Spectral Analysis of ULXs in Pairs of Interacting Galaxies M51 and NGC 4485/90 Using Swift-XRT

Sulistiyowati, Kiki Vierdayanti, Hesti Wulandari, Premana W. Premadi, Febrie A. Azizi, Mahadipa Priajana, Institut Teknologi Bandung, Bandung, Indonesia

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Abstract

In this preliminary study, we report the examinations of the spectra of ULXs in two nearby (< 10 Mpc) pairs of interacting galaxies M51 and NGC 4485/90 collected by Swift-XRT observations from 2005 to 2014 and 2008 to 2015 for each target, respectively. We obtain 116 ObsIDs of M51 and 37 ObsIDs of NGC 4485/90. For each pair of interacting galaxy, there are about 10% data that do not meet our criteria for further analysis.

The count rate of individual observation ranges from 0.00003 to 0.05 counts/s in 0.3 - 10 keV band with typical errorbar $\sim$ 30%. Some ULXs in M51 exhibit a considerable fluctuation of intensity, up to three times, from 0.01 counts/s to 0.03 counts/s. ULXs in NGC 4485/90 show more stable light curves with no significant changes in intensity. For every source, we divide the data into two categories, e.g. hard-state (those with hardness ratio ≥ 1) and soft-state (those with hardness ratio < 1). Due to the short exposure time during the observation, we got low S/N data with wide errorbar. Therefore, we combine spectrum from many observations with similar spectral characteristics for fitting purpose. We fit the co-added spectra with simple commonly used models: disk blackbody and power law.

1 Introduction

Ultraluminous X-ray sources (ULXs) are bright, off-nuclear X-ray sources whose luminosity ranges between $10^{39} - 10^{41}$ erg/s. The nature of ULXs remains an open question since its discovery by Einstein satellite in 1970s until today. ULXs are found in all morphological types of galaxies (Swartz et al. 2004; 2011) although most of them are observed to reside spiral galaxies. Currently there are more than 500 ULXs reported from combining two most recent ULXs catalogues sourced from XMM-Newton observations (Walton et al. 2011) and Chandra observations (Liu 2011). Detailed study of ULXs are commonly focused on bright ones and those located in nearby galaxies (in the order of several MPc).

We aim to study ULXs as a population in a galaxy. Interacting galaxies are known to host a higher average number of ULXs (> 5). Therefore it is interesting to study ULXs as a population in interacting galaxies, as the first step for population study of ULXs. We choose two nearest pairs of interacting galaxies, M51 and NGC 4485/90 located at the distance of 8.4 Mpc and 7.8 Mpc respectively as our main target. Previous study on these targets are carried out using data from Chandra and XMM-Newton observations (Dewangan et al. 2005; Fridriksson 2008; Gladstone & Robets 2009; Yoshida et al. 2010). Almost all of those studies use sparse observations. In this study, we use Swift-XRT data with more frequent observations despite lower data quality, which allow us to track the spectral variability more convincingly.

2 Data

116 and 37 OBSIDs were obtained during observation from 2005 to 2014 and 2008 to 2015 for M51 and NGC 4485/90 respectively with typical exposure 2000 seconds. ULX position is determined by

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adopting Liu & Mirabel (2005) catalog instead of performing count detection on the image. Following their work, M51 and NGC 4485/90 are recorded to host 9 and 5 ULXs respectively.

2.1 Reduction and Extraction

Uniform treatments are applied to each OBSID. Level 1 photon counting images from all OBSIDs are processed to produce clean event files and exposure map images by running Swift-XRT specific task `XRTPIPELINE` from Heasoft package. Standard screening criteria (Capalbi 2005) are used, with elevation angle (ELV) should be larger or equal than 45°, bright Earth angle (BR_EARTH) to be 120° or more, Sun and Moon angle (SUN_ANGLE and MOON_ANGLE) to be not less than 45° and 14°, and angular pointing direction (ANG_DIST) in 0.08°. 107 and 36 OBSIDs from M51 and NGC 4485/90 respectively pass the data reduction and are taken to extraction process. 10 other OBSIDs are not included to keep the treatment equal for all data until this point. Products from Level 2 screened clean event files are extracted after applying region/position filtering to individual clean event files, followed by grouping and energy filtering.

2.2 Individual Spectra

We extract both source and background spectra using `XSELECT v2.4c`. Source is defined as a circle region centered at ULX position with 20 pixels radius (equivalent to $\tilde{4}7$ arcsecond) to enclose 90% of the PSF at 1.5 keV. Background is chosen as a circle region far from sources enclosing 50 pixels radius. Background is assumed to be free from sources contamination. Each pair of interacting galaxy has one background region, set to be $13^{\mathrm{h}}30^{\mathrm{m}}40^{\mathrm{s}}23$,$+47°15'15''86$ and $12^{\mathrm{h}}30^{\mathrm{m}}02^{\mathrm{s}}23$,$+41°35'19''86$ for M51 and NGC 4485/90 respectively.

Grouping is performed using task `GRPPHA` with minimum number of counts = 20 and systematic error of 0.01 to increase statistical quality of the data. Auxiliary response file `arf` is generated using `XRTMKARF` task, taking PSF correction on photon counting mode geometrical configuration into account. Applicable redistribution matrix file `rmf` depends on the time of observation. Following criteria for grade 0-12 described in `www.swift.ac.uk/analysis/xrt/rmfarf.php` (last updated in July 2$^{\mathrm{nd}}$, 2014), we have 6 groups of observing time and hence use 6 `rmf` also.

Individual spectra has count rate in the range of 0.00003 to 0.05 counts/s in 0.3-10 keV band with typical errorbar $\sim 30\%$. This large error propagates and causes hardness ratio to also have a large error bar, some even larger than the value of hardness ratio itself.

2.3 Coadded Spectra

Better quality of spectra is needed for fitting purpose. As our extracted data produces low count rate, some spectra with similar characteristics are combined together. We first classify our spectra based on `rmf`. We then calculate the value of hardness ratio (R) which is in our case defined classically as the fraction of count rate in high energy band (H, stands for high) 1.5-10 keV and low energy band (S, stands for soft) 0.3-1.5 keV, $R = \frac{H}{S}$. The error propagation is also calculated simply by equation $\sigma_R = R\sqrt{(\frac{\sigma_H}{H})^2 + (\frac{\sigma_S}{S})^2}$, with σ represents error bar value. Given R value of individual spectra, we divide them into two groups separated by 1. Those with $R < 1$ are dubbed soft while the other ones are hard.

3 Discussion

Figure 1 provides samples of our preliminary result. The light curves (partly presented on top of Figure 1), show ULXs in M51 have more fluctuations than those in NGC 4485/90. The middle of Figure 1 provides all hardness ratio from Product 1 which is used to justify spectral addition. The bottom of Figure 1 gives sample of spectral fitting in both galaxies using simple power law.

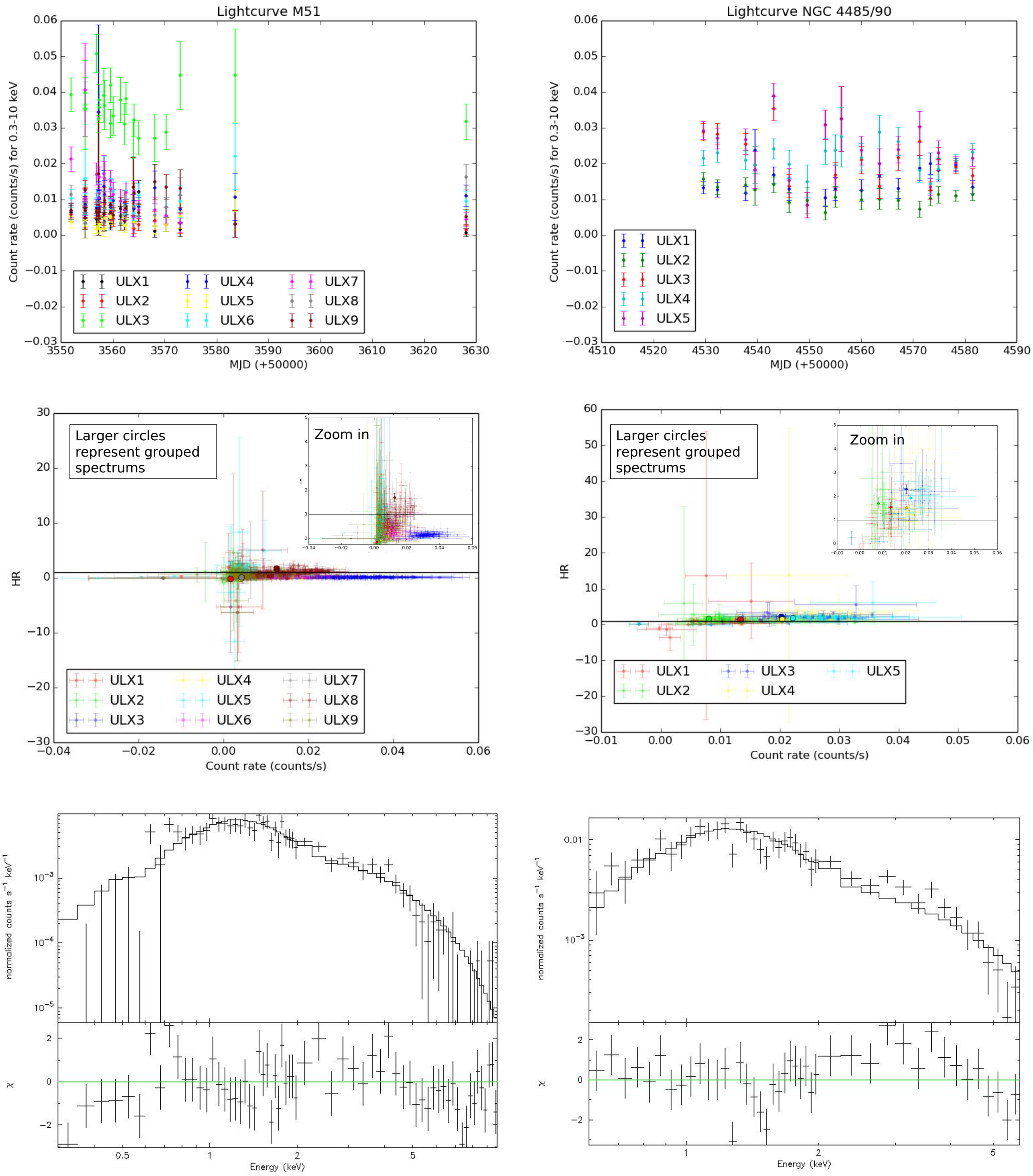

Figure 1: Left for M51, right for NGC 4485/90. Top: light curve, middle: hardness ratio, bottom: spectrum (ULX 8 in M51 and ULX 4 in NGC 4485/90).

Table 1: Fitting results, with Galactic column density $n_H = 1.55 \times 10^{20}$ cm^{-2} to the direction of M51 and $n_H = 1.78 \times 10^{20}$ cm^{-2} to the direction of NGC 4485/90 (Dickey & Lockman 1990). MCD stands for multicolor disk blackbody and PL for power law.

Host	ULX	RA (hhmmss.ss)	Dec (ddmmss.ss)	Mo	n_H (10^{22} cm^{-2})	Γ	kT_{in} (keV)	Red-χ^2 (dof)
M51	1	132939.45	+471243.70	PL	0.06 (fixed)	2.94 ± 0.28		16.20/16
	4	132953.31	+471042.30	MCD	0.06 (fixed)		0.19 ± 0.01	35.55/25
	8	133007.56	+471105.90	PL	0.46 ± 0.09	2.12 ± 0.02		57.24/53
NGC 4485/90	1	123030.60	+414142.00	PL	0.59 ± 0.14	2.38 ± 0.34		63.6/53
	2	123043.20	+413818.00	PL	0.44 ± 0.12	2.21 ± 0.24		35.35/35
	3	123030.80	+413911.00	PL	1.03 ± 0.16	2.28 ± 0.18		46.4/32
	4	123036.30	+413837.00	PL	0.37 ± 0.07	1.92 ± 0.13		51.6/40
	5	123032.30	+413918.00	PL	0.69 ± 0.16	1.89 ± 0.19		23.68/16

Spectral fitting has been successfully carried out for 3 ULXs in M51 and 5 ULXs in NGC 4485/90 assuming Gaussian data (chi-squared statistics) by using `XSPEC`. Fitting parameters are given in Table 1. ULXs in M51 show spectral transition and can be described by power law (PL) and multi color disks (MCD) while ULXs in NGC 4485/90 are more uniform. They can be explained by simple power law (PL).

This result is still preliminary. Our next steps would be: (1) applying cstat statistics for analysis since the data are likely to follow Possion distribution and chi-squared statistics might not be able to describe them well enough, (2) choose different background location, (3) combine spectrums with different `rmf` to increase statistical properties of the data.

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