Radio Halos in ACT Galaxy Clusters

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Cosmology on Safari, Bonamanzi
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Kavilan Moodley, Huib Intema, et al
Giant Radio Halos & Radio Relics: What Are They?

- ~Mpc scale, faint, diffuse synchrotron emission; not linked to individual galaxies; exhibit steep spectra → electron cooling
What do we know about GRH?

- Synchrotron emission associated with non-thermal ICM

- **In-situ particle acceleration needed!**
  - radiative lifetime of cosmic ray electrons (CRe) << than diffusion time necessary to cover cluster-scale volumes

- Can give us a better understanding of the cluster environment
  - Constrain strength of B-fields
  - Physics of the ICM
Formation Models

- Two competing theories for the in-situ CRe acceleration
  - Hadronic / Secondary Electron
    - CRe created from p-p collisions in ICM
    - Predictions:
      - \( \gamma \)-ray emission
      - Spectral index \( \alpha \) independent of position
  - Turbulent Reacceleration / Primary Electron
    - Existing CRe re-accelerated by merger-driven turbulence
    - Predictions:
      - population of Ultra-Steep Spectrum radio halos (USSRH)
      - bimodality in Radio-Xray plane related to cluster dynamical state
Cluster selection: X-ray vs SZ

- Majority of GRH studies done on X-ray selected samples → biases?

- SZ effect → an efficient way to search for massive galaxy clusters
Radio Program for ACT Clusters

- Investigate radio properties of the ACT-E sample (68 clusters)
  - Pilot study (PI: Knowles)
    - 4 targets @ 610 MHz on GMRT
  - High-z study (PI: Knowles)
    - 4 targets @ 610 MHz on GMRT
- VLA S82 (PI: Jarvis)
  - 1-2 GHz detections & stacking on ACT-E positions
Radio Program for ACT Clusters

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A giant radio halo in a low-mass SZ-selected galaxy cluster: ACT-CL J0256.5+0006

K. Knowles,1 et al.

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in preparation...
ACT-CL J0256.5+0006

- Major Merger (1:3)
- $z = 0.363$
- Low Mass:
  $M_{SZ,500} = 3.8 \times 10^{14} M_{\text{sol}}$
- $L_{X,500} = 1.49 \times 10^{45} \text{ erg/s}$
- $Y_{500} = 3.7 \times 10^{-4} \text{ arcmin}^{-2}$
- GMRT: 10 hrs @ 610 MHz + 8 hrs DDT @ 325 MHz
• Radio reduction with AIPS, SPAM (Intema et al.) & CASA

• Ionospheric & direction-dependent calibration via SPAM pipeline

• Imaging process:
  - Make PTSRC image (uv > 5 klambda)
  - FT PTSRC model into uv-plane & subtract from data
  - Re-image at full res to check if removal was successful
  - Image @ low-res to bring GRH emission to the fore (uv < 5 klambda, 4 klambda taper)
• Full resolution image

610 MHz
33 μJy/b
(6.0'' x 4.5'', 70°)

325 MHz
110 μJy/b
(10.1'' x 8.7'', -77°)
• Point source image to create model

610 MHz
37 μJy/b
(5.3'' x 3.7'', 75°)

325 MHz
99 μJy/b
(8.7'' x 6.6'', 73°)
• Point source residual
  - have we cleaned to the level of the noise?

610 MHz

325 MHz
• Full-resolution pt. source subtracted image

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Size</th>
<th>Flux Density</th>
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</thead>
<tbody>
<tr>
<td>610 MHz</td>
<td>6.0'' x 4.5'', 70°</td>
<td>51 μJy/b</td>
</tr>
<tr>
<td>325 MHz</td>
<td>10.1'' x 8.8'', -77°</td>
<td>287 μJy/b</td>
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• Low surface brightness halos

• 325: $4\sigma$ (1.58 mJy/b, 53.0'' x 49.3'', -88°)
  610: $6\sigma$ (368 uJy/b, 54.5'' x 49.0'', -57°)
- $S_{610} = 6.9 \pm 1.7 \text{ mJy}$
- $P_{1.4\text{GHz}} = 1.4 \times 10^{24} \text{ W/Hz}$

Knowles+ 2015 in prep
J0256 – X-ray Morphology

• Gives indication of spatial structure
• Not sensitive to structure along the line of sight

As per Cassano+ 2010

- $c$ – concentration parameter
- $w$ – centroid shift
- $P_3/P_0$ – power ratio
J0256 - Optical

- 85 cluster members
- $z = 0.363$
- Bimodal L.O.S. structure
- Gaussian Mixture Modelling shows peaks are statistically significant
- $v_{\text{LOS}} = 1986 \pm 390$ km/s
- $M_{500,\text{opt}} = 3.8 \times 10^{14} M_\odot$

Gemini

Knowles+ 2015, in prep
J0256 – Merger Analysis

- Improved on work by Majerowicz et al. 2004
- NFW profile for main cluster + more spec-z's
- Two sets of solutions for $v$, $d$ and $\theta$
- Can use these to estimate merger timescale
CosmoSafari 2015

Case 1 ~ 1.35 Gyr
Case 2 ~ 1.19 Gyr

Plots from Donnert+ 2013

Knowles+ 2015, in prep

<table>
<thead>
<tr>
<th>Case 1</th>
<th>3087.1$^{+58.2}_{-142.9}$ kpc</th>
<th>310.2$^{+92.1}_{-34.5}$ degrees</th>
<th>50.0$^{+9.5}_{-13.8}$ Gyr</th>
<th>1.12$^{+0.01}_{-0.03}$ Gyr</th>
<th>0.09$^{+0.03}_{-0.01}$ Gyr</th>
<th>1.31$^{+0.03}_{-0.01}$ Gyr</th>
<th>46.2$^{+0.5}_{-1.2}$</th>
</tr>
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<tr>
<td>Case 2</td>
<td>2019.2$^{+481.3}_{-411.5}$ kpc</td>
<td>1306.7$^{+613.3}_{-545.3}$ degrees</td>
<td>10.5$^{+7.7}_{-3.4}$ Gyr</td>
<td>0.71$^{+0.24}_{-0.34}$ Gyr</td>
<td>0.50$^{+0.34}_{-0.24}$ Gyr</td>
<td>1.71$^{+0.34}_{-0.24}$ Gyr</td>
<td>29.4$^{+10.1}_{-14.6}$</td>
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</table>
• New and Upcoming radio telescopes will increase the number of GRH known, e.g. TGSS, MWA, JVLA S82

• LOFAR (< 150MHz)
  – should pick up steep spectrum sources not seen at current higher frequencies

• MeerKAT, SKA (increased sensitivities)
  – Can probe deeper in redshift and find GRH too faint to detect with current telescopes
Summary

- Have a program for radio follow-up of ACT-E sample

- Successful in acquiring new radio data – has lead to a new GRH detection

- Finding GRH is important, but a multi-wavelength approach can provide the bigger picture

- Merger timescale analysis is an interesting avenue to explore – quantify transient nature of GRH?

- Need MeerKAT & SKA to find GRHs in lower-mass clusters (excellent SB sensitivity & high resolution)