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THE 1999 HERCULES X-1 ANOMALOUS LOW STATE

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ABSTRACT

A failed main-on in the 35 day cycle of Her X-1 was observed with the *Rossi X-Ray Timing Explorer* on 1999 April 26. Exceptions to the normal 35 day cycle have been seen only twice before—in 1983 and again in 1993. We present timing and spectral results of this latest anomalous low state (ALS) along with comparisons to the main-on and normal low states. Pulsations were observed in the 3–18 keV band with a fractional rms variation of 0.037 ± 0.003. Spectral analysis indicates that the ALS spectrum has the same shape as the main-on but is modified by heavy absorption and scattering. We find that 70% of the observed emission has passed through a cold absorber ($N_H = 5.0 \times 10^{23}$ cm^{-2}). This partially absorbing spectral fit can be applied to the normal low state with similar results. We find that the ALS observations may be interpreted as a decrease in inclination of the accretion disk causing the central X-ray source to be obscured over the entire 35 day cycle.

Subject headings: accretion, accretion disks — binaries: eclipsing — pulsars: individual (Hercules X-1) — stars: neutron — X-rays: stars

1. INTRODUCTION

Her X-1 is a well-known persistent accreting X-ray pulsar. It is characterized by a 1.24 s pulse period (Tananbaum et al. 1972) and a 1.7 day orbit (Deeter, Boynton, & Pravdo 1981) around the A/F star HZ Her (Doxsey et al. 1973; Gottwald et al. 1991). Her X-1 also exhibits a 35 day intensity cycle that is generally believed to be due to the precession of a tilted, warped accretion disk viewed nearly edge on, which periodically obscures X-rays from the central neutron star. For a review of earlier models of Her X-1, see Priedhorsky & Holt (1987). Recently more detailed models of the physical cause of the warping have been advanced (Schandl & Meyer 1994; Pringle 1996; Shakura et al. 1999).

During the 35 day cycle Her X-1 normally has a ∼10 day main-on state and a ∼5 day short-on state, each separated by ∼10 day low states. The peak count rate in the *Rossi X-Ray Timing Explorer* All-Sky Monitor (*RXTE*/ASM, 1.5–12 keV) for the short-on is usually ∼35% that of the main-on, while the low state is ∼3% (Scott & Leahy 1999). Eclipses are seen at the 1.7 day orbital period, as are regular preeclipse absorption dips every 1.62 days (the 1.7 day and 35 day beat period; Giacconi et al. 1973; Crosa & Boynton 1980) and anomalous dips shortly after the main-on turn-on. The X-ray absorption dips are discussed in more detail by Reynolds & Parmar (1995), Leahy (1997), Stelzer et al. (1999), and Shakura et al. (1998).

Exceptions to this usual behavior were observed in 1983 June (Parmar et al. 1985), in 1993 August (Vrtilek et al. 1994; Vrtilek & Cheng 1996), and most recently in 1999 April (Levine 1999; Parmar et al. 1999). The 1999 April anomalous low state (ALS) has continued into the year 2000. The ALS has been defined by Vrtilek & Cheng (1996) as an unexpected and substantial drop in X-ray flux that persists for more than two 35 day cycles, with no substantial change in absorbing column density, little or no change in UV and optical fluxes, an increase in pulse period, and no pulsed emission above ∼1.0 keV. The present data show that this definition of Vrtilek & Cheng needs modification. The emission is found to be pulsed, but with a factor of ∼14 reduction fractional rms variation from the main-on. Also, we find evidence for a highly absorbed component in the X-ray spectrum. In the 1983 ALS the neutron star was believed to be steadily obscured because of a temporary change in the accretion disk (Parmar et al. 1985).

The beginning of the 1999 ALS is very similar to the 1983 ALS in that the source did not turn on at the date predicted by the mean 35 day ephemeris, while in 1993 the X-ray flux suddenly decreased during the middle of the main-on (Vrtilek et al. 1994). Optical observations made during the 1983 ALS (Delgado, Schmidt, & Thomas 1983; Mironov et al. 1986) indicated that HZ Her remained heated by X-ray emission from the central source, implying that accretion was still proceeding normally onto the neutron star surface. Similarly, in 1993 the optical and UV fluxes continued to show the 1.7 day modulation (Vrtilek et al. 1994), but with a reduction in UV flux observed around eclipse. *UBV* photometry of HZ Her during the 1999 ALS revealed a light curve similar to the one from 1983 (Lyutyi & Goranski 2000).

On 1999 March 23 the first deviation from the normal behavior in 3 years of ASM observations of the Her X-1 main-on state was detected. Typical peak intensities are 40–100 mcrab in the ASM, but the upper limit for this main-on was ∼15 mcrab (Levine 1999). On 1999 April 26, during the second failed main-on, we carried out an *RXTE* observation of Her X-1 to investigate the nature of this ALS. We discuss spectral and temporal analyses of this *RXTE* observation that support the idea that the X-ray source is continuously screened by the accretion disk during an ALS.

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TABLE 1

HER X-1 OBSERVATIONS

			On-Source Live Time (ks)		PCA	
State	Date	Orbital Phase	PCA	HEXTE	PCUs[a]	Epoch[b]
ALS	1999 Apr 26	0.38–0.52	4.6	2.8	4	4
Main-on......	1997 Sep 14	0.17–0.35	15.1	9.2	5	3
Low	1997 Sep 12	0.11–0.21	3.3	2.0	5	3

[a] Number of PCA detectors operating.
[b] PCA gain epoch.

2. OBSERVATIONS AND ANALYSIS

The ALS observation was made using the Proportional Counter Array (PCA) (Jahoda et al. 1996) and the High-Energy X-Ray Timing Experiment (HEXTE) (Rothschild et al. 1998) on board the *RXTE*. The source was observed on four consecutive *RXTE* orbits spanning an elapsed time of 20 ks centered at MJD 51,294.52. We compared this observation to archival *RXTE* data taken during the normal low state and normal main-on. See Table 1 for a summary of the observations. During this discussion we refer to the ALS observation unless specifically noted otherwise.

Since main-ons were not observed, we cannot be certain that the observation fell during the second failed main-on of the current ALS. On average, main-ons occur at a period of 20.5 times the orbital period (P_{orb}) but are also observed at 20.0 and 21.0 $\times$ P_{orb} as well. If, after the last observed main-on, both of the expected turn-ons occurred at the late value of 21 $\times$ P_{orb}, then the source was observed during a low state approximately one-half of a binary orbit before turn-on. If, as is more likely, either of the unobserved turn-ons were at 20.0 or 20.5 $\times$ P_{orb}, then the source was observed during a failed main-on.

2.1. *Timing Analysis*

Figure 1 shows the ASM light curve for the last 10 35 day cycles prior to the failed main-on turn-on. Each bin in the light curve is the average counting rate in a single 1.7 day orbit of the pulsar with eclipse intervals excluded using the ephemeris of Deeter et al. (1991). The last three main-ons have a steadily decreasing count rate. Thus, the transition to this anomalous low state was a gradual process occurring over several cycles.

We generated the 3–18 keV PCA folded light curves (FLCs) (Fig. 2) by first creating a background-subtracted

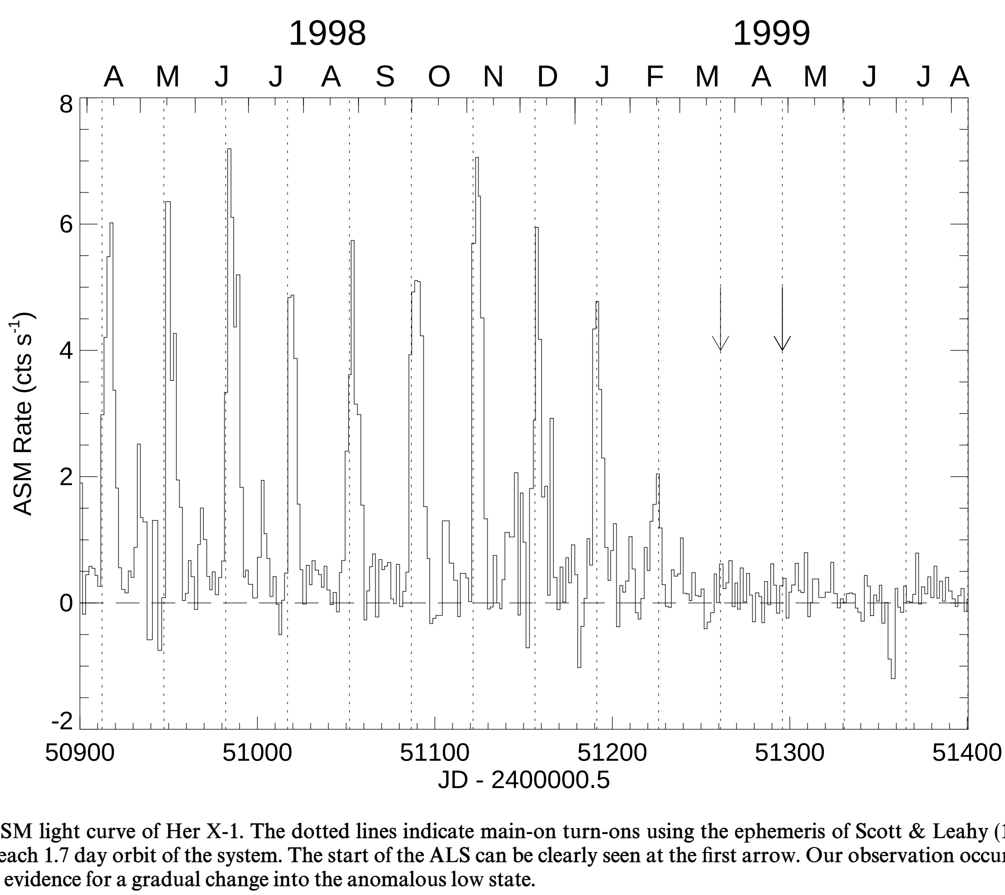

FIG. 1.—*RXTE*/ASM light curve of Her X-1. The dotted lines indicate main-on turn-ons using the ephemeris of Scott & Leahy (1999). The bins are the average count rate in each 1.7 day orbit of the system. The start of the ALS can be clearly seen at the first arrow. Our observation occurred at the second. The light curve also shows evidence for a gradual change into the anomalous low state.

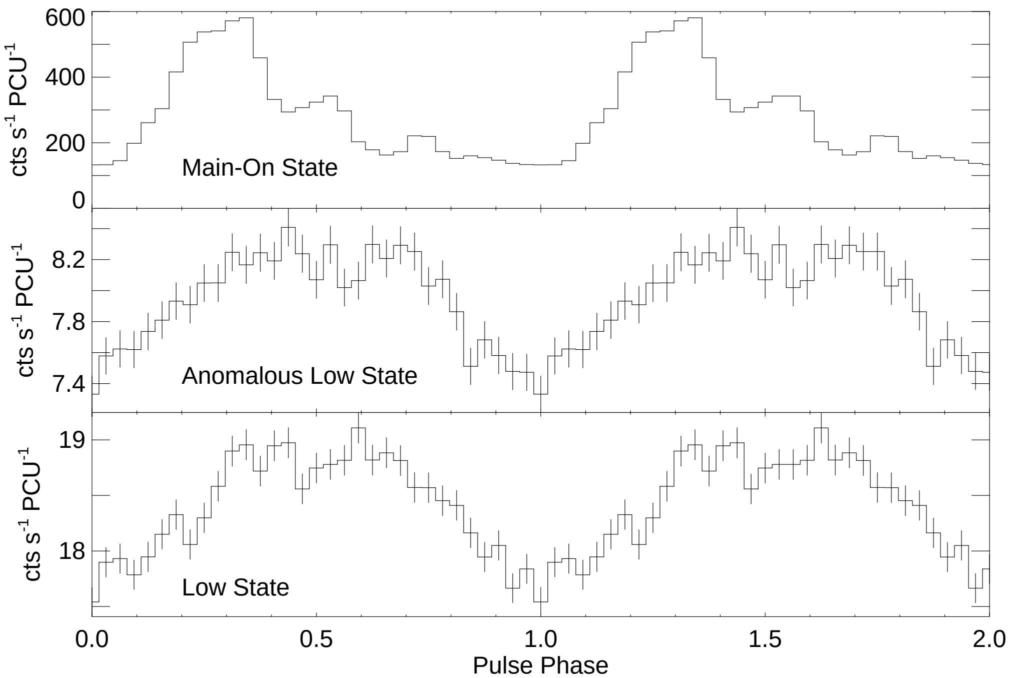

FIG. 2.—PCA 3–18 keV folded light curves of Her X-1. *Top*: Light curves from the peak of the normal main-on. *Middle*: Light curves from the 1999 anomalous low state. *Bottom*: Light curves during the low state, just before turn-on. The phase alignment of the three FLCs is arbitrary. Note the offset of the *y*-axes in the bottom two panels. The ALS folded light curve is much shallower and broader than what is seen in during the main-on but very similar to that of the low state. Despite the fact that there is less overall flux in the ALS pulse, the fractional rms variation is slightly larger than that of the low state (see § 2.1).

light curve for the observation. The background count rate per bin was estimated using the count rates from the PCA modeled background spectrum over the same channel range. We then corrected the photon arrival times to the solar system and pulsar binary system barycenters and performed a χ^2 period search. The period at epoch MJD 51,294.5 was 1.2377485(3) s. We determined the error by folding the data on nearby periods and calculating the χ^2 statistic with respect to the FLC of our best period. This best period is consistent with the 1.237747(2) s period found by Parmar et al. (1999) with the *BeppoSAX* satellite during a 1999 July 8–10 observation. Periods were found using the same method for the main-on and normal low-state data.

Compared to the main-on the ALS folded light curve is much shallower and broader (Fig. 2). But when compared to the low state the ALS FLC is similar in shape but with reduced flux. This indicates that the mechanism for creating the ALS might be similar to that of the low state, namely, occultation by the accretion disk, but also accompanied by a decrease in mass accretion rate. In and of itself this is inconclusive, however, since the pulse shape of Her X-1 is known to vary considerably with the 35 day cycle (Deeter et al. 1998; Scott, Leahy, & Wilson 2000). The nearly sinusoidal pulse shapes seen in the low and ALS states in Figure 2 have been observed before but always near the end of the main-on and secondary high state and not at turn-on.

A useful measure of the amount of pulsations is the fractional rms variation $\gamma_{\rm pulse} \equiv \langle(\Delta I)^2\rangle^{1/2}/\langle I\rangle$, where $\Delta I \equiv I - \langle I\rangle$, and the angle brackets indicate averaging with respect to the pulse phase. In this definition the Fourier power at the rotation frequency seen is proportional to $\gamma^2_{\rm pulse}$. For the ALS state, $\gamma_{\rm pulse} = 0.037 \pm 0.003$ in the 3–18 keV band. This is much lower than the value of $\gamma_{\rm pulse} = 0.5152 \pm 0.0003$ observed in the main-on, but similar to the low-state value of $\gamma_{\rm pulse} = 0.024 \pm 0.001$. We also found that the fractional rms variation remained nearly constant throughout our observation (Fig. 3). The inferred 1.2–37.2 keV upper limit for pulsations in the low state as seen with *Ginga* is $\gamma_{\rm pulse} \leq 0.017$ (Mihara et al. 1991), which is less than what we found with the *RXTE* at the same orbital phase. This implies that the fractional rms variation from one low state to another is variable. The similarity of the ALS and low-state $\gamma_{\rm pulse}$ would seem to imply that they are both due to similar mechanisms, specifically occultation by the accretion disk.

The PCA light curve (Fig. 4) shows a gradual drop of flux by 40% through the observation. The binary orbital phase of the observation is 0.38–0.52, too early for the decrease to be due to a preeclipse dip. We compared the spectra from the four *RXTE* orbits and found that the spectral shape and fractional rms variation remained the same. Figure 3 shows the pulse shape over the course of the observation. A similar reduction in flux was observed in this ALS with the *BeppoSAX* (Parmar et al. 1999). There, at orbital phase $\sim$0.3 and most strikingly in the 1.8–10 keV band, the flux began to steadily decrease until eclipse, after which it steadily increased, recovering again at orbital phase $\sim$1.3. Something similar may have been seen with *ASCA* (Vrtilek et al. 1994) in 1993, but the observation did not start until orbital phase $\sim$0.7.

2.2. *Spectral Analysis*

We generated PCA and HEXTE spectra from the data using the FTOOLS v. 4.2. To account for uncertainties in the PCA epoch 4 preliminary response matrix (1999 March 30) and background models, we added 2% energy-independent systematic errors to the PCA data. This 2% is typical of the errors in fits to the Crab Nebula/pulsar during

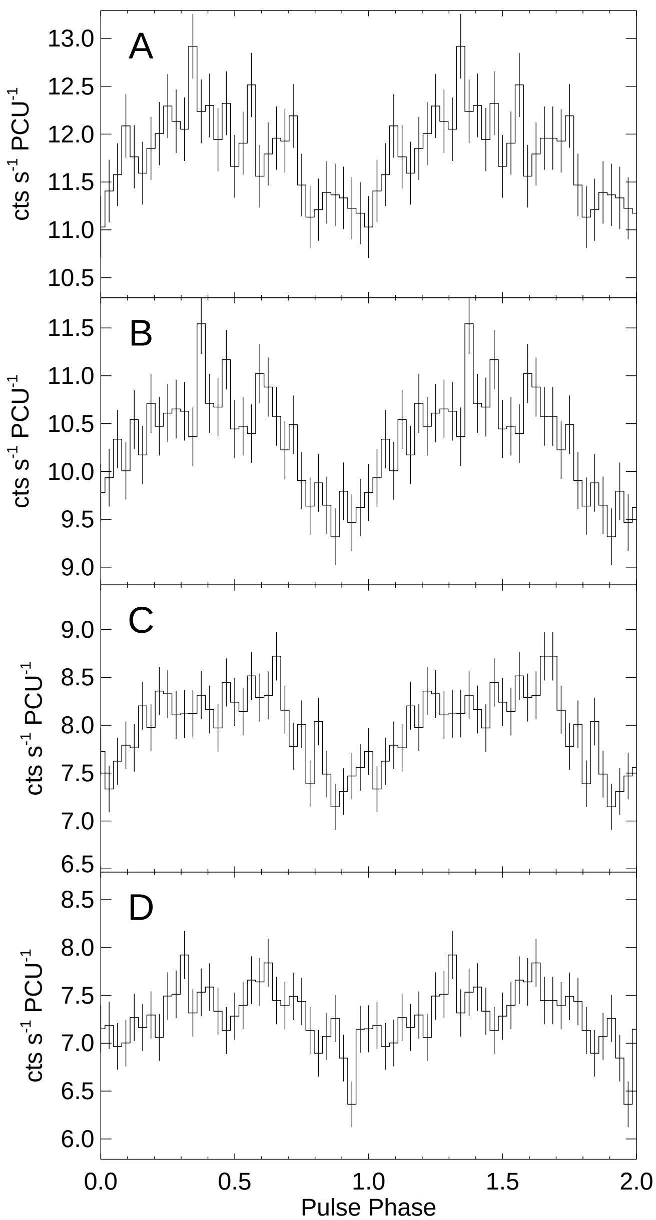

FIG. 3.—*RXTE*/PCA 3–18 keV folded light curve for four intervals as labeled in Fig. 4. Pulsations are clearly seen in all four panels. The fractional rms variation (see § 2.1) of the four intervals are $\gamma_{\rm pulse,A} = 0.038 \pm 0.005$, $\gamma_{\rm pulse,B} = 0.049 \pm 0.005$, $\gamma_{\rm pulse,C} = 0.049 \pm 0.006$, and $\gamma_{\rm pulse,D} = 0.041 \pm 0.006$.

the same epoch. We accumulated data from only the top layer of the Proportional Counter Units (PCUs) 0–3 in the PCA. PCU 4 was off during the observation.

We fit the three spectra (ALS, main-on, and normal low state) to standard accreting X-ray pulsar continuum models (high-energy cutoff [HECUT] power law, Fermi-Dirac cutoff power law, and negative-positive exponential [Mihara 1995; Kreykenbohm et al. 1999]). We restrict our discussion to fits made with the HECUT model since the HECUT has been used historically to describe Her X-1, and the statistics of the observation do not require one of the other continua. The model is of the form

$$F(E) = {\rm e}^{-\sigma(E)N_{\rm H}}({\rm GAUSS} + {\rm HECUT}) , \quad (1)$$

where $\sigma(E)$ is the photoelectric absorption cross section of the interstellar medium (Morrison & McCammon 1983), $N_{\rm H}$ is the column density, and the Gaussian represents an Fe K line. The HECUT is

$${\rm HECUT}(E) = AE^{-\Gamma}\begin{cases} 1 & (E < E_c) \\ e^{-(E-E_c)/E_f} & (E > E_c) , \end{cases} \quad (2)$$

where Γ is the photon power-law index, and E_c and E_f are the cutoff and folding energies, respectively. In previous work for the main-on state it was found that the neutral column density was less than $\sim 10^{20}$ cm^{-2} (Dal Fiume et al. 1998), so we fixed this value to zero when doing our main-on spectral fits.

The statistics of our observation of the ALS spectrum do not require the well-known Her X-1 cyclotron resonance scattering feature (CRSF) at $\sim$40 keV (Dal Fiume et al. 1998; Gruber et al. 1998). A CRSF whose fit parameters were constrained to be identical to those in the main-on fit did not significantly improve the fits. Rather than compare dissimilar models for the continuum, we also fitted the main-on spectrum without a CRSF. The primary difference between the main-on continuum shapes with and without a CRSF is the folding energy, which is important only at higher energies ($\gtrsim$20 keV) where the statistics of the ALS data become poor. The poor $\chi^2_{\rm red}$ of the high-state fit (Table 2) is due to the lack of a CRSF feature in the model.

Initially we modeled the ALS assuming only an HECUT continuum model with an FeK line and photoelectric absorption (eq. [1], see Table 2). The best fit required no low-energy absorption ($N_{\rm H} < 4 \times 10^{21}$ cm^{-2}), a photon index of 0.37 ± 0.04, and resulted in a $\chi^2_{\rm red}$ of 1.12 for 114 degrees of freedom. This spectral index is very different from the $\Gamma \sim 1$ that has been seen historically during the main-on. Because the spectral index fit with equation (1) is different from what is seen in the main-on, we decided to test if there was a fit that left the intrinsic, main-on spectral shape unchanged. A change in the accretion disk structure could lead to a combination absorption from the disk and scattering from a hot corona (physically distinct but numerically very similar is a partial-covering model). Using a similar analysis to that of Mihara et al. (1991) and Parmar et al. (1999) we fitted the ALS spectrum with a partially absorbing column of the form

$$F_{\rm pa}(E) = (1 + f \times e^{-\sigma(E)N_{\rm H}})({\rm GAUSS} + {\rm HECUT}) . \quad (3)$$

We define a covering factor $\mathscr{F}$ as $f/(1+f)$, which is the fraction of observed flux coming to us through the absorbing medium.

With the exception of the normalization, the best-fit HECUT parameters using equation (3) are consistent with those of the main-on (see Fig. 5 for the PCA/HEXTE counts spectra and best-fit model and Table 2 for fit parameters). Thus, what is seen in the ALS is a highly absorbed and heavily scattered main-on spectrum. The small improvement in the fit from the simple HECUT continuum (to $\chi^2/113 = 1.08$) is not statistically significant, but the model makes more physical sense. When the HECUT was constrained to be the same shape as the main-on, the $\chi^2/117$ is 1.07 with $N_{\rm H} = (5.0 \pm 0.3) \times 10^{23}$ cm^{-2} and $\mathscr{F} = 0.67 \pm 0.04$. In addition, the ALS and normal low-state spectra are similar (see Fig. 6). The low-state fit with equation (3) and the main-on HECUT continuum shape gives $N_{\rm H} = (4.8 \pm 0.4) \times 10^{23}$ cm^{-2} and $\mathscr{F} = 0.54 \pm 0.02$. This is a slightly lower column density and higher covering factor than what was seen by Mihara et al. (1991), implying that the low state is somewhat variable. The ALS spectrum

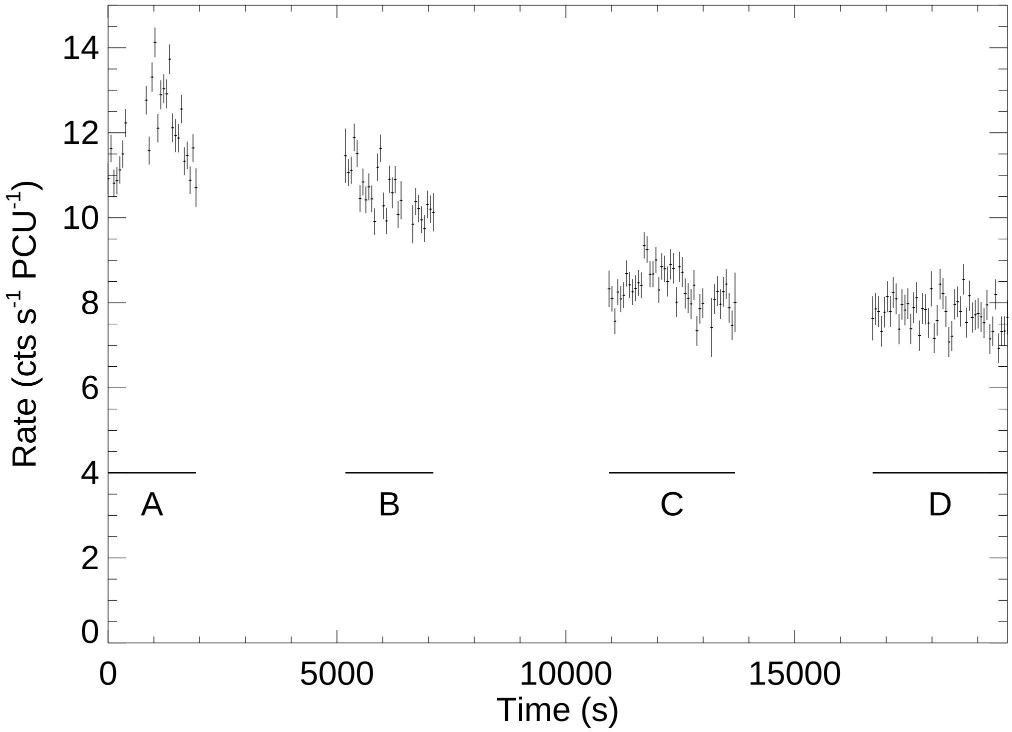

FIG. 4.—*RXTE*/PCA 3–18 keV light curve, with 64 s time resolution, beginning at MJD 51,294.4 (1999 April 26 9:40 UTC). The gaps between the data are due to Earth occultations and South Atlantic Anomaly passages. Although the flux decreased during the observation, the spectral shape of each segment remained unchanged. The FLCs for the intervals labeled A–D are shown in Fig. 3.

observed by *BeppoSAX* was found to be indistinguishable from that observed during the normal low state (Parmar et al. 1999). So the spectra are consistent with the same mechanism causing both the normal low and anomalous low states.

The Fe K line is very prominent in the ALS spectrum, with an equivalent width of 0.7 ± 0.1 keV. This is also similar to what has been observed in the low state. For example, Mihara et al. (1991) reported 1.0 ± 0.1 keV, and we find 0.5 ± 0.1 keV in the low state (Table 2). We also fitted the data with a superposition of two iron lines, at 6.4 keV and 6.7 keV, to search for evidence of an ionized iron line component. There was no improvement with a double line fit, and the best fit was for a single line at 6.4 ± 0.1 keV.

3. DISCUSSION

The measured pulse period of 1.2377485(3) s from the first *RXTE* observation during the 1999 ALS establishes a rapid spin-down of the neutron star. The period is about 25 μs longer than what would have been expected if the Her X-1 general spin-up trend (Bildsten et al. 1997) had continued. This is also the largest deviation from the general spin-up among the three observed anomalous low states: for the ALS in 1983 (Parmar et al. 1985) the deviation was about 20 μs, and in 1993 (Vrtilek et al. 1994) it was about 12 μs. In standard accretion torque theory (Ghosh & Lamb 1979) a reduction in mass accretion (with an accompanied reduction in X-ray luminosity) leads to a reduced gas pres-

TABLE 2

FIT SPECTRAL PARAMETERS FOR THE HER X-1 MAIN-ON, ANOMALOUS LOW, AND LOW STATES

Parameter	Main-On[a]	ALS[a]	ALS[b]	ALS[c]	Low[c]
N_H (10^{22} cm^2)........	0.0[d]	<0.4	45 ± 6	50 ± 3	48 ± 4
Γ	1.08 ± 0.01	0.37 ± 0.04	0.90 ± 0.07	1.08[d]	1.08[d]
E_c (keV)	21.5 ± 0.1	16.8 ± 0.4	20.1 ± 0.7	21.5[d]	21.5[d]
E_f (keV)	9.8 ± 0.1	11 ± 1	10 ± 1	9.8[d]	9.8[d]
Fe K *E* (keV)	6.48 ± 0.09	6.43 ± 0.08	6.44 ± 0.08	6.48[d]	6.48[d]
Fe K EW (keV)......	0.3 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.5 ± 0.1
Flux[e]	24.43 ± 0.09	1.50 ± 0.07	1.39 ± 0.06	1.41 ± 0.06	1.43 ± 0.04
$\mathscr{F}$	…	…	0.56 ± 0.03	0.67 ± 0.04	0.54 ± 0.02
χ^2_{red}/dof	4.01/222[f]	1.12/114	1.08/113	1.07/117	1.06/116

[a] Fitted with eq. (1).
[b] Fitted with eq. (3) and the HECUT shape free.
[c] Fitted with eq. (3) and the main-on HECUT shape.
[d] Not allowed to vary.
[e] The 20–40 keV flux in units of 10^{-10} ergs cm^{-2} s^{-1}.
[f] The high χ^2_{red} is a result of no CRSF in the fit (see text).

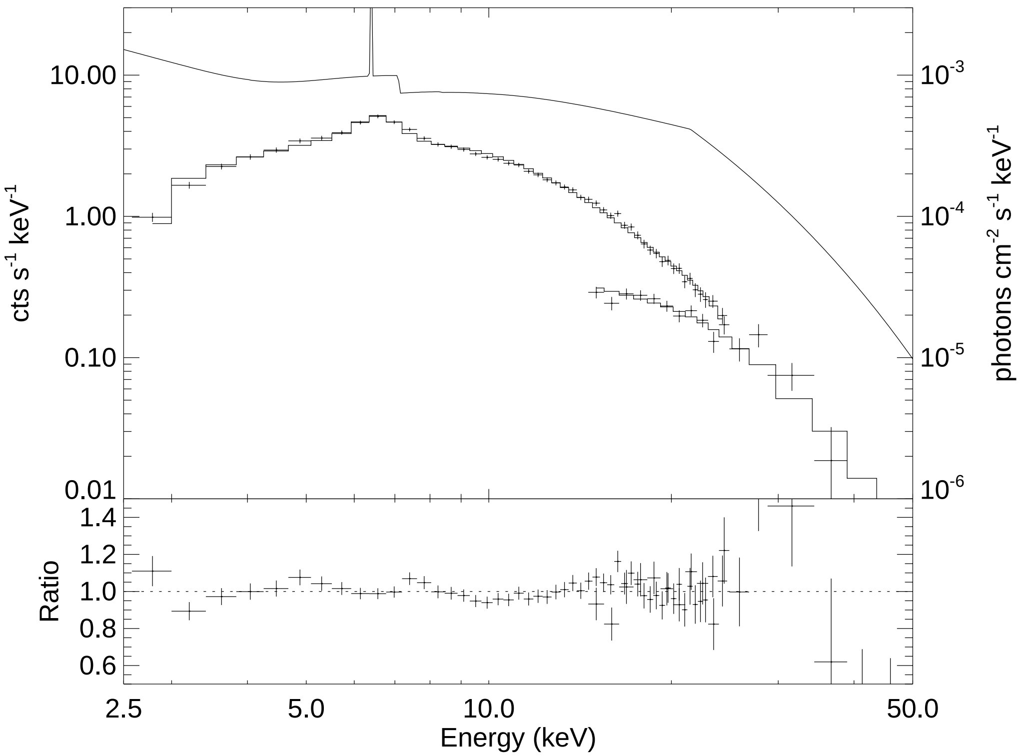

FIG. 5.—*Top*: Joint *RXTE* PCA/HEXTE spectrum of Her X-1 during a failed main-on in the 1999 ALS (*crosses*). The fit with eq. (3) (the partial absorption/transmission model, the shape of the HECUT constrained to that of the main-on) is shown as histograms, along with the model photon spectrum (*smooth curve*). *Bottom*: Ratio of the data to the fitted model.

sure in the accretion disk. This, in turn, leads to an increased magnetospheric radius and a change in the accretion torque that causes the neutron star to spin-down. It is expected that a reduction in mass accretion would also cause a reduction in the inclination of the accretion disk, either by changing the torque of the accretion stream on the disk (Shakura et al. 1999) and/or by the radiative torque from a coronal wind resulting from the X-ray heating of the

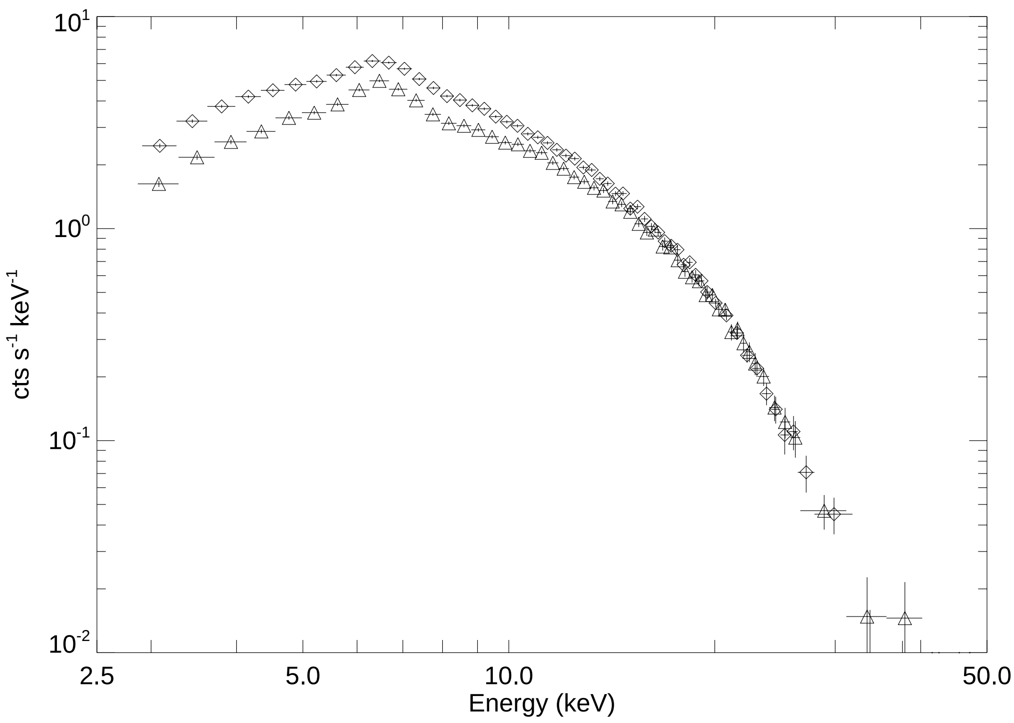

FIG. 6.—PCA counts spectra for the low state (*diamonds*) and the anomalous low state (*triangles*). The overall shape of the ALS spectrum is similar to that of the normal low state but with an overall reduction in flux at lower energies (below $\sim$15 keV) and an enhanced FeK line.

accretion disk (Schandl & Meyer 1994; Schandl 1996). If the reduction in inclination angle of the disk were large enough, it would continuously screen the central X-ray source from our line of sight. We also note that before the onset of the current ALS the X-ray flux continuously dropped (Fig. 1), possibly because of both a reduced mass accretion rate and increased obscuration by the disk.

Recent optical observations (Lyutyi & Goranski 2000) show that, as in previous ALSs, HZ Her continues to be heated by the X-ray source (Delgado et al. 1983; Mironov et al. 1986) at a level similar to what is normal. So X-rays are still being produced, and mass accretion onto the surface of the neutron star must therefore be continuing without any great change. If there were no occultation by the disk (i.e., if the main-on geometry were unchanged), then to account for the factor of 17 drop in flux at high energies ($\gtrsim$20 keV) by scattering alone would require a Thomson optical depth of $\sim$3. Whether or not this could explain the order-of-magnitude change in the fractional rms variation is unclear. The calculations by Brainerd & Lamb (1987) and Kylafis & Klimis (1987) assume Thomson optical depths $\tau \gtrsim 5$ and a relatively simple input pulse shapes. The complexity of the Her X-1 pulse shape during the main-on, with the additional complications of viewing angles and corona size, makes it difficult to directly apply their results. It is clear, however, that scattering alone cannot account for the change in spectral shape. A more reasonable explanation is that the neutron star is occulted along the line of sight by the accretion disk, just as it is known to be during the low state. This change from the normal 35 day cycle could be caused by either a change in the disk inclination or the amount of warp of the disk.

Optical observations over a binary orbit (Lyutyi & Goranski 2000) also show that the secondary minimum near the peak of the light curve, which is due to the accretion disk occulting the heated surface of HZ Her, has almost disappeared. This also provides evidence that the accretion disk has become less inclined with respect to the observer's line of sight. The decrease in the disk inclination should be accompanied by a decrease in the heating of the star's surface near the inner Lagrangian point. This can explain why, away from maximum brightness, the ALS optical light curve is lower than the average optical light curve. In turn, the decrease in heating near the inner Lagrangian point leads to a decrease in the accretion rate onto the neutron star. In the model of Shakura et al. (1999) the equilibrium inclination angle of outer parts of the accretion disk to the orbital plane is determined by the joint action of accreting streams and tidal forces, so the decrease in accretion rate leads to a smaller inclination angle. A decrease in inclination angle of the accretion disk, moving it more into the line of sight, also explains the continued occultation of the neutron star and our ALS observations.

The 2.5–50 keV *RXTE* spectrum of the ALS and normal low states are similar (see Fig. 6 and Table 2). Above $\sim$15 keV the two spectra are nearly identical, while at lower energies the ALS spectrum has less flux and a more pronounced FeK line. Fits using the main-on HECUT continuum shape (eq. [3]) and a partially covering screen of absorbing matter gave similar results for both the normal and anomalous low states. A similar analysis of the low state was done by Mihara et al. (1991). There the inferred covering factor was $\mathscr{F} = 0.55 \pm 0.03$, which is consistent with our value of $\mathscr{F} = 0.54 \pm 0.02$, but the fitted column density was $N_{\rm H} = (1.0 \pm 0.1) \times 10^{24}$ cm^{-2}, which is a factor of 2 larger than what we found. The spectra are consistent with the simple and reasonable physical picture that the cause of anomalous and normal low states are the same, specifically occultation of the X-ray source by the accretion disk.

The PCA light curve (Fig. 4) shows a gradual drop of flux by 40% through the observation. We compared the spectra from the four *RXTE* orbits and found that the spectral shape and fractional rms variation remained the same. This is inconsistent with a change in the amount of cold absorber during the observation, which would indicate an inhomogeneous screen of material moving across the line of sight. Due to this we interpret the 30% unabsorbed spectral component as scattering into the line of sight by a hot corona rather than transmission through a patchy, partially covering disk. A scattering corona of the right size can also explain the change in the pulsations. The fractional rms variation in the ALS is reduced by a factor of $\sim$14 from the main-on and the pulse itself is broader (Figure 2). A corona of moderate optical depth that is smaller than $\sim$1.2 lt-s (the pulse period) would scatter some of the pulsed emission into the line of sight without completely washing out the pulsations. The 40% reduction in flux can be explained as increased scattering or increased occultation by the accretion disk. But a reduction in X-ray production at the source with orbital phase cannot be ruled out.

Finally, the binary orbital phase of the observation is 0.38–0.52, too early for the 40% decrease in flux during the observation to be due to a preeclipse dip. Furthermore, dip light curves show a variable absorption column with a timescale of 30 s (Reynolds & Parmar 1995; Leahy 1997; Stelzer et al. 1999). There is no evidence for a variable absorption column during the observation, but the decrease could still be interpreted as an anomalous dip, a drop in the intensity that occasionally occurs shortly after main-on turn-on (Kuster et al. 1998). In ordinary main-on states the anomalous dips can be interpreted as being due to occultations of the central source by the wobbling outer edge of the accretion disk (Crosa & Boynton 1980; Shakura et al. 1999). In the model of Shakura et al. (1999) during the ALSs the outer edge of the disk continuously screens the central source because of its lower inclination to the line of sight (see above), but tidally induced wobbling should still be present. So the hot corona around the inner parts of the accretion disk is expected to be screened by the outer disk wobbling shortly after main-on turn-on, exactly in the same manner that the anomalous dips are produced. This can take place on the first orbit after the expected, but as of now unobserved, turn-on. Anomalous dips of the X-rays scattered by the hot corona should be smoother and shallower than ordinary anomalous dips because it is an extended corona and not the central source that is being occulted.

4. SUMMARY

Optical observations of HZ Her show that accretion is continuing and X-rays are being produced at the neutron star at near the normal level. The onset of the ALS was accompanied by a spin-down of the neutron star, a significant deviation from the normal spin-up trend, which implies a slight drop in the accretion rate onto the neutron star. In the model of Shakura et al. (1999) a decrease in mass accretion would cause the inclination of the accretion disk to lessen, and thus the outer edges of the accretion disk could continuously screen the X-ray source. Given the caveat that our *RXTE* observation might not have been made during an expected main-on (see § 2), the ALS is spectrally very similar to the normal low state. Both low-state spectra can be fitted with a partially absorbed, partially scattered model where the input spectral shape is the same as in the main-on. The ALS, normal low state, and main-on have the same intrinsic spectral shape, and no drastic change in the source spectrum or luminosity is necessary. So the low-state spectra (anomalous and normal) are consistent with a single mechanism, namely, occultation of the neutron star by the accretion disk. We find that the combined optical, spectral, and timing observations of the ALS are consistent with a decrease in the inclination angle of the disk, screening the X-ray source over the entire 35 day cycle, and a significant change in the warp of the disk is not required.

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