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

\[ R = 5 \]

\[ b = 500 \text{ kpc} \]

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

$R = 5$

$\beta = 500$ kpc

Isotropic Spitzer viscosity

ZuHone, Markevitch, and Johnson 2010

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Isotropic Spitzer viscosity

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Temperature (keV) slice with DM contours
Sloshing with Magnetic Fields

$T \ (\text{keV}) \quad \beta = \frac{p}{p_B}$

400 kpc

ZuHone, Markevitch, and Lee 2011

Tuesday, June 12, 12
Sloshing with Magnetic Fields

$T$ (keV) $\beta = \frac{p}{p_B}$

400 kpc

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Sloshing with Magnetic Fields

No Fields

$T \text{ (keV)}$

$\beta \sim 400$

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400 kpc
Sloshing with Magnetic Fields

$T \text{ (keV)}$

No Fields

$\beta \sim 400$

400 kpc

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Anisotropic Thermal Conduction

• The sharp temperature jumps at cold fronts indicate conduction is suppressed there.

• In the ICM, $\rho_L \ll \lambda_{mfp} \Rightarrow$ 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:
  - $\kappa_\parallel = 0, \kappa_\perp = 0$ (No conduction)
  - $\kappa_\parallel = 1, \kappa_\perp = 0$ (Spitzer conduction)
  - $\kappa_\parallel = 0.1, \kappa_\perp = 0$ (conduction suppressed by magnetic mirrors on small scales)
  - $\kappa_\parallel = 0.1, \kappa_\perp = 0.01$ (small perpendicular conduction from field line reconnection)
Temperature Jumps

arXiv:1204.6005
Density Jumps

arXiv:1204.6005

Fig. 6.— Density profiles of cold fronts in simulations without conduction and with varying prescriptions for conduction, along the profiles marked with corresponding letters in Figure 3.
Magnetic Field Lines

arXiv:1204.6005

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Magnetic Field Lines

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

arXiv:1204.6005
X-Ray Images

S1

SC3

SC1

A2319
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?