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Morphological analysis of Early type Galaxies hosting X-ray point sources

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Abstract

We report a strong association of X-ray point sources with the Sérsic index of bulges, analyzing a complete sample of nearby 28 early type galaxies with X-ray and K band observations from Chandra and 2MASS archives, respectively. From the X-ray spectral analysis, we construct a flux limited sample of 371 bright ($L_X = 0.24X10^{39} – 0.12X10^{41}$ ergs/s) X-ray point sources. Morphological analysis of these galaxies (in K band) was conducted using the code GALFIT assuming a Sérsic bulge and an exponential disk for their surface brightness profiles. The extracted structural parameters show presence of strong disk component in all these galaxies with Bulge-to-Total K band light ratio, B/T < 0.5, even though they are classified as early type galaxies in the RC3 catalog. The average Sérsic index, n shown by the sample is 1.44 ± 0.33, suggesting the existence of pseudo bulges in these systems. Further, we find that the maximum luminosity of X-ray point source is strongly correlated with Sérsic index, suggesting that the existence of X-ray point sources has strong influence from the nature of hosting bulges.

Keywords: X-rays, galaxies, infra-red, bulges, elliptical and lenticular, cD, photometry.

Introduction

The study of X-ray emission from normal galaxies became an important part in astronomy in the past decades. The Einstein Observatory, the first imaging X-ray telescope, gave a start to the systematic study of the X-ray emission of normal galaxies. However, the individual X-ray sources from the distant galaxies couldn't well resolved by the Einstein instruments. The subsequent X-ray observatories, ROSAT and ASCA were not superior to the Einstein instruments. But later, the sub-arcsecond angular resolution of *Chandra X-ray observatory* has enabled the study of population of individual X-ray point sources in nearby galaxies.

High energy processes in extreme conditions are responsible for the emission of X-rays from galaxies. Such processes have very important role in the shaping of the galaxy structure[1,2]. It is reported that hot-gaseous component is responsible for the X-ray emission from more luminous ($M_B \leq -19$) early-type galaxies[3] while accreting X-ray binaries are the reason for the same from less luminous ($M_B \sim -22$). The source population in the galaxies is dominated by X-ray binaries (XRBs), including low-mass X-ray binaries (LMXBs), high-mass X-ray binaries (HMXBs), accreting white dwarfs, evolved supernova remnants (SNR), ultra-luminous X-ray sources (ULXs) and background objects. The population of LMXBs account for a very large fraction of the X-ray emission of the Elliptical and S0 galaxies. The dependence of the population of LMXBs on stellar age has been studied and it is seen that older galaxies tend to host more LMXBs per unit stellar mass than younger ones[4]. Apart from the LMXBs, the early-type galaxies also contain ultra-luminous X-ray sources. These are off-nuclear X-ray point sources and their X-ray luminosities are in between that of the X-ray binaries and active galactic nuclei (AGNs) (i.,e 10^{39} - 10^{41} erg/s). The observed luminosities of ULXs exceed the Eddington limit for an accreting object with masses of 10 $M_\odot$ or larger. Since ULXs are off-nuclear sources, their masses must be < 10^5 $M_\odot$ from dynamical friction arguments [5]. Thus there is a possibility for them to harbour black holes in the mass range of 10^2- 10^5 $M_\odot$ called intermediate mass black holes (IMBHs), as their masses are between that of stellar mass black holes of galactic X-ray binaries (GXBs) and the super massive black holes of AGNs[6,7].

Fitting of the light distribution with parametric functions is the best approach available to quantify the wide range of galaxy morphology and luminosities. Many elliptical galaxies follow the de Vaucouleurs $R^{1/4}$ light distributions[8]. Later, Freeman[9] found that spiral and lenticular galaxies are well described by a de Vaucouleurs bulge plus an exponential disk. The study of galaxy formation and evolution is advanced much by galaxy fitting and decomposition methods. Galaxy fitting can be of two types: one dimensional[10,11] and two-dimensional fitting[12,13] of galaxy images. One dimensional profile fitting is frequently used because it is simple to implement. But many studies now implement two-dimensional galaxy fitting techniques using 2D decomposition codes such as GALFIT[14], BUDDA[15] etc.

We used the two-dimensional image decomposition code GALFIT for extracting the galaxy parameters. GALFIT allows simultaneous fitting of different galaxies and their sub structures. The Levenberg-Marquardt minimization algorithm[16], is used to find the best fit, where GALFIT minimizes the residual between the data image and the model, adjusting all the free parameters simultaneously.

In this study we analyzed 2MASS K-band images of 28 early type galaxies. The Near IR images of the galaxies were fitted with an isophotal elliptical profile and the 2D decomposition were done using the code GALFIT. We limit the present study only to early-type galaxies. Our motivation is to study the environment of the ULX host galaxies and hence to identify the relation exist (if any) between the existence of ULXs and the galaxy morphology.

In section 2, the sample description is given. The data analysis and 2D decomposition techniques are described in section 3. The results and discussion are explained in section 4, while the section 5 gives the conclusion.

Sample : In a complete sample of 82 nearby galaxies, one hundred fifty-four non nuclear ultra-luminous X-ray (ULX) sources with intrinsic luminosity $L_X \geq 10^{39}$ ergs/s in the 0.5 - 8.0 keV energy band were identified by Swartz[17]. The celestial positions and X-ray properties of these 154 ULX sources were tabulated in their study. A modified catalog with 127 galaxies has been published later by Swartz[18]. Our sample covers all the early type galaxies from both the catalog [17,18] which include 20 ellipticals and 8 lenticulars. X-ray analysis were done on the *Chandra* Advanced CCD Imaging Spectrometer (ACIS) observations and the morphological analysis were done in the 2MASS K-band (2.17μ) data. Throughout this study, we used H0 = 75 km/s/Mpc and q0 = 0.5. The sample properties are given in table 1.

Data Analysis

Chandra Data: The CIAO (version 4.4) science threads and HEASOFT (6.11.1) were used for the *Chandra* data reduction. The point sources in the 0.3-8.0 keV energy band were detected using the CIAO task *celldetect*. We identified 1315 X-ray point sources in our sample galaxies. We defined the D_{25} region (ellipse with a surface brightness of 25 mag/arcsec^2 in B as provided by the RC3 catalog) for each galaxy and selected all point sources within this region. We avoided the central 10" region of every galaxy as the central region is usually dominated by diffused emission, most probably from the central engine. This reduced the sample size of point sources to 843. After excluding the sources alligned along the jet in NGC 4486, the number of X-ray point sources reduced to 835.

First, the netcounts of 835 sources were converted into fluxes using the Energy Conversion Factor (ECF), assuming a power law emission[19]. The number of X-ray sources detected can vary with different exposures even for a single galaxy at a particular distance. Also, eventhough the exposure time is set similar for all galaxies, the number of sources detected may vary from galaxy to galaxy as they are lying at different distances. So, in order to address this bias, we made a cutoff to the luminosities of the sources. The minimum luminosity of the farthest galaxy in our sample made as the threshold value for selecting the sources. So, all sources with luminosities below the threshold value was discarded from further analysis. This resulted in a sample of 371 sources and this is our final sample of X-ray point sources.

Table-1
Sample galaxy properties

Galaxy	Type	Distance (Mpc)	Obs ID
NGC0404	SA(s)0-	3.0	870
NGC0720	E5	24.6	492
NGC0855	E	9.7	9550
NGC1316	SAB(s)0 (pec)	17.0	2022
NGC1399	E1 (pec)	18.3	319
NGC1407	E0	17.6	791
NGC1549	E0-1	19.7	2077
NGC1553	SA(r)0	18.5	783
NGC3115	S0-	10.0	2040
NGC3379	E1	11.1	1587
NGC3585	E6	20.0	2078
NGC3607	SA(s)0	22.8	2073
NGC4111	SA(r)0+	15.0	1578
NGC4125	E6 (pec)	24.2	2071
NGC4365	E3	20.9	2015
NGC4374	E1	17.4	803
NGC4382	SA(s)0+ (pec)	16.6	2016
NGC4472	E2	15.9	321
NGC4486	cD0-1 pec	15.8	352
NGC4494	E1-2	14.5	2079
NGC4552	E0-1	15.9	2072
NGC4621	E5	15.8	2068
NGC4636	E0-1	15.1	323
NGC4649	E2	16.6	785
NGC4697	E6	11.8	784
NGC5102	SA0-	3.5	2949
NGC5128	S0 (pec)	4.0	962
IC1459	E3-4	29.2	2196

Host Galaxy. Distance to the galaxy in Mpc. Observation ID.
A better estimate of the flux of the X-ray point sources can be obtained by detailed spectral fitting. However, a minimum of 60 counts are required to obtain reliable fit to the spectral data with the two-parameter model[20]. We attempted to fit each of these 186 sources (with counts ≥ 60) using a two component model; the absorbed power law and absorbed disk black body model. The XSPEC version (12.7.0) was used for this. Best fit from the two was selected for each source estimated the flux for 151 sources. Thirty five sources were not fitted well by either model. The luminosity of the point sources were calculated using the best- fit model parameters.

MASS K band Data: The profile fitting was done on 2MASS K-band Large Galaxy Atlas (LGA) data. The elliptical isophote profile fitting was done for all the galaxies using the *IRAF/STSDAS ellipse* task. We used GALFIT (version 3.0.2) for 2D decomposition. The code is driven by Marquardt–Levenberg minimization algorithm. The best-fitting model parameters and the mask file of ellipse fit was chosen as input for running GALFIT. We used the Sérsic profile for fitting the bulge and an exponential disk profile for disk. A sky component is also used for fitting the sky value. During the first run of GALFIT, the sky value is allowed to vary and the estimated sky value during this fit is used and fixed in the second time running.

Results and Discussion

The elliptical galaxies of our sample show prominent disk component in them which suggest the possibility of the sample more likely contain pseudo-bulges. The sample galaxies show only a limited range of Sérsic index n (1.44 ± 0.33) and bulge-to-total luminosity ratio B/T (0.37± 0.19). The plot of B/T ratio against the number of X-ray point sources indicates that the X-ray point sources more likely to reside in disk dominant galaxies, as all galaxies in the sample have B/T < 0.5 (figure 1). These are indicative of the existence of prominent disk in the early-type galaxies and which suggest the presence of pseudo-bulges in these galaxies. Further, it appears that the more disky the galaxy, the larger the number of X-ray sources it host, barring the very disky four galaxies with B/T < 0.2. However, as the trend is not significantly strong, much information cannot be obtained from the sample.

Further the bulge also seems to affect the nature of X-ray sources in our sample. The Sérsic index is well anti-correlated with the maximum luminosity of the X-ray point sources in each galaxy (figure 2), to the effect that the smaller the n value, the higher is the maximum luminosity of the X-ray source. This suggests that the existence of X ray point sources in the sample galaxies has strong influence from the nature of the bulges they host.

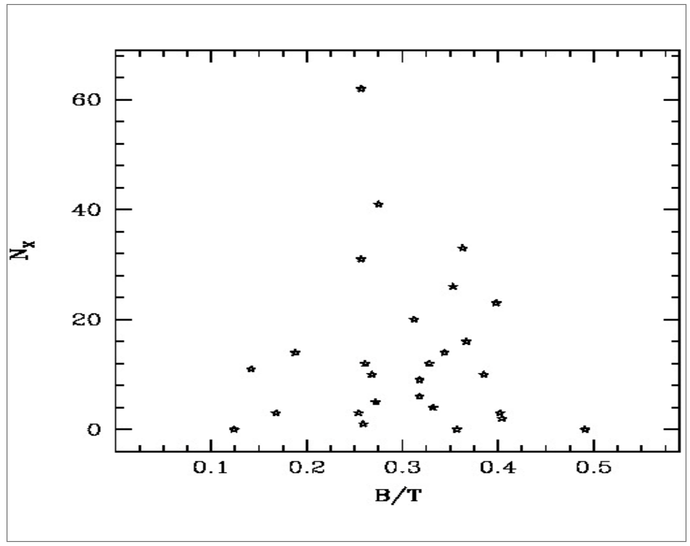

Figure-1
Plot of B/T ratio against the number of X-ray point sources

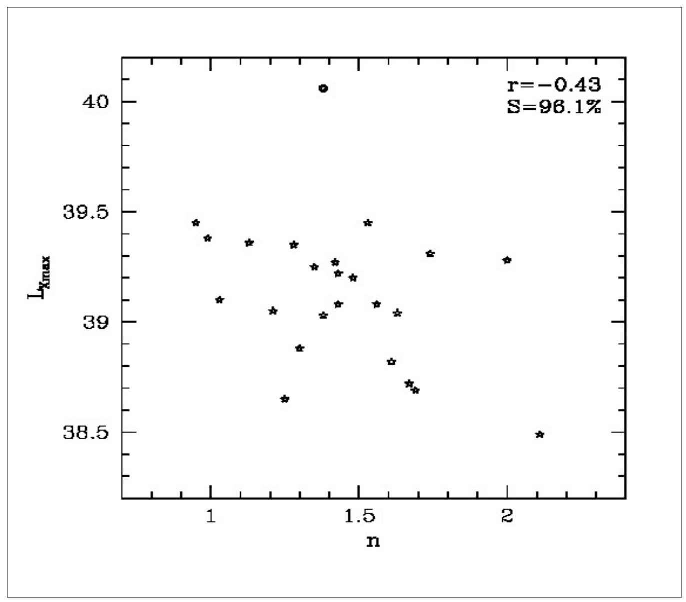

Figure-2
Sérsic index is well anti-correlated with the maximum luminosity of the X-ray point sources in each galaxy

Conclusion

We could identify a significant number of X-ray point sources in the sample galaxies. From the two dimensional decomposition analysis of our sample on the 2MASS K-band LGA data, we report the presence of pseudo-bulges inside these selected galaxies. Further we gather evidence for the nature of X-ray point sources being affected by the photometric bulge and disks existing in the galaxies. Further, the anit-correlation between the Sérsic index and the maximum X-ray luminosity of the point source indicates the dependence of the origin of the X-ray point sources on the evolution of the host galaxy.

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