# Radio Haloes in Simulated Galaxy Clusters


Julius Donnert

Supervisors:
Klaus Dolag (MPA)
Gianfranco Brunetti (IRA)


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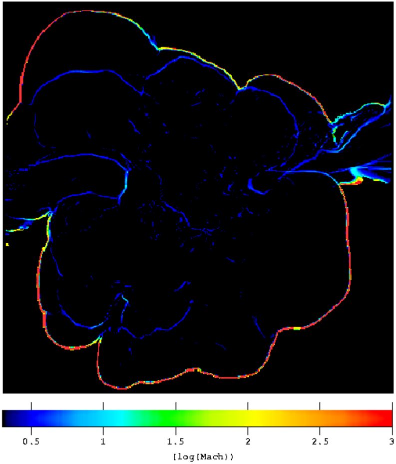
# Why Radio Haloes ?

Models for Radio Haloes require

- Magnetic fields
- CR electrons and protons
- Turbulence
- Shocks

e.g. Shocks in Clusters inject CRs in the ICM.
Hadronic models allow constrains on the injection efficiency

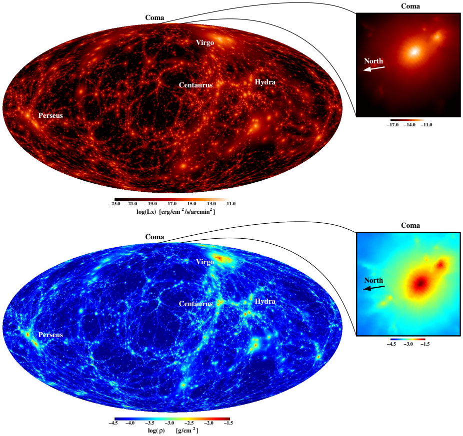



Vazza et.al. 2009

# Magnetic Fields from Galactic Outflows

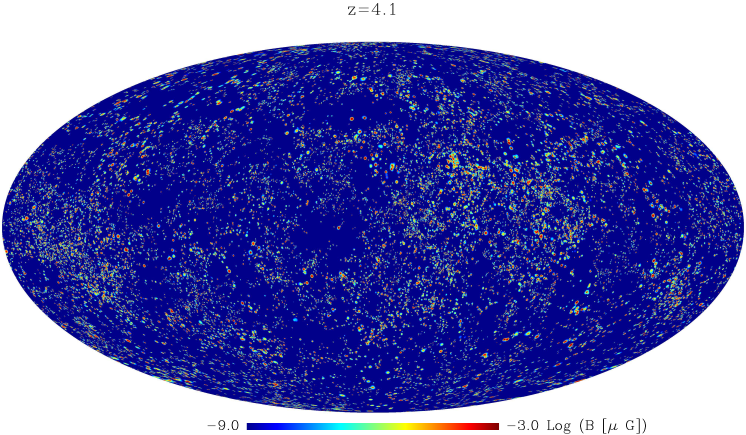
(Donnert, et.al. 2008)

- MHD-SPH Code GADGET (Springel et.al. 05, Dolag et.al. 09)
- Constrained Initial Conditions (Mathis 02)
- Semianalytic Model for Magnetic Fields in galactic outflows (Bertone 05)
- Magnetic Field Seeding in Cosmological MHD Simulations
  $\Rightarrow$ **Obtain Realistic Cluster fields**



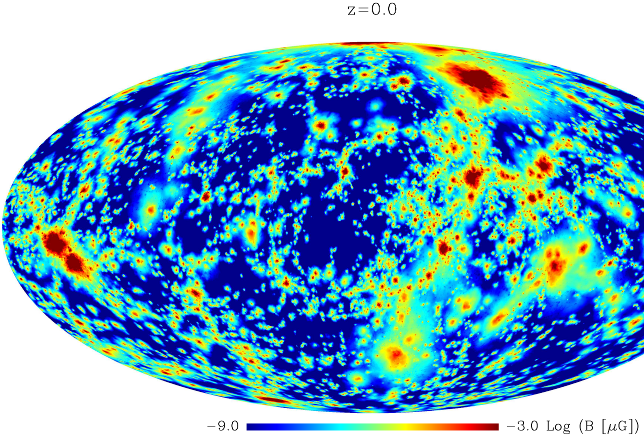
# Field Evolution

(Donnert, et.al. 2008)



# Field Evolution

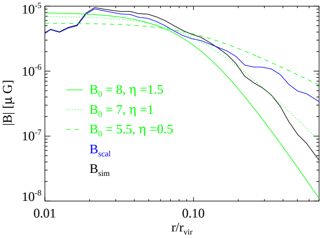
(Donnert, et.al. 2008)

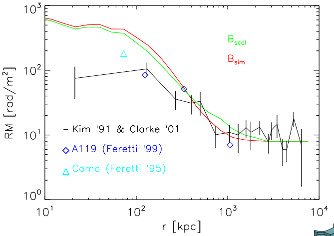


# Magnetic Field: Radial Profiles

(Donnert, et.al. 2008)

- Comparison with observed MF profile in Coma, derived from 5 different RM sources (Bonafede et. al. 2008)
- Field follows density : $\vec{B} \propto \rho$
- Comparison 16 largest clusters with sample of Abell Clusters in RM.
- **Use realistic fields to compare Radio Emission with observations**

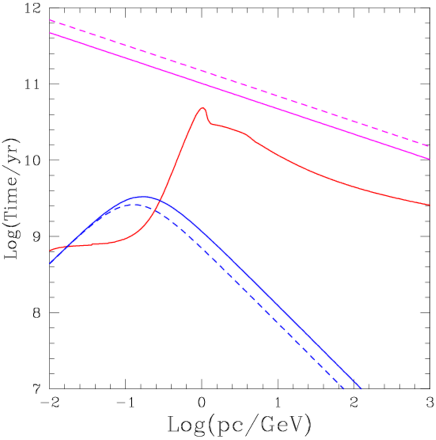


# Giant Radio Haloes: Secondary Models

(Donnert, et.al. 2009)

- Secondary Model: CRe injection via CRp scattering with thermal protons.
- CRe density is fraction of thermal density



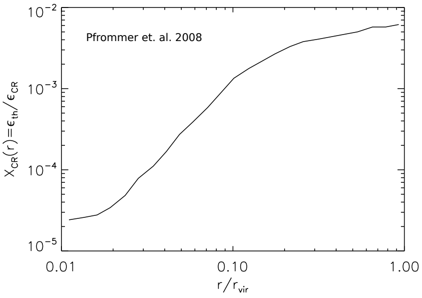

(Blasi et.al.2007)

# Giant Radio Haloes: Secondary Models

(Donnert, et.al. 2009)

- Secondary Model: CRe injection via CRp scattering with thermal protons.
- CRe density is fraction of thermal density
- Vary spatial distribution
  - Flat
  - Motivated from simulations (Pfrommer et.al.2008)
  - Fitted to observations (Deiss 1996)

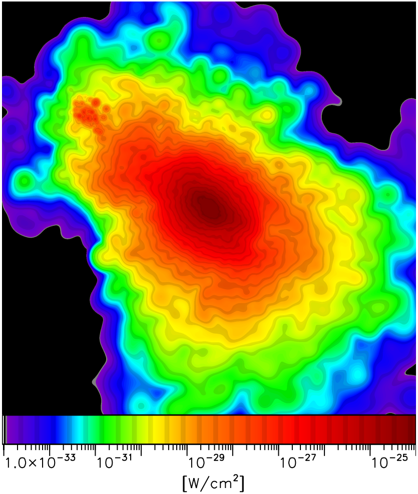
**How do these models in our simulation compare with observations?**

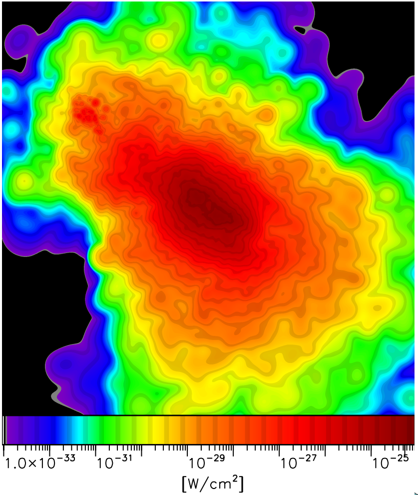



Pfrommer et.al 2008

# The Simulated Coma Radio Halo

(Donnert, et.al. 2009)

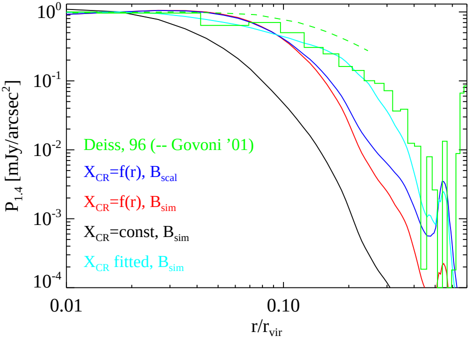


# Radial Profiles

(Donnert, et.al. 2009)

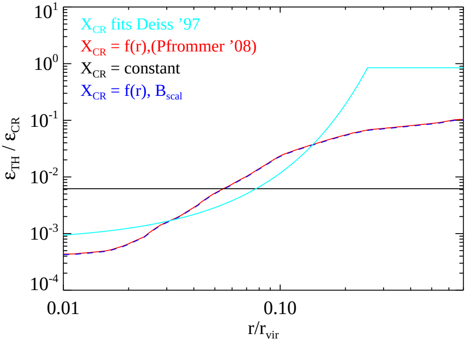
- Normalize CR relative to thermal density to fit the overall luminosity of Coma
- Both models are too small to fit the observations (black - fixed, red - scaled)
- Further fix spatial distribution to fit the radial profile (cyan)



# CR Proton Energy Density

(Donnert, et.al. 2009)

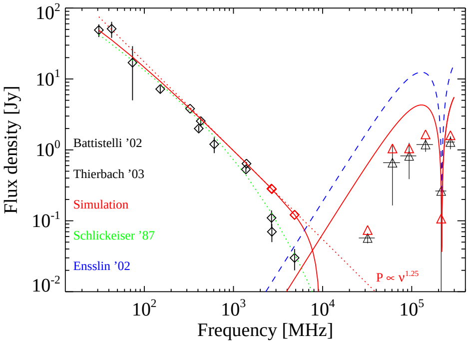
- Energy density in CR protons relative to thermal protons
- Constant model OK, spatially variing model reaches 10% at virial radius
- To fit the radial profile a hadronic model needs $> 10\%$ energy in CR protons at $r > 0.1 r_{\rm Vir}$
  $\Rightarrow$ Significant pressure contribution from CR protons, not observed



# SZ-Decrement

(Donnert, et.al. 2009)

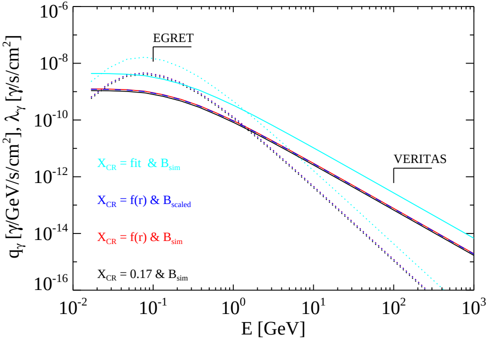
- In Coma, a spectral break at 1.4 GHz is observed
- Secondary Models predict a strict power-law at high energies
- Break due to Sunyaev-Zeldovich decrement ?
- Size of emission region important
- In Simulation : The SZ-decrement is not sufficient to explain break



# Expected Gamma-Ray emission

(Donnert, et.al. 2009)

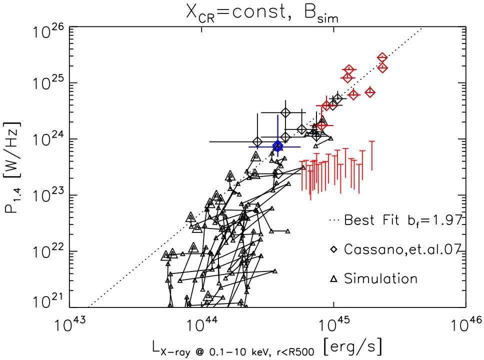
- Secondary Models can be studied best at $\gamma$-ray energies.
- Our models cannot be ruled out by current observations
- All models will be ultimately tested by the Fermi experiment (sensitivity $\approx 10^{-9} \gamma / s / cm^2$)



# Cluster Sample: Bimodality

(Donnert, et.al. in prep.)

- Observations show only a fraction of large cluster host a giant radio halo ($\approx 30\%$ (Venturi 2008)).
- Radio Haloes always observed in disturbed clusters.
- CR protons accumulate in **every** large cluster.
  $\Rightarrow$ Secondary models are not able to reproduce the observed bimodality in terms of CR population.



# Secondary Models: Conclusion

(Donnert, et.al. 2009)

Secondary models are challenged by observations:

- Radial profiles too steep - Haloes to small.
- Correct sizes not achievable with physical CRp energy densities.
- Spectral break not explainable - SZ decrement not sufficient.
- Observed bimodality not expected.

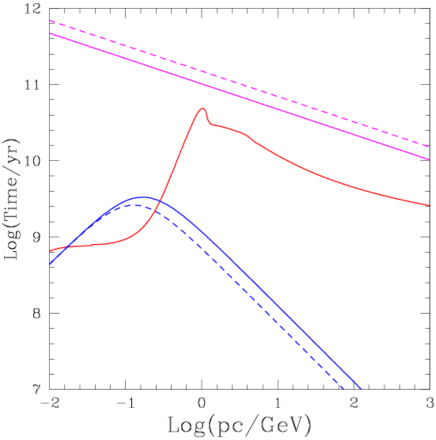
We therefore conclude that Secondary models alone are disfavoured by observations.

# 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.

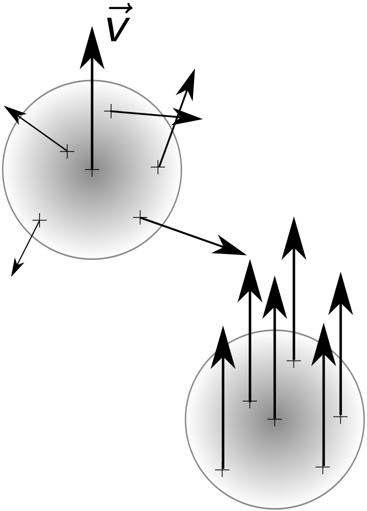
$\Rightarrow$ Estimate turbulence in simulation.
$\Rightarrow$ Solve Fokker-Planck - more complex spectra than power-laws.



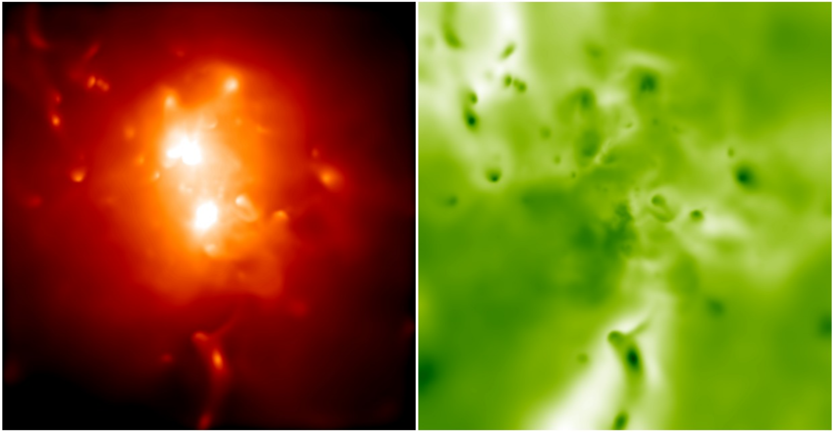

(Blasi et.al.2007)

# Local Turbulent Velocities in SPH Simulations

- 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)

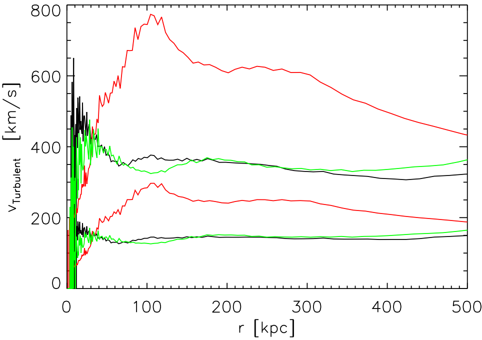


# Local Turbulent Velocity in SPH



# $v_{\mathrm{turb}}$: Radial Profiles

- Turbulent spectrum is sampled on different scales by every SPH particle.
- Upscaling to range of 300 kpc to 0.3 kpc.
- Assume Kraichnan spectrum $\propto k^{3/2}$.
- Numerics unclear at the moment.

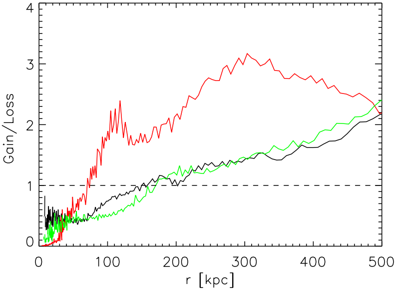


# Reacceleration Model: Gain vers. Loss Terms

- For electrons at 200 MeV
- Gain up to factor of 3 enhanced during merging phase

Next steps :

- Solve Fokker-Planck to obtain spectra
- Study numerics of turbulent velocity in SPH



Thank You !