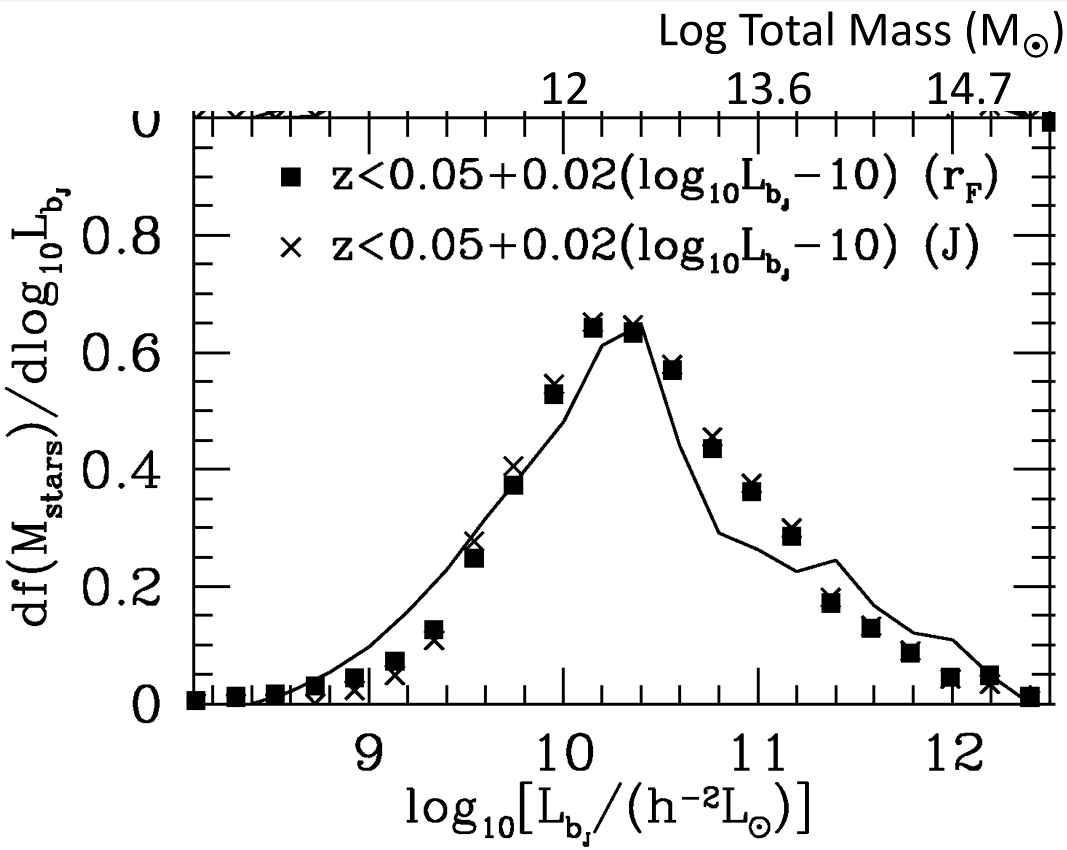
AGN feedback in galaxy groups:
a combined X-ray/low-frequency radio view

Ewan O'Sullivan (University of Birmingham)

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

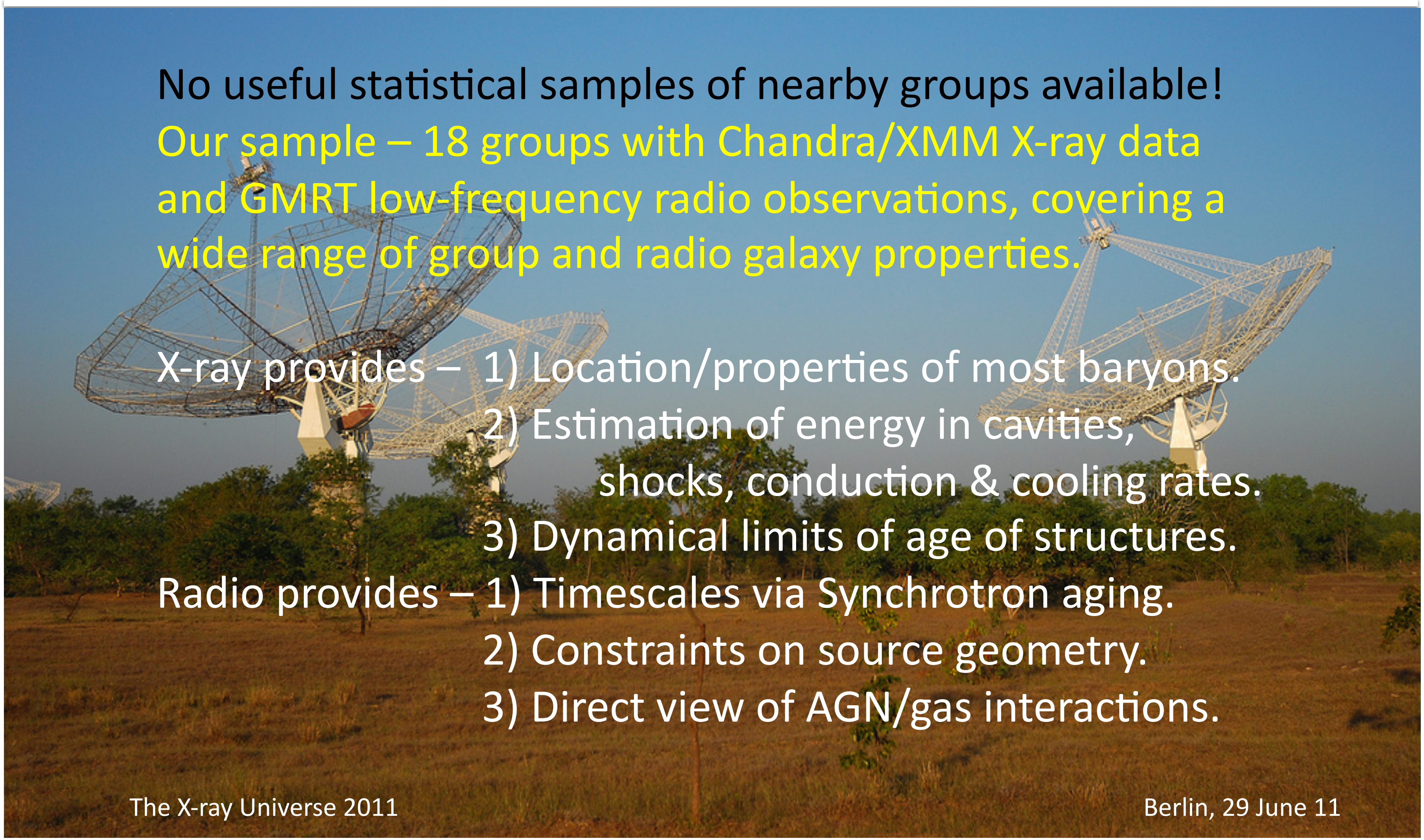
Why look at feedback in galaxy groups?

- Groups contain >50% of stars in the local Universe and most of the baryons.
- Group environment key to galaxy evolution, in which AGN play an important role.
- AGN Feedback in groups must be fine tuned. Outbursts must be weaker but occur more often (e.g., Gaspari et al. 2011)



Eke et al. (2005)

The GMRT Groups project



No useful statistical samples of nearby groups available!

Our sample – 18 groups with Chandra/XMM X-ray data and GMRT low-frequency radio observations, covering a wide range of group and radio galaxy properties.

X-ray provides – 1) Location/properties of most baryons.
2) Estimation of energy in cavities, shocks, conduction & cooling rates.
3) Dynamical limits of age of structures.

Radio provides – 1) Timescales via Synchrotron aging.
2) Constraints on source geometry.
3) Direct view of AGN/gas interactions.

Why low-frequency?
To detect old radio sources & estimate age

- Older structures easier to see at lower frequencies.
- Broader spectrum gives better estimate of total power.
- Break frequency allows age to be estimated.

GMRT sensitivity (for 2-3hr obs.):

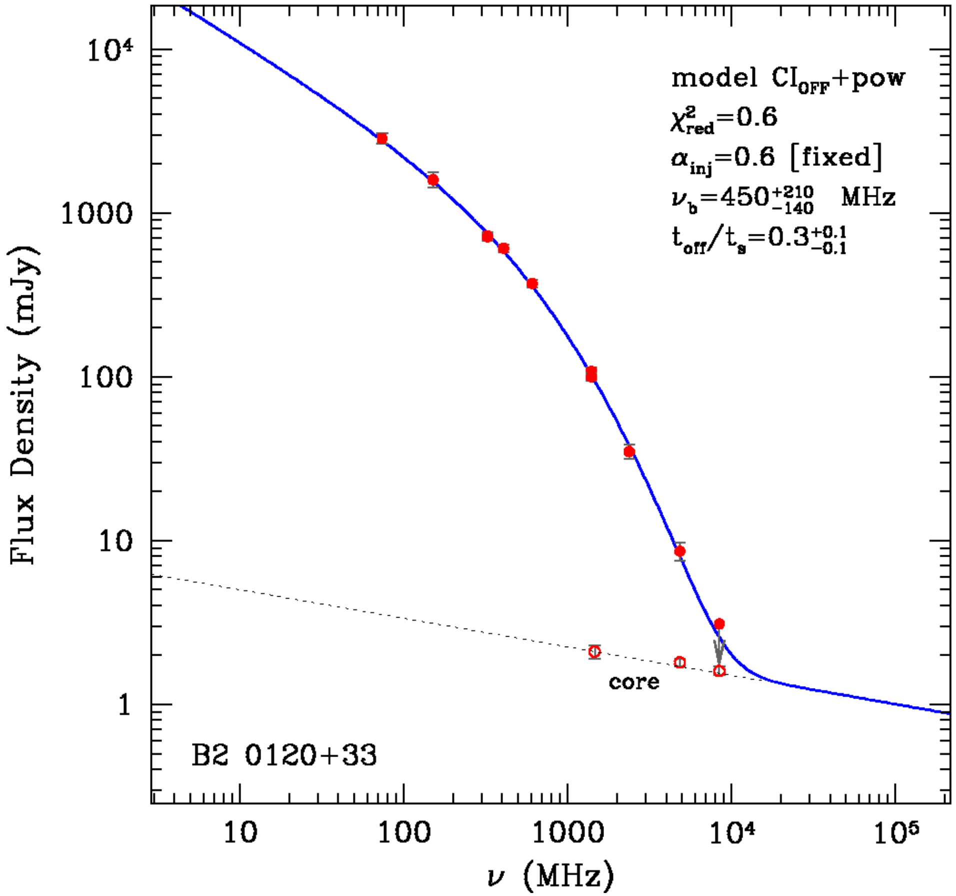
rms ≈ 50-100 μJy/b @ 610 MHz

rms ≈ 300-500 μJy/b @ 235 MHz

Resolution:

5” @ 610 MHz (HPBW)

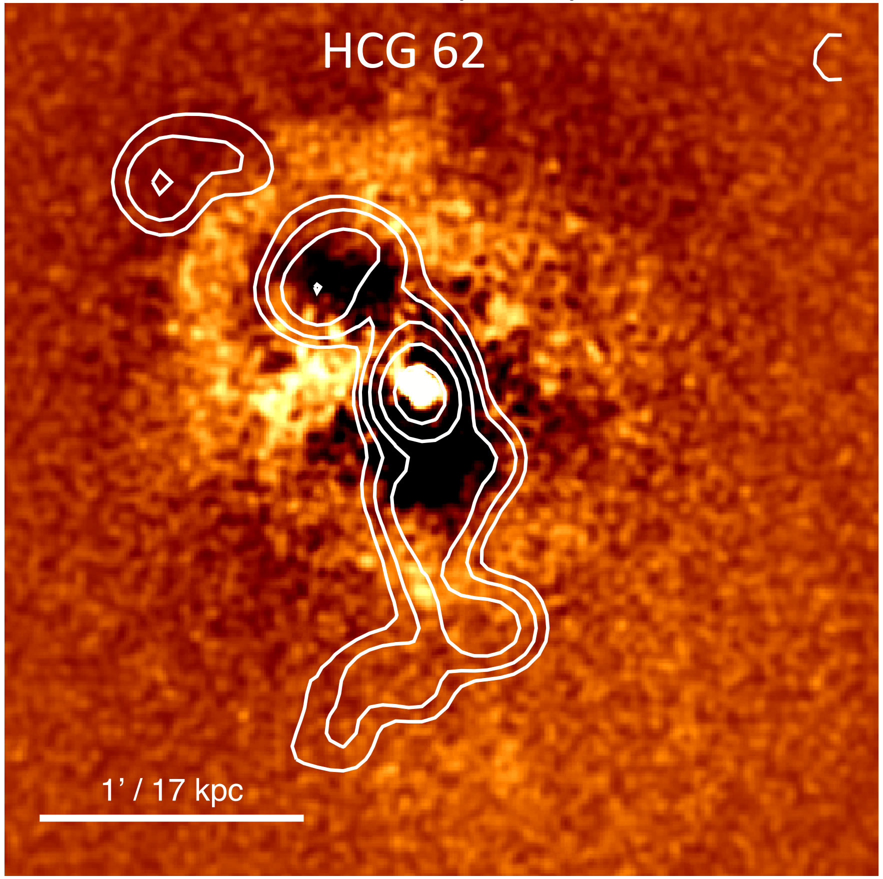
12” @ 235 MHz



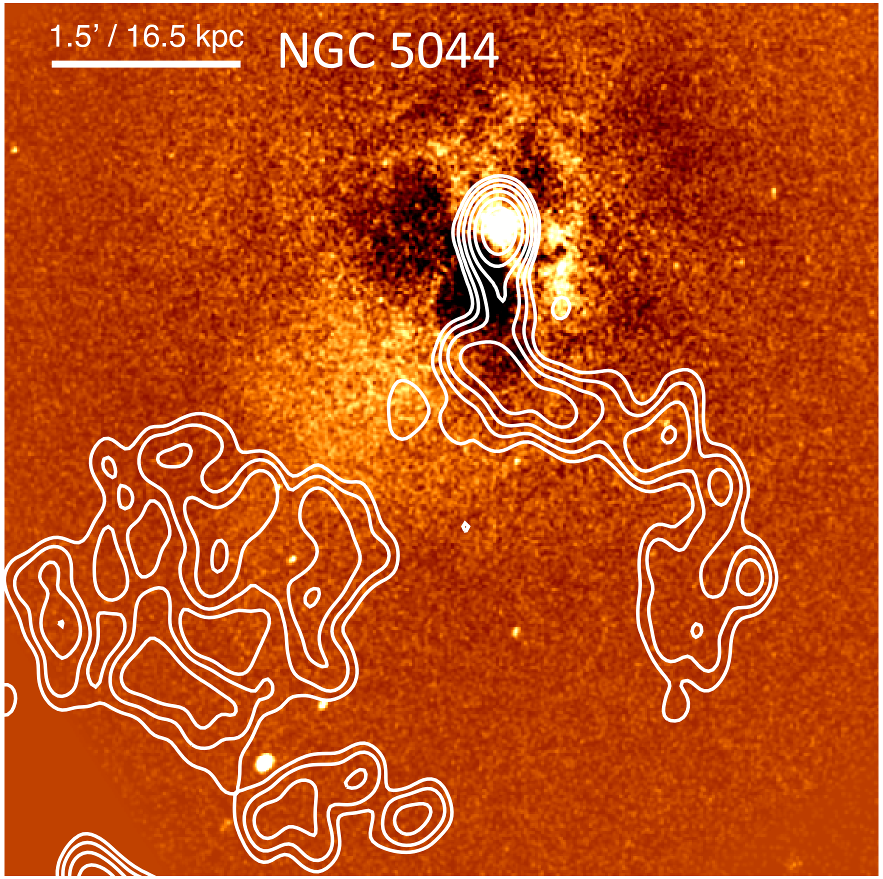
NGC 507 (Murgia et al. 2011)

Benefits of low-frequency radio data

Gitti et al. (2010)



David et al. (2009, 2011)



Smoothed Chandra 0.3-2 keV residual images 235 MHz GMRT contours

HCG62 cavities are paired, NGC5044 cavities isotropically distributed by gas motions.

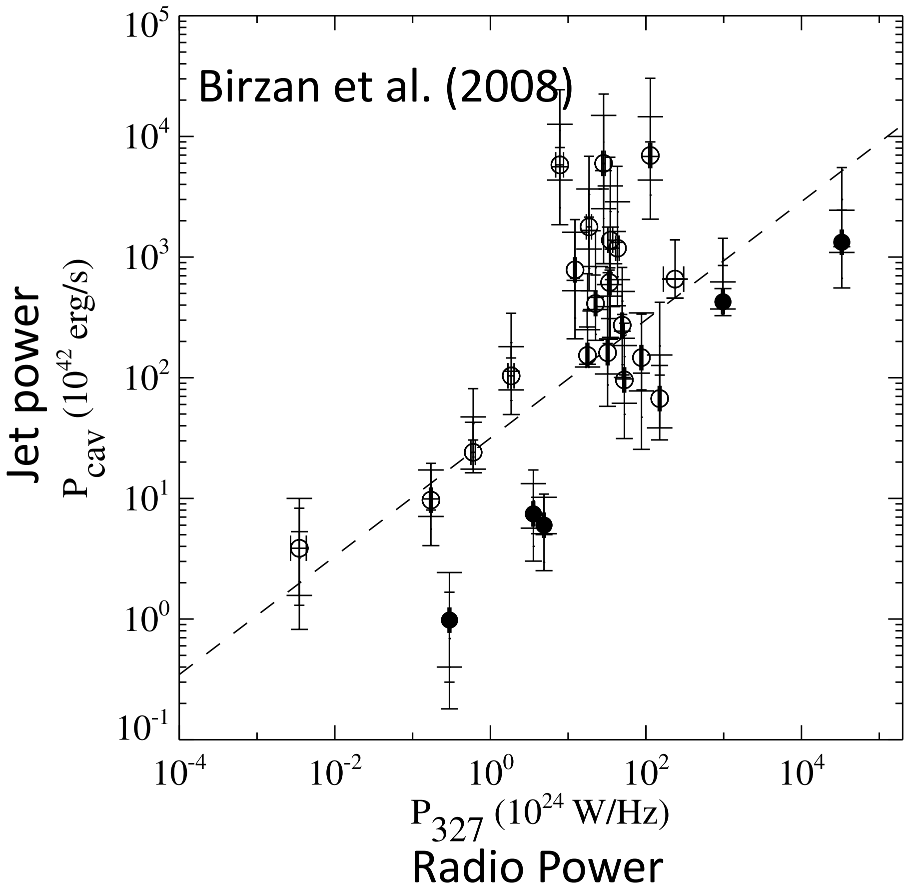
GMRT Groups sample (Giacintucci et al. 2011)

GROUP	z	Chandra	XMM	150 MHz	235 MHz	327 MHz	610MHz	Papers?
UGC 408	0.0147	✓		✓	✓		✓	CfA in prep…
NGC 315	0.0165	✓	✓		✓		✓	
NGC 383	0.0170	✓	✓		✓		✓	
NGC 507	0.0165	✓	✓		✓		✓	
NGC 741	0.0185	✓	✓		✓		✓	Jetha 08
HCG 15	0.0208		✓		✓	✓	✓	
NGC 1407	0.0059	✓	✓		✓	✓	✓	
NGC 1587	0.0123	✓			✓		✓	
MKW 2	0.0368		✓		✓		✓	
NGC 3411	0.0153	✓	✓		✓		✓	O'Sullivan 07
NGC 4636	0.0031	✓	✓		✓		✓	Jones, O'S, Baldi
HCG 62	0.0137	✓	✓		✓	✓	✓	Gitti 10
NGC 5044	0.0090	✓	✓	✓	✓	✓	✓	David 09 & 11
NGC 5813	0.0066	✓	✓	✓	✓			Randall 10
NGC 5846	0.0057	✓	✓				✓	
AWM4	0.0318	✓	✓		✓	✓	✓	SG 08,O'S 10&11
NGC 6269	0.0348	✓			✓		✓	Baldi 09
NGC 7626	0.0114	✓	✓	✓	✓		✓	Randall 09

Clear cavities Giant sources (too large) Amorphous (no clear lobes)

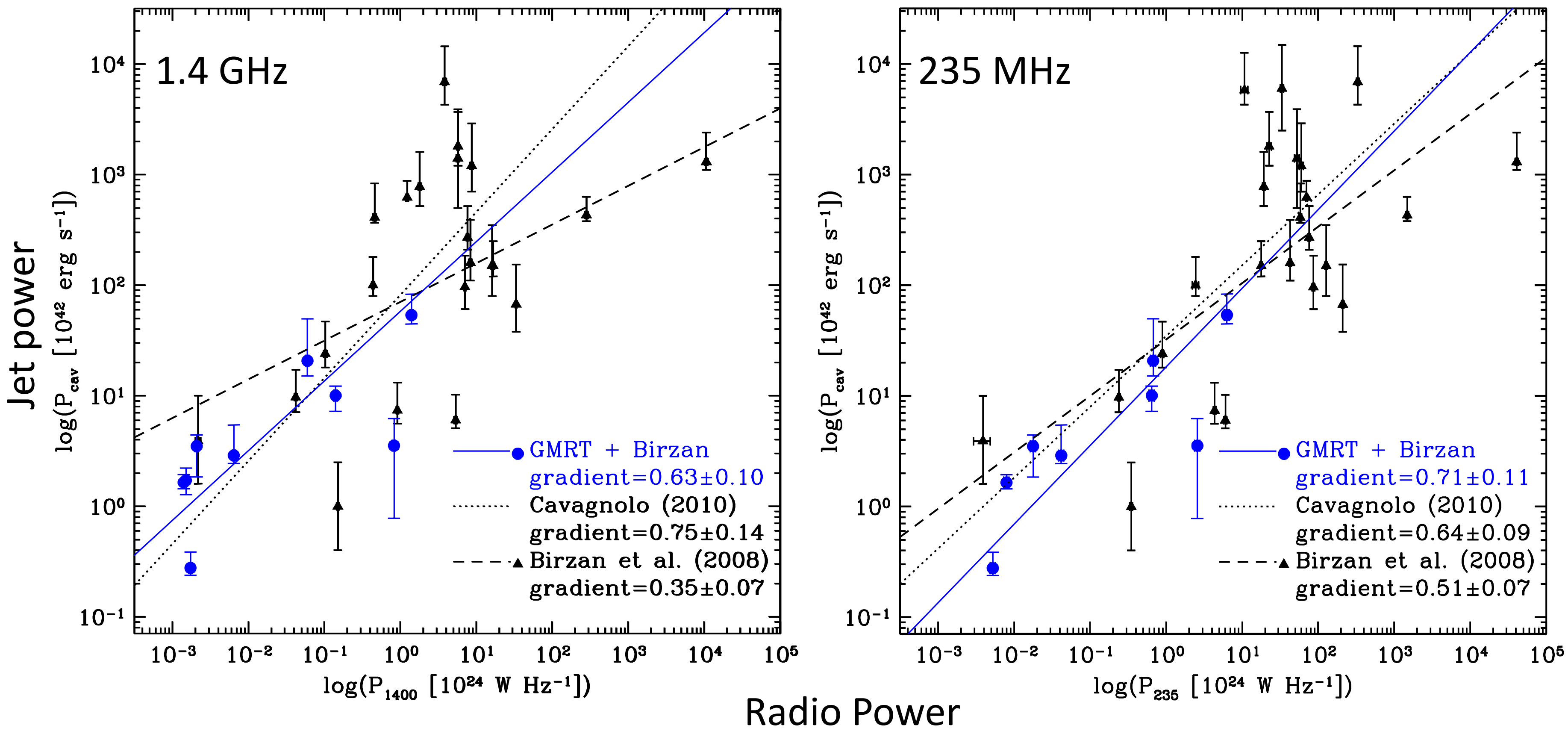
AGN jets: mechanical power vs radio power

- In the local Universe, we can estimate P_{jet} from cavity enthalpy (E=4pV) and buoyancy time.
- Measuring the $P_{jet}:P_{radio}$ relation allows us to estimate the amount of feedback from radio alone (e.g., at high redshift).
- Birzan et al (2004, 2008) used sample of ~25 clusters, VLA 1.4 GHz and 327 MHz data.
- Cavagnolo (2010) add 21 ellipticals, but with poor, low-resolution 200-400 MHz data.



- We add 9 groups, with high-quality GMRT 235 MHz data.

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



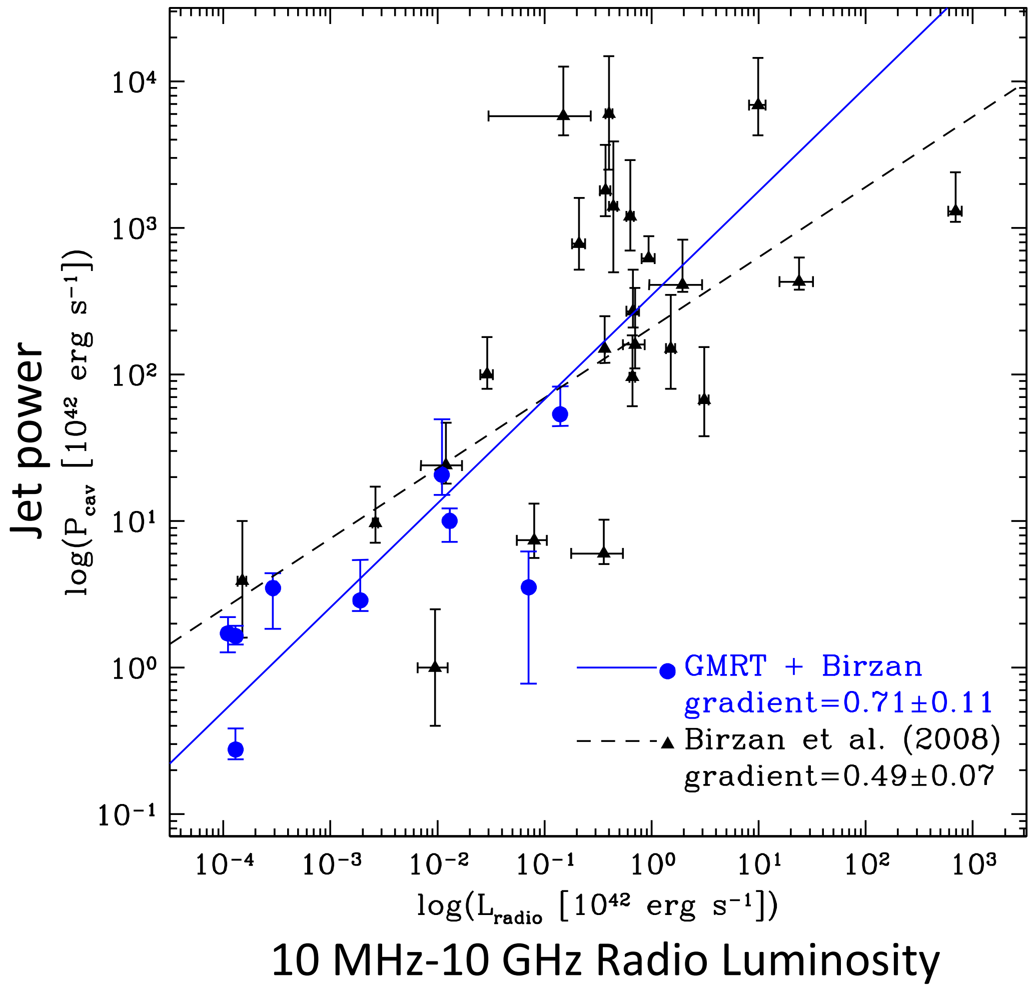
- Birzan et al used BCES Y|X fit, Cavagnolo and our fits use BCES orthogonal.

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

• Integrated radio power accounts for differences in spectral index ➔ should be better estimator of jet power than single frequency.

• Birzan et al. again used BCES Y|X fit, we use orthogonal.
• Orthogonal fit to Birzan data gives gradient = 0.78 ± 0.30 .

• Birzan et al. spectral indices from KP model fit to 3+ freqs.
• We use 610-235 MHz indices, improved fits in progress.



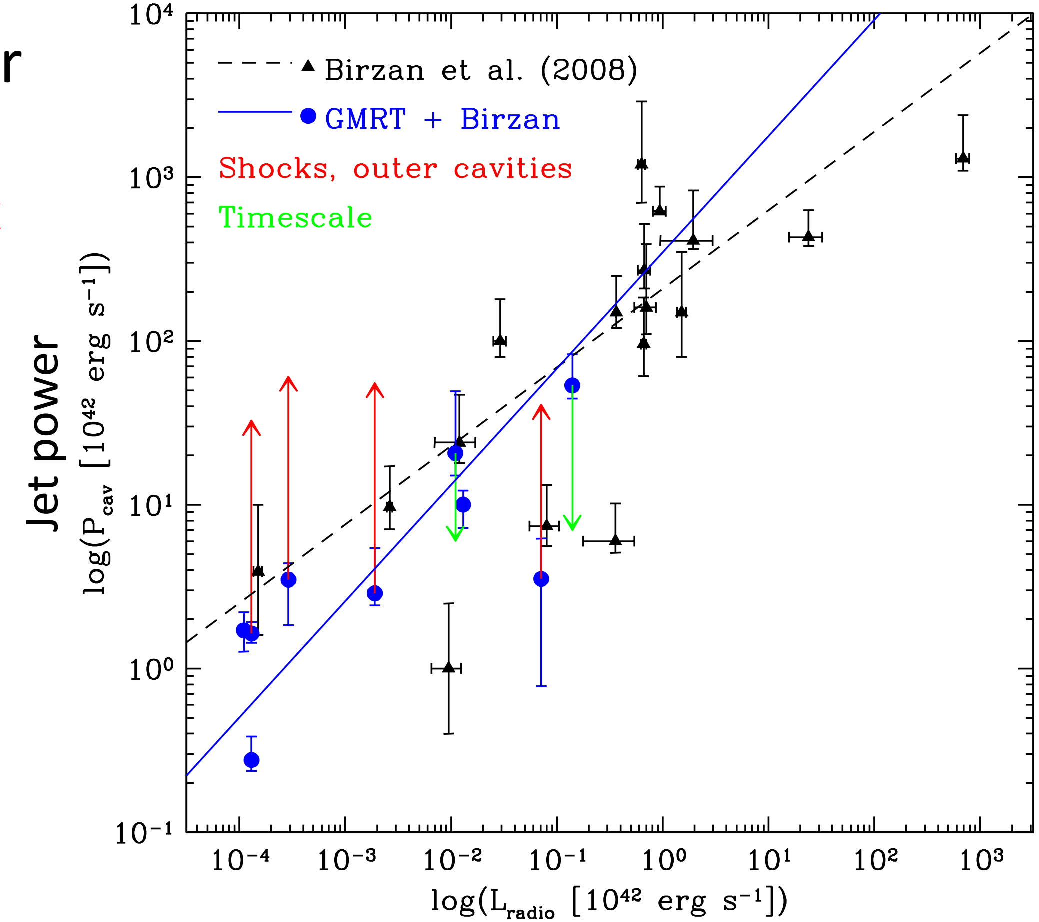
Mechanical power vs radio power: comparison of BCES orthogonal fits

Frequency	Sample	Gradient	Total Scatter	Intrinsic Scatter
1.4 GHz	Birzan	0.57±0.17	0.88	0.85
	Cavagnolo	0.75±0.14	0.78	-
	O'Sullivan	0.63±0.10	0.68	0.65
200-400 MHz	Birzan	0.67±0.19	0.80	0.76
	Cavagnolo	0.64±0.09	0.64	-
	O'Sullivan	0.71±0.11	0.62	0.58
10MHz – 10GHz	Birzan	0.68±0.19	0.80	0.76
	O'Sullivan	0.71±0.11	0.63	0.59

- Low-frequency or broad-band measures more reliable (less scatter).
- Willott et al. (1999) predict gradient = 0.86 from synchrotron theory.
- BUT Willott assumes spectral index α=0.5 . For free spectral index, gradient will be 3/(α+3), e.g. gradient=0.76 for our typical α=0.95.

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 missed. Detection of old cavities dependent on depth of data, radio freqs available.
  - Jet orientation.
  - AGN weather.
  - Filling factors <1 (c.f. AWM4).
- Correcting groups where possible flattens relation.



10 MHz-10 GHz Radio Luminosity

Mechanical Power vs Cooling

Power needed to balance cooling:

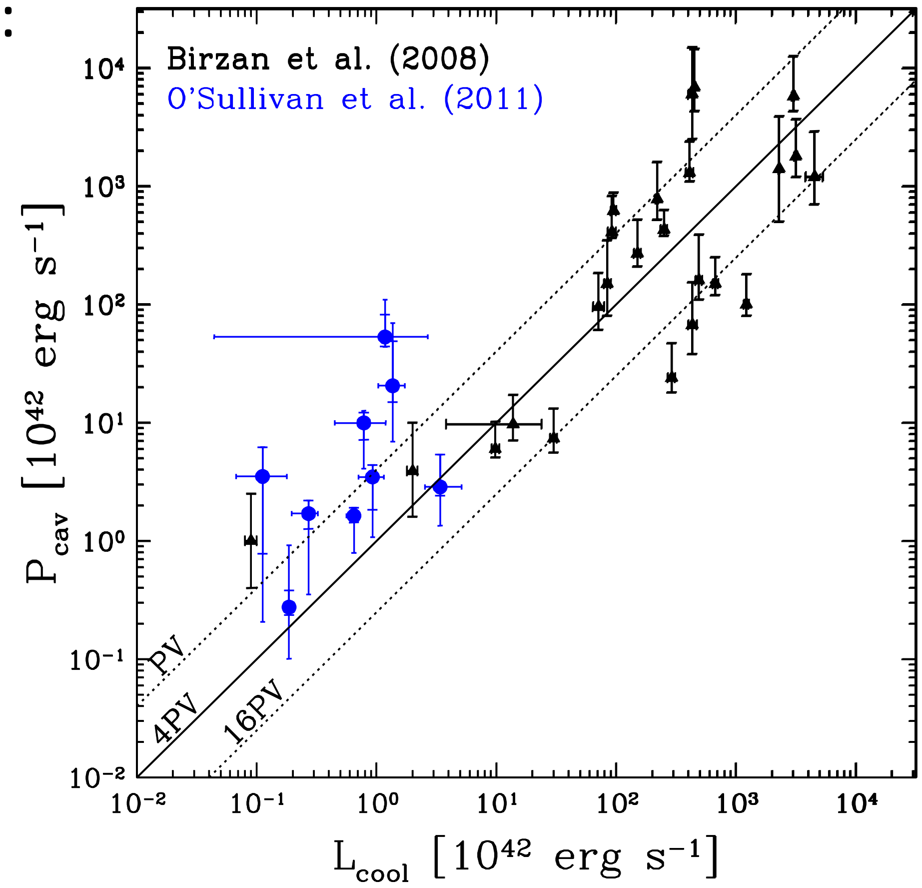
- In galaxy clusters ~4PV.
- In groups only ~1PV

(as for Ellipticals, Nulsen et al 2007).

- Scatter at least factor 4.

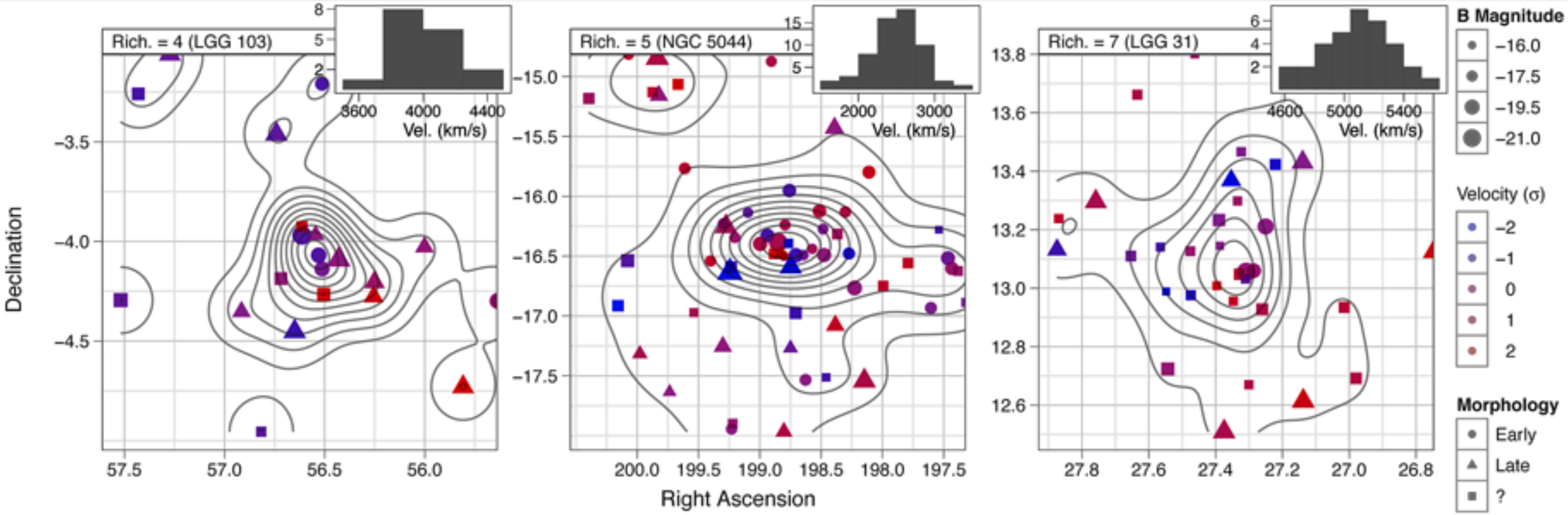
Factoring in shocks, AGN power output can reach $P_{jet} > 10\ L_{cool}$

- Most powerful outbursts in this sample still have cool cores.
- But sample is <u>selected</u> to have jet/gas interactions…



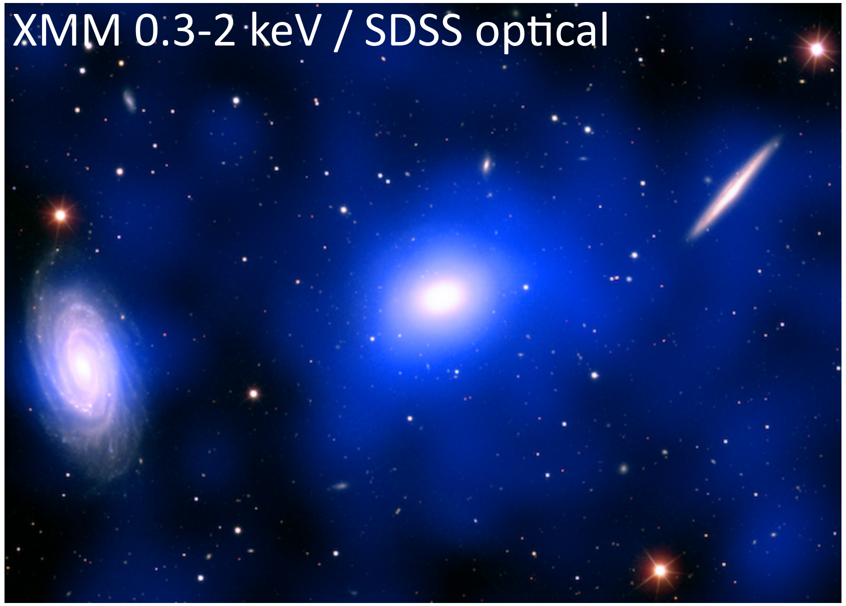
(Bolometric L_X for region $t_{cool} \leq 7.7$ Gyr)

CLoGS:
The Complete Local-Volume Groups Survey

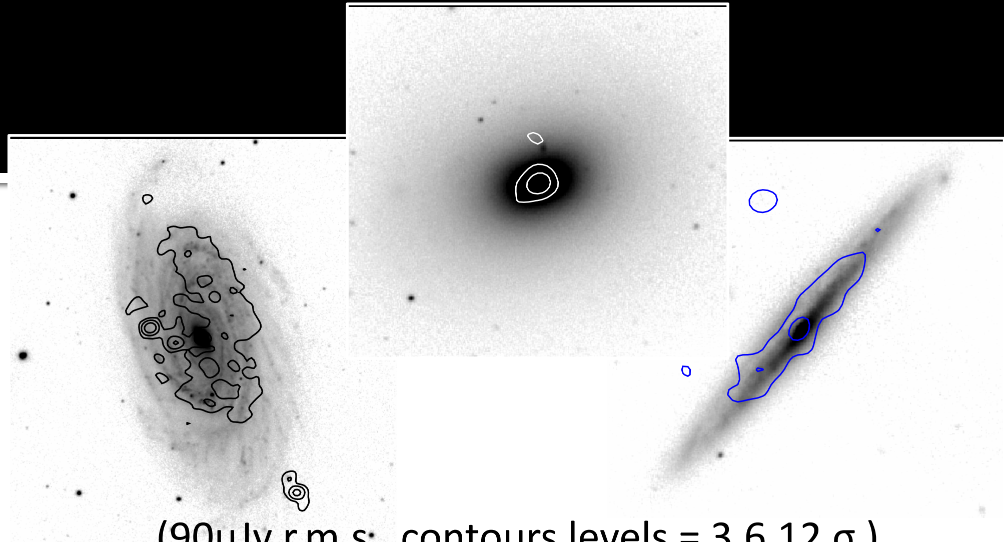


- Statistically complete, optically selected sample of 53 nearby groups, attempting to exclude uncollapsed and false systems.
- Complete coverage in X-ray (XMM/Chandra) and radio (GMRT 235/610 MHz).
- Observations of richer half of sample will be almost complete by 2012.
  - 50 ks Chandra GTO, 175 ks XMM-Newton, 76 hrs GMRT approved.
- More information at www.sr.bham.ac.uk/~ejos/CLoGS.html

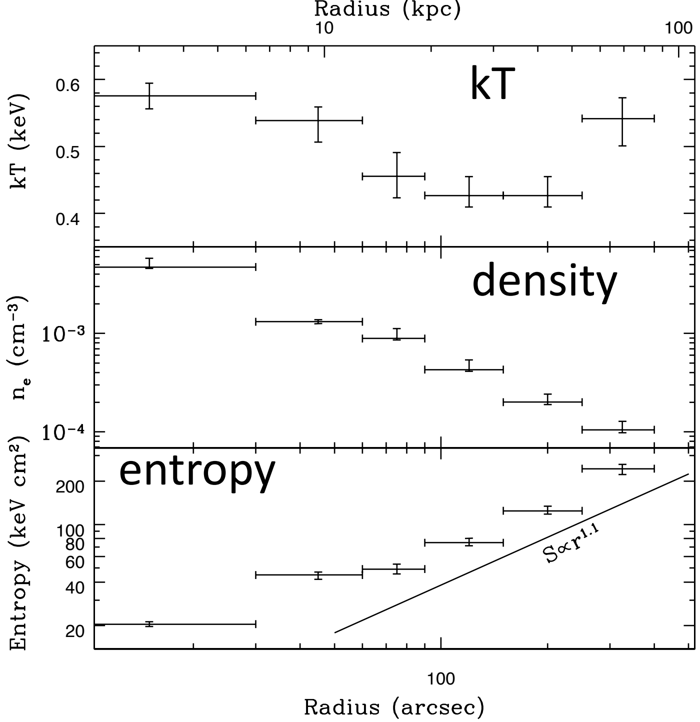
CLoGS: first results



GMRT 610 MHz contours / SDSS g'-band



(90μJy r.m.s., contours levels = 3,6,12 σ)



- XMM detects 0.5 keV group halo to ~85 kpc.
- GMRT detects SF in spirals, AGN in all galaxies.
- Group is faint (L_X=2x10^{41}) but falls on scaling relations (L:T, σ:T, etc)
- No cool core (at resolution 6.4 kpc).

Summary

1. Low-frequency or integrated radio measurements are a more reliable predictor of jet power than $L_{1.4\ GHz}$.
2. Samples including groups (and ellipticals) provide better constraints on the P_{jet}:P_{radio} relations.
   - Best fit gradient ~0.7±0.1 with intrinsic scatter ~0.6 dex.
   - Theoretical predictions of gradient=0.86 may be too steep, impacting estimates of jet feedback at higher redshifts.
3. Uncertainties on the mechanical power output of jets are large (factor of ~10).
   - ➔ further work needed to get reliable jet power estimates.
4. Energy available from AGN much more than is needed to balance cooling in groups.
   - What happens to the other 3PV? How does feedback in clusters and groups differ?