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)
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

Smoothed Chandra 0.3-2 keV residual images

HCG62 cavities are paired, NGC5044 cavities isotropically distributed by gas motions.
### GMRT Groups sample (Giacintucci et al. 2011)

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**Clear cavities  Giant sources (too large)  Amorphous (no clear lobes)**
AGN jets: mechanical power vs radio power

- In the local Universe, we can estimate $P_{\text{jet}}$ 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).
- 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: $\sigma_{\text{int}}=0.84$ dex  GMRT+Birzan 235 MHz: $\sigma_{\text{int}}=0.58$ 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 $\alpha=0.95$. 

Structure in Clusters and Groups of Galaxies in the Chandra Era

Boston, MA, 12 June 2011
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.
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 $P_{\text{jet}} > 10 \ L_{\text{cool}}$
- 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)
Complete, optically-selected sample of 53 groups:
- 4+ galaxies, 1+ early-type
- D<80 Mpc
- Dec. > -30° (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.
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 $\sim 0.7\pm0.1$ with intrinsic scatter $\sim 0.6$ 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 $\sim 10$).
   - 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?