Anisotropic thermal conduction with MHD in Gadget

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Abstract

We present an implementation of physically motivated thermal conduction including the anisotropic effects of magnetic fields for smoothed particle hydrodynamics (SPH). The diffusion of charged particles and therefore thermal conduction is mainly proceeding parallel to magnetic field lines and suppressed perpendicular. We derive an SPH formalism for the anisotropic heat transport and implement our algorithm into the GADGET code. Within galaxy clusters, the anisotropic conduction produces a net heat transport similar to an isotropic Spitzer conduction model with an efficiency of one per cent. Compared to observations, isotropic conduction with more than 10 per cent of the Spitzer value leads to an oversmoothed temperature distribution within clusters, while the results obtained with anisotropic conduction reproduce observed temperature fluctuations well. A proper treatment of heat transport is crucial especially in the outskirts of clusters and in high density regions. It's connection to the local dynamical state of the cluster also might contribute to the observed bimodal distribution of (non) cool core clusters. Our new scheme significantly advances the modelling of thermal conduction in numerical simulations and overall gives better results compared to observations.

Theoretical background of thermal conduction

- Heat exchange proceeds through statistical collisions of particles
- A simple, idealised model: Spitzer conduction:

$$\frac{dT}{dt} \propto \nabla \cdot (\kappa \nabla T) \;\; \text{with } \kappa \propto T^{5/2}$$

$\Rightarrow$ Most efficient in high temperature regimes (up to several $10^8 K$)

- Efficiency depends on particle mass $\rightarrow$ Heat flow through electron-electron collisions much more dominant than by ion collisions
- We assume a fully ionised plasma & cosmic magnetic fields (up to several μG)

$\Rightarrow$ Conduction is anisotropic: different efficiency parallel / perpendicular to $\vec{B}$ due to gyration

- Implemented in SPMHD code Gadget3 on top of existing isotropic conduction
- Splitting up heat flux in different directions:

$$\frac{dT}{dt} \propto \nabla \cdot \left[\kappa_\parallel \left(\vec{B} \cdot \nabla T \right) \vec{B} + \kappa_\perp \left[\nabla T - \left(\vec{B} \cdot \nabla T \right) \vec{B} \right] \right]$$

- Degree of anisotropy dependent on density and magnetic field strength:

$$\frac{\kappa_\perp}{\kappa_\parallel} = (\omega_g \tau)^{-\alpha} \qquad \text{with } \alpha = 1 \text{ or } 2$$

- Rewritten into matrix inversion problem and solved via implicit bi-conjugate gradient scheme
- We perform several test cases to verify numerical stability

Variation of thermal conductivity

g5699754

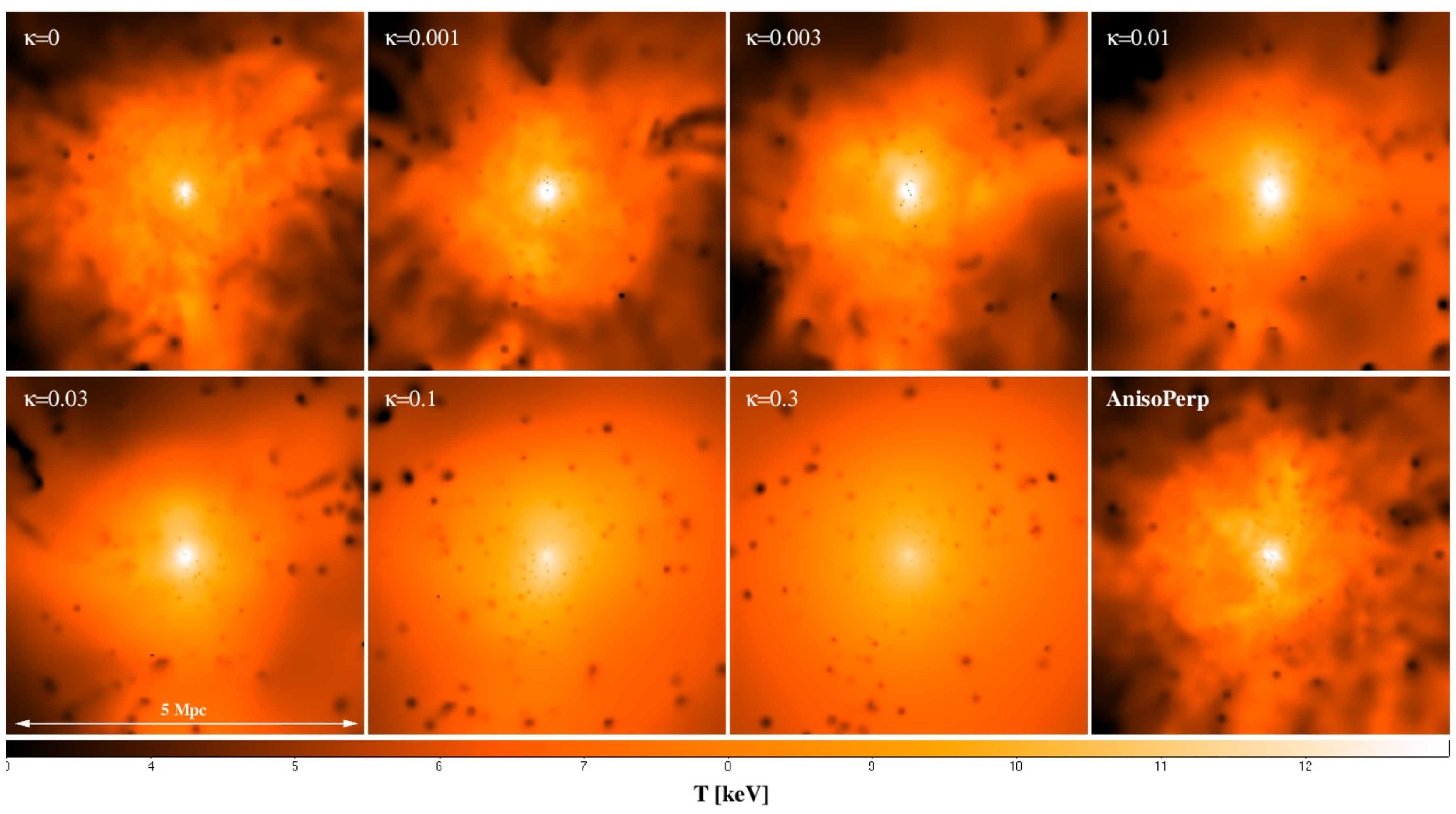

Fig. 1: Temperature maps for one simulated cluster at $z = 0$ with different conduction settings

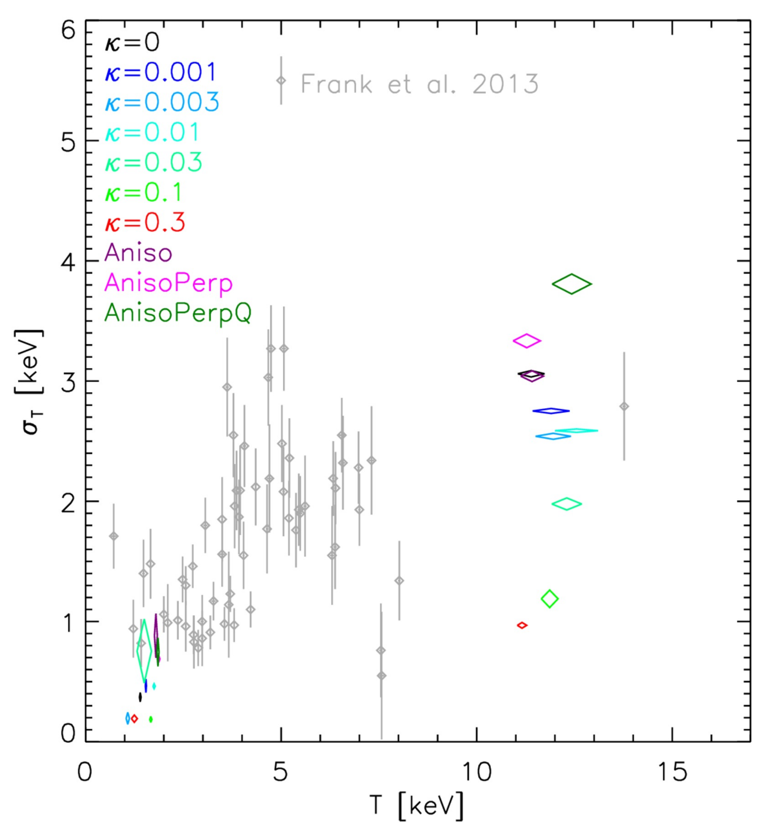

Fig. 2: Temperature fluctuations over mean cluster temperature compared to observations

- Simulating several galaxy clusters of the Dianoga sample with Gadget3 including full gas physics, star formation & cooling
- Similar properties and history as Coma: Masses $\sim 10^{15} M_\odot$, radii $\sim$ 2.5Mpc, temperatures up to $\sim$ 10keV
- Variation of isotropic conduction efficiency
- Isotropic conduction smoothes out temperature substructures and transports a significant amount of internal energy from the center to the outer parts
- Anisotropic conduction also transports internal energy similar to isotropic with $\kappa \sim 0.01$ but preserves substructures
- Strong isotropic conduction produces low temperature fluctuations due to it's smoothing effect
- Anisotropic conduction even increases fluctuations compared to weak isotropic runs by insulating regions through magnetic field lines

Sequence of simulated galaxy clusters

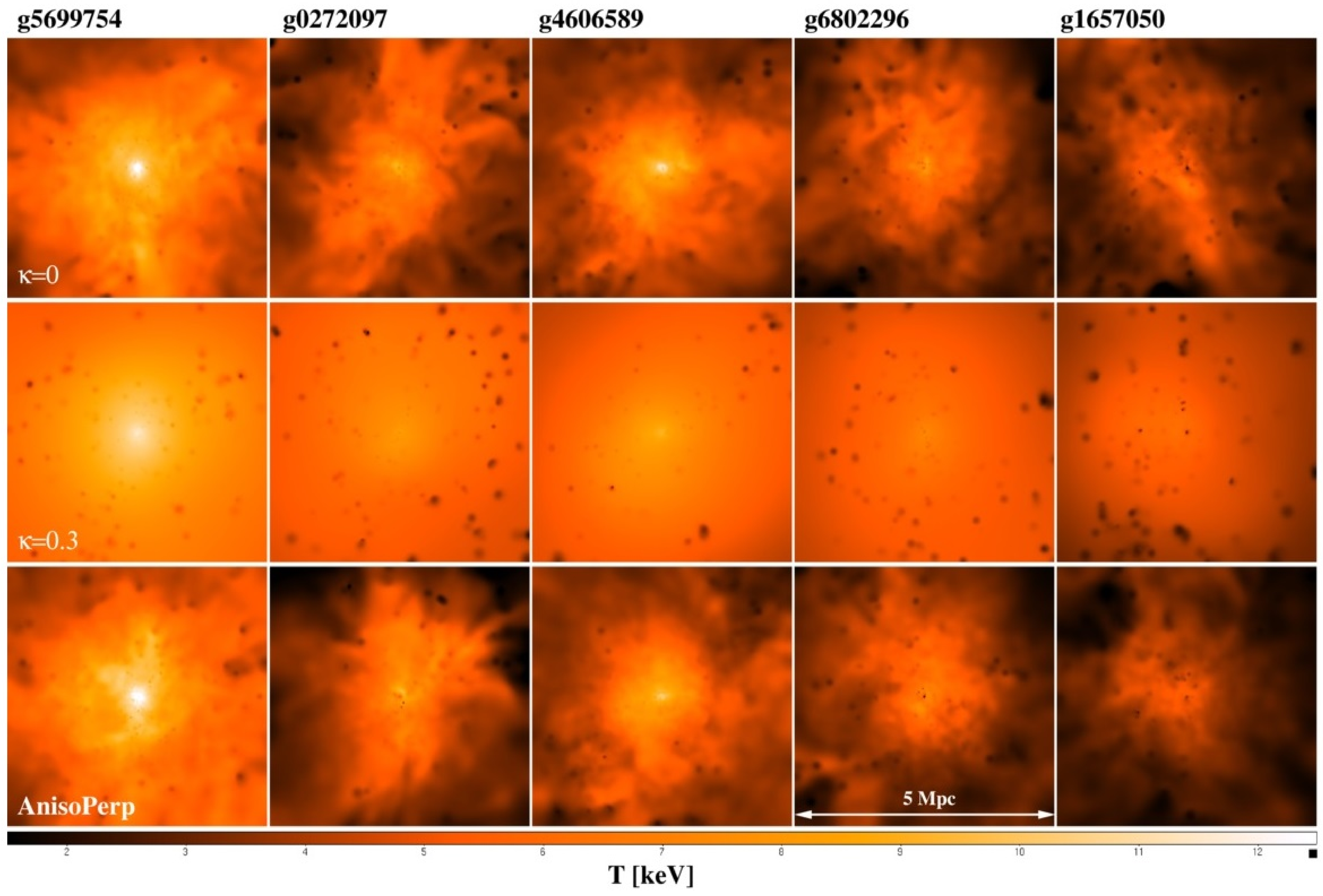

Fig. 3: Temperature maps for the simulated clusters

- Isotropic conduction flattens out radial temperature profiles
- It also generates rather isotherm profiles within 0.4 of the virial radius
- Anisotropic conduction promotes bimodality of cool-core and non cool-core clusters
- Dependent on the history the core becomes cooler or hotter compared to the non conductive run

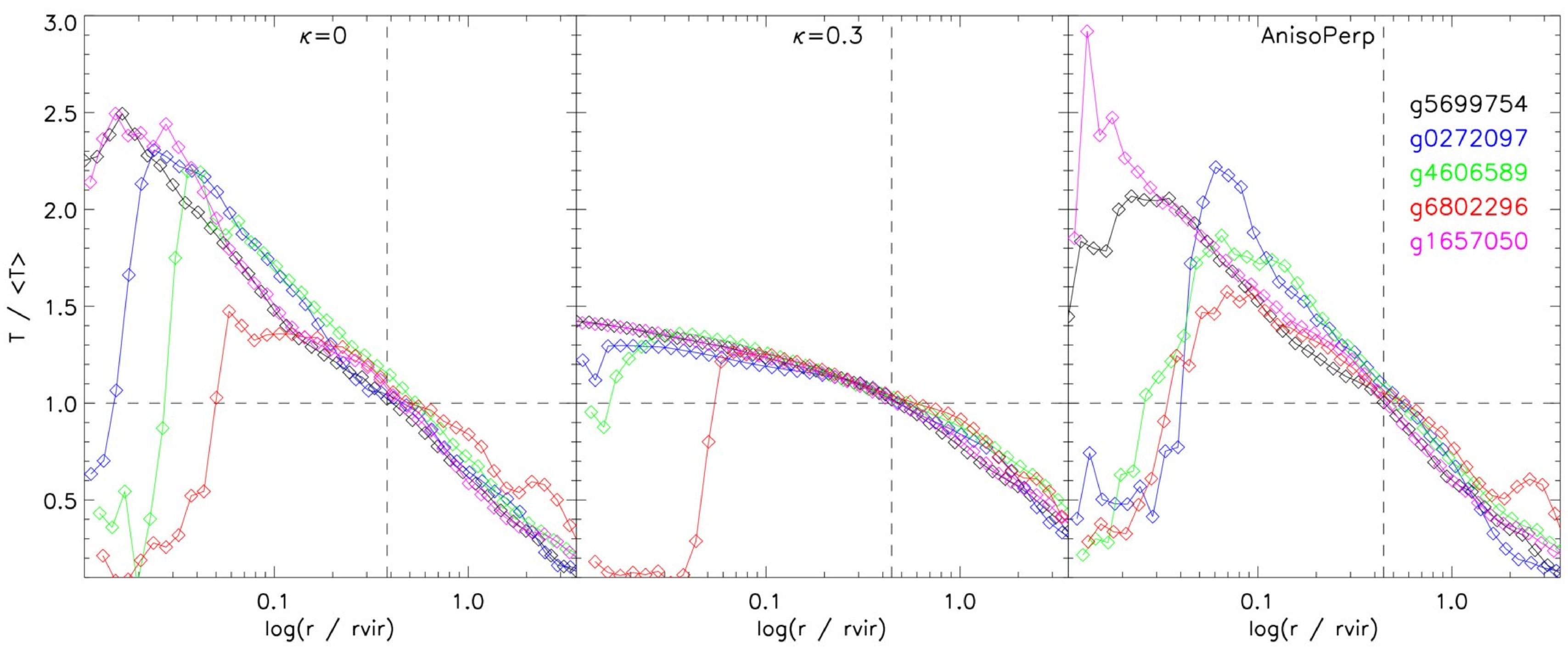

Fig. 4: Radial temperature profiles for main clusters

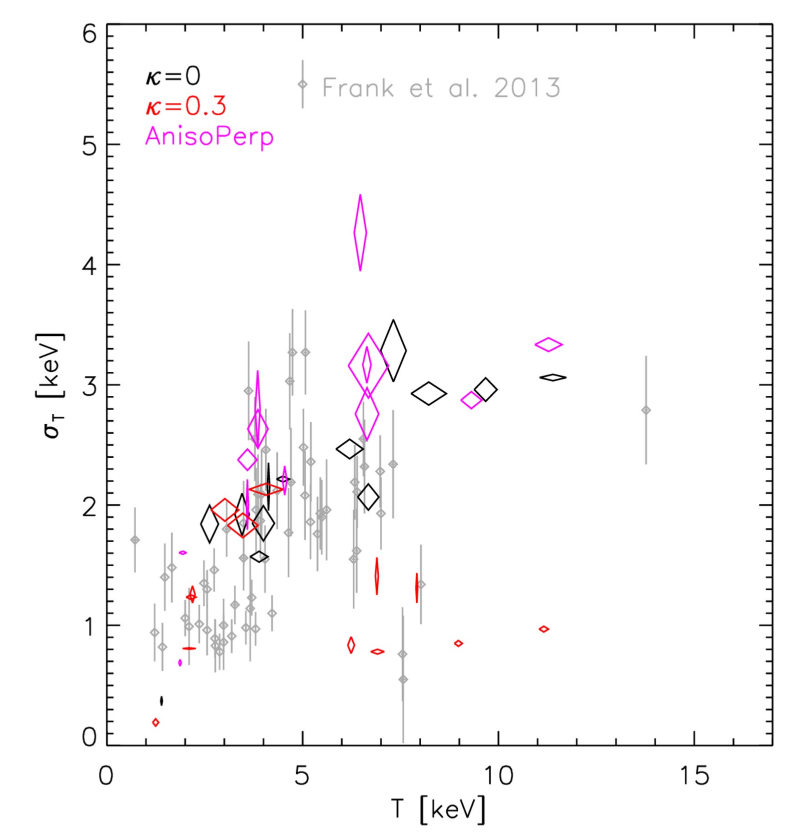

Fig. 5: Temperature fluctuations for all clusters

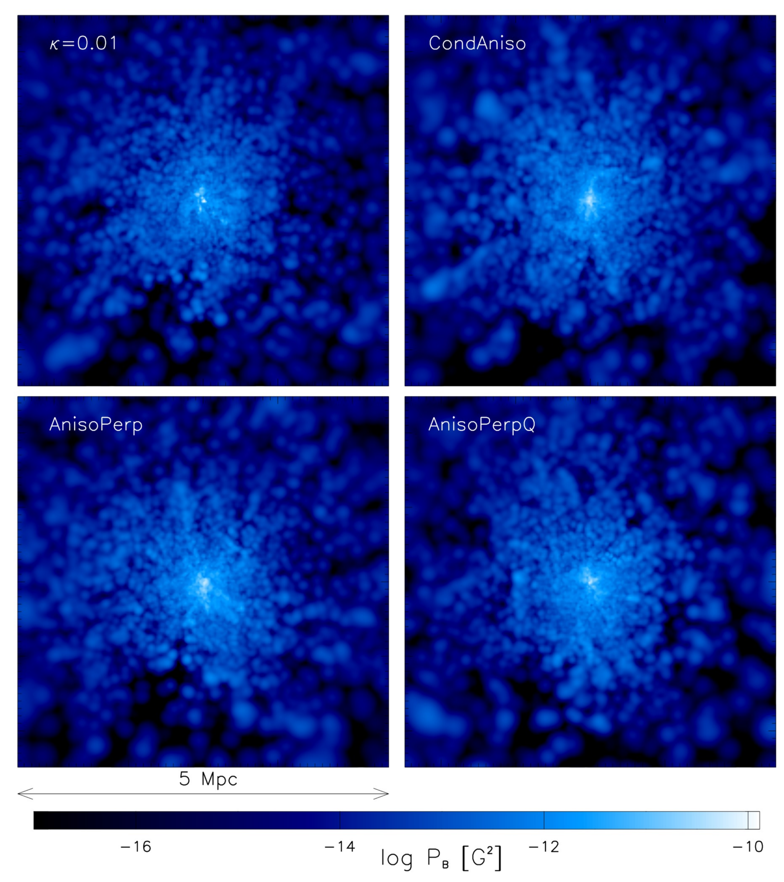

Fig. 6: Magnetic pressure maps for **g5699754**

Observed temperature fluctuations match best with anisotropic conduction run

References

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