

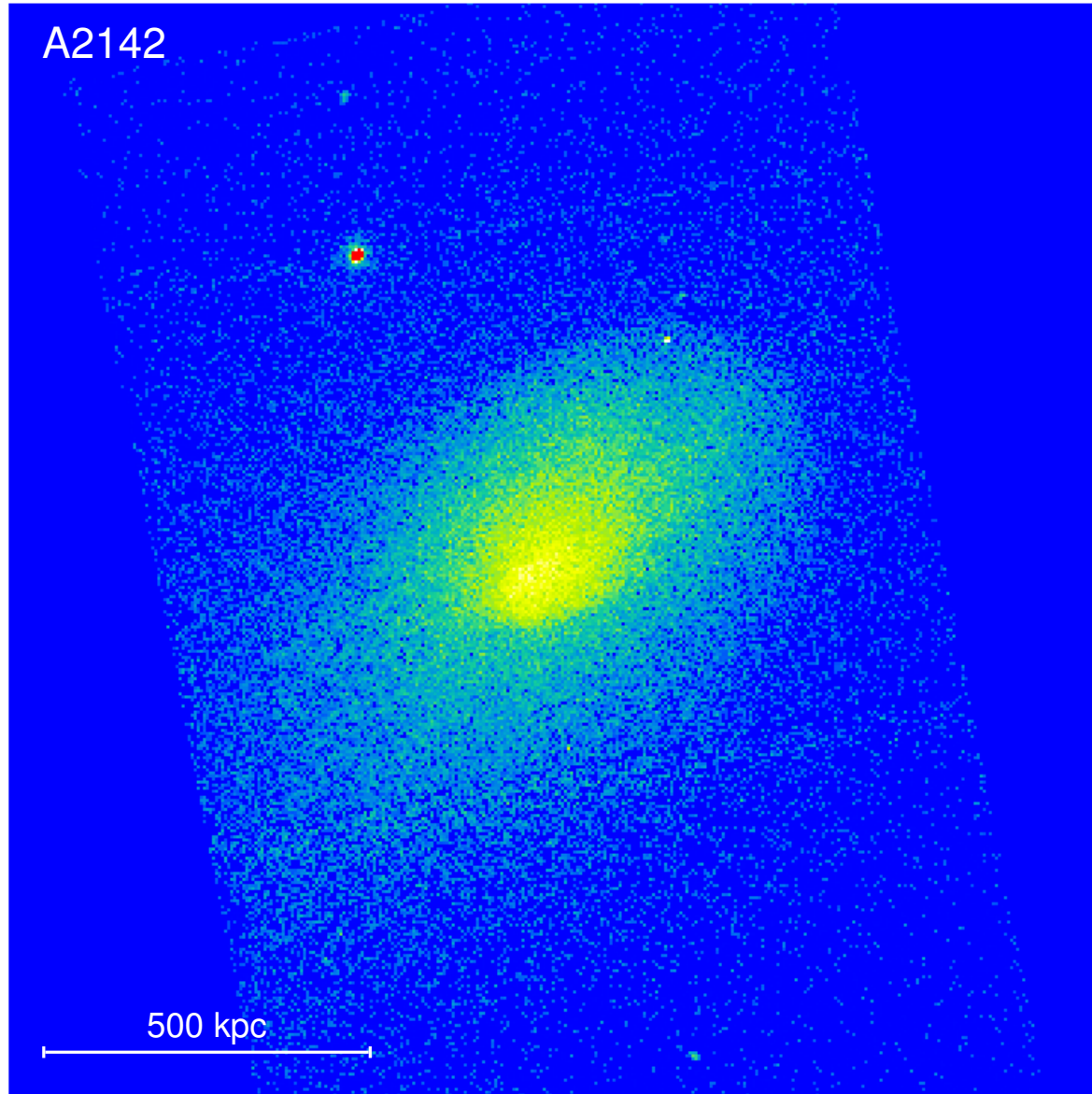
I. Kinetic energy of the cooling cores

II. Constraints on thermal conductivity

**M. Markevitch, A. Vikhlinin, P. Mazzotta,
W. Forman, S. Murray**

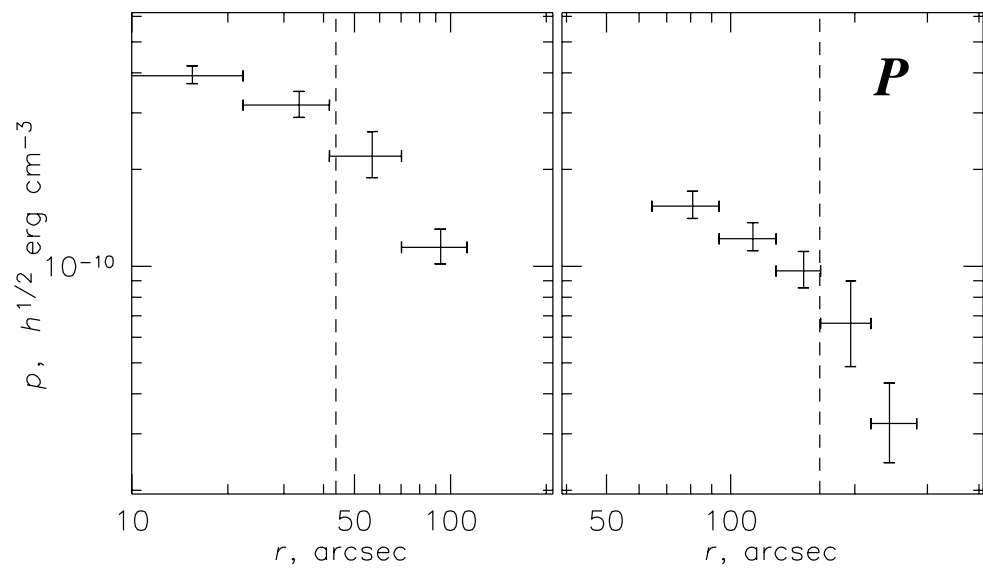
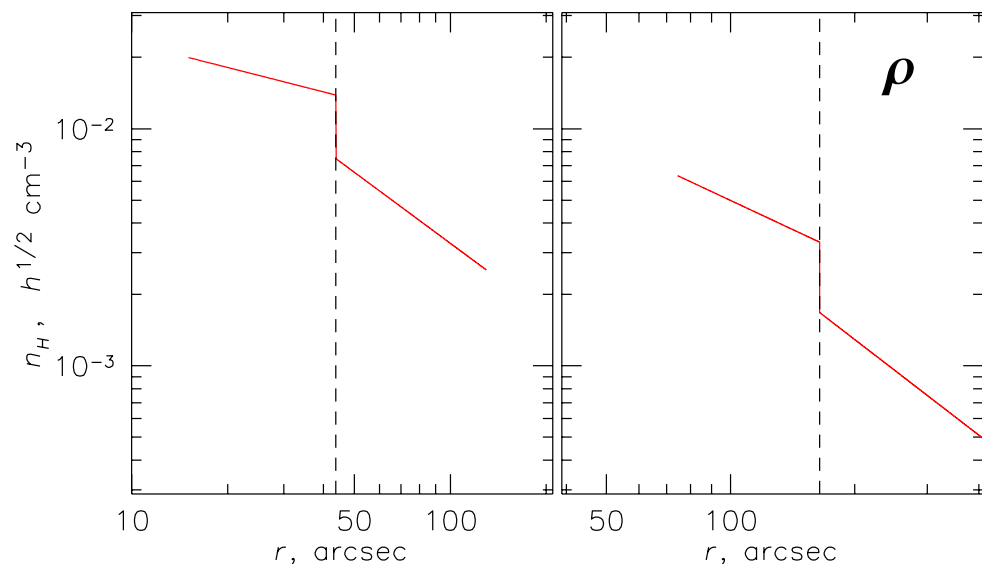
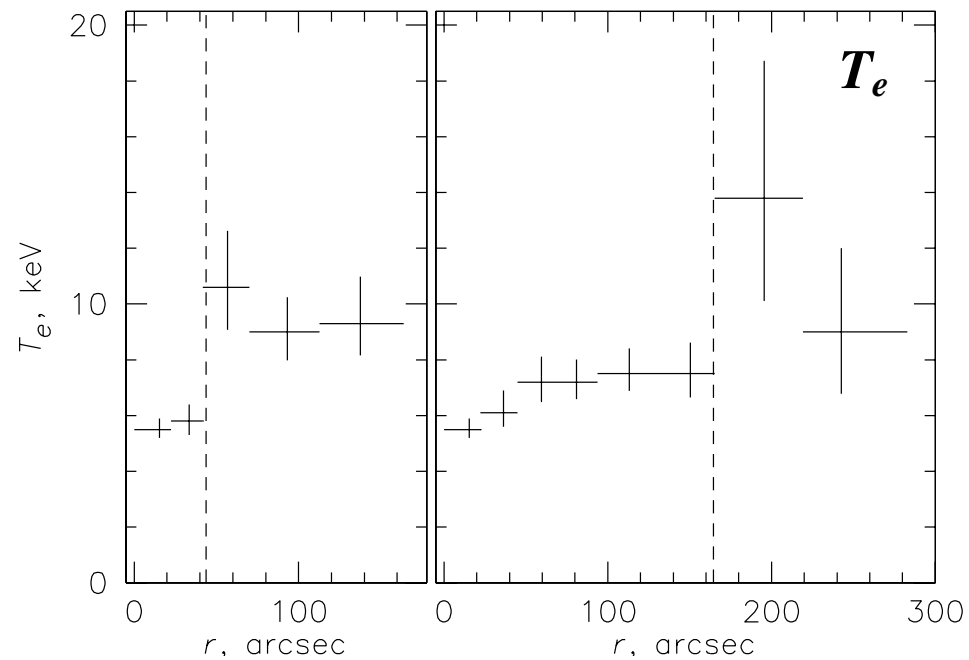
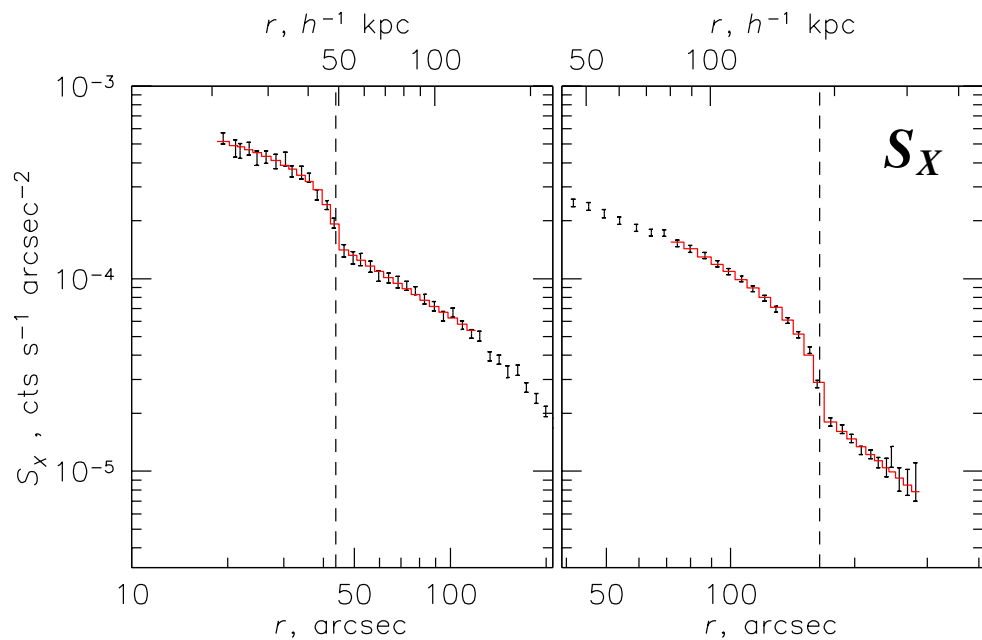
June 2003

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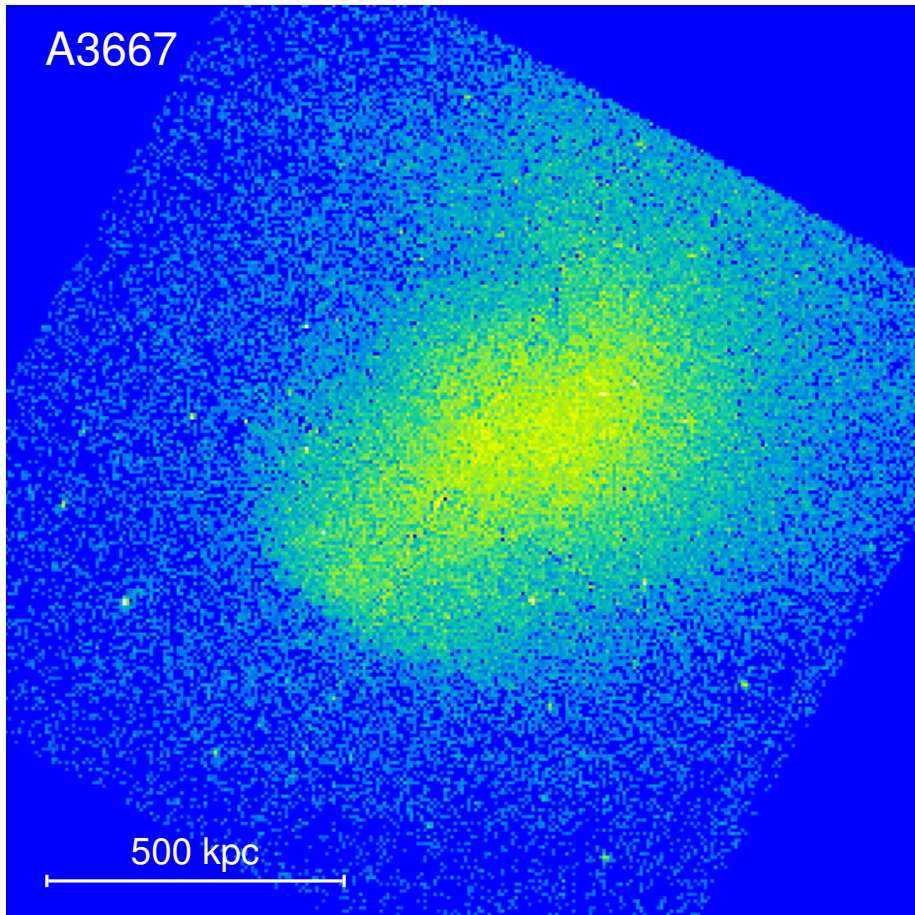
500 kpc

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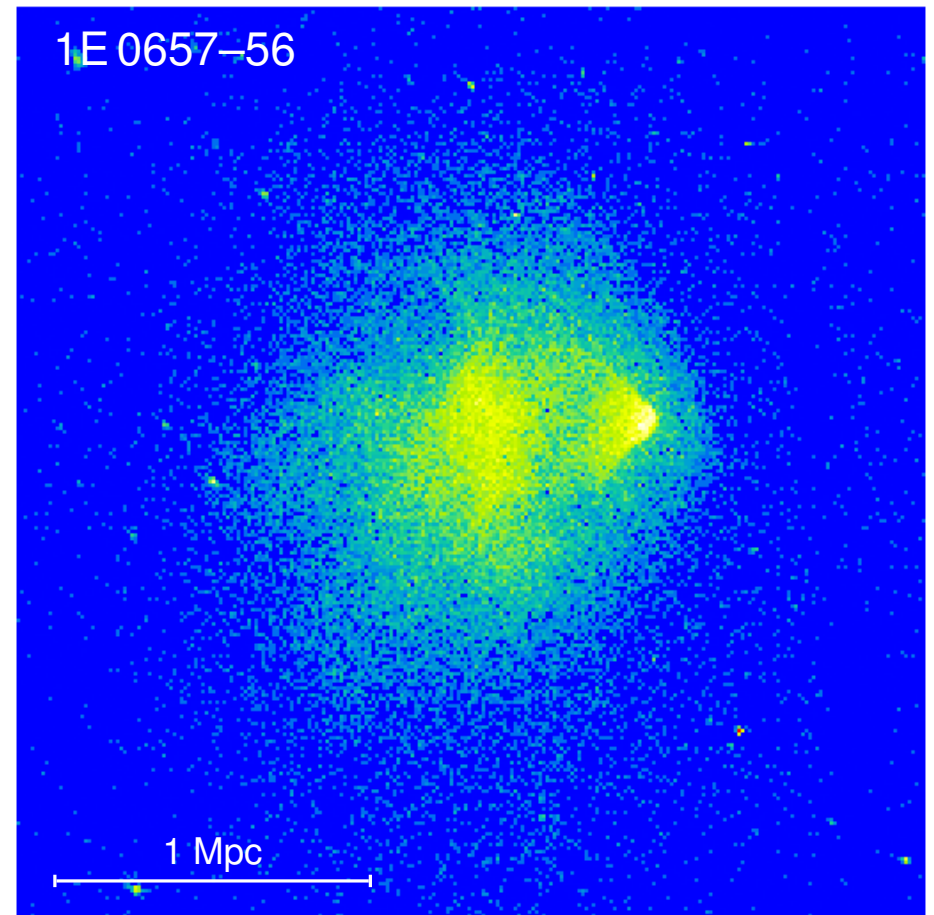


(Markevitch et al. 2000)

$M \lesssim 1$



$$M = 1 \pm 0.2 \quad (\text{Vikhlinin et al. 2001})$$



$$M = 3.2 \pm 0.7 \quad (\text{Markevitch et al., in prep.})$$

Cold fronts are now being seen in merger simulations

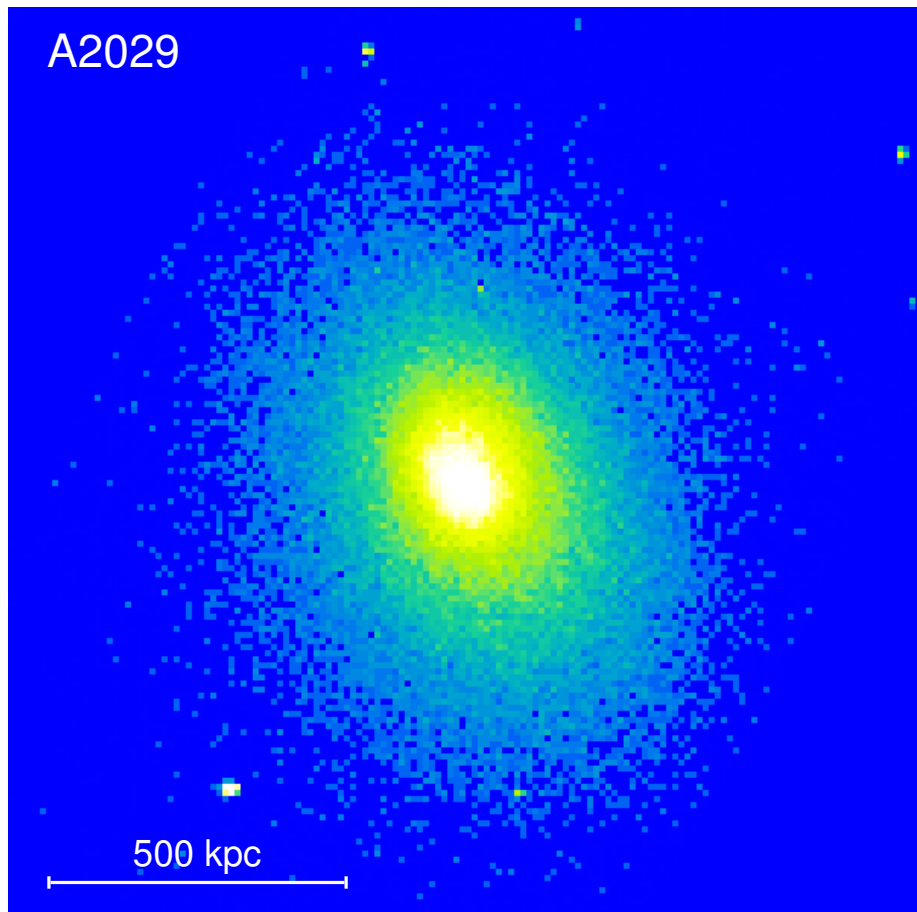
**(e.g., Nagai & Kravtsov 2002; Onuora et al. 2002; Bialek et al. 2002;
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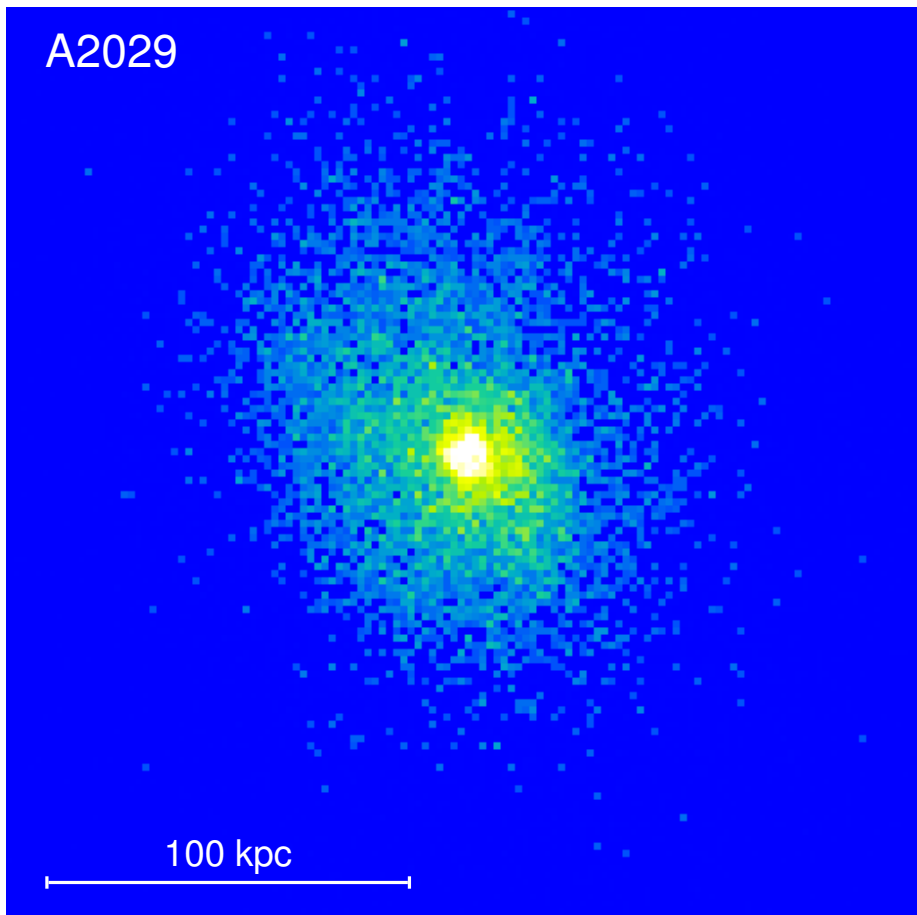
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**Not limited to mergers —
observed also in cores of “relaxed” clusters**

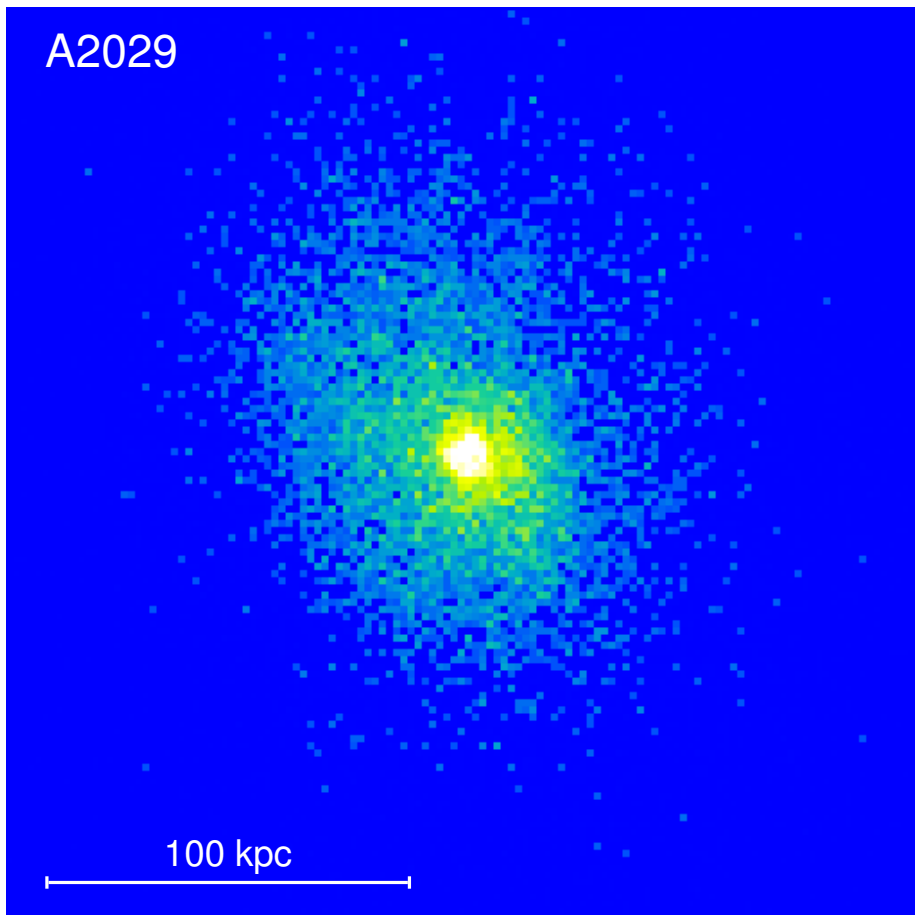
A2029



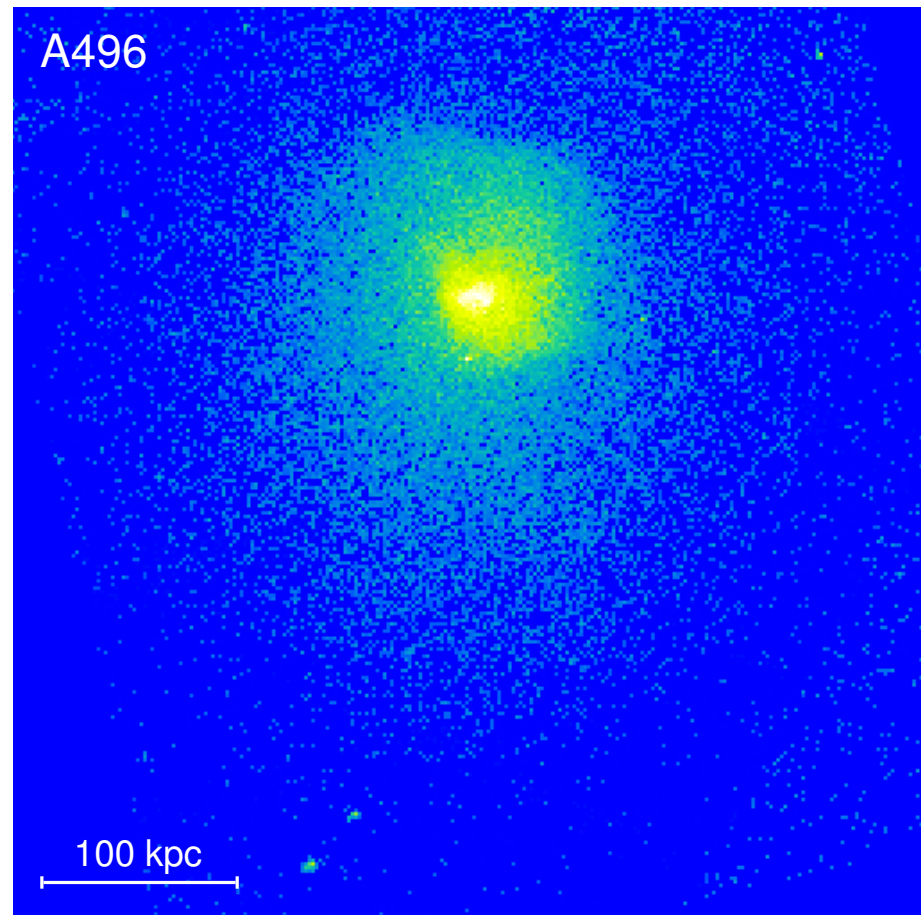
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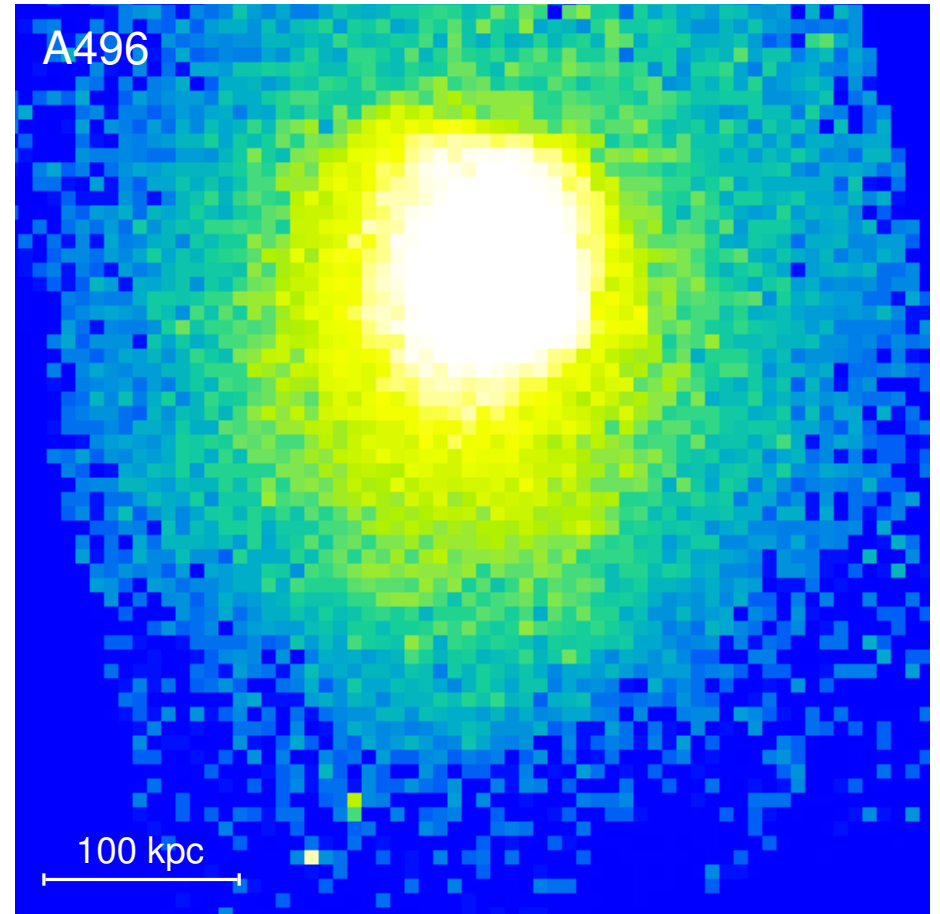
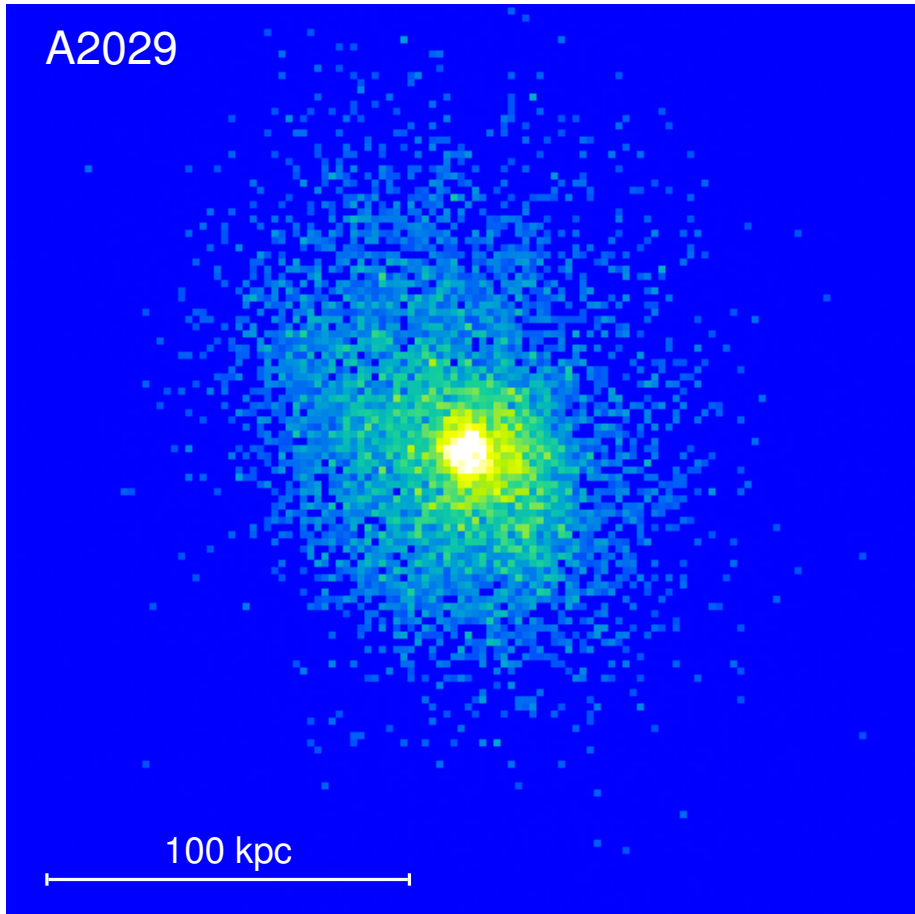


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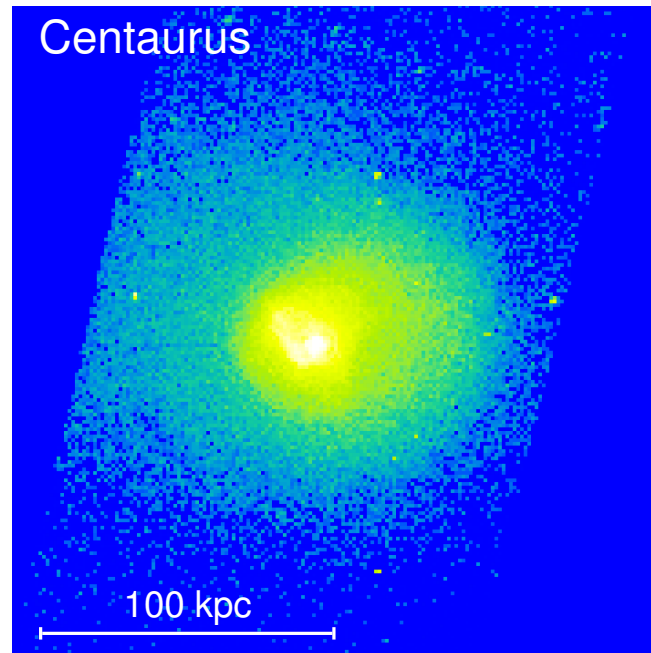
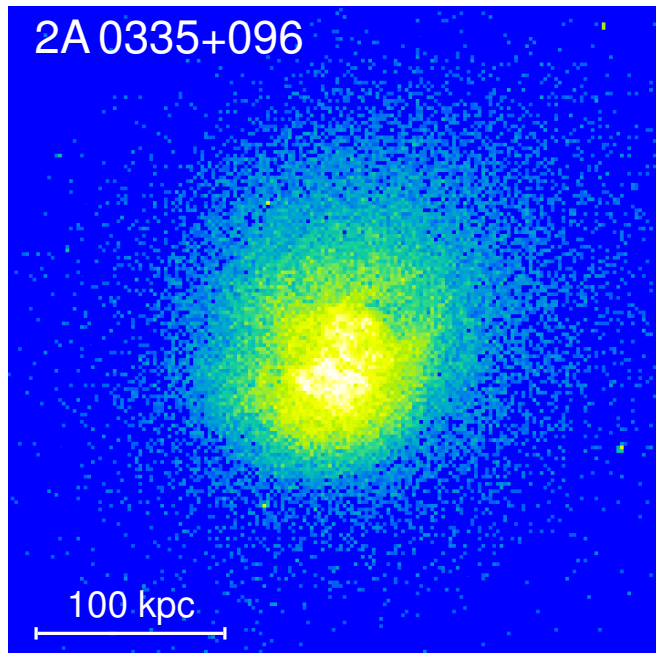
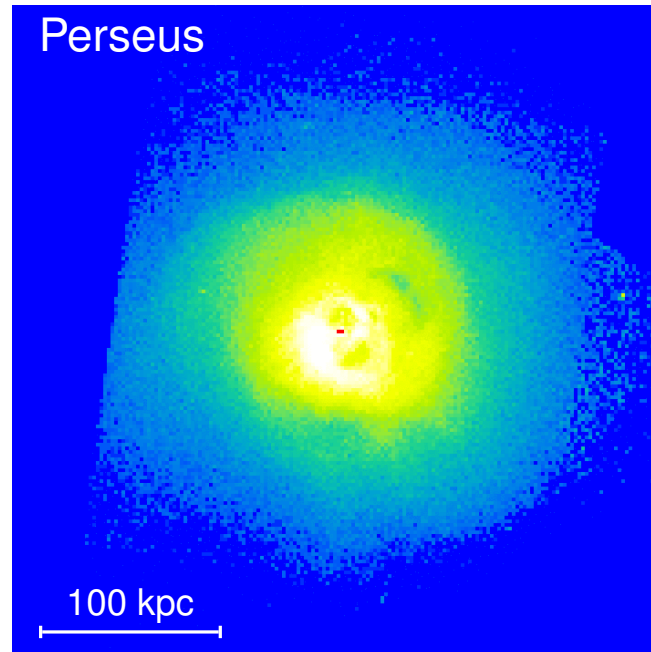
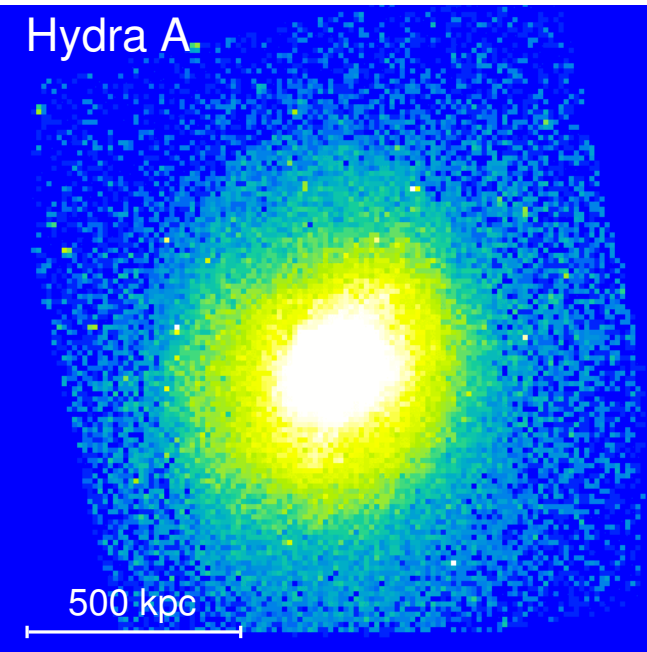


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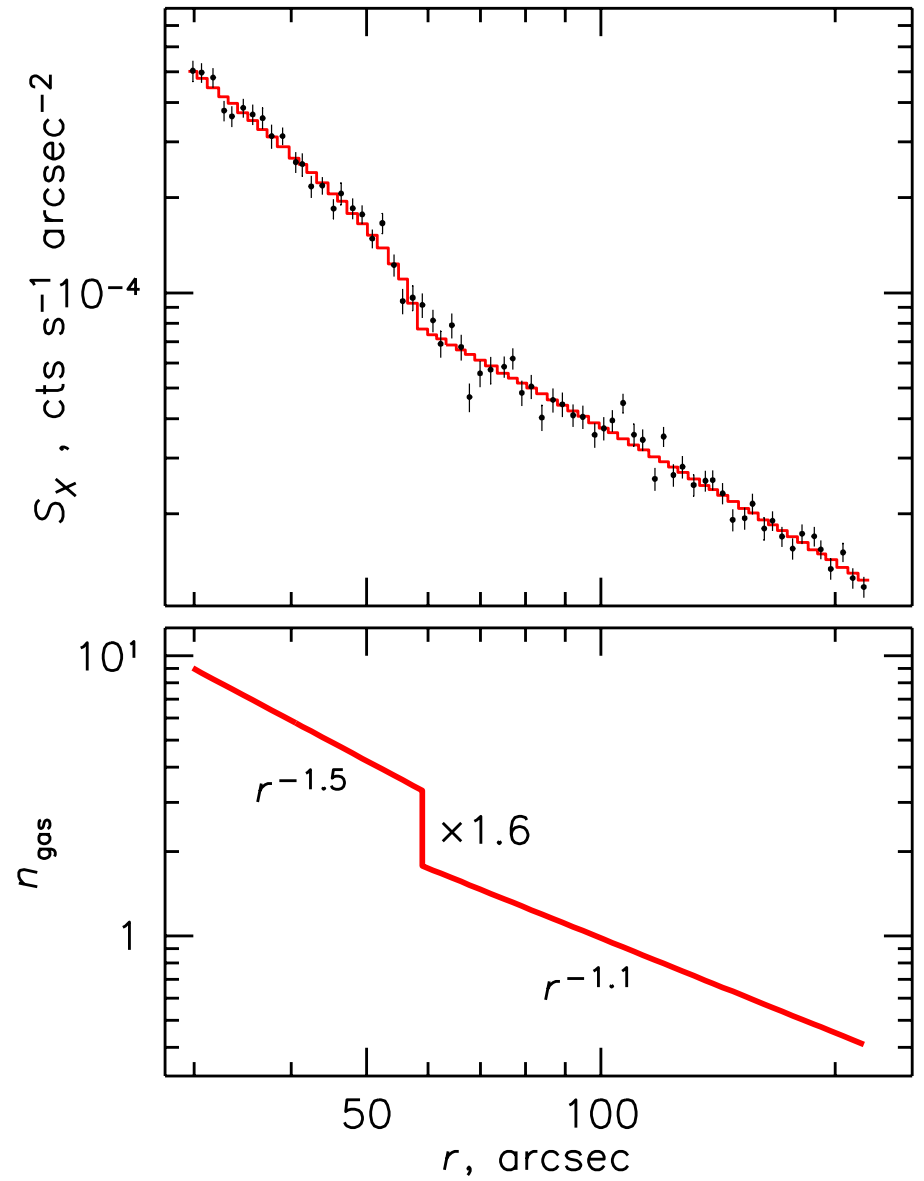
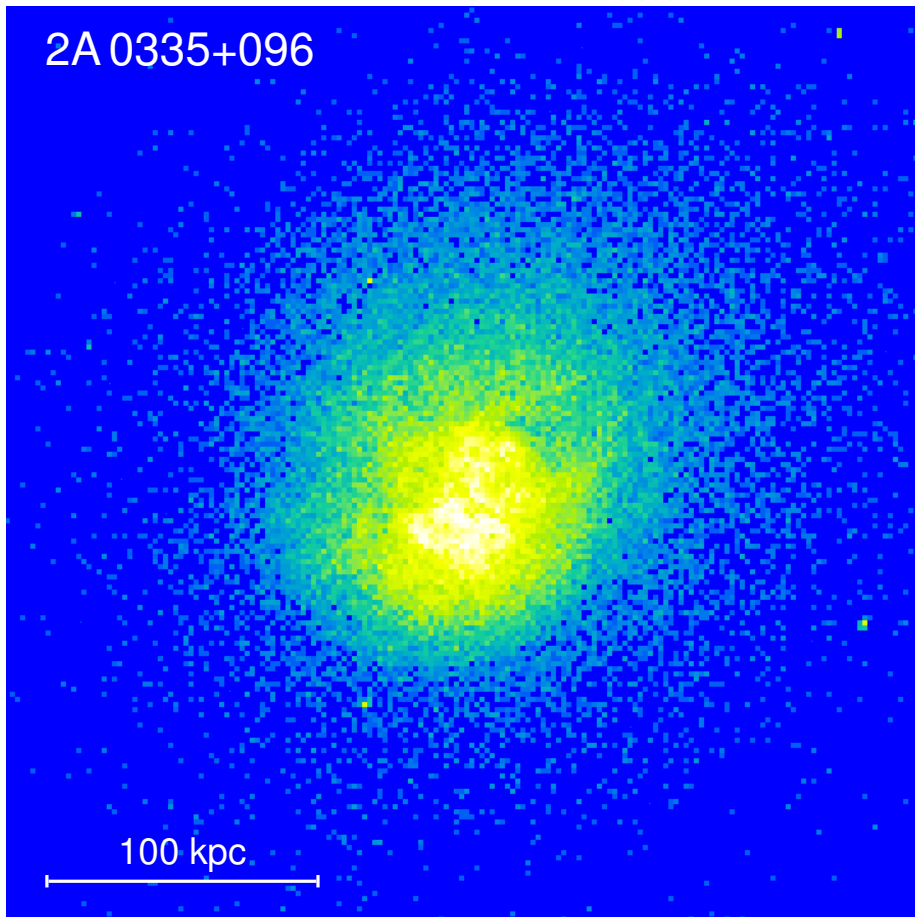




- **3 fronts at different scales**

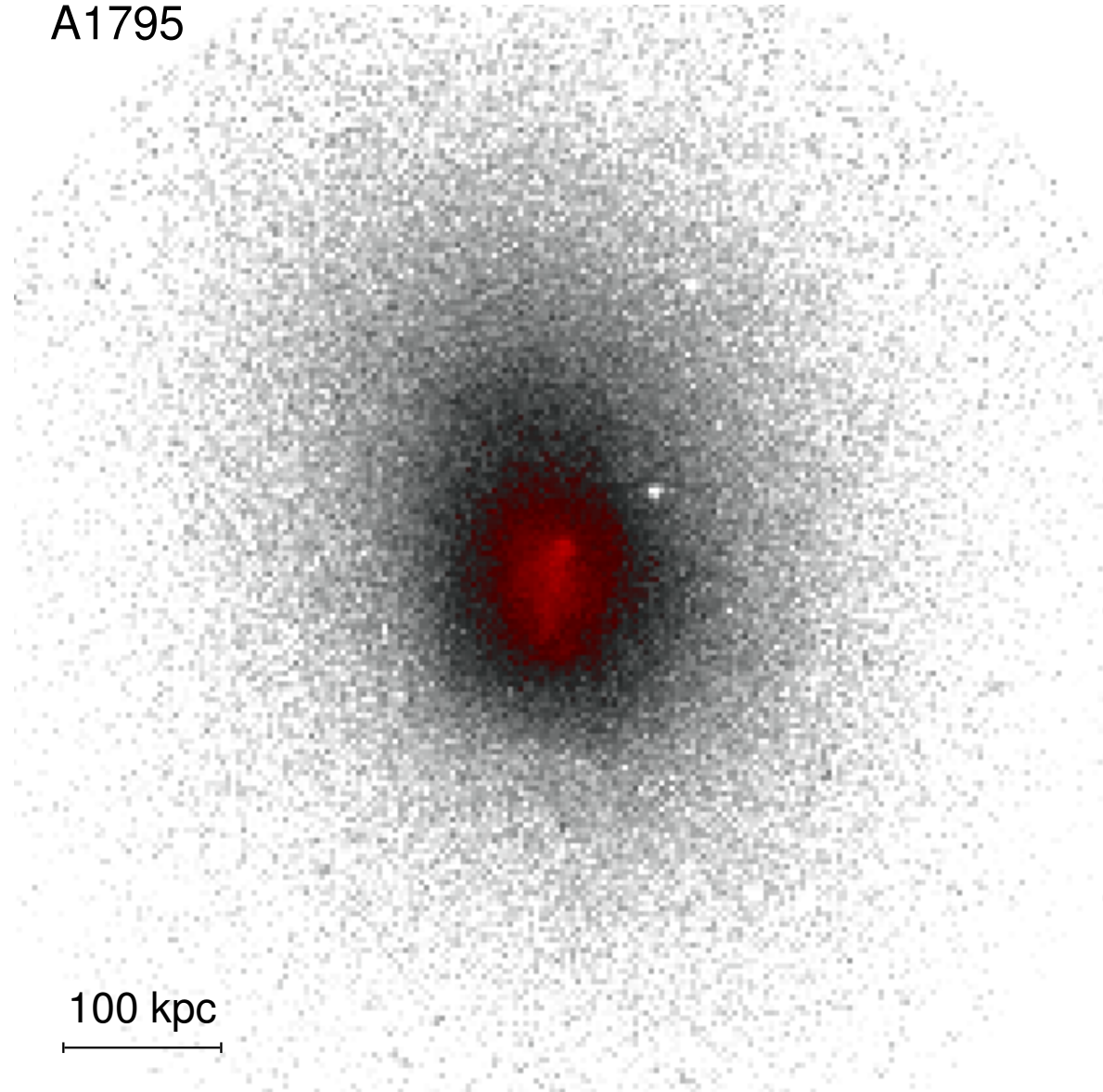


Velocities?

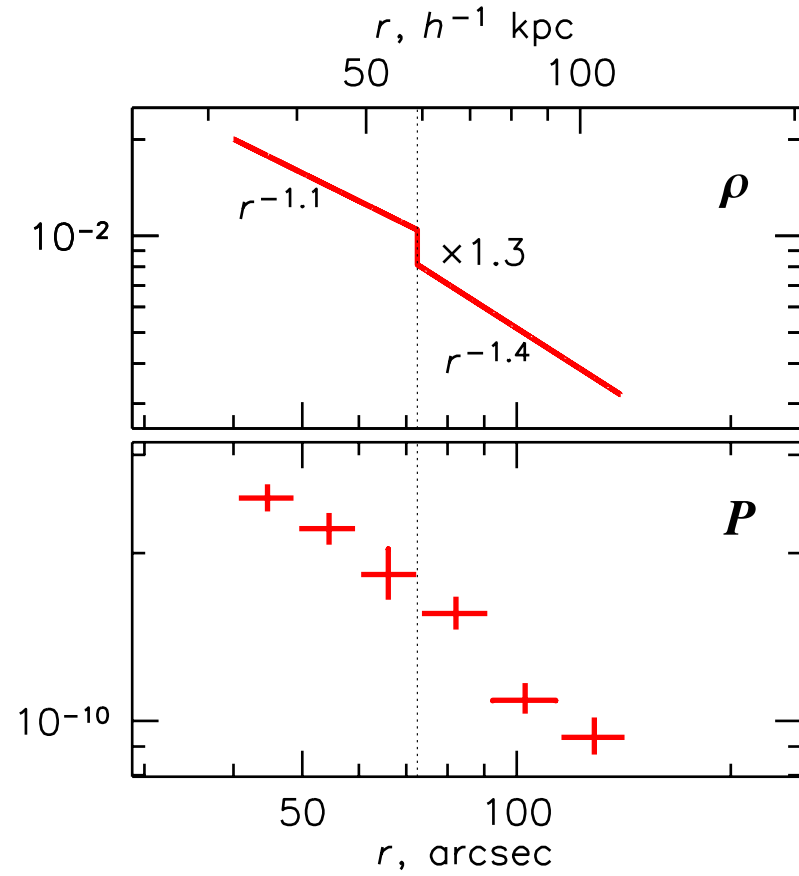
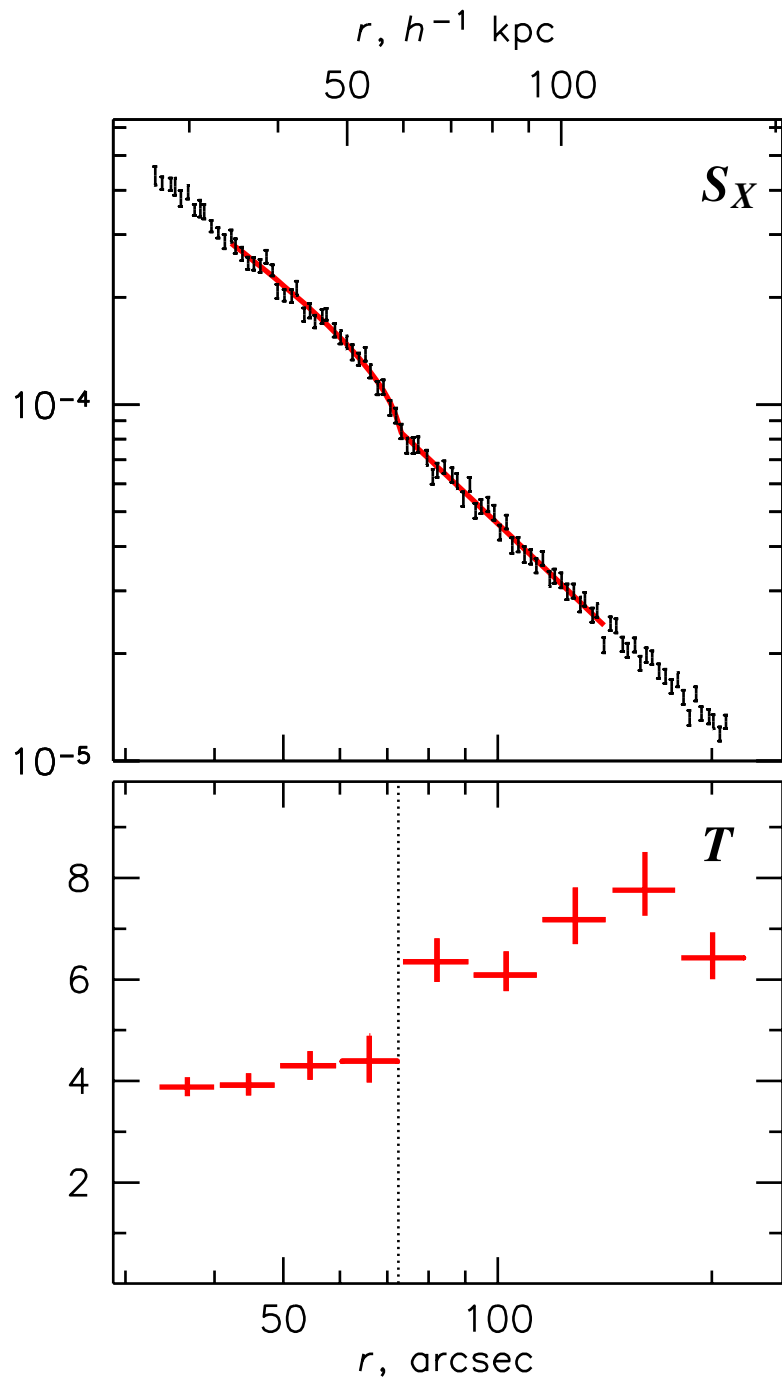


- $M = 0.75 \pm 0.2$ (Mazzotta et al. 2003)

A1795



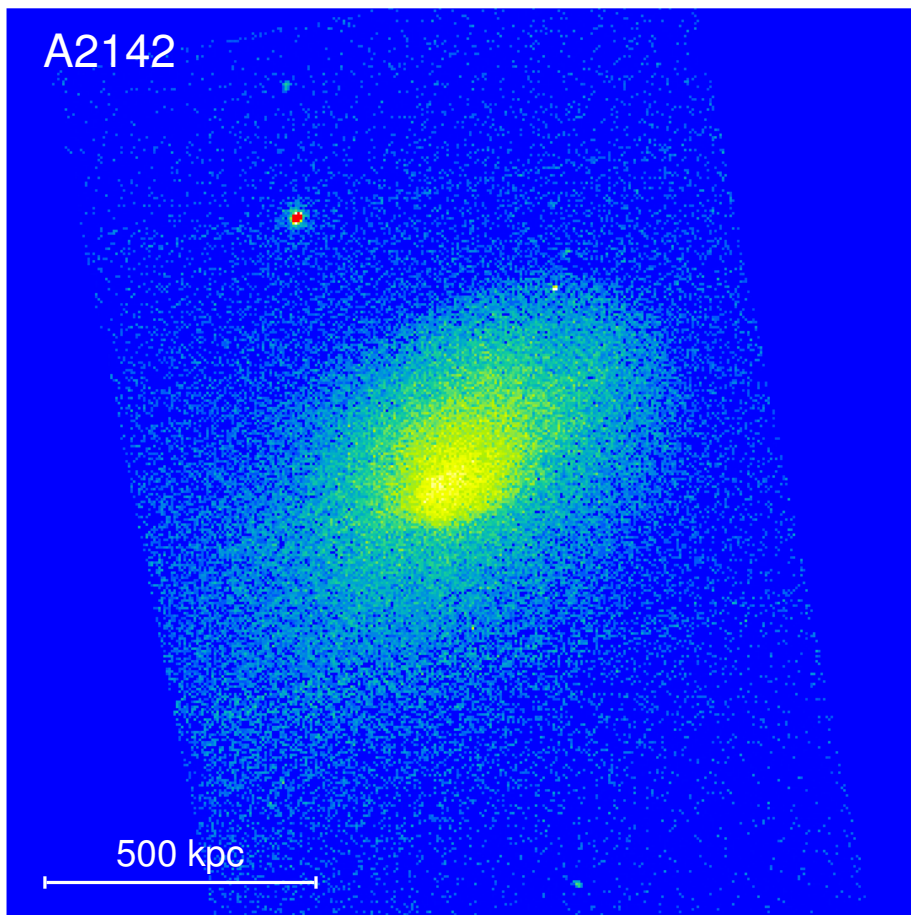
A1795



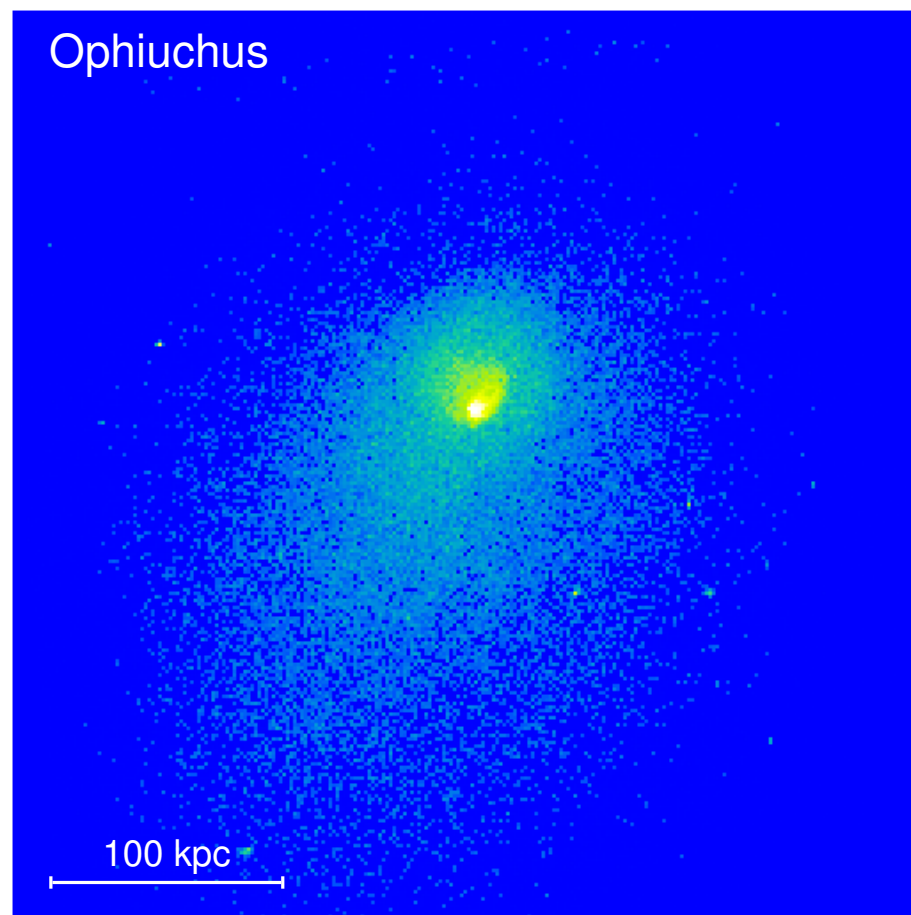
• $M = 0$

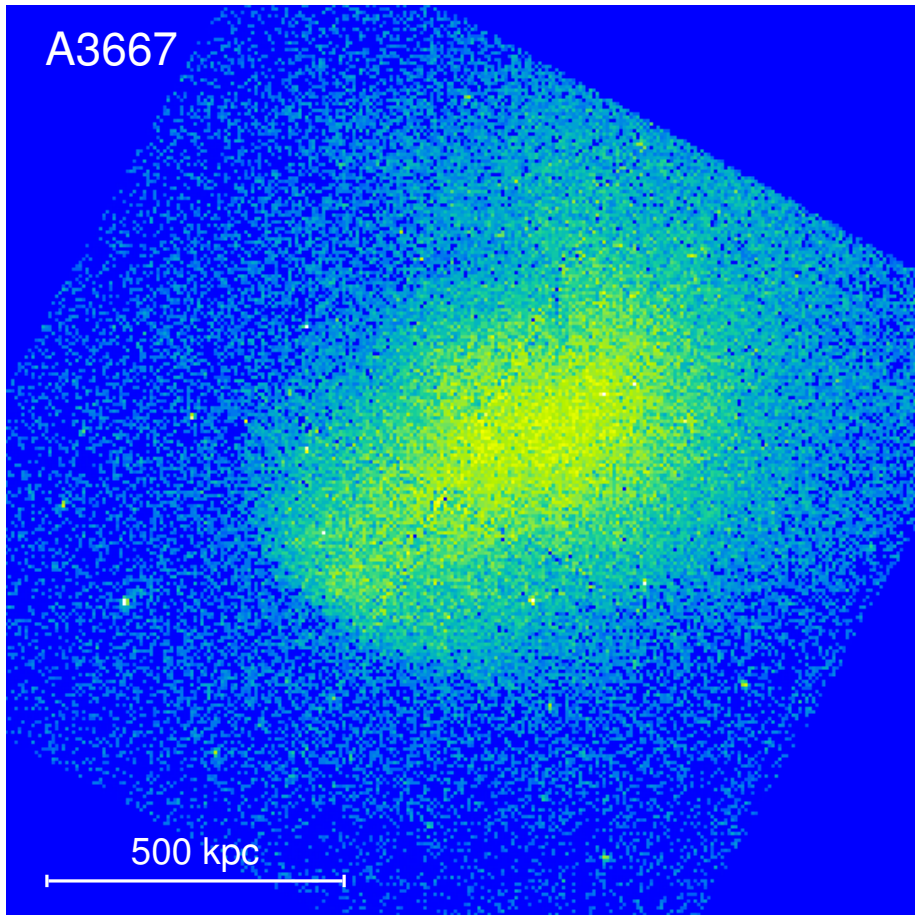
(Markevitch et al. 2001)

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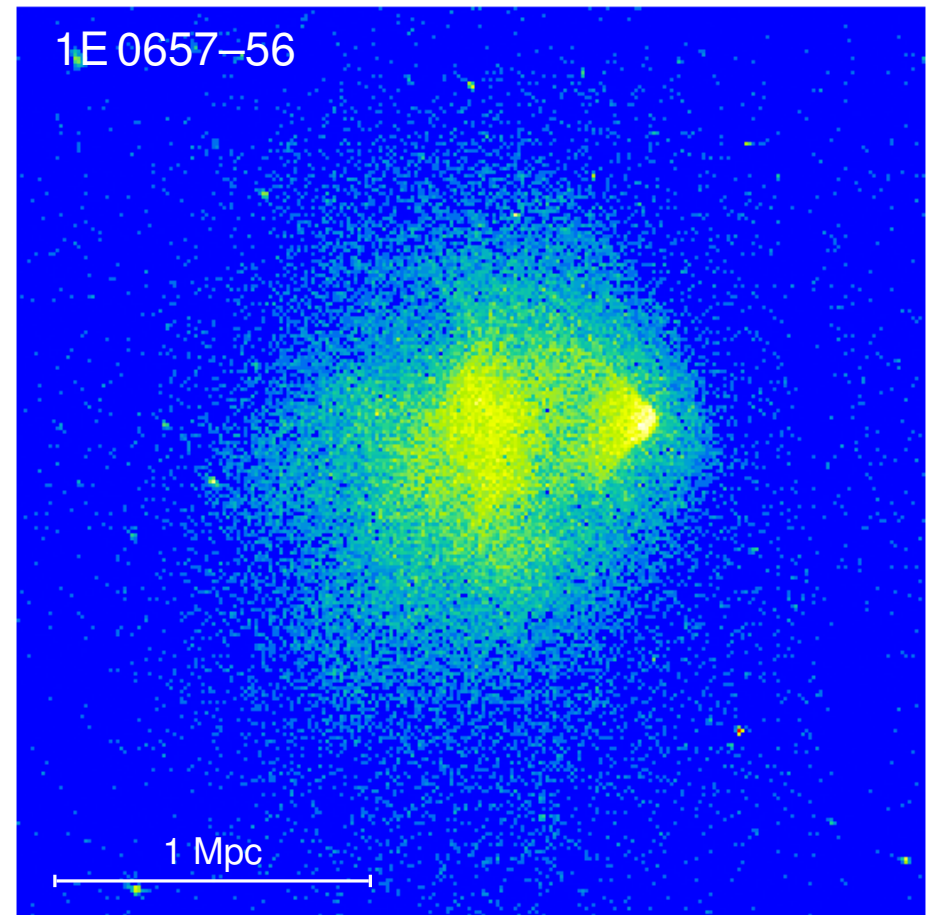


Ophiuchus





Dark matter clump inferred from X-ray image (Vikhlinin et al. 2002)



Dark matter clump seen in weak lensing mass map (Clowe et al., in prep.)

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What causes sloshing?

- **residual oscillations from old merger?**
(Churazov et al. 2003; poster by Tittley & Henriksen)
- **recent disturbance of central potential by infall of small groups?**
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Counterexample: [A2029](#)

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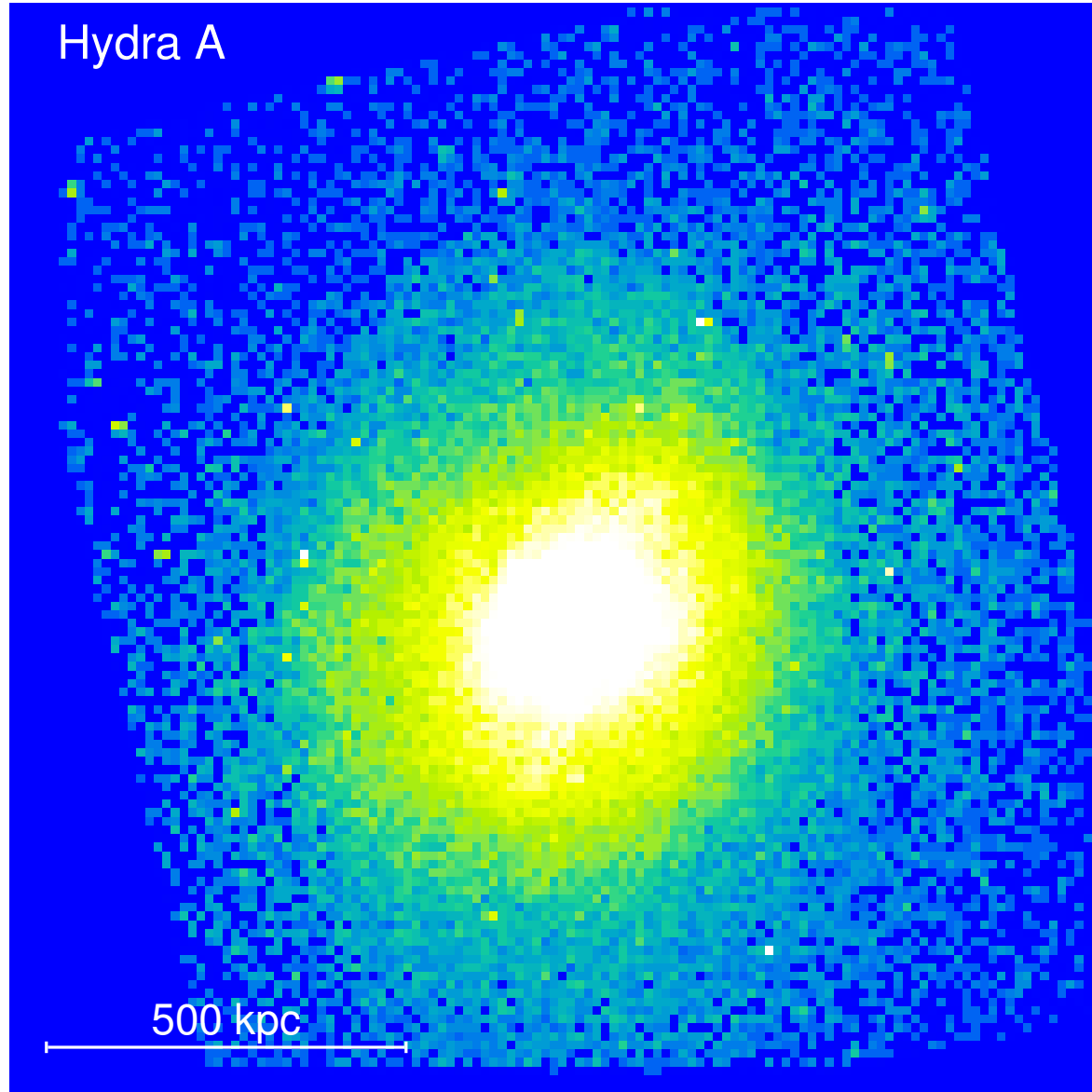
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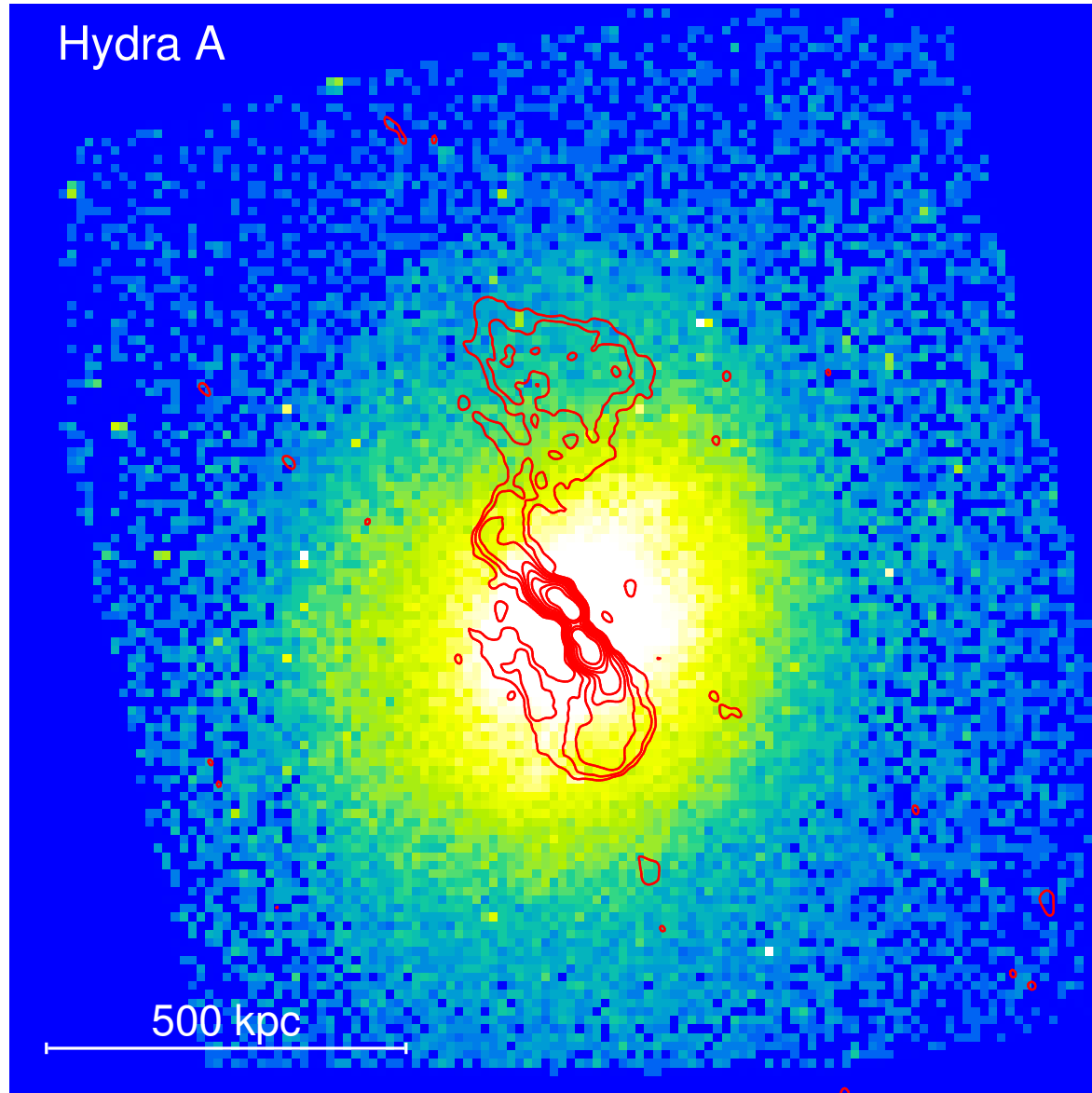
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Counterexample: [A2029](#)

- **rising hot bubbles? ([Perseus](#), Hydra-A; Quilis et al. 2001)**

Hydra A





Radio contours from G. Taylor

How common?

How common?

Out of **33** “short cooling time” clusters with good *Chandra* images

(from Peres et al. 1998, Allen et al. 1998, 2000):

- density edges seen in at least **19** (60%)

(clearly no edges in 8; bubbles at least in 13)

Conclusions on sloshing

- **Subsonic sloshing ($M \sim 0.5$) is a natural state of the dense gas in cluster centers**
- **Origin unclear, probably residual from past mergers, but maybe bubbles**
- **Whatever the origin — reservoir of kinetic energy of order 1/3 thermal, available for dissipation**

Thermal conduction

Theoretical expectations for α in clusters (due to thermal diffusion of electrons):

from \sim Spitzer /5 (Narayan & Medvedev 2001),

down another factor of 10 (Malyskin & Kulsrud 2001),

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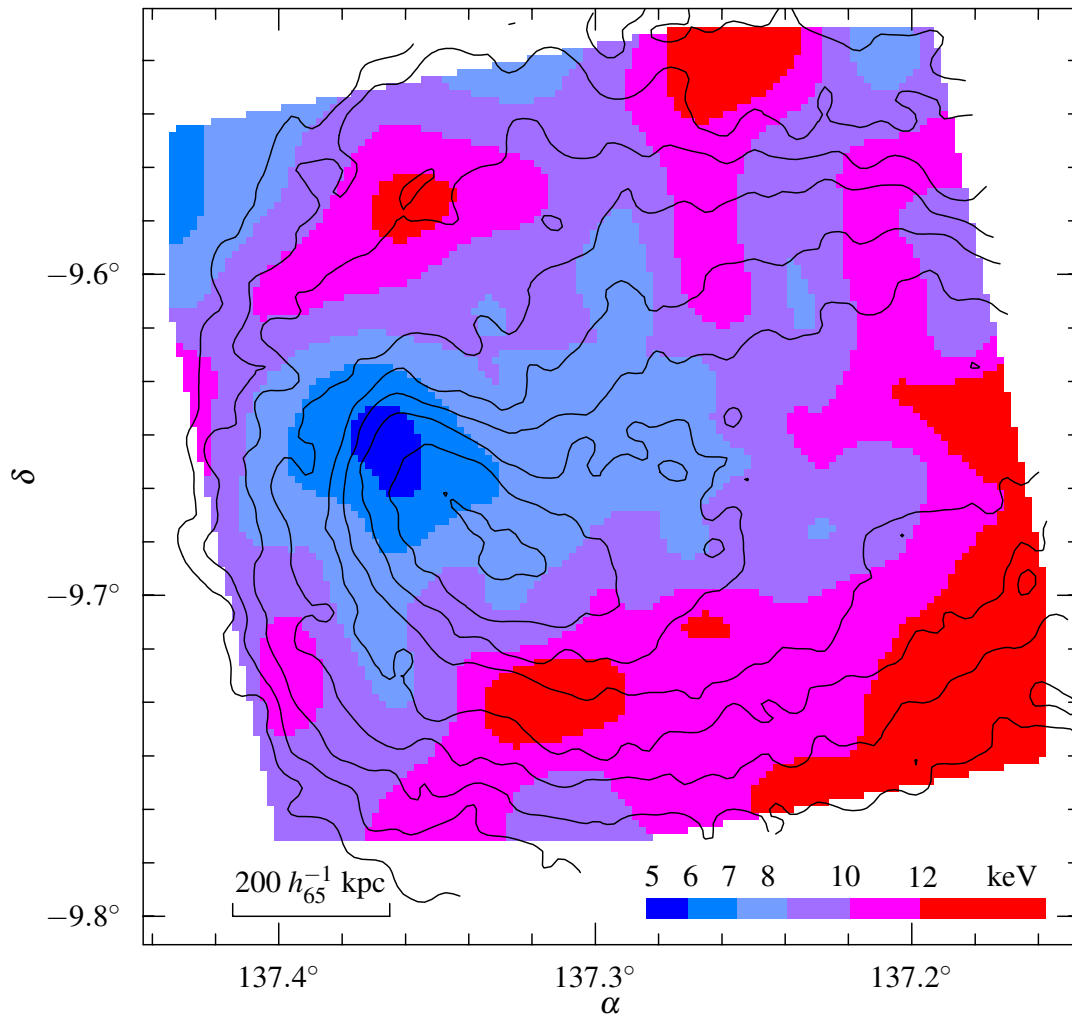
Observations:

- From temperature jumps at cold fronts: α reduced by factor > 100
(Ettori & Fabian 2000)**
- Cool gas around 2 central galaxies in Coma: reduction by factor 30 – 100
(Vikhlinin et al. 2001)**

These are very special places

Thermal conduction in the bulk of the gas

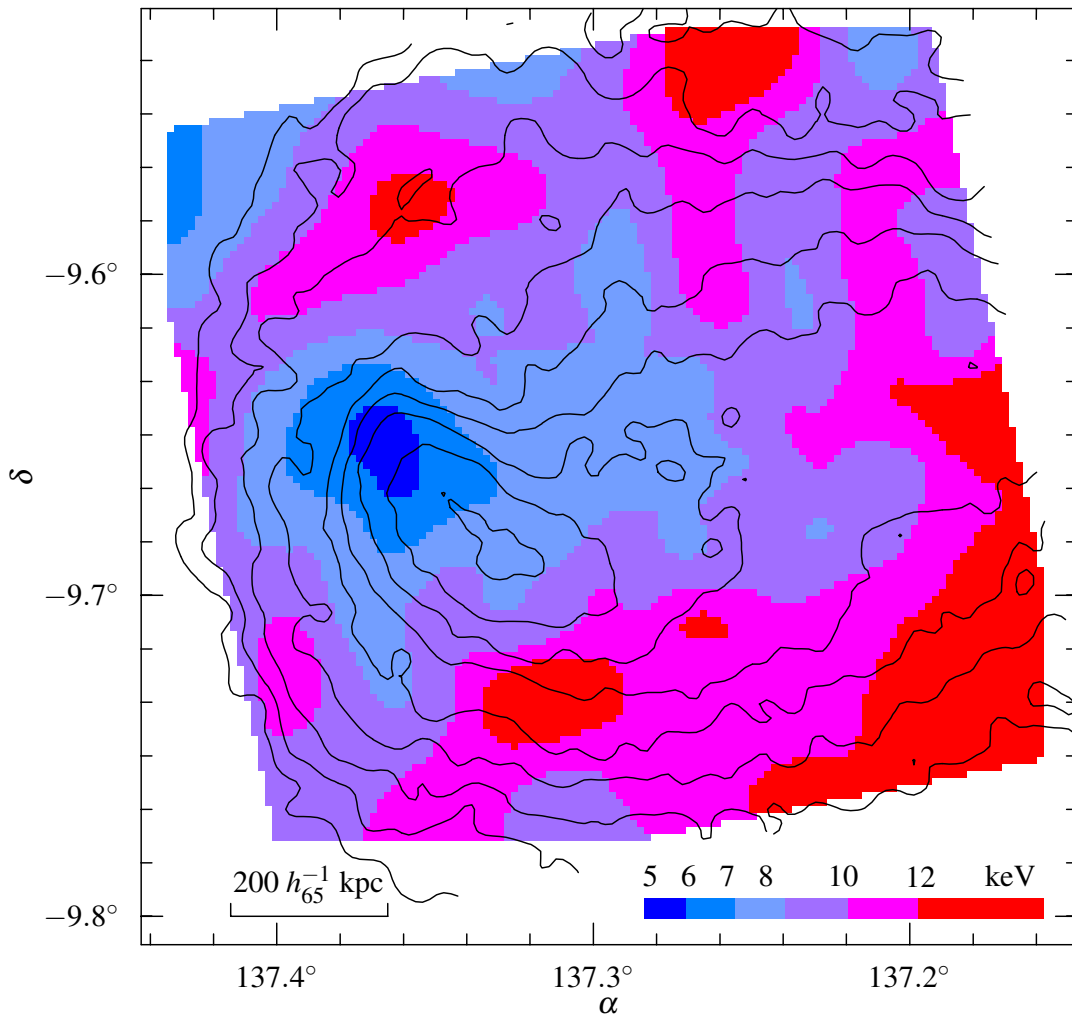
A754



(Markevitch et al. 2003)

Thermal conduction in the bulk of the gas

A754



Time for T variations to disappear
(for Spitzer κ):

$$t_{\text{cond}} \sim \frac{kn_e l^2}{\kappa} \simeq 1.2 \times 10^7 \text{ yr}$$

Age of the structure:

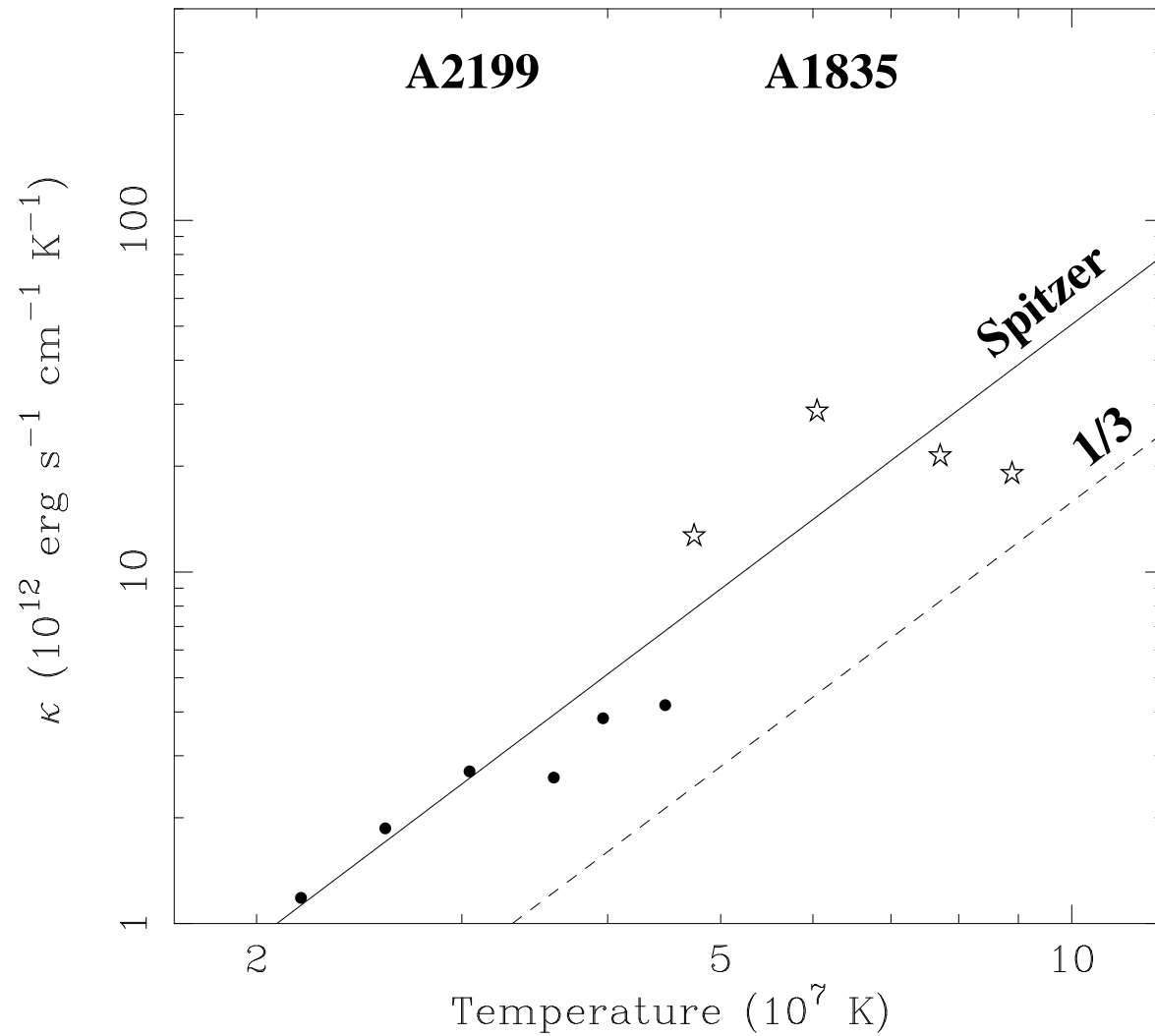
$$t_{\text{age}} \sim \frac{L}{c_s} \sim 5 \times 10^8 \text{ yr}$$

Conduction suppressed by factor

$$\frac{t_{\text{age}}}{t_{\text{cond}}} > 10 h_{65}^{1/2}$$

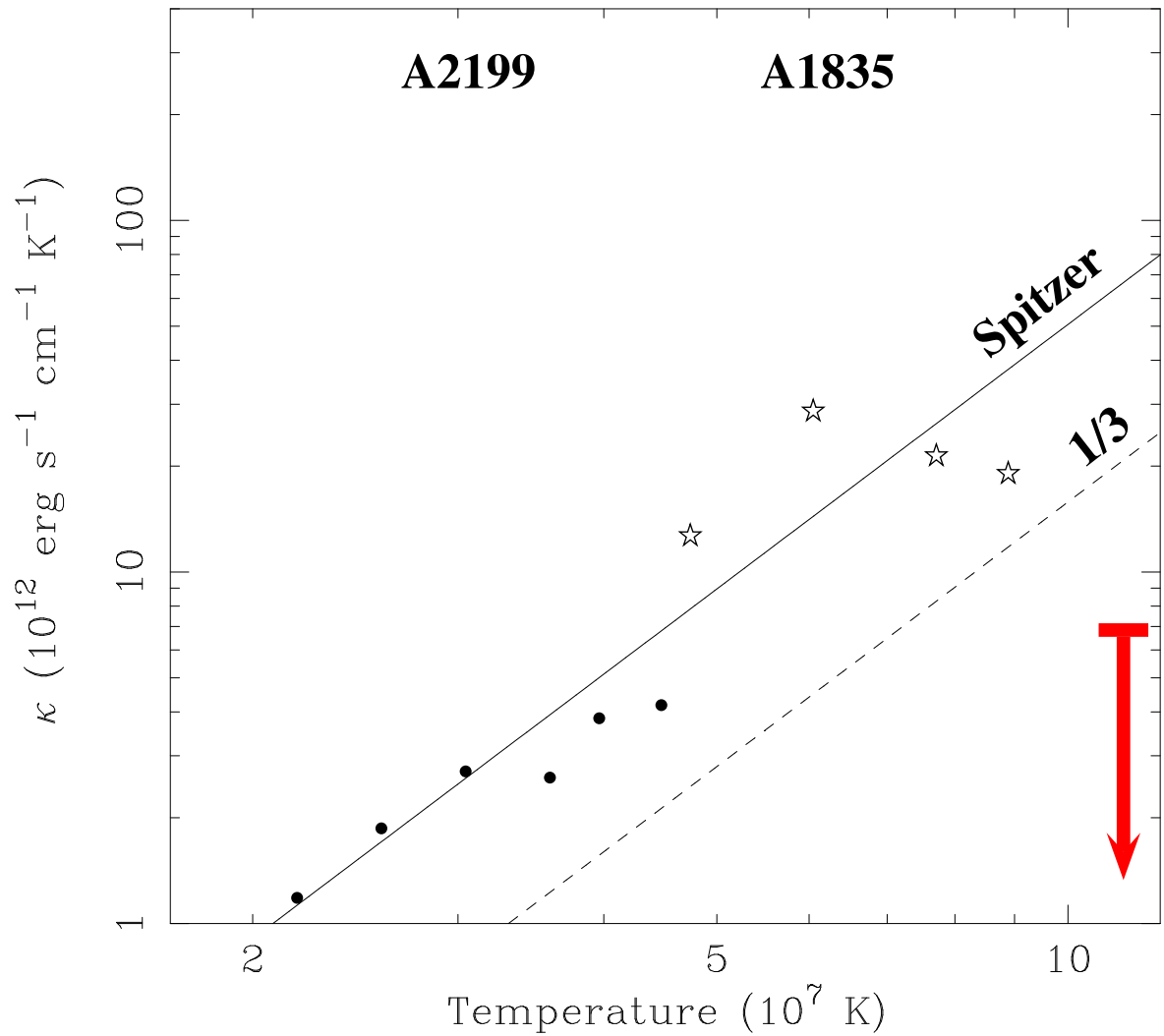
(Markevitch et al. 2003)

Thermal conduction in cooling flows



(from Voigt et al. 2002; also Zakamska & Narayan 2003)

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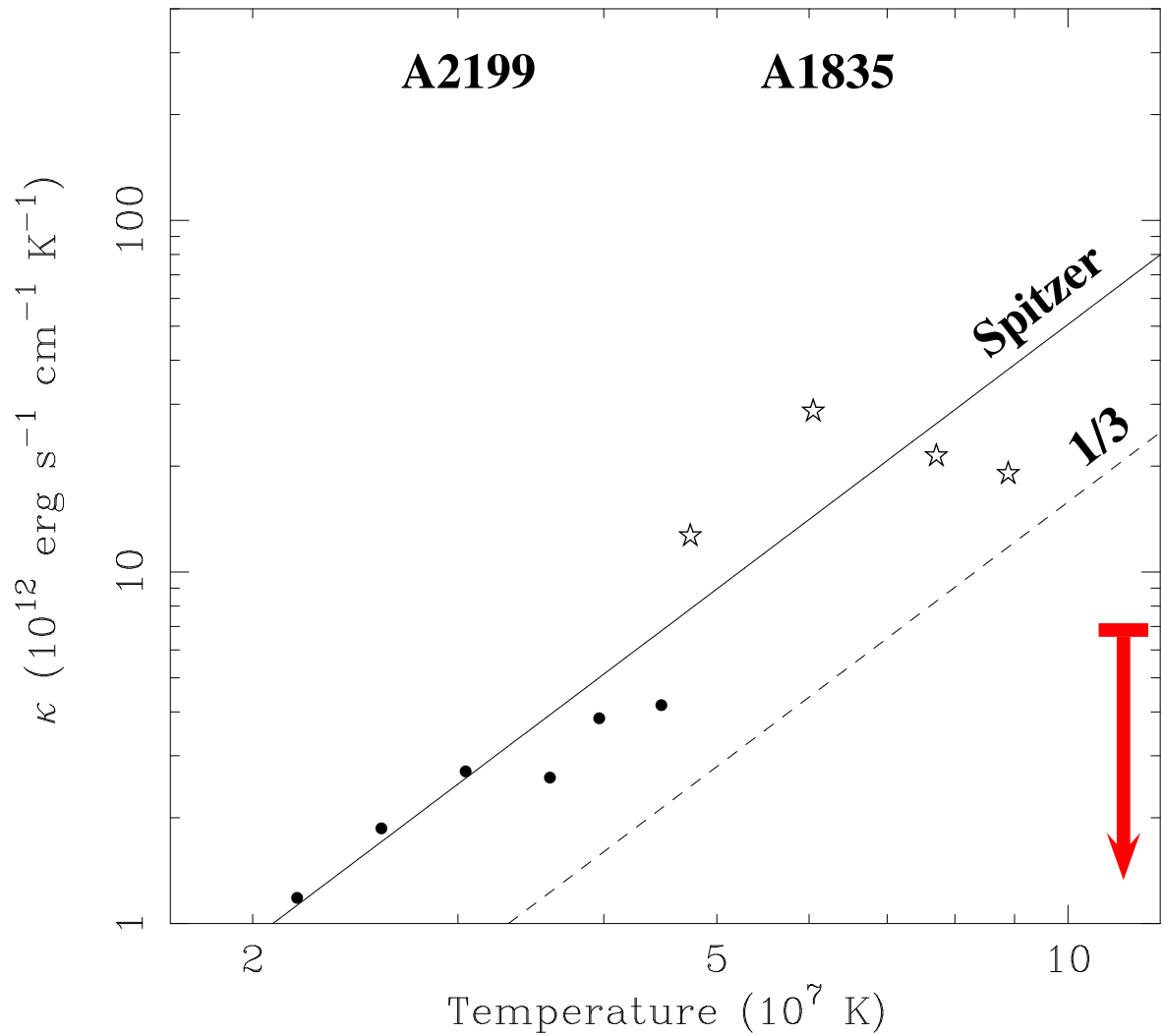


From A754:

$\kappa < \kappa_{\text{Sp}}/10$ at $T=10 \text{ keV}$

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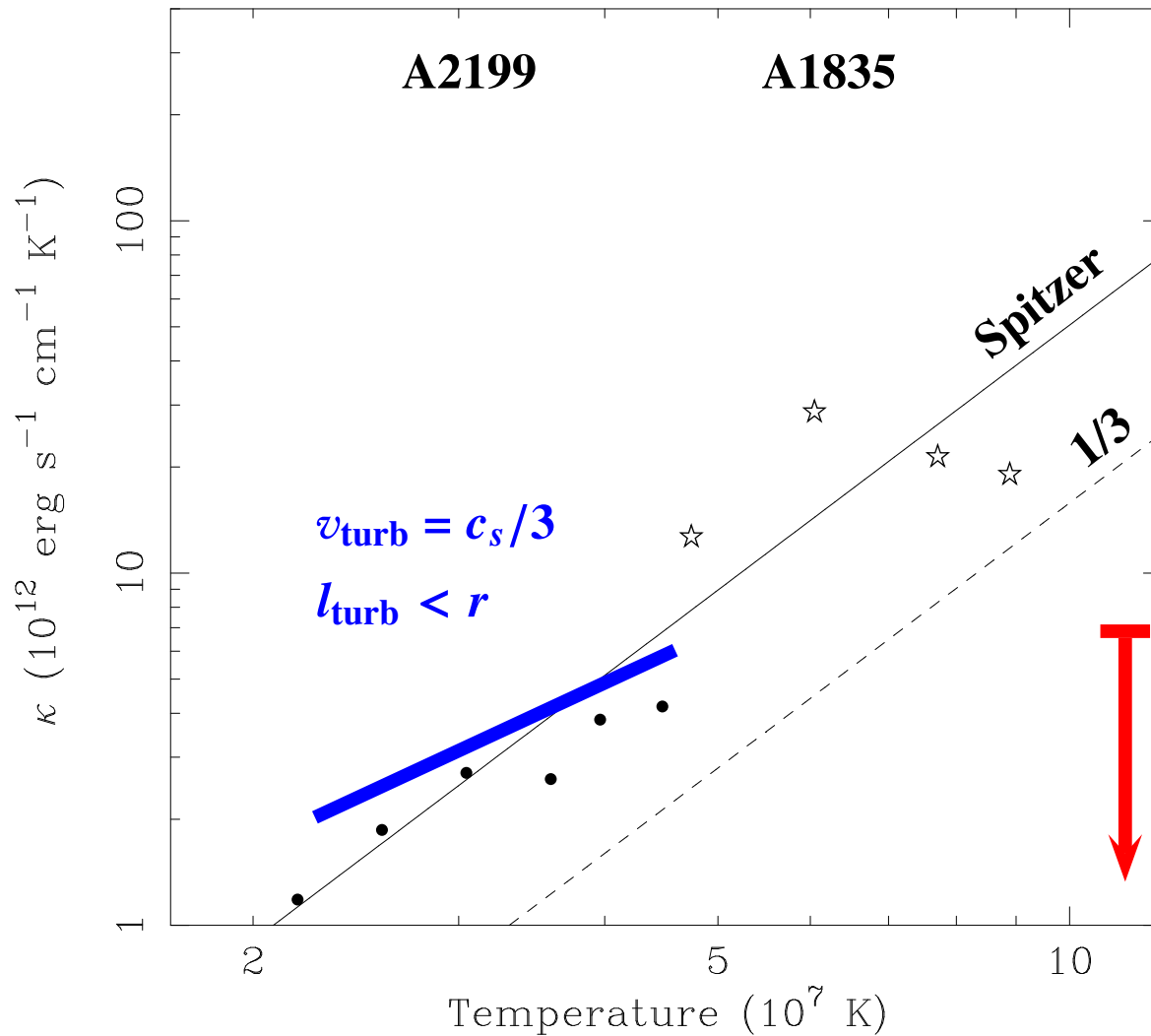
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Turbulent conduction:

$$\kappa_{\text{turb}} \sim k n v_{\text{turb}} l_{\text{turb}}$$

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Conclusions on conduction

- **Collisional conductivity < 0.1 Spitzer, so probably unimportant for cooling flows**
- **Other kinds of conduction of interesting magnitude — e.g., turbulent conduction — are not excluded**