

Study of correlation between ultraluminous X-ray sources and their host galaxies

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Abstract. Ultraluminous X-ray sources (ULXs) are defined as non-nuclear point-source objects with apparent X-ray luminosities, $L_X > 2 \times 10^{39} \text{ erg s}^{-1}$, in the 0.3-8 keV band. ULXs are often explained using two different scenarios, (1) ULXs as intermediate mass black hole (IMBH) with sub-Eddington accretion and (2) ULXs as stellar mass black hole with super-Eddington accretion. There are two methods that commonly used to study the characteristics of ULXs. One method is to study the X-ray spectra of ULXs, to determine the characteristics of their accretion flows from fitting their spectra using available spectral models. The other method is to investigate how population of ULXs correlate with their environment, in this case their host galaxies. Our goal is to find correlation between ULXs and the properties of its host galaxies, for example with Star Formation Rate (SFR), mass and morphology. From this study we found a positive correlation between ULXs number and SFR. From X-ray luminosity function, we found upper limit of black holes mass that power ULXs is about $100 M_\odot$.

1. Introduction

Ultraluminous X-ray Sources (in short, ULXs) are point source objects that lie in non-nuclear part of a galaxy that typically emits X-ray luminosities higher than Eddington limit of black holes with mass $20 M_\odot$ ($L_X (0.3-10 \text{ keV}) \geq 2 \times 10^{39} \text{ erg s}^{-1}$) [1, 2]. The true characteristics of ULXs are still unknown, but the probability that ULXs are black hole is high [1]. We may know their characteristics from study about their X-ray spectra, but in this paper we shall focus our study to find their characteristics by correlating ULXs population with their host galaxies. In Section 2, we describe about catalog and data; Section 3, we present the results of our study and discuss the results; finally, we summarize our study in Section 4.

2. ULXs catalog and dataset

For this study, we used two ULXs candidate catalog, namely Liu (2011) [2] and Walton et al. (2011) [7] as our main data. [2] used data from Chandra mission, whereas [7] used data from XMM-Newton mission. We combined these two catalogs by selecting sources that meet our criteria. We selected sources with $L_X \geq 2 \times 10^{39} \text{ erg s}^{-1}$ that reside in galaxies within 40 Mpc. For overlapping sources, we need to merge them to avoid double counting when doing correlation. From this selection process, we obtain a total of 599 ULXs in 234 host galaxies. We calculated mass of galaxies using mass-to-light ratio (M/L) and galactic color relation [3]. For Star Formation Rate (SFR), we estimated by using relation from [4]. We classified galaxies that have SFR higher than $10 M_\odot/\text{yr}$ as starburst galaxy. The information about galaxy morphology were obtained from Third Reference Catalog of Bright Galaxies (RC3) [10].



CasJob (<http://skyserver.sdss.org/casjobs/>) was used to get apparent magnitude data of the host galaxies. We derive color of the galaxies using these magnitudes. To determine the type of the galaxies (normal or peculiar), we cross-correlated host galaxies data from our catalog with Arp catalog of peculiar galaxies [11]. For instance, if we found that some of the galaxies are listed in Arp catalog, then we defined them as peculiar galaxies. Isophotal contour was also used to confirm the peculiarity of galaxies. If their isophotal contour are asymmetric, they are confirmed as peculiar galaxies.

3. Result and discussion

Our goal is to determine the characteristic of ULXs population by finding correlation with properties of their host galaxies. For this analysis, we divided our galaxy sample from combined catalog into four sub-sample, by their morphology (spiral and elliptical), interaction (normal and peculiar), color (red and blue) and starburst galaxies. The detail of Sub-sample members is stated in table 1.

Table 1. List of sub-sample. Color of the table represent the sub-sample group.

Sub-Sample	Galaxy Count	ULXs Count
Spiral Galaxy	147	353
Elliptical Galaxy	42	125
Normal Galaxy	172	340
Peculiar Galaxy	62	219
Blue Galaxy	25	61
Red Galaxy	75	122
Starburst Galaxy	44	183

Next step, we compared the ULXs population for each sub-sample. Distribution of ULXs population relative with isophotal radius (R_{25}) of their host galaxies for each subsample can be seen in figure 1. From this figure, overall trend of ULXs population distribution is declining as they have more distance from center of their host galaxies. Several samples (Spiral, Normal, Red, and Blue sample) have flat ULXs distribution from $0.1R_{25}$ to $0.5R_{25}$ before they start to decline. We also notice there are increment of ULXs population as they are going to $0.5R_{25}$ in spiral sample. This range of R_{25} coincide with star forming area within disk of spiral galaxies. From literature check, we confirm ULXs population in $0.5R_{25}$ for some spiral galaxies (e.g. NGC 1313, NGC 5194) actually is located in star forming disk.

We notice that nearly 50% ULXs candidates in elliptical galaxies are located outside R_{25} . The ULXs candidates that reside outside R_{25} most likely are contaminant source, like background or foreground source. Walton [5] argue that about 60% of ULXs candidates outside R_{25} of the host galaxies in Liu catalog are contaminants. Fraction of contaminants in elliptical galaxies tend to be higher than in spiral galaxies. Contamination analysis performed by [6] show that large fraction of ULXs candidate in elliptical galaxies may be contaminant (e.g., ULXs in NGC 1399). For several sources that are confirmed as contaminant, they analyzed them spectroscopically and found that these sources are QSOs.

For peculiar and starburst galaxies sub-sample, we found high number of ULXs population near the galactic center ($0.1R_{25}$). Galactic inclination might be take part in this case, especially for galaxy that has high inclination, we could misinterpret the ULXs position to be in the center of galaxies instead of in the disk or bulge. To get the actual distribution of ULXs in their host galaxies, using inclination class data from MCG catalog, we only choose galaxy that have face-on orientation and then plot the distribution like Figure 1 for normal and peculiar galaxies. We got peculiar galaxies still have higher numbers of ULXs candidate near the center than normal galaxies with difference is about 10%. ULXs are highly correlated with star formation rate of galaxies [7]. The higher SFR of the galaxy, the more ULXs we expect to find. Excess number of ULXs candidate near center of peculiar and starburst galaxies may be due to circumnuclear starburst area that tend to occur in galaxies that undergo interaction, but further investigations are needed to confirm this hypothesis. From table 1 we can calculate the average number of ULXs candidate that reside in each sub-sample galaxies. For spiral galaxies, we calculate the average number of ULXs candidate is about 2.4 ULXs per galaxy. In elliptical galaxies, we get slightly

higher number than in spiral galaxies, about 2.9 ULXs per galaxy. The same result is also obtained by Colbert and Ptak [8]. But we must aware that the rate of contaminant in elliptical galaxies is higher than spirals. If we exclude ULXs candidate outside R25, the average number of ULXs candidate in spiral and elliptical galaxies respectively are 2.13 and 2.21 ULXs per galaxy. As for peculiar galaxies, they have higher ULXs per galaxies than normal galaxies (3.5 ULXs per galaxy for peculiar, 1.9 for normal). This strengthen hypothesis that ULXs tend to occur at galaxies that undergo interaction or merging [9]. Due to interaction, gas in galaxies will experience compression because of the shockwave. This event can trigger star forming activity. The excess of ULXs in interacting galaxies may be correlated with increment of SFR due to interaction. For complement, the highest ULXs per galaxy can be found in Starburst sample (4.15 ULXs per galaxy), which can be used to support idea that ULXs are correlated with SFR. Figure 2 shows how number ULXs/galaxy correlate with far infrared (FIR) luminosity for spiral and starburst galaxies (SFR positively correlated with LFIR).

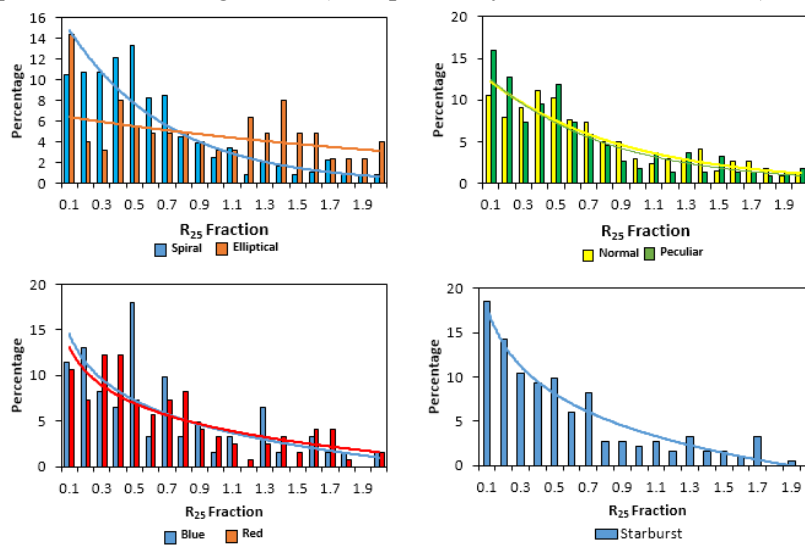


Figure 1. Distribution of ULXs in host galaxies relative of R₂₅

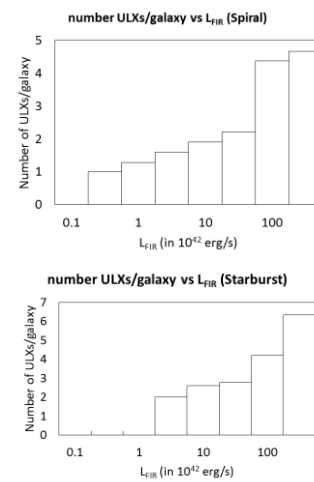


Figure 2. Number ULXs/galaxy vs L_{FIR}

We also constructed X-ray luminosity function (XLF) of ULXs for each sub-sample. We fit the luminosity function using power-law (CL_X^a) and power-law with cut-off model ($CL_X^a \exp(L_x/L_c)$). Parameter C is normalization coefficient, L_x is X-ray luminosity of the source, a is power-law index and L_c is cut-off luminosity. The results are presented in figure 3. The second model give better fit for ULXs XLF. We found that in general luminosity function of ULXs has cut-off when luminosity goes around $2 \times 10^{40} \text{ erg s}^{-1}$. This indicates there are upper limit for black holes that power ULXs, about $100 M_\odot$.

Next we tried to correlate specific luminosity of ULXs with stellar mass of galaxies to find how mass of galaxies correlate with ULXs populations. We defined specific luminosity of ULXs as total luminosity of ULXs in specific stellar mass bin divided by total mass of galaxies in the same stellar mass bin. We obtained a tendency that specific luminosity of ULXs goes lower with increasing stellar mass bin. There are two explanations for this tendencies [5]. First, lower mass galaxies have higher SFR specific than the massive one. We know that ULXs have positive correlation with SFR. This can be the reason why lower mass galaxies have higher specific luminosity of ULXs. Second, lower mass galaxies also tend to have lower metallicities than massive galaxies. Metallicity have a role to determine whether a star became low or high mass black hole. In lower metallicity region, it is easier to form more massive black holes [5] and ULXs prefer more massive black holes than less massive one.

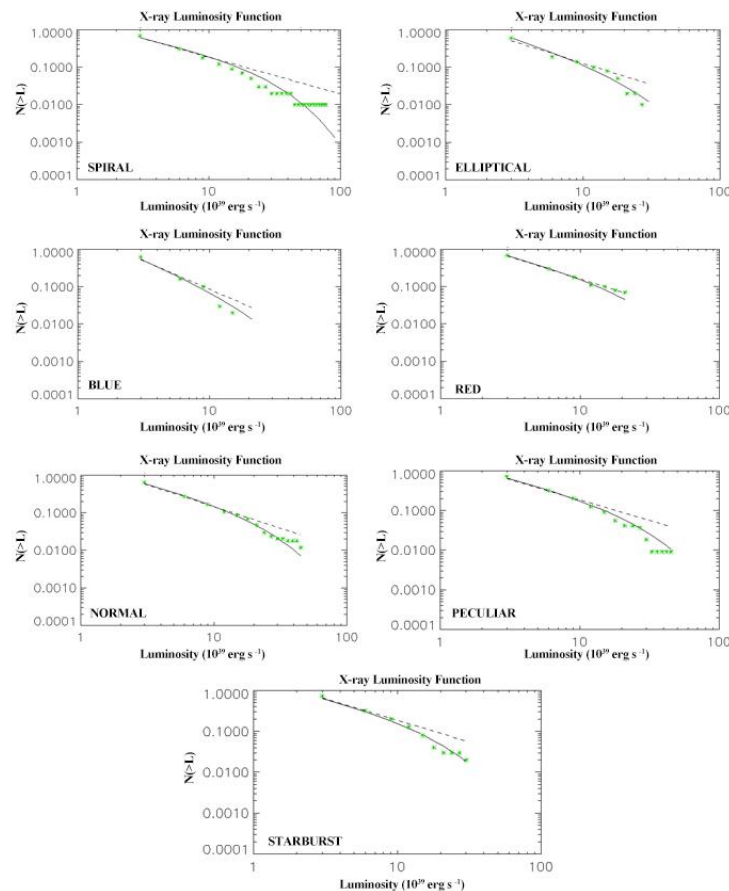


Figure 3. XLF for each sub-samples. Green asterisk indicate the data, dash line indicate fitting using power-law model and solid line indicate fitting using power-law with exponential cut-off model.

4. Summary

From this study, we summarize several results: (1) ULXs tend to be found at spiral galaxies, (2) nearly 50% ULXs in elliptical galaxies are suspected as contaminant, (3) there are higher number of ULXs in peculiar and starburst galaxies, show that there are positive correlation between interaction and SFR with number of ULXs, (4) Excess of ULXs near center of peculiar and starburst galaxies may be due to circumnuclear starburst, (5) ULXs luminosity function give upper limit for black hole mass about 100 $M_{\odot}$, (6) distribution of specific luminosity of ULXs are declining with the increase of galaxies stellar mass.

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