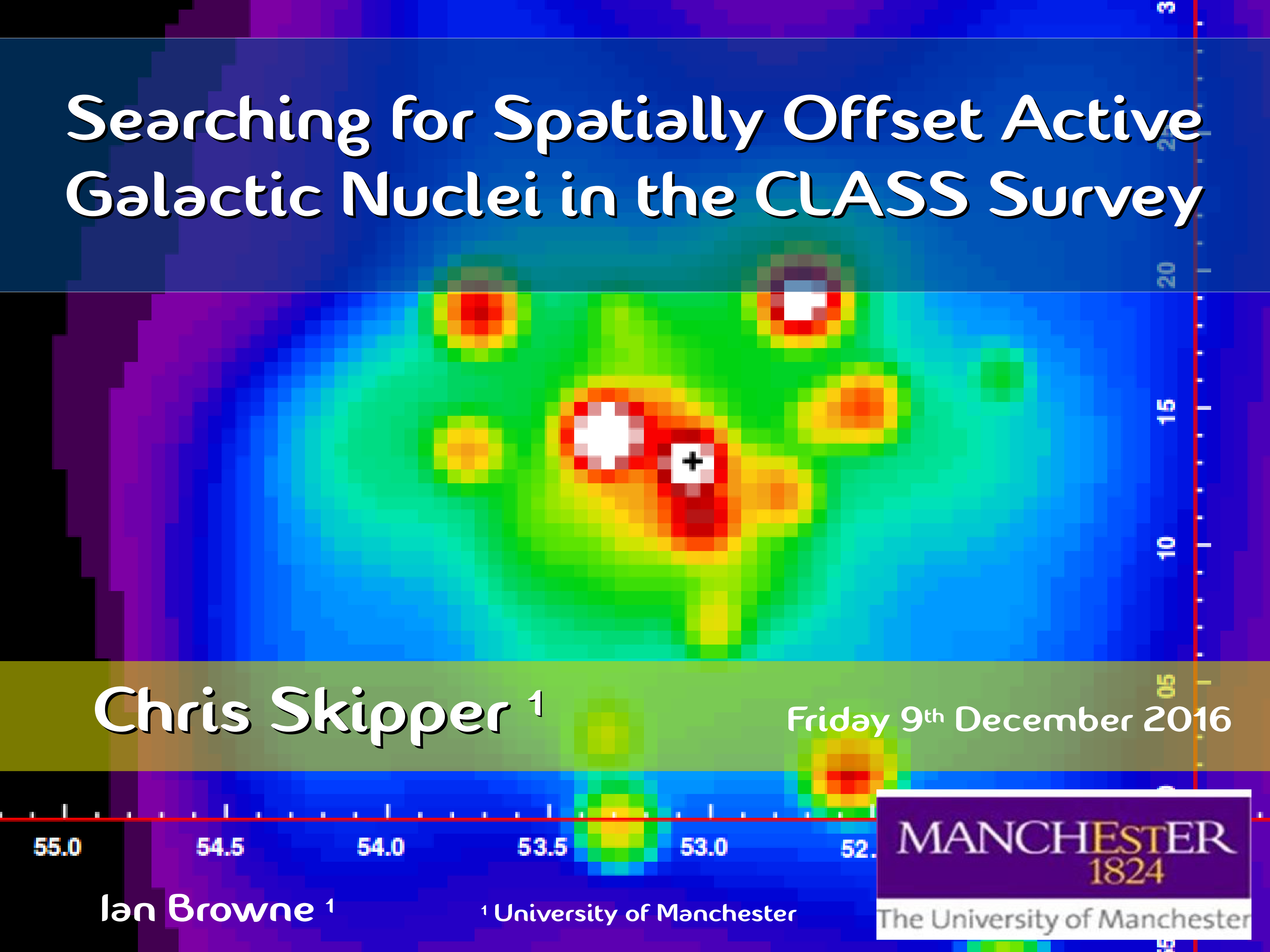
Searching for Spatially Offset Active Galactic Nuclei in the CLASS Survey



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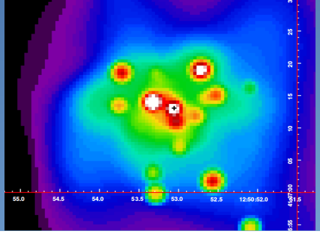
Friday 9th December 2016

MANCHESTER 1824
The University of Manchester

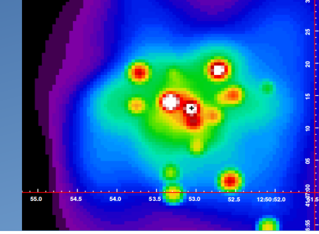
Introduction



Active galactic nuclei (AGN) are usually found in the centre of their host galaxy, identified by compact X-ray and radio emission from matter accreting onto, and being ejected from, the supermassive black hole (SMBH).

Galaxy mergers cause significant disruption to the galaxy morphology, and, additionally, can result in a spatial or kinematic offset between the AGN and the host galaxy. Following a galaxy merger, the two SMBHs should form a dual SMBH system, but unambiguously confirmed cases are rare (Liu et al, 2012).

Spatially-offset AGN can be identified in either X-ray or radio, and here we complement a recent Chandra survey by Barrows et al (2016) by looking for spatially-offset AGN in the CLASS survey of compact radio sources.

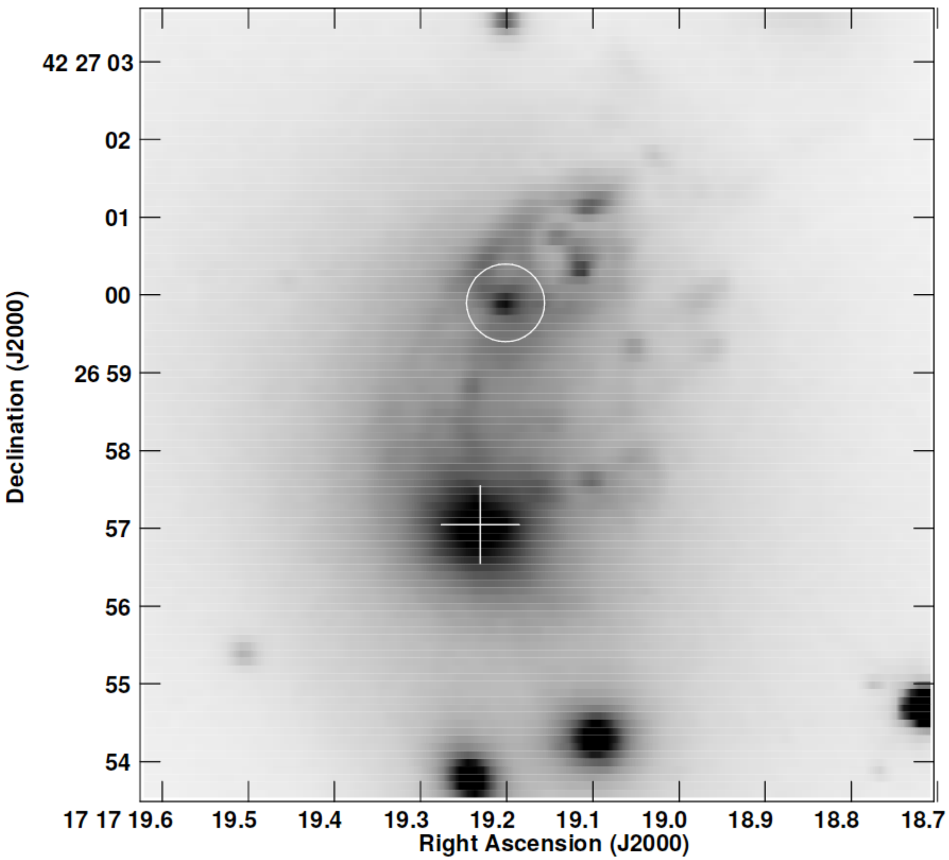


Offset AGN: Caused by What?

1) 'Naked' Supermassive Black Holes:

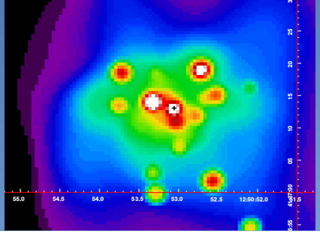
A supermassive black hole that has been left 'naked' when its host galaxy was tidally shredded by a larger galaxy in the early stages of a merger.

Much more difficult to detect than supermassive BH binaries – look for a compact source with a radio luminosity that can only be powered by an AGN.



B3 1715+425
Condon et al, 2016

Offset AGN: Caused by What?

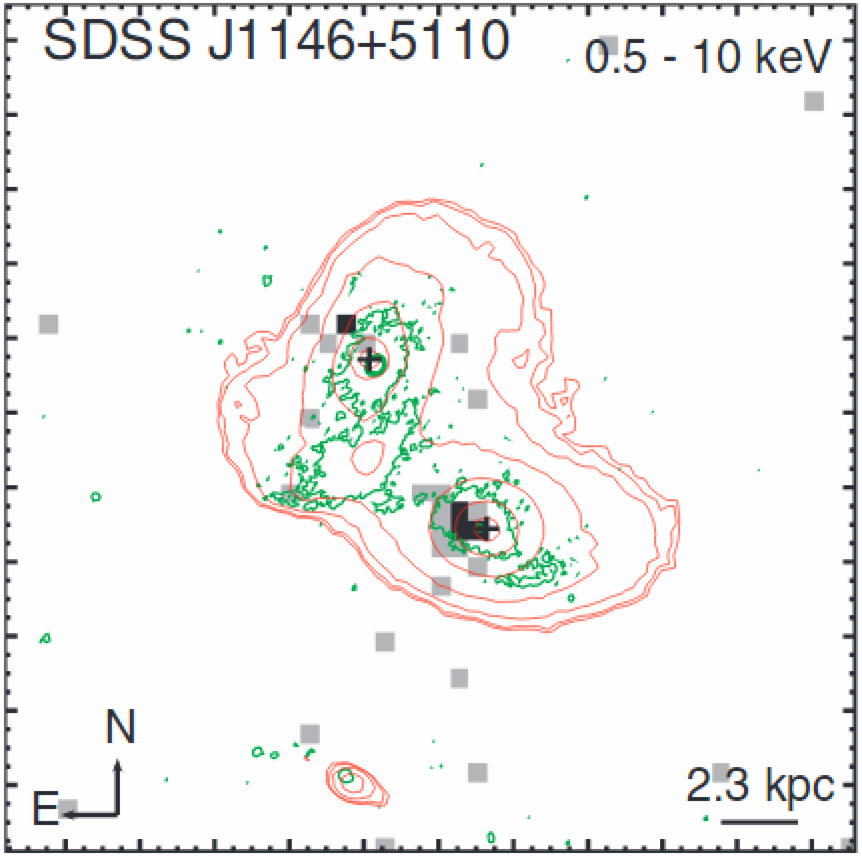


2) Merging Black Hole Binaries:

Supermassive black hole binaries in post-merger galaxies, in the process of coalescing.

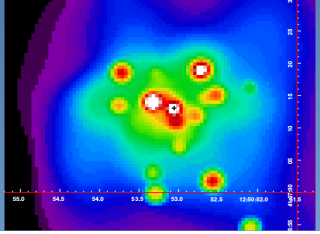
Usually expect a see a double peak in the brightness profile, but it is possible that only one source is detectable.

During the 'pairing' phase, the two black holes are still resolvable at cosmological distances (with a separation of a few tens parsecs to a few tens kiloparsecs).

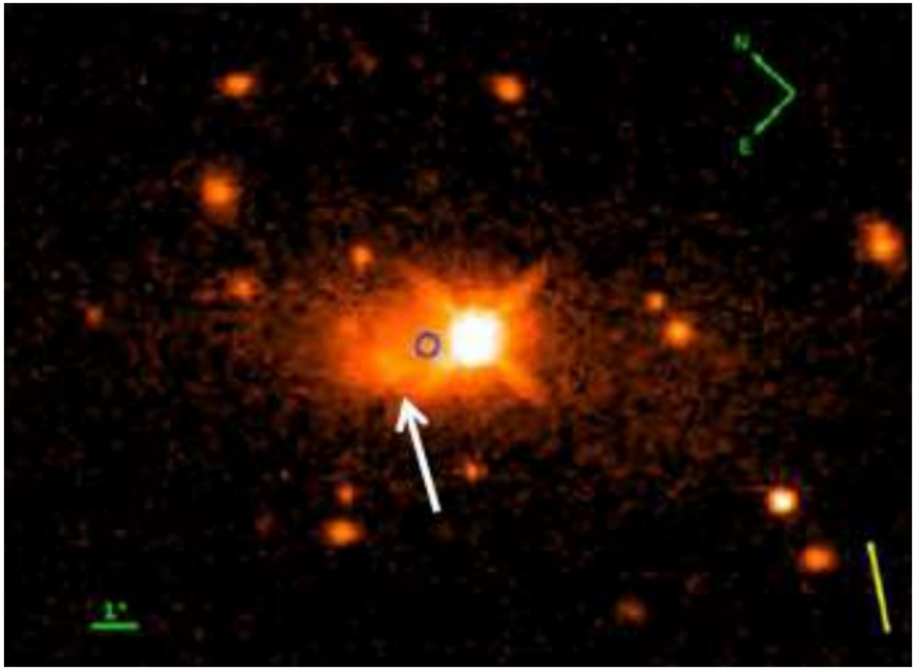


SDSS J1146+5110
Liu et al, 2013

Offset AGN: Caused by What?



3) Recoiling Black Holes:



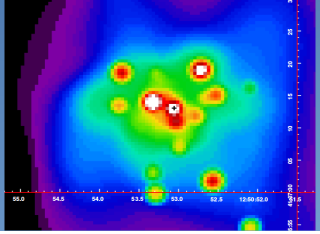
QSO 3C 186
Chiaberge et al, 2016

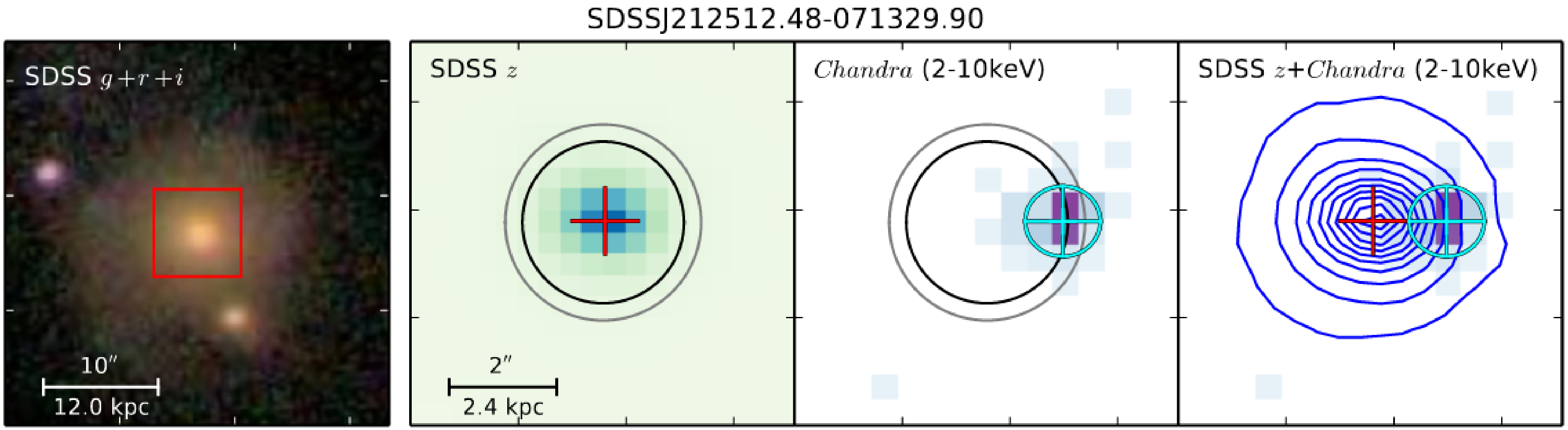
Caused by the anisotropic emission of gravitational waves (Peres 1962; Beckenstein et al 1973).

Typically, for non-spinning black holes, the expected velocity is around a few hundreds of km s^{-1}, or less.

Broad- and narrow-line regions expected to show different velocity shifts, as the BLR is dragged out with the recoiling BH.

Offset AGN from Chandra (Barrows et al, 2016)



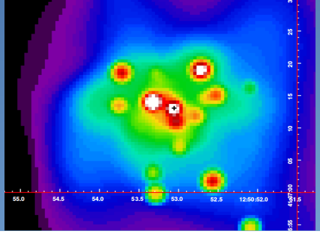


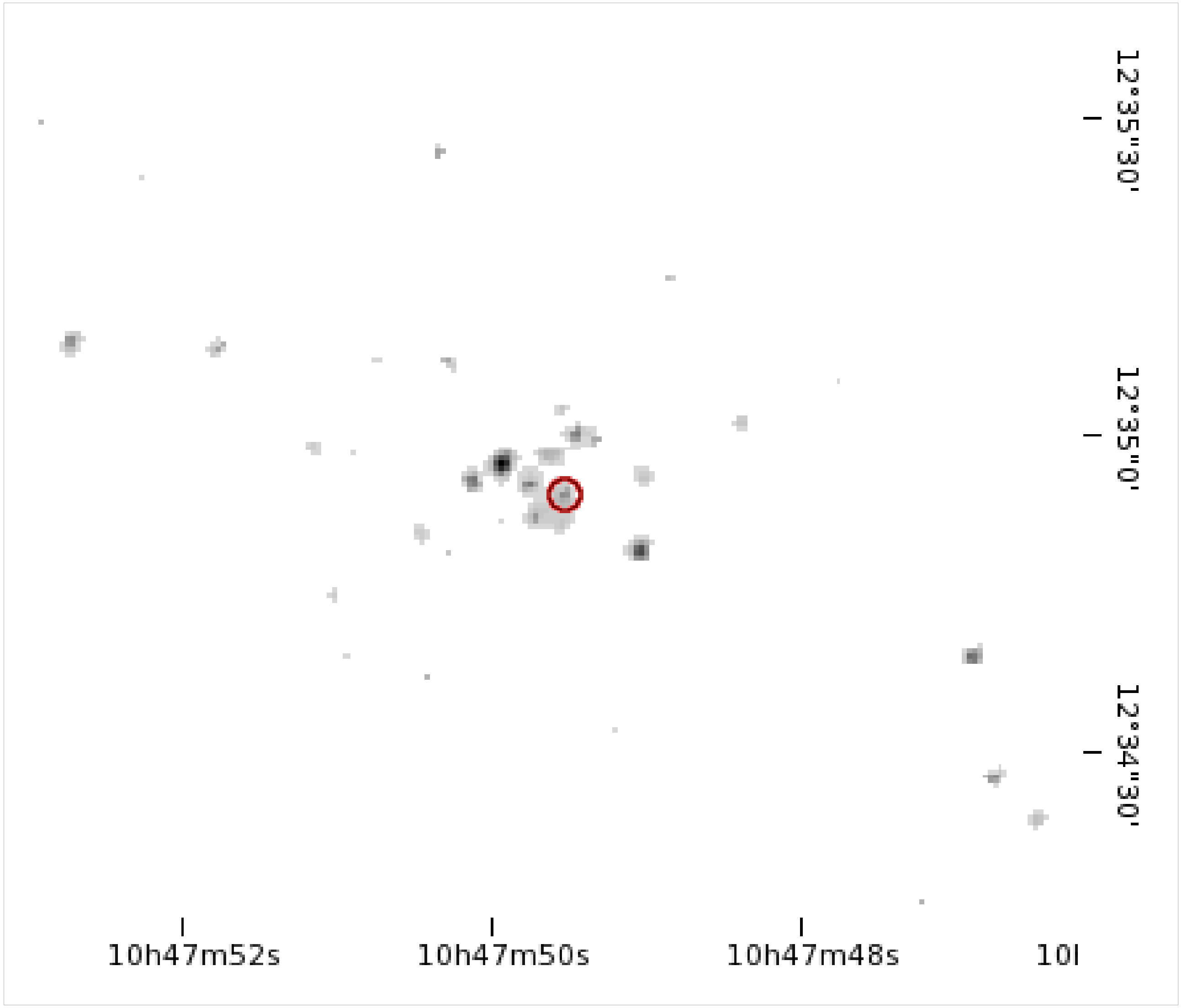
Search for spatially-offset AGN using archival Chandra ACIS images

Sample of **48** Type II AGN from the SDSS galaxy catalogue – **18** were found to have X-ray AGN spatially offset from the galactic stellar core by between 0.6 and 17.4 arcsec. This is **37.5 %**.

Only galaxies found in the OSSY catalogue of emission and absorption lines measurements were included.

X-ray Detection of AGN: NGC 3379 (LINER 2.0) - Chandra ACIS



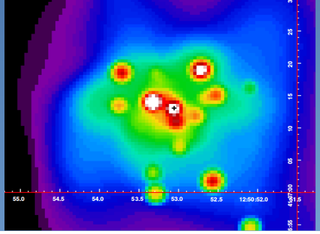


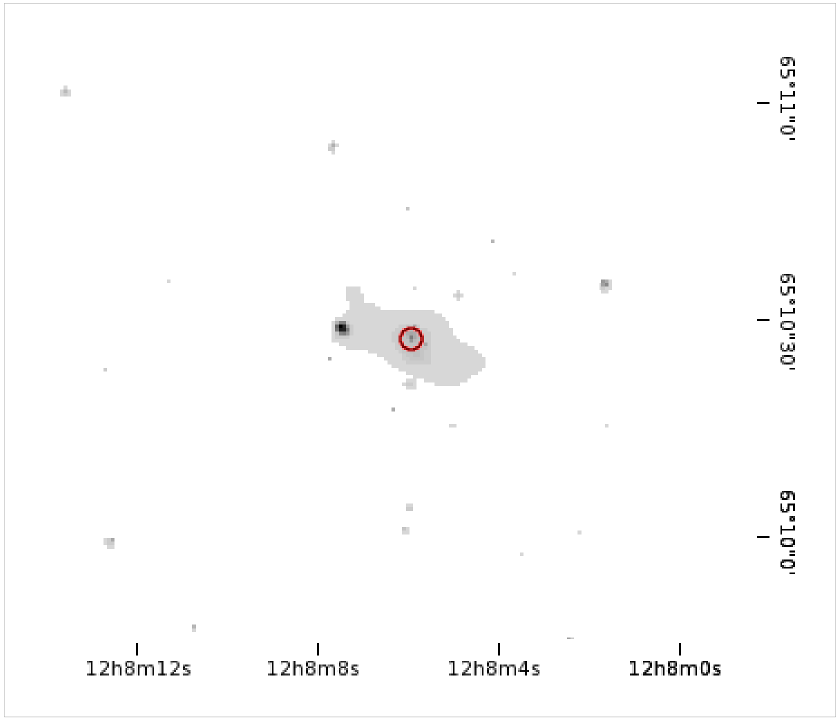
Illustrates the dangers of identifying AGN using X-ray only

However, NGC 3379 was not included in the CLASS survey.

Position confirmed by Fabbiano et al 2006

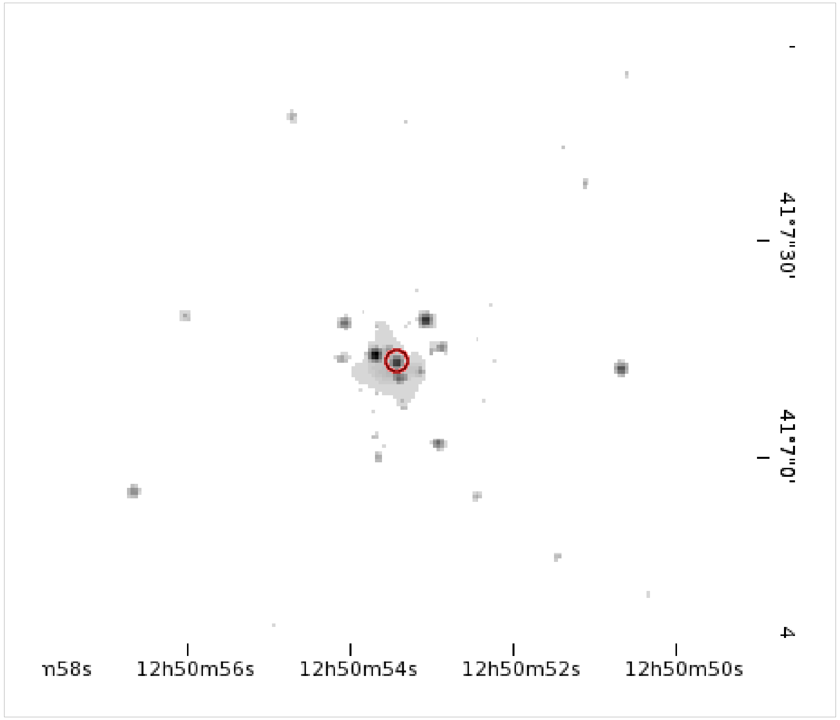
X-ray Detection of AGN: NGC 4125 and NGC 4736 - Chandra ACIS





NGC 4125 (LINER 2.0)

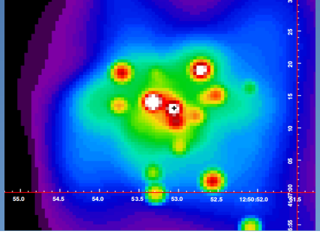
Position confirmed by Grier et al 2011



NGC 4736 (LINER 2.0)

Position confirmed by Pellegrini et al 2002 and Eracleous et al 2002

Fundamental Plane of Black Hole Activity



An empirical relationship between radio luminosity, X-ray luminosity and black hole mass.

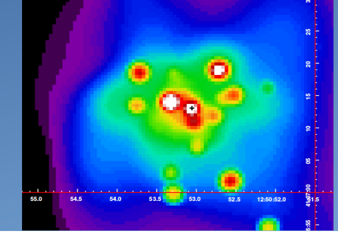
Fundamental plane holds across many orders of magnitude in mass, from X-ray binaries to AGN.

$$\log L_r = \left(0.60^{+0.11}_{-0.11}\right) \log L_x + \left(0.78^{+0.11}_{-0.09}\right) \log M_{BH} + 7.33^{+4.05}_{-4.07}$$

Merloni et al 2003

Emission from the supermassive black hole is easier to identify in a crowded field by using radio rather than X-ray, because of the 'boost' from the black hole mass term.

The CLASS Survey



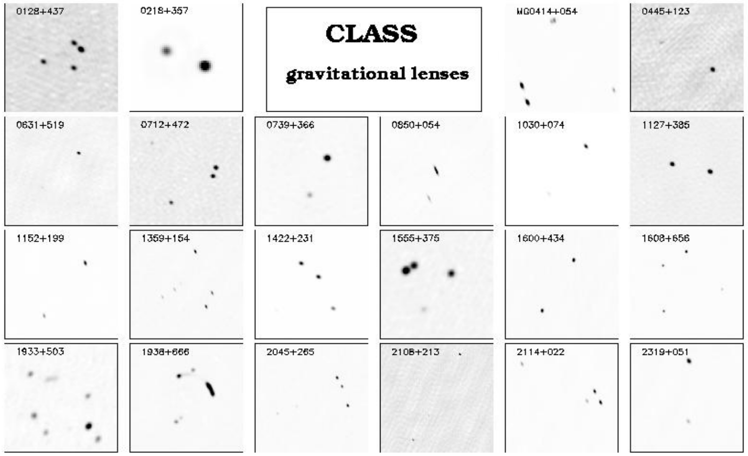
CLASS: Cosmic Lens All-Sky Survey

Myers et al 2003; Browne at al 2003

A search for gravitationally lensed compact radio sources. CLASS has identified **22** gravitational lens systems.

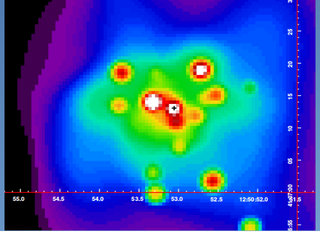
Declinations above approx 0 deg, observed first with the VLA, and then follow-up observations with MERLIN and VLBA.

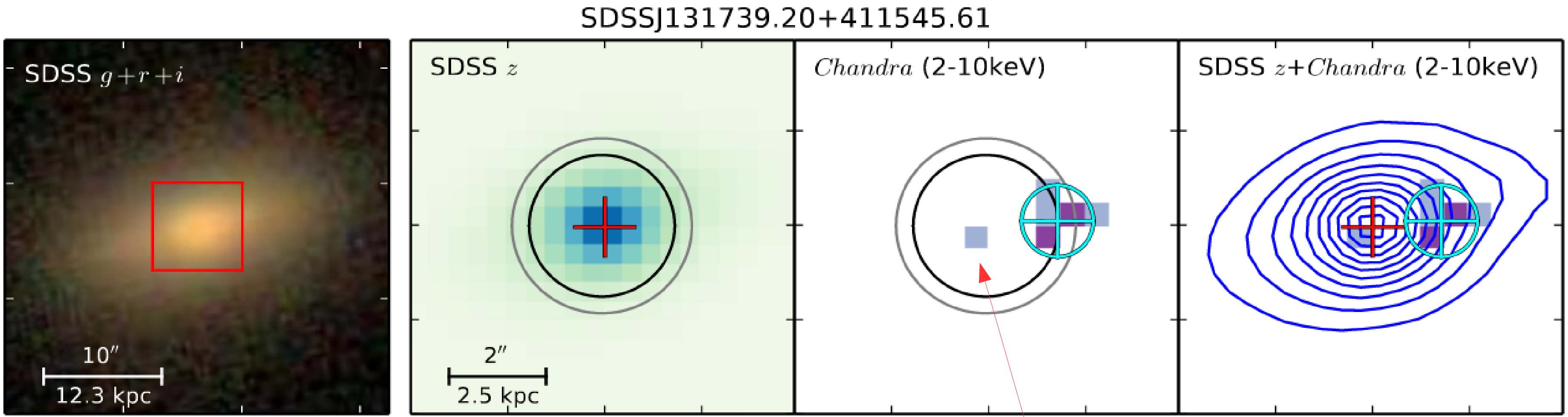
16,682 pointings, **23,418** components detected.



http://www.jb.man.ac.uk/research/gravlens/class/class.html

X-ray v Radio Identification of the AGN





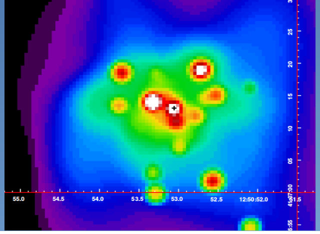
Barrows et al 2016

CLASS: 171.4 mJy
compact source

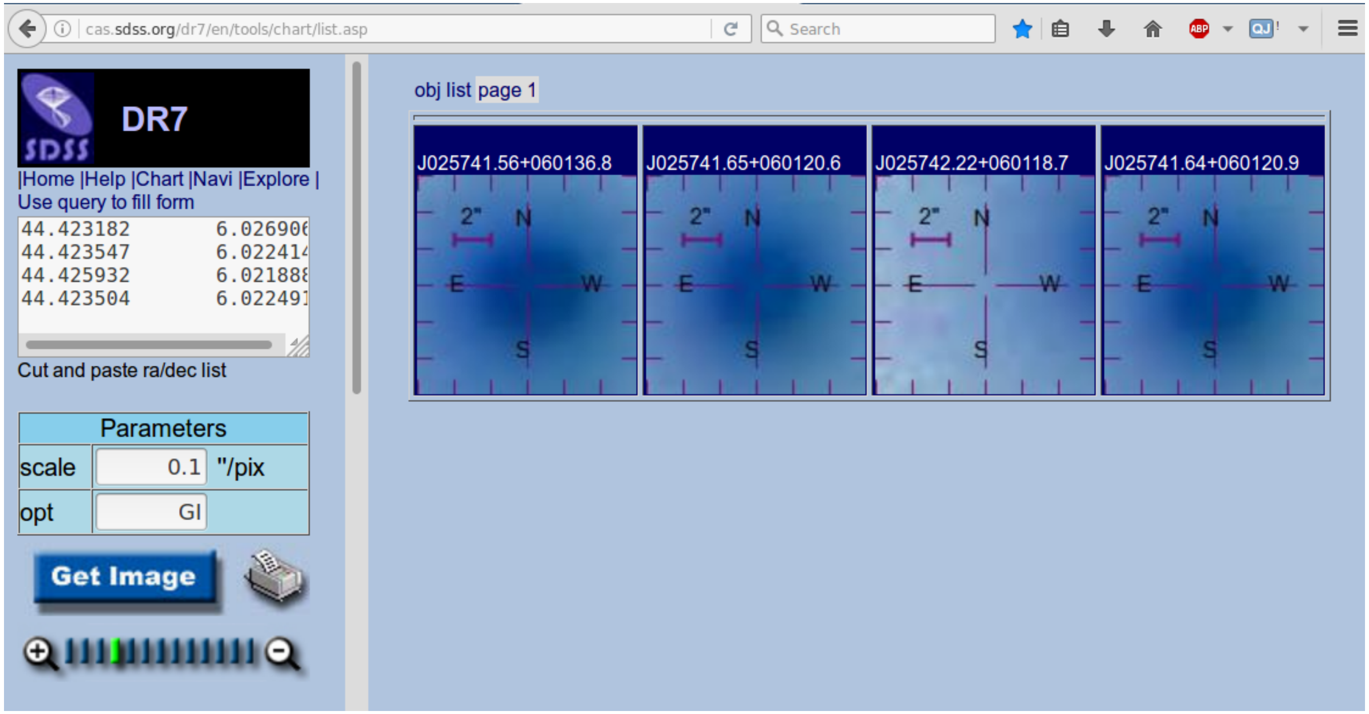
Barrows et al (2016) identified 18 offset AGN from a sample of 48 AGN using Chandra images.

In one of these 18 AGN the only detected compact radio source is coincident with the galaxy centre, and NOT the brightest X-ray source.

Method 1: Visually-Offset CLASS Sources

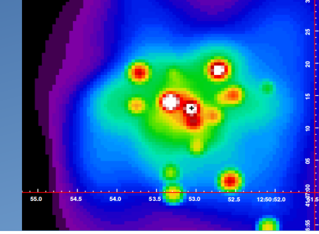


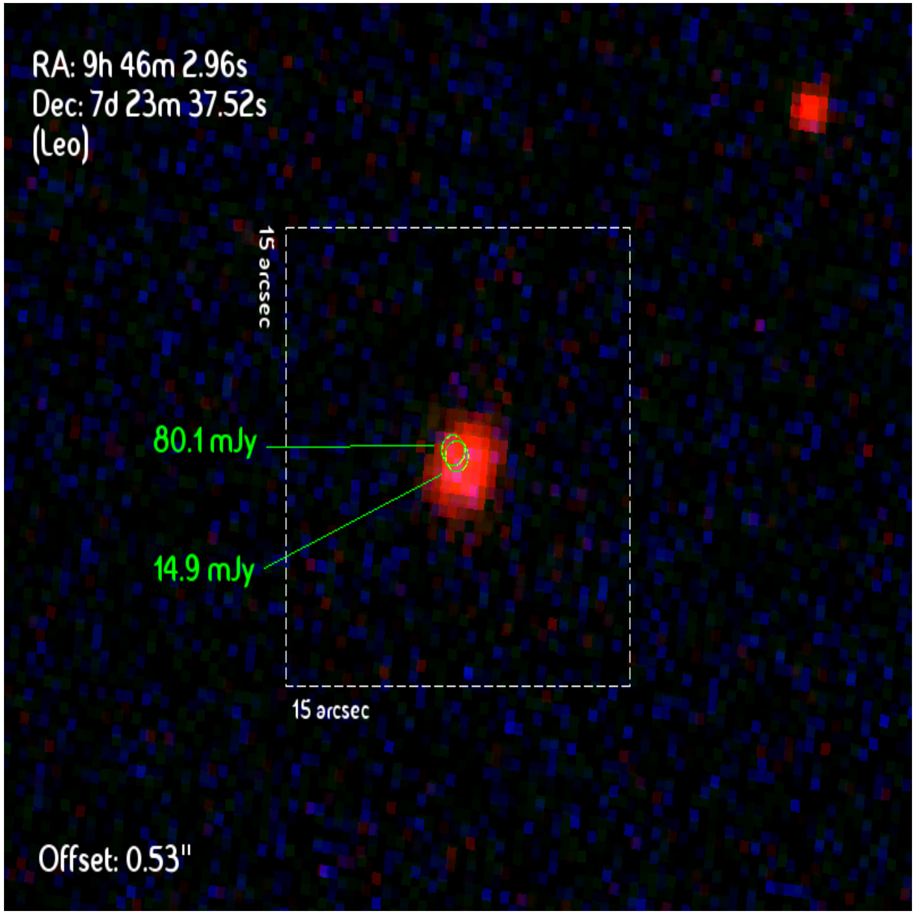
- Examine all 23,418 CLASS sources in the SDSS Image List Tool to identify components that appear, to the eye, to be offset from the galaxy centre.



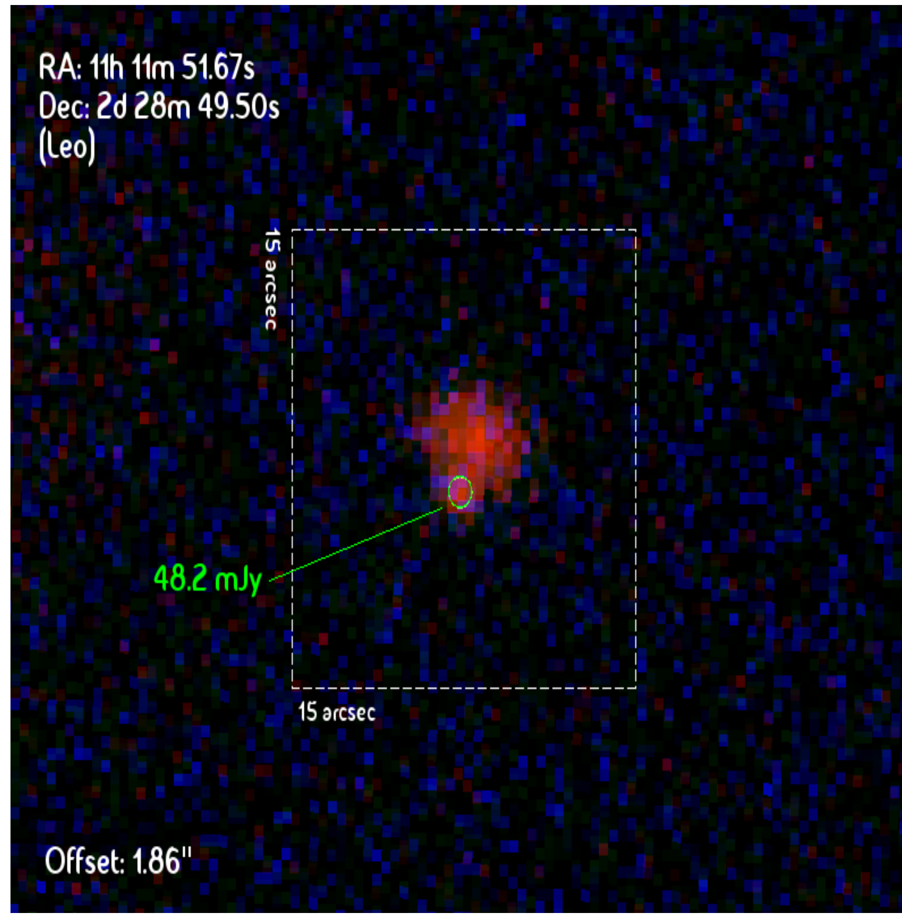
- Check position against NED to ensure that the object is listed as a galaxy.

Method 1: Visually-Offset CLASS Sources



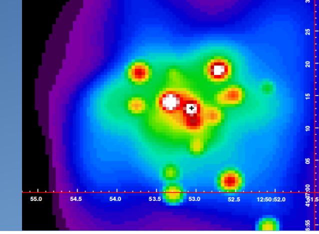


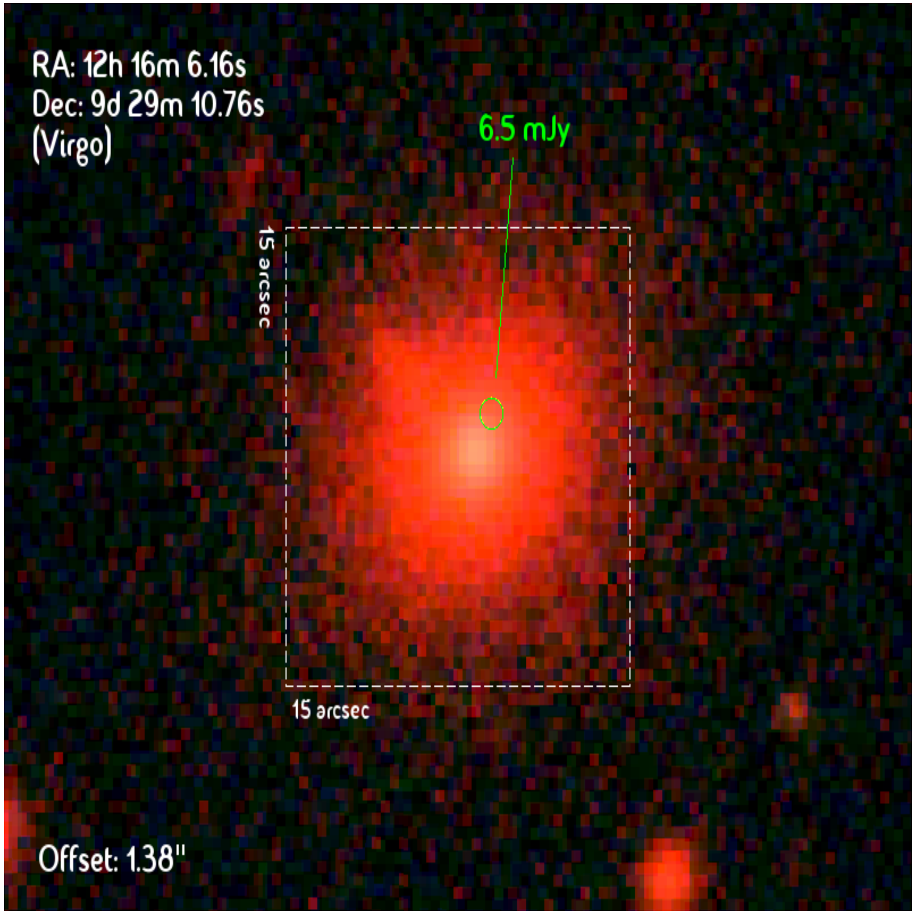
SDSS J094602.92+072337.0



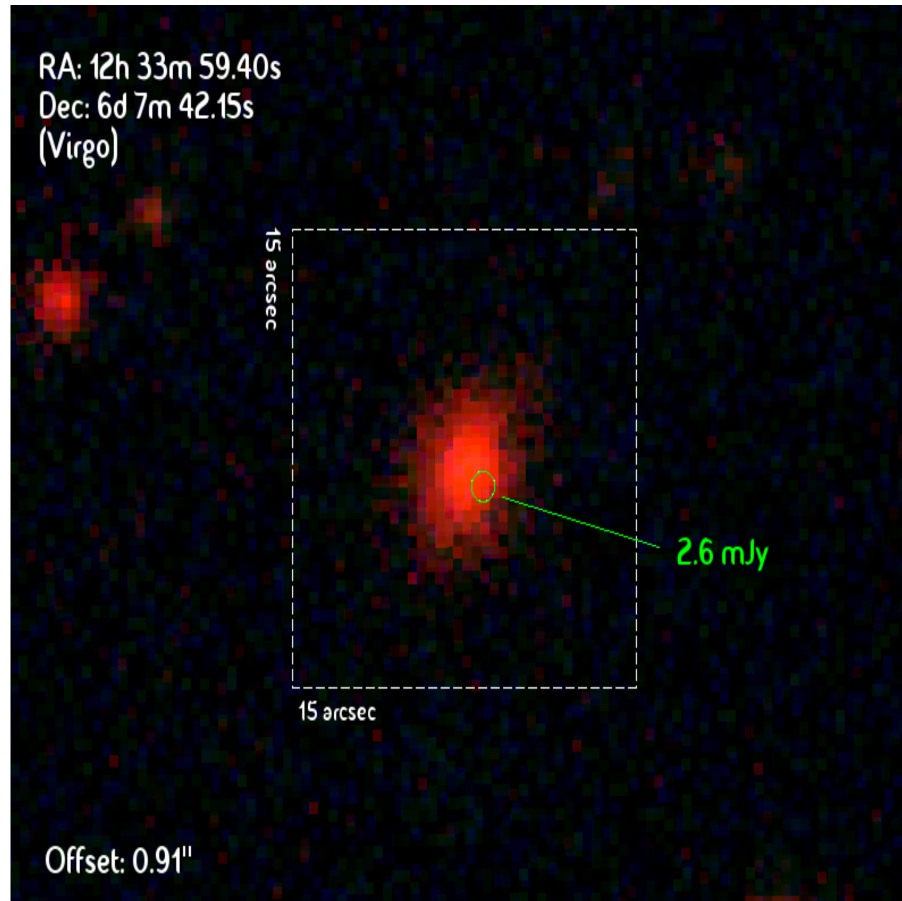
SDSS J111151.62+022851.2

Method 1: Visually-Offset CLASS Sources



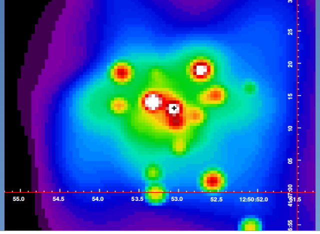


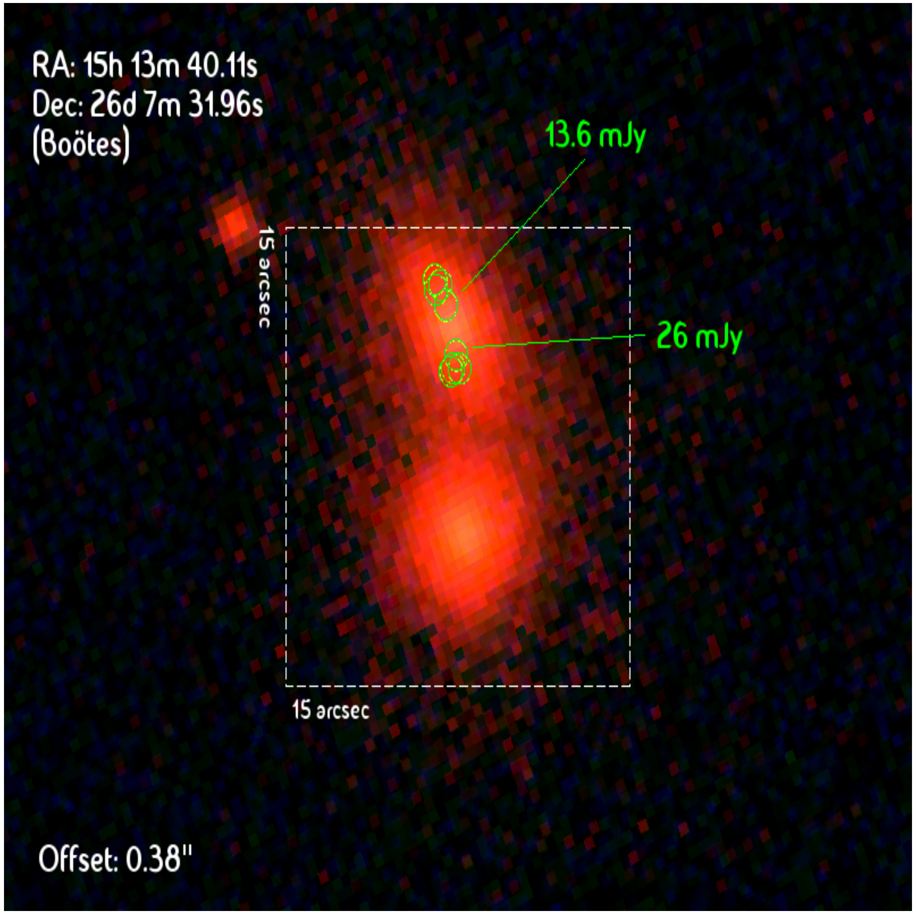
2MASX J12160619+0929096



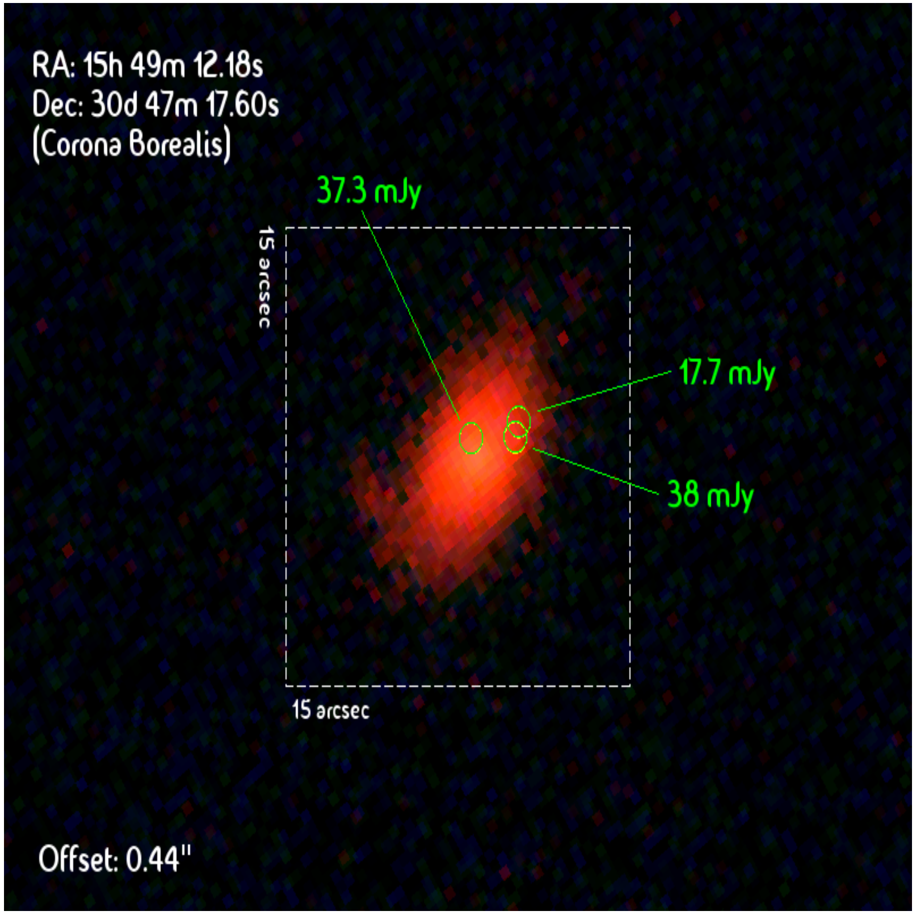
SDSS J123400.37+060751.1

Method 1: Visually-Offset CLASS Sources



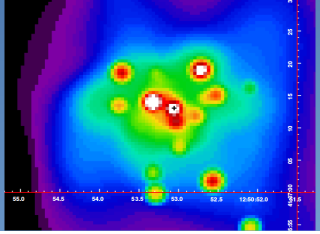


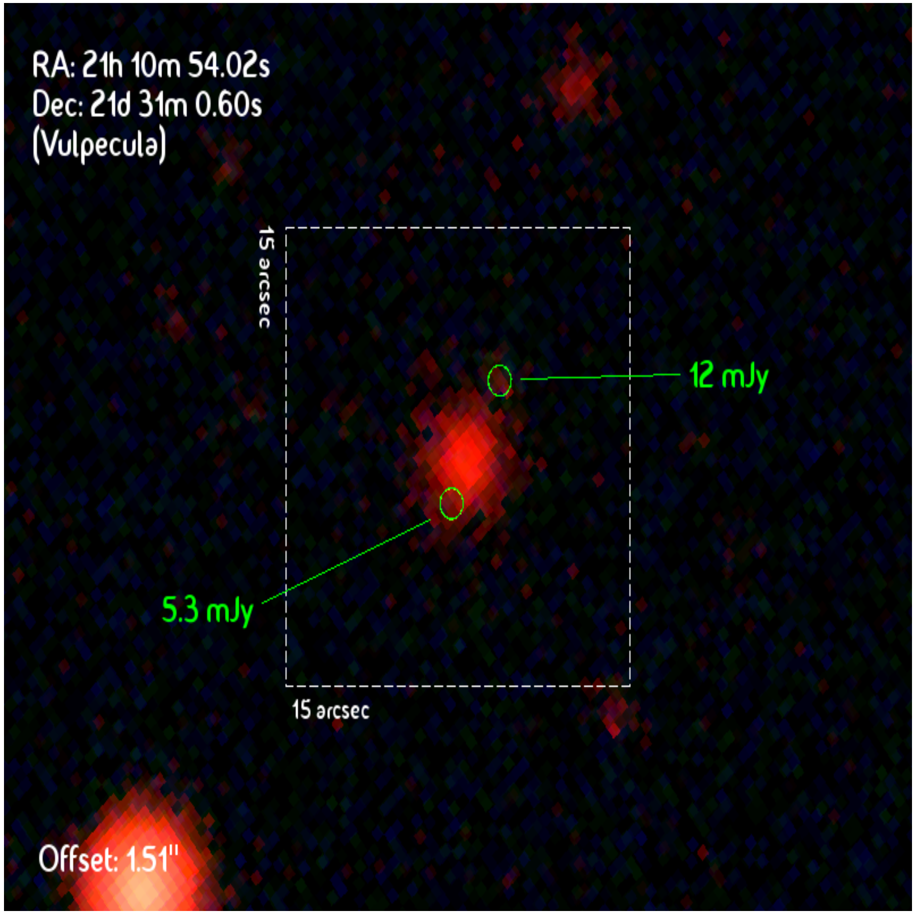
SDSS J151341.14+260703.8



4C +30.29

Method 1: Visually-Offset CLASS Sources





2MASX J21105414+2130583

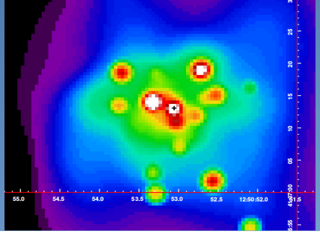
Summary of Visually Offset Sources

11,782 CLASS pointings have coverage in SDSS - **4,900** do not.

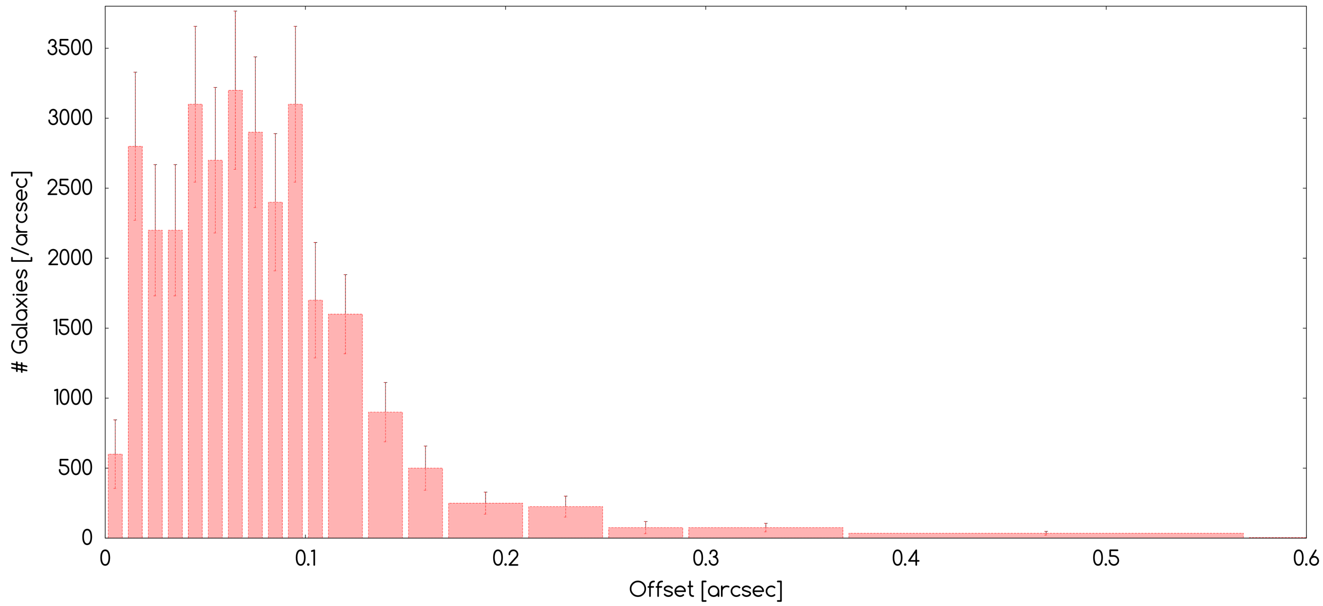
4,033 CLASS pointings do not appear to be obviously associated with any optical source – galaxy, star, etc – at the positions of any of the detected components.

7 CLASS pointings are associated with an external source listed as a galaxy in NED, and have components that are all visually offset from the centre – i.e. the offset is detectable by eye.

Method 2: CLASS (Radio) and SDSS (Type II AGN) Cross-Matching

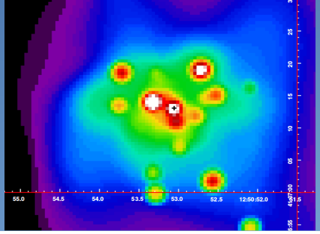


Position-matched sources from the CLASS catalog and SDSS galaxies catalog of Type II AGN (matched to the OSSY catalogue of emission and absorption lines measurements).

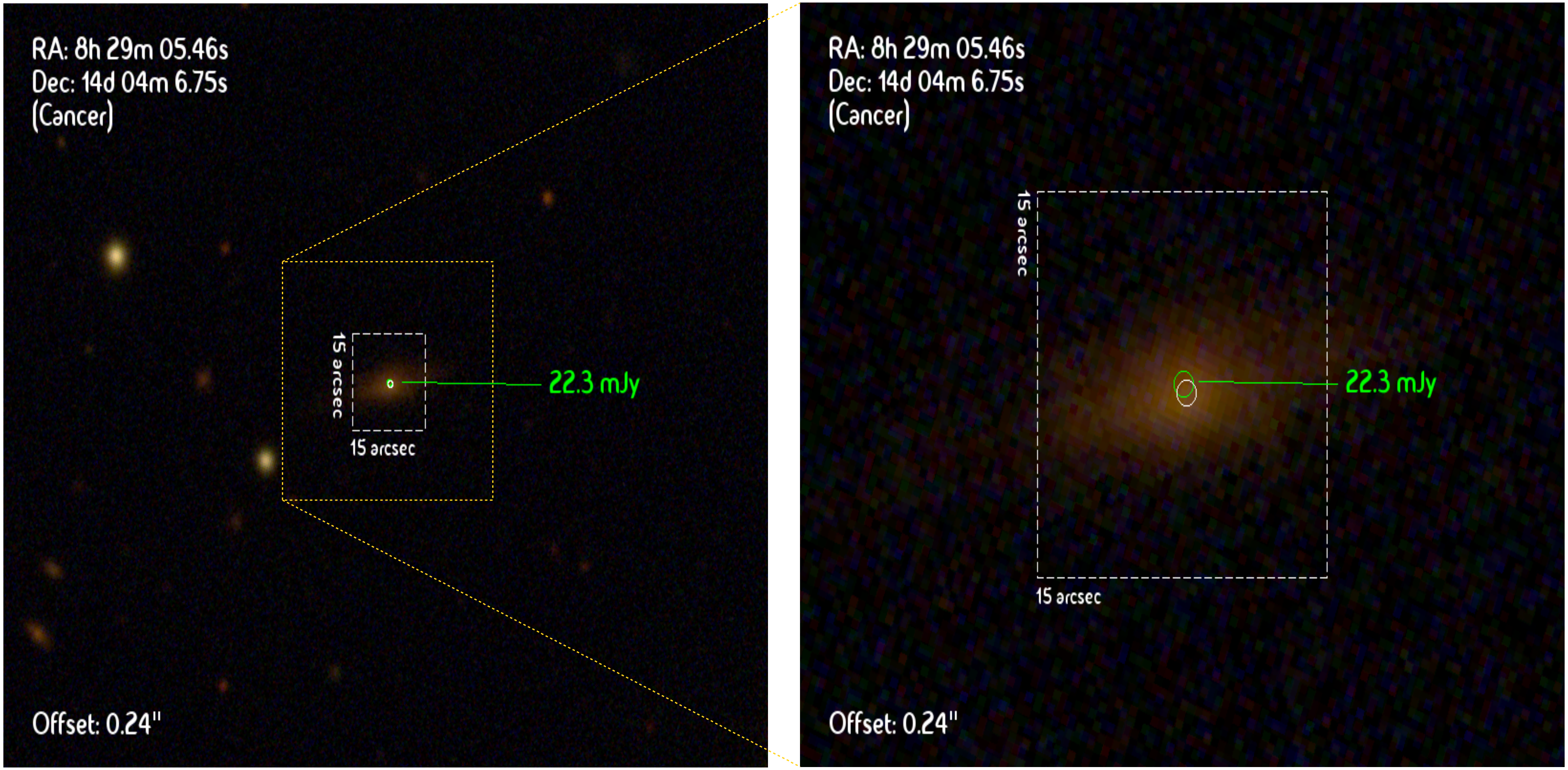


377 cross matches – i.e. an offset between the CLASS component position and the OSSY galaxy position of less than **17.4** arcsec. All matches verified in SDSS Image List Tool to ensure they are matched to the same optical source.

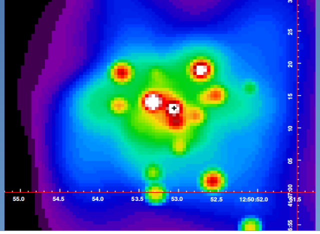
Method 2: CLASS (Radio) and SDSS (Type II AGN) Cross-Matching



31 galaxies with CLASS/SDSS offsets of between **0.2** and **1** arcsec
2 further galaxies with offsets of between **1** and **2** arcsec



The Different Results From X-ray and Radio-Selected Samples



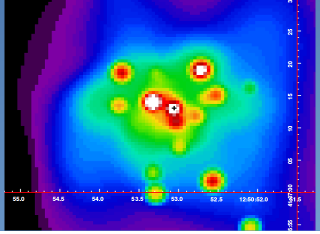
By matching the CLASS sources to OSSY we follow the same method used by Barrows et al (2016), who matched the positions of X-ray sources detected with Chandra to the OSSY catalog.

	X-ray Selected (Barrows et al 2016)		Radio Selected (This work)	
Sample Size	48		377	
0.6″ < Offset < 17.4″	18	(37.5%)	8	(2.1%)
0.2″ < Offset < 2″			33	(8.8 %)

Barrows et al applied a couple of additional requirements to their sample selection:

- Hard X-ray source detected within SDSS Fiber
- X-ray source passes L_X ($L_{2\text{-}10\ keV} > 10^{42}$ erg s^{-1}) or HR criteria ($(H-S)/(H+S) \geq -0.1$)

The Different Results From X-ray and Radio-Selected Samples

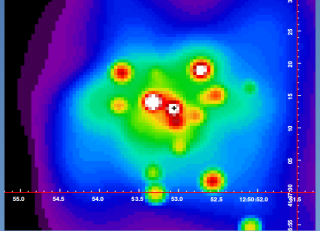


The radio-selected sample has far fewer sources offset from the galaxy centre by more than 0.6 arcsec than the X-ray-selected sample.

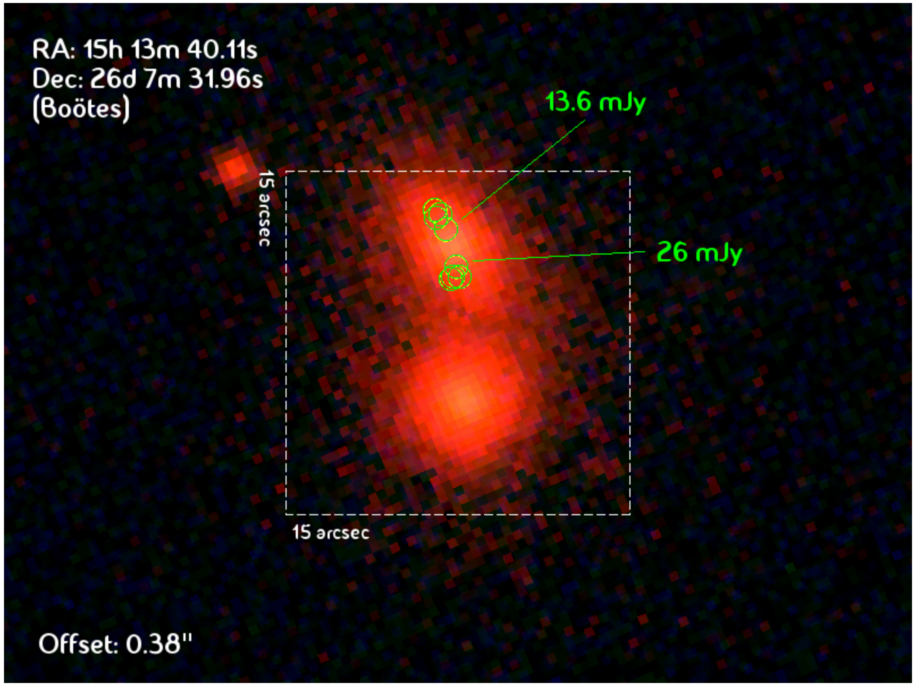
Possible reasons:

- **CONTAMINATION:** X-ray selected samples may be contaminated by X-ray binaries and ULXs, which may be brighter in X-ray than the AGN. X-ray observations alone are usually not sufficient to identify a low-luminosity AGN amongst a field of compact nuclear sources.
- **EVOLUTION:** It is possible that the radio emission switches on at a much later stage of the merger process than the X-ray emission. i.e. after the SMBH binaries have coalesced.
- **SELECTION EFFECTS:** Most of the offset AGN reported by Barrows et al (2016) are not detected by CLASS, and our sample therefore overlaps little with theirs.

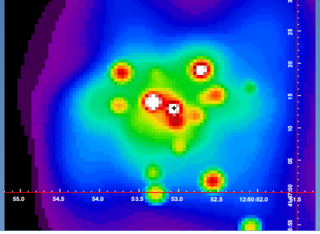
What Next ?



- Follow-up spectroscopic measurements:
    - BPT diagrams: Does the galaxy really host an AGN ?
- Chandra and XMM archive search:
    - Is the source detected in hard X-rays (> 2 keV) ?
    - X-ray spectroscopy
- Follow-up radio observations



Summary



We have looked for spatially-offset AGN in the CLASS survey of compact radio sources.

A visual inspection found that only **26** CLASS pointings out of **11,782** with SDSS coverage have components that are all clearly offset from the centre of the extended optical source. Only **7** of these sources are listed as galaxies in NED.

By cross-matching the CLASS catalog with type II AGN found in the SDSS galaxies catalog and the OSSY catalog we found that only **8** out of **377** matches are offset by between **0.6** and **17.4** arcsec.

These fractions are much lower than the figures obtained by Barrows et al (2016) from their Chandra survey (**18** out of **48** offset by between **0.6** and **17.4** arcsec).