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A newly-discovered cataclysmic binary near the ROSAT galactic plane source RX J1910.8+2856

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Abstract. We report the discovery of a new cataclysmic binary star from the ROSAT Galactic Plane Survey. The star has $V \gtrsim 18.5$ at minimum light and we have measured it as bright as $V = 15.7$. Spectroscopy shows broad hydrogen and helium emission lines; HeII $\lambda 4686$ is not detected. Hα radial velocities yield an orbital period of 0.1429 ± 0.0004 d (3.430 ± 0.010 h). Time-series photometry covering one orbital cycle near maximum light shows irregular variability, but no evidence of an eclipse. The system appears to be a new dwarf nova of the U Gem or Z Cam type, and is unlikely to be a magnetic system. Its period is unusually short for a U Gem star.

Curiously, the new cataclysmic binary is 83″ from the original ROSAT PSPC survey position, which puts it outside the PSPC positional uncertainty. Follow-up observations with the HRI reveal that the PSPC source is the superposition of two sources, and the cataclysmic is much the weaker of the two in X-rays. Its discovery in this survey is therefore essentially accidental. A $V = 19.4$ mag star is located 1.2″ from the stronger source's HRI position.

Key words: stars: binaries: close – stars: individual: RX J1910.8+2856 – stars: individual: RX J191059.6+285639 – stars: novae, cataclysmic variables – X-rays: stars

1. Introduction

As expected, many X-ray sources discovered by ROSAT have been identified with previously unknown cataclysmic binaries (e.g., Motch et al. 1996). For a description of the ROSAT mission and the X-ray detectors (Position Sensitive Proportional Counter, PSPC, and High Resolution Imager, HRI) sensitive in the 0.1 – 2.4 keV band see Trümper (1983), Pfeffermann et al. (1986) and David et al. (1993), respectively. Here we report the discovery of a new cataclysmic variable near the position of a source from the ROSAT Galactic Plane Survey (RGPS; Motch et al. 1991). The source, RX J1910.8+2856, lies in Lyra at $b = +8.^\circ 9$ and is contained in the ROSAT Bright Source Catalogue (1RXS J191053.2+285622; Voges et al. 1996).

2. Identification

2.1. Optical

On 1994 May 1 UT we obtained spectra of several stars near the PSPC position (Table 1) in an effort to identify the optical counterpart. We used the Hiltner 2.4m telescope at MDM Observatory on Kitt Peak, the Mark III spectrograph, and a Tektronix 1024^2 thinned CCD detector. The spectra covered from 4700 to 6700 Å with a resolution of ~ 5 Å. Because the aim was a quick search, exposure times were only 180 s, and the signal-to-noise was low. None of the stars observed (stars A-C and number 2 in Fig. 1) showed any sign of being the counterpart; all appeared to be ordinary late-type stars. The spectrograph had a long slit, and the field was rather crowded, so we examined the 2-dimensional CCD spectra in case a more promising candidate had fortuitously landed anywhere in the 1″ slit. Amazingly, in the frame containing the spectrum of star ‘A’ we found a spectrum showing the broad Balmer emission characteristic of a cataclysmic! On the following night we obtained ~ 3 h of time series spectra, which were sufficient to show an orbital period of ~ 3.5 h (Sect. 4).

We derived the position of the cataclysmic using a direct image taken with the MDM 1.3 m McGraw-Hill telescope. A fit to six stars from the HST Guide Star Catalog (version 1.2) yielded the optical position listed in Table 1, with an uncertainty (estimated from the fit residuals) of $\pm 0.3''$.

2.2. X-ray

The optical position is 83″ from the PSPC position, which is much worse than typical location errors for a source this strong (0.20 cts s^{-1}). To clarify the identification, we observed the source with the HRI, once for 22.9 ksec in 1997 April and again for 5.2 ksec in 1997 November (Sect. 5). In both observations we found *two* HRI sources near the position (see Table 1). Source 1, the stronger of the two, was located well within the error circle of the PSPC source RX J1910.8+2856, while the position of the weaker Source 2 was nearly coincident with that of the cataclysmic binary. We assign the name RX J191059.6+285639 to the cataclysmic variable (source 2) derived from the position found in the longer HRI observation. The PSPC source was apparently the superposition of two sources, the *weaker* of which

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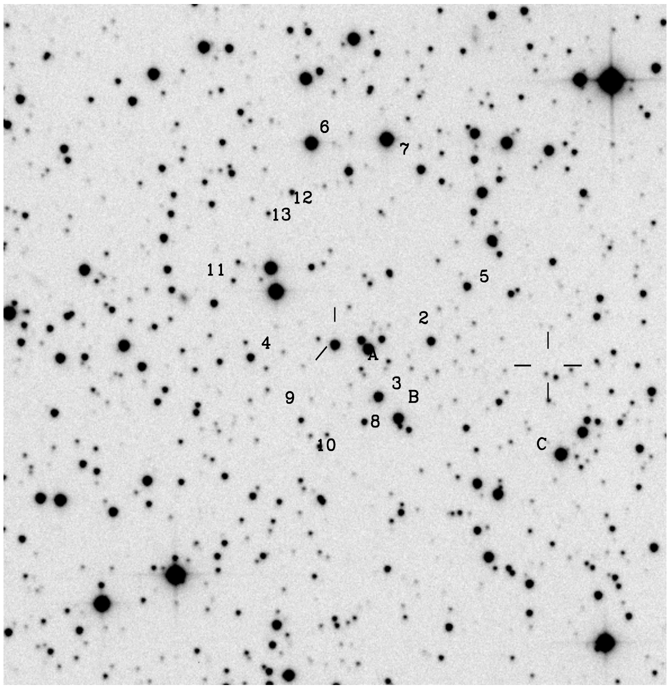

Fig. 1. Finding chart, 5×240 s V-band exposure with the MDM 1.3 m telescope, from 1997 June 22 UT. The field is $5'$ square with north at the top and east to the left. The new cataclysmic (center) is indicated by two short lines; its J2000 position is $\alpha = 19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 59^{\mathrm{s}}.41$ and $\delta = +28^\circ\ 56'\ 38''.7$. The cataclysmic is $V = 15.7$ in this picture, as bright as we have seen it. V-band magnitudes for the numbered stars are: 2, 16.49; 3, 15.72; 4, 16.79; 5, 16.71; 6, 14.26; 7, 13.94; 8, 17.72; 9, 18.13; 10, 18.37; 11, 18.76; 12, 18.26; and 13, 18.91. Spectra of stars A, B, C, and 2 showed them to be ordinary. The open cross-hairs to the west indicate the corrected position of HRI Source 1

is the cataclysmic, so the cataclysmic's discovery is essentially accidental!

What about Source 1, the stronger of the two? The HRI position error is dominated by the $\sim 7''$ uncertainty in the satellite aspect. Assuming that Source 2 is the cataclysmic, for which we have an accurate position, we correct for the aspect uncertainty and derive a position for Source 1 accurate to $\sim 1''$. This position (Table 1), derived using the longer HRI observation, is bracketed by the open cross-hairs in Fig. 1. There is no bright star at the position, but a $V = 19.4$ object is 1.2″ NE of the position, and a $V = 18.6$ object is 3.4″ W. The fainter of the two appears to be a good candidate for the identification based on its position, while the brighter one is less likely.

3. Photometry

Our most extensive photometry is from 1997 June, with the 1.3 m McGraw-Hill telescope at MDM and a Tektronix 1024^2 CCD direct camera. Photometry obtained on two nights referred to Landolt (1992) standards yielded the magnitude sequence in the caption to Fig. 1. Although all our observations of the source were in the V passband, fits to the standard star magnitudes showed that the color term for V was very small. On 1997 June 21 UT, we found the cataclysmic at $V = 16.02$ in a set of eight 1-min exposure; a longer sequence of 4-min exposures obtained 1997 June 22 yielded an average $V = 15.68$. The June 22 observations extended for almost exactly one orbital period, to search for an eclipse. Fig. 2 shows the result of differential photometry. There is no eclipse evident, but the star does show small but significant irregular variability compared to a check star.

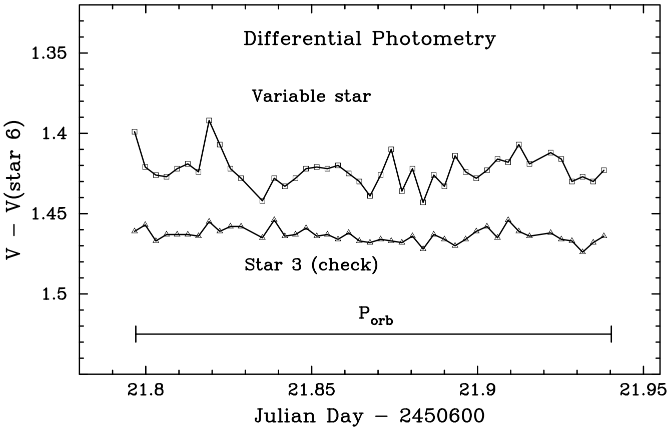

Fig. 2. Differential photometry of the cataclysmic binary and a check star. Magnitudes are referred to Star 6 ($V = 14.26$). The horizontal bar indicates the orbital period

Table 1. X-Ray and Optical Positions

Object	α_{J2000}	δ_{J2000}
PSPC survey position	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 53^{\mathrm{s}}.2$	$28^\circ\ 56'\ 22''$
HRI obsn 1 Source 1	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 52^{\mathrm{s}}.35$	$28^\circ\ 56'\ 24''.1$
HRI obsn 2 Source 1	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 51^{\mathrm{s}}.76$	$28^\circ\ 56'\ 23''.4$
HRI obsn 1 Source 2	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 59^{\mathrm{s}}.69$	$28^\circ\ 56'\ 39''.1$
HRI obsn 2 Source 2	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 59^{\mathrm{s}}.12$	$28^\circ\ 56'\ 39''.4$
Cataclysmic (optical)	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 59^{\mathrm{s}}.41$	$28^\circ\ 56'\ 38''.7$
Corrected HRI Source 1	$19^{\mathrm{h}}\ 10^{\mathrm{m}}\ 52^{\mathrm{s}}.07$	$28^\circ\ 56'\ 23''.7$

We obtained a single 120 s direct CCD picture with the 1.3 m telescope on 1994 May 1.50, contemporaneous with the discovery and initial observations. This showed the star at $V = 17.67 \pm 0.08$.

Magnitudes can also be inferred from the continuum levels of the spectra (discussed below), though the small slits used limit the accuracy to $\sim \pm 0.3$ mag. The mean spectrum observed 1994 May 2.35 UT implies $V = 17.9$, consistent with the more reliable magnitude measured the previous night. However, the long series of observations obtained 1997 June 29 – July 2, about a week after the extensive photometry, show the star considerably fainter, near $V = 18.9$ on average. The true magnitude was probably somewhat brighter, because poor seeing marred many of the observations, but it is likely that it was at least as faint as $V = 18.5$.

In summary, the cataclysmic has a range from $V = 15.68$ down to $V \gtrsim 18.5$. We have no information on the variability beyond this, but the fading on a 1-week time-scale observed 1997 June/July suggests a dwarf nova declining from outburst.

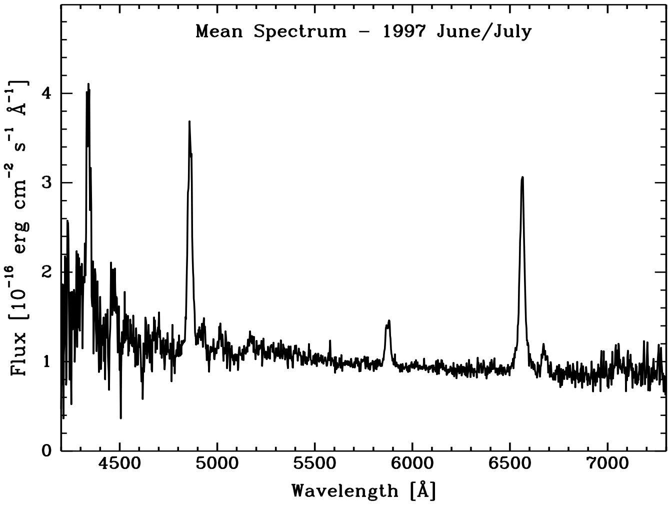

Fig. 3. Mean spectrum obtained in 1997 June and July. The continuum level suggests $V = 18.9$, though this probably underestimates the flux

Table 2. Spectral Features

Feature	E.W. (Å)	FWHM (km s^{-1})
Hγ	30	1500:
HeI λ4471	13:	...
Hβ	56	1600
HeI λ5015	4:	...
FeII λ5169	4:	...
HeI λ5876	16	1500
Hα	88	1360
HeI λ6678	12:	...

4. Spectroscopy

Our spectra are from two observing runs. The discovery on 1994 May 1 UT occurred on the penultimate night of the first run; on the final night (May 2) we obtained seventeen 600 s spectra, spanning 3.2 hours. We returned to the object 1997 June 29 – July 2, and obtained 35 more exposures using the 2.4 m telescope, modular spectrograph, and a SITe 2048^2 CCD detector. These spectra covered 4000 – 7500 Å at 3.5 Å resolution, with considerable vignetting toward the ends. In order to minimize ambiguities in the period-finding caused by aliasing with the earth's rotation, we arranged our observations to cover a 7.1 h range of hour angle. The average spectrum from 1997 appears in Fig. 3; the 1994 spectrum is similar but at a stronger flux level. Spectral features are listed in Table 2, with their emission equivalent widths and full-widths at half maximum. The lines are single-peaked, except for a slight doubling at the top of HeI λ5876; Hα has weak emission wings which can be traced to ± 3000 km s^{-1} from the line center. The spectrum appears normal for a dwarf nova at minimum light. He II λ4686 in particular is not detected; magnetic cataclysmics usually show this line rather prominently, so this is probably not a magnetic system.

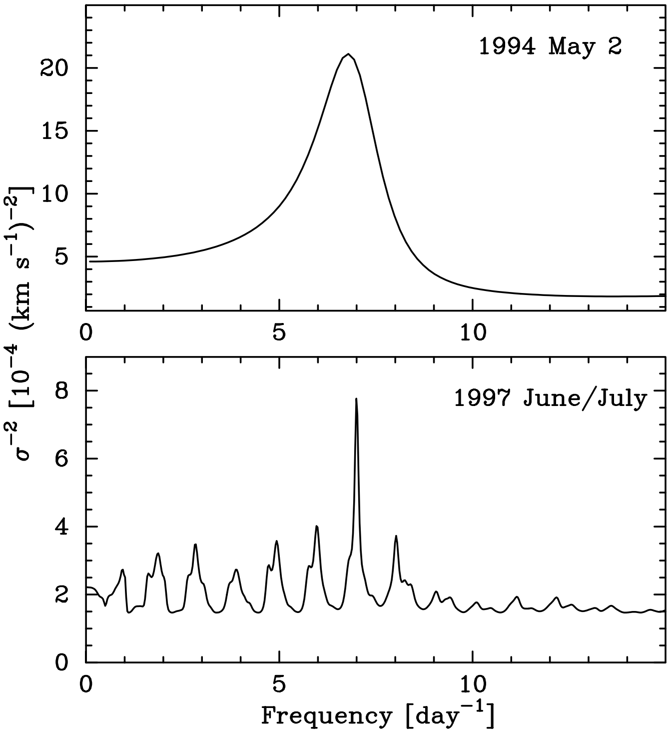

Fig. 4. Period searches of the radial velocities from the two observing runs. These are generated by fitting a least-squares sinusoid at each trial frequency and plotting the inverse of the variance. The different appearance of the two panels reflects the different sampling; the greater height of the 1997 May peak results from the lower noise of those data

We measured radial velocities of the Hα line (Table 3) using convolution methods explained by Schneider & Young (1980). Four of the 35 spectra from 1997 were rejected from the analysis because of insufficient signal-to-noise. Period searches of the 1994 and 1997 data are shown in Fig. 4. Both data sets are consistent with a frequency near 7.00 d^{-1}; the longer time base of the 1997 data gives the more precise value. The 1997 search shows aliases at ± 1 cycle d^{-1} which reflect different choices of cycle count between the nights, but the Monte Carlo test of Thorstensen & Freed (1985) shows that these may be rejected with high confidence. Sinusoidal fits to the 1997 velocities of the form

$$v(t) = \gamma + K \sin[2\pi(t - T_0)/P]$$

yielded

$$\begin{aligned} T_0 &= \text{HJD } 2450630.674 \pm 0.002, \\ P &= 0.1429 \pm 0.0004\ \text{d}, \\ K &= 111 \pm 12\ \text{km s}^{-1}, \\ \gamma &= -40 \pm 8\ \text{km s}^{-1},\ \text{and} \\ \sigma &= 36\ \text{km s}^{-1}, \end{aligned}$$

where σ is the uncertainty of a single measurement inferred from the goodness-of-fit, and the uncertainties quoted are formal 1σ. While the uncertainty in P should be realistic, we caution that γ and (especially) K in cases where they can be checked, are often serious mis-estimates of the systemic velocity and radial

Table 3. Hα Radial Velocities

HJD	V (km s^{-1})	HJD	V (km s^{-1})	HJD	V (km s^{-1})	HJD	V (km s^{-1})	HJD	V (km s^{-1})
49474.851	−20	49474.931	−30	50629.752	−63	50630.780	−202	50630.962	20
49474.858	−86	49474.945	23	50629.759	−104	50630.789	−127	50630.972	7
49474.866	−54	49474.957	76	50629.765	−129	50630.797	−150	50631.675	−3
49474.873	−134	49474.964	57	50630.709	79	50630.805	−119	50631.684	16
49474.884	−145	49474.971	47	50630.724	68	50630.812	−85	50631.693	47
49474.892	−179	49474.979	49	50630.731	37	50630.820	−46	50631.705	54
49474.899	−145	49474.986	42	50630.739	−57	50630.829	−71	50631.714	93
49474.906	−115	50628.810	−39	50630.757	−137	50630.935	−173	50631.722	66
49474.916	−153	50628.816	−79	50630.765	−80	50630.944	−42	...	...
49474.923	−78	50628.822	15	50630.772	−91	50630.953	−54	...	...

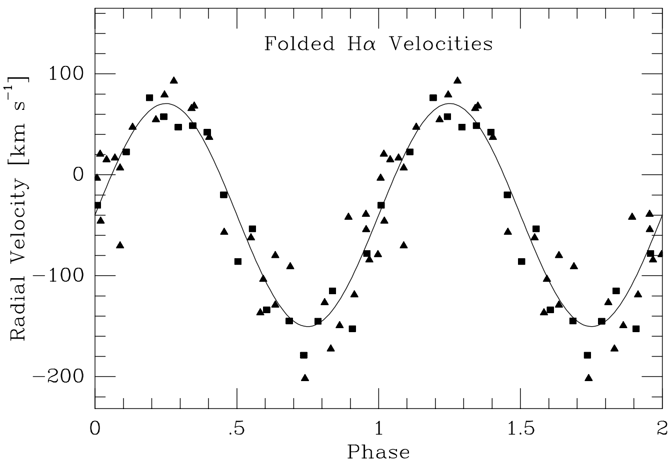

Fig. 5. Radial velocities folded on the best period. Squares are from 1994 May, and triangles are from 1997 June/July. All data are plotted twice for continuity. The period used for the fold was computed using an arbitrary choice of 8090 cycles between the observing runs. The sinusoid is fitted to the 1997 July data

velocity amplitude of the white dwarf, so they should be viewed only as fitting parameters. A fit to the 1994 data alone with the period fixed at 0.1429 d yielded $K = 114 \pm 9$ km s^{-1}, $\gamma = -48 \pm 6$ km s^{-1}, and $\sigma = 23$ km s^{-1}. The improved σ probably reflects the somewhat brighter state of the star during the 1994 observations. The time interval between the 1994 and 1997 data sets is so long that there is no unique choice of cycle count between them, but if one assumes phase coherence, the two runs constrain the period to

$$P = (1155.745 \pm 0.003 \text{ d})/\text{N}, \text{ where N} = 8090 \pm 55$$

is an integer. The uncertainty in N keeps P within ±3 standard deviations of the value above. Fig. 5 shows all the velocities folded on the best period,

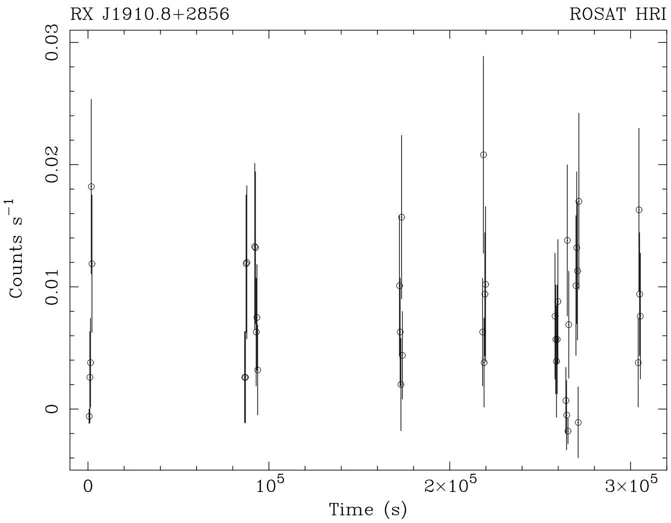

Fig. 6. Background subtracted soft X-ray light curve of RX J191059.6+285639 between 1997, April 7, 10:05 UT and April 10, 23:06 UT. The last minor part of the observation which followed after a gap of 13 days is not shown. The time resolution is 400 s

5. HRI observations

As mentioned in Sect. 2, two ROSAT HRI pointed observations were performed, centered on the PSPC survey position (see Table 4 for a summary). Both sources varied in intensity by a factor of two between the observations, seven months apart. Also on short time scales of hours both sources are variable with intervals with source count rates consistent with zero. The HRI light curve for RX J191059.6+285639 (the cataclysmic variable) obtained from the April 1997 observation is shown in Fig. 6. A temporal analysis to search for periodic modulation in the range of 1 to 1000 s yields no significant period with an upper limit for sinusoidal variations of 23% (semi-amplitude modulation). This is consistent with our optical results that RX J191059.6+285639 contains a non-magnetic white dwarf. The X-ray light curve folded with the orbital period of 3.43 h shows no significant variations, however the statistics is too low to rule such completely out. The flaring-like activity seen in Fig. 6 is probably unrelated to the binary orbit.

6. Discussion

The discovery of the cataclysmic binary RX J191059.6+285639 is a curious coincidence – it required the star to lie close to a

Table 4. HRI observations

Date	exposure (s)	count rate (cts s^{-1}) Source 1 RX J1910.8+2856	Source 2 RX J191059.6+285639
1997, April 7 – April 23	22940	0.0206 ± 0.0010	0.0075 ± 0.0006
1997, Nov. 3 – Nov. 10	5189	0.0401 ± 0.0028	0.0032 ± 0.0010

brighter, as yet unidentified, X-ray source. The limited variability information available and the optical spectrum at minimum light both suggest that it is a dwarf nova, and probably not a magnetic system. A longer-term variability study is needed to classify it firmly.

Of the dwarf novae listed in Ritter & Kolb (1998) as having periods long-ward of the ~ 2 to ~ 3 h 'gap', only BX Pup appears to have a well-established period shorter than the 3.43 h period of RX J191059.6+285639. Thus this accidental little star may yet find fame as one of the the shortest-period dwarf novae long-ward of the gap.

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