Magnetic Field Structures in Merging Clusters of Galaxies

(Takizawa 2008 ApJ, 687, 951)

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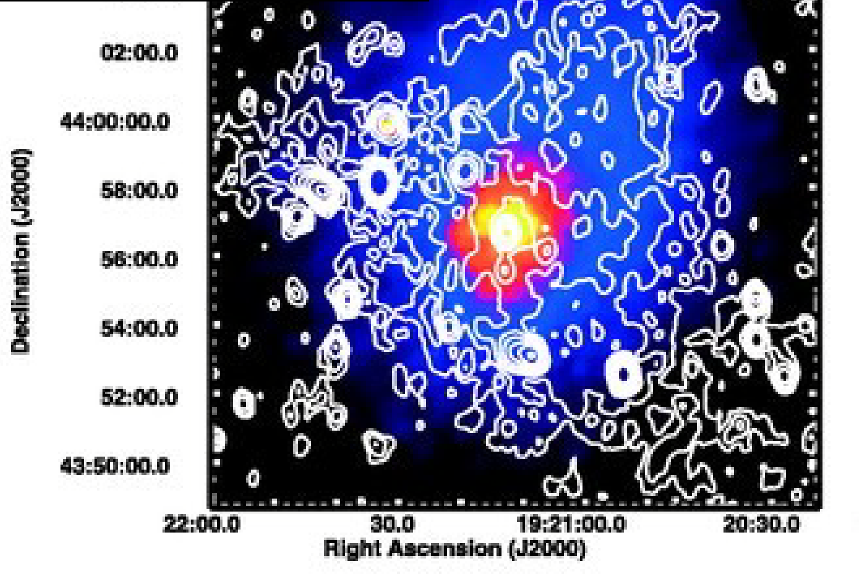
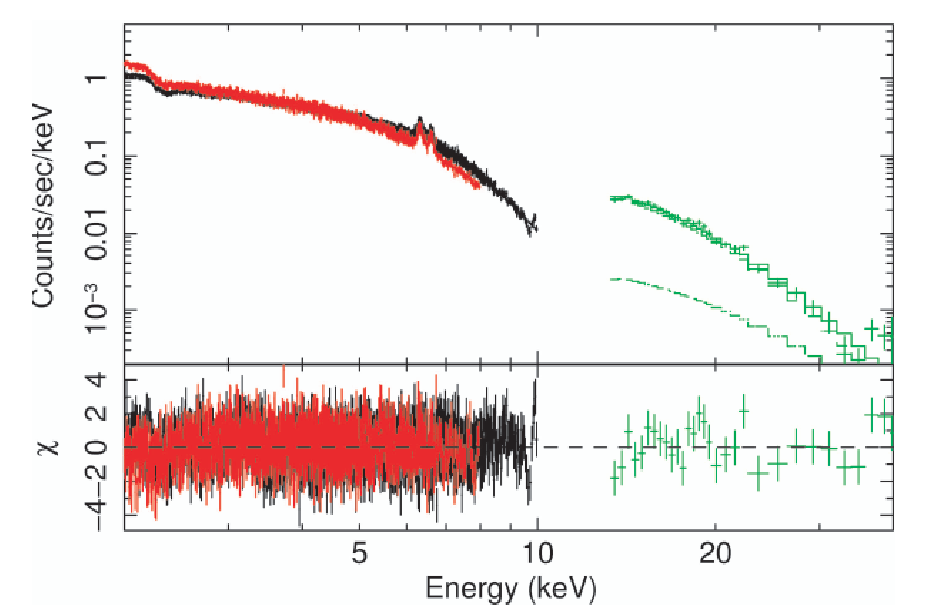
Observational Evidence of Intracluster Magnetic Field (1): Synchrotron Radio Halos/Relics

Abell 2319
Radio (contours)
X-ray (colors)
Govoni et al. 2004



Abell 2319
Wide band X-ray spectrum by Suzaku
(Sugawara, Takizawa, & Nakazawa,
PASJ in press, arXiv:0909.1358)



radio flux + upper limit of inverse Compton flux
--->B>0.2 μG (volume averaged)

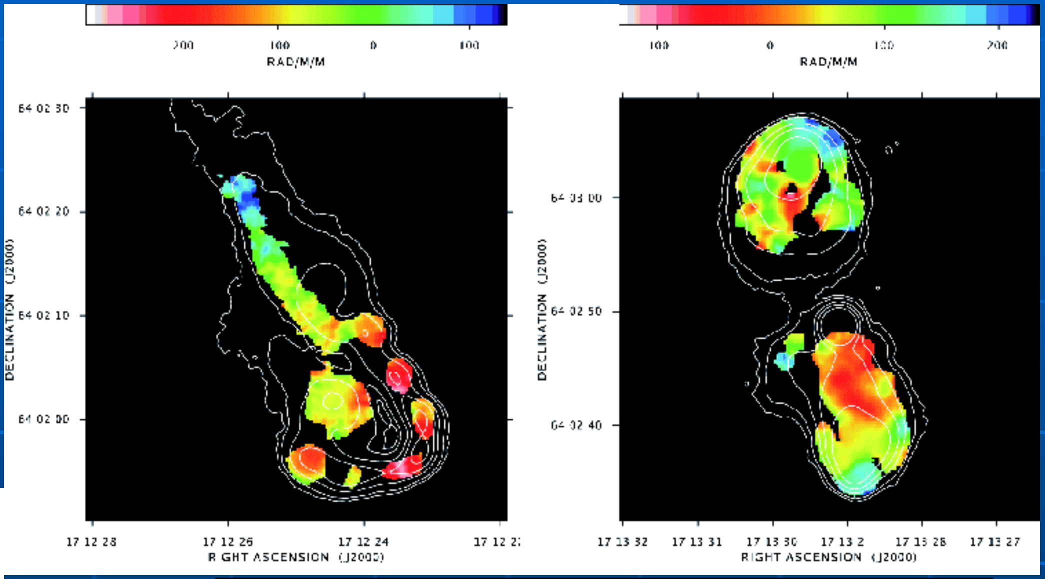
Non-thermal electrons with E_e ~ GeV and B~μG

Observational Evidence of Intracluster Magnetic Field (2): Faraday Rotation

- Polarized plains of linear polarized radio wave rotate when propagating through the magnetized plasma.

$$\Delta\theta = \frac{2\pi e^3}{m^2 c^2 \omega^2} \int_0^d n B_{\parallel}\, ds.$$

- Polarized radio sources observations in and behind clusters suggest random magnetic field structures.



Faraday rotation measure map of the radio sources in Abell 2255
Color: FRM
Contour: radio
Govoni et al. 2006

Intracluster Magnetic Field

- There is random magnetic field in the intracluster space, whose typical strength is ~ μG.
  - Shyncrotron radio halos/relics
  - Faraday rotation measure
- $P_B \sim 0.01 P_{th}$ not important? This is not the case.
  - suppression of fluid instabilities
  - suppression of heat conduction
  - Particle acceleration (magnetic turbulence, shock)
- Not only field strength, but also field structures are important.

Magnetic Field Structures and Mergers

- Cluster mergers and resultant moving substructures

  --->

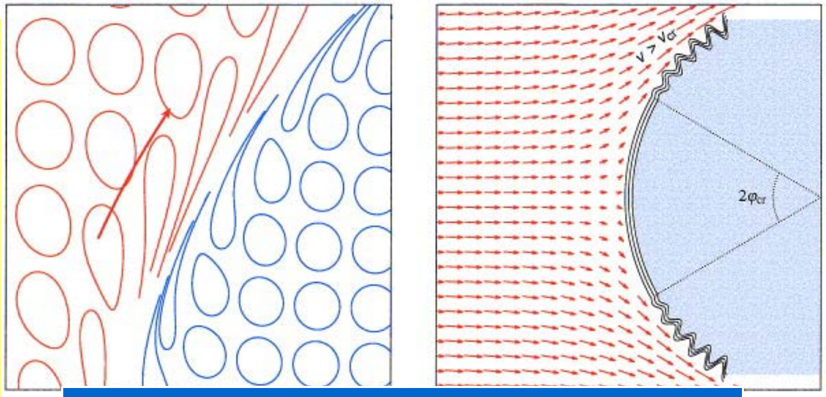
  bulk flow motions and turbulence in the ICM

  --->

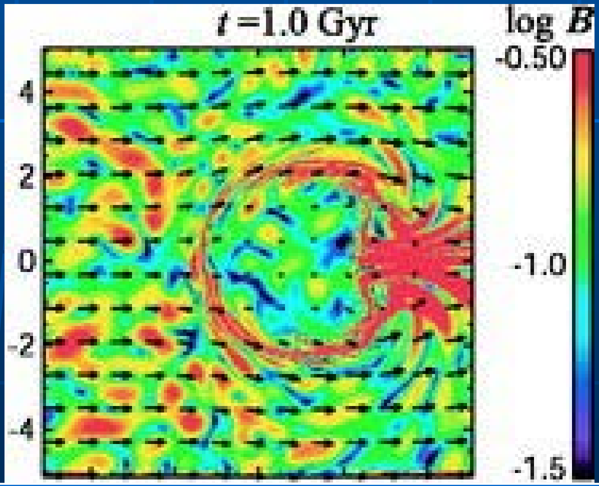
  impact on magnetic field structures

- Field structures parallel to the contact discontinuity???
- Ordered magnetic field???

- Investigate mergers of clusters with random magnetic field



Schematic view of field structure near the cold front
Vikhlinin et al. (2001)



MHD simulation of moving subclump (Asai et al. 2007)

Numerical Method

- N-body: Particle Mesh (PM) method
- MHD: Roe-like TVD (Brio&Wu 1988, Ryu & Jones 1995)
- Self-gravity: FFT with isolated boundary conditions
- Simulation Box $(9.4\text{Mpc})^3$
- Mesh number $(256)^3$
- Particle number $(128)^3$

Initial Model

- Dark matter density--NFW profile
- ICM density--β model

$$\rho_{\mathrm{DM}}(r) = \frac{\delta_c \rho_{c0}}{(r/r_s)(1 + r/r_s)^2},$$

$$\rho_{\mathrm{g}}(r) = \rho_{\mathrm{g},0}\left\{1 + \left(\frac{r}{r_{\mathrm{c}}}\right)^2\right\}^{-\frac{3}{2}\beta}$$

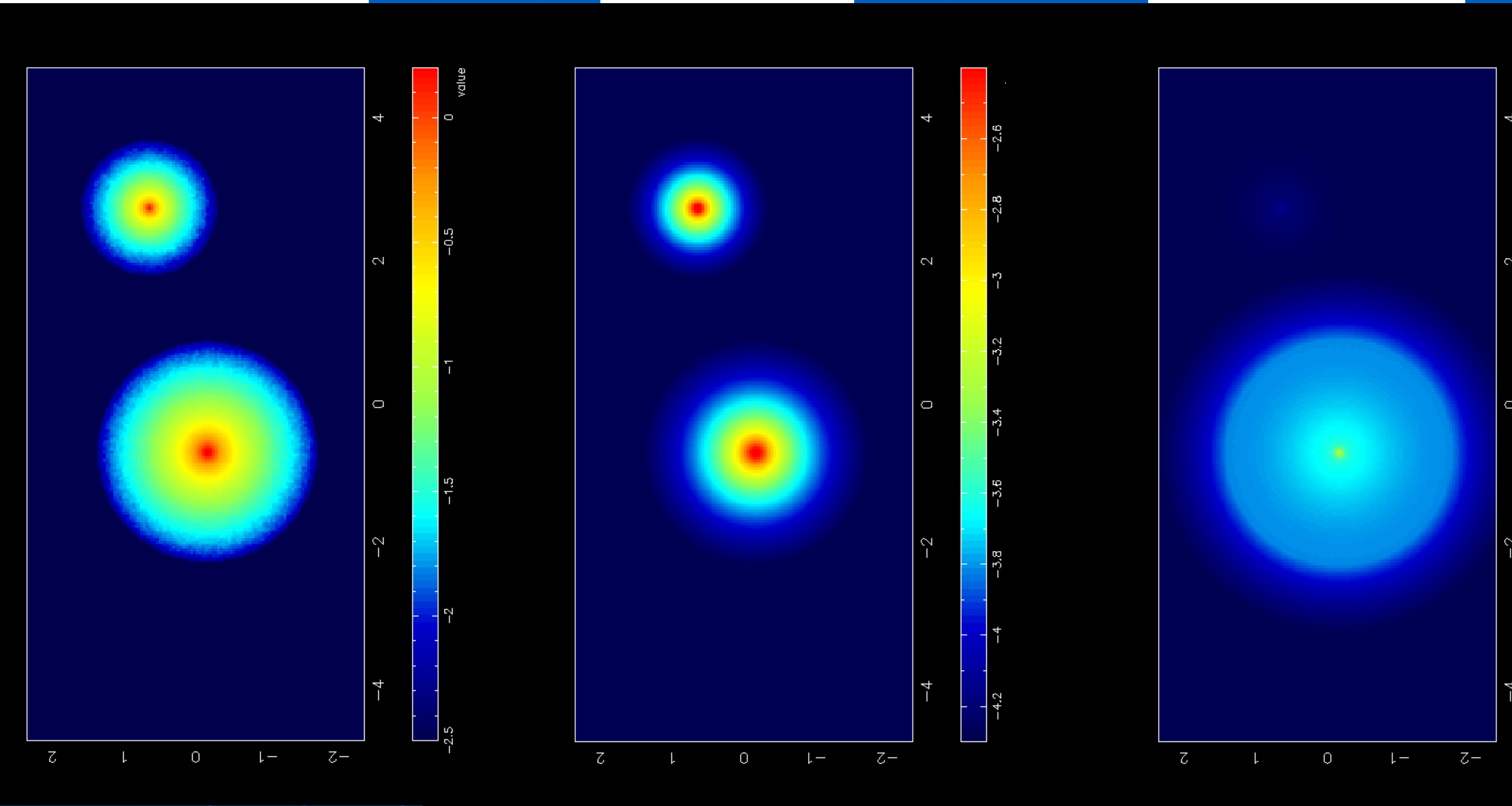
- How to generate initial random magnetic field scaled with ICM density
  - Realize random Gaussian vector potential in k-space, with $A(k) \propto k^{-(5/3)}$.
  - Inverse FFT $A(k_x,k_y,k_z) \dashrightarrow A(x,y,z)$
  - Multiply $A(x,y,z)$ by $\rho_{gas}(x,y,z)^{(2/3)}$.
  - $B = \nabla \times A$
  - Normalize B so that magnetic energy becomes 1% of thermal energy in whole cluster.

Movies

Mass density
(mostly dark matter)

Gas density

Gas temperature

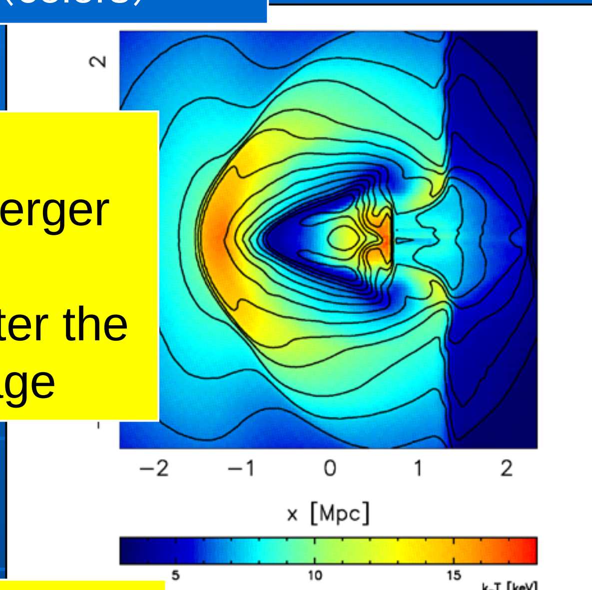


Results(1)

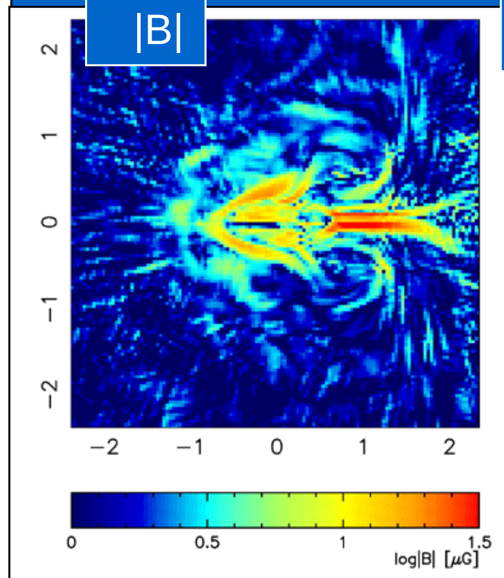
density（contours） &kT（colors）

1：4
head-on merger

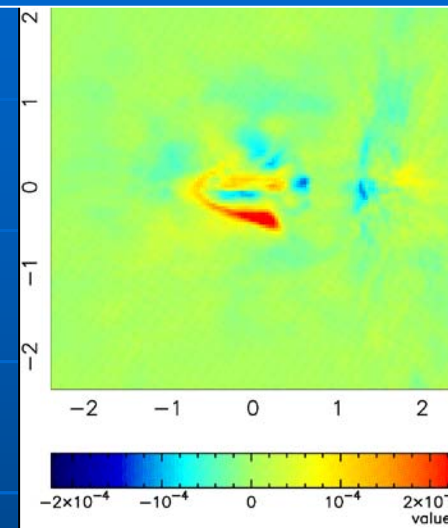
0.66Gyr after the core passage



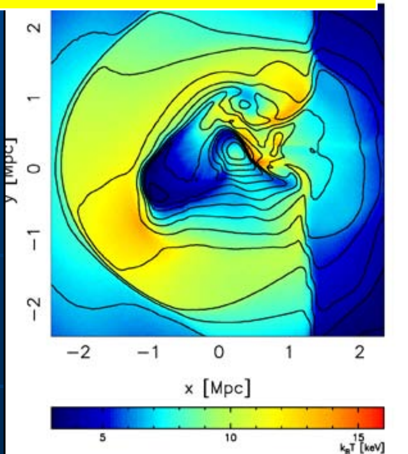
|B|

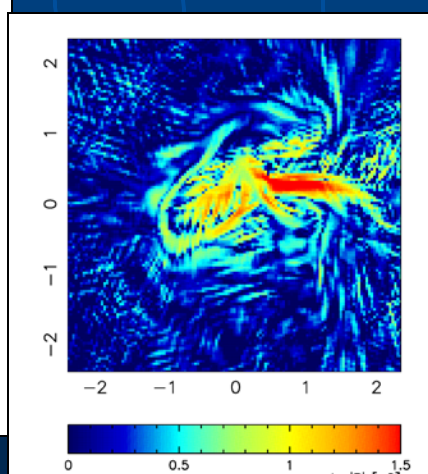


Faraday Rotation Measure
($\int n_e B_{//} dl$)



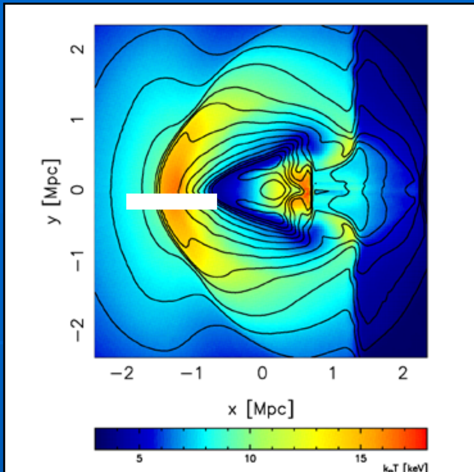
1：4
off-center merger





◆Low temperature region surrounded by the magnetic field （high Faraday Rotation Measure）
◆ordered magnetic field structure behind the small subclump
◆These structures are partly recognized in Faraday rotaion measure maps.

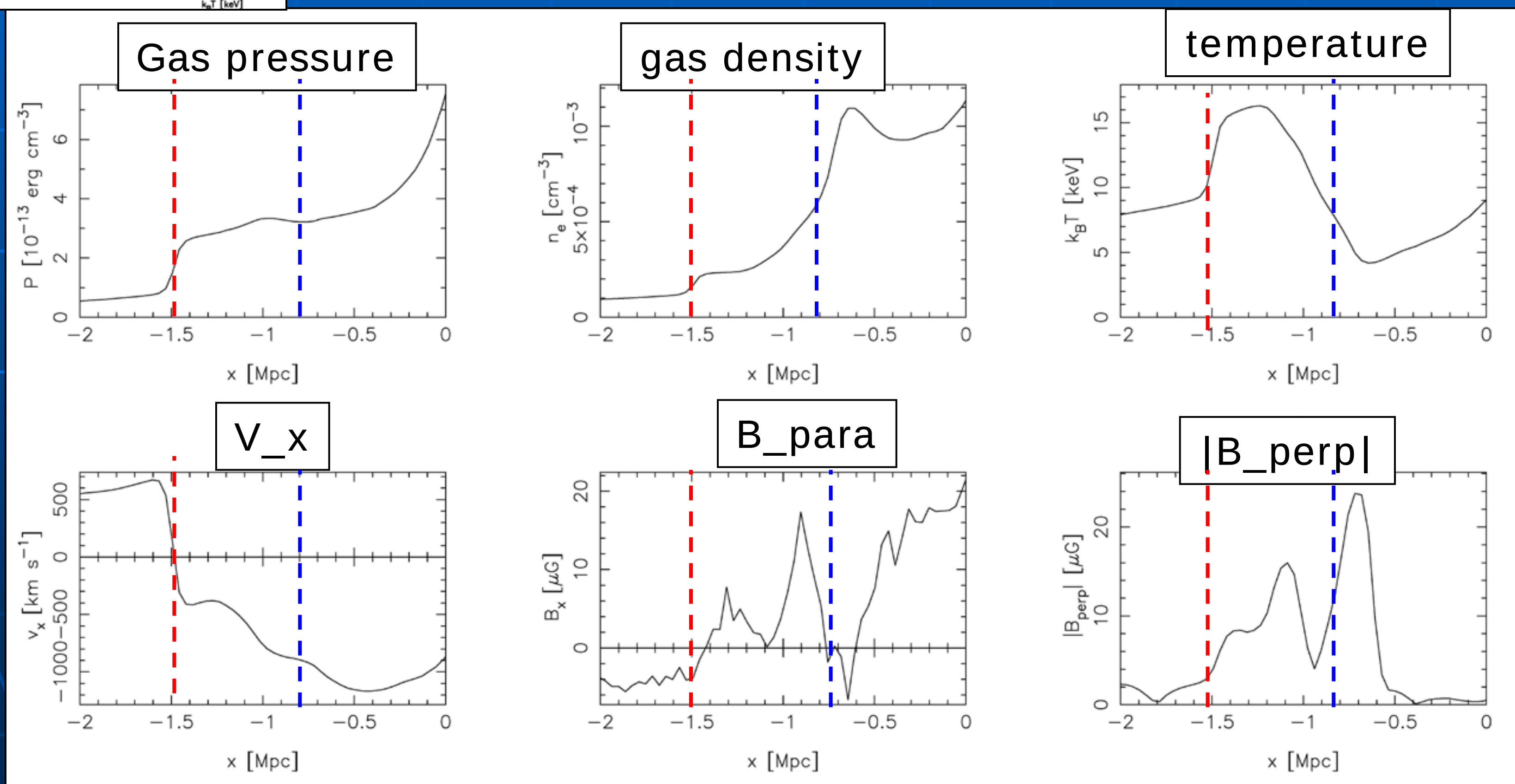
Results(2)



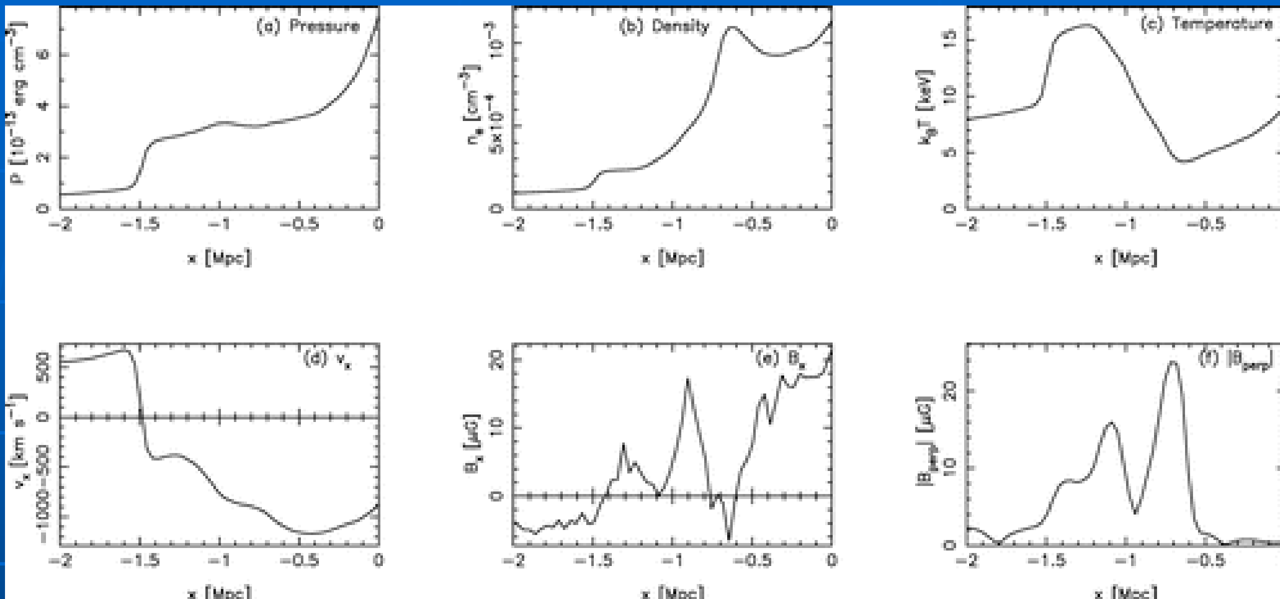
Physical quantity profiles in front of the substructure along the collision axis.

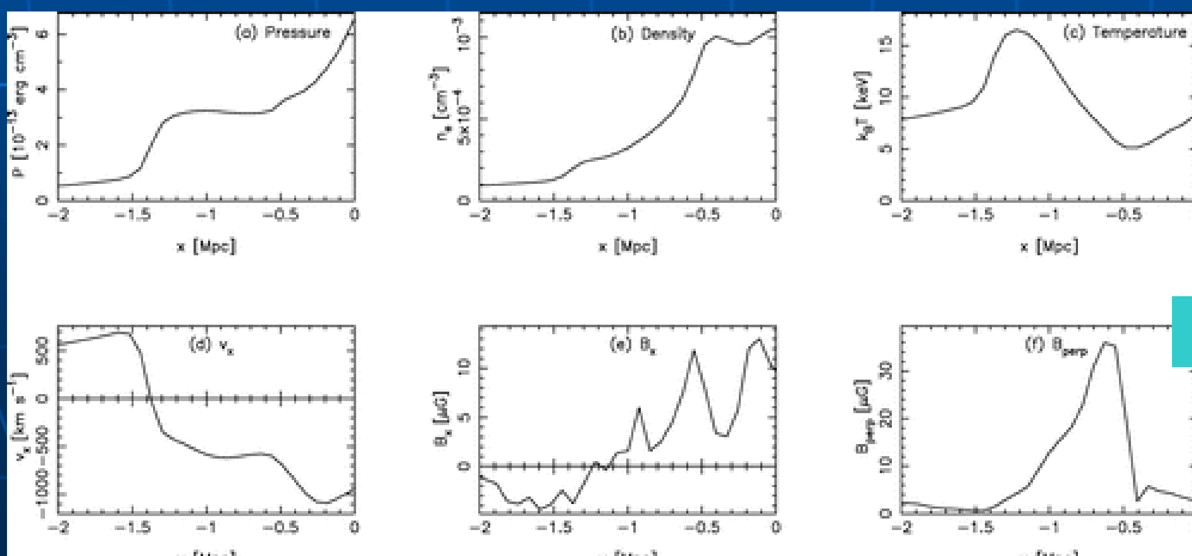
Red: bow shock, blue: contact discontinuity

Magnetic field perpendicular to the collision axis is amplified around the contact discontinuity.



Resolution dependence





mesh size ×2

Summary

- We study magnetic field structure evolution in merging clusters of galaxies using N-body + MHD (PM + Roe-like TVD) simulations.

- Several kinds of characteristic magnetic field structures
  - Low temperature region surrounded by the magnetic field
  - Magnetic field structures perpendicular to the temperature gradients are naturally generated near the contact discontinuity, which could suppress the heat conduction.
  - Ordered magnetic field structures behind moving substructures. -->direction dependence of rotation measure
  - Field structures associated with KH eddies

- If we have Faraday rotaion measure maps that cover cluster entirely, we can get information not only magnetic field structures but also gas motion.

  ----->observation of CMB polarization (Ohno et al. 2003)