The role of magnetic fields in galaxy clusters and groups

(A5, A6, A7)

Magnetisation of Interstellar and Intergalactic Media:
The Prospects of Low-Frequency Radio Observations
Research Unit 1254

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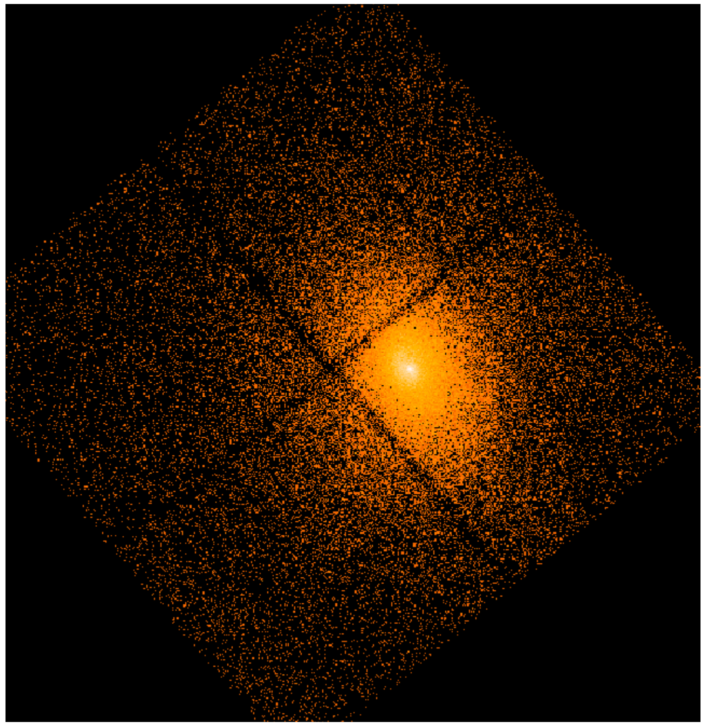
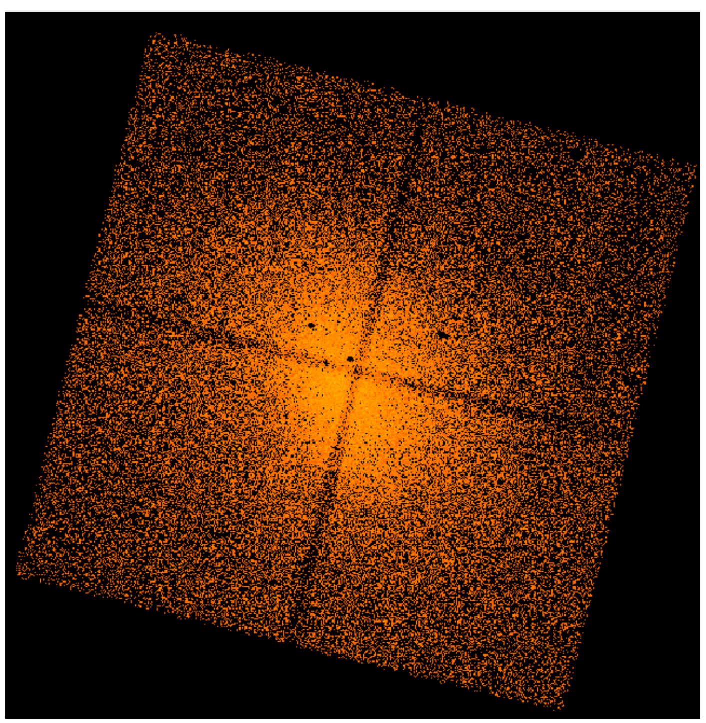
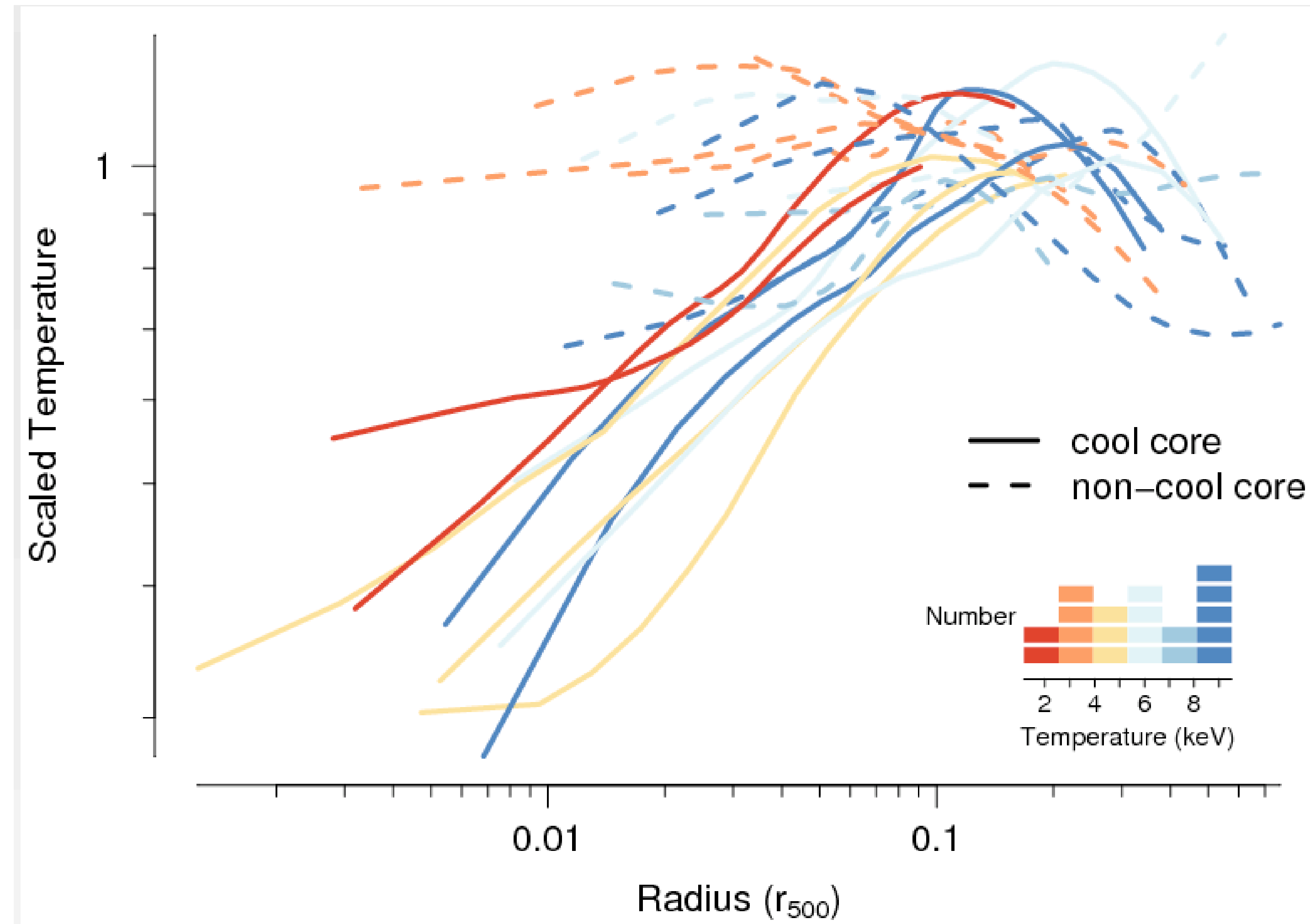
Two kinds of galaxy clusters







$$n \sim 10^{-4} - 1 \text{ cm}^{-3}$$

$$T \sim 1 - 15 \text{ keV}$$

$$L_X \sim 10^{43-46} \text{erg/s}$$

$$l_e \sim 2 \left(\frac{T}{3\text{keV}}\right)^2 \left(\frac{n}{0.01\text{cm}^{-3}}\right)^{-1} \text{ kpc}$$

large electron mean free path

thermal conduction important

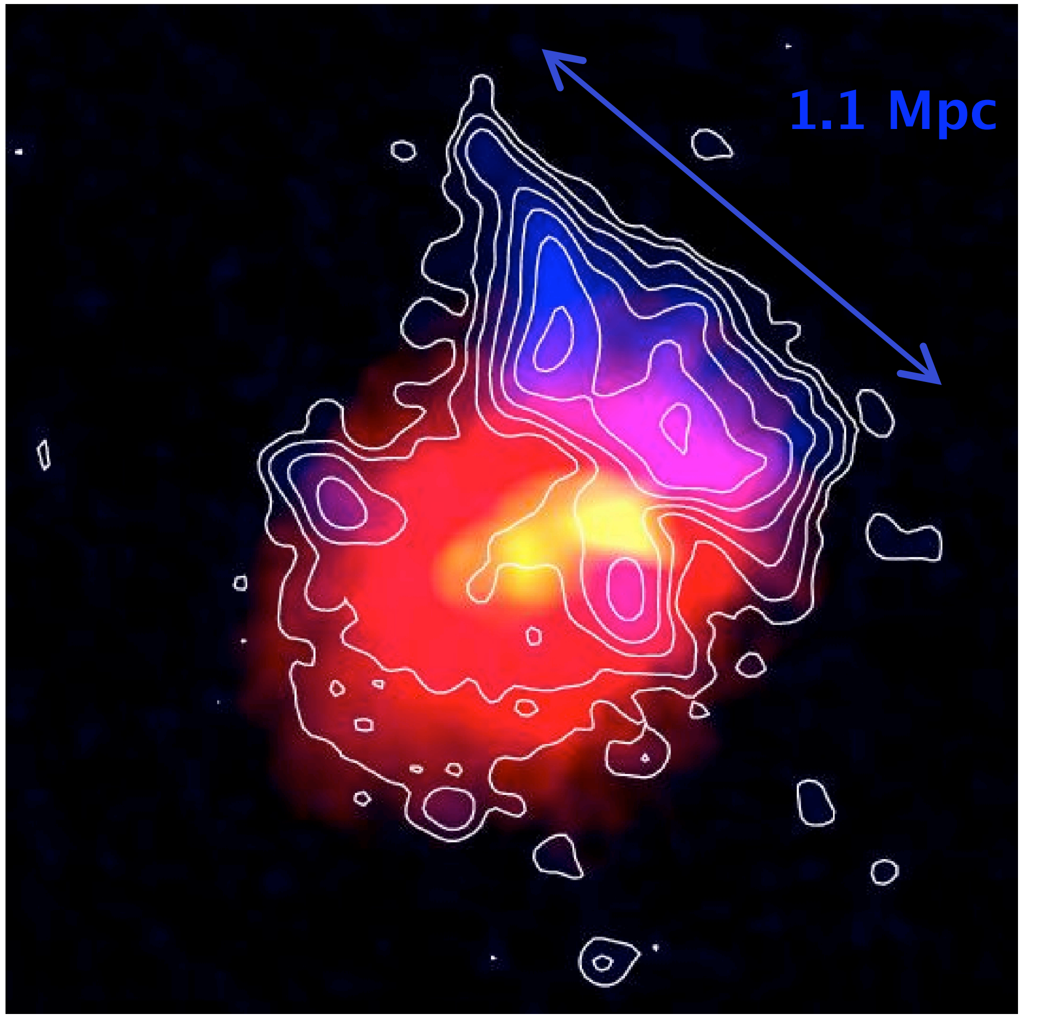
The gas in galaxy clusters is magnetised

small halo
large relic

red: x-ray
blue: radio

Abell 2256

[Clarke & Enßlin 06]



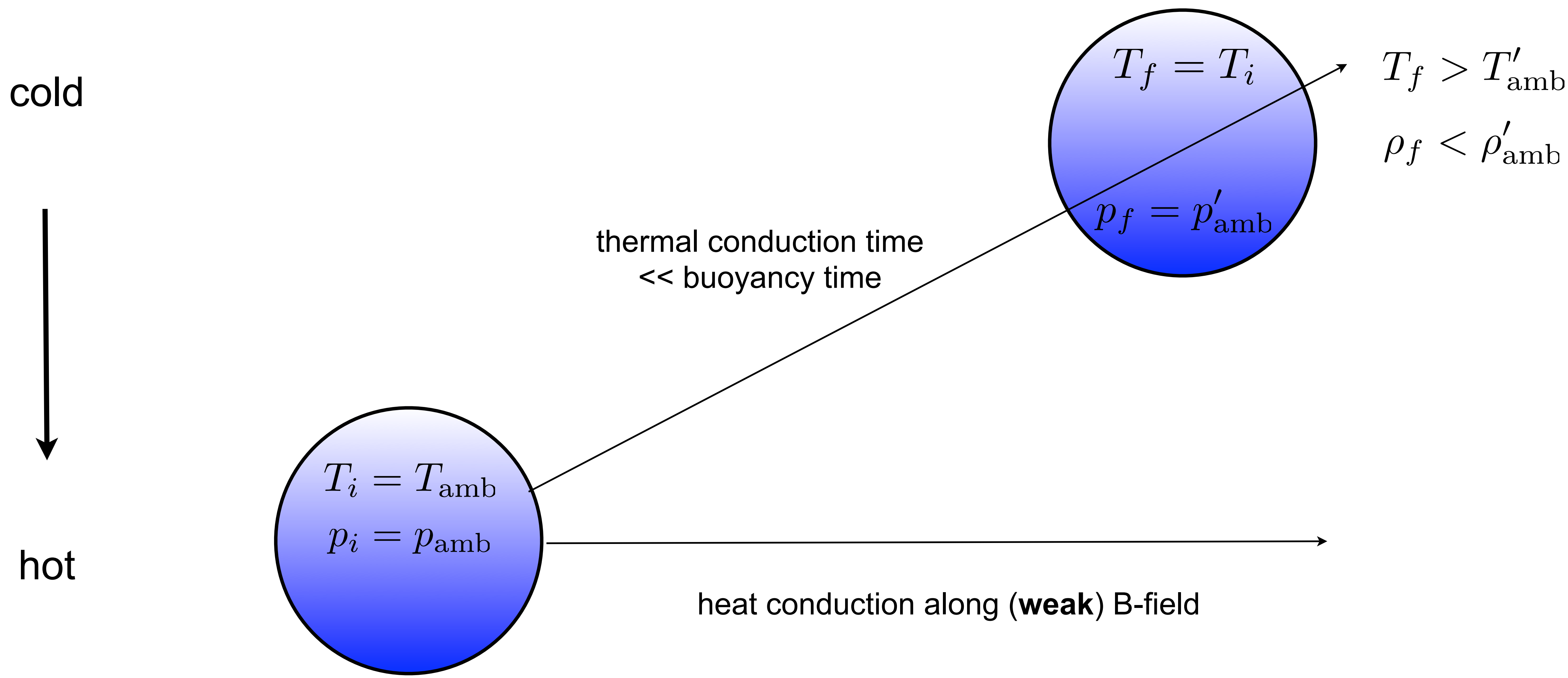
Abell 2256

- cluster cores can host fields as high as 10 muG
- field in cool cores higher than in non-cool cores
- correlation lengths around 10 kpc

Is the magnetic field dynamically important in clusters?

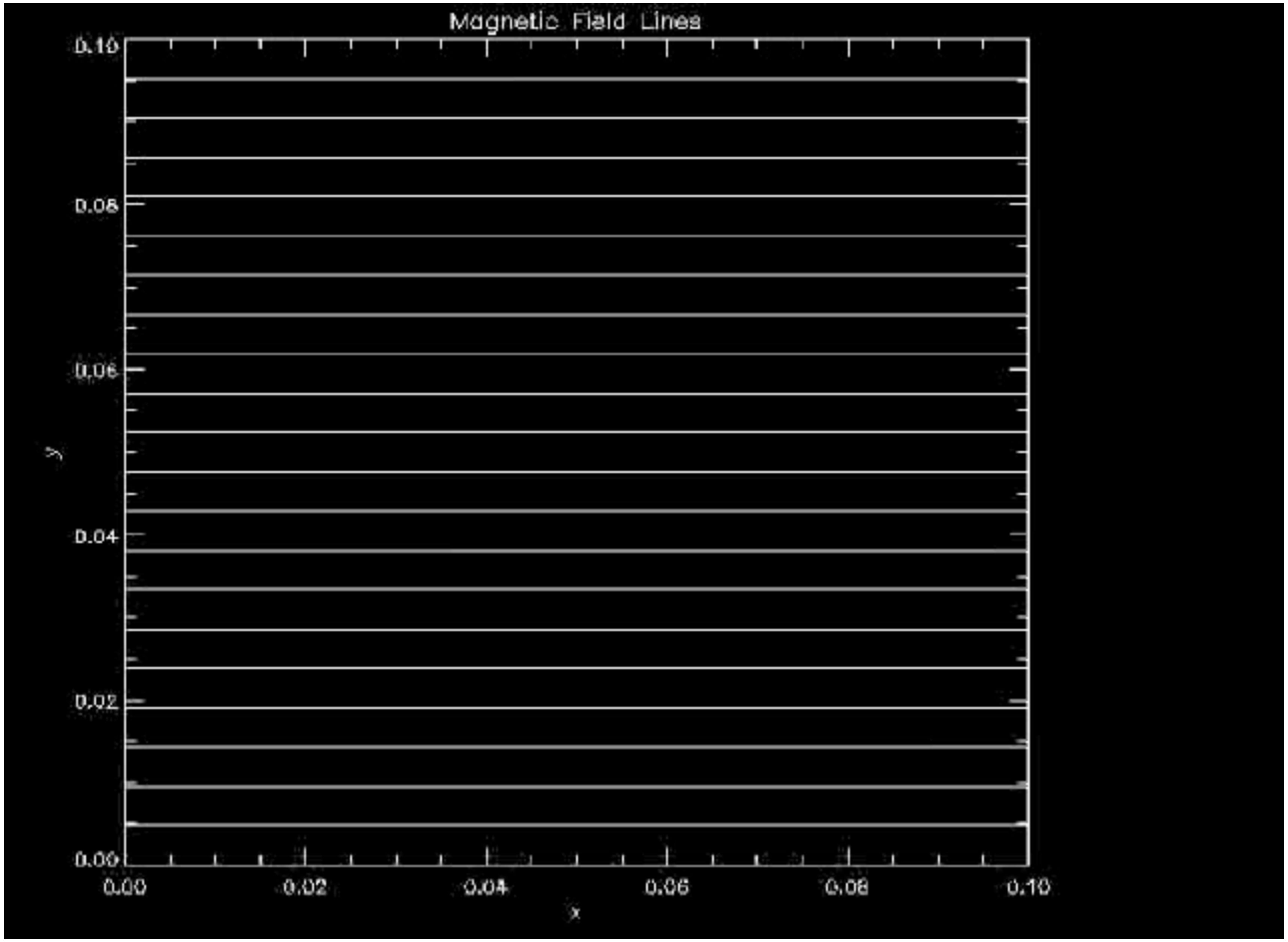
One example:
The three letter instabilities
or
Why is nothing ever stable?

The Magnetothermal Instability (MTI)



convectively unstable: dT/dz < 0

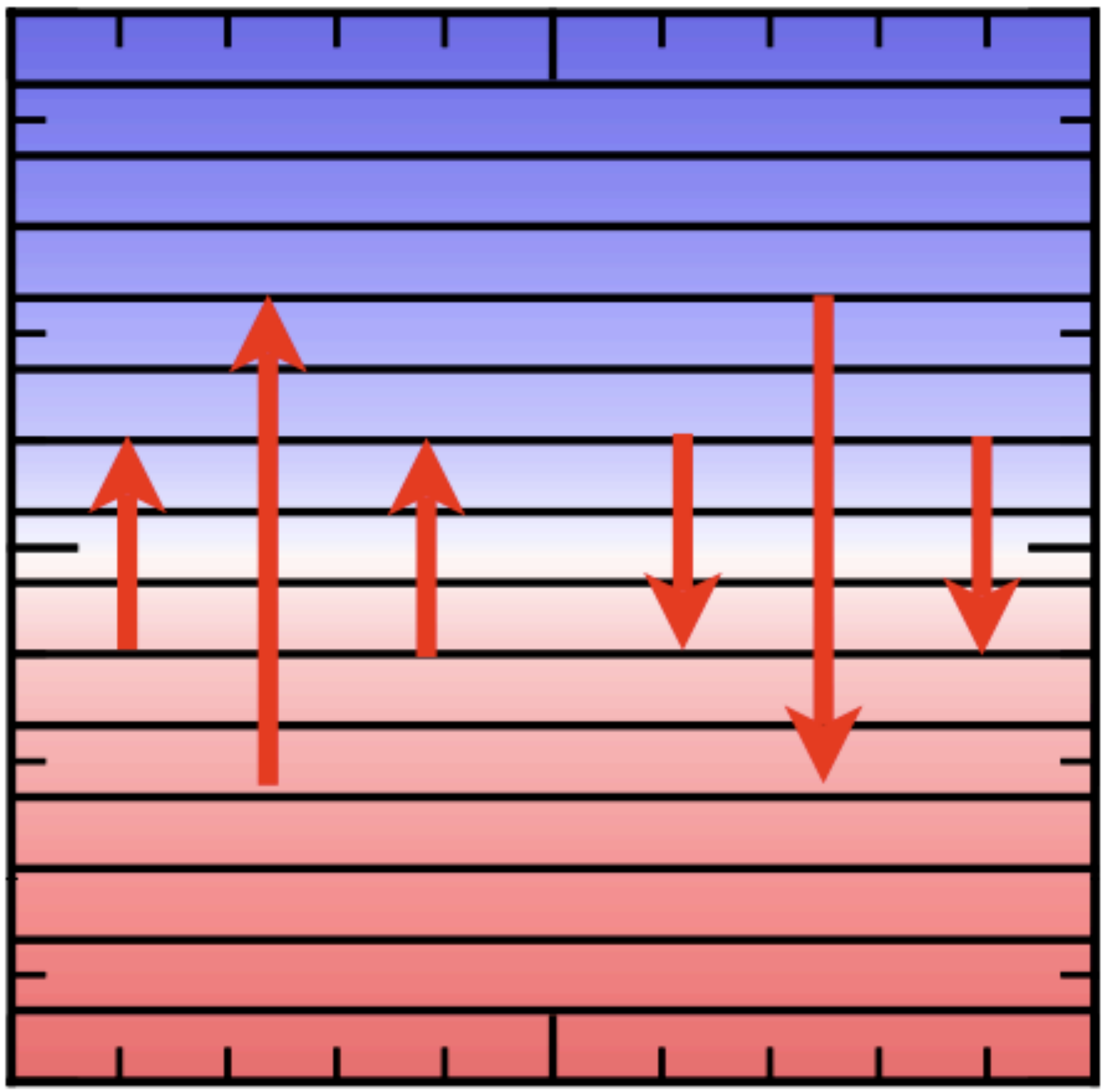
2D simulations of the MTI



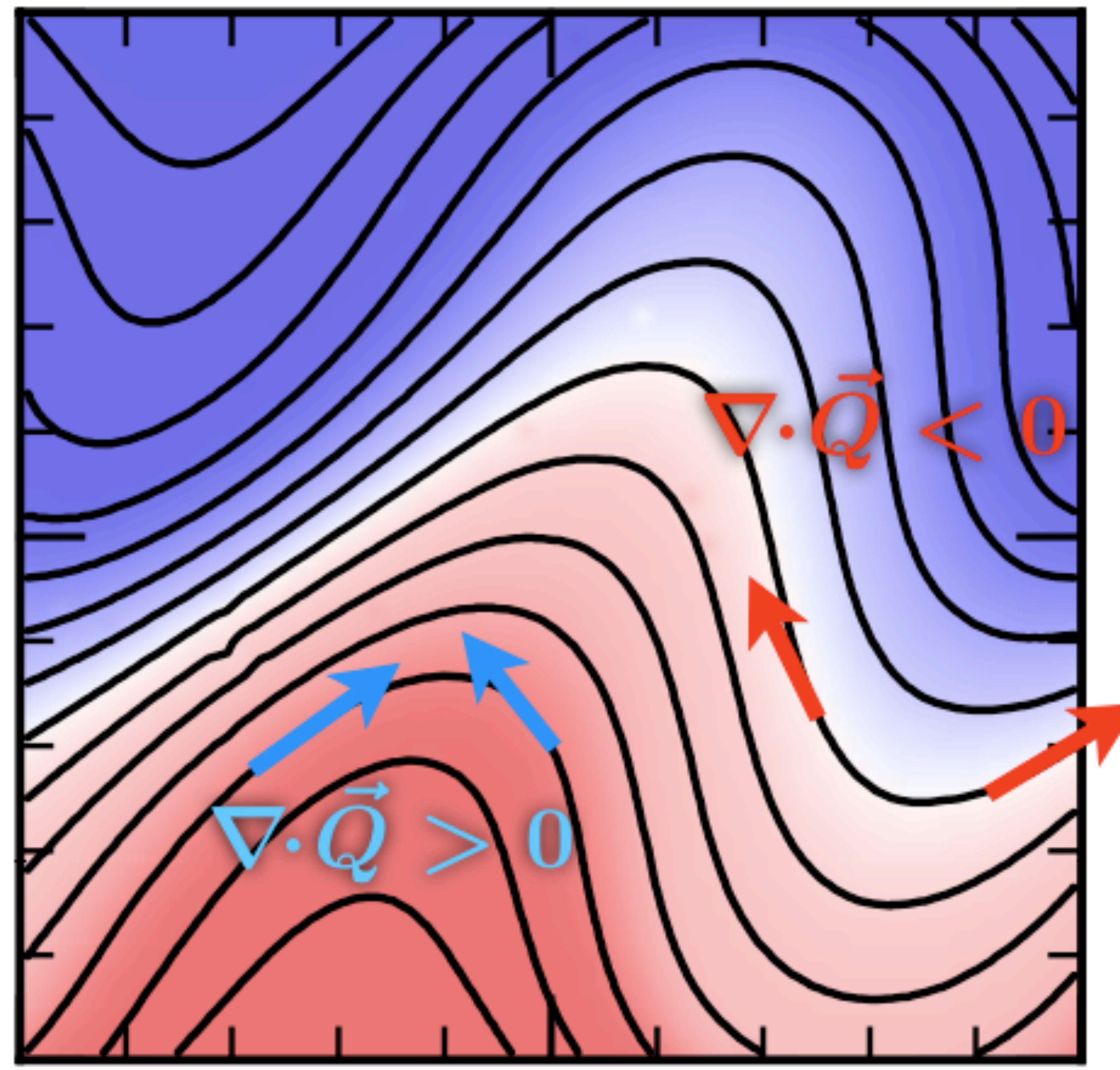
Simulation by I. Parrish

Linear Evolution of the MTI

Temperature ($t = 0$)

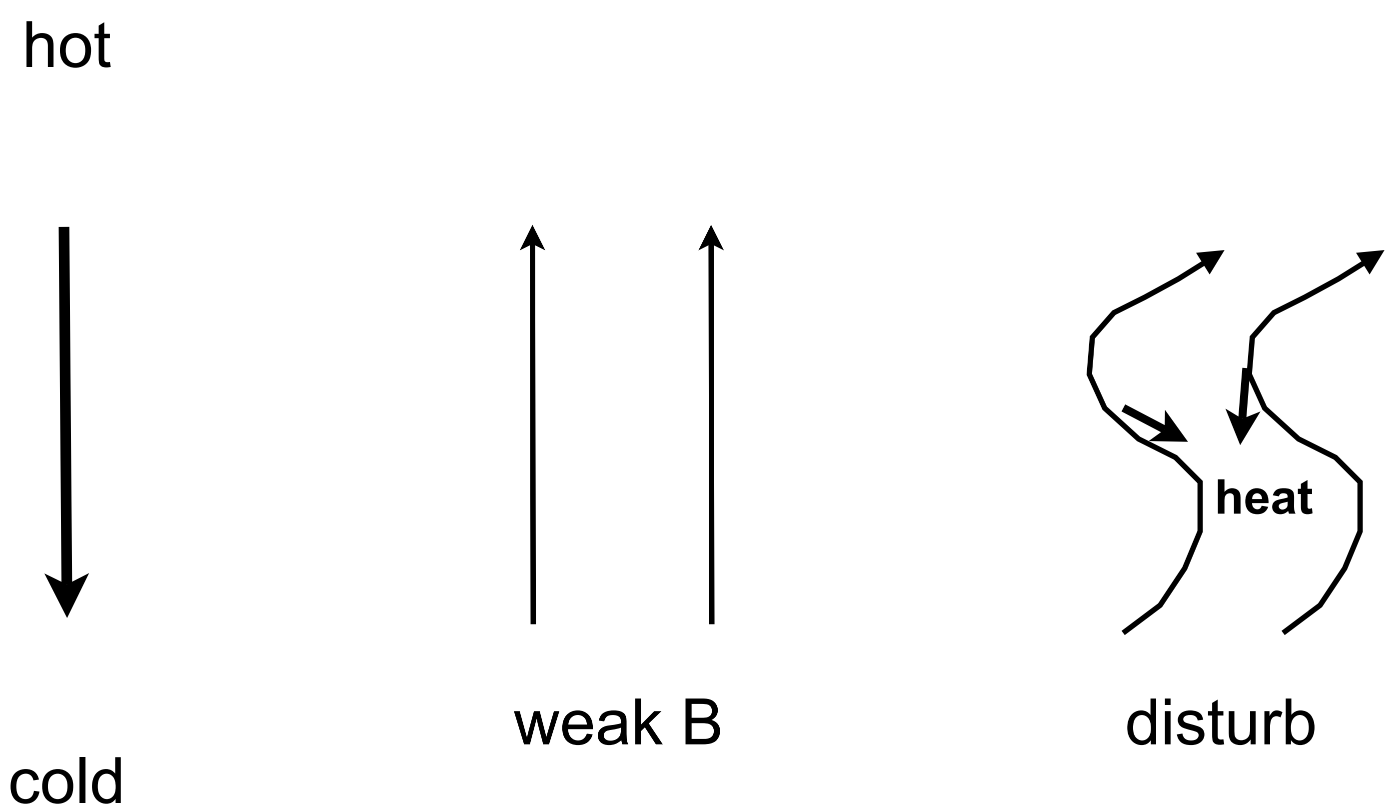


Temperature ($t = 5\ t_{buoy}$)



The Heat flux-driven Buoyancy Instability (HBI)

Quataert 2008, Parrish & Quataert 2008



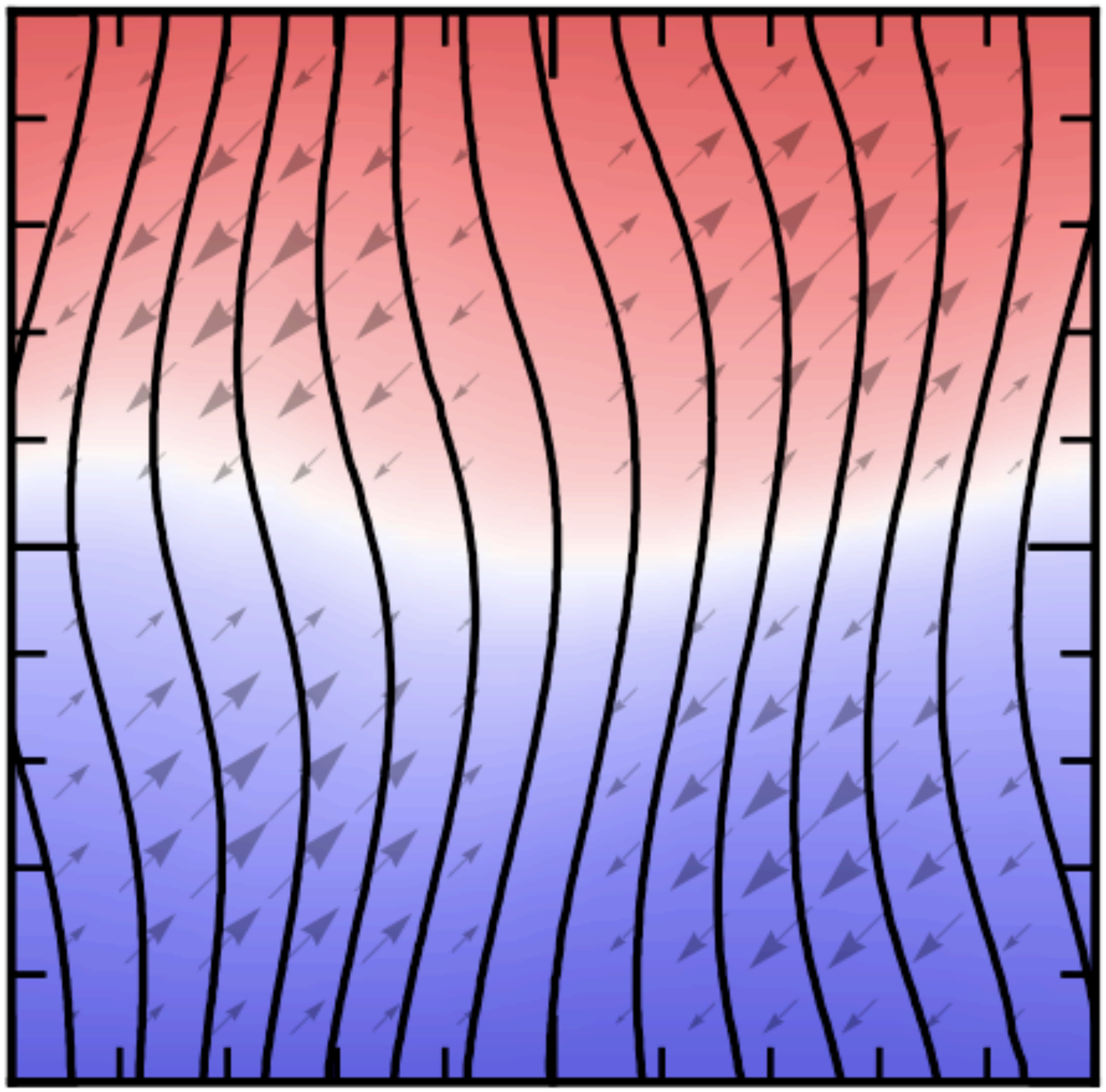
converging & diverging
heat flux

for dT/dz > 0
upwardly displaced fluid
is heated and rises

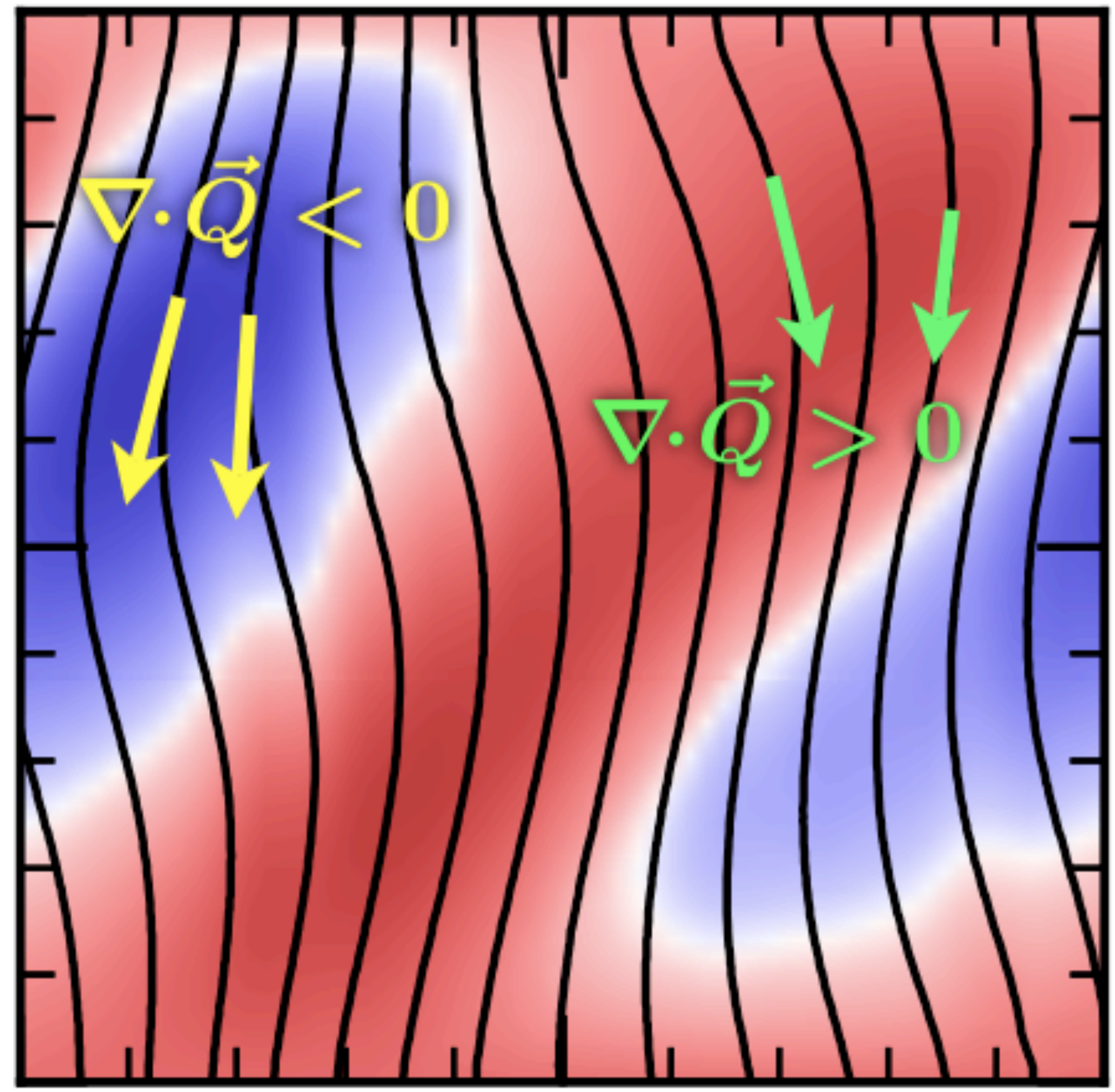
convectively unstable: dT/dz > 0
most unstable for B parallel to g
drives fields to horizontal
amplifies magnetic fields

Linear Evolution of the HBI

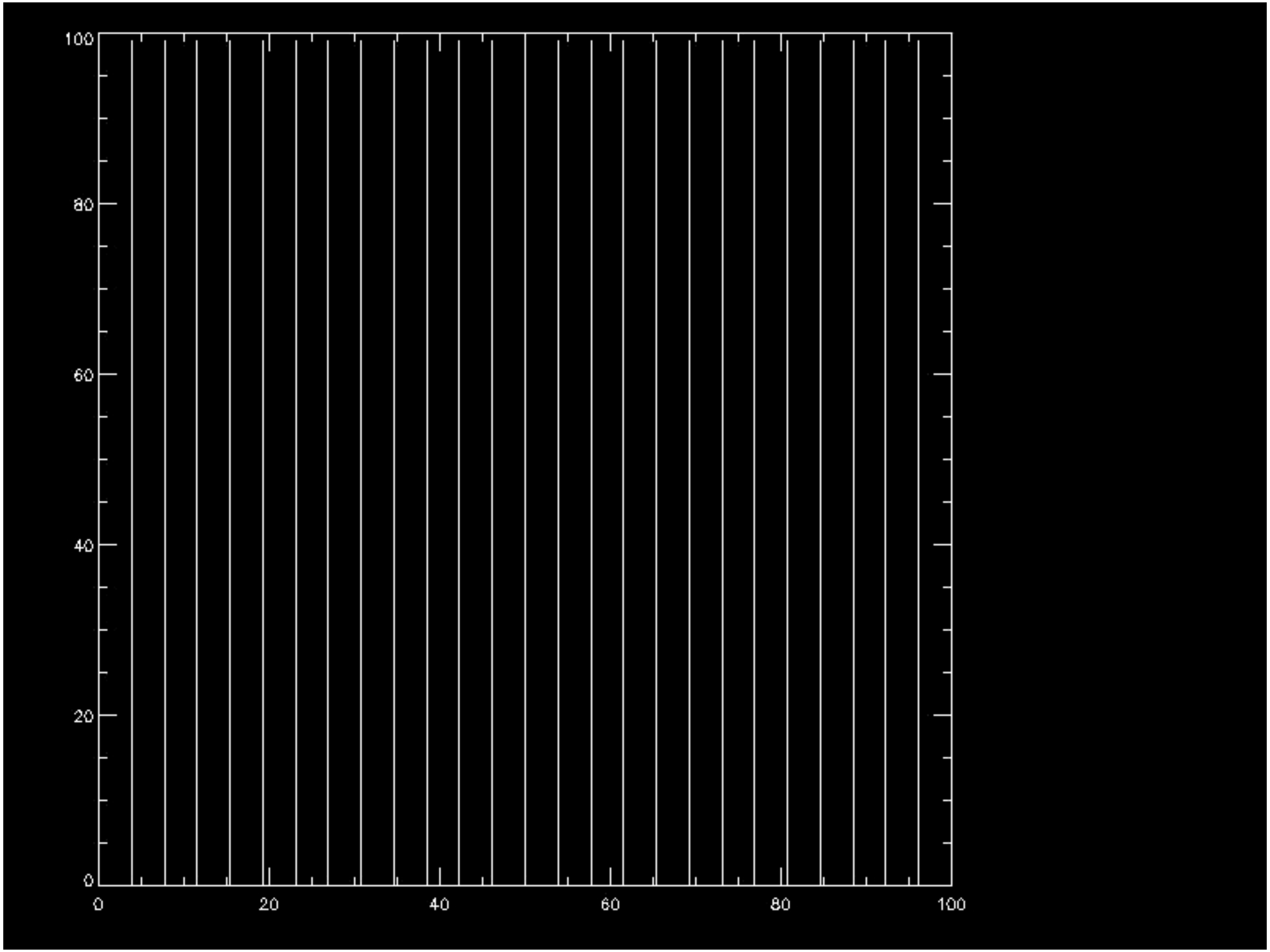
Temperature $(t = 5\ t_{buoy})$



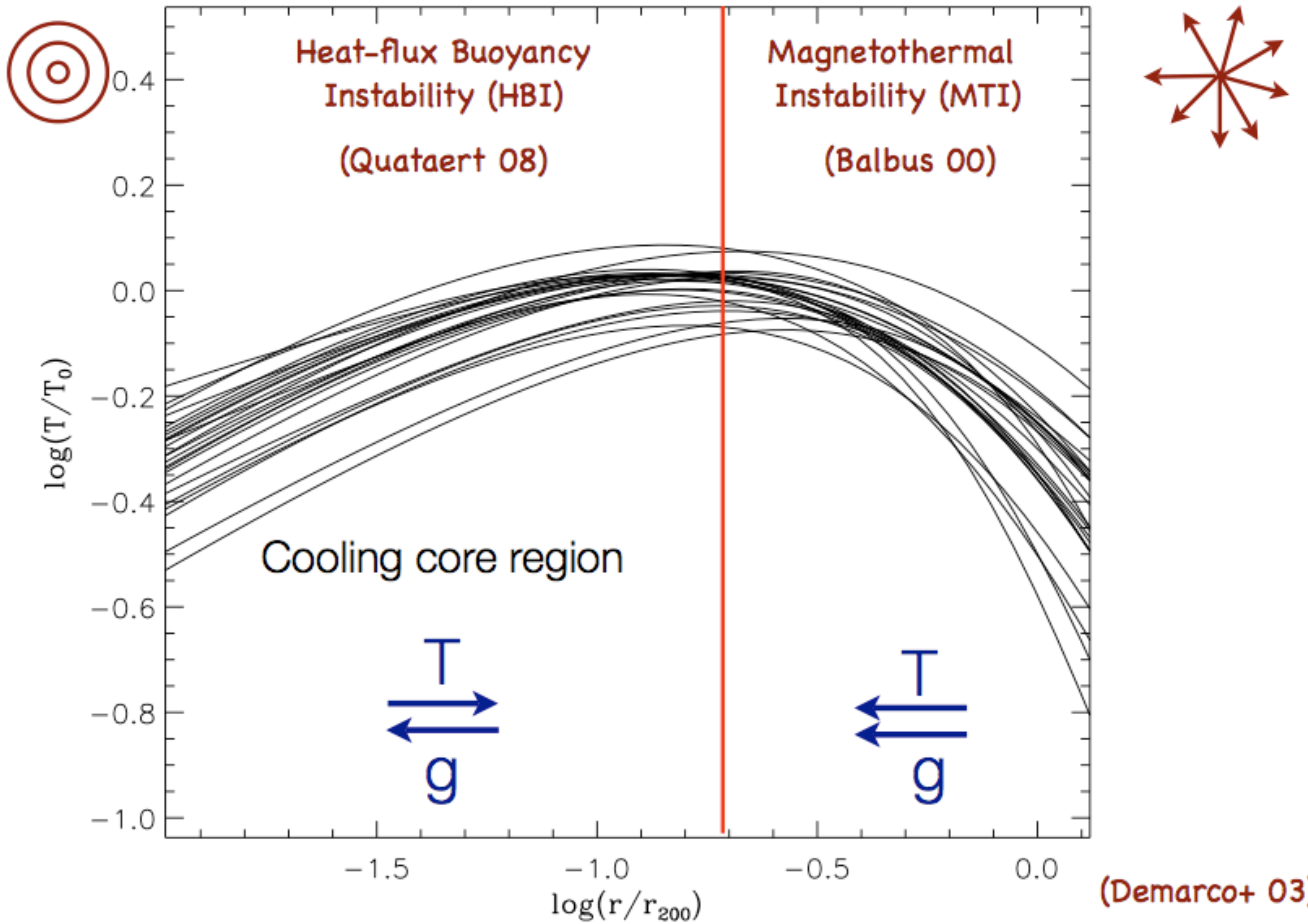
ΔT



2D simulation of the HBI (by I. Parrish)



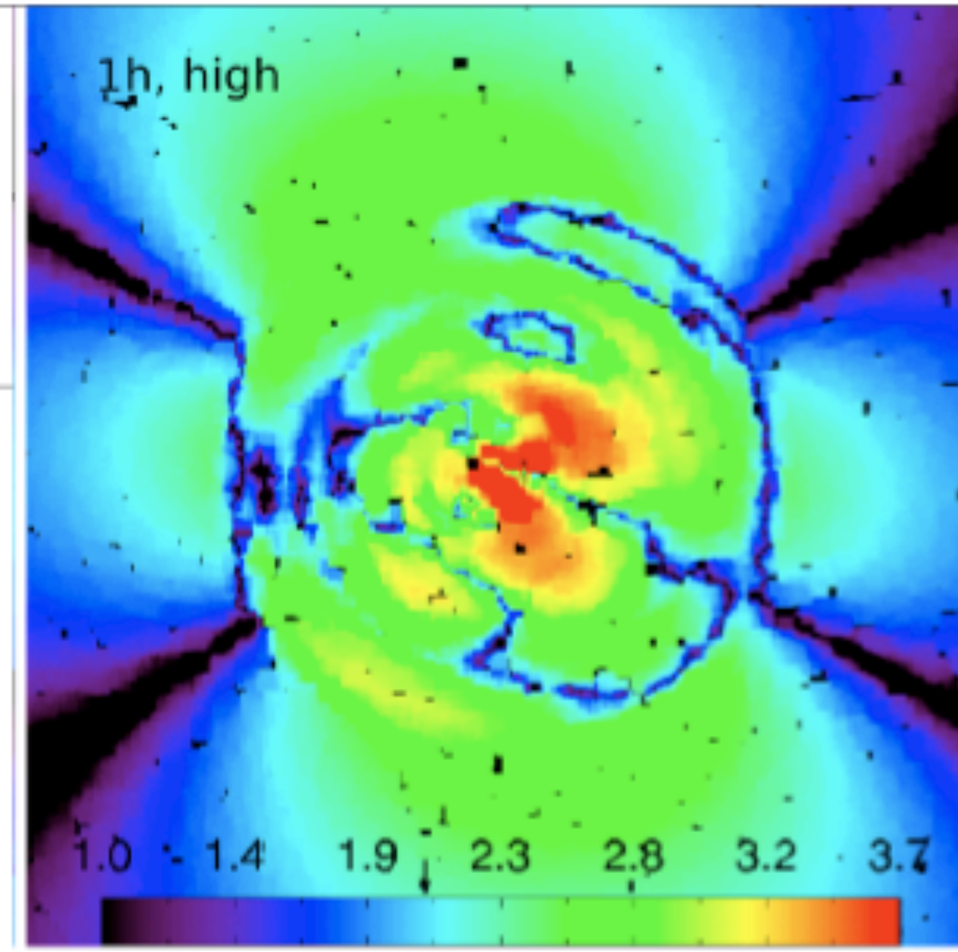
MHD instabilities at all radii in ICM

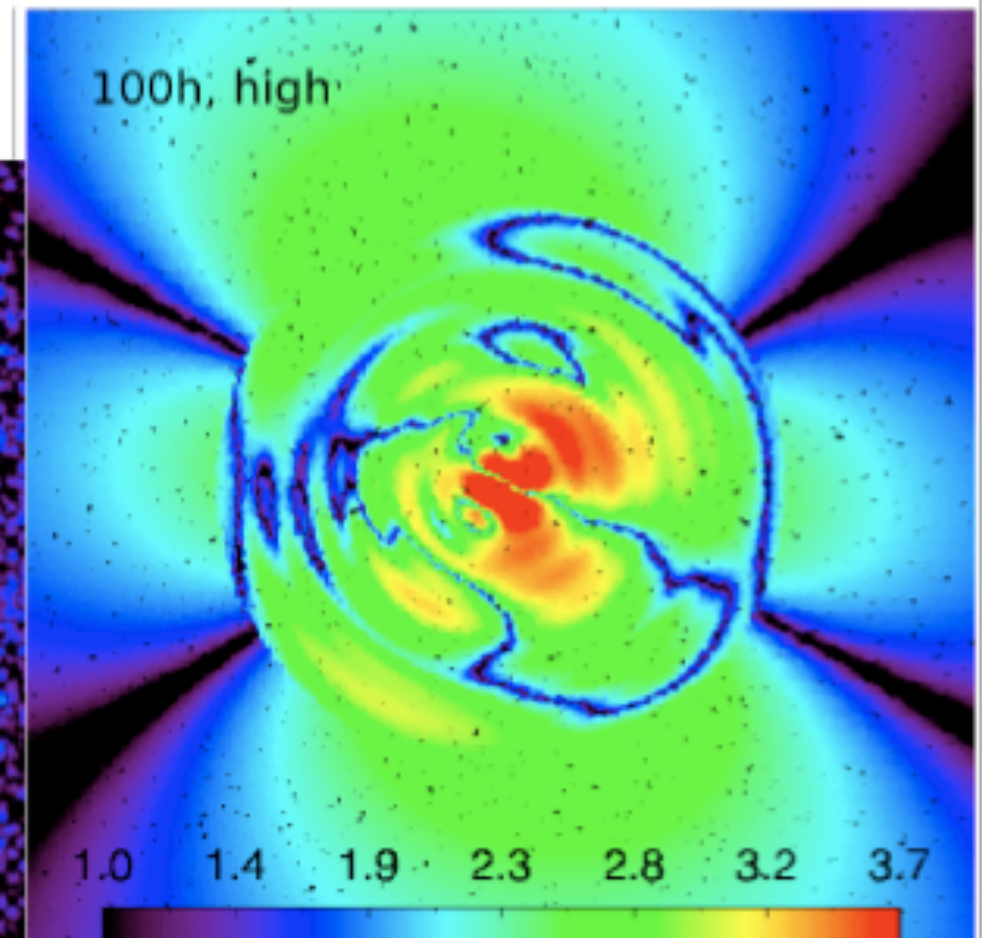


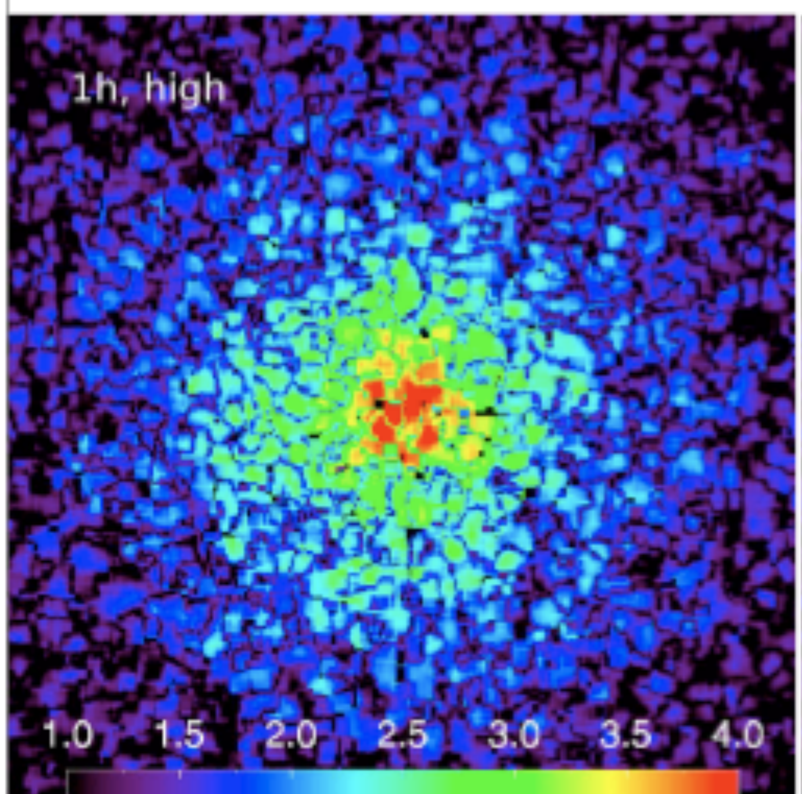
(TB+ 2010)

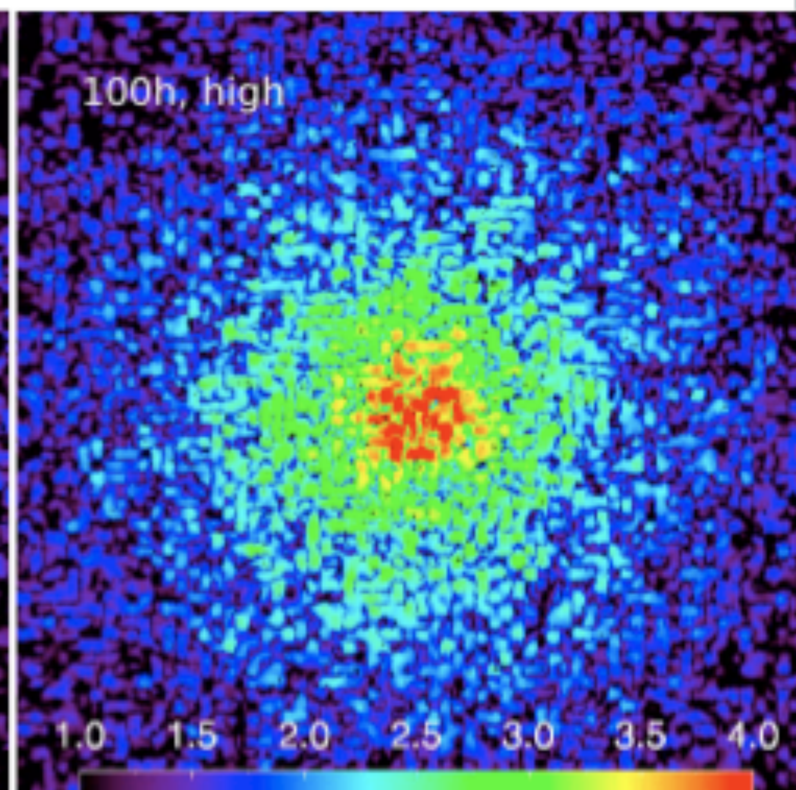
Simulated observations with SKA

- **Key idea:** Search for imprints of instabilities in dynamically relaxed cooling core clusters.
- Field geometry likely to be perturbed by AGN activity, mergers, shocks, bubbles, relics.
- eVLA will also offer improved sensitivity

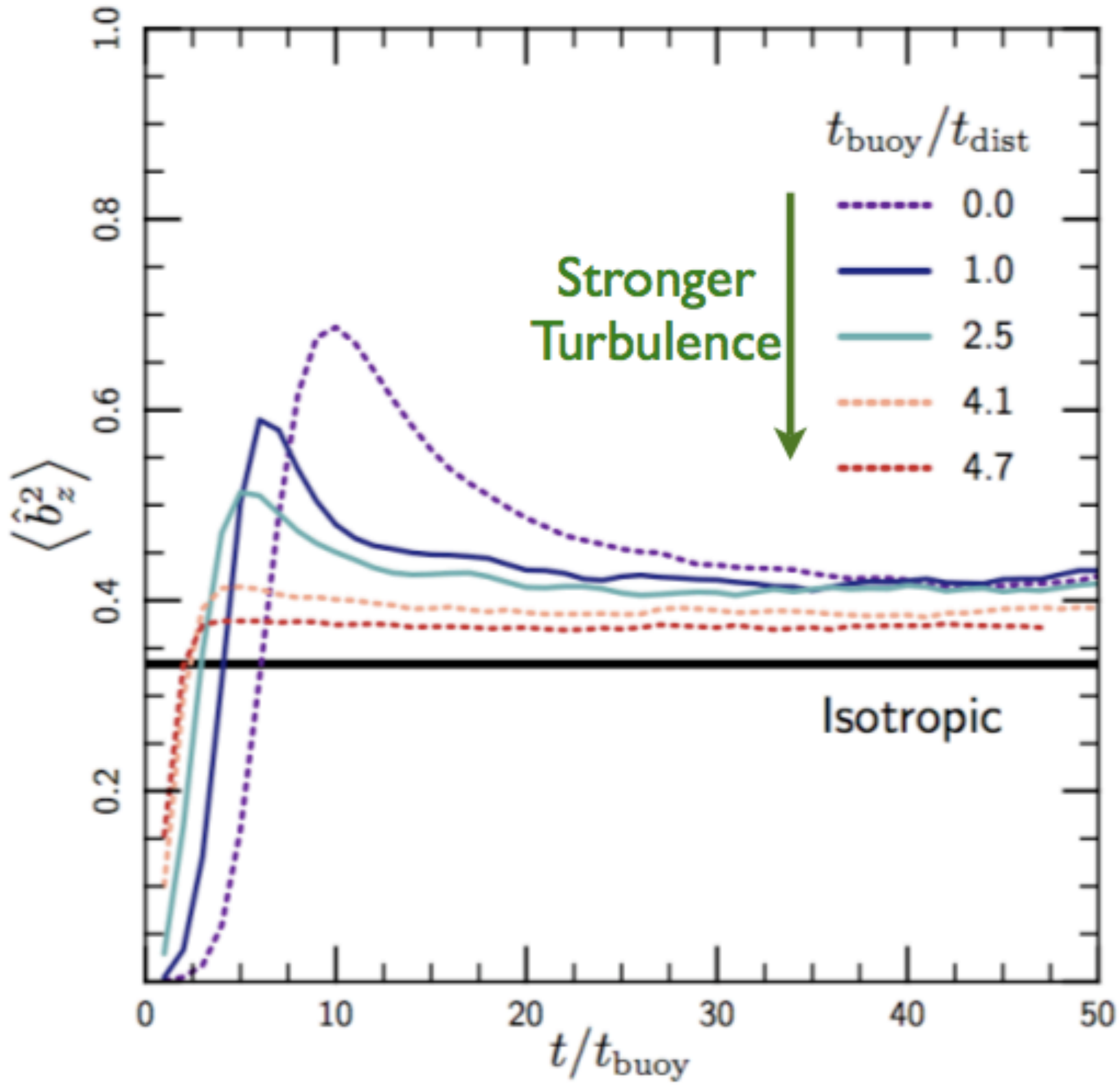








But what about in a real cluster in a cosmological setting?



$t_{\rm buoy}/t_{\rm dist}$
0.0
1.0
2.5
4.1
4.7
Stronger Turbulence
Isotropic
$\langle \hat{b}_z^2 \rangle$
$t/t_{\rm buoy}$
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
50

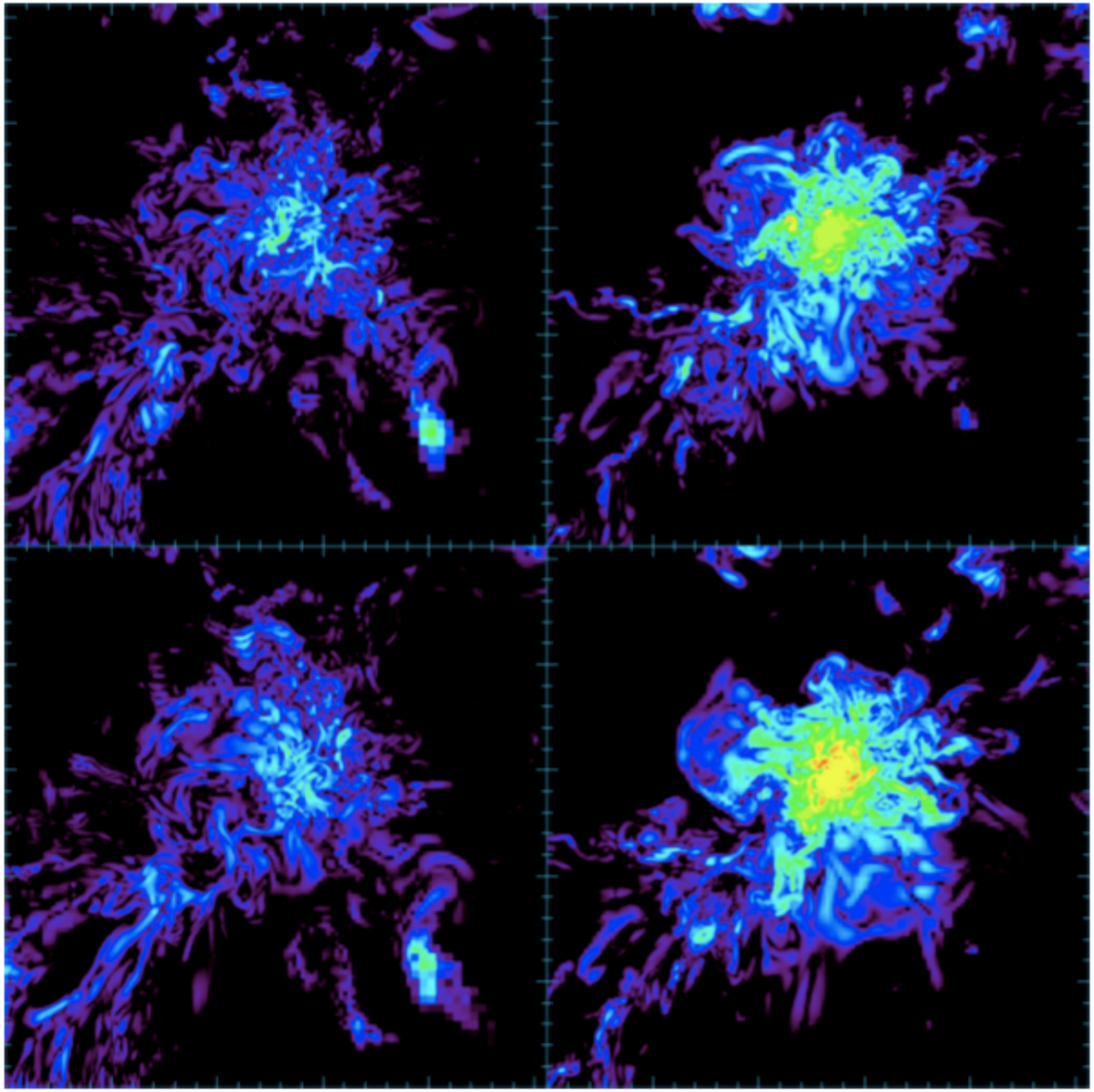
B-Field

no cooling

no conduction

cooling

no conduction



no cooling

conduction

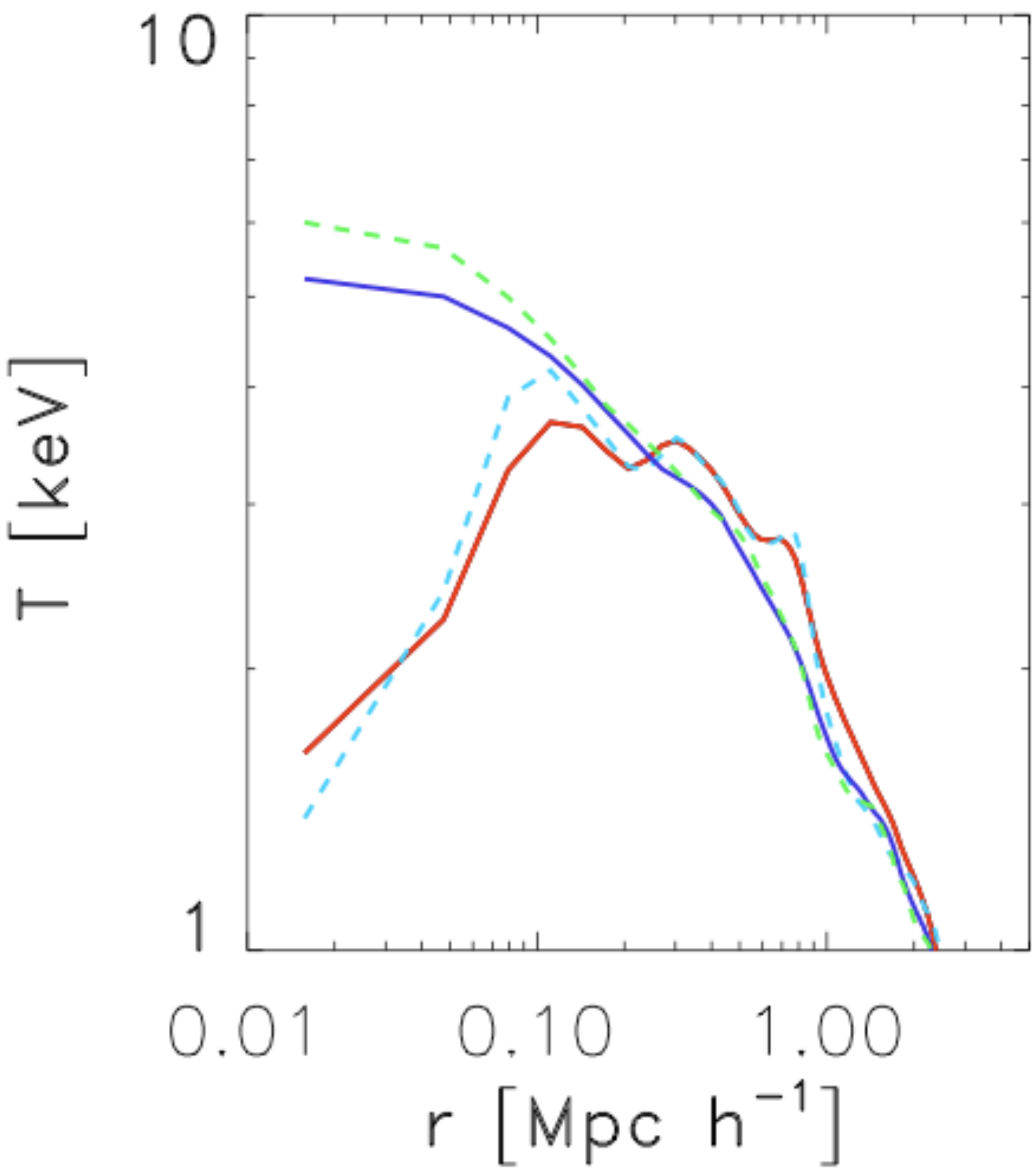
cooling

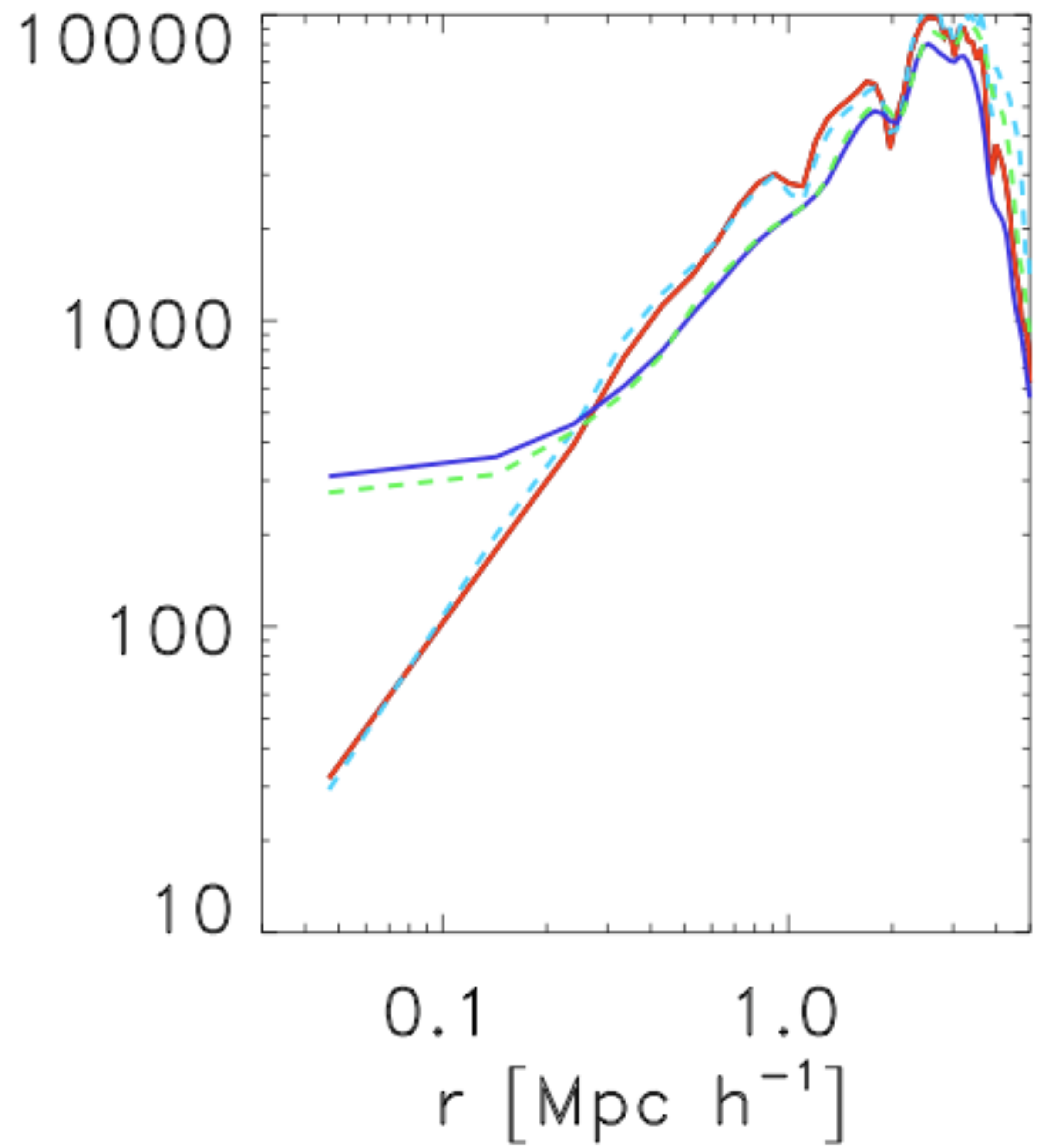
conduction

32/ h kpc

FIG. 7.— Cross sections through the cluster center showing the distribution of the logarithm of the magnetic field pressure. The minimum and maximum range of magnetic field values is the same in all panels. The arrangement of the figures is the same as in Figure 1 that shows the temperature distribution: right column is for radiative runs and bottom row is for the runs with anisotropic thermal conduction. All panels show the central region that measures $8h^{-1}$ Mpc on the side.

Ruszkowski, Brüggen, Oh, Parrish 2010





Ruszkowski, Brüggen, Oh, Parrish 2010

FIG. 2.— Temperature profiles of the cluster. Dashed green curve is for the adiabatic run, solid dark blue for anisotropic conduction, dashed light blue for radiative cooling, and solid red is for radiative cooling with anisotropic conduction. The profiles are not density-weighted.

FIG. 3.— Entropy profiles of the cluster. The meaning of the curves is the same as in Figure 2. Entropy is defined as $K = k_{\mathrm{boltz}} T / n_e^{2/3}$ and the plot units are [keV cm^2].

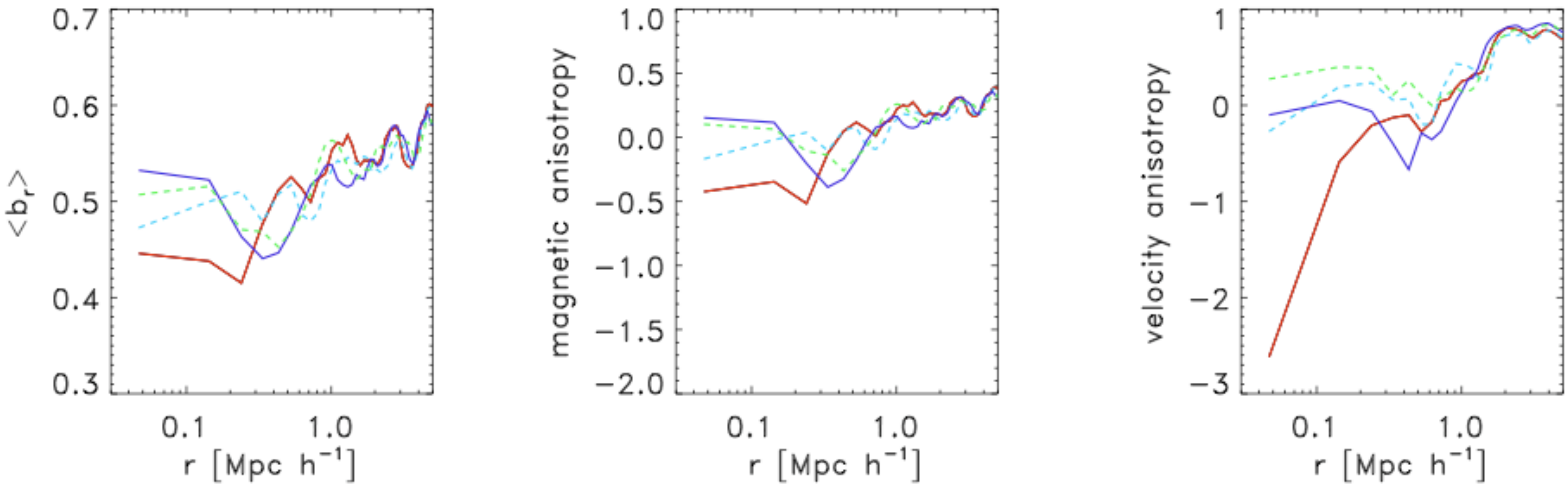


FIG. 4.— Left panel: absolute value of the radial component of the magnetic field vector. Middle and right panels show anisotropy parameters for the magnetic (middle panel) and velocity fields. Negative values correspond to tangential fields, zero is for the isotropic case. Anisotropy is defined as $\beta = 1 - \sigma_t^2/2\sigma_r^2$, where σ_r and σ_t are the dispersions of either the magnetic field or the velocity field. The color coding of all curves is the same as in Figure 2.

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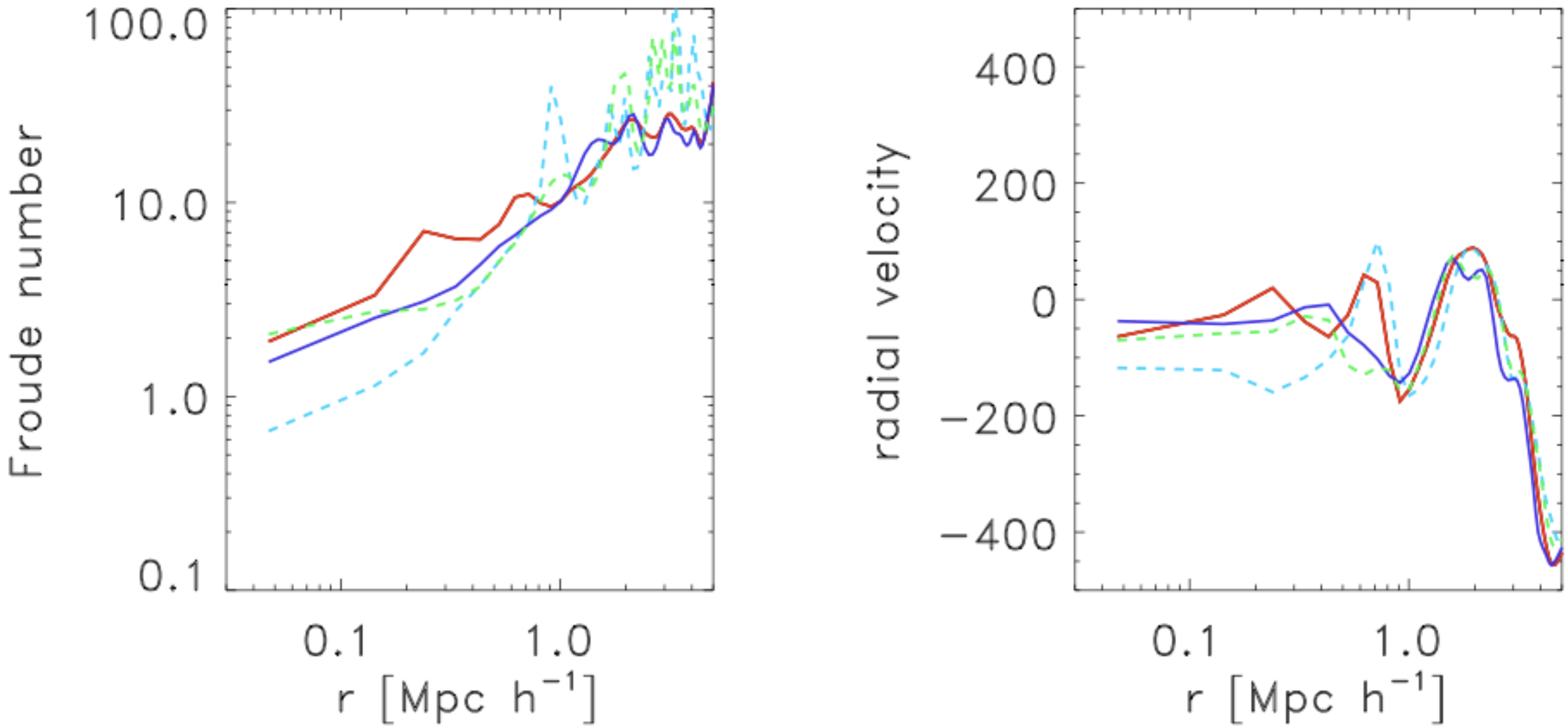

FIG. 5.— Froude number Fr as a function of the distance from the cluster center (left panel) and the radial component of the gas velocity. The color coding of the curves is the same as in Figure 2. For $Fr \gg 1$ the turbulence is expected to randomize the magnetic field that would otherwise be established by MTI and HBI instabilities.

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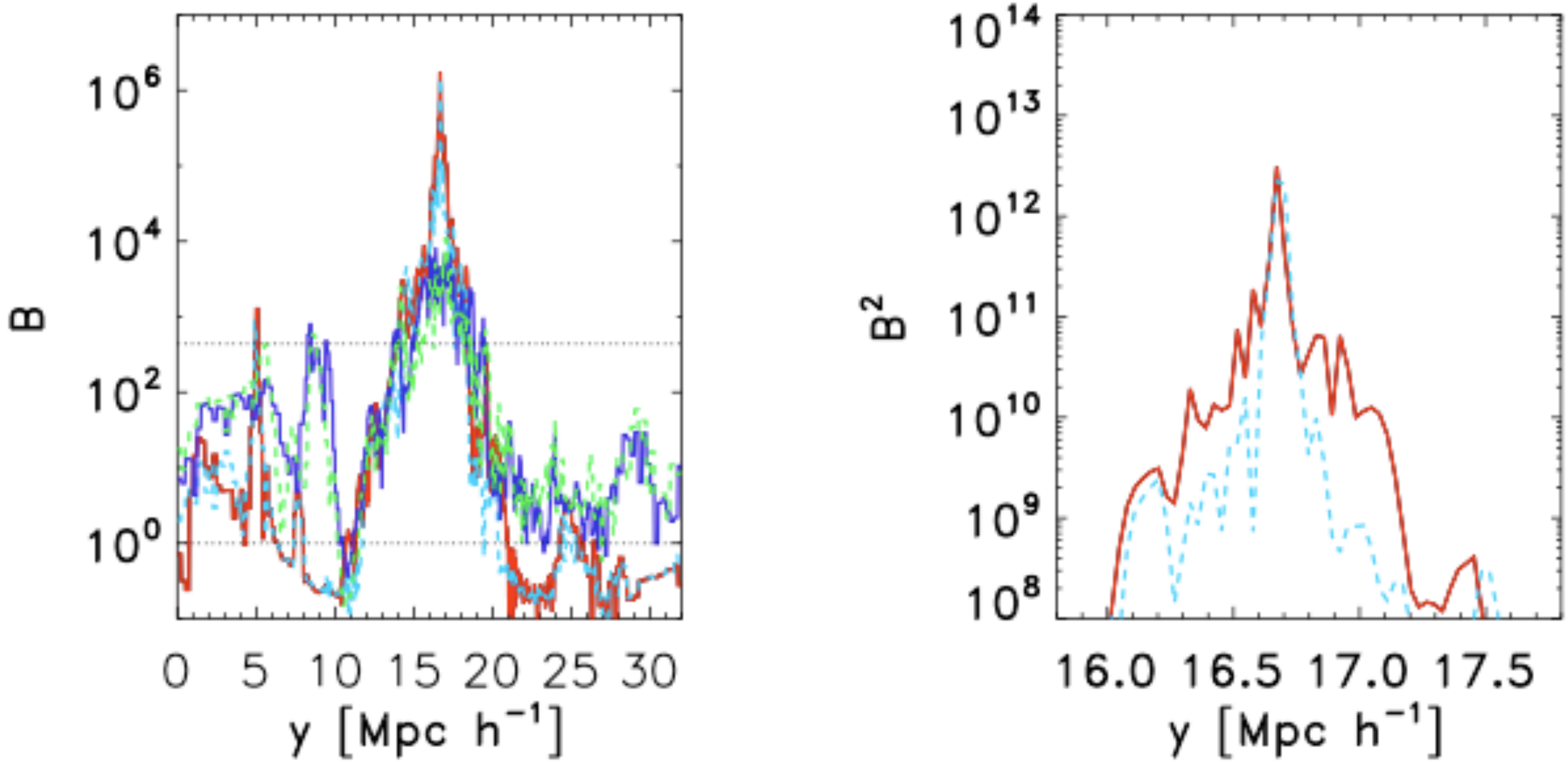


FIG. 8.— The distribution of the magnetic field along the line passing through the cluster center (left panel). The color coding of the curves is the same as in Figure 2. The top horizontal line denotes the physical field at the initial redshift ($z = 20$) and the bottom one is for the value of the field that would result from cosmological expansion down to $z = 0$ without any structure formation effects. Right panel shows the magnetic pressure along the line passing through the cluster. Here the solid red line is for the anisotropic conduction and cooling while the dashed light blue line is for the run that includes only radiative cooling.

Ruszkowski, Brüggen, Oh, Parrish 2010

First results

- In cluster outskirts, the magnetic field is preferentially radial
- This radial field is caused by the accretion of matter
- The MTI has no strong effect
- Cooling + anisotropic conduction lead to higher B-field amplification than

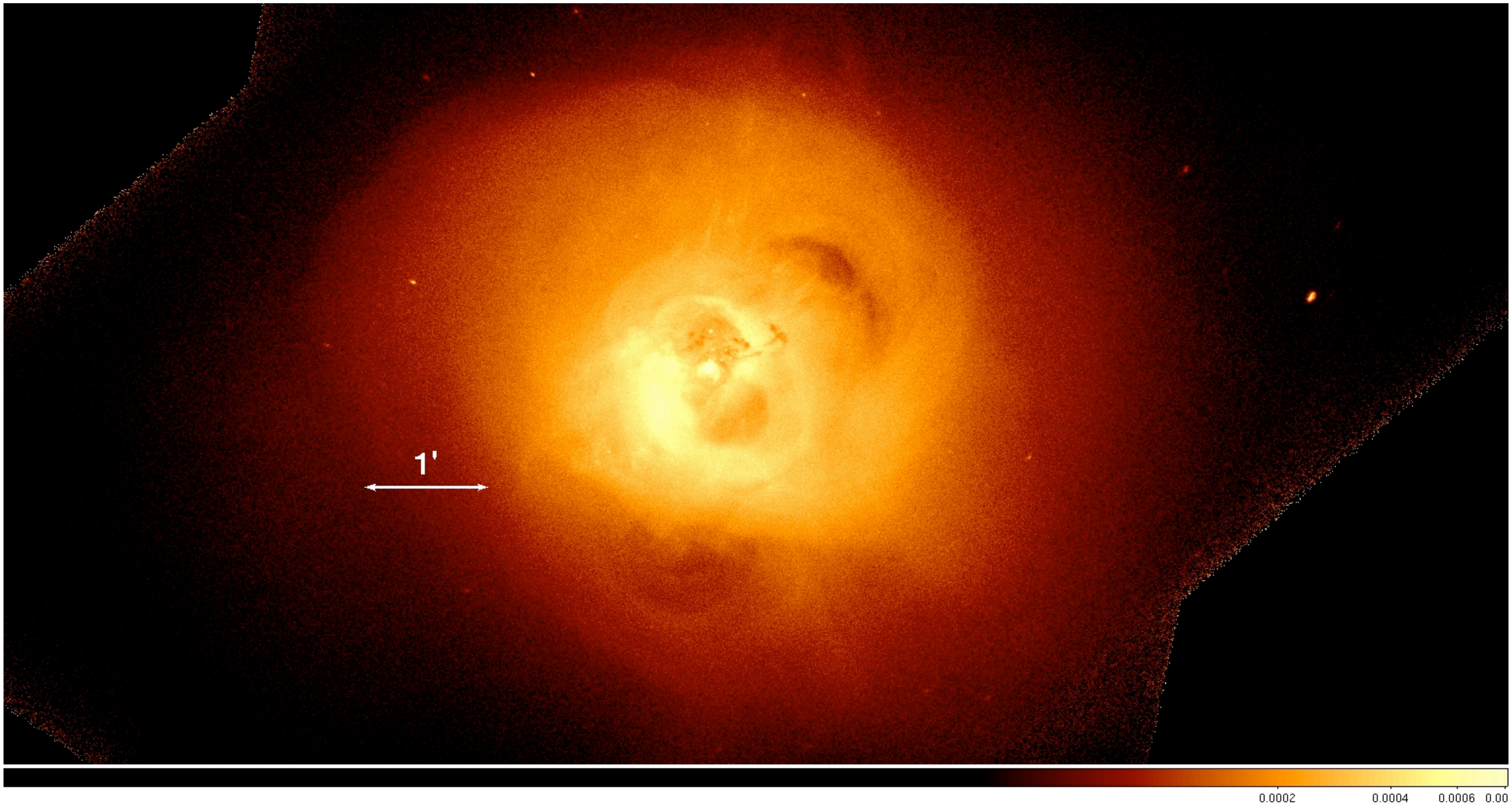
cooling only

- Cooling causes shallow T gradients
- This makes ICM neutrally buoyant and permit easier wind-up of B-field

Caveats

- In cluster outskirts, MHD approximations begin to break down
- electron-proton equilibration time > buoyancy time
- MTI growth rates are reduced
- What happens in shocks? Magnetic bootstrap, Bell-Lucek amplification
- *Sausage* shows that magnetic field is azimuthal

Finally, what about the bubbles?



AGN feedback with B fields

We will perform 3D AMR MHD simulations of individual clusters with mechanical feedback. We will

1. study the effect of X-ray cavities on field structure in ICM
2. Analyse turbulence produced by AGN and make estimates for particle acceleration

Thank you.