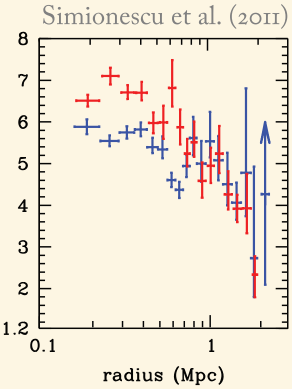
# Why Aren't Clusters Isothermal?

## — Sculpting Cosmic Gas into Galaxy Clusters —

*Mike McCourt, Eliot Quataert, & Ian Parrish*

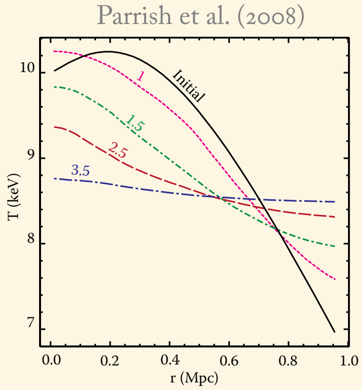
## Introduction

Simionescu et al. (2011)



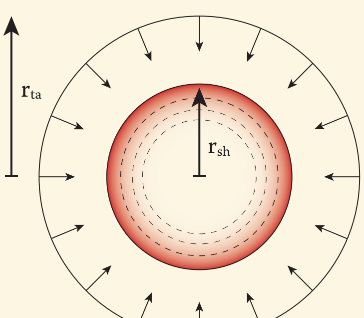

X-ray observations reveal that the hot gas in galaxy clusters steadily cools with distance from the center — this result is significant because it renders clusters unstable to a powerful convective instability known as the *magnetothermal instability*, or MTI. This result is also very surprising however, given that thermal conduction and convection should erase such temperature gradients, and have plenty of time to do so within the age of the universe.

Parrish et al. (2008)




Indeed, simulations of isolated clusters consistently show that the ICM becomes isothermal after a Gyr or so. Clearly, the temperature gradient is a cosmological effect, and cannot be studied in isolated simulations which neglect the cosmological context.

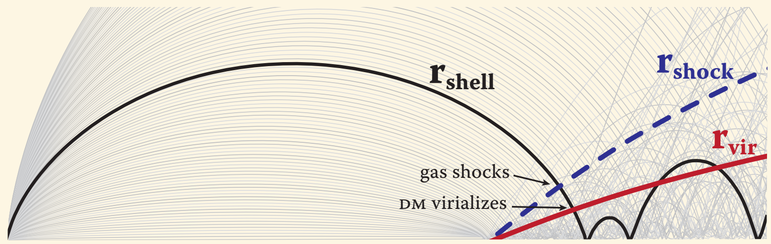
## Entropy Generation at the Virial Shock




We build a simple, spherically symmetric model to study how galaxy clusters develop large-scale temperature gradients. Our approach includes the key effects of *Cosmological Accretion*, *Hydrostatic Equilibrium*, and *Thermal Conduction*. This model allows us to explore how conduction, halo growth, and accretion shocks shape the ICM temperature structure over time — without relying on opaque and computationally expensive simulations.

## Numerical Method

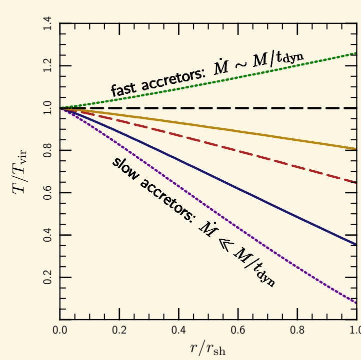
We model Lagrangian shells of gas and dark matter, centered on the location of the cluster. Shells initially expand from the *Big Bang*, decelerate, and turn around due to gravity. When they fall in towards the cluster, the dark matter virializes via shell-crossing, and the gas thermalizes in a shock.



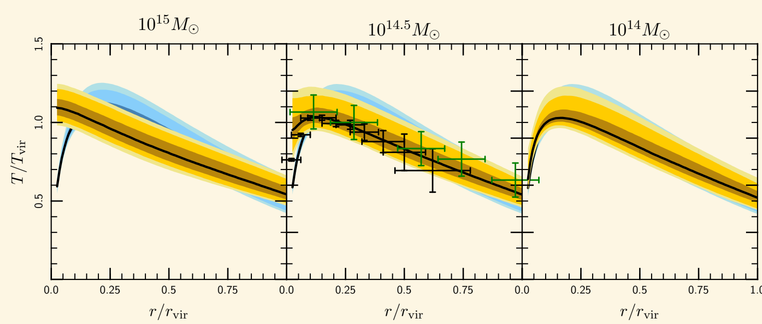

Inside the virial radius, the gas is in hydrostatic equilibrium and the dark matter follows an NFW profile. Outside the shock radius, we simply have cosmological conditions.

Between the shock radius and the virial radius, however, the dynamics have not had time to equilibrate. We model this region with a 1D time-dependent Lagrangian numerical calculation.

## Results




In the case of an isothermal potential, this is a simple problem: the temperature at the center matches the virial temperature, and the temperature in the outskirts is determined by jump conditions at the shock. The global temperature gradient is thus determined by the accretion rate $t_{dyn} d \ln M/dt$.




Results from the full calculation agree closely with observations.

## References

**McCourt et al. (2012)**, *Sharma et al. (2012a,b), McBride et al. (2009), Parrish et al. (2008)*

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