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The Symbiotic System SS73 17 Seen with Suzaku

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Abstract

We observed with Suzaku the symbiotic star SS73 17, motivated by the discovery by the INTEGRAL satellite and the Swift BAT survey that it emits hard X-rays. Our observations showed a highly-absorbed X-ray spectrum with $N_{\rm H} > 10^{23}\,{\rm cm}^{-2}$, equivalent to $A_{\rm V} > 26$, although the source has B magnitude 11.3 and is also bright in UV. The source also shows strong, narrow iron lines including fluorescent Fe K as well as Fe XXV and Fe XXVI. The X-ray spectrum can be fit with a thermal model including an absorption component that partially covers the source. Most of the equivalent width of the iron fluorescent line in this model can be explained as a combination of reprocessing in a dense absorber plus reflection off a white dwarf surface, but it is likely that the continuum is partially seen in reflection as well. Unlike other symbiotic systems that show hard X-ray emission (CH Cyg, RT Cru, T CrB, GX1+4), SS73 17 is not known to have shown nova-like optical variability, X-ray flashes, or pulsations, and has always shown faint soft X-ray emission. As a result, although it is likely a white dwarf, the nature of the compact object in SS73 17 is still uncertain. SS73 17 is probably an extreme example of the recently discovered and relatively small class of hard X-ray emitting symbiotic systems.

Key words: stars:binaries:symbiotic, stars:individual (SS73 17), X-rays: stars

1. Introduction

SS73 17 has long been known as a moderately bright (V$\sim$ 10) symbiotic star — until recently, undistinguished from many other such systems (Sanduleak & Stephenson 1973)(SS73). ROSAT observations from 1992 showed the source was a faint ($F_X(0.5-2\,{\rm keV}) = 3.6\times10^{-13}$ erg cm^{-2}s^{-1}) soft X-ray source (Bickert et al. 1996), but beyond that little was known at UV or higher energies. In 2005, however, this system was independently discovered to be a hard X-ray source by both INTEGRAL (IGRJ10109-5746; Revnivtsev et al. (2006)) and Swift (Swift J101103.3-574814; Tueller et al. (2005)). Before these sources were identified as being associated either with each other or with *SS73 17*, we successfully proposed for *Suzaku* observations of the Swift source, with the goal of finding potential members of the newly-identified class of "highly-absorbed X-ray binaries" discovered by INTEGRAL (Kuulkers 2005). Our choice of Swift J101103.3-574814 was driven by its hard X-ray flux, as seen by the Swift BAT ($F_X(20-60{\rm keV}) = 1.6\times10^{-11}$ ergs cm^{-2}s^{-1}), and its low Galactic latitude ($l,b = 282.9°, -1.3°$).

Although Tueller et al. (2005) noted that this source is only 30′ from GRO J1008-57, a transient XRB with a pulse period of 93.6 s, ROSAT PSPC observations which also detected the pulsations confirmed GRO J1008-57's position to within 15″ (Petre & Gehrels 1993). Based on the Swift XRT and ROSAT PSPC data, we can be confident that SWIFT J1010.1-5747, IGR J10109-5746 and *SS73 17* are all names for a single symbiotic system that is distinct from GRO J1008-57.

A symbiotic star consists of a red giant and a hot blue companion, frequently a white dwarf accreting material from the red giant wind (Kenyon 1986). Although many symbiotic stars emit soft X-rays (Mürset et al. 1997), only small number of those with white dwarf companions are known to emit hard X-rays, including CH Cyg (Ezuka et al. 1998), RT Cru (Masetti et al. 2006), and T CrB (Tueller et al. 2005). In addition to hard X-rays, each of these have also shown optical flares or novae at some point (Deutsch et al. 1974; Masetti et al. 2005; Cordova & Mason 1984). Another type of symbiotics, the "symbiotic low mass X-ray binaries," with M giant/neutron star systems such as GX1+4 and 4U1954+31 (Mattana et al. 2006) also shows hard X-ray emission, frequently with a periodicity of minutes to hours. *SS73 17* is particularly intriguing because it could *only* be identified as unusual in hard X-rays, since its soft X-ray emission is nondescript. Its optical emission history is patchy, appearing in catalogs roughtly every few decades since its initial listing as CD-57 3057. If in fact it has little optical variability, *SS73 17* may be first example of a new class of symbiotic/X-ray binary that has a significant hard X-ray flux **without** significant soft X-ray emission or optical outbursts.

2. Previous Observations

SS73 17 was listed as an "interesting" star in the SS73 catalog, where it was described as a M3ep + OB binary system. Henize (1976) noted the star shows Balmer lines in emission through H 10. Subsequently, Pereira, Franco & Araújo (2003) obstained spectra from a number of SS73 stars, and identified *SS73 17* as a Mira-type system, including a normal-type M4 giant star, with emission lines of Hα and Hβ along with TiO absorption bands. They suggested that Henize's observations were likely done at object maximum phase, since they did not see such strong emission lines. Although not observed by IUE, we now know that the source is UV bright as it saturates the Swift UVOT, with UVW1 magnitude greater than 11.3 ± 1.09.

The optical survey of variable stars by Pojmanski (2003) found weak evidence for a 577 day period for *SS73 17*, with V magnitude variations between 9.68-9.89. Unlike other hard X-ray symbiotic systems (CH Cyg, RT Cru, T CrB), *SS73 17* has not shown any sign of a optical brightening or "slow nova" in its sparse historical record. The distance to *SS73 17* is not known, although it was observed by the Hipparcos satellite as part of the Tycho catalog. The measured parallax was 94.9 ± 30.2 mas ($10.5^{+4.9}_{-2.5}$ pc), but this value is not credible for an M4III star with $V \sim 9.7$. Allen (2000)(p.406) notes that the absolute V magnitude of Mira variables is $\approx 0.0040P - 2.6$. For P=577 days, this corresponds to $M_V = -0.3$, or a maximum distance (assuming no absorption) of 1 kpc. The line of sight absorption to *SS73 17* is also unknown, but assuming the M giant dominates emission in the J and K bands, $E(J-K) = 0.56$ and $A_V \approx 3.3$ (Allen 2000)(p.158), equivalent to $N_H \approx 6 \times 10^{21}\,cm^{-2}$, implying a distance of ~ 220 pc. Finally, *SS73 17* is ~ 1.5 mag fainter than the apparently similar CH Cyg system (at $D = 245 \pm 50$ pc, Perryman et al. (1997)), suggesting a distance of 500 pc. We combined these results to estimate *SS73 17*'s distance to be 500^{+500}_{-250} pc.

As noted above, *SS73 17* was observed both by the ROSAT All-sky survey and in a 7 ksec pointed observation. EXOSAT also observed a field containing *SS73 17* with the Medium Energy detector, finding $F_X(2-10\mathrm{keV}) \sim 10^{-11}$ erg cm^{-2}s^{-1} for a absorbed spectrum hotter than 3 keV with $N_H \sim 1-5 \times 10^{22}\,cm^{-2}$. The EXOSAT observation also showed that the source did not show any strong variability during the 5 hour observation.

3. Observations and Analysis

SS73 17 was observed by *Suzaku* for 20 ksec on June 5, 2006 (obsid 01055010). The pointing direction was chosen to center the source on the HXD detector, which has the effect of reducing the effective area of the XIS detectors by 10% due to vignetting. All four XIS detectors were in standard imaging mode. The data were processed using version 1.2 of the standard *Suzaku* pipeline software.

We extracted all events within 4.34′ of *SS73 17* for each of the four XIS detectors to create the source spectra. The lightcurve of both the XIS and HXD events showed no sign of flares either in the complete event list or the source events, so all events were kept. We generated response matricies for the XIS detectors using version 2007-05-14 of `xisrmfgen`, and used the standard effective area files for HXD-nominal pointings using a 6 mm (4.34′) extraction circle[1]. The XIS background data was taken from a circular region with no apparent sources that was offset from both the source and the corner calibration sources.

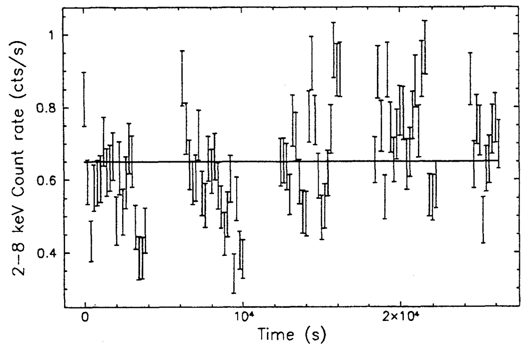

Fig. 1. *Suzaku* XIS (all 4 coadded) lightcurve between 2-8 keV; the average rate is shown as a straight line. Although some short term variability is seen, there are no obvious periodicities.

The source was not bright enough to appear in the HXD GSO, so we only consider the HXD PIN detector in this paper. Since the observation was done after the W0 PIN diode voltage was reduced to 400V from 500V but before this mode was calibrated, we eliminated these events from our dataset and used only the W123 events[2]. We then used the PIN response matrix appropriate for the W123 diodes, correcting for dead time using the `hxddtcor` routine. We used the PIN background events file (v1.2) generated by the Suzaku HXD team[3] to make the PIN non-X-ray background (NXB) spectrum. The cosmic X-ray background was included in the spectral modeling itself, at the level found by Boldt (1987).

4. Results

Figure 2 shows *SS73 17*'s X-ray spectrum as observed by the *Suzaku* XIS and HXD and demonstrates its primary features:

1. weak emission below 2 keV
2. a strongly absorbed hard X-ray spectrum
3. three narrow, strong emission lines at 6.38, 6.66, and 6.98 keV.

Suzaku's energy calibration between 6-8 keV is accurate to ± 6 eV (Koyama et al. 2007), so the three emission lines can be identified as an iron K fluorescence line as well as Fe XXV and Fe XXVI emission. However, the exact position and strength of the lines depends upon the shape of the underlying continuum. In addition to the spectral analysis, we show *SS73 17*'s lightcurve (between 2-8 keV)

1 Available at ftp://legacy.gsfc.nasa.gov/caldb/data/suzaku/xis/cpf/ae_xi{0,1,2,3}_hxdnom6_20060615.arf
2 See http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/pinbias.html
3 Available at http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/pinnxb/pinnxb_ver1.2_w123/401055010/ae401055010hxd_pinnxb_cl.evt.gz

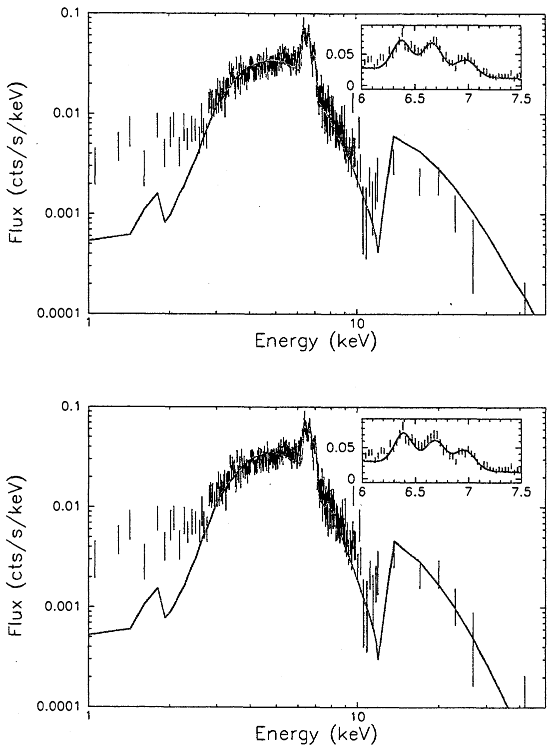

Fig. 2. [Top] *Suzaku* XIS (all 4 coadded) and HXD PIN background-subtracted spectra between 1-50 keV, with best-fit absorbed power law plus three emission lines model. The inset spectrum shows the 6-8 keV range where the iron lines appear. [Bottom] Same, for an absorbed thermal model plus a single emission line to reproduce the 6.4 keV Fe fluorescence line. In both cases, the soft emission is not reproduced by the model.

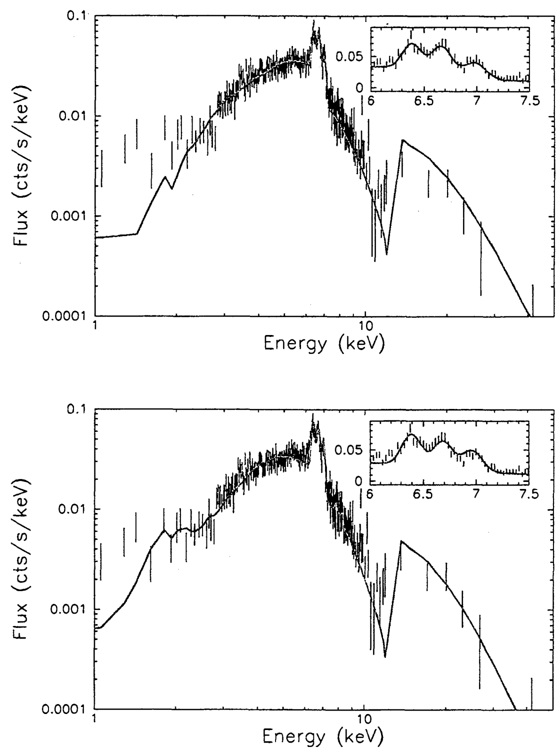

Fig. 3. [Top] *Suzaku* XIS (all 4 coadded) and HXD PIN background-subtracted spectra between 1-50 keV, with best-fit model that includes both a normal and a partial-covering absorber model combined with a power law and three emission lines model. The inset spectrum shows the 6-8 keV range where the iron lines appear. The soft emission is not well-modeled. [Bottom] Same, for an similarly-absorbed thermal model with a single additional emission line to reproduce the 6.4 keV Fe fluorescence line.

in Figure 1. The background-subtracted count rate averaged 0.7 cts/s, fluctuating between 0.5-1 cts/s without an apparent period. This stability is similar to what was seen in the earlier EXOSAT ME observation, and suggests that the accretion process creating the X-ray emission is relatively steady.

We considered four different models for the X-ray spectrum, based on both a synchrotron (power law) origin and a thermal model for the continuum emission. The synchrotron model assumes that the emission comes from relativistic electrons near the compact object, perhaps emitted as a yet-unseen jet. In contrast, the thermal model supposes that the emission is due primarily to a hot stream of accreting material falling onto the compact object. In both cases we added a Gaussian to model the iron fluorescence line, which presumably arises from a combination of fluorescence in the absorbing material and scattering from the surface of the hot star or in the accretion disk. In the power law model, we also added two additional Gaussians to model the Fe XXV and Fe XXVI emission features. In the thermal model we assumed these latter two lines arose from the plasma itself. All four models included at least one absorption component; we also considered models with a second absorber that only partially covered (noted with "PC" in Table 1) the source. This second absorber is motivated by the low interstellar absorption ($A_V \approx 3.3, N_H \approx 6 \times 10^{21}\,\mathrm{cm}^{-2}$) to the Mira variable companion, which strongly suggests the X-ray absorption is extremely local to the X-ray source in the binary system. The soft X-ray emission seen from *SS73 17*, which is only well-fit by the partial-covering thermal model, amounts to $F_X(0.5-2) = (2.3^{+0.9}_{-0.6}) \times 10^{-14}$ erg cm^{-2}s^{-1} when fit with a simple thermal model absorbed with the Galactic emission. This soft flux is an order of magnitude fainter than either the ROSAT all-sky or pointed observation result, although these are rather uncertain values as only ~ 200 total counts were observed (Bickert et al. 1996). The soft X-ray variation suggests the partial absorber periodically changes to allow more photons to escape the system, evidence that the local absorber does not enshroud the X-ray source. Our results for all four models are shown in Figures 2 and 3 and in Tables 1 and 2 for the model parameters and iron line strengths, respectively. All quoted errors show 90% confidence intervals. Assuming a distance of $0.5^{+0.5}_{-0.25}$ kpc, the $F_X(2-10\mathrm{keV}) \approx 8.5 \times 10^{-12}$ absorbed flux implies a luminosity of $L_X(2-10) = (0.6-10) \times 10^{32}$ erg/s. The unabsorbed flux depends upon the model used; in the "Abs PC TH" case, it is $(1.5-23)\times10^{32}$ erg/s.

The high energy ($E=10-50$ keV) result from the PIN is at the limit of detectability, but is in line with other results. INTEGRAL detected with source with significance $\sigma=5.57$ and $F_X(17-60)=1.3\pm0.3$mCrab (Revnivtsev et al. 2006). We find (using the partial covering thermal fit) $F_X(17-60)=(1.16\pm0.04)\times10^{-11}$ ergs cm^{-2}s$^{-1}\approx$ 1 mCrab. The Swift BAT detection of the source found $F_X(20-60)=1.6\times10^{-11}$ ergs cm^{-2}s$^{-1}\approx1.4$ mCrab, in line with both results. Any differences between our results and those of INTEGRAL and Swift are well within the systematic uncertainties in the PIN background subtraction (which are at the $\sim5\%$ of background level, or ≈0.6 mCrab).

5. Discussion and Conclusions

Mürset et al. (1997) classified 16 symbiotics seen with ROSAT into three types: (1) supersoft emission from the atmosphere of the hot star, (2) emission from an optically-thin plasma with $kT\sim0.2$ keV, or (3) an ill-defined catch-all of relatively hard X-ray sources. They found only two sources in class (3), the X-ray binary GX1+4 and Hen 3-1591 (which they suspected might also contain a neutron star). Although not in the Mürset et al. (1997) survey, the ROSAT observation of *SS73 17* suggests it would likely have been placed in category (2), albeit with some uncertainty due to the large column density ($N_H=1.8\times10^{22}$ cm^{-2}) required to fit the ROSAT data.

However, subsequent X-ray observatories have discovered hard X-rays from the symbiotic systems CH Cyg, RT Cru, T Crb in addition to *SS73 17* (Kennea et al. 2007) whose emission does not fit with the physical mechanisms described by Mürset et al. (1997). Curiously, the X-ray spectrum of *SS73 17* above 2 keV appears be quite similar to the Polar magnetic Cataclysmic Variable (mCV) star AM Her. Ezuka & Ishida (1999) fit the 1993 ASCA observation of AM Her using an Abs PC bremsstrahlung model, finding $kT=10.0$ keV with $58\pm10\%$ of the source absorbed by a column density of $(36\pm7)\times10^{22}$ cm^{-2}, $20\pm3\%$ absorbed with a column density of $(3.6\pm0.6)\times10^{22}$ cm^{-2}, with the remaining area effectively unabsorbed. The fluorescent iron line equivalent width in this model was 0.17 ± 0.04 keV, and the bolometric luminosity of the system was $L_X(2-10)=1.4\pm0.1\times10^{32}$ ergs/s. These parameters are quite similar to our Abs PC TH model, with the (significant) change that the 20% moderate absorption seen in AM Her is 100% in the case of *SS73 17.* Of course, unlike the wide separation in symbiotic systems, CVs are close binaries which show classical nova outbursts (Ibin & Tutukov 1996). However, the similarity of the hard X-ray emission seen in *SS73 17* and AM Her suggests that the underlying accretion processes are related in this object.

The Kennea et al. (2007) study of symbiotic systems seen by the Swift BAT (which includes *SS73 17*) showed that these spectra usually showed X-ray absorption that exceeded the optical extinction by orders of magnitude, as was found here as well. Kennea et al. (2007) found a good fit to the *Swift* XRT and BAT spectra using a fit similar to our absorbed partial covering thermal model ("Abs PC TH"), with a best-fit temperature similar to ours, although with a somewhat higher partial covering fraction and somewhat lower local absorption. The *Swift* XRT data they used could only constrain a single iron line at 6.61 keV with width $0.18^{+0.21}_{-0.11}$ keV, which they noted was likely the sign of blended lines. Our deeper observation shows this is in fact the case, as *Suzaku* can easily resolve the three lines.

The three iron emission lines visible in Figures 2 and 3 are all strong and narrow; none of our fits require broadening beyond the instrumental resolution. Although the Fe XXV and Fe XXVI lines can be understood in the thermal models as due to the hot plasma, the Fe K 6.4 keV line must be generated via fluorescence. Ezuka & Ishida (1999) showed that an 10 keV bremsstrahlung source embedded in an absorber will generate (due to absorption and fluorescence into the line of sight) a predicted equivalent width of the Fe K line of 0.67 ($N_H/10^{24}$cm^{-2}) keV. Using this result with the "Abs PC TH" case (including both absorption components), we find an equivalent width of 0.13 keV. In addition, there may also be fluorescence due to reflection from the surface of the compact object (assumed here to be a white dwarf). In this case, George & Fabian (1991) calculated that a 10-20 keV bremsstrahlung reflector subtending a 2π solid angle would generate an equivalent width of 0.1 keV, assuming an observed angle to the reflecting surface of 60°. We thus get a total equivalent width of 0.23 keV, similar to (but still less than) the actual value of $0.26^{+0.06}_{-0.04}$ keV. We also note that this calculation assumes that the reflected emission line is not absorbed before escaping, making this result an upper limit. It seems therefore that the continuum around 6.4 keV is at least partially reflected, so our spectral models (which do not include reflection) are incomplete.

With the existing data, we cannot distinguish (statistically) between the power-law and thermal models after including a partial absorber. Figure 3 shows that the weak soft X-ray emission is much better fit with the thermal model, although between 3-5 keV the power-law model provides a better description. Physically, the thermal model represents an accretion column falling from the accretion disk onto the surface of the white dwarf. This column is likely to have a range of temperatures peaking around our single-temperature value (Ezuka & Ishida 1999). Including a distribution of lower temperatures which would improve the 3-5 keV fit, although more complex models are not justified with the existing data. In similar systems, such as the symbiotic CH Cyg, the thermal origin of the plasma is confirmed by multiple emission lines from ions such as Mg, Si, and S at lower energies than the iron features. The strong absorption seen here obscures these lines; a longer or higher resolution observation is needed to determine if in fact they are present.

The *lack* of soft X-ray emission seen in *SS73 17*, as compared to CH Cyg, is also interesting. Although similar to *SS73 17* in hard X-rays, CH Cyg is $10-100\times$ brighter

Table 1. Spectral Fit Results

Model	$N_{\rm H}$ $10^{22}\,{\rm cm}^{-2}$	Covering Fraction	$N_{\rm H}$ $10^{22}\,{\rm cm}^{-2}$	kT keV	Γ	χ^2_ν	$F_X(2-10)$ 10^{-12} erg cm^{-3}s
Abs PL	15.8 ± 1.1	...	...	...	1.78 ± 0.04	1.3	$8.4^{+0.4}_{-1.1}$
Abs TH	16.3 ± 0.7	...	...	9.3 ± 0.5	...	1.3	$8.5^{+0.1}_{-1.9}$
Abs PC PL	10.7 ± 2.0	85 ± 2	41^{+10}_{-7}	...	2.6 ± 0.1	1.2	$9.1^{+0.1}_{-3.6}$
Abs PC TH	3.5 ± 1.4	92^{+3}_{-5}	18 ± 1.5	9.4 ± 0.5	...	1.2	8.5 ± 0.2

Table 2. Emission Lines from *SS73 17*

Model	Fe K		Fe XXV		Fe XXVI	
	Flux (10^{-5} ph cm^{-2}s^{-1})	Eq. Width keV	Flux (10^{-5} ph cm^{-2}s^{-1})	Eq. Width keV	Flux (10^{-5} ph cm^{-2}s^{-1})	Eq. Width keV
Abs PL	6.8 ± 0.6	0.25 ± 0.05	7.1 ± 0.6	0.23 ± 0.05	3.7 ± 0.5	0.17 ± 0.05
Abs TH	$7.1^{+0.7}_{-0.5}$	0.27 ± 0.05	...	...	...	...
Abs PC PL	9.5 ± 1.5	$0.19^{+0.06}_{-0.03}$	9.2 ± 1.3	$0.19^{+0.06}_{-0.04}$	4.1 ± 0.8	$0.12^{+0.07}_{-0.05}$
Abs PC TH	$7.7^{+0.05}_{-0.8}$	$0.26^{+0.06}_{-0.04}$	...	...	...	...

than *SS73 17* in the soft (0.5-2.0 keV) X-ray band (Mukai et al. 2007). Wheatley & Kallman (2006) showed that this soft X-ray emission from CH Cyg could be explained as scattering in the ionized absorbing material surrounding the hard X-ray source. Their model is similar to that of a Seyfert 2 galaxy, with a hard X-ray source surrounded by an edge-on torus of neutral material with an ionized absorber above and below the torus. This anisotropic absorber removes any direct soft X-rays, but soft X-rays emitted in other directions are still scattered into the line of sight by a nearby absorber photoionized by the hard X-rays emitted by the system. The most significant difference between their hard X-ray model and ours is that the partial covering fraction was $66 \pm 4\%$ rather than our value of $\geq 85\%$. Possibly in the case of *SS73 17* the soft X-rays are simply absorbed by more distant neutral material, or there is no ionized absorbing material above the accretion disk. In the former case, however, the relatively low Galactic absorption of the system suggests this neutral material must still be quite near the compact object.

Our initial observation of this source was done in the hope of discovering a new "highly-absorbed X-ray binary" of the type described by Kuulkers (2005), and was driven by its BAT detection and location near the Galactic plane. Unlike the other symbiotic systems that emit hard X-rays, *SS73 17* has apparently not shown any signs of nova activity in the optical in the 100+ years since its first description (although we emphasize that published observations have been rather intermittent), and it has always shown weak soft X-ray emission, particularly in our observation. We cannot confirm the nature of the companion, although it seems likely it is a white dwarf based on the relatively low luminosity and iron lines similar to other white dwarf symbiotics. However, *SS73 17* may be the first example of a system with significant Fe K emission lines **without** significant soft X-ray emission or optical outbursts. This characteristic is potentially important in explaining the Galactic ridge X-ray emission (GRXE) which includes a hard continuum with broad fluorescent Fe K, Fe XXV, and Fe XXVI iron lines in the ratio 1:1.18:0.38 (Koyama et al. 1996). Mukai & Shiokawa (1993) as well as Revnivtsev et al. (2006); Revnivtsev et al. (2006) have suggested that the continuum emission from the GRXE could be due to dwarf novae and coronally-active stars, but did not explain the observed iron lines. The ratio of the three iron lines strengths in *SS73 17* is 1:1:0.63 (errors of $\sim 15\%$). If a large number of as-yet undiscovered sources like *SS73 17* are common in the Galactic ridge, they could explain the origin of its line emission as well.

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