銀河団磁場に関する話題

X線観測による磁場強度制限
Nakazawa et al.(2009), Sugawara et al. (2009)

衝突銀河団のMHDシミュレーション
Takizawa (2008)

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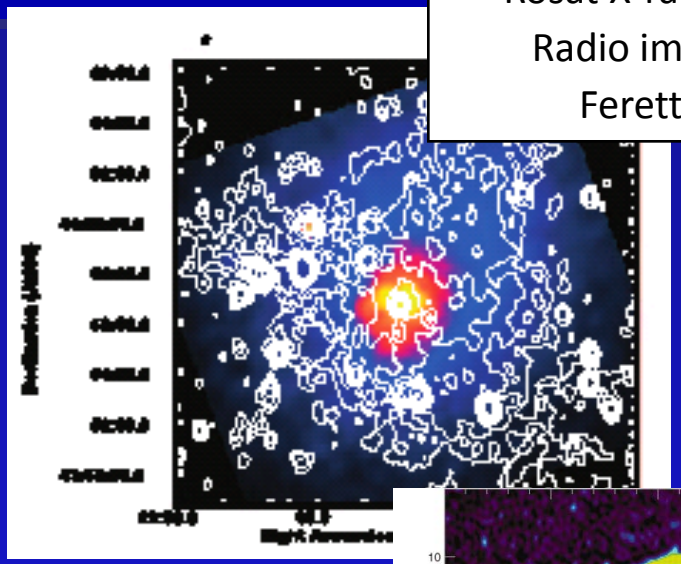
Observational Evidence of Intracluster Magnetic Field (1): Radio Halos / Relics

Non-thermal radio emission from merging clusters of galaxies

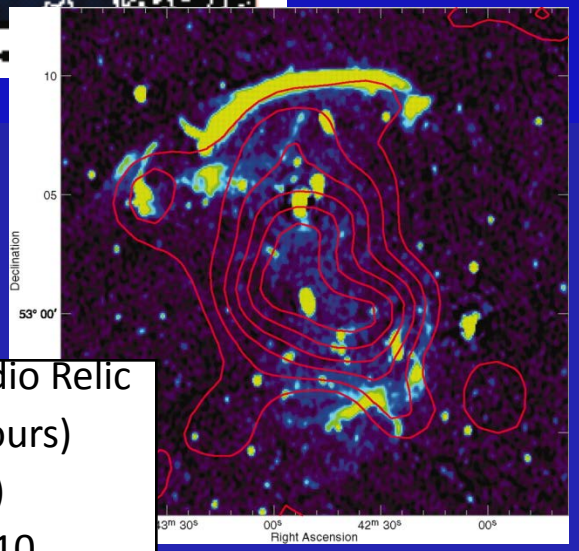
synchrotron radio

$\gamma \sim 10^4$ electrons + 0.1-10μG B

Hard X-ray will be emitted through Inverse compton with CMB



Abell 2319 with Radio Halo
Rosat X-ray image (colors)
Radio image (contours)
Feretti et al. 1997



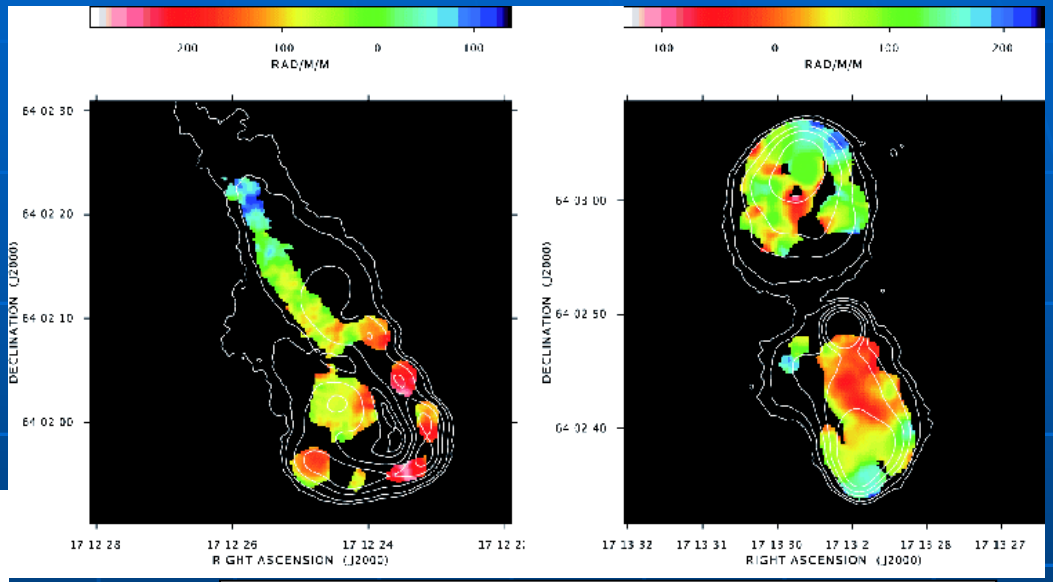
CIZA J2242.8+5301 with Radio Relic
Rosat X-ray image (contours)
Radio image (colors)
Van Weeren et al. 2010

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

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

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

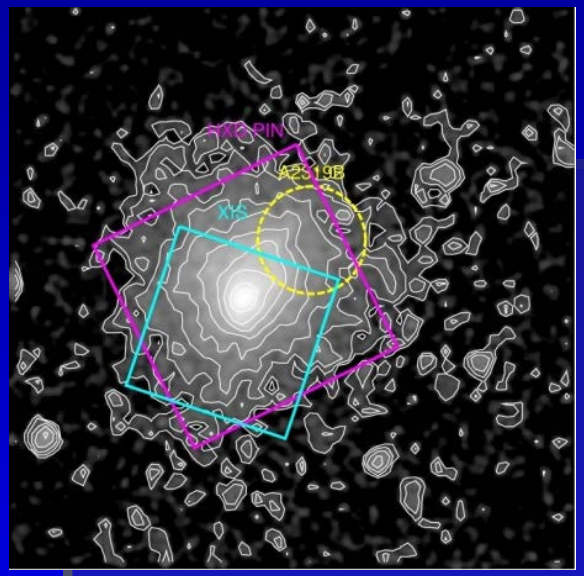
- Polarized radio sources observations in and behind clusters suggest random magnetic field structures.



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

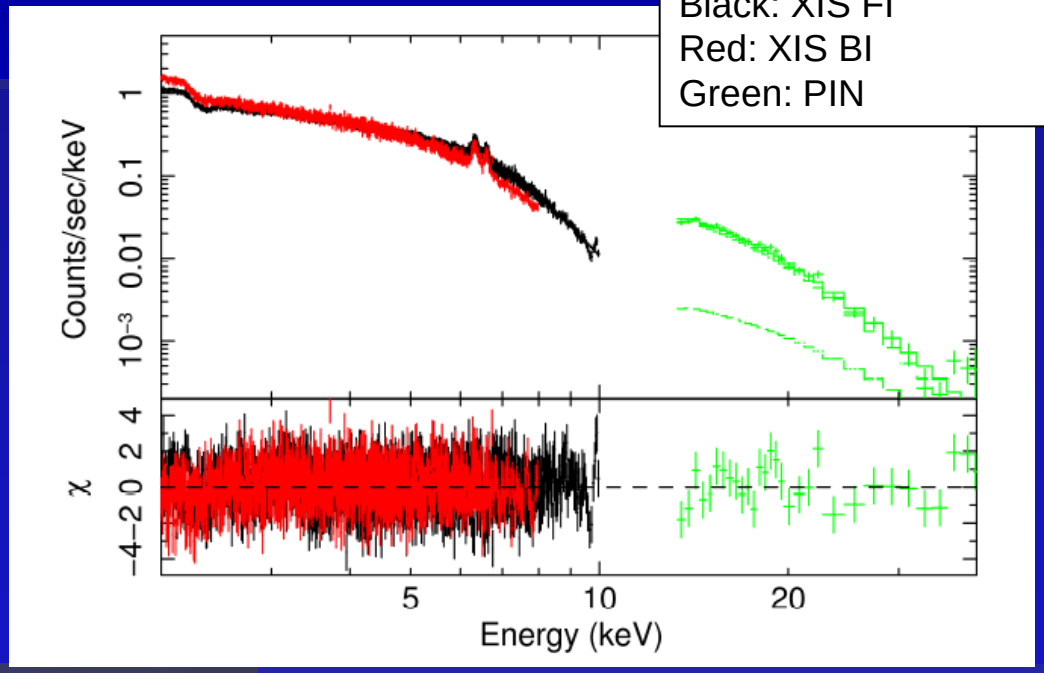
Suzaku Results of Abell 2319

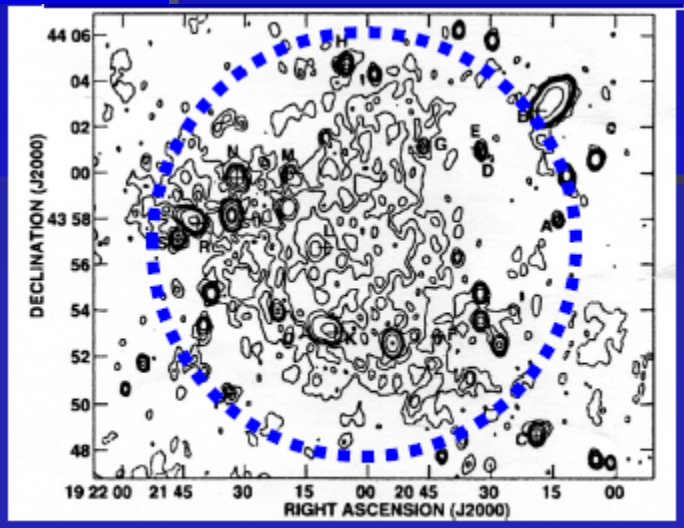
(Sugawara, Takizawa & Nakazawa 2009)



Wide band spectrum

Black: XIS FI
Red: XIS BI
Green: PIN



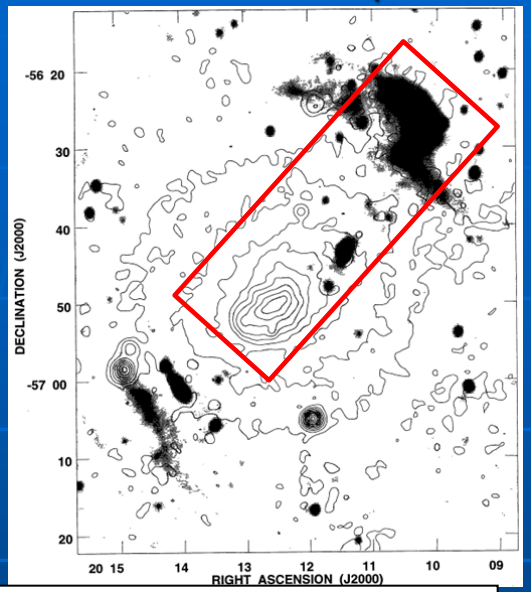


Feretti et al.1997

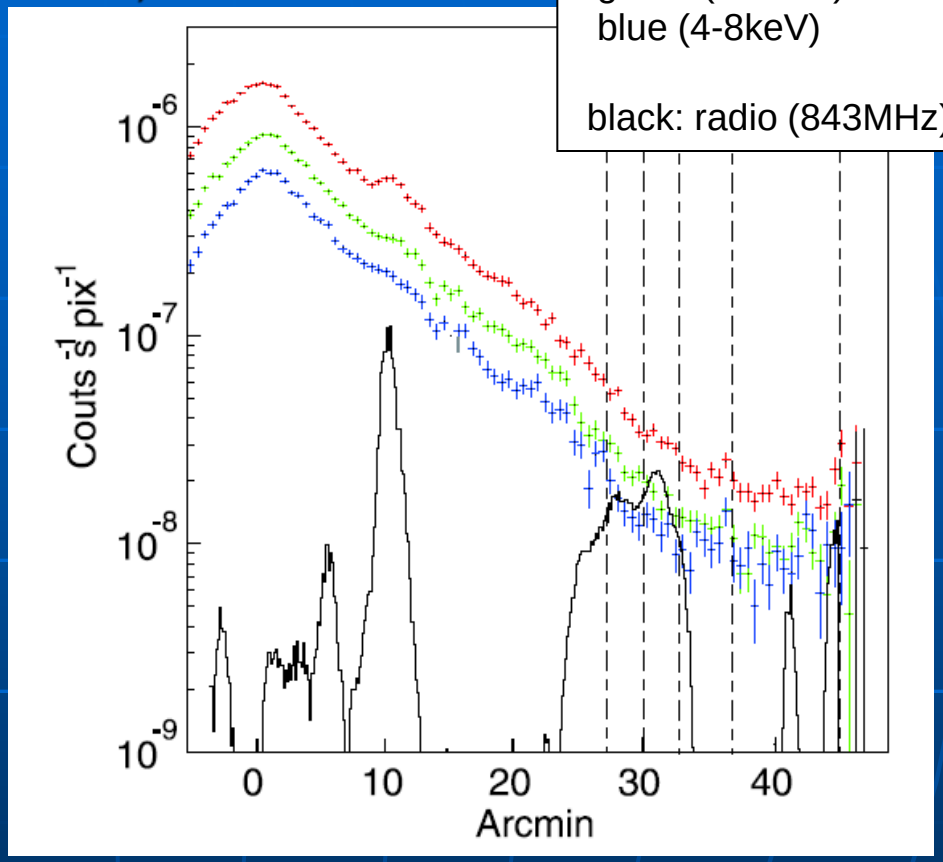
- F_nth(10-40keV) < 3×10^{-11} erg/s/cm^2
- B>0.3μG
- $U_B/U_{th} > 3 \times 10^{-5}$
- $U_{CRe}/U_{th} < 5 \times 10^{-4} (5.7 \times 10^3 < \gamma < 1.1 \times 10^4)$

Suzaku Results of Abell 3667

(Nakazawa et al. 2009)



X-ray (contours)
Radio (gray sacles)
Rottgering et al. (1997)



- $F\_nth(10\text{-}40keV) < 3.9 \times 10^{-13}$ erg/s/cm^2
- $B > 2.2\mu G$
- $U_B/U_{th} > 0.12$
- $U_{CRe}/U_{th} < 0.15$ $(5 \times 10^2 < \gamma < 4 \times 10^4)$

Magnetic Field Structures and Mergers

- Cluster mergers and resultant moving substructures

  --->

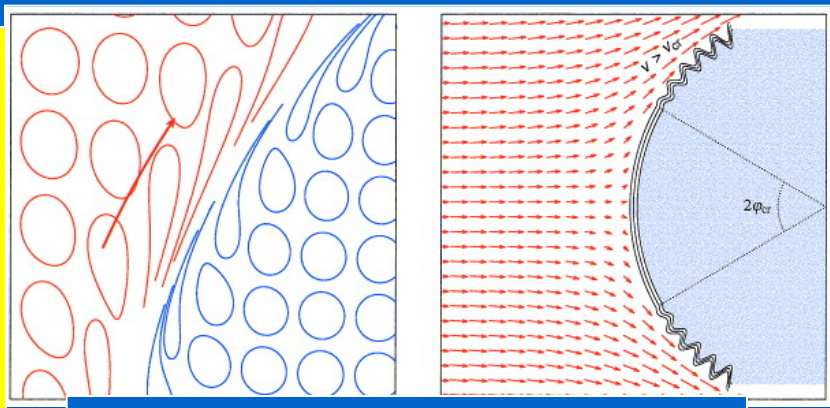
  bulk flow motions and turbulence in the ICM

  --->

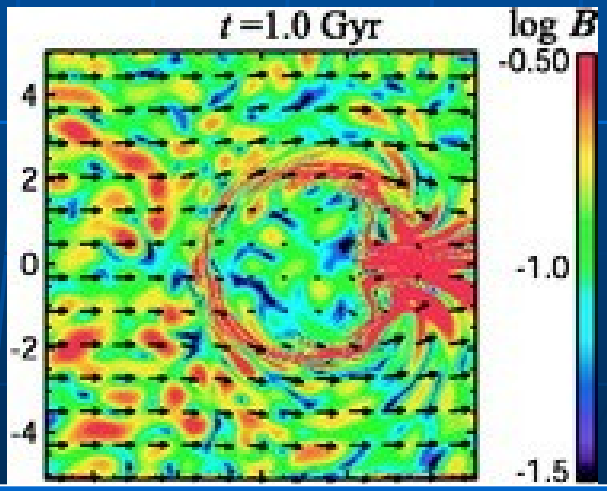
  impact on magnetic field structures

- 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)

Initial Model

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

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

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

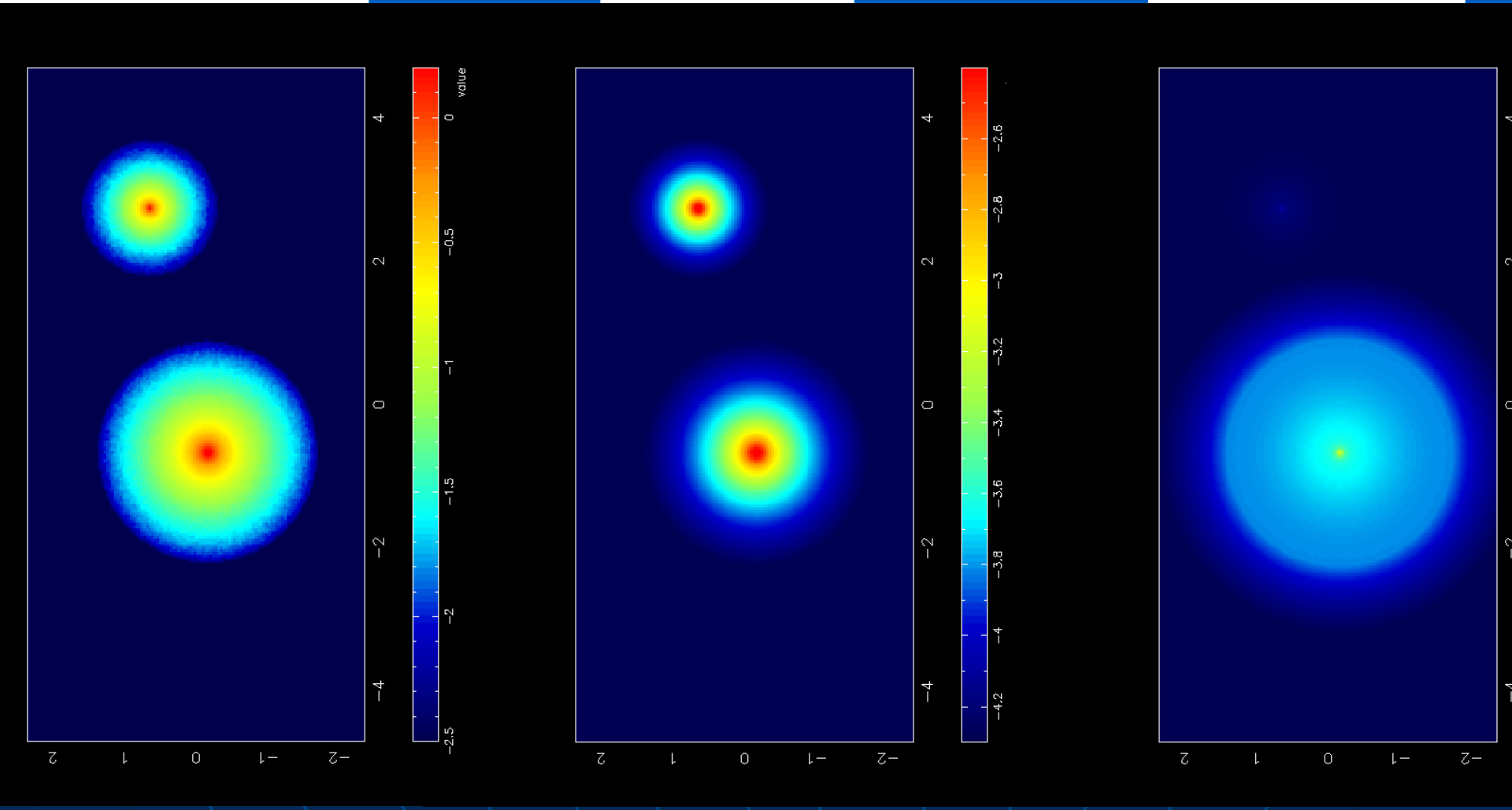
- How to generate initial random magnetic field scaled with ICM density
  - Realize random Gaussian vector potential in k-space, with $A(k) \propto k^{-(5/3)}$.
  - Inverse FFT $A(k_x,k_y,k_z)$ --> $A(x,y,z)$
  - Multiply $A(x,y,z)$ by $\rho_{gas}(x,y,z)^{(2/3)}$.
  - $B = \nabla \times A$
  - Normalize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

Movies

Mass density
(mostly dark matter)

Gas density

Gas temperature

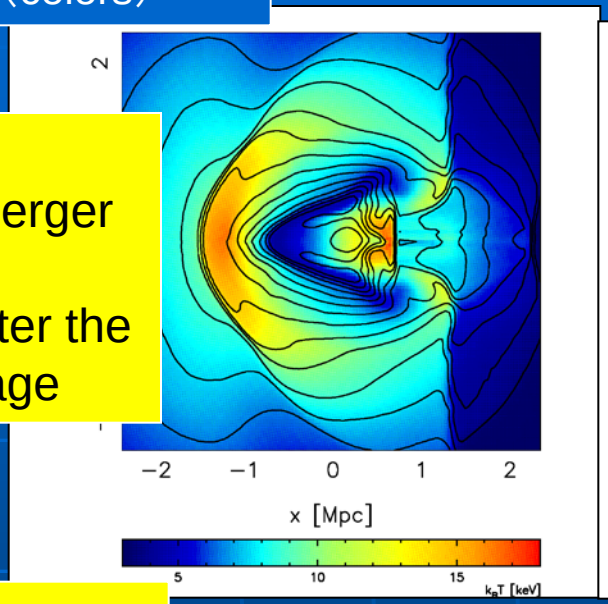


Results(1)

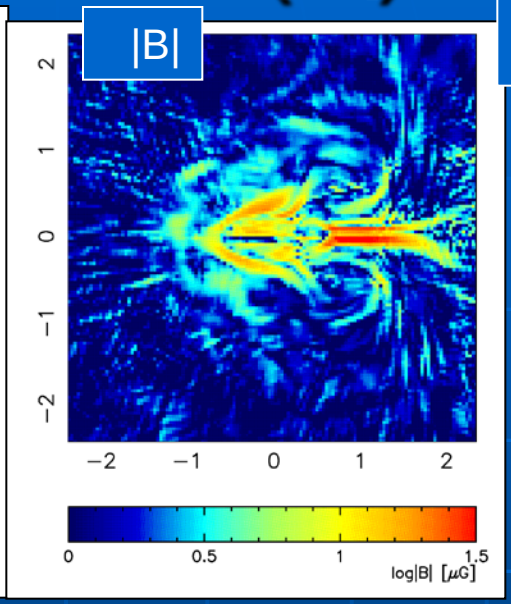
density（contours）
&kT（colors）

1：4
head-on merger

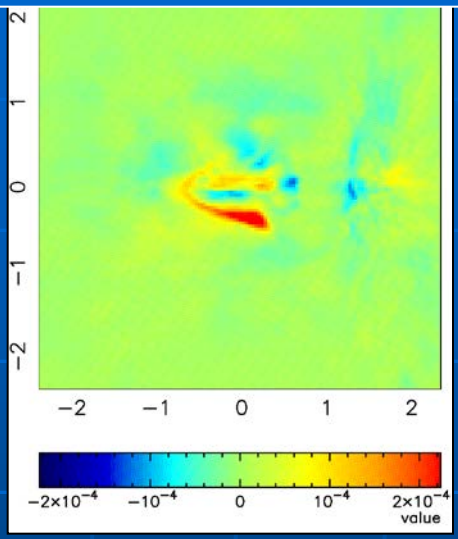
0.66Gyr after the core passage



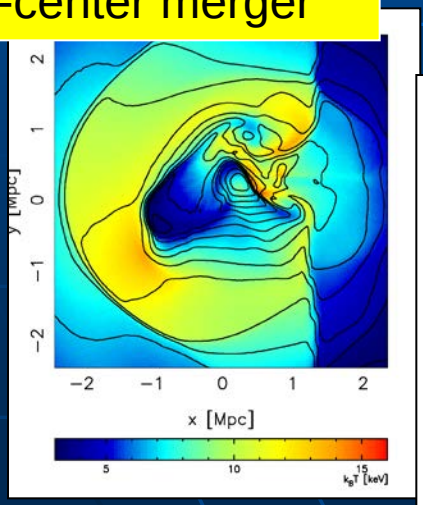
|B|

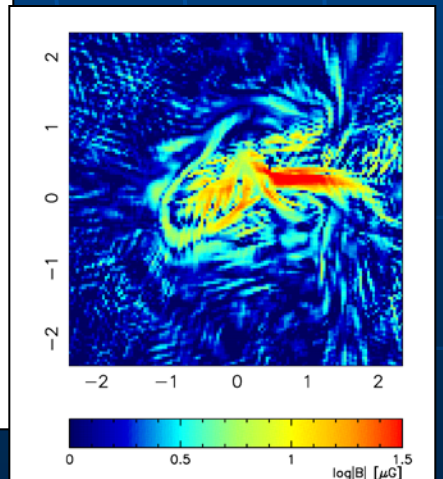


Faraday Rotation Measure
($\int n_e B_{//} dl$)

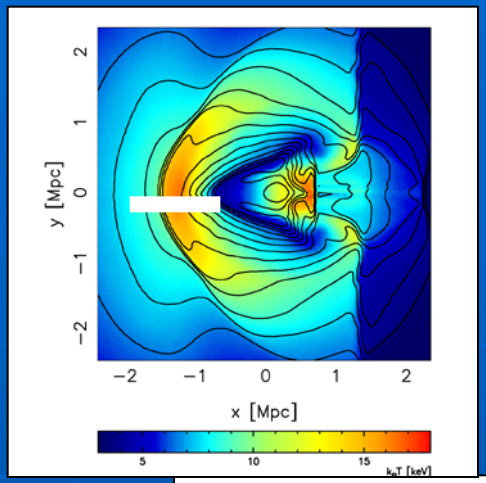


1：4
off-center merger



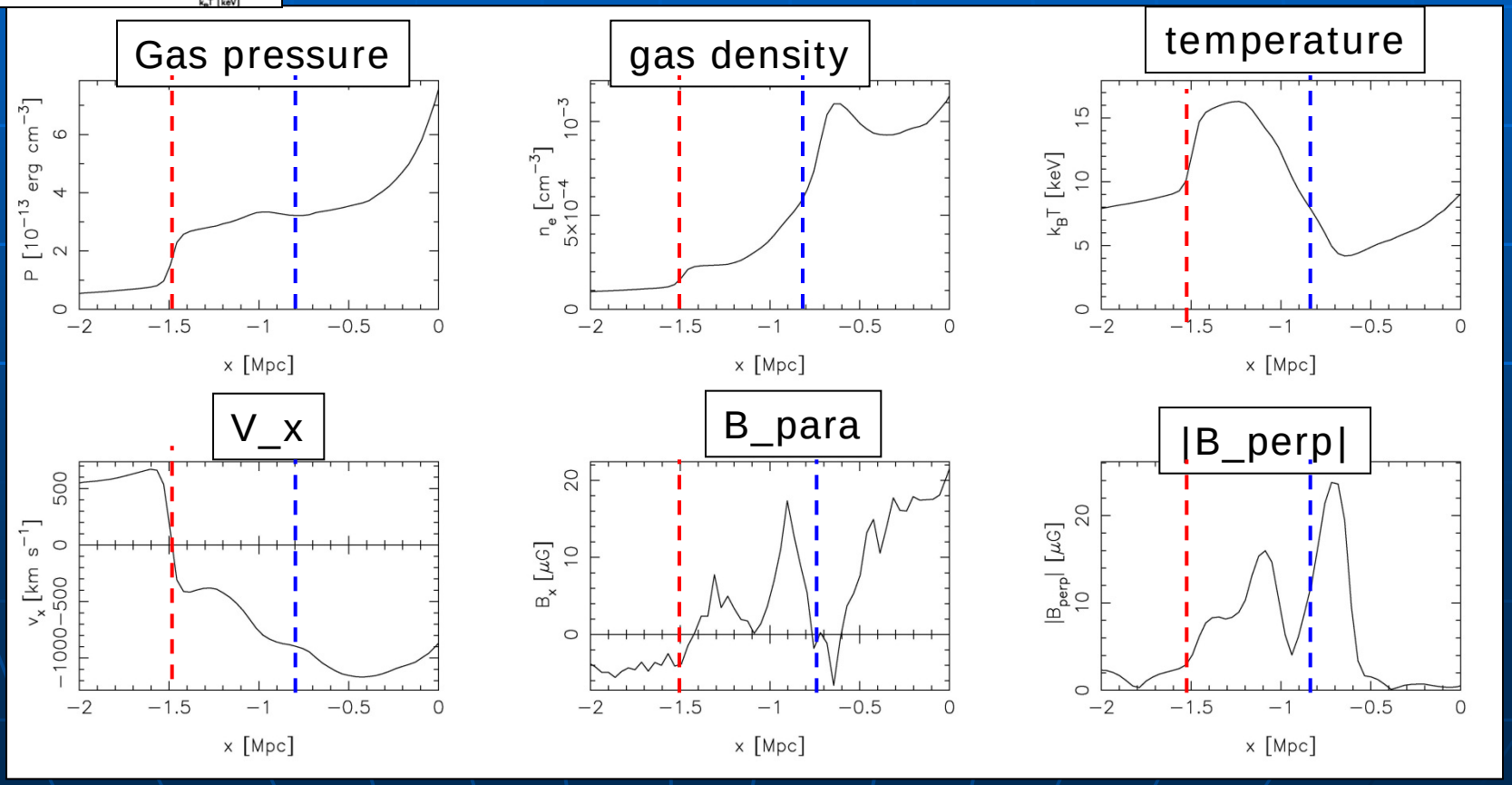


◆Low temperature region surrounded by the magnetic field（high Faraday Rotation Measure）
◆ordered magnetic field structure behind the small subclump
◆These structures are partly recognized in Faraday rotaion measure maps.



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.



Summary

- Constraint on the magnetic energy density in the intracluster space with Suzaku
  - Radio halo of A2319
  - Radio relic region of A3367

- Magnetic field structure evolution in merging clusters of galaxies using N-body + MHD 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)、How about SKA????