Constraining CRs in galaxy Clusters using Radio Halos and Simulations

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Why Radio Haloes ?

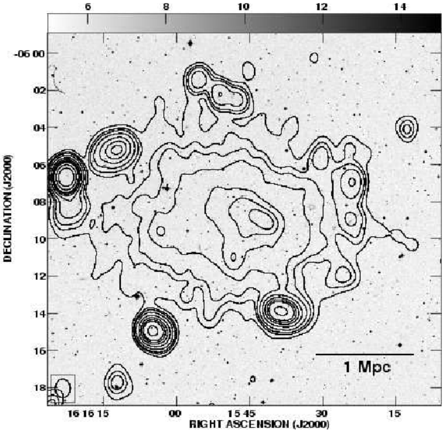
Large scale diffuse radio emission in clusters.
Power Law Spectrum,

$\Rightarrow$ *Synchrotron Emission*

Models for Radio Haloes require

- CR electrons
- Magnetic fields

Use simulations to study Magnetic Fields and constrain CRs.



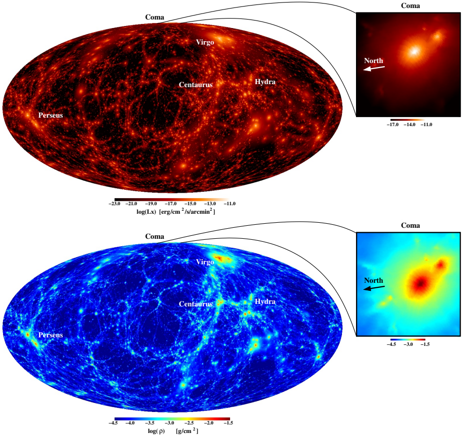
(Ferreti et al. '04) A2163,z=0.2 @ 1.4GHz

Magnetic Fields from Galactic Outflows

(Donnert, et al. 2010)

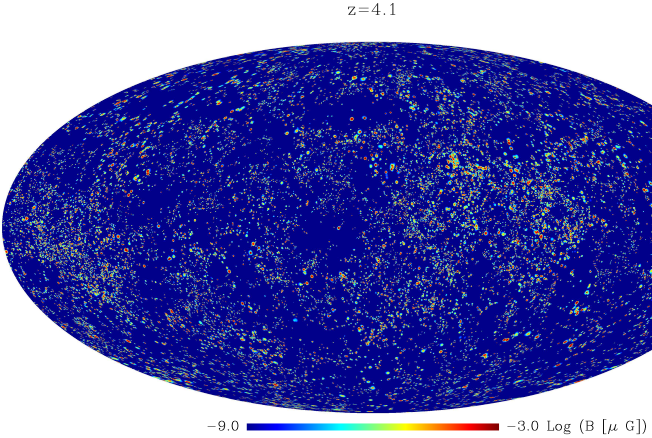
- MHD-SPH Code GADGET (Springel+ 05, Dolag+ 09)
- Constrained Initial Conditions (Mathis 02)
- Semianalytic Model for Magnetic Fields in galactic outflows (Bertone 05)
- Instantaneous Magnetic Field Seeding by galactic winds at $z = 4$

Obtain Realistic Cluster fields



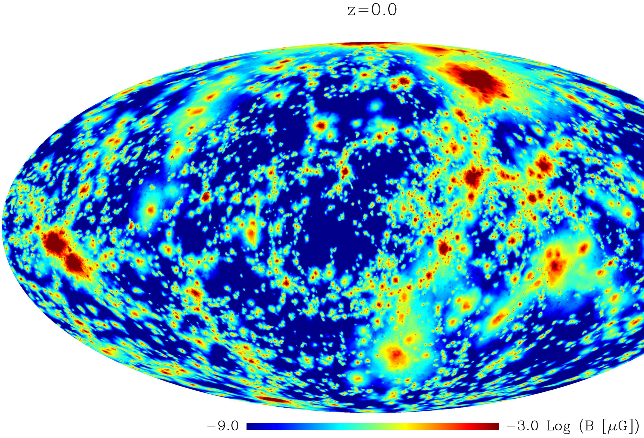
Field Evolution

(Donnert, et al. 2009)



Field Evolution

(Donnert, et al. 2009)



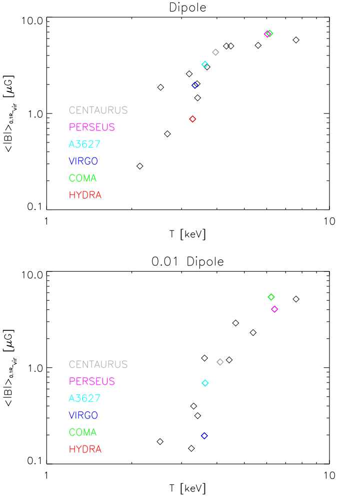
Different Field Models

(Donnert, et al. 2009)

- Seeding strength varied by factor 100 rel. to M82.
- Seeded halo mass $5 \times 10^8 - 10^{10} M_{sol}$.
- Strong seeding models show saturation in large clusters.

  MF suppresses turbulent motions & amplification.
- All models produce μG MF in the largest clusters.

  Amplification by structure formation very efficient.

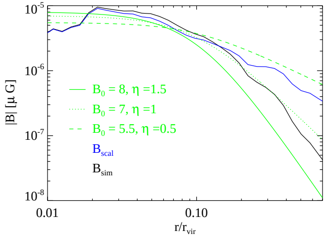


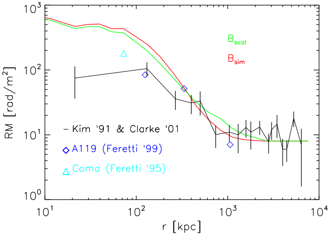
Magnetic Field: Radial Profiles

(Donnert, et al. 2009)

- Comparison with observed MF profile in Coma, derived from 5 different RM sources (Bonafede et al. 08)
- Field follows density : $|\vec{B}| \propto \rho$
- Comparison 16 largest clusters with sample of Abell Clusters in RM.

No additional seeding mechanism needed to explain current observations



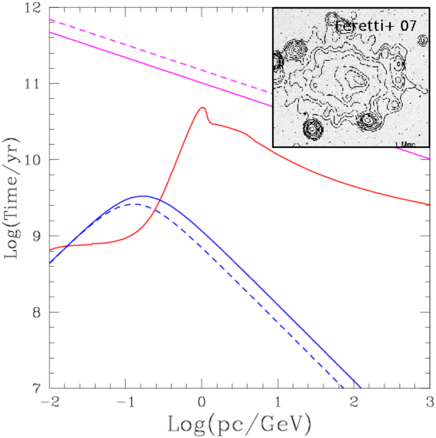


Giant Radio Haloes: Secondary Models

(Donnert, et al. 2010)

Problem :

- CRe injected locally,
  cooling time $\ll$ *diffusion time*
- Secondary Model: Global CRe injection via CRp scattering.



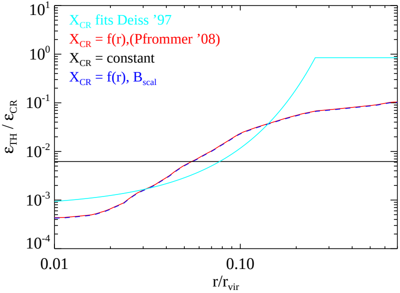
(Blasi et al. 07)

Giant Radio Haloes: Secondary Models

(Donnert, et al. 2010)

Problem :

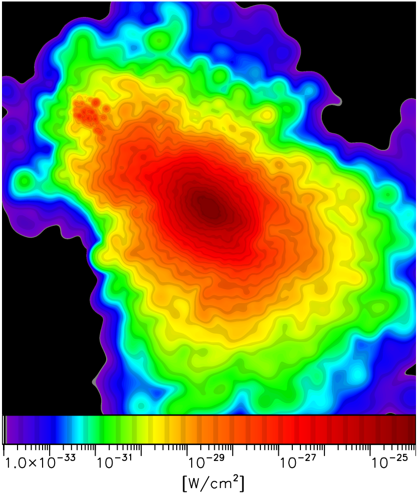
- CRe injected locally,
  cooling time $\ll$ *diffusion time*
- Secondary Model: Global CRe injection via CRp scattering.
- Assume $\epsilon_{\mathrm{CRp}} = X_{\mathrm{CR}}\epsilon_{\mathrm{Thermal}}$
- Vary spatial distribution
  - Flat
  - Motivated from simulations (Pfrommer et al. 08)

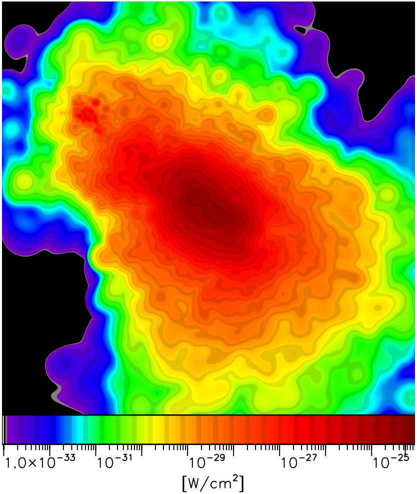


How do these models compare with observations using simulations ?

A Simulated Radio Halo

(Donnert, et al. 2010)



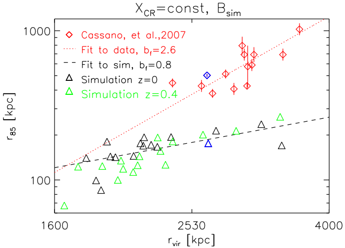


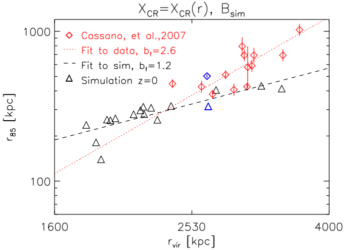
Self-Similarity

(Donnert, et al. 2010b)

- Observed Radio Haloes break self-similarity (Cassano+ 07), $R_{\mathrm{Halo}} \propto R_{\mathrm{Vir}}^{2.6}$
- Simulated hadronic haloes *follow* self-similarity.
- Flat model gives halo sizes too small - increasing model better.

Scaling with thermal properties and size problematic in Secondary models



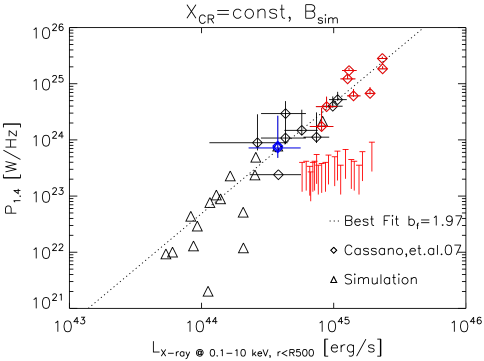


Cluster Sample: Bimodality

(Donnert, et al. 2010b)

- Only 30 % of large clusters host a giant radio halo (Venturi 08).
  $\Rightarrow$ *Bimodality* observed
- Radio Haloes always observed in merging clusters.
- CR protons accumulate in **every** large cluster.

A priori secondary models do not predict the observed bimodality.

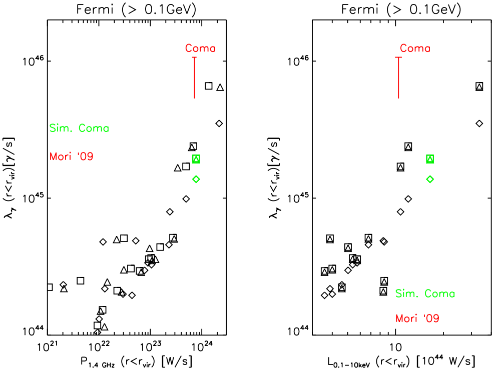


Gamma-Ray emission

(Donnert, et al. 2010b)

- CRp - proton collisions produce γ-rays.
- *Direct* probe of CRp population possible !
- So Far FERMI satellite did not report detections (Mori 09).
- Most extreme models for Coma are expected to be excluded soon.

FERMI will clarify in the next years



Secondary Models: Conclusion

(Donnert, et al. 2010)

Secondary models are challenged by observations:

- Break in self-similarity not expected.
- Radial profiles too steep - Haloes to small.
- Observed bimodality not expected by CR model alone.
- Correct sizes not achievable with physical CRp energy densities (not shown).
- Spectral break not expected (not shown).

We therefore conclude that Secondary models alone are disfavoured by observations.

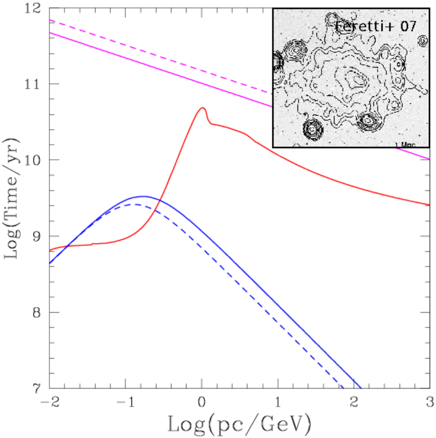
Turbulence & Reacceleration model

preliminary work

- CR electrons accumulate at $\approx 100\,\mathrm{MeV}$.
- Coupling to magnetosonic waves. (Cassano & Brunetti 06)
- Merger induced Reacceleration explains Bimodality and spectral break.

Estimate turbulence in simulation.

Solve Fokker-Planck - more complex spectra than power-laws.

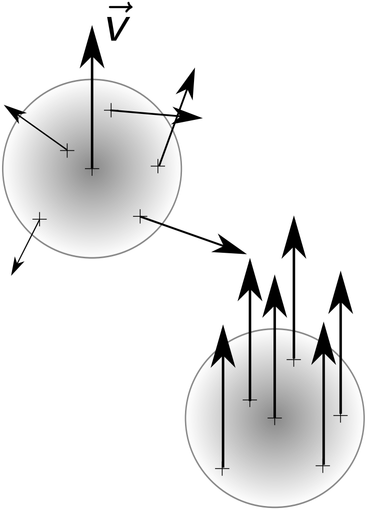


(Blasi et.al.2007)

Local Turbulent Velocities in SPH Simulations

preliminary work

- SPH - mass discretisation of flow - Smoothing of N neigbours inside smoothing length Hsml
- Local turbulent velocity - RMS of velocity
- Extrapolate to relevant scales :
  - Injection scale $\approx 300\mathrm{kpc}$ (Vazza 2009)
  - Damping scale $\approx 0.3\mathrm{kpc}$ (Brunetti & Lazarian 2007)

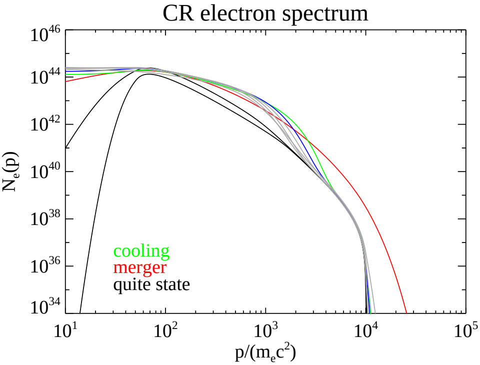


Spectra from Acceleration

preliminary work

- CRe energies of 1-100 GeV visible for $B \approx 1 \mu G$ and $\nu = 1.4 GHz$
- Number density increases during major merger - bimodality
- Lifetime around 0.1 Gyr - explains bimodality

Promising model for radio haloes



Low resolution simulation, turbulence not sufficiently resolved

Thank You !