Searching for X-ray shock fronts at radio relic edges in PLCKESZ G200.9-28.2, Abell 2345 with Chandra

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Radio relics

Corresponding X-ray feature?

Elongated morphology

“Sausage” relic

van Weeren+ 2010

Steepening of spectrum

Polarization
Radio relics

“Toothbrush” relic
van Weeren+ 2010

Abell 2744
Pearce+ 2017
Radio relics

... and more.

Things in common:

- Elongated morphology
- Large linear size
- Highly polarized
- Spectral index steepens

“Bullet” cluster
Shimwell+ 2015
Radio relics

What happens at shocks?

- **Adiabatic compression increases synchrotron brightness:**
  - $I \sim n B^2 \sim n^2$ (radio spectrum unchanged)

- **Diffusive shock acceleration (DSA) of electrons:**
  - **From thermal pool?**
    - Low acceleration efficiency; needs strong shock
      (compare with supernovae remnant $M \sim 10^3$)
    - Radio spectral index

- **From pre-existing fossil population?**
  - Seed electrons required (aka fossil electrons)
  - Different radio spectra

\[
\alpha = \frac{M^2 + 1}{M^2 - 1}
\]

Stronger shock, flatter spectrum
PLCKESZ G200.9-28.2

$z = 0.22$

Discovered by SZ, confirmed with XMM
(Planck Collaboration I, 2012)
Some edge feature (maybe a cold front)

Radio relic

1 Mpc radius

SZ centroid

kT ~ 5 keV

Marginal difference between N and S subclusters
Shape, and spectral index steepening, consistent with shock seen edge-on. Very offset SZ centroid also suggests presence of shock heated gas.
- Use Rankine-Hugoniot jump conditions at the shock to calculate Mach number

\[
\frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{(\gamma + 1)M_1^2}{(\gamma - 1)M_1^2 + 2}
\]

Model:

\[
n = n_0 \left( \frac{r}{r_{edge}} \right)^{\alpha_1}, \quad r \leq r_{edge}
\]

\[
n = \left( \frac{n_0}{\chi} \right) \left( \frac{r}{r_{edge}} \right)^{\alpha_2}, \quad r > r_{edge}
\]

Density just behind edge

Density jump position

\[
S_X = A \int_{los} [n(r)]^2 dV + S_{bg}
\]

ACIS background 3% error (90% confidence)
- Use Rankine-Hugoniot jump conditions at the shock to calculate Mach number

\[ \frac{\rho_2}{\rho_1} = \frac{u_1}{u_2} = \frac{(\gamma + 1)M_1^2}{(\gamma - 1)M_1^2 + 2} \]

Model:

\[ \log n(r) \]

- slope \( a_1 \)
- slope \( a_2 \)

\[ n_0 \]

- \( r_{edge} \)
- \( \log r \)

\[ S_X = A \int_{lobs} [n(r)]^2 dV + S_{bg} \]

ACIS background
3% error (90% confidence)
This is what \( M = 2.4 \) looks like

Abell 520

Integrated spectral index \( 1.21 \pm 0.15 \)
Requires \( M > 2.6 \)

\[
M^2 = \frac{\alpha + 1}{\alpha - 1}
\]

Kale+ 2017

\( 1 \text{ Mpc} \)

Abell 520

This is what \( M = 2.4 \) looks like
Integrated spectral index $1.21 \pm 0.15$
Requires $M > 2.6$
90% upper limit
\[ x = 2.00, \ M = 1.7 \]
95% — \[ M = 1.9 \]

Edge position is fixed

If allowed to be free, there is a preference for a model of a single power law profile truncated where SB falls below background.
Samples from MCMC
Radio spectral index requires $M > 2.6$ shock for DSA from thermal

- X-ray surface brightness rule this out, suggesting a weak shock
- Re-acceleration of fossil electrons can do this

PLCKESZ G200.9-28.2’s radio relic

Radio galaxy — a source of fossil electrons for the re-acceleration scenario, potentially the origin of the relic electrons here

Kale+ 2017
Abell 2345

Pending one last observation