1. New constraints on large-scale thermal conductivity of the intracluster medium

2. New way to constrain effective plasma viscosity of the ICM

3. Another shock for the Bullet cluster, and the origin of peripheral radio relics

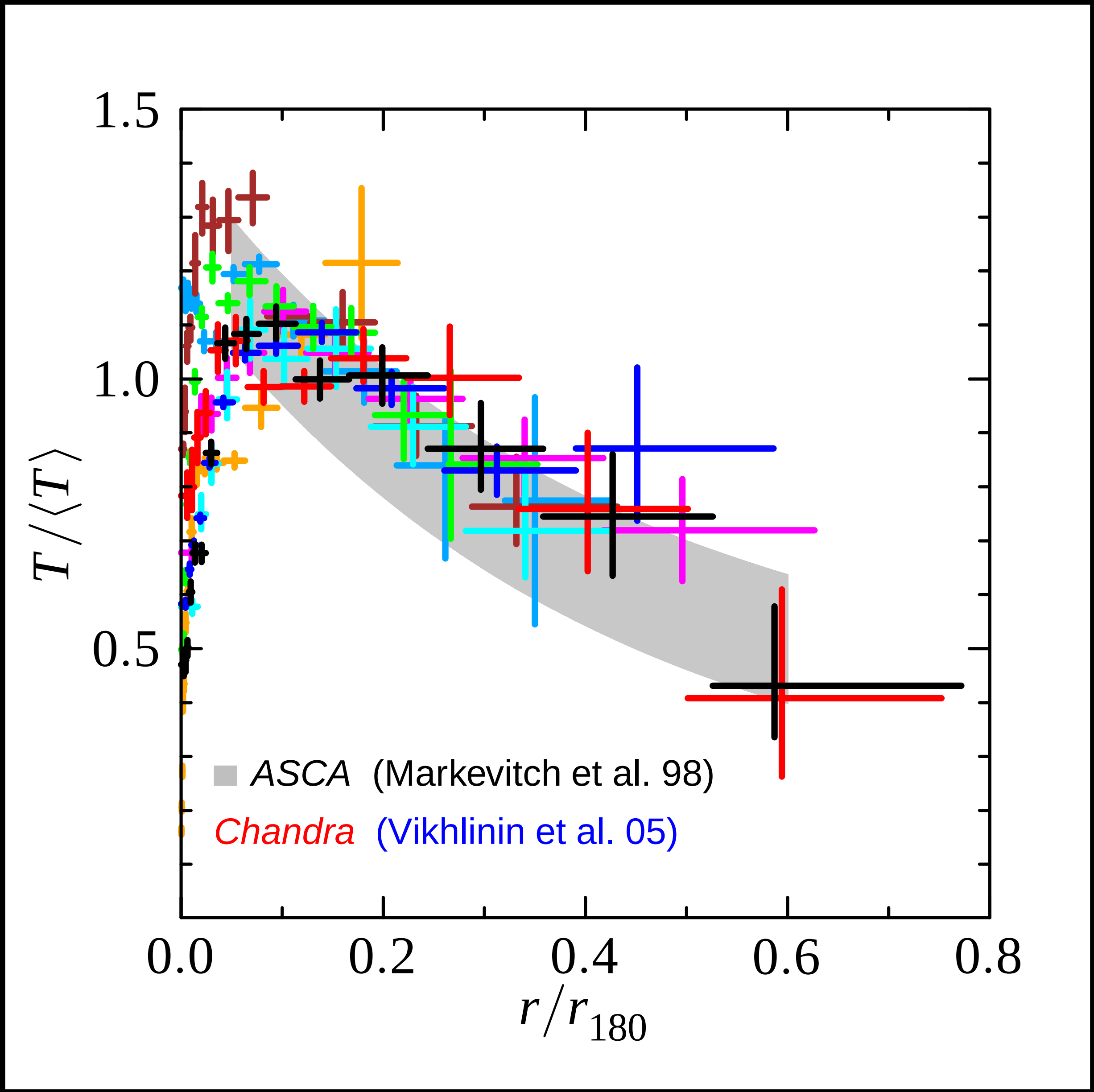
Maxim Markevitch (NASA GSFC)

November 10, 2014

New constraints on large-scale thermal conductivity in galaxy clusters

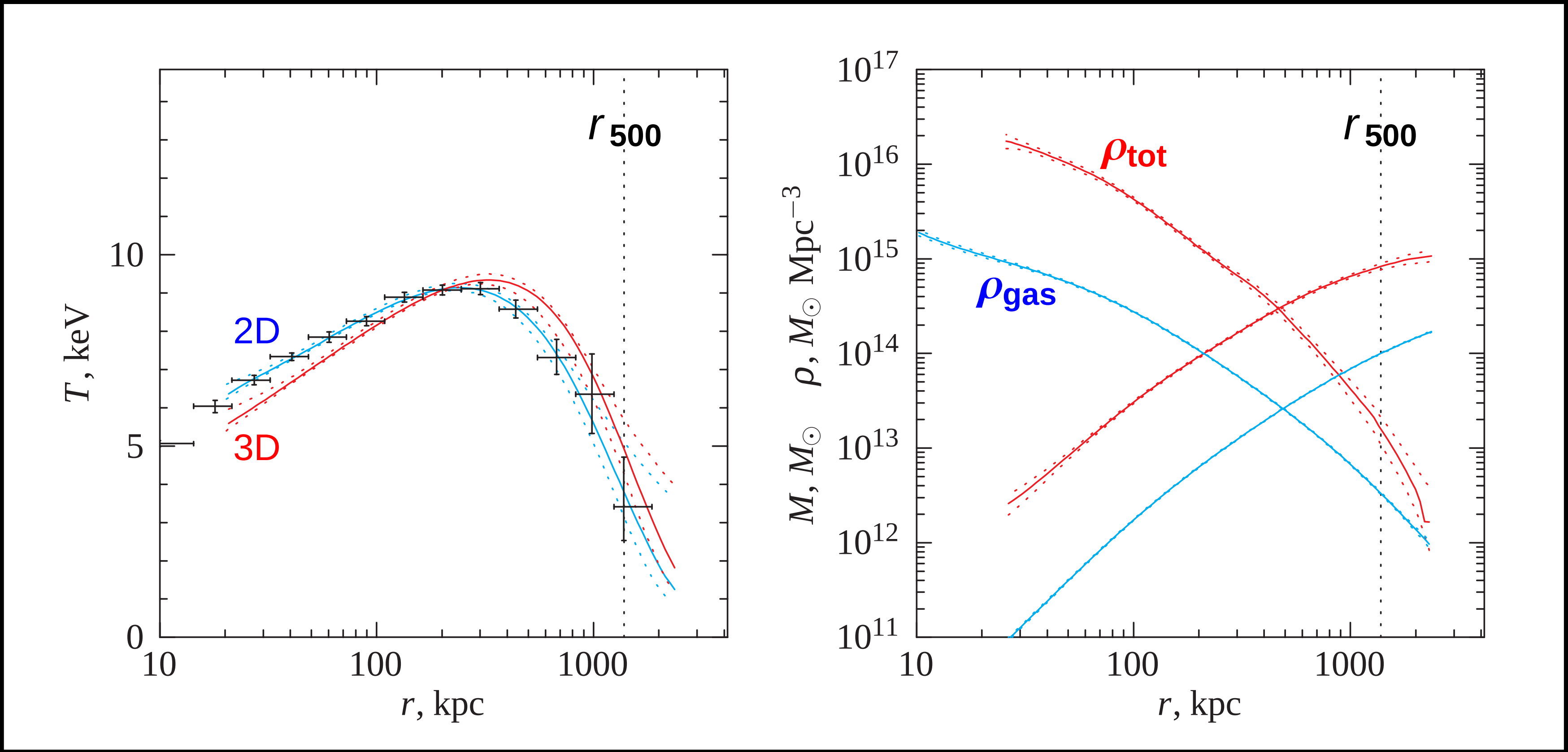
B. Russell (PhD thesis, UMD), M. Markevitch (GSFC), J. ZuHone (GSFC)

Cluster radial temperature profiles



- *XMM*, *Suzaku* results similar (Molendi & Leccardi 08; George et al. 09; ...)

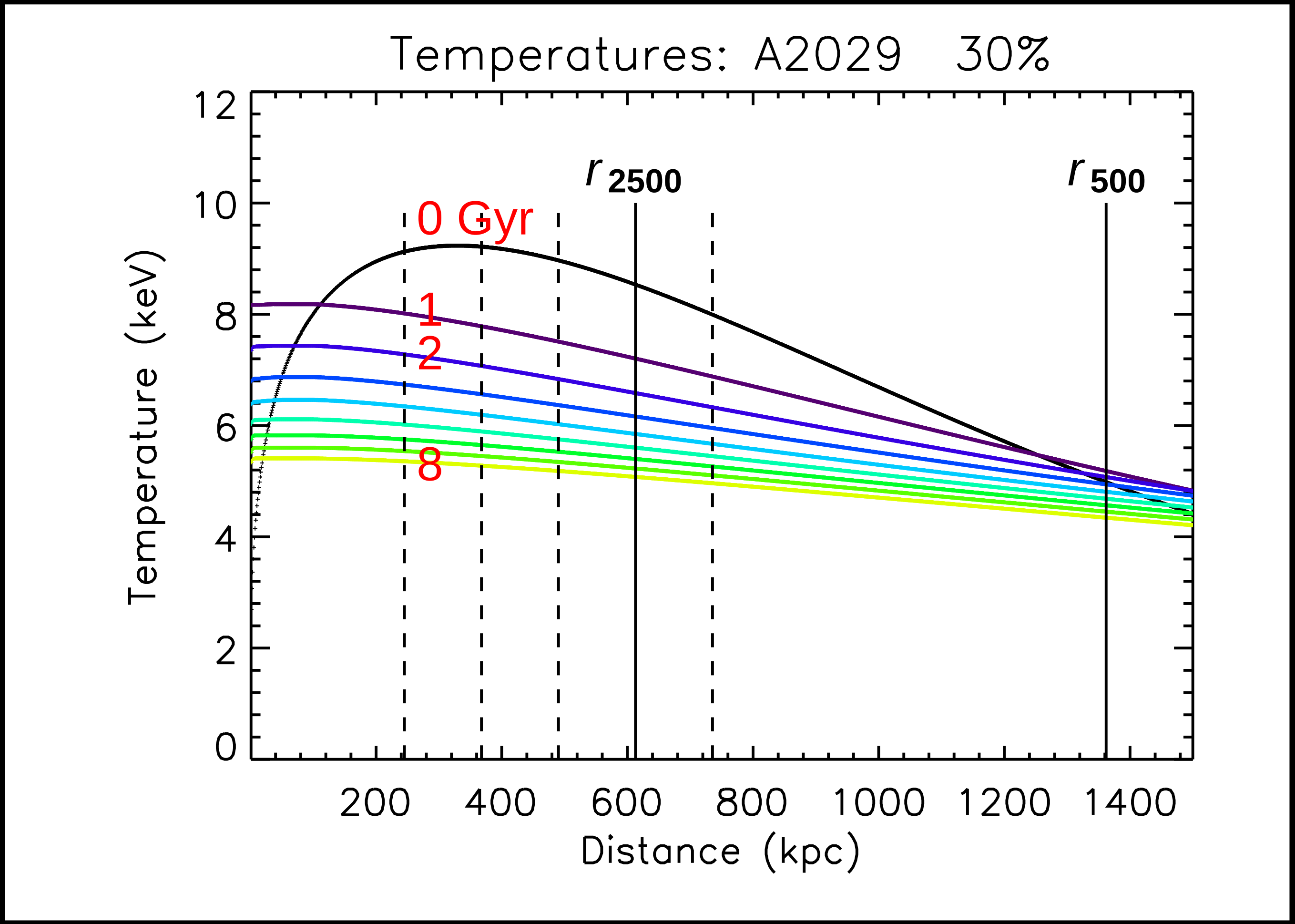
A2029, a prototypical hot relaxed cluster



Chandra data, Vikhlinin et al. 06

If the cluster were a solid body ...

no cooling, 0.3 Spitzer isotropic conduction



Russell 14

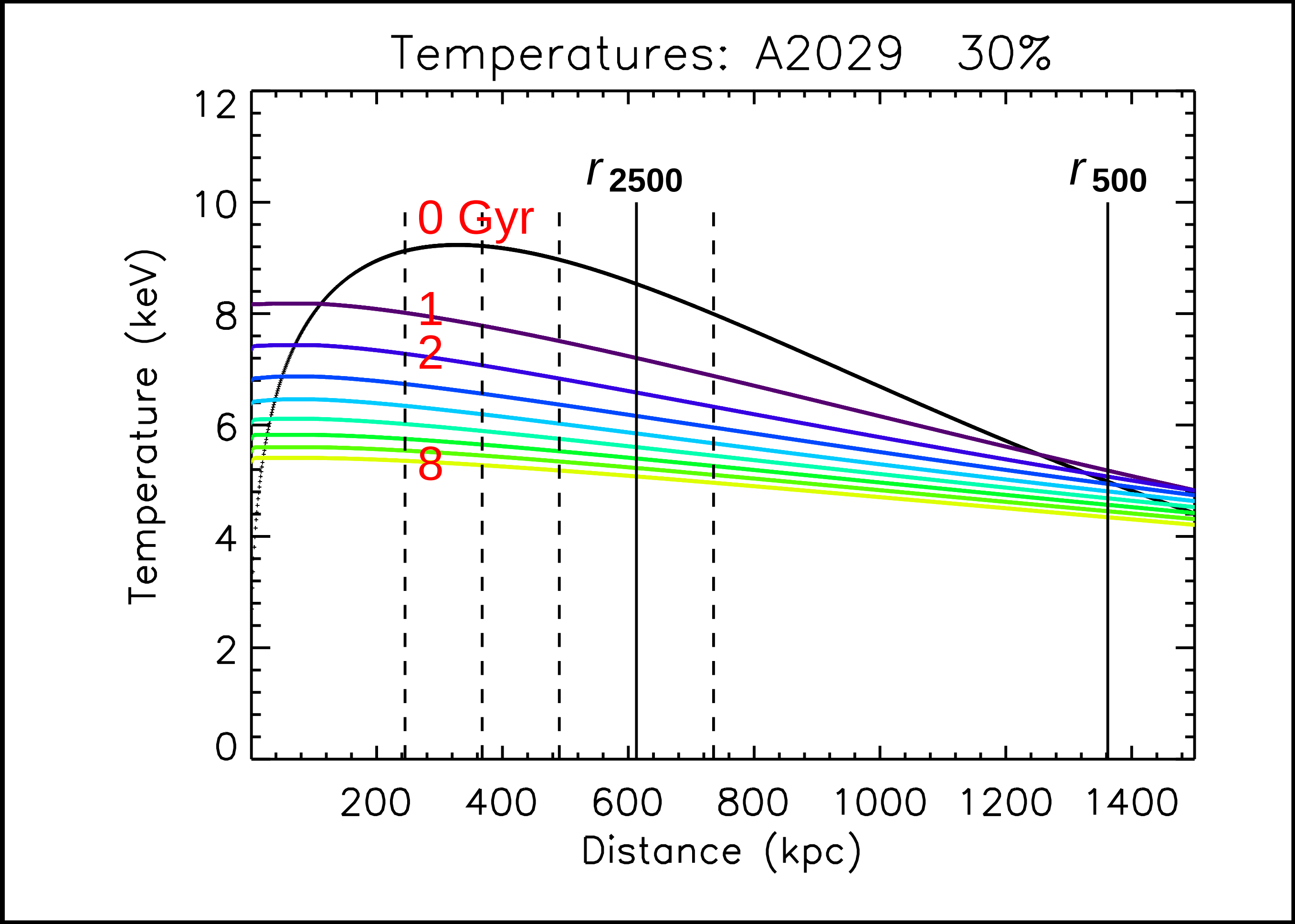
- conduction erases *T* gradient

Allow the cluster to maintain hydrostatic equilibrium:

- Assume constant grav. potential
- Let the gas redistribute quasistatically
- Outer boundary (at $r \sim$ 3 Mpc) open for gas and heat flow

If the cluster is hydrostatic ...

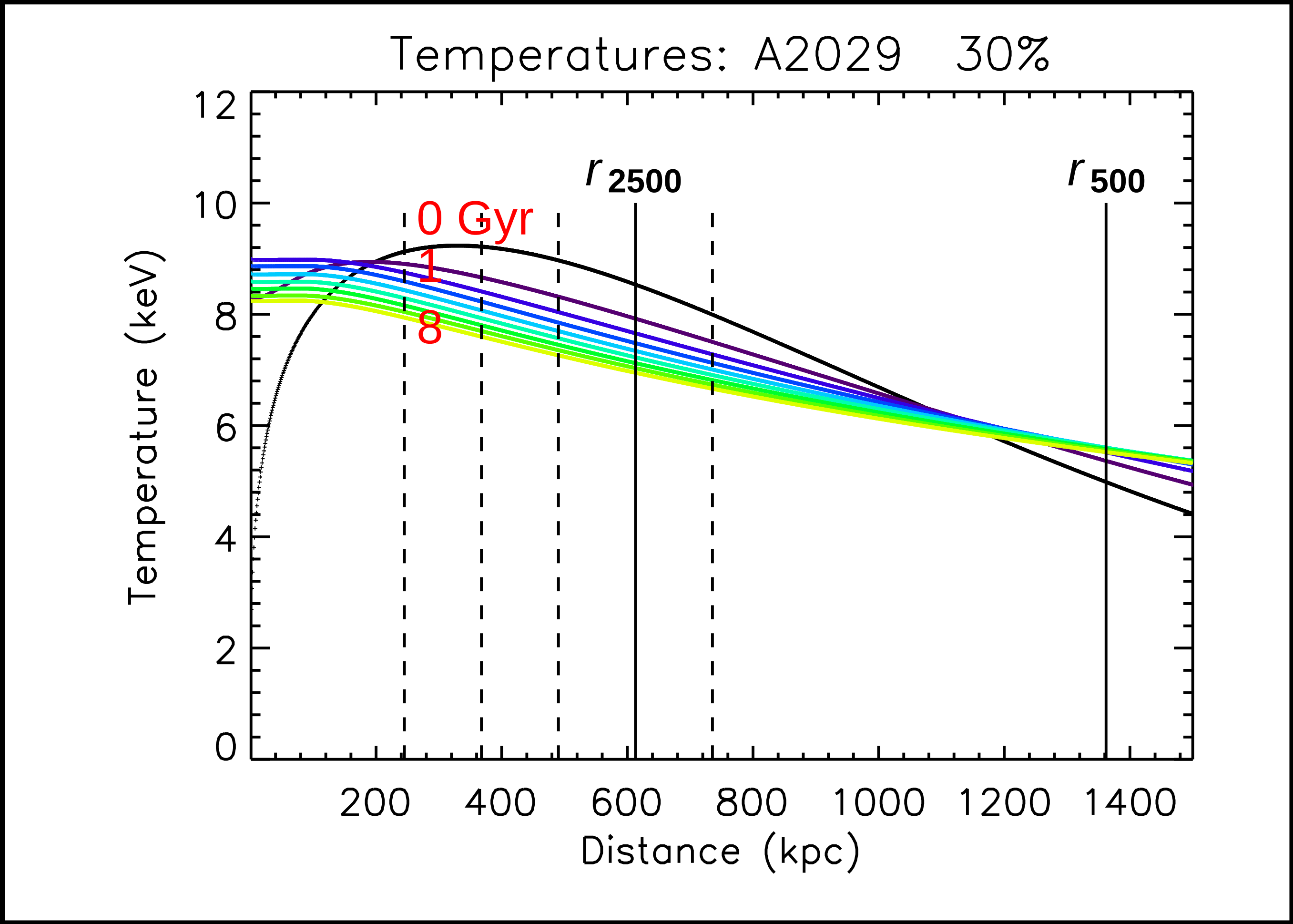
no cooling, 0.3 Spitzer isotropic conduction, no gas redistribution



Russell 14

If the cluster is hydrostatic ...

no cooling, 0.3 Spitzer isotropic conduction, gas redistribution



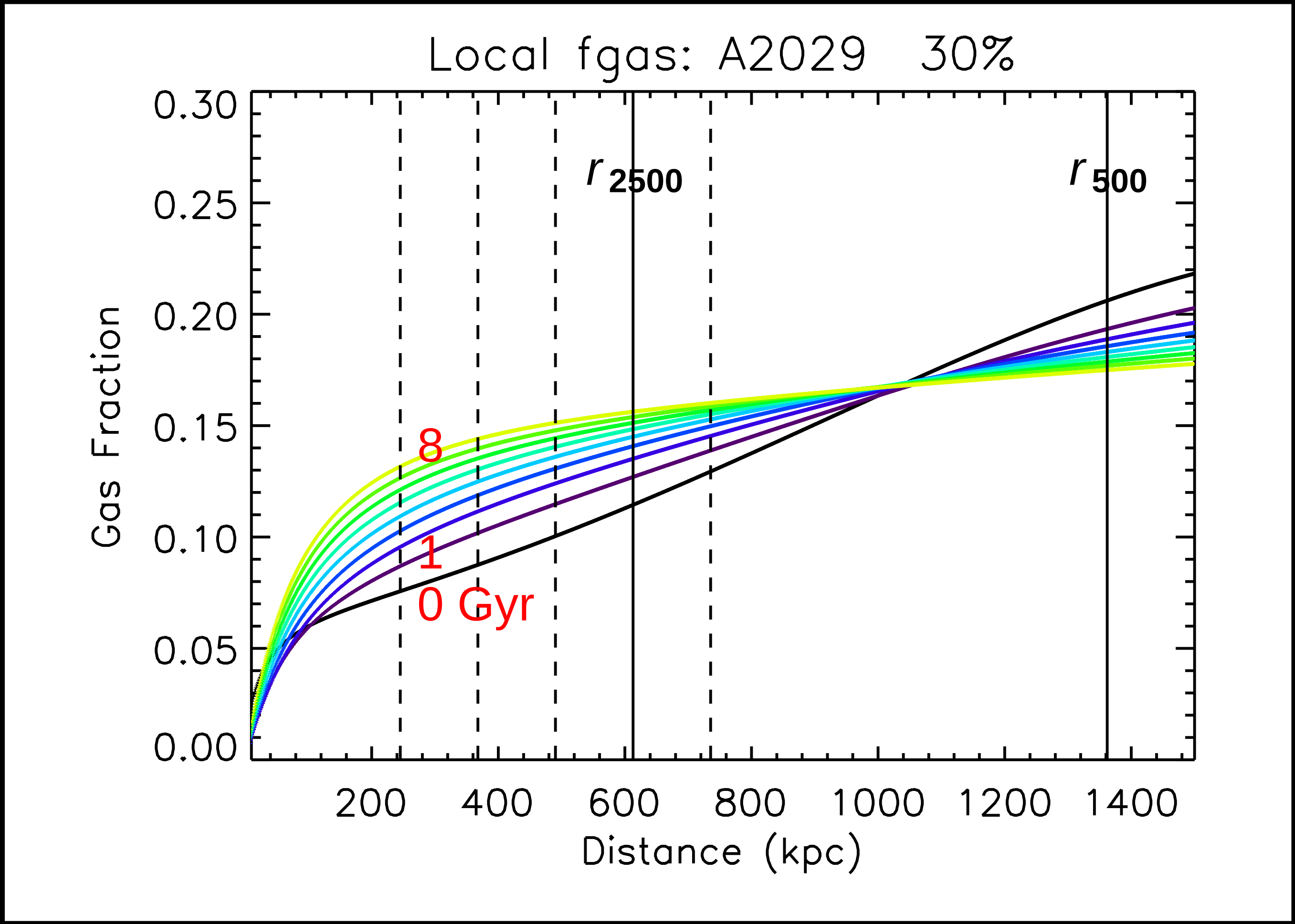
Russell 14

- T gradient maintained because of cluster compression

(result very similar to McCourt 13)

Evolution of gas density profile

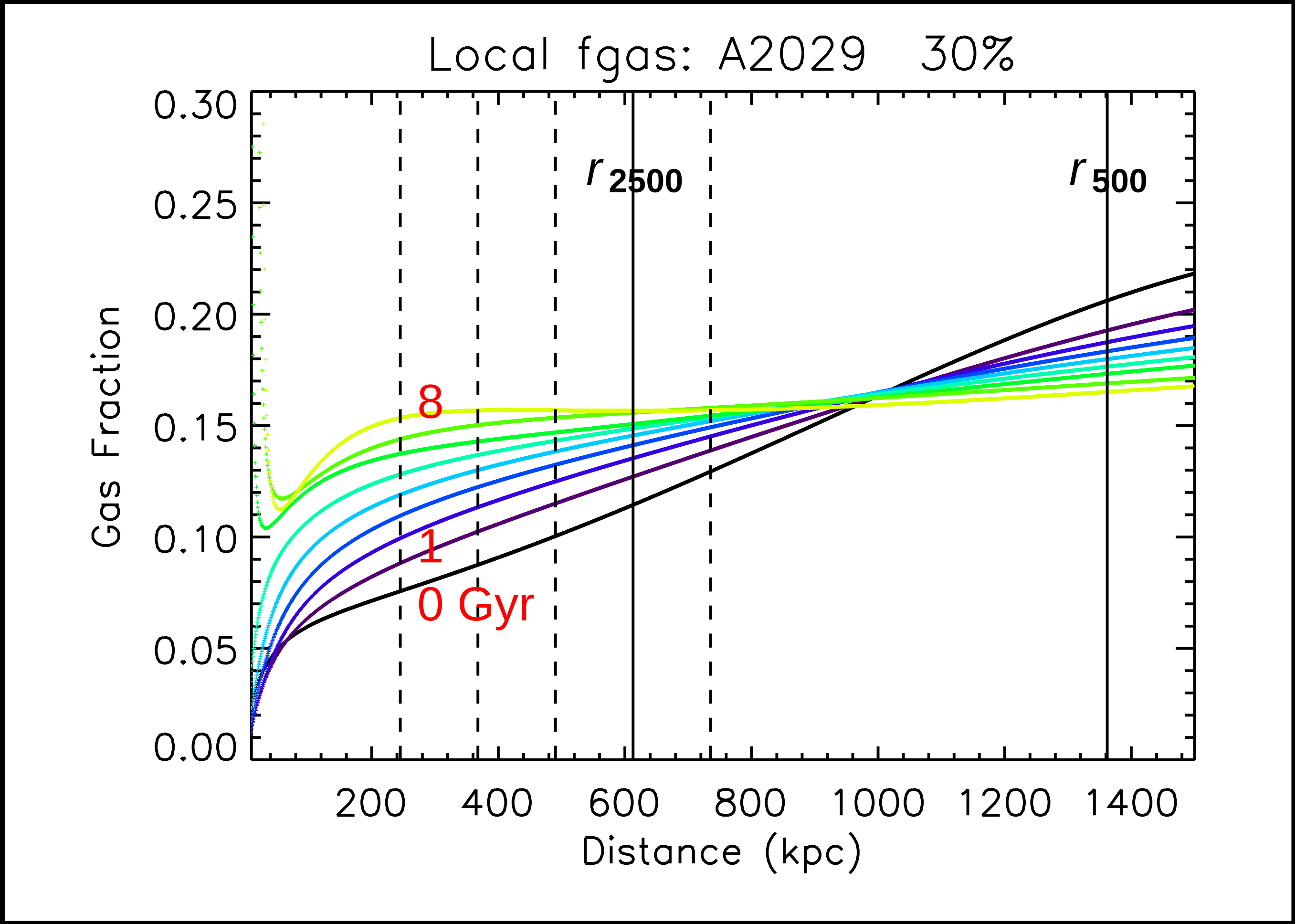
no cooling, 0.3 Spitzer isotropic conduction



Russell 14

Evolution of gas density profile

cooling, 0.3 Spitzer isotropic conduction

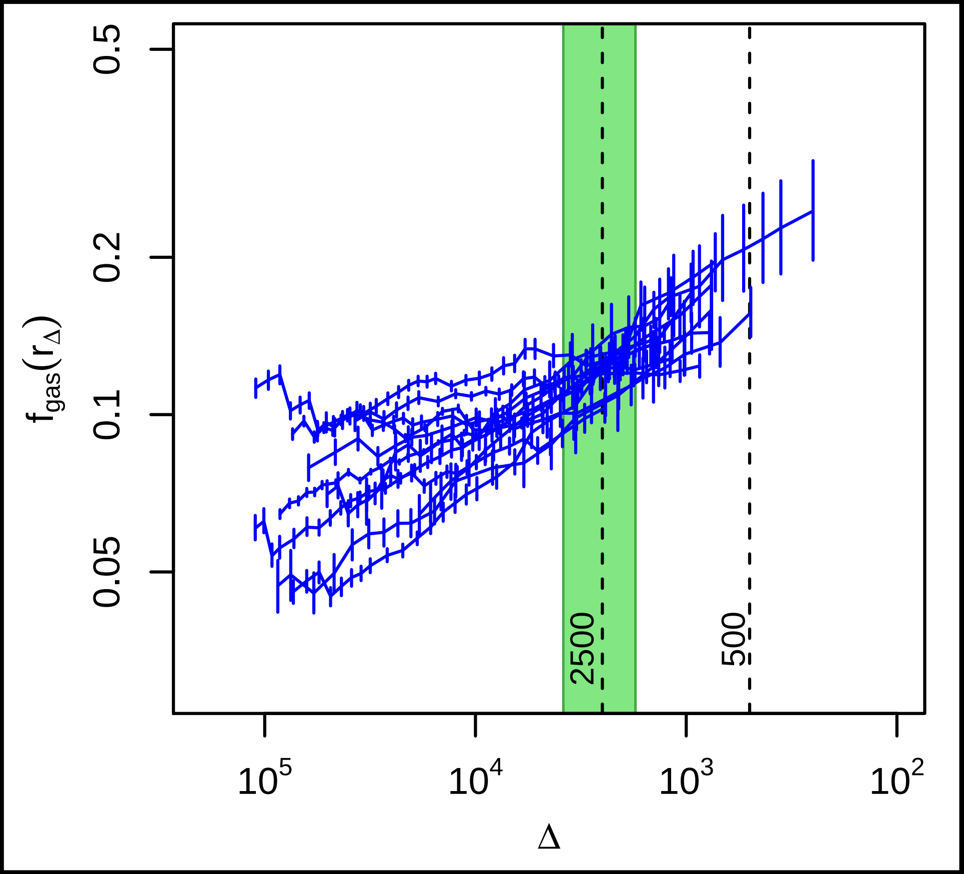


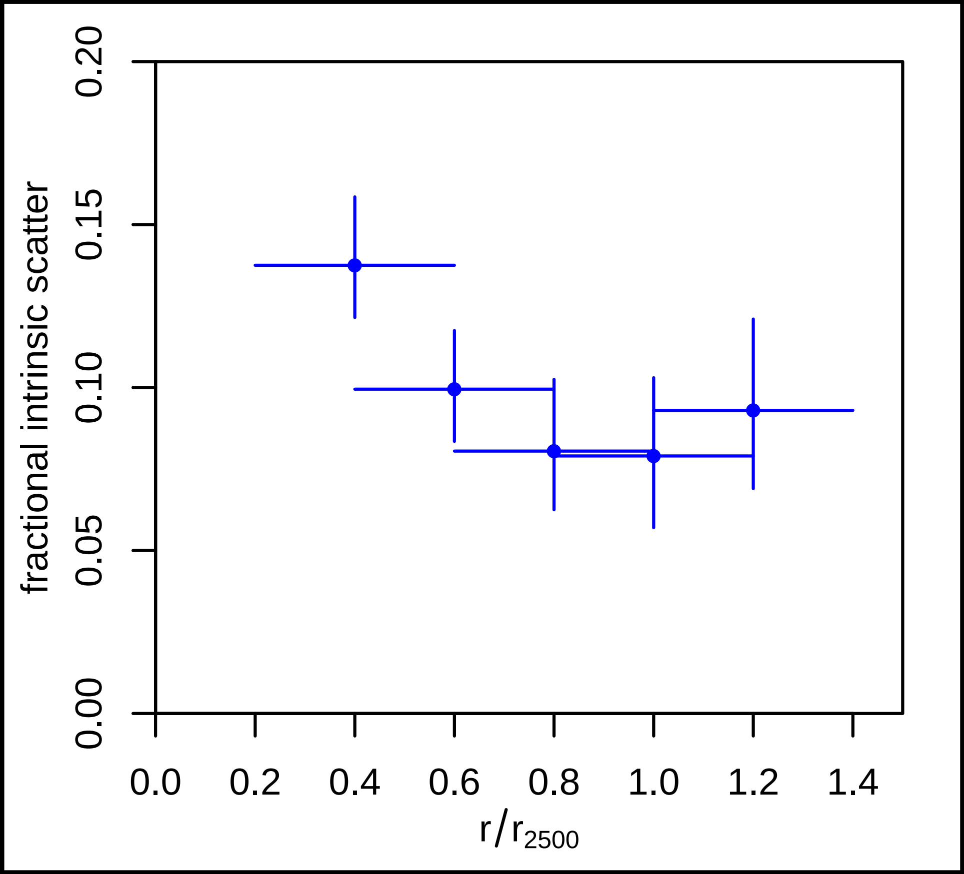
Russell 14

- for $r > 0.5\, r_{2500}$, result doesn't depend on details of heating and feedback in cool core

Observed differential f_{gas} profiles in hot relaxed clusters

T > 5 keV, *z* < 0.25 relaxed clusters





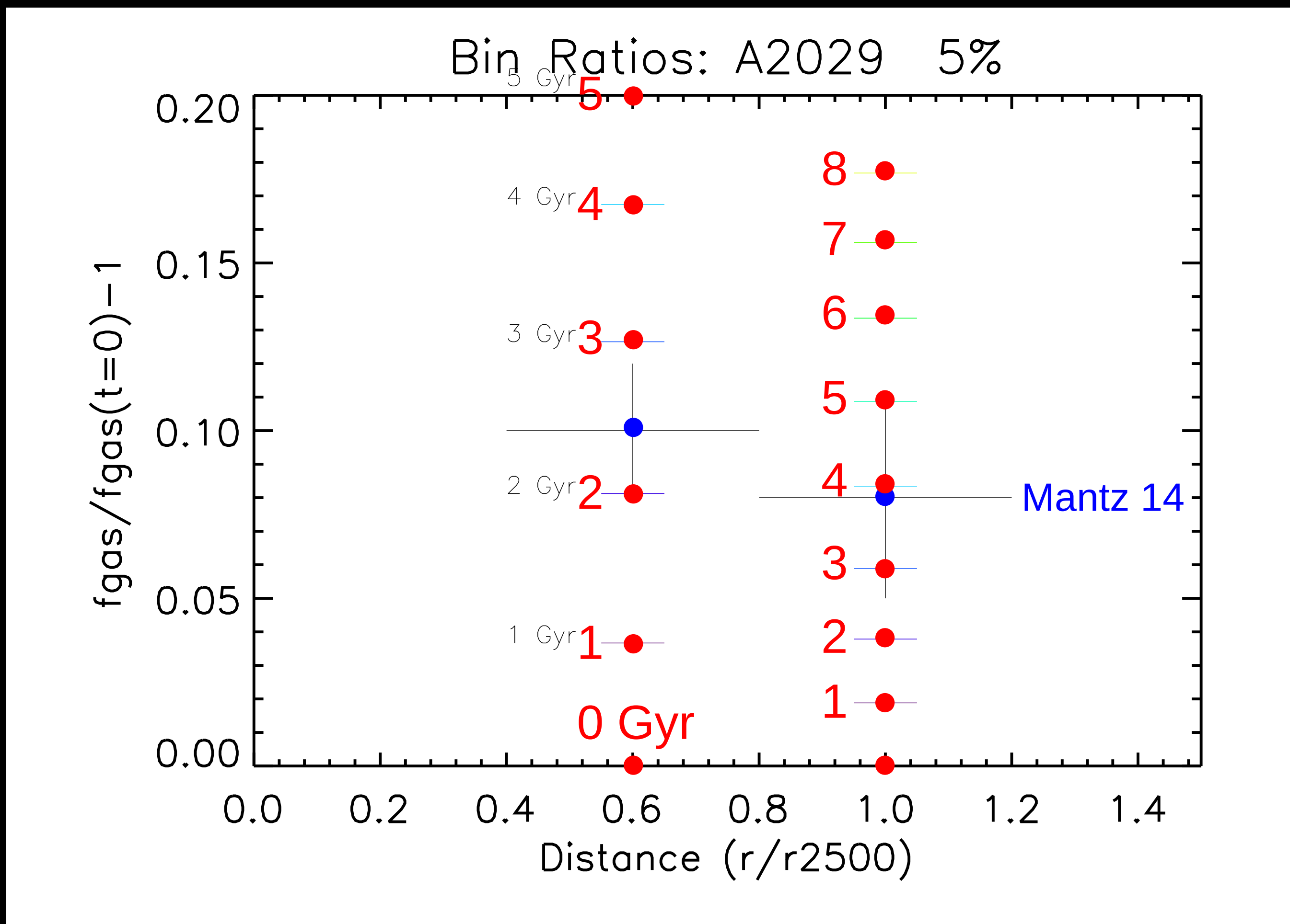
Mantz et al. 14

- The sample of relaxed clusters should contain clusters of different “ages” (time since last major disturbance)

- If conduction is present, clusters of different age should have different $f_{\mathbf{gas}}$ = scatter in the sample

Evolution of differential f_{gas} profile with conduction

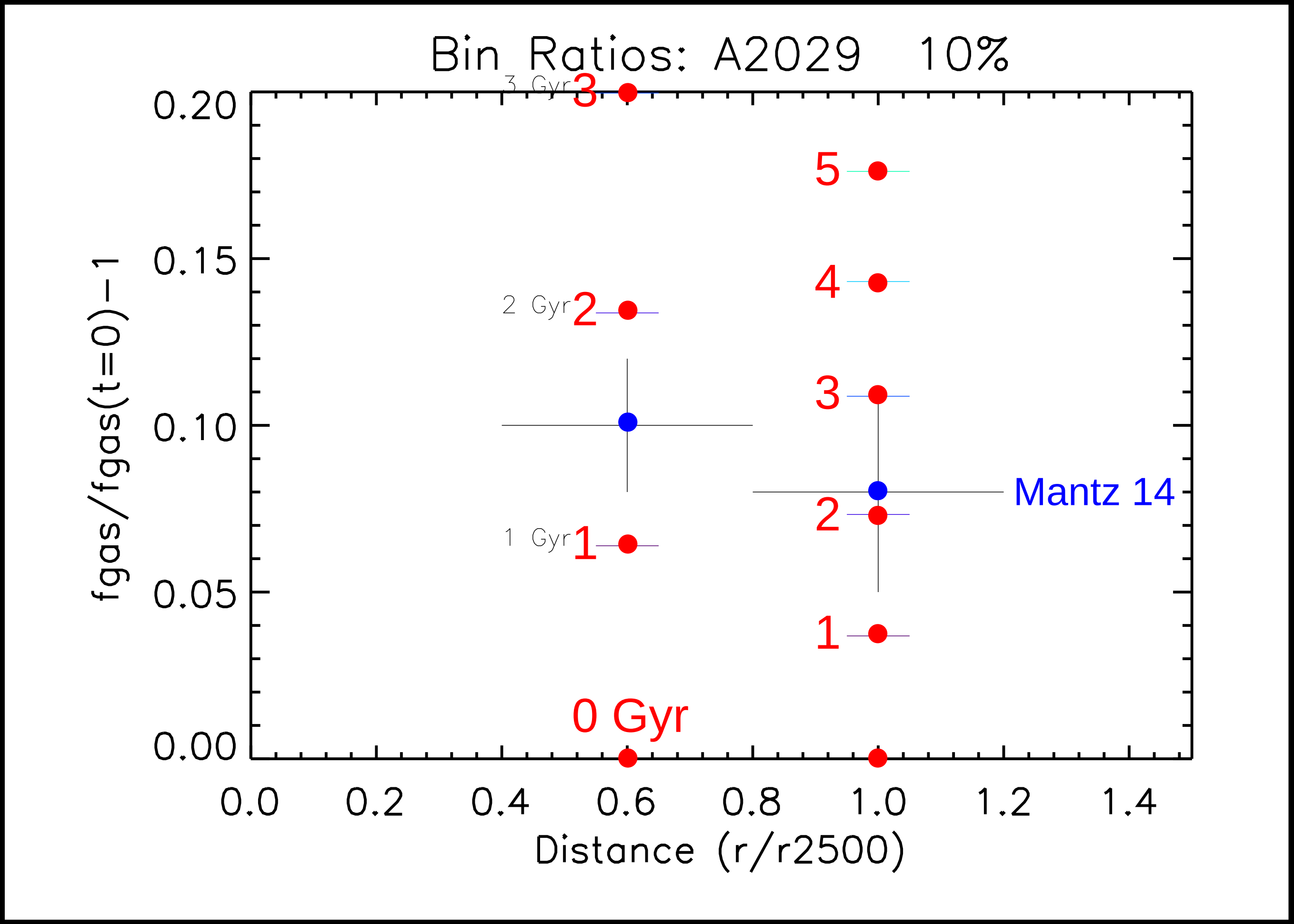
5% Spitzer



Russell 14

Evolution of differential f_{gas} profile with conduction

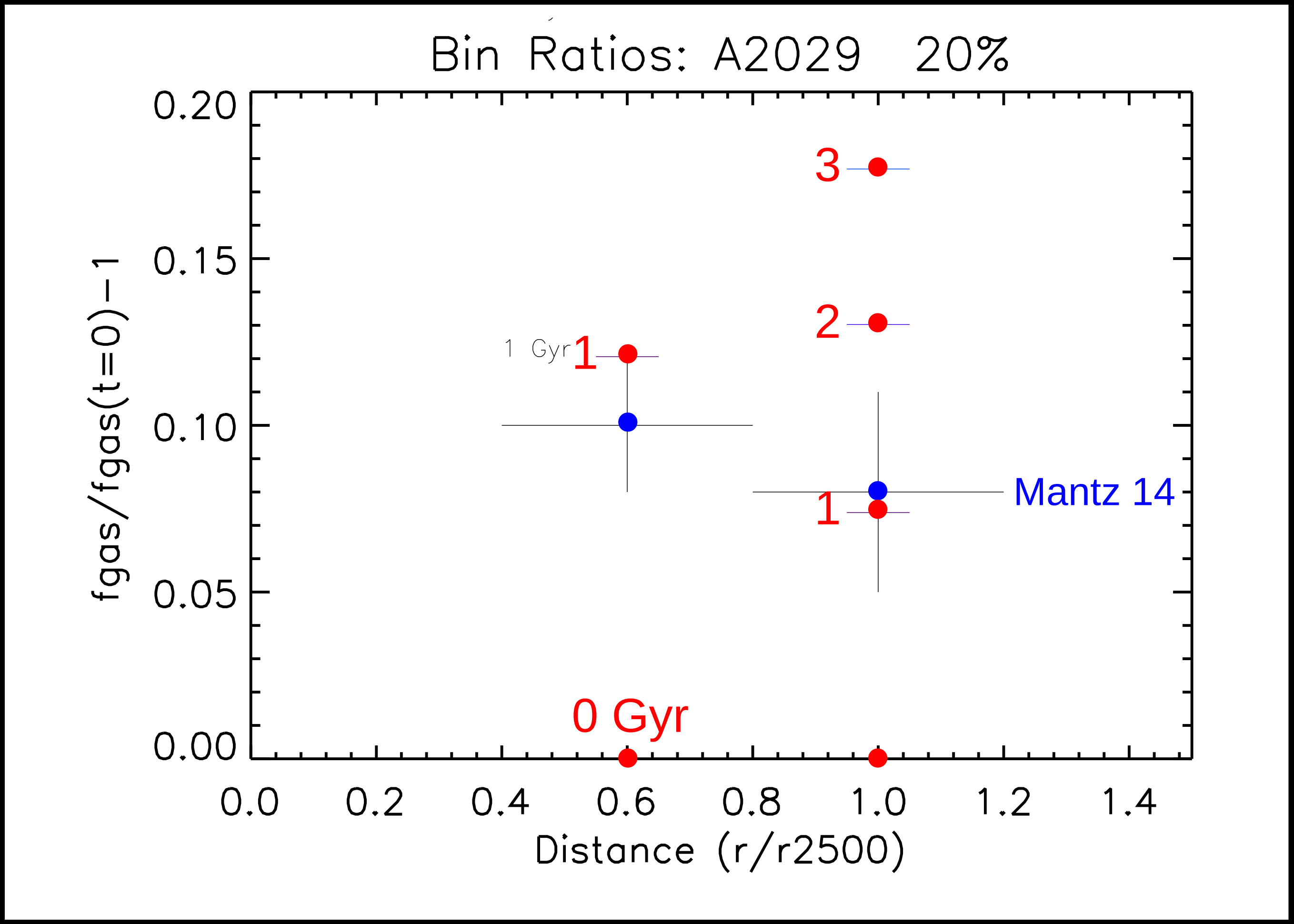
10% Spitzer



Russell et al. 14

Evolution of differential f_{gas} profile with conduction

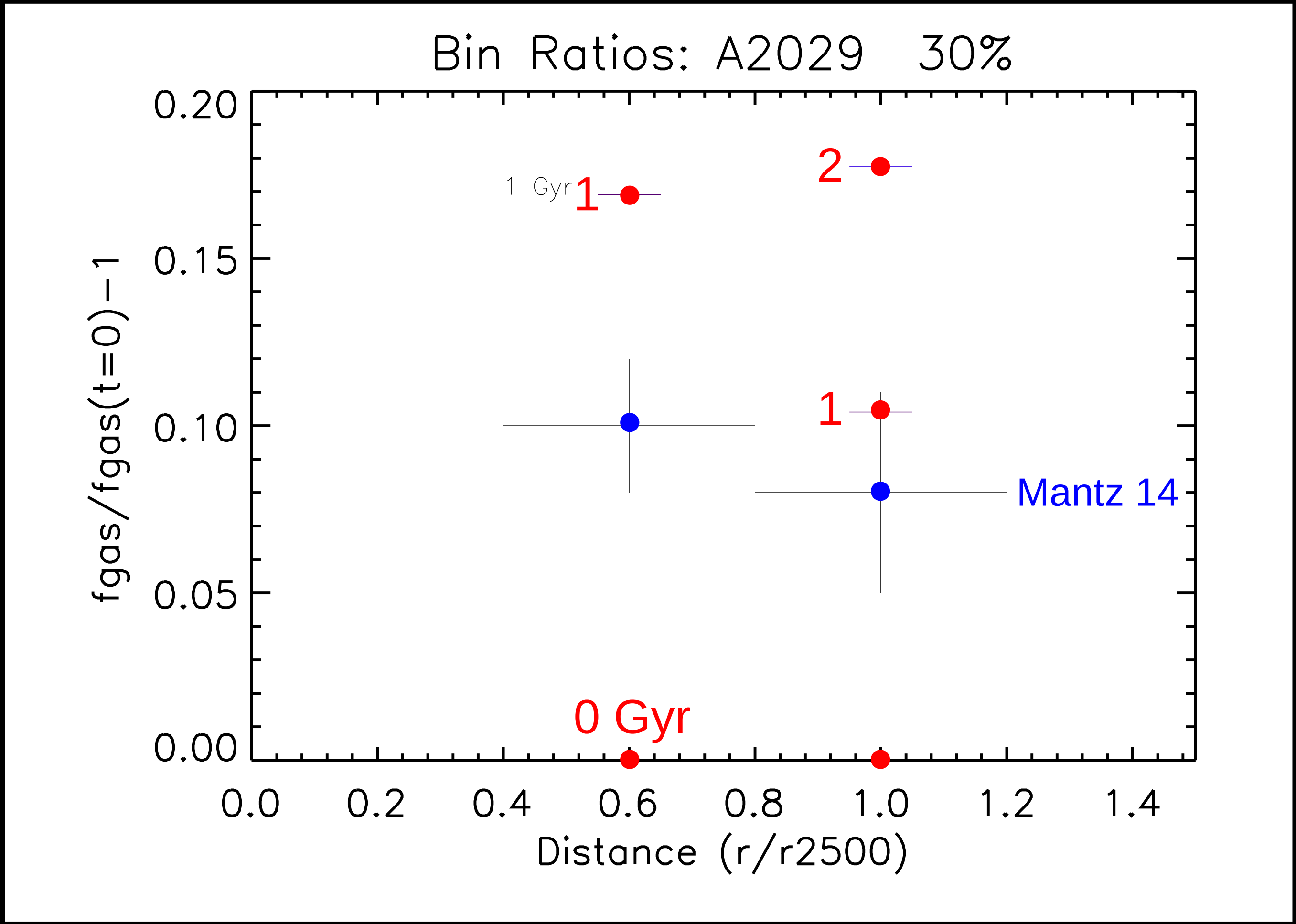
20% Spitzer



Russell 14

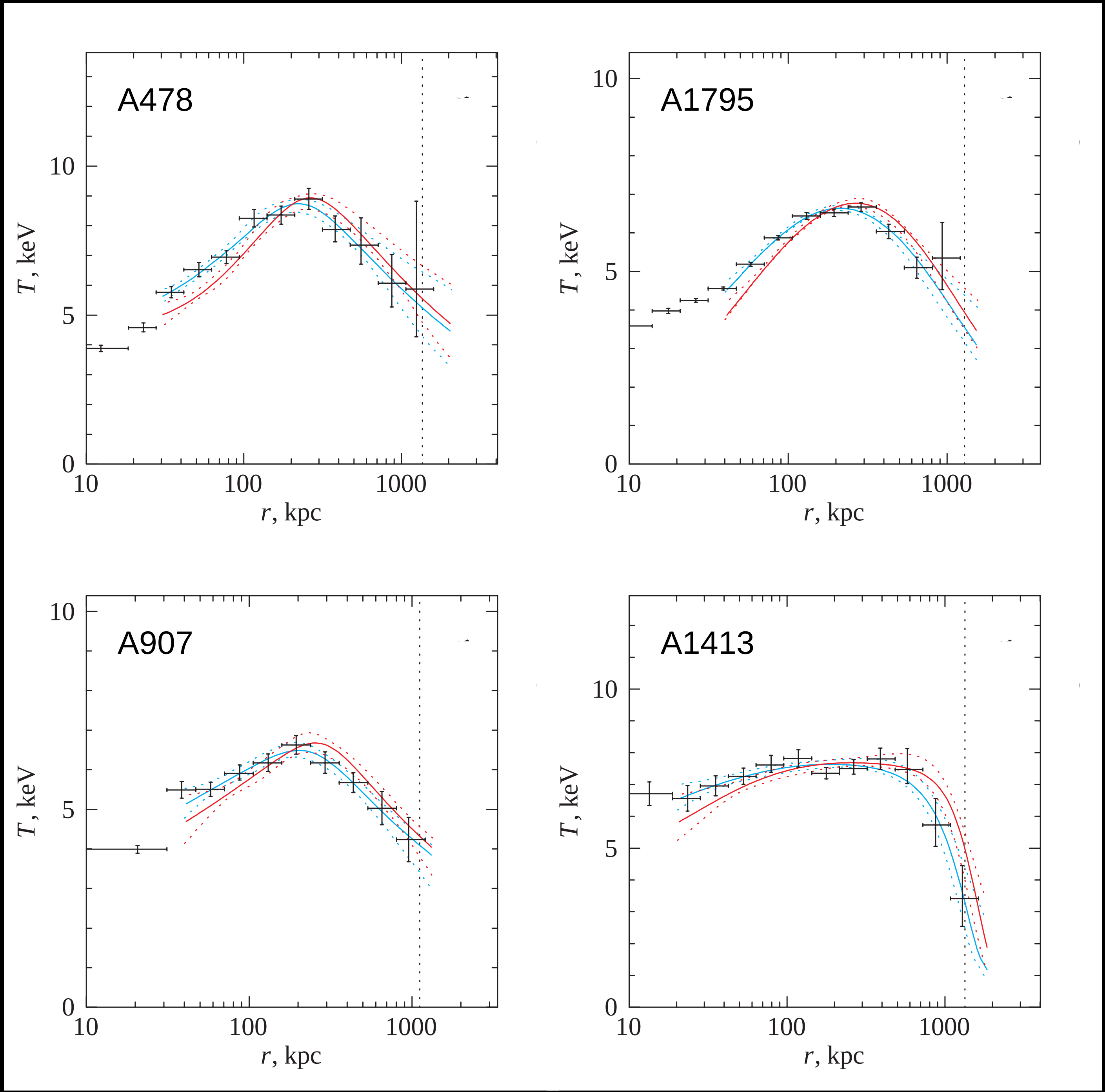
Evolution of differential f_{gas} profile with conduction

30% Spitzer



Russell 14

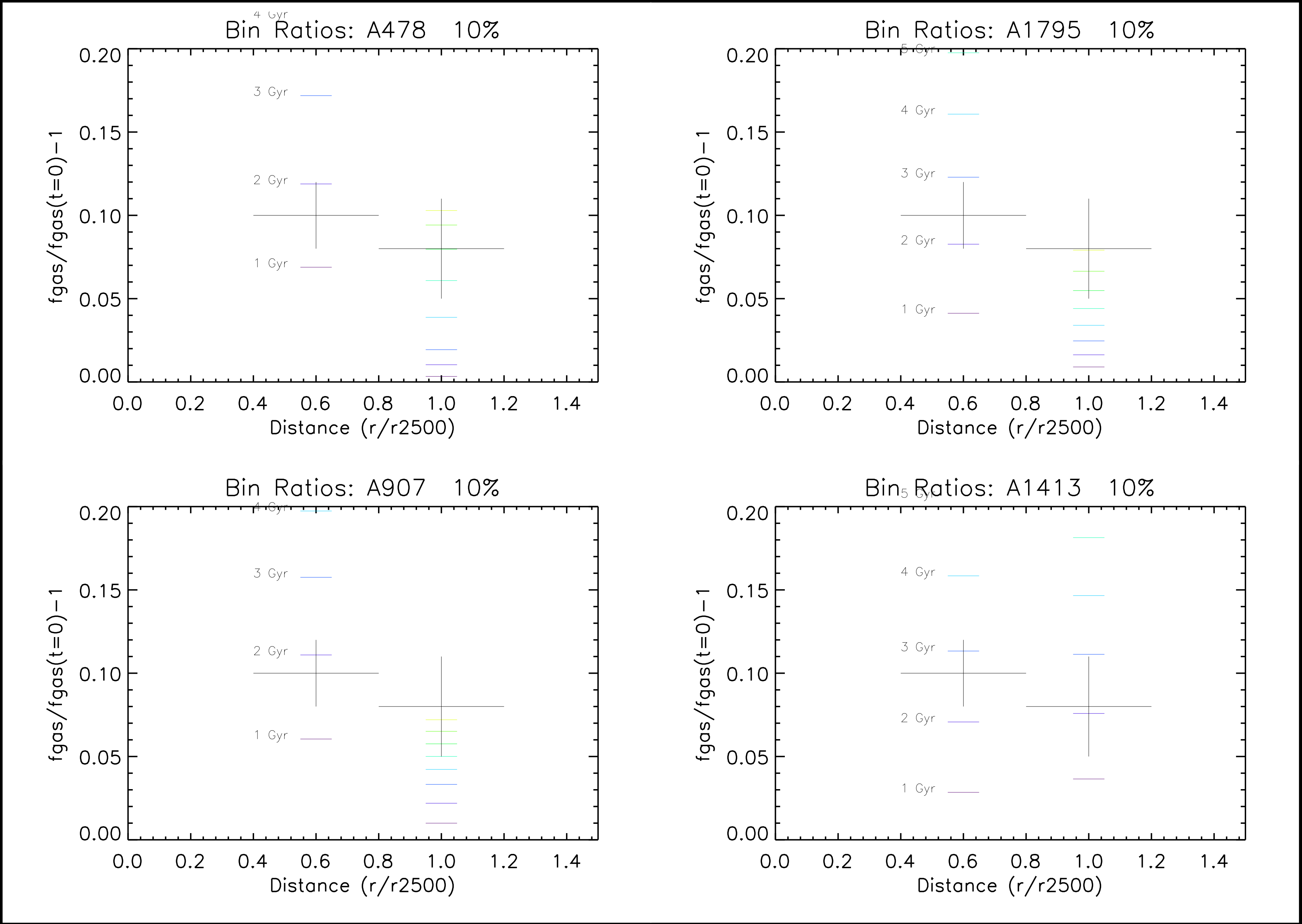
Other hot relaxed clusters



Chandra data, Vikhlinin et al. 06

Other hot relaxed clusters

10% Spitzer

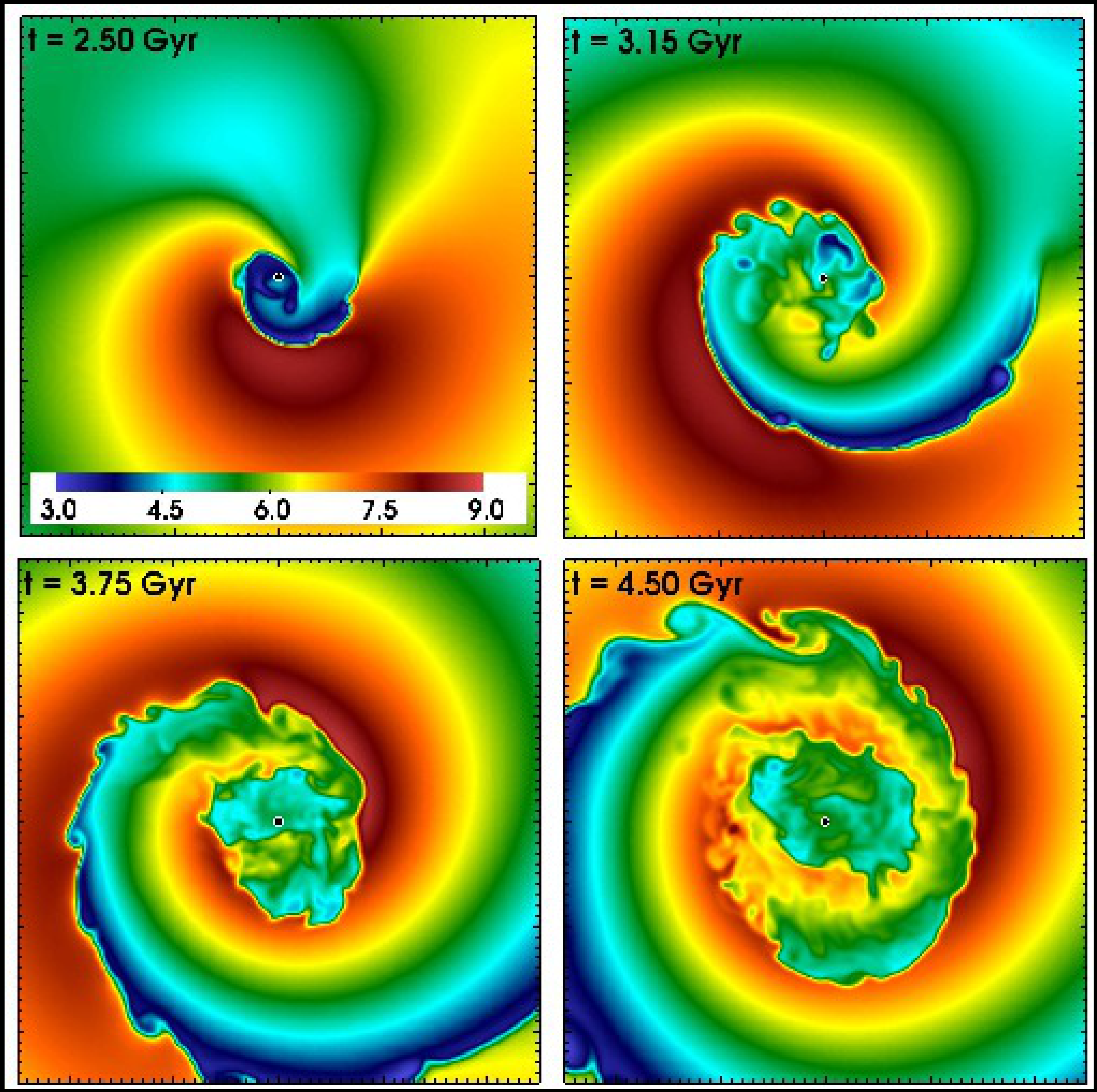


Conclusions

- Large-scale heat conduction does not erase the cluster radial temperature gradients (as shown before)
- What it does change is f_{gas} profile
  (effect seen in cosmological simulations with conduction, E. Rasia, priv. comm.)
- Under simple assumptions, $\kappa > 5 - 10\%$ Spitzer (in the cluster radial direction) contradicts the observed small scatter in f_{gas} at $r \sim r_{2500}$ in hot, relaxed clusters
- Cosmological simulations including heat conduction and cooling, and the relaxed cluster selection as in Mantz 14, may place stronger constraints

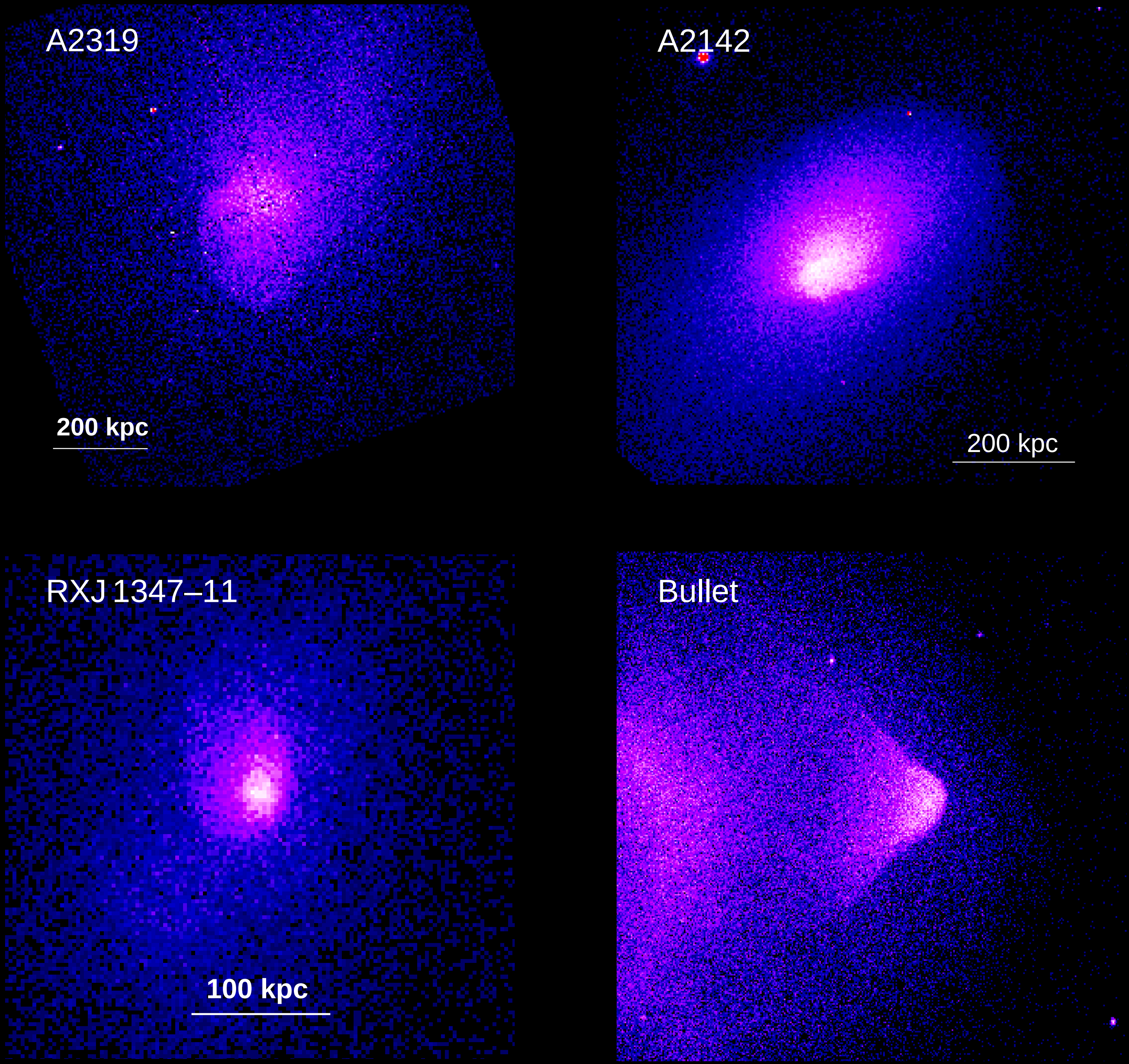
Constraining plasma viscosity using cold fronts

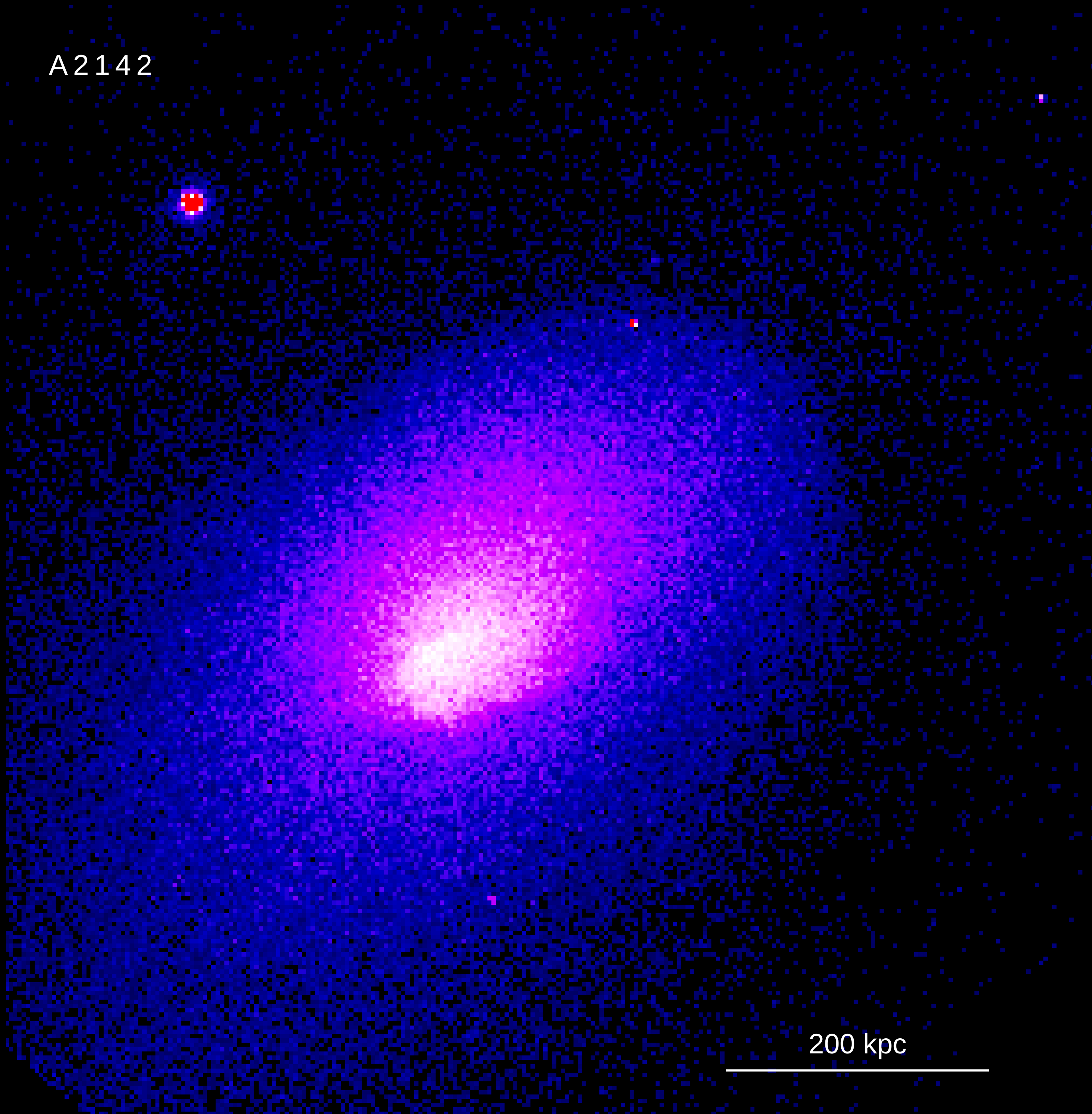
Evolution of a cold front

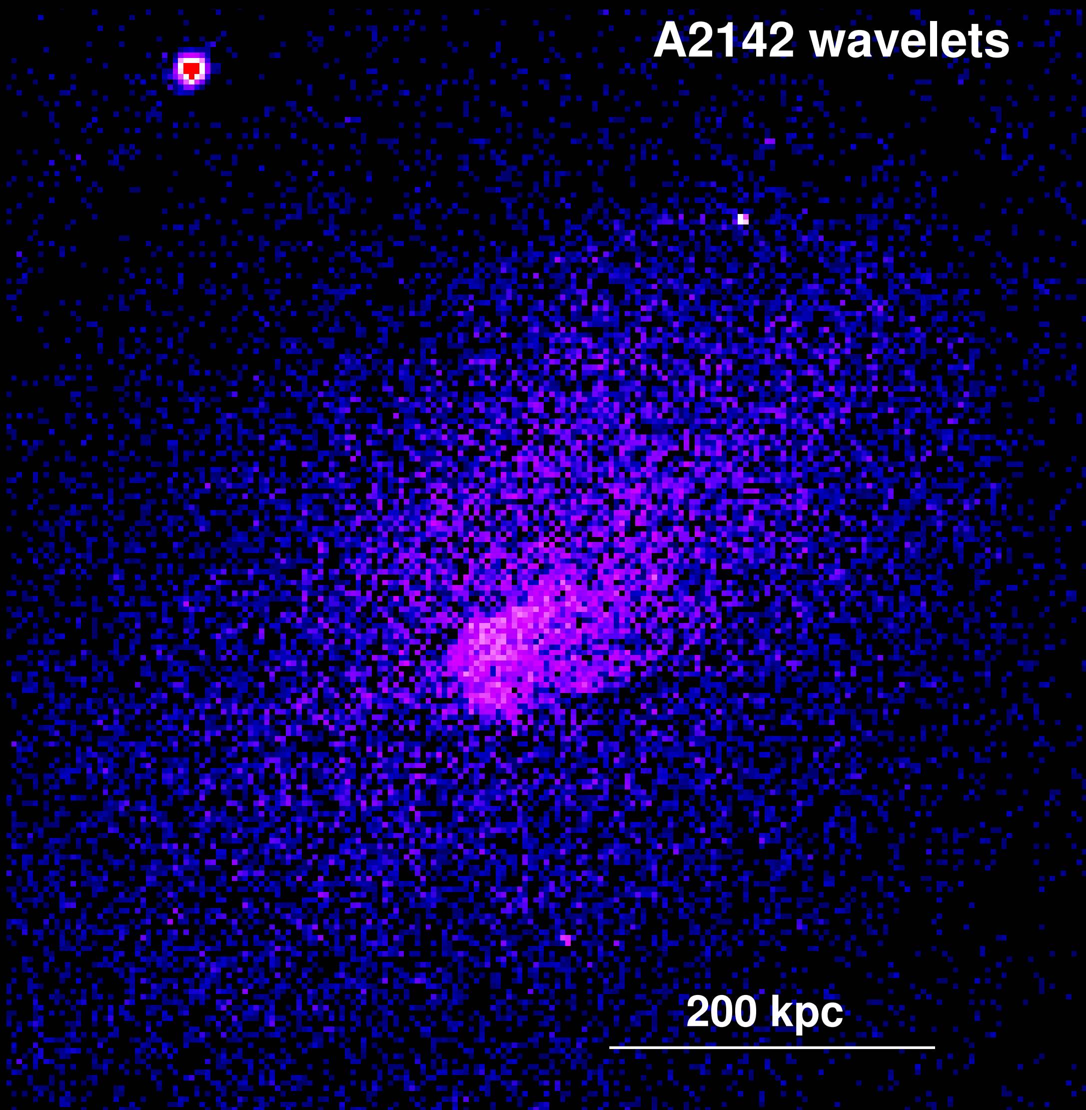


ZuHone 11 (FLASH, resolution 2 kpc, no magnetic field, no viscosity)

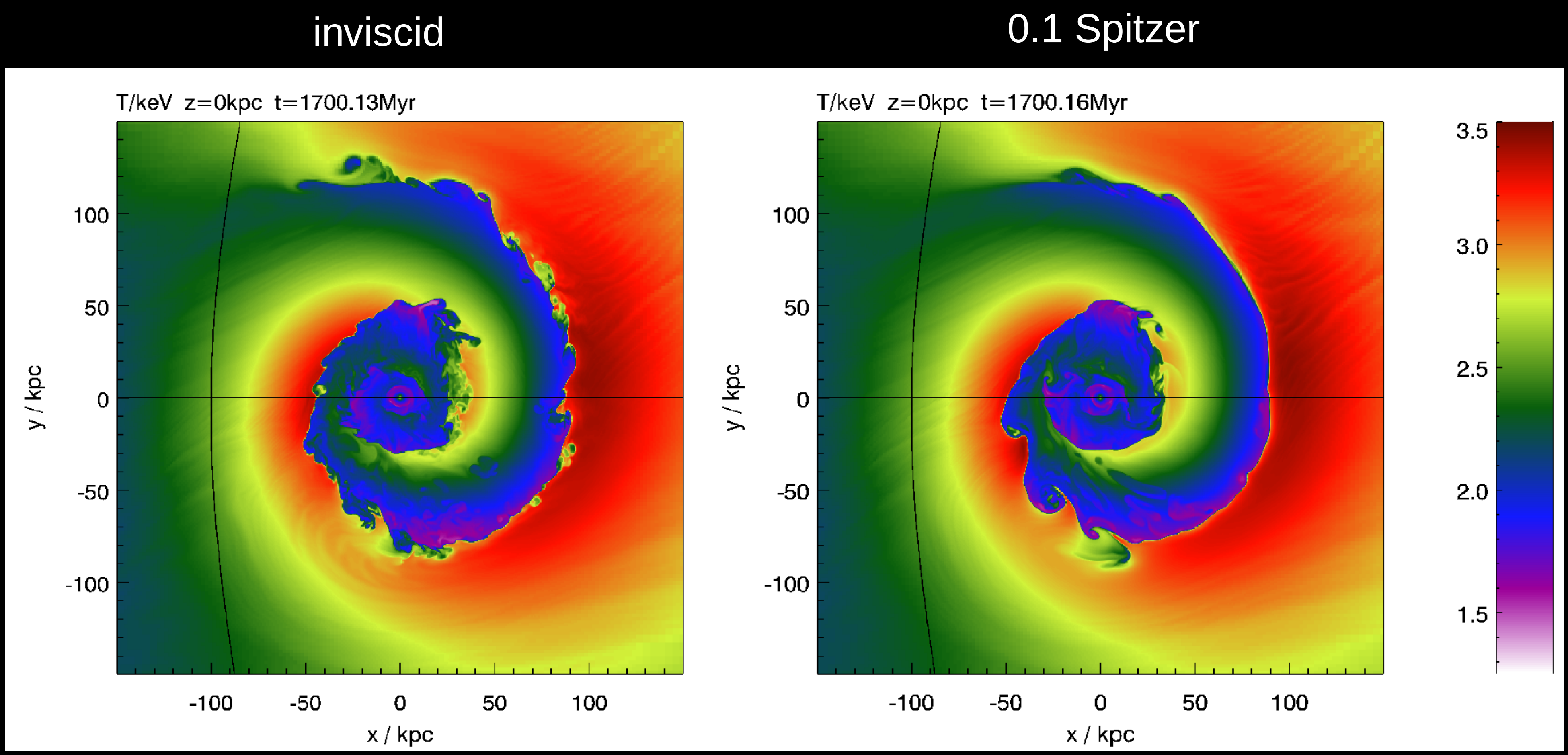
Observed cold fronts are sharp and mostly stable




A2142
200 kpc


A2142 wavelets
200 kpc

Effect of isotropic viscosity on cold front stability



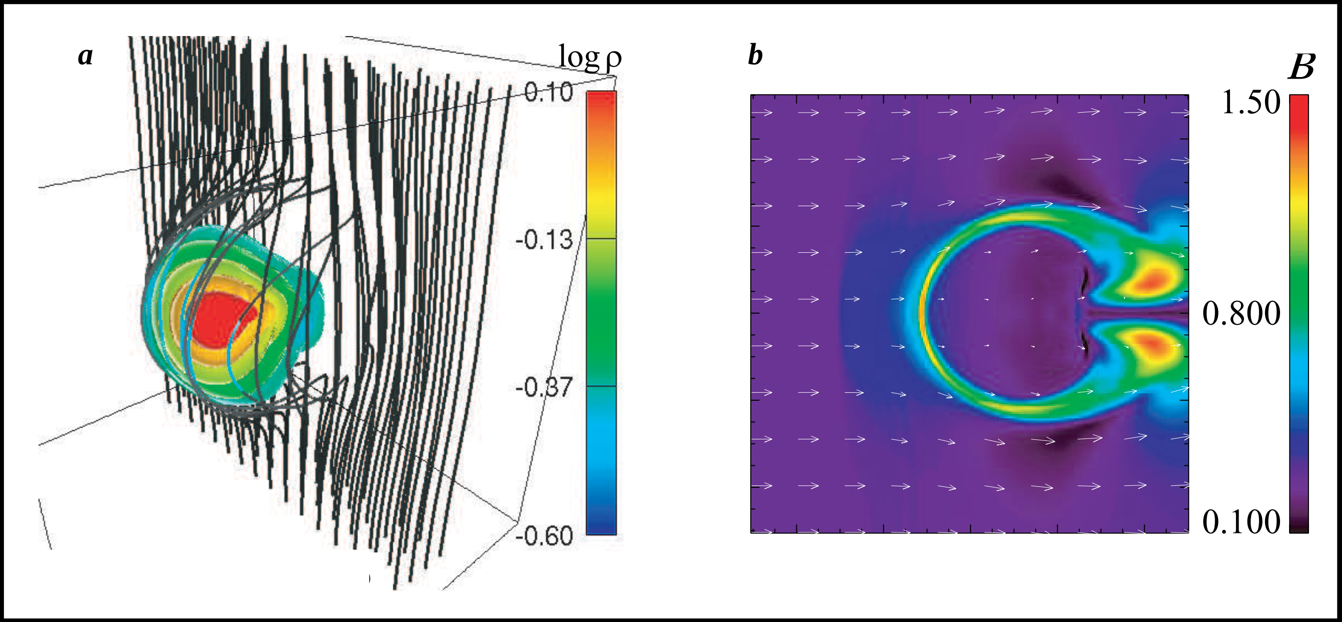
Roediger 13, Virgo-like cluster

- slightly perturbed front in Virgo cluster indicates viscosity $\gtrsim$ 0.1 Spitzer

Magnetic field structure at cold fronts

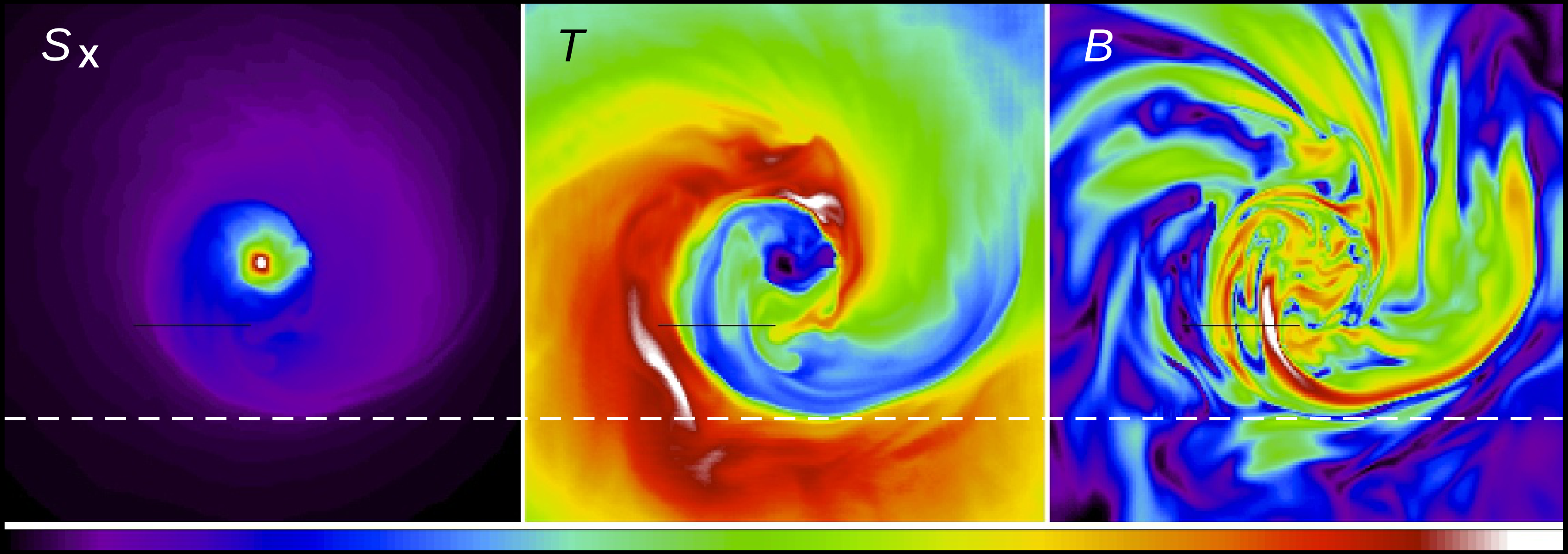
stripping front

Asai 05

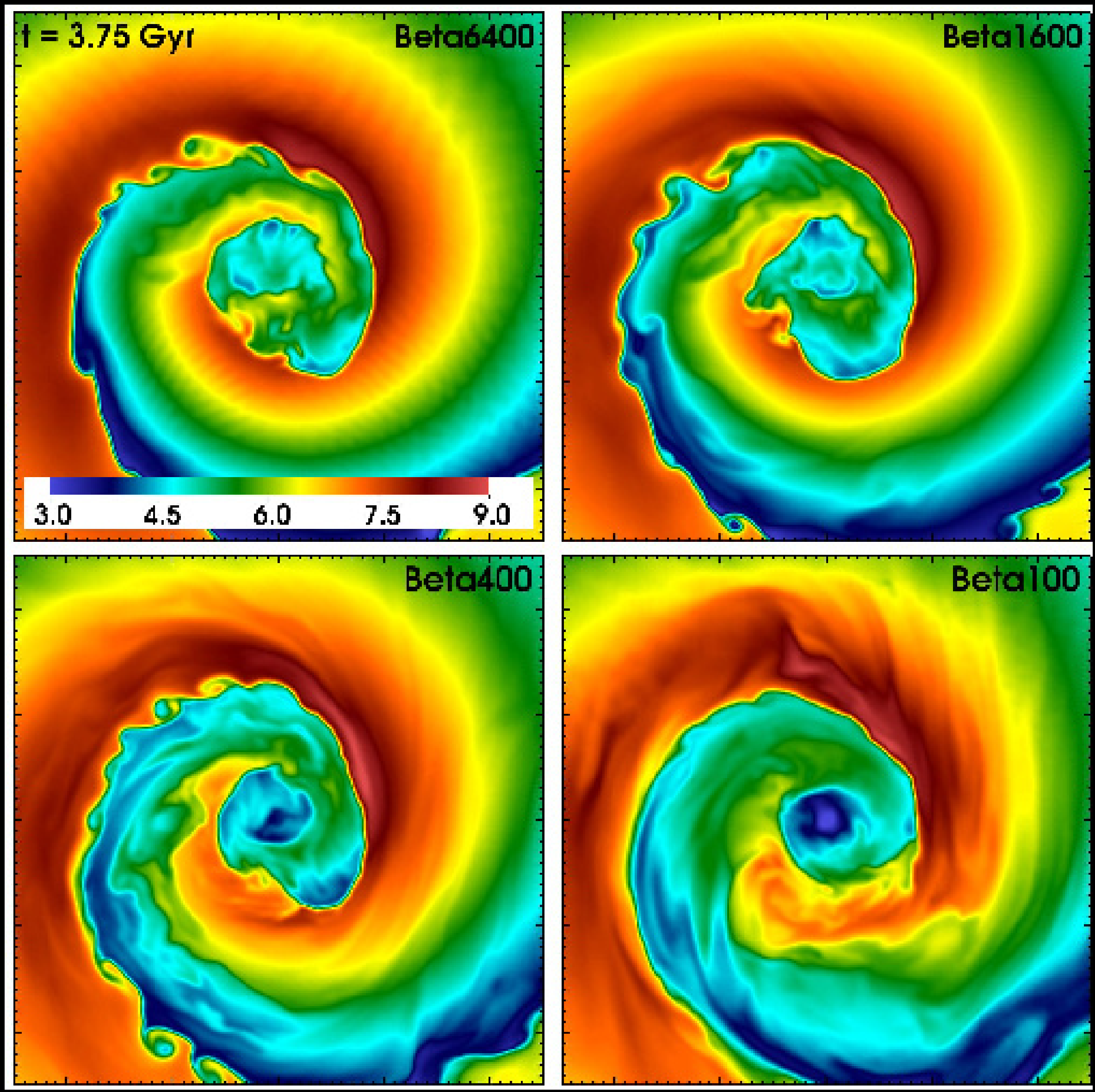


sloshing front

ZuHone 11



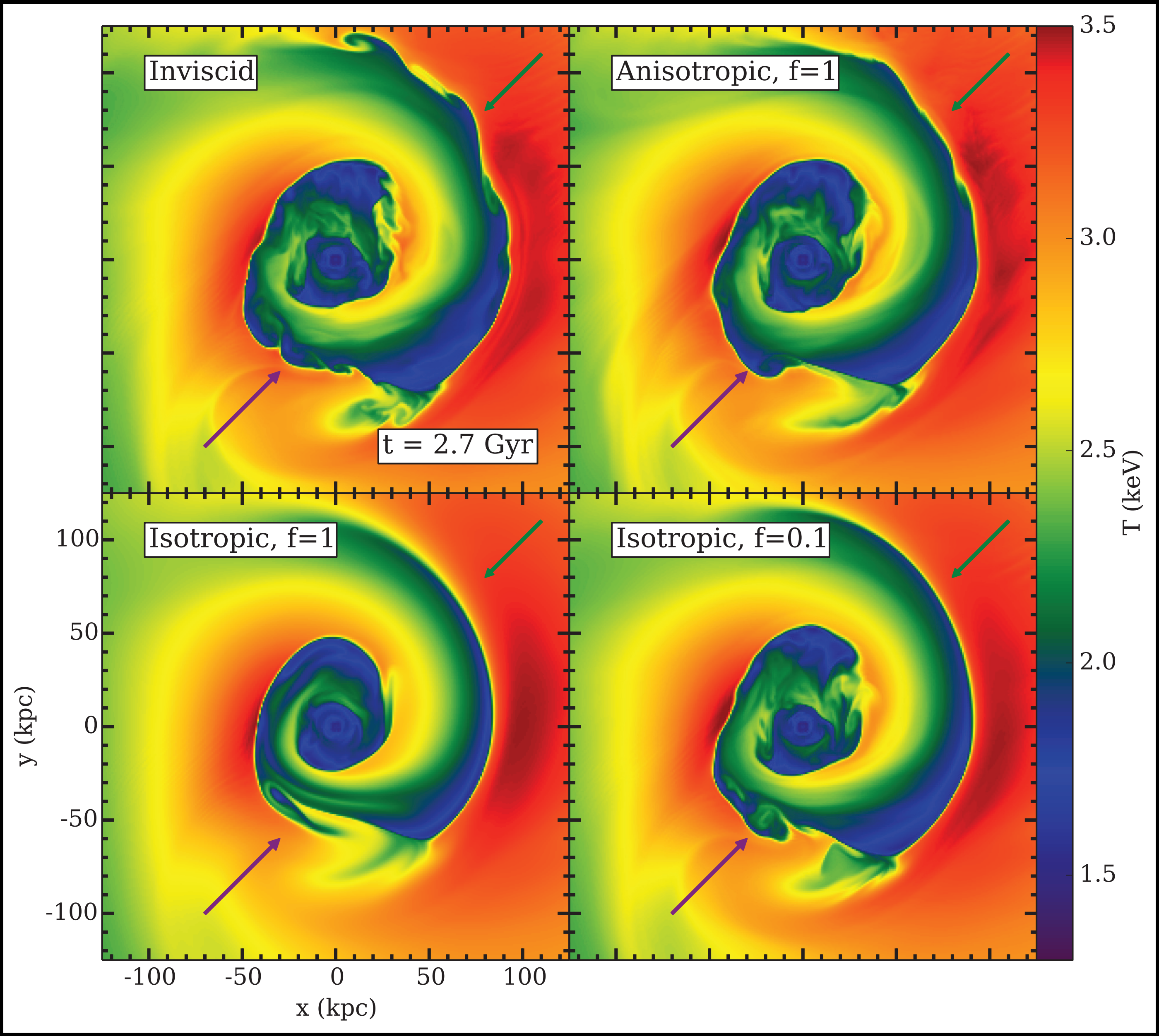
Magnetic field suppresses instabilities



ZuHone 11 (FLASH, MHD, resolution 2 kpc)

Magnetic field makes viscosity anisotropic

Spitzer (isotropic) and Braginskii (anisotropic) viscosity:



ZuHone 14 (Athena, MHD, resolution 1 kpc)

Conclusions (viscosity)

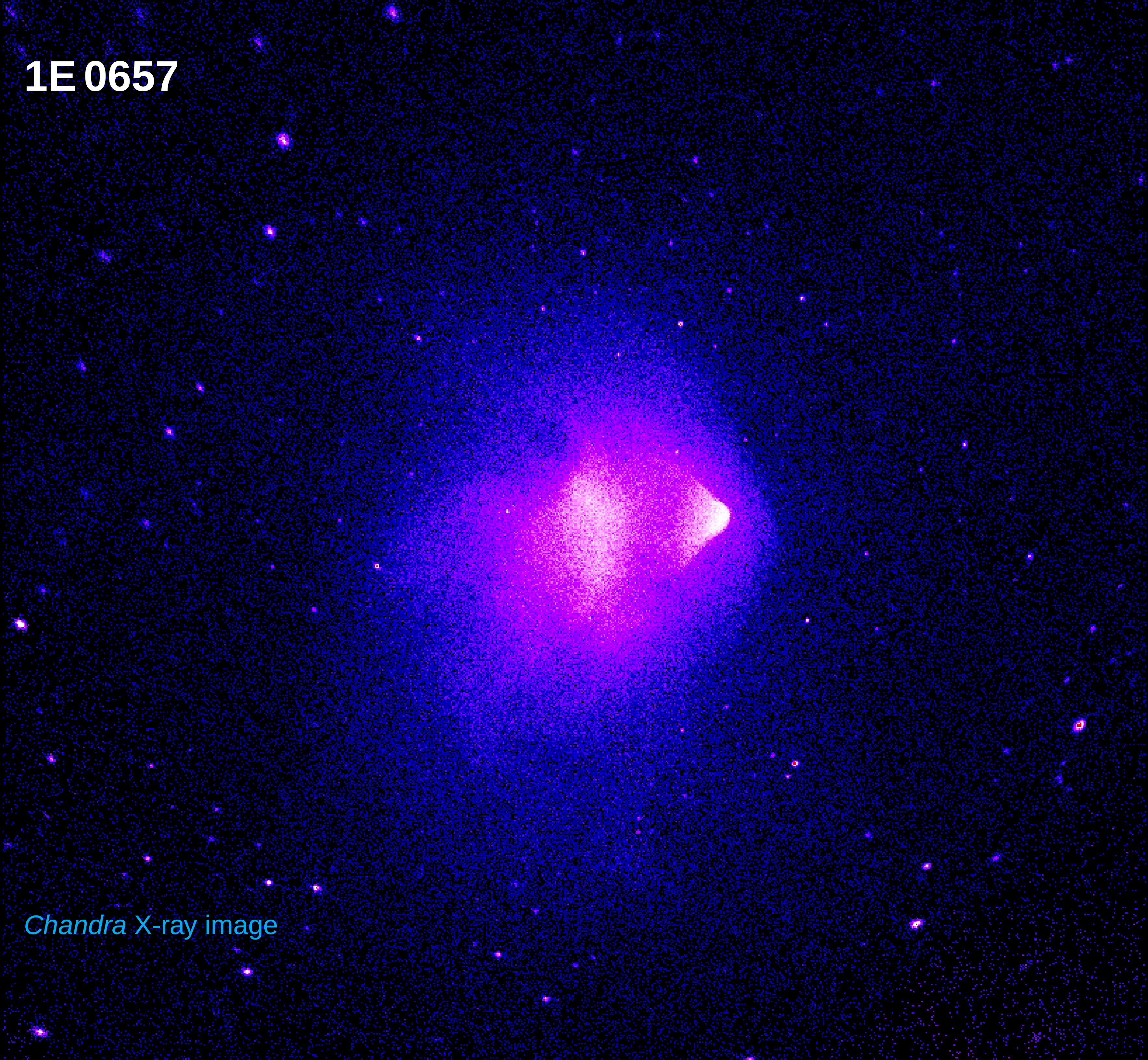
- Difficult to distinguish observationally a suppressed isotropic viscosity (say, 0.1 Spitzer) from unsuppressed anisotropic + effect of stretched magnetic fields

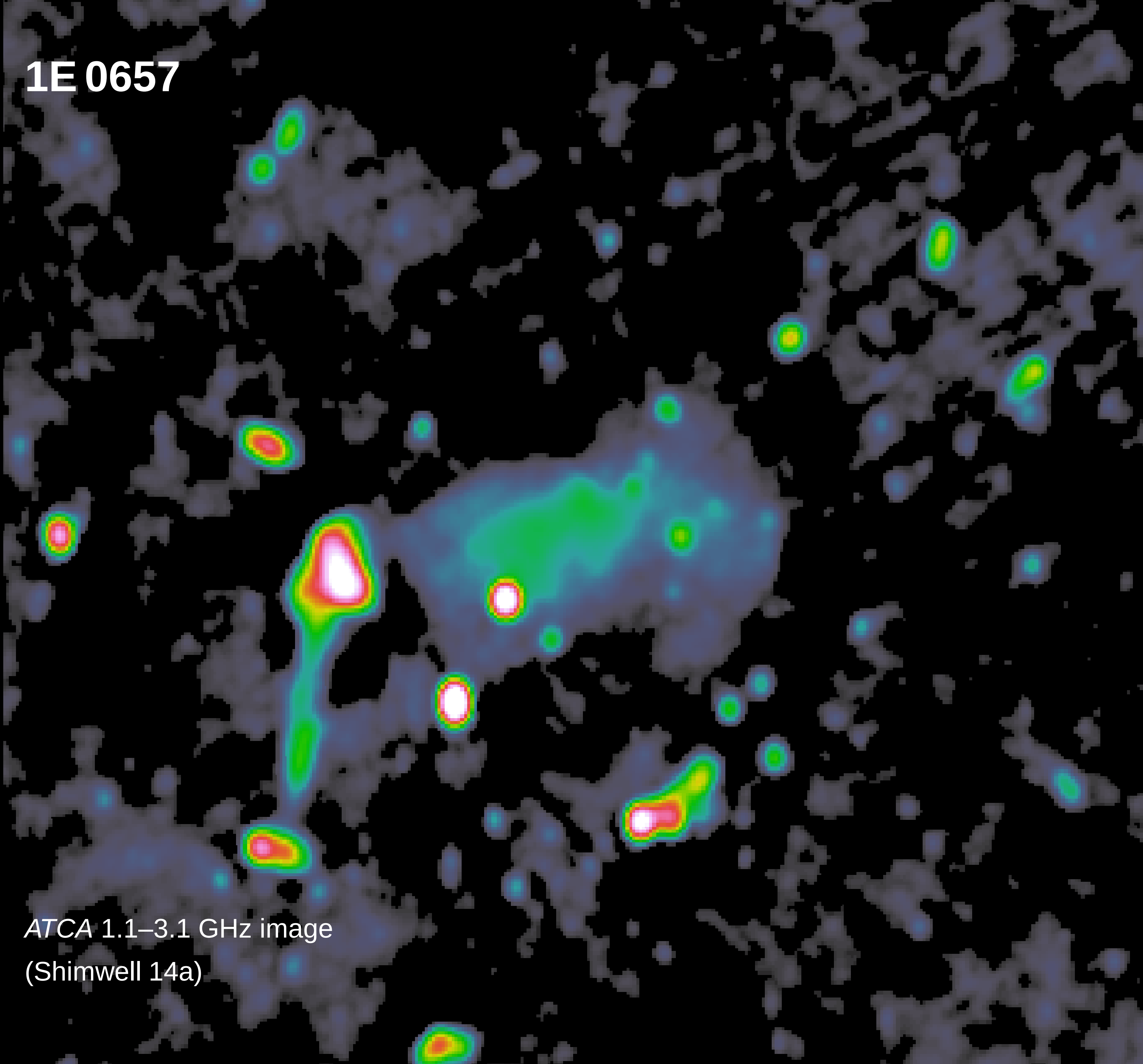
- Accurate comparison with well-observed cold fronts promising (coming soon)

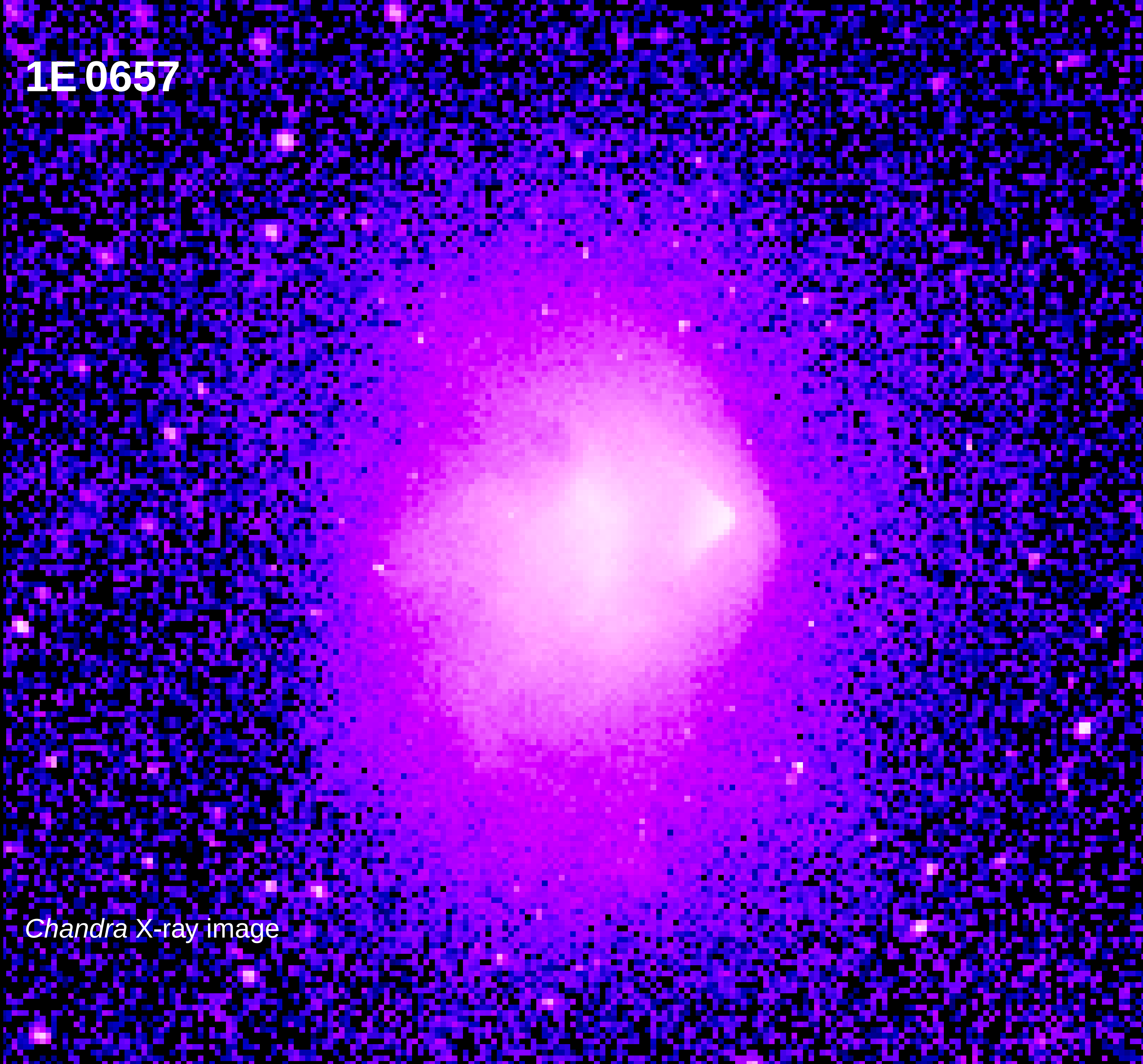
  Qualitatively, front shapes are consistent with full Braginskii viscosity and the expected magnetic field, or 0.1× Spitzer isotropic

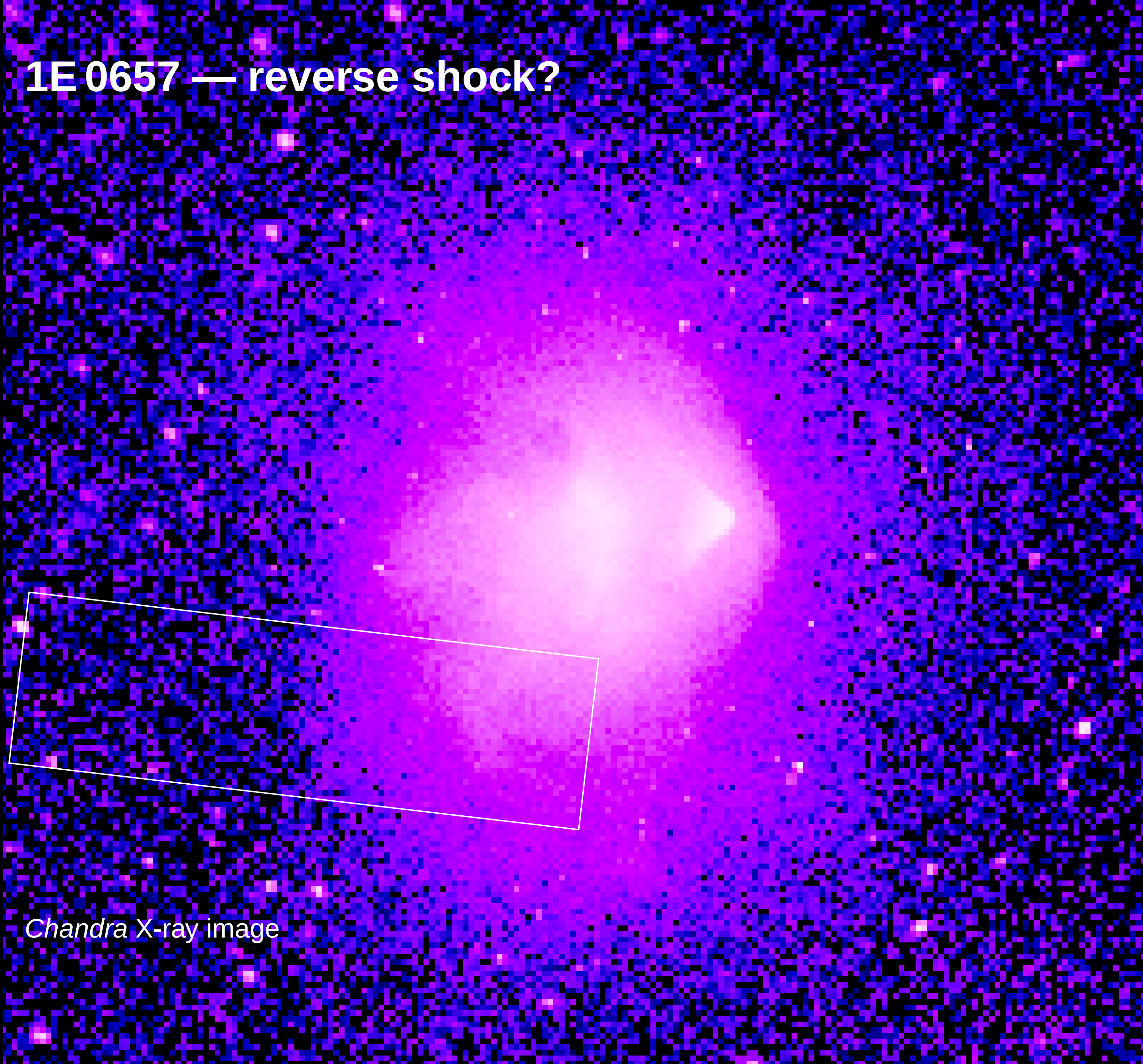
Another shock for the Bullet Cluster
and a “smoking gun” model for radio relics

Tim Shimwell (Leiden), Maxim Markevitch (GSFC)


1E 0657
Chandra X-ray image

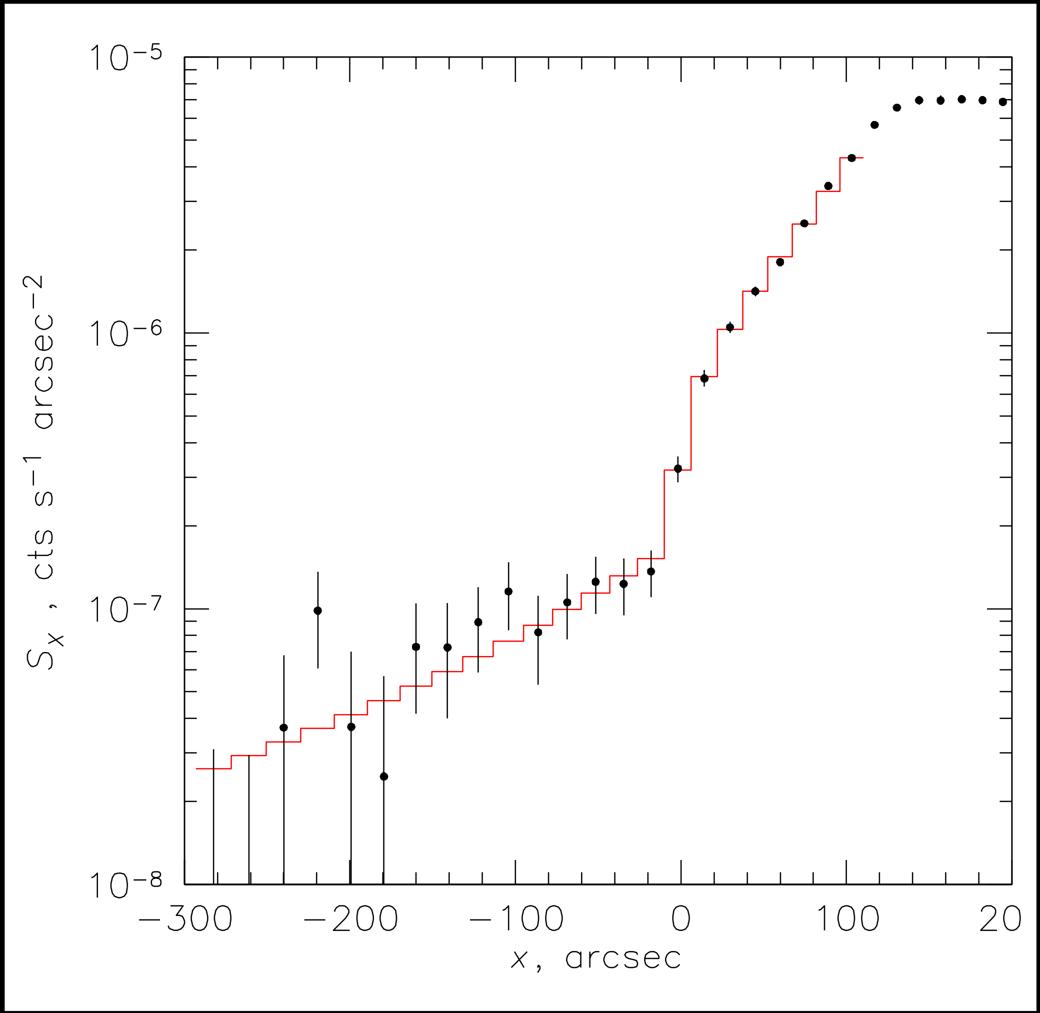

1E 0657
ATCA 1.1–3.1 GHz image
(Shimwell 14a)


1E 0657
Chandra X-ray image


1E 0657 — reverse shock?
Chandra X-ray image

1E 0657 — reverse shock?

X-ray brightness across relic

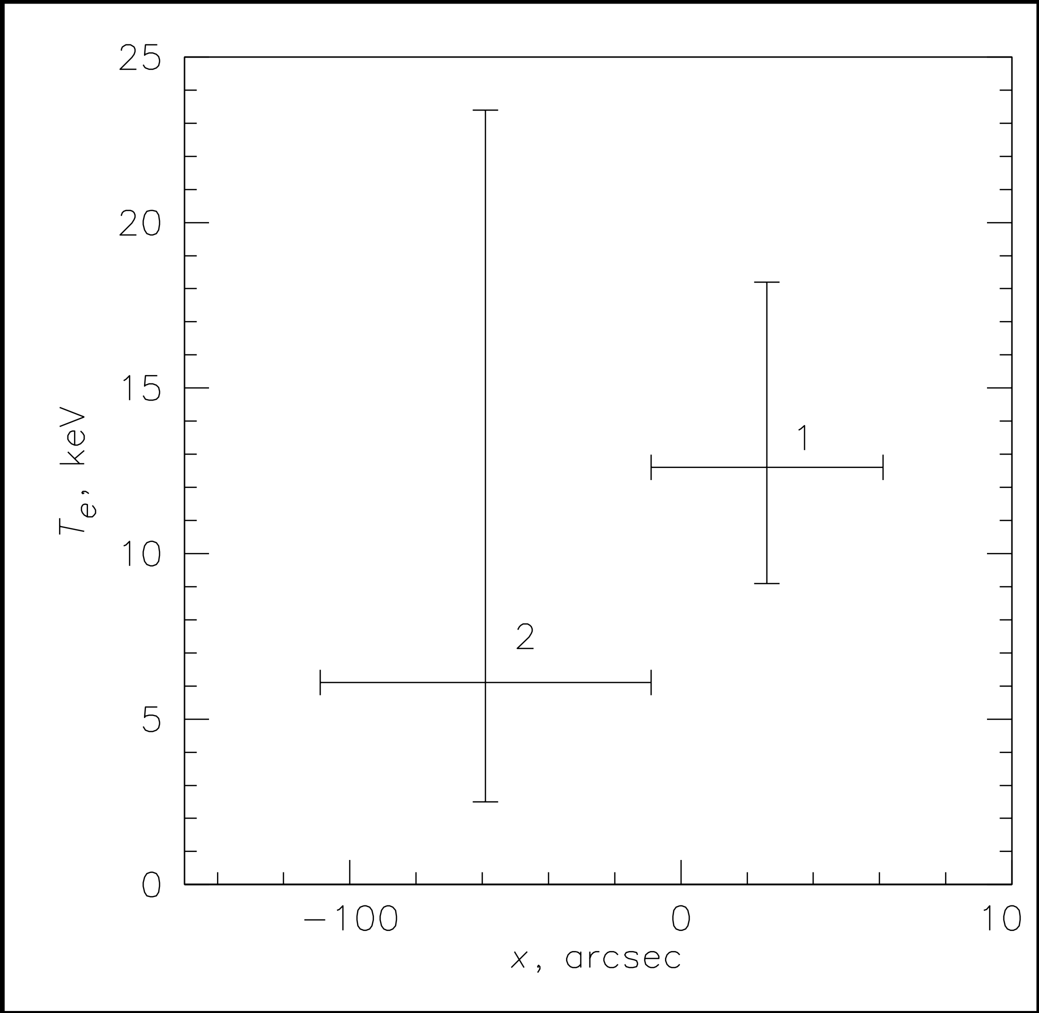


Fit corresponds to shock with M = 1.7 – 5.5 (uncertain 3D geometry)

(Shimwell 14b)

1E 0657 — reverse shock?

Gas temperature across relic



90% error bars (Shimwell 14b). Shock front “suggested” but not unambiguously confirmed

A “reverse shock” to the famous western shock

- Although *T* jump inconclusive, unlikely to be anything else

- X-ray *M* = $\mathbf{2.5^{+1.3}_{-0.8}}$ (combining gas density and *T* constraints)

- Radio slope of tail region of relic + Fermi type I acceleration → *M* = 1.9 – 2.2

  Radio and X-ray *M* in agreement — as in other *well-observed* shock fronts

- Tail is connected to a bright “bulb”, which looks like a just-died radio galaxy

  — source of aged electrons for re-acceleration? (a gun that’s still smoking)

- Conjecture: ICM cloud polluted by a radio galaxy (disrupted ghost bubble) stays in the periphery, forming a well-defined pancake (or sausage) along the equipotential surface, waiting for a shock passage to re-accelerate it.
  Would explain a few of Huub’s riddles