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FOUR X-RAY–SELECTED CATACLYSMIC VARIABLES IN THE GALACTIC PLANE

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ABSTRACT

We have identified four X-ray sources from the *Einstein* Galactic Plane Survey with faint cataclysmic variables. The optical counterparts to 1E 0830.9−2238, 1E 1449.7−6804, 1E 1516.6−6826, and 1E 1719.1−1946 were selected because of their blue excesses, and confirmed through spectroscopic observations. One source, 1E 0830.9−2238, may be an AM Her type magnetic variable based on the presence of a strong He II λ4686 emission line. The other three sources all have low X-ray luminosities ($L_x < 10^{31}$ ergs s^{-1}) and two of them, 1E 1449.7−6804 and 1E 1719.1−1946, are also optically faint ($M_v > 11.5$) and nearby ($d < 200$ pc). The latter two sources are inferred to have mass accretion rates among the lowest observed for active cataclysmic variables ($\dot{M} < 2 \times 10^{-12}\ M_\odot$ yr^{-1}). The existence of a population of intrinsically faint cataclysmic variables, which are difficult to discover through traditional means but can be identified through their X-ray emission or very blue colors, implies that the observed local space density of active cataclysmic variables is at least as high as a few × 10^{-5} pc^{-3}.

Subject headings: stars: dwarf novae — stars: stellar statistics — X-rays: binaries — X-rays: sources

I. INTRODUCTION

A survey of low Galactic latitude X-ray sources discovered serendipitously in the field of view of the Imaging Proportional Counter (IPC) on board the *Einstein Observatory* has been undertaken (Hertz and Grindlay 1984, hereafter HG). Many of the scientific goals of this Galactic Plane X-ray (GPX) Survey rely on optical identification of the X-ray sources. A program of optical identification is therefore in progress (Grindlay and Hertz 1983; Hertz and Grindlay 1988).

On the basis of a statistical analysis of the X-ray data from the entire plane, HG predicted that ~23% of the X-ray sources are accreting binary X-ray sources (including cataclysmic variables, hereafter CVs) with a concentration in their distribution toward the Galactic center. A long-term effort to identify GPX sources in the northern celestial hemisphere indicated that there was no excess of unidentified sources consistent with a large population of accretion-powered X-ray sources (Hertz and Grindlay 1988), yet such a population was still indicated for the southern celestial hemisphere, where the Galactic bulge and center are found. We therefore have continued our program to identify southern GPX sources.

The X-ray error circles of GPX sources are often crowded with optical candidates; thus the algorithm of obtaining optical spectra of most candidates within the error box, which is successful at high Galactic latitudes (e.g., Grindlay *et al.* 1980; Chanan, Margon, and Downes 1981; Stocke *et al.* 1983; Gioia *et al.* 1990), is impractical due to the limited time available on large-aperture telescopes. Instead we obtain CCD images of the X-ray error circles in three colors in order to select ultraviolet or blue excess objects for spectroscopic follow-up observations. This strategy yielded the UV-excess candidates which were found by us, in follow-up spectroscopy, to be the long-sought X-ray–selected CVs (Grindlay *et al.* 1987).

We report briefly on the X-ray and optical observations of these new, X-ray–selected CVs, and estimate their luminosities, distances, and accretion rates. We also estimate the implied spatial density of X-ray selected CVs based on the identification of at least five CVs (four reported here plus one previously reported) in a complete sample of 39 southern GPX sources.

II. X-RAY OBSERVATIONS

The southern GPX sample contains the 39 serendipitous X-ray sources reported by HG which are found south of the celestial equator. The southern section of the GPX survey covered 144 deg^2, and sources detected at a signal-to-noise ratio of 5 or more were selected for the southern GPX sample. Details of the survey may be found in Hertz (1983) and Hertz and Grindlay (1984, 1988).

The four sources which we have identified with previously unknown cataclysmic variables are 1E 0830.9−2238, 1E 1449.7−6804, 1E 1516.6−6826, and 1E 1719.1−1946 (see Table 3 of HG). In Table 1 we report the X-ray data on these sources; these data have been taken from the REV.1 IPC processing output (Harnden *et al.* 1984) and supersede those reported by HG. Each source is too faint by one to two orders of magnitude to have been detected by any of the X-ray surveys conducted prior to the launch of *Einstein.*

Too few X-ray photons were detected from these three sources to justify fitting X-ray spectra. However, we can determine broad-band soft X-ray colors and compare these to the

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TABLE 1

X-RAY OBSERVATIONS AND DATA

X-Ray Source	IPC Sequence Number	Date of Observation	Exposure Time (ks)	R.A./Decl. (1950)	$r_{90\%}$[a]	X-Ray Flux[b] (IPC counts s^{-1})
1E 0830.9−2238[c]...........	10722	1981 Apr 15	10.0	$8^h30^m54\overset{s}{.}6$ $-22°38'27''$	±27″	0.016 ± 0.003
1E 1449.7−6804............	5926	1980 Oct 3	5.2	14 49 49.2 −68 03 54	±51	0.035 ± 0.006
1E 1516.6−6816............	841	1979 Aug 14	5.8	15 16 40.7 −68 27 09	±52	0.011 ± 0.002
1E 1719.1−1946...........	6477	1981 Mar 23	7.3	17 19 08.3 −19 46 08	±48	0.035 ± 0.004

[a] The radius of the 90% confidence limit error circle is in arcseconds.

[b] The X-ray flux is in the 0.2–3.5 keV *Einstein* broad energy band; a typical energy conversion is 1 IPC count $s^{-1} \simeq 2.5 \times 10^{-11}$ ergs cm^{-2} s^{-1} and is spectrally dependent.

[c] Source not detected by IPC REV.1 software; results from REV.0 processing (see Hertz 1983).

soft X-ray colors of identified X-ray sources. All four sources have moderately hard X-ray colors $[F_x(1\text{–}3.5 \text{ keV})/F_x(0.5\text{–}1.0 \text{ keV}) > 3]$, typical of CVs or (possibly) active galactic nuclei, but inconsistent with the observed colors of nearby stars or single white dwarfs (Córdova, Bell, and Kolb 1985). There are also too few X-ray photons to set meaningful limits on X-ray variability.

III. OPTICAL OBSERVATIONS

a) Photometry

In order to search for blue objects in the X-ray error circles of GPX sources, we have obtained CCD images of GPX source error circles during observing runs on the CTIO 4 m and 1.5 m telescopes beginning in 1985. Our data was obtained with a RCA CCD chip at the 4 m telescope's prime focus and at the 1.5 m telescope's Cassegrain focus. For each GPX source we obtained at least six images, including long exposures and short exposures through standard *U*, *B*, and *V* filters. Standard stars were observed on each night, and transformation coefficients were derived which gave rms residuals of less than 2% in all three colors.

Each CCD image was analyzed independently using DAOPHOT (Stetson 1987) and as many stars as possible were detected to within prescribed sensitivity limits. For each star, a position and instrumental magnitude was determined. We then combined the CCD star lists and determined which stars in each GPX field were detected in all three colors. The use of both long and short exposures in each color allowed us to use the short exposure for bright stars (which saturate in the long exposure), use the long exposure for faint stars, and average the instrumental magnitudes for moderate stars. Finally, we converted instrumental magnitudes into standard magnitudes using the adopted transformation coefficients.

During our five observing runs to date (1985 January, 1985 May, 1987 May, 1988 June, and 1989 July), we have obtained *UBV* CCD photometry of 28 GPX error circles, including 14 sources in the southern GPX sample. Three of these fields are so reddened that the *U* images are essentially blank. In only six fields was there a strong ultraviolet/blue excess star $(U-B, B-V)$ within the X-ray error circle. Two of these were subsequently discovered to be previously known, but overlooked by us, CVs.

In Figures 1*a*, 2*a*, 3*a*, and 4*a* we show $(U-B)$ versus $(B-V)$ color-color diagrams for each of the fields containing unidentified ultraviolet/blue excess objects within the X-ray error circles. In these diagrams we have plotted all stars which DAOPHOT found in three colors and which have 1 σ uncertainties less than 0.1 mag in both $(U-B)$ and $(B-V)$. Stars which are within the 90% confidence limit X-ray error circle are plotted with an open symbol. Note that in each field there is a single star within the error circle which has both ultraviolet $(U-B)$ and blue $(B-V)$ excess over the bulk of main-sequence stars in the field.

Stars with such an excess are quite rare. We observed 25 GPX X-ray error circles with low to moderate reddening; in these we typically detected stars fainter than $U \gtrsim 20$. These 25 fields included 14 sets of images taken with the 4 m telescope (15.2 arcmin^2 each) and 11 sets of images taken with the 1.5 m telescope (7.0 arcmin^2 each). The 25 X-ray error circles had radii ranging from 23″ to 60″, and included 35.9 arcmin^2. We detected only one ultraviolet/blue excess star in the 255 arcmin^2 surveyed outside of X-ray error circles but within the CCD frames.[2] The probability of detecting one within an X-ray error circle by a chance superposition is ~0.006 for a single X-ray source and ~0.08 for any of the 14 sources we observed from the southern GPX sample.

We selected the four unidentified blue objects in X-ray error circles for subsequent spectroscopic observations. In Figures 1*b*, 2*b*, 3*b*, and 4*b* we show finding charts of the GPX source fields; we have indicated the blue excess objects. The positions of these stars, as well as their magnitudes and broad-band colors, are given in Table 2.

b) Spectroscopy and the Cataclysmic Variable Identification

On 1987 May 1 we obtained spectra of three of the four blue stars using the CTIO 2D-Frutti on the 4 m telescope. These spectra cover the wavelength range 3850–5300 Å with a resolution of ~3 Å. The CV nature of these three stars was immediately apparent (Grindlay *et al.* 1987). We subsequently obtained time-resolved spectra of 1E 1449.7−6804 on 1988 June 11 (see § IIIc, below). A spectrum of 1E 1719.1−1946 was obtained with the MMT Spectrograph in 1989 July yielding a fourth CV. We have reduced all of the spectra using the standard IRAF packages.

In Figures 5–8 we show spectra of the four CVs. Note that

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[2] The lone ultraviolet/blue excess object not associated with a GPX source lies in the CCD field of 1E 1449.7−6804 (Star B in Fig. 2). Spectroscopic follow-up observations show a blue continuum with no strong emission or absorption lines.

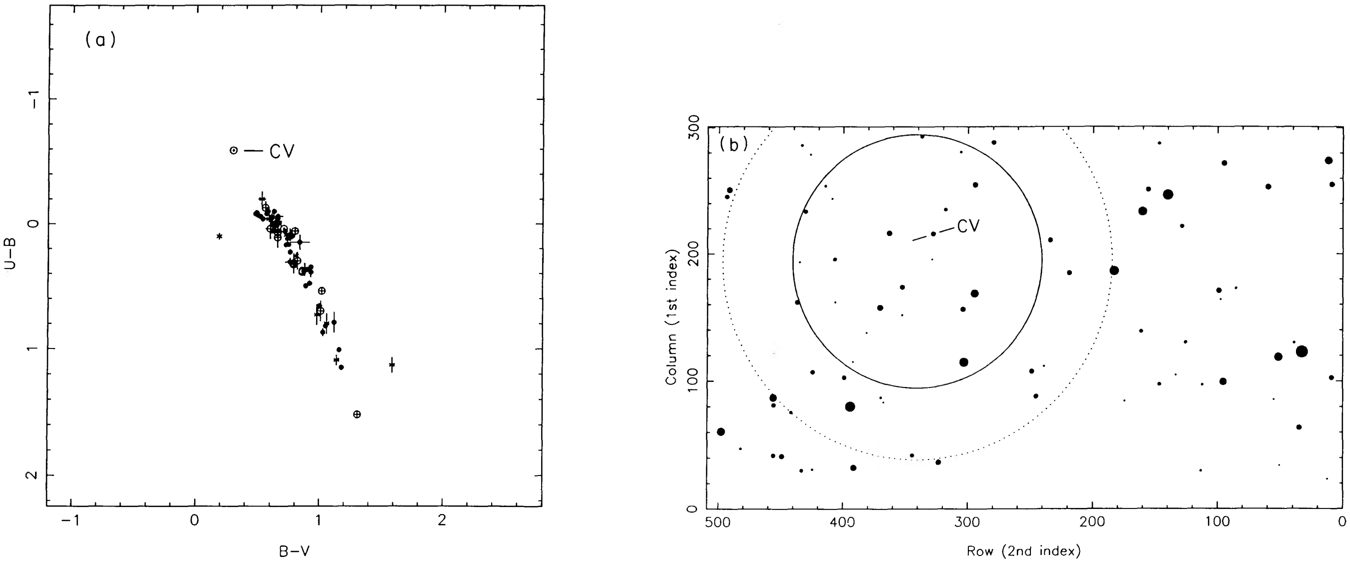

FIG. 1.—Results from CCD observations of 1E 0830.9−2238 in *UBV*. (*a*) A $(U-B)$ vs. $(B-V)$ color-color diagram of point sources ("stars") found in all three colors and having statistical uncertainties of less than 0.1 mag in both $(U-B)$ and $(B-V)$. Stars within the 90% confidence limit X-ray source error circle are indicated by an open circle, stars within the 99% confidence error circle are indicated by an asterisk, and stars outside the error circle are indicated by a filled circle. Error bars are statistical only and do not include systematic errors in the transformation from instrumental to standard magnitudes (< 2%). The new cataclysmic variable is indicated. (*b*) A finding chart generated from the lists of all stars found in the CCD diagrams. The solid circle is the 90% confidence limit X-ray source error circle, and the dashed circle is the 99% confidence limit error circle. The axes are labeled in pixels, where 1 pixel is 0″.6. North is up, and east is to the left. The new cataclysmic variable is indicated.

each shows a strong Balmer series with Hβ through at least Hϵ clearly visible. He I λ4471 is present in 1E 1449.7−6804; it is weakly present in 1E 1719.1−1946. The He II λ4686 line is one of the strongest emission lines present in 1E 0830.9−2238. The H and He lines are broad and, typically, double-peaked. In Table 3 we give equivalent widths and flux ratios for selected identified lines in each source spectrum.

We identify these sources as X-ray–selected cataclysmic variables for several reasons. First, we selected each optical candidate by its blue color, a known property of cataclysmic variables. Second, and most compelling, the appearance of the optical spectrum is typical for a cataclysmic variable, including the presence of the Balmer, He I, and He II emission lines. The flux ratios, in particular the Balmer ratio $F(H\gamma)/F(H\beta)$, are typical for cataclysmic variables in quiescence (Oke and Wade 1982). The double-peaked, or split, emission lines are indicative of emission from a rapidly rotating accretion disk. Third, the X-ray to optical flux ratio, $\log(F_x/F_v)$ (see Table 2), is appropriate for cataclysmic variables (Córdova and Mason 1982; Patterson and Raymond 1985), as is the correlation of the flux ratio to the equivalent width of the Hβ line (Patterson and Raymond 1985, hereafter PR). The high ionization levels in 1E 0830.9−2238 (i.e., strong He II λ4686) are consistent with this source being a member of the AM Her subclass of magnetic cataclysmic variables, or polars. However, He II λ4686 is not a universal indicator of magnetic activity (Szkody 1990). Finally, we note that CV identifications are consistent with the prediction of HG that a reasonable fraction of the GPX X-ray sources would be cataclysmic variables.

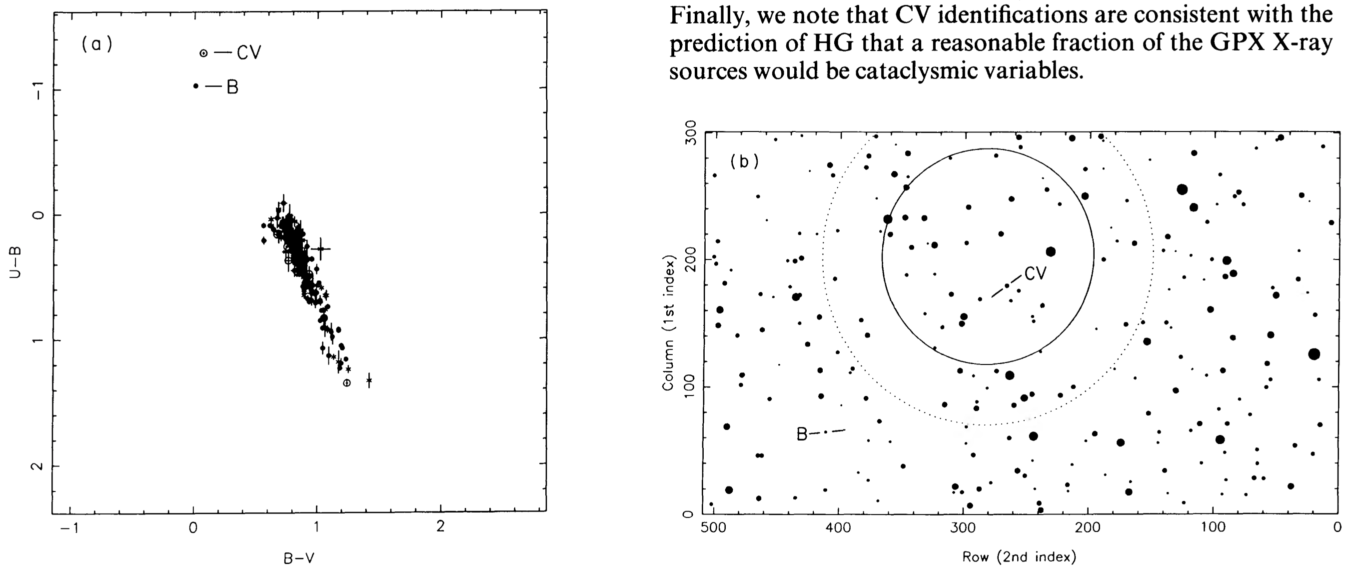

FIG. 2.—As in Fig. 1, but for 1E 1449.7−6804. Star B is discussed in the text.

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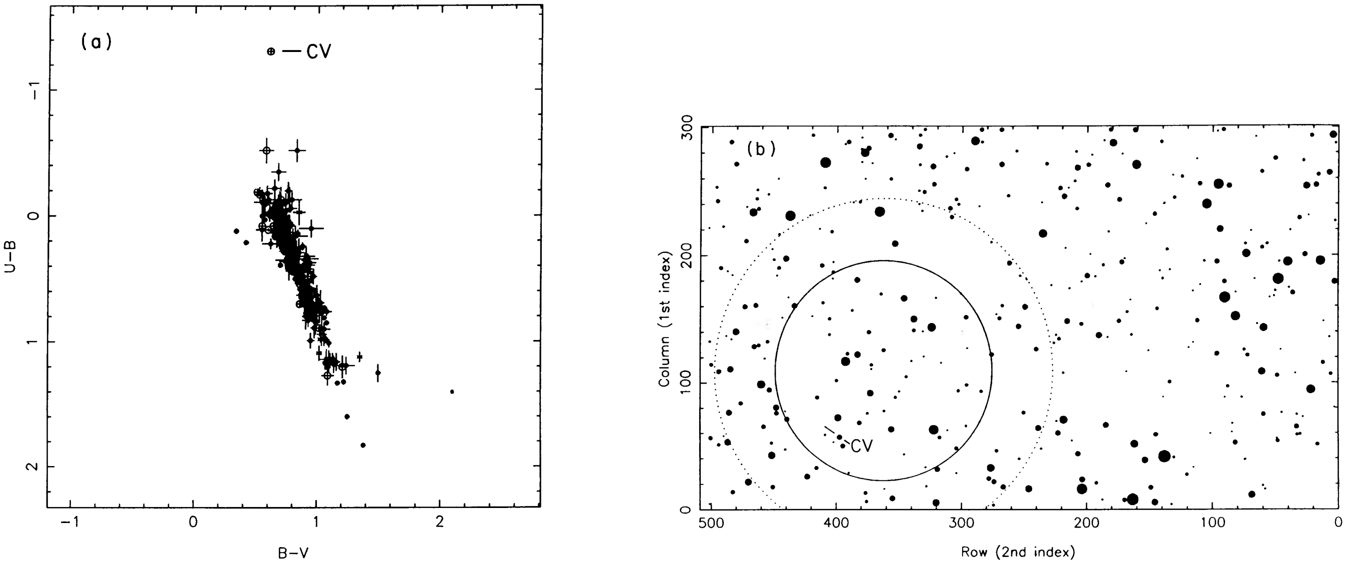

FIG. 3.—As in Fig. 1, but for 1E 1516.6−6826

TABLE 2

OPTICAL PHOTOMETRIC DATA

X-Ray Source	R.A./Decl.[a] (1950)	V[b]	$B-V$[b]	$U-B$[b]	$\log (F_x/F_v)$
1E 0830.9−2238............	$8^{h}30^{m}54\overset{s}{.}1$ −22°38′15″	17.74 ± 0.03	0.29 ± 0.04	−0.59 ± 0.03	0.18
1E 1449.7−6804............	14 49 47.5 −68 04 04	18.15 ± 0.02	0.08 ± 0.03	−1.29 ± 0.03	0.68
1E 1516.6−6826............	15 16 42.8 −68 27 39	17.52 ± 0.03	0.59 ± 0.04	−1.32 ± 0.04	−0.07
1E 1719.1−1946............	17 19 06.6 −19 46 17	19.02 ± 0.04	0.08 ± 0.05	−0.77 ± 0.05	1.03

[a] The positions were determined with the CfA measuring engine and have an uncertainty of ∼1″.

[b] The 1 σ uncertainties in the magnitudes and colors contain both statistical and systematic errors.

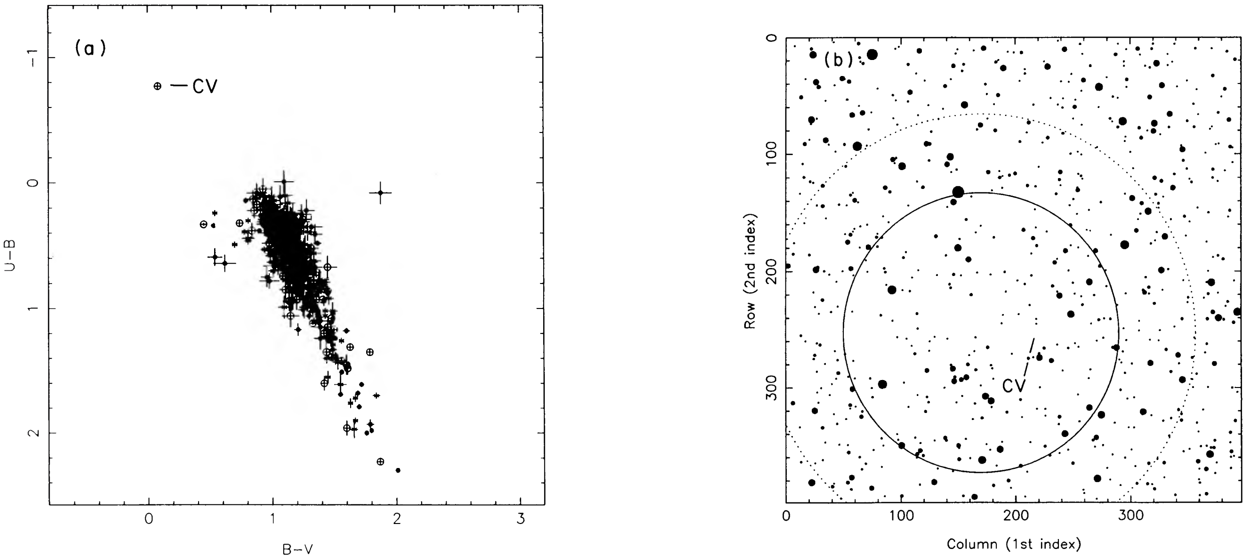

FIG. 4.—As in Fig. 1, but for 1E 1719.1−1946. In this finding chart, 1 pixel is 0″.4.

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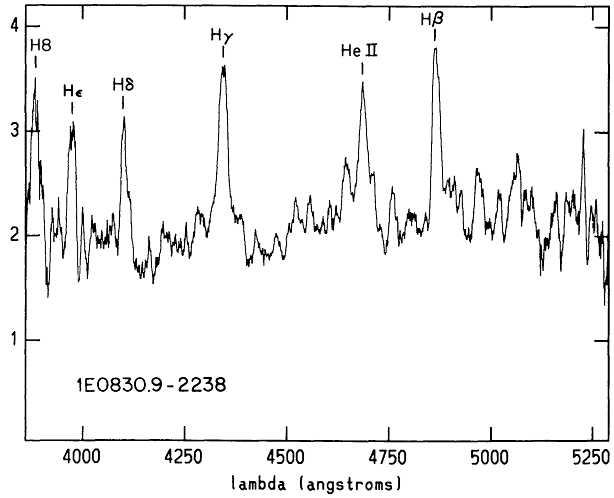

FIG. 5.—Optical spectrum of 1E 0830.9−2238 taken on 1987 May 1 with the CTIO 4 m telescope and 2D-Frutti spectrograph.

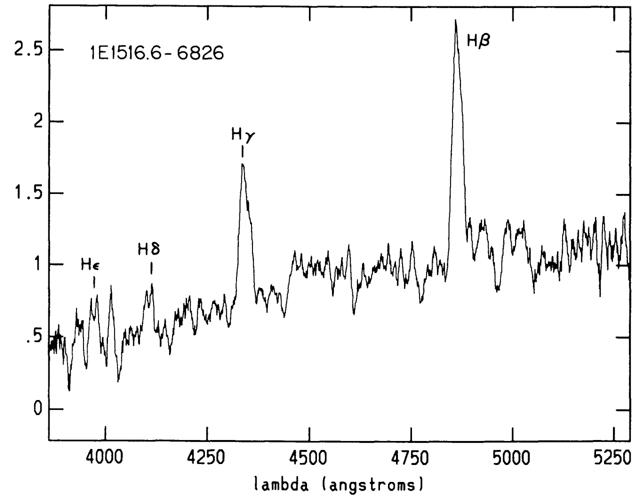

FIG. 7.—Optical spectrum of 1E 1516.6−6826 taken on 1987 May 1 with the CTIO 4 m telescope and 2D-Frutti spectrograph.

c) Time-resolved Spectroscopy of 1E 1449.7−6804

On 1988 June 11 we searched for spectroscopic variations in 1E 1449.7−6804 by obtaining time resolved spectroscopy. Spectra were obtained with the 2D-Frutti Spectrograph at the CTIO 4 m telescope every 5 minutes for 3 hr, with calibration lamp spectra obtained every 50 minutes during the observations. After reducing and flux-calibrating the data, we searched for variability, hopefully periodic, in the equivalent widths and line centers of the strongest emission lines (Hβ, He II λ4686, Hγ, Hδ). The equivalent widths of the four lines, as well as the total flux, varied by a factor of 3 over a 2 hr period, suggesting a possible period around 3.5–4 hr. No significant variation in the line centers was seen.

d) Derived Quantities: Distance and Luminosity

Since (nonmagnetic) cataclysmic variables are all morphologically similar, consisting of a white dwarf primary accreting matter from a lower main-sequence companion star through Roche lobe overflow, there are many empirical correlations between the properties of CV systems. These correlations are physically reasonable as the emission from a CV system is (essentially) a one-parameter system; that parameter is the mass accretion rate $\dot{M}$. $\dot{M}$ is most likely the mass transfer rate from the secondary to the accretion disk surrounding the white dwarf—the acceleration rate onto the white dwarf may be different.

Patterson (1984) showed that the absolute magnitude of the accretion disk, M_v, in nonmagnetic systems can be estimated, to within a scatter of ±1.5 mag, from the observed equivalent width of the Hβ line, EW(Hβ):

$$\mathrm{EW}(\mathrm{H}\beta) = 0.3M_v^2 + e^{0.55(M_v-4)} . \qquad (1)$$

From our EW(Hβ) measurements (Table 3) we can estimate M_v for the disk. Assuming that the optical emission is dominated by the accretion disk, and ignoring interstellar absorption, we estimate the distance, d, to the CV from the absolute and apparent magnitudes (Table 4). Since the distances are small, we are justified in ignoring extinction.

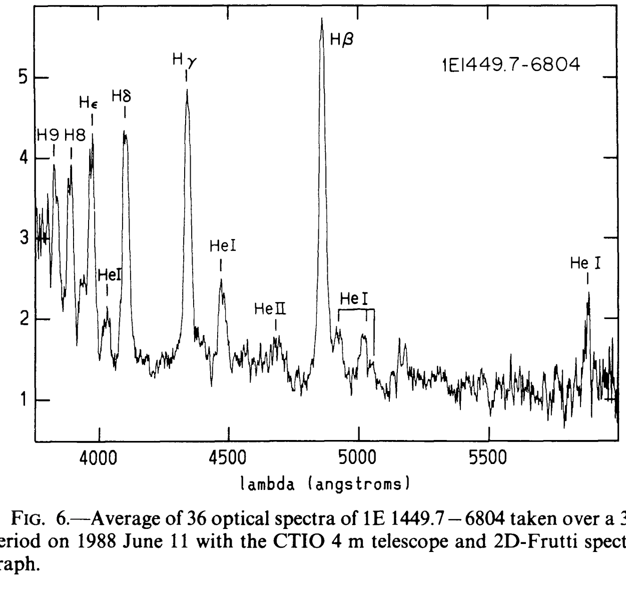

FIG. 6.—Average of 36 optical spectra of 1E 1449.7−6804 taken over a 3 hr period on 1988 June 11 with the CTIO 4 m telescope and 2D-Frutti spectrograph.

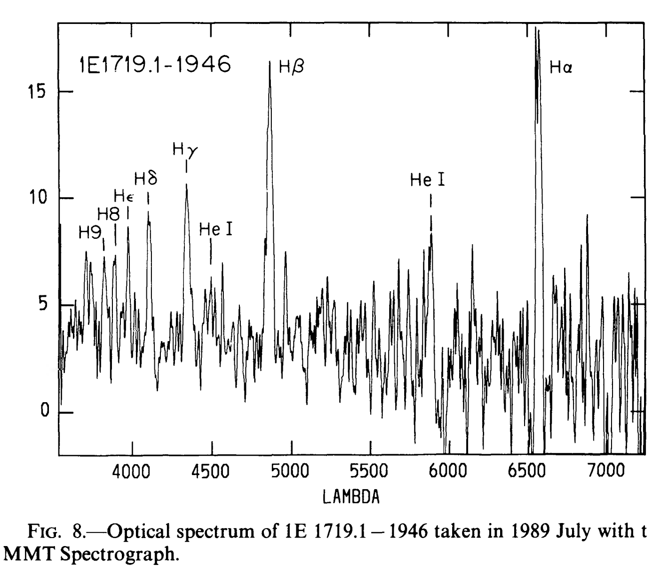

FIG. 8.—Optical spectrum of 1E 1719.1−1946 taken in 1989 July with the MMT Spectrograph.

TABLE 3

OPTICAL SPECTROSCOPIC DATA

X-RAY SOURCE	EQUIVALENT WIDTHS (Å)								RATIO
	Hα λ6562	Hβ λ4861	Hγ λ4340	Hδ λ4101	Hϵ λ3970	He I λ5875	He I λ4471	He II λ4686	$\frac{F(\mathrm{H}\gamma)}{F(\mathrm{H}\beta)}$
1E 0830.9−2238............	...	18	24	10	15	...	...	17	1.19
1E 1449.7−6804............	...	116	77	62	43	27	26	15	0.76
1E 1516.6−6826............	...	48	43	6	13	...	...	...	0.52
1E 1719.1−1946............	271	163	89	56	34	...	...	...	0.60

These are optically faint systems. Only 5%–10% of the CVs cataloged by Patterson (1984), PR, and Ritter (1987) are fainter than $V = 17.5$, whereas all four of these X-ray–selected CVs are. However, they are not faint because they are distant. Two of the sources (1E 1449.7−6804, 1E 1719.1−1946) are less than 200 pc away, with absolute magnitudes $M_v \lesssim 12$. They are intrinsically less luminous [observationally, they have larger EW(Hβ)] than any of the 66 CVs observed with *Einstein* and cataloged by PR.

An independent correlation can be used to check these conclusions. PR have shown that there is a tight empirical correlation between the X-ray–to–optical flux ratio, $\log(F_x/F_v)$ (Table 2), and EW(Hβ) (Table 3). They interpret this correlation as supporting a simple model of the disk boundary layer, where accreting gas settles onto the surface of the white dwarf primary. For nonmagnetic systems,

$$\log(F_x/F_v) = -2.21 + 1.45 \log \mathrm{EW}(\mathrm{H}\beta)\,, \qquad (2)$$

to within an empirical scatter of ±0.5 in $\log(F_x/F_v)$. The CVs reported here obey this empirical relation well (Fig. 9). From this we conclude that (1) these X-ray–selected CVs are physically similar to the well-studied, optically selected CVs, (2) absorption is small as assumed, since $\log(F_x/F_v)$ is a strong function of the visual extinction A_V for $A_V > 2.5$ (Hertz 1983), and (3) the distances based on the EW(Hβ)-M_v relation are reasonable, and therefore these sources are intrinsically very faint.

In Table 4, we also give the estimated X-ray luminosity, L_x, and the estimated accretion rate, $\dot{M}$. We obtained $\dot{M}$ from yet another empirical correlation (PR),

$$\log(F_x/F_v) = -0.3 - 0.55 \log(\dot{M}/10^{-10}\ M_\odot\ \mathrm{yr}^{-1})\,, \qquad (3)$$

with a scatter of ±0.5 in $\log(\dot{M})$.

TABLE 4

DERIVED QUANTITIES

X-Ray Source	M_v[a]	d[b] (pc)	L_x[c] (ergs s^{-1})	$\dot{M}$[d] ($M_\odot$ yr^{-1})	V_{max}[e] (pc^3)
1E 0643.0−1648[f].....	...	100[g]	1.7×10^{31}	...	1.3×10^{6}
1E 0830.9−2238[h].....	6.7	1600	1.2×10^{32}	1.4×10^{-11}	2.4×10^{7}
1E 1449.7−6804......	11.8	190	3.8×10^{30}	1.7×10^{-12}	1.3×10^{5}
1E 1516.6−6826......	9.5	400	5.3×10^{30}	4.0×10^{-11}	2.2×10^{5}
1E 1719.1−1946......	12.6	190	3.8×10^{30}	3.8×10^{-13}	1.3×10^{5}

[a] Derived from EW(Hβ) (eq. [1]).

[b] Derived from V and M_v, assuming no interstellar absorption.

[c] Derived from F_x and d, assuming no interstellar absorption.

[d] Derived from F_x/F_v (eq. [3]).

[e] Derived from survey sensitivity curve and L_x (eq. [4]).

[f] HL CMa.

[g] Patterson and Raymond 1985.

[h] The correlations used to derive these quantities are invalid if 1E 0830.9−2238 is a magnetic variable of the AM Her class.

Further spectroscopic, photometric, and polarimetric observations are required to determine additional parameters of these sources, the most critical being the orbital period.

IV. SPACE DENSITY OF CATACLYSMIC VARIABLES

The four new X-ray–selected cataclysmic variables which we have reported here are from a complete sample of 39 GPX sources lying south of the celestial equator, $\delta \leq 0°$, and exceeding a 5 σ signal-to-noise threshold. These 39 sources were detected in 172 IPC fields covering ~144 deg^2 with a median X-ray flux threshold of ~0.03 IPC counts s^{-1}. Although optical identification of the southern GPX sample is still in progress, we know the number of cataclysmic variables present to within a factor of 1.5. We use that information here to estimate their space density.

In Table 5 we show a summary of the identification status of the 39 sources in this sample. The largest category of sources in the GPX are nearby stars; we identify 21 of these GPX sources with coronal emission from nearby, bright stars. Coronal sources are identified on the basis of their very low value of log (F_x/F_v)—here we adopt a cutoff of −1.5 (Hertz and Grindlay 1988). We have identified five sources with noncoronal, non–CV counterparts. These sources include one extragalactic source (cluster of galaxies) and four Galactic sources (supernova remnant, low-mass X-ray binary, two binary X-ray pulsars).

In addition to the four X-ray–selected CVs whose discovery is reported here, an additional GPX source in this sample has been identified as a CV. The GPX source 1E 0643.0−1648 was discovered as a serendipitous X-ray source in an *Einstein*

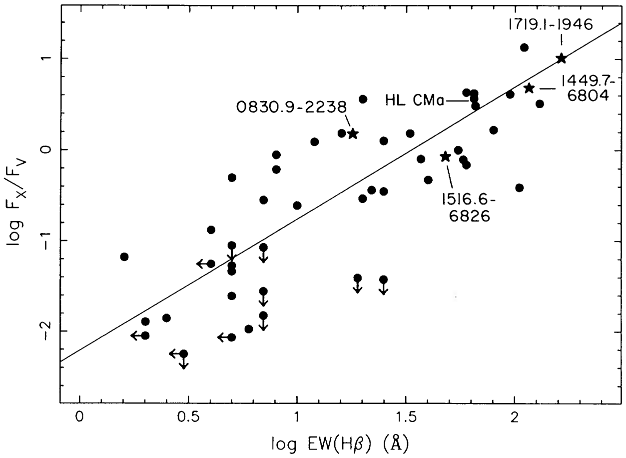

FIG. 9.—The correlation of the X-ray–to–optical flux ratio, F_x/F_v, with the equivalent width of the Hβ emission, EW(Hβ). We have plotted the four CVs discussed here with the CVs cataloged by Patterson and Raymond (1985); the X-ray–selected CVs are indicated. The straight line indicates Patterson and Raymond's best linear fit to the data in the log-log plane (eq. [2]).

TABLE 5

IDENTIFICATION STATUS OF SOUTHERN GPX SAMPLE[a]

Class	Number
Coronal sources (stars)	21
Cataclysmic variables	5
1E 0643.0−1648[b]	
1E 0830.9−2238	
1E 1449.7−6804	
1E 1516.6−6826	
1E 1719.1−1946	
Other identifications	5
Unidentified—no CV	6
Unidentified—possible CV	2
Total southern GPX sources	39

[a] As of 1989 September.

[b] HL CMa.

observation of Sirius, and subsequently identified as a dwarf nova by Chlebowski, Halpern, and Steiner (1981). A period of 5.3 hr was reported by Hutchings *et al.* (1981). 1E 0643.0−1648 is also known as HL CMa.

Of the eight unidentified sources, six have been observed in *UBV* photometry as part of our program to optically identify GPX sources. Given that all of these six sources are brighter than 0.015 IPC counts s^{-1}, and that $\log (F_x/F_v) \lesssim 1$ for known CVs (Córdova and Mason 1983; PR), we expect a CV optical counterpart to be no fainter than $V \lesssim 20.2$ unless it is heavily reddened. On the basis of our observations, we can eliminate (unreddened) CV counterparts brighter than $V \approx 20.5$ for these six sources. Thus there are, at most, two unidentified CVs among the 39 GPX sources in this sample. Based on our identification success so far in identifying noncoronal sources, we expect about one of these to be a CV. There are thus five to seven CVs among the 39 southern GPX sources, about six being our favorite estimate.

In order to estimate the space density of X-ray–selected CVs, ρ_x, we use the $1/V_{\max}$ method. For each CV, we calculate the maximum volume, $V_{\max}$, surveyed for X-ray sources at the X-ray luminosity of the CV. That CV then contributes $1/V_{\max}$ to ρ_x. The maximum volume can be determined from the differential sensitivity curve for the survey, which gives area surveyed as a function of limiting flux. For the estimate here, we have used the sensitivity curve for the 5 σ GPX survey (Fig. 3 of HG) scaled for the reduced area of the southern GPX sample. We find that $V_{\max}$ is given by

$$V_{\max} = (1.8 \times 10^4 \text{ pc}^3)(L_x/10^{30} \text{ ergs s}^{-1})^{3/2} . \quad (4)$$

For each CV, we give $V_{\max}$ in Table 4.

The observed space density for the five CVs is

$$\rho_x = \sum 1/V_{\max} = 2.1 \times 10^{-5} \text{ pc}^{-3} ; \quad (5)$$

if we take into consideration the possible CV counterparts still to be discovered in the southern GPX sample, we find that $\rho_x \simeq 2\text{–}3 \times 10^{-5}$ pc^{-3}. This can be compared with values derived from optical surveys, $\rho \simeq 6 \times 10^{-6}$ pc^{-3} (Patterson 1984). The factor of 3–5 difference represents a serious discrepancy.

The bulk of the contribution to ρ_x comes from the three nearby and intrinsically faint CVs 1E 1449.7−6804, 1E 1516.6−6826, and 1E 1719.1−1946. These CVs would be extremely difficult to discover optically. The implication is that there may be a large population of low-luminosity CVs that release the majority of their accretion energy as X-rays. One must take caution here—this conclusion is based on a very small number of sources.

We also note that the distance estimate for 1E 0830.9−2238 is invalid if it is an AM Herculis–type magnetic variable, or polar. In this case, however, it would most likely be closer and less luminous, and its contribution to ρ_x would be larger. In addition, significant reddening toward these faint CVs has the effect of increasing the derived space density. Thus, our value for ρ_x errs on the low side, and our conclusions are unaffected if these assumptions are wrong. In fact, we emphasize that ρ_x is the observed space density, and thus must be a lower limit to the true space density.

If there is a large population of these sources, they might be expected to show up in other X-ray surveys. In particular, since they are a local population they should be detected in the *Einstein* Extended Medium Sensitivity Survey (EMSS). This survey is the high Galactic latitude complement to the GPX Survey. The EMSS covers 778 deg^2 at $|b| > 20°$; of the 835 sources, four or five have been identified as CVs and 74 remain unidentified (Gioia *et al.* 1990). The known CVs imply a space density of $\sim 2 \times 10^{-6}$ pc^{-3}, considerably lower than that implied by the GPX survey and consistent with the optical space density. Only one of the five (possible) CVs (MS 1140.7+7158 = DO Dra = YY Dra; Patterson *et al.* 1982) has the large EW(Hβ) characteristic of the CVs which imply low L_x and low $V_{\max}$ (Williams 1983; PR), and DO Dra dominates the estimate of ρ_x from the EMSS. We note that the remaining unidentified EMSS sources are predominantly the faintest X-ray sources, and the optical counterparts of any unidentified CVs will be faint and difficult to identify. Only two or three of the 74 unidentified EMSS sources need to be intrinsically faint CVs to drastically boost ρ_x for EMSS CVs.

V. DISCUSSION

With apparent *V* magnitudes between 17.5 and 19, the four X-ray–selected cataclysmic variables reported here are relatively faint compared to other known cataclysmic variables, both optically (e.g., Ritter 1987) and in X-rays (e.g., PR). One CV, 1E 0830.9−2238, is probably an AM Herculis–type magnetic variable, based on the strong He II λ4686 emission line.

Two of the other three CVs have unusually strong Hβ emission lines [EW(Hβ) > 100 Å] and high X-ray–to–optical flux ratios ($F_x/F_v > 5$). All three lie on the empirical correlation of EW(Hβ) versus $\log (F_x/F_v)$ given by PR, and thus appear to be standard nonmagnetic CVs with very low accretion rates ($\dot{M} < 2 \times 10^{-12}$ $M_\odot$ yr^{-1}). Since they are optically faint, and thus difficult to discover, their presence in a small X-ray sample implies a very high observed space density, $\rho_x \simeq 2\text{–}3 \times 10^{-5}$ pc^{-3}. This is a lower limit, as the true space density must exceed the observed space density. The observed space density is already 3–5 times higher than densities estimated from optical surveys (Patterson 1984; Downes 1986).

We suggest that low accretion rate CVs may be very common. The existence of large numbers of low $\dot{M}$ CVs has been predicted by proponents of the "hibernation theory," who suggest that ρ may be as high as 10^{-4} pc^{-3} (Shara *et al.* 1986; Shara 1989) consistent with that predicted by theory and observed in M31 (Bath and Shaviv 1976). Surveys for optically faint ($V \approx 19\text{–}21$) blue objects have yielded several new CVs with very strong Balmer lines, and the implied space density is 10^{-5} to 10^{-4} pc^{-3} (Shara, Moffat, and Potter 1990).

We note that X-ray surveys are an excellent method for discovering low-$\dot{M}$ CVs. For nonmagnetic CVs, those with the highest X-ray–to–optical flux ratios are expected to have the lowest mass accretion rates. Of the nine CVs with the highest F_x/F_v tabulated by PR, six were discovered (or rediscovered) in X-ray surveys. The GPX survey and the EMSS should yield additional low-luminosity CVs. Hundreds of these CVs should be present in the *ROSAT* all-sky survey, being conducted in 1990–1991, although isolating these sources from the $\sim 10^5$ X-ray sources expected to be seen is a daunting task.

Many avenues of further work are obvious. The GPX survey and EMSS X-ray samples need to be completely identified so that stringent limits on ρ_x can be determined. In particular, the faint CVs detected in the southern GPX sample are nearby and should be present in the northern GPX sample of Hertz and Grindlay (1988) as well. Identification of the 22 unidentified sources in that sample, all of which have $V > 15$, should confirm the space densities reported here. The results of further surveys for optically faint CVs, such as those by Shara, Moffat, and Potter (1990), will yield interesting constraints on ρ as well. The *ROSAT* all-sky X-ray survey will also allow X-ray fluxes or limits to be obtained for all optically selected faint CVs. From this combination of optical and X-ray surveys, we can determine the true space density of intrinsically faint, low-luminosity CVs.

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