Long Term Temporal and Spectral Evolution of Point Sources in Nearby Elliptical Galaxies

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Abstract

We used archival Chandra X-ray Observatory (CXO) observations of the nearby elliptical galaxies NGC 4472, NGC 4552, NGC 4649, NGC 3379 to study the spectral and temporal evolution of all the detected point sources, over the course of the observations of the host galaxies. We also created color-color diagrams to approximately classify the X-ray sources. In this poster, we present the preliminary results of this study, which allows us to further constrain the X-ray source population in nearby elliptical galaxies and also better understand the nature of individual point sources.

1 Purpose

Study of point sources in galaxies other than our Milky Way allows us to explore and study the nature of X-ray source populations in different types of galaxies since it provides a complete, yet flux limited, view of the whole population of the host galaxy. Such a view in turn provides clues to stellar evolution and compact object populations at different venues. Long term monitoring of nearby galaxies also allow us to study the duty cycle of transiently accreting X-ray sources.

Here, we aim to study temporal and spectral evolution of the point sources of all the point sources detected in nearby elliptical galaxies, NGC 4472, NGC 4552, NGC 4649, NGC 3379 using CXO data, which successfully combines spatial resolution capabilities with decent effective area. We also create hardness diagrams to discern different types of X-ray sources using the method defined by Prestwich et al. (2003).

Our ultimate goal is to expand this study to public archival data of XMM-*Newton* and to other nearby elliptical galaxies, namely NGC 4552, NGC 4649, M32, Maffei 1, NGC 3379, IC 1101, M87, NGC 4477, NGC 4621, and NGC 5128 galaxies.

2 Data Analysis

Elliptical galaxies, NGC 4472, NGC 4552, NGC 4649, NGC 3379 were observed with CXO 43 times with a total exposure time of 1306.69 ks, 622.68 ks, 193,79 ks, 313.22 ks, 470.44 ks respectively. We downloaded all the publicly available data from these observations and applied standard calibration procedures using the *chandra repro* tool in CIAO v4.8 and CALDB v.4.7.0. Because the High Resolution Camera (HRC) onboard CXO offers very limited energy resolution we eliminated these data.

We used the *wavdetect* script within CIAO package to detect all the point sources in the observations. We detected 2165, 791, 1289, 760 point sources that are above 3σ of the background in the most deep observation of each galaxy, namely NGC 4472, NGC 4552, NGC 4649, NGC 3379, respectively. We then matched the individual source catalogs of each observation of a galaxy using the astrometric information available, to create the final catalog of unique sources and to be able to follow them from one observation to another. At this stage we also eliminated all the possibly spurious sources detected by wavdetect (i.e. sources having regions with negative radii). To make sure that the objects we study are members of the host galaxies we compared the distance of each source to the center of each galaxy. We only performed analysis of the sources that are within the estimated major axes of the galaxies (De Vaucouleurs et al. (1991). Since the spatial resolution of CXO is limited we also did not perform spectral analysis of the sources that can not be resolved at the central region of each galaxy (See Table 1).

Table 1: Distance,Morphology R_{25}, R_{center} and nH information table for selected galaxies.

Name	Morph.[1]	Distance	R_{25}	R_{center}	nH[2]
		(Mpc)	(')	(')	10^{22} cm^{-1}
NGC 4472	E-2	16.1	614	16.94	0.153
NGC 4552	E0-E1	15.8	314	3.6	0.262
NGC 4649	E-21	6.8	444.8	8.32	0.204
NGC 3379	E-1	10.6	322.2	10.44	0.275

Galaxies' distances are from Tully et al., 2013, [2] Mei et al., 2007, [3] Blakeslee et al., 2001, [4] John L. Tonry et al., 2001.
[1]Morphology classes of all galaxies are obtained from De Vaucoulerus et al., 1991.
[2] Hydrogen column density (nH) from Kalberla et al., 2005.

To extract X-ray spectra of these sources, we created a Python script to automatically select the blank regions in each observation of each Advanced CCD Imaging Spectrometer (ACIS) CCD used in a given observation. Our criteria for these regions was to have a radius of 70 pixels and to be as far away from every detected source at least twice as much as its own radius.

We used *specextract* tool to extract the X-ray spectra of each of the unique sources detected in each observation and have at least 150 counts in each observation. We fit all the spectra using Sherpa and custom tailored *Python* scripts with a power-law model. We took into account the interstellar extinction both in our galaxy, in the field of view of the object and the extinction in the host galaxy using the *tbabs*model (Wilms et al. 2001). For the amount of local extinction we used the weighted average of all the observations of Kalberla et al., 2005 and fixed this value in the spectral fits. These values are given in Table 1.

Table 2: Number of detected sources for each galaxy by utilizing *wavdetect* task for the whole field of view within our effective radius criteria.

Name	Sources	Member Sources
NGC 3379	760	24
NGC 4472	2165	64
NGC 4552	791	32
NGC 4649	1289	40

Our analysis resulted in the tables of absorbed flux, photon index, nH of the host galaxy in the source direction values together with the 1σ formal uncertainties of these parameters. For each source these values are given in Tables 1, 3, 7,5.

For sources that have less than 150 counts per observation we only report the estimated fluxes using *srcflux* tool provided within the CIAO package. *srcflux* tool calculates the net count rates and fluxes together with their 1σ statistical uncertainties, of a source in a Chandra observation taking into account the effective area of the instrument. This tool can also make use of a spectral model in the calculation of the flux, and for this purpose we assumed that the model we used for the spectral analysis is valid for these dim objects as well.

We also estimate X-ray count rates for difference energy bands defined as soft (0.5-1.2 keV), medium (1.2-2.0 keV), and hard (2.0-7.0 keV) following Evans et. al. (2010) and we calculate the x-ray colors which are defined as soft color =(m-s)/(h+m+s) and hard color =(h-m)/(h+m+s) following Prestwich et al. (2003). Using these values for all the sources we obtained color-color diagrams for each galaxy. According to Prestwich et al. (2003) if an object has a soft color that is greater than -0.5, then it is likely that the object is an low mass X-ray binary (LMXB). On the other hand if an object has a soft color that is less than -0.5 then it is most likely a black hole (BH) or a supernova remnant (SNR).

Our ultimate goal is to expand this study to public archival data of XMM-*Newton* and to other nearby elliptical galaxies, namely NGC 4552, NGC 4649, M32, Maffei 1, NGC 3379, IC 1101, M87, NGC 4477, NGC 4621, and NGC 5128 galaxies.

3 Results

3.1 NGC 4472

IDs of all the used observations are as follows, 11274, 12978, 15758, 16260, 322, 8107, 12888, 12889, 15756, 12759, 16261, 7845, 8127, 15757, 15760, 321, 8095. Using Chandra ACIS observation and Hubble Space Telescope (HST) observation (Maccarone, et al., 2002) reported 144 X-ray point sources outside the nuclear region. 30 of these were classified as LMXBs and matched with globular clusters within the galaxy using the HST data. Utilising the color-color diagrams we classified 19 sources as possible LMXBs (see Figure 2), of these 2 are located to be within globular clusters.

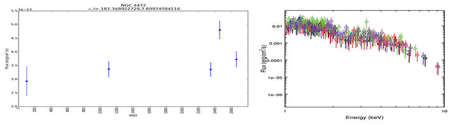

Figure 1: Light curve and observed spectra of an LMXB candidate in NGC 4472.

Figure 1 we present the spectra and time evolution of an example. Table 3 gives the inferred spectral parameters for this example source.

Table 3: Results of the spectral analysis of an LMXB candidate in NGC 4472 point source(α,δ=187.34892273, 7.89974594).

nH[1]	Γ	Flux[2]	χ^2/ν
$6.4^{\pm 0.344}$	$1.839^{\pm 0.407}$	$3.37^{\pm 5.6}$	1.338
$0.4^{\pm 0.162}$	$1.671^{\pm 0.227}$	$3.36^{\pm 5.0}$	1.068
$18.8^{\pm 0.344}$	$1.908^{\pm 0.370}$	$4.80^{\pm 6.4}$	0.672
$0.2^{\pm 0.000}$	$1.519^{\pm 0.233}$	$3.73^{\pm 5.7}$	1.785

[1] in units of 10^{20}cm^{-2}
[2] Absorbed fluxes are given in units of 10^{-13} erg/s/cm^2

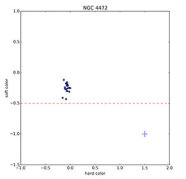

Figure 2: NGC 4472 color-color diagram. Typical errors on the colors are shown in the lower-right corner.

3.2 NGC 4552

IDs of all the used observations are as follows, 13985, 14359, 16033, 2072, 8058, 8098, 14358, 16032, 1621, 8050, 8083. Using Chandra ACIS observation Xu et al. (2005) reported 47 point sources. 10 of these were classified as LMXBs and matched with globular clusters within the galaxy. Using the hardness diagrams we classified 15 sources as possible LMXBs (see Figure 4), of these sources 3 are located to be within globular clusters.

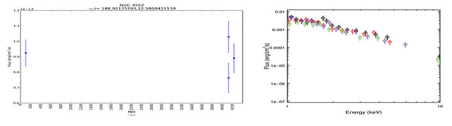

Figure 3: Example light curve and x-ray spectra for a source in NGC 4552.

Figure 3 we present the spectra and time evolution of an example source. Table 4 gives the inferred spectral parameters for this example source.

Table 4: Results of the spectral analysis of an LMXB candidate in NGC 4552 point source (α,δ=188.92175293,12.58094215)

nH[1]	Γ	Flux[2]	χ^2/ν
$3.5^{\pm 0.00}$	$1.446^{\pm 0.37}$	$1.03^{\pm 0.19}$	1.422
$3.7^{\pm 0.00}$	$1.233^{\pm 0.61}$	$8.92^{\pm 0.19}$	1.377
$0.1^{\pm 0.51}$	$1.315^{\pm 0.92}$	$0.764^{0.19}$	0.186
$23.0^{\pm 0.00}$	$1.783^{\pm 0.58}$	$0.926^{\pm 0.16}$	1.250

[1] in units of 10^{20}cm^{-2}
[2] Absorbed fluxes are given in units of 10^{-13} erg/s/cm^2

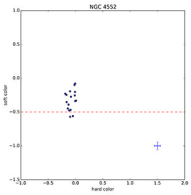

Figure 4: NGC 4552 color-color diagram. Typical errors on the colors are shown in the lower-right corner.

3.3 NGC 3379

IDs of all the used observations are 11782, 1587, 7073, 7075, 13829, 46492, 7074, 7076 in Chandra. Using Chandra ACIS observation and Hubble Space Telescope (HST) observation (Brassington et al., 2008)reported 70 ULX sources and 9 of these were classified as LMXBs and matched with globular clusters within the galaxy. Using the hardness diagrams we classified 5 sources as possible LMXBs.

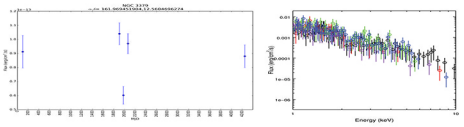

Figure 5: Light curve and observed spectra of an LMXB candidate in NGC 3379.

Figure 5 we present the spectra and time evolution of an example source. Table 5 gives the inferred spectral parameters for this example source

Table 5: Results of the spectral analysis of an LMXB candidate in NGC 3379 point source (α,δ=161.9694519,12.56046963)

nH[1]	Γ	Flux[2]	χ^2/ν
$4.9^{\pm 0.00}$	$1.510^{\pm 0.39}$	$0.88^{\pm 0.16}$	0.916
$3.6^{\pm 0.00}$	$1.259^{\pm 1.63}$	$0.912^{\pm 0.23}$	0.180
$27.5^{\pm 0.00}$	$1.718^{\pm 0.38}$	$1.04^{\pm 0.16}$	1.369
$16.1^{\pm 0.00}$	$1.968^{\pm 0.49}$	$0.60^{\pm 0.13}$	1.042
$10.5^{\pm 0.19}$	$1.608^{\pm 0.33}$	$0.97^{\pm 0.14}$	0.526

[1] in units of 10^{20}cm^{-2}
[2] Absorbed fluxes are given in units of 10^{-13} erg/s/cm^2

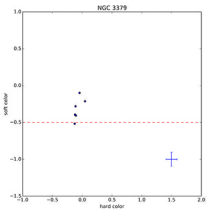

Figure 6: NGC 3379 color-color diagram. Typical errors on the colors are shown in the lower-right corner.

3.4 NGC 4649

IDs of all the used observations are 12975, 14328, 8046, 8507, 12976, 785, 8182. Using a Chandra observation (Randall et al., 2004) reported 165 X-ray point sources. 14 of them have observed DSS and 20 of them have matched globalar clusters. Using the hardness diagrams we classified 17 sources as possible LMXBs, of these sources are located to be within globular clusters.

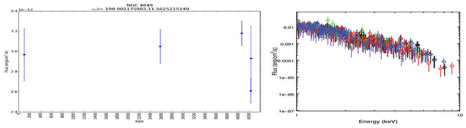

Figure 7: Light curve and observed spectra of an LMXB candidate in NGC 4649.

Figure 7 we present the spectra and time evolution of an example source. Table 6 gives the inferred spectral parameters for this example source

Table 6: Results of the spectral analysis of an LMXB candidate in NGC 4649 point source (α,δ=190.9021759, 11.50252151).

nH[1]	Γ	Flux[2]	χ^2/ν
$0.1^{\pm 0.17}$	$1.914^{\pm 0.12}$	$2.61^{\pm 0.24}$	1.121
$0.0^{\pm 0.26}$	$1.958^{\pm 0.11}$	$3.18^{\pm 0.24}$	1.083
$4.6^{\pm 0.00}$	$1.698^{\pm 0.65}$	$2.93^{\pm 0.64}$	0.268
$4.1^{\pm 0.00}$	$2.228^{\pm 0.49}$	$2.97^{\pm 0.52}$	0.580
$0.0^{\pm 0.00}$	$1.837^{\pm 0.14}$	$3.05^{\pm 0.33}$	0.805

[1] in units of 10^{20}cm^{-2}
[2] Absorbed fluxes are given in units of 10^{-13} erg/s/cm^2

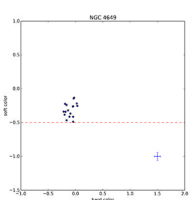

Figure 8: NGC 4649 color-color diagram. Typical errors on the colors are shown in the lower-right corner.

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