Cluster Radio Halos at the crossroads between astrophysics and cosmology in the SKA era

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Synchrotron radiation from the ICM
Relativistic electrons (protons?) and B distributed on Mpc-scales...

- ORIGIN ??
- IMPACT on thermal ICM ?? (microphysics & dynamics)

Cluster-scale radio emission

- Steep spectrum sources ($\alpha \sim 1.2-1.4$, $f(\nu) \sim \nu^{-\alpha}$)
- Low brightness
  e.g., Feretti et al. 2012, for a review

Giant Radio Halos

Giant Radio Relics

★ Syngergonars from the ICM
Relativistic electron (protons?) and B distributed on Mpc-scales...
RHs are not ubiquitous in clusters (Brunetti et al. 07, Venturi et al. 07, 08, Cassano et al. 08) and are always found in merging clusters (recently confirmed in radio-SZ, Cassano et al. 2013)

RH probe the dissipation of kin energy in the DM-driven merger events into CRs and B
Observational Milestones: RH & cluster-cluster merger

RHs are not ubiquitous in clusters (Brunetti et al. 07, Venturi et al. 07, 08, Cassano et al. 08) and are always found in merging clusters (recently confirmed in radio-SZ, Cassano et al. 2013)

RH probe the dissipation of kin energy in the DM-driven merger events into CRs and B

The prevalent current view is that RH trace turbulent regions in the ICM where particles are trapped and accelerated during mergers, an additional (non-dominant) contribution can be provided by secondary particles injected by p-p collisions in the ICM (Brunetti & Jones 2014, for a review)
SKA1 would allow to explore low massive clusters ($M_{500} \sim 10^{14} M_\odot$) that are $\sim 100+$ times more numerous than clusters observable by present facilities.

Going to smaller masses does not necessarily imply that more (much more) RHs will be found! This depends on the occurrence of RH in smaller systems (MODELS!)
Basic theoretical expectations (turbulence)
Cassano & Brunetti 05; Cassano et al. 2006, 2010, 2012

Radio Halos with very steep spectrum ($\alpha > 1.5$, USSRH) in the classical radio band must exist (Cassano et al. 06, Brunetti et al. 2008, Nature 455, 944)

★ RH common in massive-merging GCs
★ RH rare in less massive-merging GC
★ RH occurrence depends on observing frequency
Expectations from a two population scenario

2-Population model:

- RHs in turbulent clusters (including ultra-steep...)

- Off-state/hadronically induced emission in relaxed systems

THEORETICAL MOTIVATION
Calculations based on $CR_p + CR_e + MHD$ turbulence
(Brunetti & Blasi 05, Brunetti & Lazarian 11)
Luminosity functions of RHs at low and high frequency from Monte Carlo simulations (see Cassano et al. 2010, 2012)

Complex population of RH: depending on freq. and on sensitivity of Obs.

USSRH show up at low frequency and are peaked at low radio power

High sensitivity Obs. would find off-state hadronic halos and USSRH
Luminosity functions of RHs at low and high frequency

Cassano et al. in prep.

\[ \nu_0 = 120 \text{ MHz} \]

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<table>
<thead>
<tr>
<th>configurations</th>
<th>rms (\mu Jy/beam)</th>
<th>\theta_p (arcsec)</th>
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<tbody>
<tr>
<td>LOFAR (120 MHz)</td>
<td>400</td>
<td>25</td>
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<tr>
<td>SKA1-low (120 MHz)</td>
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<td>10</td>
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<tr>
<td>EMU (1.4 GHz)</td>
<td>13</td>
<td>15</td>
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<tr>
<td>SKA1-SUR (1.4 GHz)</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
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- LOFAR and ASKAP (EMU) => mainly turbulent halos in merging GCs
- SKA1-low and SKA1-sur => off-state (hadronic) halos in relaxed GCs
- LOFAR and SKA1-low => USSRH
- SKA1-low => bulk of USSRH

The detection of USSRRH would be a powerful test for models
SKA-LOW and SKA-SUR could detect up to 2600 and 750 RH, respectively, on 3π sr out to z~0.6.

SKA-LOW and SKA-SUR could detect ~7 and ~3 times more RH than LOFAR and EMU, respectively

SKA-LOW is more efficient in the detection of RH than SKA-SUR
- better sensitivity to the extended emission
- presence of USSRH
**RHs to detect galaxy clusters in radio survey**

Cassano et al. in prep.

**SKA1-low surveys** (120-150 MHz, rms=20 μJy/beam)
- detection of clusters with RH (and off-state RH) up to high z
- competitive with X-ray and SZ-survey in the detection of galaxy clusters
- SKA1 will provide fundamental complementary info. to the next-generation of multi-wavelength surveys (DES, LSST, Euclid, eROSITA)
Conclusions

★ RHs are not ubiquitous in galaxy clusters and are connected with cluster-cluster merger

current view: RH trace turbulent regions in the ICM where particles are trapped and accelerated during mergers

SKA1 promise a good improvement in the science achievements with respect to pathfinders and precursors (LOFAR, ASKAP …)

★ Both SKA1-sur and low surveys could detect, for the first time, off-state (hadronic) halos in relaxed GC

★ SKA1-low would be extremely powerful in the detection of USSRH, providing a powerful test of models

★ SKA1-LOW and SKA1-SUR could detect up to 2600 and 750 RH, respectively, on $3\pi$ sr out to $z \sim 0.6$.

★ SKA1-low surveys ⇒ use RHs to detect galaxy clusters up to high-$z$, would be competitive with SZ and X-ray cluster surveys