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

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Are there any indications of cooling?

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

![Graph showing cooling curves]

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, $|b| > 20^\circ$.
- $f_X (0.1 - 2.4) \text{ keV} \gtrsim 2 \times 10^{-11} \text{ ergs/sec/cm}^2$.
- $\langle z \rangle \sim 0.05$ ; $z_{\text{max}} = 0.21$
- 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

Projected Separation (kpc)

Cluster Number

Rupal Mittal (AlfA, Bonn) AGN heating in the HIFLUGCS sample
Spectral of CCRSs in the *HIFLUGCS* sample
Spectral breaks as indicative of cavity ages

\[ t \sim \frac{B^{0.5}}{B^2 + \frac{2}{3} B_{\text{CMB}}} \nu^{-0.5} \]

(See Birzan arXiv:0806.1929)
\[ \frac{L_R}{10^{42} \, h_{71}^{-2} \, \text{ergs} \, \text{s}^{-1}} = (1.085 \pm 0.024) \times \left( \frac{L_{1.4 \, \text{GHz}}}{10^{32} \, h_{71}^{-2} \, \text{ergs} \, \text{s}^{-1} \, \text{Hz}^{-1}} \right)^{0.986 \pm 0.005} \]
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, $r_{cool}$
- $\dot{M}_{spec} / M_{500}$
- Scaled core luminosity $[L_X / (M_{gas} k T_{vir})]$  
- $M_{gas}( < 0.048 R_{500}) / M_{500}$

Central → 0.4% $R_{500}$. 

- $\dot{M}_{classical} / M_{500}$
- Central cooling time
- Central entropy, $K_0$
- Central temperature drop $(T_0 / T_{vir})$
- Cuspiness ($\alpha$)
Classical Mass Deposition Rate

\[ \dot{M}_{\text{classical}} / M_{500} \left(10^{-14} \, h^{-1} \, \text{yr}^{-1}\right) \]

# of HIFLUGCS Clusters

<0.1  1  10  100

\( \dot{M}_{\text{classical}} / M_{500} \left(10^{-14} \, h^{-1} \, \text{yr}^{-1}\right) \)

# of HIFLUGCS Clusters

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AGN heating in the HIFLUGCS sample
Central Cooling Time

<table>
<thead>
<tr>
<th>Central Cooling Time ($h_{71}^{-1/2}$ Gyr)</th>
<th># of HIFLUGCS Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>SCC</td>
</tr>
<tr>
<td>NCC</td>
<td>WCC</td>
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</tbody>
</table>

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AGN heating in the HIFLUGCS sample
Peculiarities at Central Cooling Time < 1 Gyr

Central Temperature Drop  Cuspiness

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

![Bar chart showing SCC, WCC, and NCC fractions](chart.png)

- SCC: 44%
- WCC: 28%
- NCC: 28%

![Diagram showing Loge Radio Luminosity](diagram.png)

- Loge Radio Luminosity (10^{42} h^{-2}_71 ergs/s)
- Loge t_{cool} (Gyr)

NGC1550 MKW4
NGC4636
NGC5044

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AGN heating in the HIFLUGCS sample
X-ray – Radio correlation

\[ L_R \propto L_X^{(1.85 \pm 0.38)} \]

\[ L_R \propto \dot{M}_{\text{classical}}^{(2.62 \pm 0.52)} \]
Mass of the SMBH vs. radio luminosity of the BCG

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

\[
\frac{L_R}{10^{42} h_{71}^{-2} \text{ ergs s}^{-1}} = (0.004 \pm 0.002) \times \left( \frac{M_{\text{BH}}}{10^9 M_\odot} \right)^{3.99\pm0.49}
\]
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 $t_{\text{cool}}$, there is an increasing probability for the BCG closest to the X-ray peak to harbor an active AGN with decreasing cooling time.

   - SCC, $t_{\text{cool}} \leq 1$ Gyr $\rightarrow 100\%$
   - WCC, $1$ Gyr $\leq t_{\text{cool}} \leq 7.7$ Gyr $\rightarrow 67\%$
   - NCC, $t_{\text{cool}} \geq 7.7$ 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 $\dot{M}_{\text{classical}}$ for CC clusters.
   - $L_R$ of the BCG increases with $M_{\text{BH}}$ in SCC clusters.
Upcoming Papers

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

2. “AGN-heating and ICM cooling in the HIFLUGCS sample of galaxy clusters”
   R. Mittal, D. S. Hudson & T. H. Reiprich
Central Cooling Time

\[ t_{\text{cool}} \sim \frac{K^{3/2}}{T} \]

Rupal Mittal (AlfA, Bonn)  AGN heating in the HIFLUGCS sample
Outliers

Entropy (keV cm²)

R/R

A1650
A2589
A2657
A1060

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AGN heating in the HIFLUGCS sample
BCG and large-scale environment

\[ L_{K,\text{bul}} \propto L_X^{(0.37 \pm 0.03)} \]

\[ L_{K,\text{bul}} \propto M_{500}^{(0.49 \pm 0.07)} \]
BCG $K$-band Bulge Luminosity vs Central Temperature

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AGN heating in the HIFLUGCS sample