Fire burn, and cauldron bubble:
Regulating the plasma in galaxy cluster cores

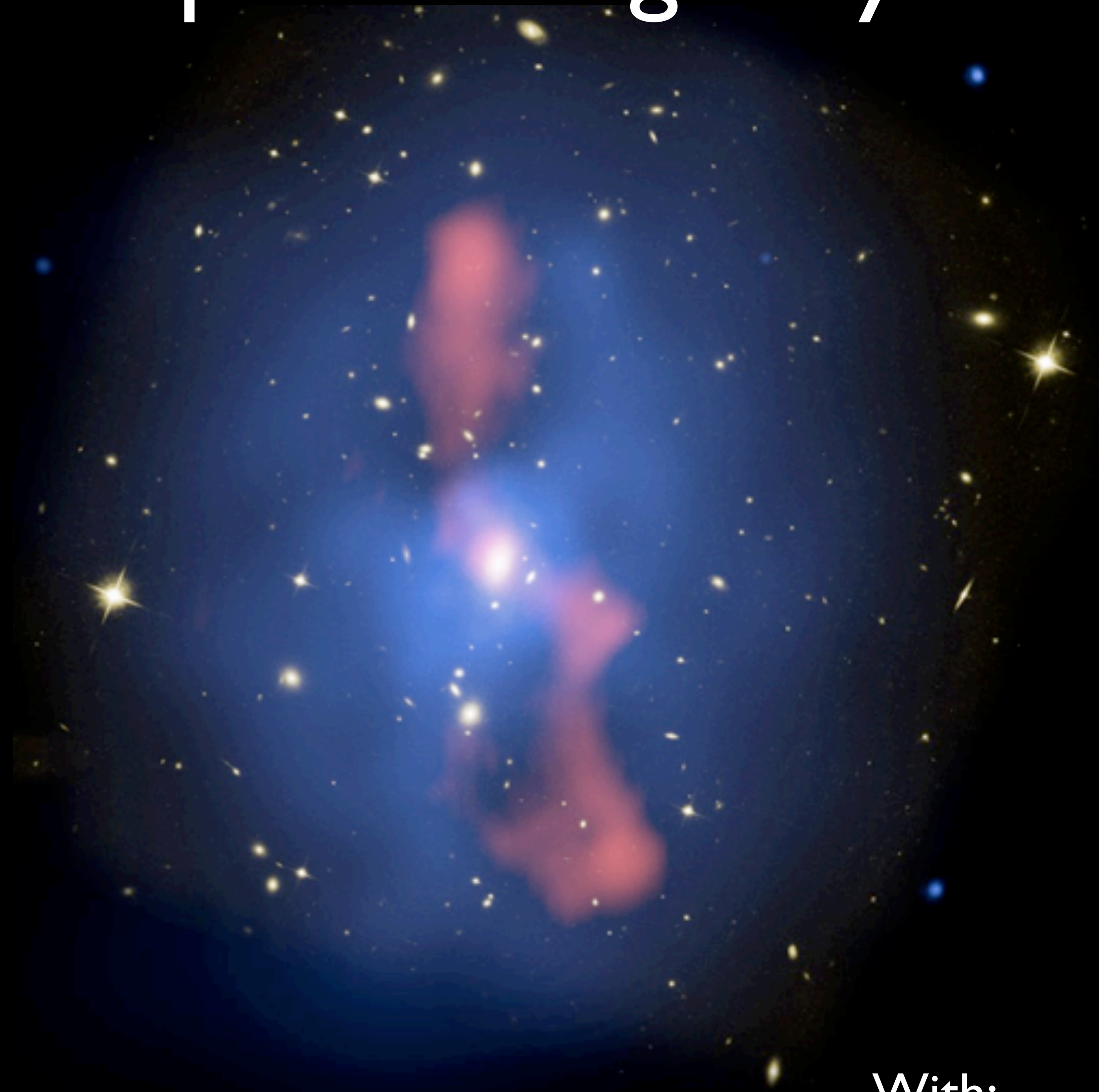
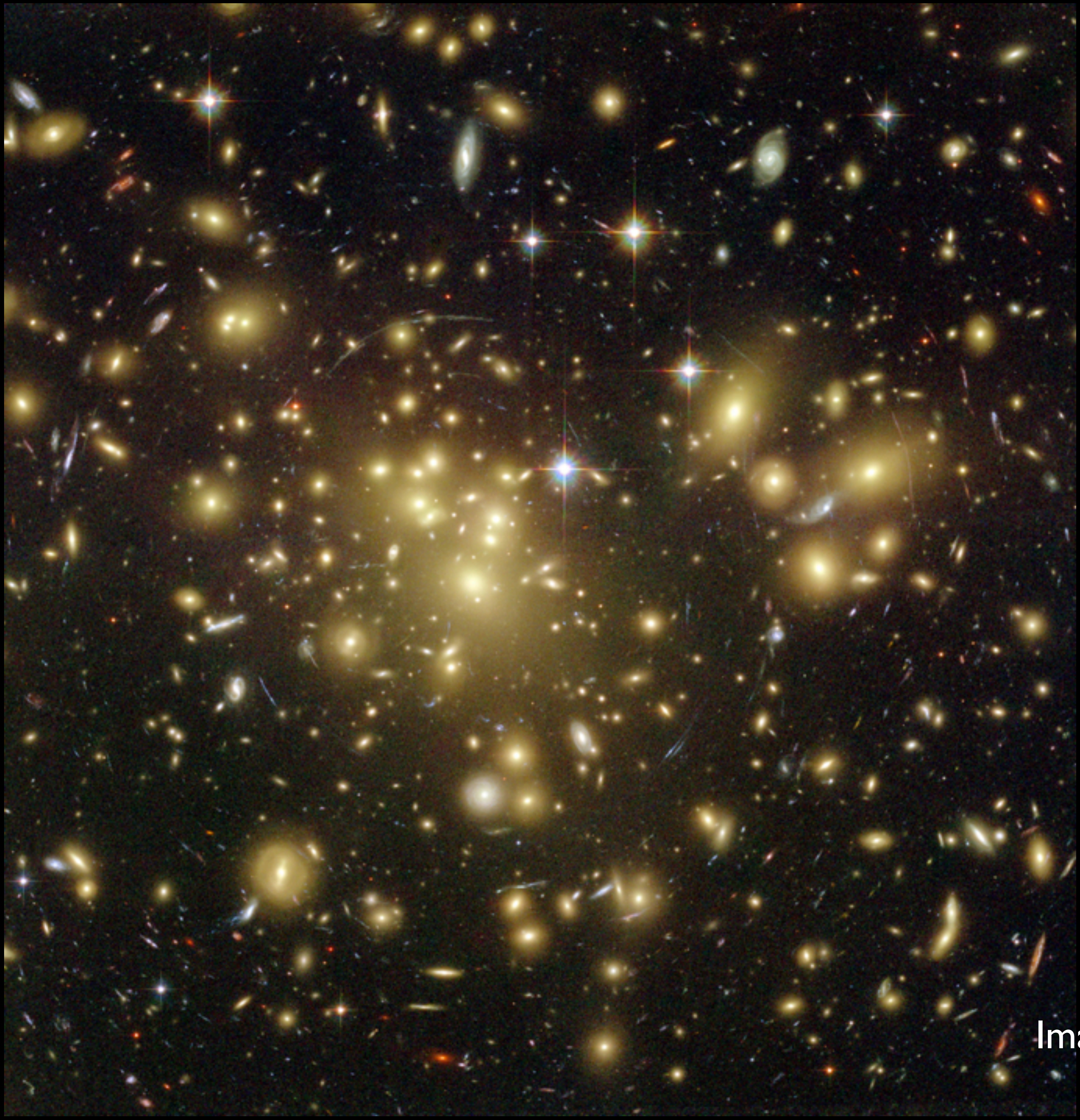


Image c/o
NASA, ESA, and
B. McNamara

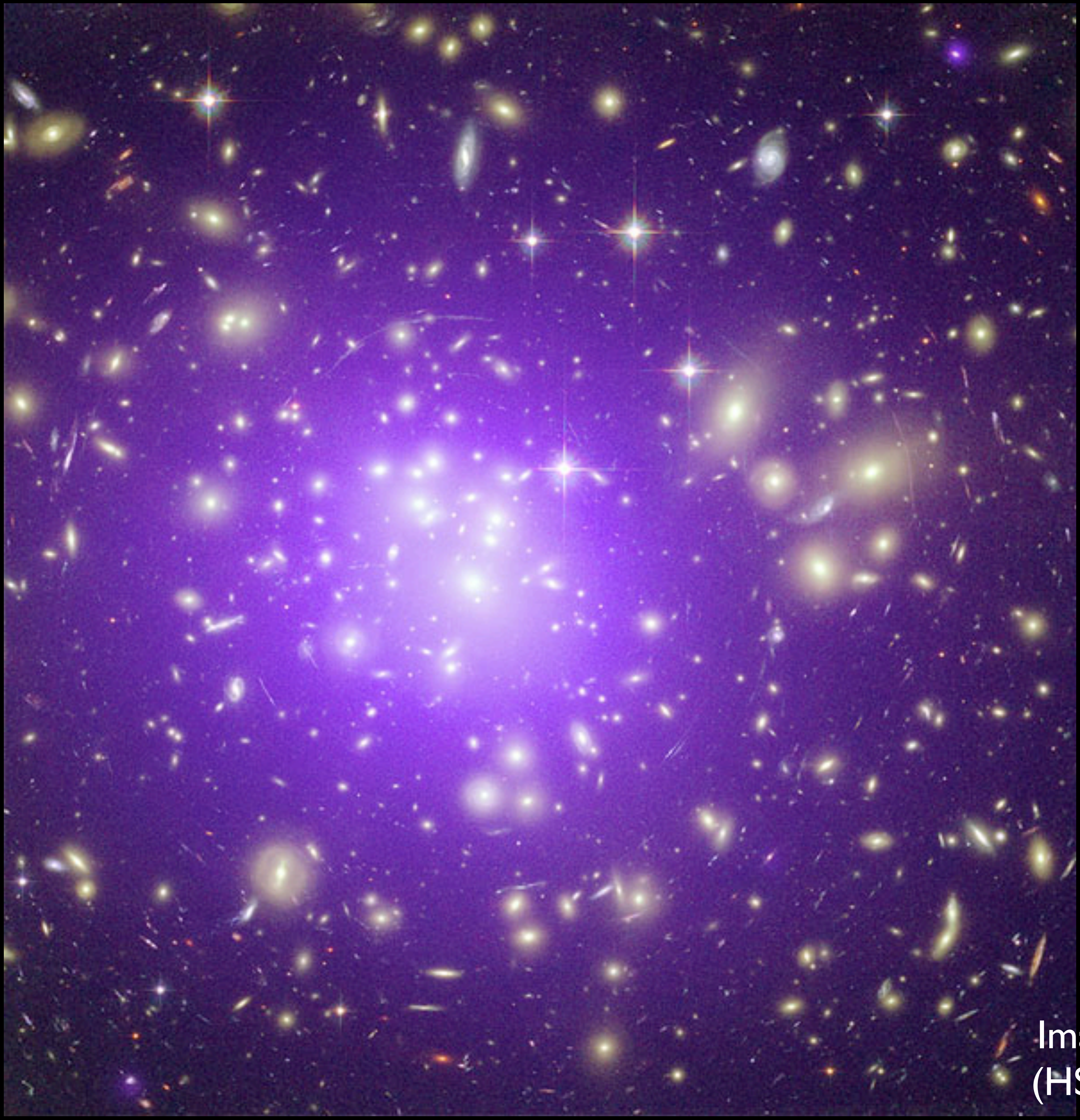
Brian O’Shea
Michigan State University

With:
Greg Meece, Mark Voit (MSU)
Britton Smith (U. Edinburgh)
Sam Skillman (Stanford/KIPAC)

[many thanks to Christoph
for providing an introduction]

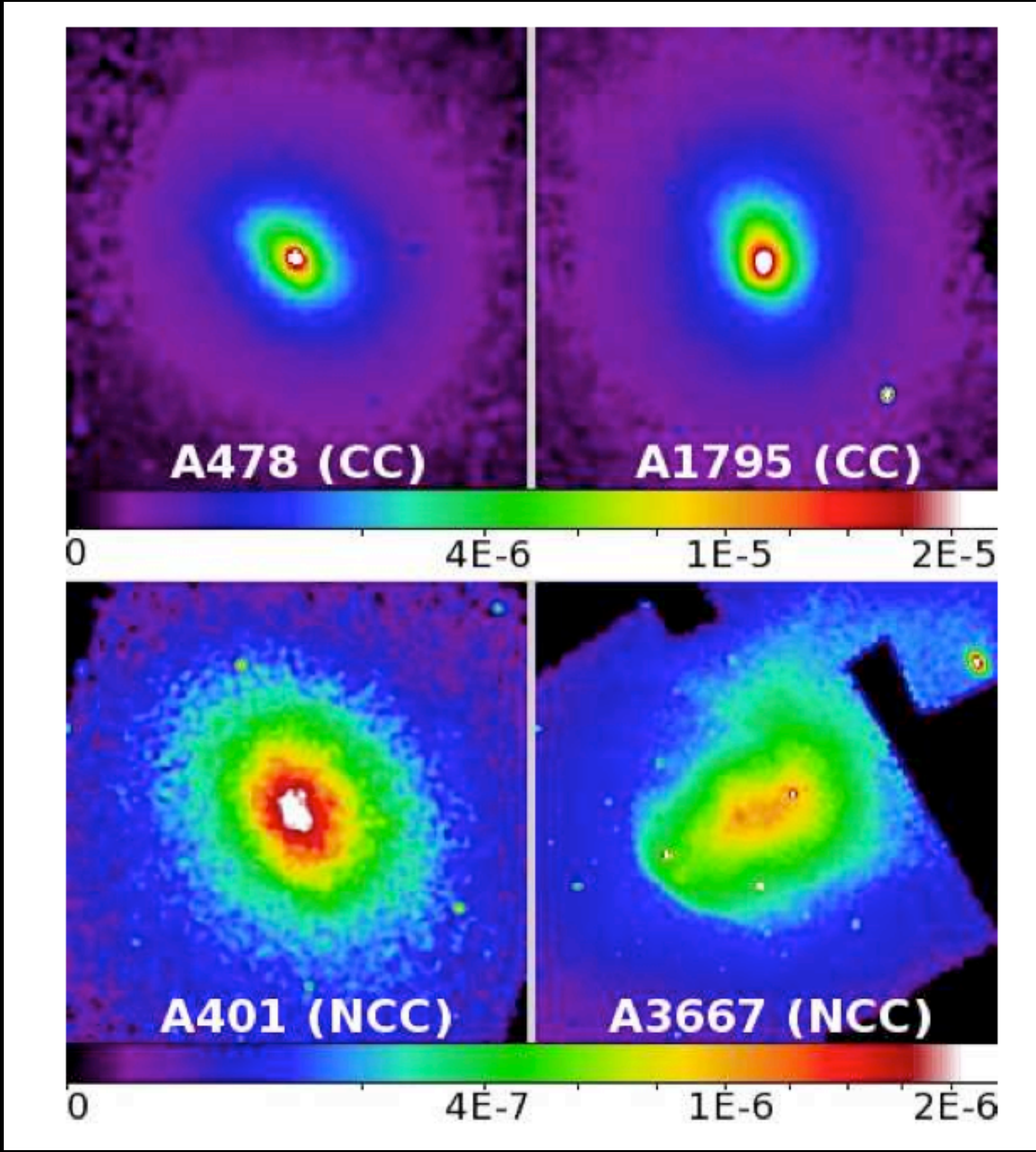


Abell 1689
Image c/o NASA
(HST)



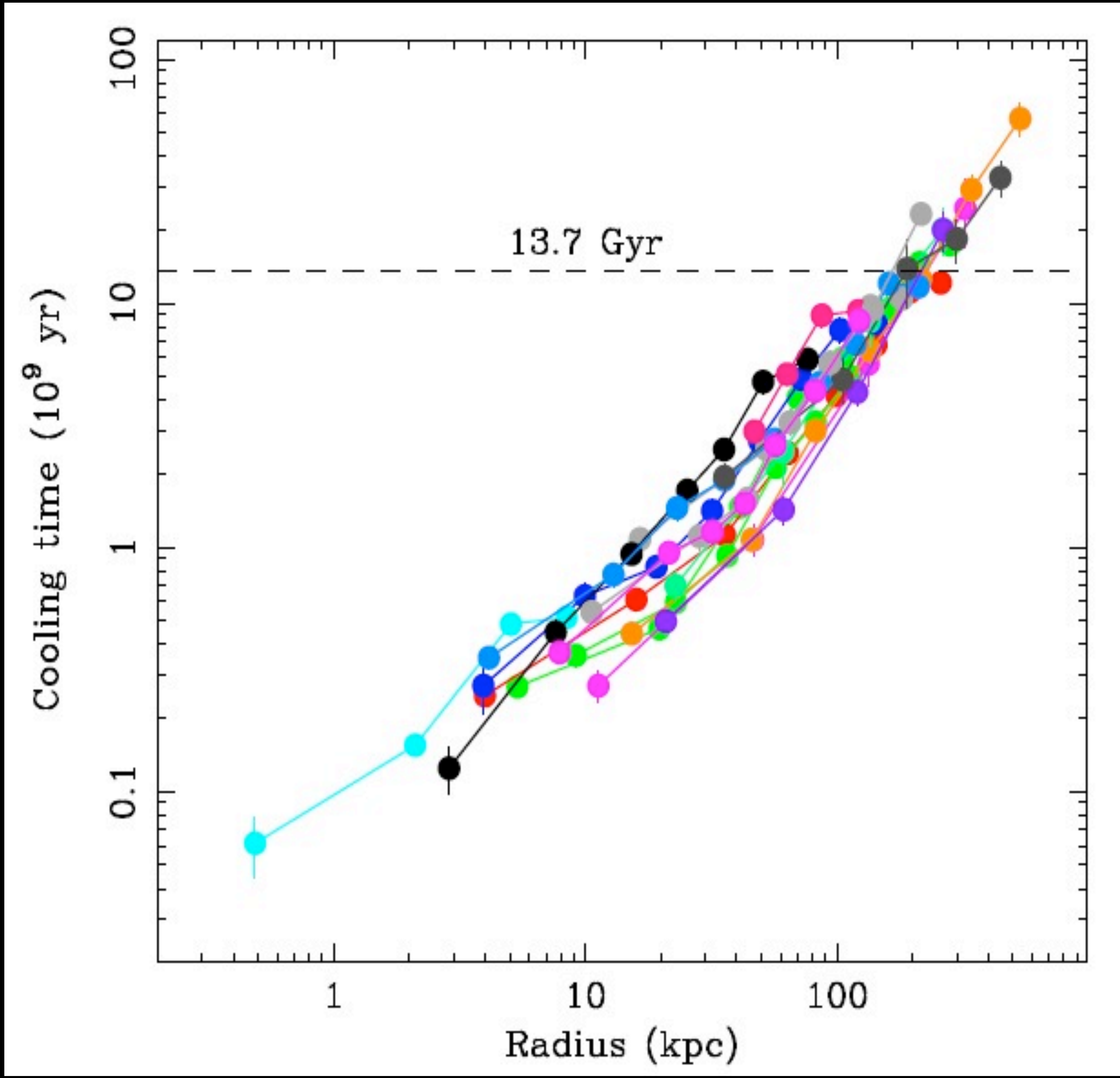
Abell 1689
Image c/o NASA
(HST + Chandra)

Cool core vs. non-cool-core clusters



From Henning et al. 2009, ApJ, 697, 1597

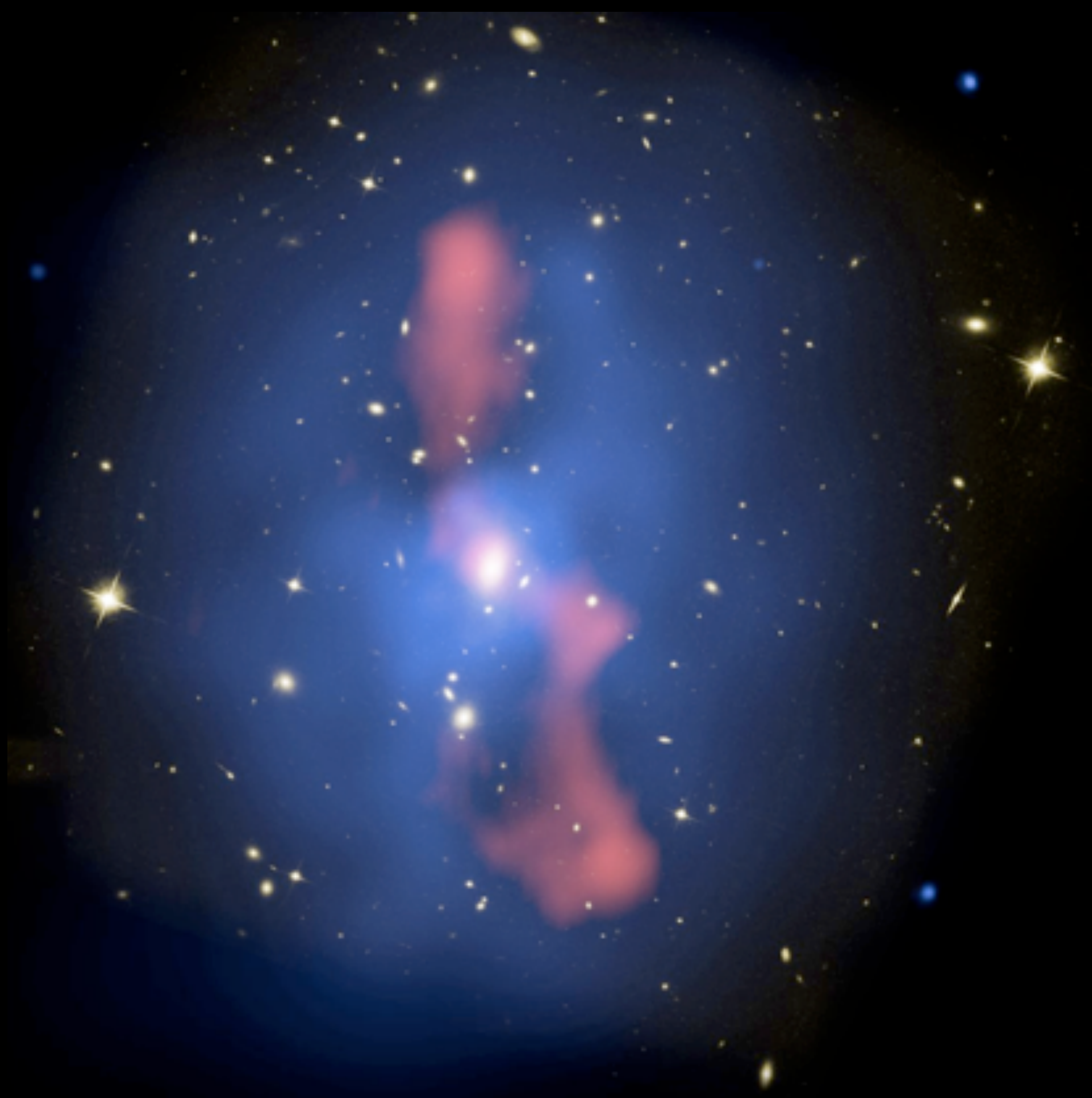
The cool core problem



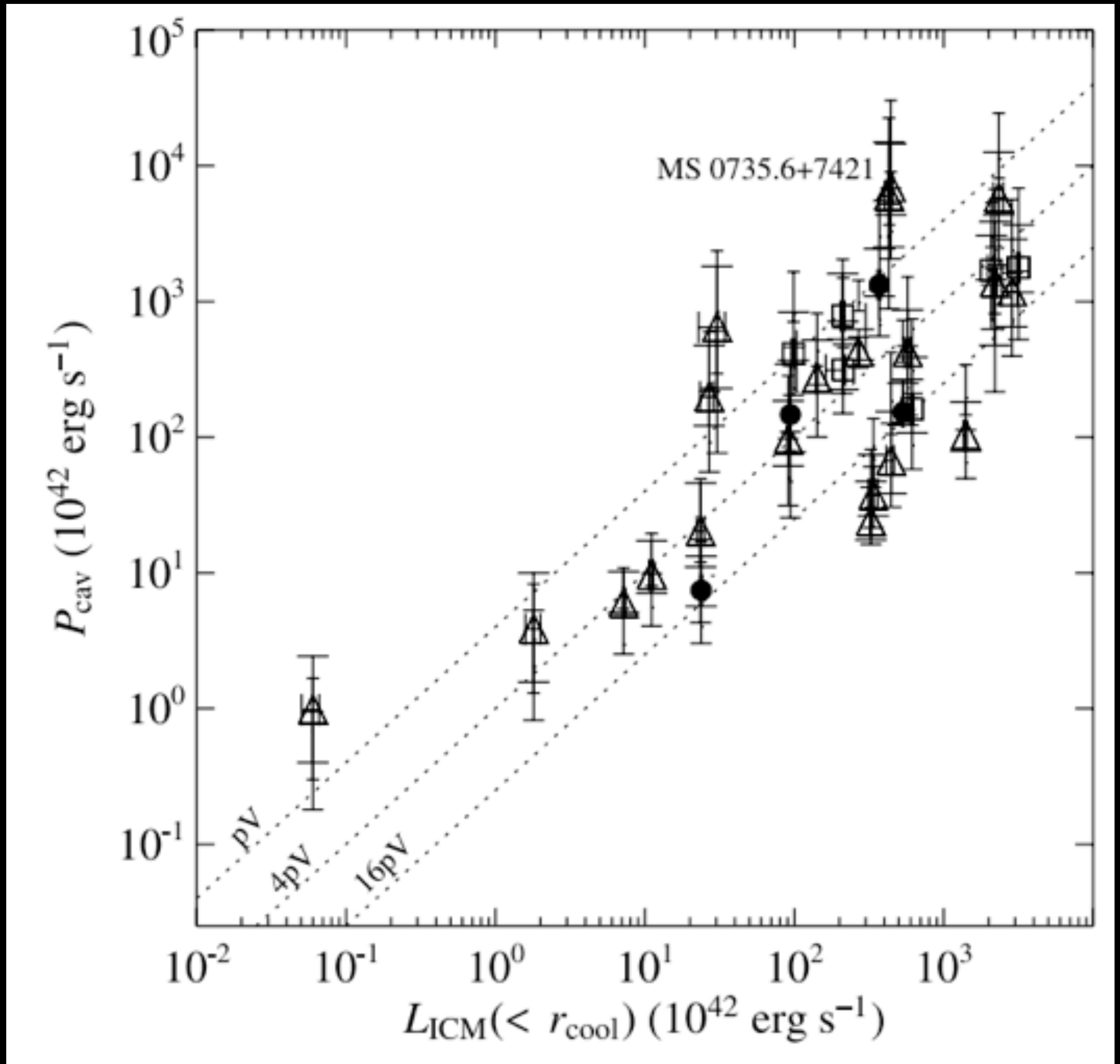
Peterson & Fabian
2006

How to heat the cluster core?

- Merger shocks/turbulence/sound waves
- Cold clump accretion
- Supernova feedback
- Cosmic rays
- Thermal conduction
- AGN feedback (of various sorts)
- (probably many more ideas)

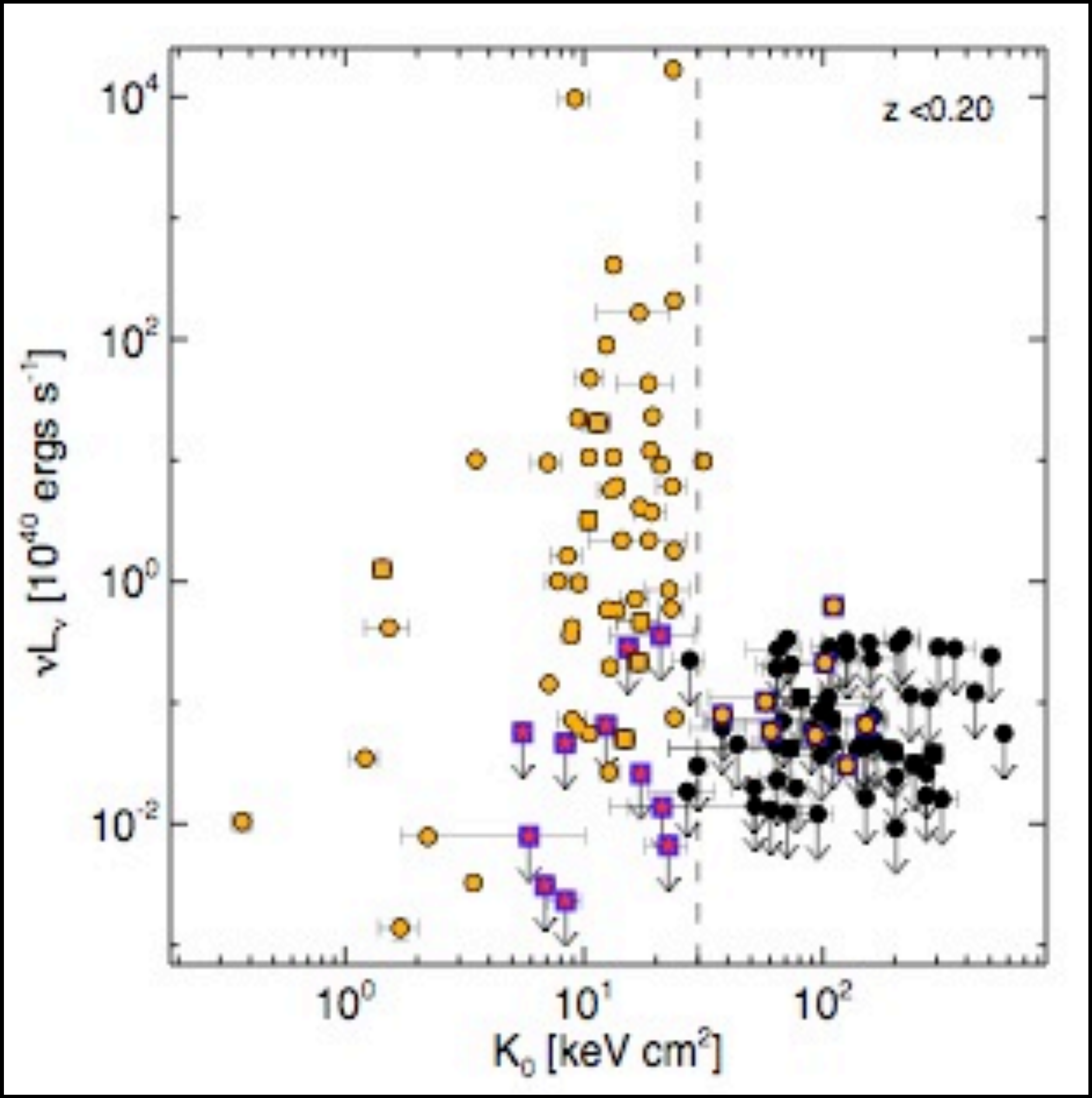


McNamara+



Rafferty+ 2006

Important clue: Cluster entropy and AGN activity



Central AGN is a radio source if K_0 < 30 keV cm^2

Cavagnolo+ 2008

note:

$K = k_b T n_e^{-2/3}$

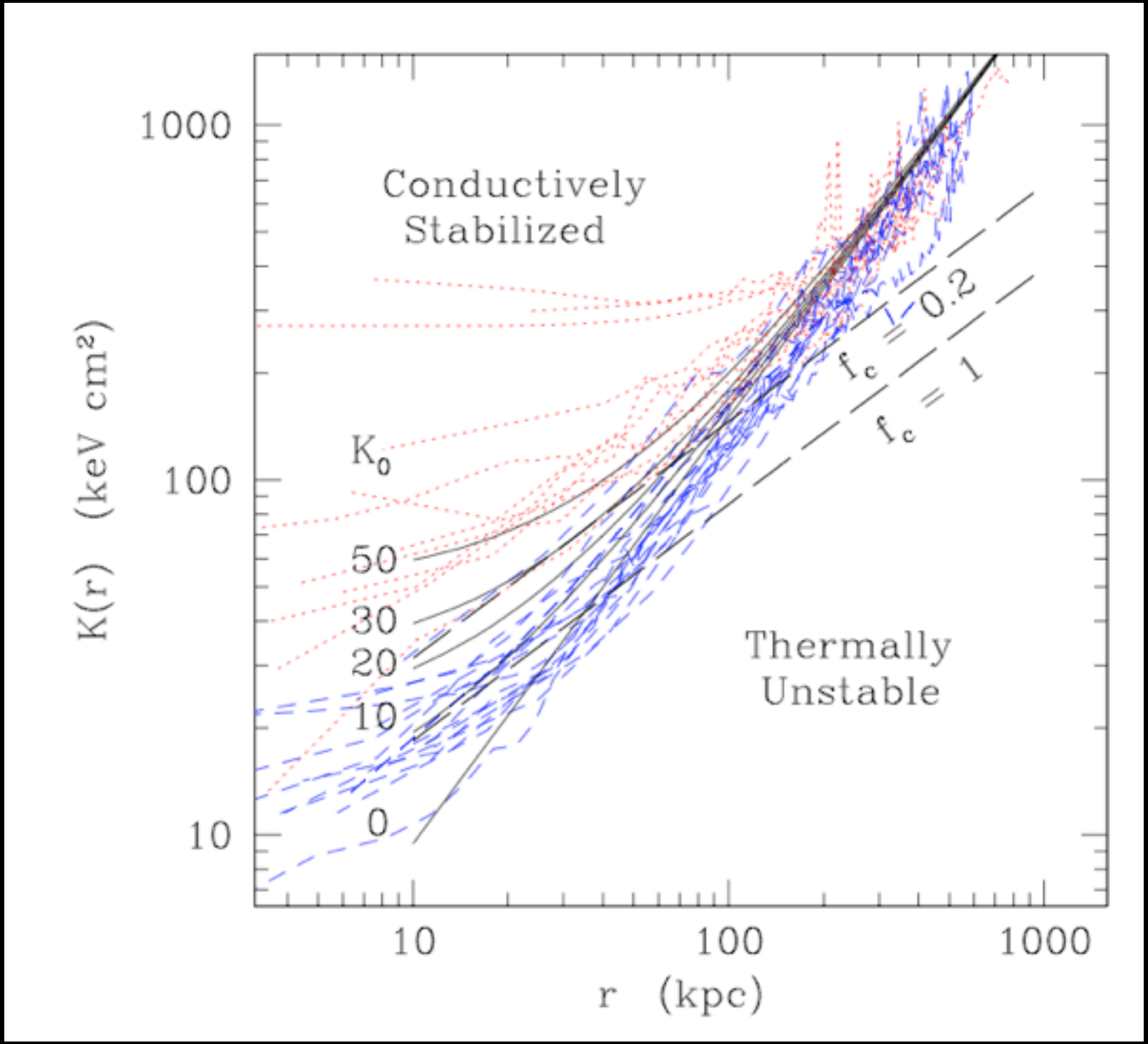
What could generate and regulate the (possibly stable) multiphase medium that feeds the AGN?

Thermal conduction

with Britton Smith (Edinburgh), Mark Voit, David Ventimiglia (MSU), Sam Skillman (Stanford/KIPAC)

Smith et al. 2013, ApJ, 778, 152

Conduction may be important in regulating cluster cores



Voit et al. 2008, ApJL, 681, L5

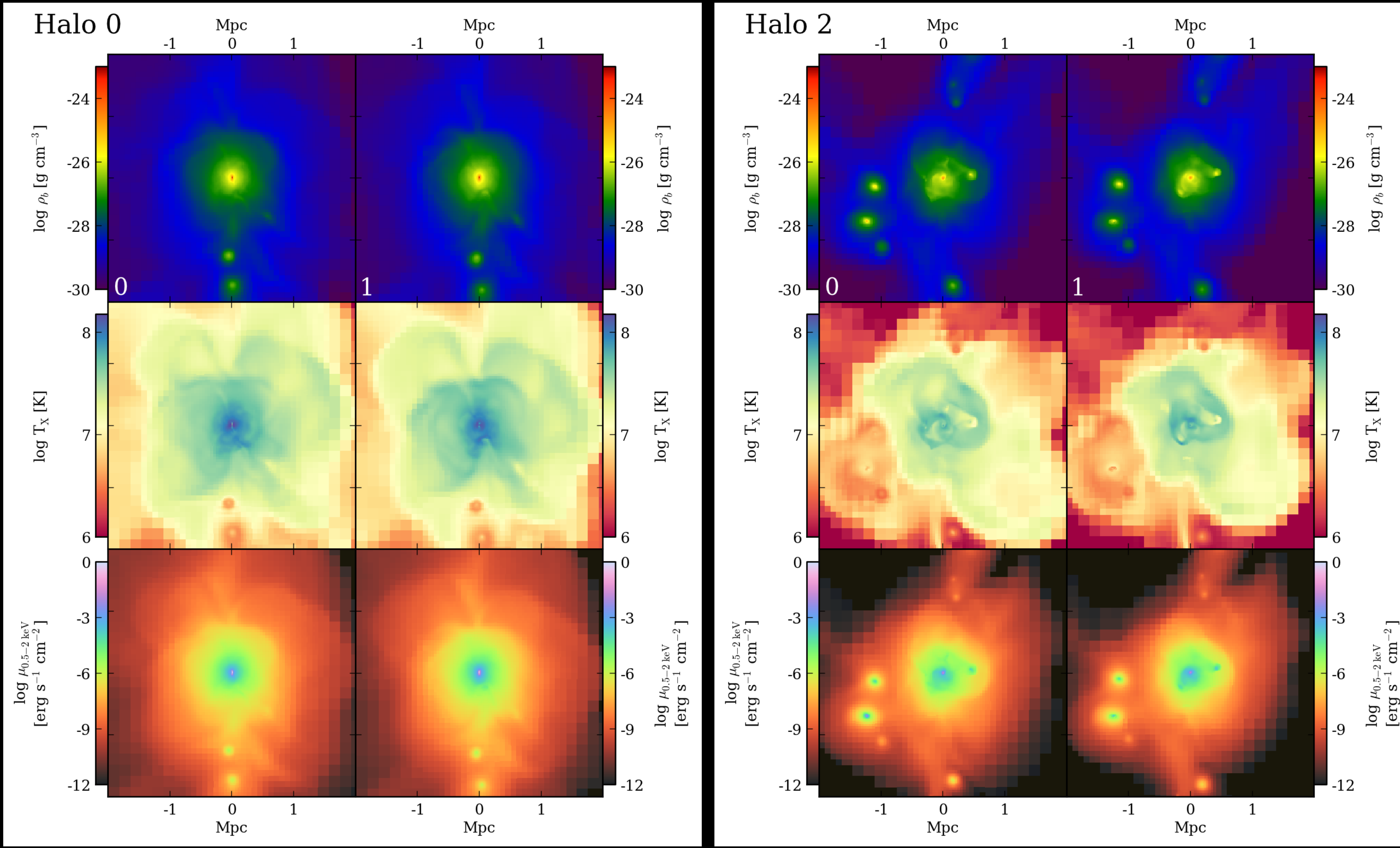
$$\lambda_F \equiv \left[\frac{T\kappa(T)}{n^2\Lambda(T)}\right]^{1/2} = 4\,\mathrm{kpc}\,\left[\frac{K}{10\,\mathrm{keV\,cm^2}}\right]^{3/2} f_c^{1/2}$$

A study of conduction in the ICM

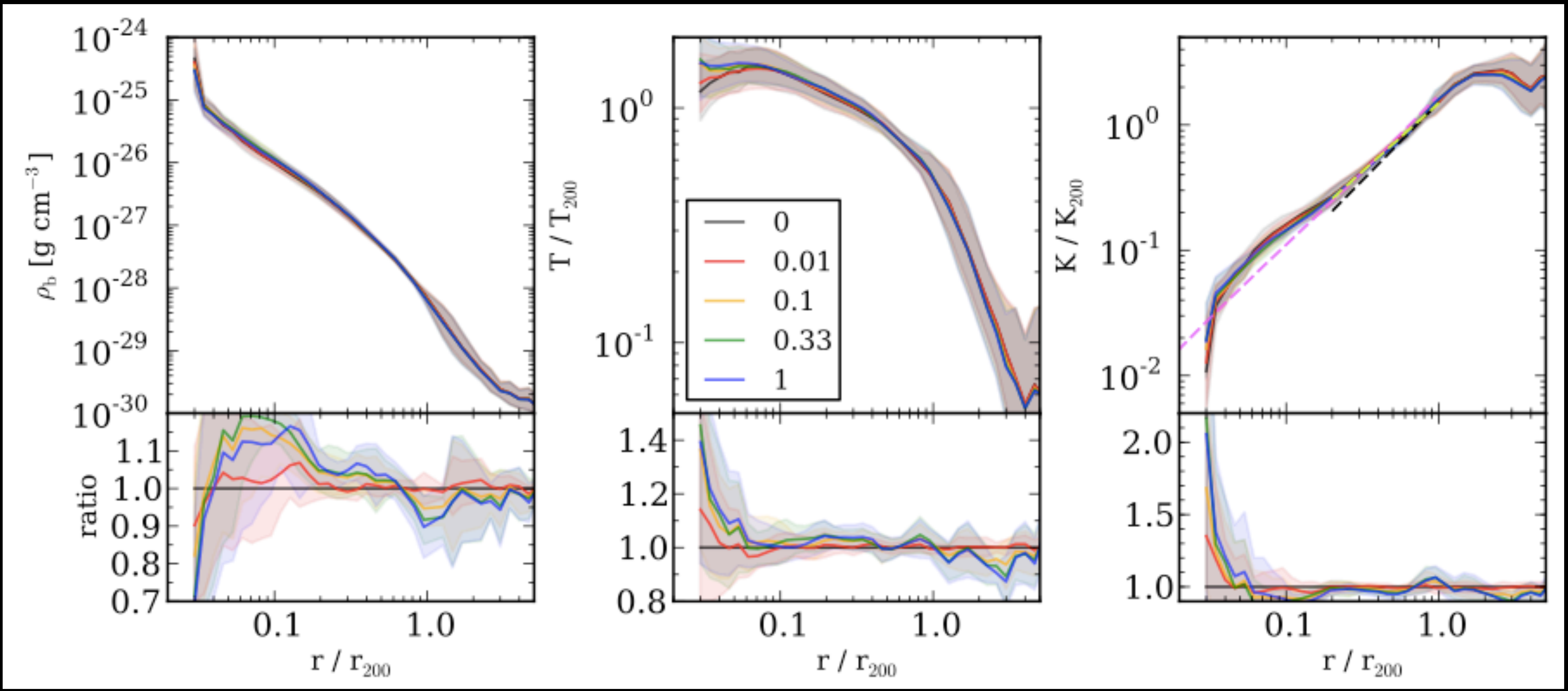
- AMR simulations of cluster formation
- N-body + hydro, primordial+metal cooling, star formation and thermal feedback (no AGN yet!)
- **Isotropic** conduction with f_{sp} = 0, 0.01, 0.1, 0.33, 1
- 10 individual clusters run, identical except for f_{sp}.

Smith, BWO et al. 2013

Are conduction effects observable?

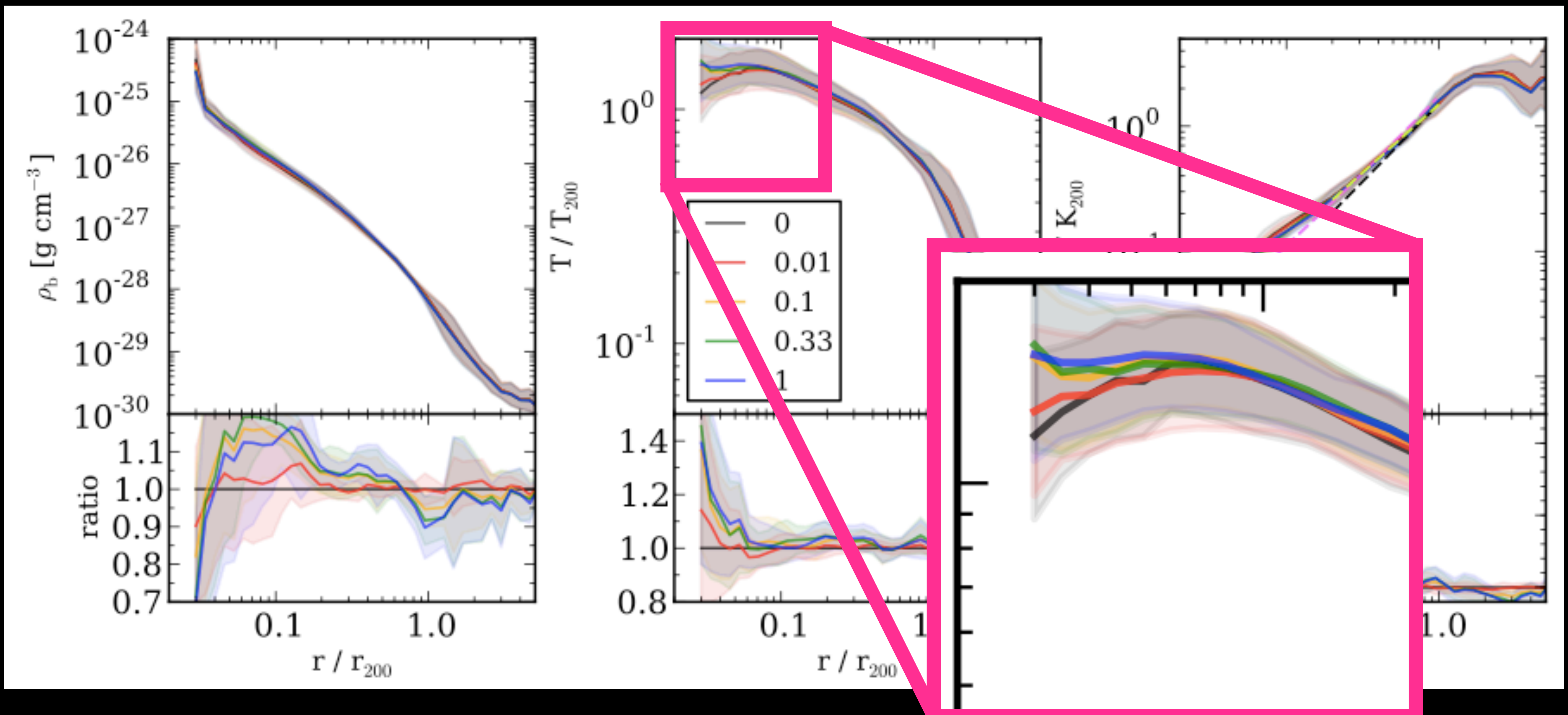


Radial profiles



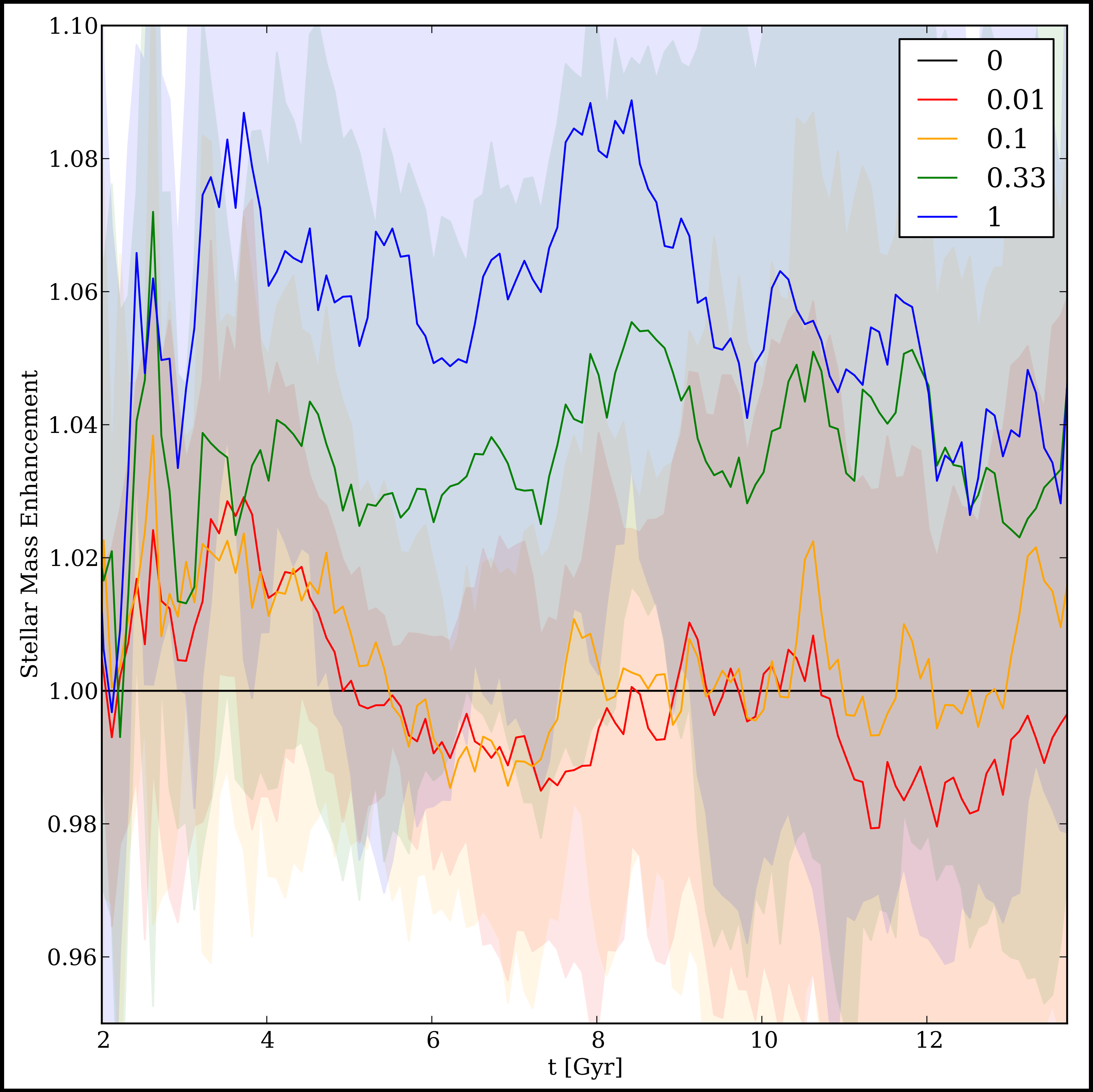
Density Temperature Entropy

Radial profiles



Density Temperature Entropy

Does conduction affect gas condensation?



Normalized SFR

Time

Conduction...

- increases T_{core} by 20-30% and makes cores *slightly* puffier
- Slightly enhances star formation in BCG - maybe also slightly enhances AGN feedback?
- Different/more powerful feedback mechanisms (AGN?) required to remove core gas and suppress star formation

Exploring thermal instability in cluster cores

(exploring the Anything Goes Now hypothesis)

Meece, O'Shea & Voit 2014, in prep.

Hypothesis:

Gas in global thermal balance can form a multiphase intracluster medium if the ratio of cooling time to free-fall time is small enough.

(McCourt et al. 2012; Sharma et al. 2012)

How robust is this to feedback mechanism and plasma structure?

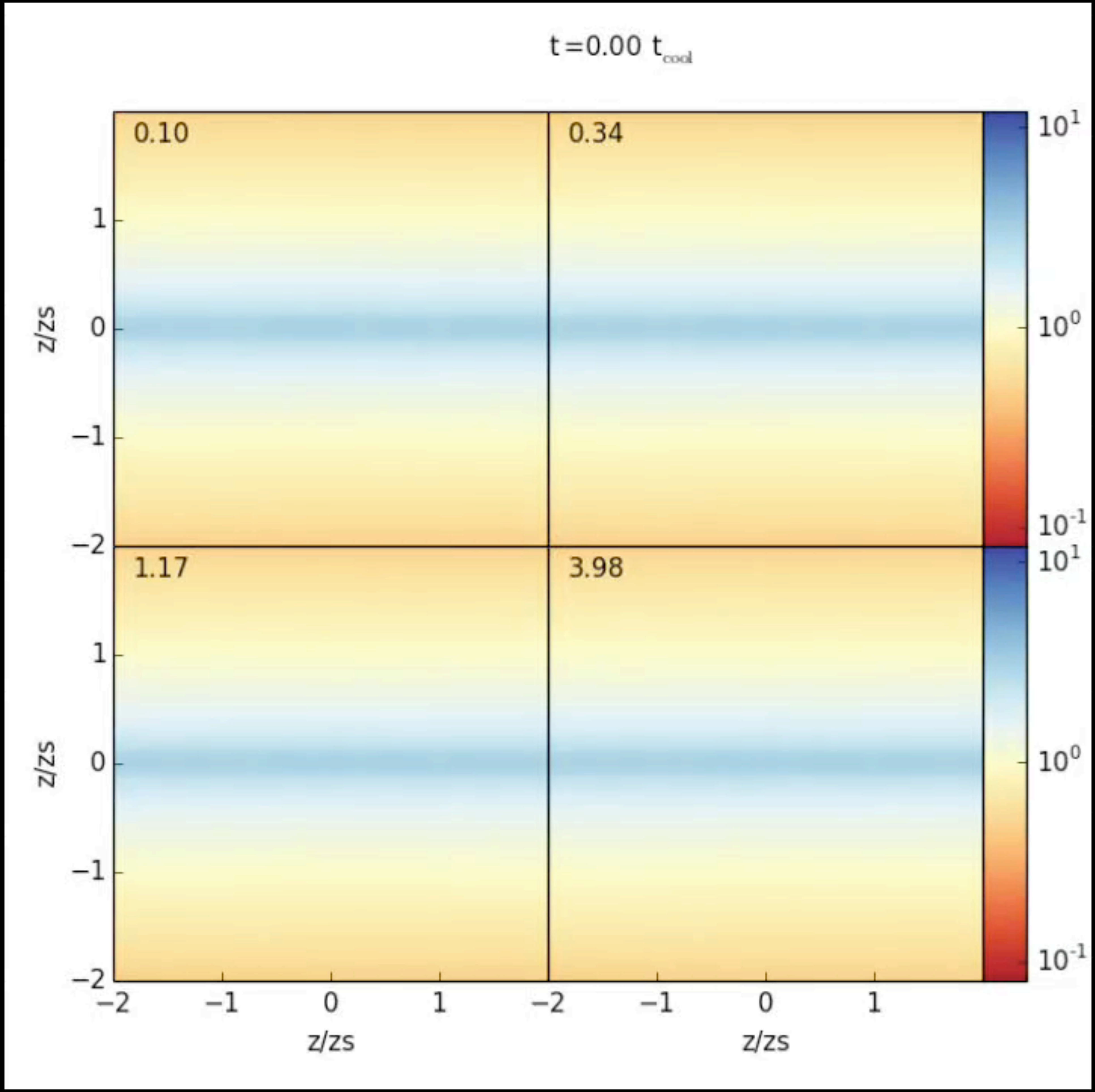
Simulations

- 2D cartesian/cylindrical and 3D spherical, fixed gravitational potential
- Control density, temperature structure of gas
- Heating balances cooling at every height/ radius: input energy in various ways.
- Ratio of cooling time to dynamical time set at 1 scale height (unless constant everywhere)

Meece, O'Shea & Voit 2014, in prep.

t_{cool}/t_{ff} = 0.1

t_{cool}/t_{ff} = 0.34



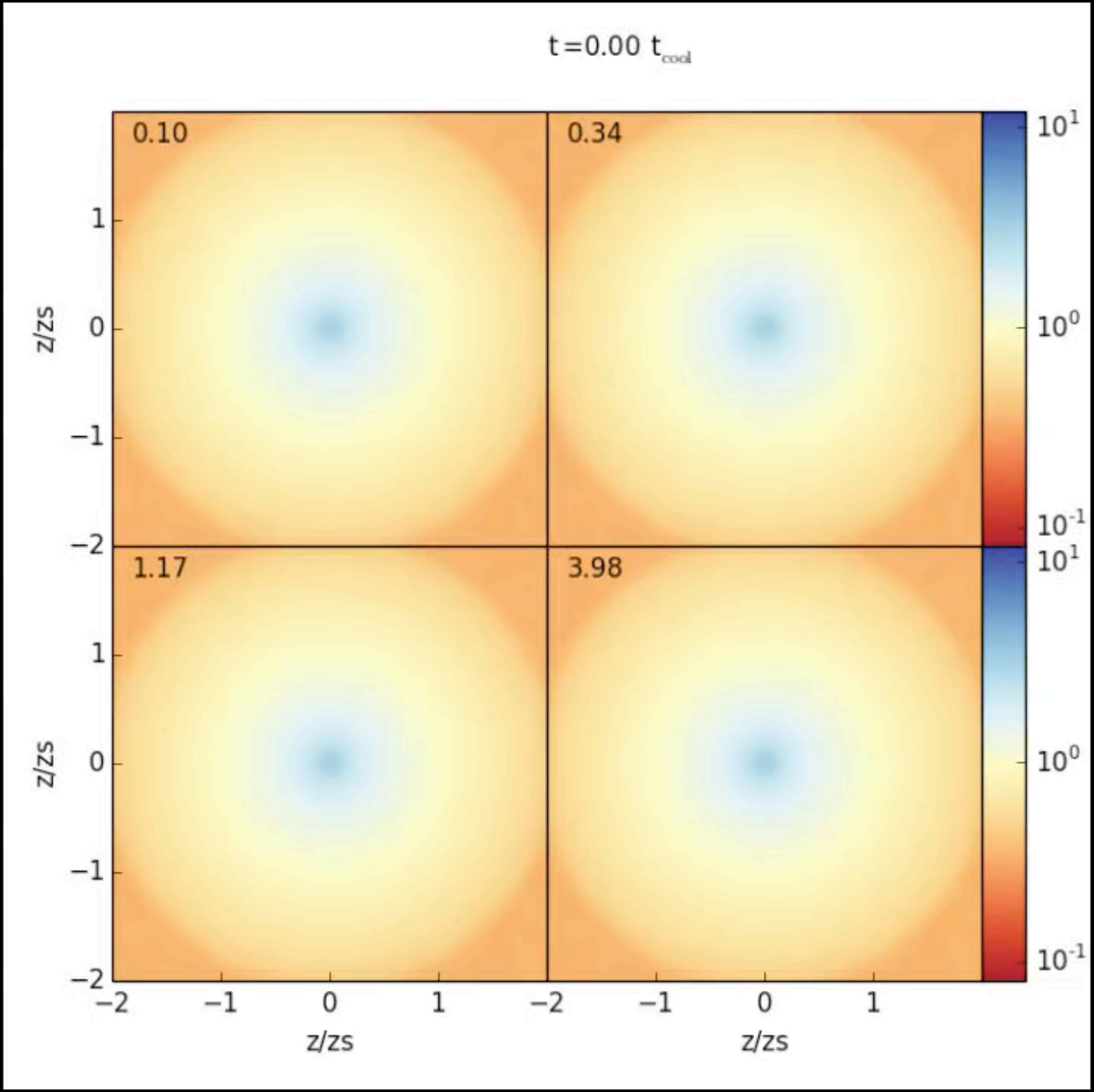
Colorbar: density

t_{cool}/t_{ff} = 1.17

t_{cool}/t_{ff} = 3.98

t_{cool}/t_{ff} = 0.1

t_{cool}/t_{ff} = 0.34



Colorbar: density

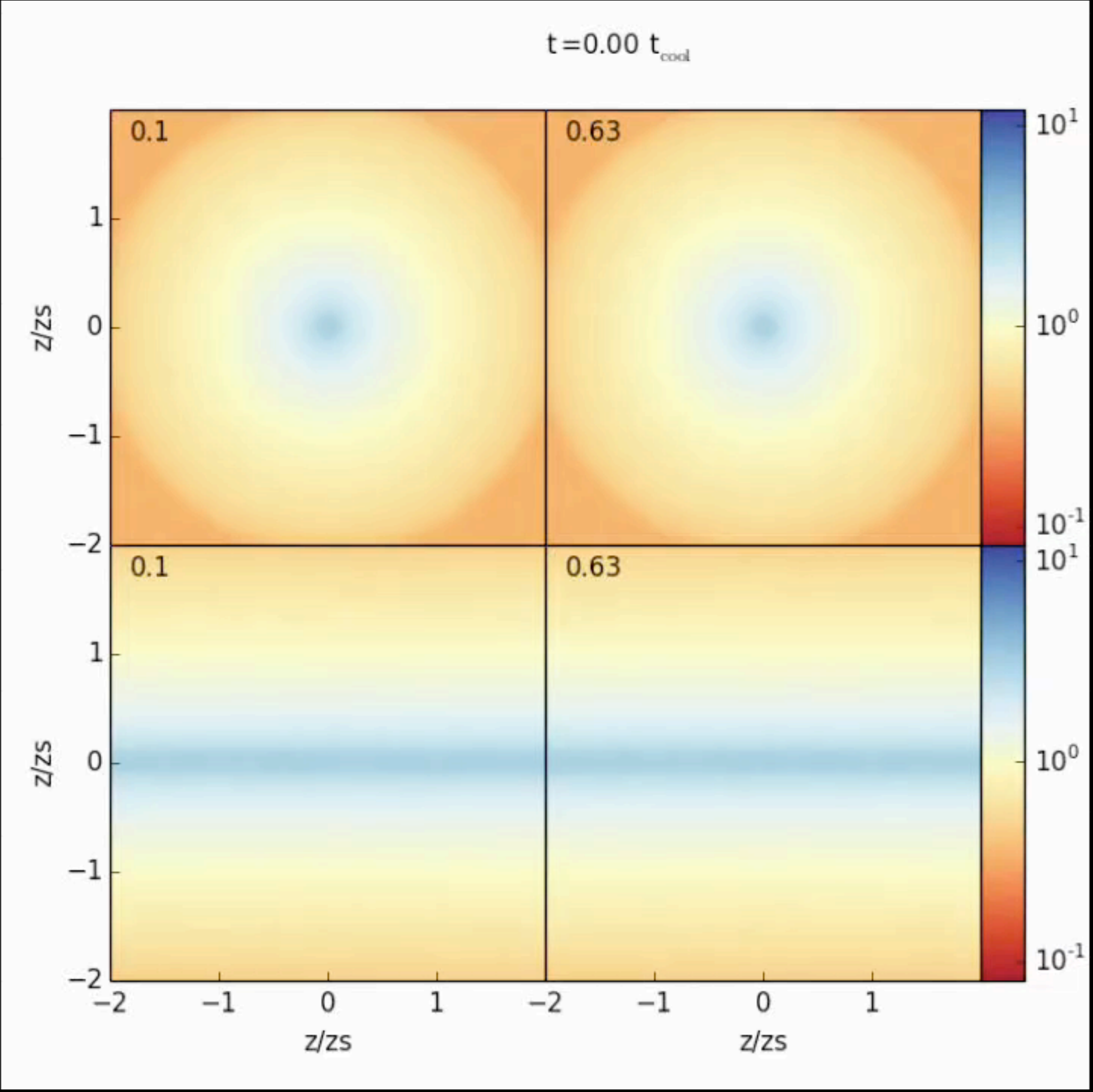
t_{cool}/t_{ff} = 1.17

t_{cool}/t_{ff} = 3.98

t_{cool}/t_{ff} = 0.1

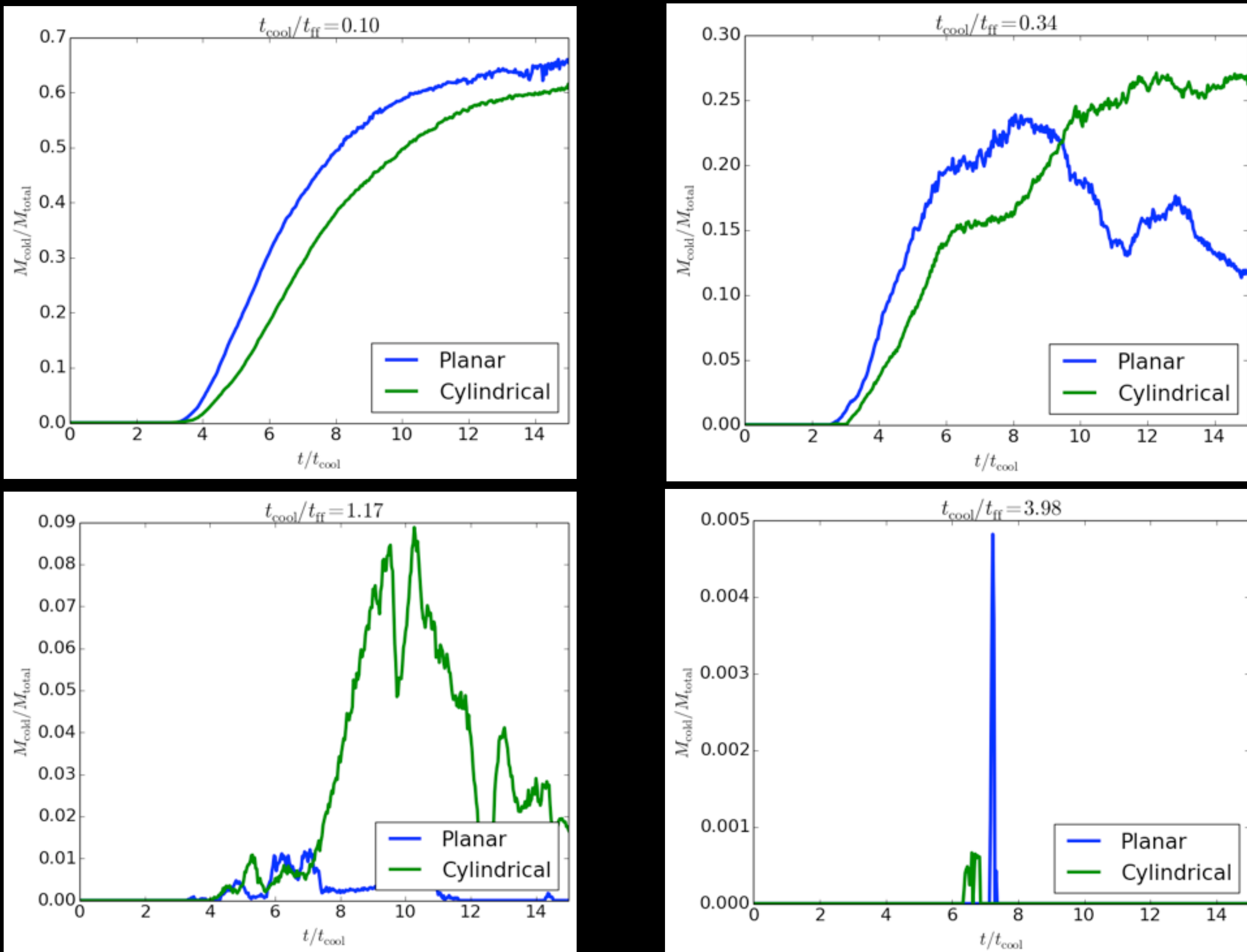
Cylinder

Planar



t_{cool}/t_{ff} = 0.63

Colorbar: density



$t_{cool}/t_{ff} = 0.10$
$t_{cool}/t_{ff} = 0.34$
$t_{cool}/t_{ff} = 1.17$
$t_{cool}/t_{ff} = 3.98$
M_{cold}/M_{total}
t/t_{cool}
Planar
Cylindrical

Creation of a multiphase medium...

- Can create a multiphase medium even in the presence of global thermal equilibrium in many circumstances
- Depends primarily on the local ratio of cooling and free-fall times ($t_{cool} < t_{ff}$)
- Rate of cold gas creation is only somewhat affected by geometrical effects
- Rate of accretion does seem to depend significantly on how energy feedback occurs

Main points

- Thermal conduction may be able to *enhance* cooling of gas in some circumstances, but globally does not affect the structure of the cluster.
- Multiphase medium formation/gas accretion/AGN feeding is not a particularly robust problem as we have characterized it. Maybe this is a good thing. Anything Does Not Go!