Further Observations of the Intermediate Mass Black Hole Candidate ESO 243-49 HLX-1

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Abstract. The brightest Ultra-Luminous X-ray source (ULX) currently known (HLX-1) was discovered in the second XMM-Newton Serendipitous Source Catalogue [2XMM; 1] in the outskirts of the edge-on spiral galaxy ESO 243–49 [2]. Its 0.2 – 10 keV unabsorbed X-ray luminosity, assuming the galaxy distance (95 Mpc), exceeded $1.1 \times 10^{42}$ ergs s$^{-1}$. Follow-up observations have revealed large scale luminosity and spectral variability in X-rays, in a way similar to Galactic black hole binary systems [3]. The extreme luminosities of ULXs, if the emission is isotropic and below the Eddington limit, imply the presence of an accreting black hole with a mass of $\sim 10^2 – 10^5$ M$_\odot$. However, the existence of such intermediate mass black holes (IMBHs) is in dispute. Both super-Eddington accretion and beaming of the X-ray emission could account for X-ray luminosities up to $\sim 10^{40}$ ergs s$^{-1}$ for stellar mass black holes (10 – 50 M$_\odot$), but would require extreme tuning to explain an X-ray luminosity of $10^{42}$ ergs s$^{-1}$. Hence, HLX-1 is an excellent candidate IMBH [2]. The existence of IMBHs has profound implications for massive star evolution, and the formation and evolution of star clusters and galaxies in general [e.g. 4]. In this paper we present the results of new and archival multi-wavelength observations of HLX-1 in an attempt to confirm an association with ESO 243-49 and determine in particular where it lies within the galaxy (e.g. in a star cluster, star forming region, globular cluster etc.).
X-RAY DATA

We obtained a 1 ks observation of HLX-1 under the Director’s Discretionary Time (DDT) program with the HRC-I camera onboard Chandra on 2009 July 4 (ObsID: 10919). No source was detected within the XMM-Newton error circle of HLX-1, indicating the count rate must have dropped down to $< 0.006 \text{ cts s}^{-1}$, compared to the expected $0.03 \text{ cts s}^{-1}$ based on the most recent XMM-Newton flux and spectrum measurements [2]. Swift XRT monitoring observations of HLX-1 confirmed the drop in flux and found that one month later the flux increased significantly [3]. Following this re-brightening we obtained a second deeper DDT observation of 10 ks with the HRC-I on 2009 August 17 (ObsID: 11803). A total of 11 sources were detected, including a source consistent with the position of HLX-1 with a net count rate of $0.098 \pm 0.003 \text{ cts s}^{-1}$. After applying astrometry correction by cross-matching detected sources against the 2MASS catalogue [see 5, for a full discussion], a final position of RA = 01h 10m 28.29s, Dec = $-46^\circ 04' 22.3''$ was obtained for HLX-1, with a 95% error of 0.3''.

UV DATA

The Swift UVOT observed the field of ESO 243-49 on 2009 August 5, 6, 16, 18, 19 and 20 for a total exposure of 38 ks. Observations were performed in the $uvw2$ ($\sim 160 – 250$ nm) filter only. At the location of the core of ESO 243-49 there is an extended object (Figure 1), with some hints of an elongated emission towards the position of HLX-1. No point source is observed above the flux level of the galaxy at the Chandra position of HLX-1, although given the spatial resolution of 2.9'' FWHM in the $uvw2$ band\(^1\) we cannot rule out a point source unresolved from the nuclear emission. We estimate a 3$\sigma$ upper-limit of 20.3 mag at this position [see 5, for details].

The field of HLX-1 was observed by GALEX as part of the deep survey on 2004 September 27 for $\sim 13$ ks in the near-UV (NUV, $\sim 180 – 280$ nm) and $\sim 8$ ks in the far-UV (FUV, $\sim 150 – 200$ nm). A clear extension towards the location of HLX-1 from the nucleus of ESO 243-49 can be seen in both images (Figure 2), with the dominant emission occurring in the FUV. No point source was detected coincident with the position of HLX-1 in either band, although again an unresolved point source cannot be ruled out due to the spatial resolution [4 – 6'' FWHM; 6]. 3$\sigma$ upper limits of 20.4 mag and 21.4 mag were determined in the NUV and FUV respectively [see 5, for details].

RADIO DATA

The field of ESO 243-49 was observed as part of the Phoenix Deep Survey (PDS) with the Australia Telescope Compact Array at 1.4 GHz [7]. The final mosaic and a series of source catalogues are in the public domain\(^2\) and we have used these data products

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\(^1\) http://heasarc.nasa.gov/docs/heasarc/caldb/swift/docs/uvot/
\(^2\) http://www.physics.usyd.edu.au/~ahopkins/phoenix
to search for radio emission from HLX-1. A source is clearly detected coincident with the nucleus of ESO 243-49, but no source is present at the position of HLX-1. The flux density at the location of HLX-1 is \(\sim 5 \mu\text{Jy}\). This is below the \(3\sigma\) local rms noise level of 45 \(\mu\text{Jy}\), which we thus adopt as the flux density upper limit for HLX-1. We fitted a Gaussian to the radio source at the nucleus of ESO 243-49, yielding an integrated flux density of \(0.15 \pm 0.03 \text{ mJy}\). The derived position is consistent with the PDS position of RA = 01h 10m 27.69s, Dec = -46\degree 04’ 27.8” with uncertainties of 0.2” and 0.5” respectively. Given the accurate astrometry in both radio and X-ray it is extremely unlikely that the 0.15 mJy source detected in the nucleus of ESO 243-49 is associated with HLX-1. The spatial resolution of the PDS observations is high enough such that any significant radio emission at the position of HLX-1 would be distinct from that arising from the nucleus of ESO 243-49.
CONCLUSIONS

Using Chandra observations of HLX-1, we have determined an improved position with a 95% confidence error radius of 0.3". Coincident with this new position there appears to be some evidence for possibly extended UV emission. Although we cannot definitively say that this emission is related to HLX-1, the fact that no similar extended emission is seen in the radio, infrared, optical or X-ray domains [2, Webb et al. in prep.], makes it unlikely that this is either a foreground or background source. The fact that this emission appears to be stronger in the FUV could hint towards star formation taking place in that region, as the UV flux primarily originates from the photospheres of O- through later-type B-stars (M > 3 M☉), and thus measures star formation averaged over a 10^8 yr timescale [e.g. 8]. Alternatively, if the UV emission is truly extended it could indicate the presence of a trail of star formation created by ram-pressure stripping of material from a dwarf galaxy that has recently interacted with ESO 243-49 [e.g. 9]. In this case HLX-1 could be an IMBH which was once at the centre of the dwarf galaxy, but has now had most of the gas and stars stripped from it via the gravitational interaction with ESO 243-49. The lack of radio emission down to 45 µJy rules out a blazar [10] and strengthens the argument that a background AGN is not the source of the X-ray emission.

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