LONG-TERM X-RAY MONITORING OF THE TeV BINARY LS I +61 303 WITH THE ROSSI X-RAY TIMING EXPLORER

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ABSTRACT

We report on the results of a long-term X-ray monitoring campaign of the galactic binary LS I +61 303 performed by the Rossi X-ray Timing Explorer. This data set consists of 1 ks pointings taken every other day between 2007 August 28 and 2008 February 2. The observations covered six full cycles of the 26.496 day binary period and constitute the largest continuous X-ray monitoring data set on LS I +61 303 to date with this sensitivity. There is no statistically strong detection of modulation of the flux or the photon index with orbital phase; however, we do find a strong correlation between the flux and photon index, with the spectrum becoming harder at higher fluxes. The data set contains three large flaring episodes, the largest of these reaching a flux level of $7.2 \pm 0.2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the 3–10 keV band, which is a factor 3 times larger than the flux levels typically seen in the system. Analysis of these flares shows the X-ray emission from LS I +61 303 changing by up to a factor of 6 over timescales of several hundred seconds as well as doubling times as fast as 2 s. This is the fastest variability ever observed from LS I +61 303 at this wavelength and places constraints on the size of the X-ray emitting region.

Key words: X-rays: binaries – X-rays: individual (LS I +61 303)

1. BACKGROUND

The galactic binary LS I +61 303 is one of the most heavily studied binary star systems in the Milky Way, and is one of the only three so-called “TeV Binaries” to be regularly detected in the >100 GeV gamma-ray regime; the other two being LS 5039 (Aharonian et al. 2005a) and PSR B1259-63 (Aharonian et al. 2005b). Although the subject of many observational campaigns, the fundamental identification of the components of the system, remains relatively unclear. From observations detailed in Hutchings & Crampton (1981) and Casares et al. (2005) it is clear that the system can be classified as a high-mass X-ray binary (HMXB) located at a distance of 2 kpc; the components of the system consisting of a compact object in a 26.496(±0.003) day orbit around a massive BO Ve main-sequence star. Although the range of masses derived for the compact object favor a neutron star component, a black hole cannot be ruled out (Casares et al. 2005). Periastron passage of the compact object occurs at $\phi = 0.23$ (here $\phi$ represents the orbital phase ranging from 0.0 to 1.0) set at JD 2443,366.775, with apastron passage occurring at 0.73, and inferior and superior conjunctions occurring at 0.26 and 0.16, respectively (Casares et al. 2005).

The two main competing scenarios to explain the system can be summarized as microquasar (i.e., nonthermal emission powered by accretion and jet ejection) or binary pulsar (i.e., nonthermal emission powered by the interaction between the stellar and pulsar winds). The microquasar model (Massi et al. 2001; Bosch-Ramon et al. 2006) used to describe this system has several drawbacks (for example, lack of blackbody X-ray spectra), however the scenario has not been ruled out, for example, see Romero et al. (2007). There is growing evidence for the binary pulsar model of the system (Maraschi & Treves 1981; Dubus 2006), most strongly supported by the result of Dhawan et al. (2006) in which Very Long Baseline Array monitoring of the system revealed a cometary radio structure around LS I +61 303 which was interpreted as the interaction between the pulsar and Be star wind structures. However, there is currently no evidence for the presence of a pulsar within the system either in radio or X-rays.

LS I +61 303 has been historically an object of interest due to its quasi-periodic outbursts at radio (Paredes et al. 1998; Gregory 2002) and X-ray wavelengths (Taylor et al. 1996; Leahy et al. 1997; Paredes et al. 1997; Harrison et al. 2000; Greiner & Rau 2001). The radio outbursts are well correlated with the orbital phase (Gregory 2002), although the phase of maximum emission can vary between 0.45 and 0.95. The first high-energy association of the source was with the COS-B source 2CG 135 +01 (Hermens et al. 1977). LS I +61 303 has also been identified with the EGRET source 3EG J0241+6103, a source which also shows evidence for a 26.5 day modulation in the GeV band (Massi 2004). More recently, LS I +61 303 has been detected as a variable TeV gamma-ray source (Albert et al. 2006; Acciari et al. 2008) with high emission appearing near apastron.

The collection of X-ray observations on LS I +61 303 is expansive, however, the exact character of the X-ray emission from this source remains unclear. The X-ray source was originally weakly identified by the Einstein satellite (Bignami et al. 1981). Further observations of the system by ROSAT in 1991 and 1992 (Goldoni & Mereghetti 1995; Taylor et al. 1996) in the 0.01–2.4 keV band showed the source to be variable by a factor of 3 over a single orbital cycle; a peak flux occurring between orbital phases 0.4 and 0.6. The first accurate observations in the >5 keV range were performed by ASCA (Leahy et al. 1997) in the 0.5–10 keV band. ASCA performed two separate 30 ks exposures near orbital phases 0.2 and 0.45 showing relatively low flux states (0.6/0.4 × 10^{-11} erg cm$^{-2}$ s$^{-1}$). The spectra from these observations were well fit by an absorbed power law with photon indices of 1.7 ± 0.1 and 1.8 ± 0.1, respectively. RXTE observed LS I +61 303 for an entire orbital cycle in 1996, seeing
a clear increase in the flux between $\phi = 0.3$ and 0.7, with a peak occurring near phase 0.45 at a flux of $2 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (Harrison et al. 2000). There have been three separate published analyses of this data set (Harrison et al. 2000; Greiner & Rau 2001; Neronov & Chernyakova 2006). All three analyses find that a simple absorbed power law provides a reasonable fit to the derived spectra. In 2002, *XMM-Newton* was used to monitor LS I +61 303 in the 0.2–12 keV range (Neronov & Chernyakova 2006). Four 5–6 ks pointings were taken spread out over a single orbit, with a single 6 ks pointing taken several months later. These pointings showed the 2–10 keV flux to be highly variable, having a minimum near periastron and peaking near phase 0.55. The spectral fitting (again, using an absorbed power law) was consistent with a photon index value of 1.5 for four out of five of the pointings, with a much softer index of 1.78 resulting for the data point just preceding the transition from a high to low X-ray flux. Neronov & Chernyakova (2006) interpreted this as evidence for correlation between spectral behavior and flux states.

Several years later in 2005, *XMM-Newton* was again used for an extended pointing (48.7 ks) on LS I +61 303 during orbital phase 0.61 (Sidoli et al. 2006). This observation showed evidence for variation of the hardness ratio (defined as the ratio between 0.3 $\rightarrow$ 2 keV and 2 $\rightarrow$ 12 keV emission) over the timescale of hours. These observations also showed a sharp decrease in the flux of the order of a factor of 3 over a time period of a few thousand seconds, with flux decreasing from 1.2 $\rightarrow$ 0.4 $\times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$, which were the first observations to detail such a rapid variability of the X-ray flux from this system. The *Chandra* satellite carried out a 50 ks pointed observation of LS I +61 303 in 2006 April (Paredes et al. 2007) near orbital phase 0.04. These observations (0.3–10 keV) revealed the presence of kilosecond scale miniatures in the source, with emission increasing by a factor of 2 over a timespan of roughly 1 hr. Similar to the *XMM-Newton* extended exposure, the *Chandra* observations also show an implied correlation between harder emission and increased flux. The mean flux was determined to be $0.71^{+0.18}_{-0.14} \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ which is also consistent with previous measurements near that orbital phase. The derived photon index, however, was determined at $\alpha = 1.25 \pm 0.09$, much harder than any previous measurements made. The *Chandra* exposure also found evidence (3.2$\sigma$ significance) for extended emission between 5$^\circ$ and 12$^\circ$5 toward the North of LS I +61 303, an indication that particle acceleration resulting in X-ray emission may be taking place as far away as 0.05–0.12 pc from LS I +61 303.

Taken as a whole, the X-ray observations conducted on LS I +61 303 indicate that the source is an extremely unpredictable one. Although long-term X-ray monitoring conducted by the All Sky Monitor aboard *RXTE* indicate that the system exhibits a long-term 26.42 ± 0.05 day period in X-ray emission (Leahy 2001), the X-ray observations described above show that extreme variation in the light curve is seen between different orbital cycles. As for spectral behavior it is clear that a simple absorbed power law provides an effective fit to the observational data, however, there is mounting evidence that the photon index may be correlated to the flux level of the system.

2. **RXTE OBSERVATIONS AND DATA REDUCTION**

Between 2007 August 28 and 2008 February 2 (MJD 54340-54504) a total of ~80 ks of observation time was accumulated with the Proportional Counting Array (PCA) instrument aboard *RXTE* (Jahoda 2006). One kilosecond exposures were taken every other day which resulted in good observational coverage of a total of six 26.5 day orbital cycles of the binary system. Two separate data modes were used in this analysis: for light curve and spectral analysis the “Standard 2” mode was used (16 s accumulation time, 129 energy channels), for analysis requiring greater time resolution the “Good Xenon” mode was utilized (1 $\mu$s resolution, 256 energy channels). Data in both modes were reduced using NASA HEASARC’s FTOOLS 6.5 package (Blackburn 1995). Data were selected using standard quality criteria cuts as suggested by the *RXTE* Guest Observer Facility data reduction Web site$^6$ with the exception of the use of a slightly looser restriction on the suggested “Time Since South Atlantic Anomaly (SAA) passage” (25 minutes as opposed to the suggested 30 minutes). It was determined that the quality of the data was not affected by this relaxation and the exposure time was significantly increased for a significant percentage of the pointings.

During the time that this data set was accumulated, the number of PCA units which were activated changed per observation, therefore, for the Standard 2 analysis, a spectrum from 3 to 10 keV was extracted from each night’s individual PCA configuration utilizing combinations of PCA units 2, 3, and 4 (since Proportional Counter Units, PCUs, 0 and 1 have lost their propane layer). The rationale behind this was that LS I +61 303 is typically not a strong X-ray emitter above this energy range, and due to *RXTE* instrument degradation the energy channels below 3 keV are not reliable (Jahoda 2006) at this point in time. Only the top PCU layer was utilized in order to maximize signal to noise. After generating simulated background spectra using *pcabackest* and creating PCA response matrices with *pcarsp*, *XSPEC12* was used to fit each night’s background-subtracted spectra. Previous observations of LS I +61 303 with *RXTE* (Harrison et al. 2000) as well as *XMM-Newton* (Sidoli et al. 2006) and *Chandra* (Paredes et al. 2007) found that the best fit to the observed spectra was provided by a simple, absorbed power law (without a blackbody component) and this is the approach that we adopt in the analysis presented here. In this fitting, as with previous *RXTE* analyses of this source, the value of the galactic $N_H$ was kept constant; fixing the absorbing hydrogen column density at $N_H \rightarrow 0.75 \times 10^{22}$ cm$^{-2}$ (Kalberla et al. 2005). Therefore, the spectral fit used here takes the form of

$$ A(E) = K e^{-N_H \sigma(E) \left(E \over keV \right)^{-\alpha} ,} (1) $$

where $K$ is a normalization constant at 1 keV, $\sigma$ is the photoelectric cross section, and $\alpha$ is the photon index. The $\chi^2$/degrees of freedom (dof) values for these fits were acceptable, with all values falling between 0.25 and 1.2 for 14 dof. Keeping with standard convention, the flux values were then generated by integrating the best-fit spectra from 2 to 10 keV along with the associated $\sigma$ error levels, which are used throughout this work. When producing Standard 2 data combining multiple observations (and PCA configurations), such as the phase and flux binned data sets, it was necessary to produce spectra (and fluxes) in a slightly different manner. Since combining large spectral data sets with differing PCA configurations (with associated differing calibrations) can produce large systematic errors, it is preferable to only use a single common PCU for all available data sets. Since PCU 2 was active for all observations in the current data set, spectra from PCU 2 were produced and combined to give a single spectrum for each bin in question.

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$^6$ http://heasarc.gsfc.nasa.gov/docs/xte/data_analysis.html
For Good Xenon data (<16 s time resolution), the same overall quality-selection criteria were utilized to produce light curves from PCU 2 only. Background subtraction for these light curves was carried out by using the FTOOLS routine lcmath to subtract an estimated background light curve (produced from Standard 2 data) from the Good Xenon observation as recommended by the RXTE guest observer facility.

3. RESULTS

3.1. Overall Results

Shown in Figure 1 is the overall light curve in daily bins along with 1σ error bars. As can be seen, the flux typically modulates between $0.5 \times 10^{-11}$ and $2 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ over the timespan of the 26.5 day orbital cycle. The average flux presented was $1.67 \pm 0.02 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$, with a reduced $\chi^2$ value of 30.6 (75 dof) for a constant flux fit; demonstrating strong variability over the span of the data set (<0.01% probability of being constant). The most immediately obvious feature of the light curve is the presence of three exceptionally large flares (FL1, FL2, FL3) within the data appearing on 2007 September 13, 15, and 29 (MJD 54356, 54358, 54372) presenting flux levels of $7.2^{+0.1}_{-0.2}$, $3.5^{+0.1}_{-0.2}$, and $4.9^{+1.0}_{-0.5} \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$, respectively. These powerful flares represent the most extreme X-ray activity detected from LS I +61 303 to date, with the largest of these flares, FL1, presenting an inferred luminosity (at a distance of 2 kpc) of $3.4 \times 10^{34}$ erg s$^{-1}$. These flares will be discussed in greater detail below.

To examine the overall structure of the RXTE data with respect to the 26.5 day orbital cycle of the system, the individual observations were placed in 0.1φ bins and analyzed together as described in Section 2. The extracted 2–10 keV flux and fitted spectral indices from PCU 2 for these bins are shown in Figure 2 (left) and Table 1. A constant flux fit to the data gives a reduced $\chi^2$/dof value of 33.68 (9 dof) indicating that the flux value has a <0.01% probability of being constant over the orbital phase.

When examining the orbital phase versus photon index behavior on the right side of Figure 2, it is not clear that the index changes significantly over the orbital phase. Although it appears that the spectrum gets softer beneath orbital phases 0.5 → 0.7, a constant index fit to this light curve gives a reduced $\chi^2$ value of 2.58 (9 dof), indicating a <5.5% probability of being constant over the orbit.

The harder spectral indices of the flaring episodes motivated a search for a possible correlation between the flux and photon index. To carry this out, the data were binned by flux levels and re-analyzed by extracting a single PCU 2 spectrum from all data falling within the flux windows of $F < 1.0$, $1.0 < F < 1.5$, $1.5 < F < 2.0$, $2.0 < F < 2.5$, and $F > 2.5 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ (see Table 2 and Figure 3 left). As can be seen there is a clear correlation between the flux level and photon index, with the higher emission states resulting in a harder photon index. This relationship has a Pearson product–moment correlation coefficient of $-0.9867$ at >99% confidence level. To provide a check that this result is not biased by the process used for extracting the flux from the fitted spectra (i.e., a harder spectrum will naturally result in a higher flux for a given normalization), the count rate per second for PCU 2 only was extracted for each of the flux bins used (see Figure 3 right). The Pearson product–moment correlation between the count rate and photon index is $-0.966$ at >99% confidence level.

3.2. FL1, FL2, and FL3

As with the overall light curve shown in Figure 1, the data covering the three flaring episodes were taken with varying combinations of PCUs which were combined and fit with a single spectrum. For each flare, the count rates from all PCU units were compared in order to ensure that the flaring behavior was not due to spurious electrical discharging in a single PCU unit. All PCU units showed similar count rates for the flare data, indicating that the flaring behavior was due to the source flux and not the instrumental error. It is also worth noting that none of the flare data presented here were taken near an SAA passage, therefore contamination due to this can be ruled out. The specific properties of each flare can be seen in detail in Table 3.

FL1 (MJD 54356) stands as the most powerful of the three flares observed within this data set as well as the most powerful detected from this source to date, presenting a flux of $7.2^{+0.1}_{-0.2} \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$. When analyzed in Good Xenon event mode, the data have a sufficient count per second rate to be binned in 2 s intervals (see Figure 4). As can be seen, the flux varies by up to a factor of 6 within the tens of seconds timescale. To illustrate this point and investigate the fastest doubling time within the flare, the first 100 s of the flare are zoomed in upon in Figure 4 (right). Directly after both $t = 20$ s and 60 s the count rate increases by more than a factor of 2 within the bin time of the data points, placing a flux-doubling time limit of <2 s on the X-ray emission from this source.

FL2 (MJD 54358) was observed at a flux level of $3.5^{+0.1}_{-0.2} \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$. This flux level is not as high as FL1, but is still large enough to merit closer investigation. Since the count rate is sufficiently smaller than that in FL1, the Good Xenon data shown in Figure 5 are binned in 5 s intervals. The data do not show as large variations as FL1, however it does contain several well-defined flares which rise and fall on the 10–20 s timescale. One of these episodes is shown in Figure 5 (right). FL3 (MJD 54372) was observed at a flux level of $4.9^{+0.1}_{-0.2} \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$. The flux levels are nearly as chaotic as those seen in FL1, with the X-ray varying by nearly a factor of 6 over the 100 s timescale (see Figure 6 left). The zoomed region to the right of Figure 6 shows another example of a rapid flare within the data.

To search for periodic signals in these flares, a timing analysis was carried out in the following manner: the data from the Good Xenon mode were re-extracted from PCU 2 with no quality-selection criteria (in order to maximize the temporal length of the testable data set). Although the removal of filtering criteria
4. SUMMARY

The current RXTE data set demonstrates the overall variability of the X-ray behavior of the system. Additionally, we find a strong correlation between the photon index and flux from the system. While previously believed to be an X-ray source with somewhat dependable modulation, the observations reported here show strong flares which complicate the measurement of this feature as periodic or quasi-periodic is not warranted.

The three large flares observed in this data set represent the strongest X-ray activity recorded from this system to date with luminosities exceeding \(3 \times 10^{34} \text{ erg s}^{-1}\). These flares show that the flux levels within the flare structures rise and fall by factors of up to 6 on the 100 s timescale, with doubling times as short as 2 s (FL1). Through this variability, the causal size of the emission region can be constrained to be less than \(R < c \Delta t = 6 \times 10^{10} \text{ cm}\). It should be noted that this constraint does not account for the scenario in which the emission is originating from a relativistic jet with a Doppler factor which would modify the above calculation. Since the existence of such a jet within the system is not clearly evident (and much less its Doppler factor), this modification is neglected at this time. Although rapid flaring over the kilosecond timescale has been demonstrated in both systems, the typically expected flux and spectral variations as a function of binary orbital phase. The X-ray behavior (with respect to the orbital phase) is not completely understood.

The current RXTE data set re-analyzed in phase bins of 0.1\(\phi\). The left figure shows the 2–10 keV flux vs. orbital phase, and the right figure shows the photon index as a function of orbital phase.

Table 1

| Orbital Phase (\(\phi\)) | \(\alpha\) | Flux (2–10 keV) \((10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1})\) | \(\chi^2/\text{dof}\) |
|-------------------------|--------|-------------------------------|------------------|
| 0.0 → 0.1              | 1.85 ± 0.13 | 1.26 ± 0.05                  | 47.7/14          |
| 0.1 → 0.2              | 1.90 ± 0.09 | 1.32 ± 0.04                  | 5.5/14           |
| 0.2 → 0.3              | 1.83 ± 0.12 | 1.21 ± 0.04                  | 4.9/14           |
| 0.3 → 0.4              | 1.87 ± 0.10 | 1.54 ± 0.05                  | 7.9/14           |
| 0.4 → 0.5              | 1.80 ± 0.12 | 1.24 ± 0.05                  | 6.7/14           |
| 0.5 → 0.6              | 2.29 ± 0.16 | 1.17 ± 0.05                  | 11.6/14          |
| 0.6 → 0.7              | 1.97 ± 0.13 | 1.22 ± 0.05                  | 4.0/14           |
| 0.7 → 0.8              | 2.01 ± 0.10 | 1.55 ± 0.05                  | 6.8/14           |
| 0.8 → 0.9              | 1.62 ± 0.07 | 2.03 ± 0.05                  | 5.2/14           |
| 0.9 → 1.0              | 1.96 ± 0.11 | 1.53 ± 0.05                  | 12.4/14          |

Table 2

| Flux Bin \((10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1})\) | \(\alpha\) | Average Flux (2–10 keV) \((10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1})\) | Count Rate (Counts s\(^{-1}\)) | PCU 2 |
|-----------------|--------|---------------------------------|-------------------------------|-------|
| \(F < 10\)      | 2.06 ± 0.15 | 0.79 ± 0.04                    | 0.62 ± 0.03                     |       |
| \(10 < F < 15\) | 1.97 ± 0.05 | 1.25 ± 0.02                    | 1.04 ± 0.02                     |       |
| \(15 < F < 20\) | 1.83 ± 0.08 | 1.69 ± 0.02                    | 1.37 ± 0.02                     |       |
| \(20 < F < 25\) | 1.82 ± 0.06 | 2.19 ± 0.05                    | 1.80 ± 0.05                     |       |
| \(F > 25\)      | 1.46 ± 0.07 | 4.72 ± 0.1                     | 3.83 ± 0.09                     |       |
Table 3
Properties of the Observed Flaring Episodes FL1, FL2, and FL3 as Described in the Text

| Flare  | MJD (UTC)       | Usable Data (s) | PCUs | Flux (2–10 keV) (10\(^{-11}\) erg cm\(^{-2}\) s\(^{-1}\)) |
|--------|-----------------|-----------------|------|-----------------------------------------------|
| Flare 1 | 54356 (11:09–11:25) | 528             | 2, 4 | 1.4 ± 0.1                                     |
| Flare 2 | 54358 (10:13–10:28) | 560             | 2, 3, 4 | 1.7 ± 0.1                                     |
| Flare 3 | 54372 (03:31–03:35) | 553             | 2, 4 | 1.6 ± 0.1                                     |

Note. Shown are the MJD and UTC of the observation, the usable window of observation after quality cuts, the number of PCUs operating during the observation, and the fitted photon index and integrated flux of the observation.

Figure 3. 2–10 keV flux vs. the associated photon index from the flux bins described in the text. A clear correlation between higher flux and harder spectral behavior. On the right is shown the PCU2 counts from the same bins compared to the photon index.

Figure 4. Flare 1 binned in 2 s bins (left) with \( t = 0 \) representing the beginning of the observation window. The flux increases by over a factor of 6 during 10–100 s timescales. The shaded gray region is expanded in the right figure showing the source count rate doubling in less than the 2 s bin time.

Chandra and XMM-Newton data, this is the first indication that the X-ray flux from the system varies on such a rapid scale.

We note that fast X-ray flaring behavior has been observed in binary X-ray pulsars such as IGR J16465-4507 and AX J1841.0-0536 (Lutivinov et al. 2005; Sguera et al. 2006). Following along these lines, a possible scenario which could be used to explain the available observations is the binary pulsar model of Zdziarski et al. (2008). In this scenario, the radio through TeV emission results from the interactions between the pulsar wind and a two-component Be star wind. The two components consist of a fast “clumpy” polar wind and a dense circumstellar disk. When the pulsar is close enough to the Be star to be heavily exposed to the fast polar wind, clumps of relativistic electrons in the polar wind are maintained by magnetic field inhomogeneities and are sufficiently energetic to cause mixing with the pulsar wind. Shocks between the clumps and the pulsar wind accelerate electrons which can then inverse-Compton (IC) scatter off of the Be star photons, giving rise to the highly variable X-ray emission. Clumps such as these have been observed on the scale of 10\(^{11}\) cm in 2S 0114+65 (Apparao et al. 1991), which agrees (within error) with the implied timescale for variability observed in this work. However, even if clumps are much larger than this, it is believed that the interaction between a clump and the pulsar wind will cause a flare in a region with characteristic size equal to the stand-off distance between the pulsar and equatorial stellar wind (G. Dubus 2008, private communication). At periastron passage the stand-off distance can be as small as 5 \( \times 10^{10} \) cm, which is consistent with the variability reported in this work.
On a larger timescale, the pulsar wind moves through the region of varying density of the equatorial wind. During traversal of the densest parts of the disk, X-ray emission is quenched due to Coulomb losses, and when the pulsar moves toward the more spare regions of the disk, IC losses can dominate over both Coulomb and synchrotron mechanisms, giving rise to an orbital modulation of the X-ray flux. Although this data set does not strongly indicate modulation of the X-ray flux with orbital phase (possibly due to complications from shorter timescale flares), the possibility of low amplitude modulation is still consistent with the observations reported here.

We also note that fast X-ray variability such as that reported here has been observed in good candidates for galactic black hole systems such as Cygnus X-1 (Gierlinski & Zdziarski 2003) and GRS 1915 +105 (Belloni et al. 2000); which are both known accretion driven sources. RXTE observations of the TeV binary LS 5039 (Bosch-Ramon et al. 2005a) show the photon index versus flux correlation and hourly timescale flux variations similar to what we find for LS I +61 303, but not very rapid variability. The authors interpret these results in an accretion driven scenario where a stellar wind feeds a disk around either a black hole or a neutron star and argue that the X-ray emission is caused by a population of relativistic electrons accelerated within the jet, which is in turn fed by the wind-fed accretion disk. These electrons are responsible for the observed X-ray emission via either the synchrotron process or IC scattering of local stellar photons. In this scenario, fast variations in the stellar wind are responsible for the observed “miniflares,” while sudden increases in accretion (higher flux) would also result in a higher electron acceleration efficiency in the jets. This efficiency increases results in a higher peak of the electron energy distribution, in turn resulting in a harder emission spectra. Additionally, in the model described in Bosch-Ramon et al. (2005b), they predict a jet length of $\sim10^{11}$ cm, which is consistent with the several second variability described in this work. It should be noted that no X-ray spectral signatures of an accretion disk (i.e., a blackbody spectral component) are found in LS 5039 either, further reinforcing the link between the X-ray emission of the two sources.

Recently, Swift-BAT has reported the detection of a short (0.23 s), extremely powerful X-ray burst with a luminosity of $10^{37}$ erg in the 15–150 keV energy range within the 90% containment radius of LS I +61 303 (Barthelmy et al. 2008). Follow-up observations with the Swift-XRT instrument 921 s later showed no significantly elevated flux in the 0.3–10 keV energy range ($0.92 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$). While the authors of this paper note the possibility that this emission was due to an unrelated short gamma-ray burst, they claim that the evidence is in favor of activity from a source within LS I +61 303. Dubus & Giebels (2008) submit that this burst could be evidence in favor of magnetar-like activity from a source within LS I +61 303. Although reconciling the presence of a magnetar within LS I +61
In conclusion, while neither conclusively ruling out or confirming either the microquasar or binary pulsar scenarios, the observations reported here will aid further modeling work of LS I +61 303 by the demonstrated constraint on emission region size, as well as the correlation between the flux and photon index.

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**Facilities:** RXTE.

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303 with previous X-ray observations is somewhat problematic (V. Bosch-Ramon 2008, private communication; Dubus 2008), this could be the first magnetar to be discovered within a HMXB system. If confirmed with following observations, this type of extremely powerful bursting may resolve the question of the identification of LS I +61 303.