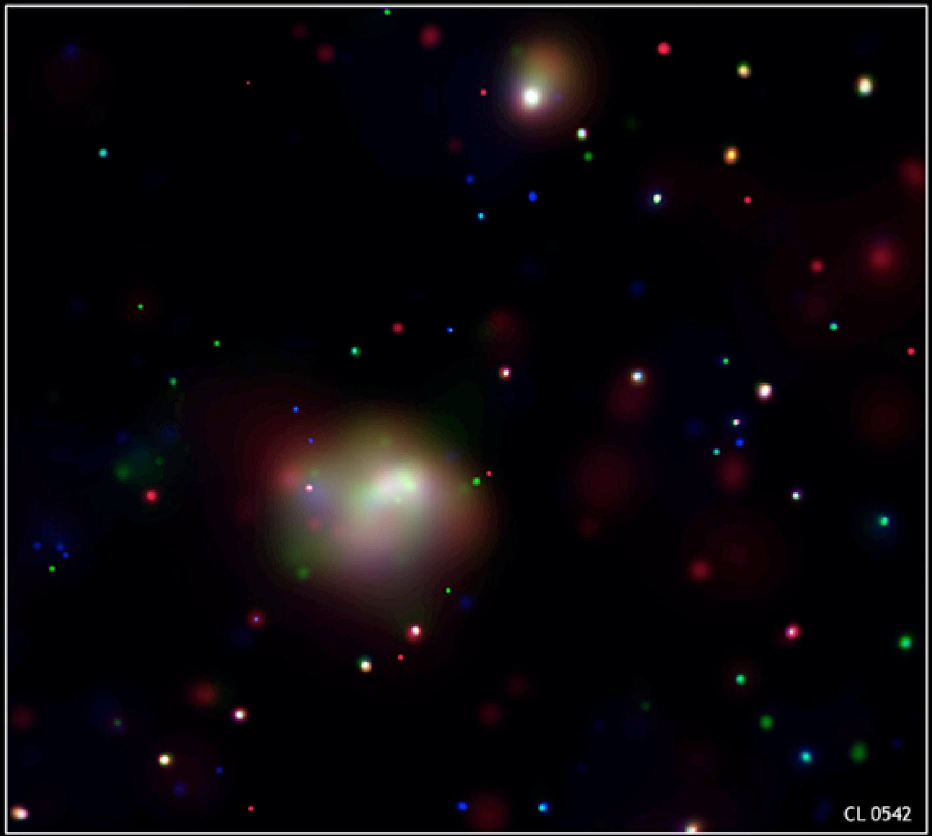
AGN in Clusters of Galaxies



Paul Martini
The Ohio State University

UC Berkeley Colloquium - 24 April 2008

Collaborators

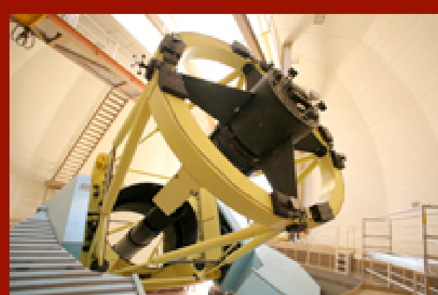
Carnegie:
- John Mulchaey
- Dan Kelson
- Alex Athey

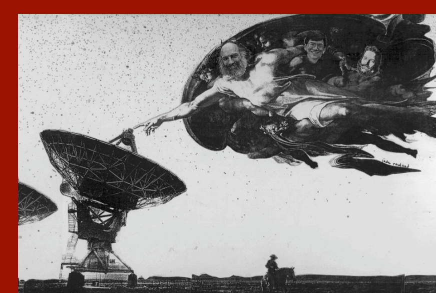
Southampton:
- Christian Kaiser

Arizona:
- Ann Zabludoff

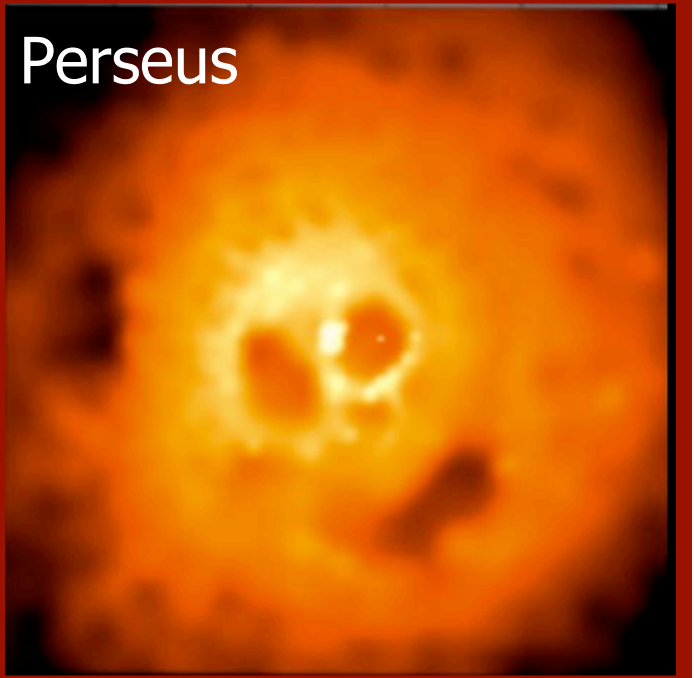
The Ohio State University:
- Timothy Arnold
- Jonathan Bird
- Jason Eastman
- Greg Sivakoff

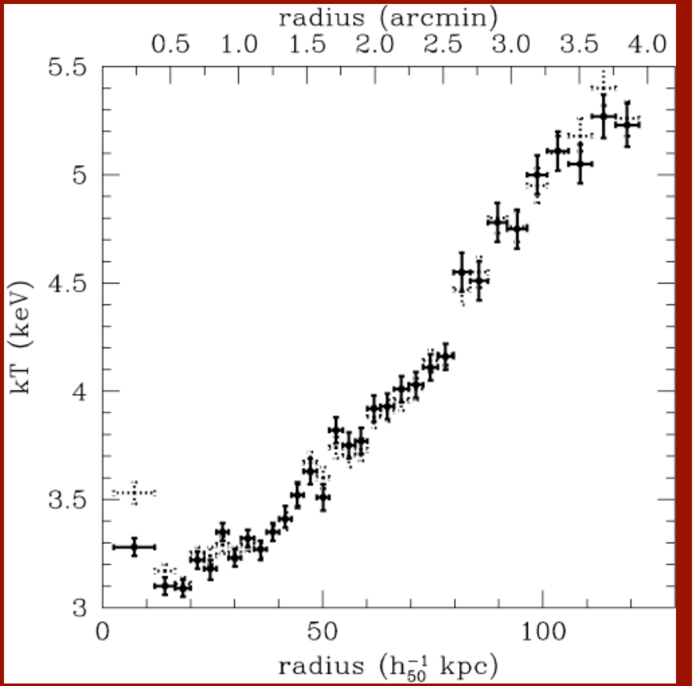
Harvard-Smithsonian CfA:
- Eunhyeuk Kim



Cluster Physics & the Cool Core Problem

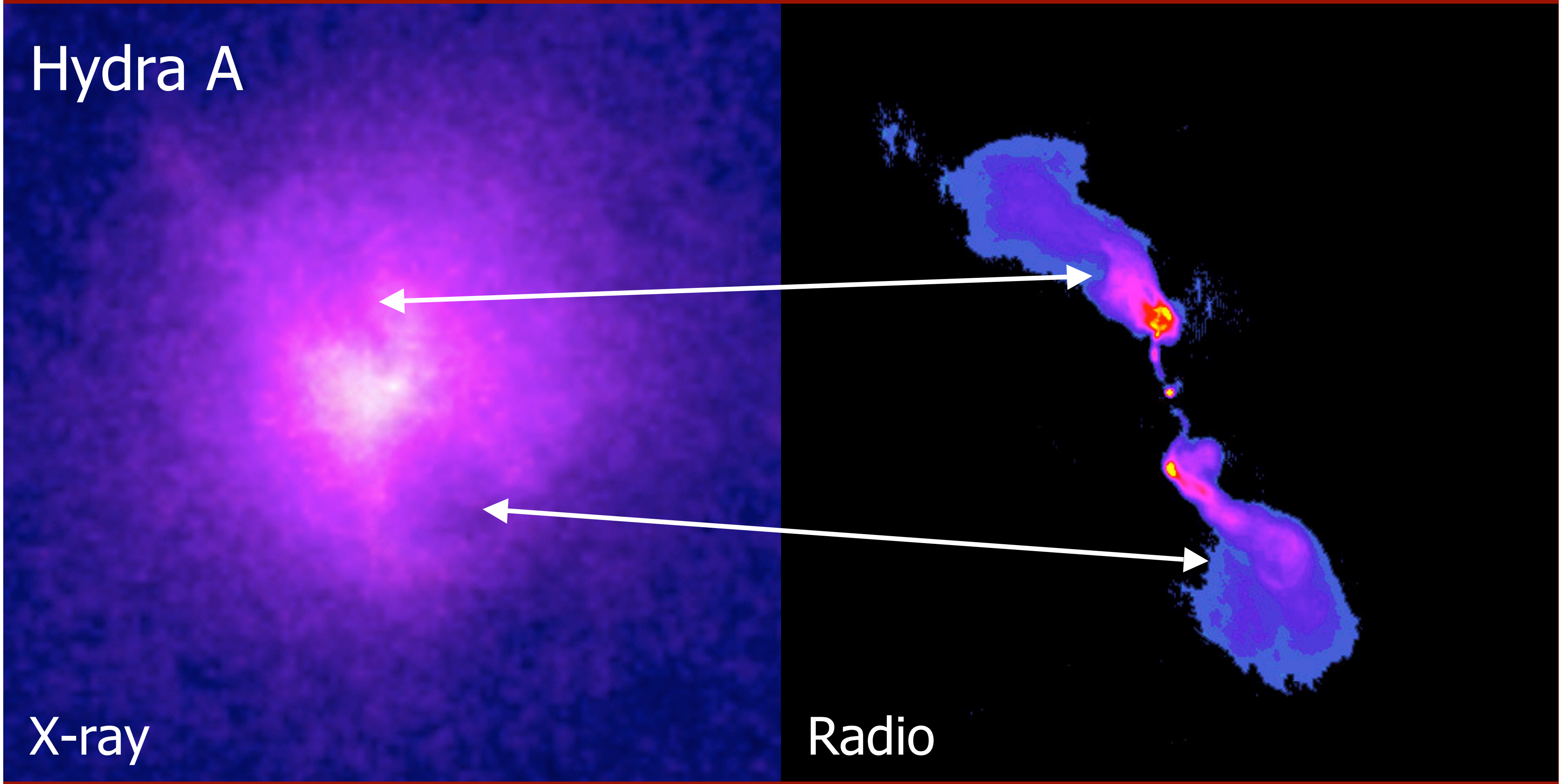




- Clusters of galaxies are filled with hot ($T \sim 10^8$ K) and diffuse ($n \sim 10^{-3}$ cm^{-3}) gas
- The gas in the core should radiatively cool in less than a Hubble time, but not enough cool gas is observed
- Burns (1990) noted most cool cores harbor powerful AGN

Fabian et al. (2005); Schmidt et al. (2002)

AGN Feedback Observed

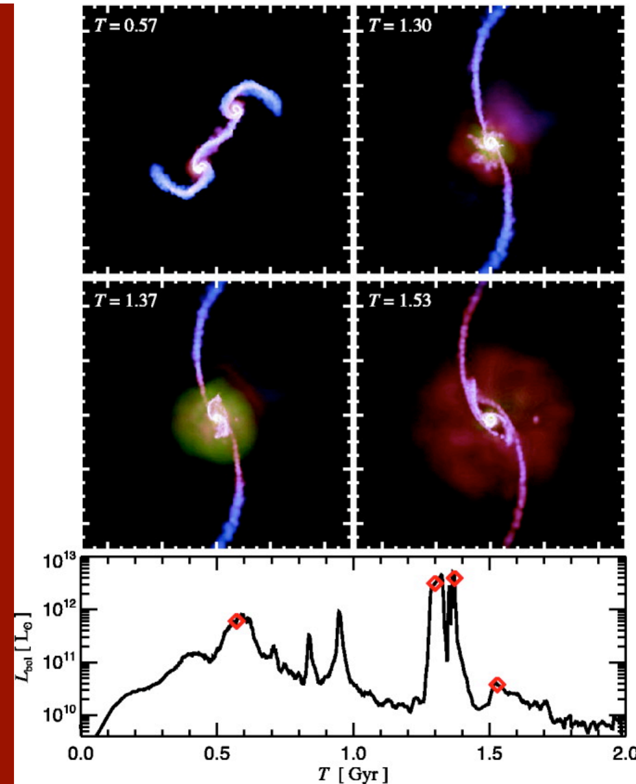


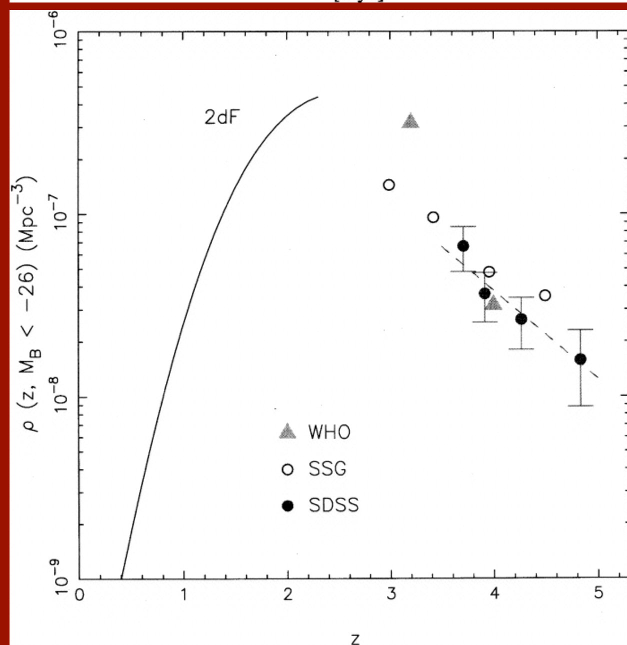
Cavities in the hot intracluster gas formed by radio jets

McNamara et al. (2000)

Black Hole Evolution

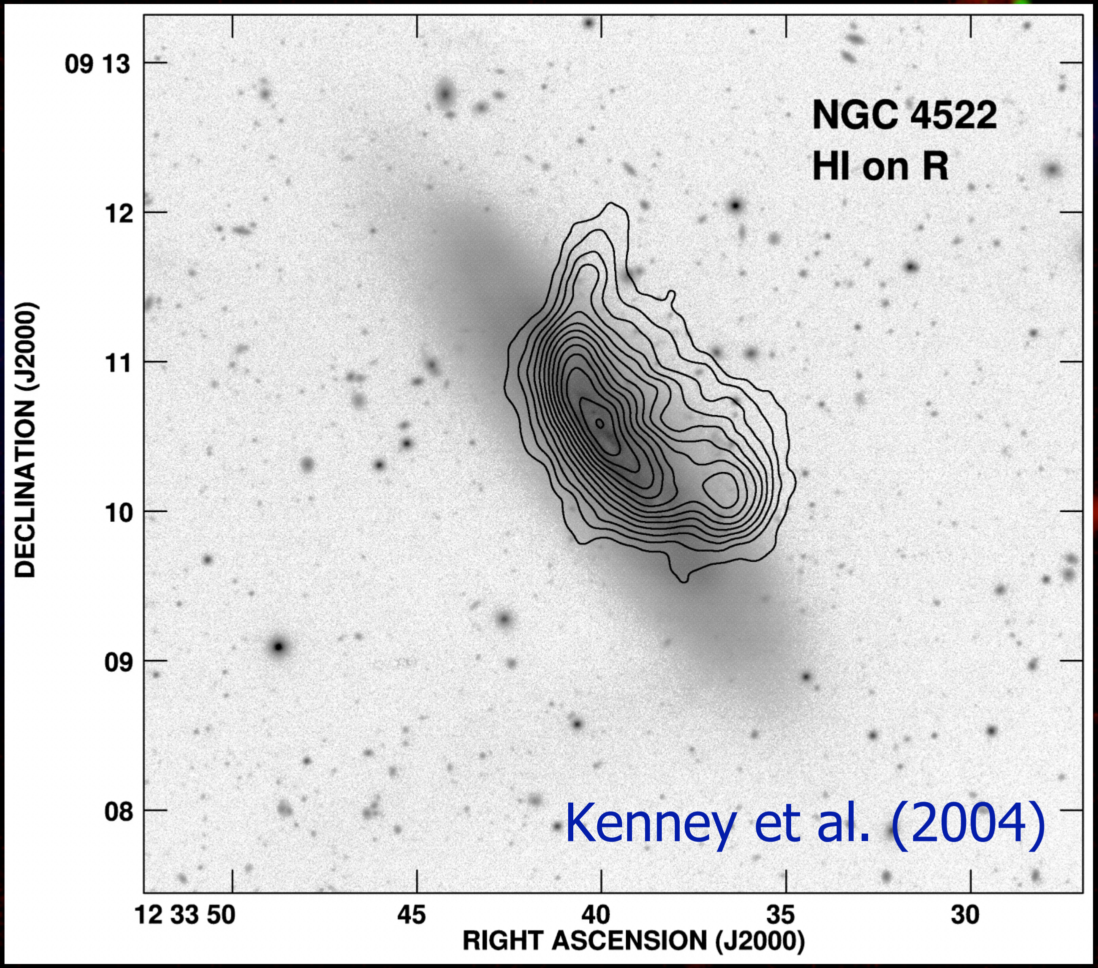
- Rapid black hole growth produces an AGN
- An AGN requires:
  - triggering
  - fuel supply
- The cluster environment offers an opportunity to test this picture in the context of galaxy evolution





Hopkins et al. (2005); Fan et al. (2001)

Galaxy Evolution in Clusters



ICM pressure:

$P_r \sim r_e v^2$

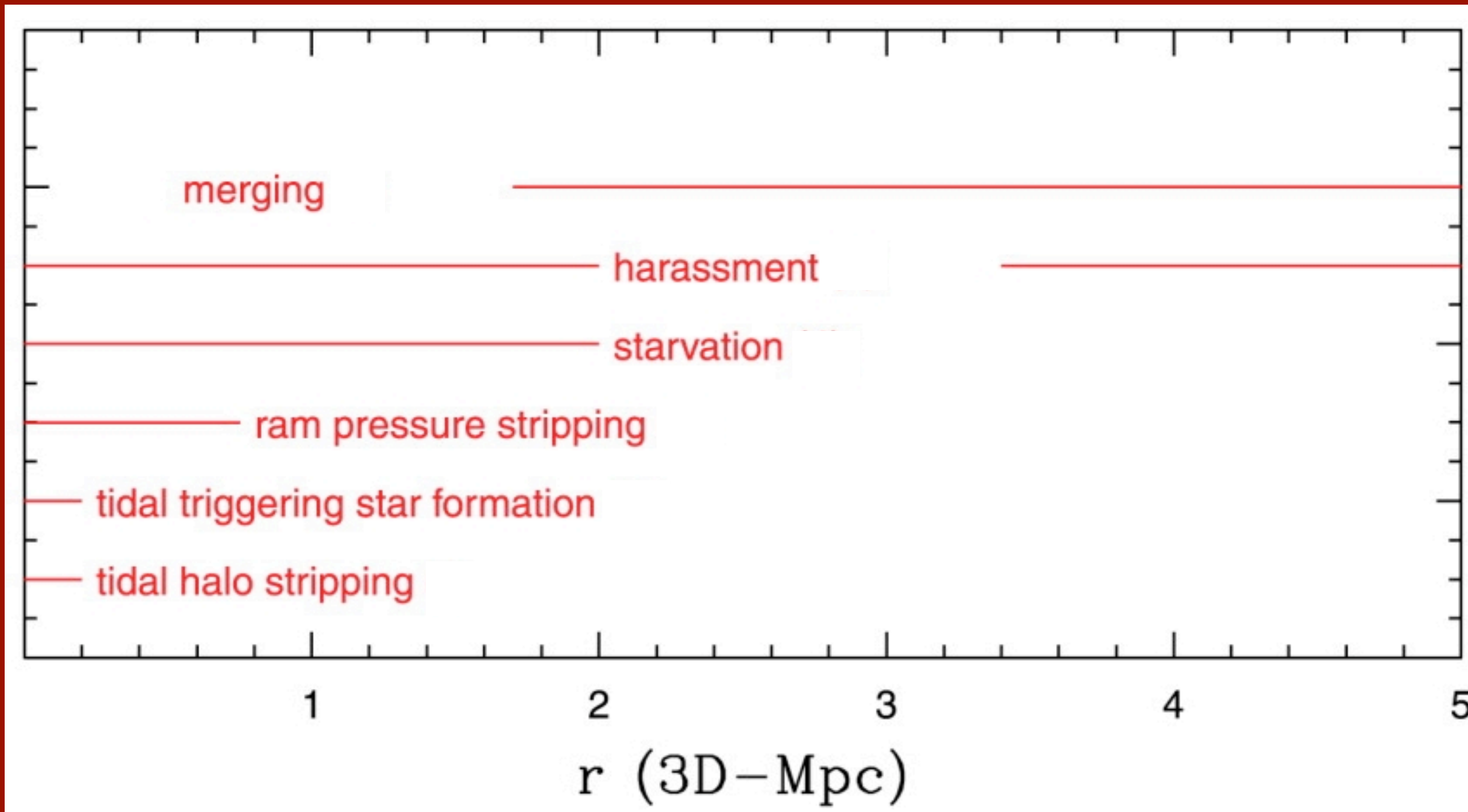
Restoring force:

$F/A = 2\pi G \sigma_s \sigma_g$

For typical galaxies, v~1000 km/s can strip their cold gas

Sun et al. (2004)

Galaxy Evolution in Clusters



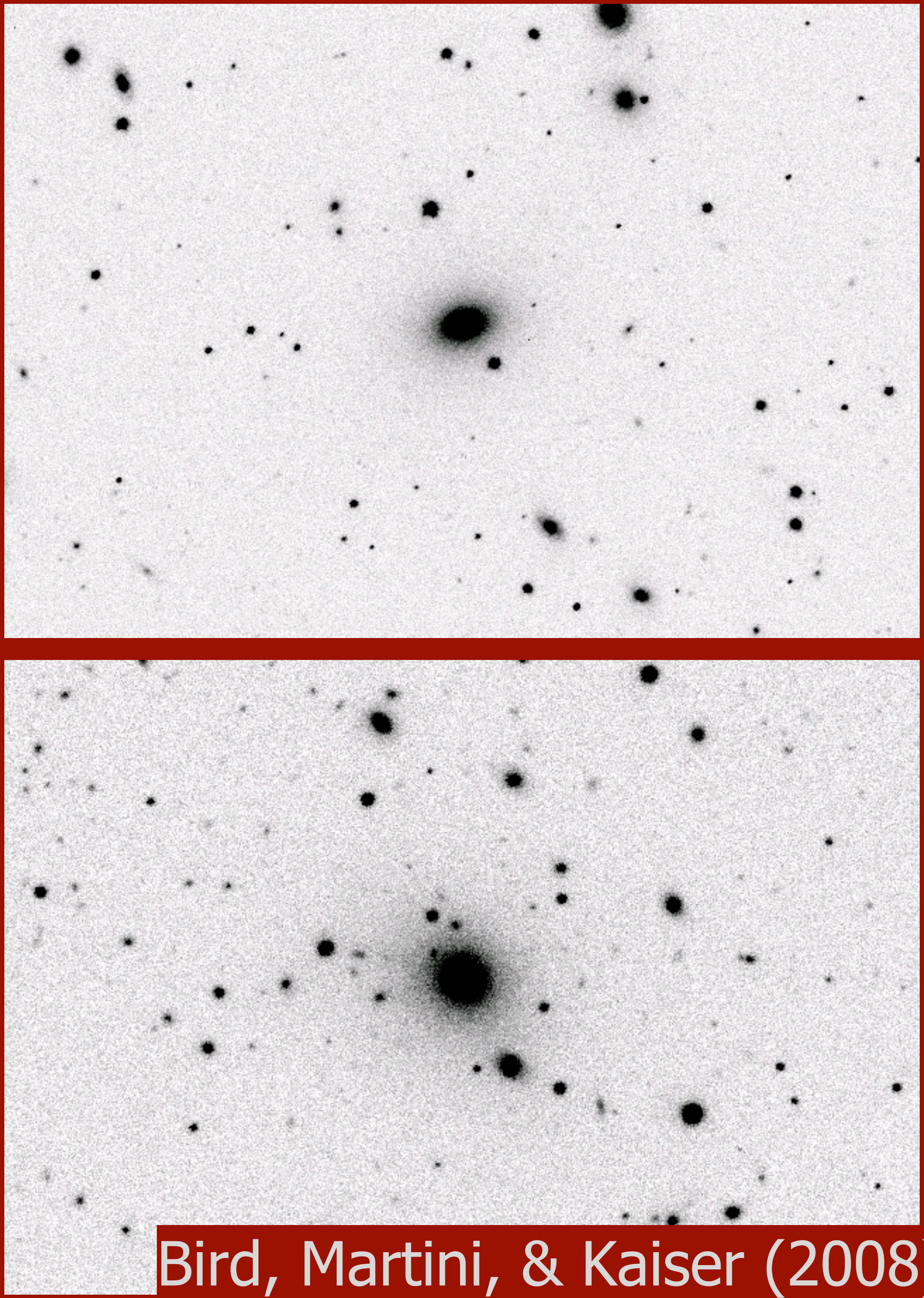
Do these processes similarly affect AGN evolution?

From Treu et al. (2003)

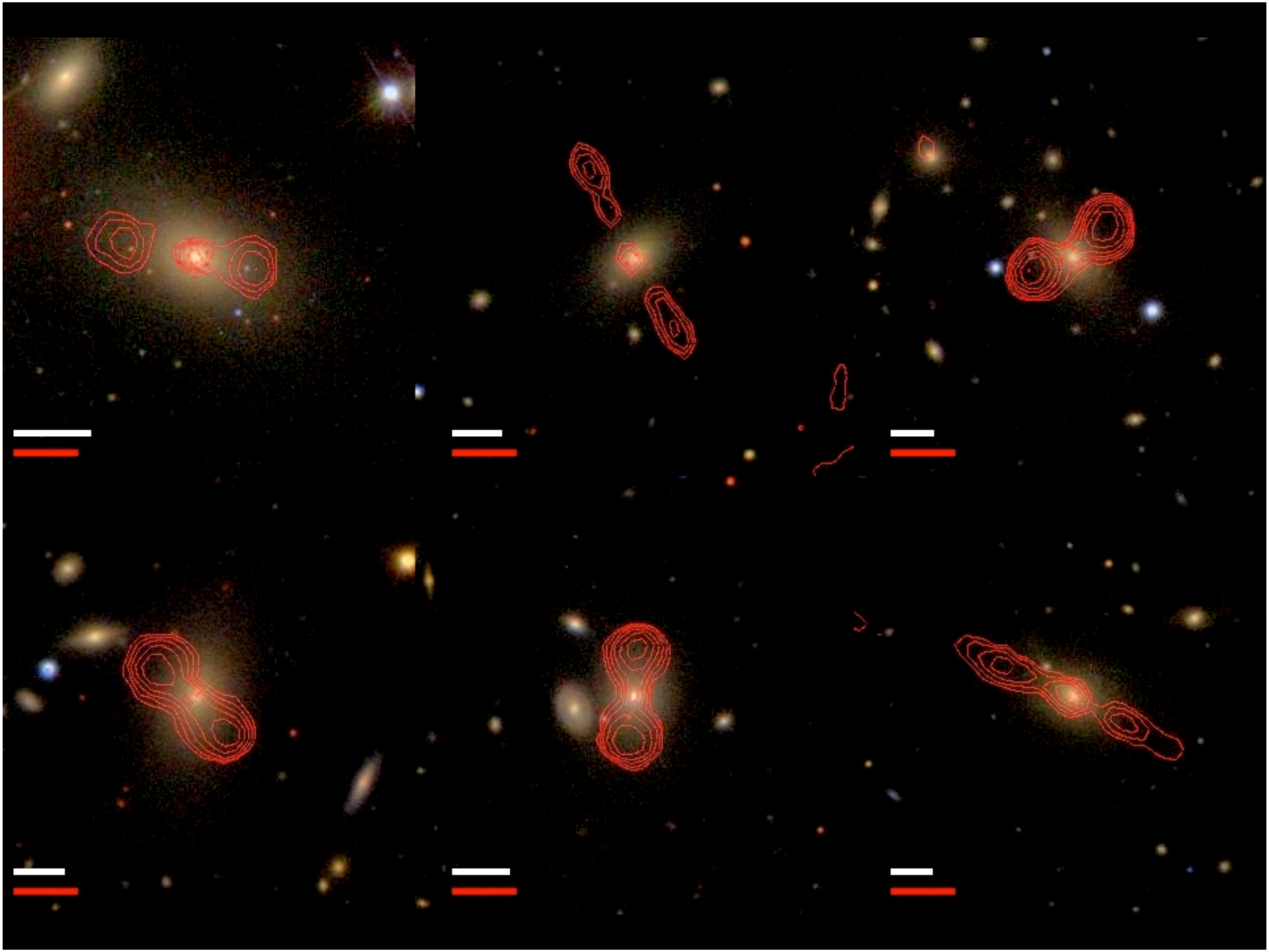
Lifetime of Radio AGN in Groups & Clusters

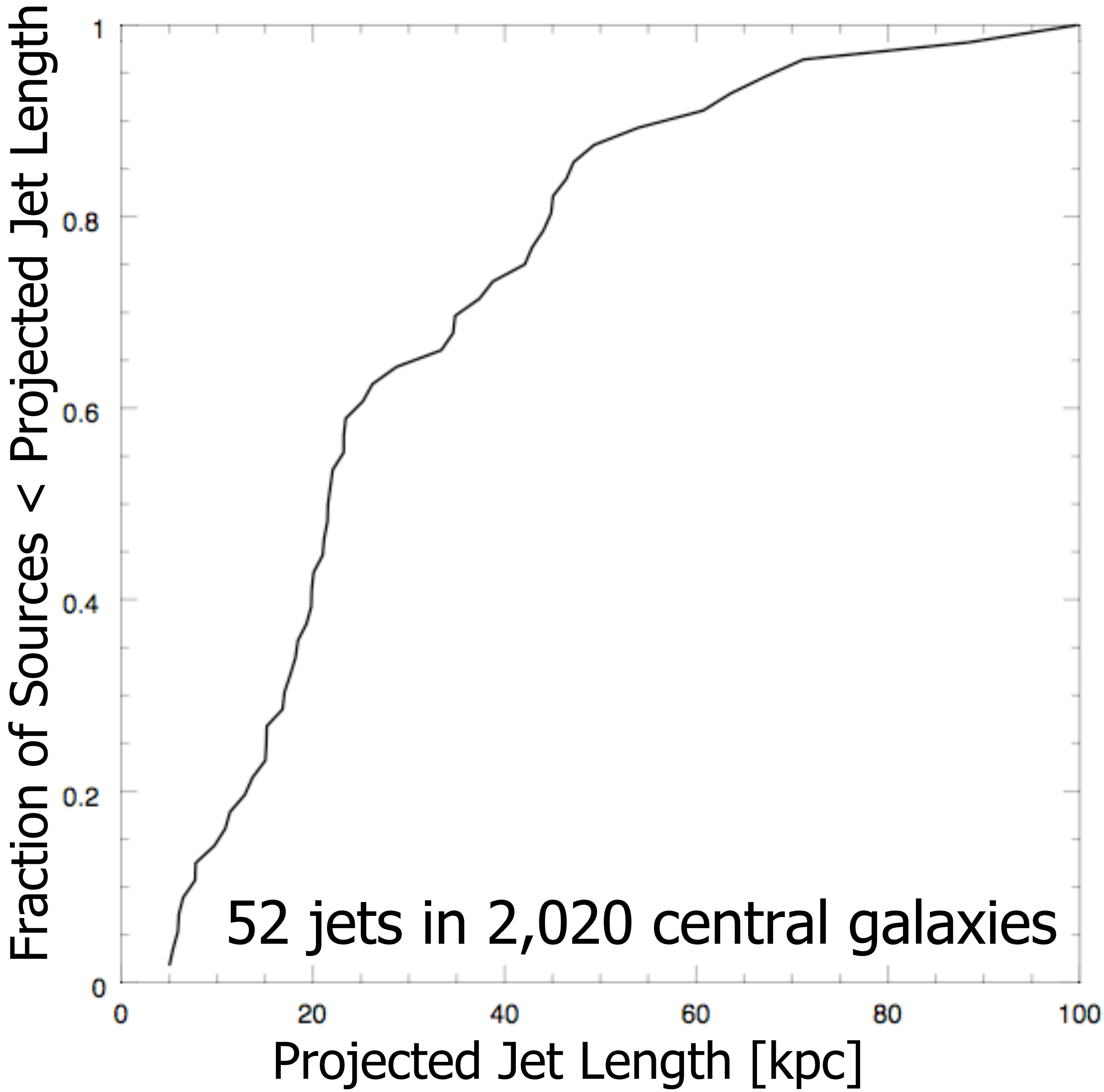
Demographics

- Berlind et al. (2006) SDSS catalog
  - 3945.1□°
  - 57,138 galaxies to z=0.1
  - Complete to M_r= -19.9
- Magnitude cut:
  - $M_r \leq$ -22.0 ~2000 groups
- Cross-correlate central group/cluster galaxy with FIRST



Bird, Martini, & Kaiser (2008)





Fraction of Sources < Projected Jet Length
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
52 jets in 2,020 central galaxies
Projected Jet Length [kpc]

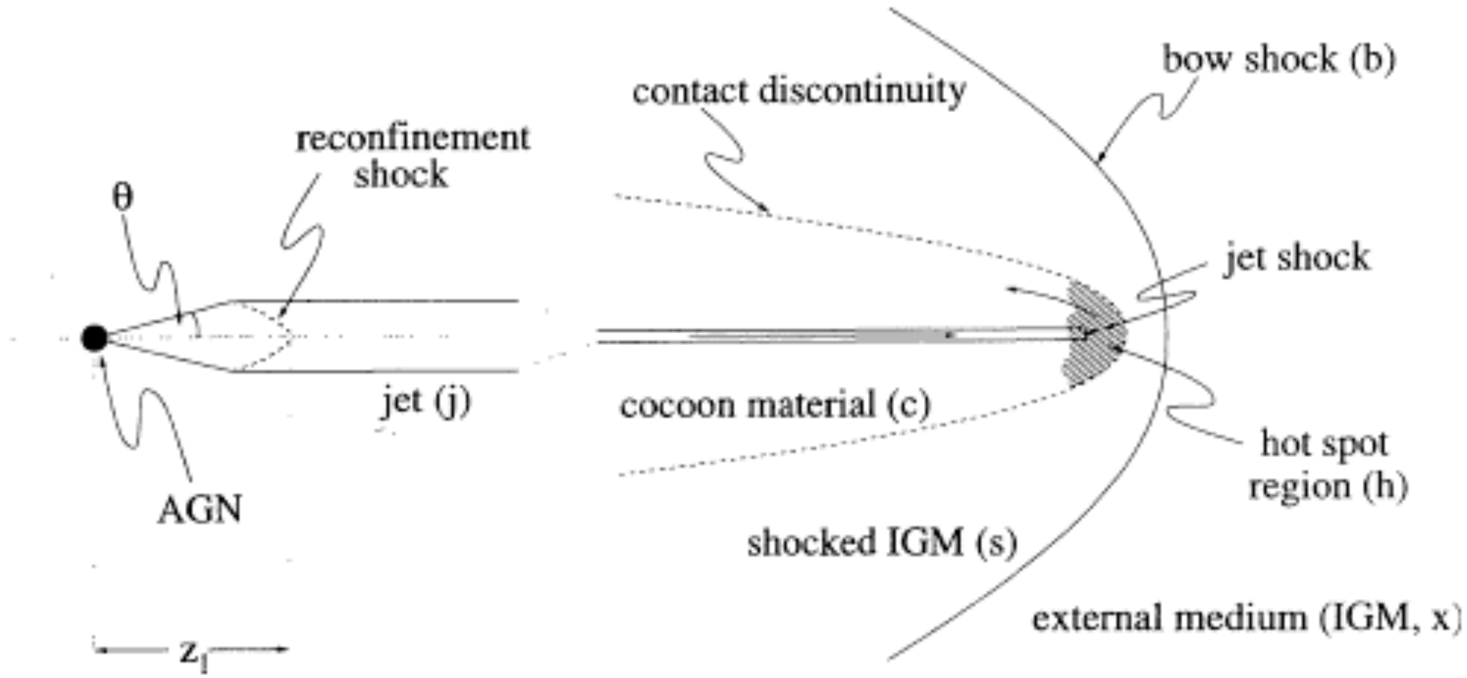
Mock Catalogs

Create a mock catalog of 100,000 jets

Assign each a random age up to t_{max}

Calculate how much they have faded as they age with the Kaiser et al. (1997) self-similar analytic model for jet evolution (FRIIs)

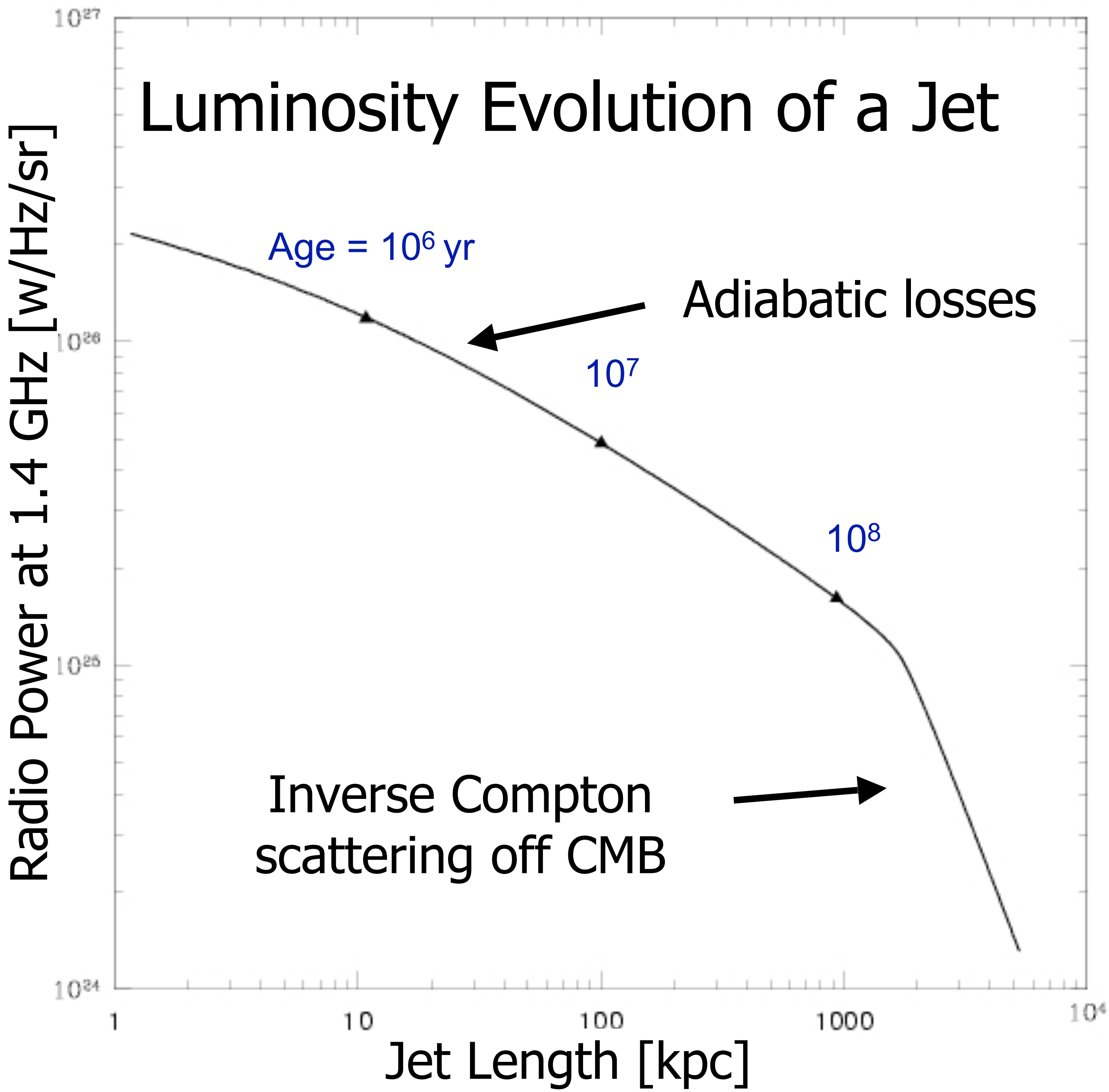
Model Jet Structure



Jet of relativistic fluid from the AGN

Strong magnetic field in cocoon around jet shock produces synchrotron emission

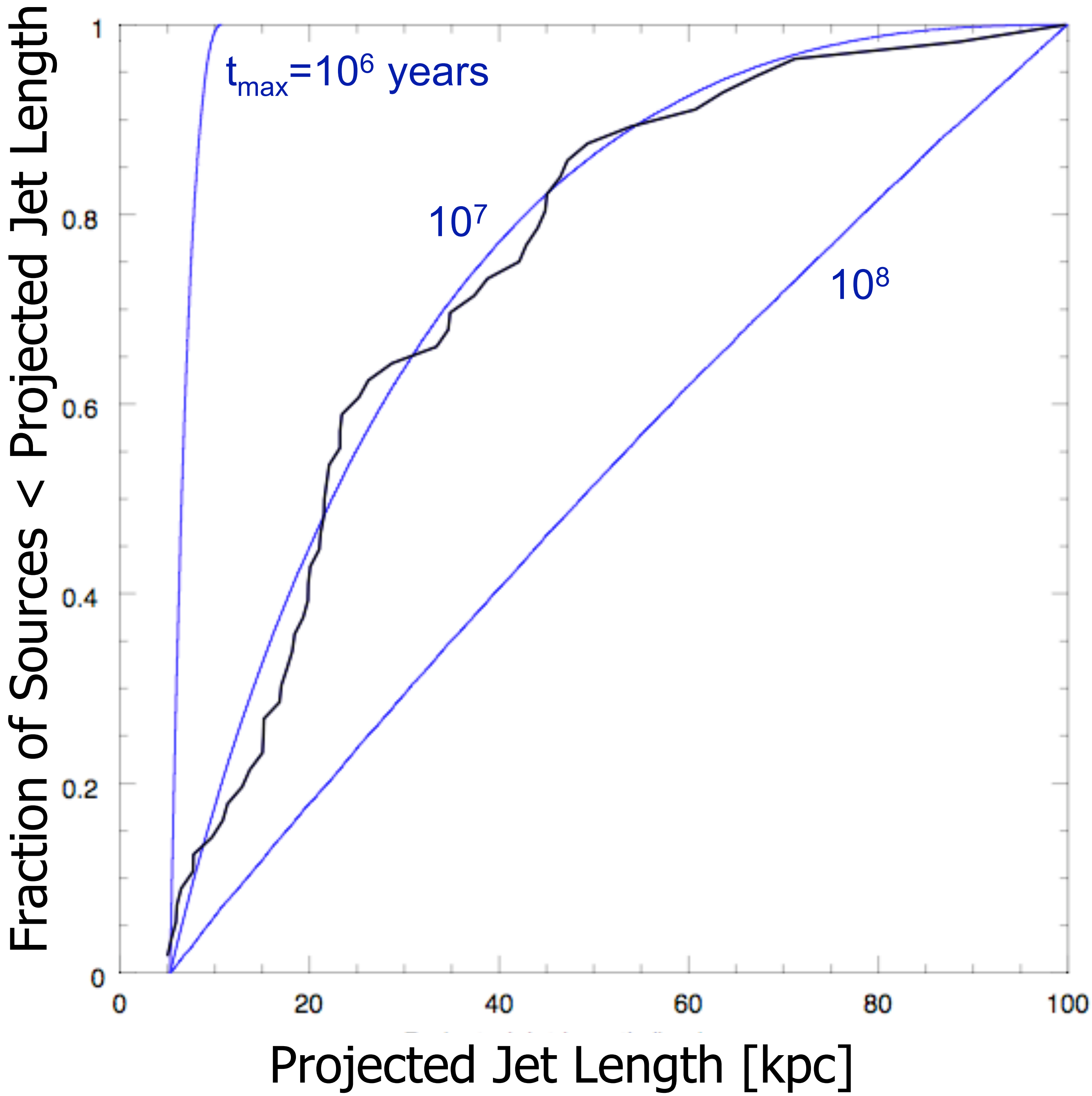
Kaiser & Alexander (1997)



Luminosity Evolution of a Jet
Age = 10^6 yr
Adiabatic losses
10^7
10^8
Inverse Compton
scattering off CMB
Radio Power at 1.4 GHz [w/Hz/sr]
Jet Length [kpc]
10^27
10^26
10^25
10^24
1
10
100
1000
10^4

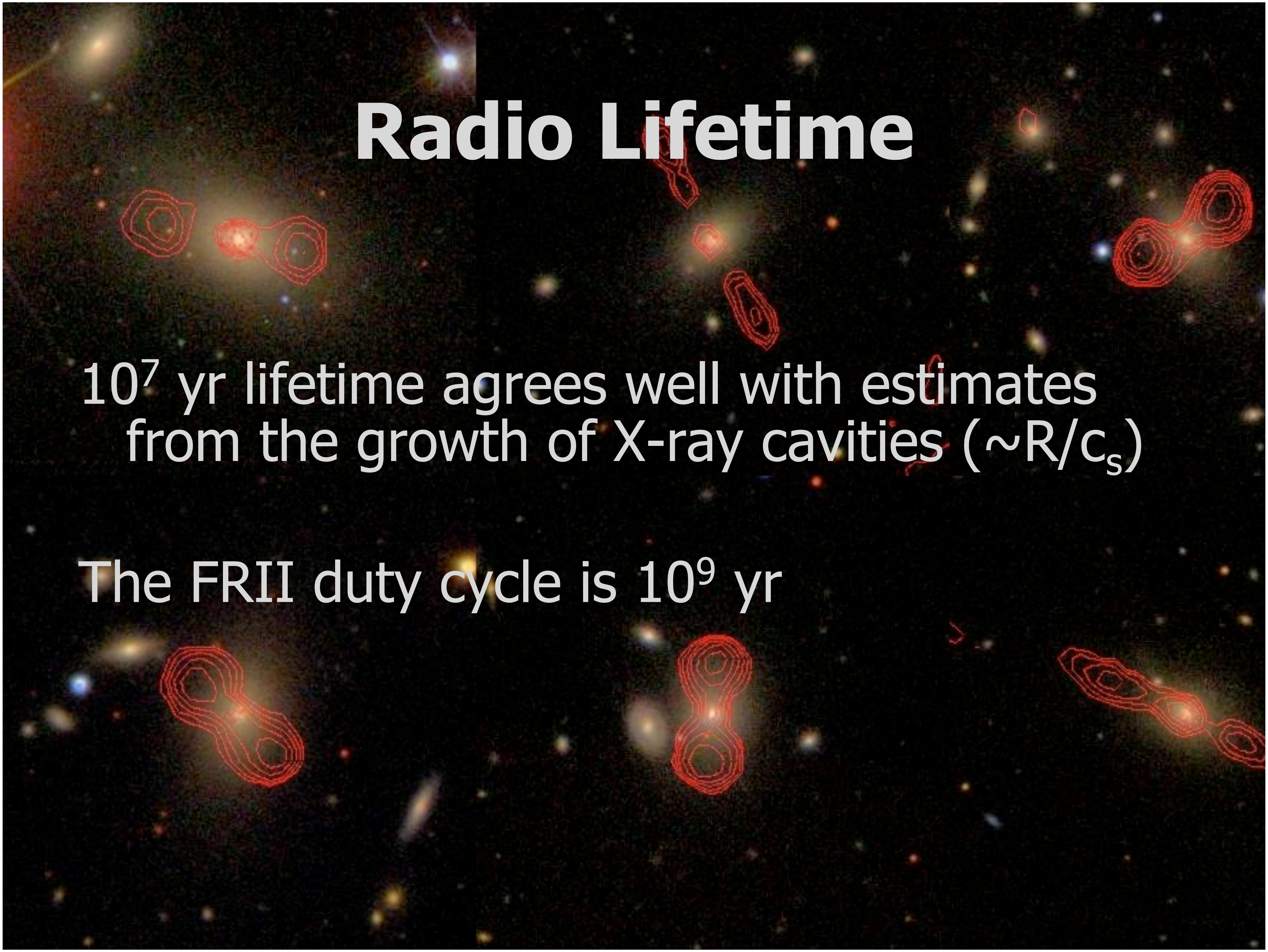
Mock Catalogs

- Create a mock catalog of 100,000 jets
- Assign each a random age up to t_{max}
- Calculate how much they have faded as they age with the Kaiser et al. (1997) self-similar analytic model for jet evolution (FRIIs)
- Constrain the initial power distribution to match the local RLF (Sadler et. al 2006)
- Redshift distribution matches the groups
- Random projection on the sky
- Flux, size must meet FIRST selection



Bird, Martini, & Kaiser (2008)

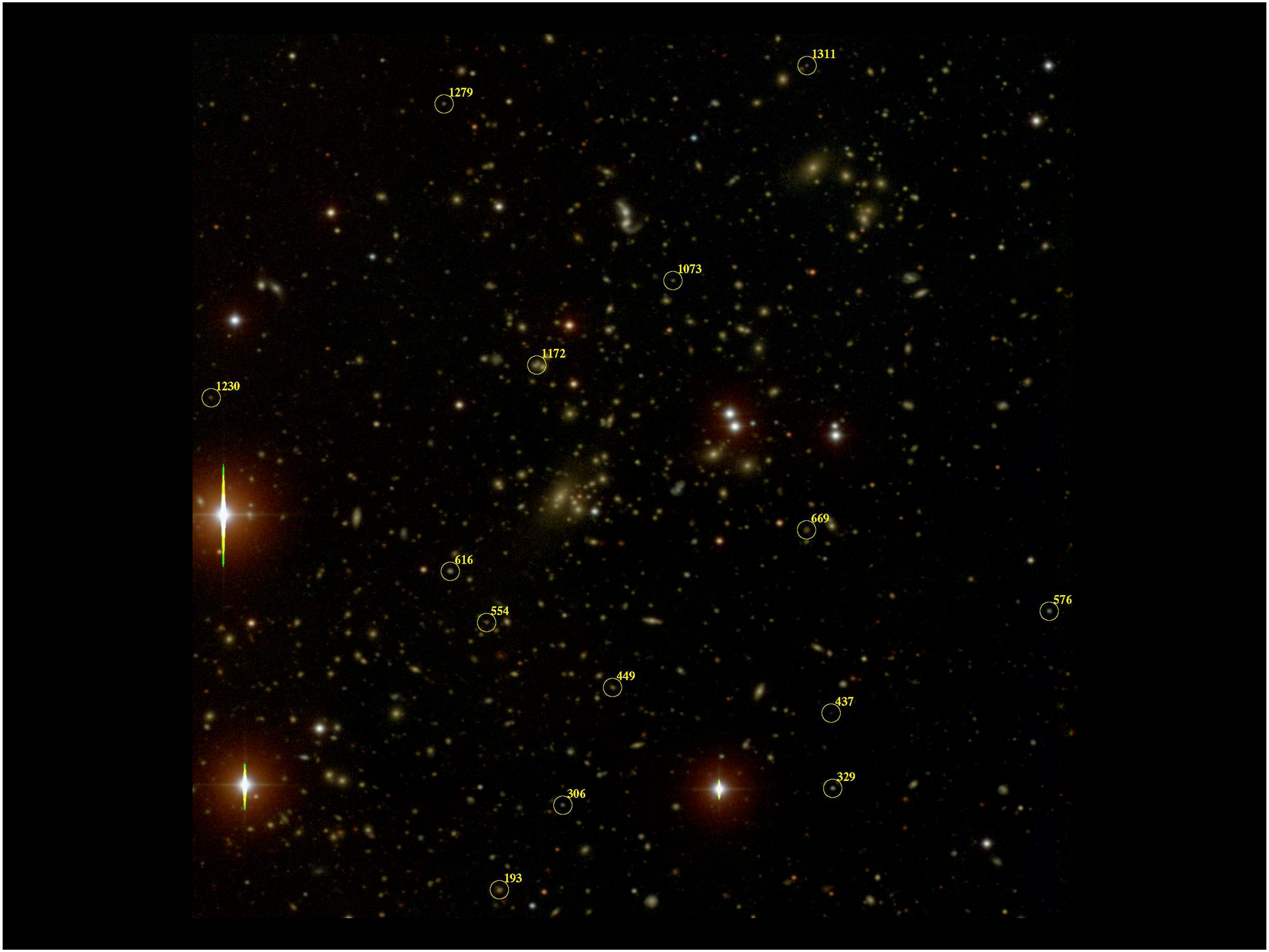
Radio Lifetime



10^7 yr lifetime agrees well with estimates from the growth of X-ray cavities ($\sim R/c_s$)

The FRII duty cycle is 10^9 yr

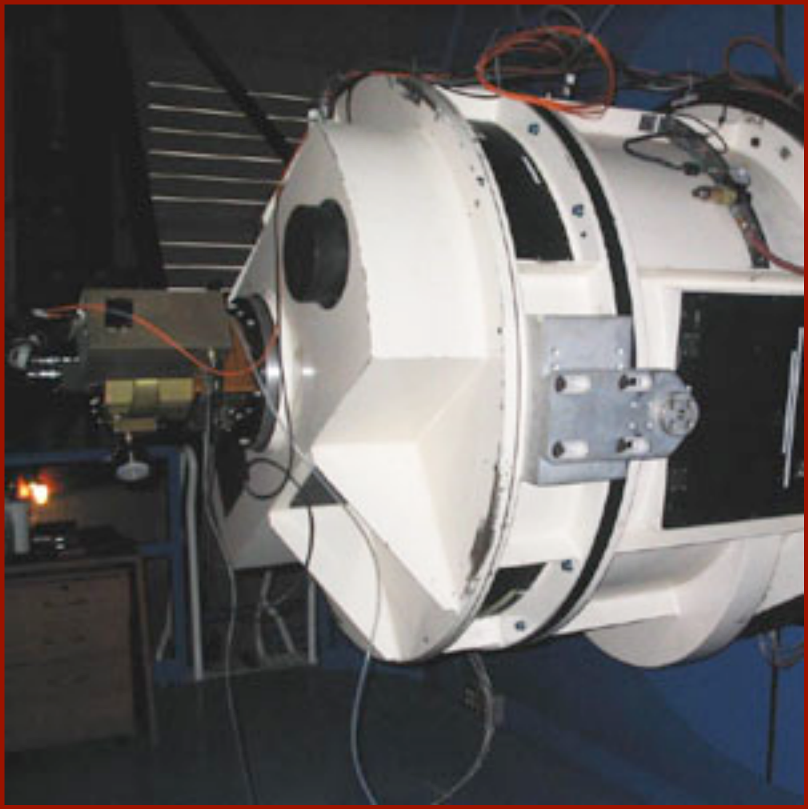
Distribution of AGN within Clusters



1311
1279
1073
1172
1230
669
616
576
554
449
437
329
306
193

Spectroscopy of Candidates

Magellan 6.5m Telescopes



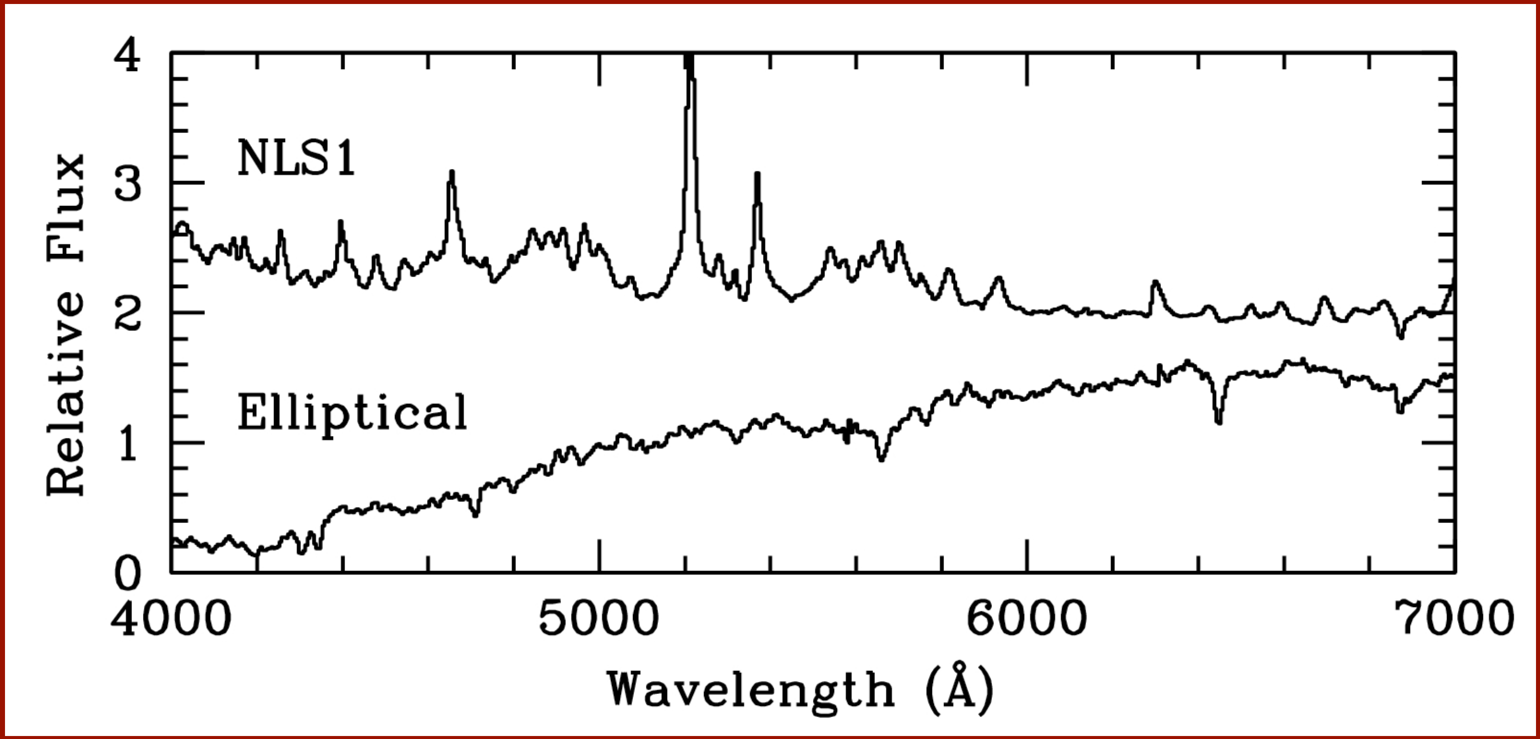
LDSS Multi-Object Spectrograph

Las Campanas Observatory, Chile

Spectroscopic Confirmation

Identified a total of 57 cluster members with X-ray emission in eleven clusters of galaxies.

Only 6/57 have AGN spectral signatures – *almost all would not be classified as AGN in a purely spectroscopic survey*

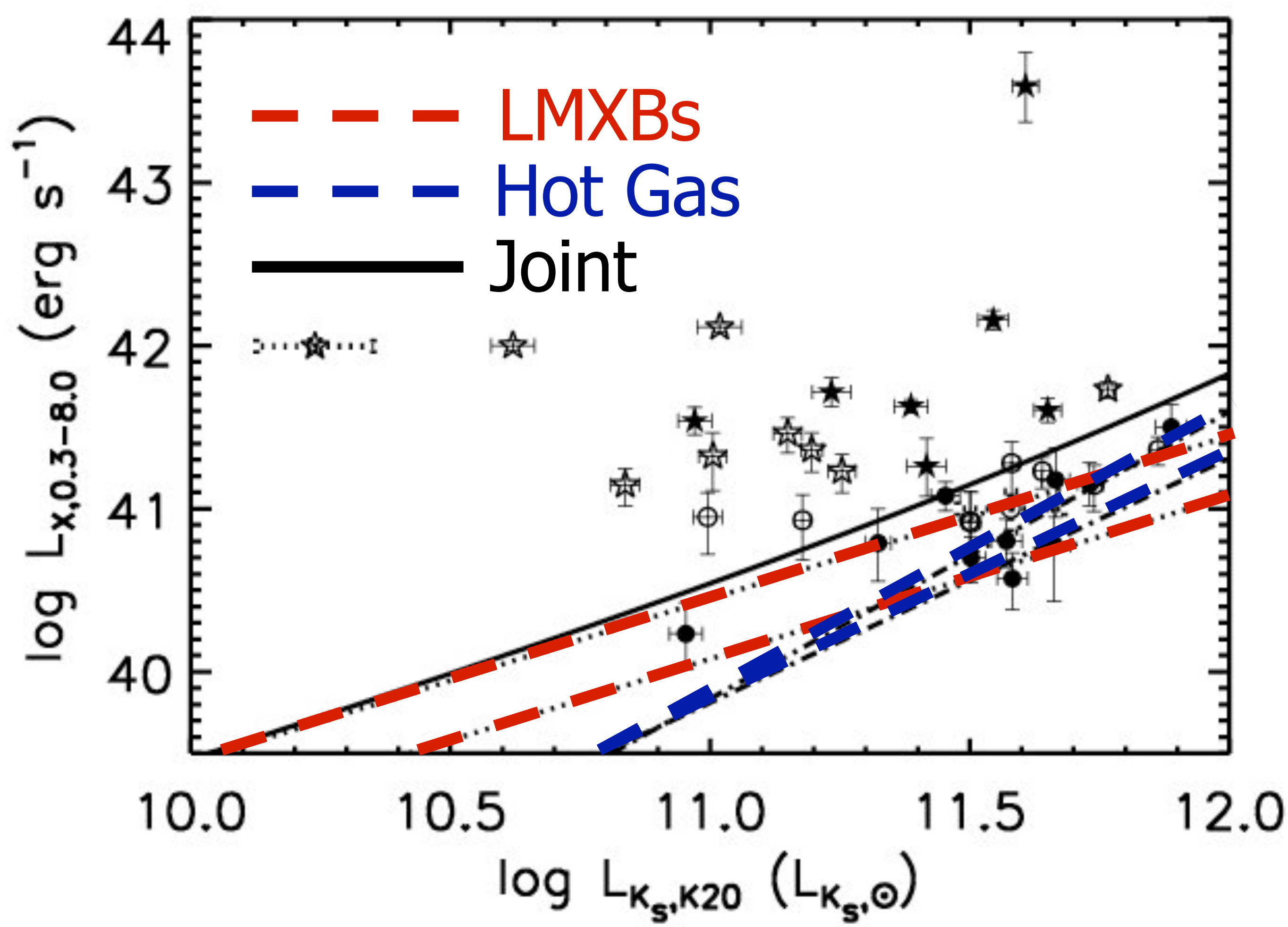


Martini et al. (2006)

Sources of X-ray Emission

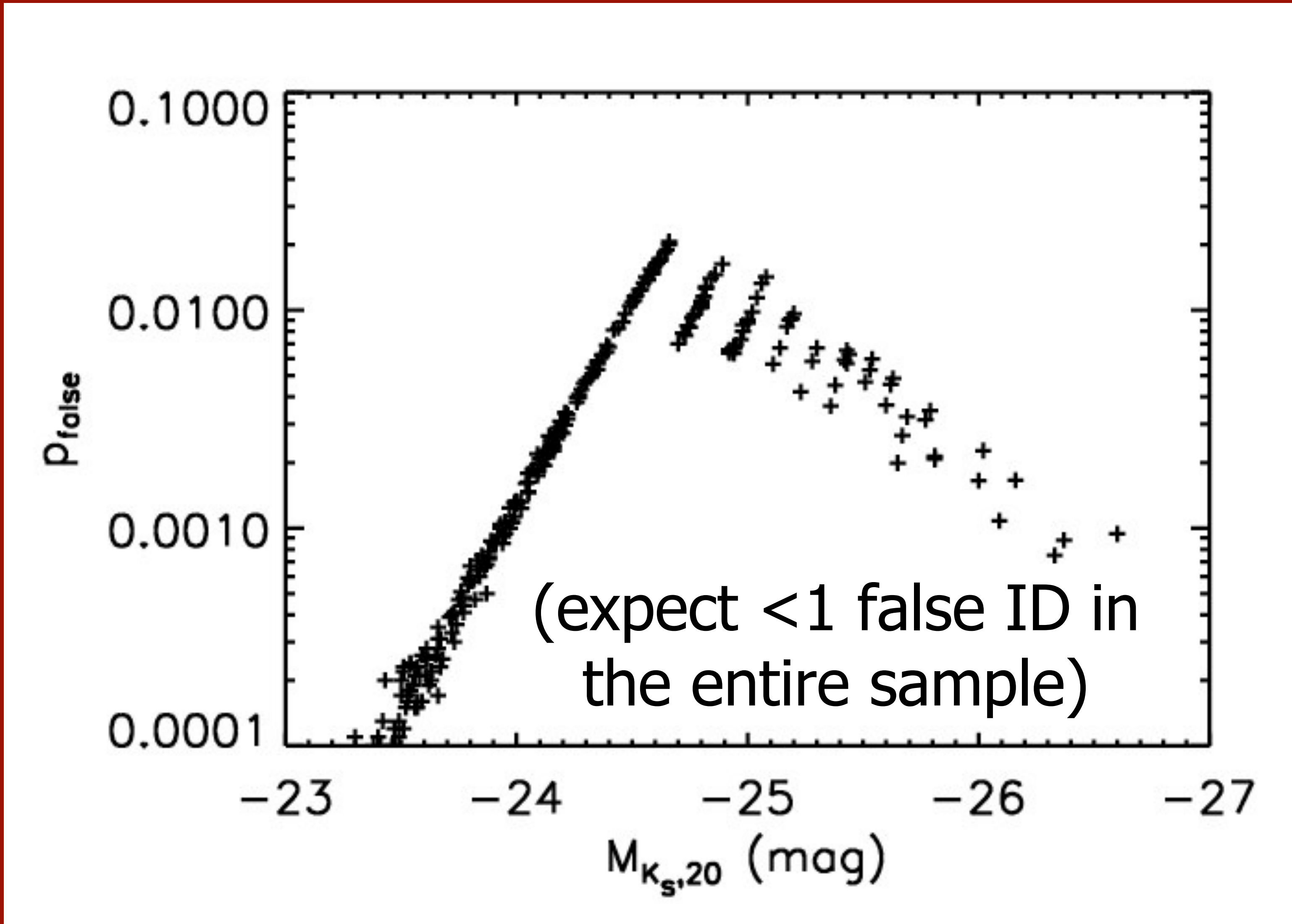
1. Accretion onto supermassive black holes
   - evidence that galaxies retain cold gas
   - can easily produce $L_X > 10^{42}$ erg/s
2. Low mass X-ray binaries
   - can produce $L_X < 10^{41}$ erg/s in massive galaxies
3. Hot X-ray halos
   - interesting if still present in cluster ellipticals
   - may be as luminous as $L_X \sim 10^{41}$ erg/s
4. Starbursts
   - rare in clusters and would exhibit strong [OII], etc.
   - the most extreme local starbursts have $L_X \sim 10^{41}$ erg/s

AGN Identification



Sivakoff et al. (2008)

Probability of False ID

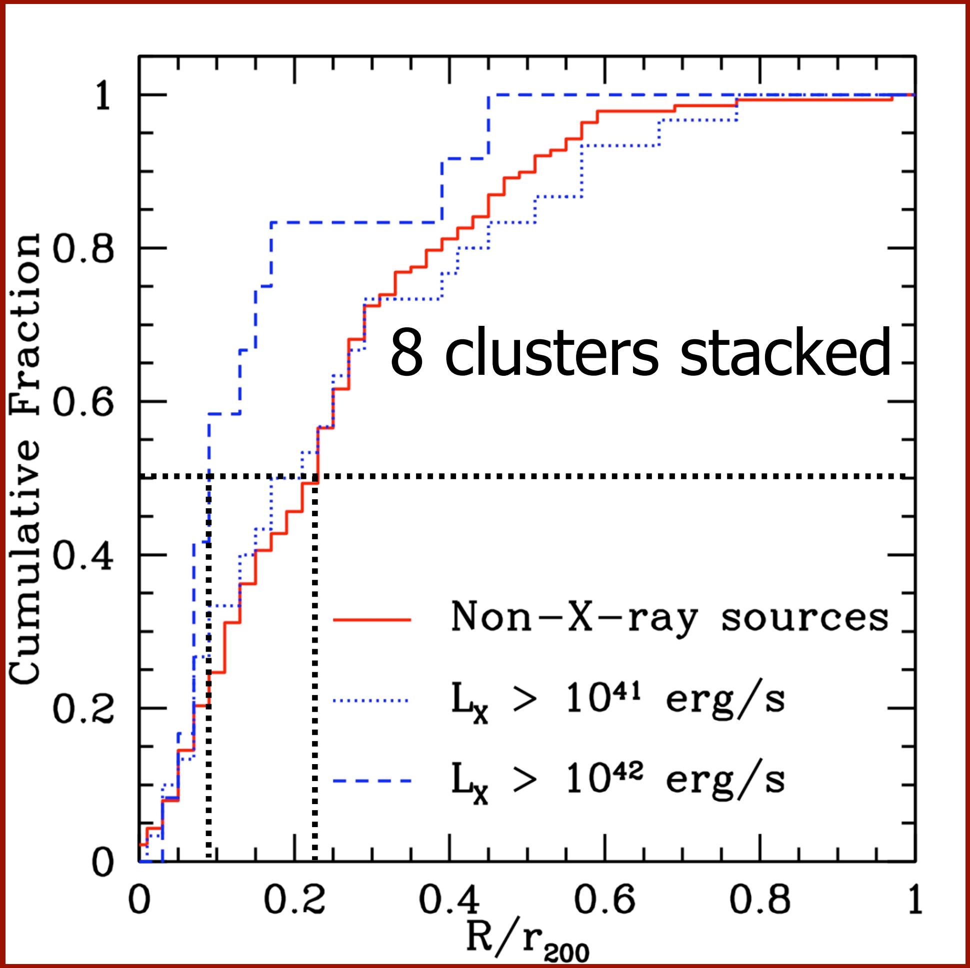


Sivakoff et al. (2008)

Centrally Concentrated AGN

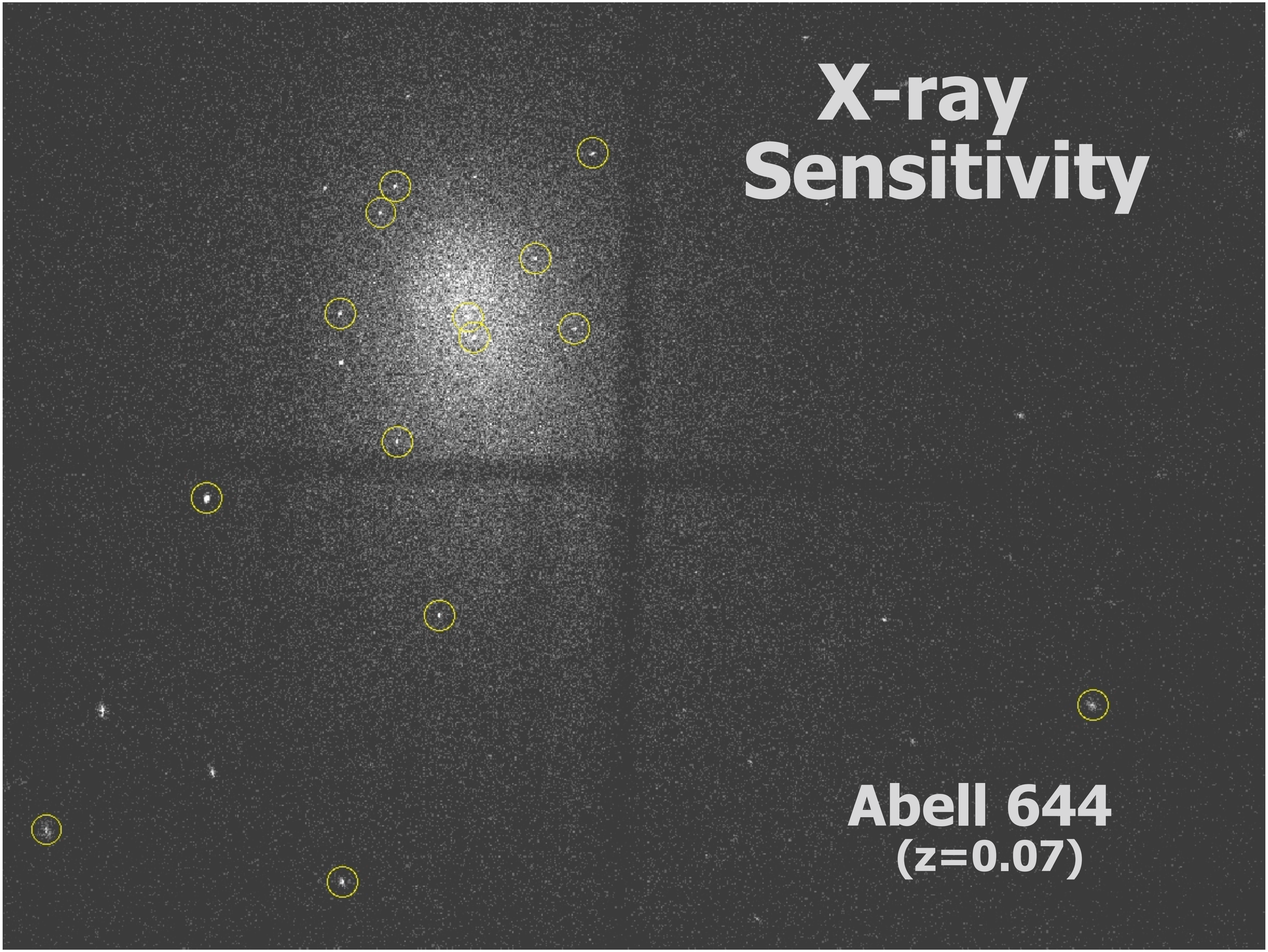
Luminous AGN are more centrally concentrated
50% within 0.1 r_{200}

Non-X-ray sources are all galaxies with M_R<-20



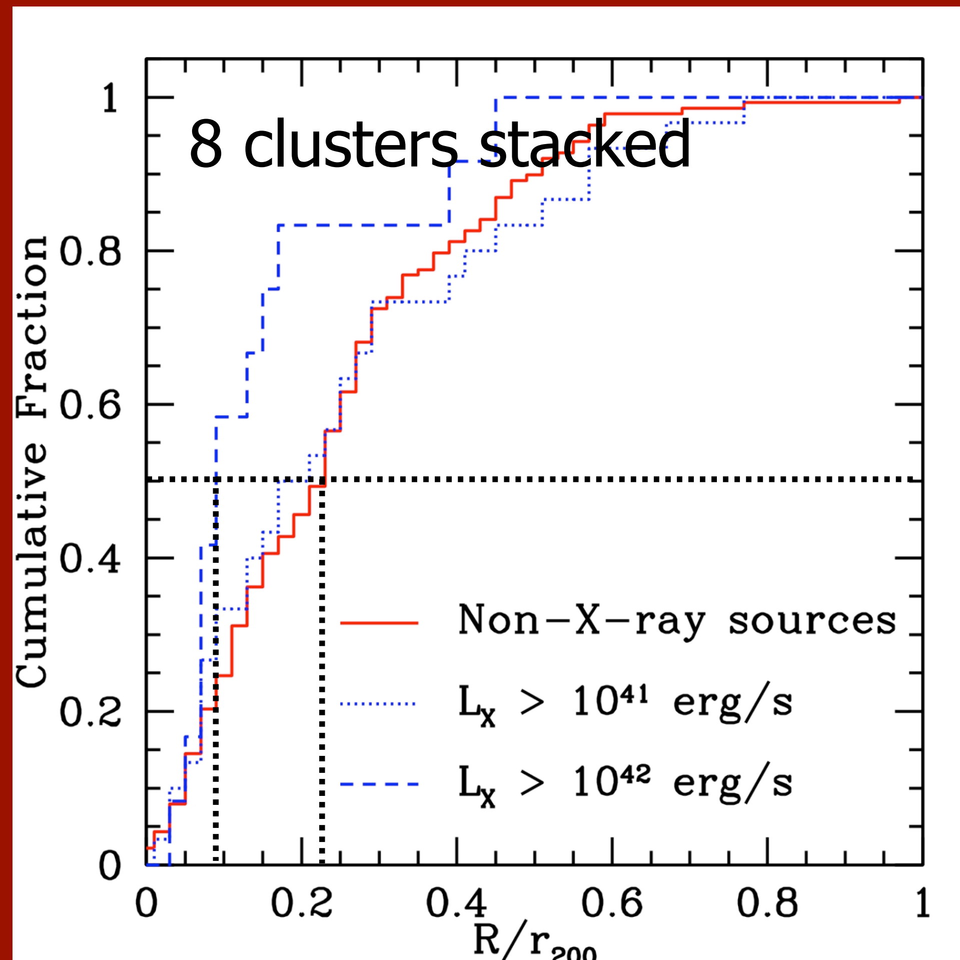
Does not include BCGs
Most data only extend to 0.5 r_{200}

Martini et al. (2007)


X-ray
Sensitivity
Abell 644
(z=0.07)

Centrally Concentrated AGN

Implication: *the most luminous cluster AGN have been re-triggered, rather than are newly infallen, gas-rich galaxies*



Martini et al. (2007)

AGN Fraction Measurement

Abell 3128 (z=0.06)

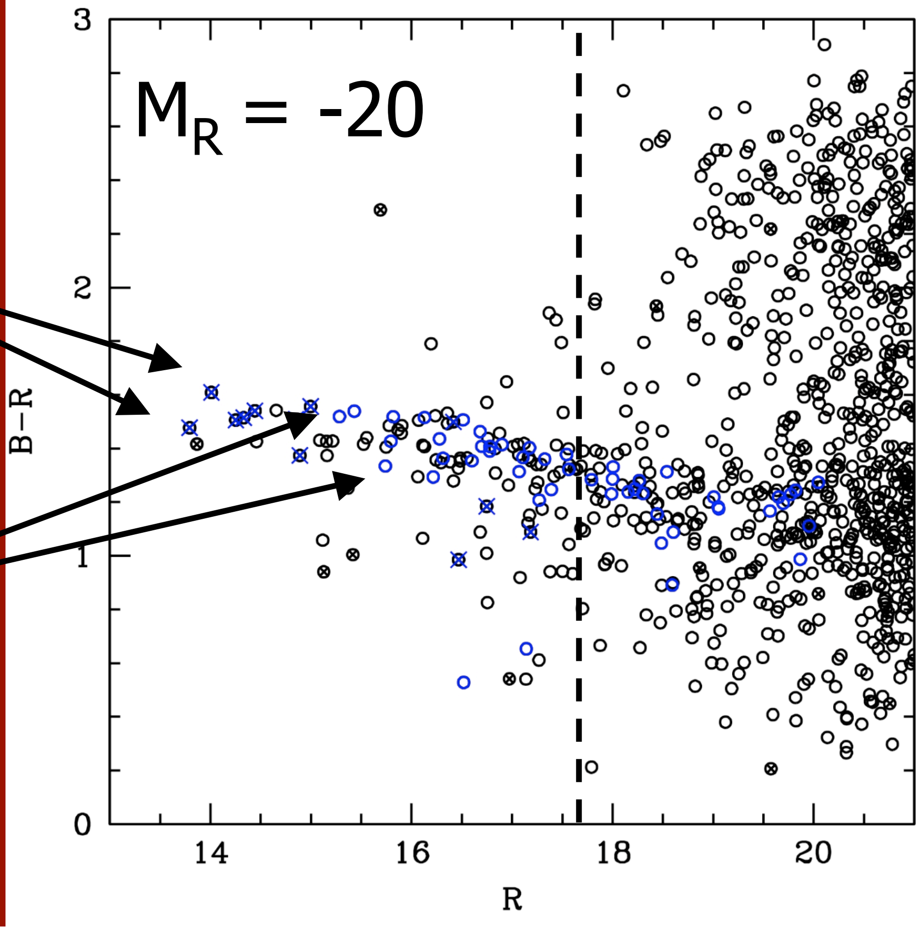
$$f_A = \frac{N_X\ (L>L_X;\ M_R<-20)}{N_{gal}\ (M_R<-20)}$$

N_X

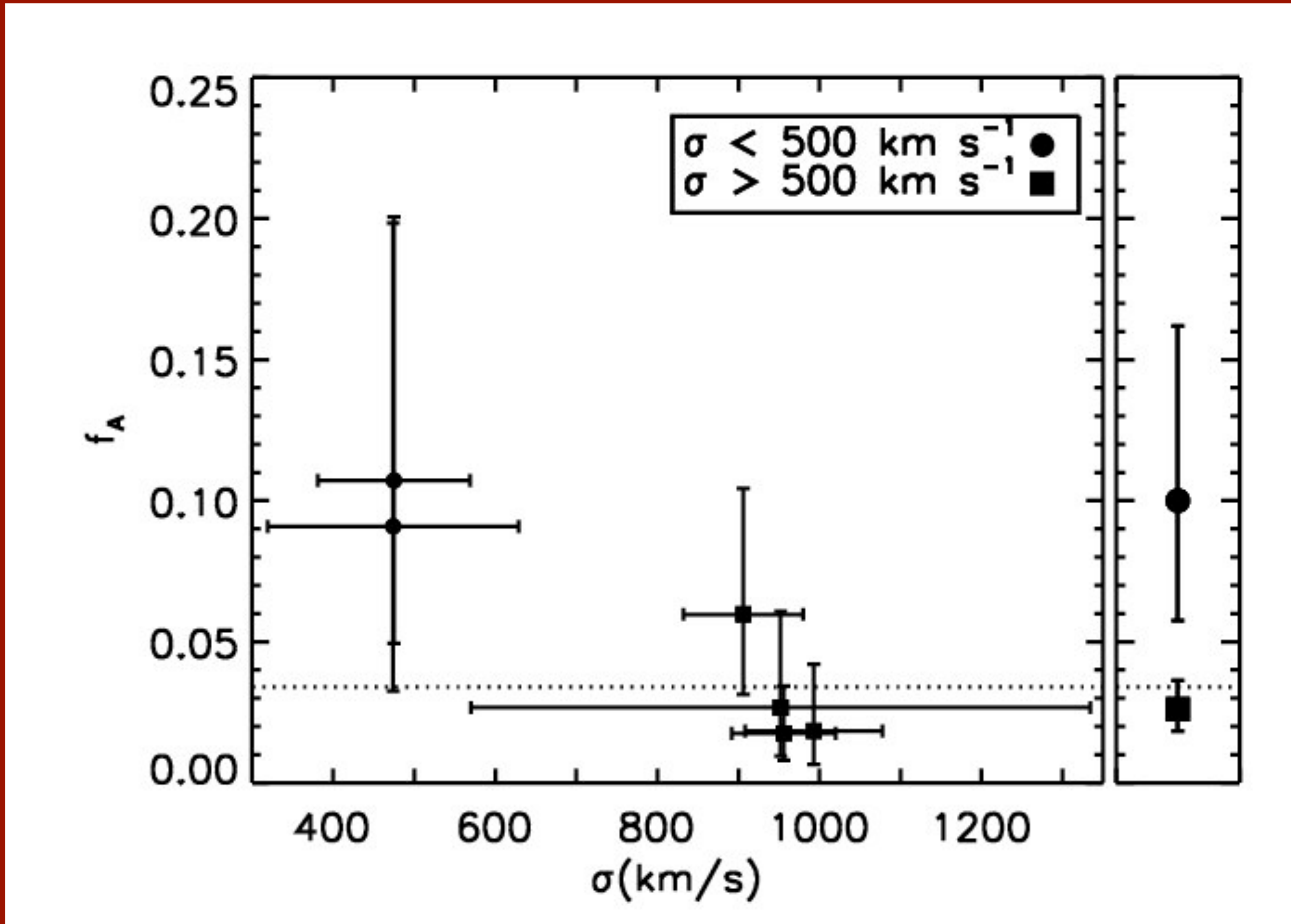
f_A = 5% for $L_X>10^{41}$
(8 clusters with z<0.3)

N_{gal}

This is 5x the Dressler et al. (1985) value



AGN Fraction vs. Environment

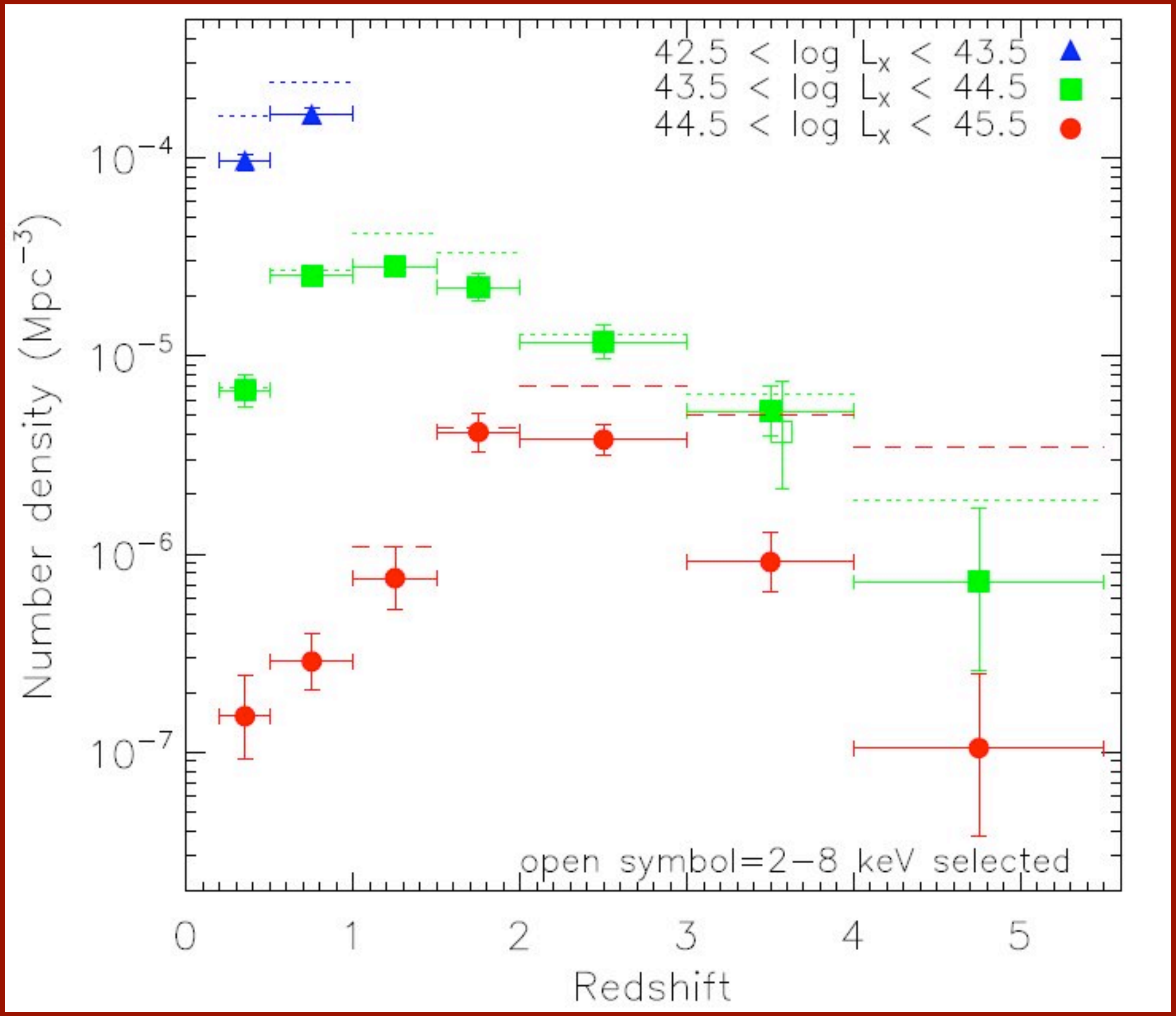


>95% probability they are different

Sivakoff et al. (2008)

Environment-Dependent AGN Evolution

Field AGN Downsizing



Silverman et al. (2008)

The Butcher-Oemler Effect

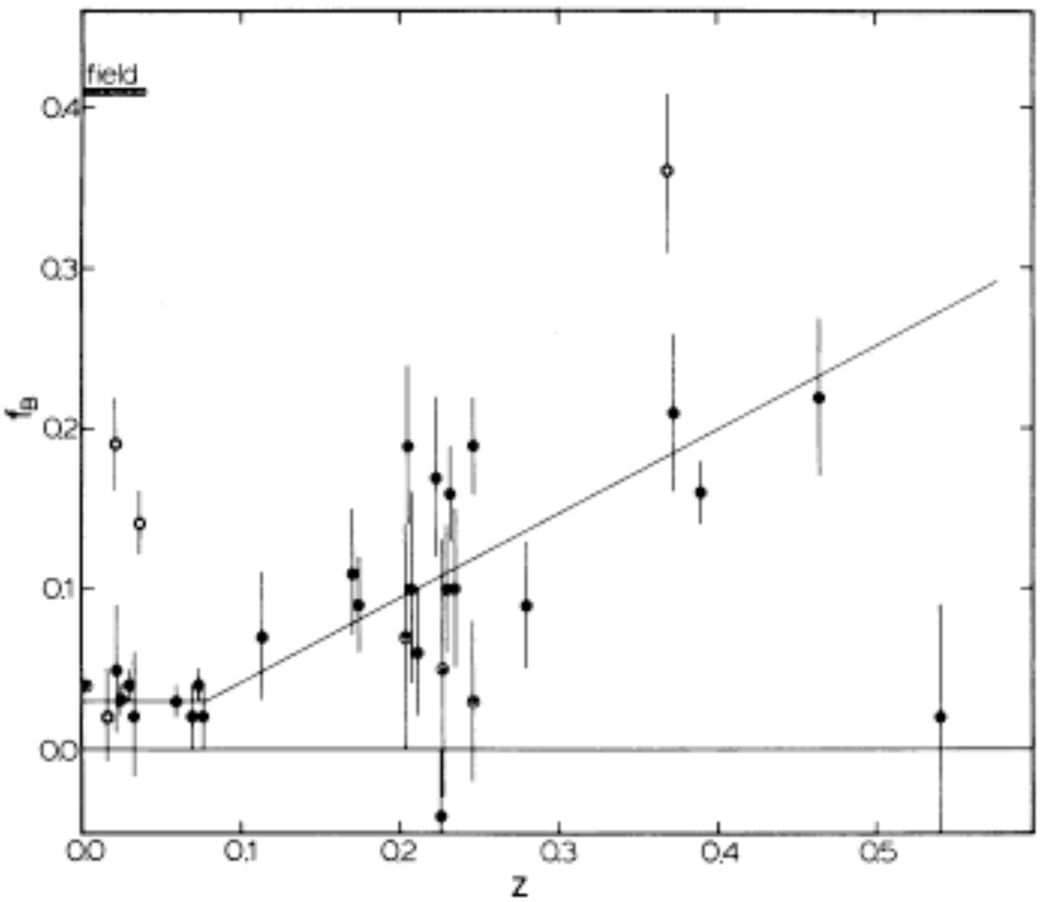


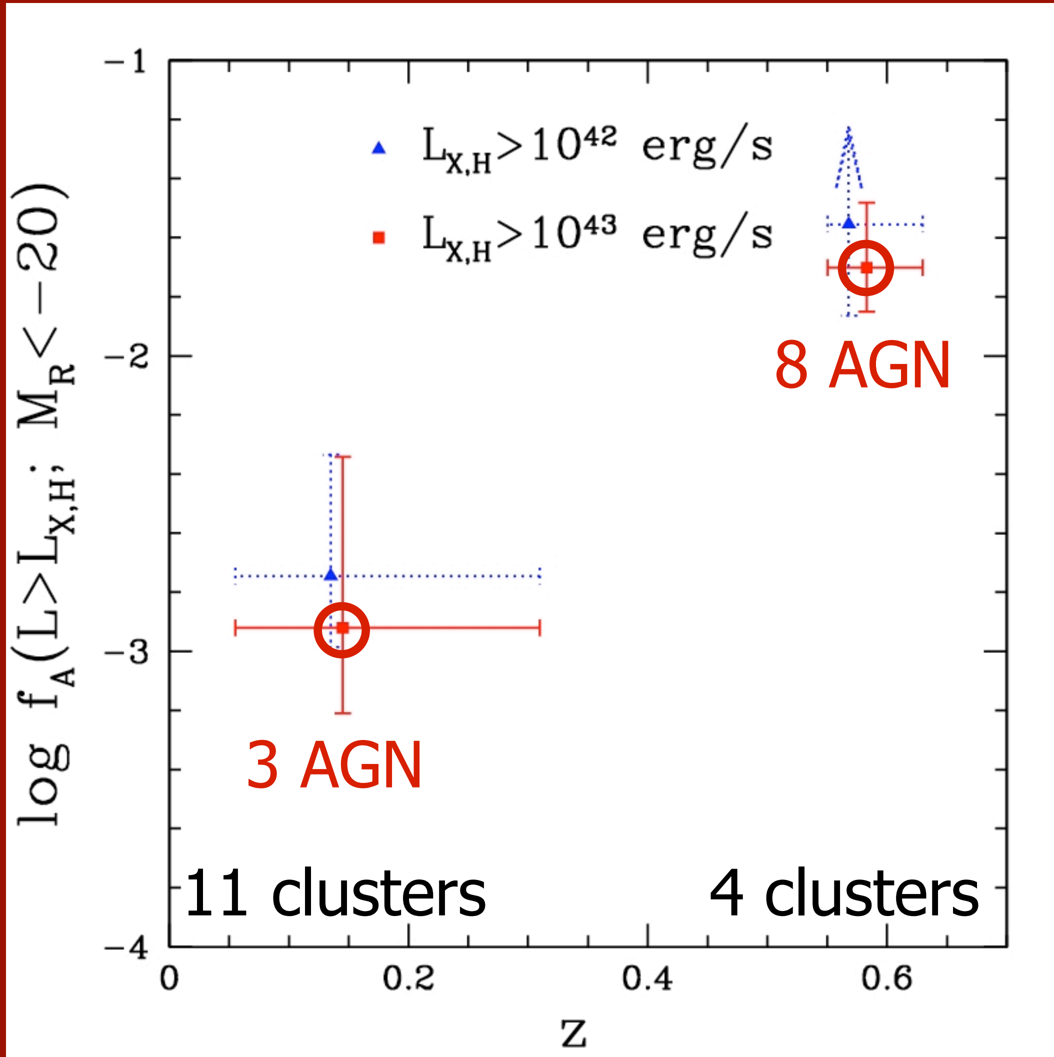
FIG. 3.—Blue galaxy fraction versus redshift. *Filled circles*, compact clusters ($C \geq 0.40$); *open circles*, irregular clusters ($C < 0.35$); *dotted circles*, intermediate clusters ($0.35 \leq C < 0.40$).

Butcher & Oemler (1984)

AGN in z>0.5 clusters

An AGN Butcher-Oemler Effect

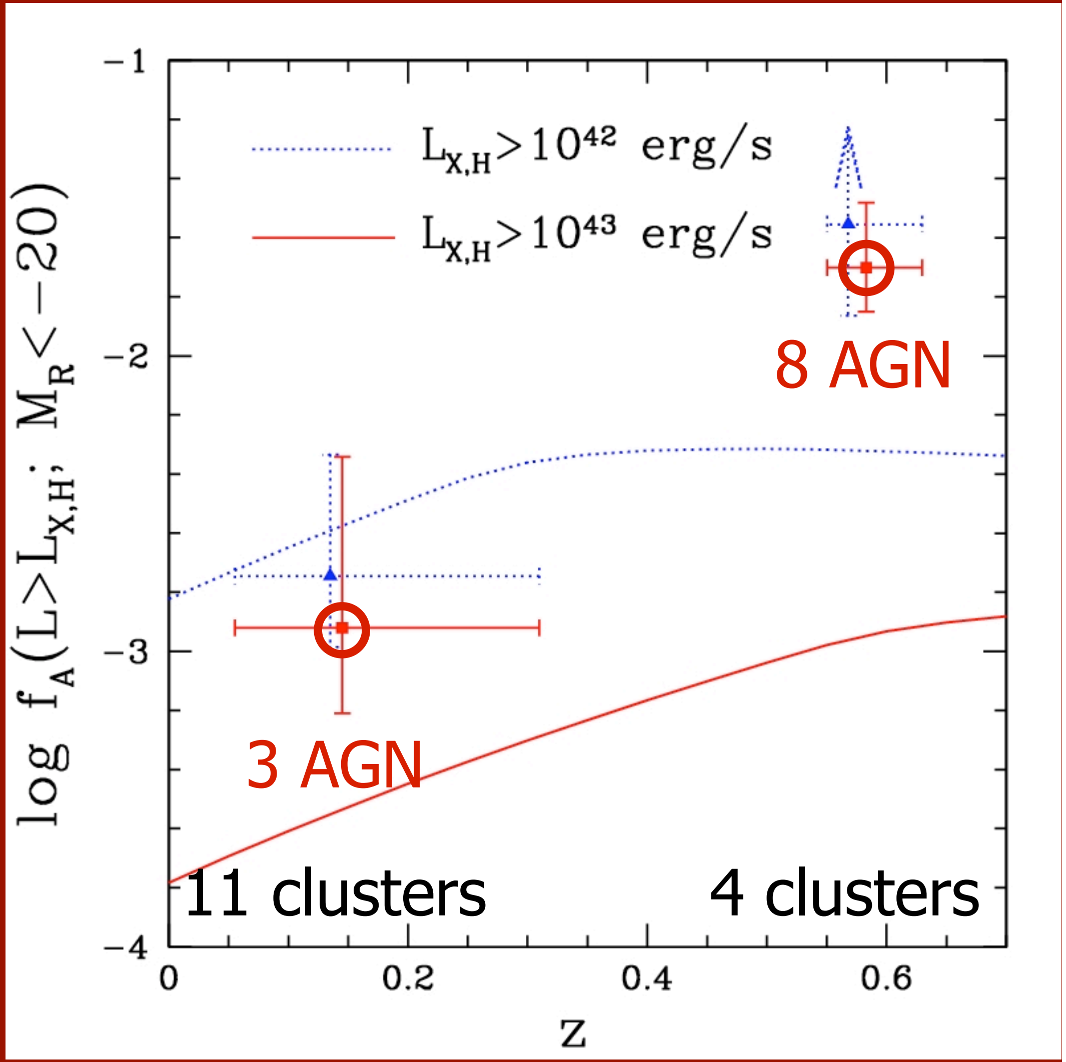
- Factor of ~15 increase in the cluster AGN fraction
- Due to systematics, this is likely an underestimate



Eastman et al. (2007) + Sivakoff et al. (2008)

Comparison to Field AGN

- More pronounced than the field evolution (Ueda et al. 2003)
- Evidence for environment-dependent AGN downsizing

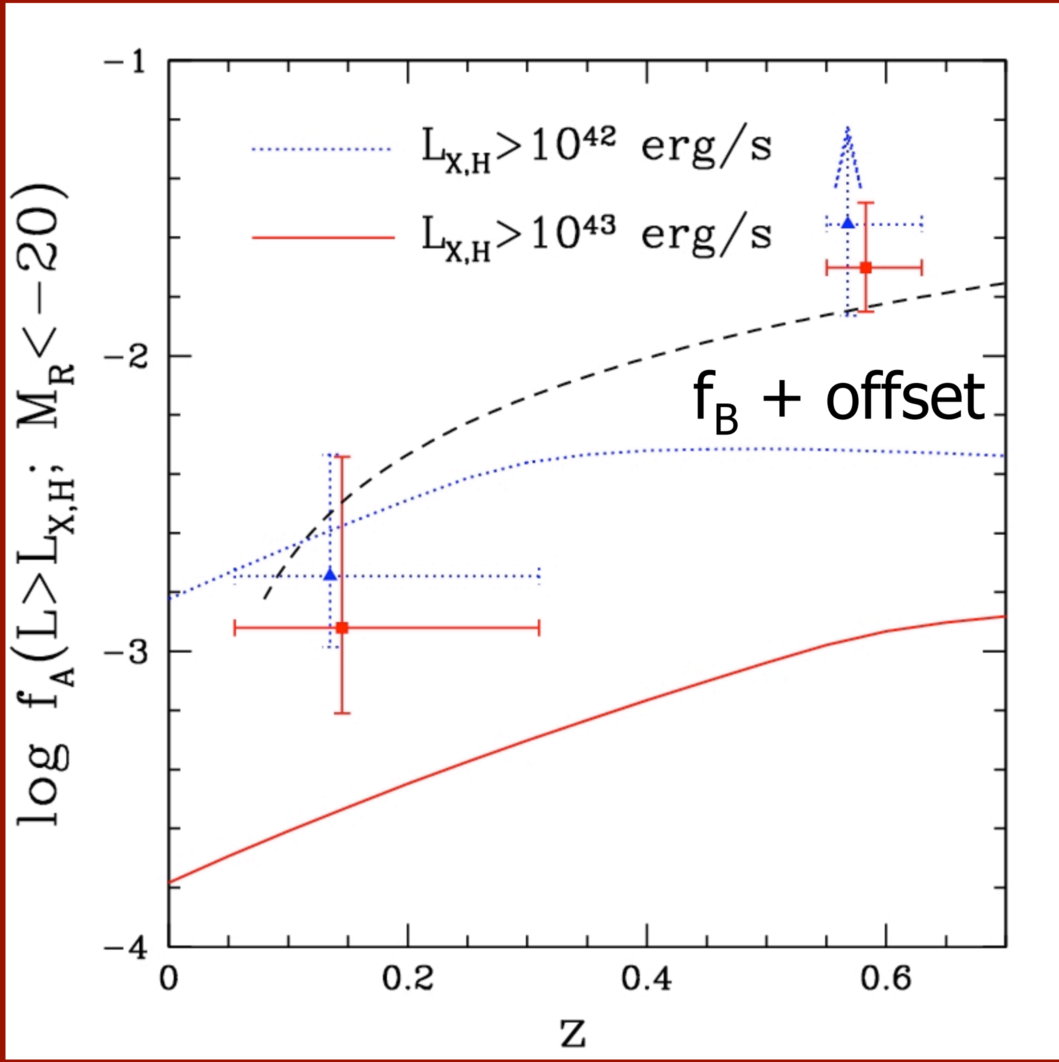


Eastman et al. (2007) + Sivakoff et al. (2008)

AGN and SFR Coevolution?

Rate of evolution is consistent with blue galaxy fraction

Do AGN quench star formation?
Does star formation quench AGN?



Eastman et al. (2007) + Sivakoff et al. (2008)

Summary

The FRII lifetime is $\sim 10^7$ yr, duty cycle is $\sim 10^9$ yr

More luminous AGN ($>10^{42}$ erg/s) are more centrally concentrated, suggestive of retriggering

The AGN fraction in clusters is higher than expected:

$$f_A(L_X > 10^{41} \text{ erg/s}, M_R < -20) \sim 5\%$$

AGN fraction is higher at lower velocity dispersion

There is an AGN Butcher-Oemler Effect

Environment-dependent AGN downsizing