Probing the Microphysics of the Intracluster Medium with Cold Fronts

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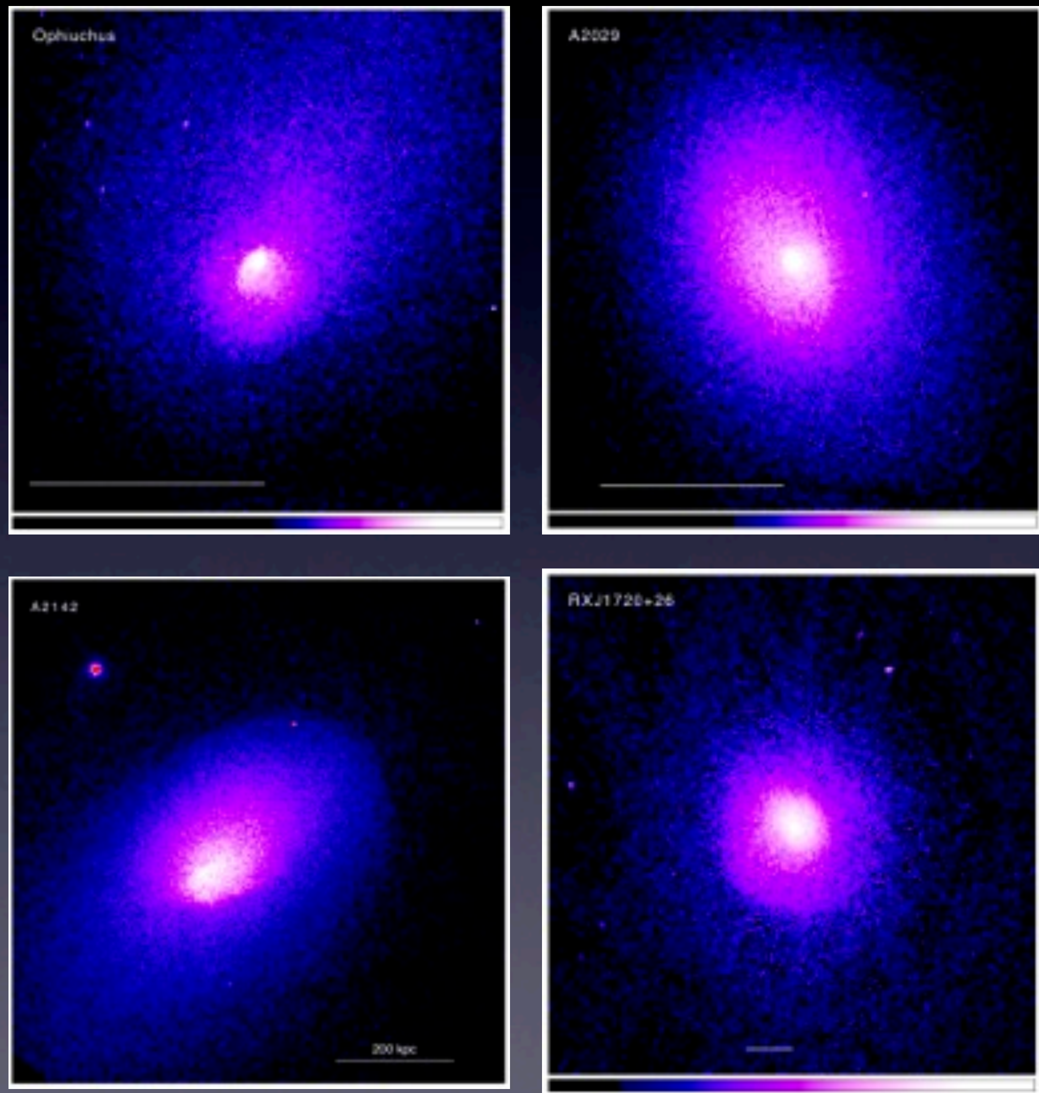
Observations of Gas Sloshing

- The signature: cold fronts in relaxed cool-core clusters
- Spiral-shaped discontinuities in surface brightness and projected temperature
- Most easily explained by the “sloshing” of the cool core gas in the dark matter potential well
- Cold gas has been uplifted from the gravitational potential minimum and formed a contact discontinuity in pressure equilibrium with the hotter, less dense gas



Why Are the Fronts Stable?

- Large velocity shears exist across the cold front; the fronts should be susceptible to the effects of the Kelvin-Helmholtz instability
- Thermal conduction, if present, should smooth out the temperature gradient
- What could stabilize the front surfaces?
    - Viscosity?
    - Magnetic fields?
- The fronts could tell us something about the physics of the ICM

Interaction with a gasless subcluster

$R = 5$

$b = 500$ kpc

ZuHone, Markevitch, and Johnson 2010

Temperature (keV) slice with DM contours

Interaction with a gasless subcluster

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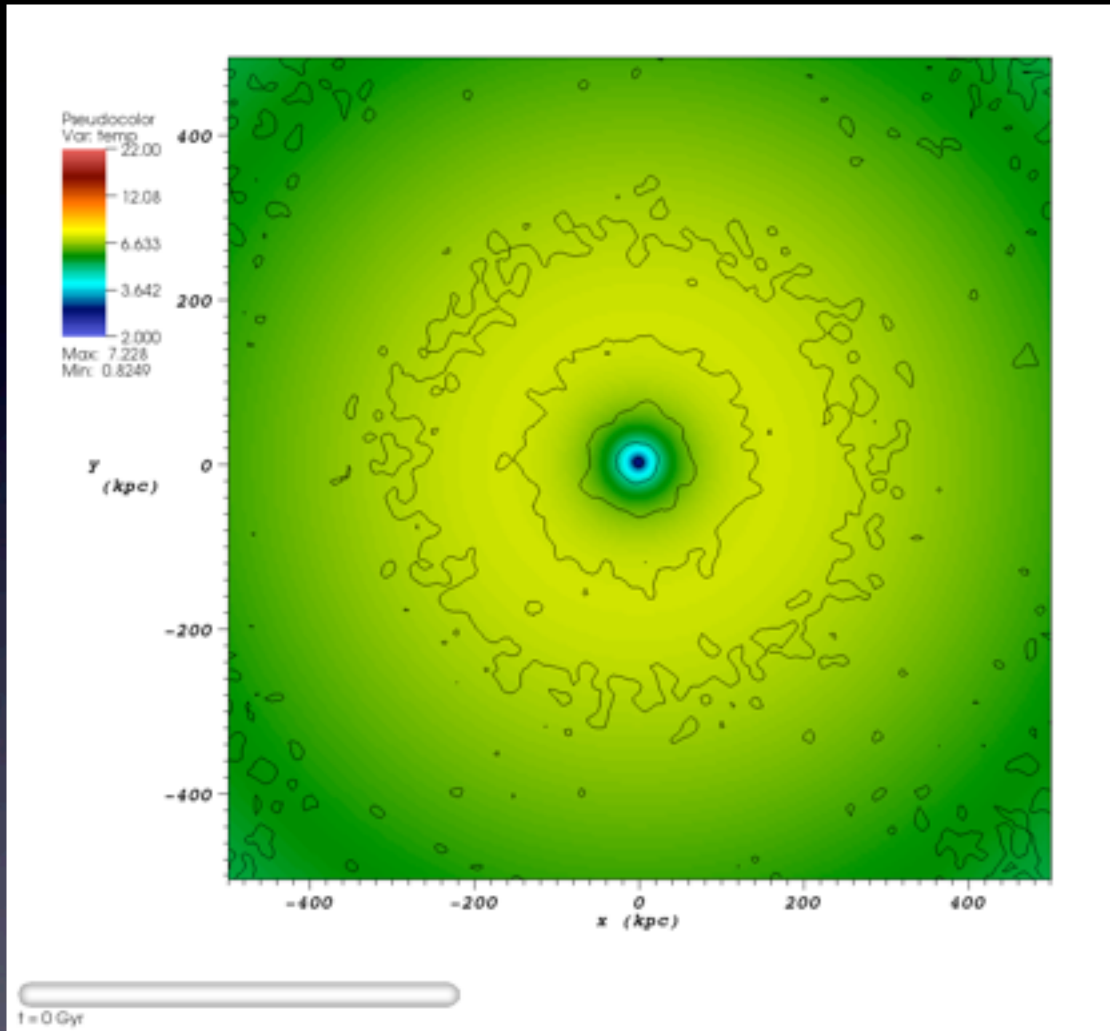

Temperature (keV) slice with DM contours

Gasless subcluster

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b = 500 kpc

Isotropic Spitzer viscosity

ZuHone, Markevitch, and Johnson 2010

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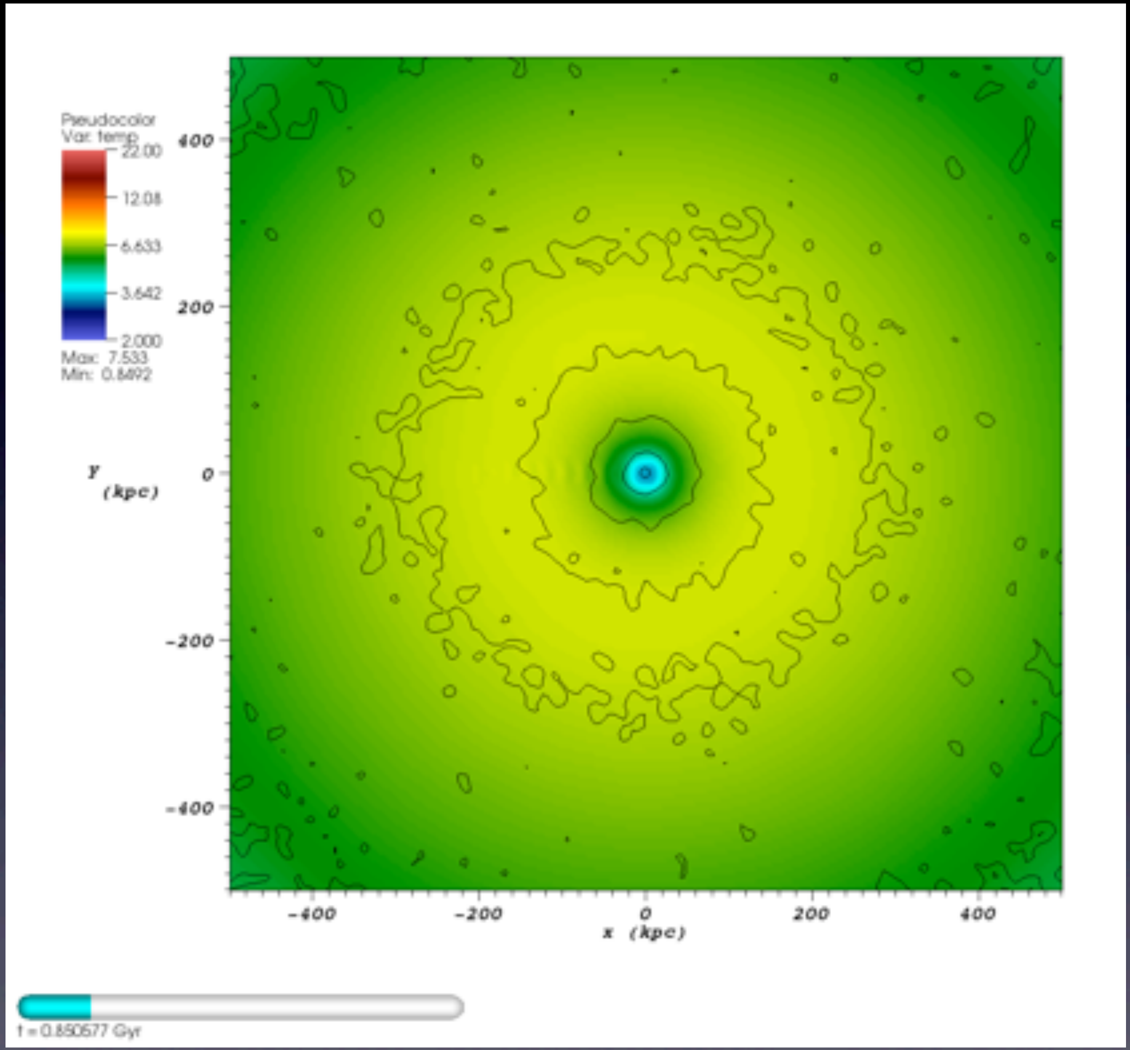


Temperature (keV) slice with DM contours

Sloshing with Magnetic Fields

T (keV)

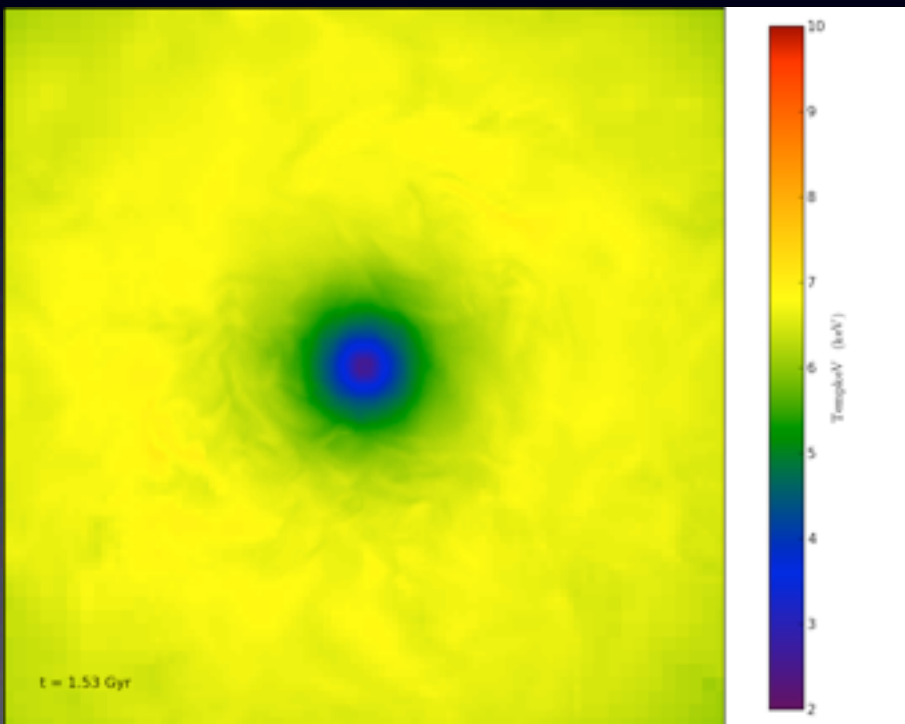
$\beta = p/p_B$

400 kpc

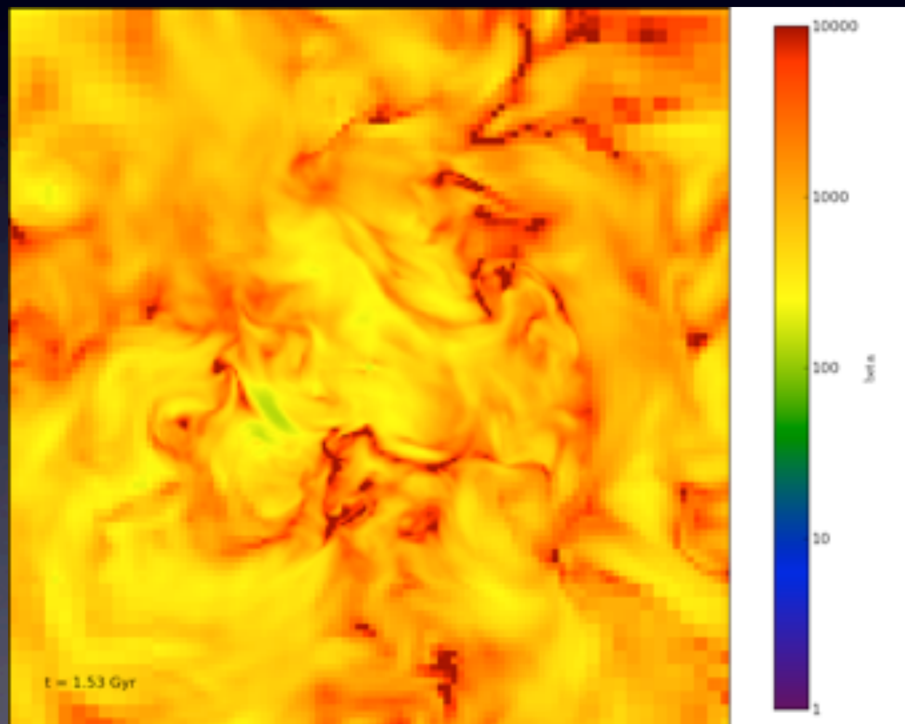
ZuHone, Markevitch, and Lee 2011

Sloshing with Magnetic Fields

T (keV)



$\beta = p/p_B$



400 kpc

ZuHone, Markevitch, and Lee 2011

Sloshing with Magnetic Fields

T (keV)

No Fields

$\beta \sim 400$

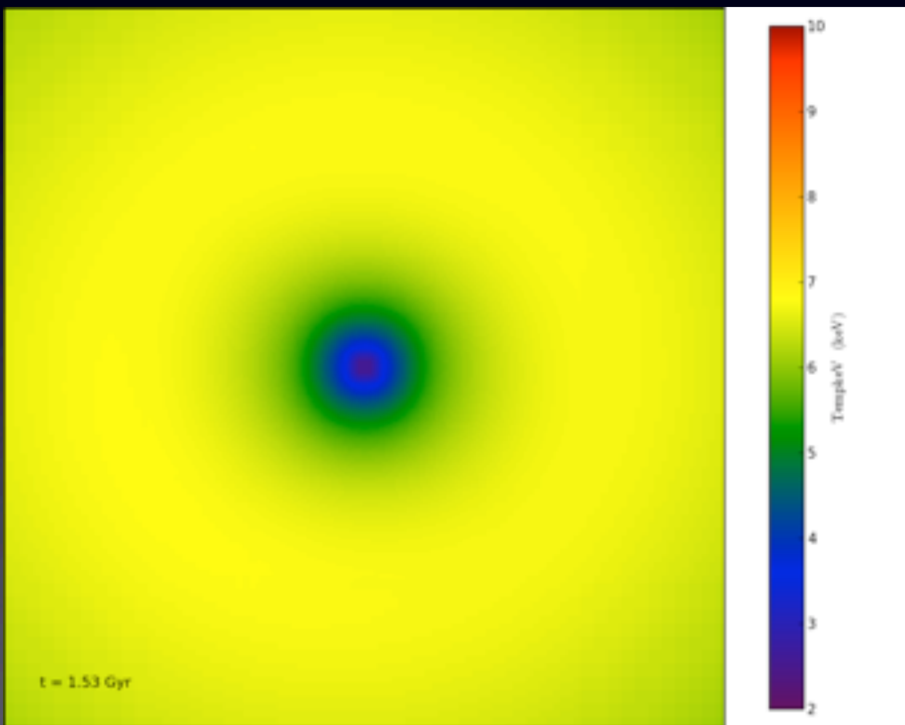
400 kpc

ZuHone, Markevitch, and Lee 2011

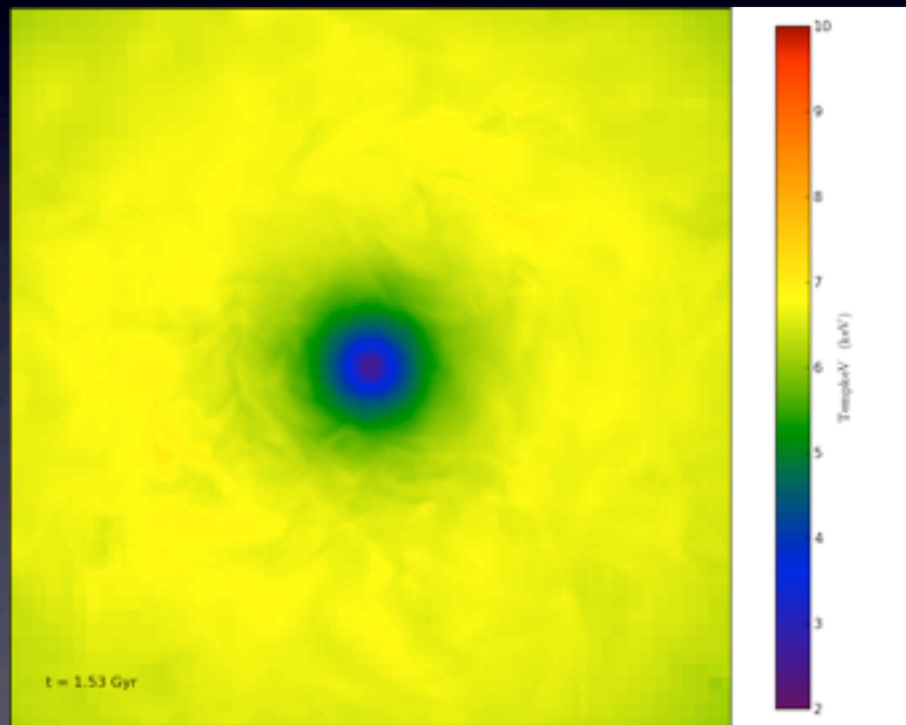
Sloshing with Magnetic Fields

T (keV)

No Fields



β ~ 400



400 kpc

ZuHone, Markevitch, and Lee 2011

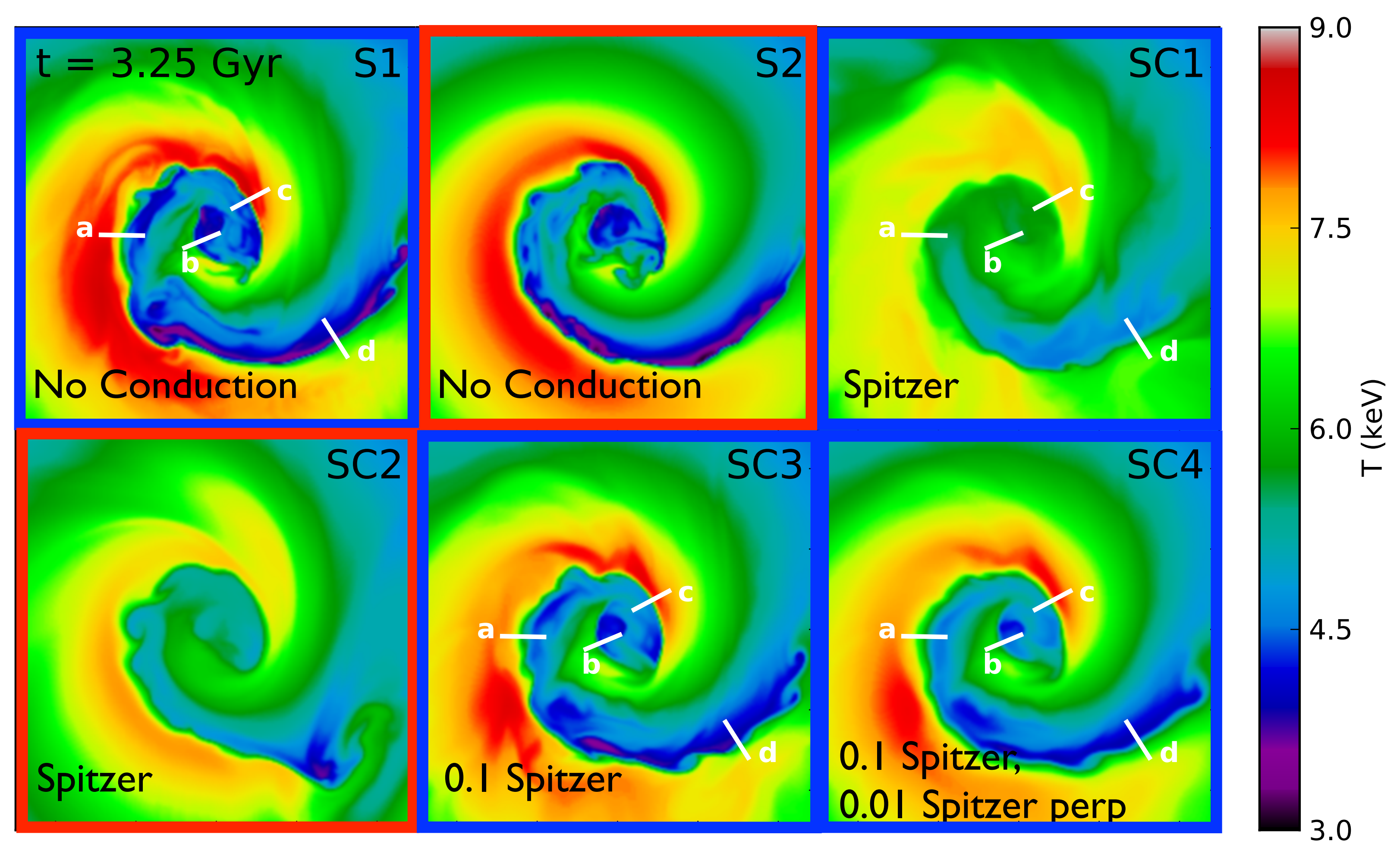
Anisotropic Thermal Conduction

- The sharp temperature jumps at cold fronts indicate conduction is suppressed there
- In the ICM, $\rho_L << \lambda_{mfp} \Rightarrow$ conduction is anisotropic, along the field lines
- Perhaps the draping layers will do the trick?

Anisotropic Thermal Conduction

- Exploring a parameter space of conduction coefficients:
  - $\kappa_{||} = 0$, $\kappa_{\perp} = 0$ (No conduction)
  - $\kappa_{||} = 1$, $\kappa_{\perp} = 0$ (Spitzer conduction)
  - $\kappa_{||} = 0.1$, $\kappa_{\perp} = 0$ (conduction suppressed by magnetic mirrors on small scales)
  - $\kappa_{||} = 0.1$, $\kappa_{\perp} = 0.01$ (small perpendicular conduction from field line reconnection)

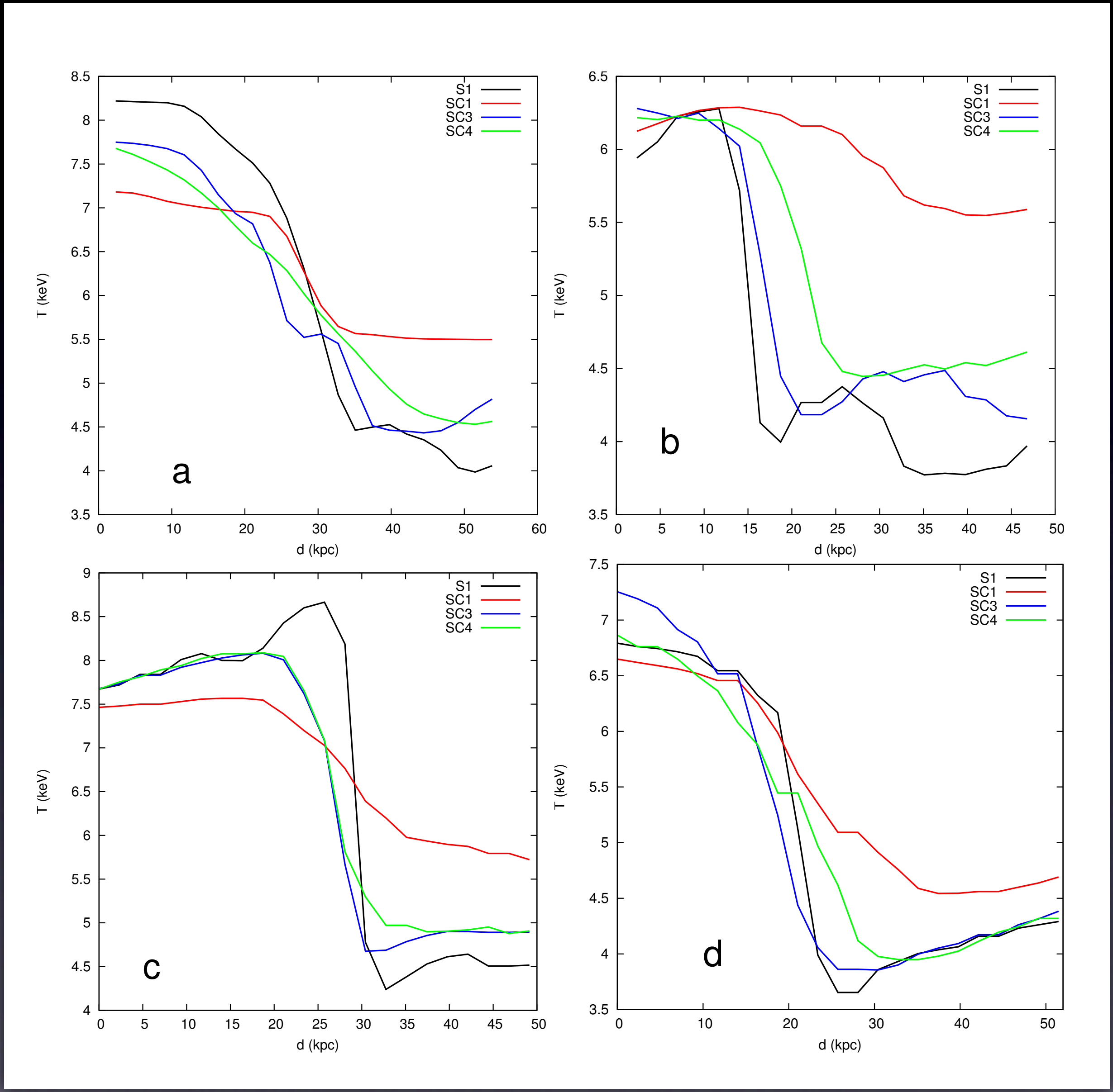
Temperature Slices



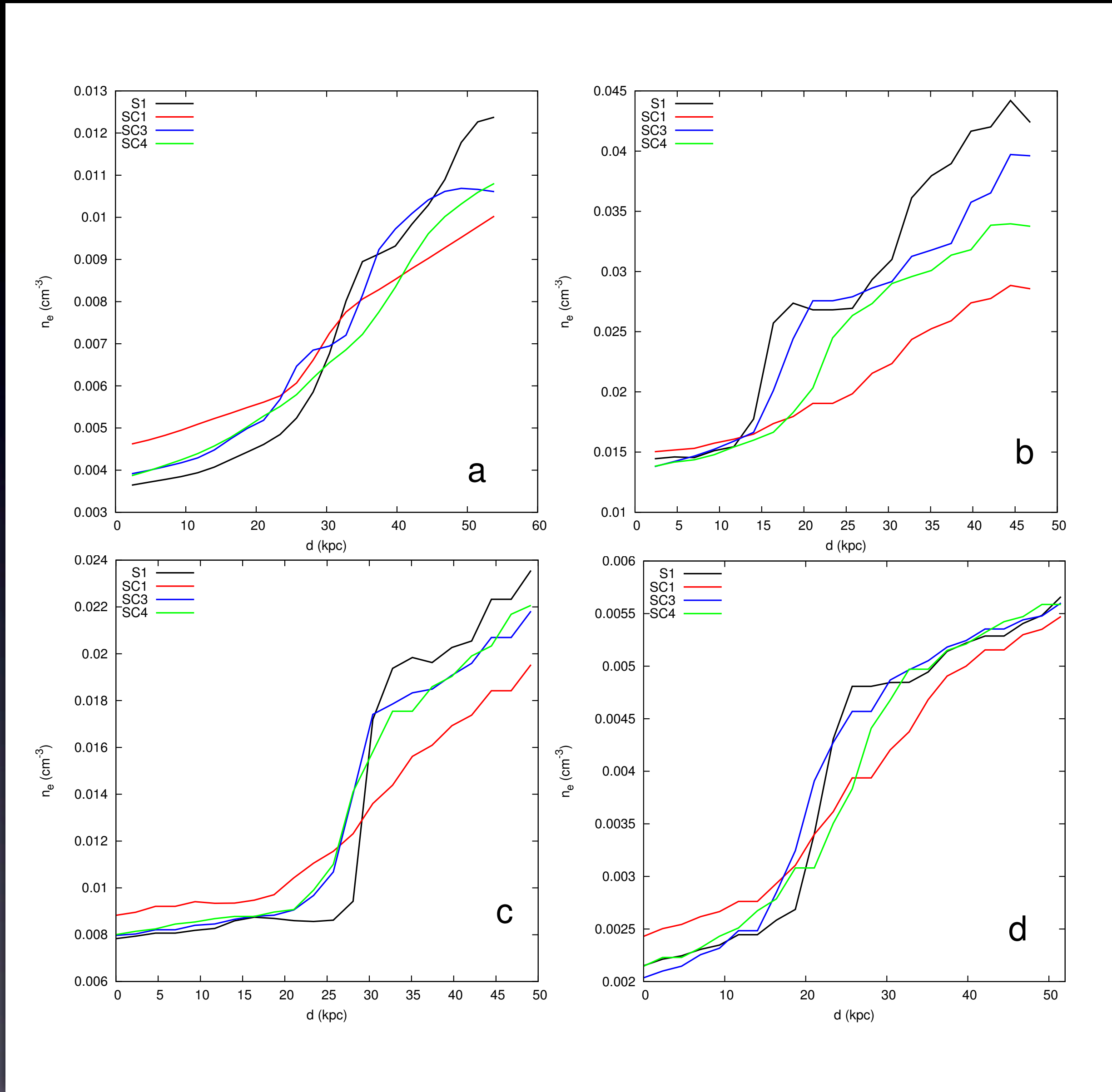
arXiv: 1204.6005

Temperature Jumps

arXiv:1204.6005

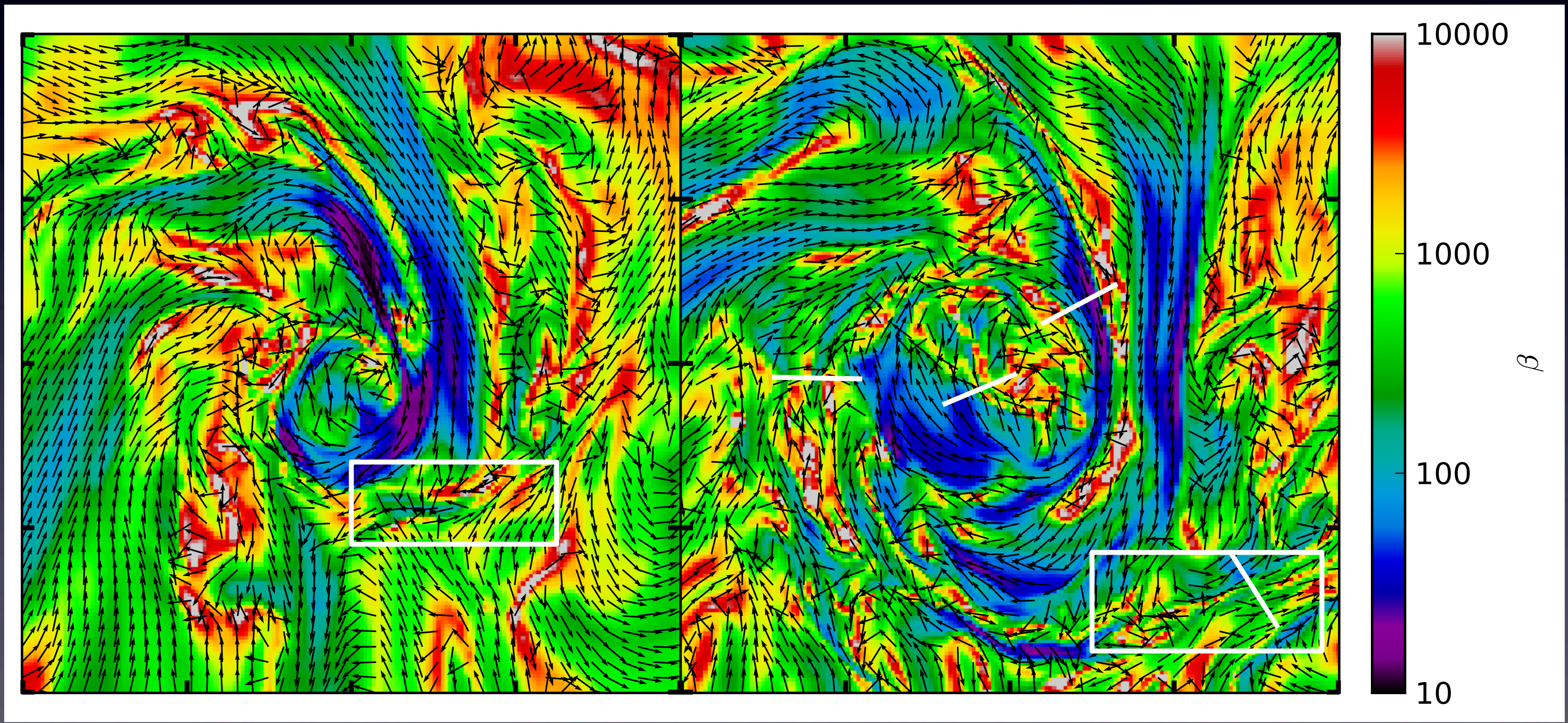


Density Jumps



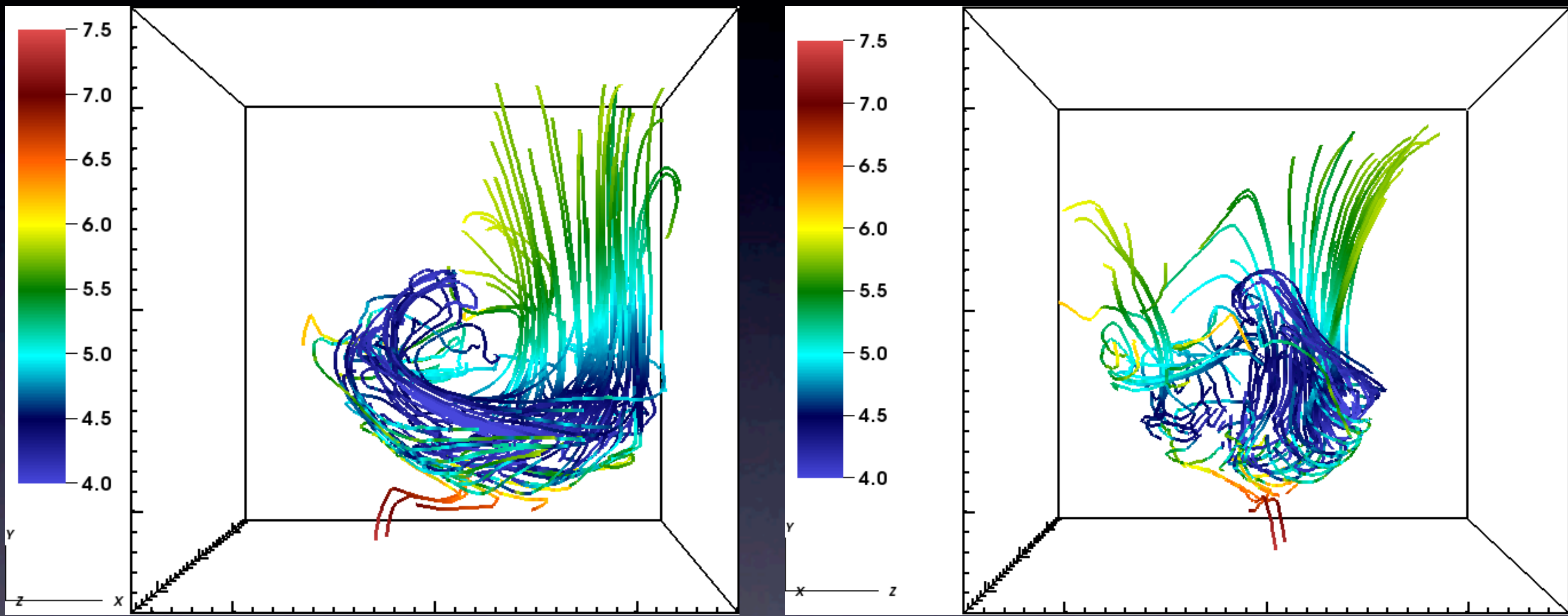
arXiv:1204.6005

Magnetic Field Lines



arXiv:1204.6005

Magnetic Field Lines

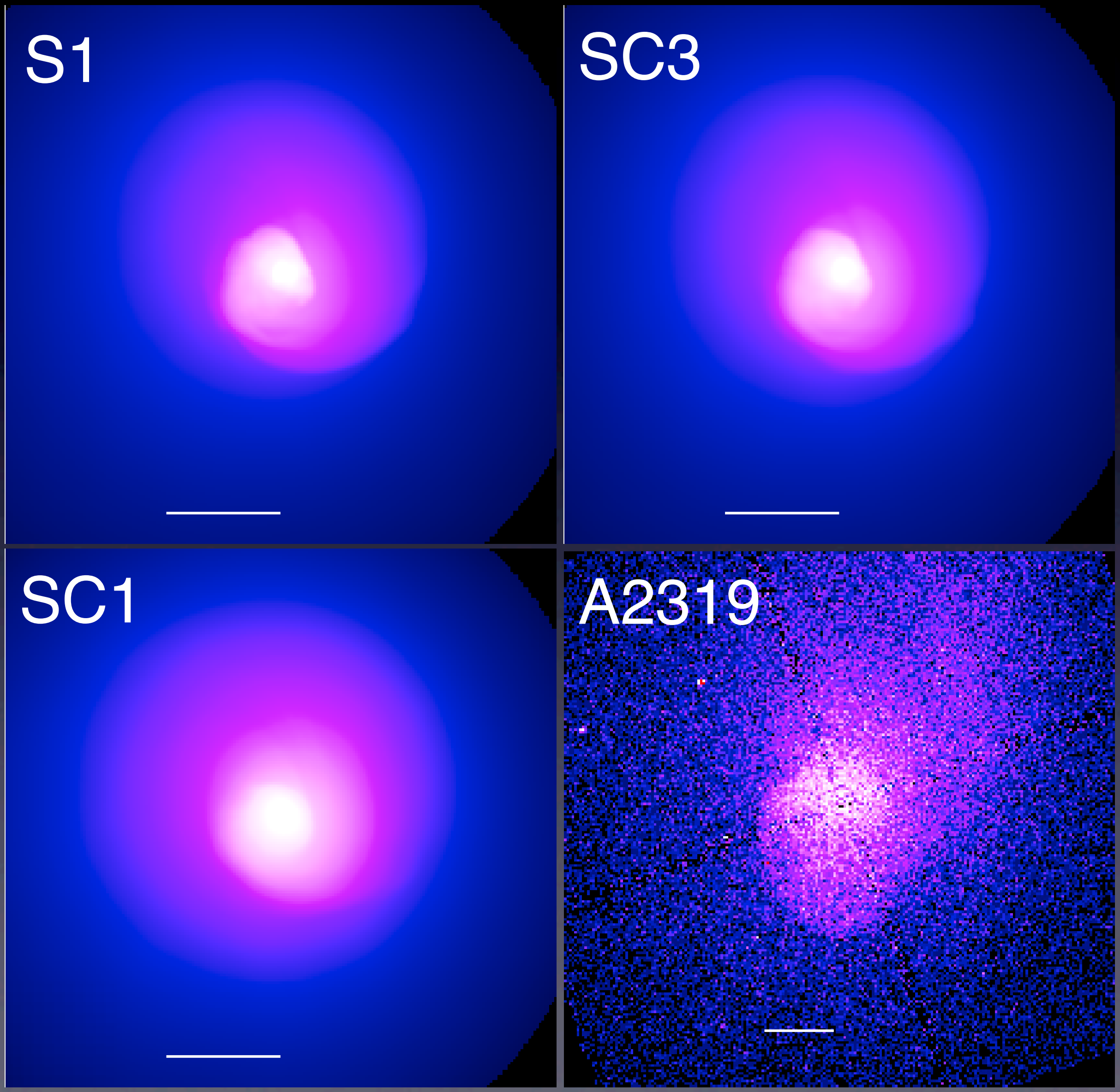


z-axis x-axis

Beginning at points with T < 4.5 keV
and continuing for 100 kpc

arXiv:1204.6005

X-Ray Images



Summary and Conclusions

- Spiral cold fronts in galaxy clusters appear to have arisen as a result of encounters with small subclusters
- Viscosity and/or magnetic fields in galaxy clusters can act to stabilize cold fronts against instabilities
- Despite the draping magnetic fields, anisotropic thermal conduction can smear out cold fronts... maybe place constraints on conduction in the *bulk* of the ICM?