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New spectroscopic and photometric observations of CV J0644+3344

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Abstract. We report photometric and simultaneous spectroscopic observations of the cataclysmic variable J0644+3344 and present calibrated Doppler tomography results of the object. We have calibrated the spectra for slit losses using simultaneous photometry. This has been used to construct reliable Doppler images in the Hα, Hβ and He II 4686 Å emission lines. We have also performed a radial velocity analysis using these emission lines to derive the primary semi–amplitude and used a cophasing method to determine the secondary K_2 best value. We have improved the ephemeris of the object based on the published and our new photometric eclipse timings to obtain $HJD = 254474.7927 + 0.26937446E$. We derived a $K_1 = 123.2 \pm 6.6$ km s^{-1}and $K_2 = 205.4 \pm 6.7$. Assuming a $i > 76$, the orbital parameters are $M_1 = 0.91 \pm 0.04$ M$_\odot$, $M_2 = 0.83 \pm 0.04$ M$_\odot$ and $a = 2.10 \pm 0.03$ R$_\odot$. Based on the Doppler tomography we conclude that J0644+3344 is a nova–like SW Sex type system.

Key words. method: Doppler tomography – stars: cataclysmic variables, J0644+3344

1. Introduction

Cataclysmic variables (CV) are semi–detached binary systems in which mass transfer occurs after the Roche lobe is filled. The system consists of a primary star, usually a white dwarf (WD) and a lower main sequence star, referred as secondary star. The mass transferred goes from the secondary star to the primary star through the inner Lagrangian point. Often, this process creates an accretion disk surrounding the primary star that dominates the emission in the optic range of the spectrum.

This bright CV ($V \sim 13.29 \pm 0.24$) was discovered during the Northern Sky Variability Survey (NSVS, Wozniak 2004). It was catalogued by Hoffman et al. (2008) as a β Lyrae but discarded later in the same work. Only one study of this object has been published by Sing et al. (2007), S07 hereafter. It was identified as a deep eclipsing CV with orbital period of 6.4649 hr and derived the physical parameters of the system, such as $M_1 = 0.66 \pm 0.03$, $q = 0.78$ and $\gamma = -32.2$ km s^{-1}. It presented a hot inner region + WD $\sim$ 20000 K which suggested either a subdwarf or a optically thick accretion disk. It was classified as a nova-like CV of the type UX UMa or SW Sex. Since the nature of the object is still unclear, we found interest in doing follow-up observations on this CV.

We performed radial velocity measurements and Doppler tomography on Balmer

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lines and high-excitation line HeII λ4686 emission lines. We used to cophasing method to obtain K_2 star since most absorption lines are hidden by the bright accretion disk.

2. Observations

2.1. Spectroscopic observations

Time-resolved spectroscopy was done at the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, México, from January 8-17, 2008. These were taken using the REOSC – echelle spectrograph and SITe3 CCD detector at the f/7.5 Cassegrain focus of the 2.1 m telescope. Exposures of 600s were used to obtain a resolution of 0.025 in orbital phase. We covered a full orbital period on most nights except when we focused the observations around the primary eclipse. A Th-Ar calibration lamp was used before and after ten images in average. Standard IRAF[1] procedures were used to reduce the data. All spectra were corrected by heliocentric movement.

2.2. Photometric observations

Differential photometry was carried out at the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, México, in two seasons. All of the observations were done with the Thomson 2k CCD detector at the 1.5m Cassegrain telescope. The first one, January 8-17, 2008 were taken using 10s exposure in the V filter with the RUCA filter wheel and the second one, used unfiltered 3s exposures.

Time-series analysis (TSA) was performed using the analysis of variance (*AOV*) (Schwarzenberg-Czerny 1989, Devor 2005) included in the *Vartools* suite (Hartmann et al. 2008) and *Period*04 (Lenz & Breger 2005). The most likely frequency from both analysis coincides with the one published by S07. In order to improve the ephemeris, we fitted a gaussian to the eclipses to determine the time at mid-eclipse. We used all the information available to us: our photometric observations and the data kindly given to us by S07, from their observations in the Johnson R filter in 2005. In total, the fit spanned from 2005 to 2010. We performed a linear least square fit to the data, which improved the error in one magnitude. We present our new ephemeris, where phase 0.0 is considered as the primary conjunction of the secondary star.

$$T_0 = 254474.7927 + (0.26937446) \times E \tag{1}$$

where the errors are: ± 0.0003d for T_0; $\pm 5 \times 10^{-8}$d for the period.

During the 2008 observation season a mini–outburst of $\sim$0.5 mag was observed, as shown in Figure 2.2. Sing et al. (2007) reports a constant brightness out of the eclipse thought all their observations. Follow–up observations are required to verify it's a systemic condition of the object.

3. Radial velocity analysis

3.1. Primary star radial velocity

Radial velocity measurements were performed on Hα, Hβ and He II 4686 Å emission lines for the 2008 nights using the standard double-Gaussian technique and diagnostic diagram (Shafter et al. 1986). We measured the lines with the IRAF *convrv* routine of the *rvsao* package modified by J. Thorstensen (2008, private communication). We fitted varying the two parameters that define both curves, the width of the gaussian profiles, α, and separation between both of them, ω. We performed diagnostic diagrams to constrain the orbital parameters using the $\sigma(K)\,\mathrm{K}^{-1}$ as a sensible measure when the wings of the line are comparable to the velocity width of the line and blend with the noise of the continuum. For each configuration we performed a non-linear least squares fit using the *MPCURVEFIT* routine written for

[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.

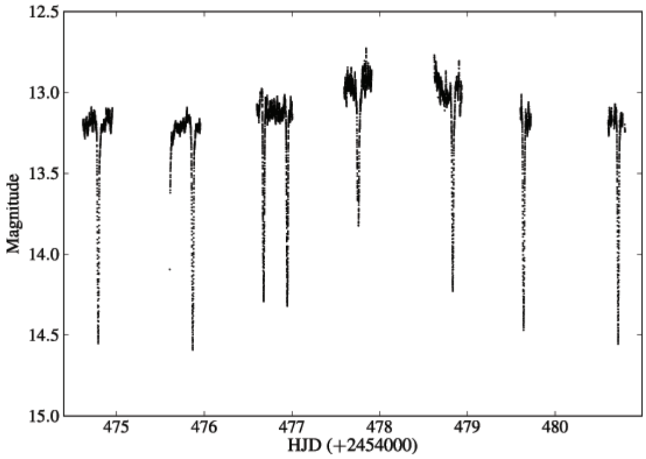

Fig. 1. Photometry in V filter for all nights in the 2008 observation season.

IDL[2] by Markwardt (2009), fitting the equation, assuming no eccentricity in the orbit:

$$V(t) = \gamma + K_{em} \sin\left[\frac{2\pi(t - HJD_0)}{P_{orb}}\right] \quad (2)$$

The results for K_1 of are presented in Table 1.

3.2. Secondary star radial velocity

Most of the secondary star features in the individual spectra are hidden in the bright emission arising from the accretion disk. In order to obtain better signal to noise ratio, we used the cophasing method (Echevarría et al. 2007). This method consists in Doppler shift the spectra to match the radial velocity of the secondary star using the K_2 as a free parameter. Then, we coadded the spectra and measure the maximum absorption for a chosen semiamplitude. Figure 2 shows the maximum flux depth for the absorption lines Fe I 4918 Å and Fe I 4469Å. We vary the semiamplitude from 150 –230 km s^{-1} and find the best solution to be for K_2 = 205 km s^{-1} and K_2 = 201 km s^{-1}, respectively.

4. Doppler tomography

Doppler tomography was made using an IDL routine developed by Spruit (1998) based on the maximum entropy method [3]. Hα (Figure 3), Hβ (Figure 4) and He II 4686 Å (Figure 5) emission lines maps were done using all the spectra of the 2008 season.

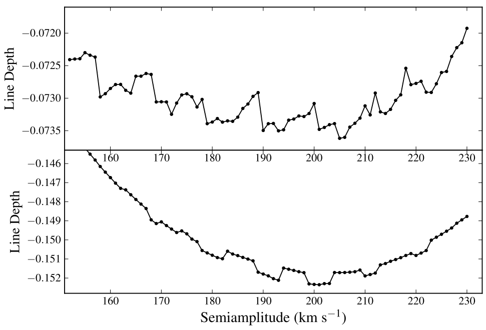

Fig. 2. Maximum depth flux of Fe I absorption lines as a function of K_2. *Top*: 4918 Å. *Bottom*: 4469 Å

As a first step, we calibrated the spectra using the V Johnson simultaneous photometry to account for slit losses. We performed an average of the photometric data covering exactly each spectroscopic exposure and then summed all the spectral pixel fluxes centered at 5380 Å with a width of 98 Å, and converted

[2] Interactive Data Language

[3] `http://www.mpa-garching.mpg.de/~henk/pub/dopmap/`

Table 1. Radial velocity semi–amplitudes solutions for emission lines.

Line	K_1 km s^{-1}	γ km s^{-1}	$\phi - \phi_{phot}$
Hα	186.8±3.9	-51.2±2.6	0.0468±0.006
Hβ	157.3±5.1	-40.7±3.9	-0.038±0.005
He II λ4686	123.19±6.6	-249.2±5.0	-0.0017±0.003

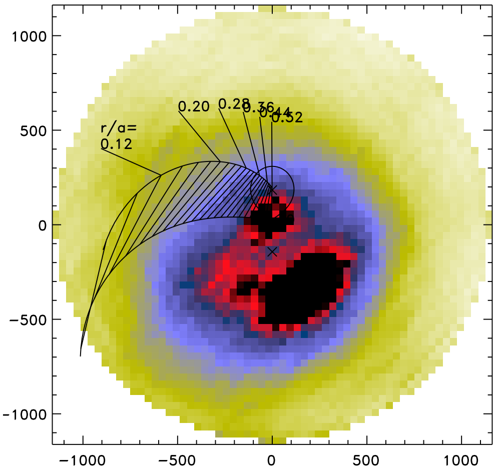

Fig. 3. Doppler Tomogram in Hα. The units in both axis are km s^{-1}.

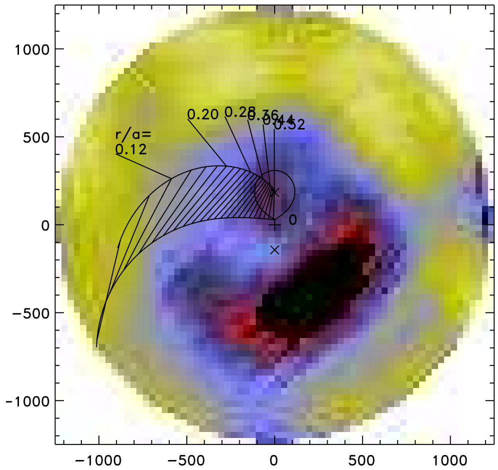

Fig. 4. Doppler tomogram in Hβ. Axis units are km s^{-1}.

then to magnitude, to obtain a V Johnson–like filter (not convolved with the filter spectral response). The spectra was then calibrated by subtracting the photometric and spectroscopy magnitudes. This procedure is enough to account for the spectroscopic slit losses.

Hα and Hβ tomograms presented emission arising from $-V_x$,$-V_y$) ~ (200,-300) km s^{-1}and it extends throughout the map up to ($-V_x$,$-V_y$) ~ (-200,-300) km s^{-1}. This kind of emission it's a characteristic of nova–like subtype SW Sex (Warner 2003). The emission of Hβ shares similarities with confirmed SW Sex type systems as BT Mon, LX Ser y DW UMa (Kaitchuck et al. 1994). The high excitation line He II λ4686 is seen in the tomogram rotating at the velocity of the WD around ($-V_x$,$-V_y$) ~ (0,-200) km s^{-1}.

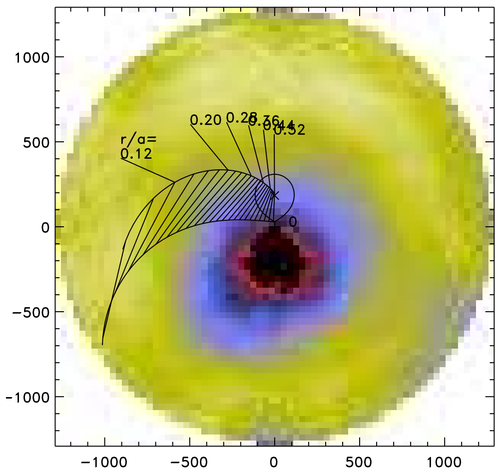

Fig. 5. Doppler tomogram in He II 4686 Å. The units in both axis are km s^{-1}.

5. Conclusions

We improved the ephemeris of the object through differential photometry with errors under one minute. For the first time, a mini–outburst of ~ 0.5 mag was observed in 2008. Our radial velocity analysis showed higher values of K_1 and K_2 than the ones published by Sing et al. (2007). Thus, assuming a $i > 76°$, the orbital parameters of they system are:

$$M_1 = 0.91 \pm 0.04\ M_\odot$$
$$M_2 = 0.83 \pm 0.04\ M_\odot$$
$$a = 2.10 \pm 0.03\ R_\odot$$

We found emission in Balmer and He II lines consistent with SW Sex NL subtype. Doppler tomography revealed the He II emission rotating with the WD radial velocity. Follow–up observations, specially simultaneous spectroscopy and photometry, are needed to determine the nature of this object. A full analysis of the object will be presented in Hernandez–Santisteban et al. (to be submitted to A&A).

6. Discussion

DIMITRY KOMONOV: You use a package developed by H. Spruit, but the method itself was develpoed and proposed by Lucy in 1994. What method do you use to measure radial velocities of the emission lines?

JUAN HERNANDEZ–SANTISTEBAN: We used the two gaussian method to determine the velocity of the wings of the emission lines and a diagnostic diagram to select the best solution.

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