

# Mid-infrared counterparts of X-ray sources in NGC1399

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## ABSTRACT

We have used archival Spitzer IRAC images to look for mid-infrared counterparts of 35 X-ray sources in the elliptical galaxy, NGC1399 and study their multi-wavelength properties. The IRAC  $F_{5.8}/F_{3.6}$  ratio has been used to identify 8 sources with AGN-like properties. The X-ray luminosities for these AGN-like sources are found to be highly correlated with the MIR flux, implying that the dusty environment is influenced by the X-ray source. The SEDs of the sources are constructed by using Spitzer data in conjunction with optical and X-ray data from HST and *Chandra*.

## INTRODUCTION

NGC1399 is an elliptical galaxy which hosts a large number of off nuclear X-ray point sources. Out of these, some sources have X-ray luminosities exceeding  $10^{39}$  ergs/s, known as Ultra-luminous X-ray sources or ULXs. According to one theory, if the emission is isotropic, the central object could be an intermediate-mass blackhole of mass  $10-10^5 M_{\text{sun}}$  (Colbert & Mushotzky 1999; Makishima et al. 2000). ULXs could also be stellar mass BHs in high mass XRBs with mild beaming (Shakura & Sunyaev 1973; King 2008), as they seem to be associated with star-formation in galaxies (Zezas & Fabbiano 2002). Some of these sources could also be supernova remnants (Ryder et al. 1993; Fox et al. 2000), background AGNs (Gutiérrez 2006; Bonfini et al. 2009) or starburst galaxies. It may be possible to distinguish between these different types of sources using observations at other wavelengths.

ULXs have been found to influence their environment like AGNs. Berghea et al. (2010a) used the Spitzer IRS instrument and detected [OIV] 25.89  $\mu$ m emission from ULX Holmberg II. This emission is associated with high excitation as in AGNs which was an indication that ULXs influence their environment. For 6 ULXs in NGC4485/4490, Vázquez et al. (2007) used Spitzer IRS spectra in order to derive infrared spectral diagnostics that are characteristic of their interactions with the surrounding gas and dust. From the line ratios such as [NeIII]/[NeII] and [SIII]/[SII], Vázquez et al. (2007) found 5 of the ULXs to have ratios similar to AGNs and 1 corresponding to a star forming region.

## SPITZER IRAC OBSERVATIONS

Spitzer IRAC has observed the sky in four mid-infrared bands, namely, 3.6, 4.5, 5.8 and 8.0 $\mu$ m with a resolution of  $\sim 2''$ . Here we have used archival Spitzer IRAC images to look for infrared counterparts of the X-ray point sources in NGC1399. The IRAC Post Basic Calibrated Data (PBCD) mosaic files of NGC1399 were obtained from the Spitzer Heritage Archive. We have used the data corresponding to AOR 5529856 which was part of the Spitzer Infrared Nearby Galaxies Survey (Kennicutt et al. 2003).

## MIR-X-RAY CORRELATIONS

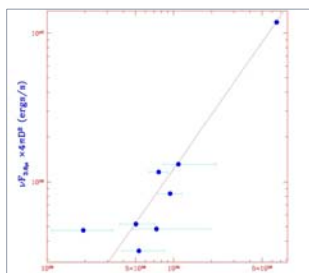


Fig.1. IR(3.6 $\mu$ m) v/s X-ray luminosities for point sources with positive ( $\log(F_{5.8}/F_{3.6})$ ) ratios. The correlation co-efficient is 0.86 (prob=0.007).

Out of the 35 sources with X-ray spectra, 16 sources have point source counterparts at 3.6 $\mu$ m. We have used the APEX software in order to derive the aperture fluxes for the counterparts. We have calculated the IRAC  $F_{5.8}/F_{3.6}$  flux ratios for these sources. These ratios can be used to separate AGN-heated from stellar radiation heated dust. 8 sources have positive flux ratios characteristic of AGNs. For these sources the 3.6 $\mu$ m luminosities are plotted against the X-ray luminosities in Fig. 1. The luminosities are calculated assuming the distance to NGC1399 ( $D = 18.95$ Mpc).

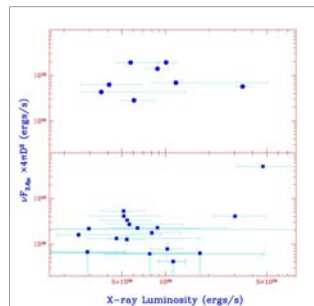


Fig.2. IR(3.6 $\mu$ m) v/s X-ray luminosities for point sources negative ( $\log(F_{5.8}/F_{3.6})$ ) ratios (above) and extended sources (below). The correlation co-efficient for the point sources is 0.23 (prob = 0.57). The 3 $\sigma$  upper limits are plotted for the non-detections.

The Spearman Rank correlation co-efficient between the 3.6 $\mu$ m and X-ray luminosities is 0.86 with a probability of 0.007. For the rest of the 8 sources the correlation reduces considerably to 0.28 (prob = 0.49). Similarly the correlation co-efficient between the 5.8 $\mu$ m fluxes and X-ray luminosities reduces from 0.76 (prob=0.03) for sources with positive flux ratios to 0.05 (prob= 0.91) for negative ratios.

## SPECTRAL ENERGY DISTRIBUTIONS

We have constructed the SEDs for the 35 X-ray sources in NGC1399.

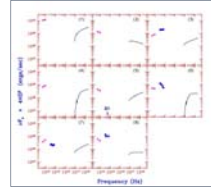


Fig. 3. SEDs for the AGN-like sources.

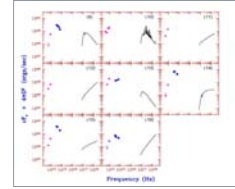


Fig. 4. SEDs for the remaining IR point sources

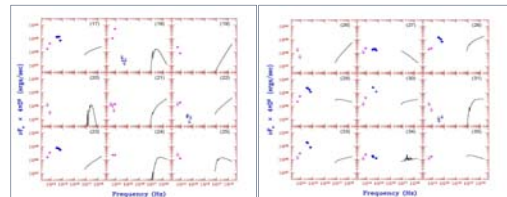


Fig. 5. SEDs for the extended IR sources

For the AGN-like sources, it can be seen that all except source 6 have a bluer spectrum in the optical. We have compared these with the globular cluster candidates of Paolillo et al. (2011) and find that 5 of the 8 sources for which  $g-z$  colours are available, belong to the blue globular cluster population. The remaining point and extended sources, do not belong to any particular category.

## CONCLUSIONS

- We have used archival Spitzer IRAC data of NGC1399 to look for MIR counterparts of 35 bright X-ray sources detected by *Chandra*.
- 16 of the X-ray sources have a point source counterpart in the IRAC 3.6 $\mu$  image.
- For 8 of these sources, the IRAC flux ratio, ( $F_{5.8}/F_{3.6} > 0$ ) which indicates that they are AGN-like sources.
- The X-ray luminosity is found to be highly correlated with the MIR flux for these AGN-like sources. This implies that the dusty environment which produces the MIR emission is influenced by the X-ray source.
- For the remaining non AGN-like 8 point sources, there is no correlation between the X-ray and MIR luminosities, indicating either a different radiative mechanism and/or geometry.
- Using the Spitzer data in conjunction with optical and X-ray data we have constructed the SEDs for all 35 sources.
- The optical photometry shows that 7 of the 8 AGN-like sources are hosted in blue globular clusters.

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