# THE ULTRA LUMINOUS X-RAY SOURCES IN THE HIGH VELOCITY SYSTEM OF NGC 1275

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## ABSTRACT

We report the results of a study of X-ray point sources coincident with the High Velocity System (HVS) projected in from of NGC 1275. A very deep X-ray image of the core of the Perseus cluster made with the *Chandra Observatory* has been used. We find a population of Ultra-Luminous X-ray sources. As with the the ULX populations in the Antennae and Cartwheel galaxies, those in the HVS are associated with a region of very active star formation. Several sources have possible optical counterparts found on *HST* images, although the brightest one does not. Absorbed power-law models fit the X-ray spectra, with most having a photon index between 2 and 3.

Key words: Perseus - NGC 1275- ULX.

## 1. INTRODUCTION

The study of Ultra-Luminous X-ray sources (ULX) has been greatly expanded by the high spatial resolution and spectral grasp of the *Chandra* and *XMM-Newton* observatories, respectively. ULX sources (Fabbiano & White 2003; Miller & Colbert 2004) have 2–10 keV X-ray luminosities exceeding $10^{39}\,\mathrm{erg\,s^{-1}}$ and they are not active galactic nuclei. Their luminosity exceeds that for a $10\,\mathrm{M_\odot}$ black hole accreting at the Eddington limit which radiates isotropically and so have created much interest in the possibility that they contain even higher mass black holes, such as InterMediate Black Holes (IMBH) of $\sim 10^3\,\mathrm{M_\odot}$ (Makishima et al. 2000). Alternatively they may appear so luminous because of beaming (Reynolds et al 1999) or due to super Eddington accretion (Begelman 2002).

Here we report on the discovery of a population of 8 point X-ray sources to the N of the nucleus of NGC 1275, which is the central galaxy in the Perseus cluster. A datailed analysis of the optical counterpart and X-ray spectral energy distribution have been performed.

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## 2. IMAGING AND SPECTRAL ANALYSIS

The total exposure time, after removing periods containing flares, is 890 ks. All of the datasets were reprocessed to use the latest appropriate gain file. The CIAO LC_CLEAN tool was used to remove periods 20 per cent away from the median count rate for all the lightcurves. The CIAO CELLDETECT source detection routine was then used on the reprocessed level 2 event data to produce a preliminary list of point sources. As the X-ray diffuse emission of the NGC 1275 is very strong, the source list may well include false detections in high background level regions. Therefore problematic sources embeded in such regions have been excluded in our analysis. We have detected 8 bright sources close to the nucleus of NGC 1275, located in the northen inner radio lobe of 3C 84 (in the same region as the HVS). There are no sources associated with the southern lobe, thus we assume these sources are associated with the HVS.

We have used archival *HST* observations of NGC 1275 in order to search for optical counterparts. The galaxy was imaged with the WFPC2 camera on *HST* using the F814W ($\sim$ I) and F702W ($\sim$ R) broad-band filters. Several coincidences between X-ray sources and optical knots of emission (F814W) can be seen in Fig. 1. The *HST* image shows many highly absorbed features. When we compare in detail, sources N7 and N8 are located in star forming regions, while N2 and N6 have a point-like counterpart. Therefore, we have found a possible correlation between compact X-ray sources and regions of vigorous star formation. In order to investigate the emission mechanism of these ULX, the X-ray to optical flux ratios have been computed between the F702W and F814W *HST* bands and 1.0–7.0 keV band.

We extracted X-ray spectra for all the detected sources close to the HVS. The background region was either a source-free circular annulus or several circles surrounding each source. We extracted spectra from each of the datasets. These spectra were summed to form a total spectrum for each source. The spectra were fitted using XSPEC v.11.3.2., grouping the data to include at least 20 counts per spectral bin. In spectral fitting we excluded

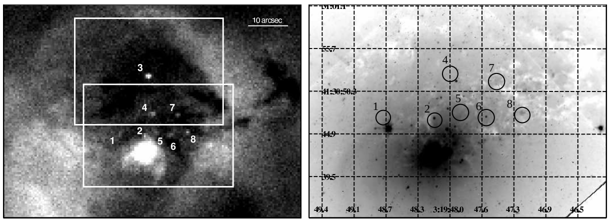


*Figure 1. Left: Broadband (0.5–7.0 keV) X-ray smoothed image. Right:* HST/*WFPC2 F814W broadband image centred in source 5. Note that source N3, out of HST image, have not optical counterpart.*

| N | $N_H(10^{21}cm^{-2})$ | $\Gamma$ | $\chi^2$/d.o.f. | $\log L_X$ |
|---|---|---|---|---|
| 1 | $2.5^{(a)}$ | $3.20^{+0.23}_{-0.37}$ | 112.90/101 | 39.51 |
| 2 | $2.72^{+1.43}_{-0.87}$ | $1.78^{+0.30}_{-0.24}$ | 101.50/109 | 39.86 |
| 3 | $2.49^{+0.40}_{-0.40}$ | $2.08^{+0.09}_{-0.09}$ | 153.86/142 | 40.22 |
| 4 | $2.05^{+0.91}_{-0.96}$ | $2.29^{+0.44}_{-0.28}$ | 156.24/152 | 39.91 |
| 5 | $2.64^{+1.23}_{-0.93}$ | $2.92^{+1.44}_{-0.36}$ | 124.09/139 | 39.90 |
| 6 | $3.74^{+1.57}_{-1.39}$ | $3.51^{+0.48}_{-0.66}$ | 102.58/92 | 39.84 |
| 7 | $4.03^{+1.78}_{-1.45}$ | $3.20^{+1.39}_{-0.48}$ | 133.69/135 | 39.95 |
| 8 | $2.66^{+1.00}_{-0.91}$ | $2.13^{+0.52}_{-0.25}$ | 150.81/138 | 39.93 |

*Table 1. Spectral fits and 0.5–7.0 keV luminosities. (a) The column density of source N1 has been fixed.*

any events with energies above 7.0 keV or below 0.5 keV. Table 1 summarizes our spectral results in terms of the absorbing column density, photon index and luminosities. Note that in all the cases the single component power law give satisfactory fits. The lower limit of the luminosity of point sources in the image, if at the distance of NGC 1275, is $L_X(0.5 - 7.0\,keV) = 3.2 \times 10^{39} erg\ s^{-1}$, which is already above the Eddington limit for a neutron star binary ($L_X \sim 3 \times 10^{38} erg\ s^{-1}$) and is also above the limit of canonical ULX, i.e. $\geq 10^{39} erg\ s^{-1}$.

Time variability analysis has been performed. The data characteristics allows us determine short variation in 16 days and long-term variability of 2 years. We extracted light-curves, using DMEXTRACT CIAO task for the two brightest sources (N3 and N4) binned with bin sizes between 500 and 5000 s. In both cases the points were consistent with the respective mean values and variability has not been found.

## 3. DISCUSSION

*Chandra* has revealed significant populations of ULX in the interacting systems of the Antennae (NGC 4038/9; Zezas et al. 2002) and the Cartwheel ring galaxy (Gao et al. 2003), where dramatic events have stimulated massive star formation. We have reported here on another example in the HVS of NGC 1275 which is interacting with the ICM of the Perseus cluster. The sources are spatially associated with the distribution of absorbing clouds seen in soft X-ray and optical (Fig.1) images. Furthermore, optical identification has been found in several of the X-ray sources. The optical brightness of these counterparts are too high to be individual stars and so they may be associated with young star clusters. Our interpretation of this correspondence is that the regions are especially active, indicating a real link between ULX and star-forming regions. In M31 and the Milky Way (Grimm et al. 2002), XRB have luminosities consistent with the Eddington limit of a $\sim 2M_\odot$ accreting object. They produce luminosities about one order of magnitude below the limiting luminosity in our sample. It is possible that our ULX consist of at least 15 'normal' XRB clustered together, perhaps in a young star cluster. However in other objects we know that variability requires the presence of intrinsically luminous X-ray sources Alternative possibilities are that black hole sources, with masses in the range of galactic black hole binaries, are mildly beamed (Reynolds et al. 1999). Spectral and timing features however rule out this possibility in some ULX.

Our optical studies have clearly shown that the ULX have very high X-Ray to optical flux ratios. X-ray selected AGN from the *Rosat all sky survey* tend to have $\log(F_X/F_{opt}) \sim 1$. Thus the ULX do not have the optical properties expected if their were simple extensions of AGN (IMBH). However, low mass X-ray binaries in the Milky Way have $F_X/F_{opt} \sim 100 - 10000$ (Mushotzky 2004). The results found in our system indicate that we have a mixed group of objects. At least 4 out of 8 sources (N3, N4, N5 and N8) have high X-ray to optical flux ratios. At least 3 out of 8 (N1, N2 and N6) have lower X-ray to optical ratios, possibly because they lie in star clusters.

Time variability is frequently observed in ULX (e.g. Liu et al. 2002), arguing that most of them are single compact objects. Unfortunately, our data are consistent with no significant variability.

Finally, our results add to the growing evidence that some episodes of rapid star formation lead to the production of ULX. Young, massive, star clusters may be involved in some, but not all of the sources.

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