X-RAY OBSERVATIONS OF V4641 SGR (SAX J1819.3–2525) DURING THE BRIEF AND VIOLENT OUTBURST OF 2003

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ABSTRACT

We present the results of detailed analysis of pointed X-ray observations by RXTE of the black hole X-ray binary (BHXRB) system V4641 Sgr (SAX J1819.3–2525) during its outburst of 2003 August. Soft X-ray (3–20 keV) flux variations by factors of 10 or more on timescales of minutes or shorter were seen. The rapid and strong variability of this source sets it apart from typical XRBs. In spite of large luminosity fluctuations, the spectral state of the source did not change significantly during the dwells, which suggests that the physical emission processes did not change much during the observations. The energy spectra during the dwells were dominated by a hard Comptonized power-law component, indicative of the canonical low/hard state observed in other BHXRBs. No soft thermal component was found in three out of the four RXTE pointings. However, spectral deconvolution of the observation with the largest average luminosity suggests an obscured, hot accretion disk. During one of the observations, we detected a short-term (~100 s) soft X-ray dropout, which is apparently due to variability in the observed column density. A strong Fe Kα fluorescent emission line near 6.5 keV was detected with large equivalent widths in the range 700–1000 eV. In the temporal domain, the Fourier power spectra were dominated by red noise below a few hertz. Poisson noise dominated at higher frequencies, and no high-frequency features were detected. The strong Comptonized spectra, broad iron emission line, absence of a disk component in the spectra, absence of any timing variability above a few hertz, and occasional large changes in the column density along the line of sight all support an enshrouded black hole with occasional outflow and a very dynamic environment.

Subject headings: accretion, accretion disks — black hole physics — X-rays: binaries — X-rays: individual (V4641 Sgr)

1. INTRODUCTION

Outbursts in transient X-ray binary systems typically span orders of magnitude in luminosity and mass accretion rate. This allows one to study accretion physics over a wide range, as well as general relativity in the strong-field limit. During a complete outburst cycle, the sources exhibit a multitude of states that have very different spectral and temporal characteristics. Two canonical states that most transients seem to go through are (1) a hard, power-law–dominated state, with high rms variability in the light curve, termed the low/hard state; and (2) the high/soft or thermal dominant state, with soft photon–dominated spectra from the accretion disk and little rms variability. Sometimes a very high state with steep power law is also seen (see Tanaka & Lewin [1995] and McClintock & Remillard [2006] for a recent review).

V4641 Sagittarii (SAX J1819.3–2525) was discovered by Goranskij (1978) when it went through an optical flare, and hence it was categorized as an irregular optical variable. Initially this system was confused with another neighboring long-period variable called GM Sgr; therefore, much of the older literature erroneously refers to GM Sgr as the optical counterpart of the strong X-ray source. The system was first detected in X-ray wavelengths between 7.4 and 12.3 kpc, and an orbital inclination between 60° and 70°. We have used an inclination of 65° and a distance of 10 kpc for all the calculations in this paper.

During the outburst of V4641 Sgr in 1999, RXTE observations showed flaring X-ray activity with super-Eddington luminosity (Wijnands & van der Klis 2000; Revnivtsev et al. 2002) on September 15. Rapid variability in optical brightness was also reported (Stubbings & Pearce 1999; Uemura et al. 2002) during this outburst. Radio observations during the outburst revealed a marginally resolved structure (Hjellming et al. 2000). The inferred superluminal proper motions of the radio structure (≥0.22 day−1) were attributed to relativistic motion of a radio jet. This led to its classification as a possible galactic microquasar like GRS 1915+105 (Mirabel & Rodriguez 1994) and GRO 1655–40 (Tingay et al. 1995; Hjellming & Rupen 1995). Based on the X-ray observations, Revnivtsev et al. (2002) suggested the formation of an extended envelope/outflow around the source during the outburst. Optical spectroscopy by Charles et al. (1999) also suggested the presence of strong wind.

Since the 1999 outburst, activity from the source has been reported in 2000 (Hjellming 2000), 2002 (Uemura et al. 2004), 2003 (Buxton et al. 2003), and 2004 (Swank 2004). In all cases, the entire span of the outburst cycles for this source is much shorter than that of typical compact transient systems. Also, V4641 Sgr does not exhibit a typical fast rise, exponential decay (FRED; Chen et al. 1997) light-curve profile during the outburst.

In 2003, signs of activity were first noted by the Variable Star Network (VSNET)1 group on 2003 August 1 and shortly

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1 VSNET group information is available at http://ooruri.kusastro.kyoto-u.ac.jp/mailman/listinfo/vsnnet-alert.
thereafter by the Small and Moderate Aperture Research Telescope System (SMARTS) consortium telescopes at the Cerro Tololo Inter-American Observatory (CTIO) in Chile (Buxton et al. 2003). Subsequent multiwavelength observations showed that the source was active in X-rays (Bailyn et al. 2003) and radio (Rupen et al. 2003) as well. As is characteristic for this enigmatic source, rapid time variability was observed in data obtained from radio, optical, and X-rays. The observed X-ray spectrum was very hard in nature; i.e., a strong contribution of hard X-rays was seen compared to the soft X-ray flux. The source of the hard X-ray radiation is believed to be either inverse Compton scattering of soft thermal photons from the accretion disk (Sunyaev & Titarchuk 1980) or/and synchrotron emission from a jet (Markoff et al. 2001). Broad and strong iron fluorescent emission lines near 6.5 keV were observed. These lines are thought to be produced by the reprocessing of hard X-rays impinging on cold matter, usually the accretion disk (George & Fabian 1991; Reynolds & Nowak 2003), where the principal factors that cause the line to broaden are a strong gravitational field near the compact source and relativistic motion of the radiation emitting particles (relativistic Doppler broadening). The line may also be created in a plasma (or corona) close to the central black hole. The line shape in this case is intrinsically Gaussian, the line energy depends on the dominant ionization states, and the line width depends on rotation and Compton scattering in the corona (Kallman & White 1989).

In this paper we report the detailed spectral and temporal analyses of pointed RXTE observations of the 2003 August outburst of V4641 Sgr. In § 2 we describe the general data reduction procedures adopted in this paper. In §§ 2.1, 2.2, and 2.3 the results of the color evolution, spectral, and timing analyses of the data are presented, respectively. The conclusions are summarized in § 3.

2. OBSERVATIONS AND RESULTS

We used optical observations of V4641 Sgr from the SMARTS consortium 1.3 m telescope to trigger RXTE target of opportunity observations. The optical data were obtained using the A Novel Dual Imaging Camera (ANDICAM; see Depoy et al. [2003] for details) instrument mounted on the SMARTS 1.3 m telescope at CTIO. The ANDICAM detector consists of a dual-channel camera that allows for simultaneous optical and IR imaging. The V-band light curve from MJD 52,840 to MJD 52,870 (2003 July 20–August 19) in Figure 1 shows rapid variability and short duration of the entire outburst, both of which are characteristic of previous outbursts of this source (Uemura et al. 2004; Wijnands & van der Klis 2000).

RXTE (Bradt et al. 1993) pointed observations of V4641 Sgr started on MJD 52,856 and continued until MJD 52,868 (2003 August 5–17). The observable X-ray activity ceased after MJD 52,858 (August 7; see Fig. 1). Between August 5 and 7, four RXTE pointed observations were done. A list of observation start times and durations is given in Table 1.

HEASOFT FTOOLS (ver. 5.3) software was used to perform the X-ray data reduction. A Proportional Counter Array (PCA) Science Array data mode with 16 s time bins was used for color analysis and spectral data extraction. We extracted the light curves and spectral information from the top layer of the second proportional counter unit (PCU2) using the Standard2 files. Standard screening criteria, as described in the RXTE Cookbook,2

2 SMARTS information is available at http://www.astro.yale.edu/smarts.

3 The RXTE Cookbook is available at http://rxte.gsfc.nasa.gov/docs/xte/recipes/cook_book.html.

were applied to select segments of good data when (1) the source was at least 10° away from Earth’s limb; (2) the satellite was not passing through the region of South Atlantic Anomaly; and (3) the pointing was stable, with pointing offsets less than 0.02. Since the source was not very bright, we also excluded regions with significant electron contamination (ELECTRON2 < 0.1). The errors in count rates and hardnesses are 1 σ errors, assuming a Poissonian distribution for the recorded photon count rates. Background spectra were estimated from the latest models using the pcabackest (ver. 3.0) tool; pcaresp (ver. 8.0) was used to generate the redistribution matrix files (rmf) and ancillary response files (arf) and then combined to form a single response file (rsp). We used the High-Energy X-Ray Timing Experiment (HEXTE) archive mode data from cluster A with 64 energy channels for a total energy band of 15–250 keV, with a timing resolution of 16 s. While fitting simultaneous PCA + HEXTE spectra, the normalization of the HEXTE data was left as a free parameter to match the PCA spectra.

4 Additional information is available at http://heasarc.gsfc.nasa.gov/docs/xte/pca_news.html/quick_table.
Temporal information was extracted either from the Science Event files with $2^{-13}$ $\mu$s ($\sim$122 $\mu$s) time resolution (DATAMODE = E_125us_64M_0_1s) or from GoodXenon modes of time resolution $2^{-20}$ $\mu$s ($\sim$0.95 $\mu$s), whichever was available. However, for the third pointing, we used the E_16us_16B_36_1s data mode, which covers almost the entire PCA energy spectrum from 14.9 keV and above with a timing resolution of $2^{-16}$ $\mu$s ($\sim$15.2 $\mu$s) and readout time of 1 s, since no event data with full PCA energy range were taken for this dwell. Data from all the detectors and their layers were combined. The event data for all the dwells were binned to $2^{-13}$ $\mu$s bins (corresponding to a Nyquist frequency of 4096 Hz) to ensure uniform analysis. Temporal studies were done in the Fourier domain using the powspec (ver. 1.0) tool to carry out the fast Fourier transforms and create the power density spectra (PDS) following the prescription of van der Klis (1989, 1995). Since the count rates were not high, the dead-time effect is negligible, and we did not explicitly correct the light curves for dead time. Instead we modeled the dead-time–modified Poisson noise in the PDS with a constant and subtracted this constant to calculate the Fourier power. The PDS were normalized with respect to count rate so that the resulting power spectra are in the units of (rms mean$^{-1}$)$^2$ Hz$^{-1}$. The PDS were then logarithmically rebinned in frequency space to reduce noise at high frequencies. Unless otherwise stated, the error bars in the average power spectra were calculated by evaluating the standard deviation of the average power for each frequency. However, the error bars for the individual 64 s power spectra during dwell 2 were calculated by propagating through theoretical error bars obtained from the relevant $\chi^2$ distribution. The errors in spectral and temporal model fits are 90% confidence regions for a single parameter ($\Delta\chi^2 = 2.706$).

2.1. Light Curve and Colors

The PCA light curves and 5.3–10.3 keV/2.0–5.3 keV color for the observed dwells are shown in Figure 2. Here we see the highly variable nature of this source. Intensity variations by an order of magnitude in timescales as short as minutes are seen. In dwell 3 the observed count rates were the lowest of the four dwells presented in this paper. In contrast, the immediately succeeding pointing, viz., the fourth dwell, shows the highest count rates. While the starting time of the fourth dwell is only 1.5 hr after the ending time of the third dwell, the average count rate of the source increased by a factor of 8.4 compared to dwell 3, and the peak count rate is 14.4 times larger than that of dwell 3. During the fourth dwell, simultaneous optical observations of the source were done from the Lu-Lin Observatory in Taiwan that showed strong X-ray/optical correlation and delayed arrival of the optical light (C. Bailyn et al. 2006, in preparation; Maitra et al. 2004). Also, of all the RXTE pointings during this outburst, this is the last dwell in which we observed any activity from the source (see Fig. 1).

Contrary to what is generally observed in XRBs, the count rates in the medium energy band (5.3–10.3 keV) are greater than those of the soft energy band (2.0–5.3 keV). This is due to the extremely strong and wide iron emission line flux near 6.5 keV. As shown in Figures 3a and 3b, the hardness ratios (colors) do not evolve significantly during dwells 1, 3, and 4, suggesting that the overall spectral state of the source did not change during these dwells. There is a slight softening at the highest luminosities during the fourth dwell, which is due to the appearance of an otherwise obscured soft disk photon and is discussed in detail in § 2.2. As seen in the light curves, the second dwell is highly dynamic in character. The hardness-time and color-color plots show that the spectral characteristics of the two flares are intrinsically very different. While the first flare near 200 s is very hard in nature, the second flare near 450 s is predominantly soft. The two flares occupy different regions of the color-color space, whereas the nonflaring state is distinct from both of the flaring states. There seem to be no major spectral state changes after the second flare. There is some overlap between the soft, hard, and nonflaring state in color-luminosity space. The nonflaring state in this dwell is spectrally somewhat harder than that of the other dwells.

### Table 1: Observation Log

| Serial Number | Observation ID | Calendar Date (2003) | Time* (MJD) | Exposure* (s) |
|---------------|----------------|----------------------|-------------|---------------|
| 1             | 80054-08-01-00 | Aug 5                | 52,856.06   | 992           |
| 2             | 80054-08-01-01 | Aug 6                | 52,857.37   | 2192          |
| 3             | 80054-08-02-00 | Aug 7                | 52,858.50   | 944           |
| 4             | 80054-08-02-01 | Aug 7                | 52,858.57   | 1296          |

* Start of good time interval.

a Total exposure time after screening for good time intervals.

2.2. Spectroscopy

Since the spectral state of the source did not change appreciably during dwells 1, 3, and 4, we analyzed time-averaged spectral and temporal properties of each of these dwells. The most notable feature in the combined spectrum is the strong, broad emission line complex around 6.5 keV, which is easily seen in the count spectrum in Figure 4. Since such a strong line makes determination of continuum parameters difficult, we initially modeled the spectral region harder than 10 keV, with the assumption that this region is free from strong emission/absorption features or edges. For most BHXRB systems, these energy ranges are dominated by power-law photons. However, in this case we found that a simple power-law model fails to describe the spectrum (e.g., $\chi^2/\nu = 140/45$). An appreciable amount of curvature was observed in the residuals, shown in Figure 5a, which is usually taken to be a reflection effect. We therefore used the pexrav model by Magdziarz & Zdziarski (1995), which calculates an exponentially cut off power-law spectrum reflected from neutral material. This model provides a much better fit to the data with $\chi^2/\nu = 35/44$, as shown in Figure 5b. However, the scaling factor for reflection is not well constrained by the fit and was therefore fixed to 1.0 (corresponding to an isotropic source above the disk). The overall PCA and HEXTE 3–50 keV spectrum was modeled using a warm photoelectric absorber (Morrison & McCammon 1983) of hydrogen column density $N_H = 1.0 \times 10^{21} \text{ cm}^{-2}$.
Fig. 2.—X-ray flux and hardness ratio variations with time for the observed RXTE pointings. Dwell 1 is shown at top left, dwell 2 at top right, dwell 3 at bottom left, and dwell 4 at bottom right. Each dwell is subdivided into four subpanels, where the top subpanels show 2.0–5.3 keV PCU2 count rates (soft), the second subpanels show 5.3–10.3 keV PCU2 count rates (medium), the third subpanels show the 10.3–20.4 keV PCU2 count rates (hard), and the fourth subpanels show the medium/soft hardness ratio.

Fig. 3.—(a) Medium-/soft-band hardness ratio plotted against the 3–20 keV background-subtracted count rates for dwells 1, 3, and 4. The corresponding color-color plot is shown in (b). In both plots, data from dwell 1 are shown by crosses, data from dwell 3 are shown by open circles, and data from dwell 4 are shown by plus signs. In (c) and (d) we show the same plots as (a) and (b), respectively, but only for dwell 2, where we observed some violent hard and soft flaring activities. The data taken during the hard flare are shown by squares, those during the soft flare are shown by filled circles, and the data taken during the rest of the dwell are shown by plus signs.
density fixed to $2.3 \times 10^{21}$ atoms cm$^{-2}$ (Dickey & Lockman 1990) and the Comptonized power law. The abundances were taken from the table by Anders & Grevesse (1989). Modeling the Fe line complex for dwell 1 required two Gaussians, most likely corresponding to different ionization states of iron. The moderate energy resolution of the spectrometer makes it difficult to determine the exact ionization states of these lines. We tried the relativistic line model of Laor (1991) to fit the Fe K$\alpha$ line. The Laor line energy turns out to be similar to that obtained using a Gaussian model. However, other Laor fit parameters, such as the disk inner radius or the power-law dependence of emissivity, are not constrained by the data. We therefore used the simple Gaussian model for the line. For all other dwells, the single Gaussian model gave good fits to the data. The relevant free parameters in this model, besides the normalizations for the model components, are the line energies and widths of the Gaussians, power-law photon index, and the energy of exponential cutoff. The results of the spectral deconvolution are shown in Table 2. Also shown in Table 2 are the values of reduced $\chi^2$ values obtained for the best-fit model and the corresponding $3–50$ keV isotropic luminosity for a distance of 10 kpc (see also Fig. 4).

Since the broad colors show sharp spectral state changes during the second dwell, we have not attempted to create any time-averaged spectrum of the entire dwell. Instead we present a dynamic energy spectrum (DES; Fig. 6), which shows the spectral evolution of the source during this dwell. To create the DES we extracted 69 spectra spanning the entire dwell with a timing resolution of 32 s. The spectra were then normalized by count rate. We also extracted the entire time-averaged spectrum for the whole dwell and normalized by count rate. This normalized, time-averaged spectrum of the entire dwell was used as a template spectrum. Each 32 s spectrum was divided by the template spectrum, and the resulting ratio spectrum constitutes a vertical strip in the DES. The color coding corresponds to the ratio of observed spectrum to the template spectrum at the time (abscissa) for the energy (ordinate). The overplotted solid histogram shows the variation of the PCA 3–20 keV light curve during the dwell. It is evident from the DES that the flares during 200 and 450 s are intrinsically different in their spectral natures. The first flare near 200 s is very hard, with a sharp dropout of soft photons, whereas the second flare near 450 s is essentially soft in nature. As in the previous dwell, we do not find any significant blackbody component in the spectra. The 3–25 keV spectra are dominated by an iron emission line and power-law continuum. We modeled the 10–25 keV spectra during the first 14–94 s of the dwell, i.e., before the hard flare, using the pexrav model. In Figure 7a we show the corresponding spectrum and the fit. The solid histogram is the Comptonized power-law fit to the hard 10–25 keV data, which does not account for the broad Fe K$\alpha$ emission line seen in the data near 6.5 keV. Therefore, as expected, when extrapolated to lower energies, the model is unable to reproduce the strong iron line near 6.5 keV, but the fit matches the continuum well at the lowest energies. In sharp contrast to this is the spectrum during the hard flare (222–254 s), shown in Figure 7b. The solid histogram, as before, is a Comptonized power-law fit to the 10–25 keV energy range that is not only unable to reproduce the region near the iron line complex, but also largely overestimates the soft photon count rate in the 2–5 keV range.

In fact, the spectrum during the hard flare cannot be modeled using any physical model if the column density of the absorber is fixed to its standard value of $2.3 \times 10^{21}$ atoms cm$^{-2}$ (Dickey & Lockman 1990). In contrast, the spectrum before and after the flare can be well modeled using this standard column density. We therefore allowed the fit parameter $n_{HI}$, which estimates the column density of the warm absorber to vary during the flare. A Comptonized power law (Magdziarz & Zdziarski 1995) was used for the continuum, and a Gaussian was used for the Fe line. In this model, the variation of the fit parameter $n_{HI}$ with time, is shown in Figure 8. Due to low count rates and moderate resolution of the spectrometer, it is difficult to determine precisely the column density of the warm absorber; our 90% confidence range on the estimated maximum column density during the hard flare is $(78.3 \pm 12.9) \times 10^{22}$ atoms cm$^{-2}$, almost 2 orders of magnitude greater than the rest of the dwell. One possible physical scenario that could lead to such an event is the eruption.
of a hard jet followed by an enhanced outflow of mass, as also envisioned by Revnivtsev et al. (2002). Such an outflow moving nearly along the line of sight can cause such large changes in observed column density. Other scenarios, such as variation of the partial covering fraction, cannot be ruled out. As regards the strong iron emission line, it is likely that the source is obscured and the circumstellar material is excited by hard X-ray emission, which in turn produces the line emission with strong equivalent widths.

The 10–50 keV hard energy spectrum for the third dwell could be well described by a simple power law ($\chi^2/\nu = 33.7/45$). Unlike the previous dwells, the data for the third dwell did not require any Comptonization component. Most likely, this is due to the low count rates and associated larger error bars, which make detection of the reflection component difficult. At lower energies, the data do not require any thermal disk photons. However, the column density of the absorbing column was larger than the standard value, during the entire third dwell,
which could be possible if the observation was made shortly after a (possibly super-Eddington) mass ejection event. An absorption edge near 10 keV in terms of a smeared-edge model (Ebisawa et al. 1994) was also required. The width of the smeared edge was fixed to 10 keV.

For the fourth dwell, which was the brightest of all four pointings, the HEXTE spectrum was seen to extend up to 150 keV. In Figure 10 we show the 3–150 keV PCA + HEXTE spectrum. Although the light curve showed a variation in flux of an order of magnitude over the entire dwell, the X-ray colors, or a DES, shows that the spectral state of the source did not change during the first 1000 s of the dwell. During 1000–1200 s, it appears that the source went through another faint hard flare, as seen in dwell 2. Unlike the other dwells, however, the spectra for this dwell show an excess of soft photons, most likely from an accretion disk. A smeared edge near 10 keV was also required. A simple model with a Gaussian line and two continuum components, viz., a multicolor disk (Mitsuda et al. 1984; Shakura & Sunyaev 1973) and a Comptonized power law (Magdziarz & Zdziarski 1995) gives a very high temperature of the inner edge of the accretion disk of around 3.3 keV. Assuming a Comptonized blackbody model (compbb; see Nishimura et al. [1986] for details) with an electron temperature of the hot plasma fixed to 20 keV and a Comptonized power law with a fixed photon index of 1.5 and cutoff at 150 keV, better fits ($\chi^2/\nu = 75.4/80$; see also Fig. 10) and a lower temperature of the blackbody ($\sim 1.9$ keV) are obtained. The fitted parameter values for the model are given in Table 2. However, the compbb model assumes a single-temperature blackbody emission as a seed photon spectrum, whereas in reality, the seed photons most likely are coming from an accretion disk with a varying temperature profile.

Small systematic deviations are seen in the plot of residuals (Fig. 10, bottom) and could be fitted by adding more models components, but due to lack of a thorough understanding of actual undergoing physical processes, we constrained ourselves to simple models.

### 2.3. Temporal Analysis

The rapid state changes seen in the energy spectra during the second dwell also left strong signatures in the temporal domain. The rms variability with time, during the second dwell, in the soft (2.4–4.1 keV) Fe line complex (5.3–7.8 keV) and hard (14.9–25.0 keV) energy bands shows significant changes (Fig. 9). The total rms variability in the 0.1–10 Hz range was calculated for every 64 s long data segment. We see that the line variability tracks the soft variability throughout the dwell. Therefore, it is unlikely that any of these flares are caused solely by the variability in the line. Note that the variability increases to a maximum near the hard flare (near 200 s) for all energy bands, which may be caused by an outflow crossing the observer’s line of sight, where the ejected matter has a high rms variability. An enhancement in the Comptonizing corona that surrounds the source and gives rise to the high-variability hard photons (e.g., in the low/hard states of most compact X-ray binaries) could also account for the increase in variability.

It is interesting to note that we see no change in hard-band variability during the soft flaring event near 450 s, but both the soft and line flux variabilities go through a large increase in variability during the flare. A dip in the hard-band variability is seen after the soft flaring event. The hard flaring event could cause instability in the circumstellar environment of the source, causing a decrease in the optical depth of the corona and thereby
allowing a larger number of scattered soft disk photons to reach the observer. Thus, the soft flare may be due to the appearance of a brief "window" in the obscuring circumstellar material, allowing us a glimpse of the inner regions. The soft-band variability drops just after the soft flare, while the hard-band variability slowly increases, suggesting the rebuilding of the obscuring corona/circumstellar material. After the flare around 800 s, the source activity decreased, and we see no significant evolution in spectral or temporal domains.

For the remaining dwells, viz., 1, 3, and 4, the PDS show little or no rms variability in the frequency range 0.1–10.0 Hz, in any energy bands during dwell 2.
of the soft Fe line complex or hard (14.9–25.0 keV) energy regimes. This suggests no temporal variability in the 0.1–10 Hz range over the 2.5–25 keV energy range during the entire observation. We therefore constructed a white (2.5–25 keV) PDS over the entire dwell. Below ~1 Hz the PDS is essentially dominated by featureless red noise, with little or no signature of any peaked noise. There might be some evidence of a flat-topped noise at the lowest frequencies (<0.01 Hz), but it is not statistically significant from the data. Above a few hertz the spectrum is dominated by Poisson noise. In Table 2 we present the rms variability seen in the 2.5–25 keV photons, as a Riemann sum of frequencies between 0.01 and 10 Hz and the power-law index (α) that characterizes the slope of the red noise.

3. DISCUSSION

Analysis of the data presented in this paper suggests that the compact object in V4641 Sgr is enshrouded by an optically thick cloud, at least during some periods of its enhanced activity during the outburst of 2003. Optical (Charles et al. 1999) and X-ray (Revnivtsev et al. 2002) observations during the previous outbursts also suggest a similar physical environment. The cloud could be composed of outflowing matter from the inner regions close to the central black hole. The strong power-law–dominated flux seen in the observed dwells indicates that the source was in the canonical low/hard state. The energy spectrum of dwells 1–3 does not seem to require a soft disk blackbody component.

High column density observed during the outburst can, in part, cause the lack of detection of the soft disk component. High orbital inclination, along with the presence of gas and dust, can also potentially obscure the accretion disk from the observer, and this may be the case for V4641 Sgr. In a recent work, Narayan & McClintock (2005) pointed out that the X-ray binary systems that have high inclination show strong variability and complex, non-FRED-like outbursts. The inner disk, which may be warped and combined with the modestly high inclination of the binary orbit, can have an inclination near 90°. Then small changes in the height of the disk could cause rapid obscuration and changes in the observed flux. If the material is somewhat thin, this could cause changes in column density, and if it is thick, it could cause variations in the reflection component. Although no super-Eddington events were detected in any of the dwells presented in this work, given the high variability of the source, it is possible that there were short episodes of such super-Eddington accretion that led to the formation of a dynamic environment around the central engine.

The color-luminosity diagram for dwell 2 shows that there is significant overlap in luminosity between the hard, soft, and nonflaring states. This supports the suggestion that the luminosity (and hence the associated inferred mass accretion rate, M) is not the only parameter that causes a state transition in XRBs (Homan et al. 2001; Smith et al. 2002; Maccarone & Coppi 2003; Maitra & Bailyn 2004). The data imply a second (or more) parameter determining state transition in these sources.

There is evidence for Comptonization, both from the presence of a broad Fe line complex near 6.5 keV, as well as a characteristic Compton hump in the >10 keV range. The Compton reflection fraction is not well constrained by the models, which might be due to modification of the emergent spectra by an outflow around the source. Titarchuk & Shrader (2005) have recently shown that in a relatively cold outflow of T ~ 10⁶ K, emerging photons are predominantly downscattered, which can lead to an accumulation of excess photons around 10 keV. Such excess around 10 keV was seen for V4641 Sgr and therefore strengthens the enshrouded source with an outflow model for this source. Even during periods of high luminosity, a simple multicolor disk fit gives an unrealistically high disk temperature. One possible interpretation of such high fitted disk temperatures is the existence of a hot electron cloud very near to the disk that Compton upscatters the disk photons and converts a significant fraction of the disk emission into higher energies, as also observed in another black hole binary with superluminal jet, XTE J1550–564 (Kubota & Makishima 2004). The origin of broad iron emission lines with equivalent widths up to 1 keV seen during the observations could be either Compton reflection from an accretion disk or a corona. From the data we were unable to differentiate between the origin of the lines. However, since other evidence favors an enshrouded source, the coronal line formation scenario seems more likely. Timing analysis shows that during all four observations the PSD were dominated by red power-law noise below a few hertz and Poisson noise above it. Besides the power-law continuum or the constant Poisson level, no other features, such as breaks or quasi-periodic oscillations (QPOs), were seen in any of the power spectra. The absence of any signal at frequencies higher than a few hertz and a featureless red noise at lower frequencies further supports an enshrouded obscured source where all the high-frequency/short-timescale events have been smeared out as the radiation passes through the obscuring material.

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