

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

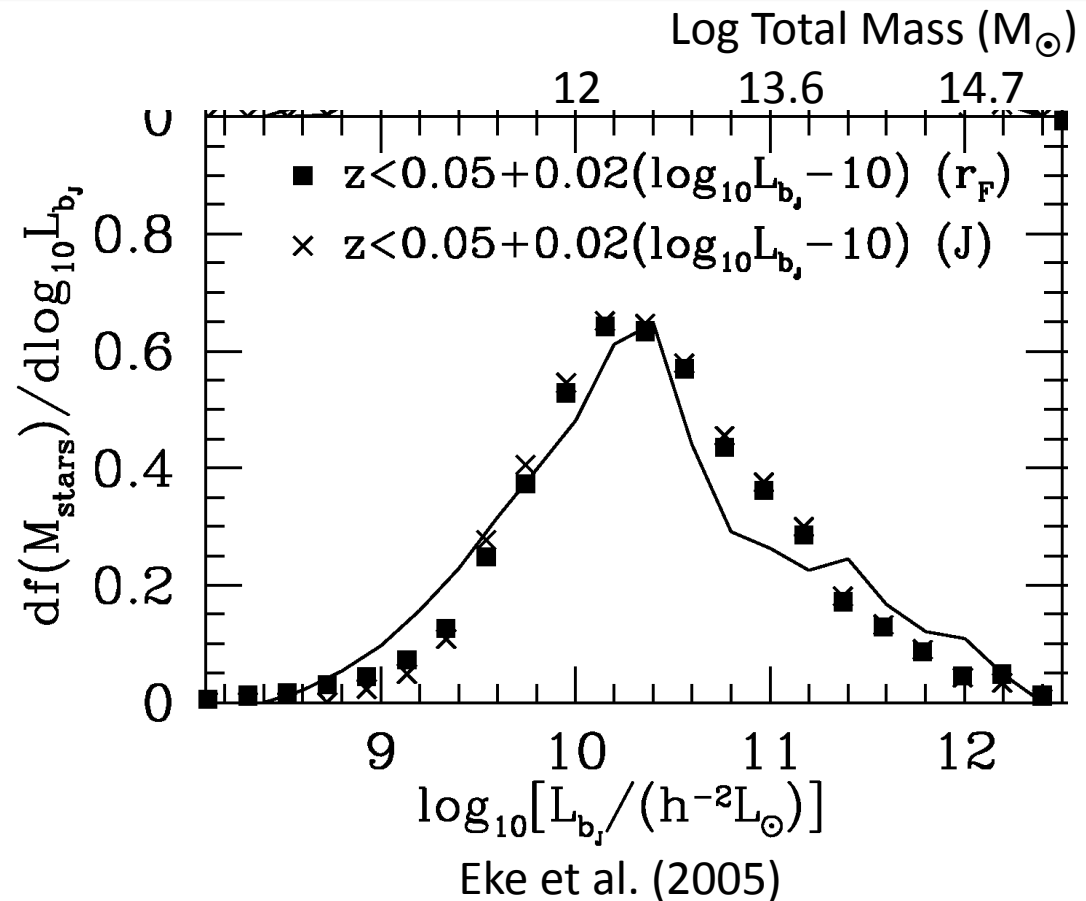


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With thanks to: S. Giacintucci (Maryland),
L. David & J. Vrtilek (SAO), M. Gitti (Bologna),
S. Raychaudhury & T.J. Ponman, K. Kolokythas (Birmingham)

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)



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 –

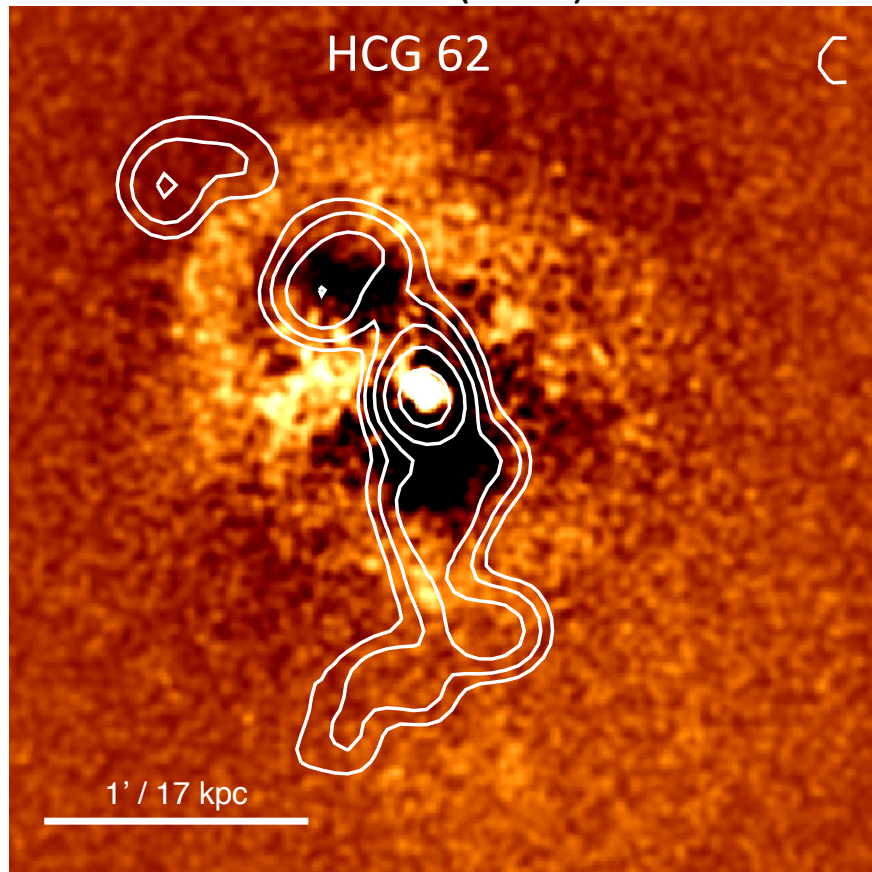
- 1) Location/properties of most baryons.
- 2) Estimation of energy in cavities, shocks, conduction & cooling rates.
- 3) Dynamical limits of age of structures.

Radio provides –

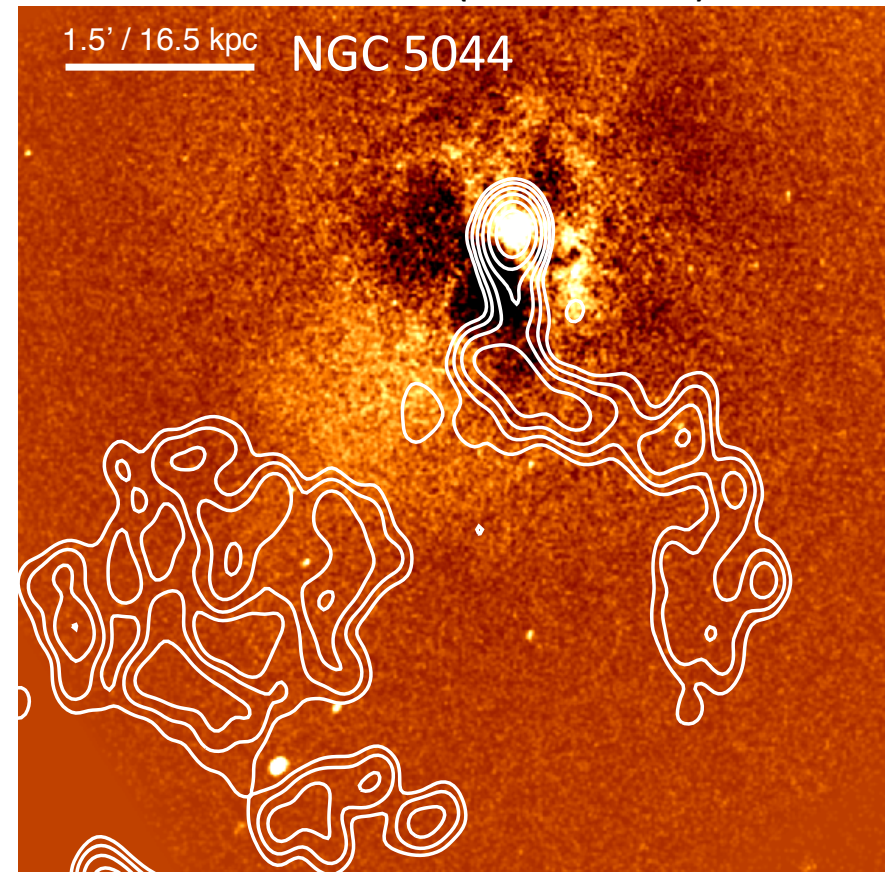
- 1) Timescales via Synchrotron aging.
- 2) Constraints on source geometry.
- 3) Direct view of AGN/gas interactions.

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 VLA/GBT contours

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



GMRT Groups sample (Giacintucci et al. 2011)

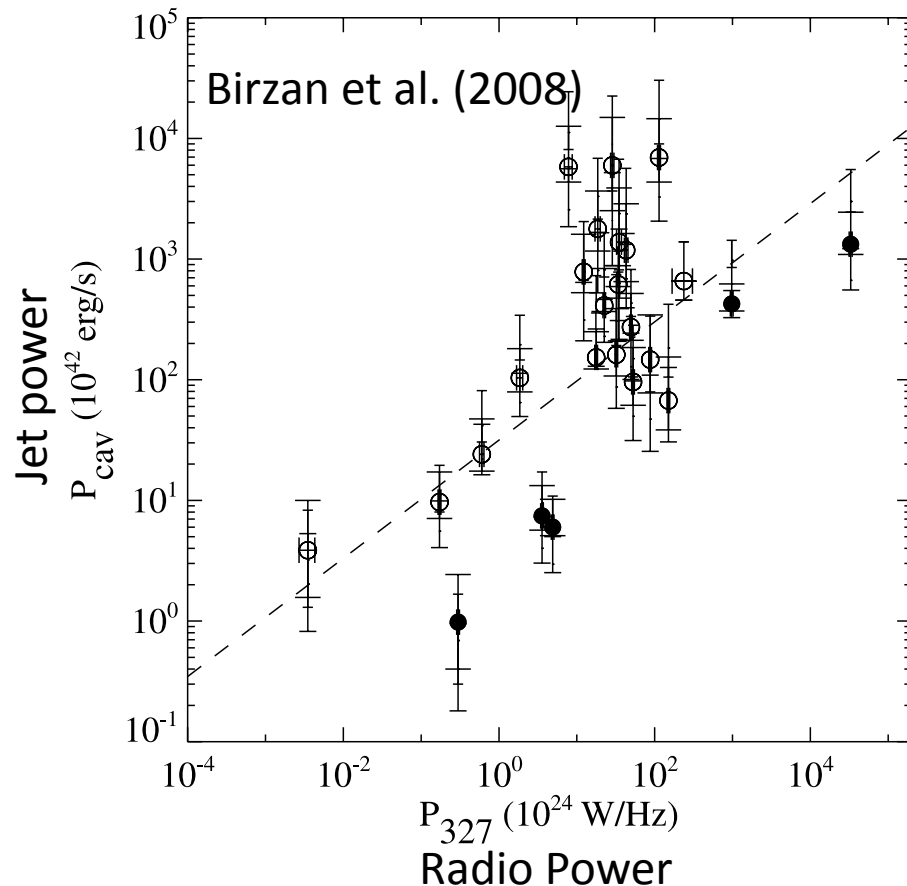
GROUP	z	Chandra	XMM	150 MHz	235 MHz	327 MHz	610MHz	Papers?
UGC 408	0.0147	✓		✓	✓		✓	CfA in prep...
NGC 315	0.0165	✓	✓		✓		✓	
NGC 383	0.0170	✓	✓		✓		✓	
NGC 507	0.0165	✓	✓		✓		✓	
NGC 741	0.0185	✓	✓		✓		✓	Jetha 08
HCG 15	0.0208		✓		✓	✓	✓	
NGC 1407	0.0059	✓	✓		✓	✓	✓	
NGC 1587	0.0123	✓			✓		✓	
MKW 2	0.0368		✓		✓		✓	
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 $P_{\text{jet}}:P_{\text{radio}}$ 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**.

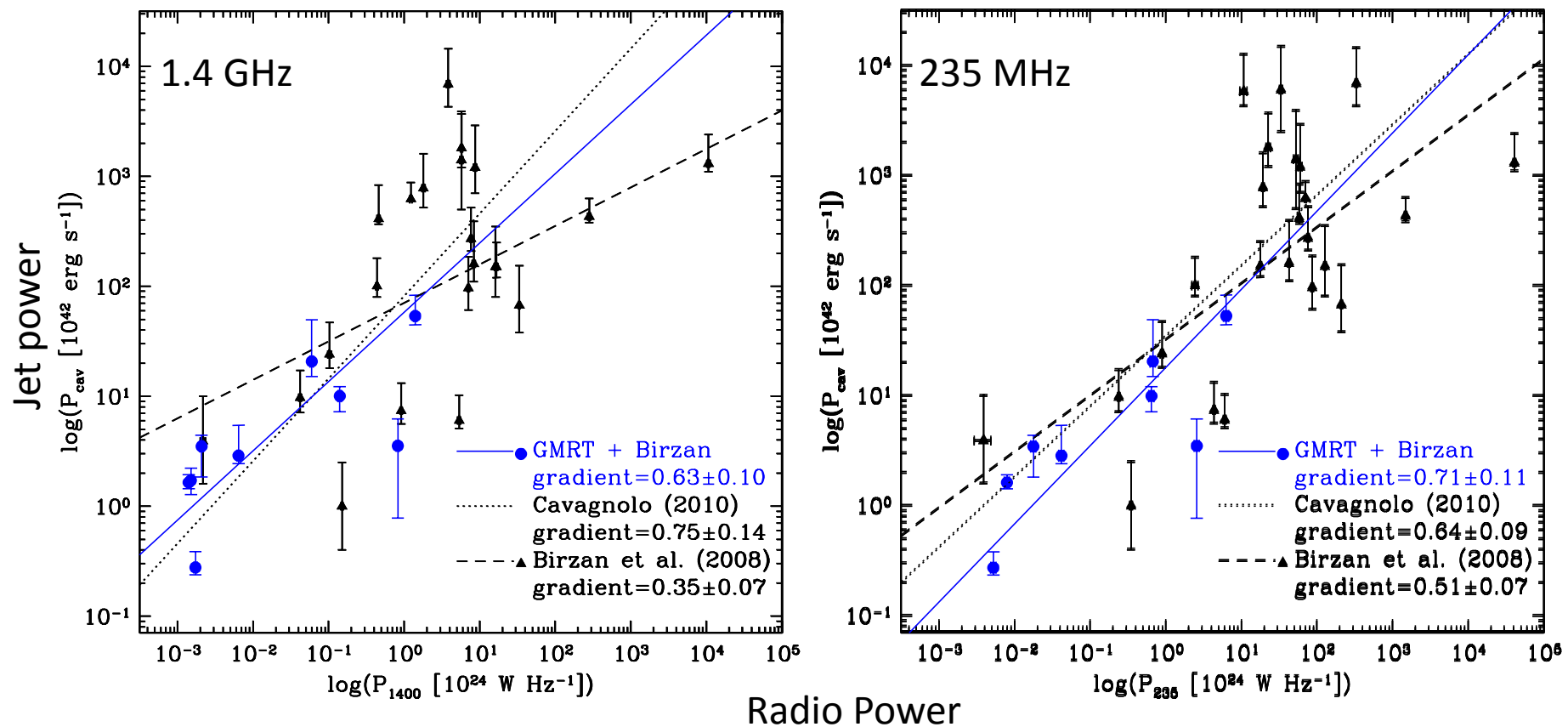


- We add 9 groups, with **high-quality GMRT 235 MHz data**.



AGN jets: mechanical power vs radio power

(O'Sullivan et al. 2011)



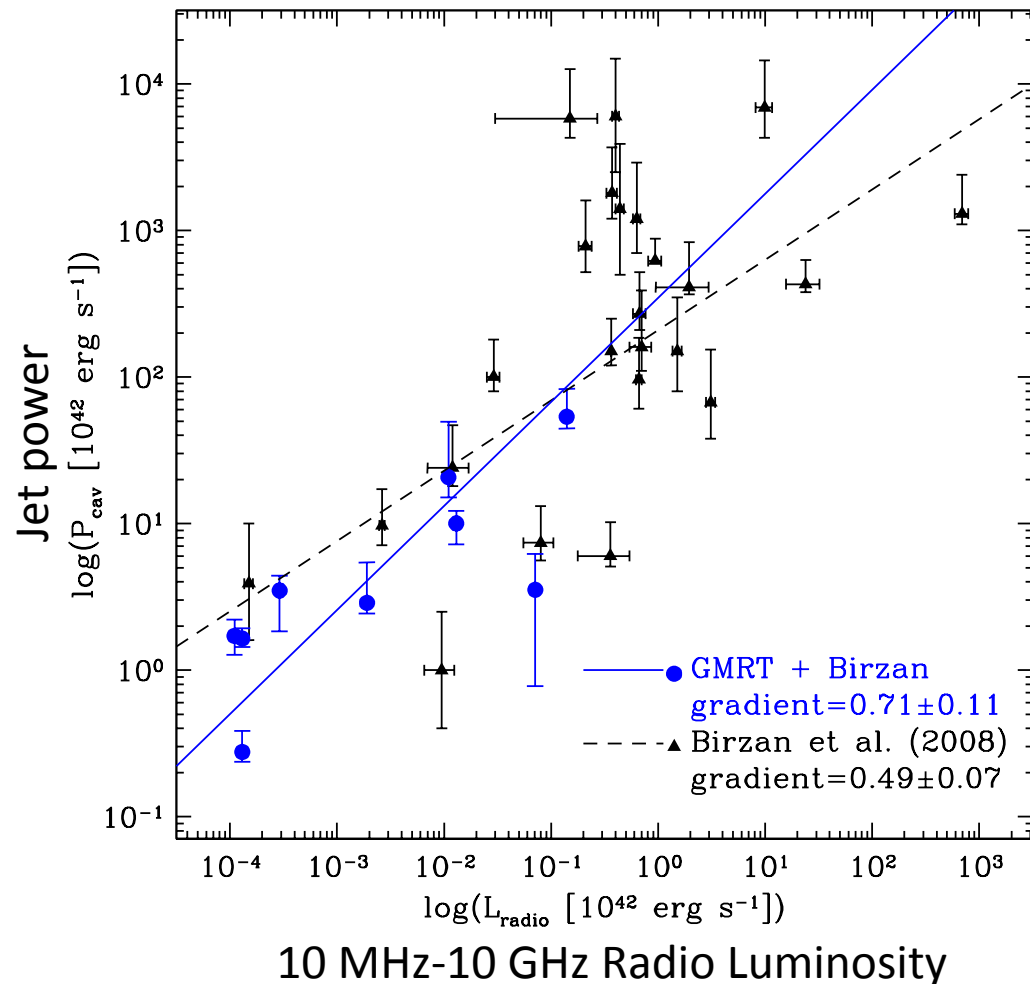
- Birzan et al used **BCES Y|X fit**, Cavagnolo and our fits use **BCES orthogonal**.
- Using low-frequencies and including groups reduces scatter:

Birzan 1.4 GHz: $\sigma_{\text{int}} = 0.84 \text{ dex}$ GMRT+Birzan 235 MHz: $\sigma_{\text{int}} = 0.58 \text{ dex}$



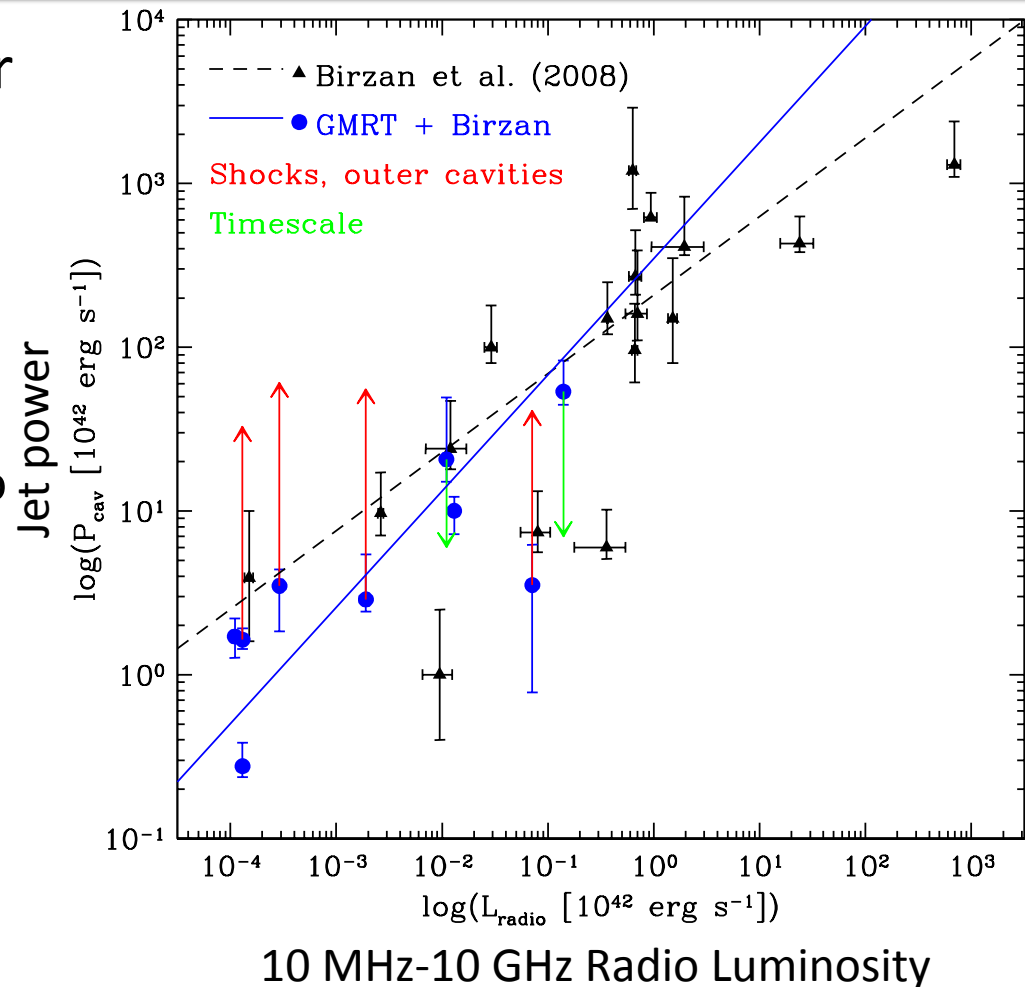
AGN jets: mechanical power vs radio power (O'Sullivan et al. 2011)

- Integrated radio power accounts for differences in spectral index → improved estimator of jet power.
- Gradient=0.71 identical to 235 MHz relation, $\sigma_{\text{int}}=0.59$ dex almost identical.
- Willott et al. (1999) use synchrotron theory to predict gradient = 0.86, assuming spectral index $\alpha=0.5$.
- For free spectral index, gradient = $3/(\alpha+3)$, e.g. gradient=0.76 for our typical $\alpha=0.95$.



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 and old cavities likely to be missed.
 - Jet orientation (factor ~ 3 , Mendygral et al. 2011).
 - AGN weather.
 - Filling factors < 1 (c.f. AWM4, O'Sullivan et al. 2010).
- Correcting groups where possible flattens relation.



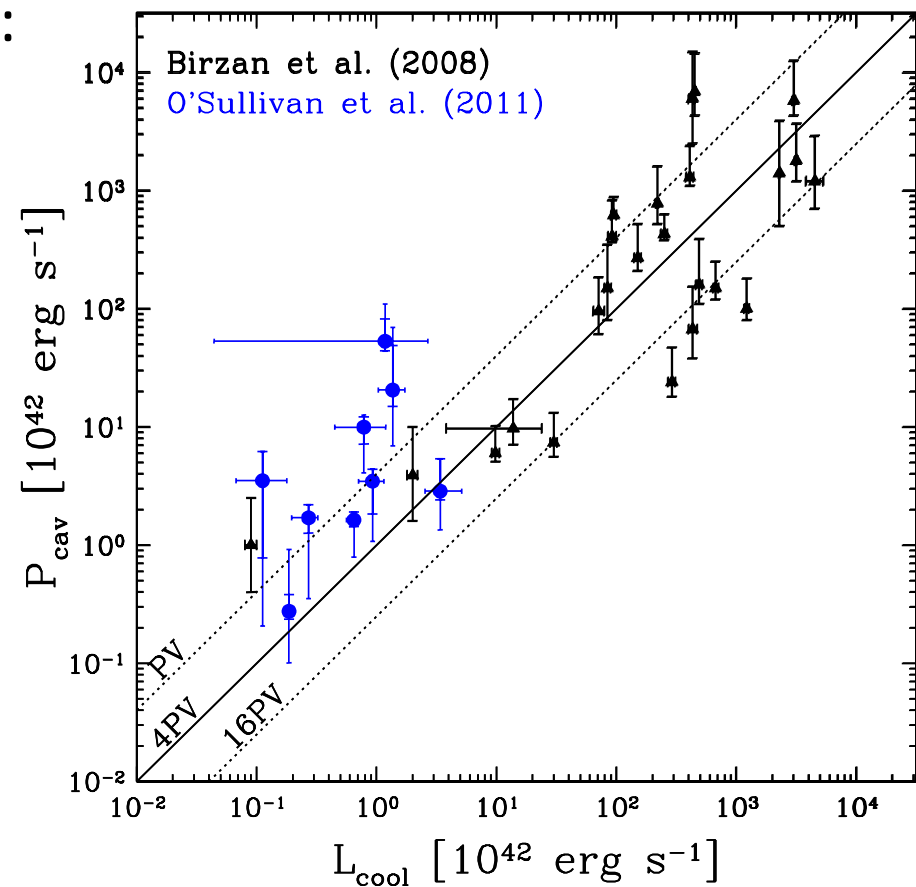
Mechanical Power vs Cooling

Power needed to balance cooling:

- In galaxy clusters $\sim 4PV$.
 - In groups only $\sim 1PV$
- (as for Ellipticals, Nulsen et al 2007).
- Scatter at least factor 4.

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

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



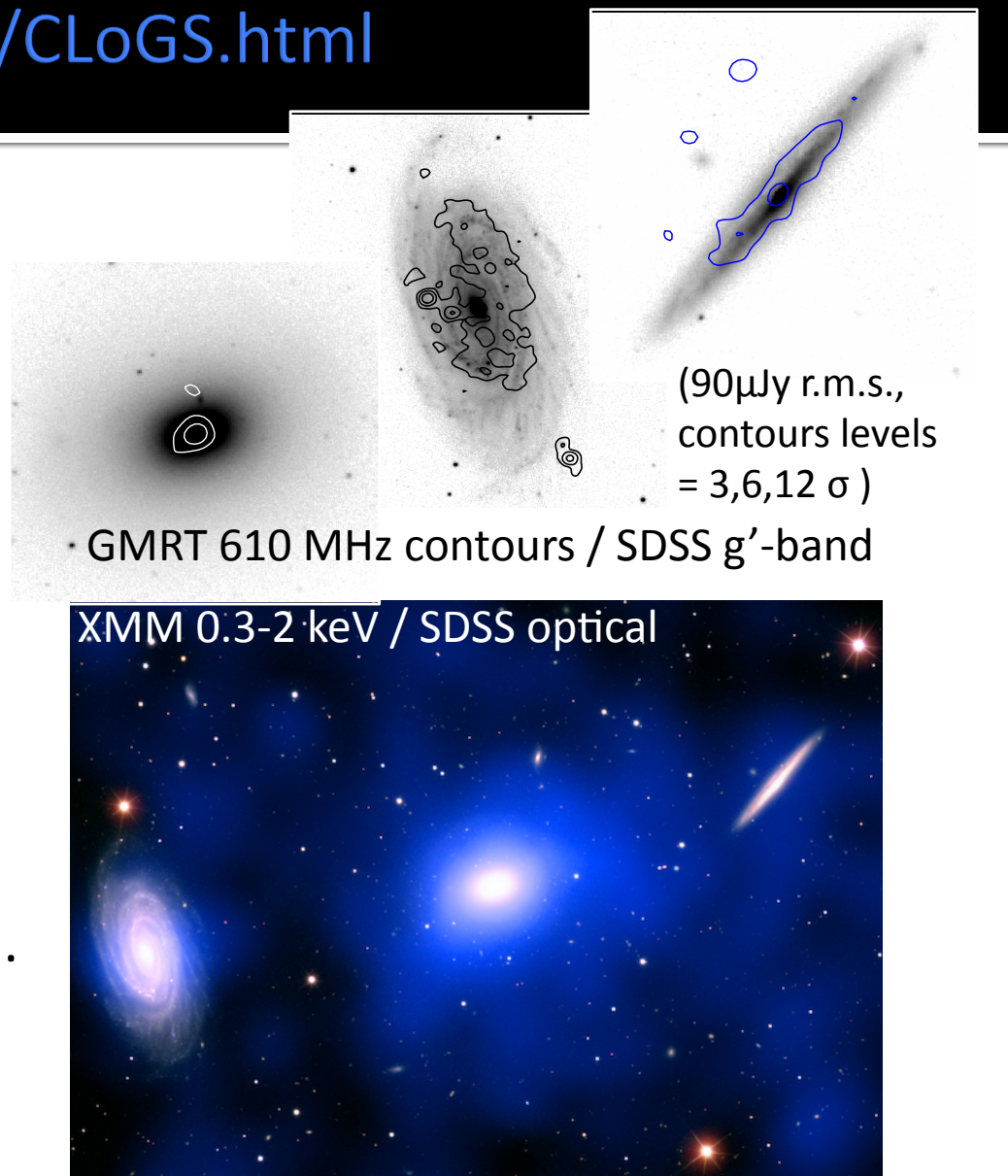
(Bolometric L_X for region $t_{\text{cool}} \leq 7.7$ Gyr)



CLoGS: The Complete Local-Volume Groups Sample

www.sr.bham.ac.uk/~ejos/CLoGS.html

- Complete, optically-selected sample of 53 groups:
 - 4+ galaxies, 1+ early-type
 - $D < 80$ Mpc
 - Dec. $> -30^\circ$ (VLA & GMRT)
- Avoids bias toward cool-core systems in RASS-based X-ray samples (Eckert et al. 2011)
- Goal: complete coverage in X-ray (Chandra/XMM) and radio (GMRT 610 & 235 MHz).
- Richer half of will be almost complete by 2012.



Summary

1. Low-frequency or integrated radio measurements are a more reliable predictor of jet power than $L_{1.4 \text{ GHz}}$.
2. Samples including groups (and ellipticals) provide better constraints on the $P_{\text{jet}}:P_{\text{radio}}$ relations.
 - Best fit gradient $\sim 0.7 \pm 0.1$ 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?

