THE DEPENDENCE OF THE ESTIMATED LUMINOSITIES OF ULTRALUMINOUS X-RAY SOURCES ON SPECTRAL MODELS

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ABSTRACT

Data from Chandra observations of 30 nearby galaxies were analyzed and 365 X-ray point sources were chosen whose spectra were not contaminated by excessive diffuse emission and not affected by photon pileup. The spectra of these sources were fitted using two spectral models (an absorbed power-law and a disk blackbody) to ascertain the dependence of estimated parameters on the spectral model used. It was found that the cumulative luminosity function depends on the choice of the spectral model, especially for luminosities $>10^{40}$ erg s$^{-1}$. A large number ($\sim$80) of the sources have luminosities $>10^{39}$ ergs s$^{-1}$ (ultraluminous X-ray sources) with indistinguishable average spectral parameters (inner disk temperature $\sim$1 keV and/or photon index $\Gamma \sim 2$) with those of the lower luminosity ones. We identify four sources whose minimum luminosity exceeds $10^{40}$ ergs s$^{-1}$. Their spectra are in general better represented by the disk blackbody model than the power-law one. These extremely luminous X-ray sources (ELXs) can be grouped into two distinct spectral classes. Two of them have an inner disk temperature of $<0.5$ keV (supersoft), while the other two have temperatures $\geq 1.3$ keV (hard). The estimated inner disk temperatures of the supesoft ELXs are compatible with the hypothesis that they harbor intermediate-size black holes, which are accreting at $\sim 0.5$ times their Eddington luminosity. The radiative mechanism for hard ELXs seems to be inverse Comptonization, which in contrast to standard black hole systems is probably saturated.

Subject headings: galaxies: general — X-rays: binaries

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1. INTRODUCTION

In the last few years, Chandra observations of nearby galaxies have detected many nonnuclear X-ray point sources (Kaaret et al. 2001; Matsumoto et al. 2001; Zezas & Fabbiano 2002), some of which have isotropic luminosities $>10^{39}$ ergs s$^{-1}$ and are called ultraluminous X-ray sources (ULXs). While some of these ULXs are supernova remnants (e.g., Ryder et al. 1993; Fox et al. 2000), it is believed that the majority of them are compact accreting systems. Indeed, ASCA X-ray spectral studies of many ULXs have revealed that they display the characteristics of accreting black holes (Makishima et al. 2000; Mizuno et al. 2001). ULXs have also been called super-Eddington sources (Fabbiano 1989, 2004) and intermediate-luminosity X-ray objects (Roberts & Warwick 2000; Colbert & Mushotzky 1999).

Since these ULX sources emit radiation at a rate higher than the Eddington luminosity for a $10^5 M_\odot$ black hole, they are believed to harbor a black hole of mass $10^5 < M < 10^6 M_\odot$ (Colbert & Mushotzky 1999; Makishima et al. 2000), where the upper limit is constrained by the fact that a more massive black hole would have settled into the nucleus due to dynamical friction (Kaaret et al. 2001). Black holes in this mass range are called intermediate-mass black holes (IMBHs), since they seem to represent the missing component of the black hole mass spectrum with masses prevailing in the gap between those of stellar mass black holes found in Galactic X-ray binaries and those associated with active galactic nuclei (AGN), $M \sim 10^{6} - 10^{9} M_\odot$ (Richstone et al. 1998).

Miller & Colbert (2004) and Miller (2005) review the present evidence for IMBHs in ULXs and Liu & Mirabel (2005) have compiled a catalog of some ULXs and properties.

Alternate models for ULXs are that their luminosities are super-Eddington (Begelman 2002) or that their emission is beamed from a geometrically thick accretion disk (King et al. 2001). However, it has been argued that in the latter case, such thick funnel-shaped disks enhance the observed flux by just a factor of few (Misra & Sriman 2003). For all of these models, the creation of such sources (Portegies et al. 2002; Taniguchi et al. 2000; Madau & Rees 2001) and process by which they sustain high accretion rates (King et al. 2001) are largely unknown.

Investigations on the nature of ULXs have been undertaken by studying the spectra and variability of individual sources. For example, analysis of the spectra of NGC 1313 X-1, X-2 (Miller et al., 2003), and M81 X-9 (Miller et al. 2004) revealed the presence of a cool accretion disk component ($kT_m \sim 0.1 - 0.5$ keV), suggesting that ULXs indeed harbor IMBHs. Transitions between two spectral states, similar to those seen in Galactic black hole systems, have been reported in NGC 1313 X-1 (Colbert & Mushotzky 1999) and two sources in IC 342 (Kubota et al. 2001). Spectral transitions have also been reported in two sources in NGC 1313 (Feng & Kaaret 2006).

The large collecting area of XMM-Newton allows for detailed spectral fits to ULXs, which are often comprised of two components (Wang et al. 2004; Feng & Kaaret 2005). However, Gonçalves & Soria (2006) have argued that such soft spectral components depend on the complexity of the fitting model. An interesting object is the brightest X-ray point source in M82, whose intrinsic luminosity has been measured to be as high as $1.6 \times 10^{41}$ ergs s$^{-1}$ (Ptak & Griffiths 1999). The detection of a 54 mHz quasiperiodic oscillation in its X-ray light curve suggests that the source is a compact object and not a background AGN (Strohmayer & Mushotzky 2003; Dewangan et al. 2006b). The spectra of this source can be fitted by a power law with photon index $\Gamma \sim 2$. 

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(Fiorito & Titarchuk 2004), but is more consistently fitted with a flatter power law with a high-energy cutoff around \( \sim 6\) keV, which can be interpreted as optically thick, saturated Comptonization (Agrawal & Misra 2006). A quasi-periodic oscillation has also been discovered in the bright X-ray source of Holmberg IX, which is similar to the source in M82 in that it has a flat spectrum (\( \Gamma \sim 1 \)) with a \( \sim 9\) keV cutoff (Dewangan et al. 2006a). Recently, Stobbart et al. (2006) found that the XMM-Newton spectra of 11 of the 18 ULXs studied by them showed such high-energy curvature. Chandra observations of NGC 5204 X-1 also reveal the presence of an optically thick Comptonized component (Roberts et al. 2006). While these results of individual ULXs are intriguing, there does not seem to be any significantly distinguishable spectral property of ULXs, and in general their spectra can be described either by steep or flat power-law indices, with and without soft components (e.g., Dewangan et al. 2005).

Another line of investigation is to construct the cumulative luminosity function and histograms of spectral parameters of a large sample of X-ray sources (e.g., Colbert & Ptak 2002). The hope here is that, in case ULXs are a distinct class of sources and/or they can be classified into distinct subgroups, the luminosity function should exhibit a break and their spectral parameters should show clustering. Swartz et al. (2004) analyzed data from 82 galaxies and estimated the luminosity function and spectral parameters of the X-ray point sources in these galaxies. They found that the average photon index (as well as the distribution) of the ULXs and of the less luminous sources is nearly same. Moreover, their spatial and variability distributions are also similar. While their analysis revealed that the luminosity functions of ULXs depend on the host galaxy type and star formation rate, they did not find any significant evidence for breaks in them.

As emphasized by Swartz et al. (2004), the power-law model they used to fit the data was chosen as an empirical one. They attempted to fit all the sources with the power-law model, and only for those sources that did not provide a reasonable fit did they use other models such as disk blackbody. They note that for many sources that are well fitted by the power-law model, other spectral models can also represent the spectra. In this work, we consider a smaller sample of 30 galaxies but fit the spectra of the point sources with both a power-law and a disk-blackbody model. In principle, the intrinsic (i.e., the absorption-corrected) luminosity inferred for a source may be different for the two spectral models. Our first motivation here is to make a qualitative estimate of this difference by noting the dependency of the luminosity function on the spectral model used. A second motivation for this work is based on the expectation that estimations of a different spectral parameter, such as the inner disk temperature (as compared to the photon index), may be better in distinguishing ULXs from other sources, or they may reveal dependencies (like correlations between luminosity and temperature) which could shed light on the nature of these sources. As mentioned earlier, the spectra of several ULXs are complex, requiring more than one component. Thus, the two spectral models, an absorbed power law and an absorbed disk blackbody, should be considered as empirical ones, which can adequately represent low-count data, and these models need not be the correct physical representation of the actual source spectrum.

It is clear that ULXs are fairly common in nearby galaxies. For example, Swartz et al. (2004) identified 154 of them in 82 galaxies. If these sources are Eddington limited, then black holes \( \sim 10 M_\odot \) may indeed be quite common. However, only a few of these sources have luminosities greater than \( 10^{40} \) ergs s\(^{-1}\). It is these sources (the best example being the bright source in M82 X-1) that require black holes with masses \( M \sim 10^2 - 10^4 M_\odot \). The development of a self-consistent theory that explains the process by which such black holes are created and undergo high accretion is theoretically challenging. Hence, it is important to estimate the number of sources whose minimum intrinsic luminosity exceeds \( 10^{40} \) ergs s\(^{-1}\). Here the minimum value of the luminosity should not only include the statistical spectral-fitting error, but also the variations in the luminosity estimation that may occur when using different viable spectral models. The third motivation of this work is to identify such sources, which we call extremely luminous X-ray sources (ELXs). To avoid possible ambiguities in determining the luminosity, we have chosen only those sources whose spectra are not contaminated by excessive diffuse emission and which are not affected by photon count pileup. Identification of such relatively “clean” systems would allow for more detailed studies of their properties to be undertaken and would be the first step toward understanding their nature.

A similar analysis has been undertaken recently by Winter et al. (2006) for 30 galaxies observed by XMM-Newton. Since their motivation was to check whether ULXs also exhibit soft and hard spectral states like black hole binaries, they limited their analysis to bright sources where detailed spectral analysis could be done. They found 16 sources as possible low-state ULXs and 26 as high-state ones. For the high-state ULXs, the observed range for the blackbody temperature was 0.1 - 1.0 keV, with the more luminous sources having lower temperatures. The Chandra analysis undertaken here can be compared with this contemporary work and as we discuss later, the analyses are more or less consistent with each other. This consistency is important, since although the larger collecting area of XMM-Newton allows for more complex spectral analysis, the higher angular resolution of Chandra ensures that a source spectrum is not contaminated by diffuse emission and flux from nearby sources.

2. OBSERVATIONS AND DATA REDUCTION

The names of the 30 host galaxies and the details of the Chandra ACIS observations are tabulated in Table 1. Distances to the galaxies were obtained from Swartz et al. (2004) and references therein. This sample of galaxies is a subset of those analyzed by Swartz et al. (2004). No particular criterion was imposed on the selection, since our motivation is limited to obtaining enough sources and not to study dependency on galaxy type.

The data reduction and analysis were done using CIAO3.2 and HEASOFT6.0.2. Using the CIAO source detection tool wavdetect, X-ray point sources were extracted from the level 2 event list. It was found that at least 60 counts are required to fit the spectral data with a two-parameter model and hence only those sources with net counts \( \geq 60 \) were chosen for the spectral analysis. Choosing a lower threshold of 50 counts resulted in a large number of sources for which spectral parameters could not be constrained. To avoid photon pileup effects, a conservative threshold of the count rate being \( > 0.05 \) counts s\(^{-1}\) was imposed, which led to the rejection of the 15 sources which have been listed in Table 2. For some sources, typically near the nucleus, it was difficult to find nearby source-free background regions, and hence these sources were also not included in the analysis. Sources embedded in excessive diffuse emission (i.e., when the background flux was larger than 2 counts arcsec\(^{-2}\)) were also rejected. Typically, this amounted to considering only those sources for which the estimated background counts were less than 20. For each data set, observation-specific bad pixel lists were set in the arclib parameter file. Using a combination of CIAO tools
and calibration data, the source and background spectra were extracted.

These selection criteria make the sample incomplete both in low- and high-luminosity ends. Thus, the results obtained should not be used for quantitative analysis of the luminosity functions. The motivation here is to evaluate dependency on spectral models and to identify sources which have high intrinsic luminosity. Thus, care has been taken to avoid possibly contaminated data, even if such criteria result in a loss of sources.

Spectral analysis was done using XSPEC version 12.2, and the data were fitted in the energy range 0.3–8.0 keV. All sources were fitted with two spectral models, the absorbed power law and an absorbed disk blackbody. Absorption was taken into account using the XSPEC model phabs. Since the number of counts in each spectrum was typically low, the C statistics were used for the analysis. Technically, the C statistics are not appropriate for high-count sources. This is reassuring, because if the results depended on the statistics used, it would be imperative to use the correct statistics for high-count sources (which need not be χ²) taking into account the correct (possibly non-Gaussian) error profiles.

An important problem when fitting low-count data with a two-parameter (plus normalization) model is the possibility of many local minima in the discerning statistic (in this case C statistic) space. Hence, we take a cautious approach and do not fit the data using the XSPEC minimization routine. Instead, we compute the C statistic for a range of parameter values (using the XSPEC command xtpar) and find the global minimum. Such a technique is numerically expensive, but it ensures that the global minimum has been found and that the correct errors are obtained for the best-fit parameters.

### 3. RESULTS

The 365 sources considered in this analysis were classified into three categories, depending on whether the data was better fit by the disk-blackbody model (23 sources), the power-law one (67 sources), or both (275 sources). The criterion chosen to determine a better fit to the data was that C-statistic difference between the models should be larger than 2.7. If the difference was less, then both model fits were considered to equally represent the data. Although such a criterion is ad hoc (considering the uncertainties in the actual error statistics) and count-rate dependent, it does serve as a qualitative guideline to differentiate between those systems which can be represented by a power-law emission and/or a blackbody one. The spectral parameters for all sources for the power-law and disk-blackbody models are tabulated in Tables 3 and 4.

For ULXs, the physically relevant parameter is the intrinsic bolometric luminosity which should be used to define and identify them. However, given the limitations of an instrument’s energy sensitivity range, the bolometric luminosity is spectral model dependent. For a power law, the bolometric luminosity cannot be estimated, and only a lower limit can be obtained using the observed energy range. Since our motivation is to show how the bolometric luminosity is affected by the use of different spectral models, we have plotted in Figure 1 the bolometric luminosity for the disk-blackbody model versus the lower limit to the luminosity using the power-law model. The figure represents only those sources which can be represented by both models. The figure shows that while for most sources the difference in luminosities is not substantial, there are sources with estimated luminosities ≥10³⁹ erg s⁻¹, where the disk-blackbody...
luminosity estimation is significantly smaller than the power-law one. This happens for sources for which the spectral index is large.

To show the dependence of the luminosity function on the fitting model, we compute the cumulative luminosity function in two ways. For the disk-blackbody cumulative luminosity function (DBCLF), the luminosity obtained form fitting a blackbody is used, except for those sources that are fitted better with a power law, for which the power-law model estimated luminosity is considered. Similarly, for the power-law cumulative luminosity function (PLCLF) the luminosity corresponds to the power-law fit, except for those sources which are better represented by a disk-blackbody spectrum. In Figure 2 the solid line represents the DBCLF, while the PLCLF is plotted as a dotted one. There are fewer sources with \( L > 10^{40} \) ergs s\(^{-1}\) for disk-blackbody preferred representation. Moreover, there is a significant difference in the slope of the two luminosity functions, and the presence of a faint break at \( L \sim 10^{40} \) ergs s\(^{-1}\) for the PLCLF is not evident in the DBCLF. Of particular interest is the number of sources whose minimum luminosity (i.e., the minimum of the two lower limits obtained by fitting the two spectral models) exceeds a certain value. In Figure 2, the dashed line represents such a minimum cumulative luminosity function, which reveals that there are eight sources with minimum luminosity greater than \( 10^{40} \) ergs s\(^{-1}\) (ELXs) and \( \sim 80 \) sources with minimum luminosity greater than \( 10^{39} \) ergs s\(^{-1}\) (ULXs).

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**TABLE 3**

**Spectral Properties of Point Sources Fitted with the Power-Law Model**

| Galaxy (1) | R.A. (2) | Decl. (3) | \( n_H \) (10\(^{22}\) cm\(^{-2}\)) | \( \Gamma \) (5) | \( \log(L) \) ergs s\(^{-1}\) | C-stat (7) | dof (8) |
|------------|---------|-----------|----------------|-----|----------------|----------|-------|
| NGC 0253   | 0 47 43.07 | −25 15 29.28 | 0.15 +0.53 | 2.52 +2.31 | 37.70 +1.20 | 9.43 | 4 |
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| NGC 0253   | 0 47 43.07 | −25 15 29.28 | 0.15 +0.53 | 2.52 +2.31 | 37.70 +1.20 | 9.43 | 4 |

**Notes:** Col. (1): Host galaxy name. Col. (2): Right ascension (measured in hours, minutes, and seconds). Col. (3): Declination (measured in degrees, arcminutes, and arcseconds). Col. (4): The \( n_H \) value, equivalent hydrogen column density. Col. (5): \( \Gamma \), photon power-law index. Col. (6): \( L \), X-ray luminosity in the energy range: 0.3–8.0 keV. Col. (7): C-statistics. Col. (8): Degrees of freedom. Table 3 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

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**TABLE 4**

**Spectral Properties of Point Sources Fitted with the Disk Blackbody Model**

| Galaxy (1) | R.A. (2) | Decl. (3) | \( n_H \) (10\(^{22}\) cm\(^{-2}\)) | \( K_{\text{in}} \) (keV) | \( \log(L) \) ergs s\(^{-1}\) | C-stat (7) | dof (8) |
|------------|---------|-----------|----------------|-----|----------------|----------|-------|
| NGC 0253   | 0 47 43.07 | −25 15 29.28 | 0.15 +0.53 | 2.52 +2.31 | 37.70 +1.20 | 9.43 | 4 |
| NGC 0253   | 0 47 43.07 | −25 15 29.28 | 0.15 +0.53 | 2.52 +2.31 | 37.70 +1.20 | 9.43 | 4 |
| NGC 0253   | 0 47 43.07 | −25 15 29.28 | 0.15 +0.53 | 2.52 +2.31 | 37.70 +1.20 | 9.43 | 4 |

**Notes:** Col. (1): Host galaxy name. Col. (2): Right ascension (measured in hours, minutes, and seconds). Col. (3): Declination (measured in degrees, arcminutes, and arcseconds). Col. (4): The \( n_H \) value, equivalent hydrogen column density. Col. (5): \( K_{\text{in}} \), inner disk temperature. Col. (6): \( L \), bolometric X-ray luminosity. Col. (7): C statistics. Col. (8): Degrees of freedom. Table 4 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.
Figure 3a shows the variation of the luminosity versus the disk-blackbody temperature. While most of the sources have an inner disk temperature $\lesssim$1 keV, as is evident from the distribution (Fig. 3b), there is a population of high-luminosity sources with low ($\sim$0.1 keV) temperature. Although the number of sources is low, there seems to be some evidence that ELXs (i.e., sources with luminosities $>10^{40}$ ergs s$^{-1}$) can be divided into two groups, a “supersoft” group with temperatures less than 0.2 keV and a harder group with temperatures $\sim$2 keV. Figure 3 can be compared with the results obtained by Winter et al. (2006) using XMM-Newton data for a different sample and selection criteria. They also find that sources with luminosities $>5 \times 10^{39}$ ergs s$^{-1}$ have a similar bimodal distribution in temperature, as shown in Figure 3. This supports the hypothesis that ELXs can be divided into two groups and that this is not an artifact of sample selection bias.

Figure 4a shows the variation of luminosity with power-law photon index for those sources which can be fitted by a power-law model. There is a clear correlation between the two. This correlation does not seem to be due to overestimation of column density, since no such correlation is seen in the luminosity versus $N_H$ plot (Fig. 5b). Similar to the analysis using the disk-blackbody model, there is a group of supersoft sources (i.e., photon spectral index $>3$) which are also highly luminous.
The column density versus luminosity plots for both the power-law and disk-blackbody models (Fig. 5) reveal an absence of correlation, which is indicative that there may not be a bias in the analysis, i.e., the luminosities are not being overestimated because of a $N_{\text{H}}$ overestimation. In this analysis, there are eight sources which have an apparent minimum luminosity greater than $10^{40} \text{ ergs s}^{-1}$. However, two of these sources (NGC 5055, R.A. 13 15 30.18, decl. +42 03 13.5 and NGC 4594, R.A. 12 39 45.22, decl. −11 38 49.8) are foreground stars, based on the optical images of the galaxies. Optical spectroscopy of a source in NGC 5775 (R.A. 14 53 55.8, decl. +3 33 28.02) reveals that it is a background AGN (Gutiérrez & López-Corredoira 2005), while a source in NGC 1399 (R.A. 14 53 55.8, decl. +3 33 28.02) is a broad-line AGN (Green et al. 2004). The spectral properties of the other four sources, which we call ELXs are tabulated in Table 5. The NGC 0628 source reported in Table 5 is a different source than the well-studied ULX, CXOU J013651.1+154547. The luminosity of this highly variable source (Krauss et al. 2005) is $\sim 10^{39} \text{ ergs s}^{-1}$ and its spectral properties are listed in Table 3. The source in NGC 6946 is a well-known variable source (Liu & Mirabel 2005) and has been called X7 with $L \sim 10^{39.22} \text{ ergs s}^{-1}$ (Lira et al. 2000), IXO 85 (Colbert & Ptak 2002), and source 56 (Holt et al. 2003). Although the best-fit parameters for C statistics are shown, these results have been checked using $\chi^2$ statistics and by C-statistics fit for unbinned and background-unsubtracted data; it was found that the parameter values are consistent within errors and that the errors on the estimated luminosities do not vary by more than a factor 2. In general, these sources are better represented by disk-blackbody emission than a power-law model, except for the source in NGC 6946, which however requires an exceptionally large power-law photon spectral index, ($\Gamma > 5$). The spectral properties of these bright sources suggest that they may be divided into two groups. The first group of four sources (Table 5) are represented by low inner disk temperatures ($<0.5 \text{ keV}$), and hence may be called supersoft sources. In contrast, the second group of three sources have harder spectra, with inner disk temperatures $\geq1 \text{ keV}$ or with power-law photon index ($\Gamma \sim 2$), and hence may be called hard sources. For this group, the spectra are marginally fitted better with a disk-blackbody emission, although...
considering the uncertainties in the spectral fitting, a power-law representation may also be acceptable.

4. SUMMARY AND DISCUSSION

Chandra observations of 30 galaxies were analyzed and the spectra of their point sources were fitted using both a power-law and a disk-blackbody emission model. Only those sources which were bright enough to allow a meaningful spectral fit were chosen, whose data was not contaminated by excessive diffuse emission and/or affected by pileup. It was found that the shape of the luminosity function, especially at the high-luminosity end, depends on the choice of the spectral model.

In accordance with earlier results, a large number of the sources (~80) have a luminosity which exceeds $10^{39}$ ergs s$^{-1}$, and hence satisfy the standard definition of being ultra luminous X-ray sources (ULXs) and do not seem to have any spectral distinction when compared with sources having lower luminosity. In this sample of 365 sources, there are four sources which we refer to as extremely luminous X-ray sources (ELXs), since their luminosities were estimated to exceed $10^{40}$ ergs s$^{-1}$. These sources are in general better described by disk-blackbody emission and can be distinctively grouped into two classes. This is consistent with the results of an independent analysis using XMM-Newton data (Winter et al. 2006). The members of the first class have soft spectra with best-fit inner disk temperature <0.5 keV, while for the other class the spectra is harder, with inner disk temperature $\geq$1.3 keV.

If disk blackbody emission is indeed the correct radiative process for the supersoft class, then the inner disk temperature should correspond to the maximum color temperature of a disk, which can be estimated to be

$$T_{\text{col}} \sim 0.3 \text{ keV} \frac{L_{40}^{-1/4}}{f} \left( \frac{L}{L_{\text{Edd}}} \right)^{-1/2}, \quad (1)$$

where $L_{40}$ is the luminosity in $10^{40}$ ergs s$^{-1}$, $f$ is the color factor, and $L_{\text{Edd}}$ is the Eddington luminosity. In Figure 3a, the two solid lines represent this relationship for $L/L_{\text{Edd}} = 1$ and 0.1. Thus within the uncertainties, the supersoft sources are compatible with having pure blackbody disk emission, and have $L \sim 0.5L_{\text{Edd}}$.

ELXs which are members of the hard class have inner disk temperatures which are higher than those expected from Eddington.
limited blackbody accretion disks. Hence, for these sources the radiative mechanism is probably inverse Comptonization of soft photons. Detailed spectral analysis, which included XMM-Newton observations of the bright X-ray source in M82 X-1 has revealed that its spectrum is better fitted by a saturated Comptonization model (Agrawal & Misra 2006), which is also the case for the bright X-ray source in Holmberg IX. Holmberg IX is not part of the sample studied here, and M82 X-1 has been excluded because of pileup effects and excess diffuse emission. Thus these sources, with estimated luminosities $\sim 10^{41}$ ergs s$^{-1}$, could also be members of the hard class of ELXs. Thus it seems that, like the hard state of standard black hole binaries, the hard-class ELXs also have spectra which is due to thermal Comptonization; however, unlike black hole binaries, in ELXs the...
Comptonization seems to be saturated. Thus it is tempting to draw an analogy, that the two spectral classes of ELXs are actually two spectral states of the same kind of object. This can be verified if spectral transition between the two classes is observed.

With the identification of these ELXs and other sources from the literature, it is now possible to undertake a more extensive study of their properties. Temporal variability of these sources will shed more light on the nature of these enigmatic sources.

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