AGN feedback in galaxy groups

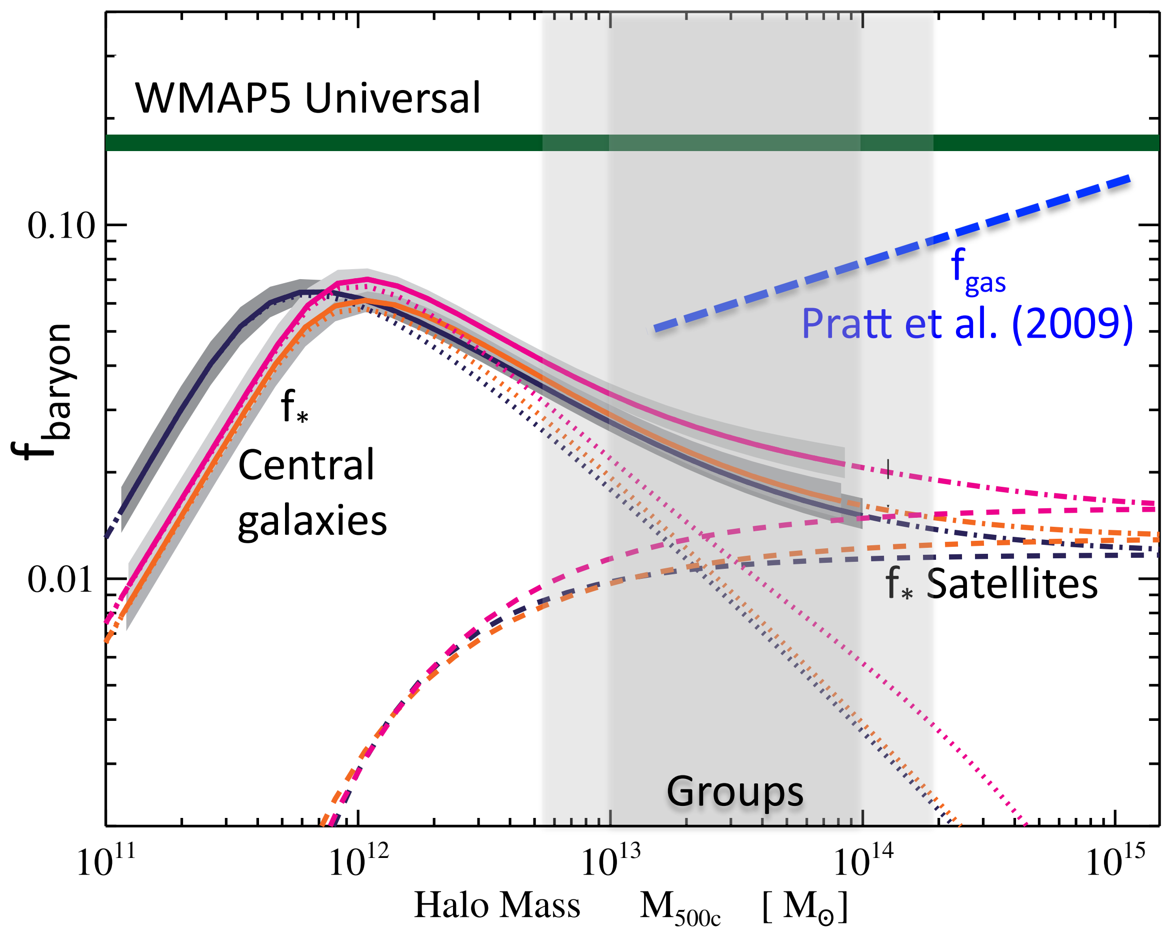
Ewan O'Sullivan (Harvard-Smithsonian C.f.A.)

With thanks to: S. Giacintucci (Maryland), L. David & J. Vrtilek (CfA), M. Gitti (Bologna), S. Raychaudhury & T.J. Ponman (Birmingham)

Why look at feedback in galaxy groups?

- Groups contain >50% of stars in local Universe, large fraction of baryons.
- In groups hot gas begins to dominate the baryon budget.
- AGN may have liberated gas from groups at *z>2* (McCarthy et al. 2010, 2011)
- AGN feedback in groups must be fine tuned. Outbursts should be weaker but occur more often (Gaspari et al. 2011)

Adapted from Leauthaud et al. (2012)

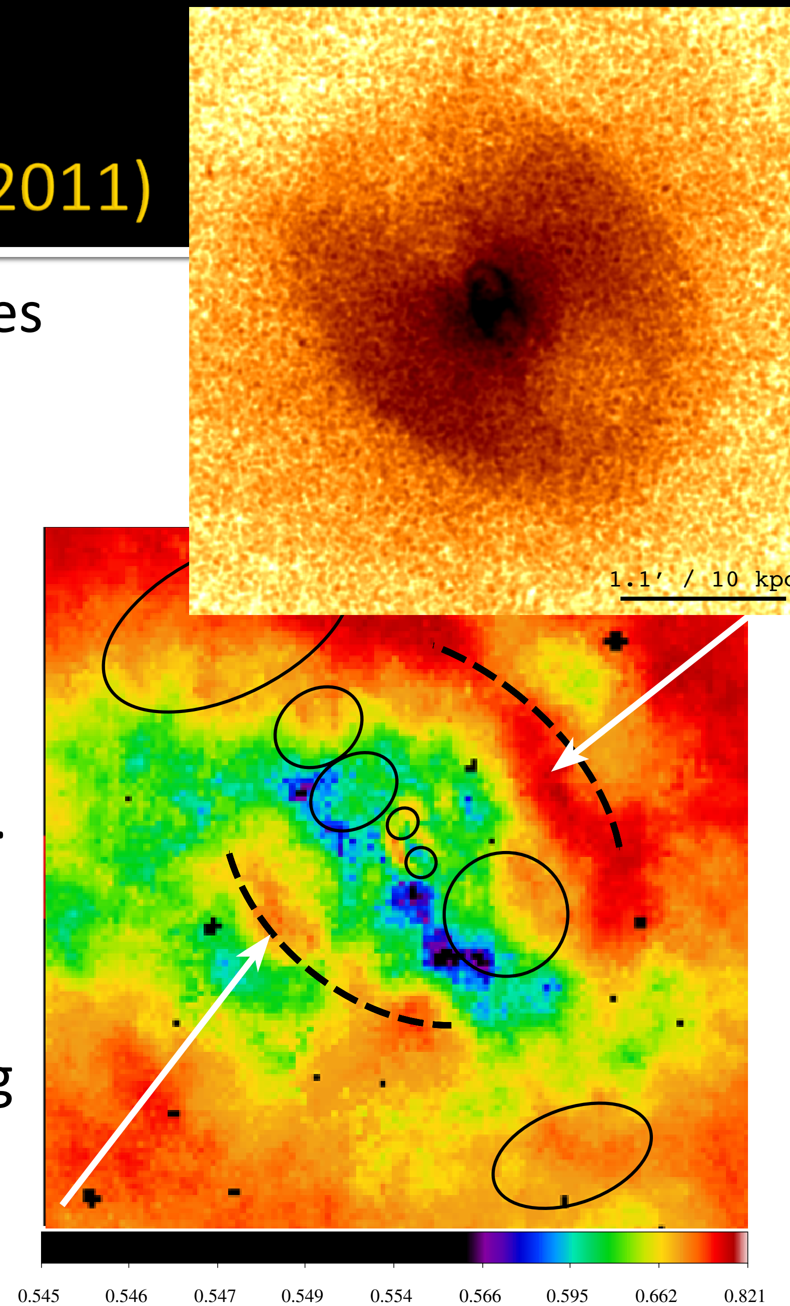


Problems

- At low redshift we lack representative samples.
  - At low luminosities, RASS X-ray selection is biased toward centrally-concentrated (cool core) systems (Eckert et al. 2011)
  - The small number of galaxy members can make optical selection unreliable for low-mass groups.
- At moderate redshift we can't observe feedback directly.
  - Detecting shocks/cavities would require unfeasibly long X-ray pointings.

Shocks and cavities
(e.g. NGC 5813, Randall et al. 2011)

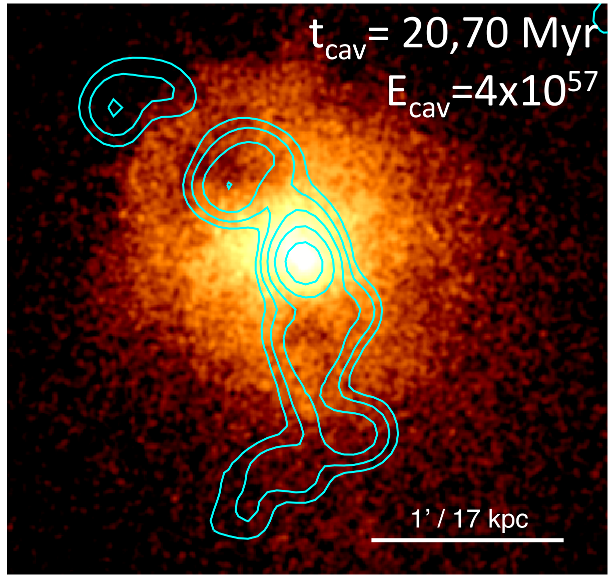
- Two shocks and three pairs of cavities
- Shock velocities Mach 1.5, 1.7
- Cavity ages 6, 20, 90 Myr
- Cavity enthalpy: 9, 11, 13×10^{56} erg
- Energy in shocks: 0.2, 3×10^{57} erg (40-80% of energy in each outburst).
- Sufficient heating from shocks to balance cooling in central 10 kpc without cavity contribution (assuming 10% efficiency) .



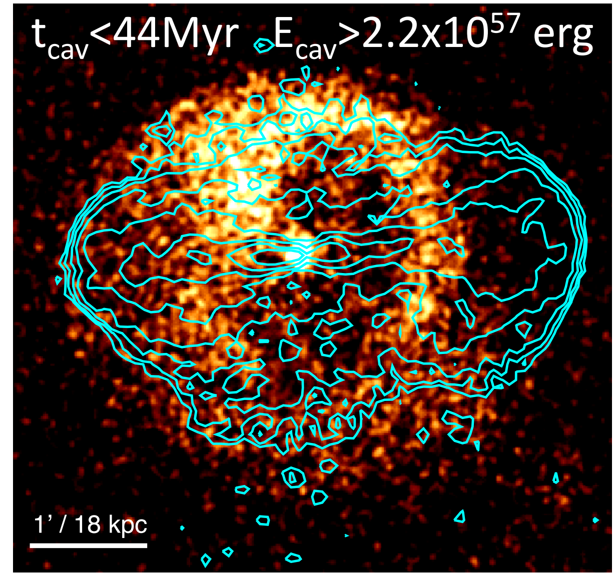
Wide variety in:

- X-ray and Radio morphology
- Age: 1-100s Myr
- Enthalpy: $10^{56\text{-}59}$erg

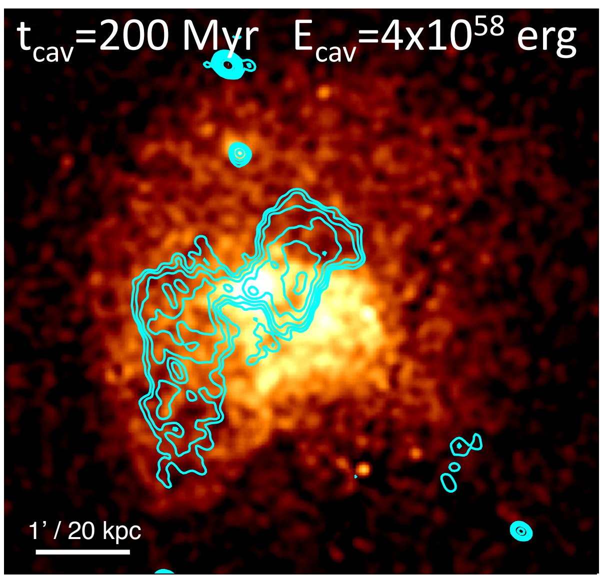
HCG 62 (Gitti et al. 2010)



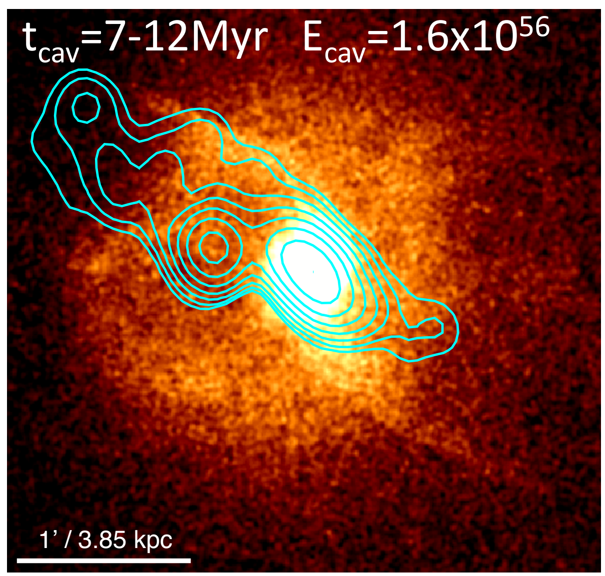
NGC 193



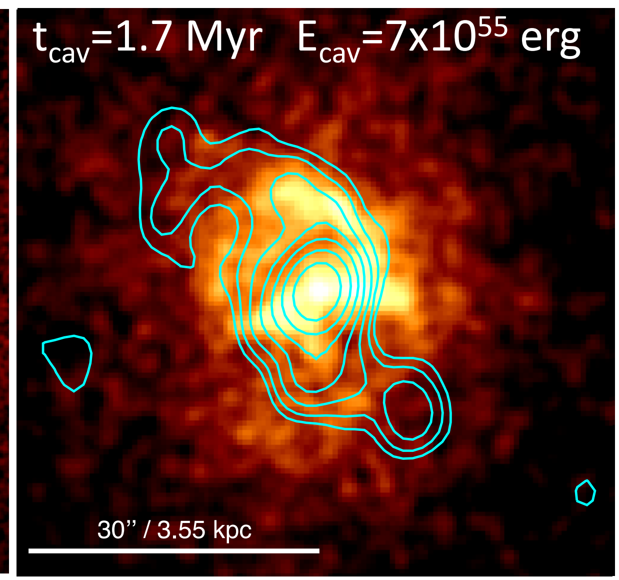
NGC 507 (Kraft et al. '04)



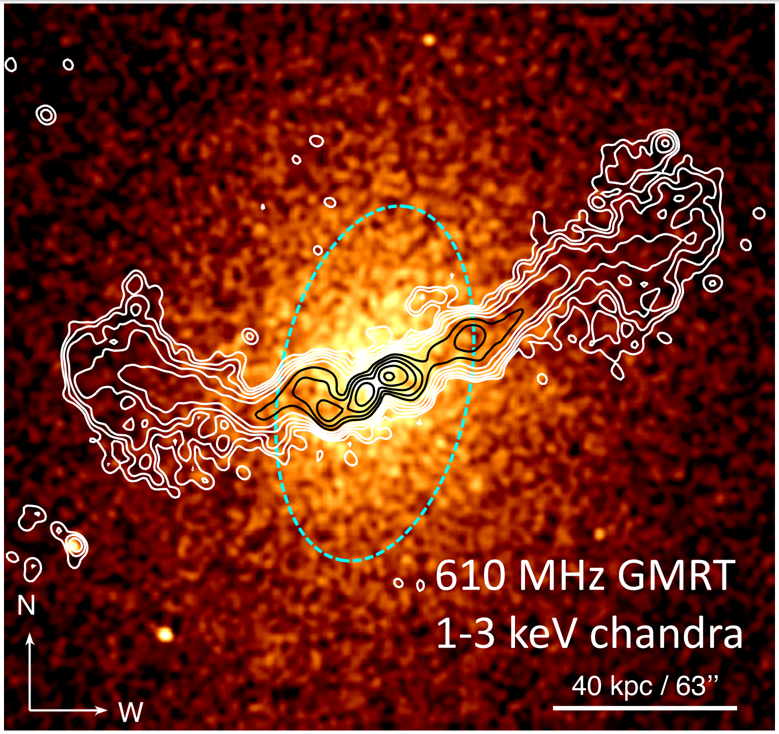
NGC 4636 (Baldi et al. '09)



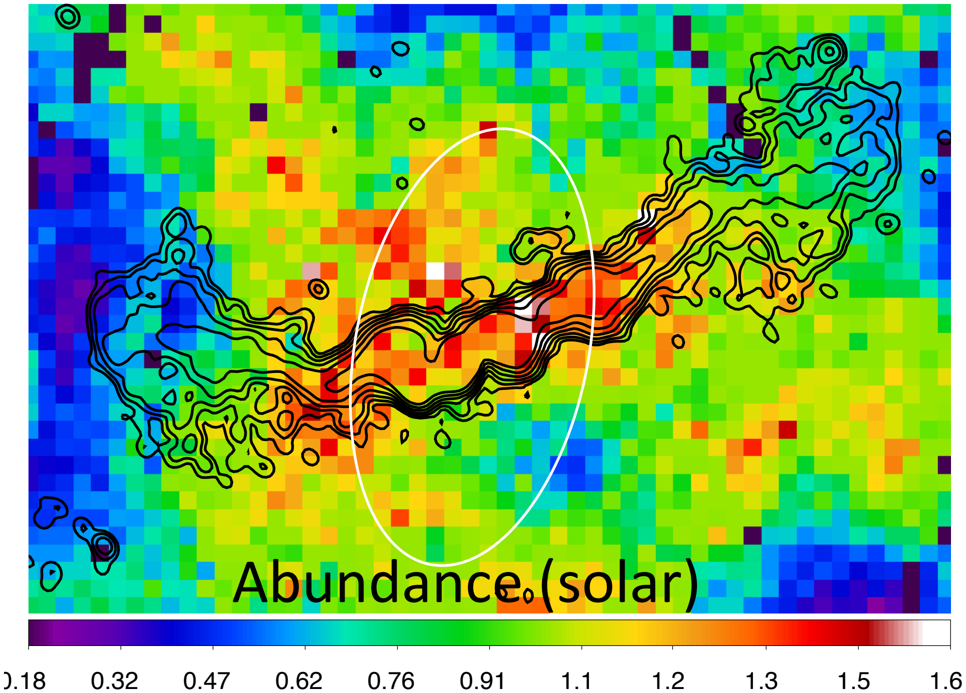
NGC 5846 (Machacek et al. '12)



Uplift and gas mixing
(e.g. O'Sullivan et al. 2011a)

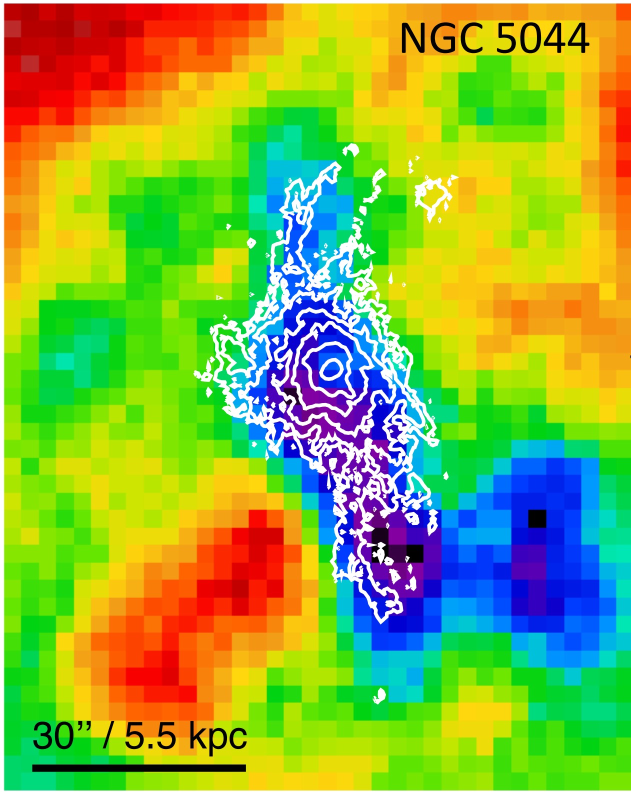


- 2.5 keV poor cluster, BCG hosts old (~170 Myr) active FR-I radio source.
- Super-solar abundances along axis of radio jets.



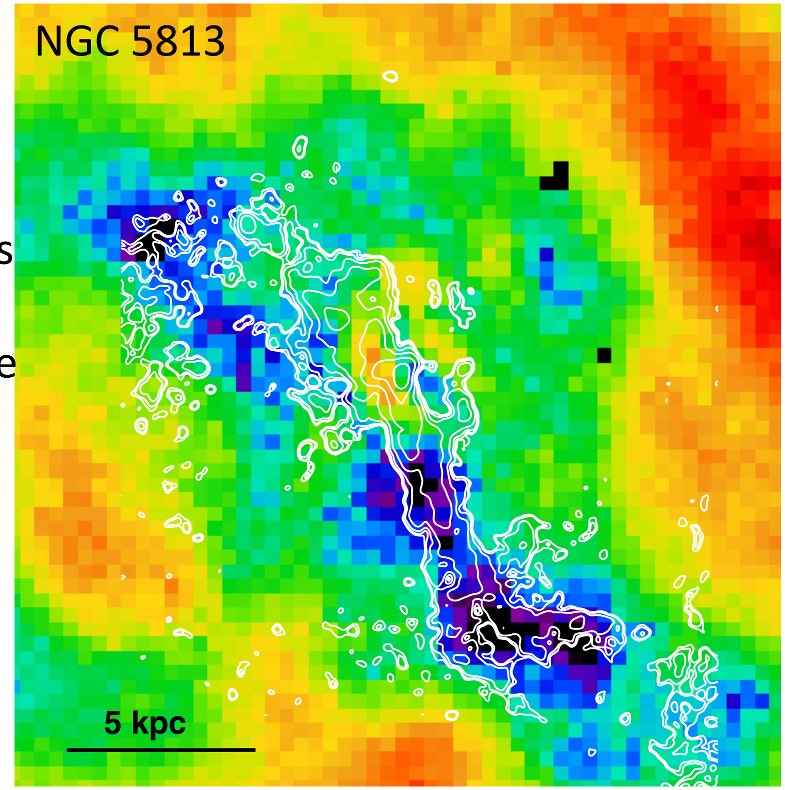
- $10^9\ M_\odot$ gas entrained
- Uplift requires 1.6×10^{57} erg, ~5% of total jet energy.

Evidence of cooling
(e.g., David et al. 2011, Randall et al. 2011)



Hα contours on temperature maps

Blue = cool
Red = hot



- Hα imaging shows filamentary correlated with coolest X-ray gas, as in clusters.
- $L_{H\alpha}$ = few $\times 10^{40}$ erg/s, suggesting <1 $M_{\odot}$/yr of cooling.
- also O_{VII} in RGS spectra (Sanders et al 2011), O_{VI} from FUSE (Bregman et al. '05)

What is the duty cycle in groups?

Modelling suggests groups require shorter but more frequent outbursts (e.g., Gaspari et al. 2010)

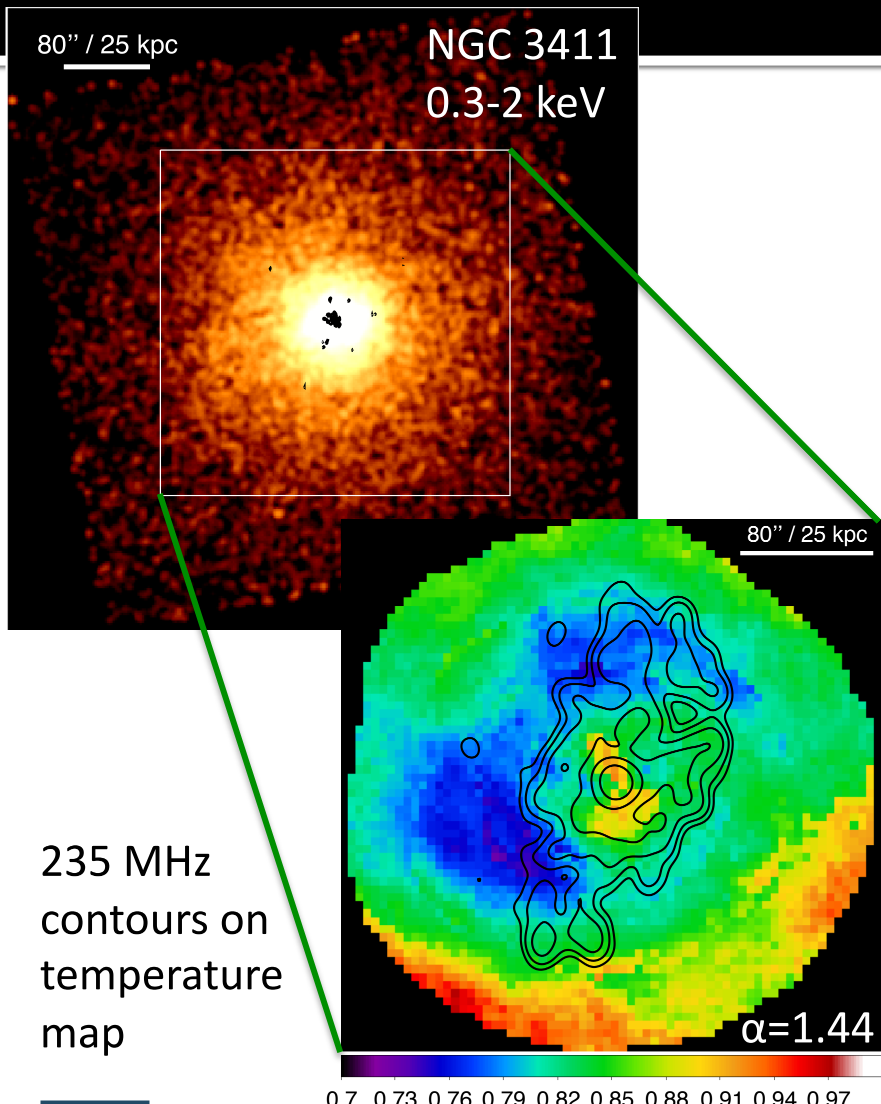
Fraction of systems with central AGN/cavities declines with mass:

- >70% in CC clusters (Blanton 2010, Mittal 2009)
- ~50% in groups? (Dong et al. 2010)
- ~30% in ellipticals (Nulsen et al 2009),
  but dependent on LX (Dunn et al. 2010)

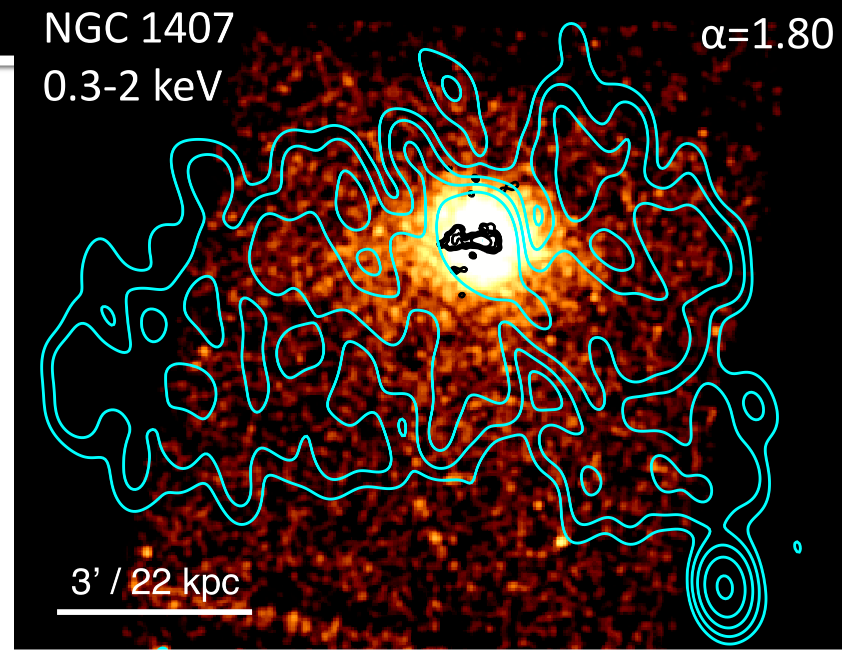
➔ Shorter duty cycle than clusters, but outbursts more frequent – confirm by looking for evidence of past outbursts?

➔ Low-frequency radio observations

Old radio plasma in groups



235 MHz contours on temperature map



235 MHz and 610 MHz contours

- Diffuse, steep spectrum radio sources.
- Some have small, young jets in core.

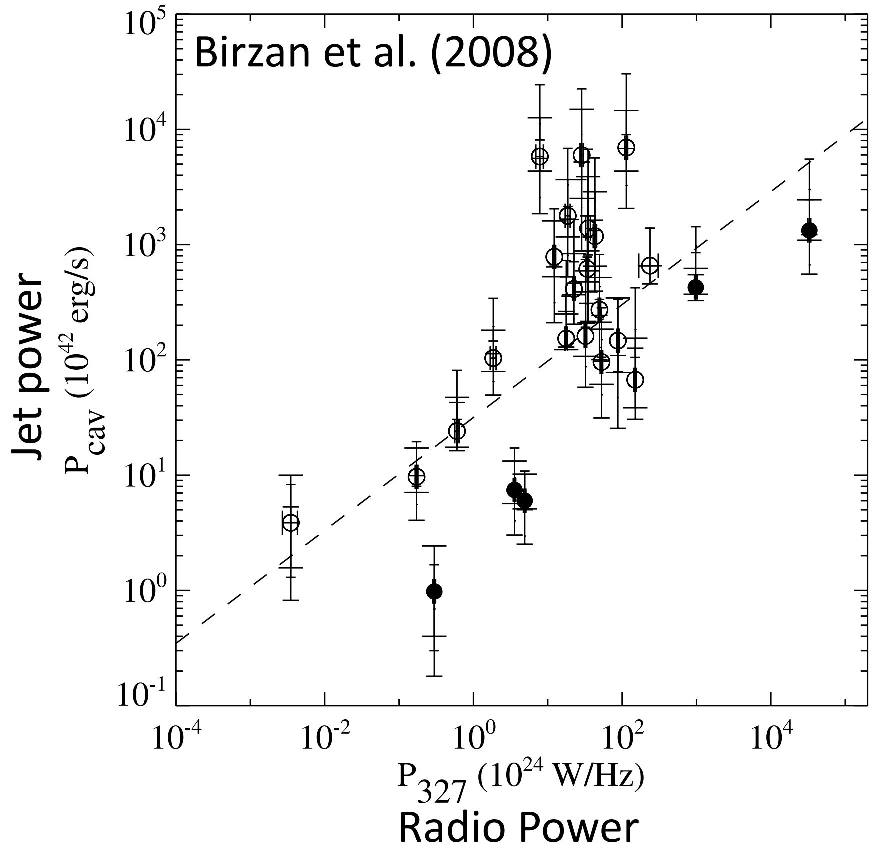
➔ Fading remnants of old radio lobes

- What happens to the energy in this plasma? Can it heat the IGM?

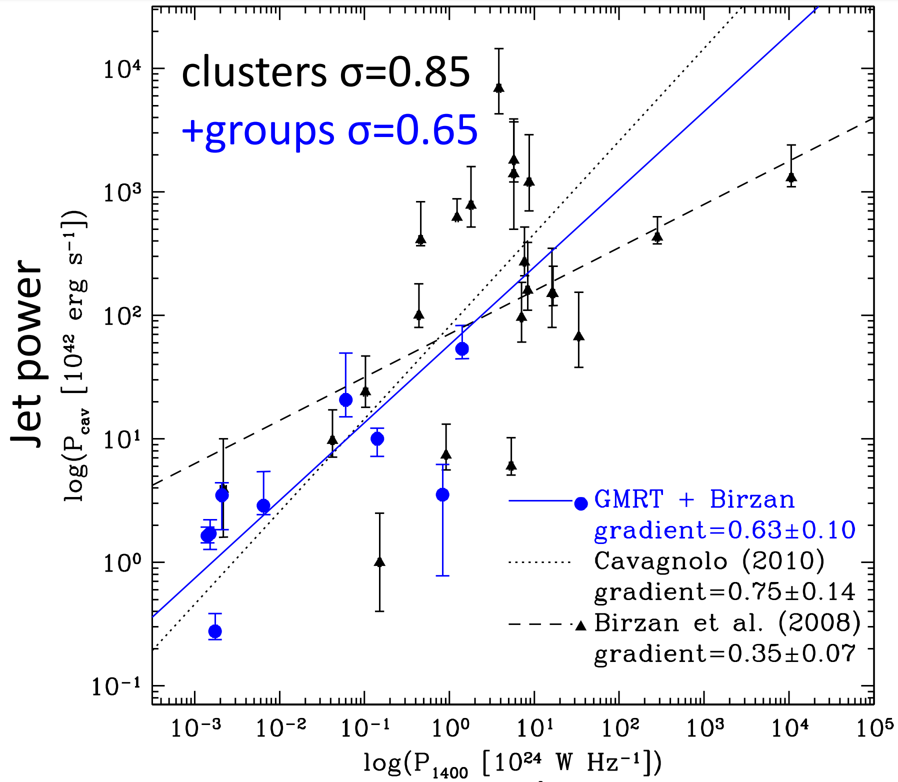
(see also posters by Vrtilek, David)

AGN jets: mechanical power vs radio power

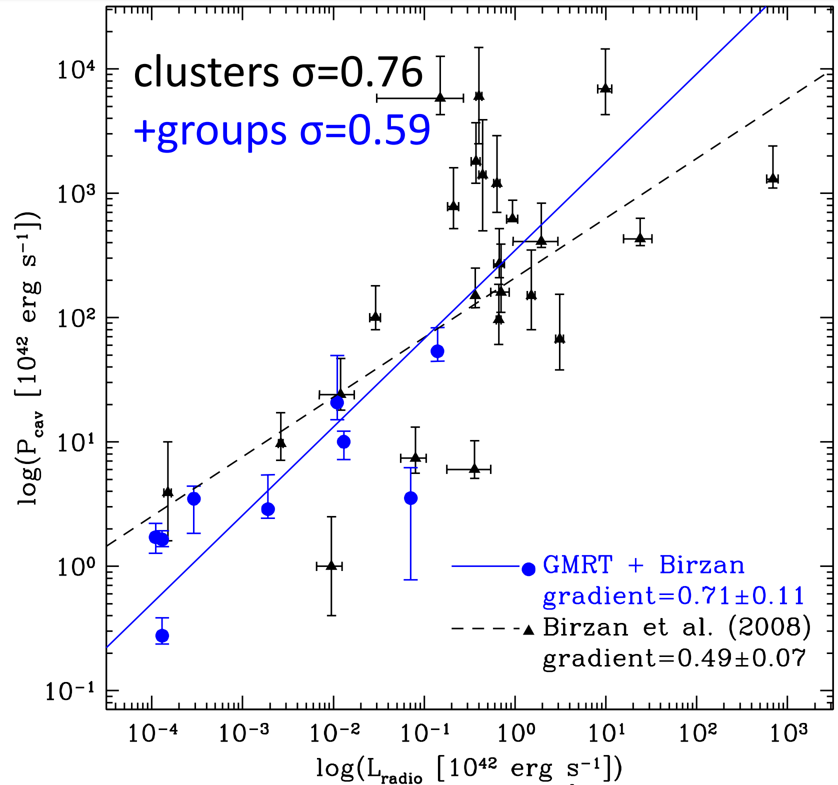
- Measuring the P_{cav}:P_{radio} relation allows us to estimate the amount of feedback from radio alone (e.g., at high redshift).
- P_{cav} = cavity enthalpy (E=4pV) ÷ buoyancy time.
- Birzan et al (2004, 2008) sample of ~25 clusters with VLA 1.4GHz and 327 MHz data
- We add 9 groups, with VLA 1.4 GHz plus high-quality GMRT 610 and 235 MHz data.
- See also Cavagnolo (2010).



AGN jets: mechanical power vs. radio power
(O'Sullivan et al. 2011)



1.4 GHz Radio Power

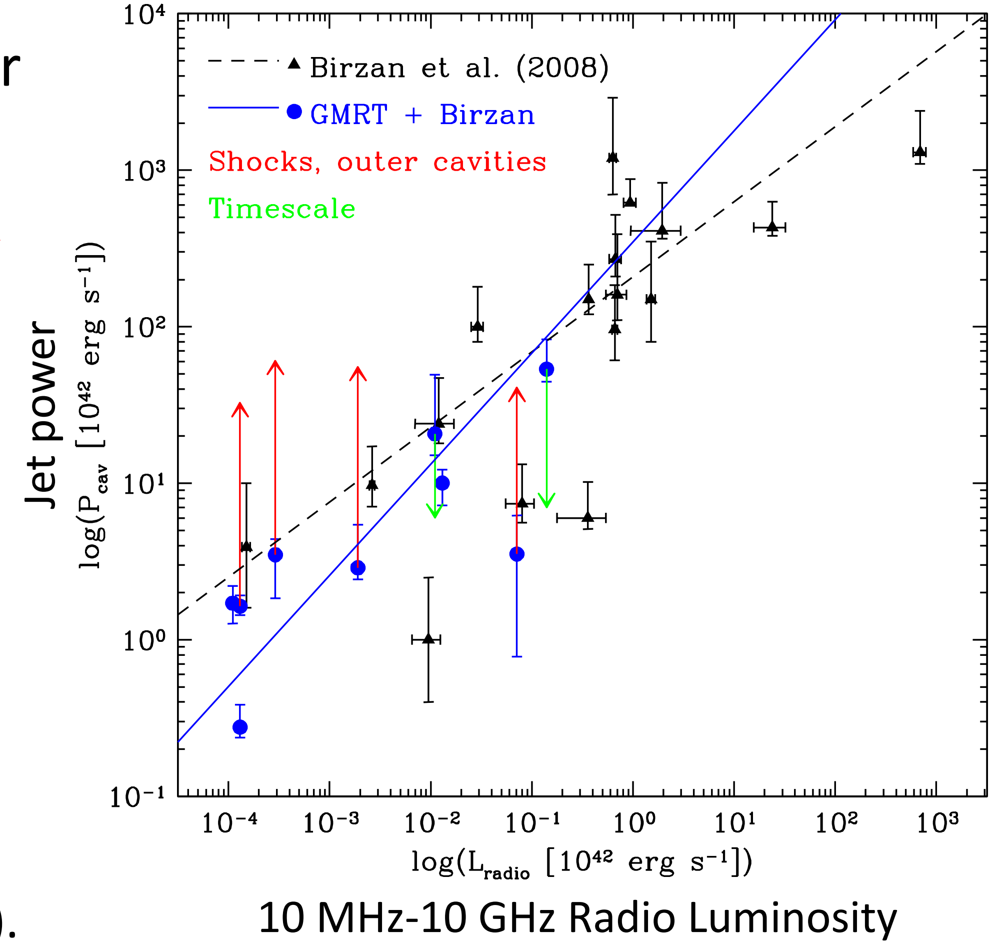


10 MHz - 10 GHz Radio Power

- Adding groups reduces intrinsic scatter, as does using low-frequency data.
- Willott et al. 1999 synchrotron model, corrected for flatter spectral index in our groups (α=0.95) predicts gradient=0.76 ➔ observations/theory agree.

Mechanical power vs radio power: Caveats

- Cavity power may be a poor measure of jet power!
  - Energy in shocks can be 5-10x energy of cavities.
  - Buoyancy timescale is not always appropriate.
  - Young cavities likely to be unresolved.
  - Detection of old cavities dependent on depth of data, radio freqs available.
  - Jet orientation.
  - Gas motions ("AGN weather").



Mechanical Power vs Cooling

Power needed to balance cooling:

- In galaxy clusters ~4PV.
- In groups only ~1PV

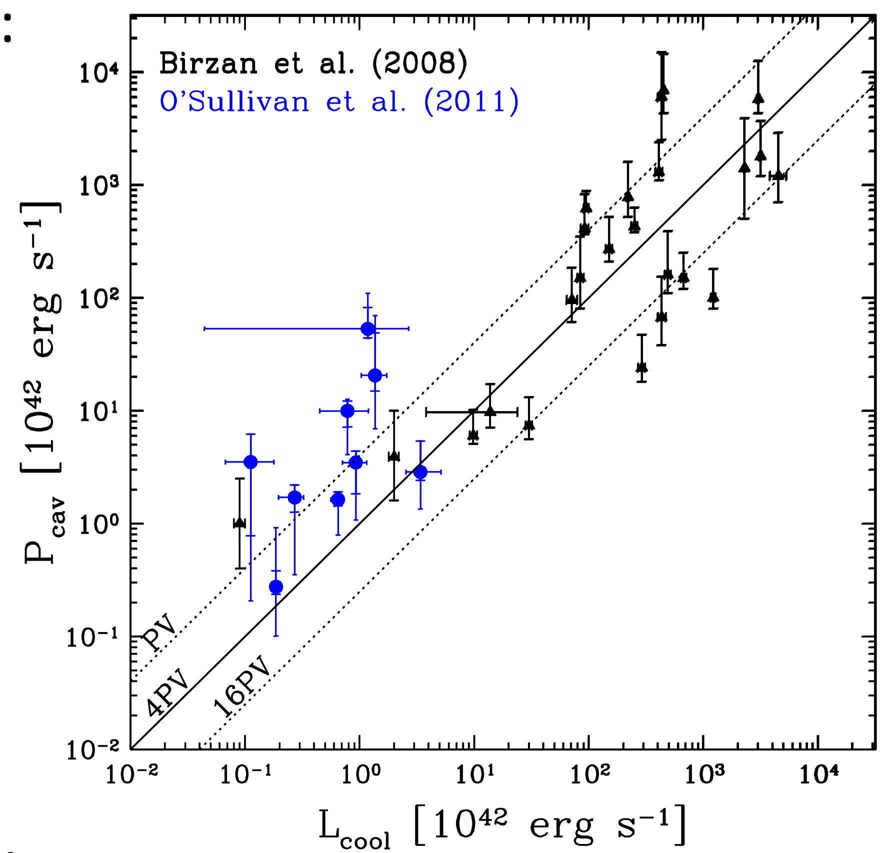
(as for Ellipticals, Nulsen et al 2007).

Shorter duty cycle in groups will reduce time-averaged difference.

Scatter at least factor 4.

Factoring in shocks, AGN power output can reach P_{jet} >10 $L_{cool.}$

Even if shocks only ~10% efficient, $P_{shock} \approx P_{cav}$

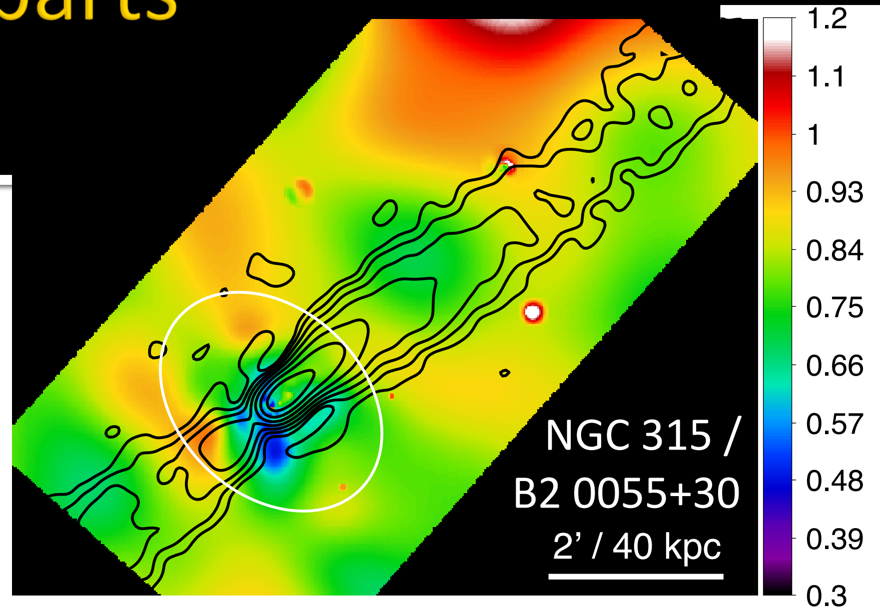


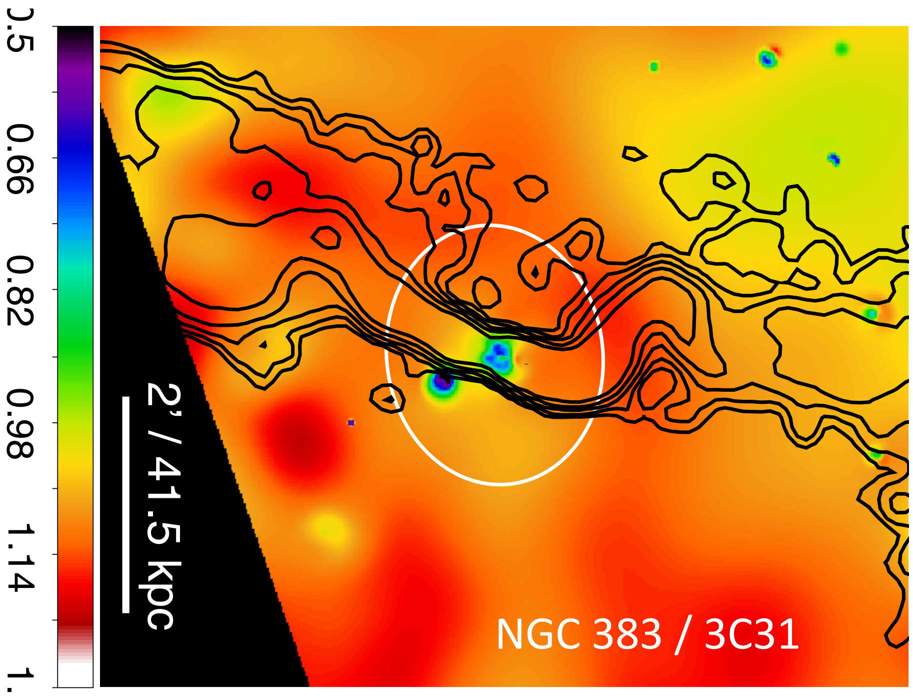
(Bolometric L_X for region t_{cool}≤7.7 Gyr)

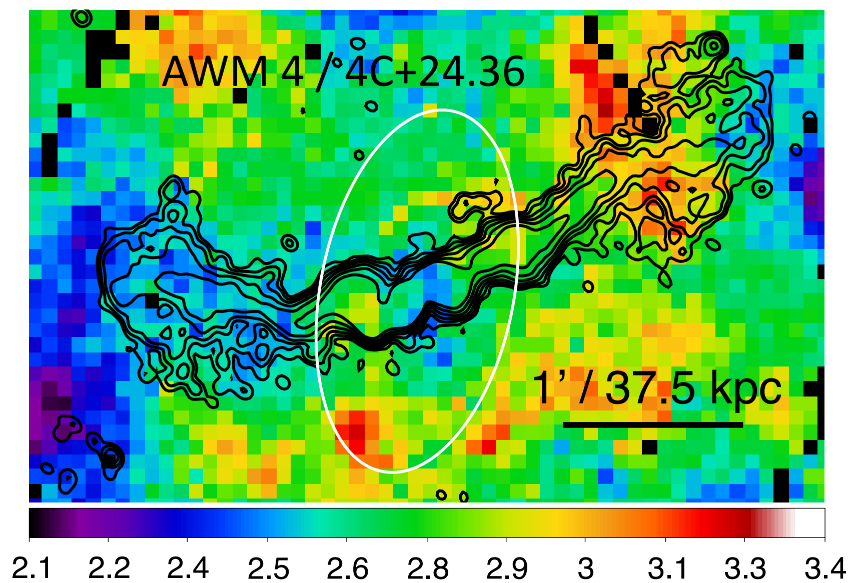
Do jets heat the right parts of the groups?

Active jets/lobes often extend beyond cooling region.

→ shocks needed to heat core and shut down AGN?

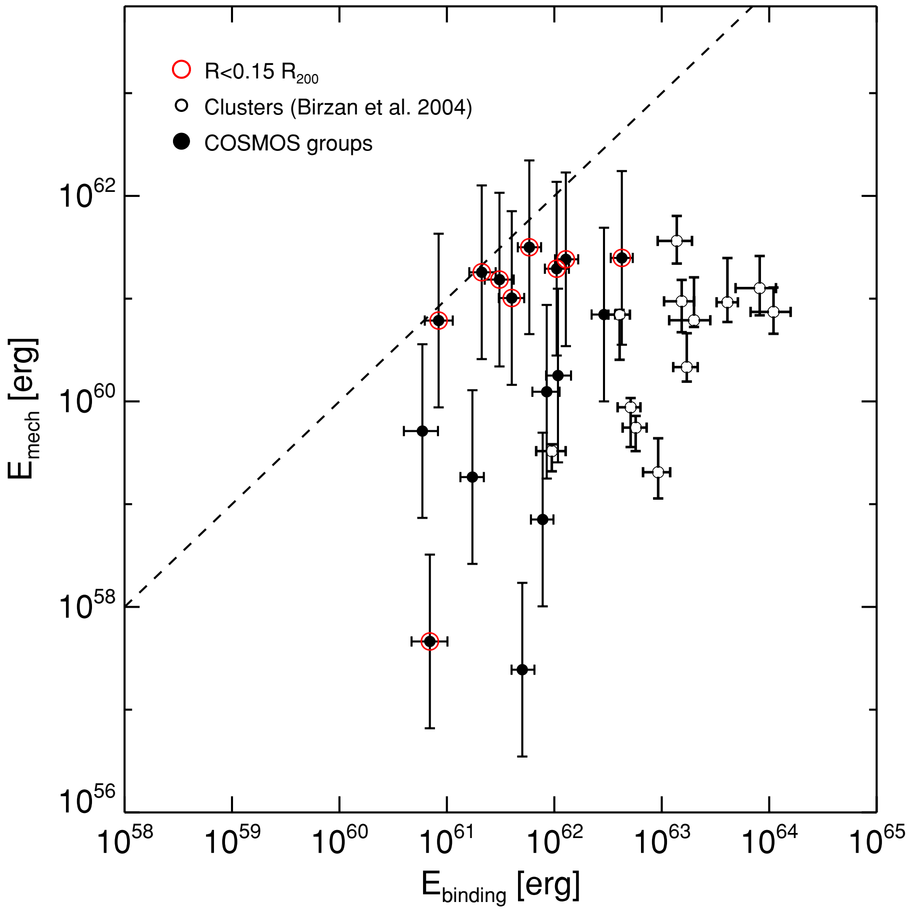




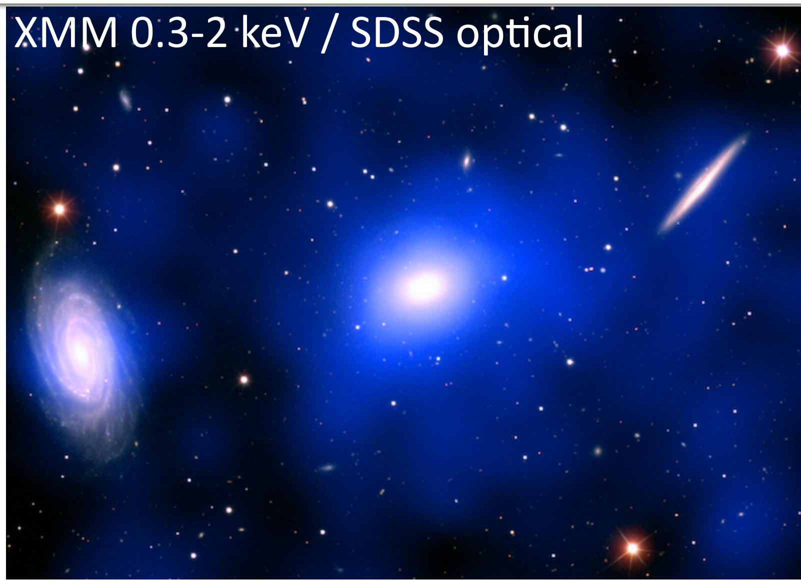


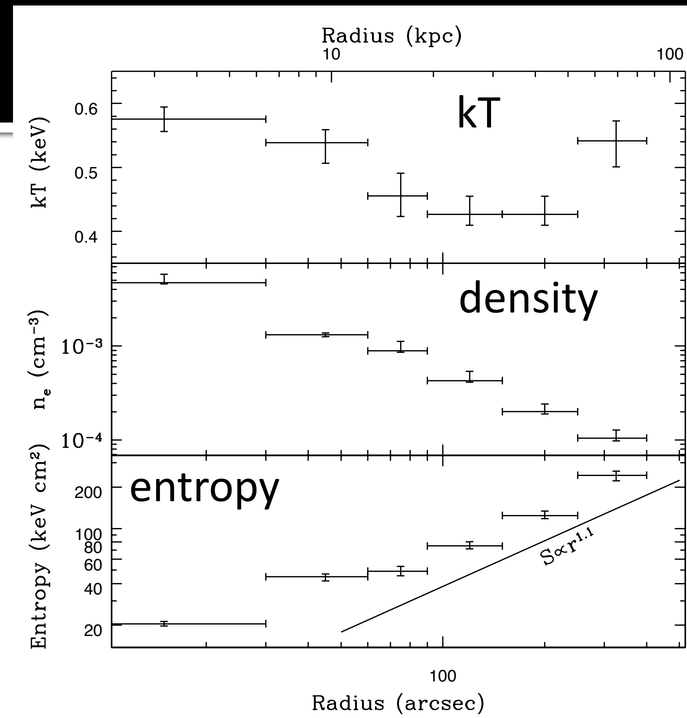
Can feedback unbind gas from groups?
(Giodini et al. 2010)

- 16 COSMOS groups, z=0.12-0.96, containing radio sources.
- Estimate energy released over lifetime of AGN
- ”...radio galaxies produce sufficient energy to unbind a significant fraction of the IGM.”
- Deeper cluster potentials better able to retain gas.



Coming soon: statistical samples of nearby groups





CLoGS – 53 group optically selected complete sample at D<80 Mpc

- 610/235 MHz obs. complete, X-ray coverage of first half by early 2013.
- For more information see my poster or www.sr.bham.ac.uk/~ejos/CLoGS.html

ZENS – 185 optically selected groups at z~0.05 with X-ray follow-up

- See John Silverman's talk tomorrow

eROSITA – will increase number of X-ray detected groups by factor 100

Summary

1. Groups are an important laboratory for feedback studies.
   - Shallower potential wells mean that AGN have strongly influenced the development of groups.
   - Impact of feedback varies across the mass scale, so we need samples that include clusters, groups and individual galaxies.
2. Low-frequency radio measurements are an important tracer of AGN activity, particularly in groups where outbursts are frequent.
3. Jet feedback appears to balance cooling, but questions remain:
   - How does the 3pV energy in radio lobe plasma contribute to heating?
   - Can jet feedback liberate gas from groups, now or at $z>2$?
4. Representative statistical samples now becoming available.
   - eROSITA should revolutionise our knowledge of the group population of the local Universe.