Radio nebulae associated with ULXs

D. Cseh[1], C. Lang[2], S. Corbel[1], P. Kaaret[2], F. Grisé[2]

[1] Laboratorie Astrophysique des Interactions Multi-echelles, CEA/DSM-CNRS-Universite Paris Diderot, CEA Saclay, France

[2] Department of Physics and Astronomy, University of Iowa, Iowa City, USA

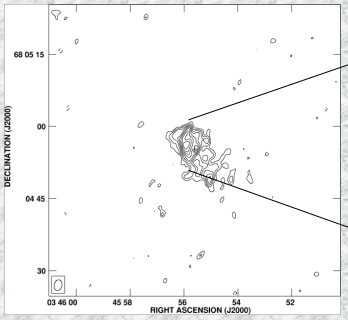
Black Hole Universe

CONTEXT

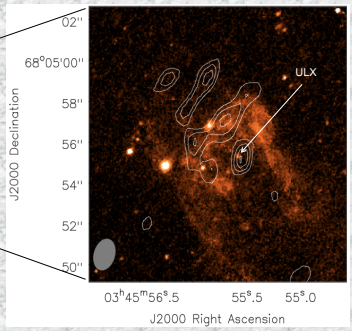
• Ultraluminous X-ray sources (ULXs) are luminous (L_X>10^{39} erg s^{-1}) non-nuclear X-ray point sources in galaxies with apparent X-ray luminosity above the Eddington limit for a typical 10-$M_\odot$ mass black hole. Assuming an isotropic X-ray emission, ULXs are the best candidate for intermediate-mass black hole with a mass of ~10^2-10^4 $M_\odot$

• Among the known ~150 ULXs there are ~11 ULXs that have associated powerful optical nebula (Pakull et al. 2003) and very few of them possess radio nebula.

•We conducted new radio observations with the ATCA and the VLA and we use these nebulae as a calorimeter to estimate the energy budget of the ULXs. In addition, if the ULX has a compact radio counterpart, we estimate the mass of the BH using the fundamental plane.



The 5-GHz VLA B- and C-array combined image. (Robust=0 weighted)



The 5-GHz VLA B- and C-array combined image overlaid on Hα HST image. (Resolving out most of the diffuse emission)

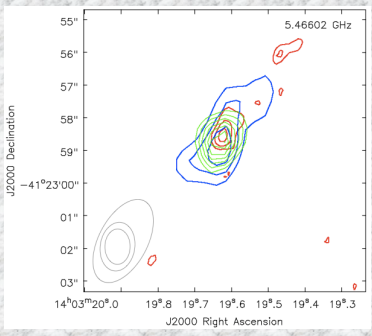
A new discovery in radio: IC 342 X-1

• The optical image shows a point-like counterpart at the location of the ULX (Feng & Kaaret 2008)

• In radio, we detected diffuse emission from a nebula with a total flux density of ~2 mJy and with a size of ~220 pc. (See Table)

• Higher resolution map shows a compact radio source at the location of the ULX with a flux density of ~100 ± 20 μJy.

•The rest of the radio morphology roughly follows the optical structures.



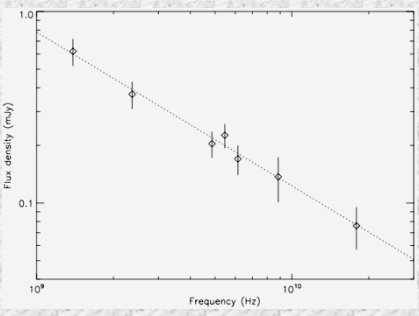
The naturally weighted, 9-GHz(blue), 18-GHz(red) and the uniformly weighted 5-GHz(green) ATCA image of our new observations.

NGC 5408 X-1

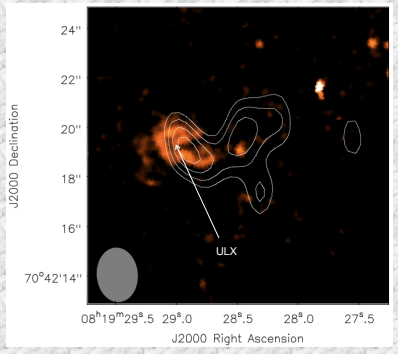
• Kaaret et al 2003 discovered the radio counterpart of this ULX. A four-point radio spectra were obtained by Lang et al. 2007.

•We conducted high-frequency ATCA observation and confirmed that the radio spectral index of -0.8 is consistent with an optically thin, synchrotron emission.

• The morphology shows a somewhat resolved radio nebula associated with the ULX.



Our new, 7-point fit of the radio spectra. Measurements obtained using ATCA.



The robust=-5 (uniform) weighted, 8-GHz VLA C-array image overlaid on He II HST image.

Holmberg II X-1

• The source was discovered by Miller et al. (2005) at single a radio frequency. We detected the nebula at 5- and 8 GHz which led to a radio spectral index of -0.53, which is consistent with an optically thin, synchrotron emission.

• The optical image shows a cavity around the ULX counterpart. In addition, an outflow-like feature is also can be seen in the E-W direction. Our highest resolution radio image of the surrounding nebula seems to follow this outflow-like structure and the other optical structures.

Comparison to SS 433

Name	Energetics* [erg]	Size [pc]	Spectral index
IC 342 X-1	9 x 10^{50}	220	-
Holmberg II X-1	3 x 10^{49}	50	-0.53
NGC 5408 X-1	4 x 10^{49}	35	-0.8
SS433	(0.5-7) x 10^{46}	46	-0.9

* Here we only consider the total power of the radio nebula

DISCUSSION

•Using the ***fundamental plane of BHs*** which is a relationship between X-ray luminosity, radio luminosity and BH mass:

$\log M_{BH} = 1.55 \log L_{Radio} - 0.98 \log L_{X\text{-}ray} - 9.95$ (Körding et al. 2006),

we can estimate the mass of the ULX. The application of the fundamental plane requires radiatively inefficiently - like advection dominated or jet dominated - accreting sources, ie. hard state objects. We detected a radio point source at the location of IC342 X-1, which can be consistent with a compact jet (though we have no spectral information). Substituting the flux of the point source of 100 μJy (and L_X=6 x 10^{39} erg/s), we obtain $M_{BH} \approx 10^4\ M_\odot$, which should be taken as an order of magnitude under the hypotheses mentioned before.

The total ***energy budget*** of the radio nebulae assuming radiation via synchrotron emission, equipartition between particles and fields, and equal energy in electrons and baryons (Lang et al 2007). For IC 342, we assume a radio spectral index of -0.8 of NGC 5408 X-1 and we use a lower frequency cutoff of 1.3 GHz and an upper frequency cutoff of 6.2 GHz. For a source diameter of ~220 pc and a filling factor of unity, ***we find:*** hat the total energy required is 9 x 10^{50} erg, the magnetic field is 7 μG. This is similar for all 3 ULXs but at least 2 orders larger than SS433.

REFERENCES

» Feng & Kaaret 2008, ApJ, 675, 1067
» Kaaret P. et al. 2003, Science, 299, 365
» Körding E. et al. 2006, A&A, 456, 439
» Lang C. et al. 2007, ApJ, 666, 79
» Miller N. A. et al. 2005, ApJ, 623, 109
» Pakull M. et al. 2003, RMxAC, 15, 197