SUZAKU OBSERVATIONS OF THE GALACTIC CENTER MICROQUasar 1E 1740.7−2942

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ABSTRACT

We present two Suzaku observations of the Galactic center microquasar 1E 1740.7−2942 separated by approximately 700 days. The source was observed on both occasions after a transition to the spectrally hard state. Significant emission from 1E 1740.7−2942 is detected out to an energy of 300 keV, with no spectral break or turnover evident in the data. We tentatively measure a lower limit to the cutoff energy of ~380 keV. The spectra are found to be consistent with a Comptonized corona on both occasions, where the high energy emission is consistent with a hard power-law ($\Gamma \sim 1.8$) with a significant contribution from an accretion disk with a temperature of $\sim0.4$ keV at soft X-ray energies. The measured value for the inner radius of the accretion disk is found to be inconsistent with the picture whereby the disk is truncated at large radii in the low-hard state and instead favors a radius close to the ISCO ($R_{\text{in}} \sim 10 - 20 R_g$).

Key words: accretion, accretion disks – black hole physics – X-rays: binaries – X-rays: individual (1E1740.7−2942)

Online-only material: color figures

1. INTRODUCTION

Since the discovery of apparently super-luminal jets from the X-ray binary GRS 1915+105 (Mirabel & Rodriguez 1994), the Galactic microquasars have assumed a position of critical importance in our efforts to understand accretion physics and relativistic jet production (Mirabel 1999). 1E 1740.7−2942 was discovered by the Einstein satellite (Hertz et al. 1984). Subsequent observations revealed 1E 1740.7−2942 to be the dominant source of hard X-rays (>20 keV) in the direction of the Galactic center (Skinner et al. 1987, 1991), where the source is located approximately 50' from Sgr A*. The microquasar nature of 1E 1740.7−2942 was discovered upon the observation of a double-sided radio jet consistent with the X-ray position (Mirabel et al. 1992). Further VLA observations showed this radio source to be highly variable (Heidl et al. 1994).

Since its discovery 1E 1740.7−2942 has been observed on numerous occasion at X-ray wavelengths. The column density toward this source is high given the proximity to the Galactic center and has been measured by Chandra to be $\sim1 \times 10^{23}$ cm$^{-2}$ (Gallo & Fender 2002). Here, the spectrum was found to be consistent with a power law ($\Gamma \sim 1.4$). INTEGRAL low-hard state (LHS) observations have detected 1E 1740.7−2942 up to energies of $\sim600$ keV, where the spectrum is found to be consistent with a power law ($\Gamma \sim 1.6$) up to 200 keV, with an additional component required at higher energies (Bouchet et al. 2009; see also Del Santo et al. 2005 for earlier INTEGRAL/RXTE observations). In the high-soft state (HSS), the hard X-ray flux decreases significantly, dropping below the INTEGRAL detection limit at energies $>50$ keV (Bouchet et al. 2009). Smith et al. (2002) reported on five years of RXTE monitoring, where they discovered a modulation with a period 12.73 ± 0.05 days which is attributed to the orbital period of the binary, in addition to a possible super-orbital modulation with a period of $\sim600$ days.

As the extinction at optical wavelengths is prohibitive ($A_v \sim 50$), counterpart searches must take place in the infrared. While a number of candidate counterparts have been identified (Marti et al. 2000; Eikenberry et al. 2001), no variability has been observed from these, rendering them unlikely to be the actual counterpart. The current upper limit for the $K_v$-band magnitude of the counterpart is $\sim19.9$ at the 95% confidence level. This is equivalent to a secondary spectral type of O or B if on the main sequence or K if a giant, at an assumed distance of 8.5 kpc.

In this paper, we describe observations undertaken with the Suzaku X-ray observatory, while 1E 1740.7−2942 was in the LHS. In Section 2, we describe the observations and extraction of source spectra. We analyze the data in Section 3. In Section 4, these results are compared to observations of other microquasars in the hard state, and finally our conclusions are presented in Section 5.

2. OBSERVATIONS

1E 1740.7−2942 was observed on two separate occasions while in the LHS by Suzaku (Mitsuda et al. 2007) from 2006 October 9 02:20 UT until 13:39 UT (ObsID: 501050010, PI: K. Koyama, epoch I) and from 2008 September 8 09:08 UT until 9 21:33 UT (ObsID: 503011010, PI: K. Koyama, epoch II), see Figure 1. Data were acquired over a broad spectral range (0.2–600 keV), with the X-ray imaging spectrometer (XIS; Koyama et al. 2007a) and the hard X-ray detector (HXD; Takahashi et al. 2007; Kokubun et al. 2007). The source was observed at the XIS nominal position for total uncorrected exposure times of $\sim22$ ks and 18 ks (epoch I) and $\sim58$ ks and 37 ks (epoch II) for the XIS and HXD detectors, respectively.

All data reduction and analysis take place within the HEASOFT 6.6.1 environment, which includes FTOOLS 6.6, SUZAKU 11, and XSPEC 12.5.0. The latest versions of the relevant Suzaku CALDB files were also used.

2.1. X-ray Imaging Spectrometer

The XIS has a field of view (FoV) of $\sim18' \times 18'$ (1024$^2$ pixels) and was operated in 5 × 5 and 3 × 3 readout mode. In addition, the data were taken in full window mode providing a time resolution of 8 s. The raw data were processed following
standard procedures (for details see Suzaku abc guide). Photon pile-up was not an issue during these observations, so a circular extraction region of radius 250 pixels was utilized (250 pixels is the recommended radius to extract ≈99% of a point source flux). In both observations 1E 1740.7–2942 is located close to the edge of the detector; hence, our extraction region is the intersection of the detector edge and the circular aperture. The resultant extraction region has an effective area equivalent to ≈95% of the 250 pixel radius, and hence we expect to have detected a commensurate percentage of the total source flux in the soft X-ray band (<10 keV). Background spectra were extracted from a neighboring region of the detector. Response files were generated using the tasksxisrmfgen were extracted from a neighboring region of the detector.

Figure 1. Swift BAT hard X-ray lightcurve for 1E 1740.7–2942 from 2005 May to 2009 January, only exposures greater than 1 ks are plotted. The times of the Suzaku observations presented in this paper are indicated. (A color version of this figure is available in the online journal.)

Figure 2. Spectrum of the soft X-ray background toward 1E 1740.7–2942. XIS1 data are displayed below 5 keV (black), with data from XIS3 displayed above 5 keV (red). A number of prominent emission lines are clearly detected (see text and Table 1). (A color version of this figure is available in the online journal.)

3. ANALYSIS AND RESULTS

3.1. Soft X-ray Background

X-ray observations of the Galactic center have revealed a diffuse X-ray emission component—the Galactic center diffuse X-ray emission (GCDX; e.g., Koyama et al. 2007b, 2007c). Observations with Suzaku have revealed this emission to be consistent with emission from a collisionally ionized plasma with a temperature of 5–7 keV. A number of distinct atomic emission lines have been observed from this plasma. In particular, emission from the iron lines Fe I Kα, Fe XXV Kα, and Fe XXVI Kα has been resolved (Koyama et al. 2007c). As such, it is important that we account for any contamination from the GCDX in our 1E 1740.7–2942 spectrum.

In Figure 2, we plot the background spectrum extracted from the 1E 1740.7–2942 epoch II spectra. Here due to the different sensitivities of the front illuminated (XIS1) and back illuminated (XIS0, XIS3) detectors in the XIS, we use the data from XIS1 for the low energy band (<5 keV) and the data from XIS0, XIS3 above this. A number of lines from the GCDX are clearly detected, the line parameters are listed in Table 1. The ratio of the fluxes for the Fe lines are consistent with those measured toward the Galactic center (Yamauchi et al. 2008).

3.2. Broadband Spectra

As the extinction is high, we do not detect any significant flux below 2 keV in either epoch. In Figure 3, we plot the spectra extracted from the epoch II data along with their associated background spectra. Assuming that the systematics in the GSO background are understood at the <2% level (Fukazawa et al. 2009), 1E 1740.7–2942 is detected out to ~300 keV. For reference, at a systematic level of 3% the flux
from 1E 1740.7–2942 is equal to that of the background at 300 keV.

1E 1740.7–2942 resides in a crowded region of the Galactic plane; as such, it is important to check for contamination from nearby sources. Fortuitously, the Galactic center was, and continues to be, observed by INTEGRAL, as part of the Galactic bulge monitoring program, e.g., Kuulkers et al. (2007). This area was observed within a couple of days of the Suzaku observations presented in this paper (revolution 488, 721), and these observations provide us with flux measurements for other sources that were bright at hard X-ray energies during our observations.

On both occasions 1E 1740.7–2942 was the dominant bright hard X-ray source in this field. The nearest bright X-ray source, 1A 1742–2942, was active during the first observation only. However, this system lies 31° from 1E 1740.7–2942 which was approximately centered in the HXD FoV, and hence lay outside our FoV during the observations presented in this paper. As such, below 100 keV we only detect flux from 1E 1740.7–2942. We are unable to rule out the presence of contaminating flux above this energy as there are a number of sources that were bright at hard X-ray energies during our observations.

Figure 3. Background subtracted XIS, PIN, and GSO spectra and their associated background spectra. 1E 1740.7–2942 is detected between 2 and 300 keV, with the low-energy cutoff due to the high column density toward this source. The XIS detects the source between energies of 2–10 keV, the PIN detects it out to 70 keV, while the GSO detects flux to ∼300 keV assuming the background is reproducible to an accuracy of <2% (see text).

(A color version of this figure is available in the online journal.)

Figure 4. Best fit to the epoch II spectrum, consisting of Comptonization modified by absorption with a variable iron abundance, zvfeabs*bmc, $\chi^2 \sim 1.04$. The thermal component temperature is $\sim 0.36$ keV, and the photon index is $\sim 1.8$, see Table 2. The XIS, XIS1, and XIS3 spectra are indicated by the black, red, and green points respectively, while the PIN (blue) and GSO (light blue) are also plotted.

(A color version of this figure is available in the online journal.)

extinction (i.e., pha*po). The fit is found to be a poor one ($\chi^2 \sim 1.45$) with large residuals present at higher energies. To account for these residuals, we considered two additional power-law models: a model with a cutoff at high energies (cutoffpl) and a broken power law (bknpo). The cutoffpl provides a significant improvement over the power-law model alone $\chi^2 \sim 1.16$, with the cutoff energy found to be $\sim 150$ keV (epoch II). The broken power law provides the best fit to the data $\chi^2 \sim 1.04$, with the spectrum observed to break from a very hard power law, $\Gamma \sim 1.4$, to a softer power law, $\Gamma \sim 1.8$, at an energy of approximately 7 keV. This clearly points toward a second component at low energies in the observed spectrum, with the most obvious culprit being thermal emission from a geometrically thin optically thick accretion disk (Shakura & Sunyaev 1973), see Table 2 for the detailed fit model parameters.

3.2.1. Power-law Models

The resultant spectrum (2–300 keV) was initially fit with a model consisting of a power-law modified by interstellar extinction (i.e., pha*po). The fit is found to be a poor one ($\chi^2 \sim 1.45$) with large residuals present at higher energies. To account for these residuals, we considered two additional power-law models: a model with a cutoff at high energies (cutoffpl) and a broken power law (bknpo). The cutoffpl provides a significant improvement over the power-law model alone $\chi^2 \sim 1.16$, with the cutoff energy found to be $\sim 150$ keV (epoch II). The broken power law provides the best fit to the data $\chi^2 \sim 1.04$, with the spectrum observed to break from a very hard power law, $\Gamma \sim 1.4$, to a softer power law, $\Gamma \sim 1.8$, at an energy of approximately 7 keV. This clearly points toward a second component at low energies in the observed spectrum, with the most obvious culprit being thermal emission from a geometrically thin optically thick accretion disk (Shakura & Sunyaev 1973), see Table 2 for the detailed fit model parameters.

Inspection of the residuals from this model reveals a number of features in the XIS spectral range. At low energies (2–3 keV), there remains a feature consistent with the expected position of the S XV line (2.45 keV), in addition to the presence of known systematic features in the 2.1–2.4 keV region. At energies 9–10 keV there is an unidentified residual (in the form of an excess possibly due to the background although its actual origin is unclear), as such in all further modeling both of these regions are ignored.

A large residual also exists at energies above the iron K absorption edge ($E = 7.11$ keV). It is clear that we must accurately account for this spectral feature. To do this we use the variable iron abundance absorption model available in xspec - zvfeabs. The absorption edge energy was frozen at 7.11 keV (allowing it to vary does not significantly improve the fit). As there exists a degeneracy in this model between the hydrogen column density and the metal/iron abundance, $N_{\text{H}}$ was frozen at a value of $1 \times 10^{22}$ cm$^{-2}$ in agreement with the previously determined Chandra value (Gallo & Fender 2002).

A blackbody accretion disk was now added to the power-law models above (e.g., zvfeabs*(diskbb+po)) and the fitting was repeated. The resulting fit is significantly improved and is equal to the broken power-law model (see Table 2). In this case, there is no difference between the cutoff power-law and
power-law models. However, the cutoff energy for both epochs pegs at the xspec hard limit of 500 keV, formally we find a lower limit for the cutoff energy of ~340 keV and ~390 keV at the 90% confidence level in epochs I and II, respectively. It is rare that spectral breaks are restricted to such high energies at the 90% confidence level in epochs I and II, respectively. It is rare that spectral breaks are restricted to such high energies at the 90% confidence level in epochs I and II, respectively. It is rare that spectral breaks are restricted to such high energies at the 90% confidence level in epochs I and II, respectively.

We note that due to the higher S/N ratio of the accretion disk inner radius is calculated assuming a distance of 8.5 kpc, additionally the inclination dependence of \((\cos i)^{-1}\) has not been included.

Likewise in order to investigate the possible contribution due to disk reflection at higher energies (20–40 keV), the best-fit power law from above was convolved with the reflection model of Magdziarz & Zdziarski (1995) \textit{reflect+po}. This model was then relativistically blurred (\textit{kdblur}) to account for the proximity of the accretion disk to the ISCO as indicated above. The inclination was held fixed (\(\cos i = 0.45\)), while the abundances of metals were tied to those of the absorption component. Any reflection fraction is negligible (\(f \sim 1\%)\). Formally, we find an upper limit for disk reflection of 10% at the 90% confidence level.

Ueda et al. (2009) have detected numerous absorption lines, in particular Fe xxv, xxvi, attributed to a disk wind in soft state observations of the microquasar GRS 1915+105. Earlier hard state observations by Lee et al. (2002) had also detected some of these lines; however, they were significantly weaker. Here we test for the presence of narrow Gaussian absorption lines in the Fe region of the spectrum. No significant absorption lines are detected, at the 90% confidence level we place an upper limit on the EW of any absorption line of \(<3\) eV.

We note that due to the higher S/N in the second epochs data, this fit provides tighter spectral constraints, which nonetheless are consistent with those from epoch I within the errors.

### 3.2.2. Comptonization Models

To investigate the Comptonizing medium/region, we use the bulk motion Comptonization model—\textit{bmc} (Titarchuk et al. 1997). This is a generic Comptonization model that includes the flux from the accretion disk and the fraction of this seed flux...
Comptonized in the corona. We use this model as it considers the general case where the Comptonization process may be either thermal or dynamic in nature. In the \texttt{bmc} model, the soft photons are those that undergo few scatterings, while those in the hard component have undergone multiple scatterings.

Our fit results in a reduced chi-squared of $\sim 1.04$ (1327/1272—epoch II, 1297/1272—epoch I, see Figure 4), with the best-fit parameters consistent with those found in the previous section. The temperature of the soft disk component for epoch II (I) is $0.36 \pm 0.02$ keV ($0.28 \pm 0.06$ keV). The spectral index $\alpha$ agrees with our expectations from the \texttt{diskbb+po} fit, i.e., $\Gamma = 1.79 \pm 0.03$ (1.82 $\pm$ 0.04) where $\alpha = \Gamma - 1$, while $A = -0.62 \pm 0.09$ ($-0.82^{+0.46}_{-0.77}$). We find both iron and metals to be over abundant relative to solar ($\sim 2\times$, $1.7\times$, respectively).

Testing for the presence of a relativistic iron line reveals results consistent with those in the previous section. We also attempted to constrain the possible presence of non-thermal electrons at higher energies using the hybrid Comptonization model \texttt{eqpair} (Coppi 2000); however, we are unable to constrain the fraction of non-thermal/thermal electrons. As discussed in Coppi (2000), this is unsurprising as in order to constrain the non-thermal fraction, one requires a source detection out to energies approaching 500 keV.

4. DISCUSSION

We present \textit{Suzaku} broadband spectra of the Galactic microquasar 1E 1740.7$-$2942 while in the LHS. The source was observed on two separate occasions after a transition from the HSS to the LHS at a luminosity of $\sim$1 Eddington, i.e., a 2$-$300 keV unabsorbed flux of $2.2 \times 10^{-9}$ erg s$^{-1}$ cm$^{-2}$ ($L_{\gamma}/L_{\text{Edd}} = 0.014 \times (d/8.5$ kpc)$^2(M_\star/10 M_\odot)$).

Given the large background at energies above 200 keV, it is worth investigating the effect of ignoring data beyond this, and how this might affect the presence of a spectral cutoff in our data. Ignoring all data in excess of 200 keV and refitting the higher quality epoch II data does not significantly change our results, with a lower limit to the spectral cutoff of $\sim 375$ keV (90% confidence) in this case. We note that the best-fit cutoff power-law model, where the spectral cutoff is fixed at an energy of 200 keV, is excluded at the $\sim 3\sigma$ level, as measured via an $F$-test, for epochs I and II respectively, see Table 2.

The observed LHS spectrum of 1E 1740.7$-$2942 as presented herein, and via the \textit{INTEGRAL} observations presented by Bouchet et al. (2009), is clearly consistent with a power law. Here 1E 1740.7$-$2942 is detected up to an energy of 300 keV. A prominent iron $K$ absorption edge is visible in the XIS soft X-ray spectra. We account for this with the \texttt{zvfeabs} model in \texttt{xspec} and find the metal and iron abundances to be super-solar for all our models in agreement with previous ASCA observations (Sakano et al. 1999). Modeling the spectrum as the sum of a blackbody accretion disk and an unbroken power law at higher energies provides a good fit, although we cannot rule out the presence of a spectral cutoff at energies $\geq 380$ keV.

The accretion disk temperature is determined to be low ($\sim 0.4$ keV), while we find the disk inner radius to be small and consistent with a disk that is continuous down to small radii approaching the ISCO (i.e., $R_{\text{in}} \lesssim 20 R_g$; see Table 2). A broad iron line is also required but at a low significance (99% as measured by an $F$-test), supporting a small inner radius for the accretion disk. The detection of a cool disk in 1E 1740.7$-$2942 is consistent with a growing body of evidence that the accretion disk is not necessarily truncated at large radii in the LHS.

The spectrum is characterized in detail using the \texttt{bmc} Comptonization model (Titarchuk et al. 1997). A cool source of thermal photons is revealed in this model consistent with the presence of a cool accretion disk, as suggested by the phenomenological modeling above. The parameter log($A$) in the \texttt{bmc} model is related to the fraction of Comptonized soft seed photons $f = A/1 + A$, in these observations the fraction is low. In epoch II the Comptonized fraction is $\sim 20\%$, while in epoch I it is lower still at 15%. Unfortunately the lower S/N in epoch I prevents us from making any definitive statements regarding the evolution of the coronal geometry between observations.

4.1. Previous Observations

Bouchet et al. (2009) have observed this system with \textit{INTEGRAL} in the hard state, and detect it out to an energy of 600 keV. The spectrum is found to be consistent with thermal Comptonization up to 200 keV with an additional component required at energies above this. They fit the spectrum with a two-component thermal Comptonization model ($kT_1 \sim 30$ keV, $kT_2 \sim 100$ keV) although they are unable to rule out non-thermal processes. Indeed fitting the spectrum above 200 keV with a power law produces a high quality fit ($\chi^2 \sim 1$). Such a power law could be produced by non-thermal processes such as those expected from a jet, e.g., Markoff et al. (2004). The measurement of a power-law spectrum for 1E 1740.7$-$2942 out to 600 keV by \textit{INTEGRAL} is consistent with the \textit{Suzaku} observations presented herein.

Del Santo et al. (2005) carried out a series of simultaneous \textit{RXTE} and \textit{INTEGRAL} observations primarily while 1E 1740.7$-$2942 was in the LHS. The spectrum was found to be consistent with a power law ($\Gamma \sim 1.3$–1.6) including a high-energy cutoff ($\sim 100$–120 keV); however, we note that the S/N of the high-energy ($>50$ keV) portion of the spectrum is very low, with only a single data bin at $>100$ keV. A significant amount of reflection from the accretion disk was also required, with typical values for the reflection fraction of 0.3–0.9. Fitting with the \texttt{compa} model reveals a seed photon temperature of 0.4–0.7 keV, consistent with the accretion disk temperature we measure here.

We do not observe any high-energy cutoff features, as observed by Del Santo et al. (2005), in our data. Although, we note that the power-law emission is clearly softer in our case ($\Gamma \sim 1.8$). We do not observe any evidence for significant disk reflection (either an iron line or Compton hump) in the spectra from either epoch, with a detection of a weak line at the 99% confidence level (EW $\sim 60$ eV) in addition to a weak disk reflection fraction ($f \lesssim 0.1$). Given the high level of Comptonization clearly present, it is likely that any fluorescent iron line emission produced in the inner disk would be smeared by the corona (Petrucci et al. 2001). The lack of these features is consistent with the expectation of a radially recessed/truncated disk in the hard state (Gierliński et al. 1997) and/or the presence of an outflow (Beloborodov 1999; Merloni & Fabian 2002; Markoff & Nowak 2004).

Observations of 1E 1740.7$-$2942 with \textit{Chandra} also measure a hard power-law spectrum consistent with the expectations for the hard state $\Gamma \sim 1.4$ (Gallo & Fender 2002). We note that a power-law fit to our \textit{Suzaku} spectrum in the 2–10 keV range also returns a photon index of $\sim 1.4$ suggesting that the \textit{Chandra} spectrum contained a significant accretion disk component.
which is only revealed through the broad energy coverage of Suzaku.

The observations listed above are in agreement with those presented in this paper, and point toward the X-ray emission from 1E 1740.7−2942 being dominated by the accretion disk and corona while the source is in the LHS. This interpretation is supported by the work of Bosch-Ramon et al. (2006) who modeled the broadband emission (radio, GeV) from 1E 1740.7−2942. They find the observed hard X-ray flux to be inconsistent with the measured radio flux in the case where the spectral energy distribution is jet dominated and instead favor the corona as the origin of the observed high energy emission.

4.2. Implications for the Low-hard State

Observations of the candidate black hole binary Swift J1753.5−0127 in the LHS with Suzaku reveal a similar picture (Reynolds et al. 2010), i.e., a low temperature accretion disk component plus an unbroken power law extending to high energies at a luminosity of ~2% $L_{\text{Bol}}$. In this case the disk temperature is found to be ~0.2 keV, while the inner radius is consistent with that measured for 1E 1740.7−2942. A low reflection fraction of ~0.2 is measured along with an unbroken power law and a weak iron line, all consistent with an inner radius $\lesssim 20 R_g$. A similar picture is revealed when modeling the soft disk component and the relativistic iron line detected by XMM (Miller et al. 2006a; Hiemstra et al. 2009). The low values measured for the reflection fraction in both 1E 1740.7−2942 and Swift J1753.5−0127 are consistent with models that do not require a recessed disk in the LHS, e.g., Beloborodov (1999), Merloni & Fabian (2002), and Markoff & Nowak (2004).

Combined with the accretion disk component and relativistically broadened iron lines observed in numerous systems, these results provide significant evidence opposing the view that the accretion disk is truncated at large radii ($>100 R_g$) in the LHS, e.g., see also Miller et al. (2006b), Tomski et al. (2008), Wilkinson & Uttley (2009), and Reis et al. (2009, 2010).

4.3. Comparison to Other Microquasars

GRS 1758−258 is the system most closely resembling 1E 1740.7−2942 among the Galactic black hole candidates. However, we first consider a series of broadband observations of the black hole binaries XTE J1650-500 and GRO J1655-40, which displayed LHS spectra similar to that presented in this paper for 1E 1740.7−2942.

XTE J1650-500 is a Galactic black hole binary that was discovered in 2001 by RXTE (Remillard 2001). The orbital period has been measured to be ~7.6 hr, and the mass of the black hole is $M_{\text{BH}} = 4.0 \pm 3.3 M_\odot$ (Orosz et al. 2004). Observations during the initial outburst with XMM-Newton detected a broad skewed Fe Kα line, which modeling revealed to be consistent with a near maximally spinning black hole ($a^* \sim 1$; Miller et al. 2002). Observations at radio wavelengths revealed significant emission consistent with an origin in a compact jet (Corbel 2004). Montanari et al. (2009) analyze BeppoSAX observations of XTE J1650−500 with the bmc model in the LHS and HSS. The photon index in the LHS is similar to our observations $\Gamma \sim 1.7$−1.8. The soft seed component is found to have a temperature of ~0.4 keV again similar to our observations of 1E 1740.7−2942. In contrast to XTE J1650−500, we find a much lower Comptonized fraction in the case of 1E 1740.7−2942 ~ 20% (versus ~60%), which implies a smaller corona. In the case of XTE J1650−500, Montanari et al. (2009) find evidence for a contraction in the size of the corona as the microquasar transitions from the LHS to the HSS state, as such one might naturally expect the corona to be smaller when the transition progresses in the opposite sense.

GRO J1655−40 was discovered by the Compton Gamma Ray Observatory in 1994 (Zhang et al. 1994) and found to lie at a distance of ~3.2 kpc (Tingay et al. 1995). Orosz & Bailyn (1997) measured an orbital period of ~2.6 days and the black hole mass to be $M_\odot \sim 0.22 M_\odot$. Highly relativistic radio jets were also detected, which appeared to be misaligned with the binary orbit (Hjellming & Rupen 1995). X-ray observations revealed a pair of high-frequency quasi-periodic oscillations consistent with Keplerian rotation at the ISCO of a spinning black hole (Strohmayer 2001). Subsequent observations detected a broadly skewed iron Kα line, which supports a high spin for the black hole ($a \gtrsim 0.9$; Miller et al. 2005, 2009). Tomsick et al. (1999) presented RXTE and OSSE observations in the HSS which revealed unbroken power-law emission out to an energy of ~700 keV. Caballero Garcia et al. (2007) presented broadband (3–500 keV) INTEGRAL observations of GRO J1655−40 during the 2005 outburst. Here an observation in the LHS ($L_\gamma \sim 0.015 L_{\text{Edd}}$) clearly detected unbroken power-law emission ($\Gamma \sim 1.7$) extending out to an energy of ~500 keV, again consistent with the observations of 1E 1740.7−2942 presented herein. This was interpreted as evidence for a significant contribution from non-thermal electrons (although see also Joint et al. 2008). Unfortunately, the INTEGRAL low-energy cutoff of 3 keV does not allow any constraints to be placed on emission from the accretion disk.

GRS 1758−258 is the second persistent microquasar to lie close to the Galactic center. It is similar to 1E 1740.7−2942, i.e., large-scale radio outflows (Rodriguez et al. 1992), X-ray bright with a high extinction (Sunyaev et al. 1991), no identified optical/NIR counterpart (Eikenberry et al. 2001) and a long orbital period (~18.5 days; Smith et al. 2002). Detailed studies of the LHS properties of this system have been carried out by Pottschmidt et al. (2006) and Sidoli & Mereghetti (2002) who observed with INTEGRAL/RXTE and BeppoSAX, respectively. Pottschmidt et al. (2006) detected the source in the energy range 3−200 keV and found the LHS spectrum to be consistent with a cutoff power-law, where $\Gamma \sim 1.5$−1.7 and $E_{\text{cut}} \sim 140 − 250$ keV. Due to contamination from GX 5-1, Sidoli & Mereghetti (2002) only detected GRS 1758−258 in the energy ranges 0.1−10 keV and 40−200 keV and found the broadband spectrum to be consistent with a cutoff power law where $\Gamma \sim 1.65$, $E_{\text{cut}} \sim 70$ keV and $E_{\text{Edd}} \sim 180$ keV. In both sets of observations a weak emission line consistent with Fe–Kα was marginally detected with an EW ~50–70 eV. New broadband Suzaku observations of GRS 1758−258 will be presented in an upcoming paper (M. T. Reynolds et al. 2010, in preparation).

5. CONCLUSIONS

We present Suzaku observations of the Galactic center microquasar 1E 1740.7−2942 in two separate epochs taken after the system had transitioned into the LHS. The system is observed to be in the LHS at the time of our observations with an X-ray luminosity of ~1% Eddington. The spectra in each epoch are similar, being described by a model consisting of a
soft thermal accretion disk component ($T \sim 0.4$ keV) and the broadband emission ($\sim 10$ keV) is found to be characterized by an unbroken power law to at least 300 keV.

Consistent with growing evidence from observations of numerous systems in the LHS (e.g., GX 339-4, Swift J1753.5−0127, XTE J1817−330, XTE J1118+480), we also find evidence that the accretion disk in 1E 1740.7−2942 is not truncated at large radii in the LHS and instead remains close to the ISCO ($R_{\text{in}} \sim 20R_g$).

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