ABELL 1682
An Ultra Steep Spectrum Radio Halo

Science At Low Frequencies II - Albuquerque, New Mexico
Radio Halos as probes of cluster magnetic fields

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An Ultra Steep Spectrum Radio Halo

Radio Halos as probes of cluster magnetic fields

LOFAR results from 44–110 MHz
## Cluster Magnetic Fields

<table>
<thead>
<tr>
<th>Method</th>
<th>Strength $\mu$G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchrotron halos</td>
<td>0.4–1</td>
</tr>
<tr>
<td>Faraday rotation (embedded)</td>
<td>3–40</td>
</tr>
<tr>
<td>Faraday rotation (background)</td>
<td>1–10</td>
</tr>
<tr>
<td>Inverse Compton</td>
<td>0.2–1</td>
</tr>
<tr>
<td>Cold fronts</td>
<td>1–10</td>
</tr>
<tr>
<td>GZK</td>
<td>$&gt;0.3$</td>
</tr>
</tbody>
</table>
Radio Halos

Ingredients:

Large scale magnetic fields + Relativistic electrons

Formation mechanisms:

A) Relativistic electrons injected by proton–proton collisions

B) Old electrons are accelerated
   Related to the merging event? Turbulence?

Ultra Steep Spectrum Radio Halos let us explore this
Abell 521 (Brunetti et al 2008 – Nature) – Spectral Index = -2.1

Steep spectrum halos are special cases that let us:

- Rule out e\(^-\) injection via proton-proton collisions
- Strongly favor particle re-acceleration via turbulence
A) Proton–proton collisions

Generating steep spectrum relativistic electrons

Expect thermal energy density to dominate over energy density of relativistic protons

This implies a limit on the spectral index of the electrons

→ we would not see steep spectrum halos via P–P collisions

Does provide possibility that clusters without radio halos have smaller magnetic fields
B) Turbulence induced by a merger event

Turbulence injects energy into the electrons on time scales of ~1 Gyr, on spatial scales of ~ sub-cluster size.

\[ E_e \approx 1.4 B_{nT}^{-1/2} (\nu_c/300)^{1/2} \]

\[ \tau \approx 0.95 \frac{B_{nT}^{1/2} (\nu_c/300)^{-1/2}}{(1+z)^4 + (B_{nT}/0.32)^2} \text{ Gyr} \]

Spectral cut off at higher frequencies (steep spectral index) is a signature of turbulent acceleration.

Low frequency observations should detect more halos.

Observed spectral cut off is a measure of the cluster magnetic field.
Abell 1682

A massive merging galaxy cluster
(z=0.226, LX[0.2−2.4keV] = 7.02 × 10^{44} erg s^{-1})

Turbulence following the merging event generates a radio halo – is it steep spectrum?
the “diffuse component”

G. Macario et al 2013:
GMRT 150 MHz contours overlaid on Chandra

Archive VLA + Hubble image
Bimodal mass distribution

Galaxy Distribution

Projected mass density from lensing

Projected mass density from galaxies

Galaxy number density

Dahle et al. 2002
LOFAR HBA
116 MHz, robust 0, contours at 5 & 10 $\sigma$
15” x 20” beam

LOFAR LBA
44 MHz, robust 0, contours at 5 & 10 $\sigma$
20” x 30” beam

noise ~6 mJy

noise ~20 mJy
HBA–LBA Spectral Index Map

LOFAR 44 (black) to 113 (red) MHz – 5,10,15 sigma contours
LOFAR LBA contours + 20 ksec Chandra X-ray
Conclusions

Radio Halos let us probe cluster magnetic fields

A1682 presents a case where low frequency observations are essential

Merger dynamics gives a cause for the halo formation mechanism

Favors the re-acceleration model for halo formation
Thanks for listening!

Alex Clarke