Heating Distant Clusters and Driving Metal-Enriched Outflows with AGN

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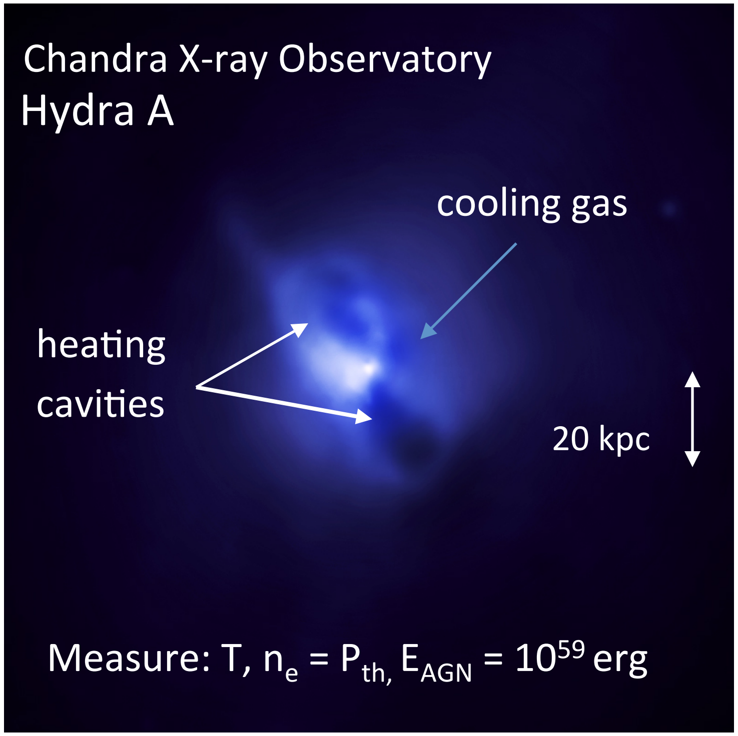
Mechanical Feedback in Cooling X-ray Halos

"*radio mode*" feedback

Even weak radio source are mechanically powerful



Measure: T, n_e = $P_{th,}$ E_{AGN} = 10^{59} erg

McN+00

Radiative cooling - AGN heating of hot gas

thermostatically controlled accretion

==> *feedback loop*

Key evidence:

-AGN mechanical power matched to cooling rates

Birzan+04, Rafferty+06, Dunn Fabian 06

-Short ($<10^9$yr) cooling times in *all* systems

Voigt & Fabian 04

consequences

- heats hot halos; regulates growth of galaxies & SMBHs

See McNamara & Nulsen 07 ARAA, Peterson & Fabian 06 for reviews

Outline

> Brief review of feedback and jet power estimation

> Radio-AGN Heating of Distant 400SD clusters – C.J. Ma Poster

> Lack of Emission Lines in Distant 160SD cluster BCGs:
Evolution of strong cooling flows

> Driving metal-enriched outflows on large cluster scales

> Summary: AGN heating important throughout history of clusters

Senior Collaborators: P. Nulsen (CfA), A. Vikhlinin (CfA), M. Wise (ASTRON)
Junior Collaborators: C.J. Ma (UW/CfA), H. Russell (UW), M. Rohanizadegan (UW), C. Kirkpatrick(UW), K. Cavagnolo (UW, Nice), R. Samuele (NGST), R. Schaffer (UW), M. Gitti (CfA/INAF)

Radio AGN Heating of Hot Atmospheres of Distant Clusters

Ma, McN, Nulsen, Schaffer, Vikhlinin 11

Please visit C.J. Ma's Poster!

AGN Heating in Distant Clusters: 400SD Survey

Distant Cluster Sample:

C.J. Ma + 2011

400SD Cluster Survey: 266 optically confirmed X-ray clusters (ROSAT PSPC) z< 1

Burenin, Vikhlinin + 2007

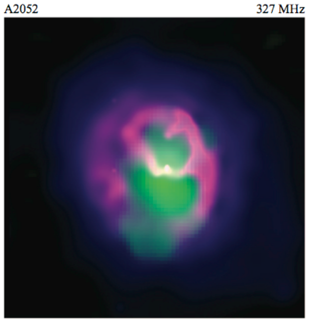
Procedure:

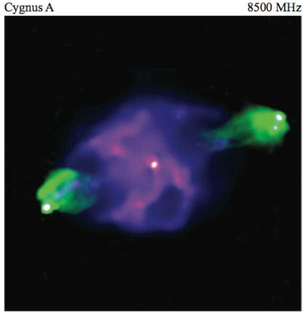
- Cross Correlate 400SD X-ray positions with NRAO VLA Sky Survey radio sources
- $10^{43} < L_x < 10^{45}$, $0.1 < z < 0.9$
- Radio detection threshold > 3 mJy
- Correct for background as function of flux
- Calculate jet power using cavity power scaling relation at 1.4 GHz

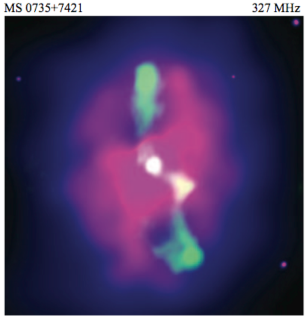
Challenge: finding a good sample, jet power proxy

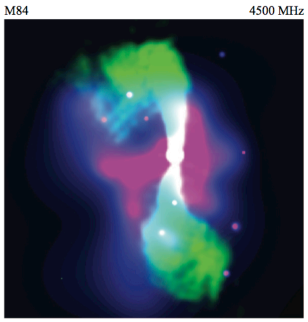
Low radiative efficiency: Mechanically Dominated

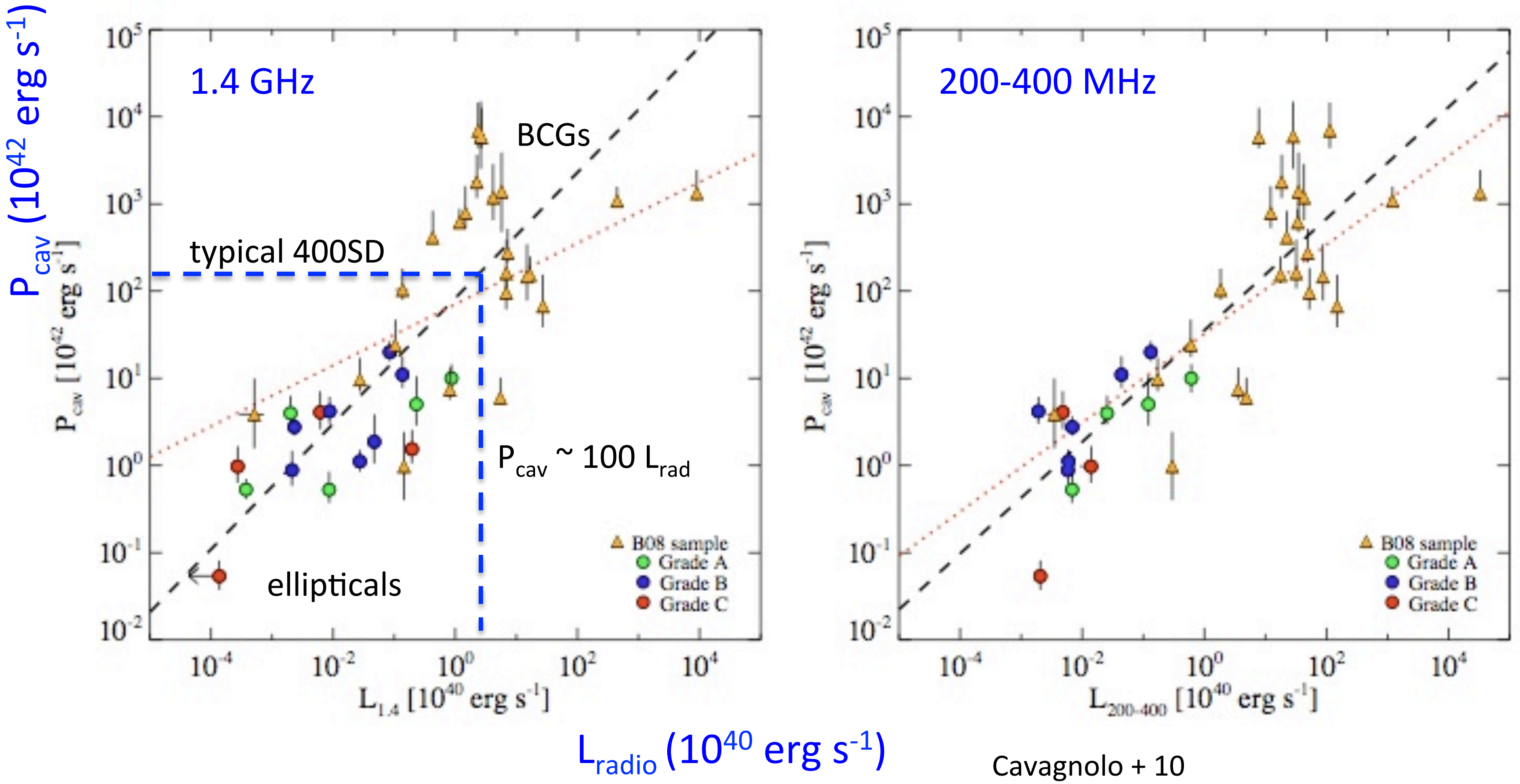
$$P_{cavity} \propto L_{radio}^{0.7}$$





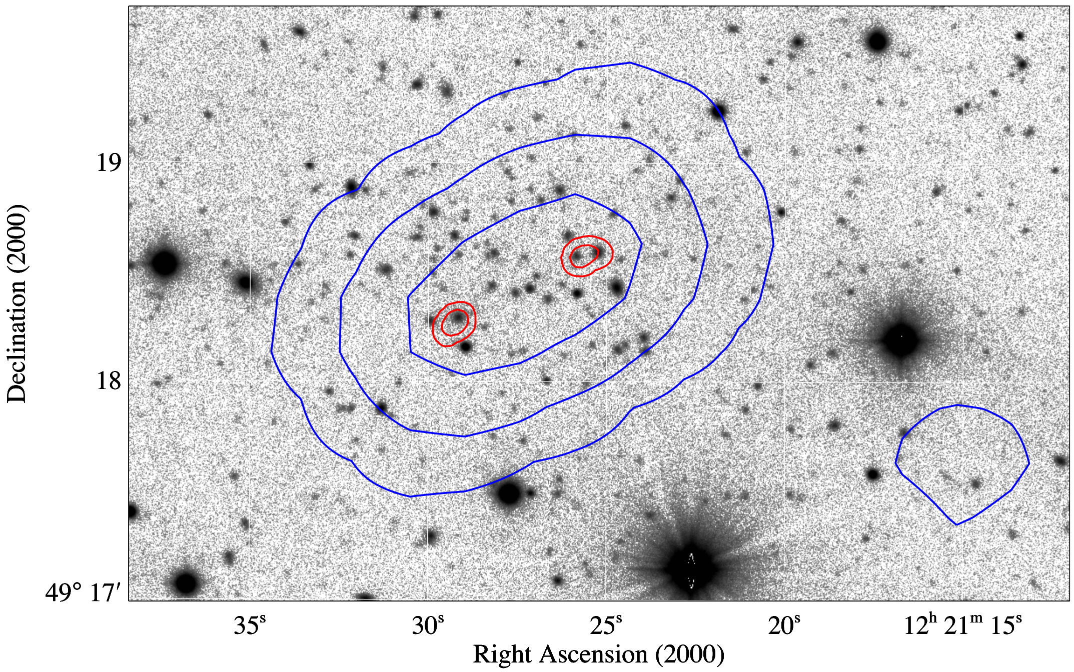






Cavagnolo + 10
Birzan + 04,08

NRAO-VLA Sky Survey-Condon + 1998



J1221+4918

$z = 0.7$

$L_x = 1.2 \times 10^{45}$ erg s^{-1}

$kT = 6.5$ keV

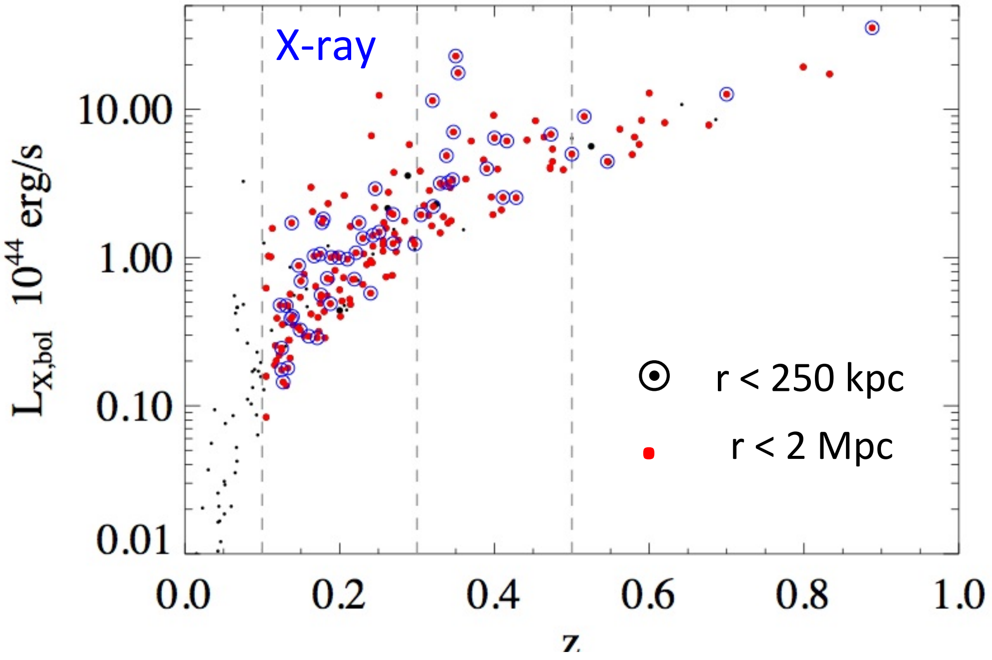
Ma + 11

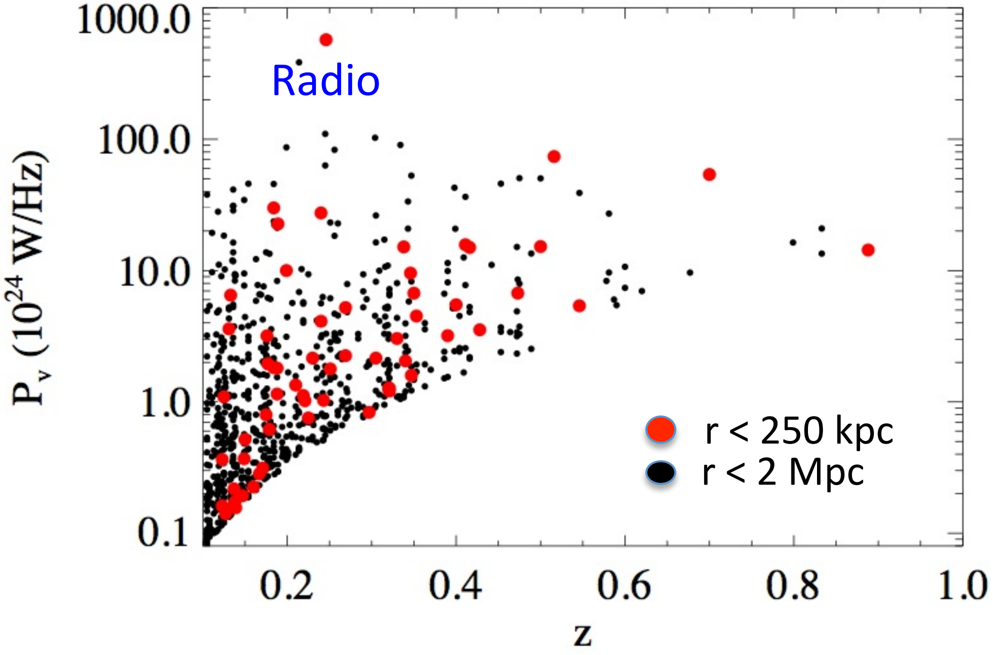
Host galaxies cannot be identified using NVSS images

FIRST survey images can begin to isolate the galaxies

Find: ~32% detected R < 250 kpc ; ~100% R< 1 Mpc

X-ray and Radio Power with Redshift in 400SD





Ma+11

Detections:

~32% (53/165) R < 250 kpc consistent with BCG

Comparison:

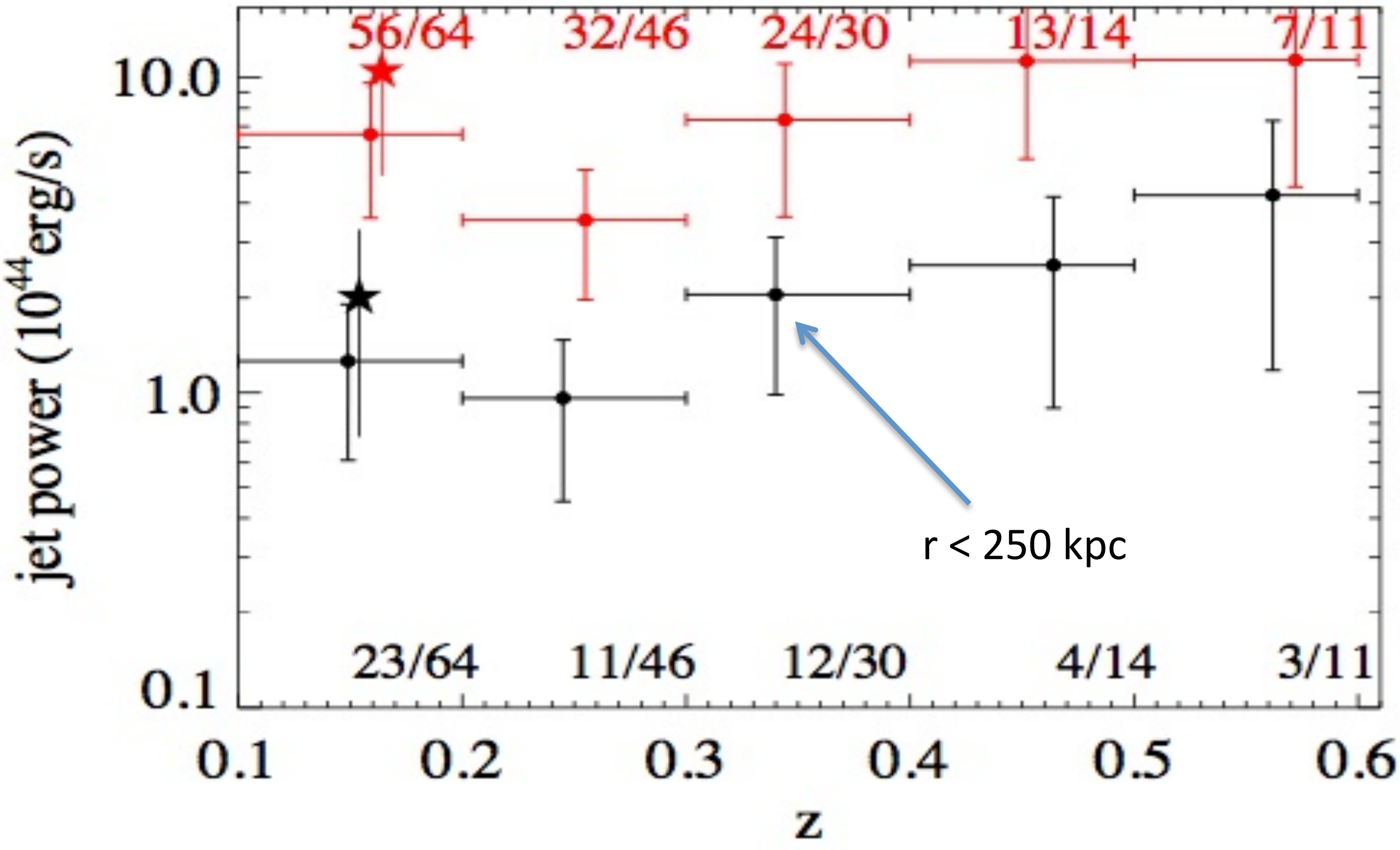
Strong cooling flows: ~100% detection in BCG

Dunn & Fabian 06

Average BCG: ~ 30%

Best + 06

Jet Power vs Redshift: not much is changing



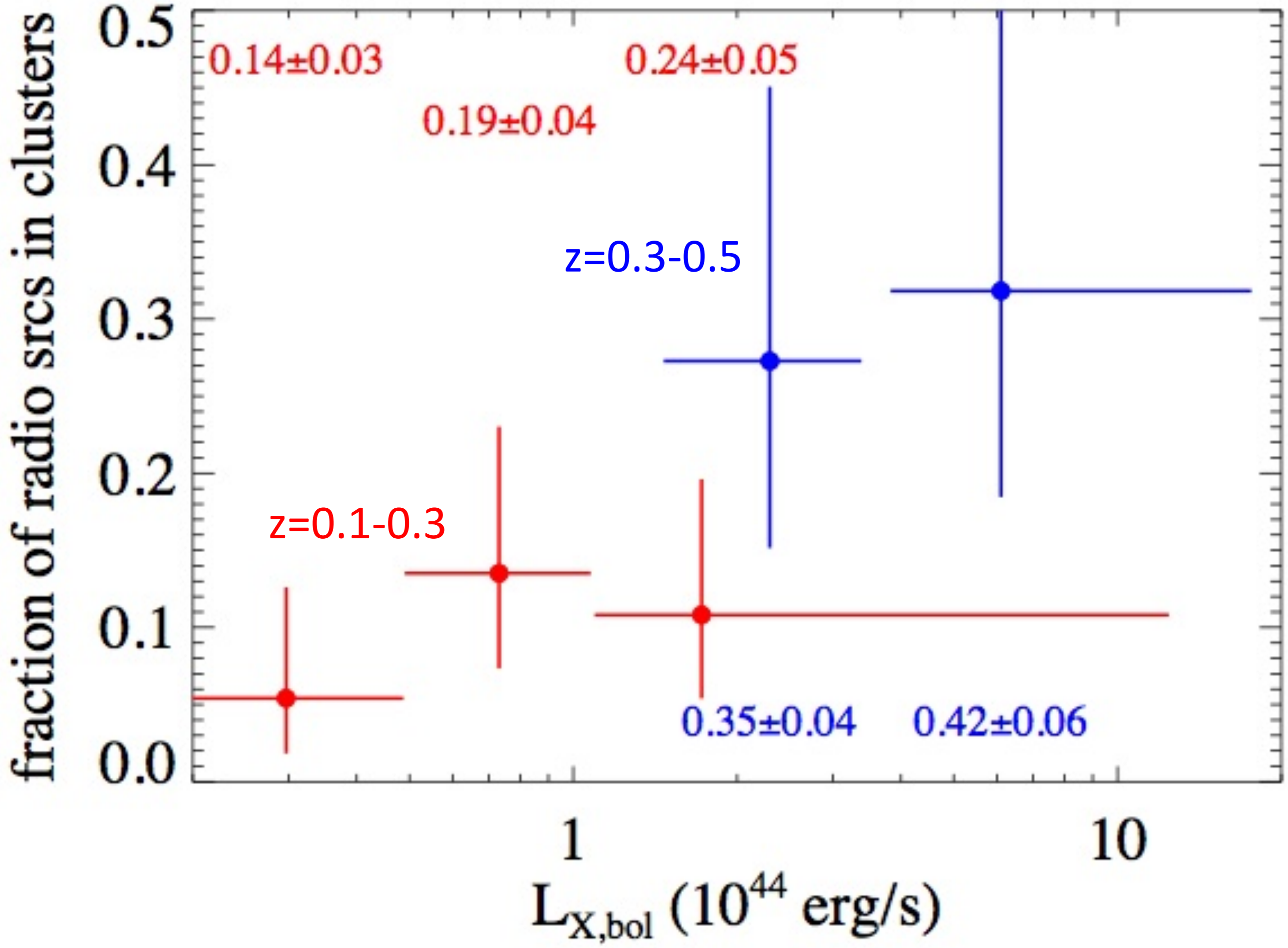
r < 250 kpc

$\langle P_{jet} \rangle \sim 2\text{x}10^{44}$ erg s^{-1}

Ma + 11

Jet power per cluster changes little with z

Detection Fraction wit L_x R < 250 kpc



Mild if any change in detection frequency with cluster luminosity

Heating per particle higher in lower luminosity clusters

Summary

> AGN heating is significant in normal clusters at high redshifts

> Weak or absent cooling flows– *feedback or heating*?

> heating per particle:

~0.2 keV R < 250 kpc

~0.5 keV R < 1 Mpc

> ~ 0.5-1 keV integrated over cluster ages

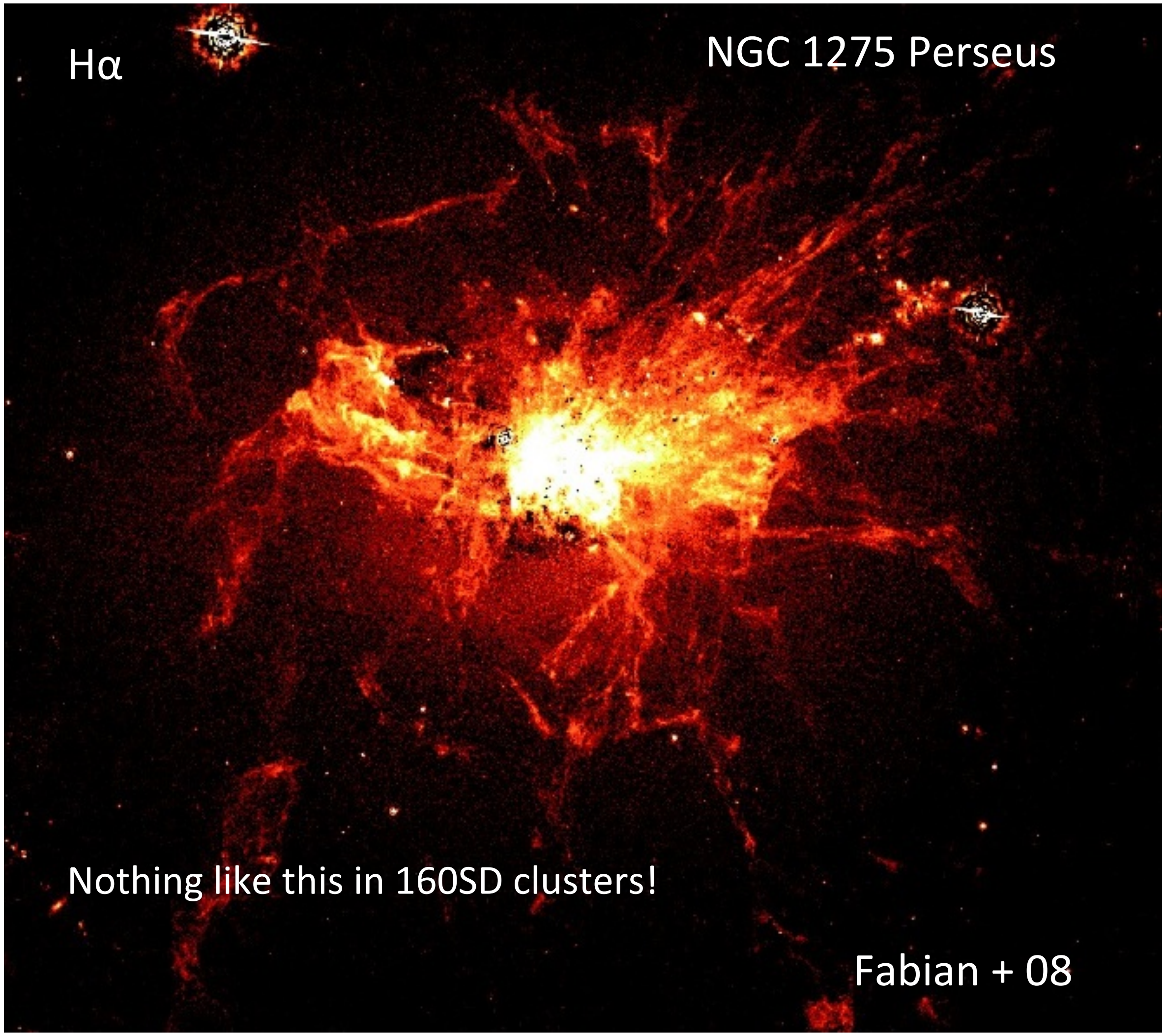
Require: ~ 1 kev to "preheat" clusters (Kaiser 01; Voit 04, Wu + 99)

AGN heating and/or mergers staving off large cooling flows?

Caveat: how reliable is jet power scaling relation?

bright hotspots/radio cores overestimate P_{jet}

Nebular Emission in BCGs Signals Strong Cooling Flows

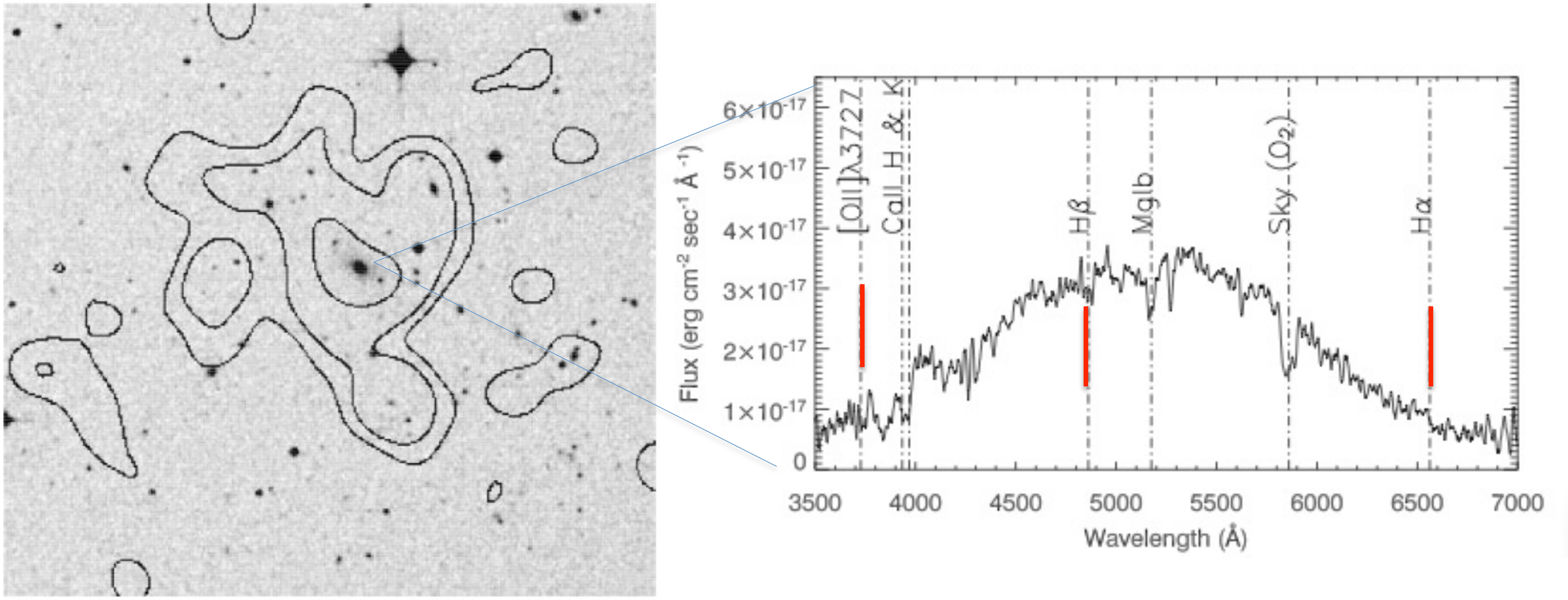


Search for Emission Lines in 160SD Brightest Cluster Galaxies

Samuele + 2011

160SD Cluster Survey

Vikhlinin, McN + 98

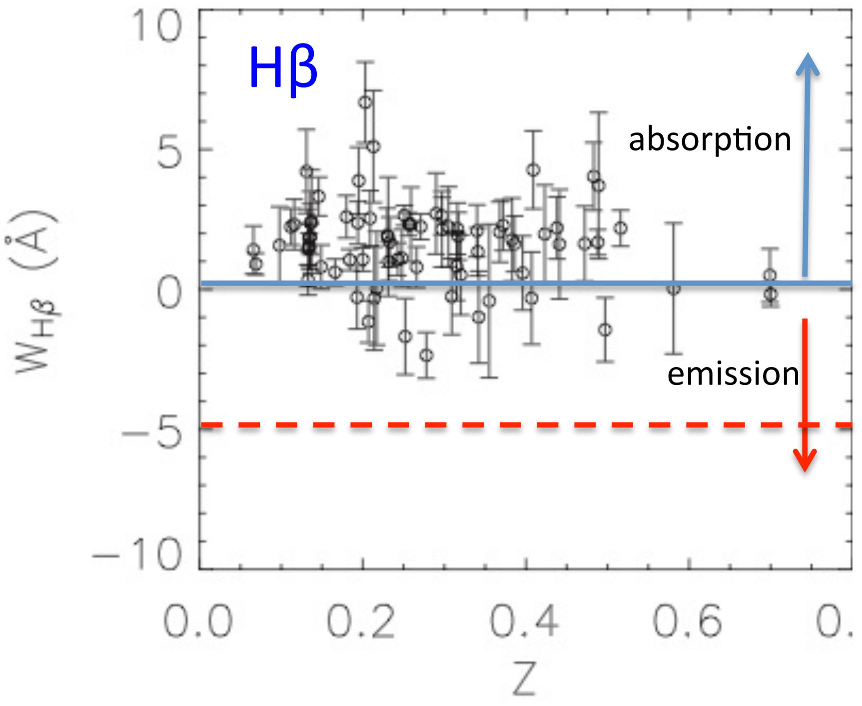


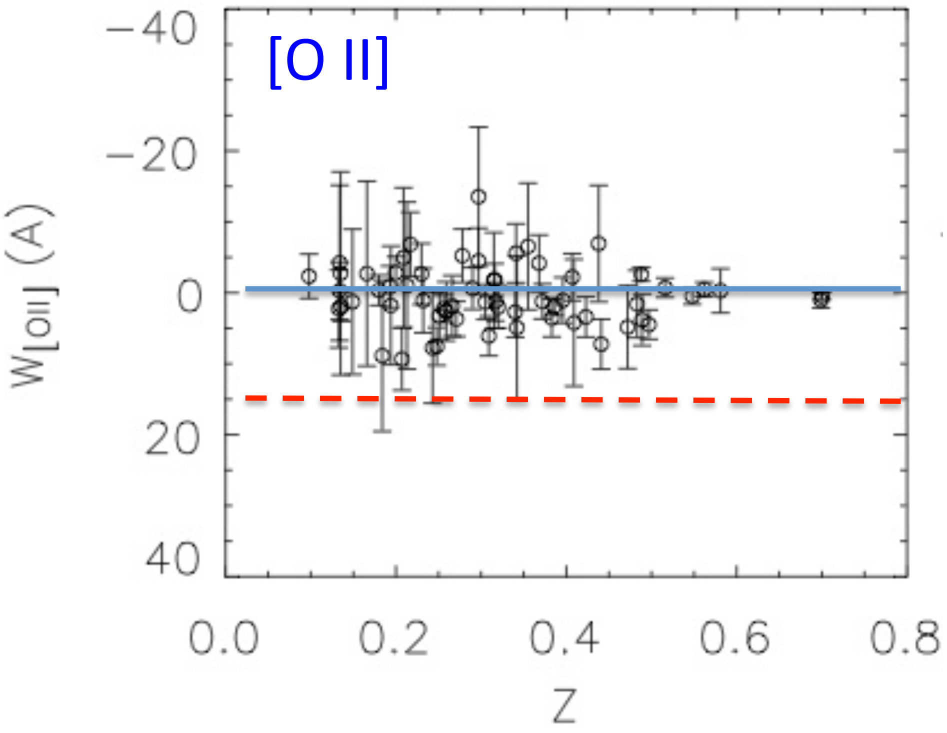
> 203 X-ray detected, optically confirmed clusters
> $10^{42} < L_x < 5x10^{44}$ erg s^{-1} $0.02 < z < 0.5$

> Searched for emission lines in 77 BCGs
> Detected none above L = 6×10^{40} erg s^{-1} (30 x below N1275/Perseus)

Samuele, McN, Vikhlinin, Mullis 11

160SD: No Strong Emission Lines



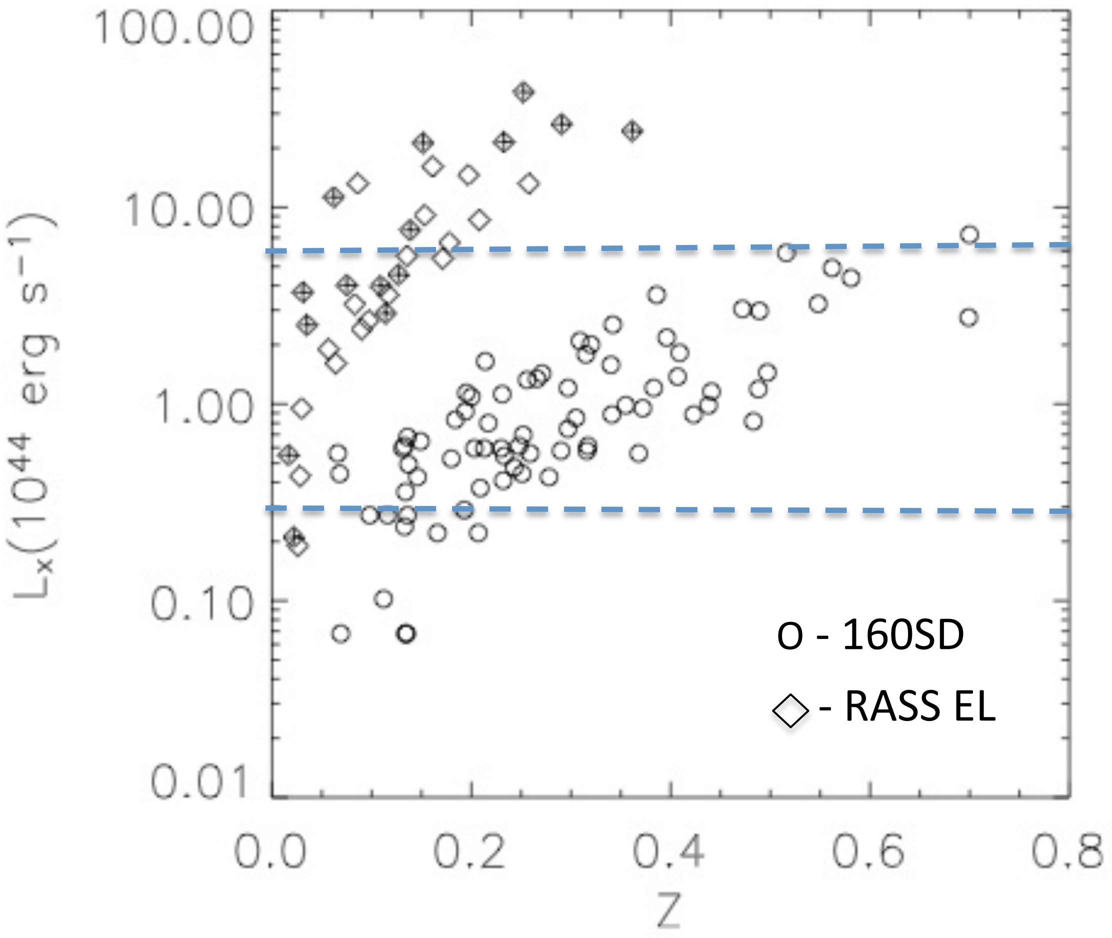


Detection thresholds: Hα, Hβ -5 Å [O II] -15 Å

Compared to RASS (Crawford + 99) expected 12/77 detections

Samuele + 11

BCS Emission BCGs- 160SD: Redshift



Samuele + 11

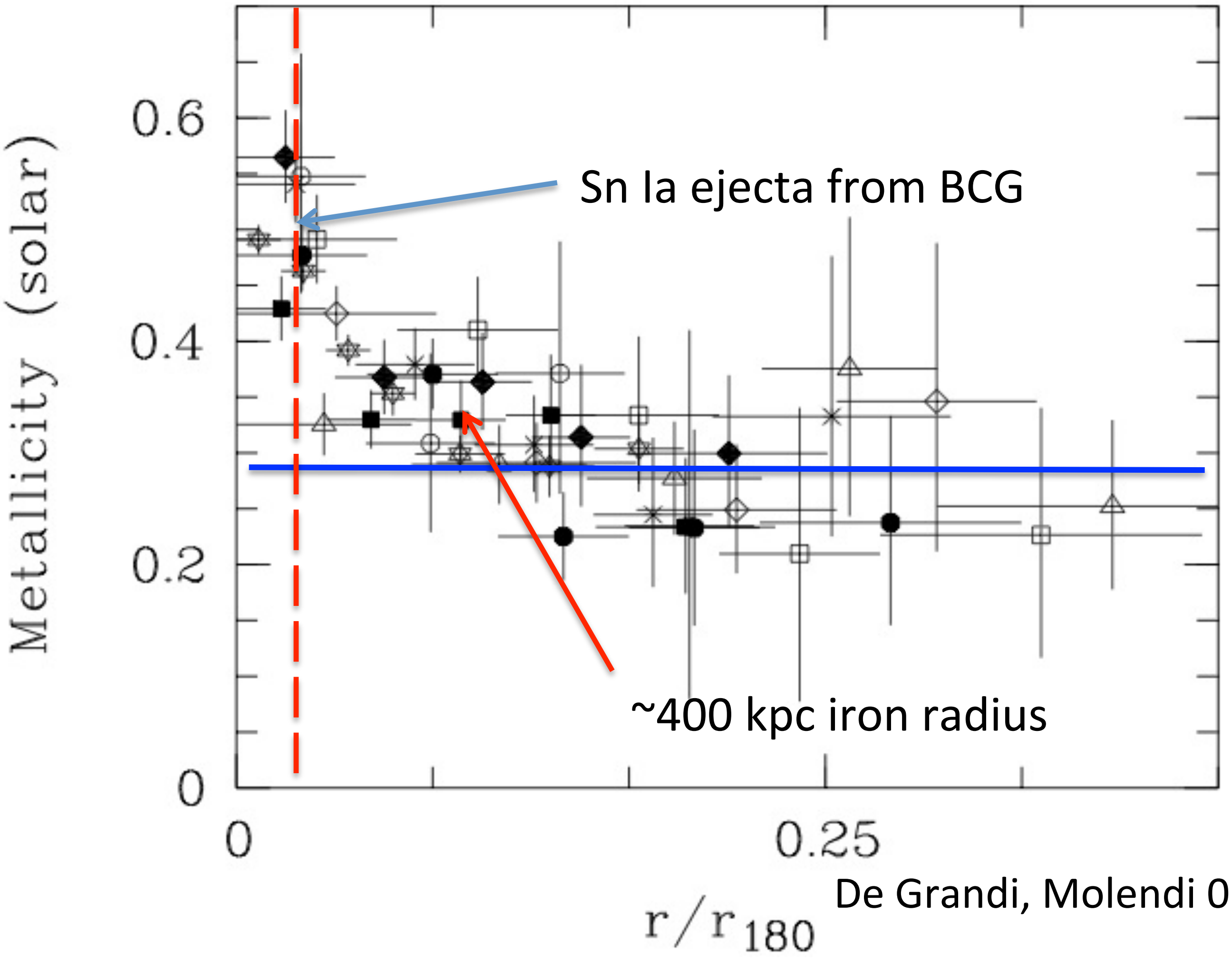
> BCS clusters reach higher Lx, but both sample overlap significantly in Lx

> Redshift is primary variable: Fewer *strong* cooling flows at z > 0.3

Consistent with lack of strong X-ray cool cores: Vikhlinin + 07, Santos + 08 (next talk)

Large-Scale, Metal Enriched Outflows in Clusters

Abundance Gradients near BCGs: AGN drive the metals out



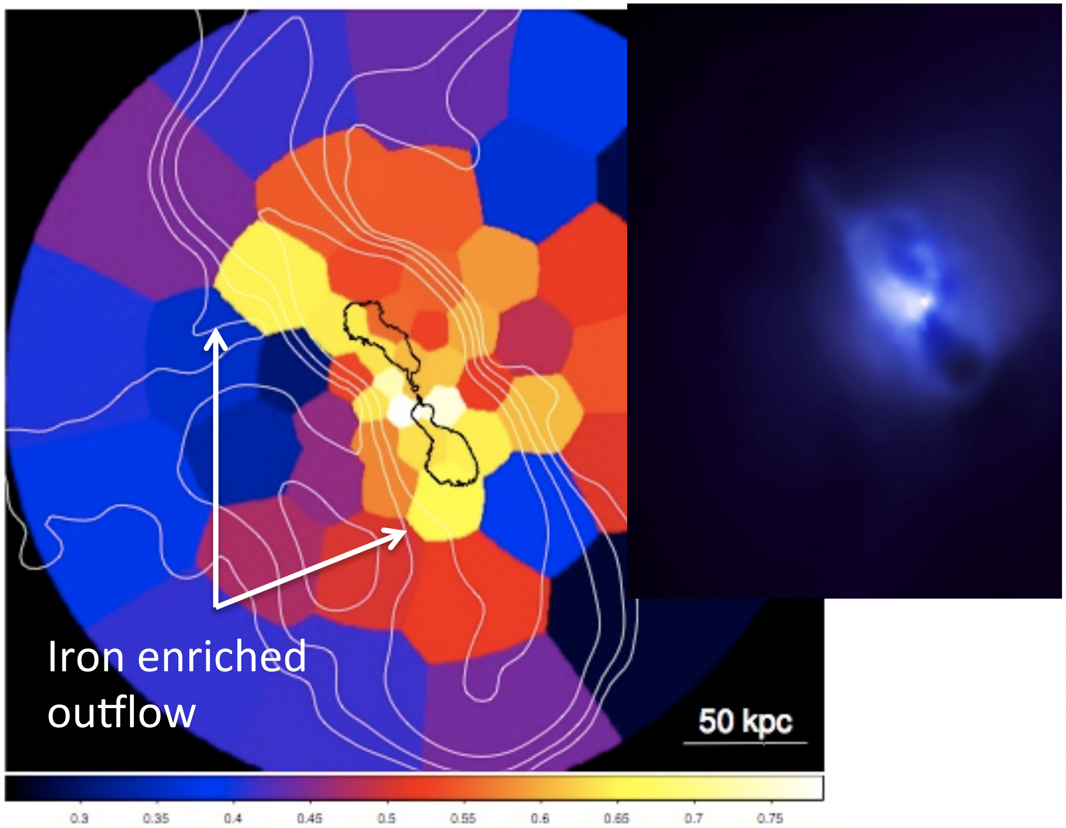
Sn Ia ejecta from BCG

~400 kpc iron radius

De Grandi, Molendi 01

See also: Rebusco + 05, 06, David & Nulsen 08, Rasera + 08

Hydra A Cool, Metal Enriched Outflow

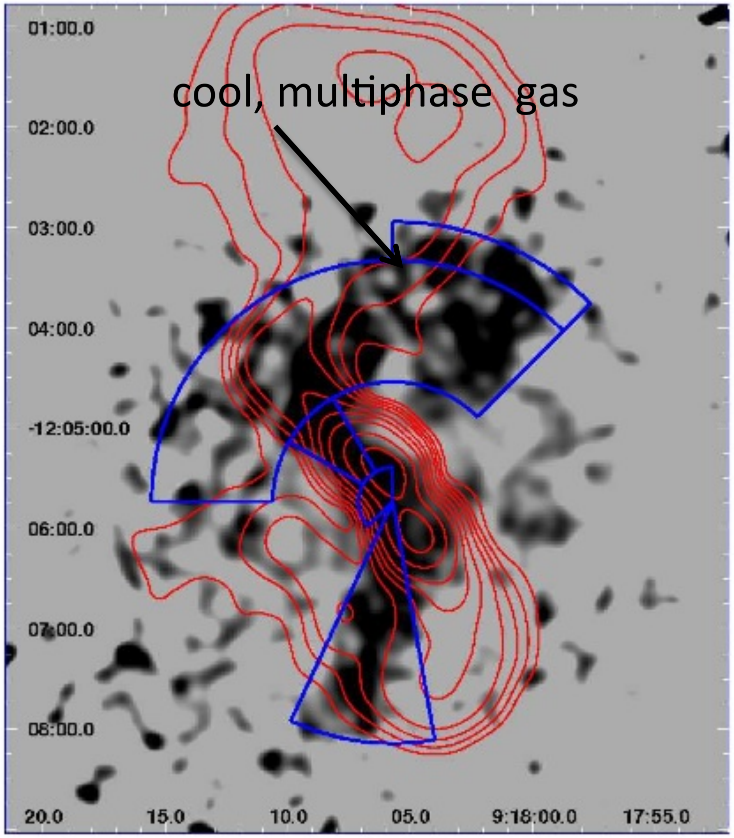


Iron enriched outflow

Kirkpatrick + 09

$$\Delta M_{Fe} = 2-7\times10^{7} M_{0}$$

R~120 kpc



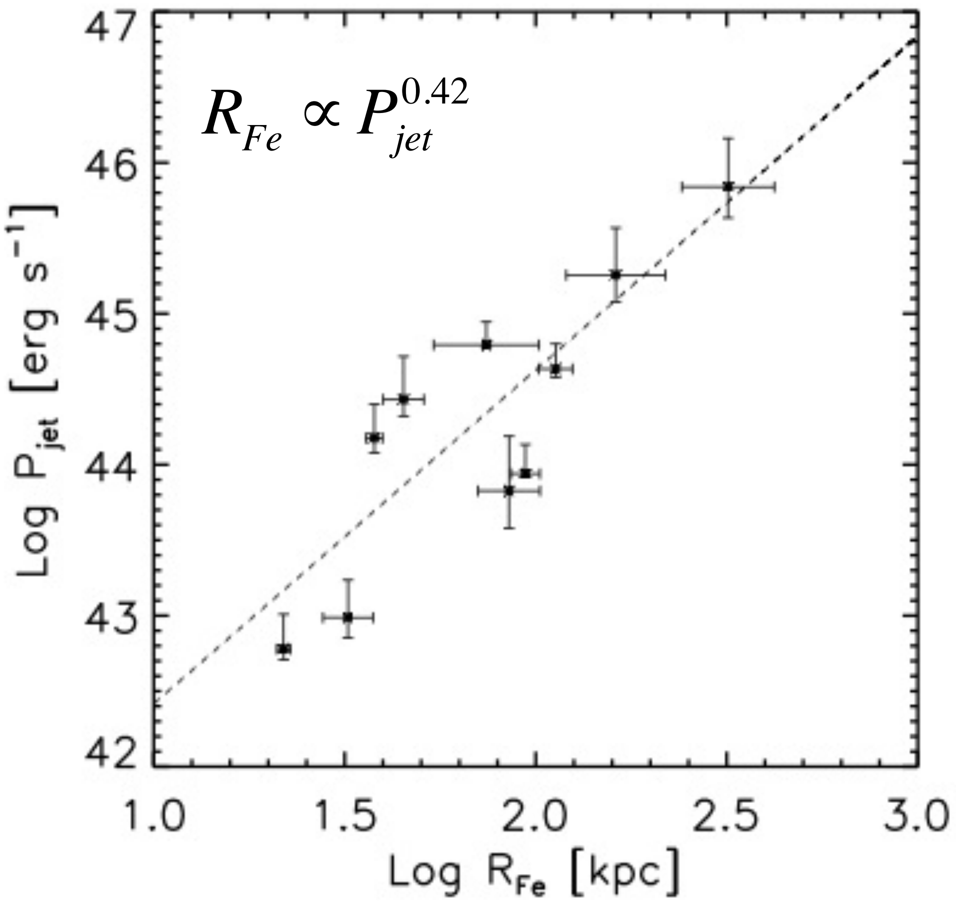
cool, multiphase gas

Gitti + 11

AGN-Jets disperse metals in the ICM

See also Simionescu + 08, O'Sullivan + 11, Nulsen + 05

Outflow iron radius correlates with Jet power

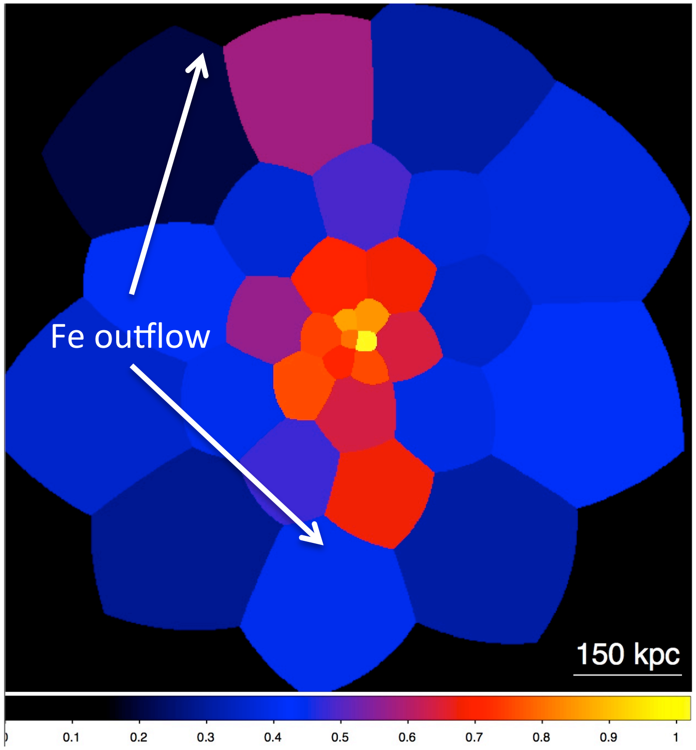


Kirkpatrick + 11

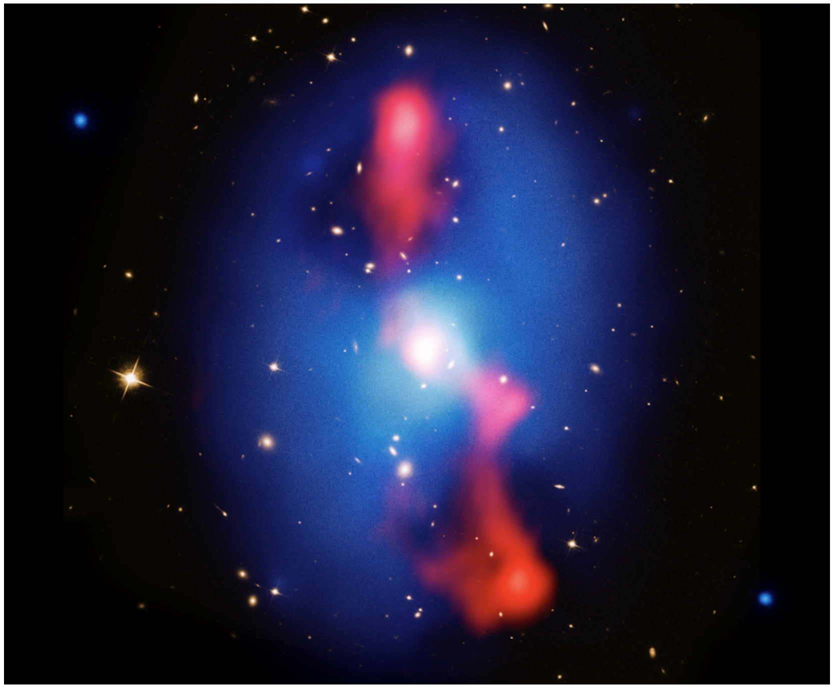
Orientation of outflow correlates with radio and cavitiy orientation: jet driven outflows

500 ks Chandra LP

MS0735 Metal-Enriched Outflow: largest yet



R_{Fe}~300 kpc P_{jet}~ 3×10^{46} erg s^{-1}



McN+11

Note: big AGN outbursts boost f_g!

General Fe scaling relation:	$R_{Fe} \sim P_{jet}^{0.42}$	Kirkpatrick + 11
Jet influence (simulation):	$R_{jet} \sim P_{jet}^{0.33}$	Morsony + 10

implication: to lift metals to 1 Mpc requires $P_{jet} > 10^{47}$ erg s^{-1}

Excesses metals observed to ~0.3 Mpc: Consistent with *powerful* AGN dispersal

Summary

- AGN heating significant in normal clusters during the early Universe
- Continuous AGN heating at levels of several tenths keV/particle

  ie., nearly at expected ‘’preheating” levels (Ma + 11)
- Dearth of *large* cooling flows beyond z~ 0.3
- AGN drive large-scale outflows of metal enriched gas into the ICM
- Enrichment radius follows powerlaw form: $R_{Fe} \propto P_{jet}^{0.42}$

Kirkpatrick + 11