THE ASTRONOMICAL JOURNAL, 119:365–368, 2000 January

SPECTROSCOPY OF GW LIBRAE AT QUIESCENCE[1]

PAULA SZKODY AND VANDANA DESAI
Department of Astronomy, University of Washington, Seattle, WA 98195; szkody@astro.washington.edu, desai@astro.washington.edu
AND
D. W. HOARD
Cerro Tololo Inter-American Observatory, Casilla 603, La Serena, Chile; dhoard@noao.edu
Received 1999 August 16; accepted 1999 September 21

ABSTRACT

Three nights of blue and red spectroscopy of the extreme-amplitude dwarf nova GW Lib at quiescence show that the orbital period is 79.4 minutes and the semiamplitude of the Hβ emission-line velocity curve is 40.0 km s^{-1}. The emission lines are very narrow and are surrounded by absorption troughs. The spectra are roughly consistent with that of a white dwarf of temperature near 11,000 K contributing 100% of the light at a distance of 114 pc. The short orbital period and low $\dot{M}$ are consistent with the general properties of extreme-amplitude dwarf novae.

Key words: binaries: spectroscopic — novae, cataclysmic variables — stars: individual (GW Lib)

1. INTRODUCTION

GW Lib was originally thought to be a nova because of its large amplitude of outburst (9th magnitude at its single known outburst peak in 1983 and 18.5 at quiescence; Duerbeck 1987). As there were no spectra obtained at outburst, the classification as a dwarf nova was made later, from quiescent spectra (Duerbeck & Seitter 1987; Ringwald, Naylor, & Mukai 1996). These spectra showed narrow Balmer emission centered on broad absorption troughs. No further attention was paid to this system until Warner (1998) and van Zyl (2000) reported photometric observations that showed a series of oscillations indicating that GW Lib has a primary star in the ZZ Ceti instability strip for nonradial pulsators. If this is the case, the white dwarf should have a surface temperature near 12,000 K and the techniques applied to ZZ Ceti stars should ultimately yield the mass and rotation of the white dwarf. To obtain further information on the white dwarf and the disk in this system, we obtained a series of spectra that enabled us to construct a radial velocity curve and a Doppler tomogram, as well as to model the absorption-line profiles with those of a cool white dwarf.

2. OBSERVATIONS

The observations were obtained with the 3.5 m telescope at Apache Point Observatory (APO) during three nights in 1998 April. The Double Imaging Spectrograph (DIS) was used with a 1.″5 slit and the high-resolution gratings to obtain ~2.5 Å resolution spectra in the regions 4300–5100 Å and 5800–6800 Å. An integration time of 7 minutes was used to obtain a series of spectra on each night (Table 1 summarizes the observations). The data were reduced using the available routines under IRAF.[2] The images were corrected with bias and flat fields; the spectra were then extracted, sky subtracted, wavelength calibrated from helium-neon-argon arc lamp spectra, and flux calibrated using spectra of standard stars from the KPNO atlas. The wavelength calibration was checked by using night-sky lines throughout the exposures. Although the sky lines had a small dispersion (5 km s^{-1}) within a given night, there was an overall shift on the order of 0.5 Å in their mean values between nights, for which a correction was applied.

3. MEAN SPECTRUM

The averaged blue and red spectra from the night with the largest amount of data (1998 April 1 UT) are shown in Figure 1. As reported by Duerbeck & Seitter (1987) and Ringwald et al. (1996), the spectra show Balmer emission surrounded by broad absorption troughs. This type of spectral appearance is typical of either dwarf novae declining from outburst, where the optically thick disk provides the broad absorption, or of very low mass transfer dwarf novae at quiescence, where the absorption is from the white dwarf, since the disk does not contribute significantly to the system light. We expect the latter situation to be the most likely interpretation for GW Lib because of its short orbital period, large outbursts, and long quiescent intervals, which are the usual signatures of low mass transfer rate in tremendous outburst amplitude dwarf novae (TOADS; Howell, Szkody, & Cannizzo 1995). Under the assumption that the broad absorption wings are from the white dwarf, we used them to determine a temperature for the white dwarf.

White dwarf models with $\log g = 8$ and temperatures between 8000 and 50,000 K were compared with the GW Lib spectrum taken at the lowest air mass on April 1. Because the model spectra represent the flux at the surface of the white dwarf, they had to be normalized to the observed spectrum. The factors by which the model spectra were divided to match the continuum levels of the observed blue spectra were taken as the normalization constants. Assuming that the white dwarf contributes 100% of the light of the system, the best temperature from the model fits (using the best match of the wings of the absorption troughs and the shape of the continuum in the blue) is 11,000 K ± 1000 K. Models with temperatures from 8000–15,000

---

[1] Based on observations with the Apache Point Observatory (APO) 3.5 m telescope, which is owned and operated by the Astrophysical Research Consortium (ARC).

[2] IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

TABLE 1

SUMMARY OF DATA

UT Date	Exposure (s)	Spectra	Total Time (hr)	Comments
1998 Apr 01......	420	16	2.14	Clear night
1998 Apr 10......	420	7	1.07	Cirrus came in
1998 Apr 19......	420	11	1.45	Clear night

K are shown superposed on the observed spectrum in Figure 2. The best-fit temperature does not change if 10% of the light comes from a $\lambda^{-2.3}$ disk. However, for a disk that contributes 20%–30% of the system's light, the best-fit temperature increases to 12,000 ± 1000 K. For even higher disk contributions, all models fail to match the observed spectrum. The low temperature found for GW Lib is consistent with that expected for a ZZ Ceti object. Assuming that a 0.6 $M_{\odot}$, 11,000 K white dwarf contributes 100% of the light of GW Lib and using the ratio of the observed and model fluxes, we estimate a distance of 114 pc. Since we expect that some of the light from GW Lib comes from a disk component, this is a lower limit on the distance. For example, if only 90% of the light from the system can be attributed to the white dwarf, its calculated distance would be 120 pc.

The presence of the emission lines means that there is some mass transfer to a disk or possibly that the secondary is irradiated. The emission lines in GW Lib are twice as narrow (FWHM and FWZI of 6 and 13 Å for Hβ and 11 and 25 Å for Hα) as most noneclipsing dwarf novae under the period gap (Szkody 1985), and the equivalent width of Hβ in GW Lib (25 Å) is only one-third the normal value. This suggests a nondisk origin. However, the lines are also much wider and the decrement is flatter than would be expected in the recombination spectra produced when the secondary is irradiated and the disk is unimportant (e.g., TT Ari and MV Lyr during low states; Szkody & Downes 1982; Shafter et al. 1985). There was also no periodic variation in the equivalent width of the emission component throughout the orbit, as would be expected for an origin on the irradiated inner face of the secondary star. To resolve the origin of the emission to the accretion disk or the secondary, we attempted to use the velocity information as described below.

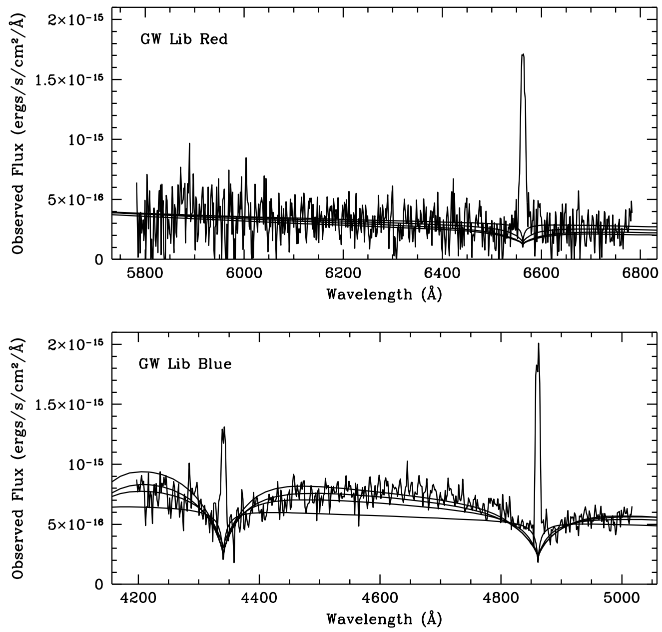

FIG. 2.—Comparison between model white dwarfs of different temperatures and the spectrum observed at lowest air mass on the night of April 1. Model white dwarfs of temperatures 15,000, 12,000, 10,000, and 8000 K (*smooth curves, top to bottom*). The normalizations for the model spectra were determined by visual comparison to the wings of the blue spectrum. A temperature of 11,000 ± 1000 K best describes the system.

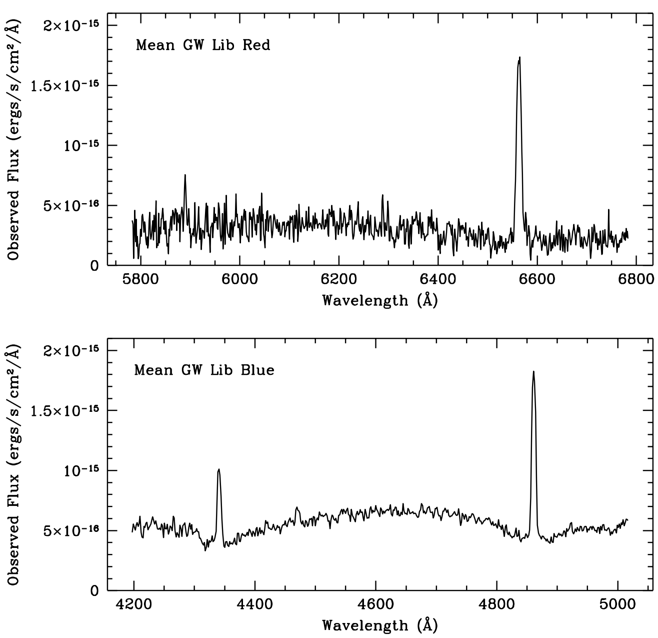

FIG. 1.—Mean spectrum in blue and red for the night of April 1

4. RADIAL VELOCITY CURVE

The central wavelengths of the Hα, Hβ, and Hγ emission lines were measured using the *e* option within IRAF's SPLOT package. The routine CURVEFIT in IDL[3] was used to fit the velocity and time data to a sinusoidal function of the form $v = \gamma - K \sin [2\pi(t - t_0)/P]$, where γ, K, P, and t_0 were left as free parameters. The Hβ and Hγ lines provided the cleanest velocity curves over about 1.5 orbits, and were averaged to determine the orbital period of the system: 79.4 ± 0.3 minutes. Using this period, phases were computed with a red-to-blue crossing at phase zero. The γ and K parameters were then recomputed with the period fixed at 79.4 minutes. Errors on these parameters were generated using Monte Carlo methods. The γ velocities were then corrected for the Earth's motion and any deviations found in the sky lines. See Table 2 and Figure 3 for the best-fit parameters and the corresponding sine function plotted over the data. Note that the γ velocities are inconsistent from night to night. While we cannot be certain, it is conceivable that the presence of the broad absorption troughs affected the determination of the emission-line centers, causing this effect.

The centers of the Hβ absorption troughs were also measured by first subtracting the Gaussian fit to the emission feature in IRAF's SPLOT package. The remaining absorption line was fit with a Lorentzian profile to determine its

[3] Interactive Data Language, a product of Research Systems, Inc.

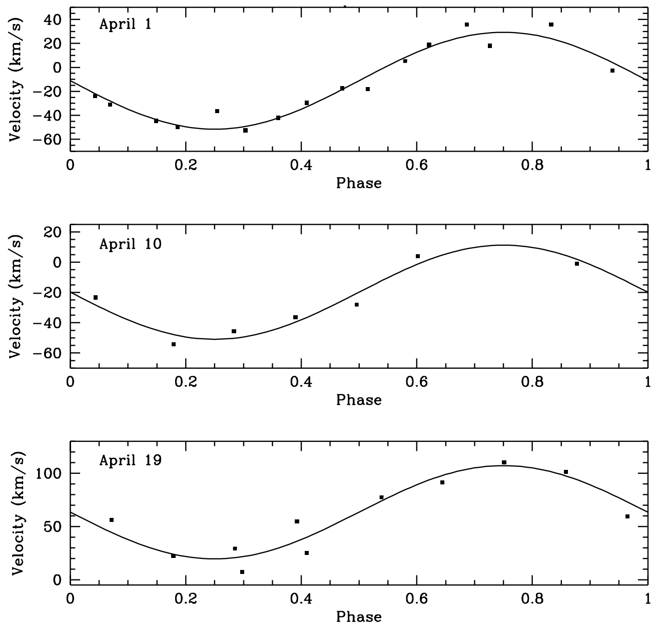

FIG. 3.—Velocities and best-fit solution for Hβ emission for each of the three nights.

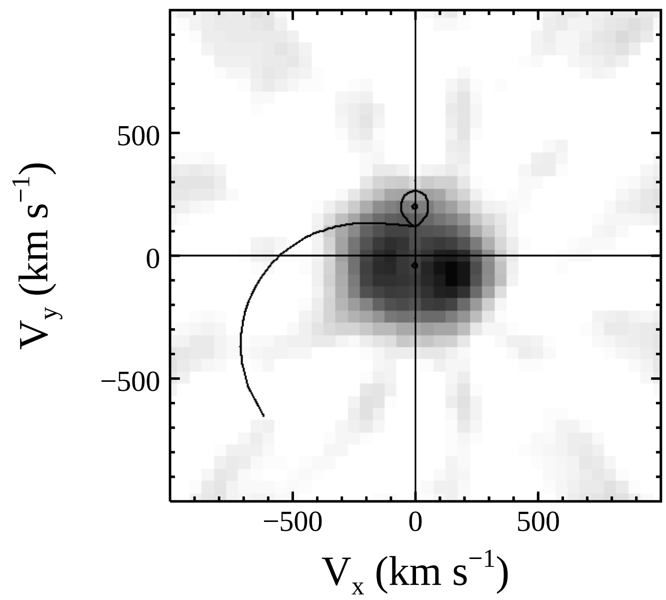

FIG. 4.—Doppler tomogram for Hβ on April 1, using the phasing in Table 2. Positions of the secondary and stream are drawn for a mass ratio of 0.2 with $K_1 = 40$ km s^{-1}.

center, as the shape of the wings more closely matched a Lorentzian rather than a Gaussian profile. The center of the absorption line was very difficult to measure, because it depends sensitively on the fit to the emission feature and its subsequent subtraction. We could not identify any periodic component in the absorption velocities for April 10 or 19, but data from the best night (April 1) showed a sinusoidal variation. The best fit that could be obtained gave a very high overall σ of 115 km s^{-1}, an extremely high amplitude (204 km s^{-1}) and a phase offset of 0.47 from the emission-line fit for that night. While this result would suggest that the absorption and emission components are 180° out of phase and thus imply that the emission is from the irradiated secondary and the absorption from the white dwarf, the large amplitude of the absorption component and small amplitude of the emission component would be counter to the general result that $q = M_2/M_1 = K_1/K_2$ is generally less than 0.25 in short orbital period systems (Warner 1995). Because of the difficulty involved in measuring the absorption centers and the lack of reproducibility over the three nights, we concluded that we could not trust the velocity parameters from the absorption lines.

To further pursue the origin of the emission component, we next tried Doppler tomography.

5. DOPPLER TOMOGRAM

Doppler tomography (Horne 1991) is a technique that allows imaging of the line-forming regions in a binary system by combining the velocity profile information obtained at all binary phases. To construct our tomogram, we used the Fourier-filtered back-projection program provided by Keith Horne and modified for our computer-user needs. Figure 4 shows the result for Hβ on the night of our best data (April 1). Because there is no observed eclipse in GW Lib, the orbital phase zero point is uncertain. We phased the spectra with the relation derived from the radial velocity fit in § 4, where phase zero is the red–to-blue crossing of the emission lines, under the assumption that these lines originate from the accretion disk surrounding the white dwarf. We also tried a phasing offset by 180° (for a location of the emission lines on the secondary). The tomogram in Figure 4 is most consistent with a disk viewed at low inclination as the origin for the emission-line region. The resulting velocity extensions are not large (reflecting the

TABLE 2

RADIAL VELOCITY SOLUTIONS

Date	Line	γ	K (km s^{-1})	HJD at Zero Phase	σ
Apr 01......	Hα	11.6 ± 1.3	32.2 ± 7.1	2,450,904.955	18.4
Apr 01......	Hβ	−11.1 ± 0.4	40.4 ± 2.8	2,450,904.959	7.4
Apr 01......	Hγ	34.4 ± 1.3	60.5 ± 7.2	2,450,904.961	16.2
Apr 10......	Hα	−15.3 ± 1.1	27.8 ± 4.5	2,450,913.904	7.0
Apr 10......	Hβ	−19.8 ± 0.8	31.1 ± 3.7	2,450,913.901	5.4
Apr 10......	Hγ	−26.9 ± 3.6	9.9 ± 13.6	2,450,913.908	22.0
Apr 19......	Hα	21.8 ± 1.7	71.3 ± 11.3	2,450,922.766	21.4
Apr 19......	Hβ	63.4 ± 0.6	43.7 ± 4.8	2,450,922.770	10.6
Apr 19......	Hγ	30.6 ± 1.7	47.0 ± 12.3	2,450,922.772	26.3

NOTES.—A period of 79.4 minutes and a red-to-blue crossing phase of zero were applied to all solutions. Velocities include heliocentric corrections and those suggested by deviations in the sky lines.

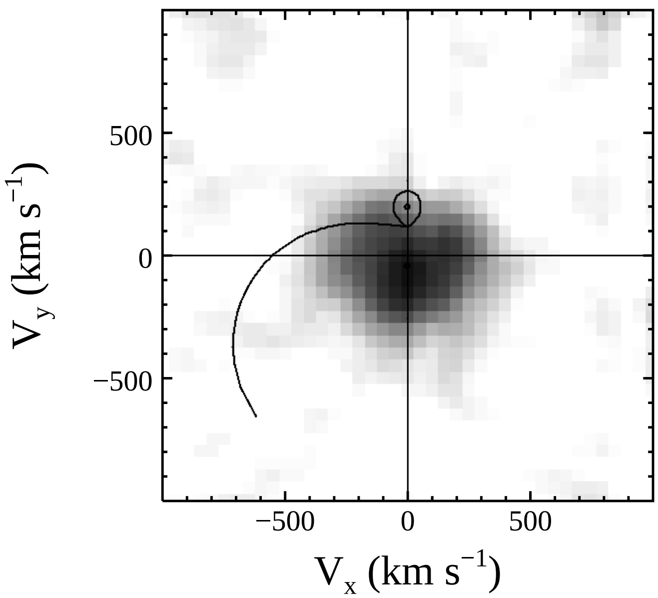

FIG. 5.—Same as Fig. 4, but for April 19

narrow width of the emission lines). However, there appear to be two concentrations of emission, the most noticeable at $(V_x, V_y) = (150, -100)$ km s^{-1} and the lesser one near $(-150, -50)$ km s^{-1}, which would correspond to phases 0.3 and 0.75. These could be due to the mass transfer stream impact and its overflow to the far side of the disk but could also be due to sporadic emission-line brightness variations or artifacts of our low phase resolution ($\delta\phi \approx 0.1$ per spectrum). To determine if these are persistent features, we also constructed the tomogram for the night of April 19 (Fig. 5). This figure shows the enhanced emission near the expected location of the white dwarf on the $-V_y$-axis. Thus, we can only conclude that the tomograms are consistent with the Hβ emission originating in a disk viewed at low inclination.

6. CONCLUSIONS

Our time series spectra of GW Lib at quiescence have shown that it has a very short orbital period and a low-amplitude radial velocity curve. These properties, along with the presence of absorption troughs surrounding the narrow emission lines, are consistent with a low-inclination system that has a low mass transfer rate. The amplitude of the emission line velocity curve is very similar to that of the similar TOAD WZ Sge at quiescence (Gilliland, Kemper, & Suntzeff 1986). The emission lines are narrower than those from typical disks but broader than those from typical irradiated secondaries. While the emission line phasing in the longest data set appears to be opposite that of the absorption lines, this could not be confirmed on other nights, and the tomogram suggests a disk origin for the emission. Ultraviolet spectra scheduled for *Hubble Space Telescope* Cycle 8 should be able to provide better information on the contribution and phasing of the white dwarf in this system.

We gratefully acknowledge B. Gänsicke for providing his low-temperature white dwarf models for our use. This research was partially supported by NASA LTSA grant NAG 5-3345.

REFERENCES

Duerbeck, H. W. 1987, Space Sci. Rev. E, 45, 68
Duerbeck, H. W., & Seitter, W. C. 1987, Ap&SS, 131, 467
Gilliland, R. L., Kemper, E., & Suntzeff, N. 1986, ApJ, 301, 252
Horne, K. 1991, in Fundamental Properties of Cataclysmic Variable Stars, ed. A. W. Shafter (San Diego: San Diego State Univ. Press), 23
Howell, S. B., Szkody, P., & Cannizzo, J. 1995, ApJ, 439, 337
Ringwald, F., Naylor, T., & Mukai, K. 1996, MNRAS, 281, 192
Shafter, A. W., Szkody, P., Liebert, J. Penning, W. R., Bond, H. E., & Grauer, A. D. 1985, ApJ, 290, 707
Szkody, P. 1985, AJ, 90, 1837
Szkody, P., & Downes, R. A. 1982, PASP, 94, 328
van Zyl, L. 2000, NewA, in press
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge Univ. Press)
———. 1998, in ASP Conf. Ser. 137, Wild Stars in the Old West; Proceedings of the 13th North American Workshop on Cataclysmic Variables and Related Objects, ed. S. Howell, E. Kuulkers, & C. Woodward (San Francisco: ASP), 2