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Optical Properties of Bright X-ray Sources in NGC 1399: Colour-X-ray Luminosity Correlation

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Abstract— Unresolved stellar populations in nearby galaxies contain valuable information regarding the formation of the galaxies. Many of such luminous point sources are detected to be brighter X-ray sources including ultra luminous X-ray sources (ULXs) which exhibit emission at super Eddington rates. We perform the aperture photometry of the optical counterparts of the bright X-ray sources in NGC 1399 with an aim to investigate their X-ray to optical association. Our sample includes 29 X-ray point sources (Lx ≥ 1038 erg/sec) in NGC 1399 of which five are ULXs. We observe that the X-ray luminosities are anti-correlated with F475W-F814W colours excepting the two ULXs, the linear correlation coefficient being -0.92 with a significance greater than 99.99%. As the optical counterparts are definitely multiple sources, the strong correlation exhibited by X-ray sources suggests the possibility of existence of multiple sources for the production of X-rays also. This suggests that the energy production in ULXs may be different from other sources in our sample, as they do not follow the correlation.

Index Terms— Aperture photometry, stellar clusters, Ultra luminous X-ray sources, X-ray point sources.

1 Introduction

THE evolutionary history of galaxies is believed to be embedded in their star clusters. The study of such stellar population proved to be a useful tool capable of unfolding the formation scenario of the whole galaxy. The easiest way to tap the information hidden in these point sources is to analyze their integrated magnitudes in multiple filters. Unresolved star clusters hosting X-ray sources are still more interesting class of objects as they provide another dimension to probe into the dynamics of the system.

Over the years, several studies were performed on the nature of X-ray point sources in nearby galaxies with an aim to unveil the formation mechanisms of the X-ray emitting sources. Out of these galaxies, the X-ray point sources in the elliptical galaxy NGC 1399 were studied extensively. NGC 1399 is the brightest member of Fornax cluster of galaxies which is referred to as the central cD galaxy of the cluster [1]. It is situated at a distance of about 19 Mpcs from our galaxy [2].

Majority of the X-ray sources in NGC 1399 were reported to be residing in globular clusters [3]. The globular clusters of the galaxy were particularly well studied [4]. Various multi band photometric studies were performed on these clusters [5]. The globular cluster system of NGC 1399 was found to exhibit colour-metallicity non linearity [6]. Low mass X-ray binaries were found to be the major sources of X-ray emission in globular clusters [7].

Another class of interesting objects known as ultra luminous X-ray sources (ULXs) was also detected among the X-ray point sources in nearby galaxies. These sources are compact non-nuclear sources with X-ray luminosities in the range 1039 - 10 41 erg/sec [8]. A number of such sources were identified in NGC 1399 and several studies were performed on the nature of these sources. As the galaxy contained sources emitting X-rays at super Eddington luminosities, the presence of Intermediate mass black holes (IMBHs) was also speculated [9]. Studies on correlations of X-ray luminosity to mid-infrared light were also conducted [10].

In spite of the large number of studies performed, the evolutionary history of the galaxy still remains to be unveiled. In this light, we investigate the X-ray to optical association of bright X-ray point sources of the galaxy.

2 Data Reduction

2.1 The Sample

We selected a sample of 29 X-ray point sources reported by Preetha et al. [11] in NGC 1399. They had carried out the X-ray analysis of the sources in nearby early type elliptical galaxies with X-ray counts ≥ 60. The X-ray reduction was performed with Chandra Interactive Analysis of Observations (CIAO) tool and HEASOFT package. The CIAO task celldetect was used to detect the point sources. The analysis was based on the Chandra Advanced CCD Imaging Spectrometer observations. The luminosities were obtained by fitting these sources with a two component model - an absorbed power law model and an absorbed black body model. Out of these 29 sources, five of them were found to be ULXs.

2.2 Identification of Optical Counterparts

To optically identify the X-ray sources, we used archival images of Wide Field Planetary Camera (WFPC) of Hubble Space Telescope (HST). We performed the photometric analysis of these sources in four different HST filters namely F475W, F814W, F850LP and F606W. In order to identify the underlying stellar populations, it was essential to subtract the light of the galaxy and obtain the residual image. We performed this task with the help of IRAF/STSDAS package. The tasks *ellipse* and *bmodel* served as effective tools to model the galaxy. We used the task *imarith* to obtain the model subtracted residual image. Bad pixels and extended objects were masked out during the ellipse fitting.

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As part of the astrometry, it was required to identify the optical sources in each filter. We used the software source extractor (SEXTRACTOR) with a threshold 3 sigma to identify the total optical sources in all four filters [12]. The X-ray contours when over plotted on the HST images, show a definite off-set in all four filters. The two instruments (Chandra and HST) differ in their angular resolutions, HST being more accurate than Chandra with a resolution of 0.05 arcsecs compared to 1 arcsecs of Chandra.

We calculated the off-set in each image and shifted the X-ray coordinates by applying a common shift. The coordinates thus obtained were combined with those given by the source extractor output to identify the optical sources. In cases where multiple optical sources were found around the X-ray detection spot, the nearest optical source was selected to be the real counterpart.

2.3 Aperture Photometry

Though the magnitudes in different bands are given by Source Extractor, we performed aperture photometry for better accuracy. This was achieved by the task *phot* given by IRAF package noao/digiphot. We fixed the aperture value as 10 pixels. This task simply gives the net flux with in a fixed radius from the center of the source. In F606W band, as we had to deal with three images covering different parts of the galaxy, we encountered a number of common sources. In such cases, the one with the higher flux was chosen as the magnitude of the counterpart.

3 Results

Of the 29 X-ray point sources, 20 of them were found to have genuine optical counterparts in at least three of the four filters. Our sample contained five ULXs. Among these sources, one of them had visible counterpart in only two filters (F814W and F850LP). Two other ULXs which have been identified in the X-ray analysis as two distinct points were found to have only one optical counterpart. We excluded these two sources from our further analysis.

Our final sample consists of 18 X-ray point sources with optical data in at least three bands. The brightest member of the sample was found to have an absolute F475W magnitude of -10.59, the faintest being -4.71.

We observe a strong correlation between the X-ray luminosities and F475W- F814W colours of the X-ray point sources as shown in Fig. 1. The two points with luminosities above 1039 on the extreme left of the plot are the two ULXs included in the analysis. As it is evident from the plot, ULXs are not following the observed anti-correlation. Although we could observe such a trend between the X-ray luminosities and other colours also, the relation was found to be tighter with F475W- F814W colour.

Excepting the two ULXs and an outlier with F475W-F814W colour 0.18, the observed relation has a linear correlation coefficient of -0.92 with a significance greater than 99.99%. Such a strong correlation had not been reported earlier. Only a weak correlation which breaks down for the brightest sources was reported. [13]

4 Discussions

The observed X-ray to optical association has wide implications. We observe that the sources showing X-ray emission in the range of 1038 to 1039 erg/sec follow the correlation whereas the ULXs do not follow the relation. Studies show that galactic globular clusters which are resolved contain stars of the order of 103-105 [14]. Since there are a number of sources predicted optically, such a strong correlation requires that the X-ray sources should also be multiple sources as the X-ray sources are highly variable. In spite of the variability detected, X-ray sources follow the correlation which makes it less probable for them to be single sources. Each of these clusters may be containing a number of sources contributing to both the integrated optical light and X-ray emission. A single object showing variability cannot be a part of such a strong correlation.

It is interesting to note that there is a discrete discontinuity at the Eddington luminosity (1039 erg/sec) in Fig. 1. The discontinuity at 1038 erg/sec might be resulting from our sample selection criteria. We selected sources with X-ray counts≥60 which must have limited our range of luminosity to be greater than 1038 erg/sec. It is evident that the two ULXs which do not follow this relation must be having a different mechanism of X-ray emission compared to the other sources. As they do not observe the relation, we cannot predict the situation unambiguously. There can be a single object accreting at the rate of super Eddington luminosities to produce the observed luminosity. It is also possible that multiple X-ray emitting objects may be present in them which contribute collectively to the X-ray and optical luminosity. The number of ULXs in our sample is inadequate to draw a definite conclusion.

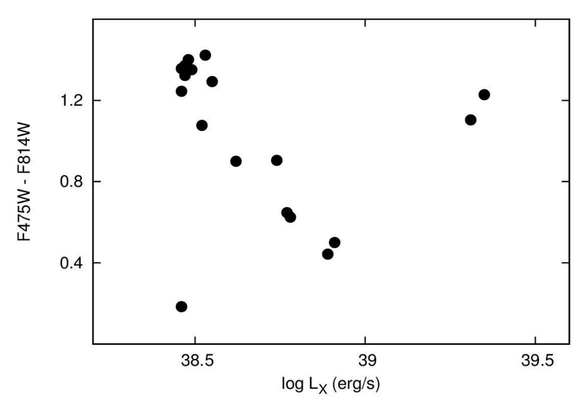

Fig. 1. The plot of X-ray luminosities against F475W – F814W colour. It shows a strong anti-correlation excepting the two ULXs and an outlier with colour 0.18.

There may be other factors governing the evolution of the star clusters such as ages and metallicities [15]. Careful interpretation of SEDs of stellar clusters is required to understand the role of such factors. As this can be achieved with stellar population synthesis, attempts in this direction are needed to unravel the role played by such factors.

5 Conclusion

We studied the nature of optical counterparts of bright X-ray sources in NGC 1399. Aperture photometry was carried out in multiple bands to check for X-ray to optical association. We observed a strong correlation between the X-ray luminosities and F475W – F814W colours excluding the two ULXs. The linear correlation coefficient was found to be -0.92 with a significance greater than 99.99%. Such a tight correlation of optical colours with X-ray luminosities suggests that X-ray emitting objects are multiple sources as the X-ray sources are highly variable.

ULXs included in the sample do not follow the relation. This indicates that the powering mechanism behind these sources may be different from other clusters in the sample. More systematic studies including larger sample to get statistically significant results are needed to characterize the nature of these sources. However, this information may be crucial in estimating the dynamical properties of the X-ray emitting object in the point sources.

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References

[1] M.J. Drinkwater, M.D. Gregg, M. Colless, "Substructure and Dynamics of the Fornax Cluster", ApJ, vol.548,no.2, pp. L139-L142, Feb. 2001.
[2] T. Richtler, B. Dirsch, K. Gebhardt, D. Geisler, M. Hilker, M.V. Alonso, J.C. Forte, E.K. Grebel, L. Infante, S. Larsen, D. Minniti, and M. Rejkuba, " The Globular Cluster System of NGC 1399:Kinematics of a Large Sample of Globular Clusters", ApJ, vol. 127, pp. 2094-2113, Apr. 2004.
[3] M. Paolillo, T.H. Puzia, P. Goudfrooij, S.E. Zepf, T.J. Maccarone, A. Kundu, G. Fabbiano, and L. Angelini, "Probing the GC-LMXB Connection in NGC 1399 : A Wide Field Study with the Hubble Space Telescope and Chandra", ApJ, vol. 736, no. 2, pp. 90-106, Aug. 2011.
[4] L.P. Bassino, F.R. Faifer, J.C. Forte, B. Dirsch, T. Richtler, D. Geisler, and Y. Schuberth, "Large Scale Study of the NGC 1399 Globular Cluster System in Fornax", A&A, vol. 451, no. 3, pp. 789-796, Jun 2006.
[5] H.S. Kim, S.J. Yoon, S.T. Sohn, S.C. Kim, E. Kim, C. Chung, S.Y. Lee and Y.W. Lee, "Wide Field Multiband Photometry of Globular Cluster Systems in the Fornax Galaxy Cluster", ApJ, vol. 763, no. 1, pp. 40-61, Jan. 2013.
[6] J.P. Blakeslee, H. Cho, E.W. Peng, L. Ferrarese, A. Jordan and A.R. Martel, "Optical and Infrared Photometry of Globular Clusters in NGC 1399 : Evidence for Color - Metallicity Nonlinearity", ApJ, vol. 746, no.1, pp. 88-103, Feb 2012.
[7] A. Kundu, S.E. Zepf, M. Hempel, D. Morton, K.M. Ashman, T.J. Maccarone, M.K. Patig, T.H. Puzia, E. Vesperini, "The Ages of Globular Clusters in NGC 4365 Revisited with Deep HST Observations", ApJ, vol. 634, no.1, pp. L41-L44, Nov. 2005.
[8] P. Kaaret, A.H. Prestwich, A. Zezas, S.S. Murray, D.-W. Kim, R.E. Kilgard, E.M. Schlegel and M.J. Ward, "Chandra High Resolution Camera Observations of the Luminous X-ray source in the starbust galaxy M82", MNRAS, vol. 321, pp. L29-L32, Nov. 2000.
[9] D.A. Swartz, K.K. Ghosh, A.F. Tennant, K. Wu, "The Ultraluminous X-ray Source Population from the Chandra Archive of Galaxies, ApJS, vol. 154, pp. 519-539, Oct. 2004.
[10] P. Shalima, V. Jithesh, K. Jeena, R. Misra, S. Raveendranath, G.C. Dewangan, C.D. Ravikumar and B.R.S. Babu, "Mid-infrared and X-ray Luminosity Correlations of X-ray Point Sources in NGC 1399", MNRAS, vol. 434, no. 2, pp. 639-651, Jun 2013.
[11] A.U. Preetha, C.D. Ravikumar, V. Jithesh, D. Joseph and R. Misra, "Morphological Analysis of Early Type Galaxies Hosting X-ray Point Sources", Unpublished.
[12] E. Bertin and S. Arnouts, "Sextractor : Software for Source Extraction", A&AS, vol. 117, pp. 393-404, Jun. 1996.
[13] L. Angelini, M. Loewenstein and R.F. Mushotzky, "The X-ray Globular Cluster Population in NGC 1399", ApJ, vol. 557, pp. L35 – L38, July. 2001.
[14] C.O. Heinke, "X-ray Sources in Galactic Globular Cluster", AIP Conf. Proc, vol. 1314, pp. 135-139, Jun. 2010.
[15] Z. Zhang, M. Gilfanov, and A. Bogdan, "Dependence of the LMXB Population on Stellar Age", A&A, vol. 546, pp. A36-A48.