Motivation

- Clusters of Galaxies: great laboratories to examine numerous effects on the host members and their supermassive black holes

  - Mergers,
  - Mass Segregation,
  - Tidal Effects,
  - Gas dynamics,
  - Shocks,
  - Strangulation,
  - Gas stripping,
  - Cooling Flows
We discuss the sample selection and radio data in Section 2.1. Our radio cluster sample consists of 183 clusters, selected from our 400+ X-ray CATS sample. This sample has been tripled since last year. Precise cluster masses and center of masses from high resolution Chandra X-ray observations have been used.

- 183 Clusters in FIRST footprint from our 400+ X-ray CATS sample
- Tripled our sample from last year!!!
- Precise cluster masses and center of masses from high resolution Chandra X-ray observations
FIRST Survey

- FIRST survey - 1.4 GHz VLA
  - $S > 3$ mJy
  - Complete
  - $L > 10^{23}$ W/Hz
    - avoid star formation contamination
- We developed an algorithm to combine multiple components into one source
  - Point Sources
  - Bipolar Outflows
  - Head-Tails
  - Extended emission & Relics
Radio AGN Model

- Differential Analysis to statistically remove the background radio sources

- Inhomogeneous Poisson Spatial Point Process (e.g. Baddeley et al. 2006)
  - We don’t bin the data into radius, cluster mass or redshift bins!
  - Probability of the data given particular model parameters
    \[ \ln P(D|\mu) \propto - \int_0^{R_{\text{max}}} \lambda(r|\mu)2\pi r dr + \sum_{i=0}^{N} \lambda(r_i|\mu) \]
  - Probability of the model given the data and model priors
    \[ \ln P(\mu|D) \propto - \int \lambda(r)2\pi r dr + \sum_{i=0}^{N} \lambda(r_i) + \ln P(\mu) \]
  - Use an MCMC to explore this likelihood space
Radio AGN Model

\[ \lambda(r) = \left( A_G \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \varepsilon^2)} e^{-\frac{r^2}{2(\sigma^2 + \varepsilon^2)}} + A_\beta \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-3/2\beta + 1/2} \right) \times D_A R_{500} (1 + z)^3 + C_{Bkg} \]

\[ \sigma = 2.2 \pm 0.2 \times 10^{-3} R_{500} \]

\[ r_c = 2.9^{+1.1}_{-0.6} \times 10^{-2} R_{500} \]

\[ \beta = 0.89 \pm 0.05 \]

- Cluster is enhancing radio AGN activity over the expected overdensity in clusters

\[ \langle n_{RAGN} \rangle = f_{500} \frac{500}{\Omega} \Phi_{RLF} \]

\[ f_{500} = 20 +/- 7 \]

- Lin & Mohr 2007 find \( f_{200} = 6.8 +/- 1.7 \), suggesting the number density is increasing toward the center
Redshift Evolution

\[ \lambda(r) = \left( A_1 \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \epsilon^2)} e^{-\frac{r^2}{2(\sigma^2 + \epsilon^2)}} + A_3 \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-3/2 + 1/2} \right) \times D_A R_{500} (1 + z)^3 + C_{Bkg} \]

Field RLF from Pracy et al. 2014

Cluster number density is consistent with the field radio luminosity function redshift evolution
\[ \lambda(r) = \left( A_G \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \epsilon^2)} e^{-\frac{\epsilon^2}{2(\sigma^2 + \epsilon^2)}} + A_\beta \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-3/2\beta + 1/2} \right) \times DR_500 (1 + z)^3 + C_{Bkg} \]

\[ A_G = A_{G,0} \left( \frac{M_{500}}{10^{15} M_\odot} \right)^{\alpha_{G,M}} \]

\[ A_\beta = A_{\beta,0} \left( \frac{M_{500}}{10^{15} M_\odot} \right)^{\alpha_{\beta,M}} \]
Inverse Mass Dependence

\[ A_G = A_{G,0} \left( \frac{M_{500}}{10^{15} M_\odot} \right)^{\alpha_{G,M}} \]

\[ A_\beta = A_{\beta,0} \left( \frac{M_{500}}{10^{15} M_\odot} \right)^{\alpha_{\beta,M}} \]

\[ \alpha_{G,M} = -0.94 \pm 0.20 \]

\[ \alpha_{\beta,M} = -0.35 \pm 0.13 \]
Inverse Mass Dependence

\begin{align*}
N (\text{Mpc}^{-2}) &\quad \text{vs} \quad R_{500} \\
0.0 < M < 4.0 &\quad \text{blue} \\
8.0 < M < 100.0 &\quad \text{red}
\end{align*}
The duty cycle of radio mode feedback in complete samples.

Table 3. No object with central cooling time less than 10.0 \times 10^8 \text{ yr} that has a separation higher than 12 kpc.

Figure 2 shows a strong relationship between central cooling time and luminosity.

- Birzan et al. 2012

\[ t_{\text{cool}} \left(10^8 \text{ yr}\right) \]

\[ L_{1400} \left(10^{32} \text{ erg s}^{-1} \text{ Hz}^{-1}\right) \]
Cooling Flows

- **Cooling timescales**
  \[ t_{\text{cool}} \propto \frac{T}{n\Lambda(T)} \]

- BCG is ```on```, N=1, if:
  \[ t_{\text{cool}} \ll t_{\text{age}} \]

- Assume a constant fraction of cool core clusters with mass - Andrade-Santos et al. 2017
  - <N> = constant

- Self-Similar Cluster Scaling
  \[ M \propto R^3 \]

- Number density scales as:
  \[ \frac{N}{V} \propto \frac{1}{R^3} \propto M^{-1} \]
• What about the outskirts?

• What about at higher redshifts when the clusters are not as relaxed?

\[ \alpha_{G,M} = -0.94 \pm 0.20 \]

\[ \alpha_{\beta,M} = -0.35 \pm 0.13 \]
Mergers and Tidal Interactions

- **Mamon 1992 & 2000**
  - **Merger** rate per galaxy
    \[ n\bar{k}_{\text{merger}} \propto \sigma^{-3} \propto M^{-1} \]
  - Number density of mergers
    \[ \rho_{\text{merger}} = n^2\bar{k}_{\text{merger}}/H_0 \propto M^{-1} \]
    \[ \alpha_{G,M} = -0.94 \pm 0.20 \]
  - **Tidal Interaction** rate per galaxy
    \[ n\bar{k}_{\text{tidal}} \propto \sigma^{-1} \propto M^{-1/3} \]
  - Number density of Tidal Interactions
    \[ \rho_{\text{tidal}} = n^2\bar{k}_{\text{tidal}}/H_0 \propto M^{-1/3} \]
    \[ \alpha_{\beta,M} = -0.35 \pm 0.13 \]
Mergers and Tidal Interactions

- **Mergers**
  - Centrally concentrated
  - Depends on galaxy mass

- **Tidal Interactions**
  - Radially increasing
  - galaxy mass independent

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Figure 4 shows the predicted number of major mergers in rich clusters. The galaxy mass function has thin curves respectively. The dashed curve yields a slope for galaxies falling into small groups.

Figure 5. Number of strong (< 0.1) mergers versus radius for an ensemble of clusters, although they were not used in the analysis. One can use the more realistic NFW density profiles to estimate the galaxy mass function. Figure 4 shows that in rich clusters, outside of the core, galaxies become more luminous towards the cluster periphery.

The strong radial dependence of galaxy masses, predicted by the tidal theory (Mamon, 1995), is clear in the cosmological simulations of Ghigna et al. (1998). Should one use the more realistic NFW density profiles to estimate the galaxy mass function? Indeed, this trend is logical simulations of clusters. Moss and co-workers (1998) found a weak trend of mean galaxy mass with (eq. [13], with eqs. [13] and [14]), extrapolated to one Hubble time, versus cluster-centric radius in an NFW cluster with (eq. [19]), extrapolated to one Hubble time, versus cluster-centric radius in (eq. [8]), and partial orbit circularization in groups.

Mergers and Tidal Interactions

Galaxy dynamics in clusters (Ghigna et al., 1998). Figure 4 shows that in rich clusters and a group with (eq. [19]), extrapolated to one Hubble time, versus cluster-centric radius in (eq. [8]), and partial orbit circularization in groups. The galaxy mass function has thin curves respectively. The dashed curve yields a slope for galaxies falling into small groups.

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Future

• Increase sample size with ATCA observations of SPT clusters, especially to higher redshifts

• Does the number density correlate with:
  • Entropy Profiles
  • Density Profiles
  • Central Cooling times
  • Metallicity
Summary

- Inhomogeneous poisson spatial point process allows us to **not bin** the data!

- We find **two components** best describe the cluster radio AGN number density (Gaussian + Beta Model)
  - Beta model is much steeper than normal galaxy distribution, but consistent with other radio AGN studies (e.g., Girardi et al. 1995, Reddy & Yun 2004, Sommer et al. 2011, Best et al. 12)

- **Redshift evolution is consistent with the field evolution**
  - Sommer et al. 2011 also find a strong redshift evolution that is roughly consistent with the field

- **Inverse cluster mass dependence**
  - Lin & Mohr 2007 find their lower mass bin has a factor of 2 higher number density than their higher mass bin (log M\textsubscript{200} > 14.2 )
  - **Gaussian** component number density inversely scales with cluster M\textsuperscript{-1}
    - Consistent with both Cooling Flows and Mergers (Mamon 1992)
  - **Beta Model** component number density inversely scales with cluster M\textsuperscript{-1/3}
    - Consistent with the expected tidal interaction rate (Mamon 2000)
SDSS Colors

Center (0 < R < 0.1)

Outskirt (0.1 < R < 1)

Field

U-R
macs1142.4+5831, z=0.322

667 x 667 pixels extracted from FIRST image 11420+58396J
Brightest pixel is 75.08 mJy/beam at
X, Y = 314, 29 pixels
RA, Dec = 11 42 28.315 +58 22 47.80 (J2000)
RMS noise 0.149 mJy
Redshift Evolution

\[ \lambda(r) = \left( A_p \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \epsilon^2)} e^{-\frac{r^2}{2(\sigma^2 + \epsilon^2)}} + A_\beta \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-\frac{3}{2} + \frac{1}{2}} \right) \times D_A R_{500} (1 + z)^3 + C_{Bkg} \]

Field RLF from Pracy et al. 2014

Cluster number density is consistent with the field radio luminosity function redshift evolution.
Cooling Flows

- Mittal et al. 2009

Fig. 6. The fraction of strong cool-core (SCC) clusters, weak cool-core (WCC) clusters and non-cool-core (NCC) clusters in the HIFLUGCS sample. Also shown are the fraction of clusters containing central radio sources for each category (shaded).

- Birzan et al. 2012
Redshift Evolution

\[ \lambda(r) = \left( A_G \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \epsilon^2)} e^{-\frac{\gamma^2}{2(\sigma^2 + \epsilon^2)}} + A_\beta \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-\frac{3}{2}\beta + 1/2} \right) \times D_A R_{500} (1 + z)^3 + C_{Bkg} \]

\[ \Phi_{RLF} = \Phi_{LERG} + \Phi_{HERG} \]

\[ \Phi_i = \int_{\text{Limit}}^\infty \frac{C_i}{(L^*_i e_i(z)/L)^{\gamma_{1,i}} + (L^*_i e_i(z)/L)^{\gamma_{2,i}}} dL \]

Pure Luminosity Evolution

\[ e_{j,i}(z) \{ (1 + z_{c,i})^{p_{1,i} + \alpha_{z,j}} (1 + \frac{1 + z}{1 + z_{c,i}})^{p_{2,i}} : z > z_{c,i} \} \]
X-ray AGN evolution

\[ N \rightarrow N_0 (1 + z)^{\eta \left( \frac{M_{500}}{10^{15} M_\odot} \right)^{\zeta}} \]

\[ \zeta \sim -1.2 \]

Scale factor has a \( M^{-1.2} \) dependence

\[ \zeta = 0 \text{ rejected at } >99.9\% \]

No other parameters are significantly different from zero

Ehlert et al. 2015
Radio AGN Model

\[ \lambda(r) = \left( A_G \Phi_{RLF} \frac{1}{2\pi(\sigma^2 + \epsilon^2)} e^{-\frac{2\epsilon^2}{2(\sigma^2 + \epsilon^2)}} + A_\beta \Phi_{RLF} \left( 1 + \left( \frac{r}{r_c} \right)^2 \right)^{-3/2\beta + 1/2} \right) \times D_A R_{500} (1 + z)^3 + C_{\text{Bkg}} \]
Mergers & Tidal Interactions

Background Model (M+T+Bkg)
Mergers
Tidal Events
Data

$N \left( \text{Mpc}^{-2} \right)$ vs. $R_{500}$
we truncate the two fields half-way to the overlapping.

eral cluster fields overlap with another cluster field and several clusters have truncated radii. In addition, sev-

sponding luminosity for our sample.

the distribution of the flux density limits and the corre-

is outside our flux limit at this redshift. Figure 3 shows

star-forming galaxies will be log $z$

show that star-formation increases in clusters at redshift

our AGN study. We do note that, Song et al. (2017)

we do not expect much star formation contamination of

a mass of $3 \times 10^{10}$.

However, in local clusters, star-forming galaxies

to that of the AGN number density (e.g. Condon et al.

the cluster redshift (red).

for each cluster (blue) and the corresponding luminosity limit given

0 . 0 0 . 2 0 . 4 0 . 6 0 . 8 1 . 0 1 . 2

Redshift

10 22

10 23

10 24

10 25

10 26

$L_{1.4\text{Hz}}$ (W Hz$^{-1}$)

10 0

10 1

10 2

10 3

10 4

Flux Limit (mJy)

Fig. 2.—

Fig. 3.—

The field of view of each cluster nominally extends to

500

$L_{1.4\text{Hz}}$ (W Hz$^{-1}$)

10 26

10 25

10 24

10 23

10 22

0.0

0.2

0.4

0.6

0.8

1.0

1.2

Redshift

Flux Limit (mJy)

$10^4$

$10^3$

$10^2$

$10^1$

$10^0$

The final catalog has 10961 sources, of which 3804 are

point sources, and 7157 are extended sources. Of the ex-

number density in the COSMOS field is in blue, and the

levels. The cluster is in black, the 1

which

$10^4$ which

$10^3$ $10^2$ $10^1$ $10^0$

$10^4$

$10^3$

$10^2$

$10^1$

$10^0$

$10^4$

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$10^3$

$10^2$

$10^1$

$10^0$

$10^4$

$10^3$

$10^2$

$10^1$

$10^0$
• Both high and low luminosity sources increase in number density at the center

• Log L= 41 is roughly the divide between FR I and FR II sources
Radio Cluster AGN

- Extended sources preferentially increase inside clusters
- Gas pressure increases in clusters, which could confine extended sources but we observe the opposite.
Motivation

- Jet power measured from pdV work need to inflate cavities scales with 1.4 GHz radio luminosities
- giant Ellipticals
- Cavagnolo et al. 2010

\[ P_{\text{cav}} \, [10^{42} \text{ erg s}^{-1}] \]

\[ P_{1.4} \, [10^{40} \text{ erg s}^{-1}] \]
• Mittal et al. 2009

Fig. 6. The fraction of strong cool-core (SCC) clusters, weak cool-core (WCC) clusters and non-cool-core (NCC) clusters in the HIFLUGCS sample. Also shown are the fraction of clusters containing central radio sources for each category (shaded).

Fig. 7. Radio and X-ray correlation plots.}

Fig. 8. Radio luminosity vs. cooling properties in clusters.
Relaxed Clusters and Cooling Flows

• Relaxation timescales

\[ t_{\text{relax}} \simeq \frac{R}{v} \frac{N}{\ln N} \]

\[ N \propto M \]

\[ t_{\text{relax}} \propto \frac{M}{\ln M} \]

• Cooling timescales

\[ t_{\text{cool}} \propto \frac{T}{n\Lambda(T)} \]

\[ M \propto T^{3/2} \]

\[ t_{\text{cool}} \propto M^{2/3} \]
X-ray AGN evolution

\[ N \rightarrow N_0 (1 + z)^\eta \left( \frac{M_{500}}{10^{15} M_\odot} \right)^\zeta \]

\( \zeta \sim -1.2 \)

Scale factor has a \( M^{-1.2} \) dependence

\( \zeta = 0 \) rejected at >99.9%

No other parameters are significantly different from zero

Consistent with Merger Triggering
Radio AGN Overdensity in Cluster Center (<1 \( R_{500} \))

The final catalog has 10961 sources, of which 3804 are radio AGN. Sources are associated with each cluster. To circumvent this, we truncate the two fields half-way to the overlapping region. Several clusters have truncated radii. In addition, several luminosity for our sample.

The distribution of the flux density limits and the corresponding luminosity for our sample.

Figure 3 shows star-forming galaxies will be log

\( z \)

show that star-formation increases in clusters at redshift.

We do note that, Song et al. (2017) we do not expect much star formation contamination of our AGN study. We do note that, Song et al. (2017)

The cluster mass.

2002). However, in local clusters, star-forming galaxies are suppressed by a factor of 2 in galaxies with a mass

The average number density in the COSMOS field is in blue, and the average cluster number density is given in Figure 4. The total number of sources. The radial distribution of 19 of those have multiple components. We note that this number density is consistent with our measured background number density given in red in Figure 4.

The plot excludes those clusters that have flux density limits above

\( S_1 \) has much smaller uncertainties due to the order
tended sources, 2589 have multiple components, 23.6% of this distribution is highly peaked and extends out past

sources above the background in the clusters. The distribution is centered on (150.11917, 2.20583) and has a radius

of 3000 arcsec. We find a total of 67 sources, 42 are expected, and 19 of those have multiple components. We

the flux density for our sample. For a given integrated flux density,

This figure plots the number of sources per square degree versus cluster radius. We only include clusters that have

\( R_{500} \). This differential measurement of the total number of radio sources in a cluster field to the expected background.

Therefore, we do not know which radio sources are associated with each cluster. To circumvent this, we can statistically identify cluster members by making

the contours show at what peak flux density the sample is 68.3%, 95.45%, and 99.73% complete, i.e. includes . We chose the empirical relation,

This plot shows both the integrated flux density limit and the corresponding luminosity limit given in red. Error bars are 1

confidence region for the background in our cluster sample taken

from the COSMOS field in blue. The COSMOS field is in black, the 1

degree versus cluster radius. We only include clusters that have

levels. The distribution is highly peaked and extends out past

from our cluster field sample.

A strong radial dependence is observed in the center of

sources in a cluster field to the expected background.
X-ray AGN Overdensity in Cluster Center (<2 R\(_{500}\))

Elhert et al. 2014

![Graph showing the projected density of X-ray bright point sources in all three bands, in units of deg\(^2\). In all three lines, the solid black line corresponds to the best-fit constant background density in the range 3-5 r\(_{500}\), and in all three cases this background density is consistent with the expected field source density derived from CDFS and COSMOS. In all three energy bands, this constant background field density is consistent with the expected field density determined from the CDFS and COSMOS data. (a): The surface density of X-ray bright full band sources (\(F_{X}(0.5-8.0 \text{ keV}) > 1 \times 10^{14} \text{ erg cm}^{-2} \text{ s}^{-1}\)) as a function of radius, in units of r\(_{500}\). A total of 2675 sources were included in the calculation of this profile. (b): The surface density of X-ray bright soft band sources (\(F_{X}(0.5-2.0 \text{ keV}) > 3 \times 10^{15} \text{ erg cm}^{-2} \text{ s}^{-1}\)) as a function of radius, in units of r\(_{500}\). A total of 3055 sources were included in the calculation of this profile. (c): The surface density of X-ray bright hard band sources (\(F_{X}(2.0-8.0 \text{ keV}) > 10^{14} \text{ erg cm}^{-2} \text{ s}^{-1}\)) as a function of radius, in units of r\(_{500}\). A total of 2933 sources were included in the calculation of this profile.

5.0.2 The XLF Model

Before presenting the results from our MCMC runs, it is important to discuss the choice of XLF for this study in more detail. For this study, we assume the Luminosity-Dependent Density Evolution (LDDE) XLF model of Ueda et al. (2014). The XLF of Ueda et al. (2014) was determined in the rest-frame 2-10 keV band, while we are using the 0.5-8.0 keV band in order to maximize the statistics of our measurement. In order to account for this energy band conversion, we convert the relevant parameters of the Ueda et al. (2014) model (\(L_?\), \(L_{a1}\), & \(L_{a2}\)) to the full band assuming a power-law...
Active Cluster AGN Fraction

**X-ray/Optical**

![Graph of X-ray/Optical Active Cluster AGN Fraction](image)

**Radio/Optical**

![Graph of Radio/Optical Active Cluster AGN Fraction](image)

**Radiative Mode**

- Fraction
- Radius ($r/r_{500}$)

**Kinetic Mode**

- $N_{Radio}/N_{Optical}$
- Radius ($r/r_{500}$)
Low Mass Accretion Rates

• Radio emission is sensitive to:
  • low Eddington Accretion
    • may be more efficient at creating jets -> ADAF/Thick Disks
  • Hot Mode Accretion
    • Cold Gas is stripped from the galaxies
    • could also result in an extended disk
  • Massive Black Holes
Mass or redshift evolution?

\[
N_{\text{obs}}(> f, r, z) = N \times D_A(z)^2 \times r_{500} \times \Phi(> L_{\text{cut}}, z) \times \left( \frac{r}{r_{500}} \right)^\beta + C
\]

Projected number density of observed X-ray AGN in a cluster field at a given cluster \(z\), \(r\) and above flux limit \(f\)

\[
= \text{Projected number density of X-ray AGN expected in cluster above flux limit} + \text{Projected number density of all field AGN above flux limit}
\]

'Scale factor' which allows number density to exceed co-moving field AGN

\[
\times \text{Scaled by radius} \times \text{Co-moving field AGN number density at } z \text{ and above luminosity related to flux limit} \times \text{Some radial dependence}
\]

Allow a mass and redshift dependence for scale factor (normalisation) and radial scaling

\[
N \rightarrow N_0(1 + z)^(\eta) \left( \frac{M_{500}}{10^{15} M_\odot} \right)^\zeta \quad \beta \rightarrow \beta_0 + \beta_z(1 + z) + \beta_m \left( \frac{M_{500}}{10^{15} M_\odot} \right)
\]
Radio AGN Evolution

- Pracy et al. 2014
- 1.4 GHz radio luminosity
  - Low-Excitation Radio Galaxies
  - High-Excitation Radio Galaxies
- LERG and HERG have separate evolutions
  - LERG are relatively constant to z~1
  - HERG evolve more like Quasars
Spectroscopic Follow-up

**VIMOS follow-up program:**

Observe 10, z=0.35 - 0.4, relaxed clusters

**Aims:**
- Examine X-ray AGN host relationship
- Does AGN fraction depend on cluster mass?
Mass and Redshift

![Graph showing the relationship between mass (in units of solar masses) and redshift. The x-axis represents redshift ranging from 0.0 to 1.2, while the y-axis represents mass (in units of $10^{-14}$ M$_{\odot}$). The data points are scattered across the graph, indicating a correlation between mass and redshift. Additional lines are drawn to highlight certain ranges.](image-url)
Feedback

Correlation Between Black Hole Mass and Bulge Mass

- One billion solar masses
- One million solar masses
- No black hole

Mass of central bulge

Increasing

K. Cordes & S. Brown (STScI)
Feedback

K. Cordes & S. Brown (STScI)
Optical follow-up

**Next step:** Need spectroscopic confirmation

**Spectroscopy:**
- Within 2” of X-ray position find 7753 objects of 11671, 318 have spectra 49/318 have velocities $+\text{-}5000$ km/s

**Imaging:**
- Quantify asymmetries and close pairs in spectroscopically confirmed cluster members
Spectroscopy

**VIMOS** follow-up program:

**Expect:** 500-700 targets per cluster (~6000 targets)
- ~860 X-ray AGN >50 within ~2x $r_{500}$,
  (15 so far)

Matched by magnitude and cluster centric distance for $V<23$

2700 seconds on target
Merger Rates

- Rate of Mergers Scales inversely with the Mass of the most massive Clusters
  \[ \sigma^3 \propto M^{-1} \]
- (e.g., Mamon 1992)
- Though the X-ray AGN are quenched in clusters, the ones that are active are consistent with being triggered by merging of galaxies.
Motivation

AGN Come in Two Flavors:

• Radiative, Quasar mode, high-Eddington accretion modes (X-ray AGN)

• Kinetic, Jet-mode, low-Eddington accretion modes (Radio AGN)
Feedback

M-sigma Relation

Gultekin et al. 2009

- Sphere of influence
- 40 pc for $10^9 M_{\text{solar}}$ BH

- The velocity dispersions are measured on kpc scales
Motivation

AGN Come in Two Flavors:

• **Radiative, Quasar mode**, high-Eddington accretion modes (X-ray AGN)
  
  • measure power:
    
    • Radiation pressure-luminosity

• **Kinetic, Jet-mode**, low-Eddington accretion modes (Radio AGN)
  
  • measure power:
    
    • Cavities
Motivation

AGN Come in Two Flavors:

- Radiative, Quasar mode, high-Eddington accretion modes (X-ray AGN)
- Kinetic, Jet-mode, low-Eddington accretion modes (Radio AGN)

What are the triggering mechanisms?

MS0735.6+7421, McNamara et al. 2009
X-ray AGN Number Density

- Excess in the center R500 above a luminosity of log$L_X$=43.5 at the cluster redshift

- The fraction of X-ray AGN compared to galaxies is suppressed as compared to the field

- We find an inverse correlation with Mass, which may suggest triggering of AGN by Mergers