

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

R. Scott Barrows

Postdoctoral Research Associate
Center for Astrophysics and Space Astronomy
University of Colorado Boulder

Collaborators:

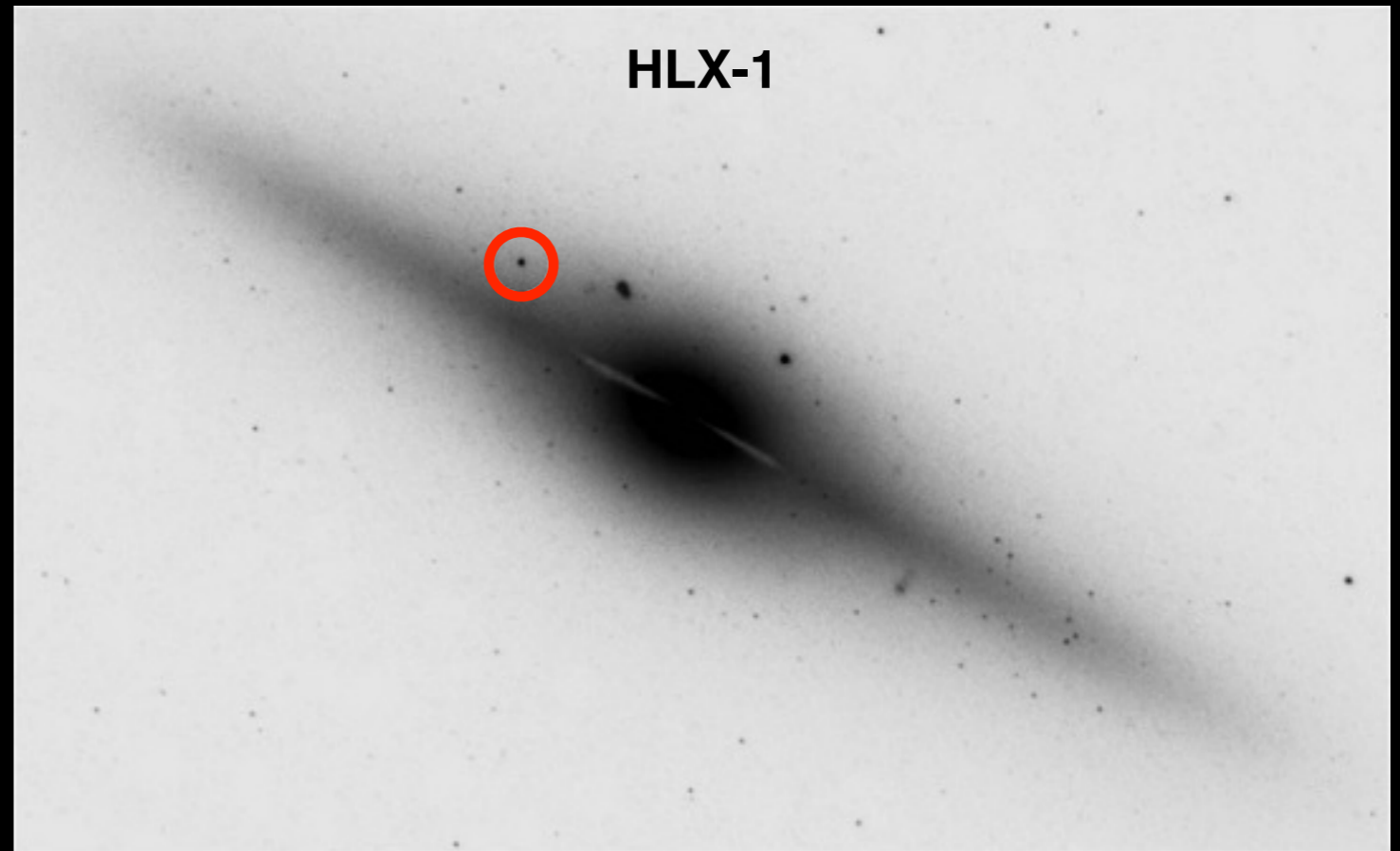
Julie Comerford (CU Boulder), Jenny Greene (Princeton), Dave Pooley (Trinity Univ.)

The role of galaxy mergers for growing massive black holes



Comerford et al. 2015, ApJ, 806, 219

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

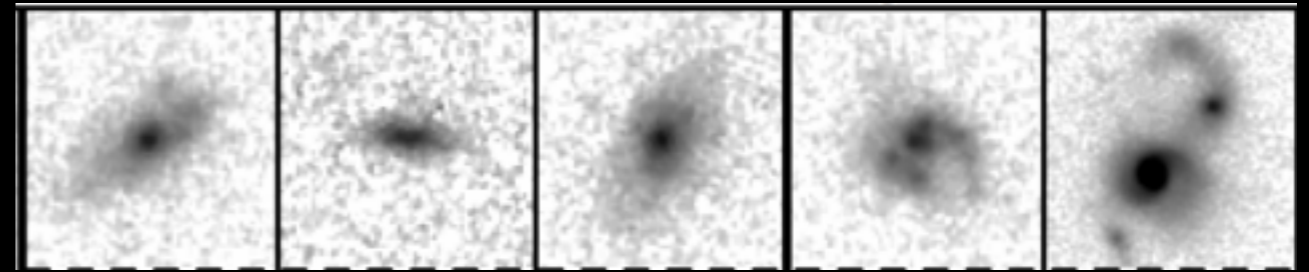


Farrell et al. 2009, Nat., 460, 73

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

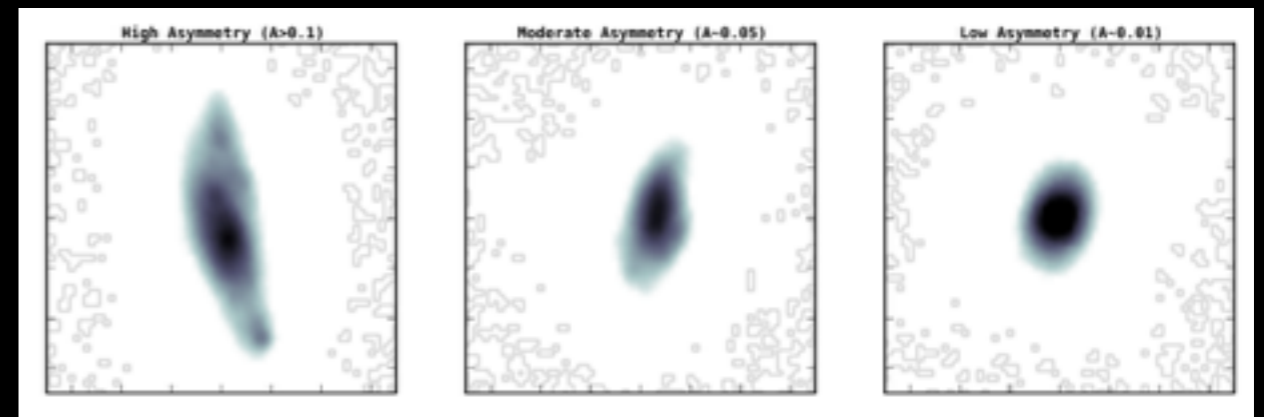
Techniques for building samples of galaxy mergers:

Visually (“by-eye”)



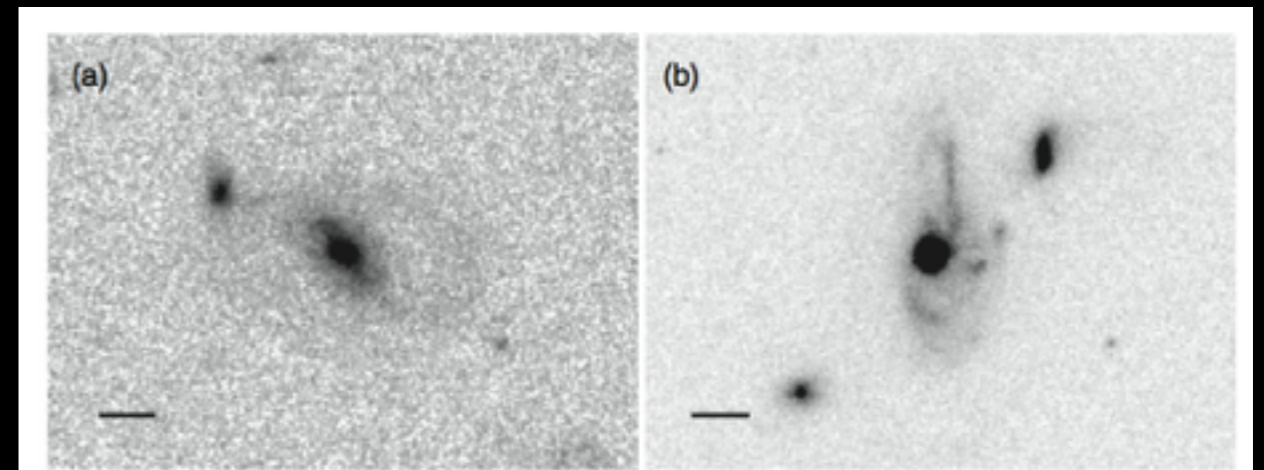
Kocevski et al. 2012, ApJ, 744, 148

Asymmetry



Villforth et al. 2014, MNRAS, 439, 3342

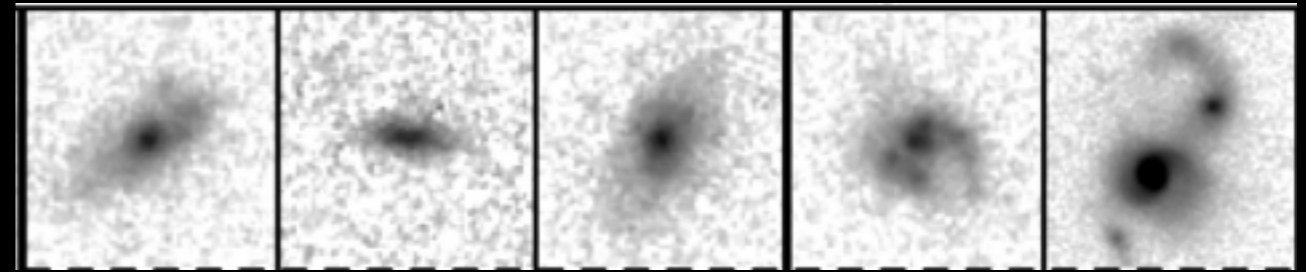
Pairs of distinct galaxies



Silverman et al. 2014, ApJ, 743, 2

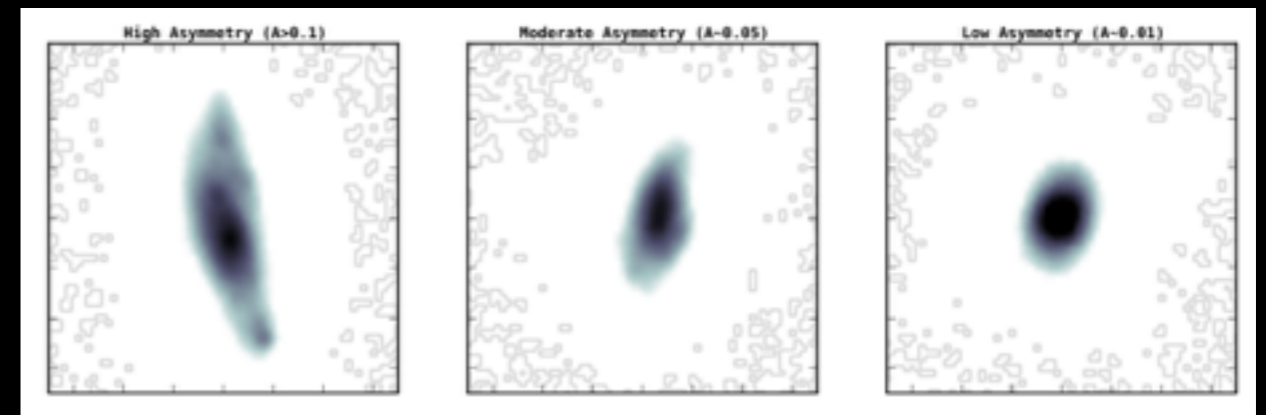
Techniques for building samples of galaxy mergers:

Visually (“by-eye”)



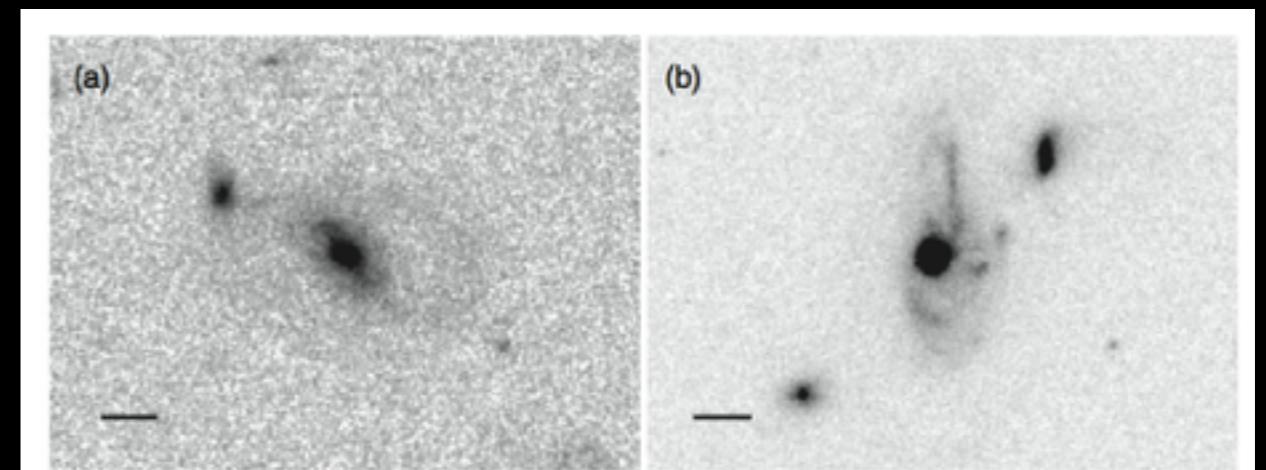
Kocevski et al. 2012, ApJ, 744, 148

Asymmetry



Villforth et al. 2014, MNRAS, 439, 3342

Pairs of distinct galaxies



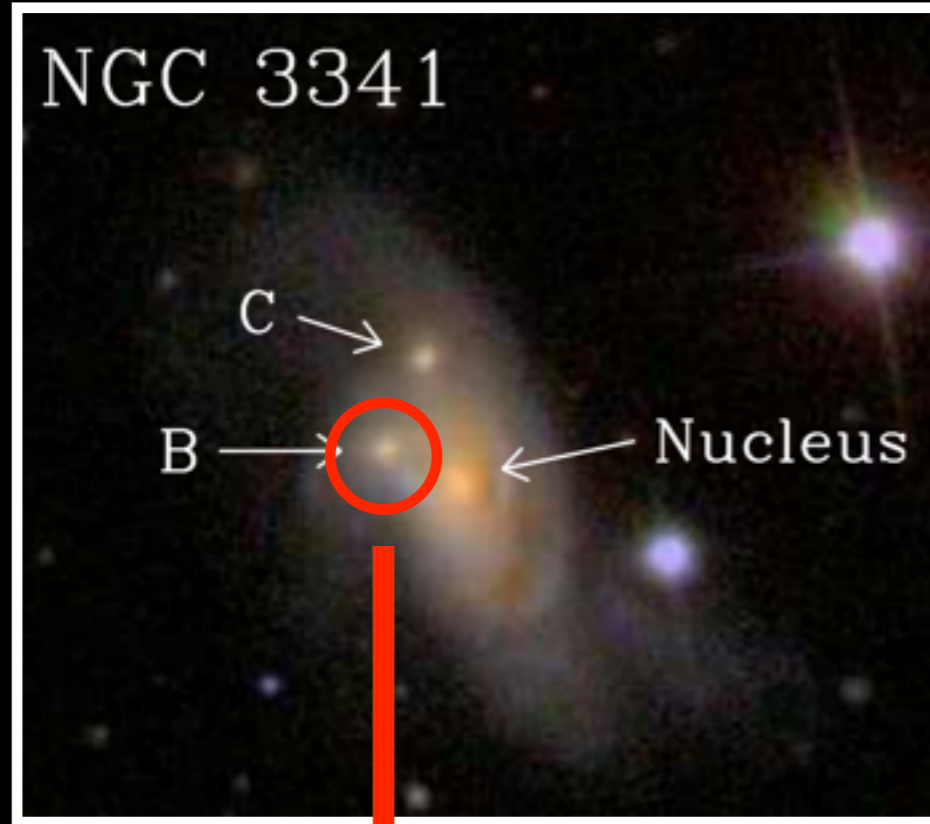
Silverman et al. 2014, ApJ, 743, 2

Spatially Offset AGN

Unambiguous galaxy mergers: Spatially Offset AGN

Optical Emission Lines

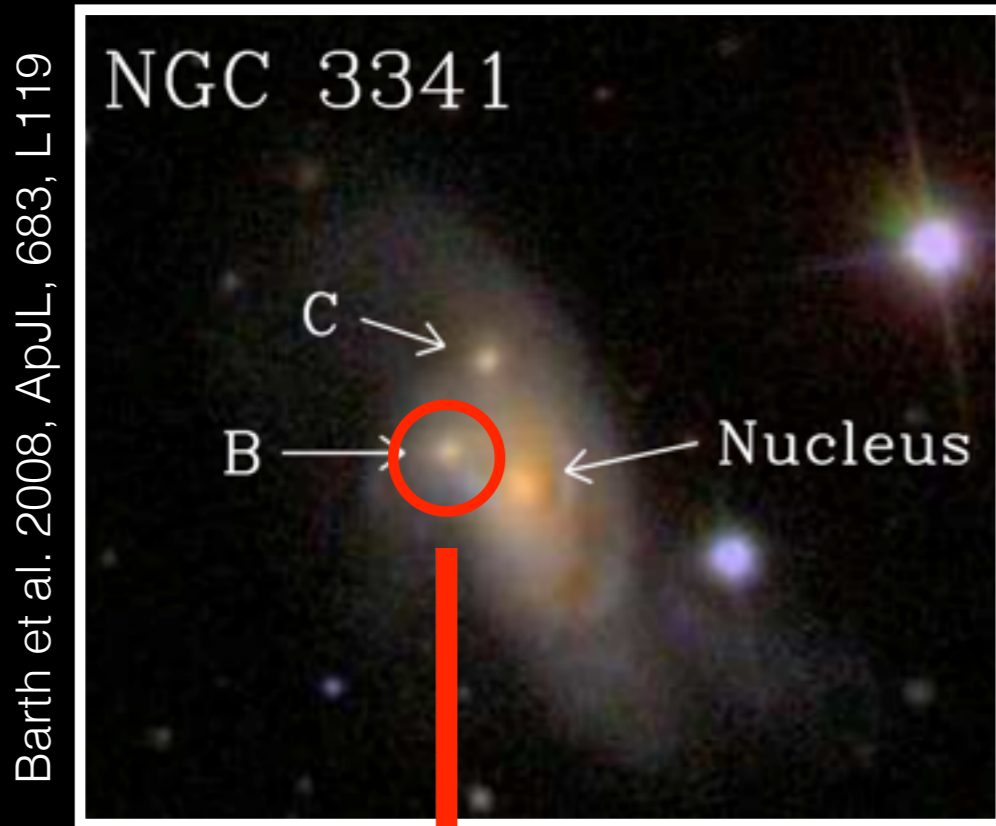
Barth et al. 2008, ApJL, 683, L119



SDSS Seyfert 2 Spectrum

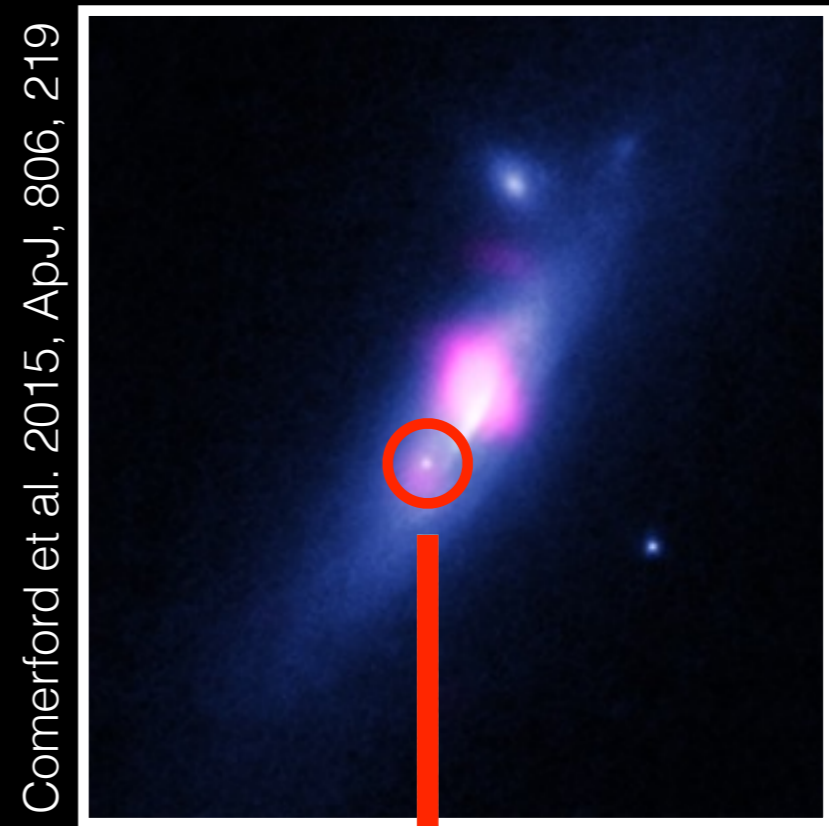
Unambiguous galaxy mergers: Spatially Offset AGN

Optical Emission Lines



SDSS Seyfert 2 Spectrum

X-ray Spectra



Chandra X-ray AGN

Select AGN from SDSS using BPT diagram at $z < 0.21$:

20,098

Crossmatch with footprint of *Chandra* archives:

2,292

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

150



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:

20,098



2,292

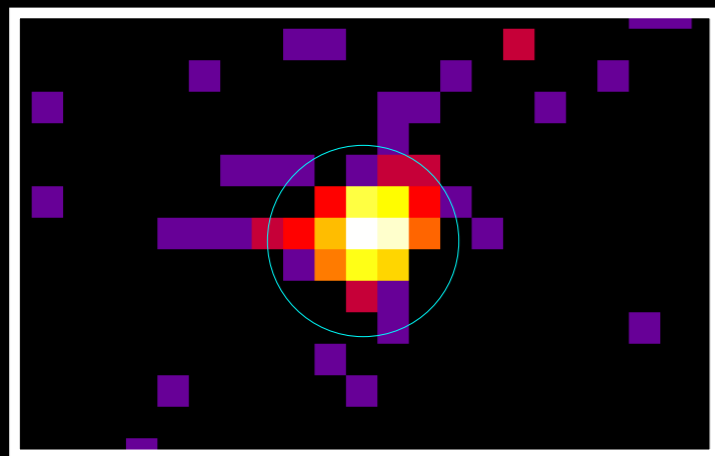


150



48

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:

20,098



2,292



150

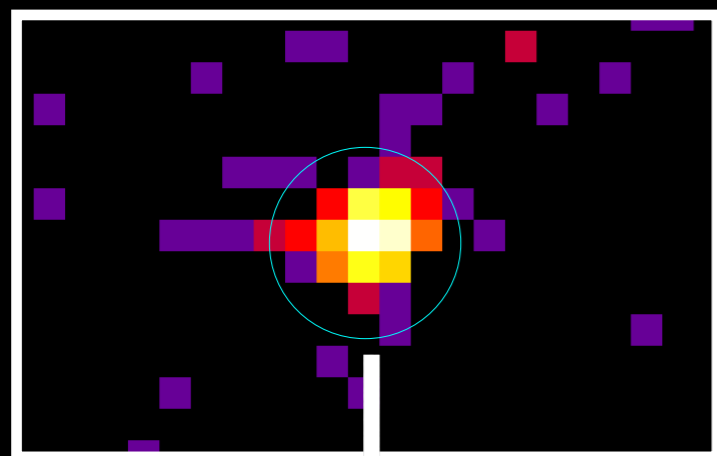


48



9

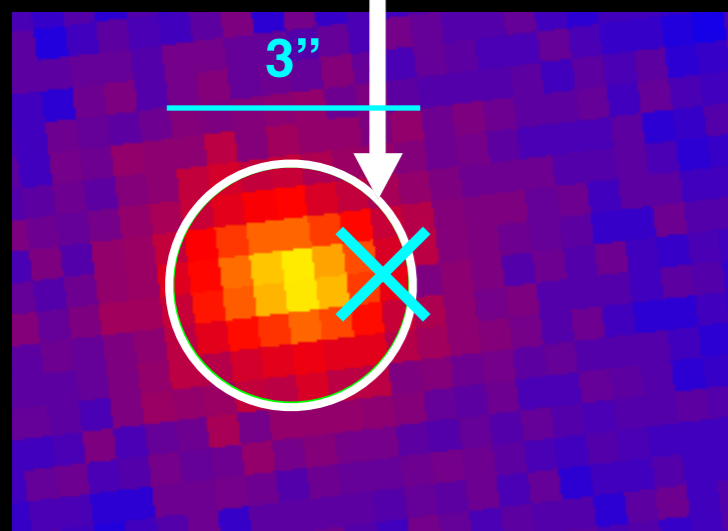
Chandra, 2-10 keV



Hard X-ray source:

- within SDSS fiber
- $L_{X,2-10} > 10^{42} \text{ erg s}^{-1}$ (AGN)

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



SDSS z-band

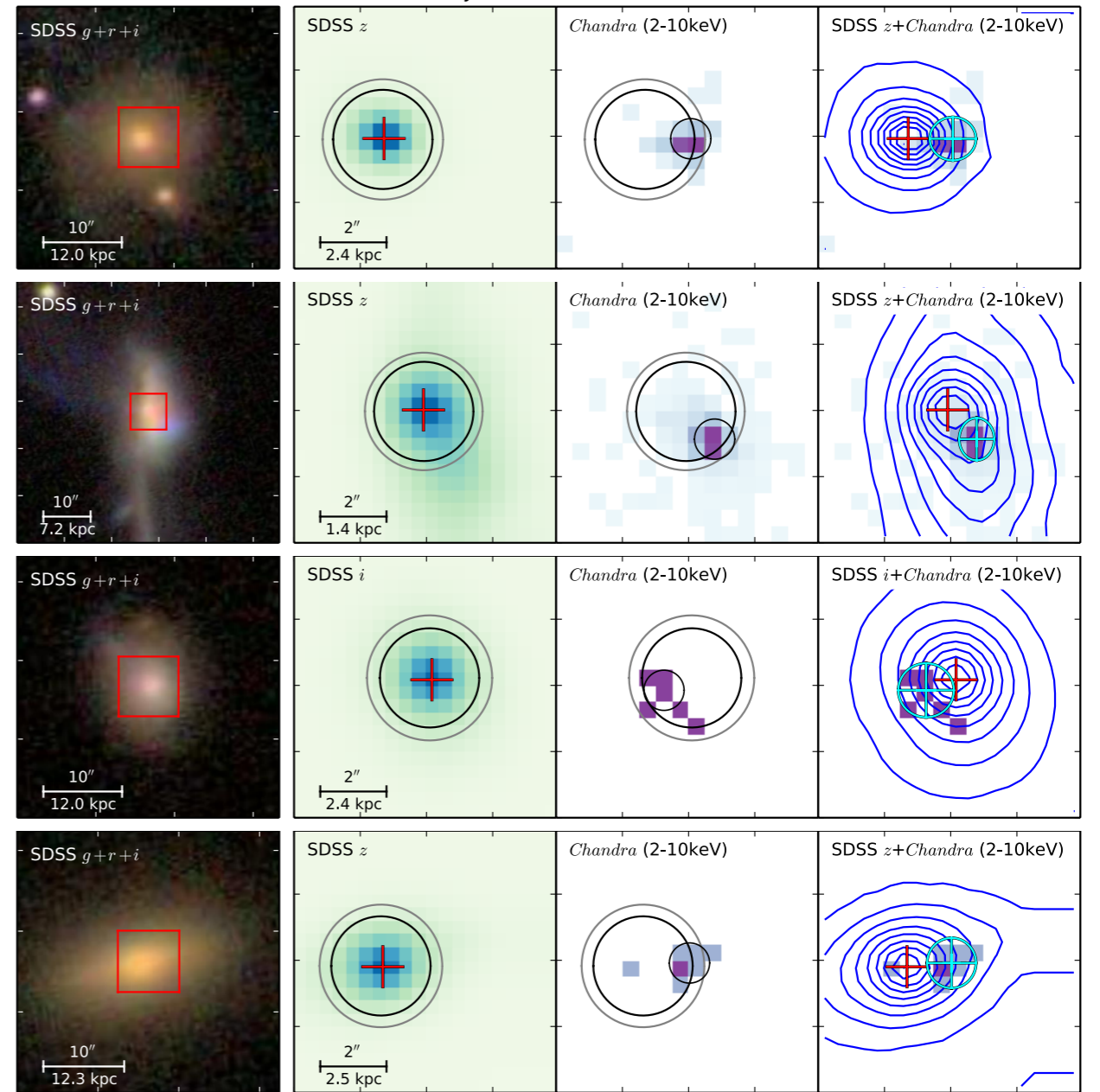
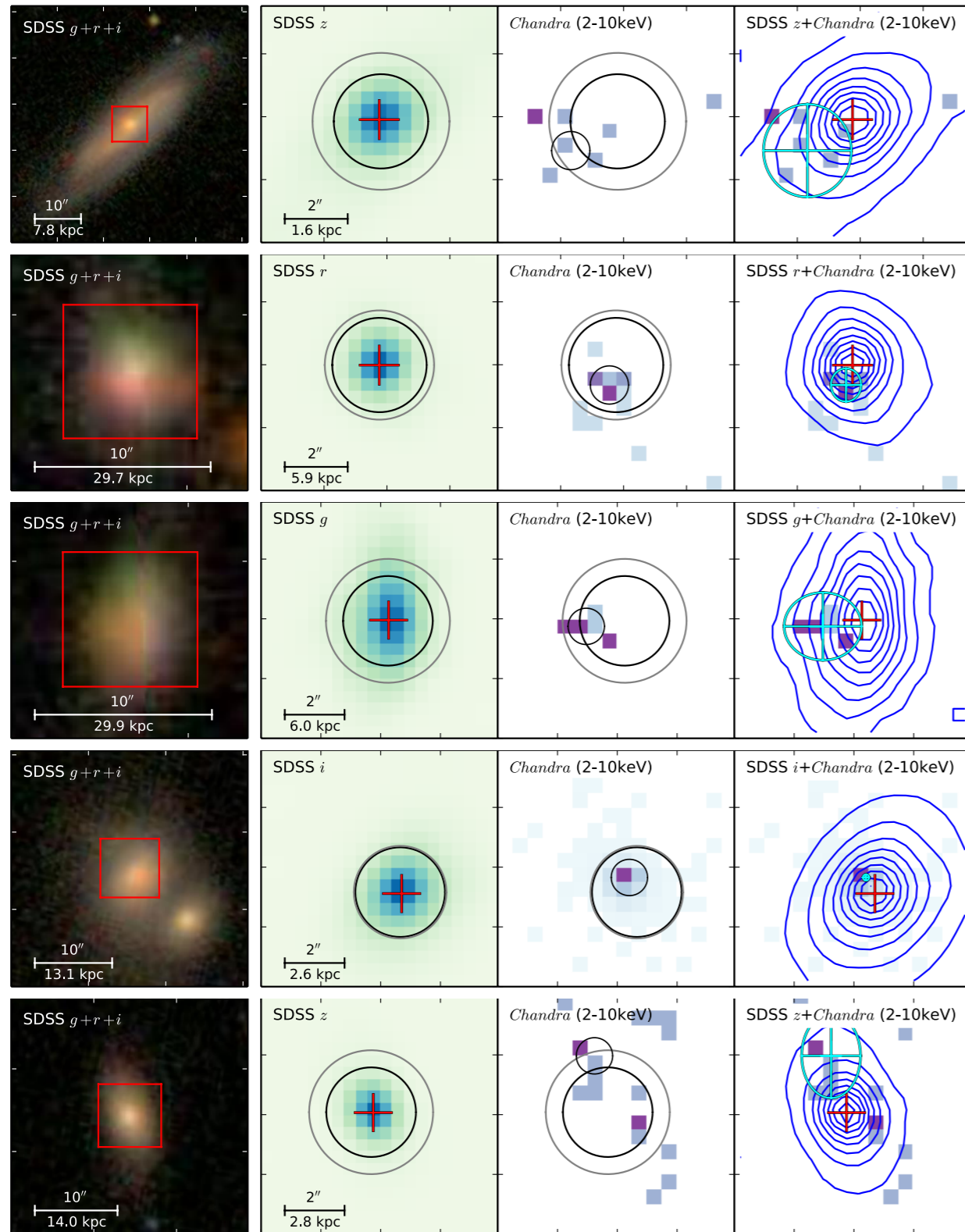
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

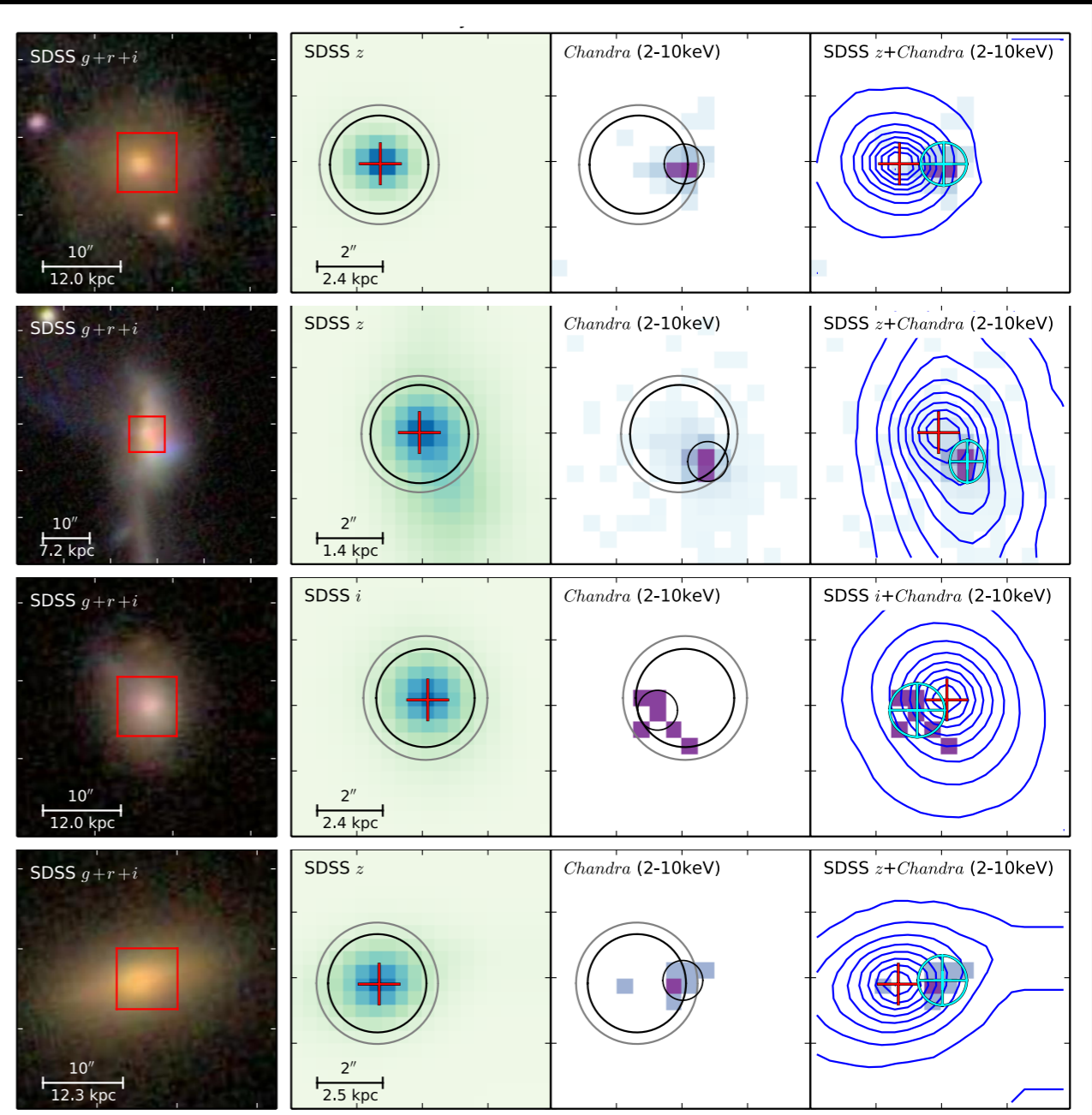
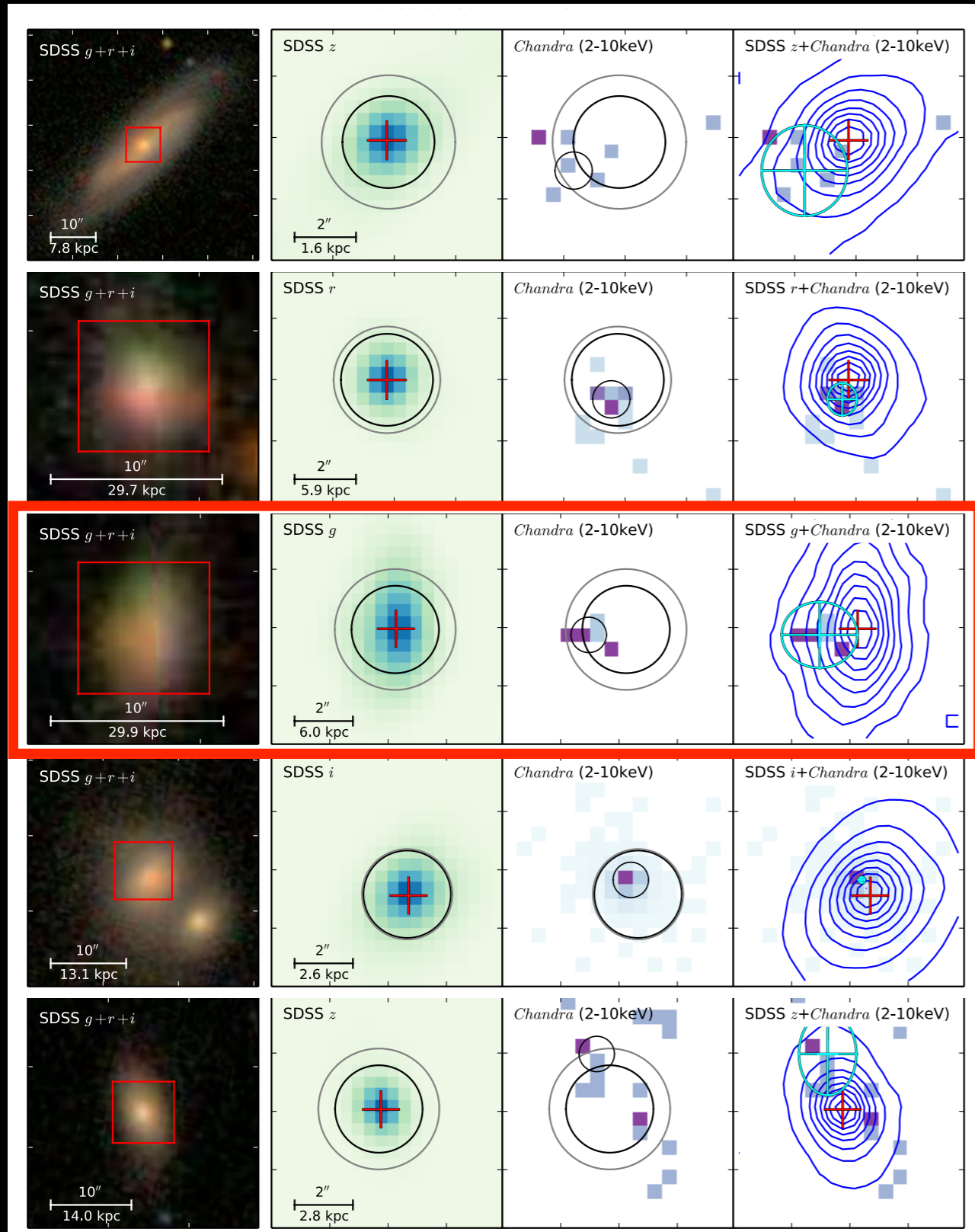
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

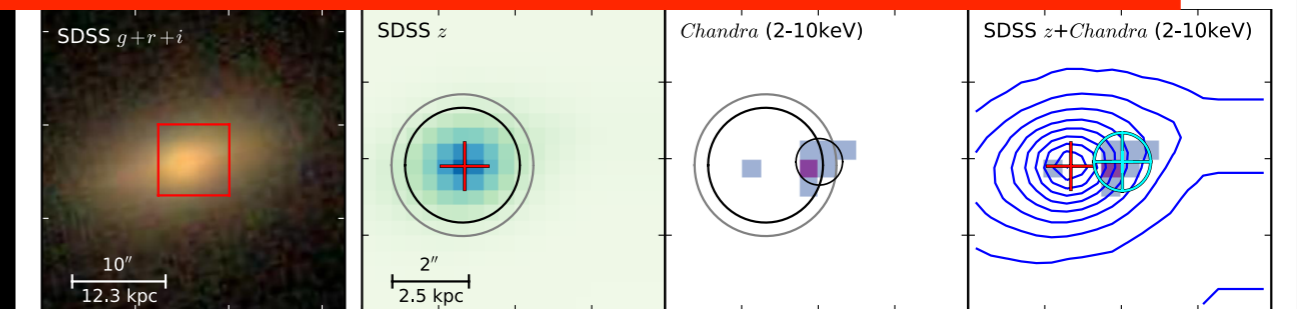
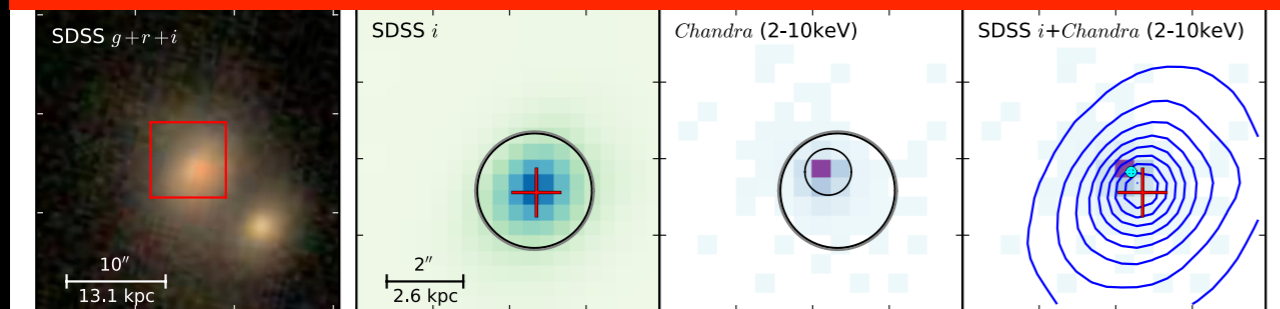
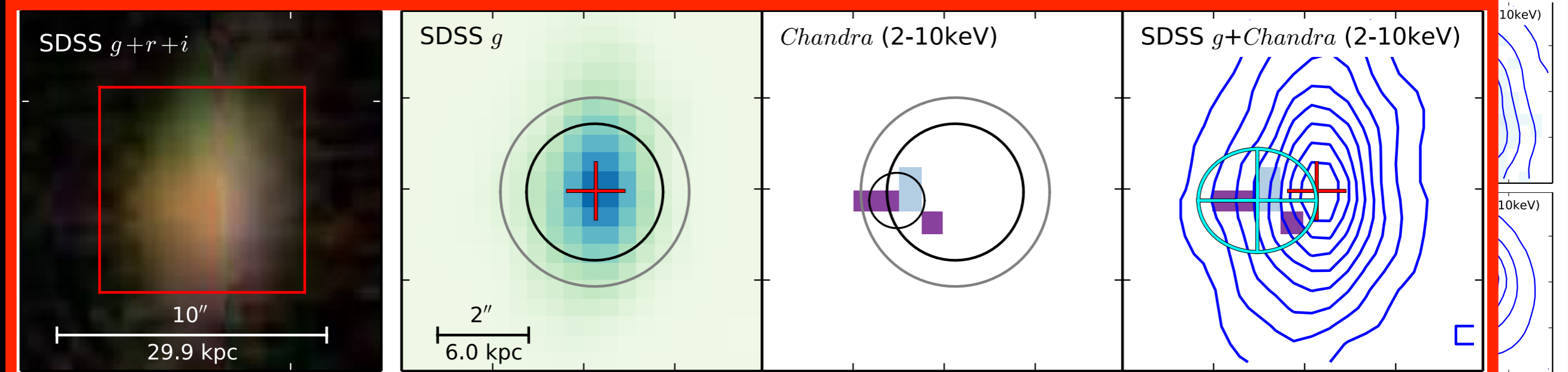
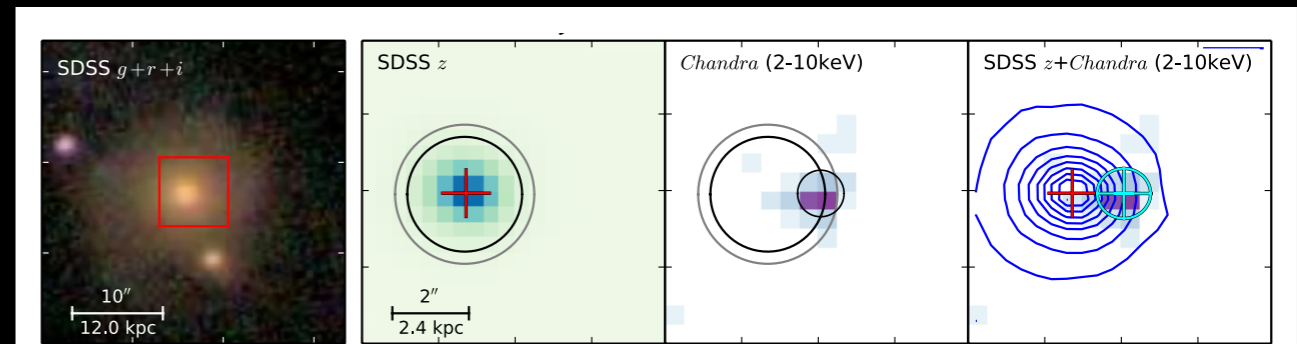
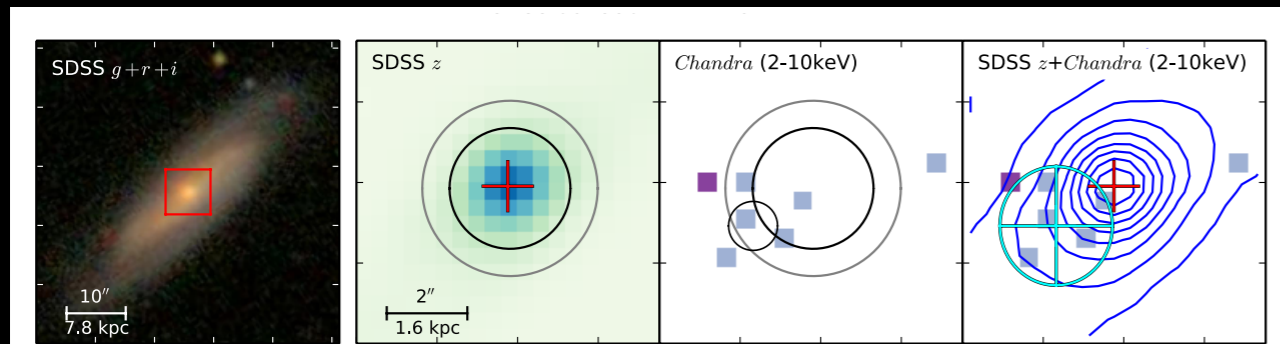
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

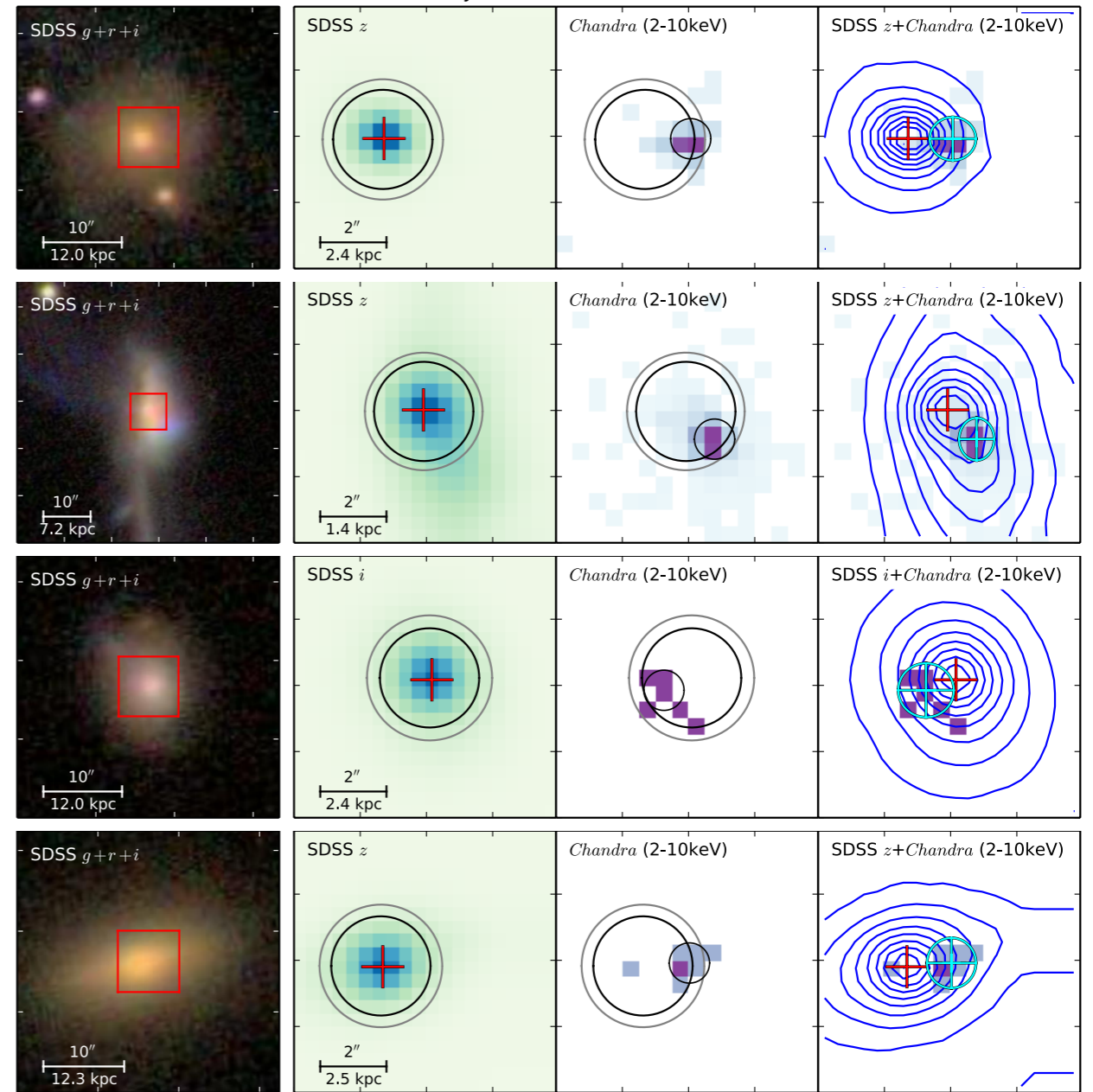
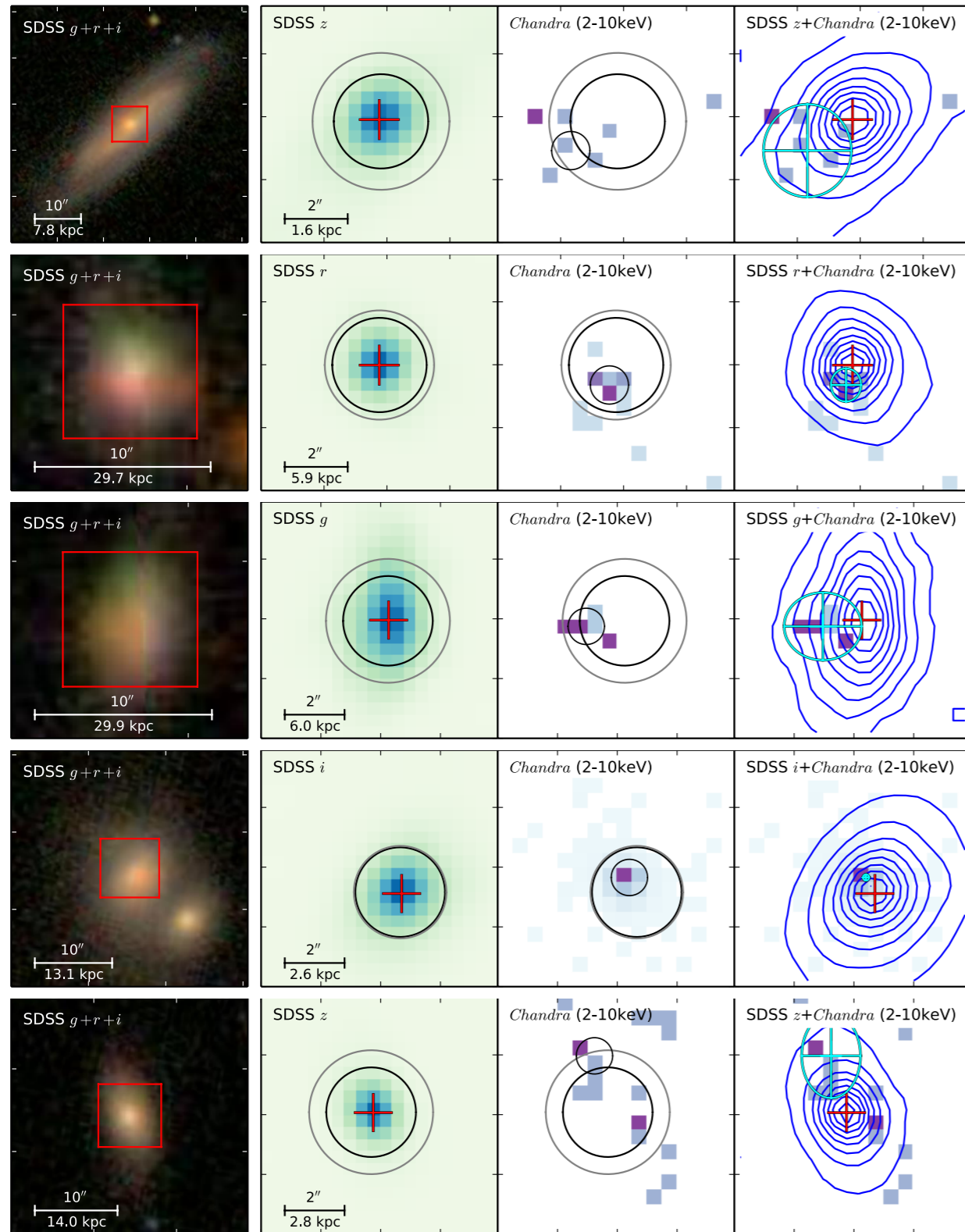
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

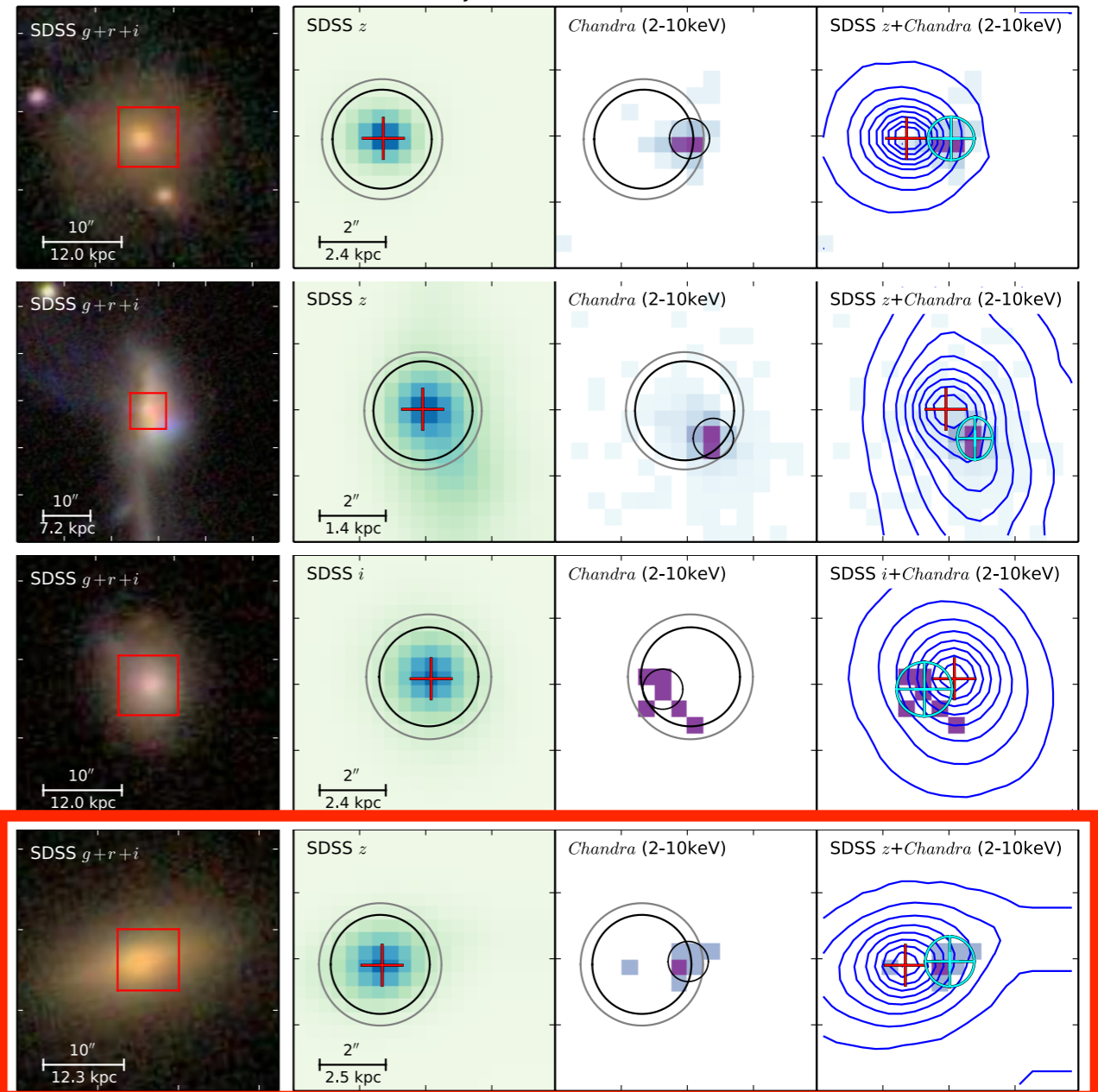
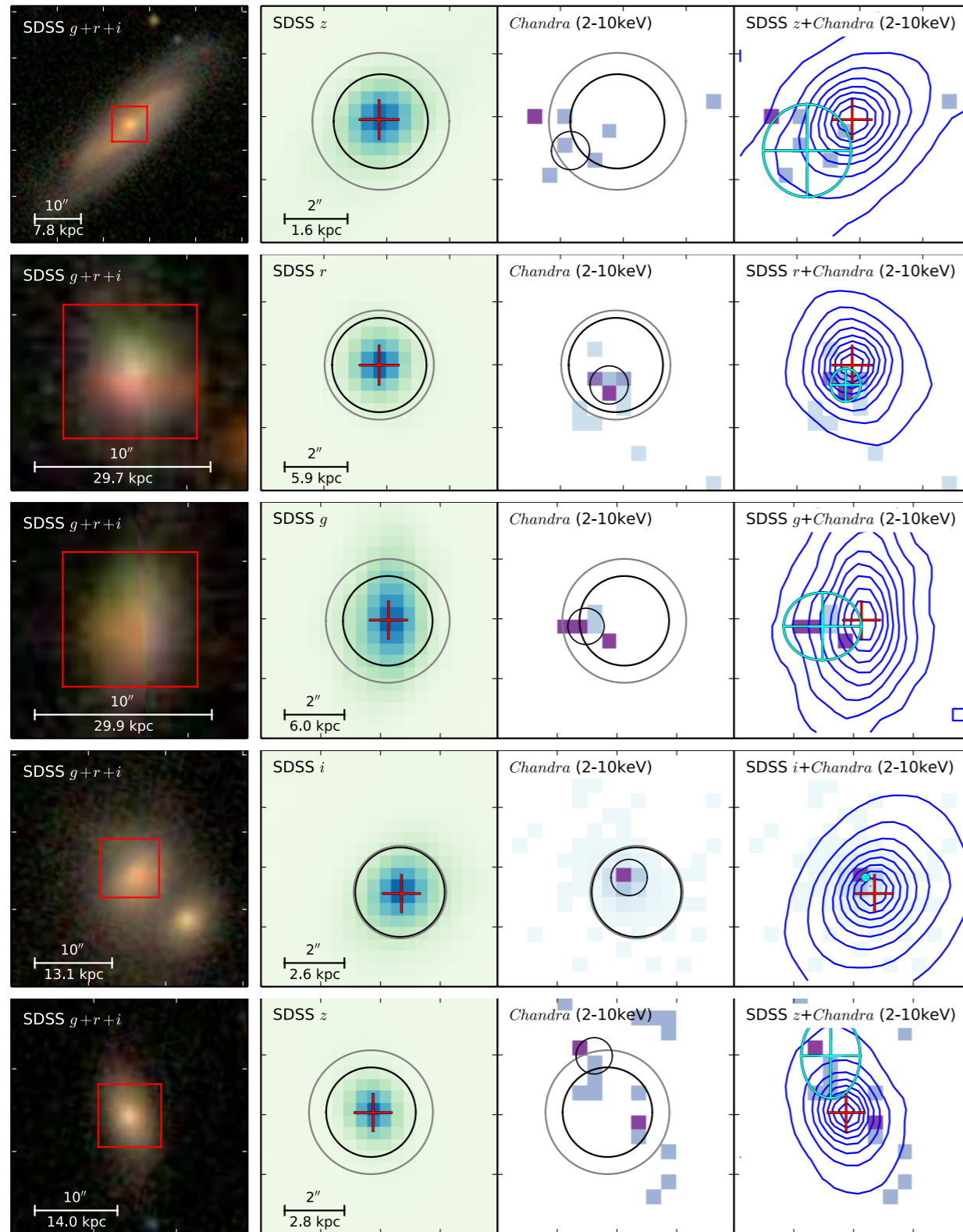
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

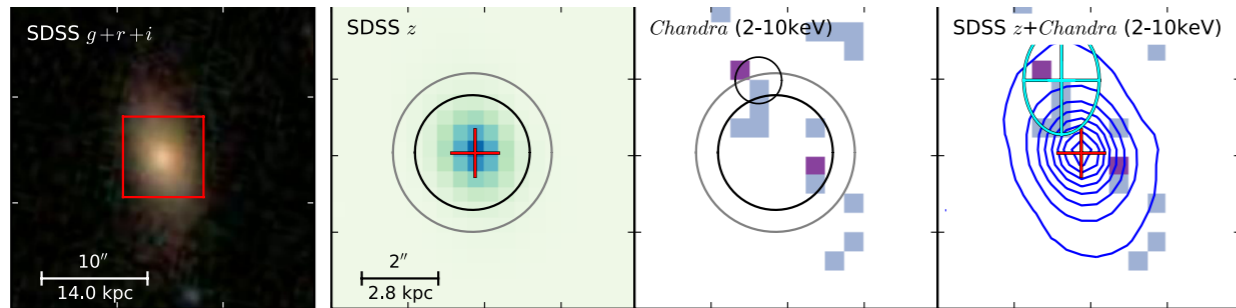
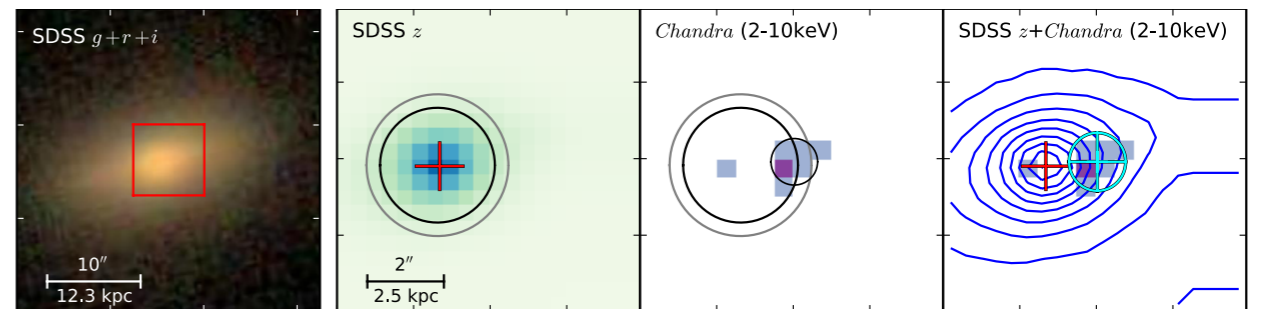
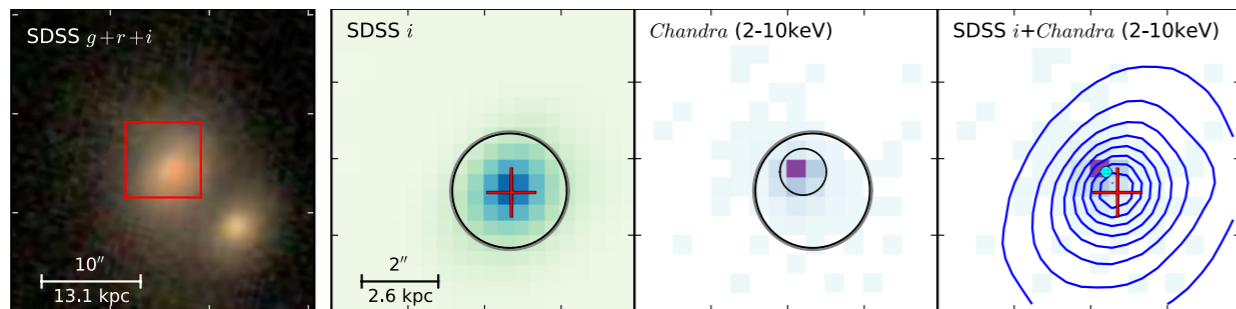
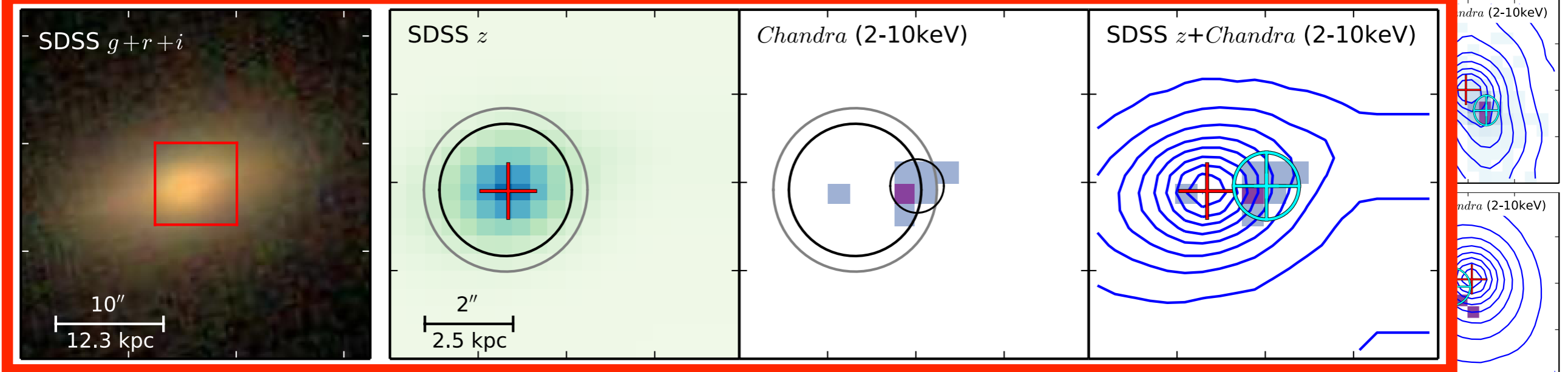
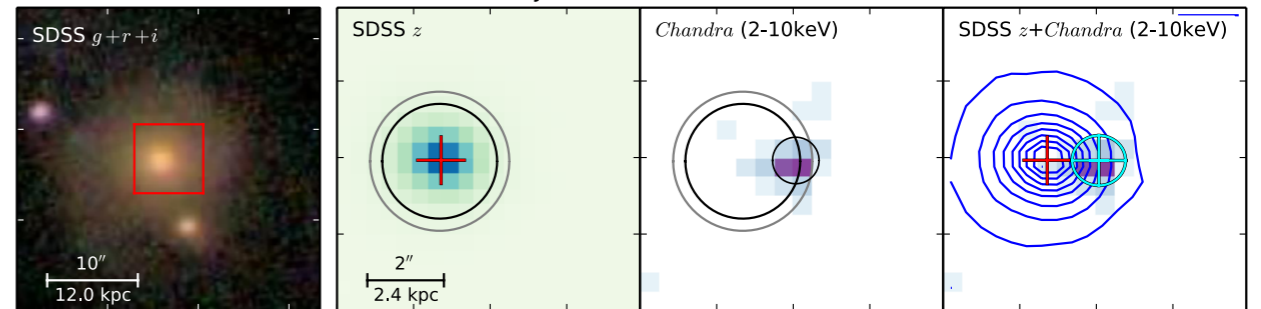
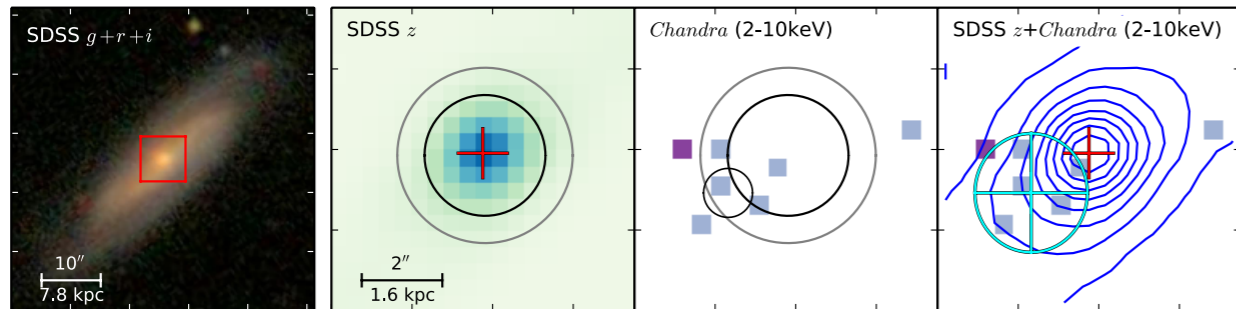
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS z

Chandra (2-10 keV)

SDSS
+2-10 keV



SDSS $g+r+i$ composite SDSS 2-10 keV SDSS +2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

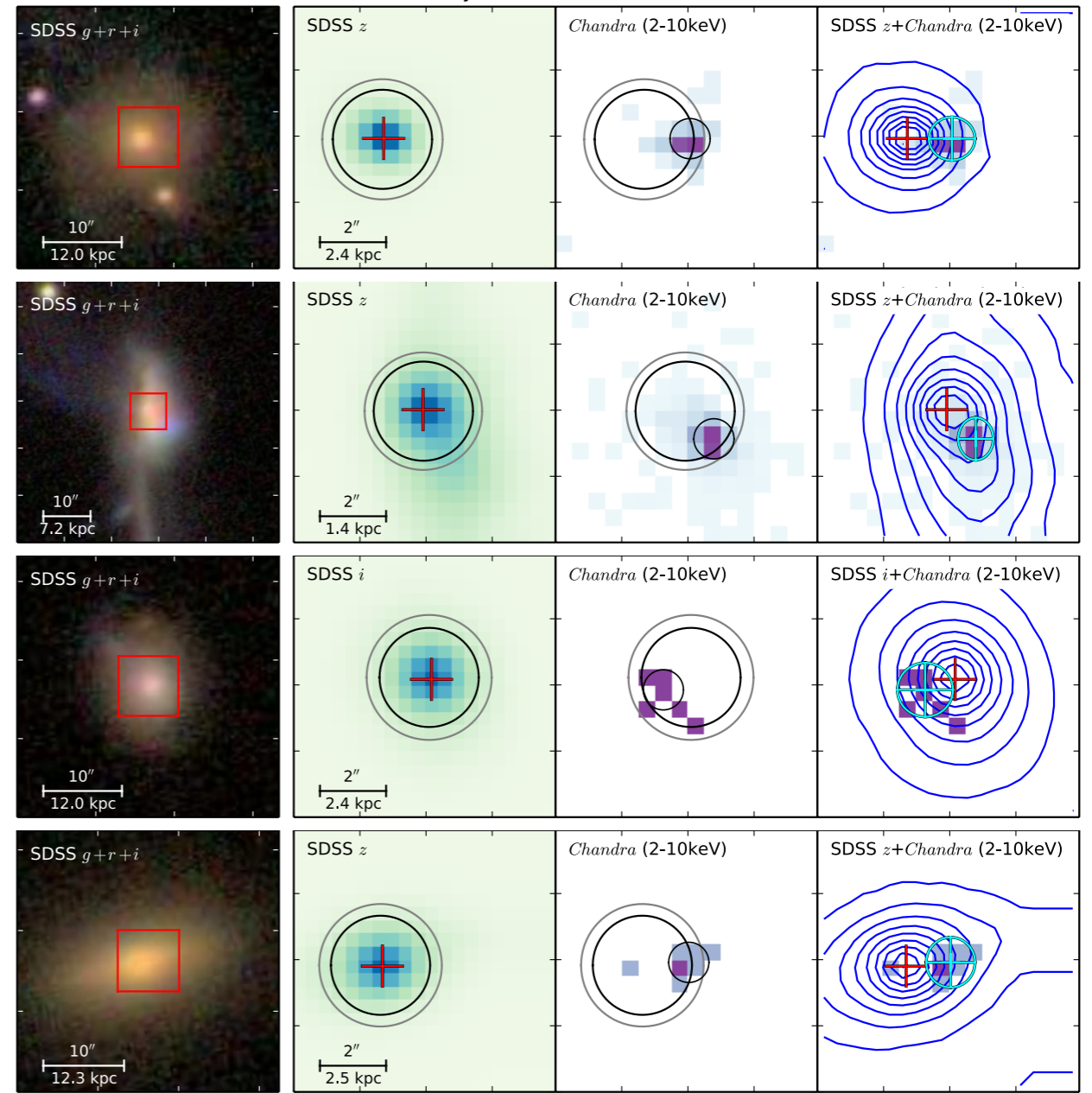
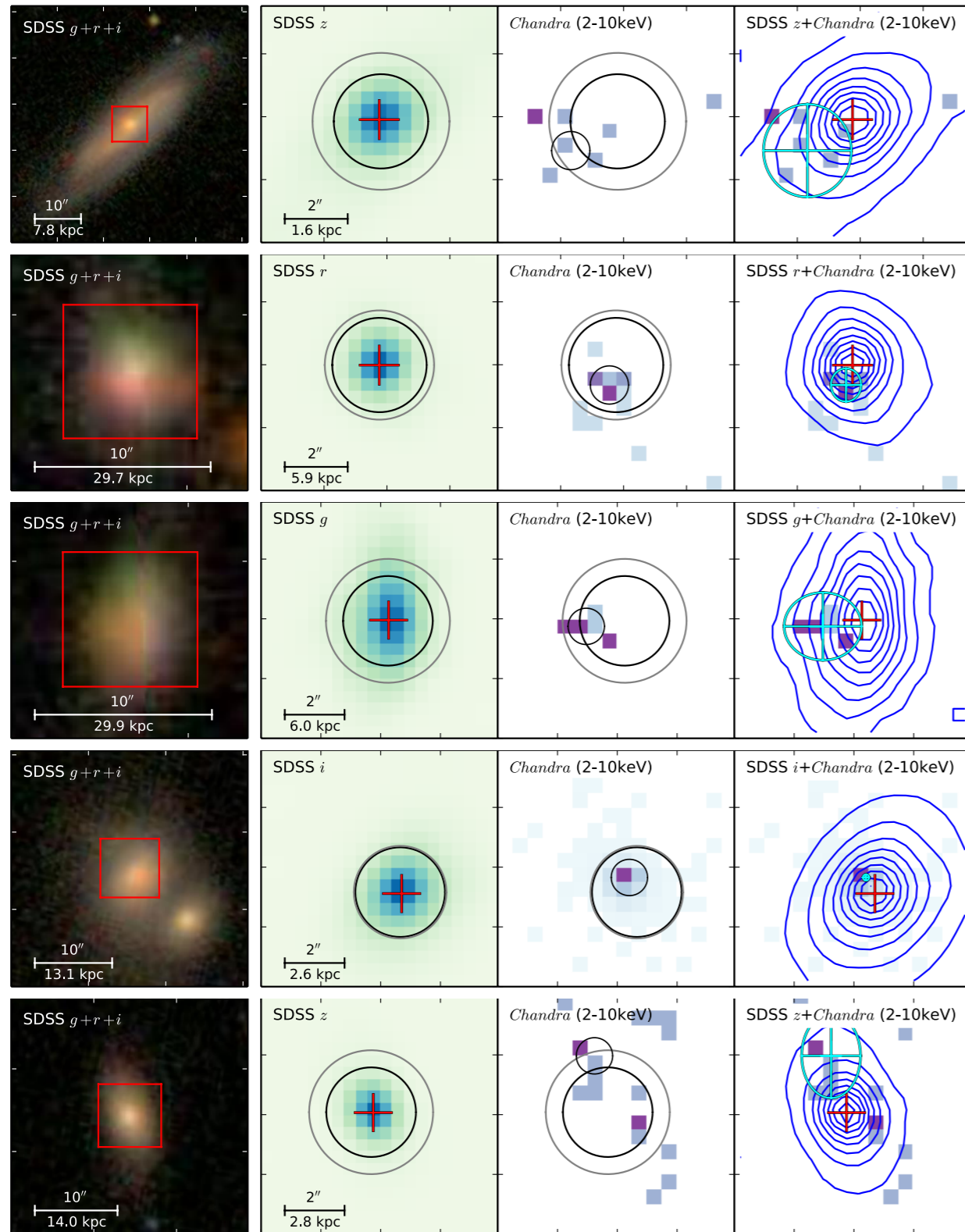
Spatially Offset AGN

SDSS $g+r+i$
composite

SDSS

2-10 keV

SDSS
+2-10 keV



SDSS $g+r+i$
composite

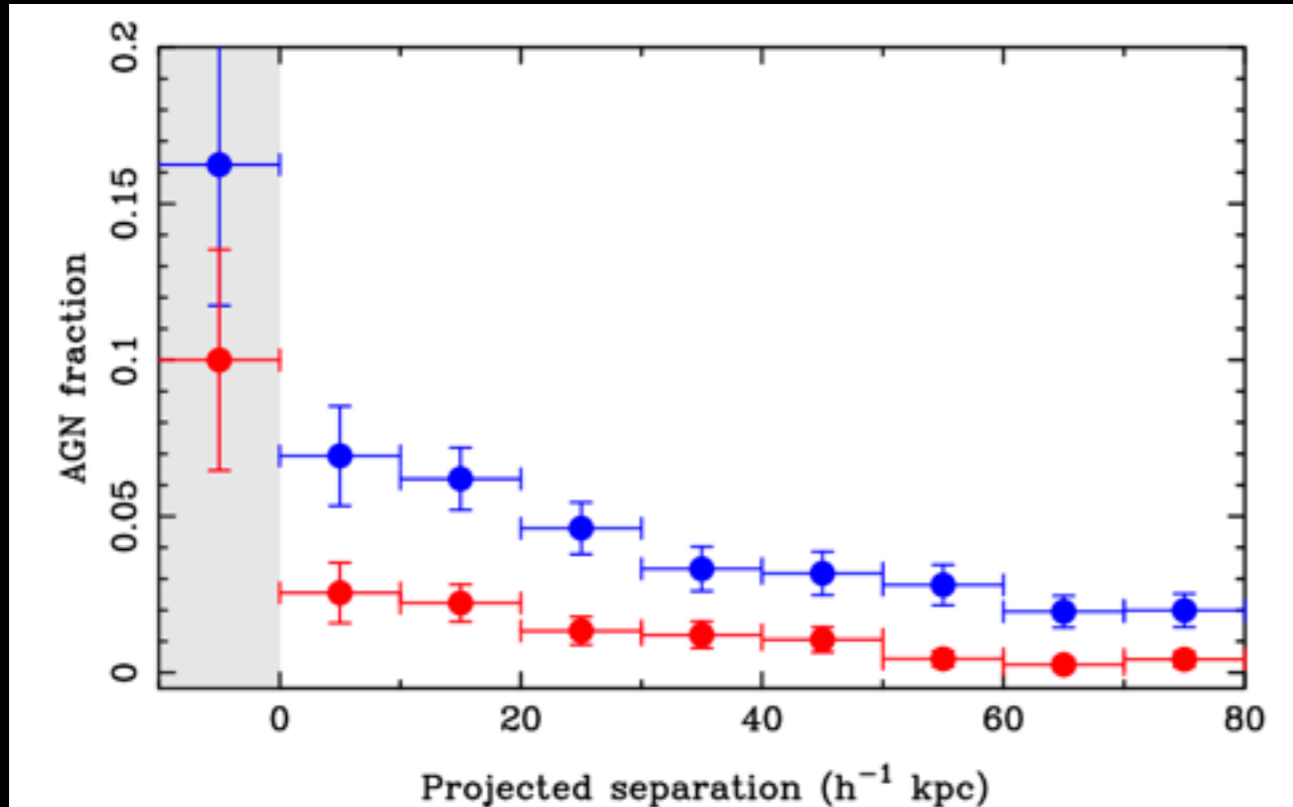
SDSS

2-10 keV

SDSS
+2-10 keV

Barrows et al. 2016, arXiv: 1606.01253
ApJ Accepted

Chandra Science: Galaxy Merger Stage

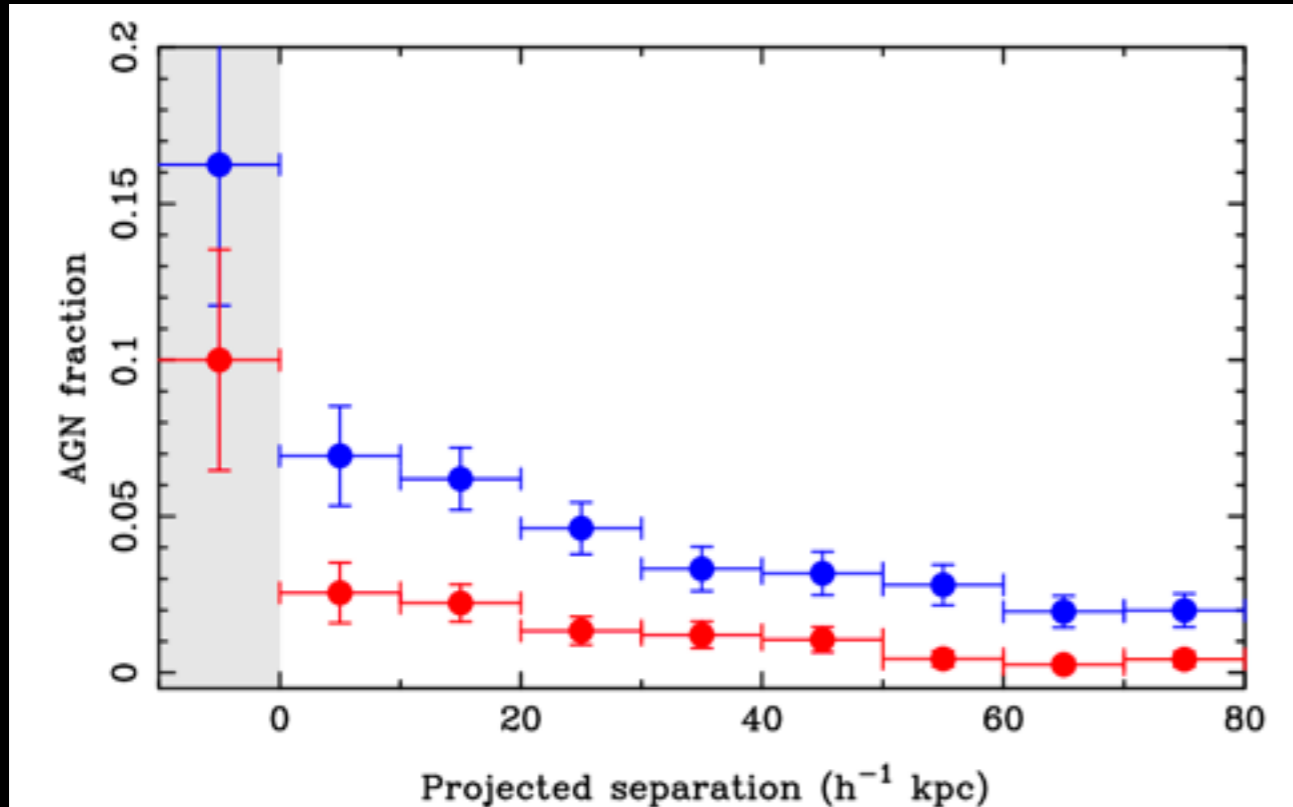


AGN merger fraction inversely correlated with separation

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

Satyapal et al. 2014, MNRAS, 441, 1297

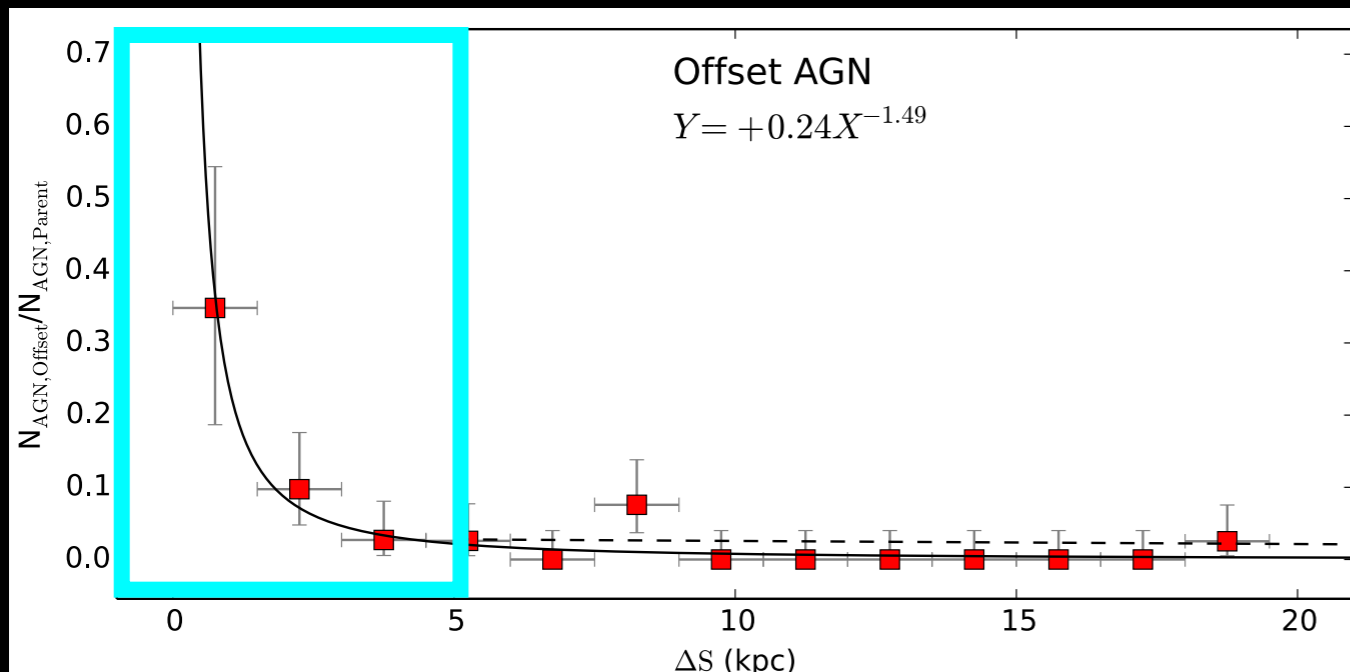
Chandra Science: Galaxy Merger Stage



AGN merger fraction inversely correlated with separation

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

Satyapal et al. 2014, MNRAS, 441, 1297

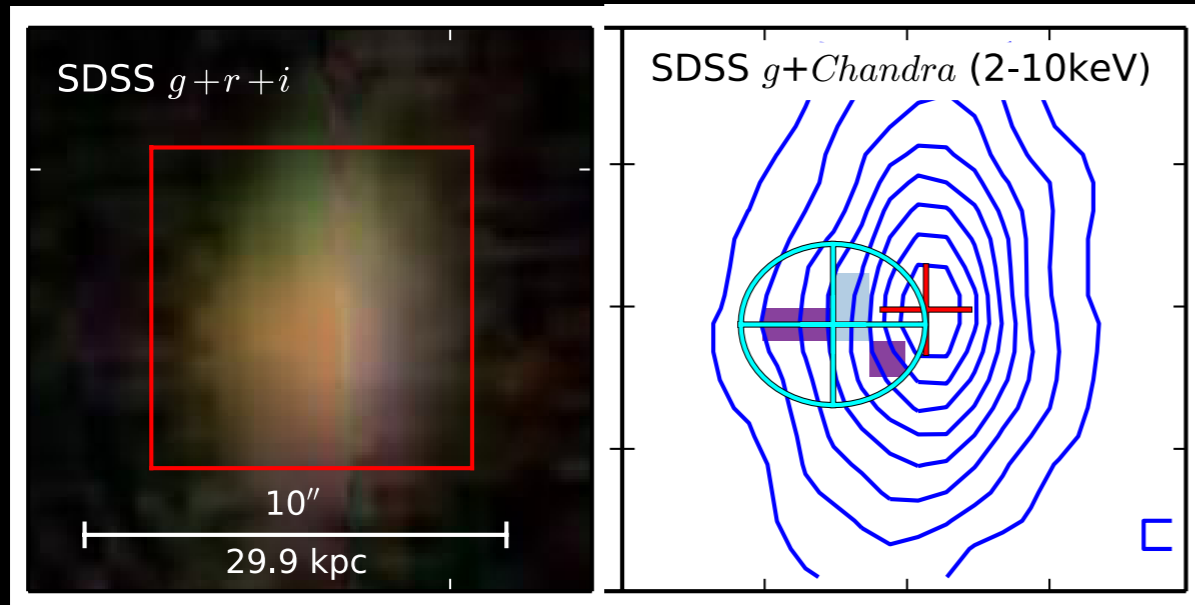


Mergers selected as spatially offset AGN (<0.8 kpc)

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

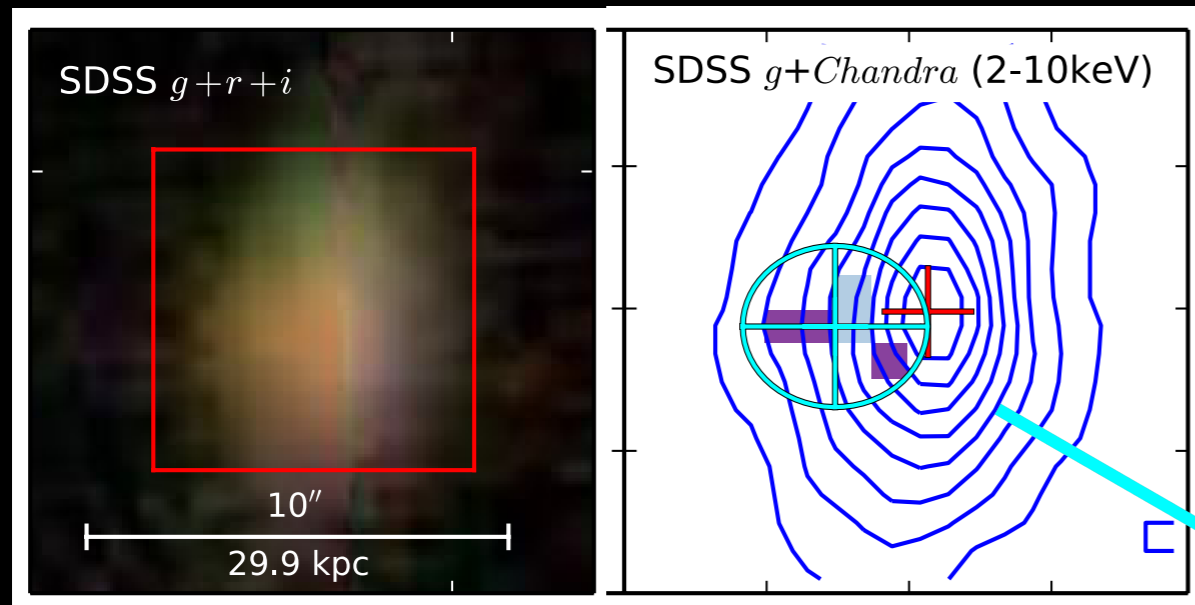
Barrows et al. *in prep*

Chandra Science: Merger Mass Ratio



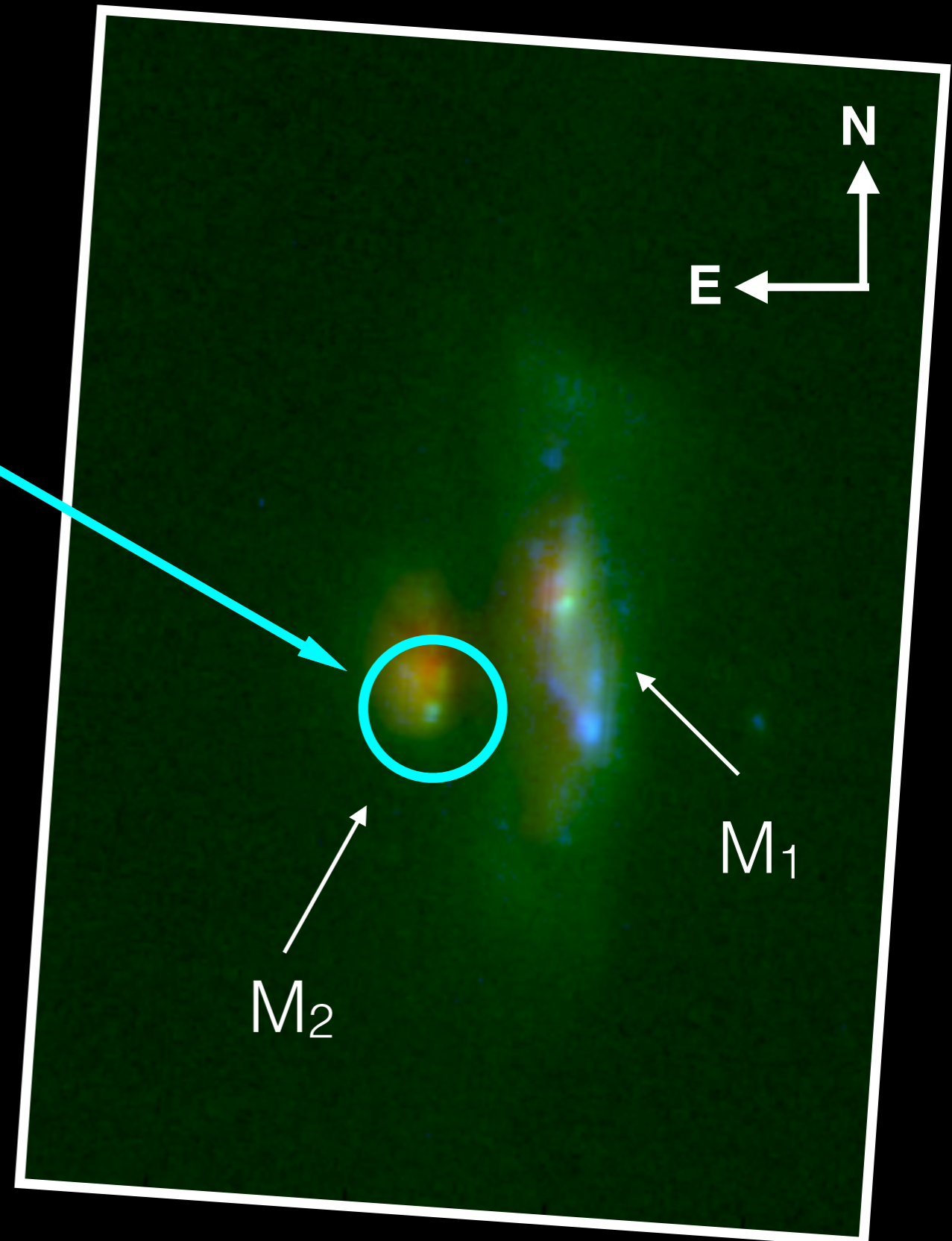
Are offset AGN preferentially found in major or minor mergers?

Chandra Science: Merger Mass Ratio



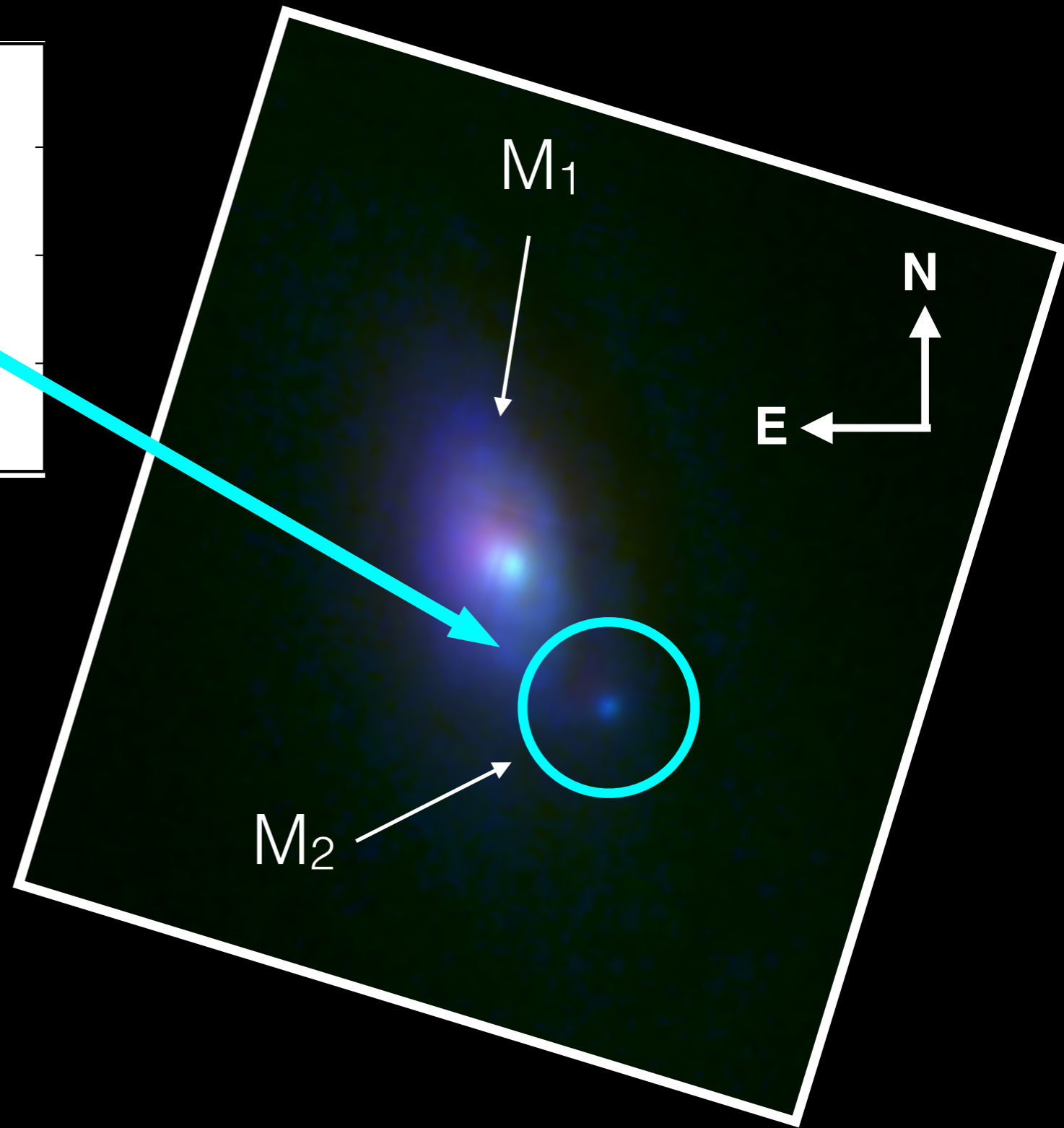
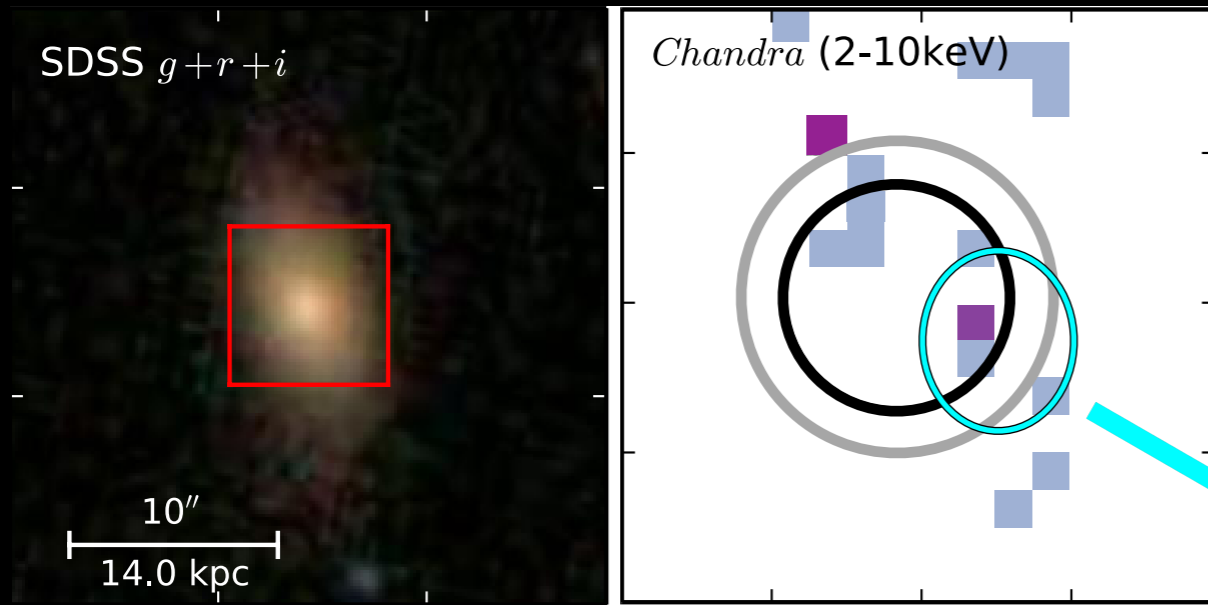
Are offset AGN preferentially found in major or minor mergers?

$M_1/M_2=3.07$ (major-ish)



HST/WFC3 F160W+F814W+F438W

Chandra Science: Merger Mass Ratio



$M_1/M_2=70$ (minor)

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*)