Discovering Spatially Offset Active Galactic Nuclei, HLXs and IMBH Candidates with *Chandra*

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The role of galaxy mergers for growing massive black holes

Major mergers of massive galaxies:
Accreting SMBHs
(Mass=$10^6$-$10^9M_{\odot}$)

Minor merger:
Accreting IMBH?
(Mass=$10^3$-$10^6M_{\odot}$)

Farrell et al. 2009, Nat., 460, 73
Techniques for building samples of galaxy mergers:

Visually ("by-eye")

Asymmetry

Pairs of distinct galaxies
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Visually ("by-eye")

Asymmetry

Pairs of distinct galaxies

Spatially Offset AGN


Unambiguous galaxy mergers: Spatially Offset AGN

Optical Emission Lines


SDSS Seyfert 2 Spectrum
Unambiguous galaxy mergers: Spatially Offset AGN

Optical Emission Lines

NGC 3341

B → Nucleus

C

SDSS Seyfert 2 Spectrum

X-ray Spectra


Chandra X-ray AGN
Select AGN from SDSS using BPT diagram at z<0.21:

Crossmatch with footprint of *Chandra* archives:

Register Chandra image with at least SDSS i- or z-band:
Select AGN from SDSS using BPT diagram at $z<0.21$:

Crossmatch with footprint of *Chandra* archives:

Register Chandra image with at least SDSS i- or z-band:

*Chandra*, 2-10 keV

Hard X-ray source:
- within SDSS fiber
- $L_{X, 2-10} > 10^{42}$ erg s$^{-1}$ (AGN)
Select AGN from SDSS using BPT diagram at $z<0.21$:

Crossmatch with footprint of *Chandra* archives:

Register Chandra image with at least SDSS i- or z-band:

![SDSS z-band](image1)

**Chandra, 2-10 keV**

Hard X-ray source:
- within SDSS fiber
- $L_{X,2-10} > 10^{42}$ erg s$^{-1}$ (AGN)

X-ray AGN significantly ($>3\sigma$) spatially offset:

- 20,098
- 2,292
- 150
- 48
- 9
Spatially Offset AGN

ApJ Accepted
<table>
<thead>
<tr>
<th>SDSS g+r+i composite</th>
<th>SDSS</th>
<th>2-10 keV</th>
<th>SDSS +2-10 keV</th>
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<td><img src="image3.png" alt="2-10 keV" /></td>
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*ApJ Accepted*
Spatially Offset AGN

SDSS g+r+i composite

SDSS 2-10 keV

SDSS +2-10 keV

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Spatially Offset AGN

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Chandra Science: Galaxy Merger Stage

AGN merger fraction inversely correlated with separation

Mergers selected as galaxy pairs down to (>5 kpc)

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Mergers selected as galaxy pairs down to (>5 kpc)


Mergers selected as spatially offset AGN (<0.8 kpc)

Consistent with simulations: AGN observability in mergers peaks at <1 kpc

Barrows et al. *in prep*
Are offset AGN preferentially found in major or minor mergers?
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\[ \frac{M_1}{M_2} = 3.07 \text{ (major-ish)} \]
Chandra Science: Merger Mass Ratio

$M_1/M_2 = 70$ (minor)

HST/WFC3 F160W+F814W+F438W
Conclusions:

With *Chandra* we can...

identify galaxy mergers via X-ray AGN with *reliable* spatial offsets:
→ Systematic catalogue of spatially offset AGN

identify mergers down to stages of $< 1$ kpc:
→ merger stages when AGN activity (is predicted) peak

identify galaxy mergers independent of morphology:
→ major and minor mergers

Soon: systematic catalogue of 300 HLXs candidates and 21 IMBH candidates (Barrows et al. *in prep*)