

X-ray Sources Population in NGC 1559

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ABSTRACT

We present Chandra observation of the nearby spiral galaxy NGC 1559 to study the X-ray sources population in the galaxy. Based on our analysis, we detect twenty-four X-ray sources in the galaxy, of which six have 0.5–8 keV luminosities exceeding 10^{39} erg s^{-1} , suggesting that they are possibly ultra-luminous X-ray source (ULX) candidates. The remaining eighteen sources have 0.5–8 keV luminosities below this threshold value, suggesting that they are likely to be X-ray binary candidates. We perform X-ray spectral analysis for the six ULX candidates and found that in general, their properties are broadly consistent with that found for other ULXs. The number of X-ray sources found in this galaxy is relatively high as compared to other galaxies with similar star formation rate of $\sim 2.8 M_{\odot} yr^{-1}$. This however could be attributed to the relatively high number of supernova occurrence (four) in the galaxy observed in the past years. We did not detect any X-ray nuclear point source in the galaxy, suggesting that NGC 1559 does not host an active galactic nucleus. This is supported by its HII optical spectral classification and our infrared analysis using WISE.

Keywords: X-ray sources; NGC 1559; Chandra

INTRODUCTION

NGC 1559 is one of the closest galaxies to our own, located at a distance of 12.7 Mpc with an optical spectral type of HII region (Goulding & Alexander 2009). It is a late-type galaxy (Scd), with a relatively high star formation rate in the massive spiral arm, and strong radio flux emitting from the bar and the disc of the galaxy (Beck et al. 2002). Four supernova explosions have been detected in the galaxy; i.e., SNe 1984J (Evans et al. 1984), SNe 1986L (Mack et al. 1986), SN 2005df (Wang & Baade 2005) and SN 2009ib (Pignata et al. 2009). All of them are classified as Type-II supernovae, which can result in the formation of binary systems consisting of compact stellar remnants such as white dwarf, neutron star and black hole. These can correlate to a relatively high number of off-nuclear X-ray sources in the galaxy, such as X-ray binaries (XRBs) and ultra-luminous X-ray sources (ULXs).

XRBs are off-nuclear X-ray emitting objects that are believed to be powered by the accretion of stars onto compact objects such as stellar-mass black holes and neutron stars. Typically, XRBs have luminosity values in the range of 10^{35-39} erg s^{-1} (Bogdán & Gilfanov 2011). They can be classified into high mass XRBs and low mass XRBs, depending on the mass of the companion stars; i.e., $\sim 8 M_{\odot}$ for high mass XRBs and $\sim 2 M_{\odot}$ for low mass XRBs. XRBs can be found in both early and late-type galaxies (Mezcua et al. 2014). However, early-type galaxies are usually dominated by low mass XRBs (Boroson et al. 2011 and Zhang et al. 2012), while late-type star forming galaxies

are typically dominated by high mass XRBs (Mezcua et al. 2014).

On the other hand, ULXs are defined as off-nuclear X-ray sources with luminosity values greater than 10^{39} erg s^{-1} , which exceeds the Eddington luminosity for stellar mass black holes (Fabbiano, 2006 and Earnshaw et al. 2019b). Intermediate mass black holes have been long proposed as the candidates for ULXs, however recent studies on several ULXs found that they are actually powered by neutron stars / pulsars (e.g., Bachetti et al. 2014; Fürst et al. 2017; Carpano et al. 2018). ULXs can be found in both elliptical and spiral galaxies, but is more dominant in spirals, most likely due to the higher star formation rates in these galaxies (Swartz et al. 2009; Owen & Warwick, 2009; Walton et al. 2011).

NGC 1559 has only been observed in X-rays by *ROSAT* and *Chandra*. In the *ROSAT* observation which was conducted in 1995, two ULXs were detected in the spiral arms of the galaxy (Liu & Bregman, 2005). No other X-ray sources were detected in the observation. In this paper, we will present the *Chandra* observation of NGC 1559 which has not been published in previous papers, to study the X-ray sources population in the galaxy. The much higher spatial resolution of *Chandra* as oppose to *ROSAT* can provide us with a much more detail insight on the X-ray sources population in this galaxy.

We present the details of the *Chandra* observation, our data reduction, source detection and X-ray spectral analysis procedures in the Methodology Section. In the next section, we present and discuss our results. This is followed by a

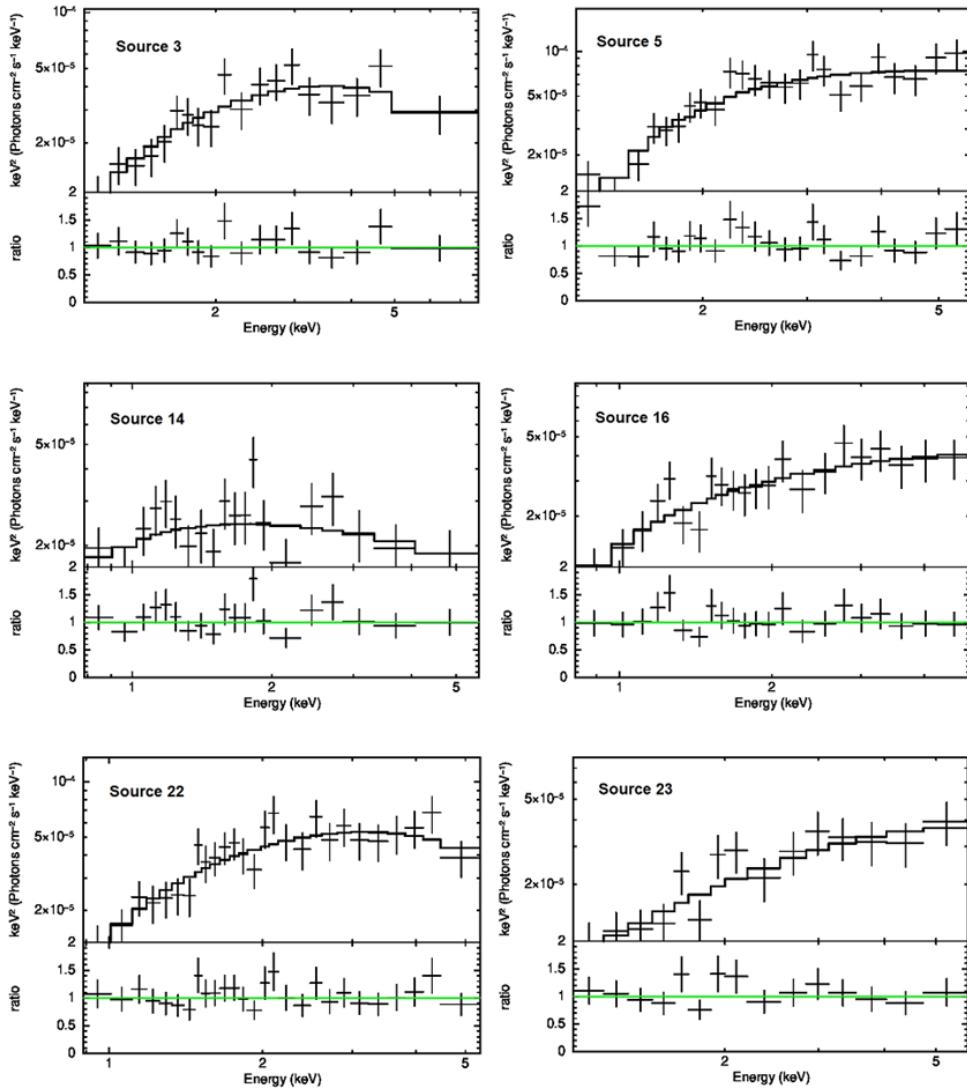


FIGURE 2. The best-fit spectra of the ULX candidates using CUTOFF model. The top panel for each plot shows the data and unfolded model, while the bottom panel shows the ratio between the data and the folded model.

Based on their calculated luminosities, we found that six out of twenty-four sources are potentially ULXs (sources 3, 5, 14, 16, 22 and 23), and the remaining eighteen sources are XRB candidates. Due to the much larger spatial resolution of *ROSAT* as compared to *Chandra*, we could not directly associate the two ULXs that were detected in the earlier *ROSAT* observation (Liu & Bregman, 2005) with those detected in the *Chandra* observation. The ULXs may be the same as the two of the six ULXs that we detected using *Chandra*, or they could actually be the combination of multiple XRBs contributing to a relatively high luminosity that leads them to be classified as ULXs in the *ROSAT* observation. On the other hand, the two ULXs might have actually decreased in luminosity, making them undetected in the *Chandra* observation.

SPECTRAL ANALYSIS

We conducted spectral analysis for sources with count rates of ≥ 200 to study more about their properties. Unfortunately,

there are only six sources with photon counts above this threshold value, and coincidentally, all of the six sources are the ULX candidates. Table 2 presents the result of our spectral analysis.

The best fit spectra of each sources using both models are shown in Figure 2 (CUTOFF) and 3 (DISKPBB). In general, our results are not well-constrained due to the relatively low number of counts in the sources spectra. Both the CUTOFF and DISKPBB models gave equally acceptable fit to the spectra of the sources (i.e., reduced chi-squared, $\chi_r^2 \sim 1$).

For the CUTOFF model, we found that the measured photon index values for source 5 and 14 are consistent with the typical value obtained for ULXs; i.e., $\Gamma = 2$ (e.g., Annuar et al. 2015 and Earnshaw et al. 2019a). The measured values for source 3, 16, 22 and 23 are < 2 , indicating hard spectra or relatively significant absorption. However, the values are consistent with 2 within their large statistical uncertainties, and the column density values measured for the sources are all $\leq 10^{22} \text{ cm}^{-2}$, suggesting lack of obscuration. This is also

TABLE 2. X-ray spectral fitting results for the ULX candidates

Model	Parameter	Unit	Source 3	Source 5	Source 14	Source 16	Source 22	Source 23
CUTOFF	N_{H}^{a}	$\times 10^{22} \text{ cm}^{-2}$	<1.0	$1.8^{+0.7}_{-0.5}$	<0.3	<0.4	<0.7	<0.6
	Γ	...	$2.2^{+0.3}_{-2.5}$	$2.2^{+0.3}_{-2.5}$	$2.0^{+0.6}_{-1.1}$	$1.2^{+0.8}_{-1.5}$	$0.2^{+2.0}_{-1.2}$	$0.3^{+2.1}_{-0.7}$
	E_{cut}	keV	>1.12	>0.01	>1.47	>0.47	>0.8	>1.32
	$\log L^{\text{b}}_{0.5-8\text{keV}}$	erg s^{-1}	$39.29^{+0.01}_{-0.30}$	>39.28	>38.93	>39.29	$39.42^{+0.03}_{-0.31}$	>38.95
	χ_r^2	...	0.706	1.063	1.006	0.638	0.657	0.824
DISKPBB	N_{H}^{a}	$\times 10^{22} \text{ cm}^{-2}$	<0.9	$1.6^{+0.2}_{-0.5}$	<0.2	$0.2^{+0.2}_{-0.2}$	<0.7	<0.6
	T_{in}	keV	>1.1	>1.4	>1.0	>3.0	$1.3^{+4.5}_{-0.3}$	$2.0^{+1.6}_{-0.6}$
	p	...	0.7	<0.9	<0.6	0.5	0.7	$0.8^{+0.2}_{-0.3}$
	$\log L^{\text{b}}_{0.5-8\text{keV}}$	erg s^{-1}	>38.98	>39.31	>38.96	>39.07	>39.11	>38.94
	χ_r^2	...	0.709	1.057	1.009	0.632	0.657	0.823

Notes. a Column density intrinsic to the source; b absorbed 0.5–8 keV luminosity measured from the spectral fitting.

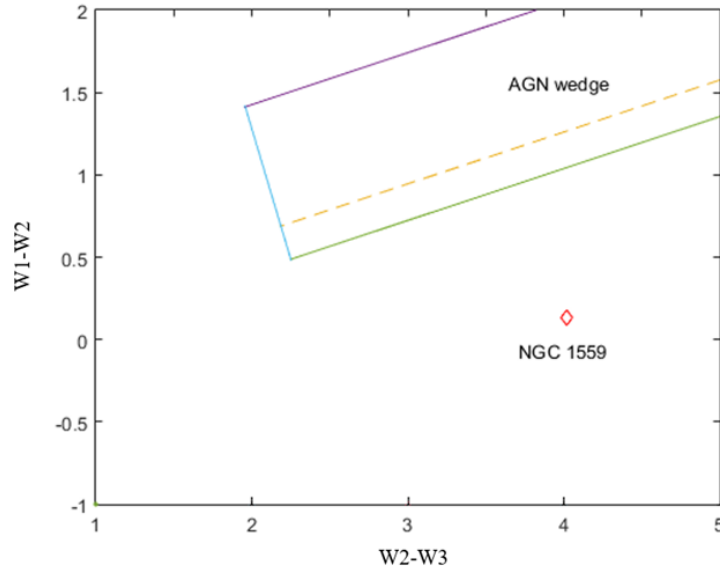


FIGURE 4. Three-band WISE colour diagram (W1, W2 and W3 bands; i.e., 3.4, 4.6 and 12 μm , respectively) built by Mateos et al. (2012) to determine the presence of AGN at infrared wavelength. If AGN is present in a galaxy, it will be located inside the AGN wedge. NGC 1559 (red diamond) is located outside of this wedge, suggesting that it does not host an AGN. This is consistent with the non-detection in X-ray wavelength at the nuclear region of the galaxy, and its HII optical classification.

The total number of X-ray sources found in this galaxy is relatively high for a star formation rate (SFR) of $2.8 M_{\odot} \text{ yr}^{-1}$ calculated for this galaxy using its infrared luminosity; i.e., $L_{\text{IR}} = 16.2 \times 10^9 L_{\odot}$ (Goulding & Alexander, 2009) and relationship derived by Kennicutt (1998). For example, the number of ULXs typically found for galaxies with similar values of SFR is two (e.g. Mapelli et al. 2010). The high number of X-ray sources found however, can be attributed to the relatively high number of supernova occurrence (four) in NGC 1559. Supernova can trigger star formation and form compact stellar remnants, and therefore plays an important role in shaping the population of X-ray sources in their host galaxies (e.g., Artale et al. 2019). Based on Figure 1, we can see that about thirteen of the XRB candidates and all of the ULX candidates are located in or very close to the spiral arms of the galaxy where star formation rate is likely to be relatively high.

AGN DETECTION

Among the twenty-four X-ray sources detected, none are located at the center of NGC 1559, suggesting the absence of an AGN activity. This is consistent with the *ROSAT* observation conducted over two decades ago in which they also did not detect any nuclear source in the galaxy. Based on the infrared AGN diagnostic diagram by Mateos et al. (2012) shown in Figure 4, NGC 1559 is located outside of the AGN wedge. This indicates that it does not host an AGN, supporting the HII optical classification of the galaxy and our X-ray analysis result.

CONCLUSION

In this paper, we conducted a study on the X-ray sources population in the nearby galaxy NGC 1559 using *Chandra* telescope. Based on our analysis, we detected twenty-four X-ray sources in the galaxy, of which we classified six as ULX candidates, and eighteen as XRB candidates on the basis of their measured luminosities. We performed X-ray spectral analysis for the six ULX candidates and found that in general, their properties are broadly consistent with that found for other ULXs. The number of X-ray sources found in this galaxy is relatively high as compared to other galaxies with similar star formation rates. This however could be attributed to the relatively high number of supernova explosions in the galaxy. We did not detect any X-ray nuclear point source in the galaxy, suggesting that NGC 1559 does not host an AGN. This is supported by its optical spectral classification and our infrared analysis using *WISE*.

DECLARATION OF COMPETING INTEREST

None.

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