 2016, AJ, 152, 48
Tody, D. 1986, Proc. SPIE, 627, 733
Toloza, O., Gänsicke, B. T., Hermes, J. J., et al. 2016, MNRAS, 459, 3929
Townsley, D. M., Arras, P., & Bildsten, L. 2004, ApJL, 608, L105
Uthas, H., Patterson, J., Kemp, J., et al. 2012, MNRAS, 420, 379
van Zyl, L., Warner, B., O'Donoghue, D., et al. 2004, MNRAS, 350, 307
VanderPlas, J. 2016, gatspy: General Tools for Astronomical Time Series in Python, Astrophysics Source Code Library, ascl:1610.007
Vican, L., Patterson, J., Allen, W., et al. 2011, PASP, 123, 1156
Woudt, P. A., & Warner, B. 2002, Ap&SS, 282, 433