Compact radio emission in Ultraluminous X-ray sources

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Introduction

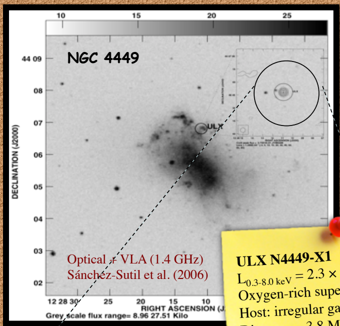
Ultraluminous X-ray sources (ULXs) are extragalactic, off-nuclear, and very bright X-ray sources with luminosities exceeding 10^{39} erg/s. The physical mechanism triggering the high X-ray luminosities still remains unknown. It has been suggested that ULXs are sub-Eddington accreting intermediate mass black holes (IMBHs) of 10^2-10^5 $M_\odot$ (Colbert & Mushotzky 1999), supernova remnants, microquasars, stellar mass BHs radiating at super-Eddington luminosities (Begelman 2002), or secondary BHs in post-merger galaxies (Lobanov 2008).

Radio observations of ULXs provide an excellent potential for uncovering the nature of these objects, by detecting and possibly resolving their compact radio emission, measuring its brightness temperature and spectral properties, and assessing the physical mechanism for its production. We have initiated a program to detect and study milliarcsecond-scale emission from ULX objects with known radio counterparts. I present the results obtained for the ULXs N4449-X1, N4088-X1, and N4861-X2.

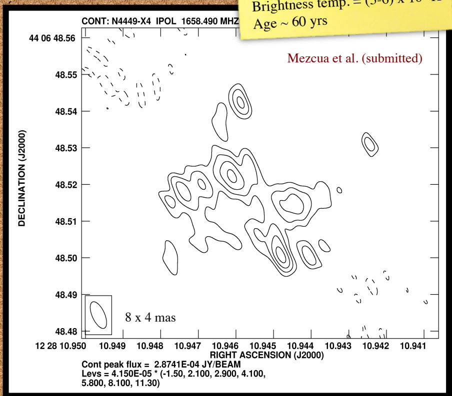
Radio observations

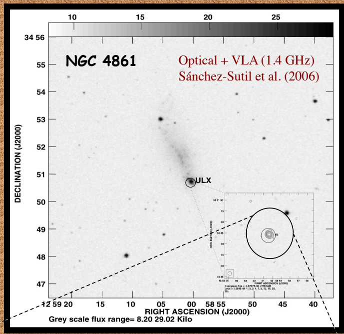
The targets are selected from a sample of 11 ULX sources detected by the ROSAT satel- lite and catalogued as ULXs by Liu & Bregman (2005), with radio counterparts (Sánchez-Sutil et al. 2006) in the VLA FIRST catalog (Becker et al. 1995). We select 3 ULXs as being less probable background AGNs, brighter than 1 mJy, and located clearly away from the nuclear region in their respective host galaxies.

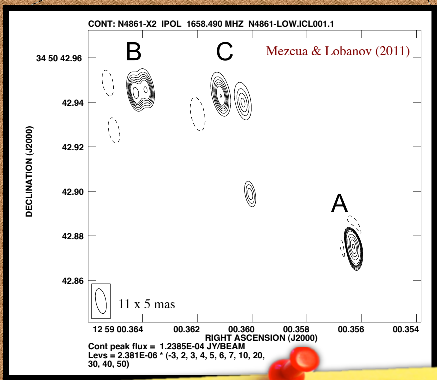
We observe them using Very Long Baseline Interferometry (VLBI) with the European VLBI Network (EVN) at 1.6 GHz.



ULX N4449-X1
$L_{0.3-8.0\,keV} = 2.3 \times 10^{38}$ erg/s
Oxygen-rich supernova remnant
Host: irregular galaxy NGC 4449
Distance = 3.8 Mpc
Shell-like radio structure
58 x 28 mas (1.1 x 0.5 pc)
$L_{1.6\,GHz} = 1.7 \times 10^{35}$ erg/s
Brightness temp. = (3-6) x 10^6 K
Age ~ 60 yrs

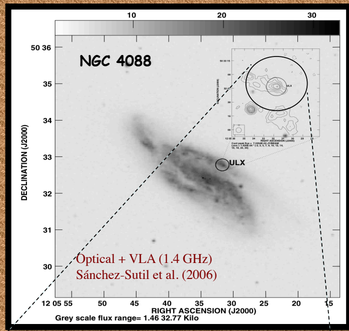


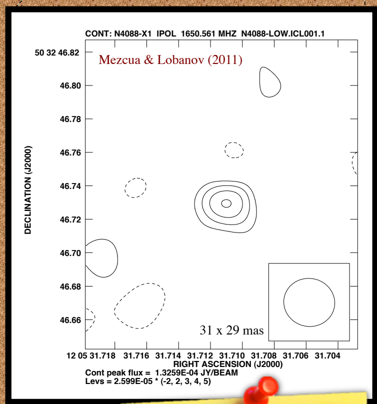




ULX N4861-X2
$L_{0.3-8.0\,keV} = 8.4 \times 10^{39}$ erg/s
Coincident with an HII region in the optical
Host: spiral galaxy NGC 4861
Distance = 14.8Mpc
Extended radio emission?
Components A, B, and C
Flux= 0.2 mJy @ 1.6 GHz
$L_{1.6\,GHz} = 7.7 \times 10^{34}$ erg/s
Brightness temp. ~ 10^5 K
HII region?
Diameter = 120 mas (8.6 pc)

Compact radio emission
Component A
Flux= 80 μJy @ 1.6 GHz
$L_{1.6\,GHz} = 3.3 \times 10^{34}$ erg/s
Brightness temp. > 10^6 K
IMBH of 10^5 $M_\odot$?





ULX N4088-X1
$L_{0.3-8.0\,keV} = 5.9 \times 10^{39}$ erg/s
Coincident with extended emission in the optical
Host: spiral galaxy NGC 4088
Distance = 13 Mpc
Compact radio emission
Flux= 0.1 mJy @ 1.6 GHz
$L_{1.6\,GHz} = 3.8 \times 10^{34}$ erg/s
Brightness temp. > 7 x 10^4 K
IMBH of 10^5 $M_\odot$?

Mass limits

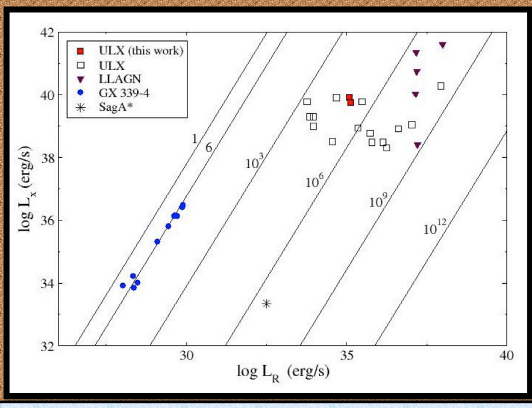
Under the assumption of sub-Eddington accretion, the location of the ULXs with compact radio emission in the fundamental plane of accreting BHs provides an estimate of their BH mass (M_{BH}).

The fundamental plane (e.g., Merloni et al. 2003; Falcke et al. 2004) is a correlation between radio core luminosity (L_R), X-ray luminosity (L_X) and M_{BH}:

$$\log L_R = 0.6 \log L_X + 0.78 \log M_{BH} + 7.33$$

The location in the fundamental plane of all ULXs with detected radio counterparts indicates a range of M_{BH} ~ 10^3-10^8 $M_\odot$.

The ULXs with compact radio emission studied here (N4088-X1 and N4861-X2 component A) fall in the range of M_{BH} ~ 10^3-10^6 $M_\odot$.



Fundamental plane. Location in the fundamental plane of the ULXs N4088-X1 and N4861-X2 (this work, red squares) and of other ULXs with radio counterparts (open squares). The parallel lines correspond to the labeled BH mass relative to that of the Sun. We show for comparison the Corbel et al. (2003) data for the X-ray binary GX 339-4 (filled circles), and the Merloni et al. (2003) data for some Low Luminosity AGN (inverted triangles).

CONCLUSIONS

VLBI observations are an excellent tool for clarifying the nature of ULX sources. Observations with the EVN at 1.6 GHz of 3 ULXs yielded the following results:

1. ULX N4088-X1. We detect a compact component with $L_{1.6\,GHz}$ = 3.8 x 10^{34} erg/s and a brightness temperature in excess of 7 x 10^4 K. This ULX could harbour a 10^5 $M_\odot$ black hole accreting at sub-Eddington rate.

2. ULX N4861-X2. We detect a compact component with a brightness temperature in excess of 10^6 K and possible extended emission that cannot be firmly localized with the present data. If the extended structure is confirmed, this ULX could be an HII region with a diameter of 8.6 pc and a surface brightness temperature of ~10^5 K. The compact radio emission may be coming from a ~10^5 $M_\odot$ black hole accreting at sub-Eddington rate.

3. ULX N4449-X1. We confirm the earlier identification of this objects with a SNR and obtain the most accurate estimates of its size (1.1 x 0.5 pc) and age (~60 yrs).

High-resolution radio observations are needed to understand the physics of those ULXs with detected radio counterparts.

REFERENCES: [1] Begelman, M.C. 2002 ApJ, 568 [2] Colbert, E.J., & Mushotzky, R.F. 1999, ApJ 519 [3] Corbel, S. et al. 2003, A&A 400 [4] Falcke, H. et al. 2004, A&A, 414 [4] Liu, J.F., & Bregman, J.N. 2005 ApJS, 157 [5] Lobanov, A.P. 2008, Memorie della Societa Astronomica Italiana 79 [6] Merloni, A. et al. 2003 MNRAS, 345 [6] Mezcua, M., Lobanov, A.P. 2011, AN, 332 [7] Sánchez-Sutil, J.R. et al. 2006 A&A, 452