Galaxy Clusters at Ultra-Low Frequencies

<100 MHz

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Snow Cluster - 21/03/2018
CRs in clusters

Outline:

• CRe in clusters
• Gently Re-Energised Tails (GReET)
• Low-frequency radio surveys
Relevance: CRs are tracers of AGN activity and merger events

Unveiling the silent majority of low-energy cosmic rays

USS radio halos
Dead AGNs
Radio phoenixes
GReETs
....

Relevance: CRs are tracers of AGN activity and merger events

Unveiling the silent majority of low-energy cosmic rays

Frequency

10 MHz

10 GHz

Flux density

cosmic rays

energetic

less energetic

....
Cosmic ray life-cycle

High Freq

- Relics
- Radio galaxies

Low Freq

- Phoenixes
- GReETs

Radiative/other losses

- Synchrotron dark CRs
- Low energy CRs
- High energy CRs

Turbulence

Shocks

Compression

New/unknown mechanisms

Synch. lifetime (Myr)

- 1000
- 100
- 1

20 -> 200 Myr

100 MHz

1 GHz

GReET
Phoenix
USS halos
Dead AGNs
Reacceleration
...
Outline:
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Gently Re-Energised Tails

$z = 0.12$

$M = 3.4 \times 10^{14} M_\odot$
GReETs

Spectra Index: -4

- GMRT 608 MHz
- GMRT 323 MHz
- GMRT 148 MHz
- LOFAR 142 MHz

150 kpc
**Assumptions:**
1. standard JP
2. injection index: $-0.65$ (measured)
3. magnetic field: $B = 1, 2.27$ (minimises losses), 5 μG
4. negligible adiabatic losses

Re-acceleration is gentle! Re-acceleration time: $\tau_{\text{acc}} = E/\langle dE \rangle \sim 700$ Myr

**Note:** re-energisation does not depend on the details of the model like the presence of adiabatic losses or spatial/temporal changes of the magnetic field
Models

- A new population of **ultra-steep** radio sources
- A new inefficient **re-energisation** mechanism
- A **seed** population of CRe in the ICM

**Compression**
- Mach number: 1.2
- Fine tuning of ICM/shock properties
- Special geometry

**Plasma interaction**
- Turbulence in tail
- Maintained constant by ICM interaction
- Magnetic pumping
GReET
(Gently Re-Energised Tail)

Is Abell 1033 an isolated case?
No: many filamentary ultra-steep structures are being discovered in low frequency observations.

Examples of Follow Up Observations (GMRT 325 MHz)

Shimwell+ 2016
Abell 2034

LOFAR

Wilber+ 2017
Abell 1132

GMRT

Courtesy: S. Mandal (see poster)
Outline:

- CRe in clusters
- Gently Re-Energised Tails (GReET)
- Low-frequency radio surveys
Frequency: 54 MHz
Pointings: 16
Coverage: 150 sqdeg
Resolution: ~45”
Rms noise: 3-6 mJy/b
Sources: ~5000
VLSSr
74 MHz, 100 mJy/b, 75"

LoLss
54 MHz, 5 mJy/b, 45"
VLSSr
74 MHz, 100 mJy/b, 75”

LoLss
54 MHz, 5 mJy/b, 45”
192 sources in VLSSr

2692 sources in LoLss

VLSSr
74 MHz, 100 mJy/b, 75"

LoLss
54 MHz, 5 mJy/b, 45"
NVSS (1400 MHz)

ROSAT

LoLss (54 MHz)

TGSS (150 MHz)

Spidx < -1.8
LoLss (54 MHz)

ROSAT

Spidx < -1.7

NVSS (1400 MHz)

TGSS (150 MHz)
Bootes 50 MHz - best published data
Resolution: 20"
Astrometry: +/- 3"
Noise: <2 mJy/b
Flux error: <5%
3CRR LOFAR LBA survey

- 173 sources
- a total of only 48 hrs of telescope
- 8 hrs synthesis per source
- 30 beams at the same time
Conclusions

• The **ultra-low frequencies** enable the exploration of low-energy CRe and (re)acceleration mechanisms

• **Gently Re-Energise Tails** (GReETs) show the potential of this observational window

• Perturbed intra-cluster medium can re-energise relativistic particles initially injected by AGN, CRe can accumulate providing a **seed population** for merger-induced acceleration mechanisms

• **LOFAR LBA Sky Survey** (LoLss) first images are promising, HETDEX (DIE) release mid-2018