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On the orbital period of the Intermediate Polar 1WGA J1958.2+3232

S. V. Zharikov[1], G. H. Tovmassian[1], and J. Echevarría[2]

[1] Observatorio Astronómico Nacional, Instituto de Astronomía, UNAM, 22800, Ensenada, B.C., México*
[2] Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F., México

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Abstract. Recently, Norton et al. (2002), on the basis of multiwavelength photometry of 1 WGA J1958.2+3232, argued that the –1 day alias of the strongest peak in the power spectrum is the true orbital period of the system, casting doubts on the period estimated by Zharikov et al. (2001). We re-analyzed this system using our photometric and spectroscopic data along with the data kindly provided by Andy Norton and confirm our previous finding. After refining our analysis we find that the true orbital period of this binary system is $4^{\rm h}\!.35$.

Key words. stars: individual: 1 WGA J1958.2+3232 – stars: novae, cataclysmic variables – stars: binaries: close – X-rays

1. Introduction

Israel et al. (1998) discovered that 1 WGA J1958.2+3232 was a pulsating X-ray source. Strong modulations of this source in X-rays were obtained from the ROSAT PSPC (721±14 sec) and a more accurate period of 734±1 sec from ASCA was presented by Israel et al. (1998) and Israel et al. (1999). Photometric observations of the optical counterpart of 1 WGA J1958.2+3232 exhibited strong optical variations, compatible with the X-ray (within 12 min) period (Uslenghi et al. 2000). This modulation was interpreted as an evidence of the spin period of the WD in a close binary system. Uslenghi et al. (2000) detected a circular polarization from the source in the *R* and *I* bands, with evidence for a possible modulation of the polarization at twice the previously observed pulsation period. 1 WGA J1958.2+3232 was announced as a new Intermediated Polar (IP) by Negueruela et al. (2000) from spectral observations. Zharikov et al. (2001) obtained time resolved spectroscopy and *R*-band photometry from which they deduced an orbital period of $4^{\rm h}\!.36$ and confirmed the pulsation period of 733 s. Later on, Norton et al. (2002) obtained *UBVRI* photometry and reported that the orbital period was 5.387 ± 0.006 h, corresponding to the –1 day alias of the period found by Zharikov et al. (2001). They had some ambiguity in determining which of the daily cycle aliases of low (orbital) frequency and intermediate (beat) frequency to pick up, because selecting the strongest peak in low frequencies was forcing the beat period into a –2 day alias of the intermediate frequency peak. Through detection of the beat frequency, Norton et al. (2002) also confirmed that the rotational period of the white dwarf is twice the pulse period, and they confirmed the presence of the circular polarization in the source by detecting oppositely signed polarization in each of the *B* and *R* bands.

In this letter, we re-analyze our spectral and photometric data together with photometric data from Norton et al. (2002) confirm and refine our previous period estimate of $4^{\rm h}\!.35$.

2. Combined data and search of period

The *UBVRI* data of the optical counterpart of 1WGA J1958.2+3232 were obtained by Norton et al. (2002) on 9-15 July 2000. The *R*-band time-resolved photometry of Zharikov et al. (2001) was obtained on August of 2 and 3. We also obtained time-resolved spectroscopy of 1 WGA J1958.2+3232 on 4–6 Aug. 2000. Details of the observations are provided in corresponding papers. It is important to note that the total duration of our spectroscopic observations on the second night was $7^{\rm h}\!.7$, thus covering almost two orbital periods. A total of 68 spectra were obtained (Zharikov et al. 2001).

As a first step to a verify the binary system orbital period, we combined the *R*-band data from both data sets. The light curves of 1 WGA J1958.2+3232 in the $R_{\rm c}$ band are presented in Fig. 1. From this figure we can see similar behavior of both lightcurves. However, our time coverage is somewhat longer and data spacing is more even and more dense.

The photometric data were analyzed for periodicities using the Discrete Fourier Transform code (Deeming 1975) with a CLEAN procedure (Roberts et al. 1987). The power spectrum at low frequencies is presented in Fig. 2. The power spectrum of our $R_{\rm c}$ data and Norton et al. (2002) *R* data are given separately in the lower panels. The power spectrum of combined data are

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Send offprint requests to: S. V. Zharikov,
e-mail: `zhar@astrosen.unam.mx`

* Use for smail PO Box 439027, San Diego, CA, 92143-9027, USA.

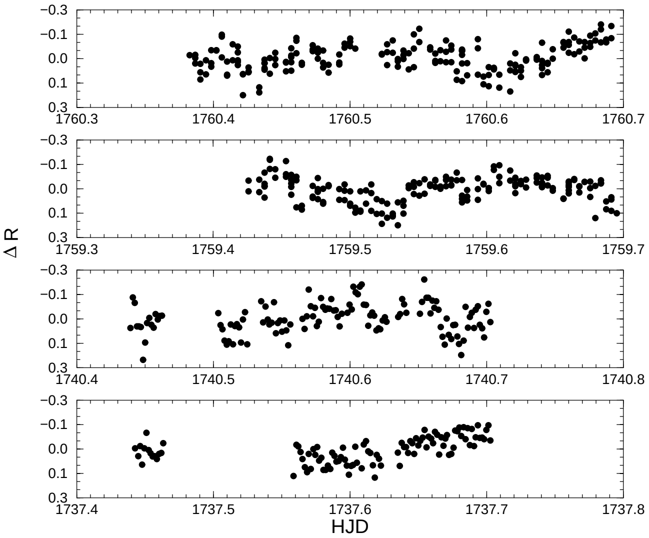

Fig. 1. 1 WGA J1958.2+3232 light curves in the R_c band are presented. The HJD = 2 541 000 + 1737 and 1740 corresponds to Norton et al. (2002) (low panels); the other 2 nights (upper panels) are from Zharikov et al. (2001).

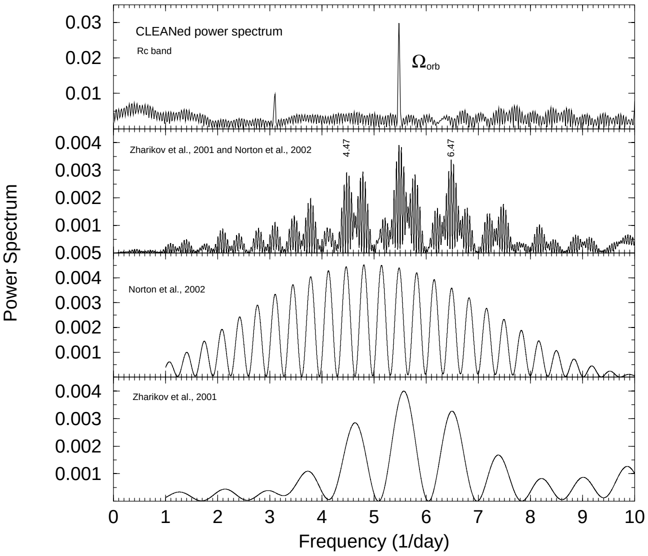

Fig. 2. The low frequency end of the power spectra of R_c light curves are given. The top panel is a CLEANed power spectrum of the R_c light curve from combined Zharikov et al. (2001) and Norton et al. (2002) data.

presented in the second from the top panel. The largest peak $\Omega = 5.47$ d^{-1} and its ±1 day aliases are marked. The top panel is a CLEANed power spectrum of the combined R_c data. The CLEANed power spectrum shows a peak at $\Omega = 5.4734054 \pm 0.0215067$ d^{-1}, corresponding to $P = 0.1827016 \pm 0.000715$ d. We note here that CLEAN will always clean data to the highest peak in the power spectrum, so on its own this is not a true test of which of the 1-day aliases is the correct one, but CLEAN helps to determine the highest frequency exactly.

After this, we tested the photometric data including all other filters. We subtracted the average magnitude from the photometric data of each night of observations and merged all data in one set. The power spectrum resulting from the all-filter photometric data (AFD) is presented in Fig. 3 (lower panel). The maximum peak corresponds to a ~5.52(d^{-1}) frequency. Naturally one day aliases also come up with lower amplitudes.

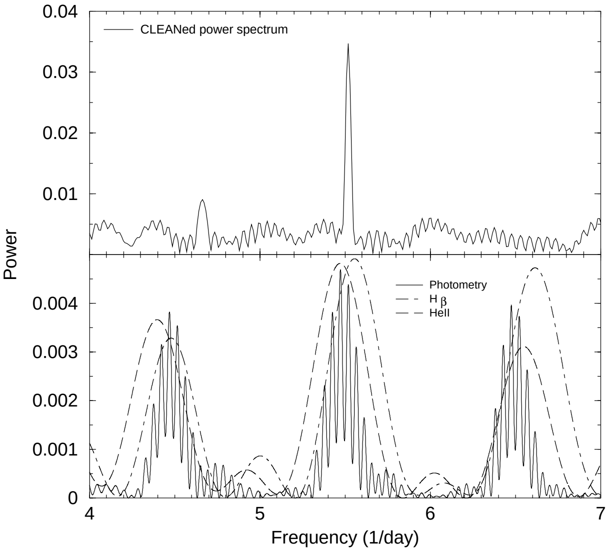

Fig. 3. The CLEANed power spectrum of AFD photometrical data from Zharikov et al. (2001) and Norton et al. (2002) (top panel). On the lower panel the uncleaned power spectrum of the AFD is shown. The aliases (±1 d^{-1}) are presented too. The power spectra of the *RV* variations of and He II 4686 and H_β are overplotted. They are scaled to the amplitude of the power spectrum of photometry. The maximum frequency peak corresponds to the orbital period of the system.

We again applied the CLEAN procedure which is aimed to distinguish the alias periods originating from uneven distribution of data and works nicely on large data sets containing well defined alias periods. The power spectrum of the AFD set (top panel in Fig. 3) again shows a single peak at $\Omega_o = 5.518908 \pm 0.010315$ d^{-1}, which corresponds to $P = 0.181195 \pm 0.000339$ d ($4\overset{h}{.}35$ period).

However, the crucial and the most unambiguous confirmation of the $4\overset{h}{.}35$ orbital period comes from the consideration of radial velocity (*RV*) data previously obtained by us. The methods used to measure the radial velocities in H_β and He II were described by Zharikov et al. (2001). The power spectra of *RV* data from Zharikov et al. (2001) are overplotted in Fig. 3. They show wide peaks coinciding with the photometric results. While the spectroscopic data do not allow a precise determination of the orbital period, they were derived from three consecutive nights of prolonged observations covering more than one orbital period, which allows us to test the ±1 day period aliases in the power spectra on the actual data.

In Fig. 4 we present unfolded radial velocity measurements of the emission lines of He II 4686 and H_β at each night of observations. The errors of *RV* measurements are presented in corresponding panels. Fits of a *sine* function to the data with the period estimated by us are overplotted as a solid line. The ±1 aliases are shown as a thin dashed lines. The −1 day (1/4.455) alias selected by Norton et al. (2002) as a true orbital period and drawn with thick dashed line can not give a

Table 1. The parameters of the sin fit of *RV* data.

Line	He II				H_β			
Ω	Ω_o	$\Omega_o - 1$	$\Omega_o + 1$	Ω_N	Ω_o	$\Omega_o - 1$	$\Omega_o + 1$	Ω_N
(d^{-1})	5.5189	4.5189	6.5189	4.455	5.5189	4.45189	6.5189	4.455
P (d)	0.18120	0.22129	0.15340	0.22447	0.18120	0.22129	0.15340	0.22447
γ_0^*(km s^{-1})	−72.1750	−77.8	−97.2	−66.63	−38.07	−45.39	−31.92	−42.2588
K_1^{**} (km s^{-1})	−189.03	−167.18	169.7	−176.73	−74.28	70.77	56.38	−71.0629
t_0^{***} (HJD)	51 763.5537	51 764.1556	51 765.9766	51 764.1750	51 763.8587	51 763.5302	51 763.6224	51 763.8733
χ^2	**140.3/57**	401.8/57	374.1/57	322.7/57	**80.2/70**	94.23/70	125.35/70	86.4/70
σ	**68.62**	113.68	95.66	100.14	**43.37**	47.57	53.97	45.40

$^*\gamma_o$ is the systematic velocity of the system.
$^{**}K_1$ is the semi-amplitude of the radial velocity.
$^{***}2\,540\,000 + t_o$.

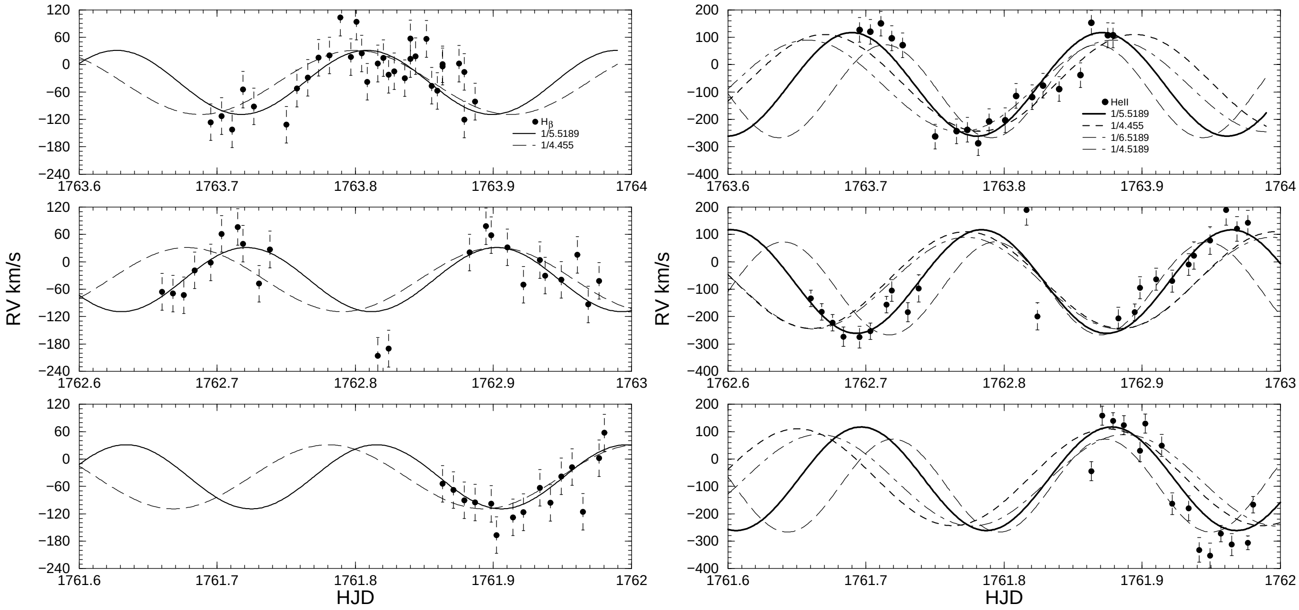

Fig. 4. The radial velocity measurements of the emission lines of He II 4686 and H_β for each night of observations. The curves correspond to *sine* fits to the radial velocity data with estimated orbital period and its ±1 d^{-1} aliases. The solid line is the best fit with the $4\overset{h}{.}35$ period.

satisfactory fit to the data from the second night, where almost two orbital periods were covered by the observations. The results of the χ^2 fit by

$$v(t) = \gamma_o + K_1 \sin(2\pi(t - t_o)/P),$$

where γ_o, K_1 and t_o were free parameters for our best orbital period estimate Ω_o, its ±1 day aliases and orbital period Ω_N by Norton et al. (2002) are given at Table 1. The best fit result was obtained for He II *RV* data at frequency $\Omega_o = 5.5189$ d^{-1} significantly exceeding fits with other frequencies. The results for H_β are less conclusive due to the smaller amplitude and larger errors of the *RV* measurements. However, in this case also we can see that at Ω_o we have the lowest values of χ^2 and σ.

Not surprisingly, the χ^2 and σ values from Table 1 confirm what can be seen with the naked eye, that the period corresponding to the strongest peak in the power spectrum is most probably the true orbital period of the system. We adopted $P_{\rm orb} = 0.181195 \pm 0.000339$ d as the final value for the orbital period of 1 WGA J1958.2+3232. A longer time base of spectroscopic observations is needed to improve this value.

3. Conclusion

Norton et al. (2002) chose the $\Omega_N = 4.455 \pm 0.005$ d^{-1}, or $P_N = 5.387 \pm 0.006$ h, as the orbital period of the system from the analysis of the power spectrum peak strength combination. They noted that the power spectrum is dominated by three sets of signals at ~5.5 d^{-1}, 55.5 d^{-1} and 117.8 d^{-1} but the strongest peaks in each of the three sets are not harmonically related to each other. The solution Ω_N was selected as the more probable. They assume that more extreme aliases combinations are unlikely, since the power at these alias are low, although such combination are not excluded. In our opinion the strength of peaks of power spectra are highly dependent on the quality of the data and sampling. The photometric data of Norton et al. (2002) is certainly undersampled for such far-reaching

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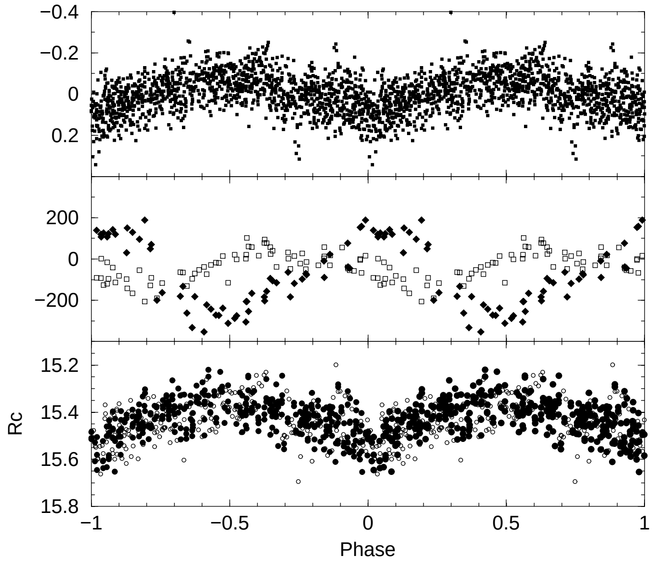

Fig. 5. The radial velocity curves of H_β and He ii 4686, folded with the spectroscopic orbital period of $4^{\rm h}.35$, are presented in the middle panel. The combined $R_{\rm c}$ light curve of 1 WGA J1958.2+3232 is presented in the lower panel. The data of Norton et al. (2002) is marked with open circles. Full circles are from Zharikov et al. (2001). The AFD (all filter data) folded in the same manner is shown in the top panel.

conclusions. On the other hand, the spectroscopic observations presented here unambiguously identify the orbital period of the system.

Adding the data kindly provided by authors of Norton et al. (2002) to our measurements, we were able to improve slightly the period estimate. The new value for the period of the Intermediate Polar 1 WGA J1958.2+3232 now stands at $4^{\rm h}.35 \pm 0^{\rm h}.01$, similar to our recently reported value (Zharikov et al. 2001). We note that this analysis does not change our previous estimates of the system parameters, but shifts the photometric minimum in the light curve exactly to the redefined epoch $T_0 = 2\,451\,762.9527 \pm 0.0001$, which corresponds to the ±zero crossing of the H_β radial velocity curve, i.e. to the moment when the secondary is located between the observer and the WD. The final phase-folded light curves in the R band, AFD, and radial velocity curves in He ii 4686 and H_β are presented in Fig. 5. The difference of amplitudes and phases of the H_β and He ii lines were discussed in our previous paper.

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