Probing the Outskirts of Clusters with Suzaku, Chandra, and XMM

Eric Miller
MIT Kavli Institute

Mark Bautz, Richard Mushotzky, Dave Davis, Jithin George, Patrick Henry
Why Study Cluster Outskirts?

- majority of dark matter, baryons, metals in cluster
- clusters are still accreting at $R_{\text{vir}}$
  - constrain cluster formation models, assembly history
  - clumping, turbulence, electron-ion non-equilibrium
  - universal temperature, pressure profiles?
- clusters as cosmological tools via mass, baryon fraction
  - helpful to understand cluster physics to use them as cosmological probes

Abell 85: X-ray (NASA/CXC/SAO/A.Vikhlinin et al.); Optical (SDSS)
Clustering with Suzaku

![Clustering with Suzaku](image)
Clusters with Suzaku

```
explain: declining kT to R_{200}
“universal” temperature profile
(Burns+10)
```
## Suzaku Cluster Outskirts Project

<table>
<thead>
<tr>
<th>Cluster</th>
<th>z</th>
<th>$R_{200}$</th>
<th>ksec</th>
<th>date obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A383</td>
<td>0.187</td>
<td>9.3</td>
<td>110</td>
<td>July 2010</td>
</tr>
<tr>
<td>A1413</td>
<td>0.135</td>
<td>14.8</td>
<td>170</td>
<td>May 2010 + archive</td>
</tr>
<tr>
<td>A1795</td>
<td>0.063</td>
<td>26.0</td>
<td>260</td>
<td>June 2009 + archive</td>
</tr>
<tr>
<td>A1914</td>
<td>0.174</td>
<td>14.5</td>
<td>160</td>
<td>June 2010</td>
</tr>
<tr>
<td>A2204</td>
<td>0.151</td>
<td>11.8</td>
<td>140</td>
<td>Sep 2010 + archive</td>
</tr>
<tr>
<td>RXCJ0605</td>
<td>0.137</td>
<td>12.2</td>
<td>150</td>
<td>May 2010</td>
</tr>
<tr>
<td>A773</td>
<td>0.216</td>
<td>9.5</td>
<td>200</td>
<td>May 2011</td>
</tr>
<tr>
<td>A1068</td>
<td>0.147</td>
<td>10.8</td>
<td>200</td>
<td>&gt;June 2011</td>
</tr>
<tr>
<td>A2667</td>
<td>0.221</td>
<td>10.0</td>
<td>200</td>
<td>June 2011</td>
</tr>
</tbody>
</table>

- selected from Snowden et al. 2008 XMM cluster catalog
- “relaxed”, no substructure
- falling, flat, and rising $kT$ profiles
- full azimuthal coverage out to $R_{200}$
Abell 2204
$z = 0.151$

12' ~ 2 Mpc
RXCJ0605

$z = 0.137$

14' ~ 2 Mpc
$M_{200} = 4.2 \times 10^{14} \ M_\odot$

$c_{200} = 12$

Voit 2005

$S \propto R^{1.1}$

non-rad gravity

assume NFW

$f_b - 10\%$ stars
Systematics

- at $r_{\text{vir}}$, cluster flux $< 30\%$ of background
- constraining the background is vital
- sources of background uncertainty
  - scattered X-ray flux from bright core ($< 10\%$; simulations underway)
  - cosmic background variations (up to 40\%) for small extraction regions ($\leq 0.01 \text{ deg}^2$), background accuracy limited by Poisson statistics of point sources (AGN) just below threshold
Cosmic Background Variations

- **Suzaku** detection limit
  \[ \sim 10^{-13} \text{ erg/s/cm}^2 \]

- **Chandra** detection limit
  \[ \sim 10^{-14} \text{ erg/s/cm}^2 \]

- expect \( \sim 1 \) source per region between Suzaku, Chandra limits

- **Suzaku** surf. brightness limit
  \[ \sigma_B \sim 4 \times 10^{-12} \text{ erg/s/cm}^2/\text{deg}^2 \]
  \( \sim 40\% \) of soft BG!

- **Chandra** surf. brightness limit
  \[ \sigma_B \sim 1 \times 10^{-12} \text{ erg/s/cm}^2/\text{deg}^2 \]
  \( \sim 10\% \) of soft BG!

Cumulative flux dist. Moretti et al. 2003
only 4 of 16 cluster fields observed with *Chandra* so far....
Summary

- 9 clusters selected from Snowden XMM catalog
- multiple directions probed to $R_{200}$
- average profiles to $R_{100} \sim R_{\text{vir}}$
- confirm falling kT profiles
- so far consistent with cosmic baryon fraction at $R_{200}$