Astron. Astrophys. 324, L57–L60 (1997)

ASTRONOMY
AND
ASTROPHYSICS

LETTER

Letter to the Editor

HE 2350-3908: a dwarf nova with a 78^m orbital period*

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Received 10 March 1997 / Accepted 18 April 1997

Abstract. We present time resolved CCD photometry and spectroscopy of the cataclysmic variable HE2350-3908 discovered in the Hamburg/ESO survey. We find that the orbital period of this source is 78.2 min. This is the shortest orbital period known to date for a cataclysmic variable with a normal hydrogen-rich secondary. The optical spectrum and the orbital light curve of HE2350-3908 is very similar to WZ Sge, and we argue that the source is a dwarf nova type cataclysmic variable with a very low mass-transfer rate, and a long recurrence time.

Key words: Stars: individual: HE2350-3908/RX J2353.0-3852 – cataclysmic variables

1. Introduction

The Hamburg/ESO survey (HES) is a wide-angle survey for bright QSOs (12.5 $\lesssim$B $\lesssim$17.5) in the southern hemisphere, based on objective prism plates taken with the ESO Schmidt telescope (Wisotzki et al. 1995). In this *Letter* we present time resolved CCD photometry and spectroscopy of the cataclysmic variable (CV) HE 2350-3908 discovered in the HES. This source was also independently discovered as a soft X-ray source RX J2353.0-3852 by ROSAT (Abbott, Fleming and Pasquini 1997: henceforth AFP).

2. Observations and Analysis

The source HE 2350-3908 was originally selected as a QSO candidate on the basis of its UV excess. In the course of follow-up observations a spectrum was obtained of the source on October 29, 1995 with the B&C spectrograph attached to the ESO 1.52m telescope at ESO in Chile. The spectrum covers the range 3250–7500Å, at a resolution of 20Å. The flux calibrated spectrum of HE 2350-3908 is shown in Fig. 1. The most striking feature of the spectrum are the double peaked Balmer emission lines which, from Hβ onward, show an onderlying broad absorption component. The He I lines at 5876 and 7065 Å can also been seen. As already noted by AFP, the spectrum is very similar to that of the well known dwarf nova type CV WZ Sge (Gilliland, Kemper and Suntzeff 1986).

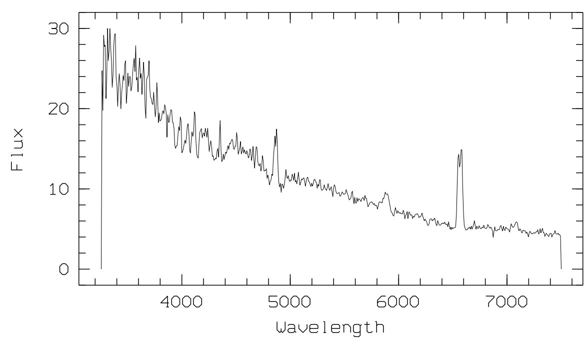

Fig. 1. A flux calibrated spectrum of HE 2350-3908 taken on October 29, 1995. The spectrum has a resolution of 20Å. The flux is in units of 10^{-16} erg/cm^2/s/Å

2.1. Time-resolved photometry

We observed HE2350-3908 during a total of 9 nights with an CCD attached to the 91cm Dutch telescope at ESO in Chile. The source was monitored using a Bessell V filter for 8 consecutive nights on November 2-9, 1995. On the nights of 5 and 6 November 1995 the source was also alternately observed with a Bessell B filter. The source was again monitored using a V filter on December 21, 1995 simultaneous with the spectroscopic observations discussed below. A log of the observations is given in Table 1. The measurements of the source were reduced differential with respect to 3 "comparison" stars within the field of view using aperture photometry. The errors in the differential magnitudes of HE 2350-3908 taking into account only Poisson noise were typically 0.5–1.0% in V, and 1.0–1.5% in B. The

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* based on observations made at the European Southern Observatory, La Silla, Chile

Table 1. Log of observations

$T_{\rm start}$(HJD) −245 0000	Duration (days)	Filter	T_{int} (sec)	No. of obs.
23.53067	0.25329	V	120	138
24.51722	0.26330	V	120	129
25.51679	0.15804	V	120	82
26.51554	0.20886	V/B	60/90	72/72
27.51435	0.28710	V/B	60/90	106/104
28.51587	0.04762	V	120	24
29.52623	0.16134	V	120	91
30.50820	0.28263	V	120	159
72.52313	0.12157	V	120	68

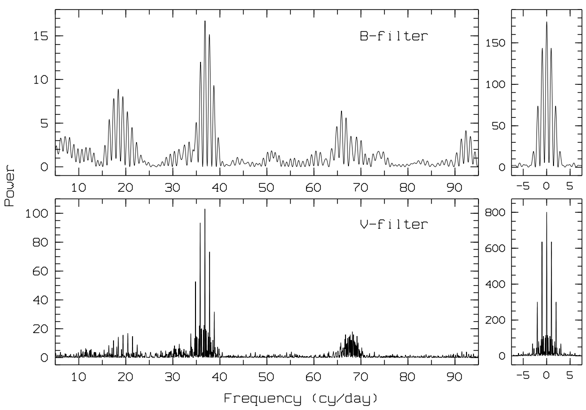

Fig. 2. Frequency spectra for all the B (top) and V filter (bottom) observations taken in November 1995. On the right side the respective window functions are shown

comparison stars where calibrated using observations of a set of standard stars.

To look for periodic variations we performed a Fourier spectrum analysis using the Lomb-Scargle method (see Press and Rybicki 1989 and references therein) of the observation. In Fig. 2 we present the frequency spectra for the B and V filter observations taken in November 1995 together with their respective window functions. The observations were first corrected by subtracting a 2^{nd}-order polynomial fit to the data in each night separately before the frequency spectra were calculated. However, the frequency spectra obtained using the uncorrected data are virtually the same. In both filters the highest peak is at frequency of ∼36.8 cy/day, i.e. a period ∼39 min. The respective window functions show that this peak corresponds to the correct period (not a 1-day alias). In the frequency spectrum of the B filter observations one can also clearly see a set of peaks centered on a frequency of ∼18.4 cy/day, which indicates that the fundamental period is in fact ∼78 min (see also below).

We performed sinusoidal fits with a fixed period of 39 min to the V filter observations in each night separately. The resulting arrival times of maximum light are listed in Table 2 together with the respective cycle numbers. From a least-squares polynomial fit to the arrival times we derive the following ephemeris:

Table 2. Arrival time of maximum light

Cycle number	$T_{\rm max}$(HJD) −245 0000	Cycle number	$T_{\rm max}$(HJD) −245 0000
0	23.65344(50)	180	28.5412(21)
37	24.65849(58)	219	29.60170(71)
72	25.60940(76)	258	30.66052(54)
109	26.61364(97)	1801	72.57157(58)
147	27.64523(90)		

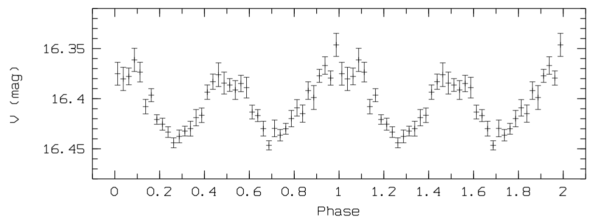

Fig. 3. The average light curve of HE2350-3908 in the V filter. The errors corresponds to the error in the mean of each phase bin. Two cycles are shown for clarity

$T_{\rm max}(HJD)$ = 245 0032.18201(23) + 0.02716172(37) × N, with χ^2_{red}= 0.38 for 7 degrees of freedom.

As we have argued above, and we will show below, the above ephemeris corresponds to the first harmonic of the true period. Selecting somewhat arbitrarily the maximum which is slightly higher and broader as the primary maximum the ephemeris becomes;

$$T_{\rm max}(HJD) = 245\,0032.20917(23) + 0.05432343(74) \times N \quad . \qquad (1)$$

In Fig. 3 we show the average light curve in the V filter in 40 phase bins as a function of phase as calculated from Eq. (1). The errors correspond to the error in the mean of each phase bin. Two cycles are shown for clarity.

2.2. Time-resolved spectroscopy

Hoping to clarify the nature of the ∼39/78$^{\rm m}$ photometric period, we obtained time-resolved spectroscopy of the source on December 21, 1995 with EFOSC2 attached to the ESO/MPI 2.2m telescope at ESO in Chile. The spectra cover the range 5840–6970 Å, at a resolution of 3.7 Å. The source was monitored during the night for a period of ∼2.7 hours. A total of 17 spectra were obtained with an integration time of 8 min each. Helium-Argon calibration exposures were obtained at the beginning, in the middle and at the end of the observations. The extracted spectra were wavelength calibrated by interpolating between the two calibration exposures closest in time. The individual spectra where normalized by dividing them by a 2^{nd}-order polynomial fit to the continuum.

To determine the radial-velocity of the Hα emission line in the individual spectra we used the double Gaussian convolution technique introduced by Schneider & Young (1980). We

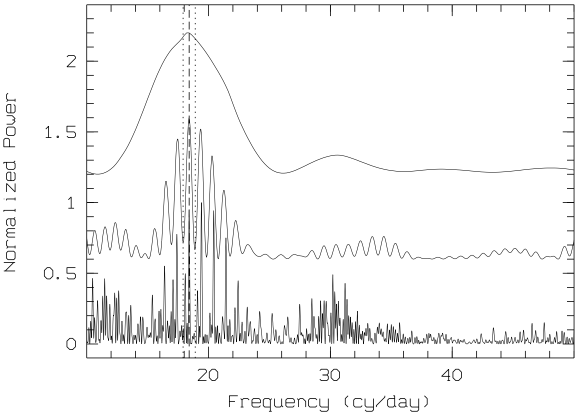

Fig. 4. The frequency spectra of the radial-velocity measurments (top curve), and of the pre-whitened (see text) B (middle) and V (bottom) filter measurements. The dashed line is at a frequency of 18.408 cy/day, i.e. a period of 2×0.0271617 = 0.054324 d. The dotted lines corresponds to half the frequency of the 1-day aliases of the 0.0271617 d period

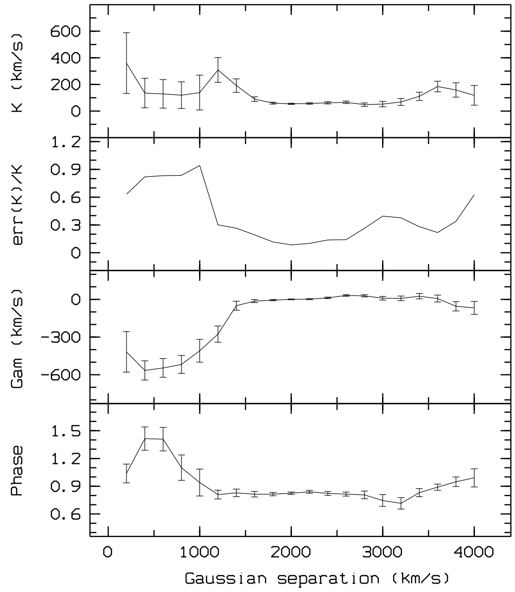

Fig. 5. The "diagnostic diagram" for Hα. We show K, its associated error σ_K/K, γ, and the phase of superior conjunction as a function of a. Phase zero corresponds to photometric maximum (see Eq. (1))

looked for periodic variations in the radial velocity measurements for a range in separations between the two Gaussians of 200–4000 km/s. Significant variations were only found for separations of 1200–2800 km/s. In Fig. 4 (top curve) we show the resulting frequency spectrum for a separation of 2000 km/s. Significant variations are found only for a frequency of ∼18.5 cy/day, i.e., a period of ∼78^{min}. The frequency spectra for the other separations are very similar. Also shown in Fig. 4 are the frequency spectra of the B filter (middle curve), and V filter (lower curve) data pre-whitened by subtracting a sinusoidal fit to the data with a fixed period of 0.0271617 d, i.e. a period of 39 min. The vertical dashed line in Fig. 4 is at half the frequency of the 0.0271617 d period, i.e., at a frequency corresponding to a period of 0.054324 d. The dotted lines on either side of the dashed line are at half the frequency of the 1-day aliases of the 0.0271617 d period. This shows that the fundamental frequency of the photometric variations in both filters corresponds to half the frequency of the 0.0271617 d period. As there are no significant radial-velocity variations at any other period, and there are no other photometric variations consistent with the period found for the radial velocities, we conclude that the brightness and the radial velocity of HE 2350-3908 vary with the same period, which corresponds to the orbital period of the source.

To investigate the radial-velocity variations in more detail we fitted the derived velocities with a non-linear least-squares fit of the form $V(\phi, a) = \gamma(a) + K(a) \cdot sin\,\phi$ where ϕ is the phase as calculated from Eq. (1). In Fig. 5 we show the corresponding "diagnostic diagram" (Shafter 1983) for Hα in which we plot K, its associated error σ_K/K, γ, and the phase as a function of the separation (a) of the two Gaussians. In this way one can see the degree of asymmetry in the emission line profile as a function of velocity from line center (i.e., as a function of the separation of the two Gaussians). From Fig. 5 one can see that no significant variations are found for small separations of the two Gaussians, and that the solutions for separations large than 1600 km/s are practically constant until for very large separations the noise in the line wings begins to dominate. This indicates that there is no strong contamination in the radial-velocities variations of the line wings by any emission component at lower velocities. To derive the orbital elements of the line wings we took the values for the separation at which σ_K/K qreaches a minimum, i.e. for a = 2000 km/s. The resulting orbital elements are γ = 1(3) km/s, K = 55(5) km/s and $T_{sup.conj.}$(HJD)= 245 0072.56191(71) which correspond to phase 0.82(2) with respect to photometric maximum.

3. Discussion

Time-resolved V filter photometry of HE2350-3908 has been reported previously by AFP. These authors found a periodicity with a frequency 16.5 cy/day (corresponding to a period of 87.4 min) and its first three harmonics. After pre-whitening their data with a sinusoidal fit to the data at this frequency and its first three harmonics, they found a second periodicity with a frequency of 37.9 cy/day (38.0 min). The former period corresponds to the ∼2 cy/day alias of the 0.05432343 d (78.3 min) period we have found above, i.e., the second peak to the left of the main peak indicated in Fig. 4. Furthermore, the first harmonic of the 87.4 min period has a frequency of 32.9 cy/day at which we find no significant power either in the uncorrected data (Fig. 2), or our pre-whitened data (Fig. 4), and we conclude that the period found by AFP corresponds to an alias of the true period. The second period found by AFP corresponds to the ∼1 cy/day alias of the main frequency we found in our data. Although the peak at this alias in the frequency spectra shown in Fig. 2 is fairly high, the window functions of our data are not consistent with the selection of this period as the correct period. Furthermore, this period cannot be the first harmonic of the true period as there is no significant power at this frequency in our data (see the dotted line to the right in Fig. 4), and we believe that the presence of this period in the pre-whitened data of AFP is the result of correcting the data using an incorrect period.

A remaining question is what type of CV HE2350-3908 is. Most CVs in the orbital period range ∼80–85 min are SU UMa type dwarf nova, while the two CVs with the currently shortest known orbital period are AM Her (or Polar) type magnetic CVs, RE 1307+535 having the shortest period of 79.7 min. As already mentioned above the optical spectrum of HE2350-3908 is very similar to the SU UMa type dwarf nova WZ Sge. Also the orbital light curve is remarkable similar to the orbital light curves of WZ Sge and AL Com (see Patterson et al. 1996), which have currently the shortest orbital period, both of 81.6 min, known for SU UMa type dwarf novae. The optical spectrum and orbital light curve of HE2350-3908 is very different from that of the Polars EF Eri (Mukai & Charles 1985), which has an orbital period of 81.0 min, and RE 1307+535 (Osborne et al. 1994). The strongest argument against HE2350-3908 being a dwarf nova is that no outburst has been detected for this source. However, AL Com and WZ Sge are the 2 dwarf novae with the longest known recurrence time between superoutburst (when such a source is most likely to be discovered) of ∼20 and ∼30 yr, respectively. One, if not the dominant reason (see Patterson et al. 1996), for a long recurrence time is a low accretion rate. Indeed, considering the underlying wide absorption line, the equivalent width of Hβ for HE2350-3908 must be high (>40 Å) which indicates a low accretion rate (see Fig. 6 in Patterson 1984). Furthermore, using the ratio of the X-ray flux (as derived from AFP) to optical flux, one can estimate the transfer rate from the relation presented by Richman (1996) from which we derive $\dot{M} \sim 2.0 \times 10^{14} g/s$. This is very low for any type of CV, and similar to that of WZ Sge. We, therefore, conclude that HE2350-3806 is most likely a SU UMa type dwarf nova with a long recurrence time.

One of the striking features of the period distribution of CVs is a cut-off at a minimum period of $\sim 80^m$. The 78.2 min period found for HE2350-3908 is the shortest orbital period known to date for a 'normal' CV (see Ritter & Kolb 1995). The value of the minimum orbital period depends on the total mass of the system and its chemical composition (Paczynski & Sienkiewicz 1981, Rappaport, Joss & Webbink 1982, Sienkiewicz 1984). A CV might actually be formed at a period below this limit, but such a system is expected to evolve quickly to its equilibrium period above the period minimum, and observing a system in this particular stage is very unlikely. Another possibility is that the secondary in HE2350-3908 consists of a degenerate core plus a hydrogen rich envelope similar to what has been proposed for the dwarf nova V485 Cen which has an orbital period of 59 min (Augusteijn et al. 1996). However, the mass accretion rate derived above is an order of magnitude lower than expected for such a system, and also the chances of finding such a system seem very small. If the secondary in HE2350-3908 is a normal main-sequence like star this system must be close to the minimum period in its evolution. The reason why its orbital period is smaller than other similar type CVs is most likely a lower total mass of the system, or a lower metal abundance (e.g., if the system is a Population II object).

A more detailed analysis of the data presented here, including a study of archival plate material and additional IR photometry is currently underway and will be presented in a future paper.

Acknowledgements. We are grateful to Tim Abbott for access to the results of Abbott, Fleming & Pasquini (1997) prior to publication.

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