

Cosmological MHD

Hui Li

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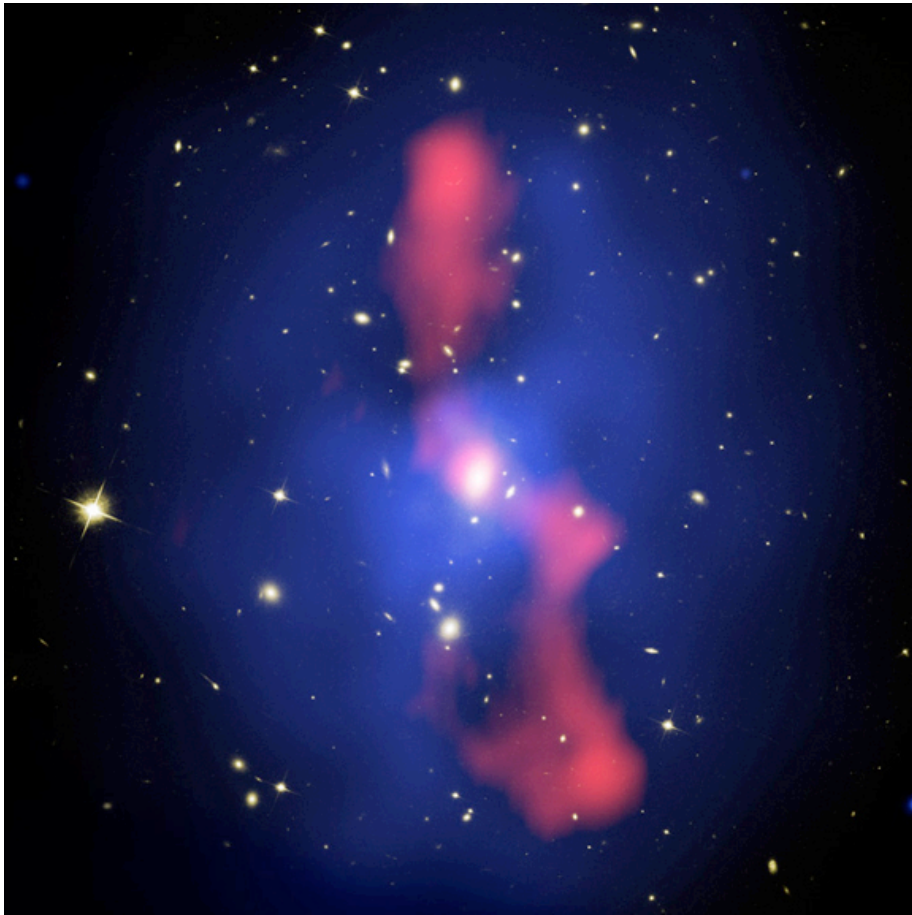
- Observational overview of large scale magnetic fields
- Several examples of numerical modeling of cosmological MHD

Part I:

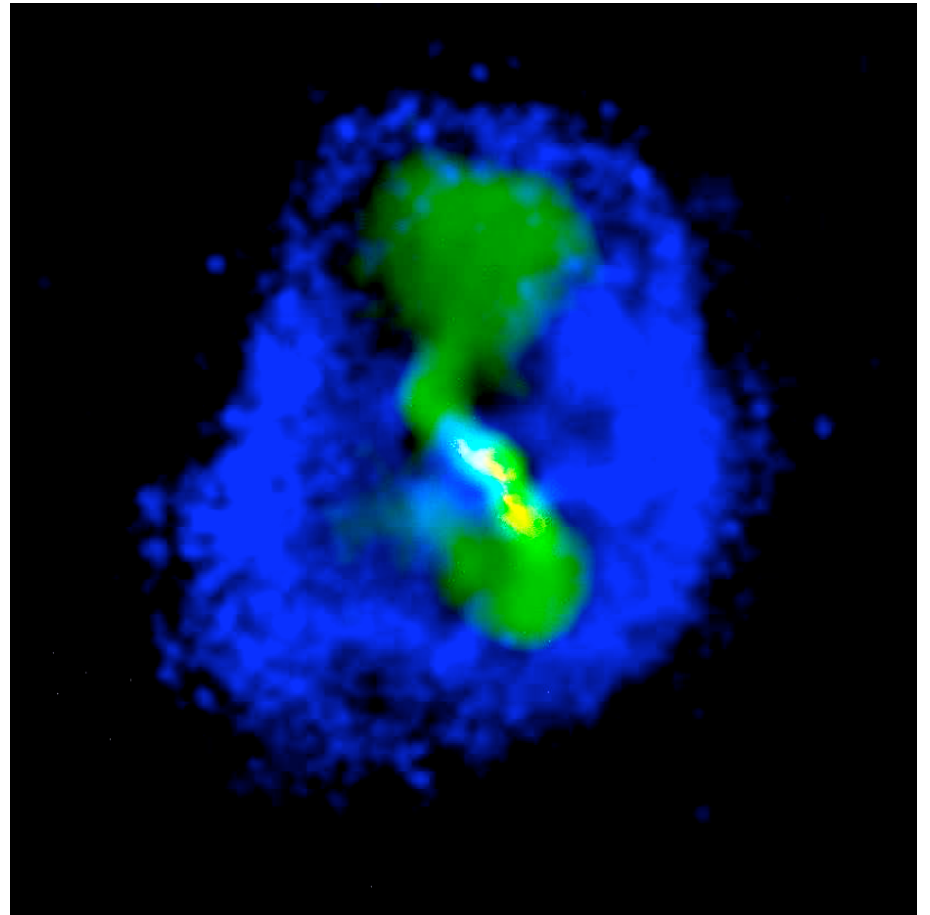
Observations

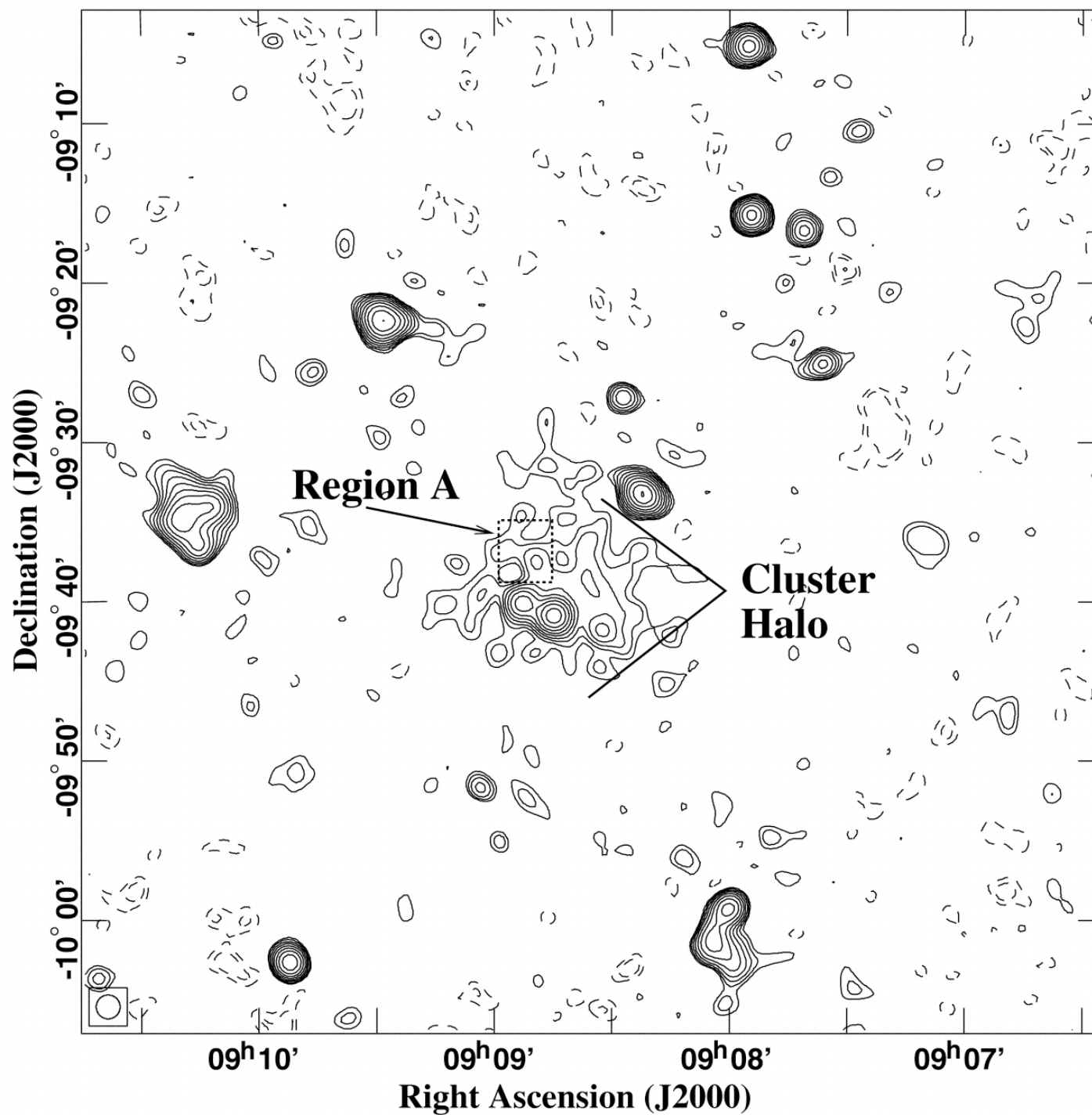
Galaxy Clusters

MS0735.6+7421



Hydra A

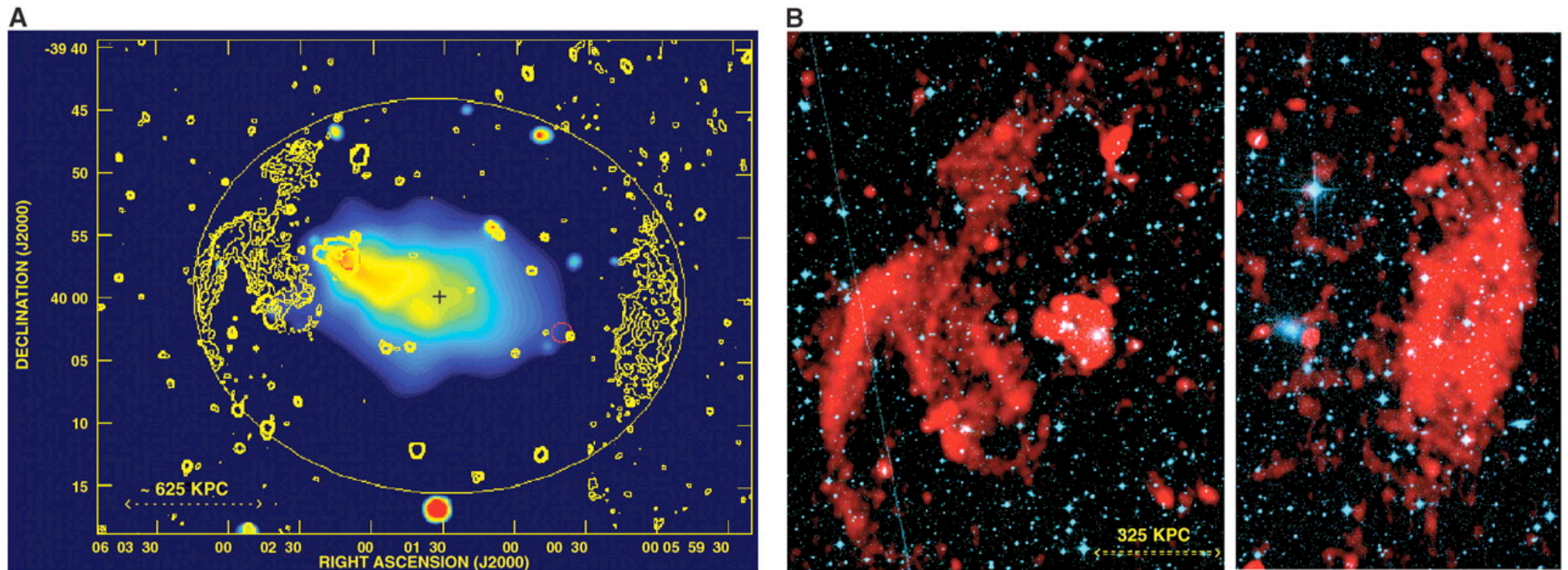




**Cluster
Radio
Halo**

**A754
Kassim et al. '01**

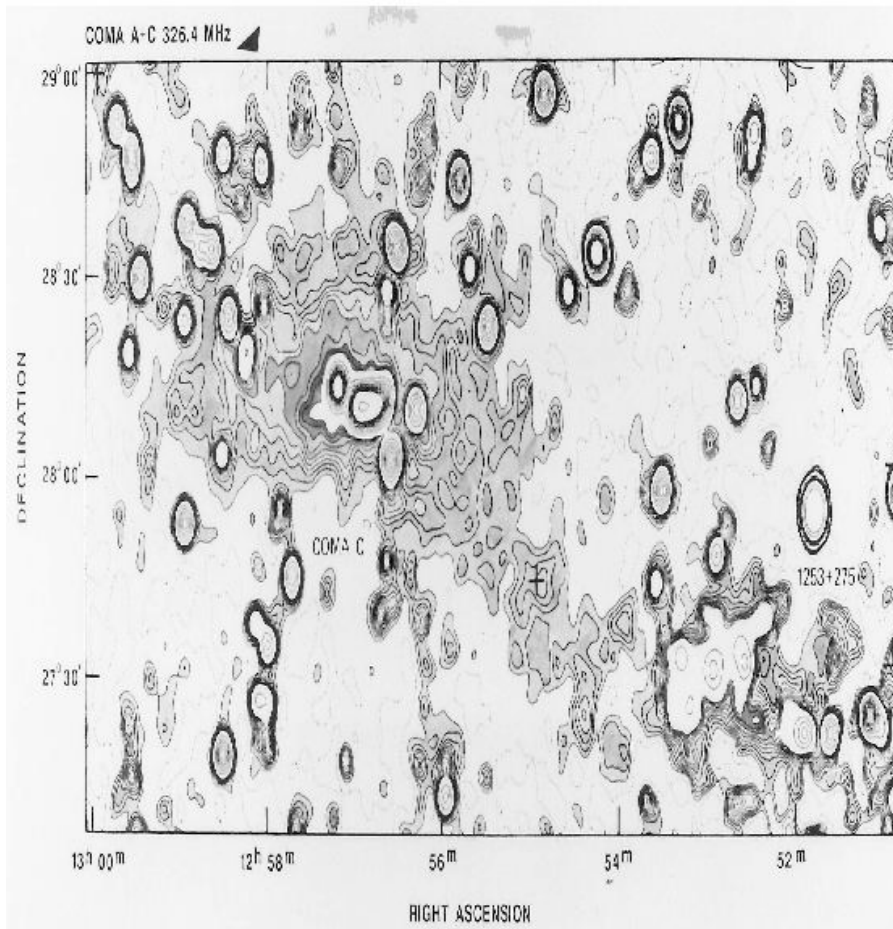
Cluster Accretion Shocks (?)



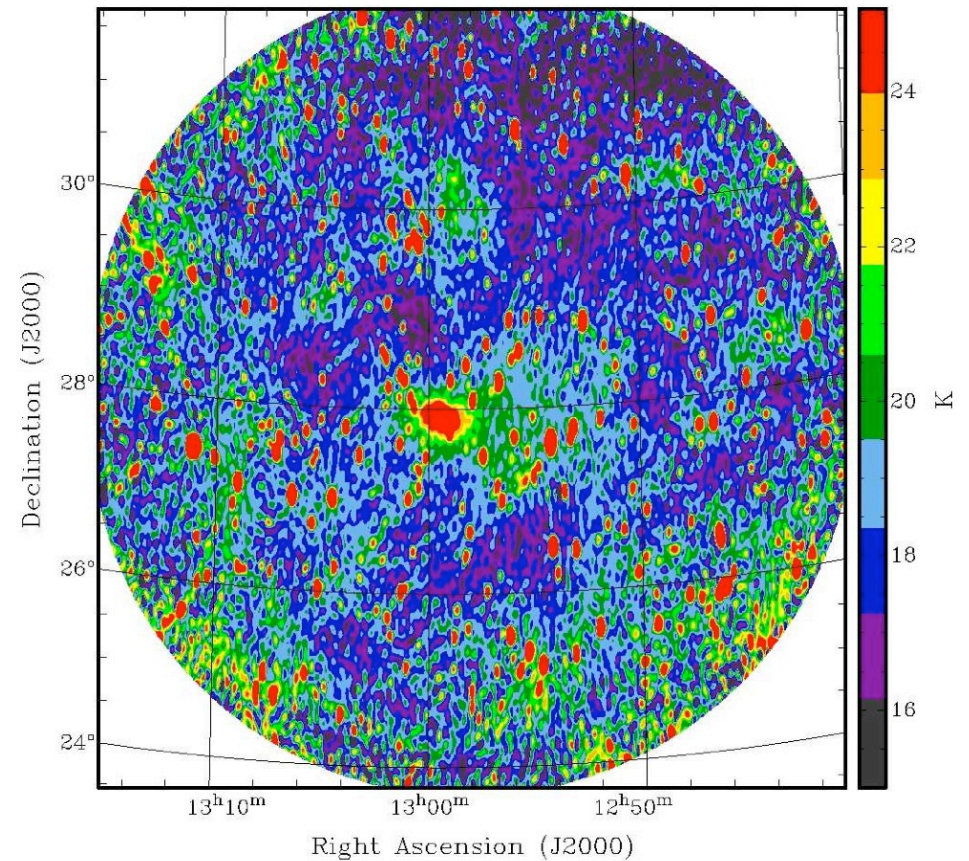
Bachigi et al. 2006, Science

Beyond Clusters.... (???)

*Adapted from: Kim, Kronberg, Giovannini
and Venturi, NATURE, 1989*



Kronberg et al. 2007, ApJ



Part II:

Origin of Extra-Galactic Magnetic Fields

Numerical simulations

- Λ cold dark matter cosmology

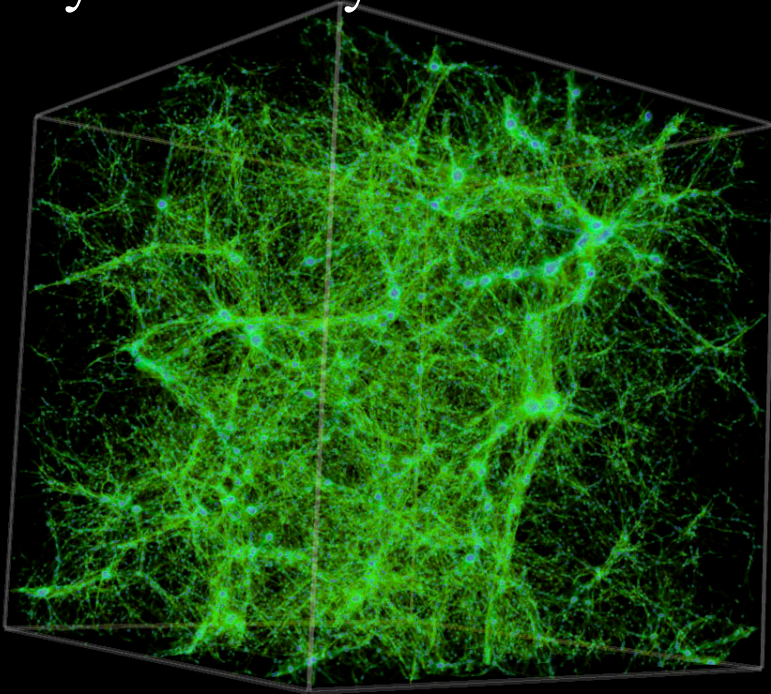
$\Omega_{\Lambda} = 0.73$, $\Omega_{\text{DM}} = 0.27$, $\Omega_{\text{gas}} = 0.043$, $h=0.7$, $n = 1$, $\sigma_8 = 0.8$
without/with gas cooling

- computational box: $(100h^{-1} \text{ Mpc})^3$

1024^3 cells for gas and gravity, 512^3 DM particles, $\Delta x = 97.7 h^{-1} \text{ kpc}$

Ryu et al. 2005

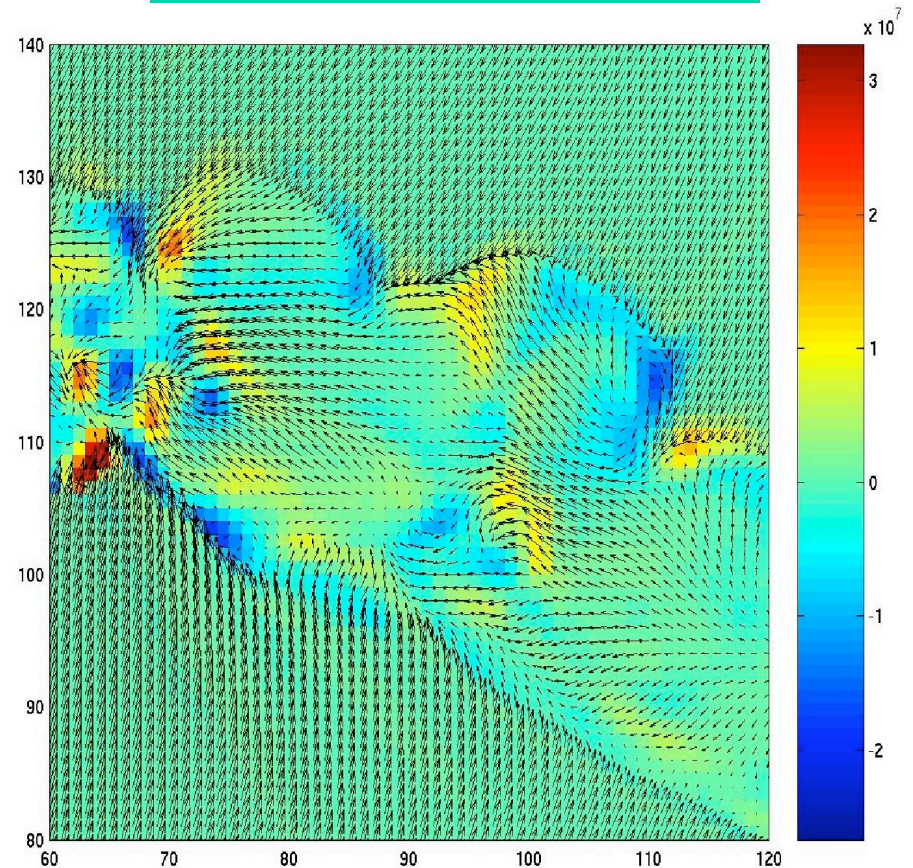
Baryon Density



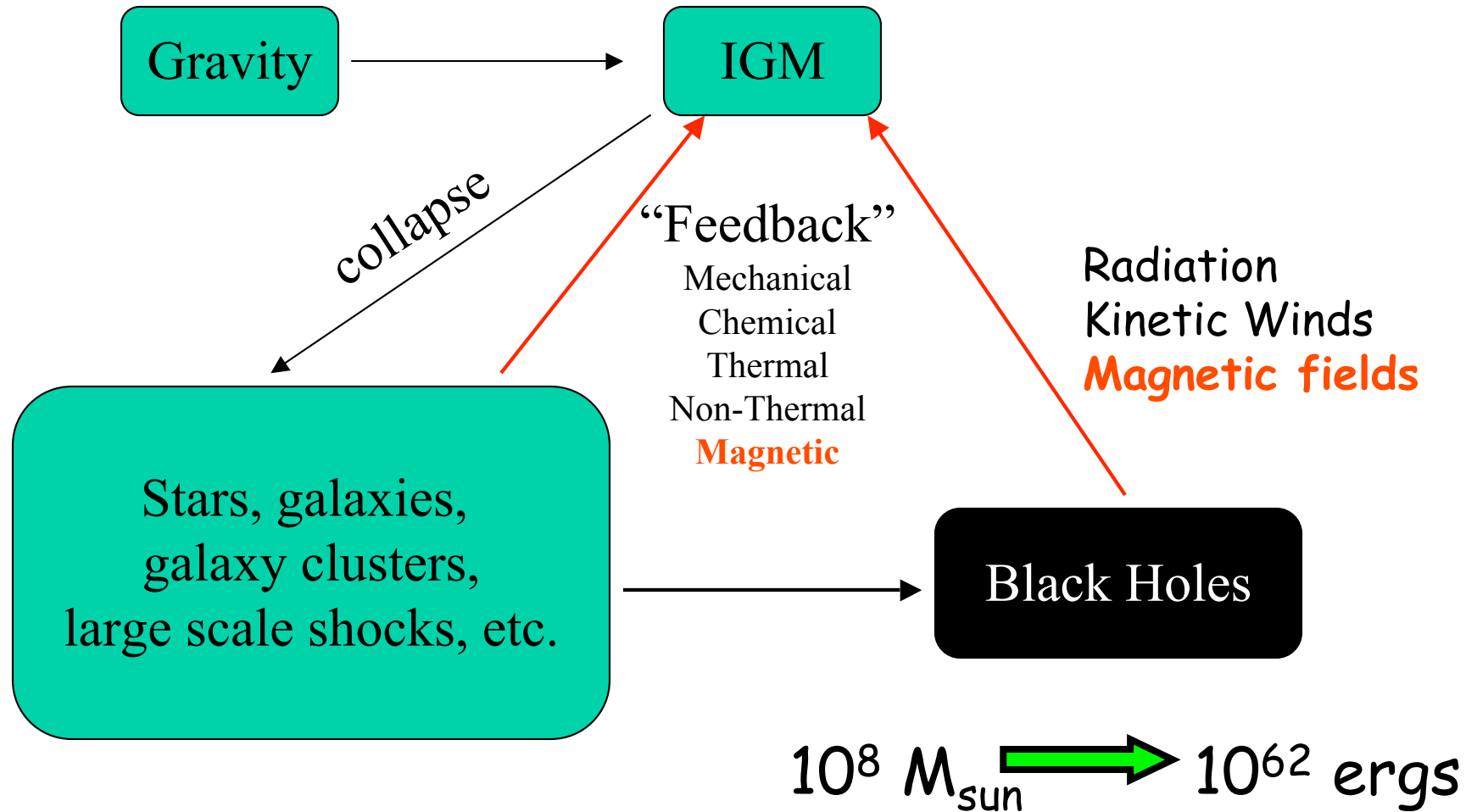
$\rho = 1 - 10^4 \langle \rho \rangle$ and higher



Vorticity Generation



Cosmic Energy Flow



Part III:

Astrophysical Jet Modeling
and Interaction with ICM

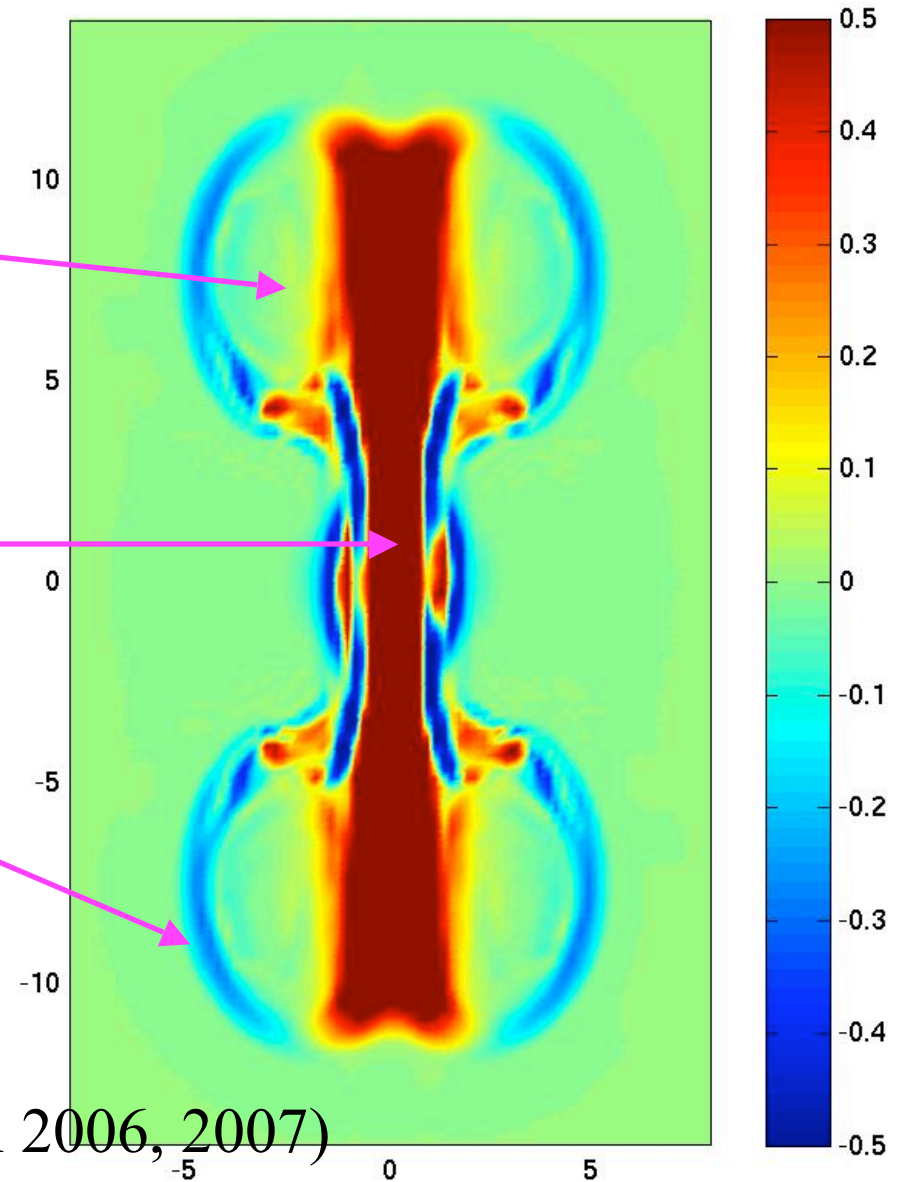
global current flow

$\mathbf{J}_z @ t = 10$

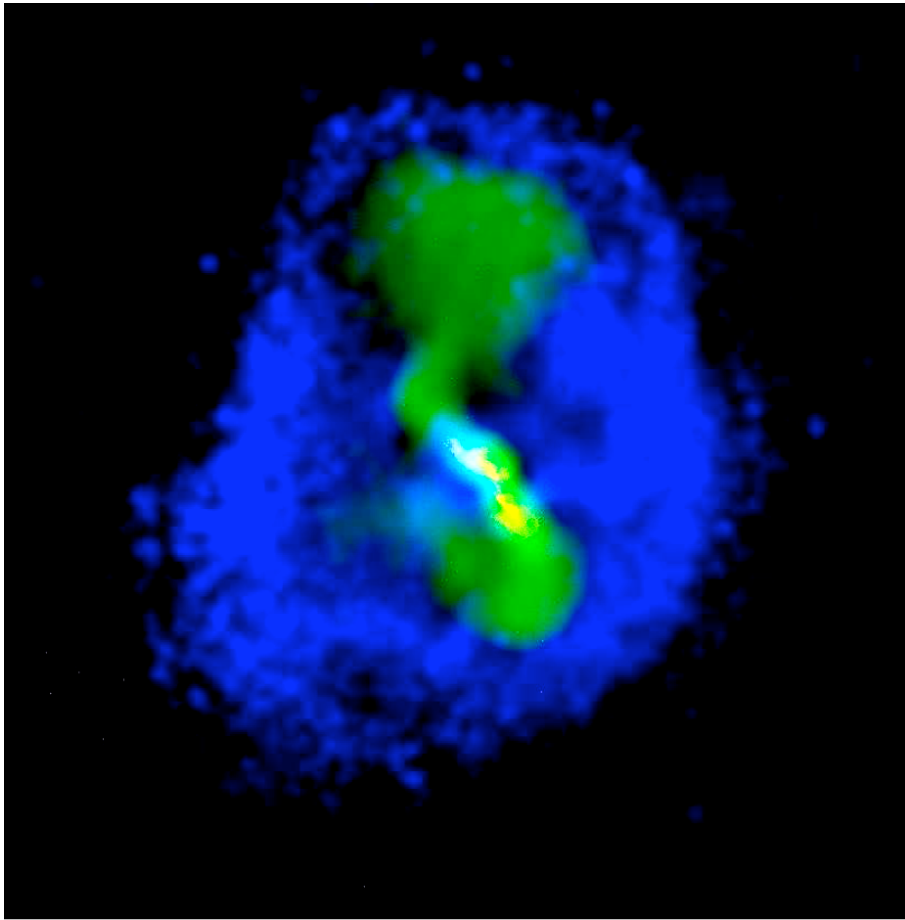
toroidal $B\phi$ from I_z
 (“lobes”)

“flux core: Ψ & I_z ”
 (“helix/jet”)

confinement
($B_\phi^2/8\pi \sim p_{\text{gas}}$)

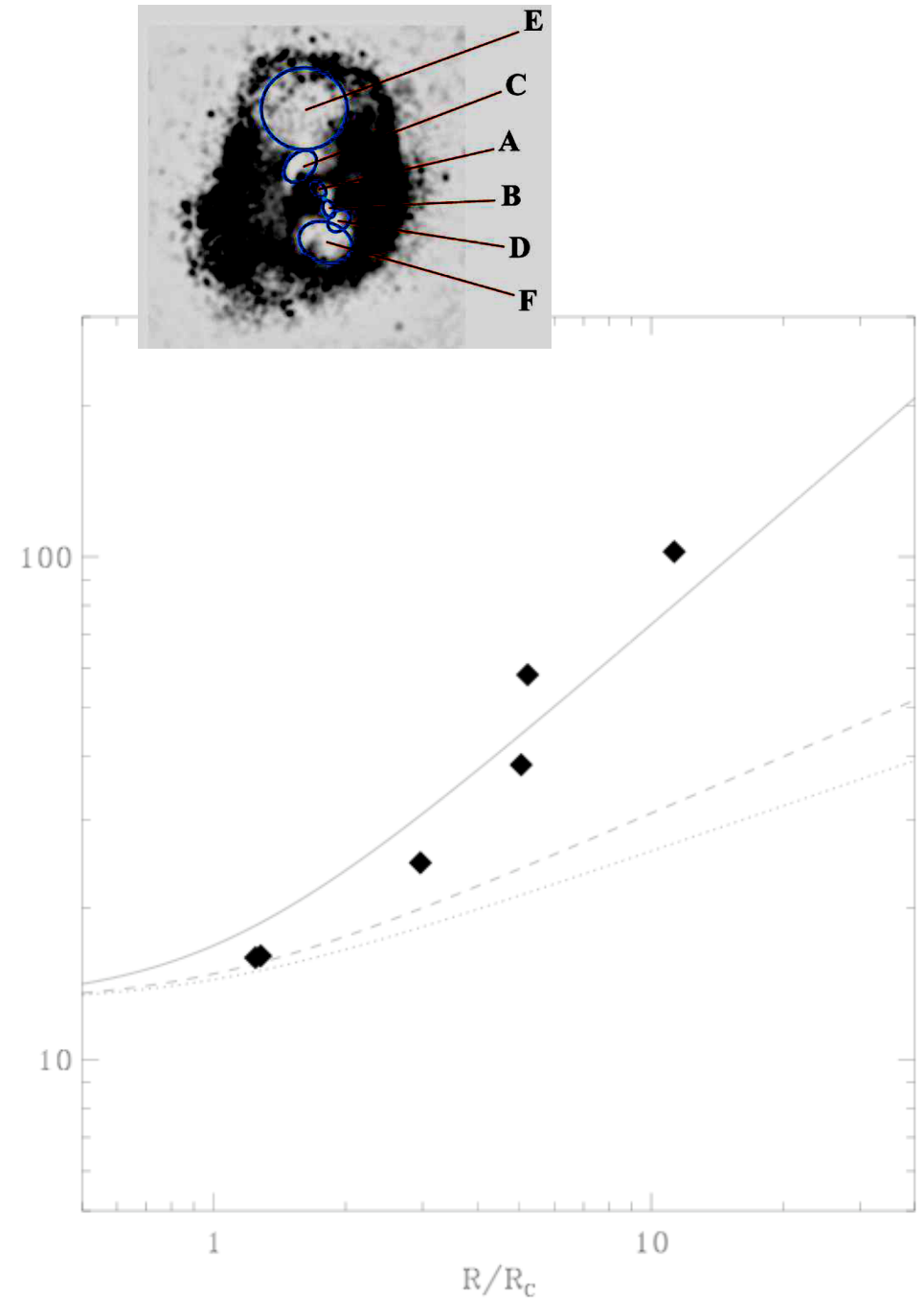


(Li et al. 2006, Nakamura, Li, Li 2006, 2007)



Hydra A

Diehl, Li, et al. 2007

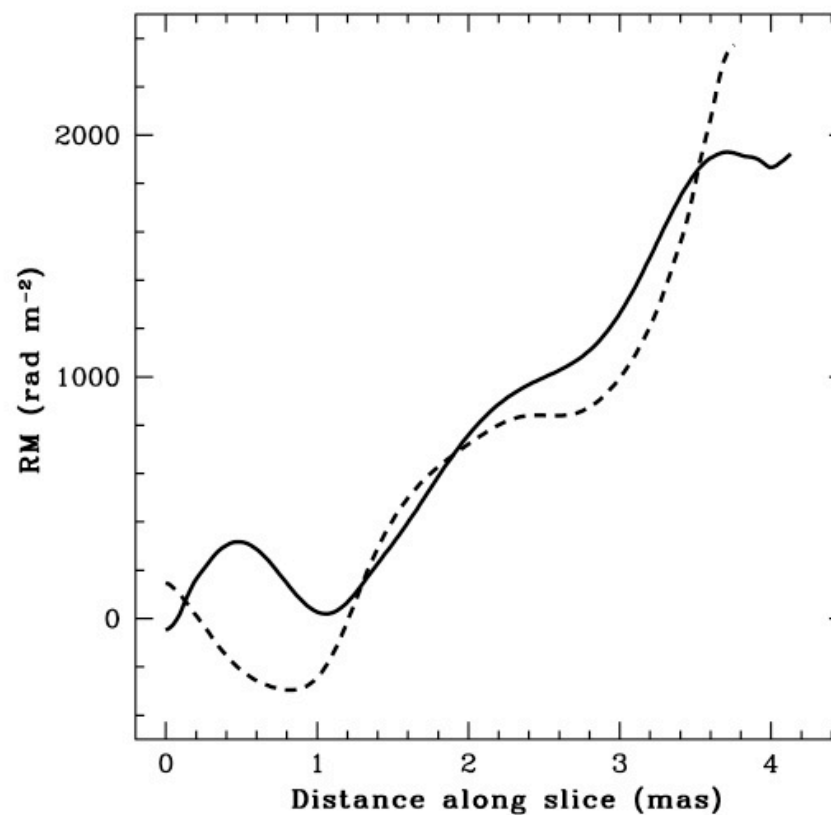
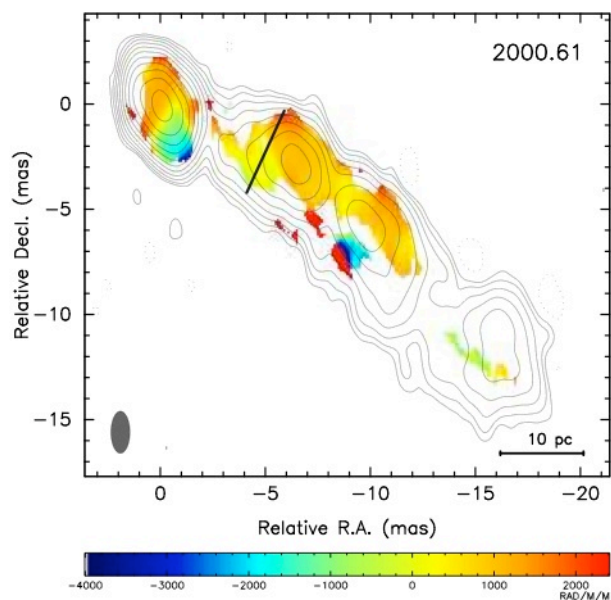
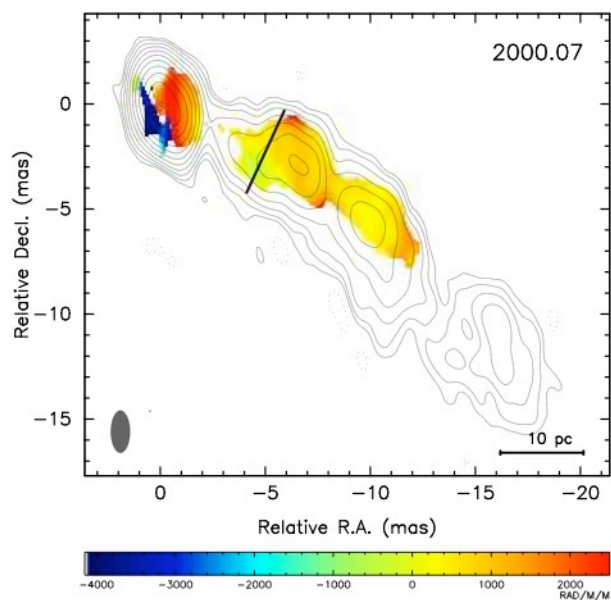


Zavala & Taylor 2005

3C273

Differential FRM

Is there current in jets?

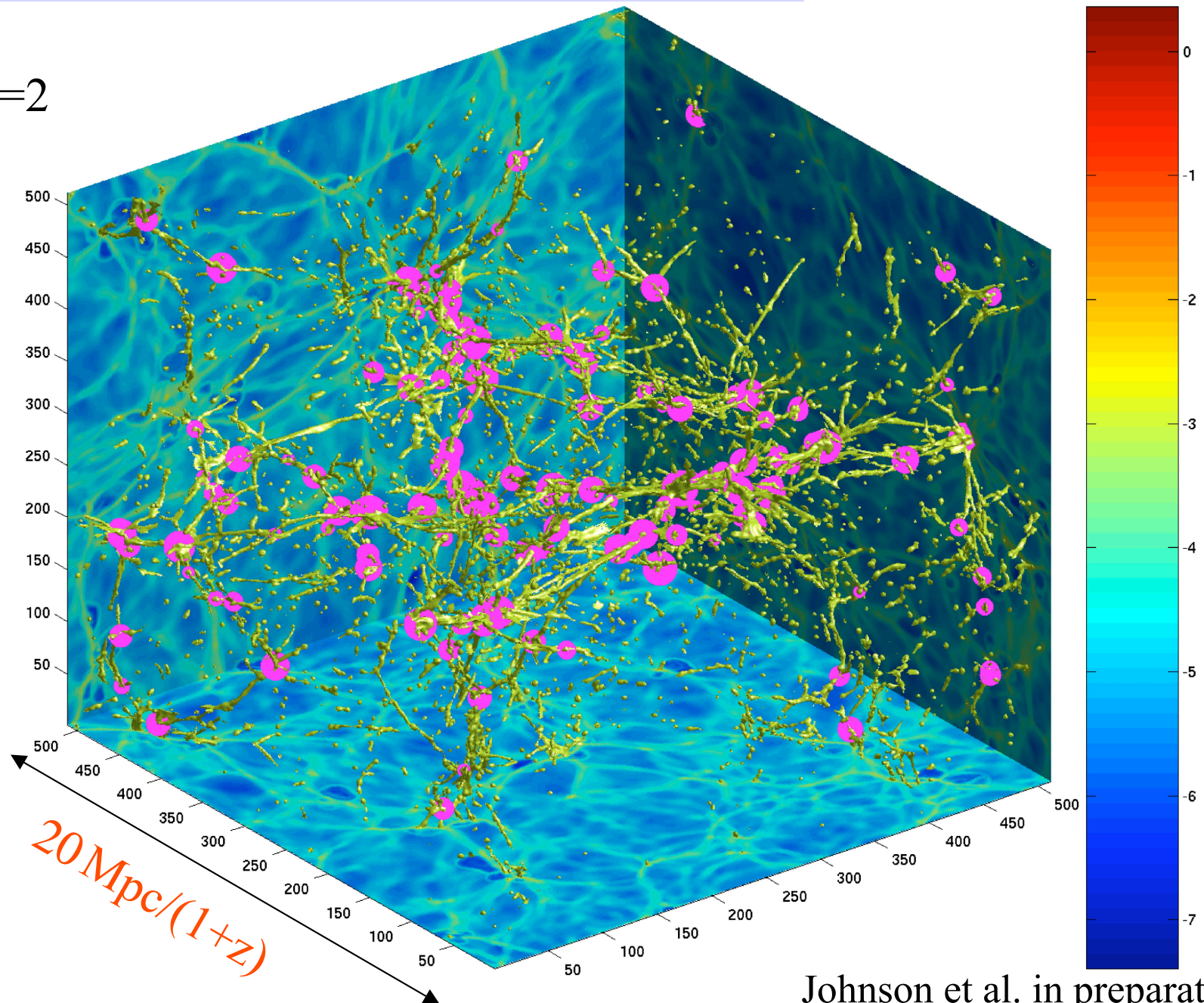


Part IV:

Magnetic Fields Injected
from SMBHs

Growing "cherries" on cosmic trees ...

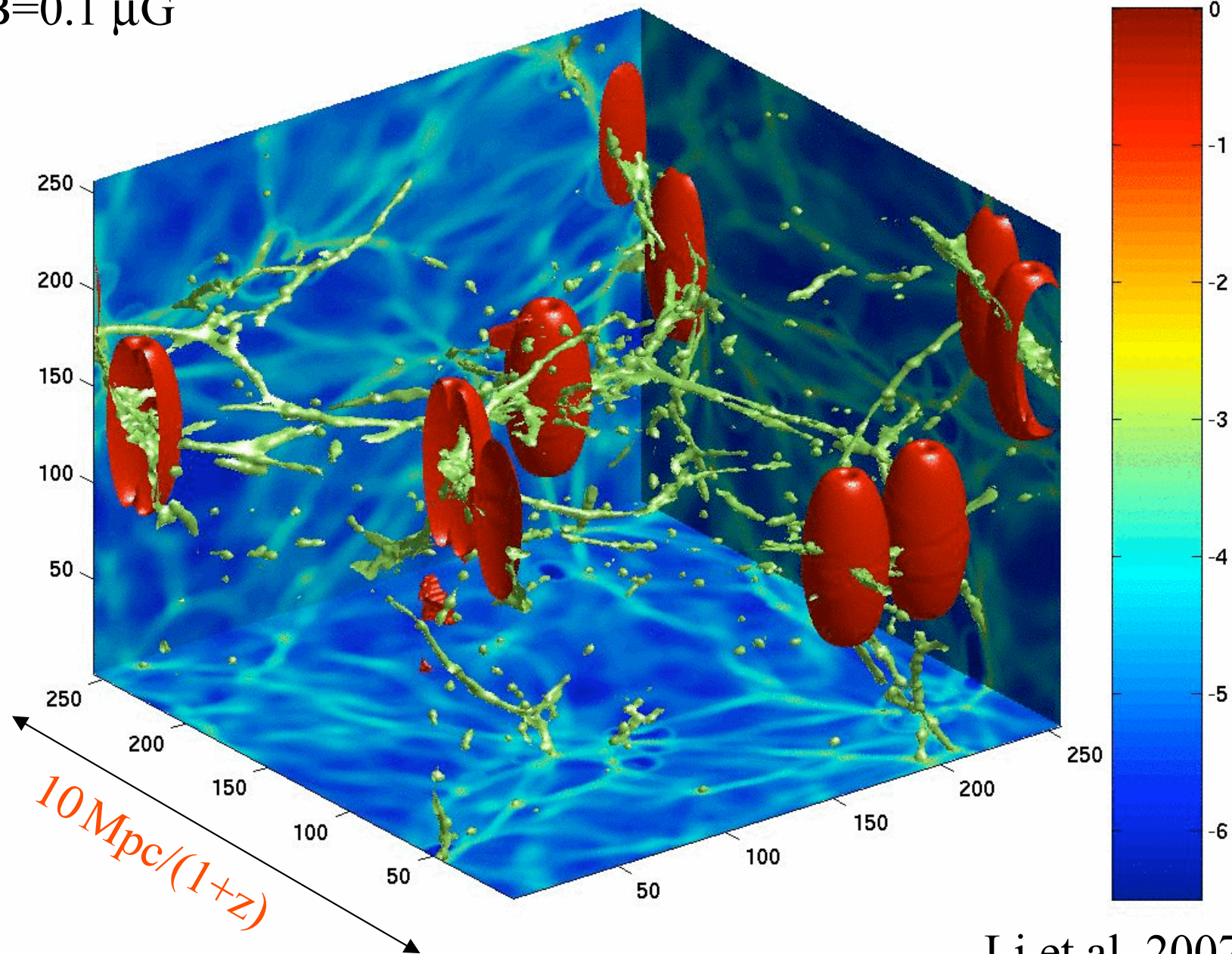
$z=2$



Johnson et al. in preparation

$B=0.1 \mu\text{G}$

$Z = 1.985 \quad t = 9.0 \times 10^6$



Li et al. 2007

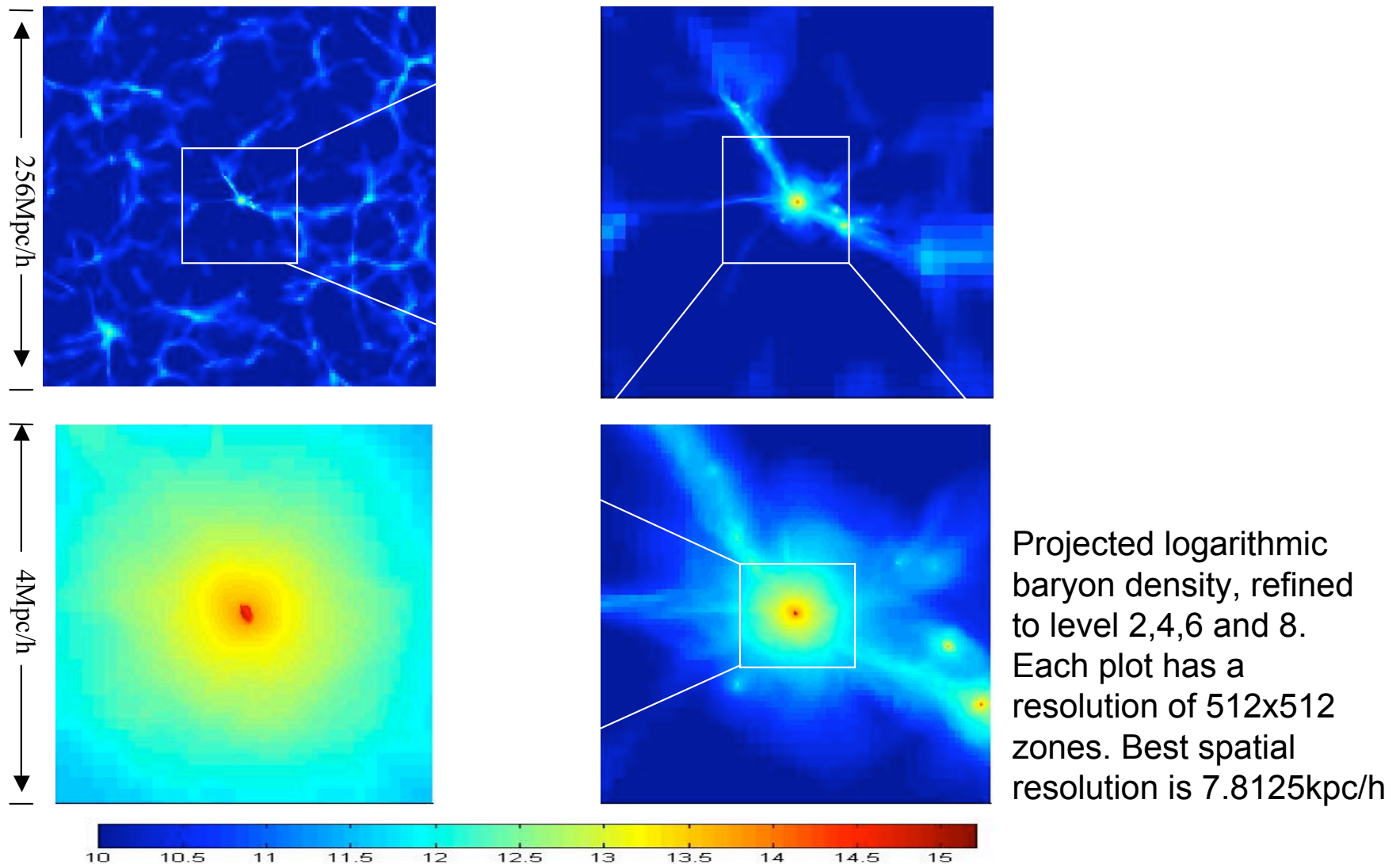
Part V:

Cosmological MHD
Simulation of Cluster
formation with Magnetic
Fields

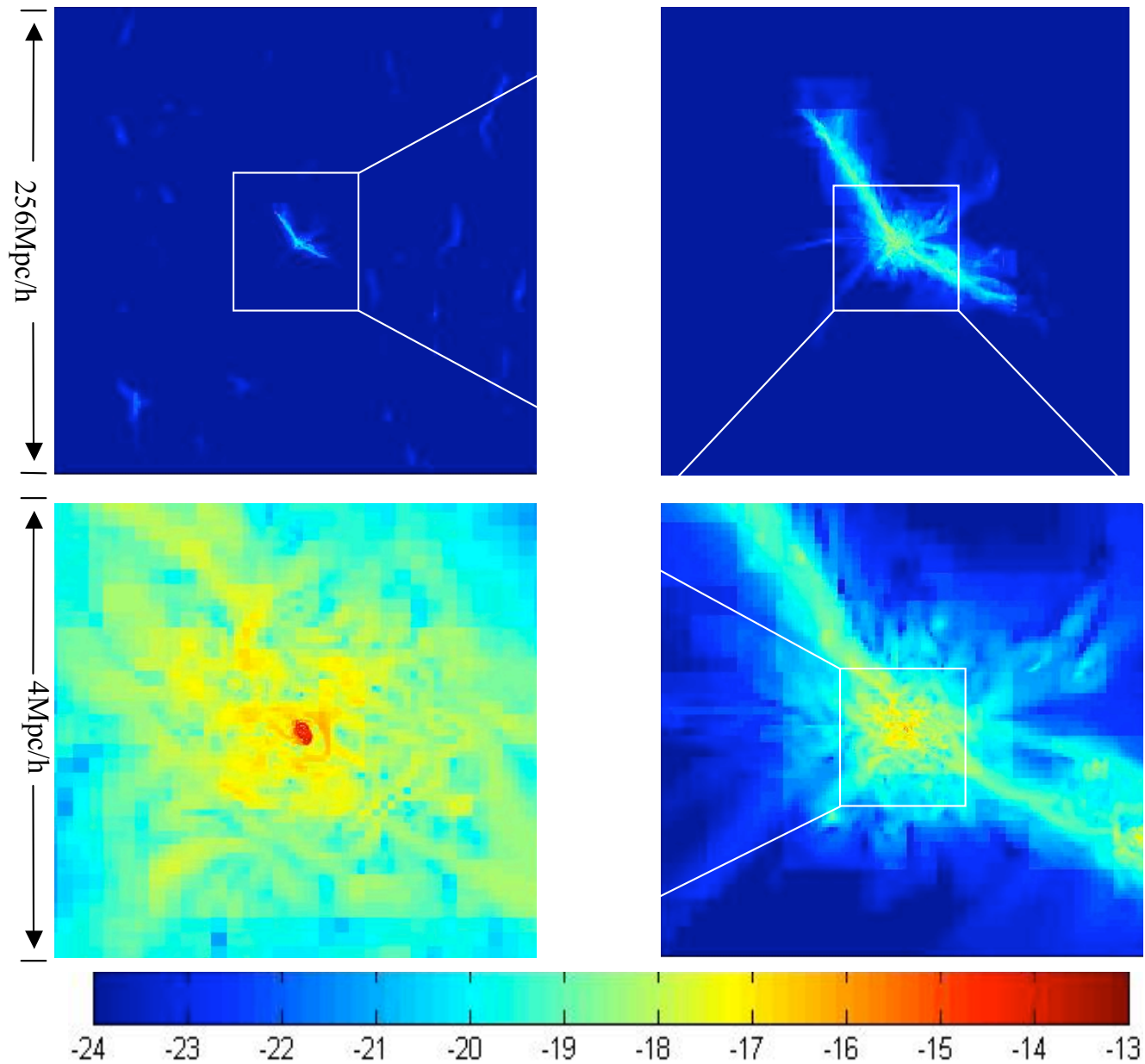
AMR MHD Cluster Formation Simulations

Λ CMD model, $\Omega=1$, $\Omega_\Lambda=0.7$, $\Omega_b=0.04$, $h=0.7$, and box size = 256 Mpc. Root grid is 128^3 , refined by 2 to level 8, simulation is from $z=30$ to $z=0$.

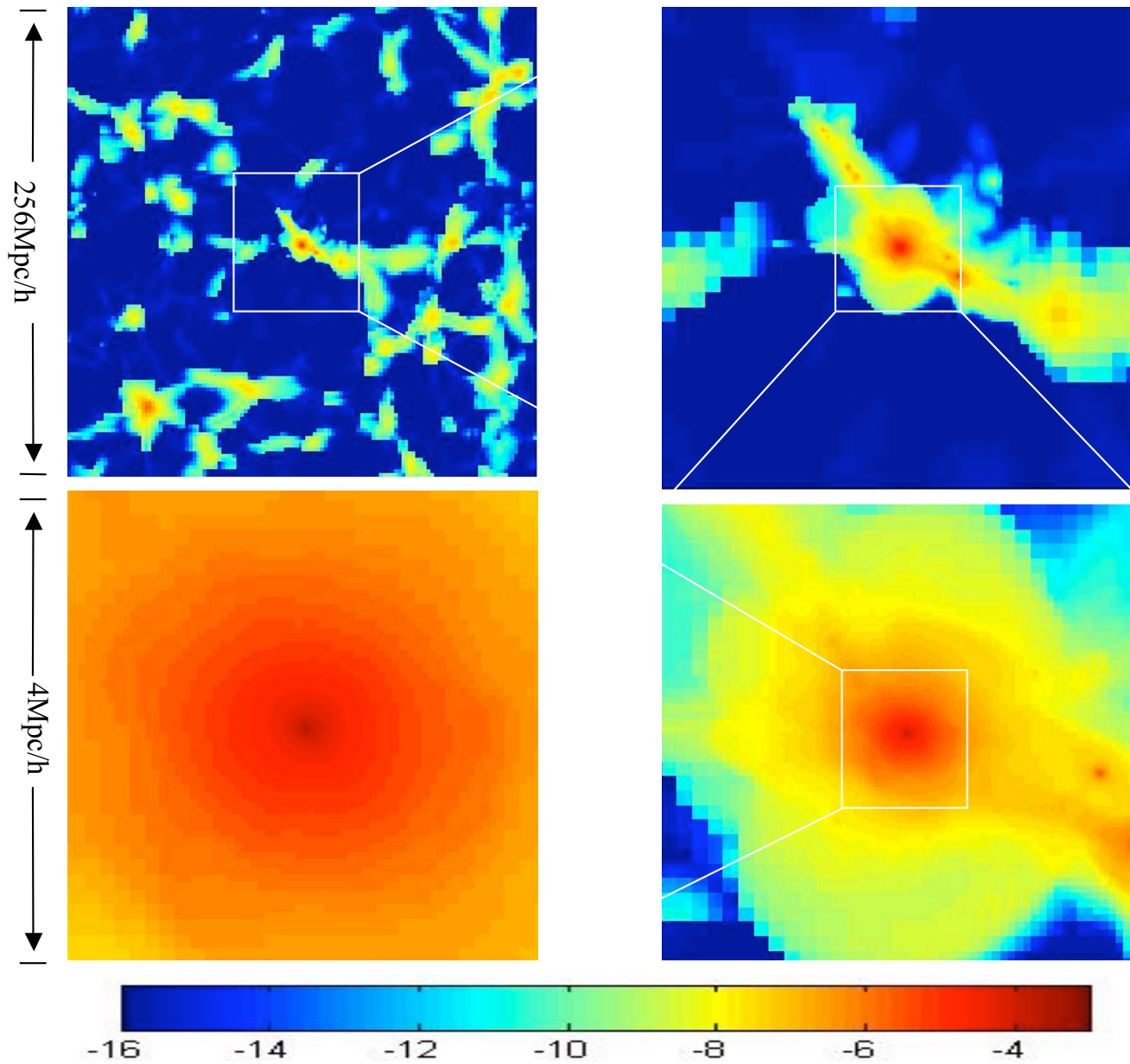
Same simulation with radiative cooling, star formation and star formation feedback, uniform initial magnetic fields of $1e-9$ G in y direction.



Magnetic Energy Density Evolution

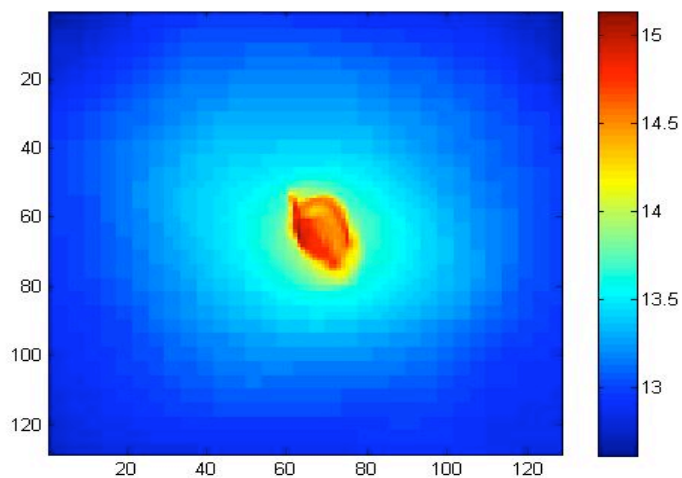


SZ Effect: y -parameter

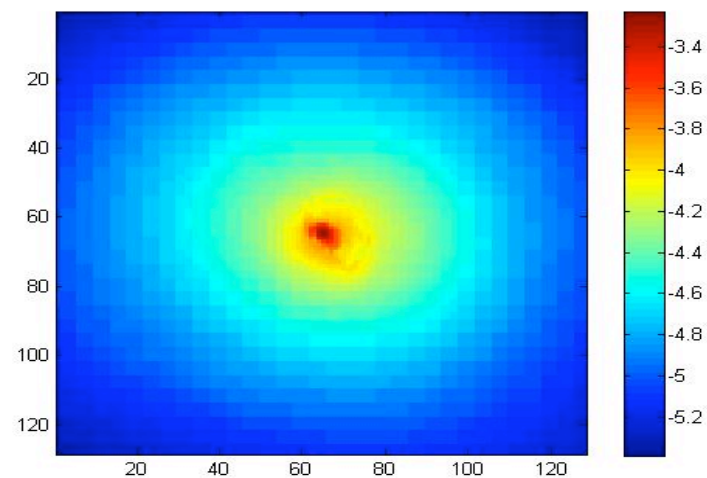


AMR MHD Cluster Formation Simulations

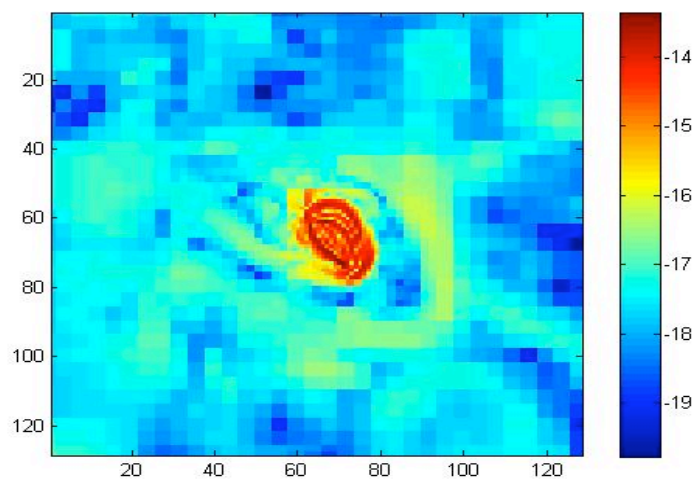
Images of cluster center(1Mpc/h)



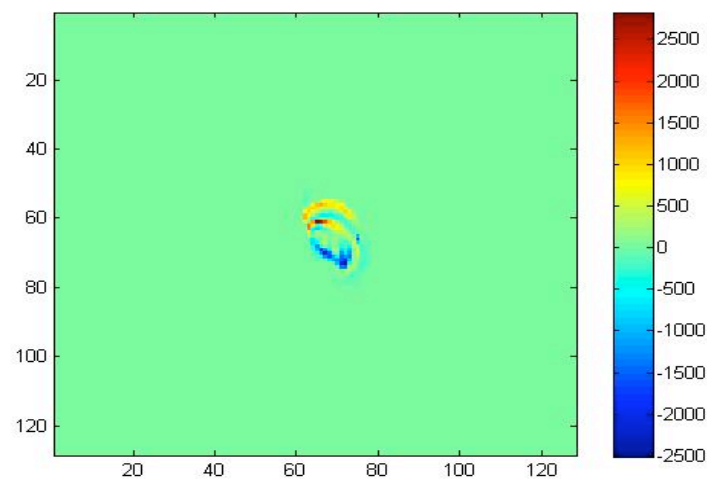
Gas density



SZ_y



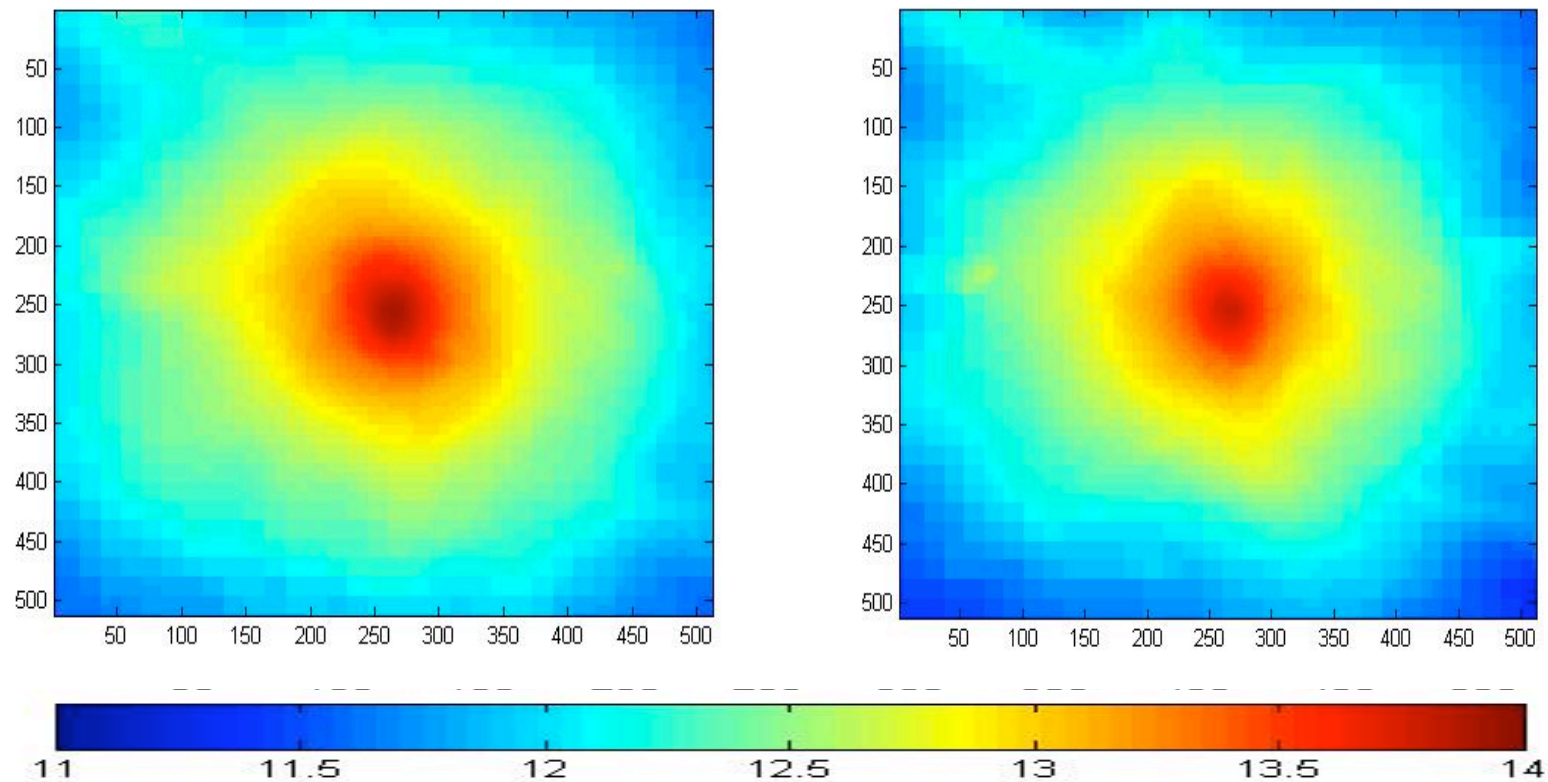
Magnetic energy density



Rotation measurement

AMR MHD Cluster Formation Simulations

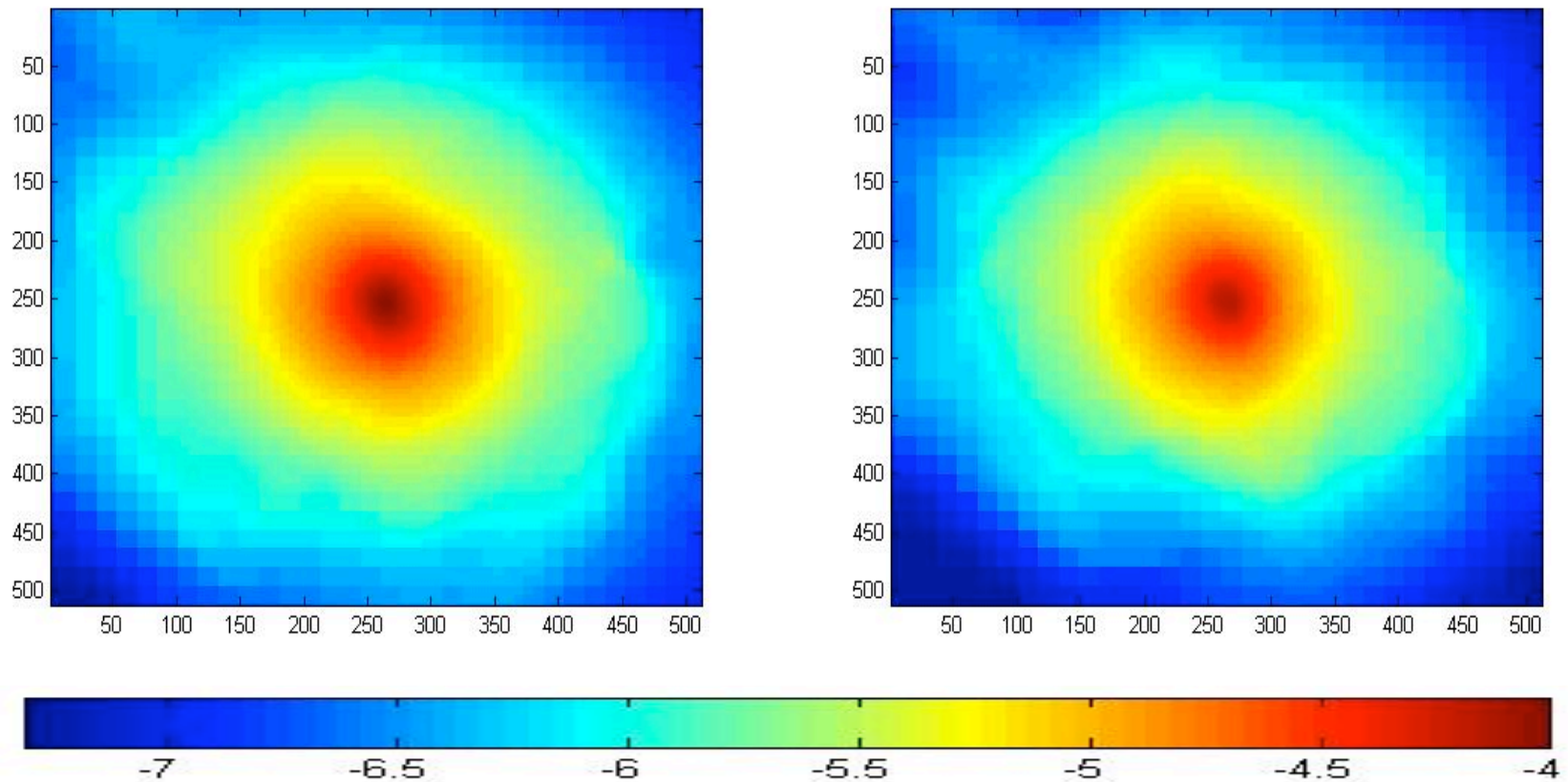
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Images of projected baryon density of inner 4 Mpc/h at $z=0$, left is from MHD solver and right is from ppm solver

AMR MHD Cluster Formation Simulations

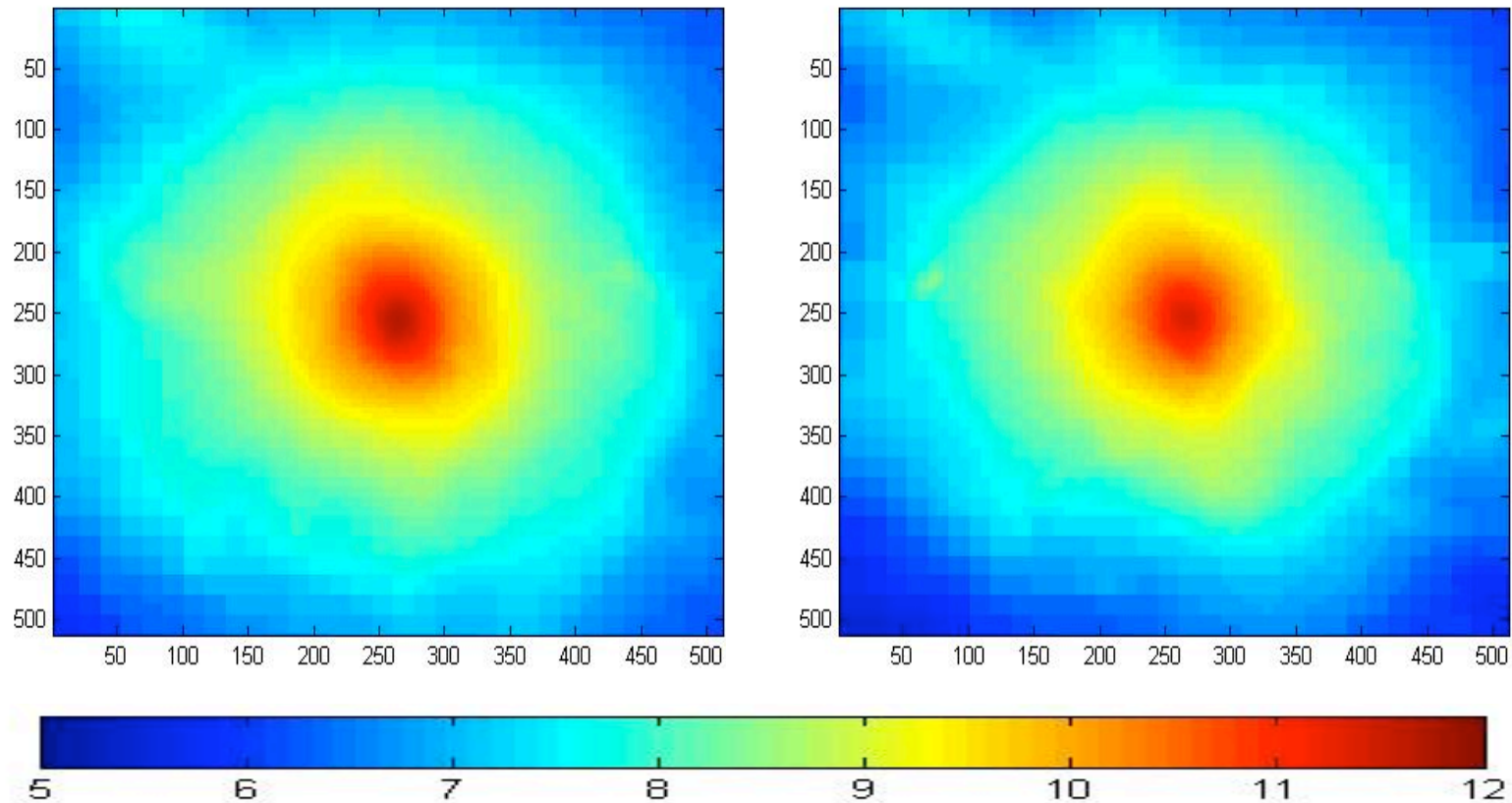
Λ CMD model, $\Omega=1$, $\Omega_\Lambda=0.7$, $\Omega_b=0.04$, $h=0.7$, and box size = 256 Mpc/h. Root grid is 128^3 , refined by 2 to level 8, simulation is from $z=30$ to $z=0$. No initial magnetic fields



Y parameter of SZ Effect of slice of inner 4 Mpc/h at $z=0$, left is from MHD solver and right is from ppm solver

AMR MHD Cluster Formation Simulations

Λ CMD model, $\Omega=1$, $\Omega_\Lambda=0.7$, $\Omega_b=0.04$, $h=0.7$, and box size = 256 Mpc/h. Root grid is 128^3 , refined by 2 to level 8, simulation is from $z=30$ to $z=0$. No initial magnetic fields



X-ray luminosity of inner 4 Mpc/h at $z=0$, left is from MHD solver and right is from ppm solver

Some Key Problems

1. **Diffused Radio Emission:** Distribution and strength of cosmic magnetic fields, seeding from first stars, dwarf galaxies, AGN feedbacks, or (turbulent) dynamo.
2. **Differential FRM of jet pc-kpc scale:** is there current?
3. **Clusters as magnetic field laboratories:** Structure formation, AGNs, heating, mixing, etc.
4. **Physical state of IGM:** impact on galaxy formation?
5. **UHECR** transport?
6. Does magnetic energy flow destroy the statistics of **Lyman-alpha forests**?