AGN heating in the *HIFLUGCS* sample of galaxy clusters: A self-regulated feedback mechanism?

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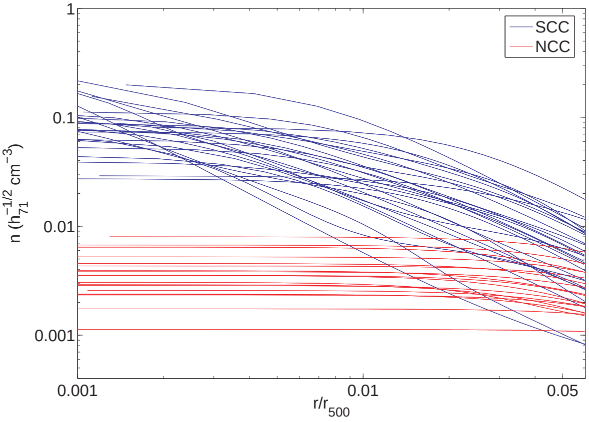
Bonn

Are there any indications of cooling?

1. Steep surface brightness profiles
2. Cooling times, $\tau \sim n^{-1}T^{0.5} \lesssim H_0$.



AGN heating in galaxy clusters

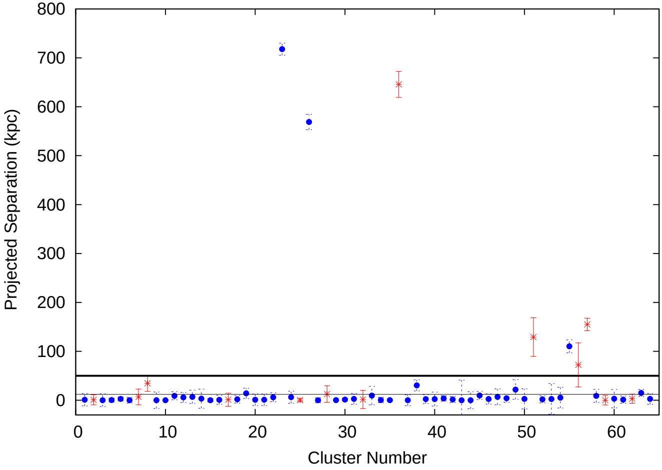
- Mechanical heating by expanding cavities: sound waves, turbulence, weak shock waves (e.g. Mathews et al. 2006, Voit & Donahue 2005, Brüggen et al. 2005, Birzan et al. 2004).
- AGN induced Convection (e.g. Chandran et al. 2007).
- AGN induced Cosmic Ray Heating (e.g. Guo et al. 2007).
- AGN induced Compton heating / photoionization (e.g. Sazonov et al. 2005).
- AGN + Conduction [e.g. Voit et. al. 2008 (see also Soker arXiv:0806.4720v1), Guo et al. 2008].

Our Sample

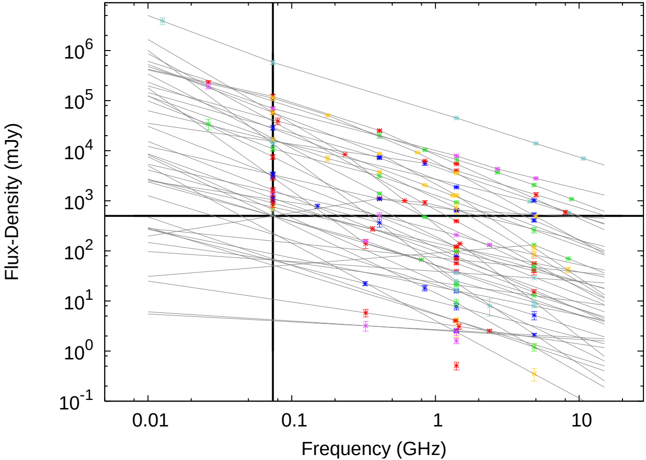
HIFLUGCS – The 64 brightest galaxy clusters

- Based on the ROSAT All Sky Survey, $|b| > 20^\circ$.
- $f_X(0.1 - 2.4)\,\mathrm{keV} \gtrsim 2 \times 10^{-11}$ ergs/sec/cm^2.
- $\langle z \rangle \sim 0.05$; $z_{\mathrm{max}} = 0.21$
- All have observations with *Chandra* and all but one with *XMM-Newton*.
- All have radio observations. Measurements for our study taken either from literature or archives.
  - 65 % have data below 500 MHz
  - 46 % have data below 80 MHz

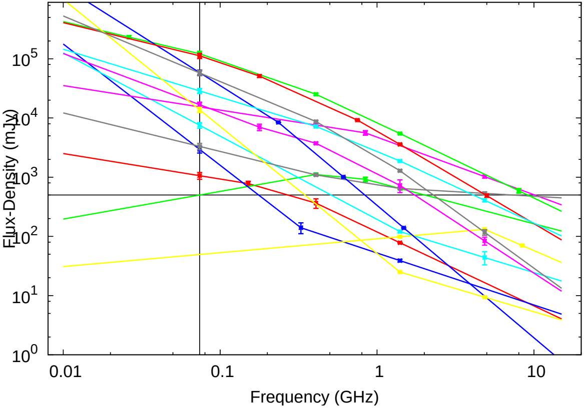
Separation between X-ray peak and BCG



Spectral of CCRSs in the *HIFLUGCS* sample



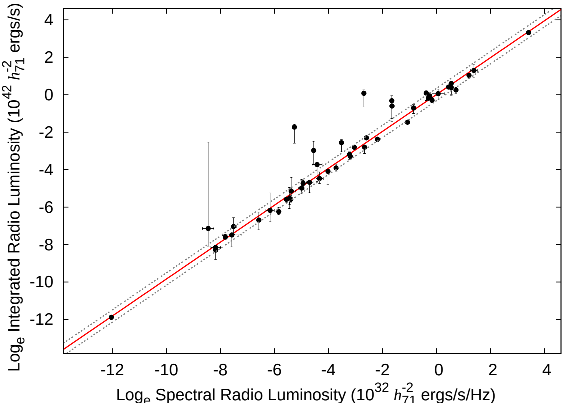
Spectral breaks as indicative of cavity ages



$$t \sim \frac{B^{0.5}}{B^2 + \frac{2}{3} B_{\mathrm{CMB}}} \nu_{\mathrm{b}}^{-0.5}$$

(See Birzan arXiv:0806.1929)

Spectral Luminosity vs. Total Radio Luminosity



$$\frac{L_{\rm R}}{10^{42}\ h_{71}^{-2}\ \ {\rm ergs\ s^{-1}}} = (1.085 \pm 0.024) \times \left(\frac{L_{1.4\ \rm GHz}}{10^{32}\ h_{71}^{-2}\ \ {\rm ergs\ s^{-1}\ Hz^{-1}}} \right)^{(0.986 \pm 0.005)}$$

Cooling activity - is there a good measure?

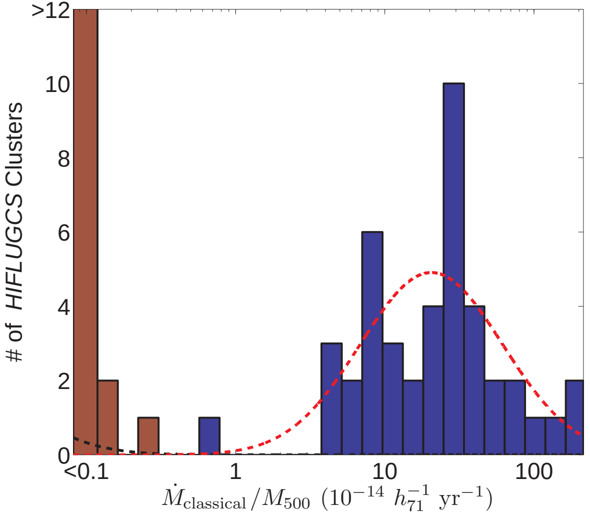
Search for bi(tri)modality

- Central surface brightness
- Scaled core radius, r_{c}/R_{500}
- Central density, n_0
- Central biased entropy, K_{bias}
- Cooling radius, r_{cool}
- $\dot{M}_{\mathrm{spec}}/M_{500}$
- Scaled core luminosity $[L_{\mathrm{X}}/(M_{\mathrm{gas}}\mathrm{k}T_{\mathrm{vir}})]$
- $M_{\mathrm{gas}}(< 0.048R_{500})/M_{500}$

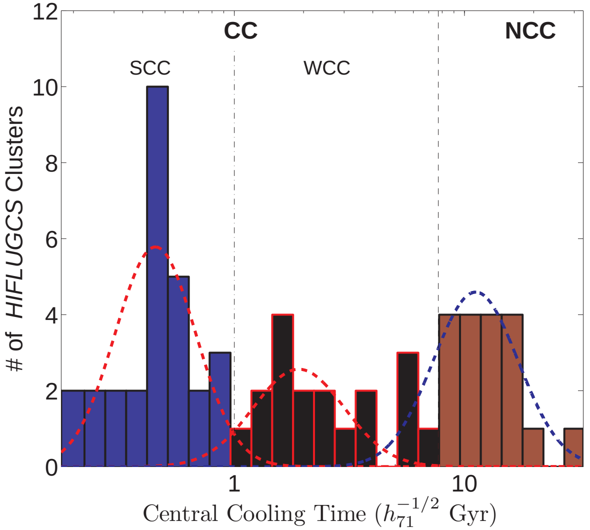
- $\dot{M}_{\mathrm{classical}}/M_{500}$
- Central cooling time
- Central entropy, K_0
- Central temperature drop (T_0/T_{vir})
- Cuspiness (α)

Central $\rightarrow$ 0.4% R_{500}.

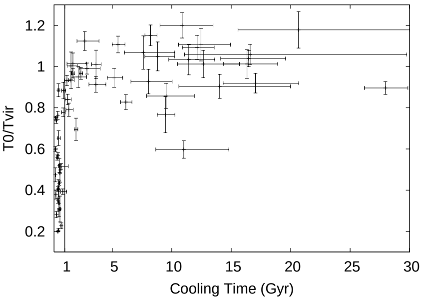
Classical Mass Deposition Rate



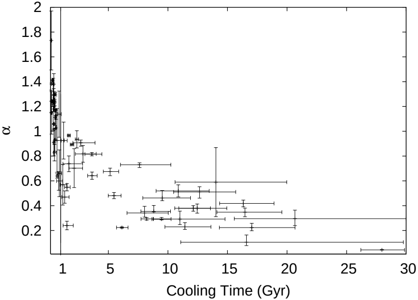
Central Cooling Time



Peculiarities at Central Cooling Time < 1 Gyr

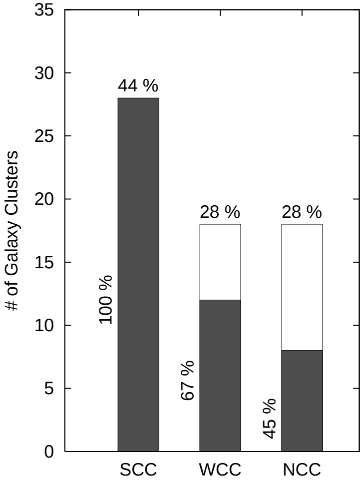


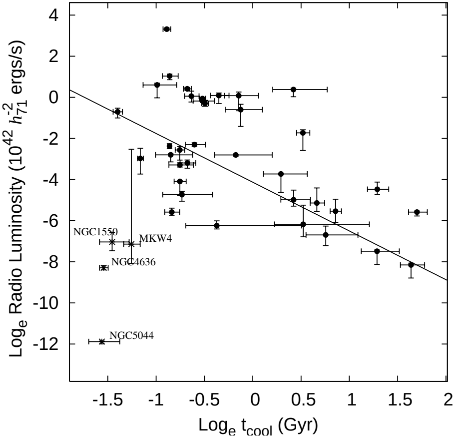
Central Temperature Drop



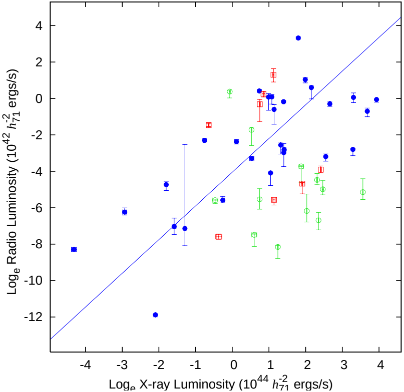
Cuspiness

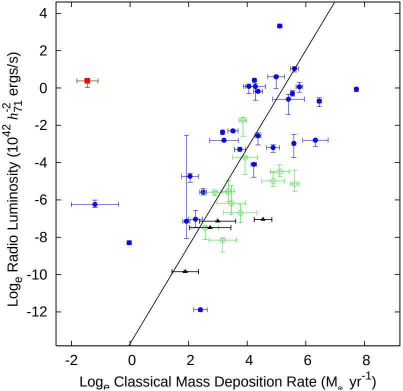
SCC, WCC and NCC fractions: With and without a CRS





X-ray – Radio correlation



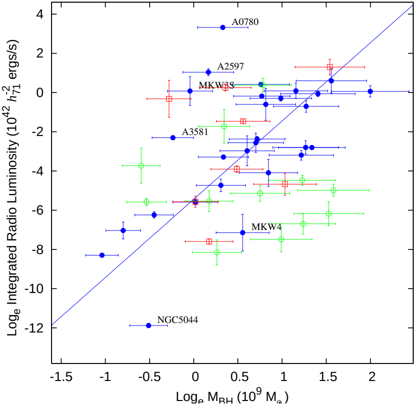


$$L_{\mathrm{R}} \propto L_{\mathrm{X}}^{(1.85\pm0.38)}$$

$$L_{\mathrm{R}} \propto \dot{M}_{\mathrm{classical}}^{(2.62\pm0.52)}$$

Mass of the SMBH vs. radio luminosity of the BCG

$$\log_{10}\left(\frac{M_{\rm BH}}{M_\odot}\right) = 8.21 + 1.13\left[\log_{10}\left(\frac{L_{\rm k,bul}}{L_\odot}\right) - 10.9\right] \rightarrow \text{Marconi \& Hunt (2003)}$$



$$\frac{L_{\rm R}}{10^{42}\ h_{71}^{-2}\ \ {\rm ergs\ s^{-1}}} = (0.004 \pm 0.002) \times \left(\frac{M_{\rm BH}}{10^9\ {\rm M_\odot}}\right)^{3.99\pm0.49}$$

Conclusions & Outlook

1. The integrated radio luminosity (L_{R}) of a CCRS is tightly correlated to its 1.4 GHz luminosity but there are exceptions; L_{R} **is better-suited for such a study**.
2. Based on t_{cool}, there is an increasing probability for the BCG closest to the X-ray peak to harbor an active AGN with decreasing cooling time.
   - SCC, $t_{\mathrm{cool}} \leq 1$ Gyr $\rightarrow$ 100 %
   - WCC, 1 Gyr $\leq t_{\mathrm{cool}} \leq 7.7$ Gyr $\rightarrow$ 67 %
   - NCC, $t_{\mathrm{cool}} \geq 7.7$ Gyr $\rightarrow$ 45 %
3. Coupling between radio and cooling activity seen in SCC clusters:
   - L_{R} scales with the cluster size (e.g. L_{X}) for SCC clusters.
   - L_{R} shows a tight correlation with $\dot{M}_{\mathrm{classical}}$ for CC clusters.
   - L_{R} of the BCG increases with M_{BH} in SCC clusters.

Upcoming Papers

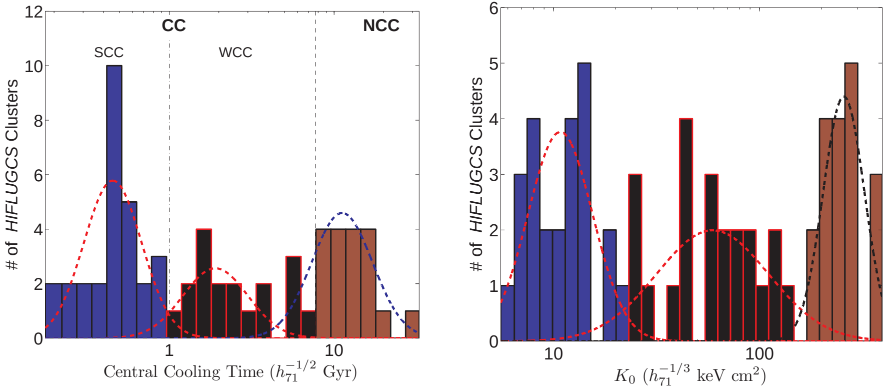
1. "What is a Cool Core Cluster? A Detailed Analysis of the Cores of the *HIFLUGCS* Clusters"

   D. S. Hudson, R. Mittal, T. H. Reiprich, P. E. J. Nulsen, H. Andernach & C. L. Sarazin

2. "AGN-heating and ICM cooling in the *HIFLUGCS* sample of galaxy clusters"

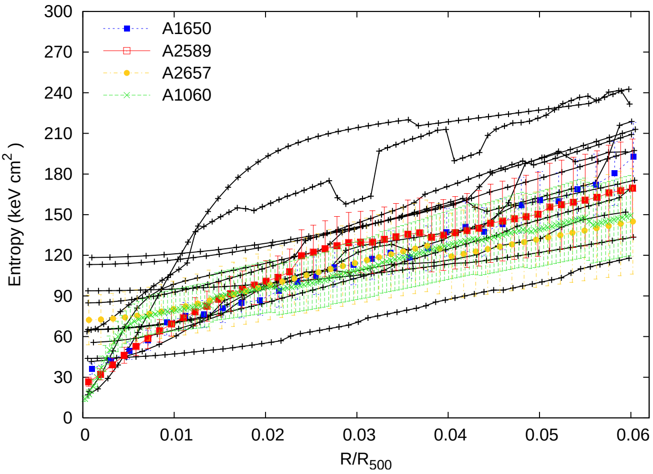
   R. Mittal, D. S. Hudson & T. H. Reiprich

Central Cooling Time



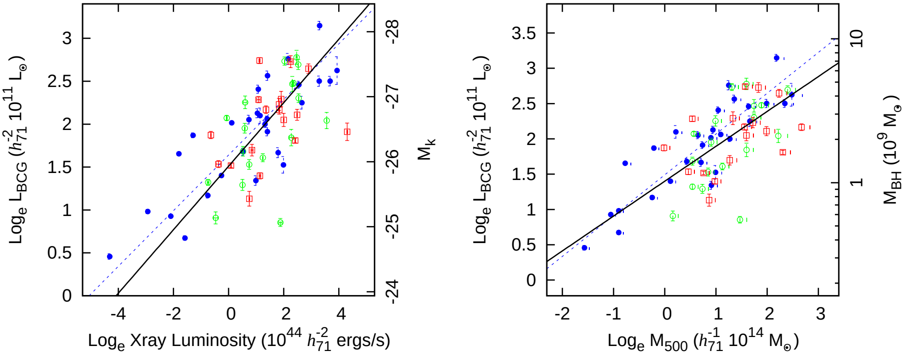
$$t_{\rm cool} \sim \frac{K^{3/2}}{T}$$

Outliers



A1650
A2589
A2657
A1060
Entropy (keV cm^2)
R/R$_{500}$
300
270
240
210
180
150
120
90
60
30
0
0
0.01
0.02
0.03
0.04
0.05
0.06

BCG and large-scale environment



$$L_{\mathrm{K,bul}} \propto L_{\mathrm{X}}^{(0.37\pm0.03)}$$

$$L_{\mathrm{K,bul}} \propto M_{500}^{(0.49\pm0.07)}$$

BCG K-band Bulge Luminosity vs Central Temperature