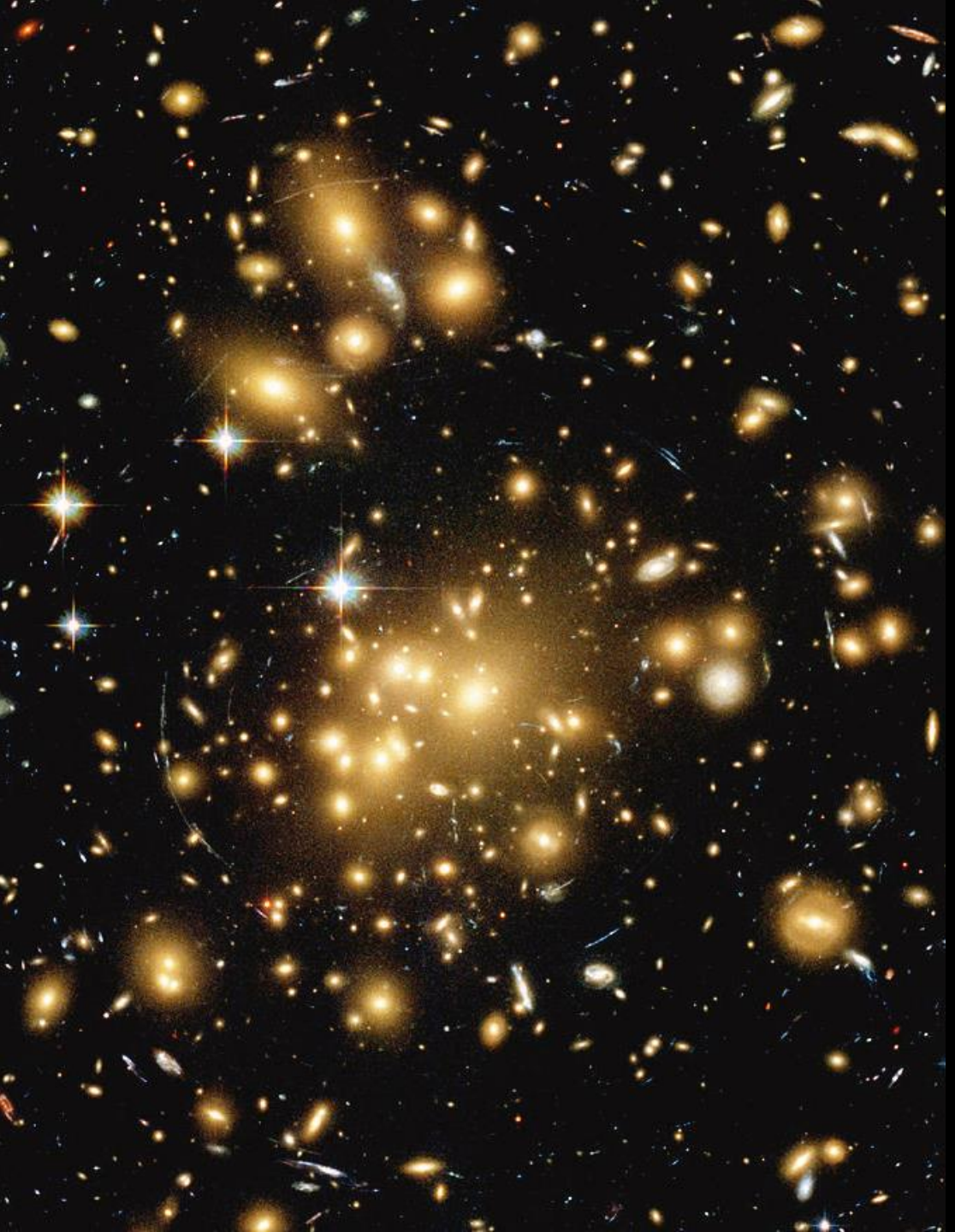


# AGN activity in massive galaxy clusters

**Emil Noordeh,** Stanford University

Allen, Brandt, **Canning**, **Ehlert**, **King**, von der Linden, Luo, Mantz, Morris, **Willis**, Xue + SPT

# AGN in the Cluster Environment

**What role does environment play in SMBH activity?**

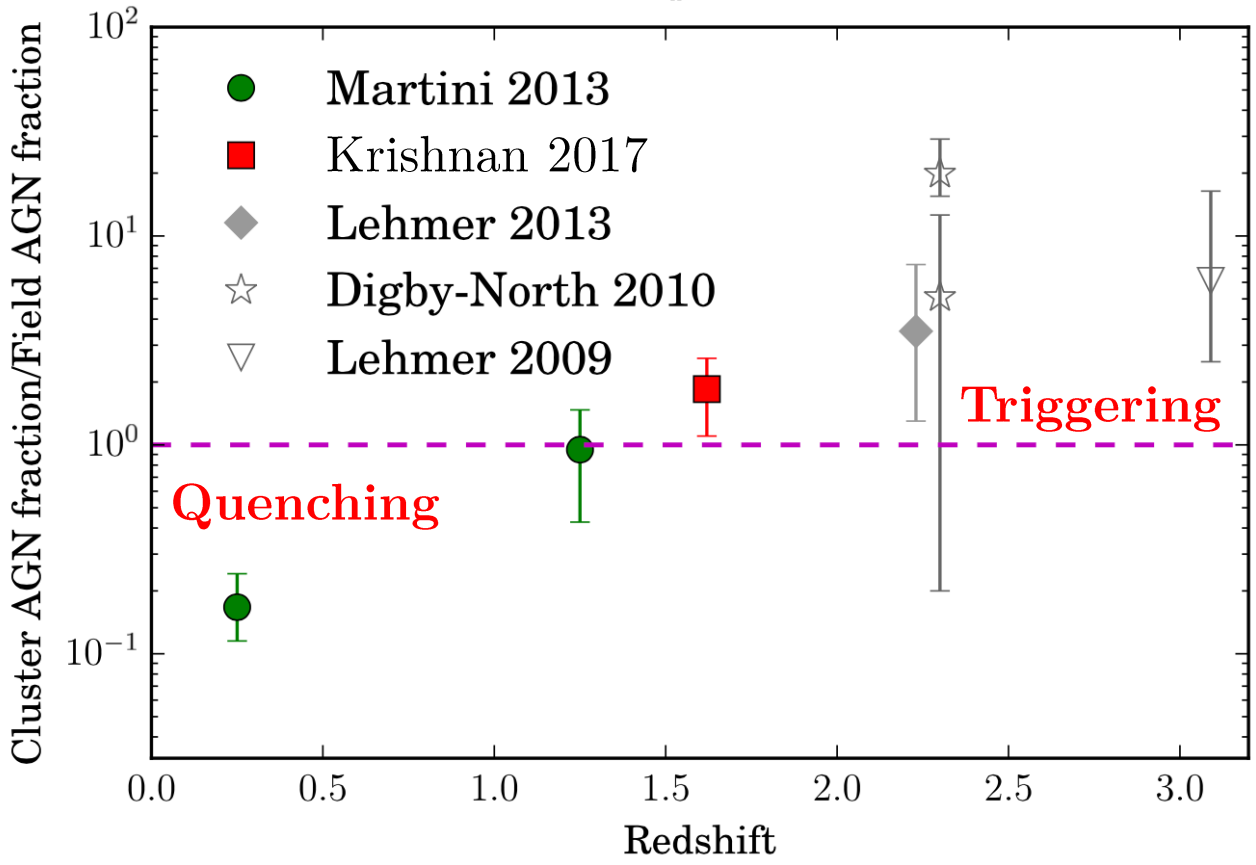
Galaxy clusters provide the ideal laboratory to explore

**Environmental effects:** Ram pressure stripping, starvation, evaporation, tidal effects, mergers and interactions

Evidence for quenching of **radiatively efficient** AGN at low-$z$ & triggering at high-$z$, but **correlation ≠ causation**
- Cluster mass-redshift relationship
- Different stellar mass & SFRs
- High-$z$ protoclusters

Goal is to disentangle dependence of AGN activity on host cluster properties from host galaxy properties
- **Focus on AGN activity vs. cluster mass**

Adapted from Krishnan+2017

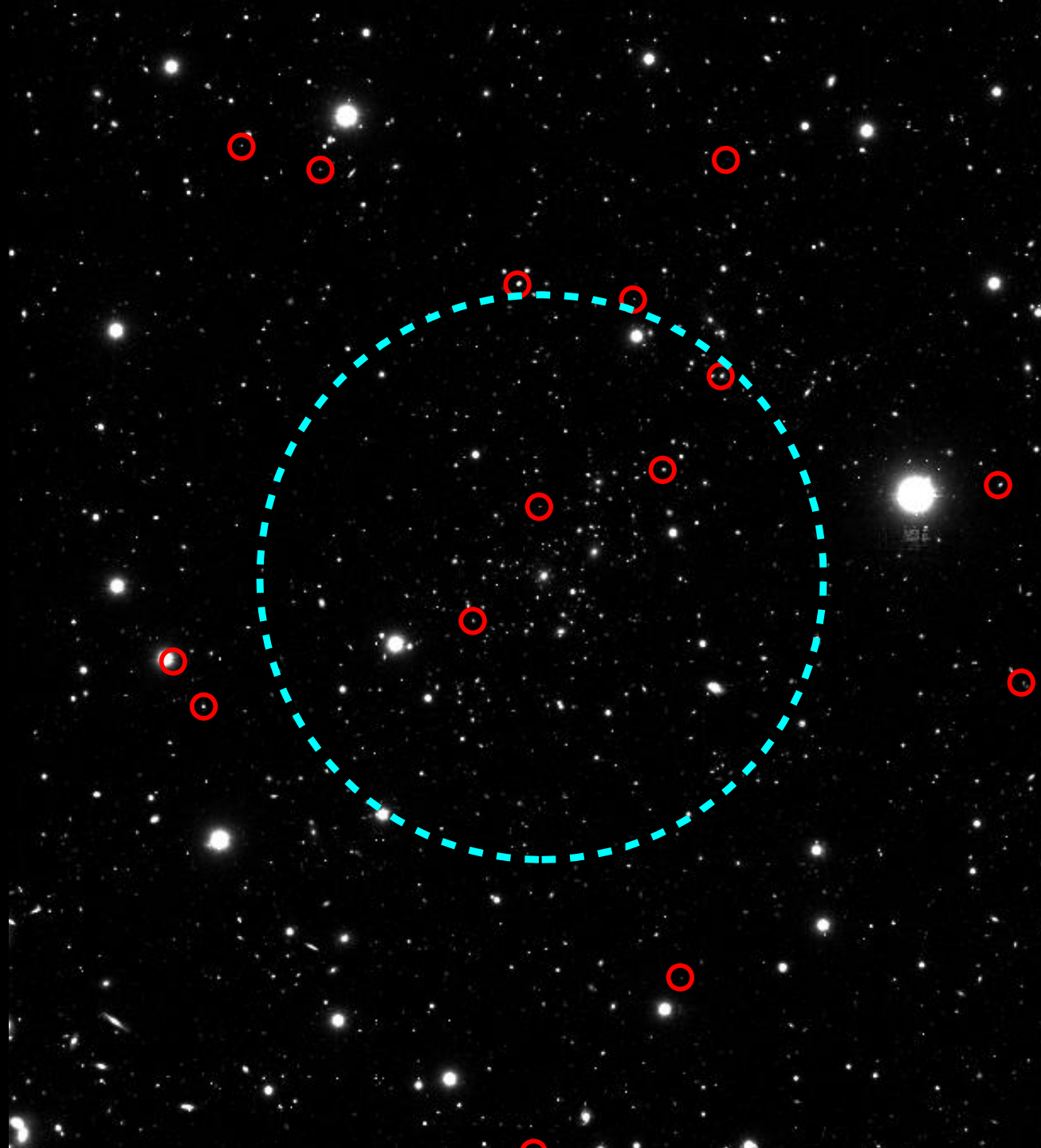


# Outline

1. Cluster X-ray AGN at $z \sim 0.4$
2. Cluster AGN Topography Survey (CATS)
   - $z \sim 0$ to $z \sim 1.5$
3. First glimpse of AGN activity in a virialized cluster at $z = 2$

# X-ray AGN in $z \sim 0.4$ galaxy clusters

**Spectroscopic Study**
**7 massive clusters**



# Cluster X-ray AGN at $z \sim 0.4$

**7 galaxy clusters**
**$z = 0.35$ - $0.45$**

Diverse cluster masses
- Isolate mass dependence

400 ks of archival *Chandra* data

Robust measures of cluster masses, radii, centroids

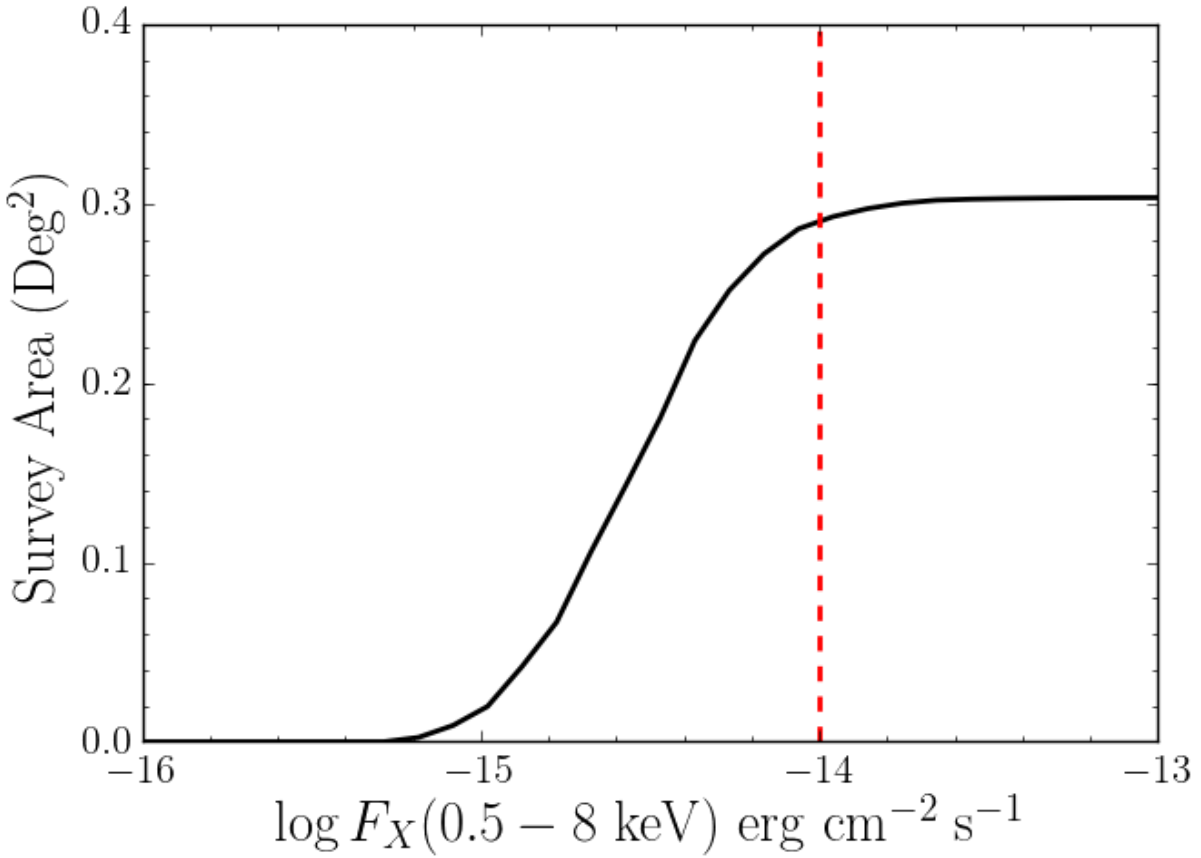
Rest frame luminosity limit

$L_X(0.5-8\ \mathrm{keV}) > 10^{43}\ \mathrm{erg\ s^{-1}}$

Pure AGN sample, no X-ray point source contamination

Highly complete down to

$F_X(0.5-8\ \mathrm{keV}) > 10^{-14}\ \mathrm{erg\ cm^{-2}\ s^{-1}}$

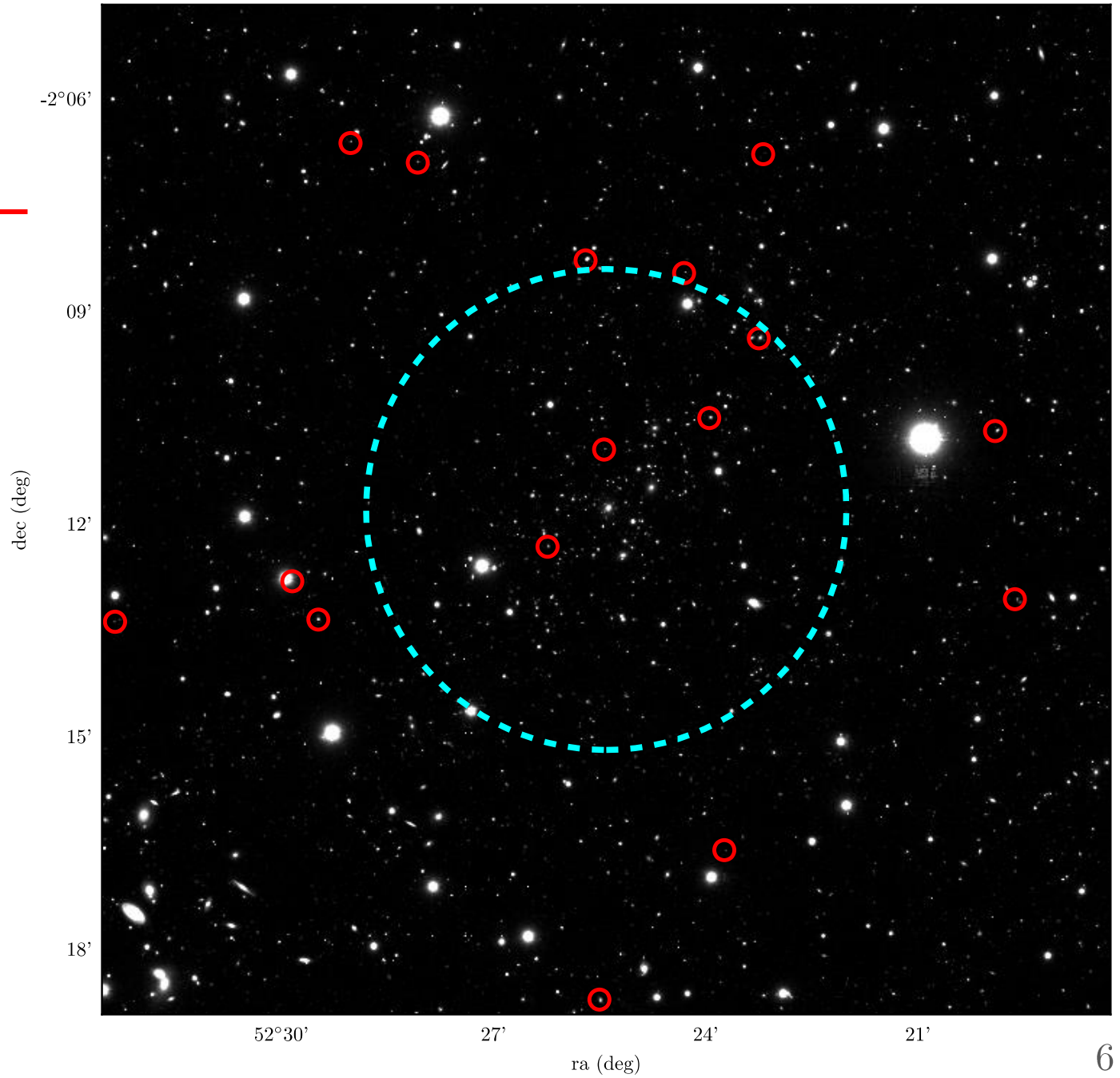


# X-ray point source detection

Chandra point source detection out to to $2r_{500}$

X-ray signal dominated by sources in projection

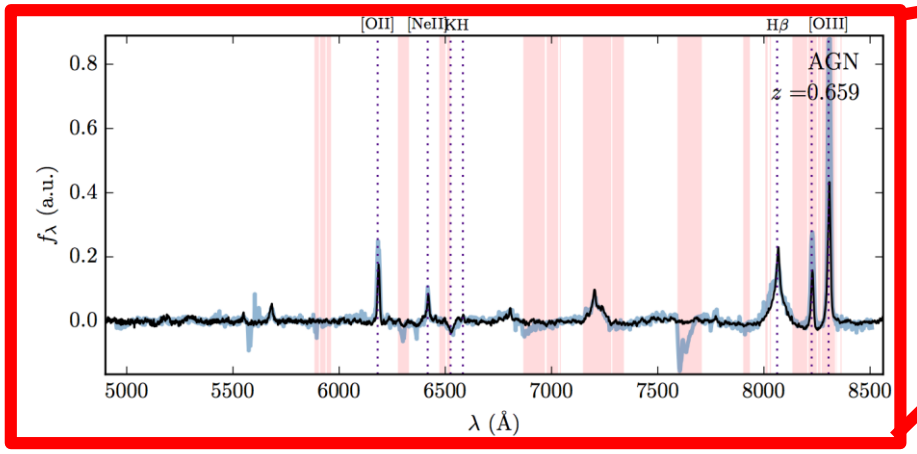
Spectroscopy required to isolate cluster AGN from the background

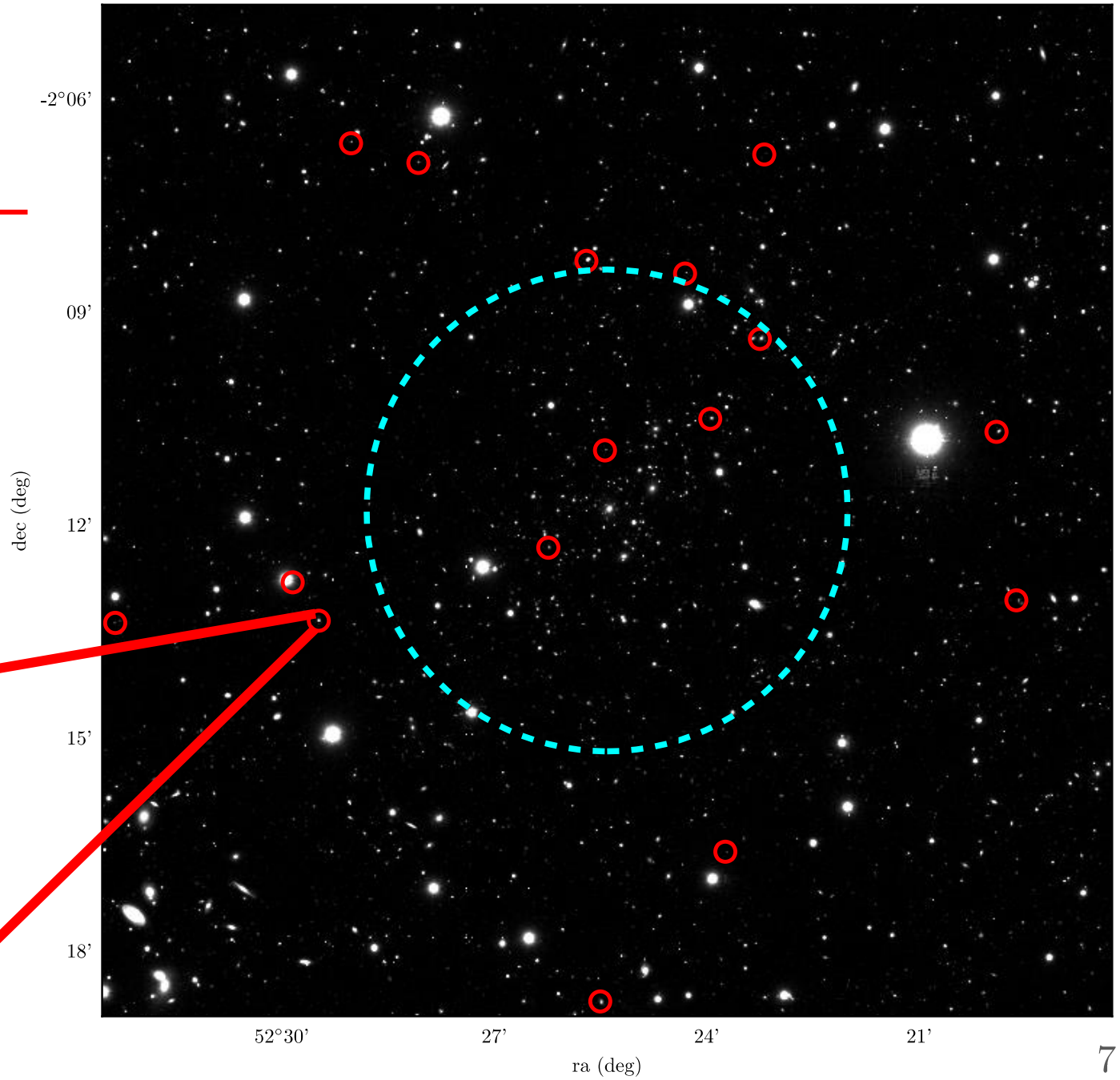


# Spectroscopic cluster confirmation

X-ray point sources matched to deep Subaru imaging

Complete VIMOS spectroscopy of host galaxies



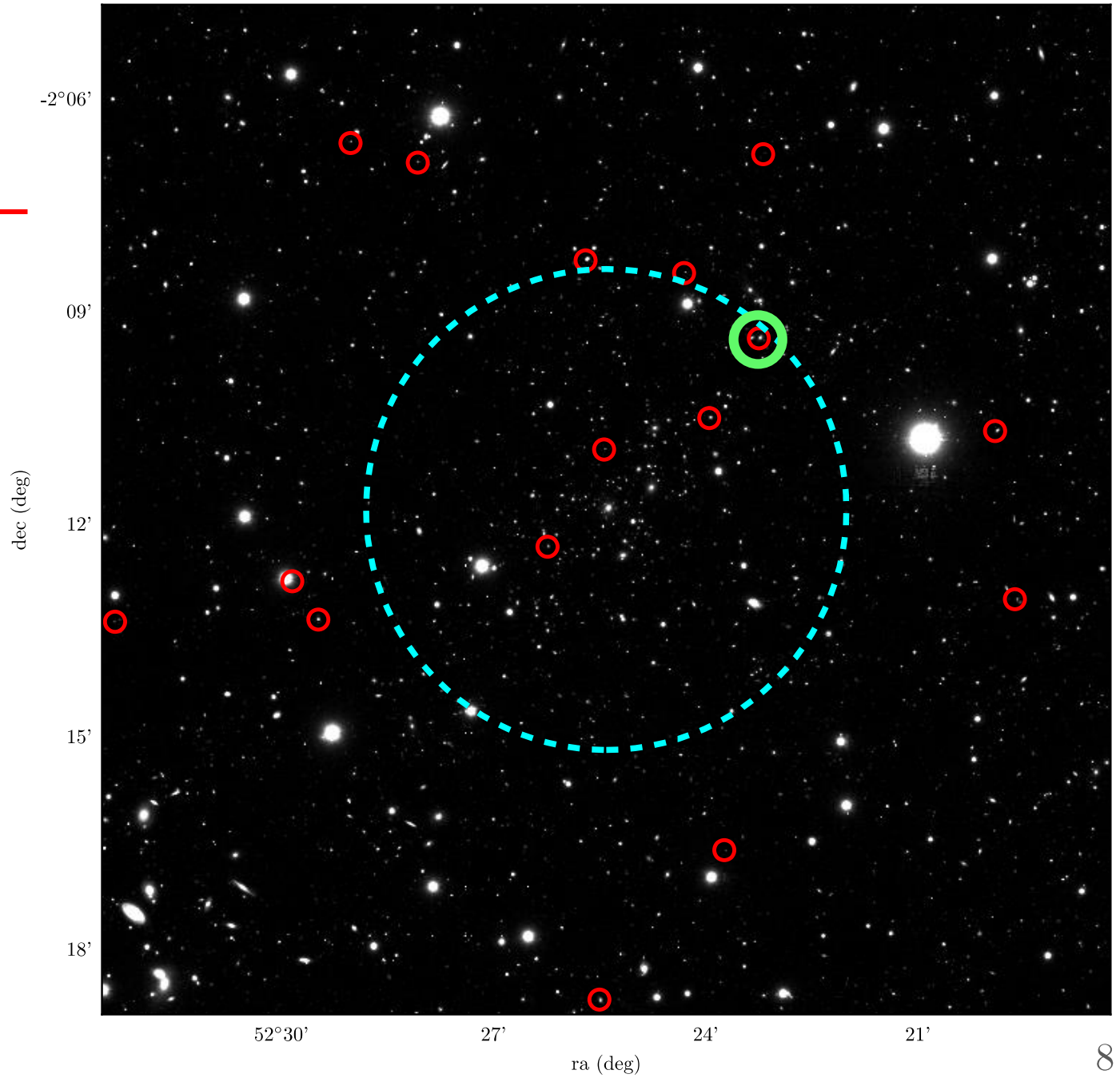



# Spectroscopic cluster confirmation

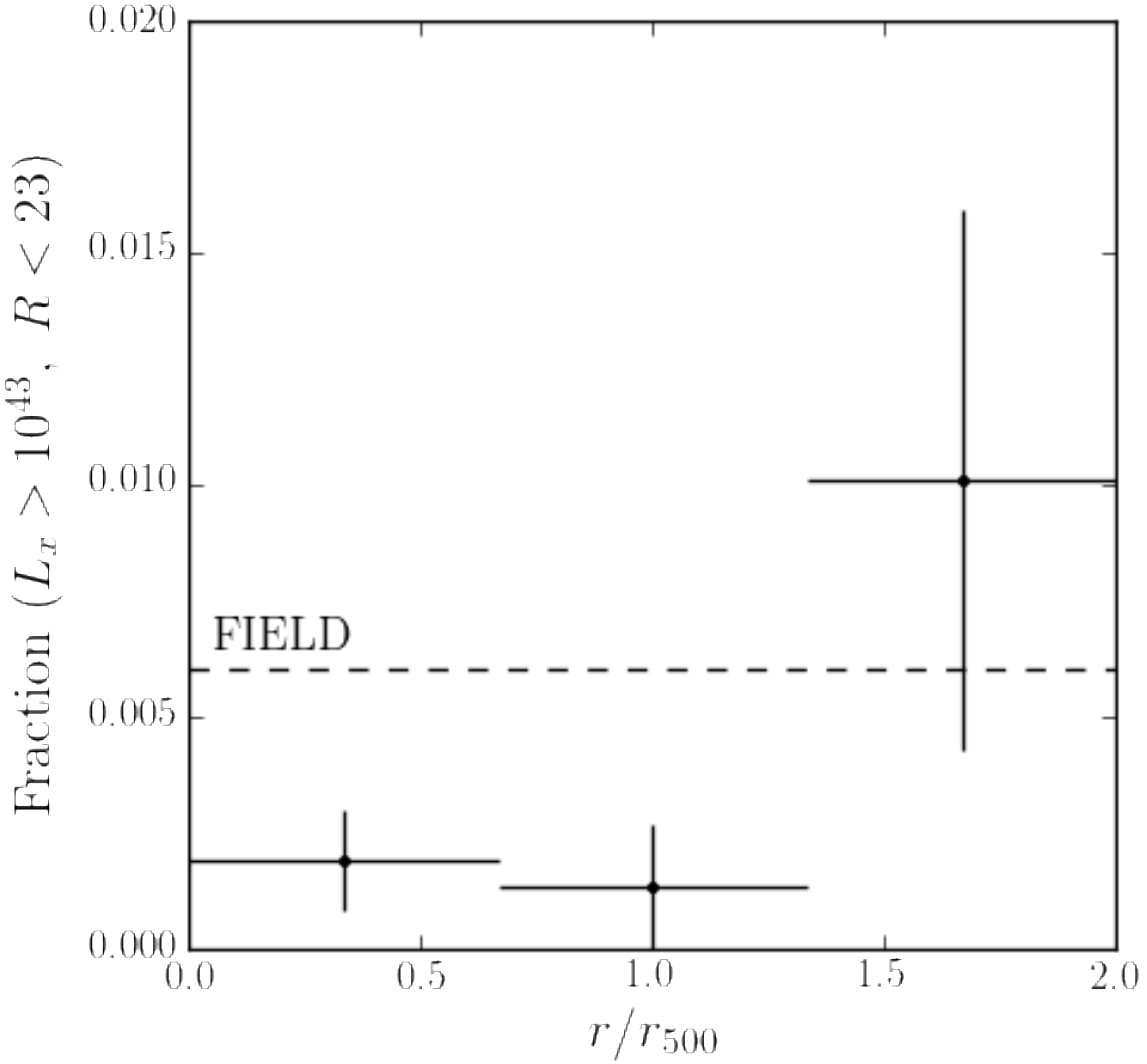
X-ray point sources matched to deep Subaru imaging

Complete VIMOS spectroscopy of host galaxies

~1 member AGN within $2r_{500}$ per cluster



# AGN activity vs. cluster-centric radius




$3\sigma$ suppression of X-ray AGN fraction in cluster core

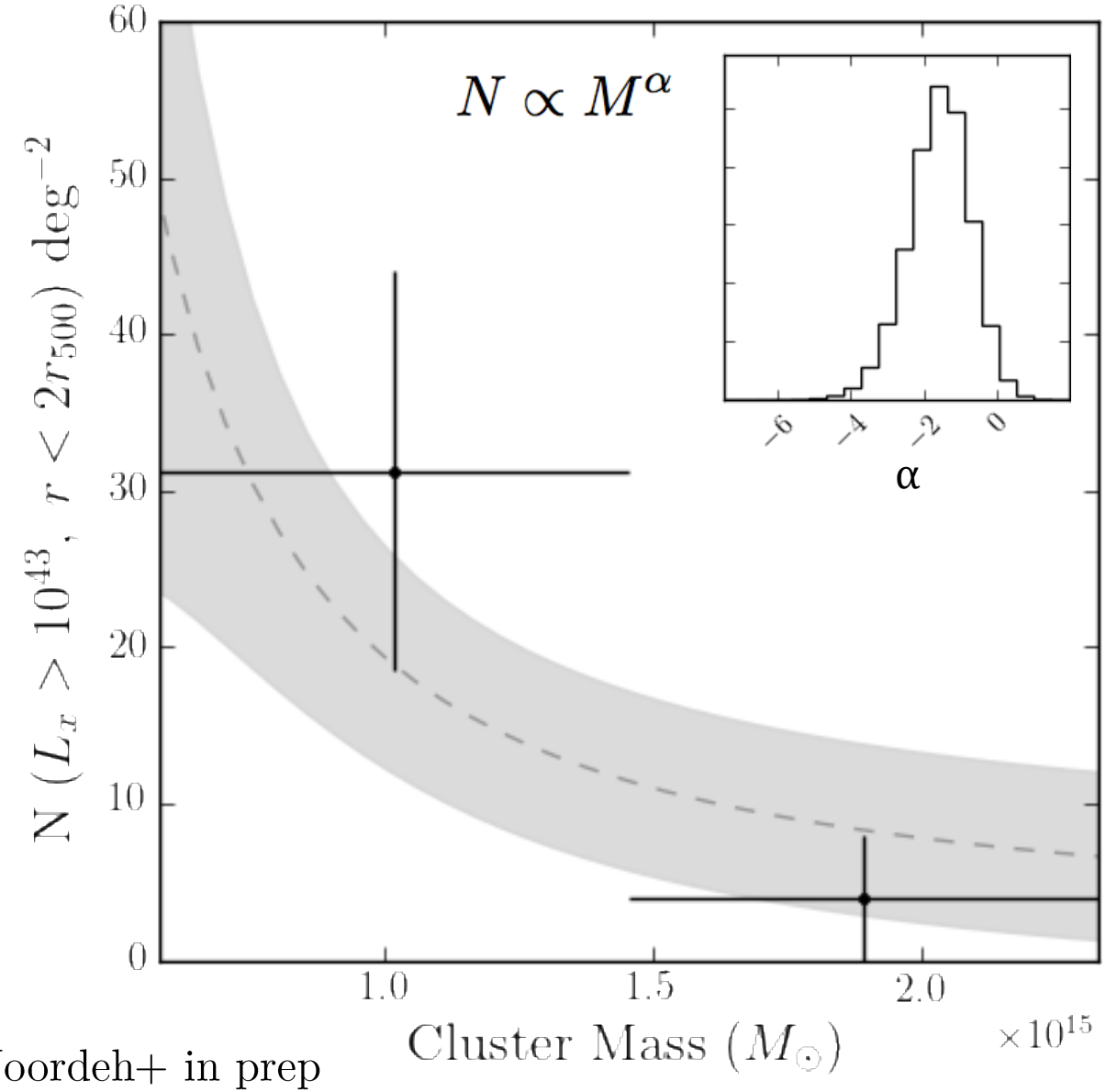
Suppression extends out to virial radius (~$1.5r_{500}$)

Consistent with other studies of X-ray, Optical, & IR AGN

i.e. Martini+2009, Ehlert+2014

Noordeh+ in prep

# Cluster mass dependence




Noordeh+ in prep

**Strong inverse dependence of AGN number density on cluster mass**

Similar behavior has been observed in smaller, local clusters

(Sivakoff+2008, Popesso+2006, Poggianti+2006)

Consistent with merger driven triggering

(Mamon1992)

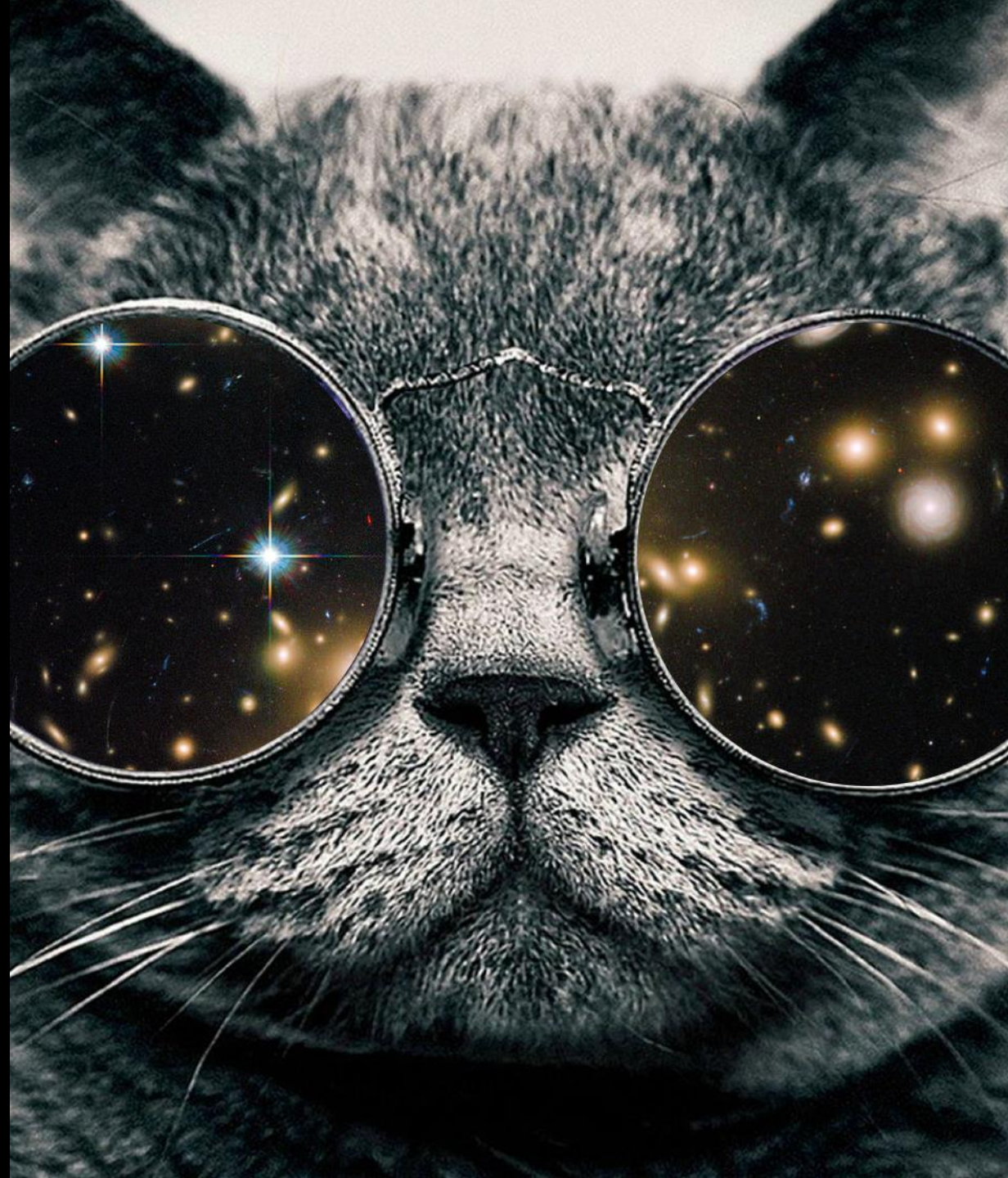
Could account for some/all of the redshift evolution in AGN fraction

- Small sample size
- Individual galaxy dynamical states could drive result
- **Need larger sample!**

# Cluster AGN Topography Survey (CATS)

**Photometric Survey**

**$z \sim 0 - 1.5$**



# CATS

Massive, multi-wavelength survey anchored by Chandra data

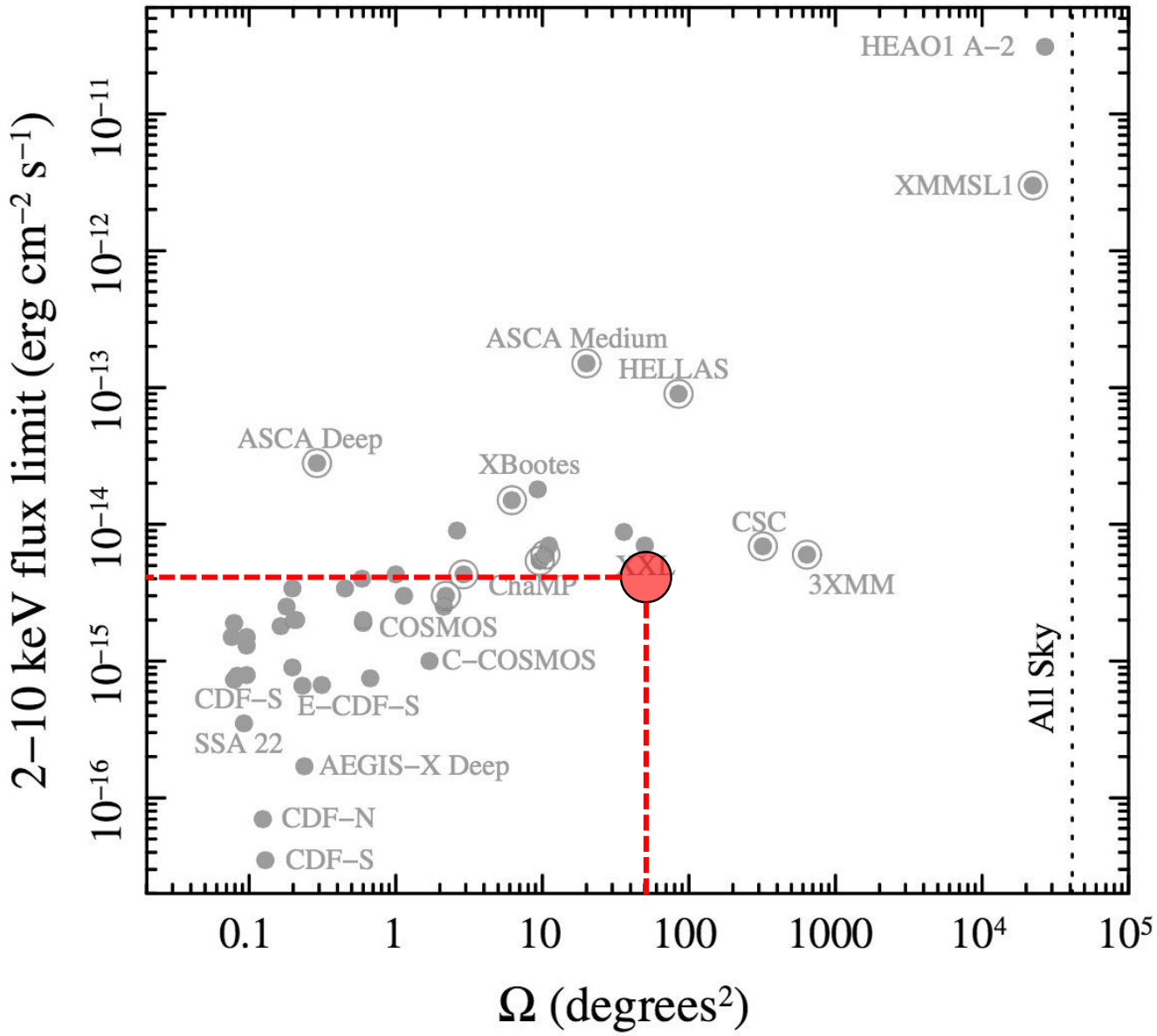
Archival, pointed Chandra X-ray observations of **550 clusters**

**25.7 Ms** archival Chandra exposures

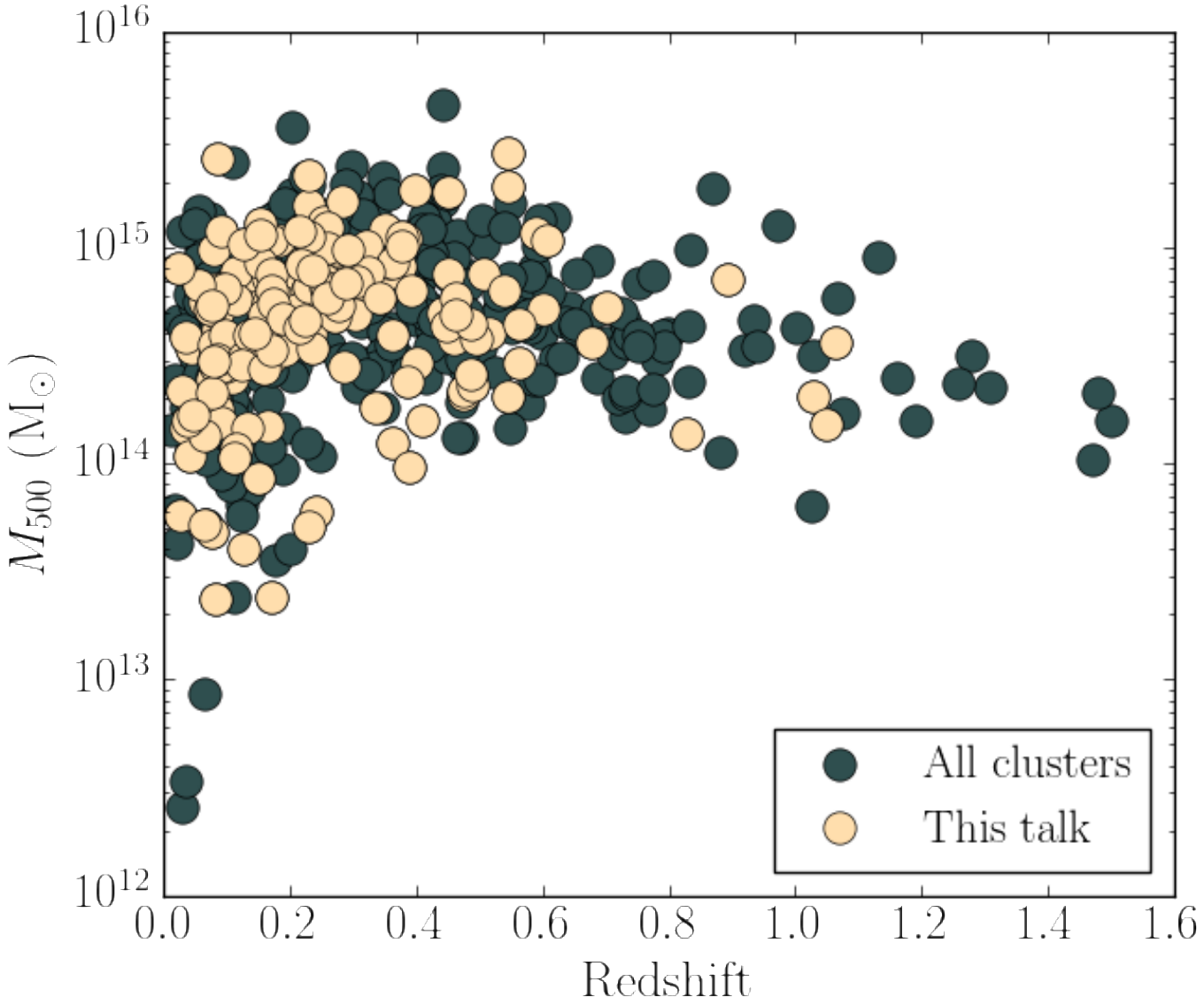
**X-ray/Radio**/IR selected AGN

Model field+cluster population simultaneously

Adapted from Brandt & Alexander 2015



# CATS sample



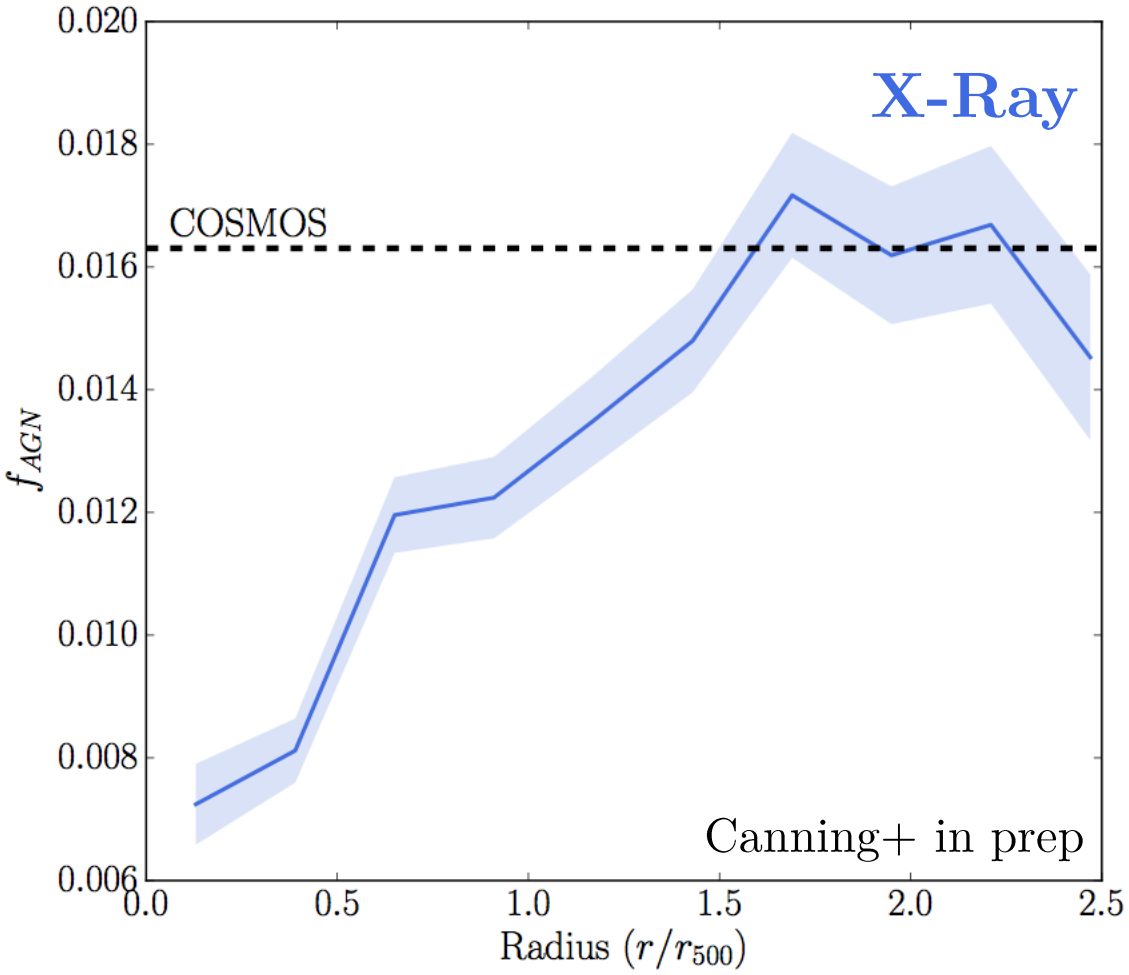

**550 clusters**
Wide range of redshifts and cluster masses

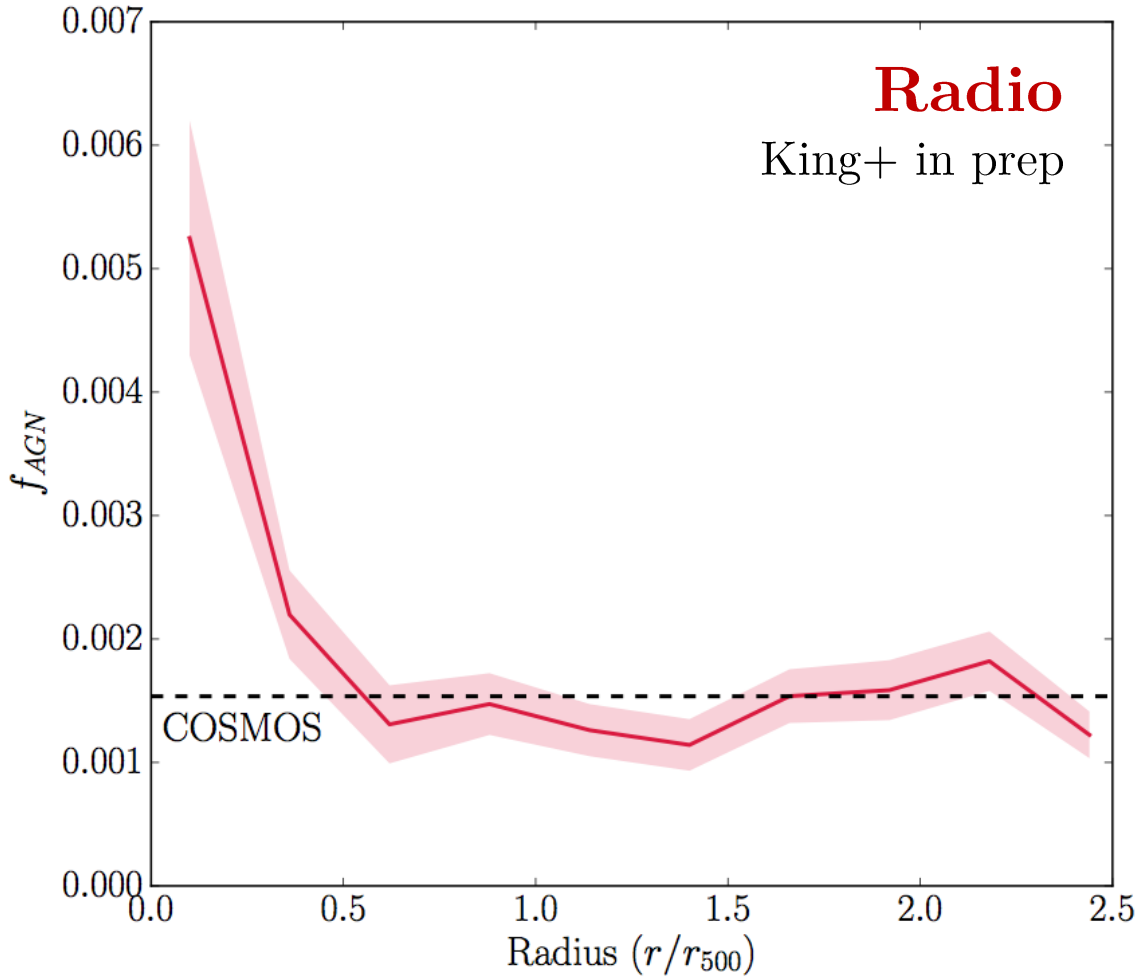
**183 clusters** analyzed thus far

**X-ray**
- >10 ks of Chandra per cluster
- Point sources identified with 2-10 keV flux $> 5 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$

**Radio**
- VLA FIRST 1.4 Ghz
- 3 mJy flux limit

# CATS AGN Fraction




X-ray AGN fraction decreases towards cluster center while radio AGN fraction increases

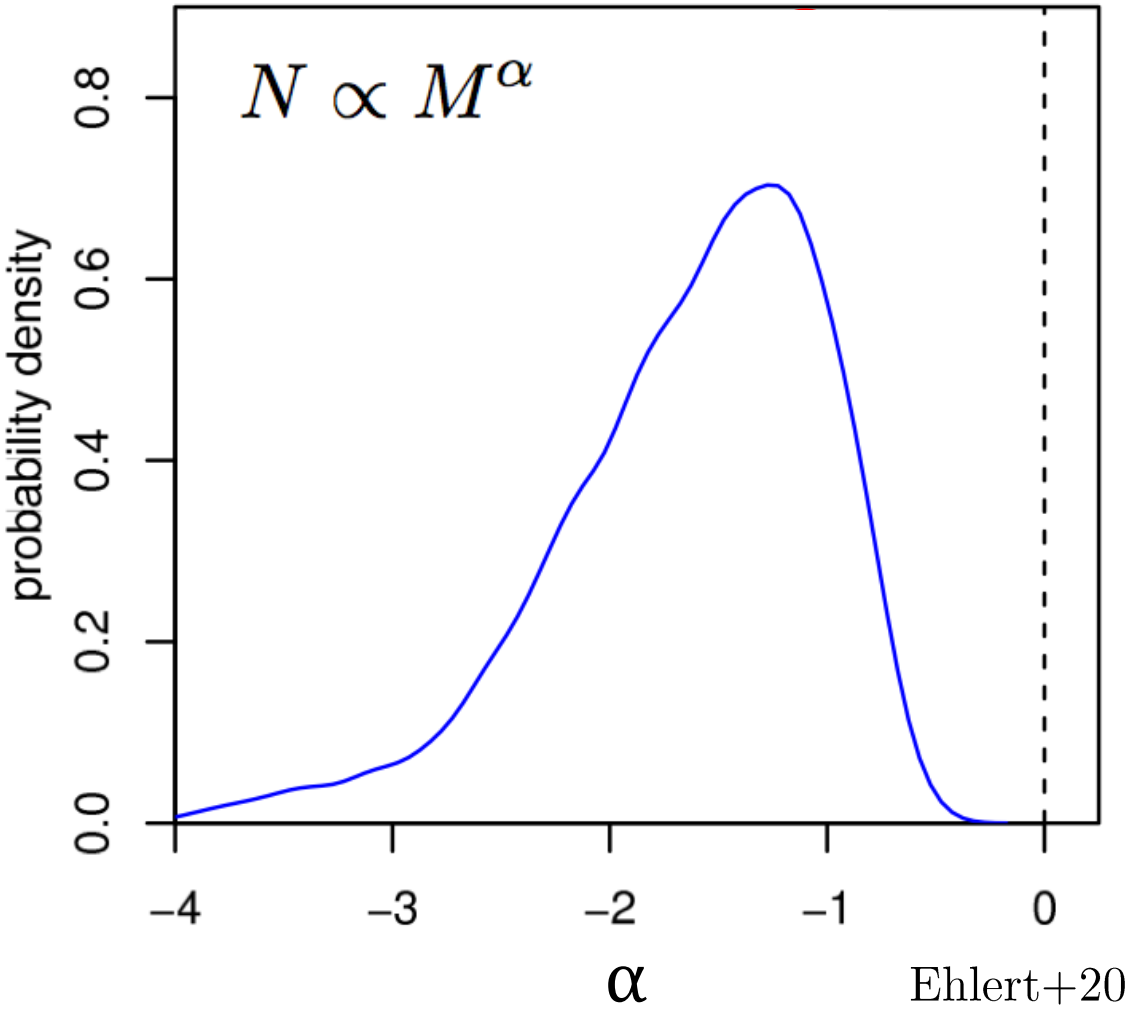
# CATS X-ray AGN & cluster mass

Power law mass dependence fit to subset of 135 clusters (6.3 Ms)

Mass dependence of $\alpha = -1.2 \pm 0.7$ with $\alpha = 0$ ruled out at >3 sigma significance

Consistent with spectroscopic result

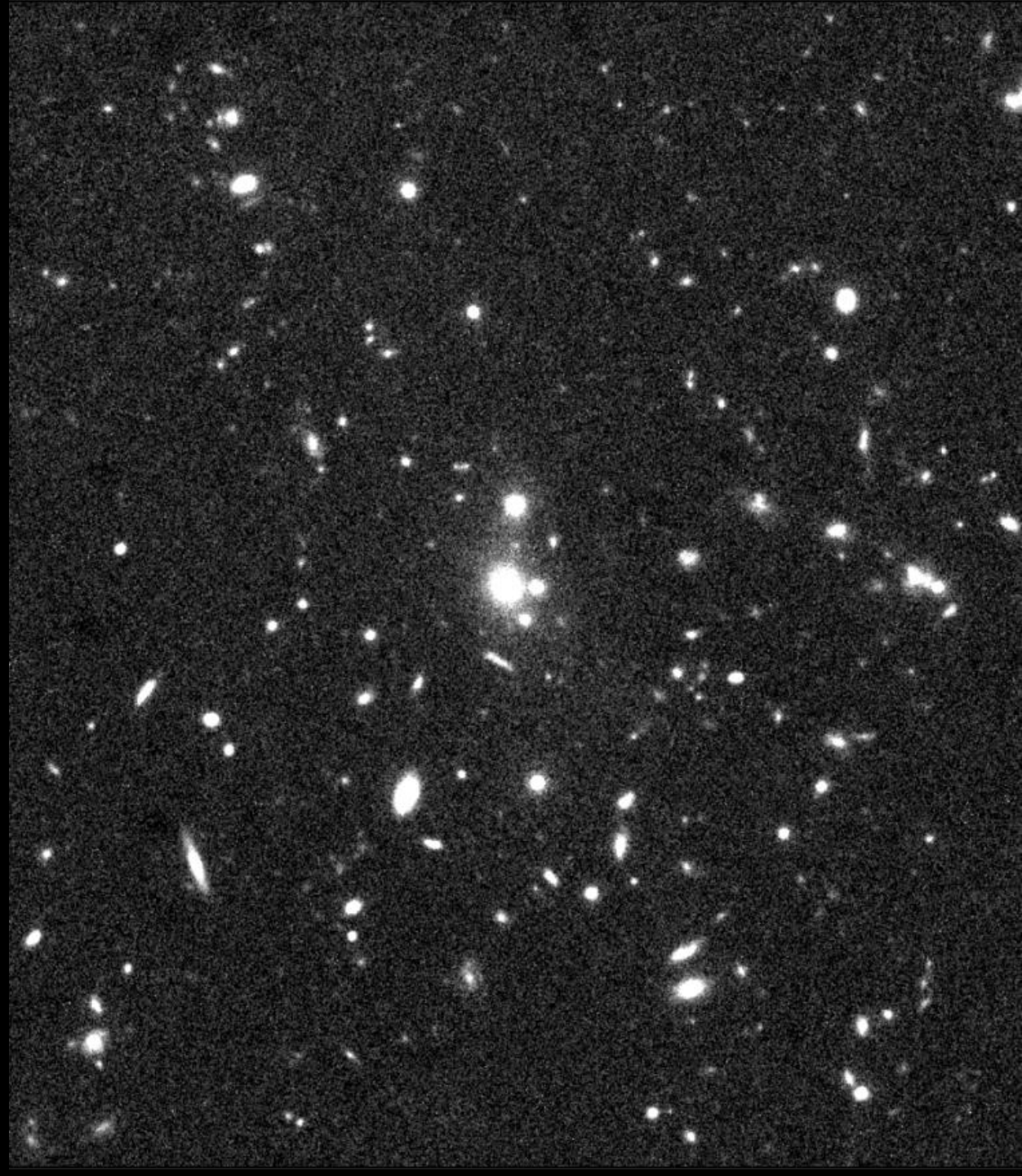
**No evidence for redshift evolution beyond that of the field**




Ehlert+2015

# Cluster AGN activity at $z = 2$

**XLSSC122**
**The highest redshift, virialized cluster known**



# Cluster AGN in the early universe

High-$z$ studies typically look at protoclusters

- Interesting signs of excess AGN triggering
  (Lehmer+2009, Digby-North+2010, Krishnan+2017)
- Very different environments compared to clusters today

## XLSSC122, $z = 2$

Highest redshift virialized system discovered to date

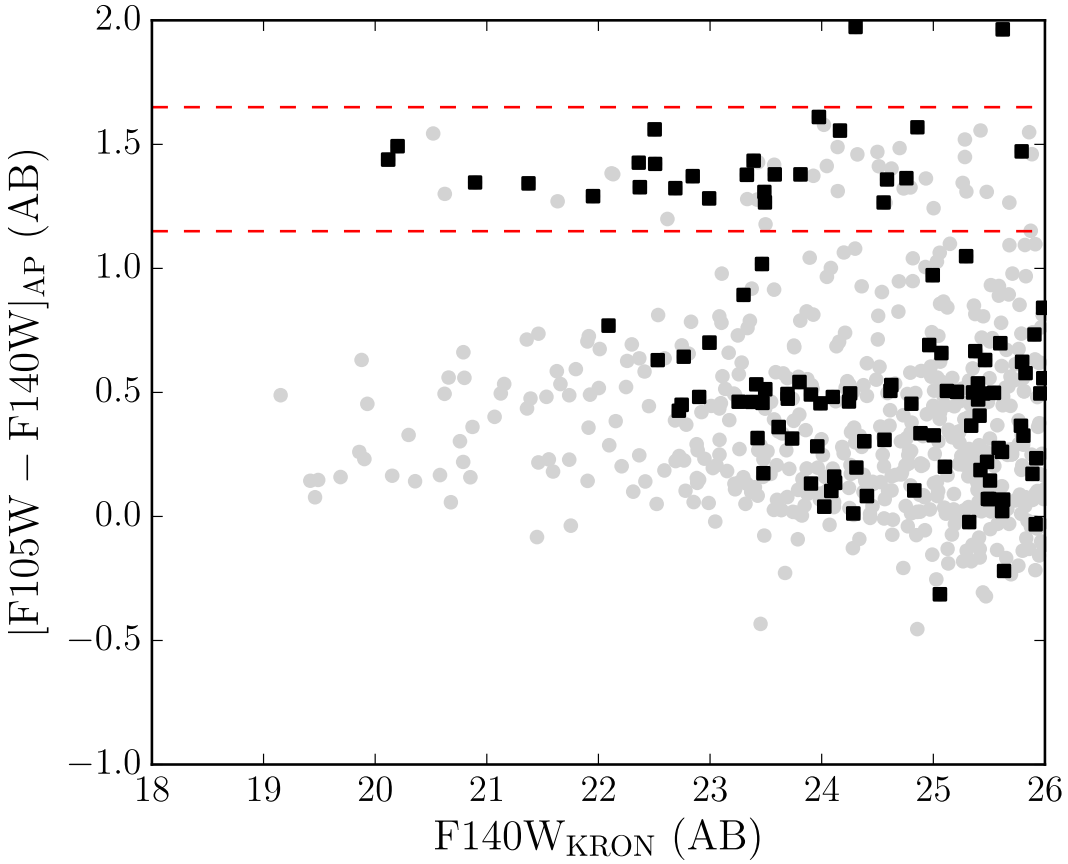
X-ray detected cluster

100 ks of XMM Newton data

$M_{500} \sim 10^{14} M_{\odot}$

Complete HST G141 grism spectroscopy obtained

# XLSSC122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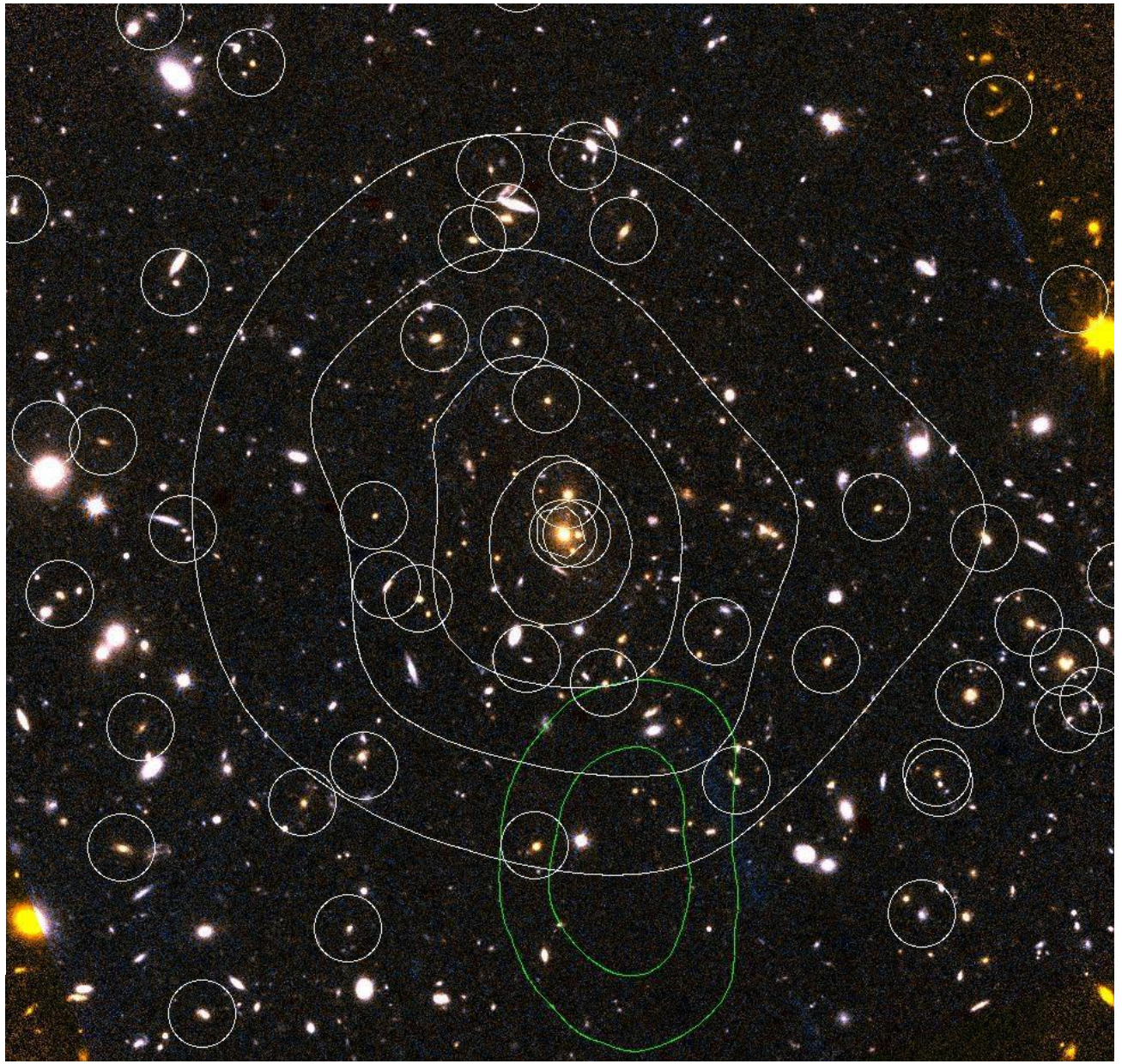
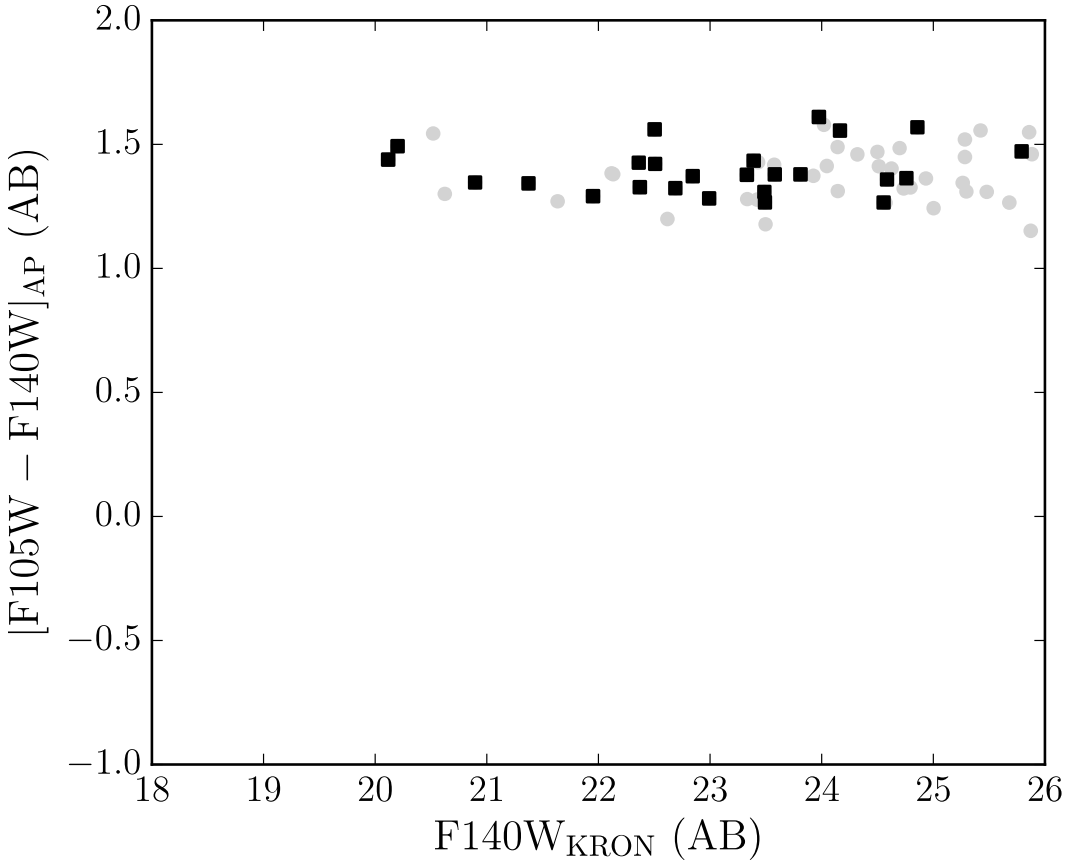
[F105W − F140W]AP (AB)
F140WKRON (AB)



# XLSSC122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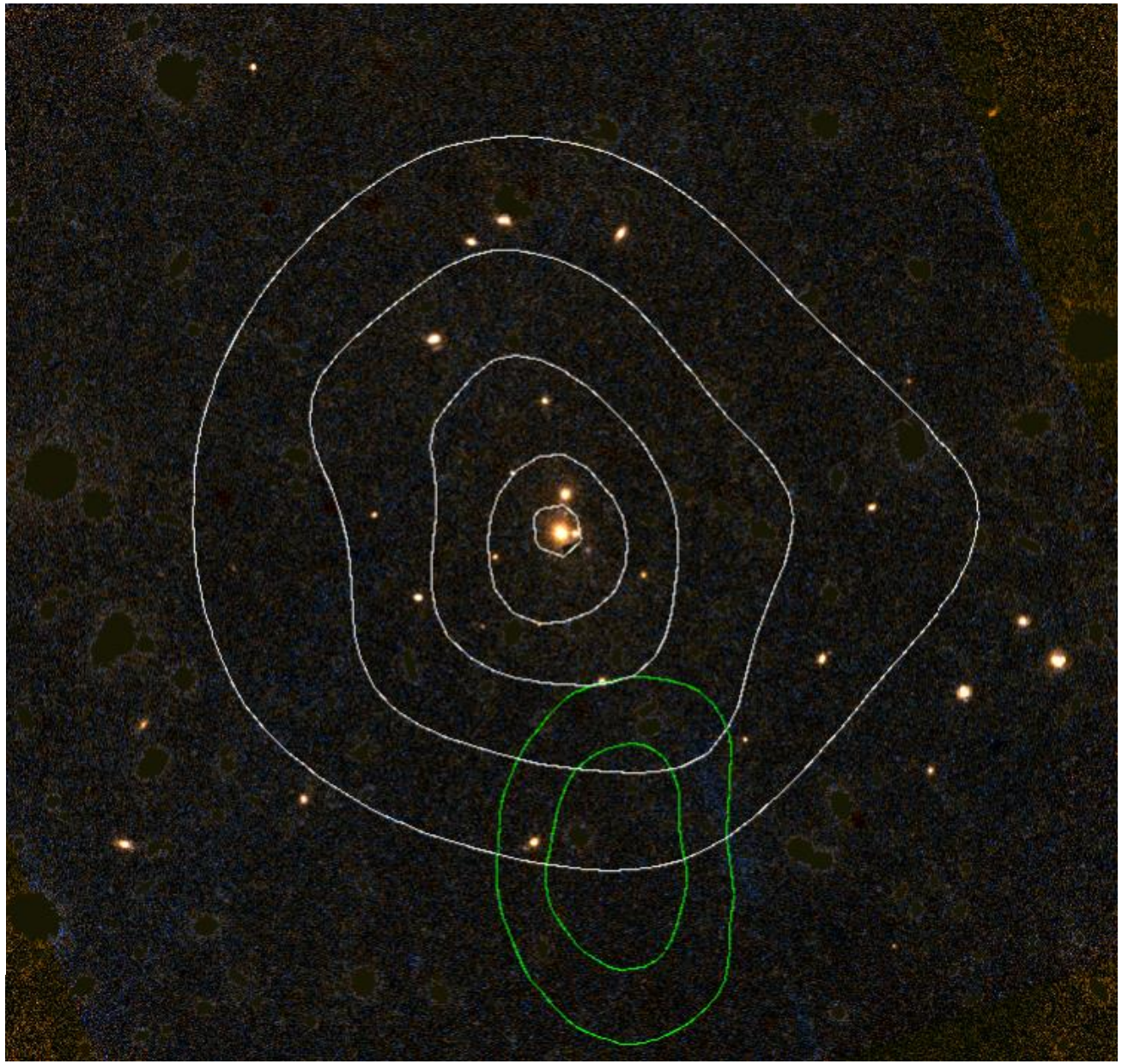
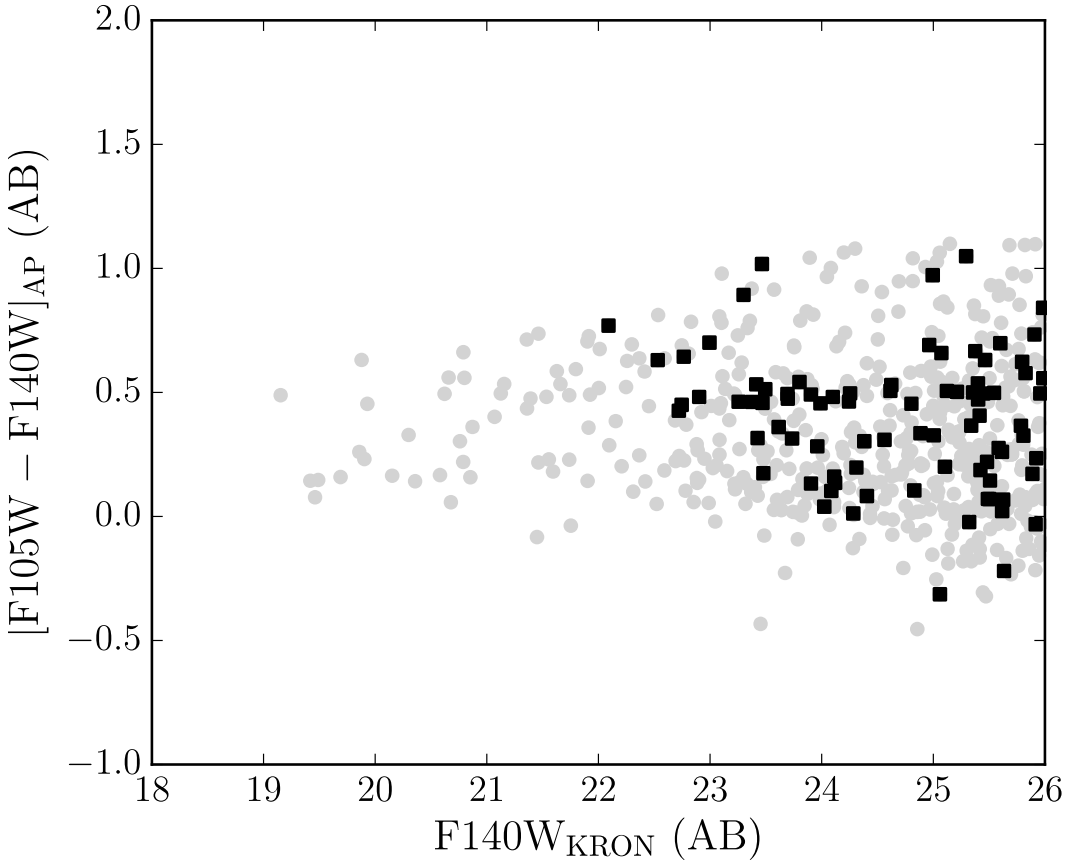


# XLSSC122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[F105W − F140W]AP (AB)
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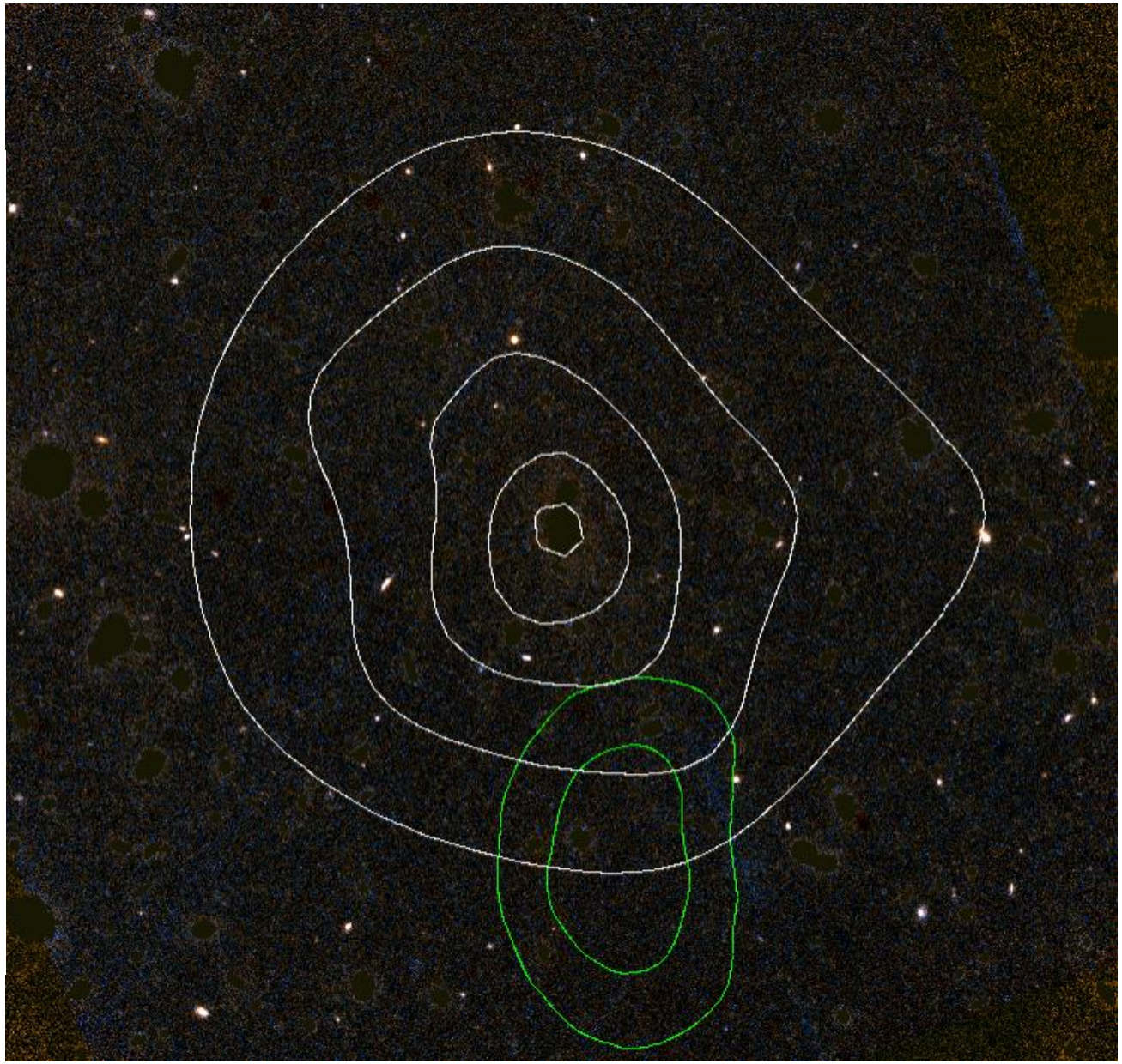
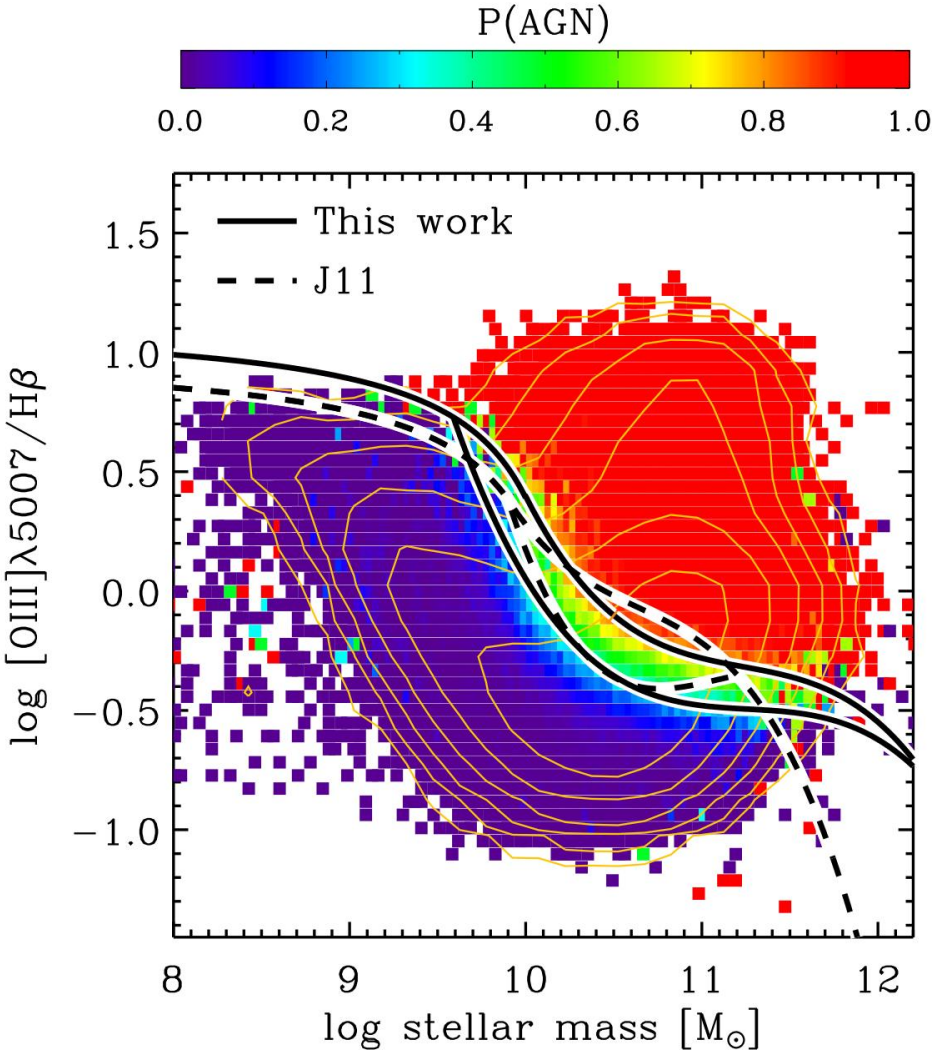
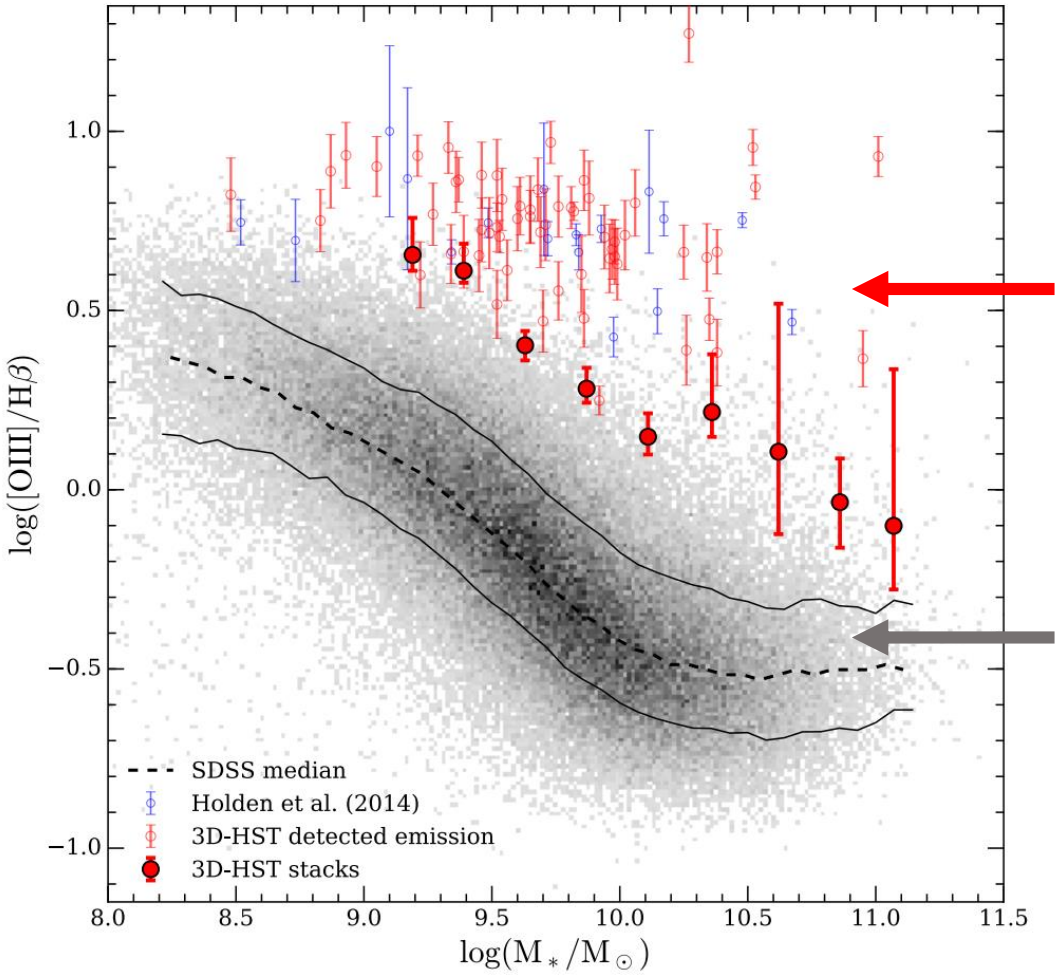


# Optical AGN selection at high-$z$

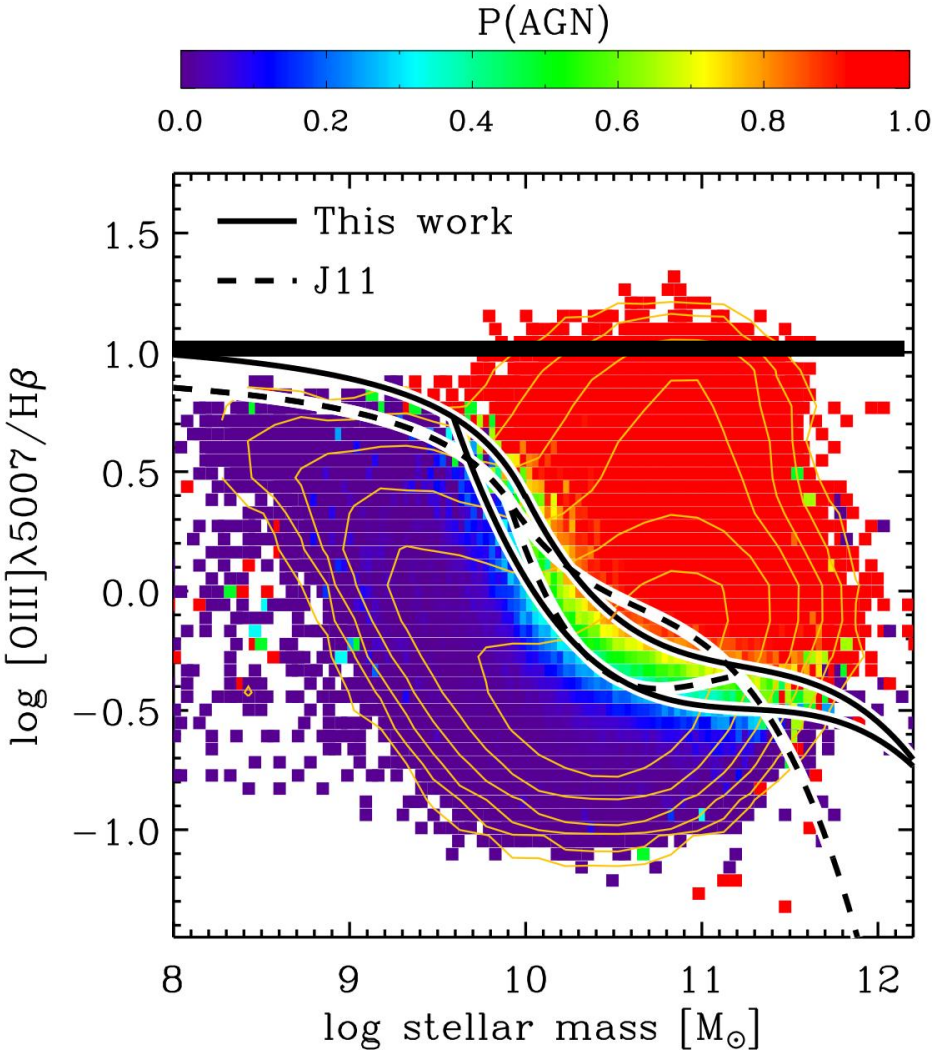



Juneau+2014

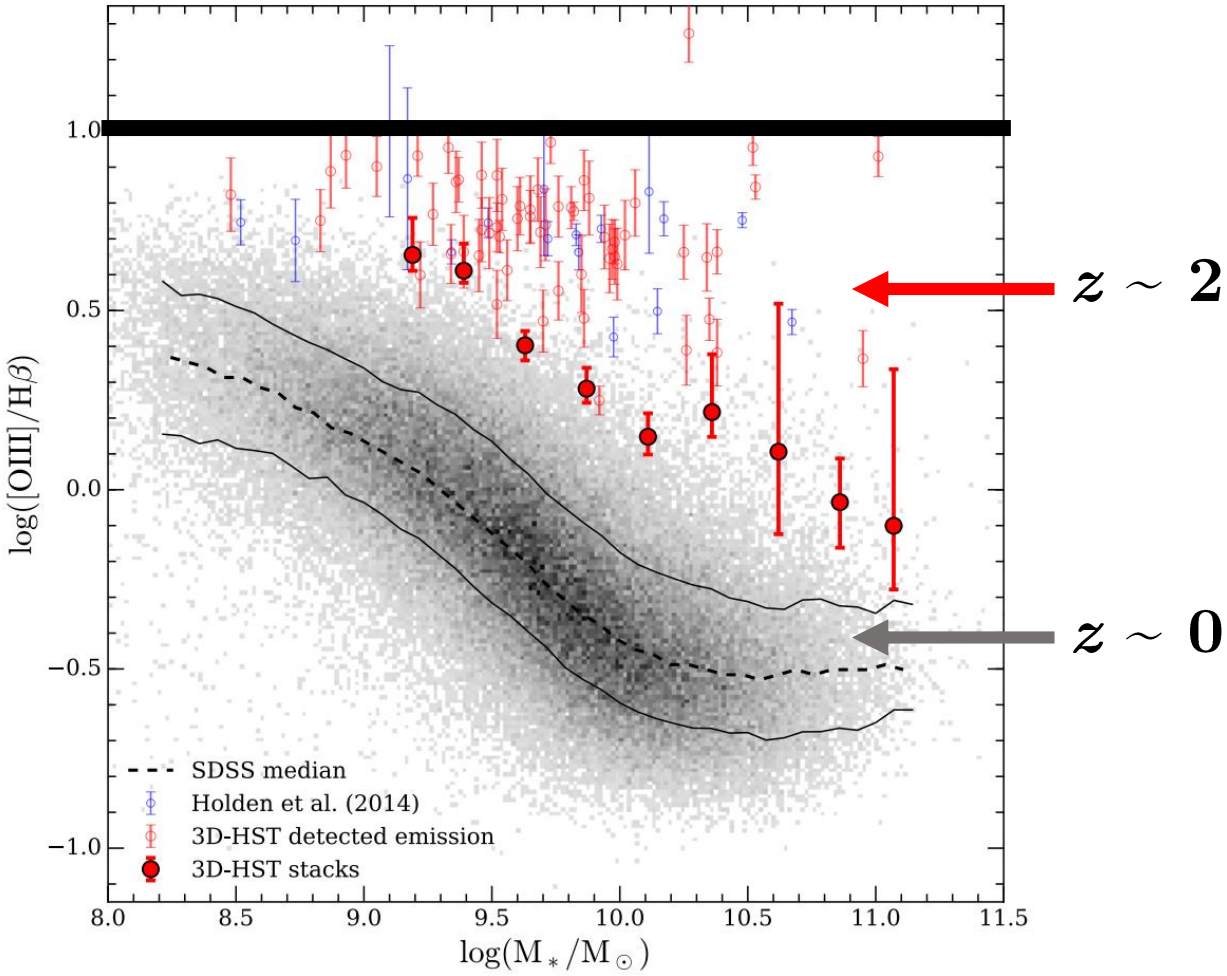



Dickey+2016

# Optical AGN selection at high-$z$

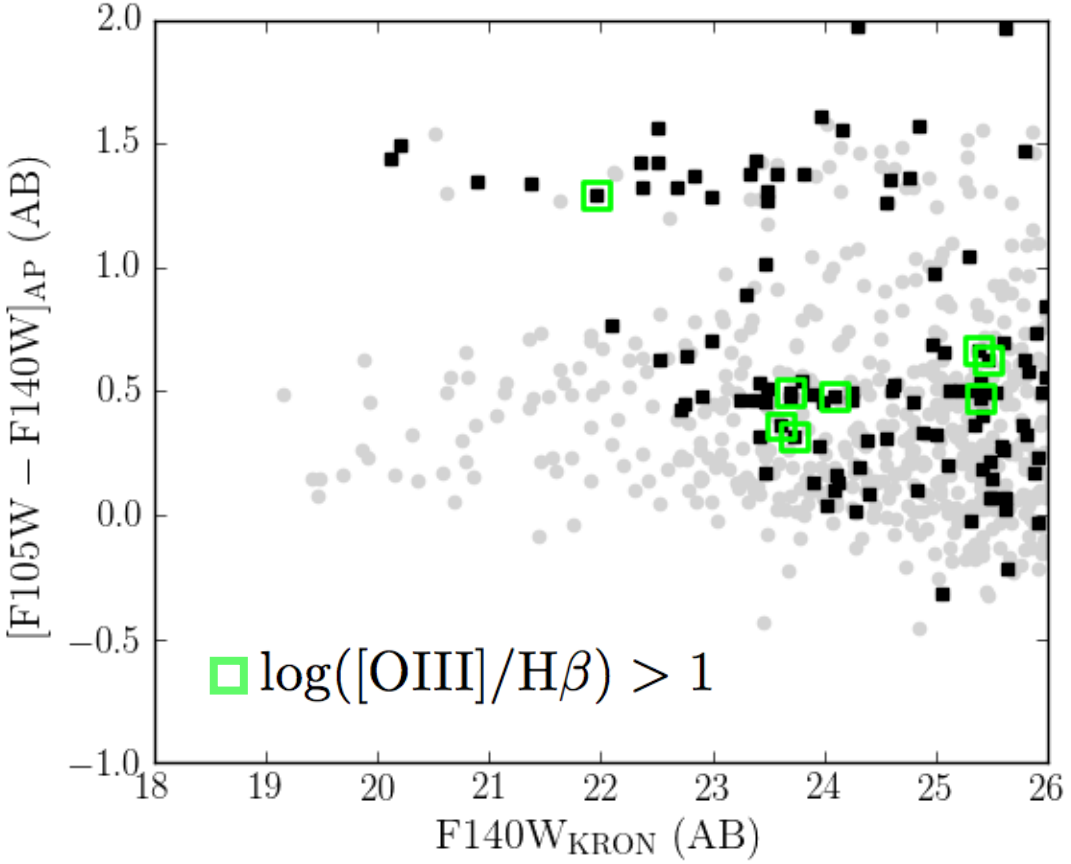



Juneau+2014




Dickey+2016

# Optical AGN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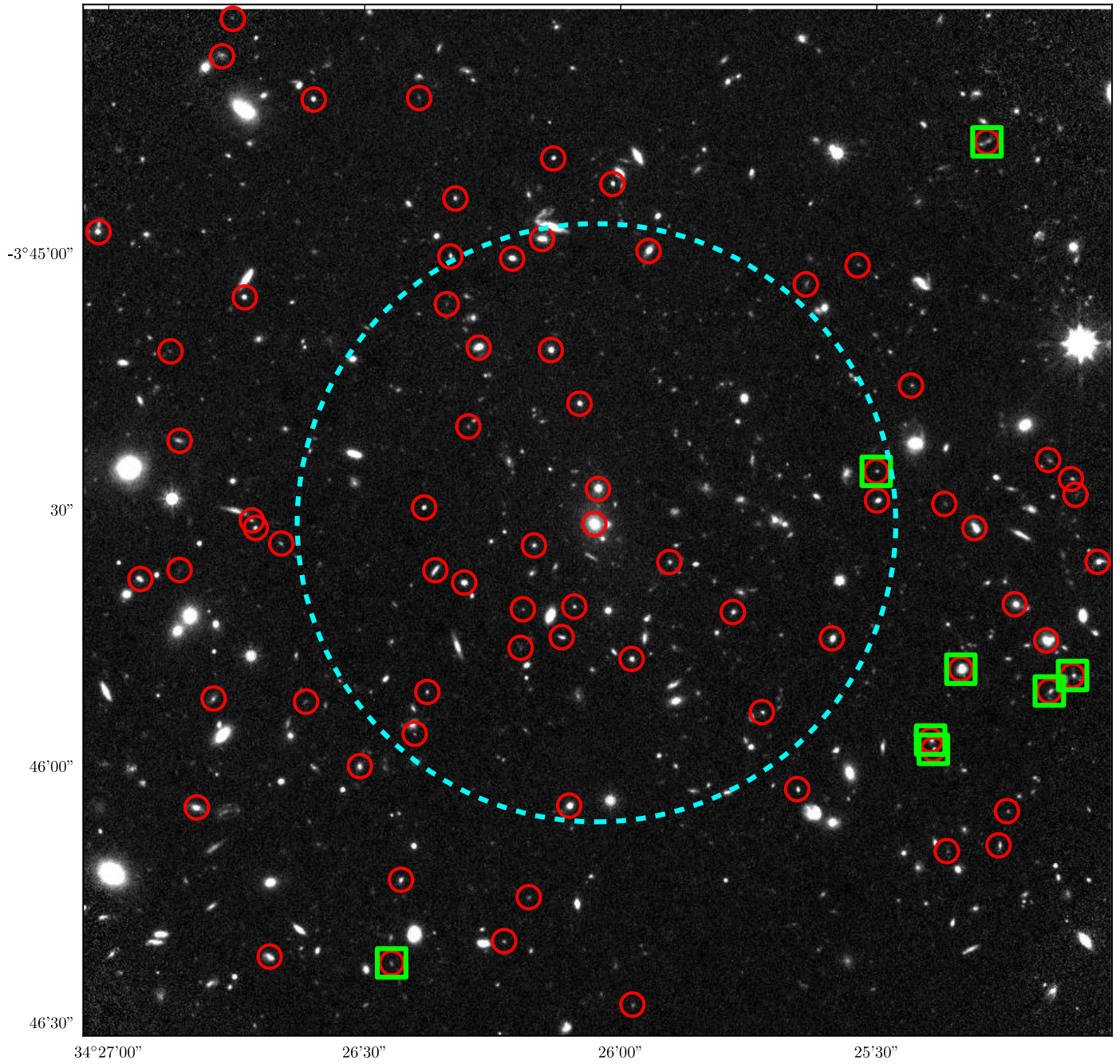
$[F105W - F140W]_{AP}$ (AB)
$F140W_{KRON}$ (AB)
log([OIII]/Hβ) > 1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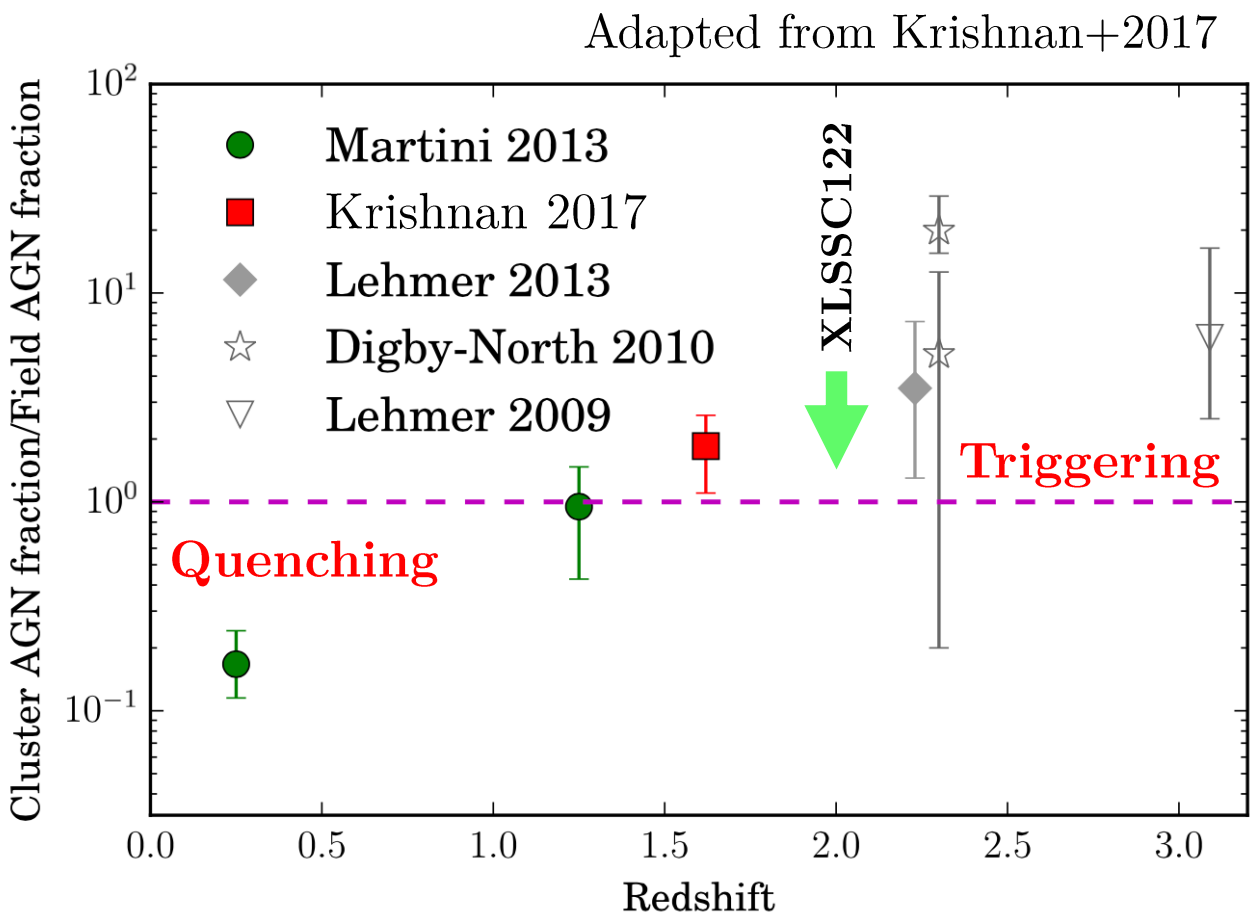
30"
46'00"
46'30"
34°27'00"
26'30"
26'00"
25'30"

# XLSSC122 AGN fraction




Lower limit on AGN fraction

Suggestive of excess triggering in virialized cluster at high-$z$

**But...**

Unique cluster dynamics

Needs to be compared to clusters of similar mass in local universe

# Summary

Observed suppression of X-ray AGN in most massive galaxy clusters

- In redshift slice at $z \sim 0.4$
- Stacked clusters from $z \sim 0 - 1.5$

AGN number density inversely dependent on cluster mass

- Consistent with merger driven triggering
- Drives redshift dependence of $f_{agn}$

First look at $z = 2$ virialized cluster suggests AGN enhancement

- Should be compared to equally massive galaxies in local universe