ON THE POLARIZATION OF THE OBSERVED EMISSION FROM RADIO RELICS

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Radio Relics (see R1 in plot)

- elongated $\sim Mpc$
- at cluster periphery
- synchrotron radiation
  - $P_{\text{radio}} \approx 10^{23} - 10^{25} \text{ W Hz}^{-1}$
  - highly polarized
- located at shocks (X-ray)
  - $\Rightarrow$ shock acceleration
- future observations (e.g. Lofar, SKA) are expected to detect few 100s of radio relics

Pearce et al. 2017
Abell 2744

contours: radio
blue: X-ray
colors: optical
**Polarization of Radio Relics**

- at least 21 studied in polarization
- avg. degree of polarization \( \sim 10 – 30\% \)
- local degree of polarization up to \( \sim 70\% \) (e.g. Abell 1240 by Bonafede et al 2009)
- different pattern of E-vectors

⇒ Are we able to reproduce the observed polarization of radio relics in simulations?
Simulations with ENZO (see Vazza et al 2018)

- solves for dark matter (N-body)
- and baryonic matter (MHD-Eq.)
- 8 levels of AMR $dx \approx 4 \text{kpc}$ (use 8 kpc)

$m \sim 10^{15} \, M_\odot$

$\langle M \rangle \approx 2.3 - 2.4$

$P_{\text{radio}} \approx 10^{31} \, \text{erg/s/Hz}$

integrated polarized emission from Burn et al. 1966

$$P_{\text{Burn}}(\lambda^2) = \frac{\int P_{\text{radio}} \pi \exp \left(2i \left(\beta + RMS\lambda^2\right)\right) \, d\text{los}}{\int P_{\text{radio}} \, d\text{los}}$$
Ingredients

emission per volume from Hoeft et al. 2007

Fractional Polarization

Mach number

magnetic fields
**Simulation**

\[ \langle RM \rangle = -3.86, \quad \sigma_{RM} = 127.87 \]

\[ \text{int.: } \langle RM \rangle = 0.17, \quad \sigma_{RM} = 1.54 \]

**Observation**

Toothbrush: \(-60 \text{ to } +110 \text{ rad/m}^2\)

COMA: \(-30 \text{ to } +26 \text{ rad/m}^2\)

strong local gradients
Degree of Polarization

The degree of polarization in general is too high, but without beam depolarization.
Mock Observations (incl. Beam Depolarization)

- **VLA, 1.4 GHz, z = 0.4, 0.5:**
  - 22-39%

- **LoTSS, 0.15 GHz, z = 0.4, 0.5:**
  - 6-8%

- **Effelsberg, 4.85 GHz, z = 0.1, 0.2:**
  - 3-16%
Observed Structures

rel_x1, at $\nu = 4.85$ GHz

500 kpc
filamentary structures in observations are most likely projection effects
Strong E-Vector Alignment

⇒ due to laminar magnetic field
Depolarized Brush

- similar to the unpolarized brush in the Toothbrush
- accreted sub-clump
  ⇒ no more laminar magnetic field

rel_xy, at $\nu = 0.074$ GHz

$500$ kpc

$\log_{10}(\rho \ [g/cm^3])$

-26.5
-27.0
-27.5
-28.0
-28.5
# Polarized Relics in the Literature

<table>
<thead>
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<th>relic</th>
<th>reference</th>
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<tr>
<td>1RXS J0603.3+4214</td>
<td>van Weeren et al 2012, 2016, Kierdorf et al 2017</td>
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<tr>
<td>Abell 1240 north &amp; south</td>
<td>Hoang et al 2018, Bonafede et al 2009</td>
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<td>Abell 2256</td>
<td>Clark &amp; Ensslin et al 2006</td>
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<td>Abell 2345-1 &amp; -2</td>
<td>Bonafede et al 2009</td>
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<td>Abell 2744</td>
<td>Pearce et al 2017</td>
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<td>Abell 3411</td>
<td>van Weeren et al 2013</td>
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<td>Abell 548b</td>
<td>Feretti et al 2006</td>
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<td>Abell 746</td>
<td>van Weeren et al 2011</td>
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<td>Bullet</td>
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<td>CIZA J2242.8+5301</td>
<td>van Weeren et al 2010, Kierdorf et al 2017</td>
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<tr>
<td>El Gordo east &amp; west</td>
<td>Lindner et al 2014</td>
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<td>MACS J0717+3745</td>
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<tr>
<td>MACS J1149.5+2223</td>
<td>Bonafede et al 2012</td>
</tr>
<tr>
<td>MACS J1752.0+4440</td>
<td>Bonafede et al 2012</td>
</tr>
<tr>
<td>PSZ1 G096.89+24.17</td>
<td>de Gasperin et al 2014</td>
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<tr>
<td>PSZ1 G108.18-11.53</td>
<td>de Gasperin et al 2015</td>
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<tr>
<td>ZwCl 0008.8+5215</td>
<td>van Weeren et al 2011, Kierdorf et al 2017</td>
</tr>
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Conclusion

- radio relics are
  - highly polarized sources found at the periphery of galaxy clusters
  - synchrotron radiation with $P_{\text{radio}} \approx 10^{23} - 10^{25}$ W Hz$^{-1}$
- in simulations:
  - the average Rotation Measure $RM$ and intrinsic degree of polarization are mostly higher than in observations
    ⇒ correlation lengths (still) too large ⇒ need more resolution
    ⇒ beam depolarization reduces the high degree of polarization
  - reproduce observed structures
    ⇒ filamentary structures ⇒ projection effects
    ⇒ locally strong aligned E-vectors ⇒ laminar magnetic field
    ⇒ locally weak align E-vectors ⇒ more disturbed medium in front of the relic
  - simulations help to understand current and future radio observations, but we need to increase the number of simulated objects to build statistics
Thank you for your attention!