The Effects of Cluster Environment on Radio AGN

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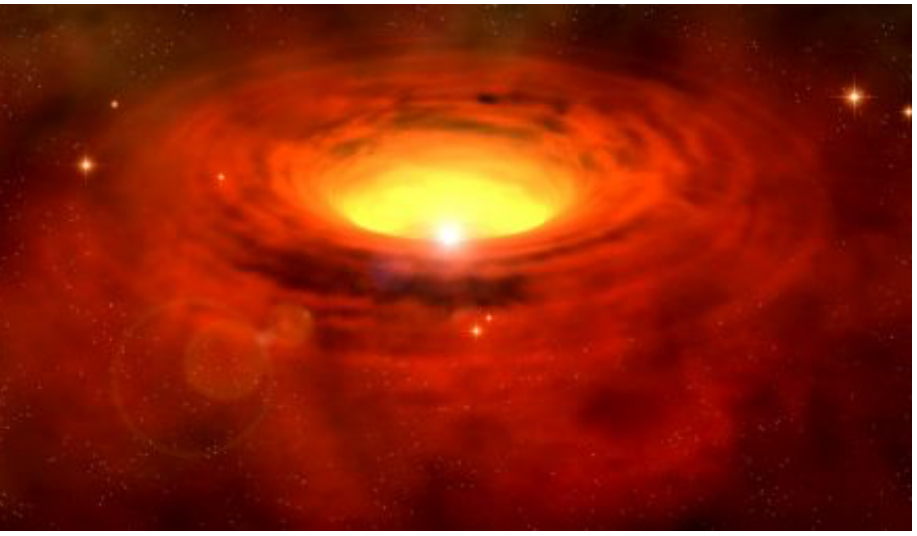
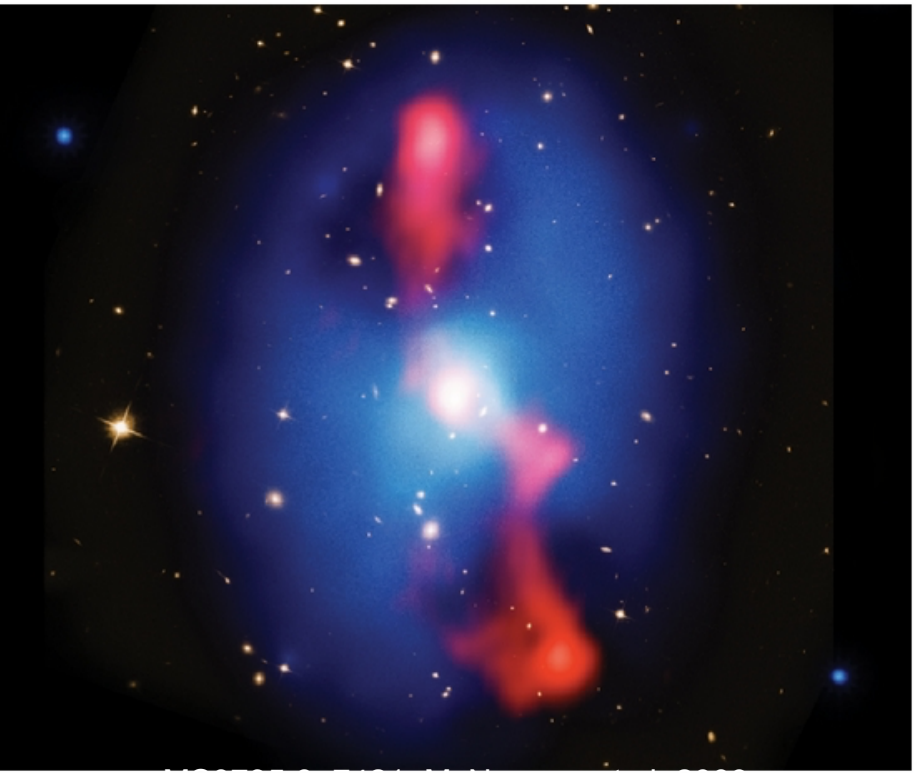
Motivation





AGN Come in Two Flavors:

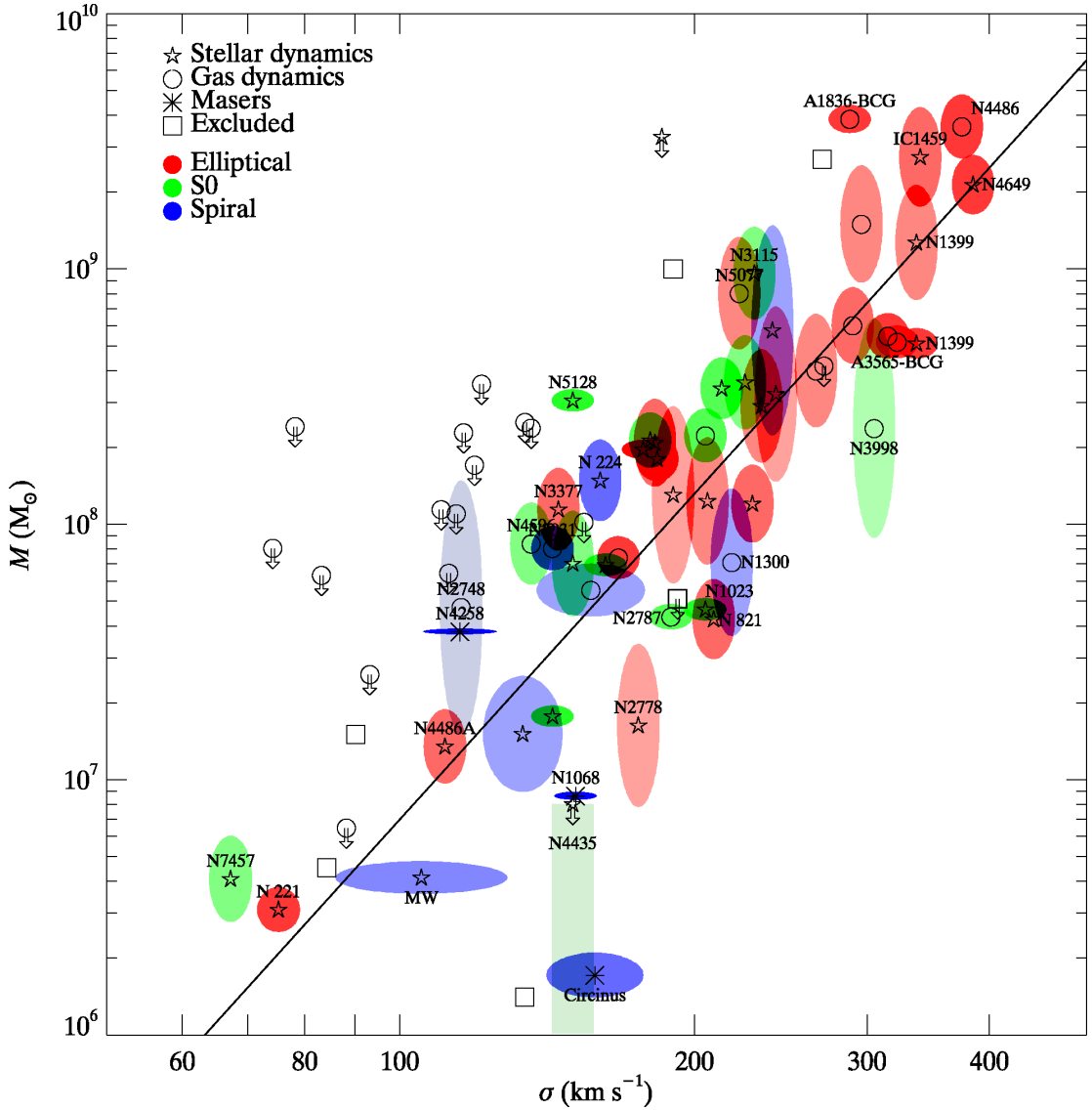
- Radiative, Quasar mode, high-Eddington accretion modes (X-ray AGN)

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

Feedback

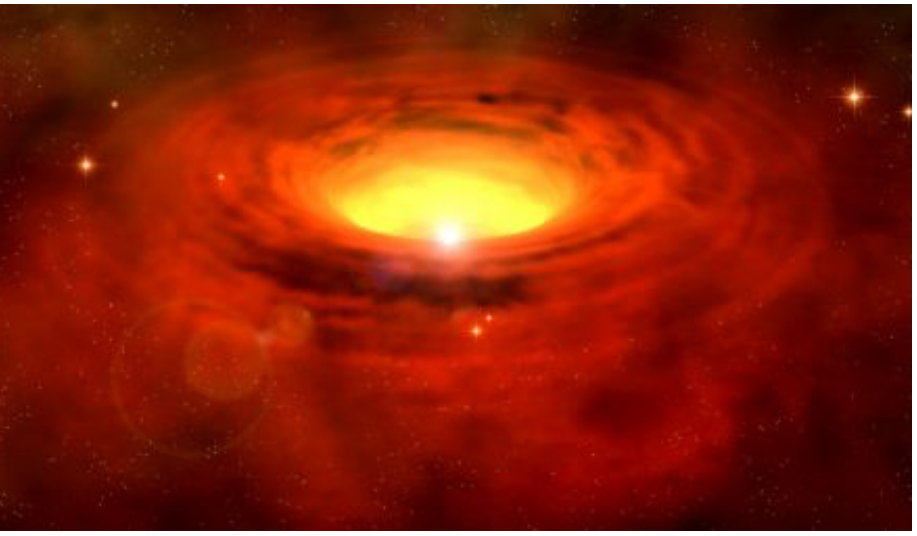
M-sigma Relation

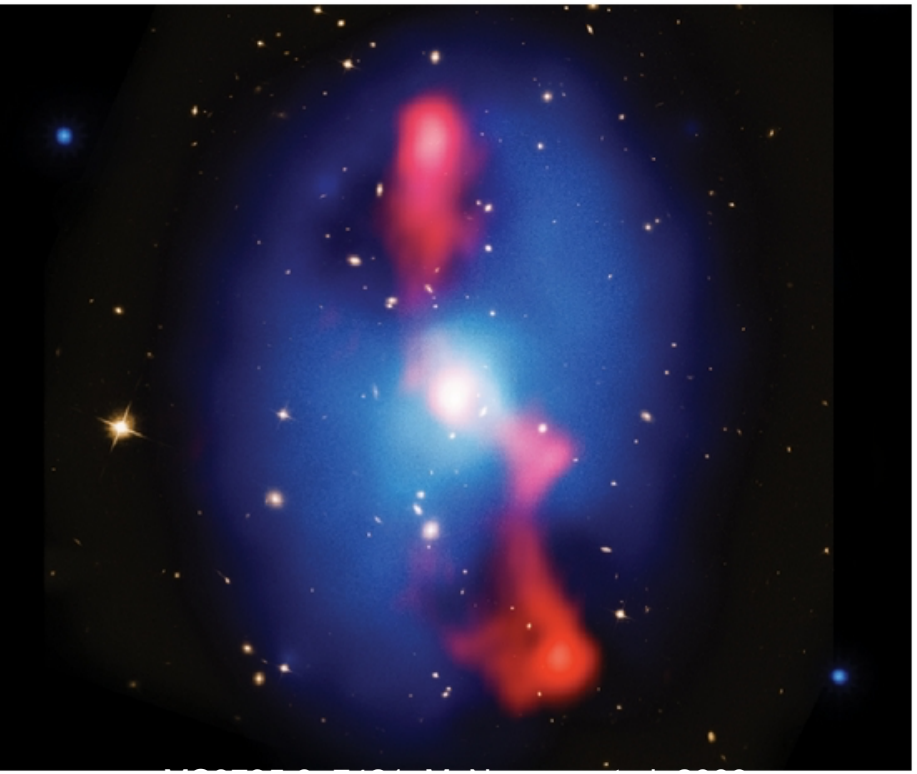
Gultekin et al. 2009



- Sphere of influence
  - 40 pc for 10^9 M_{solar} BH
- The velocity dispersions are measured on kpc scales

Motivation



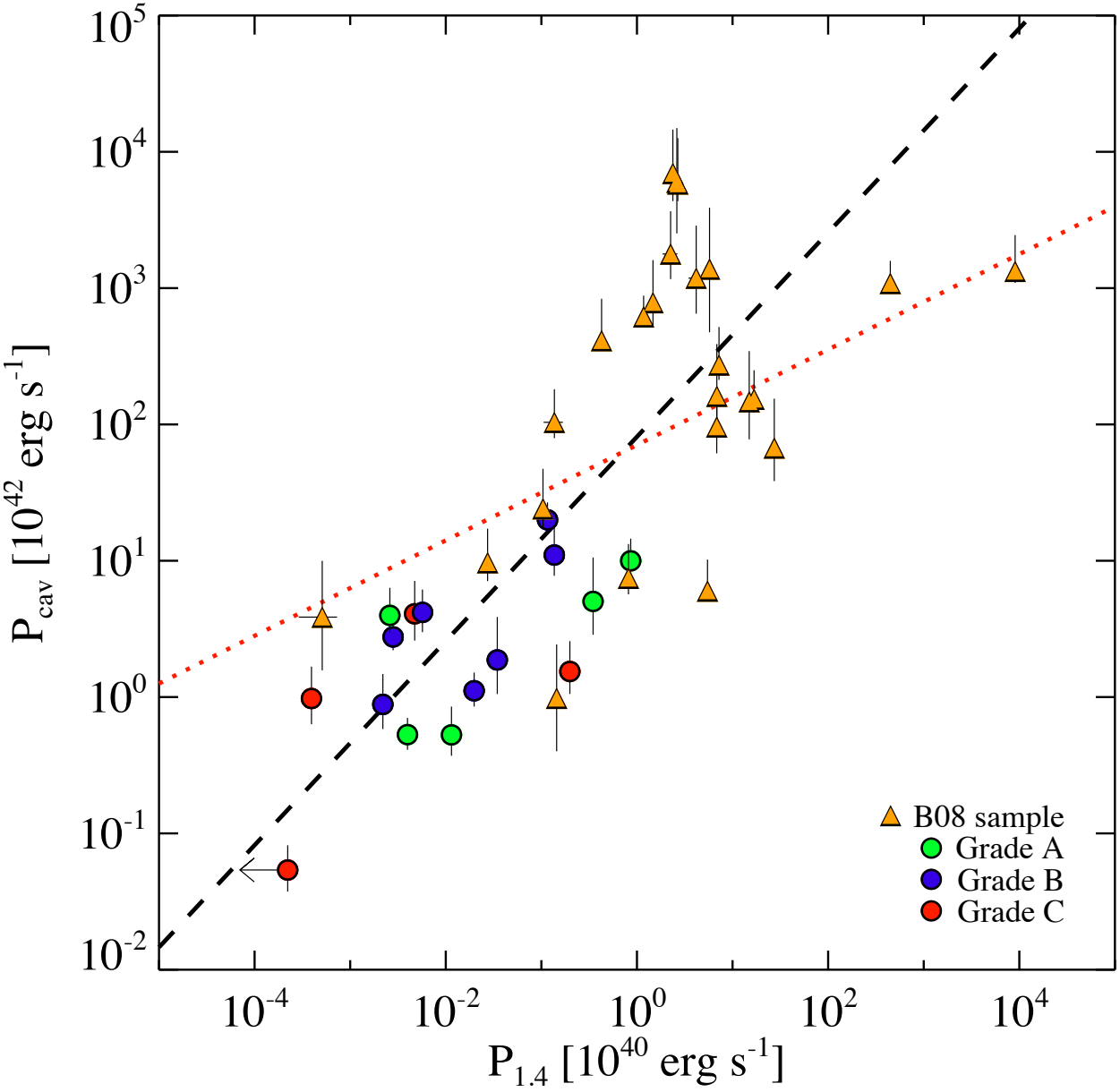


AGN Come in Two Flavors:

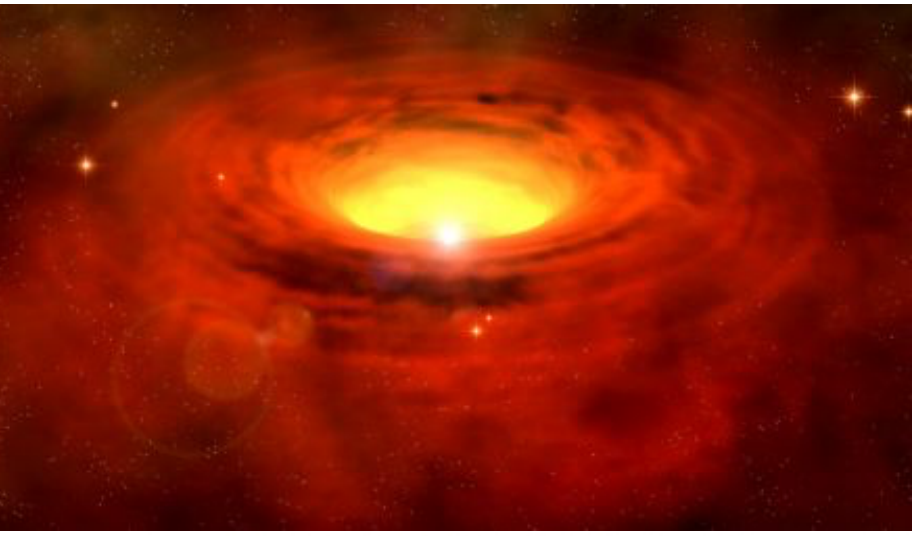
- Radiative, Quasar mode, high-Eddington accretion modes (X-ray AGN)
  - measure power:
    - Radiation pressure-luminosity
- Kinetic, Jet-mode, low-Eddington accretion modes (Radio AGN)
  - measure power:
    - Cavities

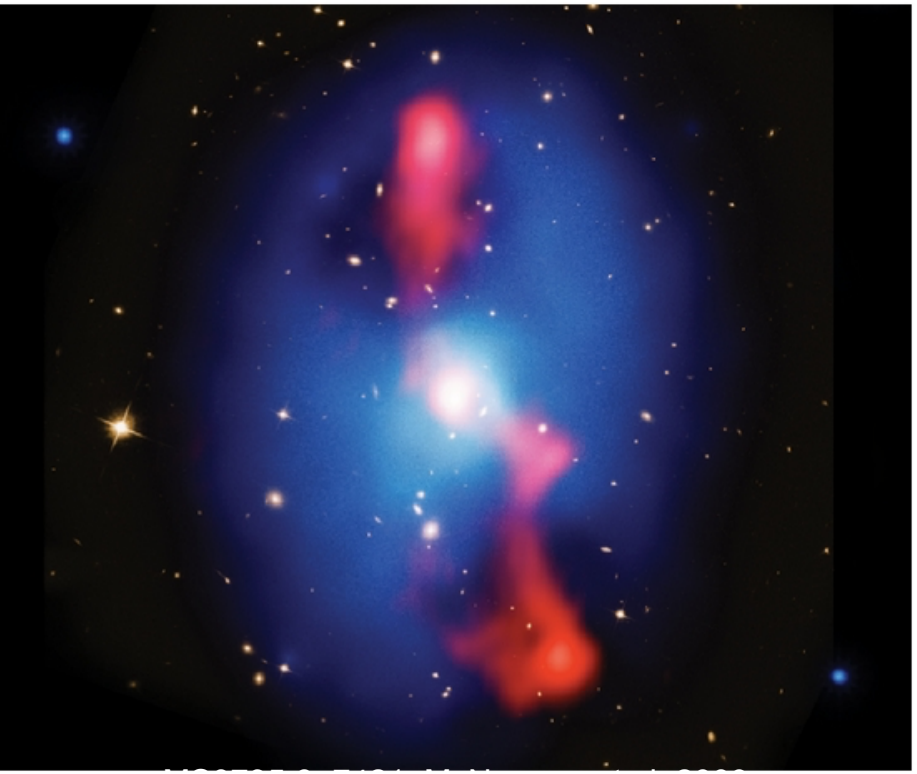
Motivation

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



Motivation





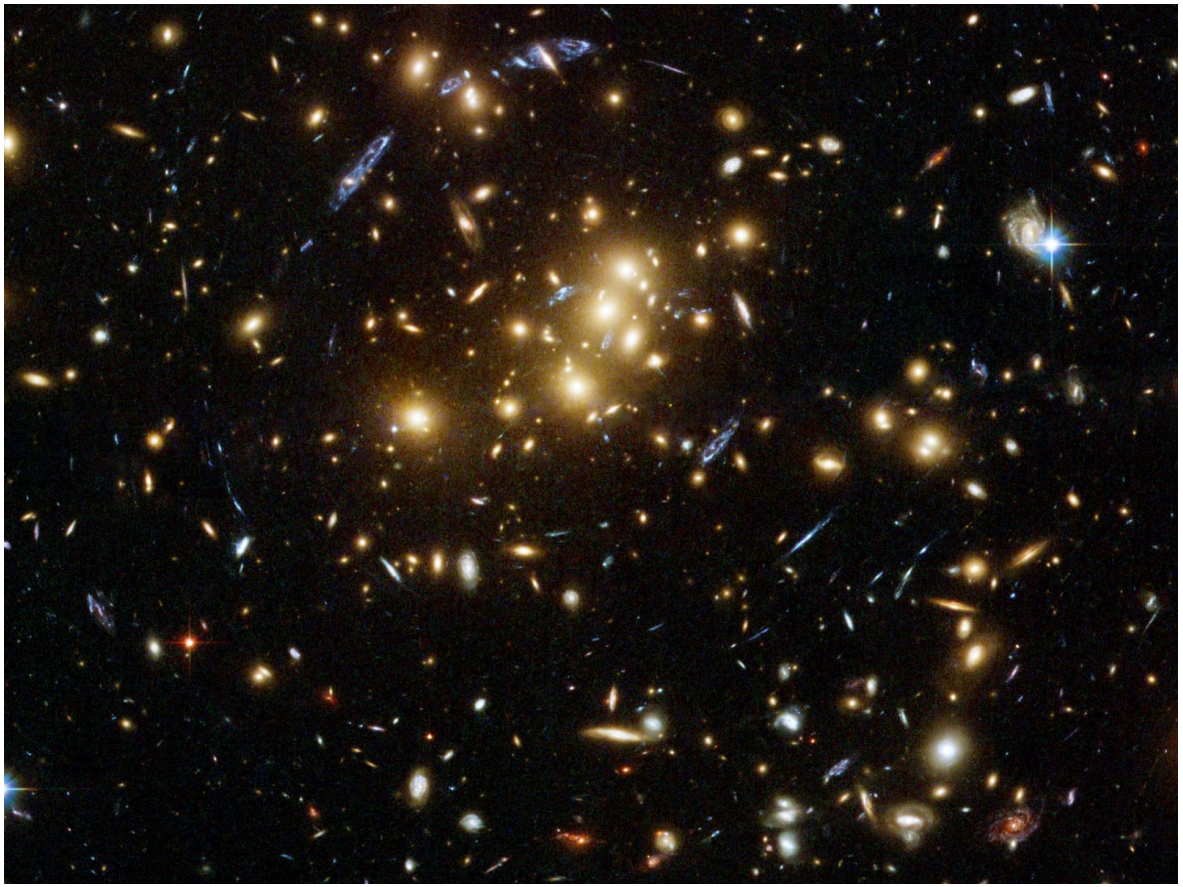
AGN Come in Two Flavors:

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

What are the triggering mechanisms?

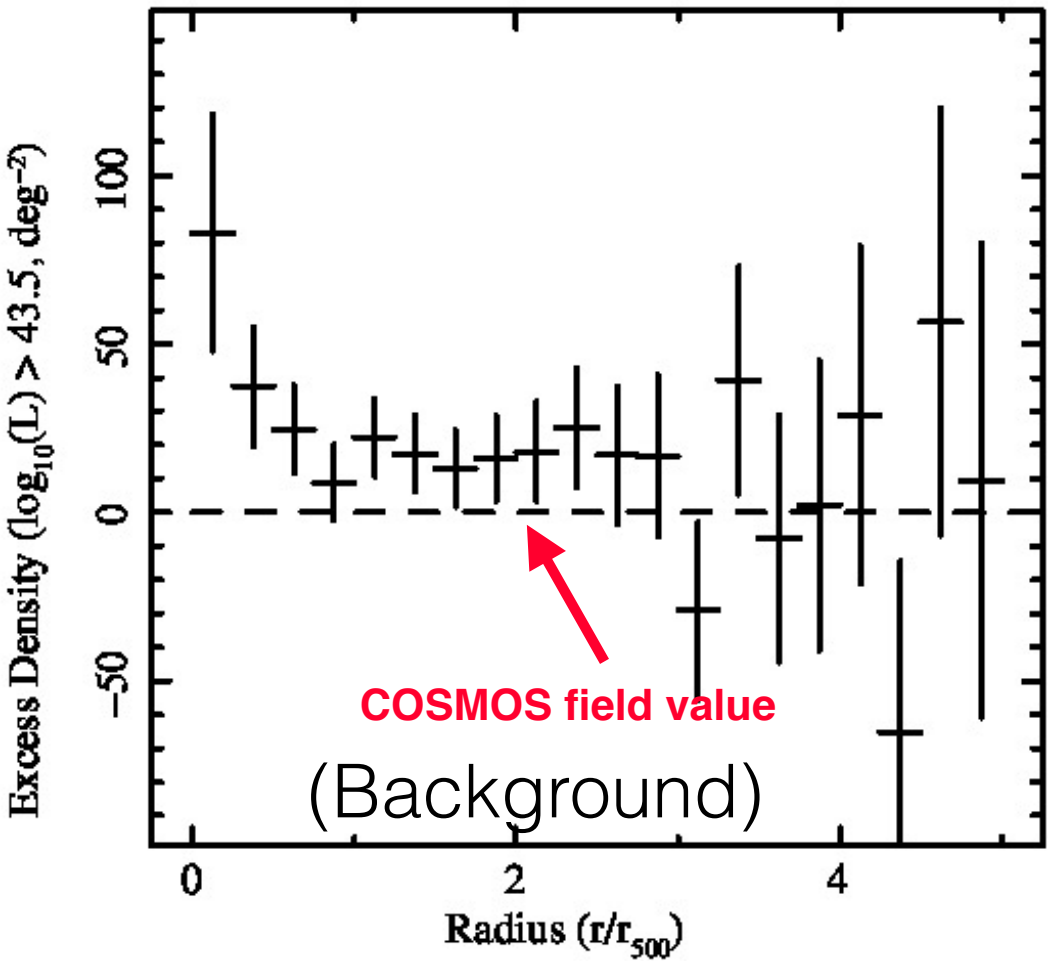
Motivation

- Clusters of Galaxies
  - largest gravitationally bound structures in the Universe
  - they are great laboratories to examine numerous effects on the host members including the supermassive black holes and their host galaxies
    - Environment,
    - Mergers,
    - Mass Segregation,
    - Tidal Effects,
    - Gas dynamics,
    - shocks
    - Strangulation/Gas stripping



X-ray AGN Number Density

- Excess in the center R500 above a luminosity of logL_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

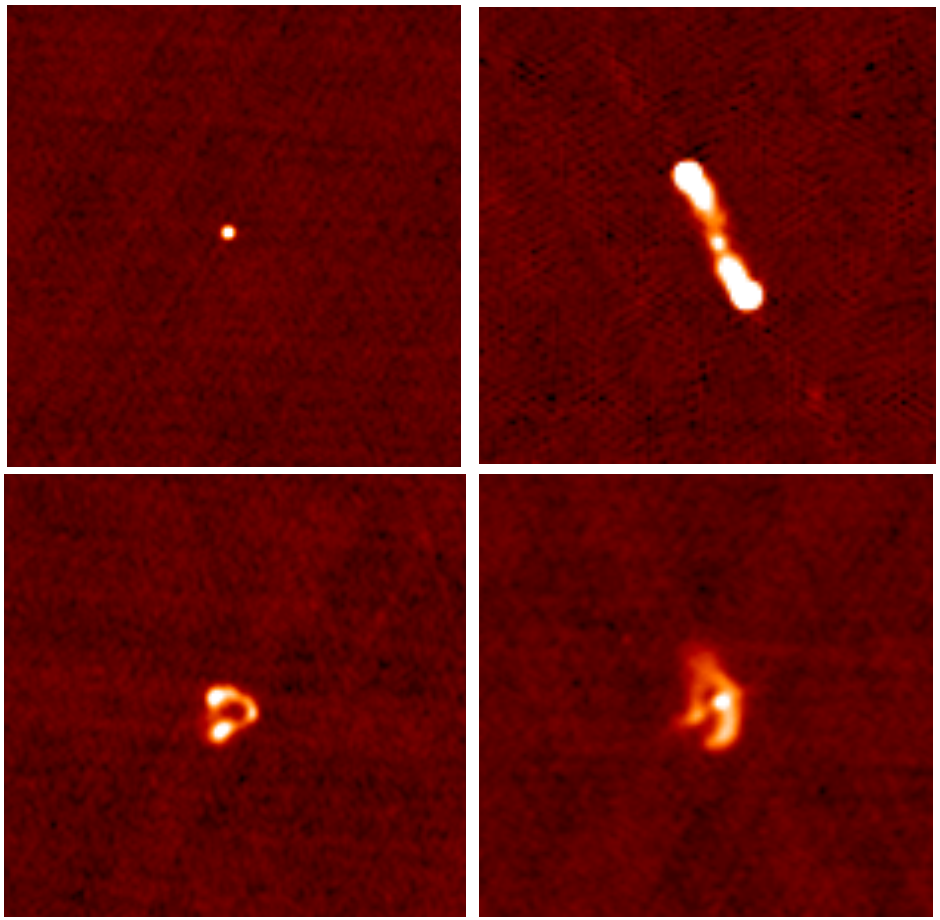


AGN Samples

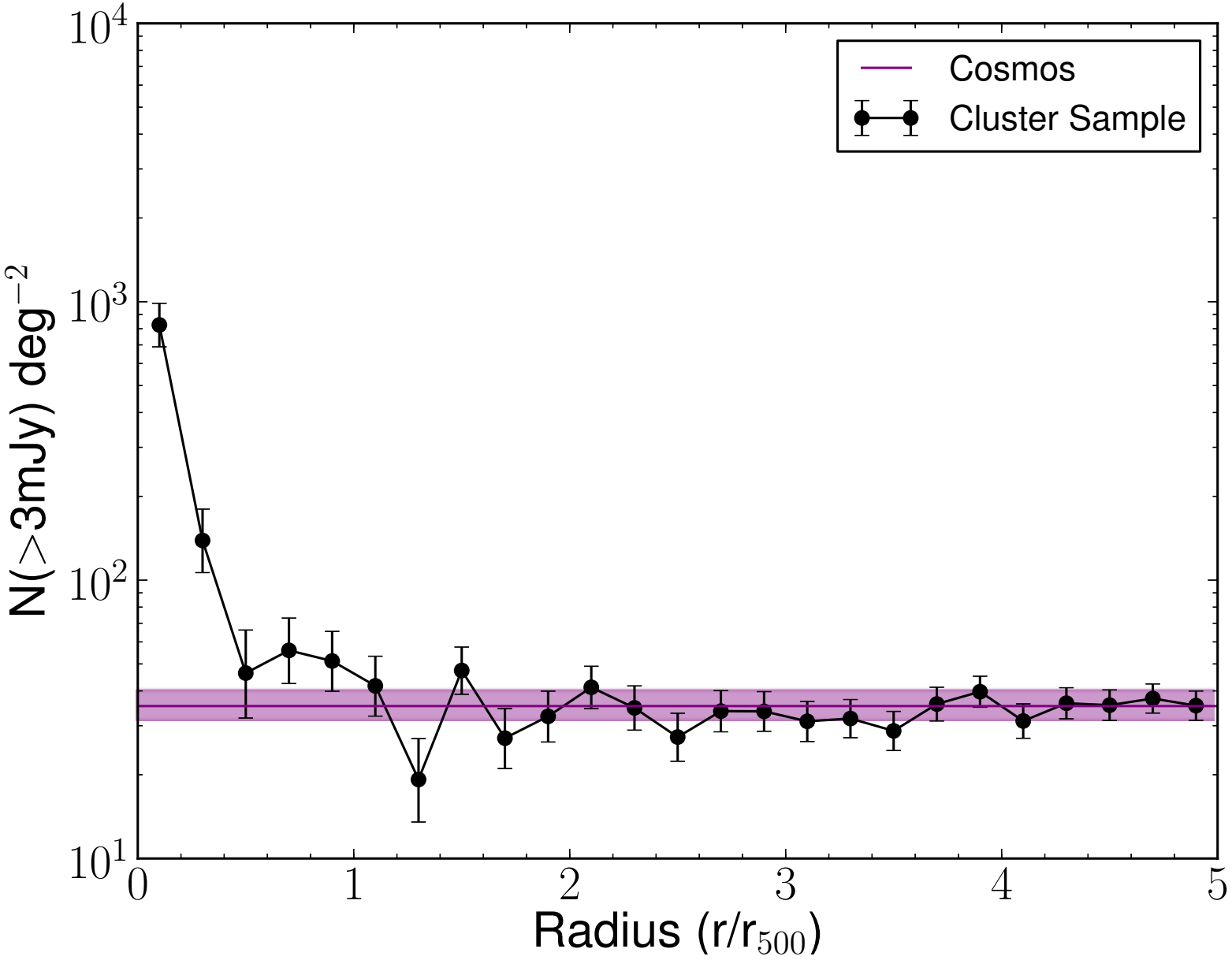
- **X-ray AGN Sample** (Elhert et al. 2012, 2013, 2014)
  - 135 X-ray selected clusters observed with Chandra and have accurate X-ray determined masses and center of masses (Mantz et al. 2010), >11000 point sources
  - $M_{Cluster} = 10^{14}$-10^{15} M_{Solar}, z=0.2-0.9, F> 10^{-14} ergs s^{-1} cm^{-2}
  - 135 -> 480 clusters (**Canning** et al. In Prep)
- **Radio AGN Sample** (**King** et al. In prep)
  - 65 of 135 X-ray Clusters are in the First Sample, 3640 sources
    - 200 in updated sample
  - $S_{1.4GHz}$ > 3mJy -> only Radio-loud AGN and avoid star formation contribution

FIRST Survey

- FIRST survey
  - Incomplete below 2 mJy
  - Star formation becomes important below 3 mJy
  - Developed an algorithm to determine real source pairs and randomly associated pairs within 70”
    - Overlapping sources were considered one source
  - Highest probability sources of being a “real” source, i.e. not a side-lobe or artifact of clean routine (effects mostly the lowest fluxes)
- Types of Sources
  - Point Sources
  - Bipolar Outflows
  - Head Tails
  - Extended emission

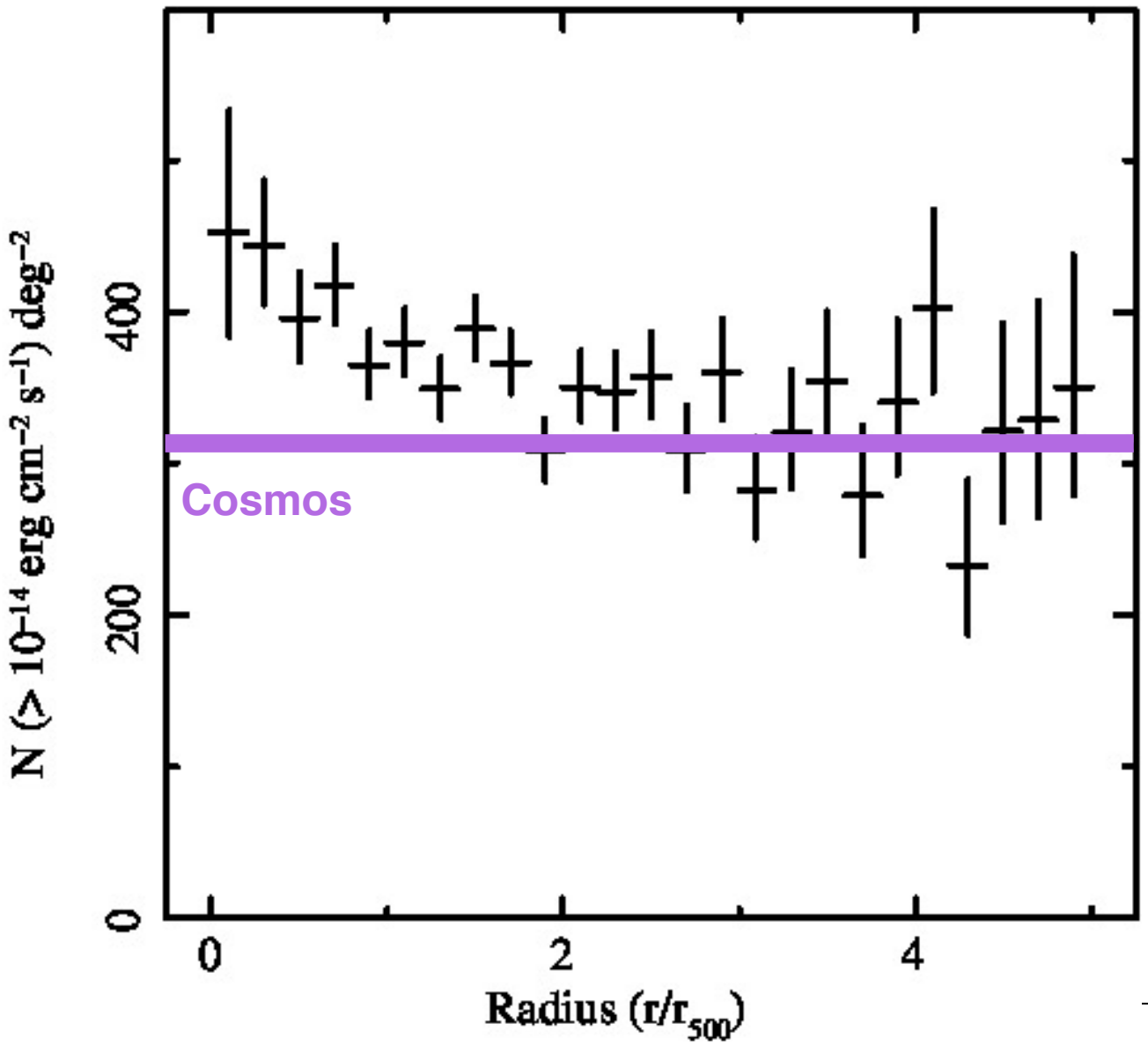


Radio AGN Overdensity in Cluster Center (<1 R_{500})



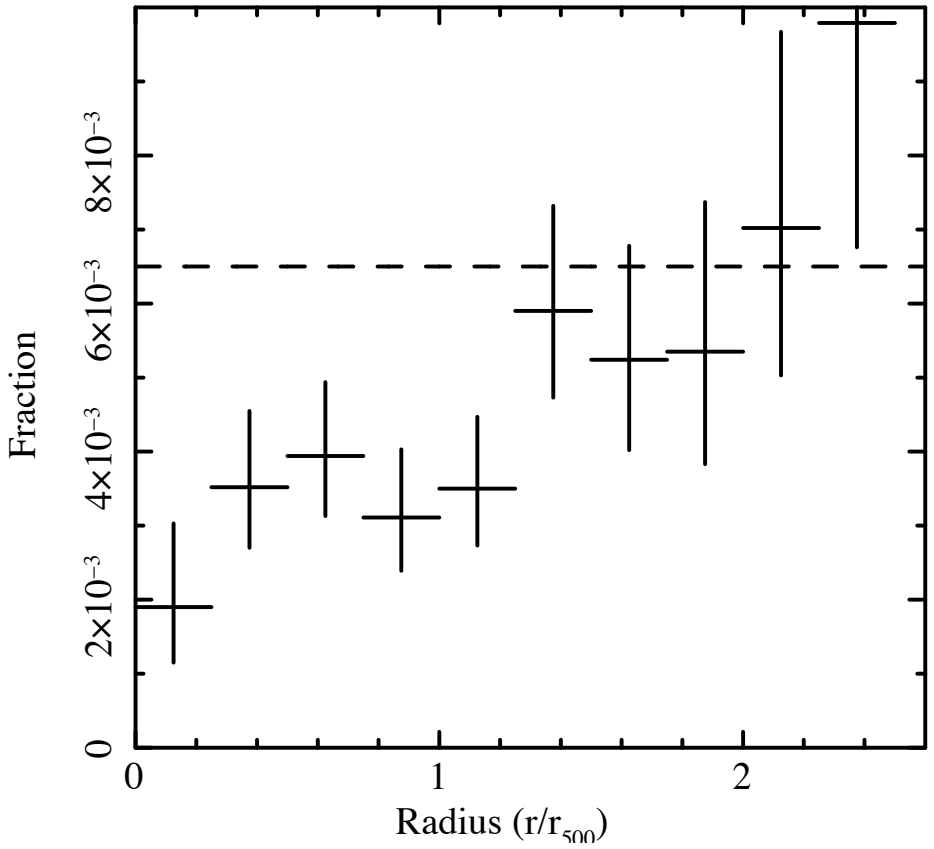
X-ray AGN Overdensity in Cluster Center (<2 R_{500})

Elhert et al. 2014



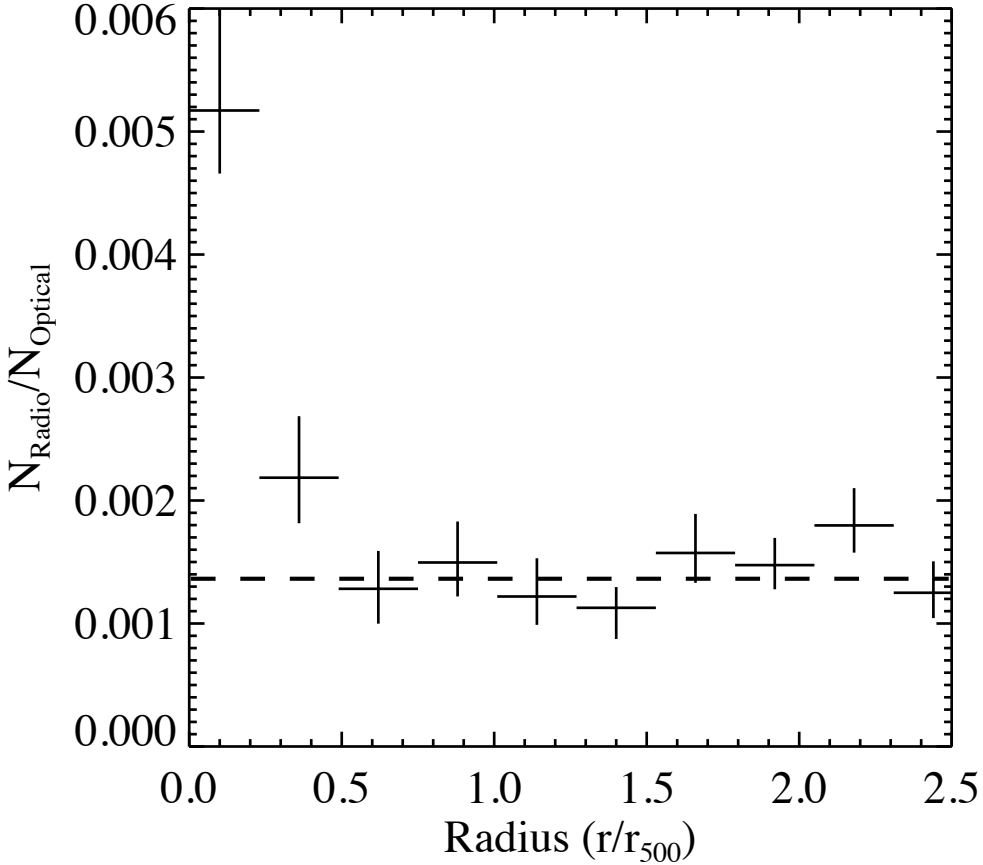
Active Cluster AGN Fraction

X-ray/Optical



Radiative Mode

Radio/Optical



Kinetic Mode

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?

$$N_{\rm obs}(>f,r,z) = N \times D_{\rm A}(z)^2 \times r_{500} \times \Phi(>L_{\rm cut},z) \times \left(\frac{r}{r_{500}}\right)^{\beta} + C$$

Projected number density of observed X-ray AGN in a cluster field at a given cluster z, r and above flux limit f = **Projected number density of X-ray AGN expected in cluster** above flux limit + **Projected number density of all field AGN** above flux limit

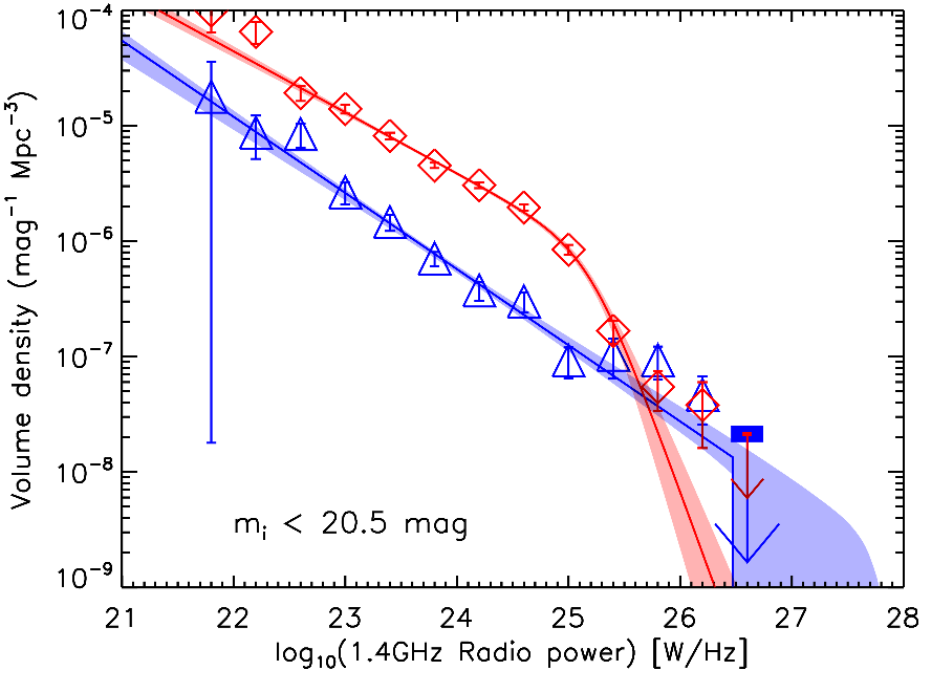
'Scale factor' which allows number density to exceed co-moving field AGN X Scaled by radius X Co-moving field AGN number density at z and above luminosity related to flux limit X Some radial dependence

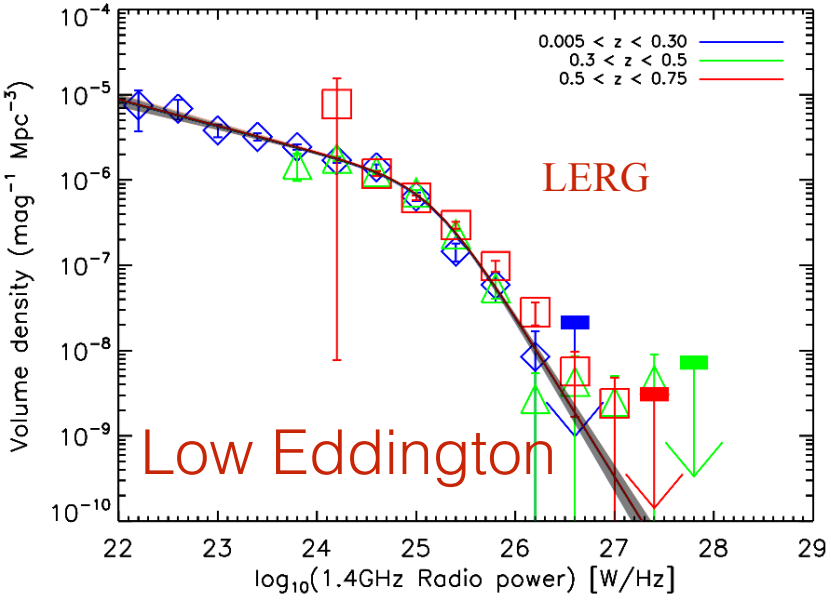
Allow a mass and redshift dependence for scale factor (normalisation) and radial scaling

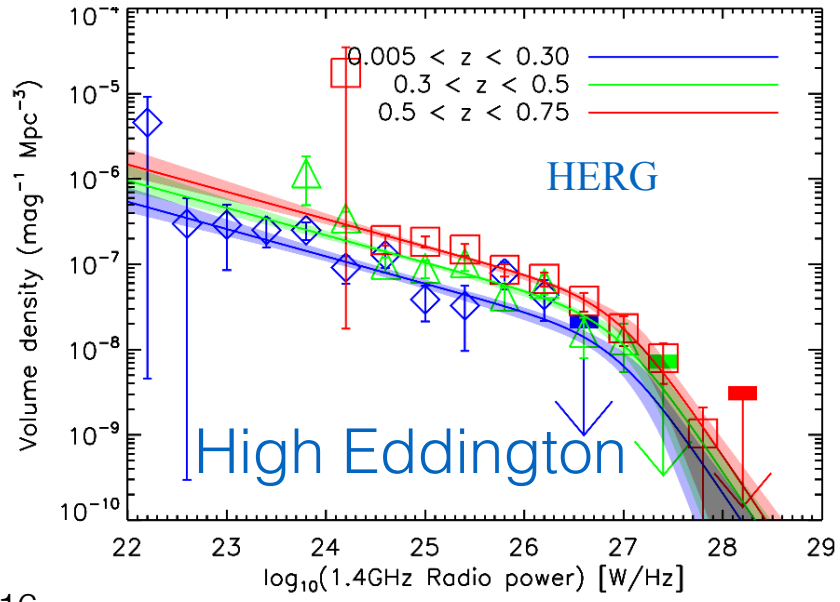
$$N \rightarrow N_0(1+z)^{\eta}\left(\frac{M_{500}}{10^{15}M_{\odot}}\right)^{\zeta} \qquad \beta \rightarrow \beta_0 + \beta_{\rm z}(1+z) + \beta_{\rm m}\left(\frac{M_{500}}{10^{15}M_{\odot}}\right)$$

Radio AGN Evolution

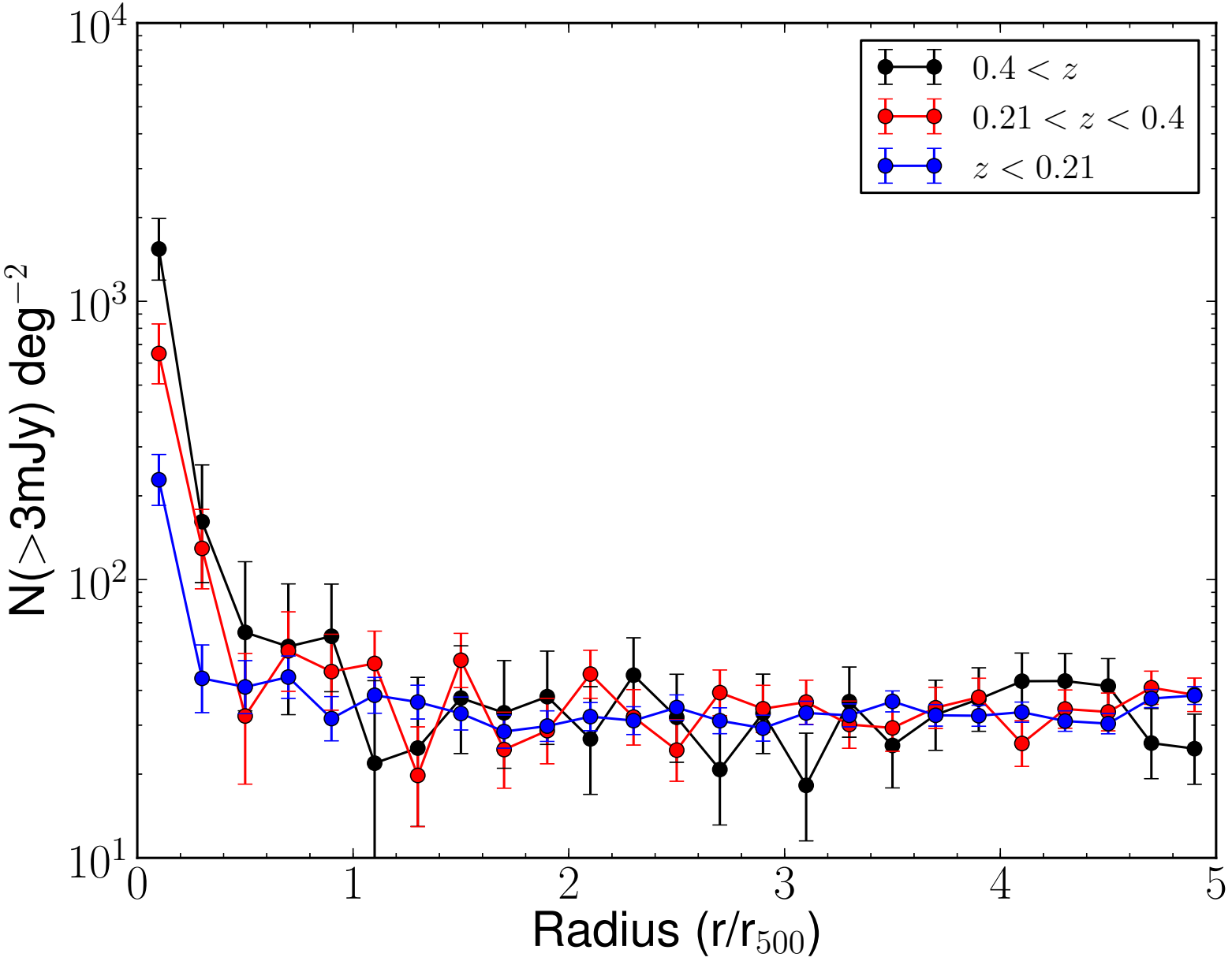
- Pracy et al. 2014
- 1.4 GHz radio luminosity
  - Low-Excitation Radio Galaxies
  - High-Excitation Radio Galaxies
- LERG and HERG have separate evolutions
  - LERG are relatively constant to z~1
  - HERG evolve more like Quasars





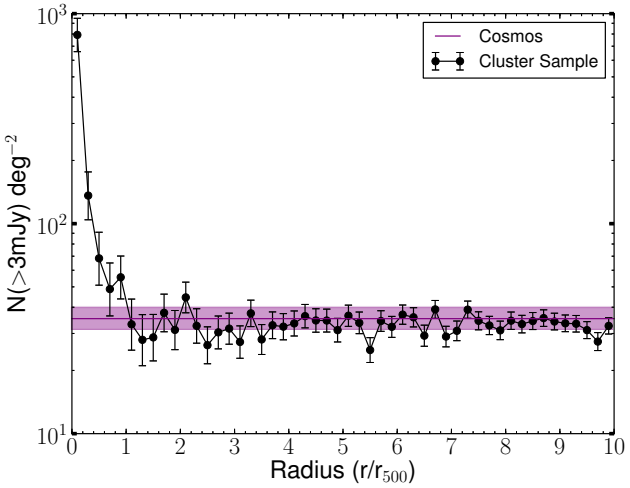


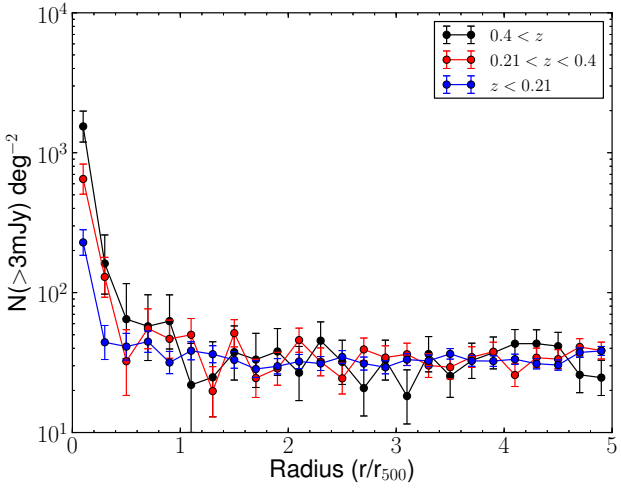
Radio AGN Redshift Evolution



Conclusions

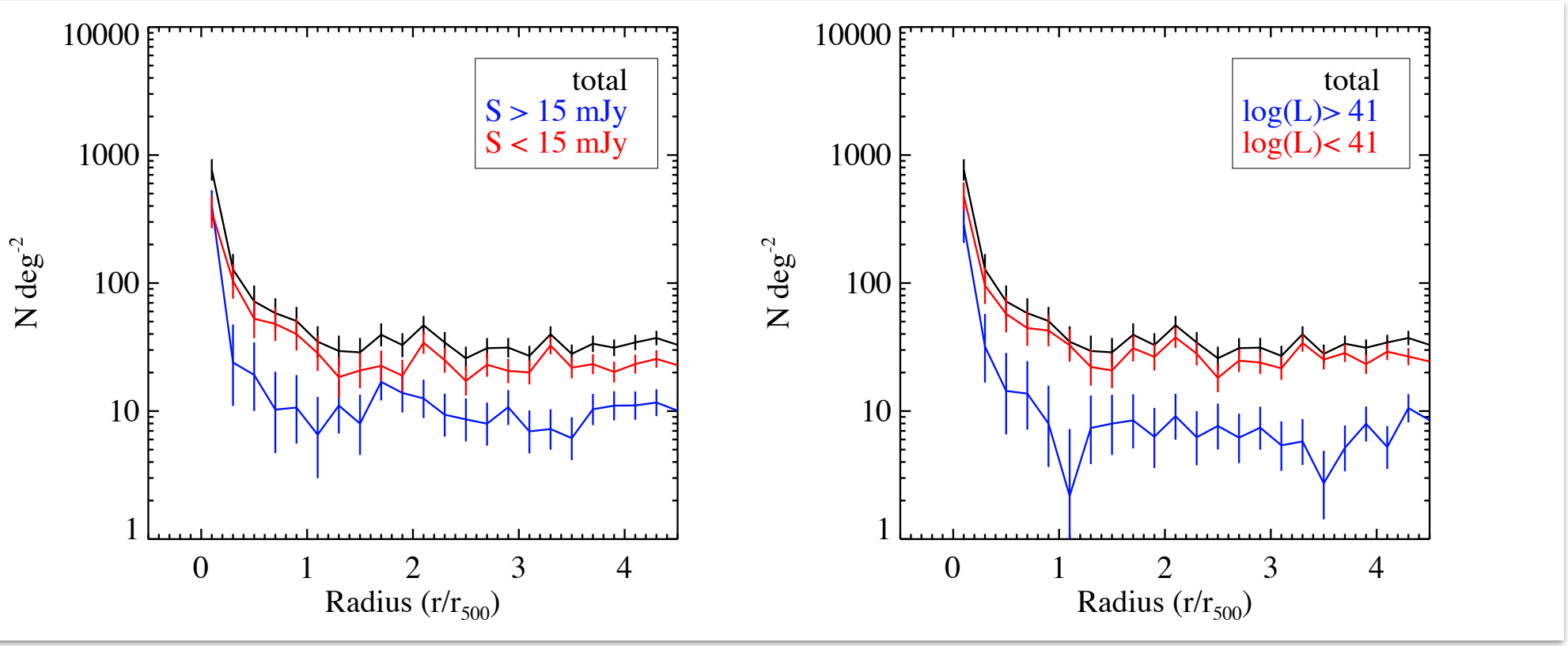
- **Radio AGN**
  - Number density is constant or slightly elevated in clusters
    - suggestive of different triggering mechanisms compared to X-ray AGN
  - We are currently investigating Cluster mass and redshift dependencies





Extra slides

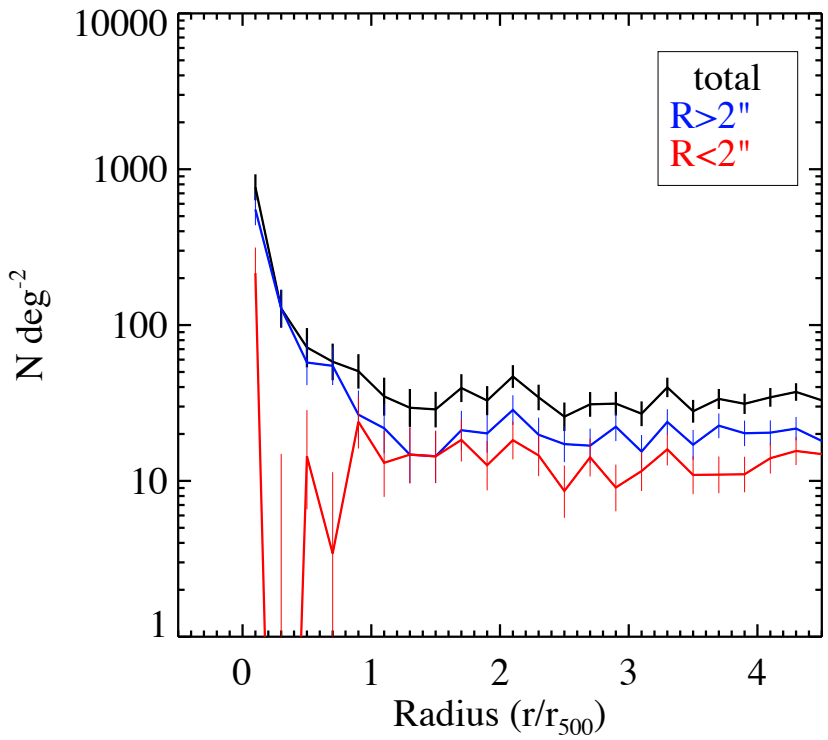
Radio Cluster AGN

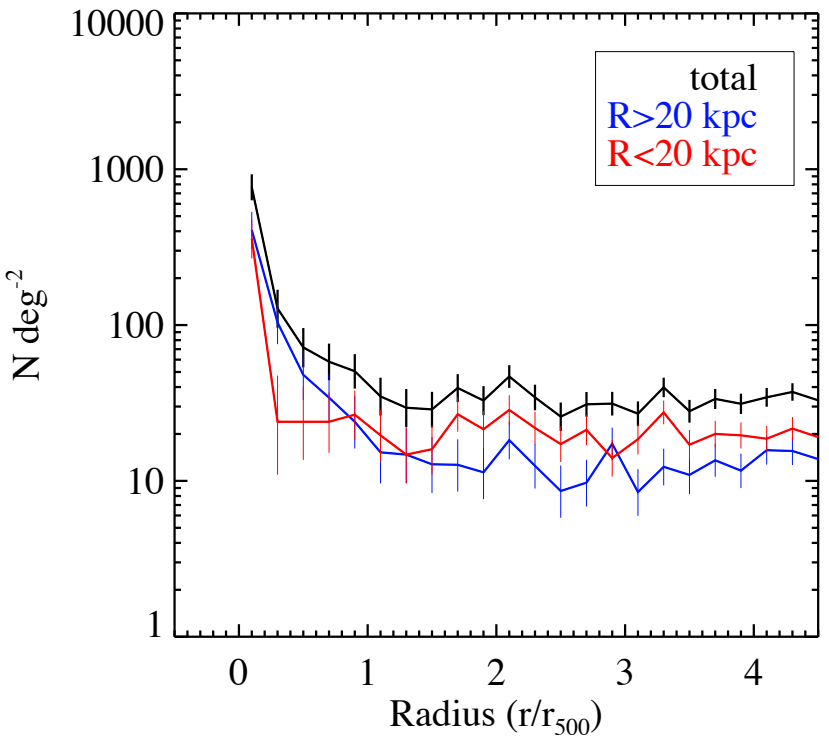


- Both high and low luminosity sources increase in number density at the center

- Log L= 41 is roughly the divide between FR I and FR II sources

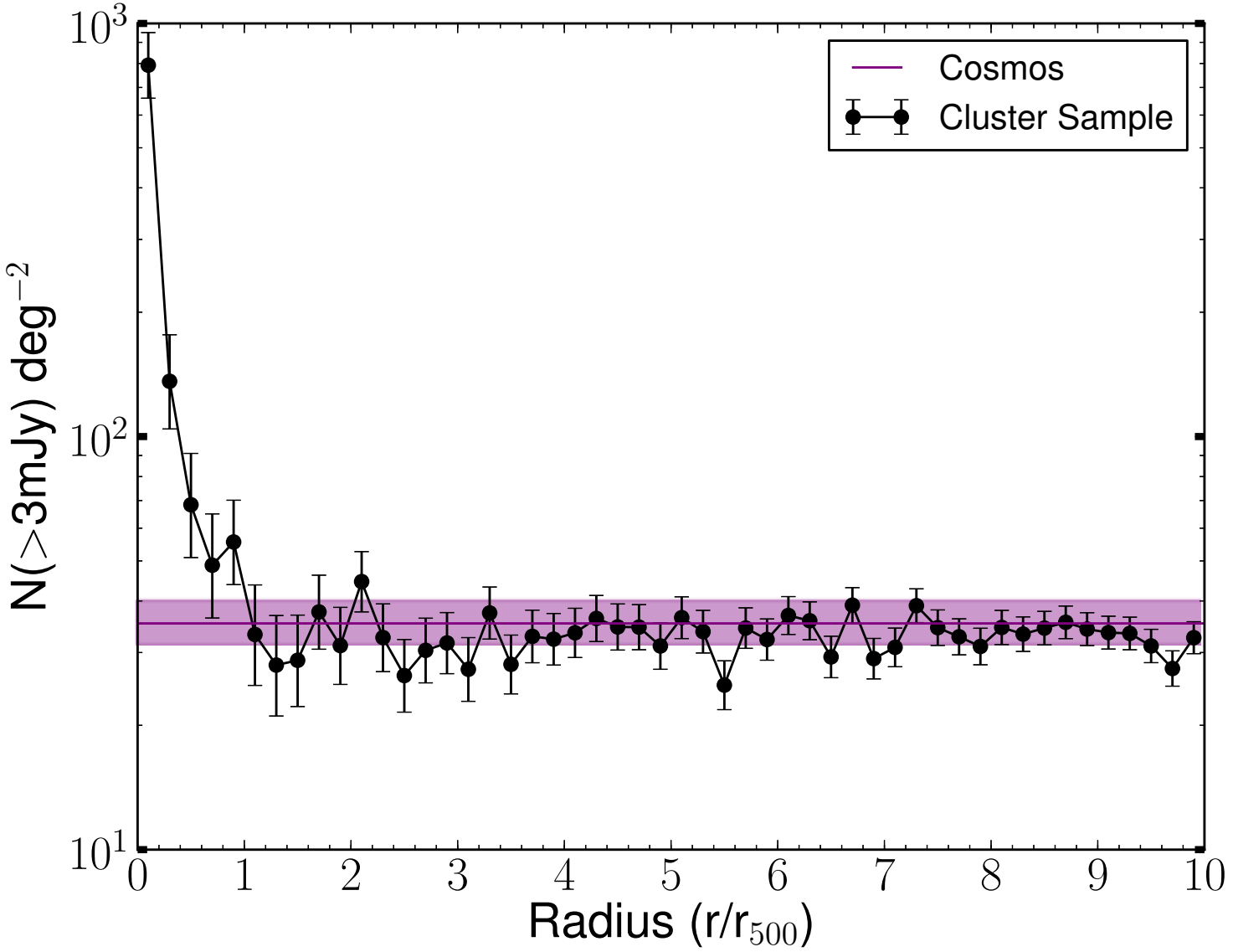
Radio Cluster AGN



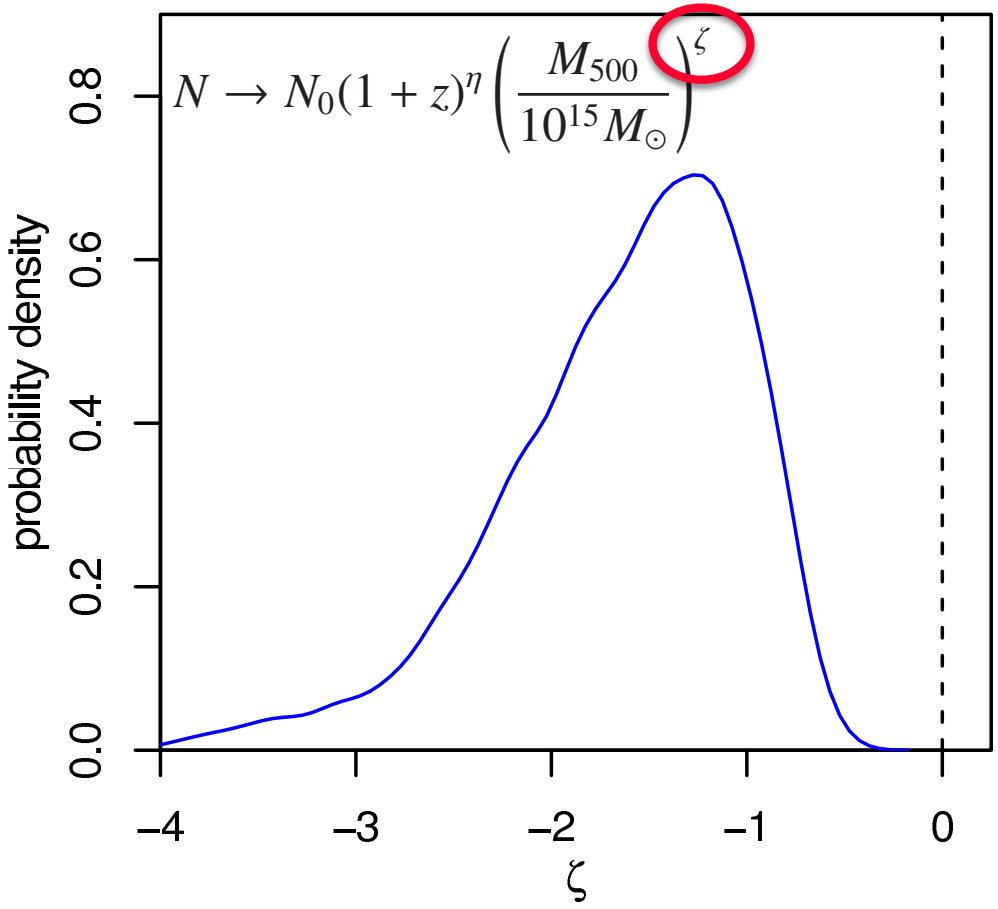


- Extended sources preferentially increase inside clusters
- Gas pressure increases in clusters, which could confine extended sources but we observe the opposite.

Radio AGN Overdensity in Cluster Center (<1 R_{500})



X-ray AGN evolution



Mass dependence of scale factor

ζ ~ -1.2

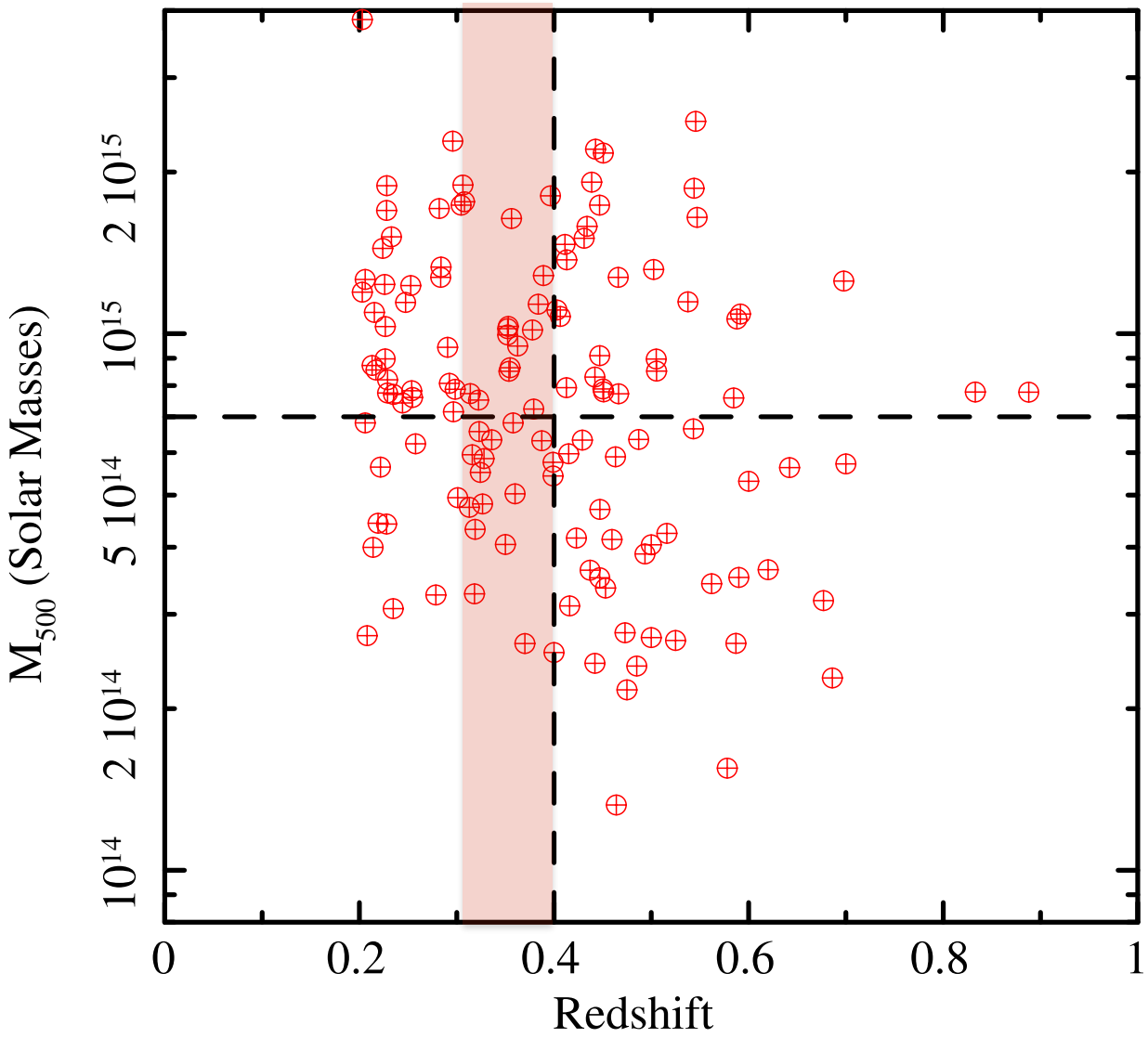
Scale factor has a $M^{-1.2}$ dependence

ζ = 0 rejected at >99.9%

No other parameters are significantly different from zero

Consistent with Merger Triggering

Spectroscopic Follow-up



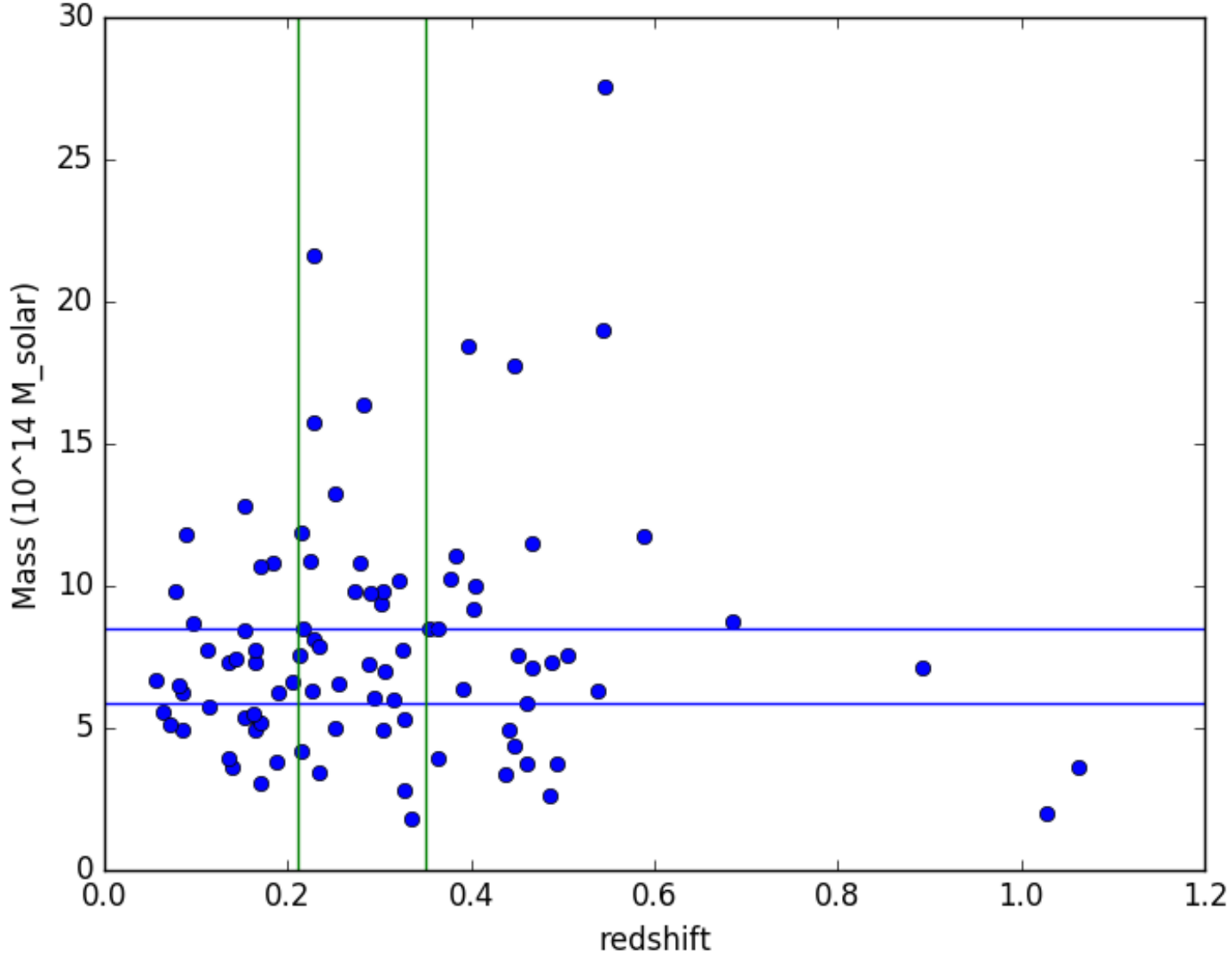
VIMOS follow-up program:

Observe 10, z=0.35 - 0.4, relaxed clusters

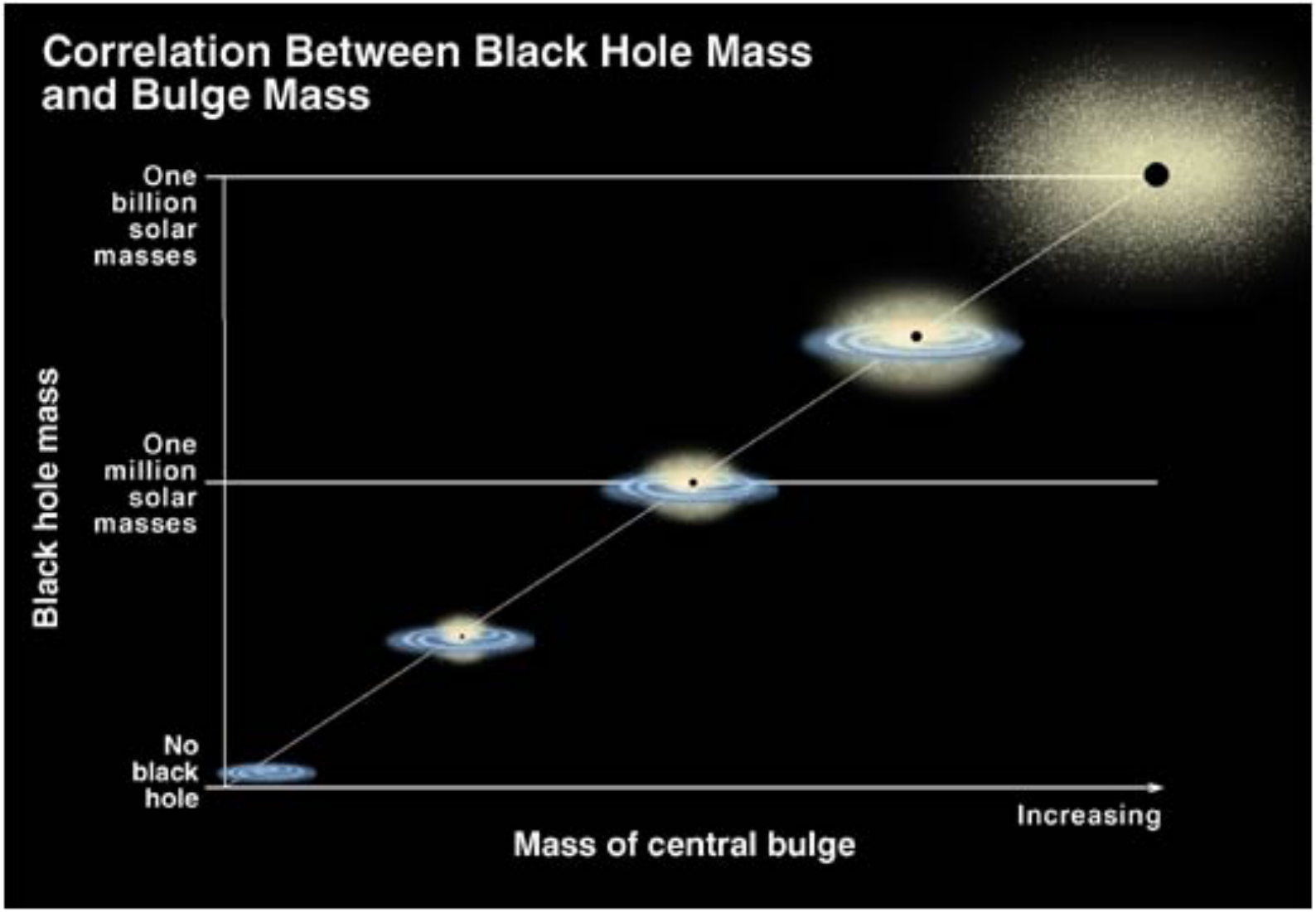
Aims:

- Examine X-ray AGN host relationship
- Does AGN fraction depend on cluster mass?

Mass and Redshift



Feedback



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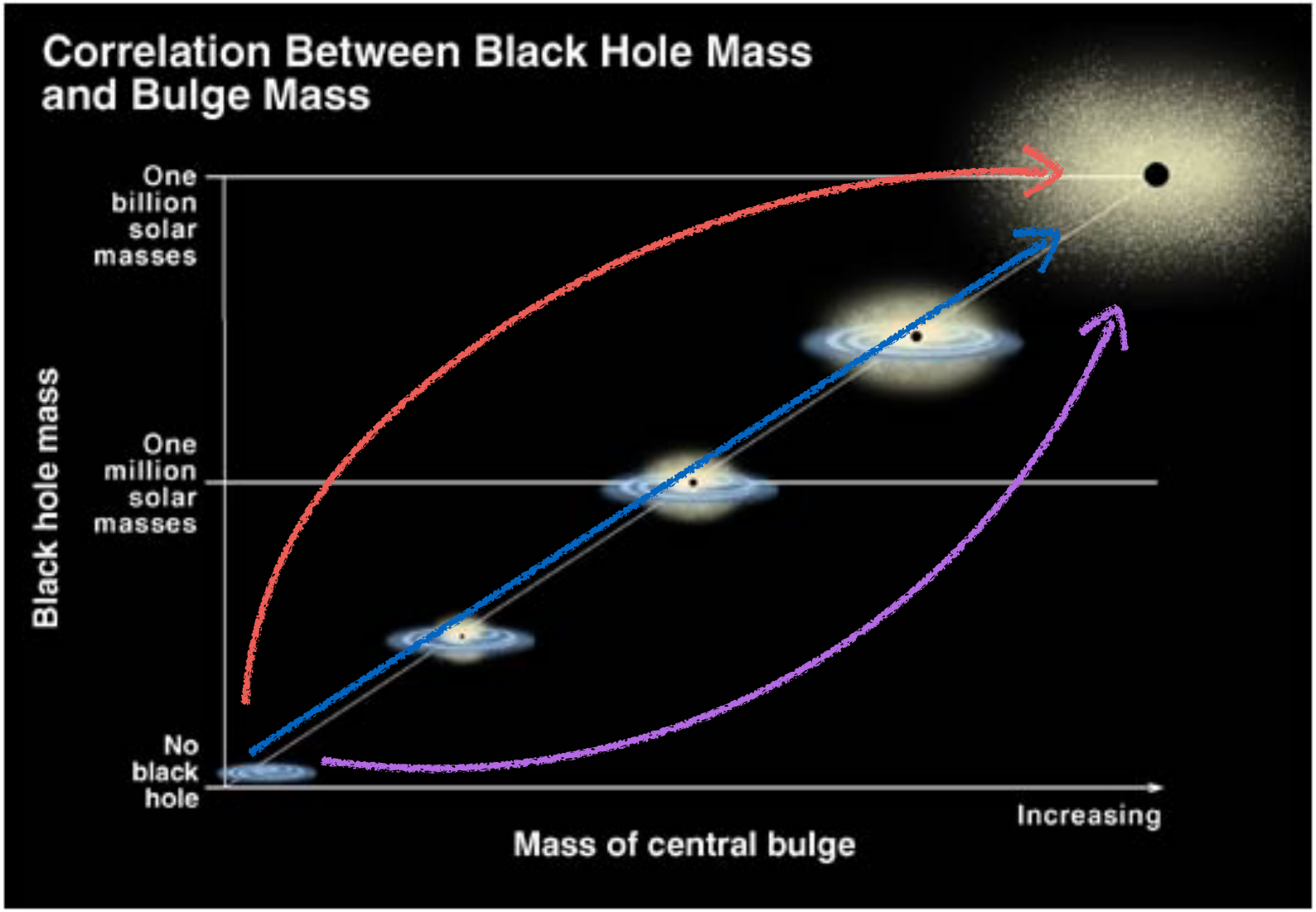
Feedback



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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 +-5000 kms^{-1}

Imaging:

- Quantify asymmetries and close pairs in spectroscopically confirmed cluster members

Spectroscopy

VIMOS follow-up program:

Expect: 500-700 targets per cluster (~6000 targets)

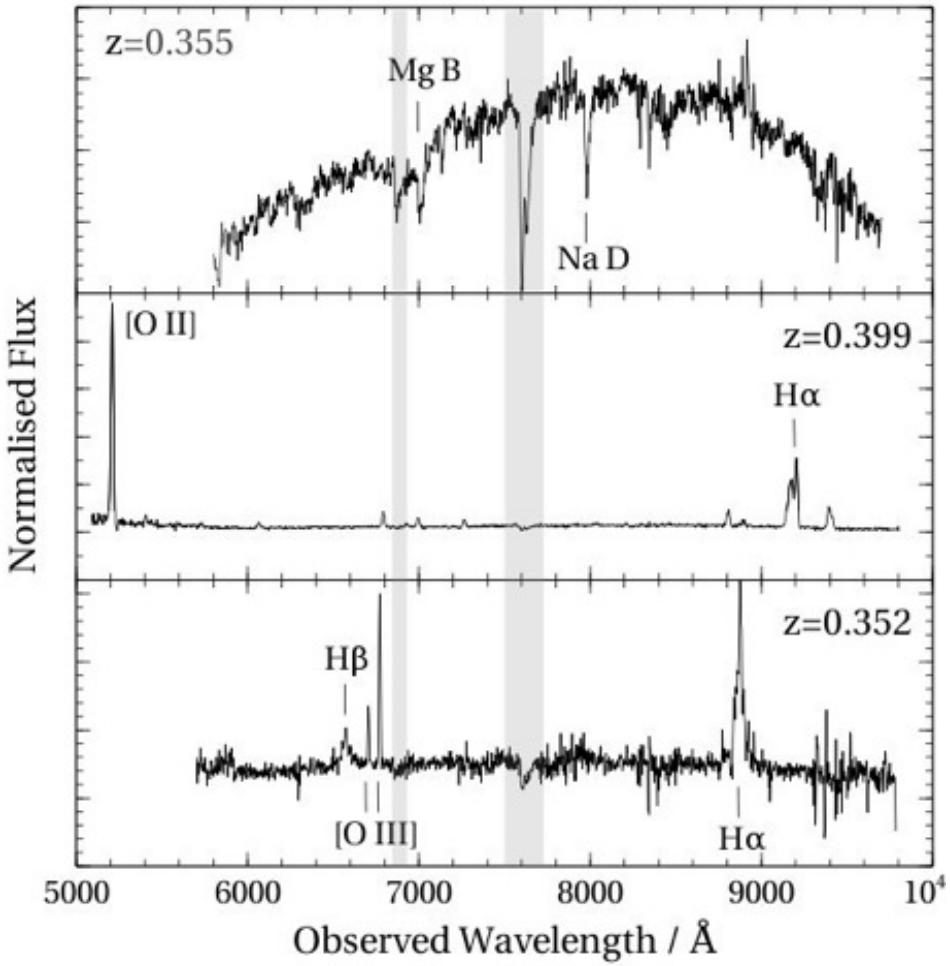
~860 X-ray AGN

>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.