Chandra and *XMM* results on cluster mergers

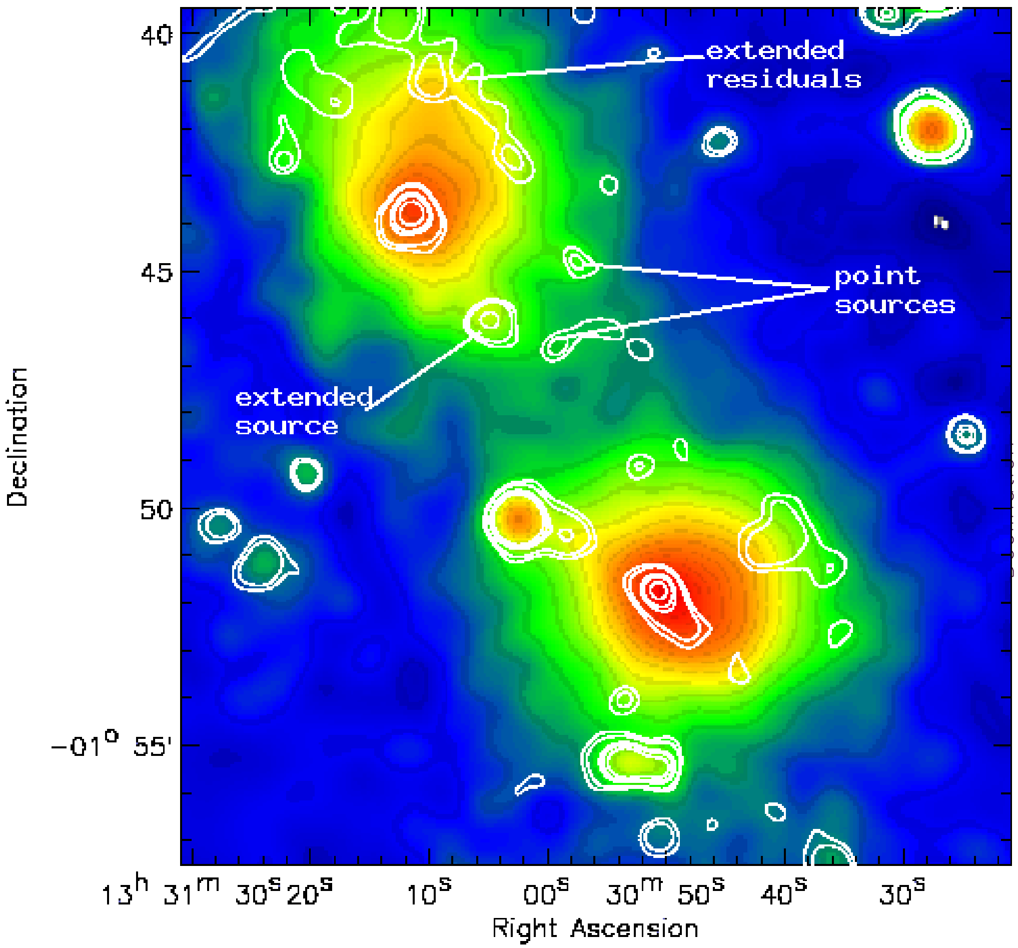
Maxim Markevitch (CfA)

August 2004

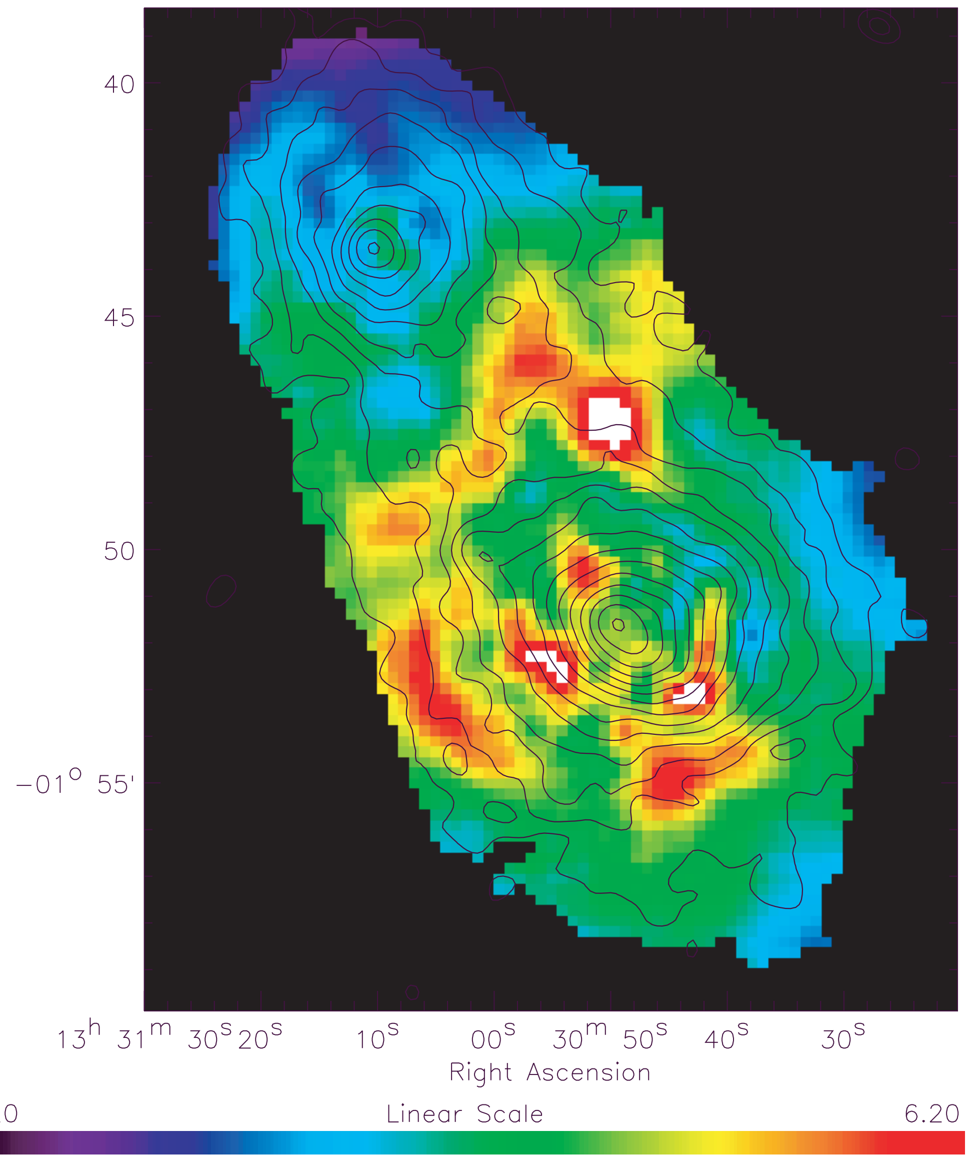
Merger gallery

A1750

XMM image

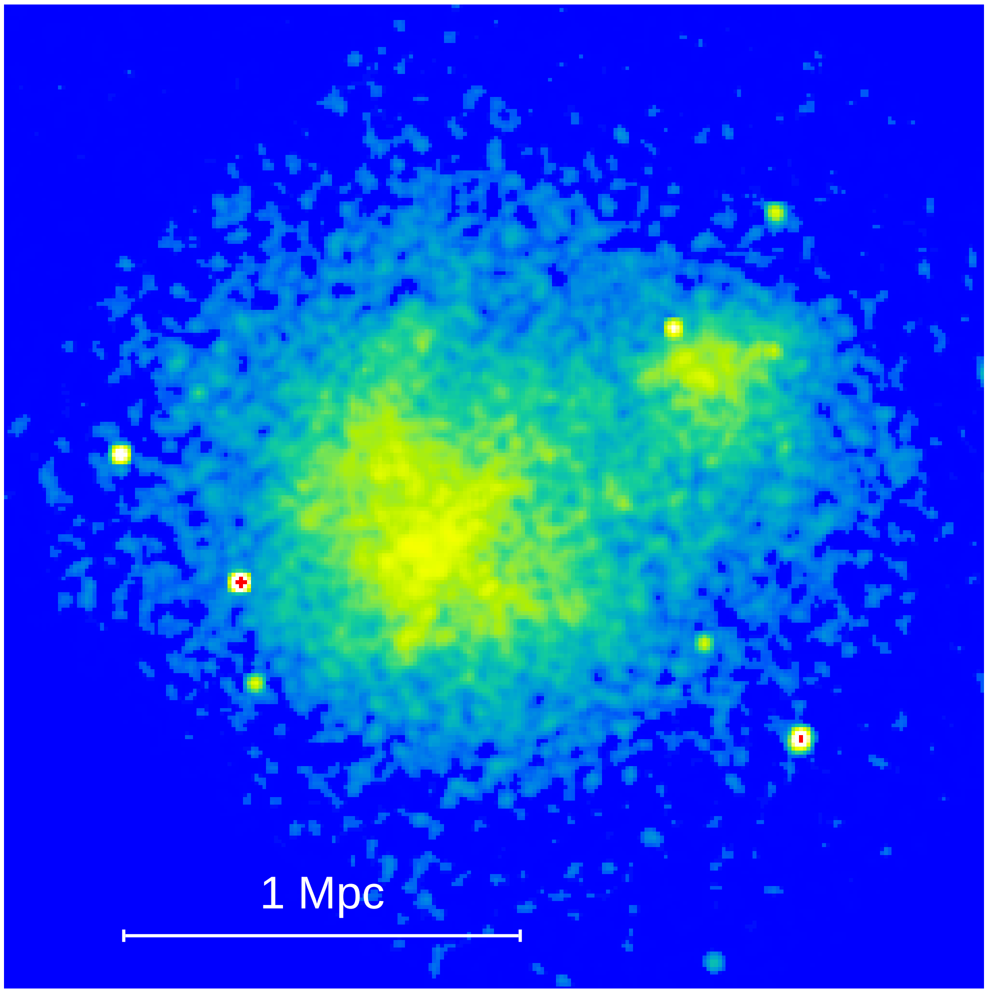


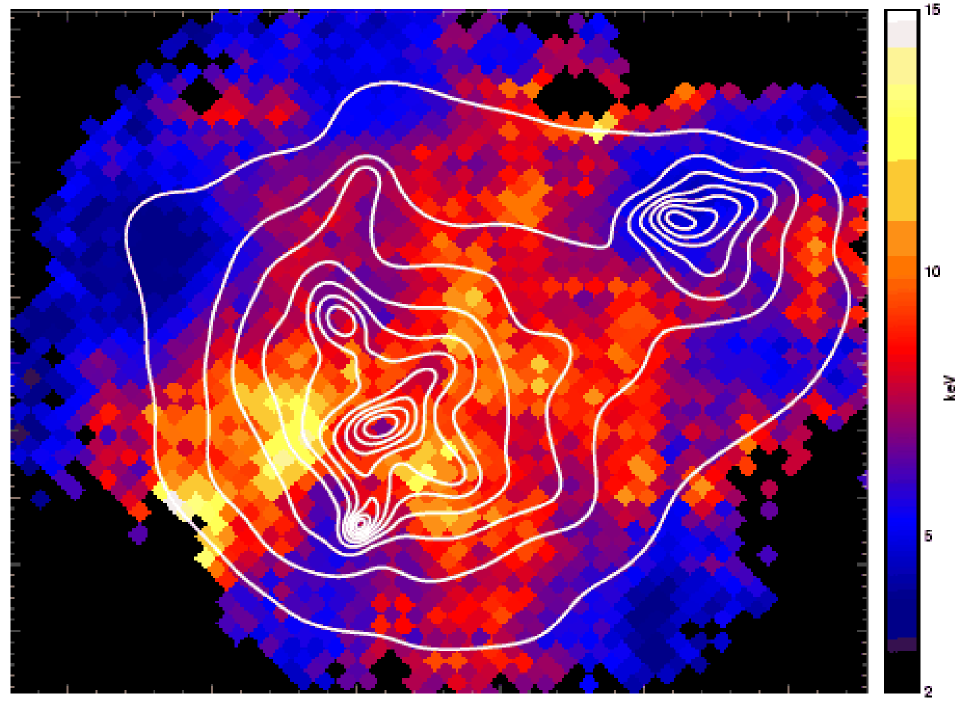
temperature map



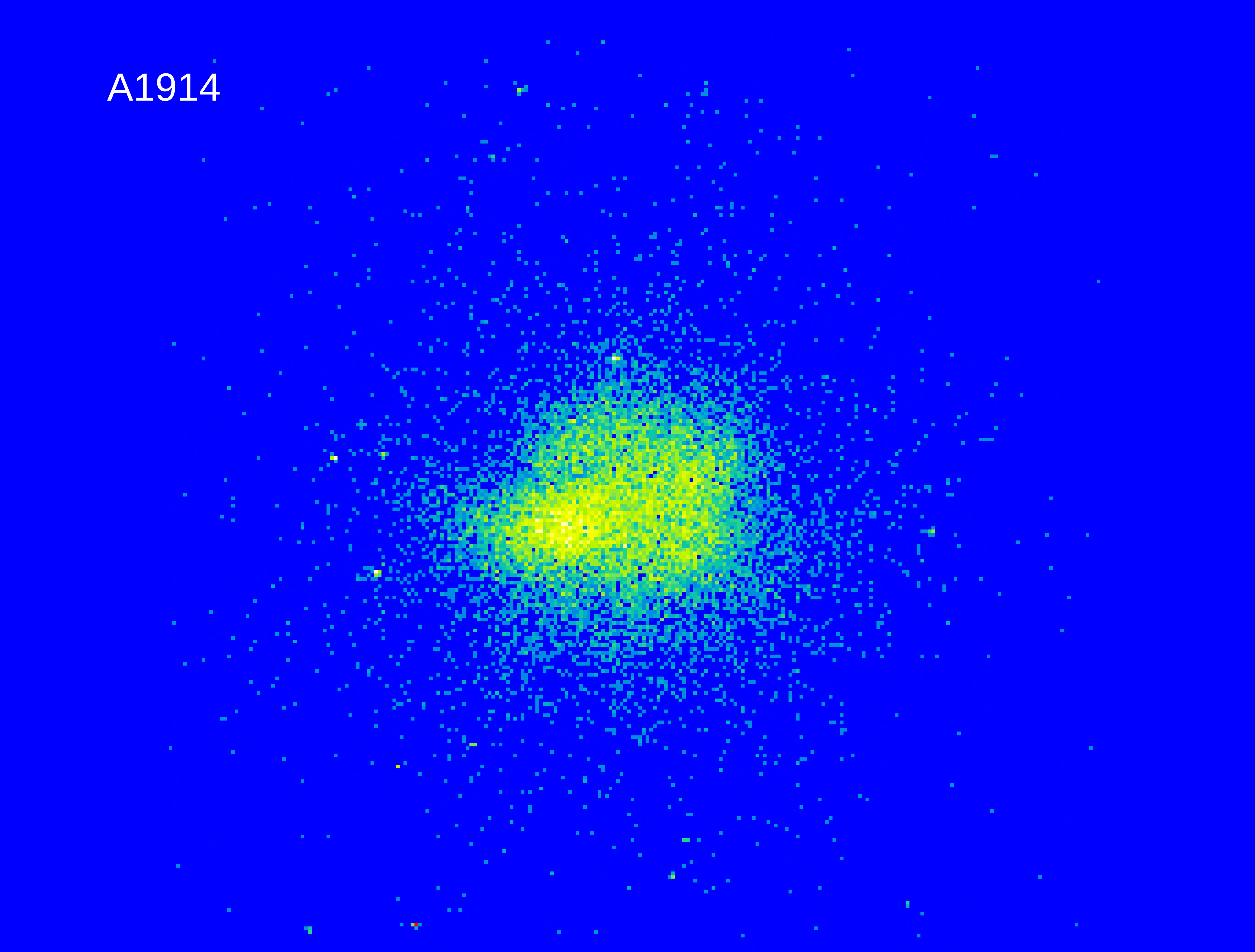
Belsole et al. (2004)

A2744

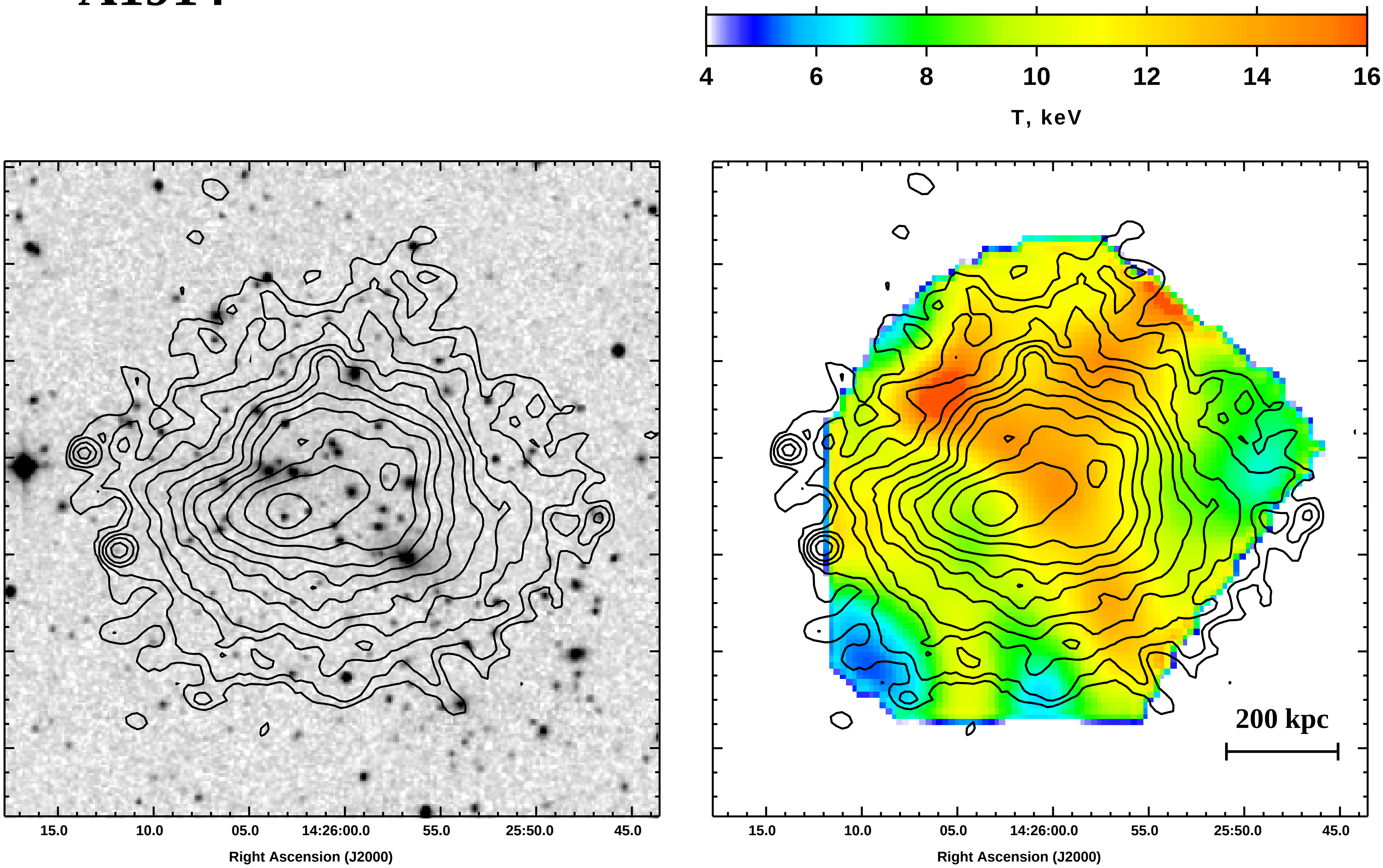




Chandra map (Kempner & David 2004)

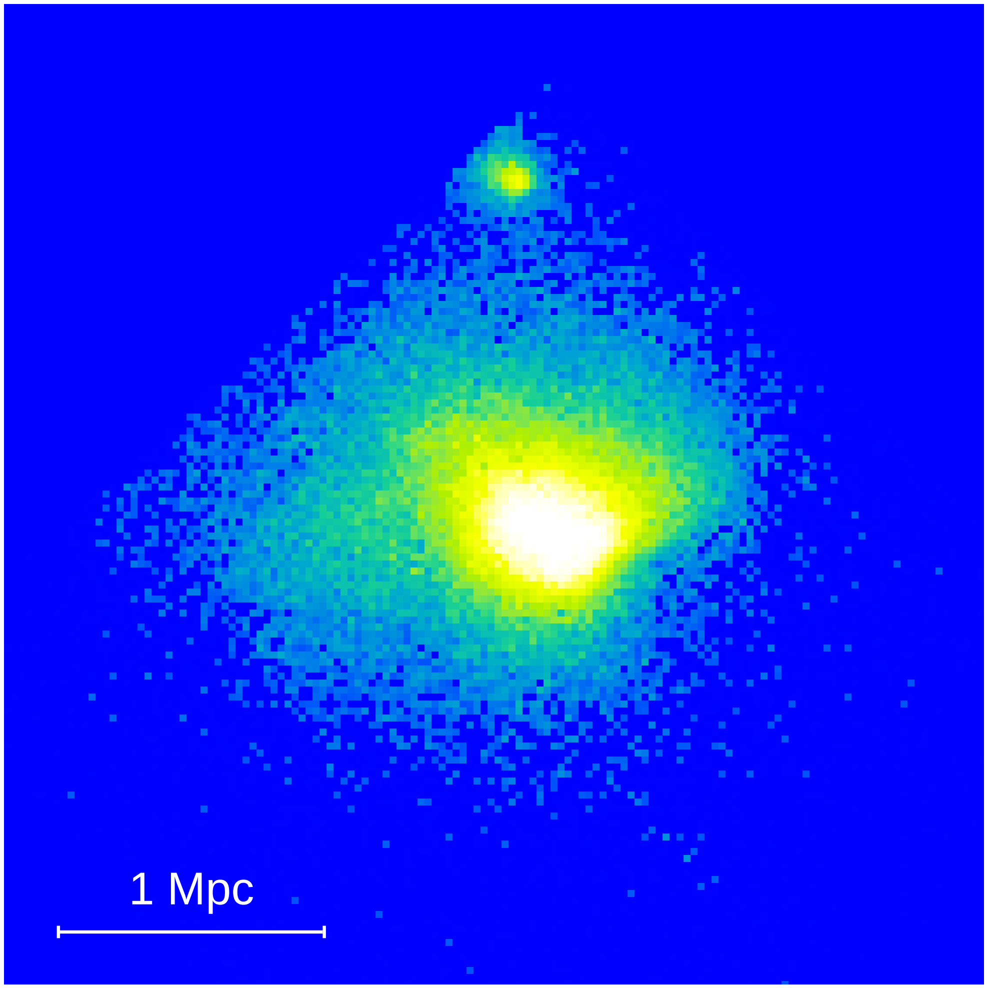

A1914

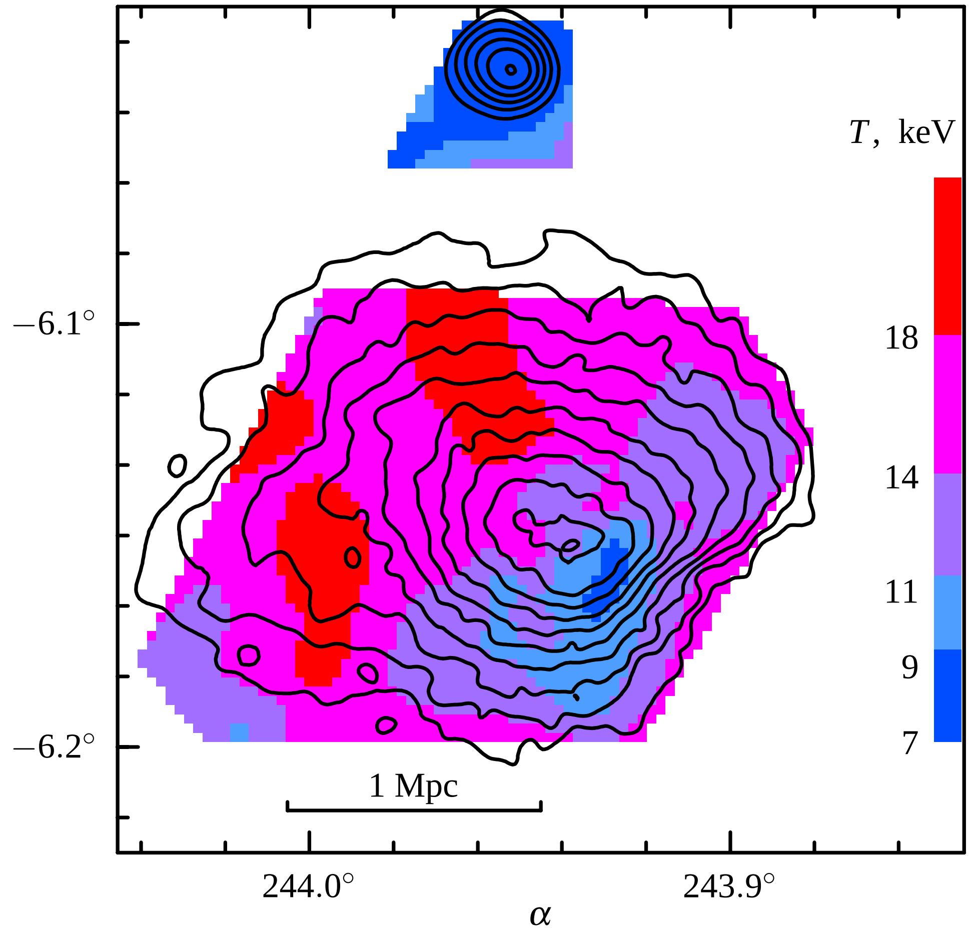
A1914



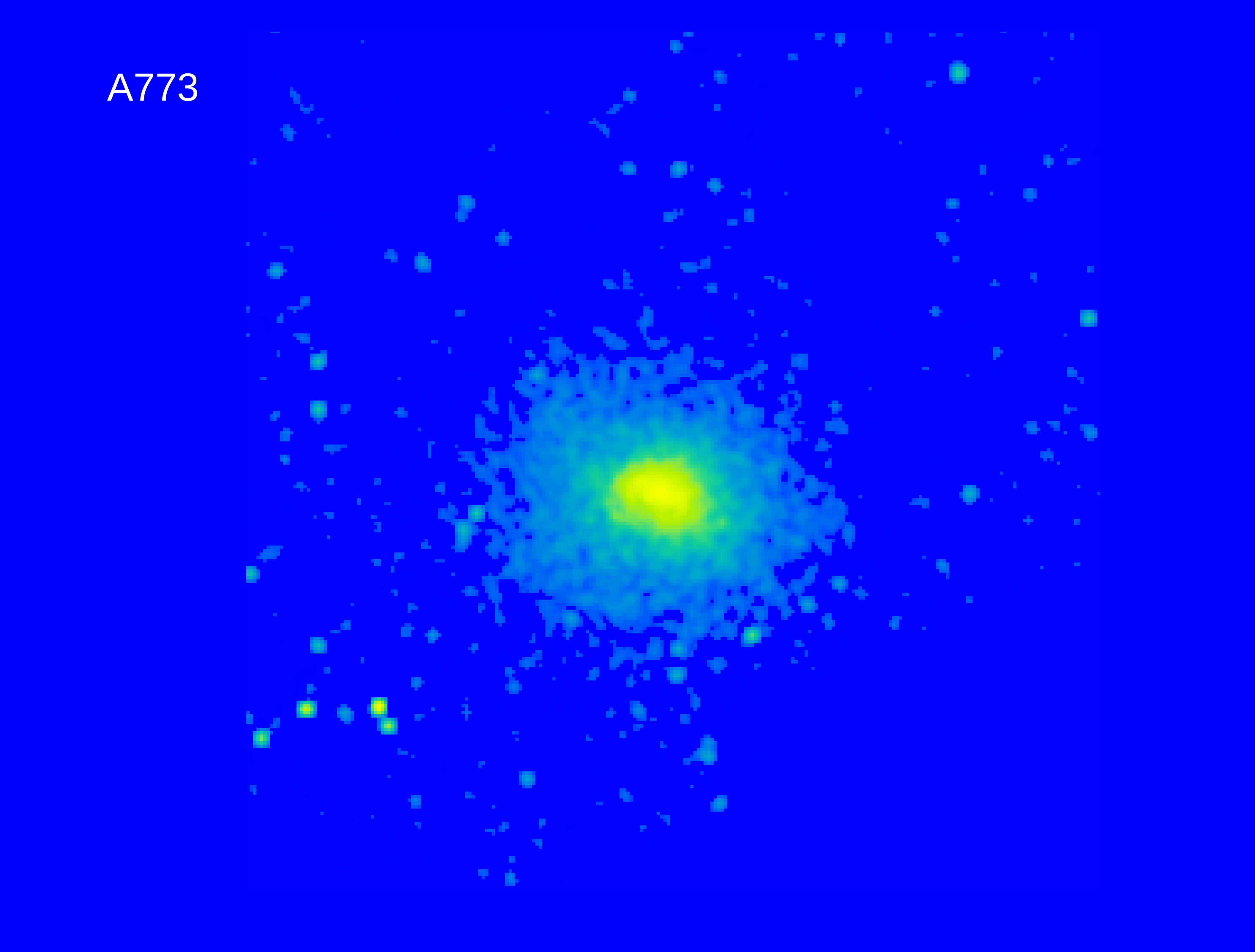
Chandra map (Govoni et al. 2004)

A2163





Chandra **map (Govoni et al. 2004)**


A773

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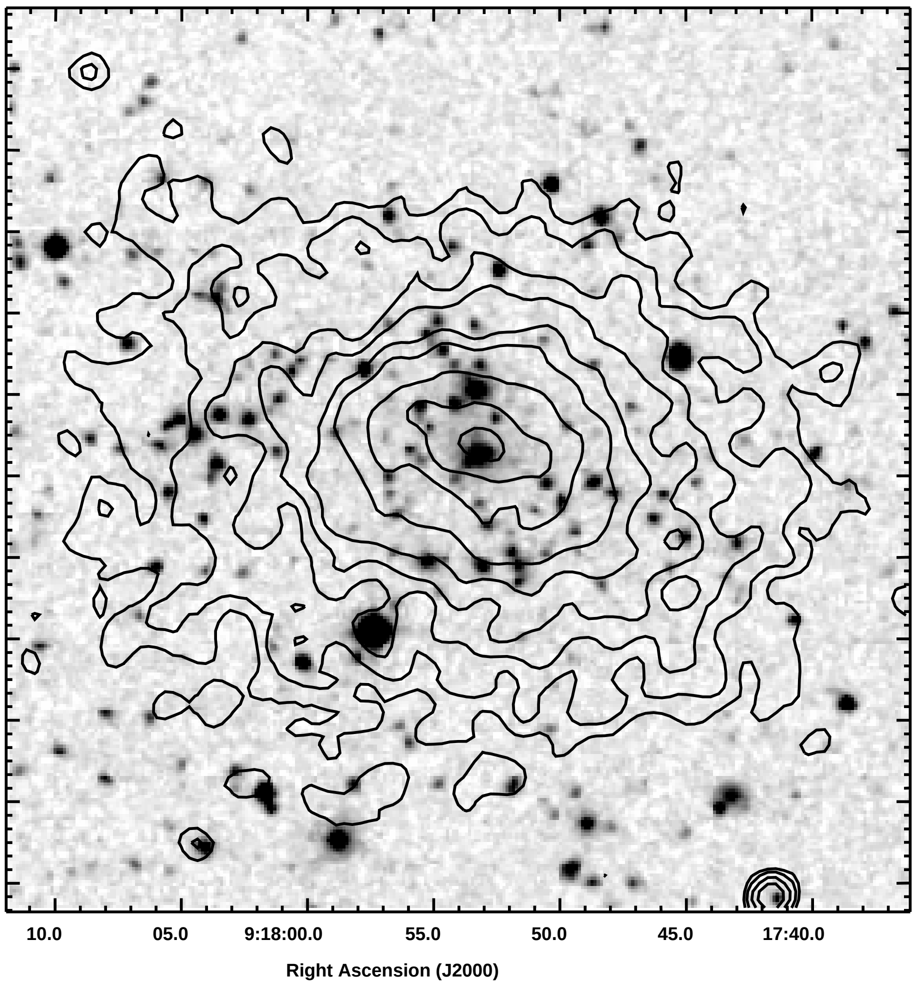
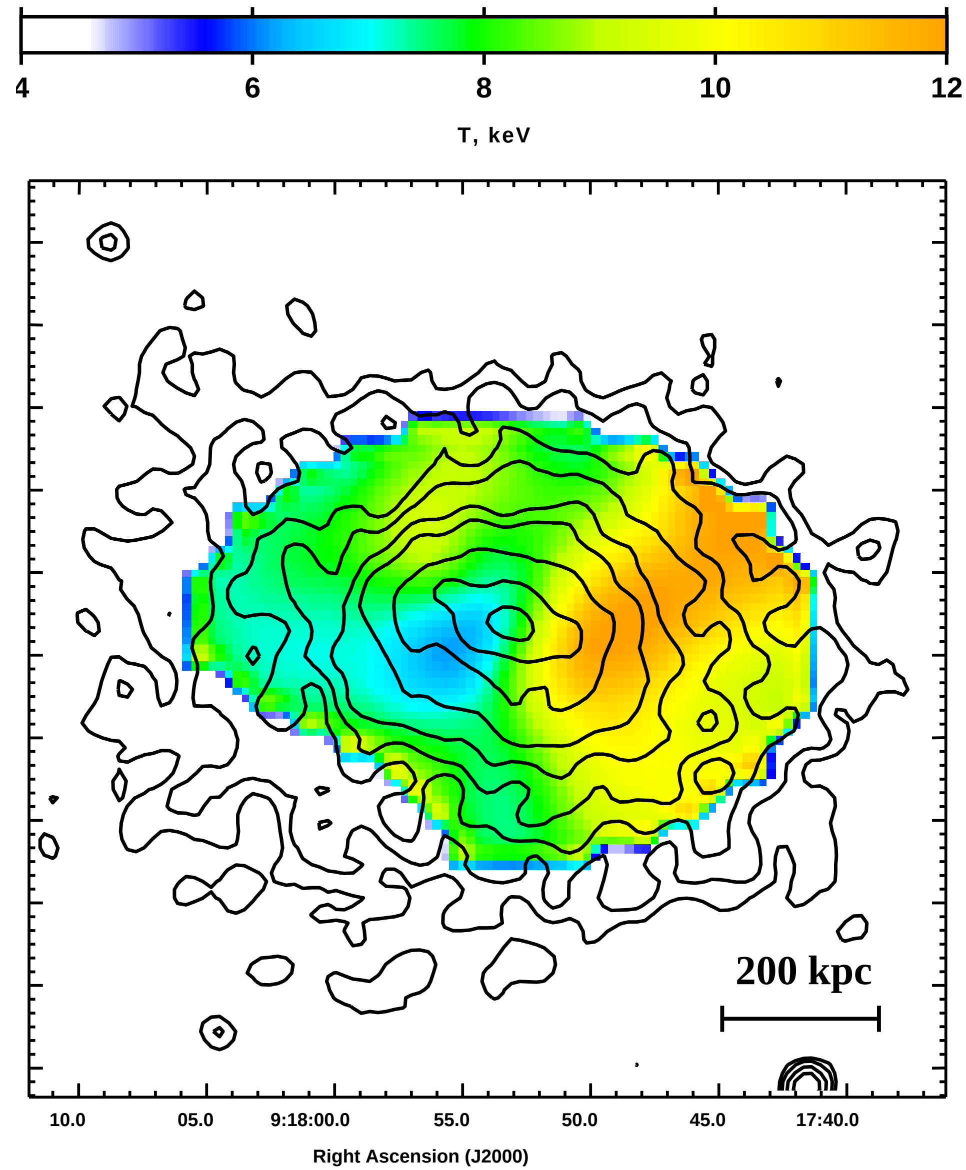
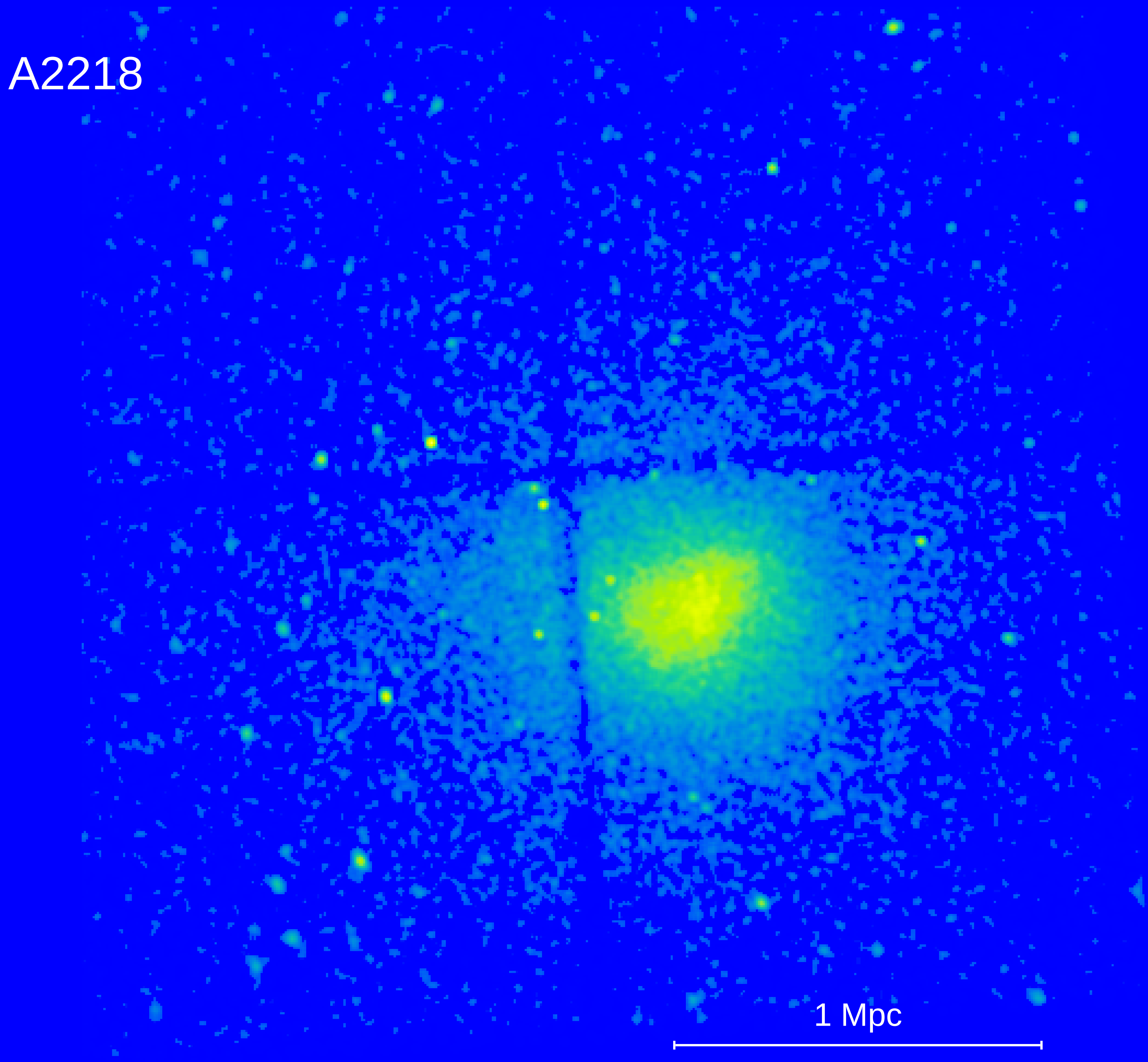


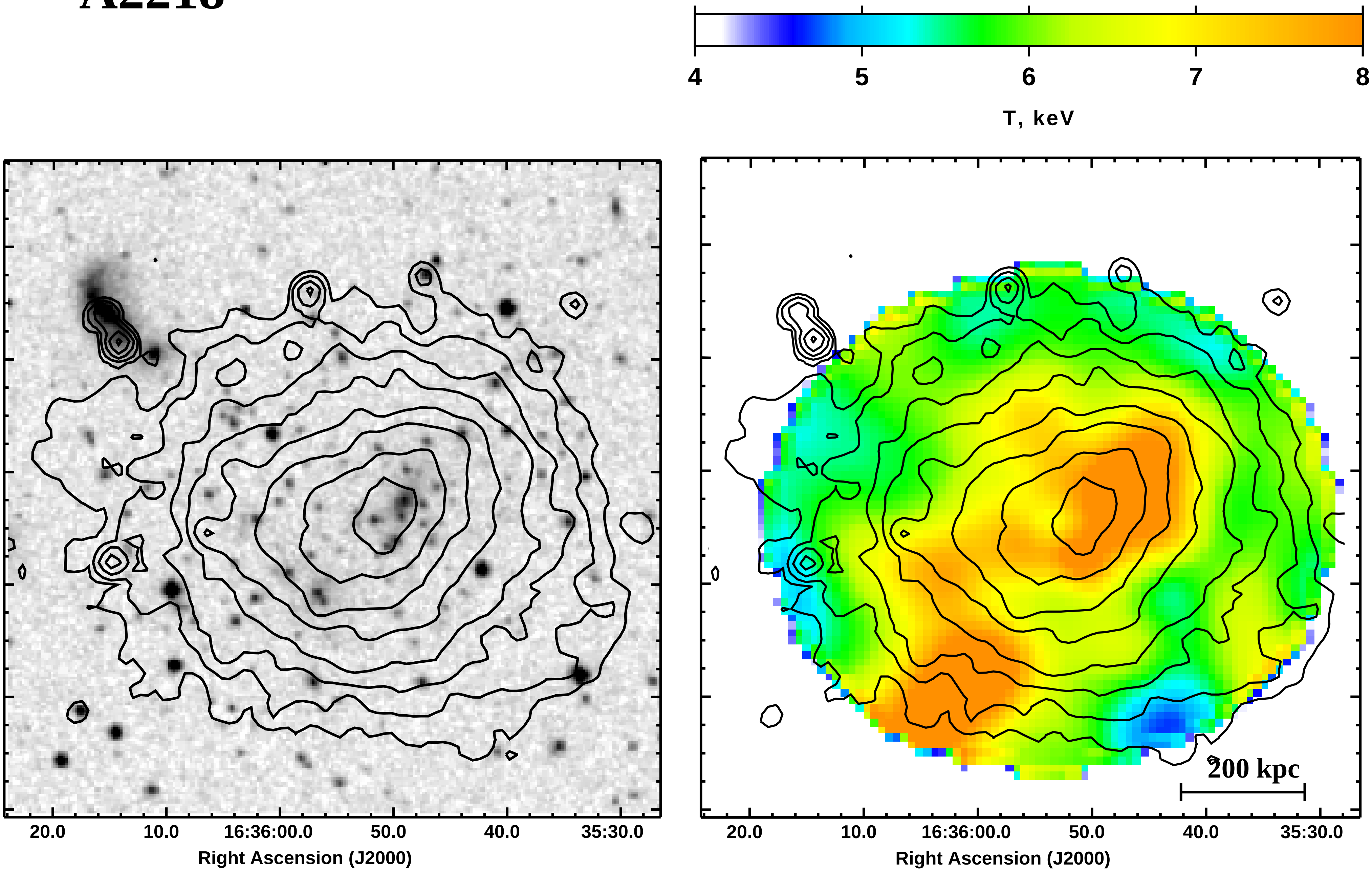


Chandra **map (Govoni et al. 2004)**

1750 2744 1914 2163 773 2218 168 Mth Cond 754cnd 3667 Hnz Ei Esh Eopt Elen Ecol 520len 520t Ei E-520 Halos Eh Hnoco 520sh Sum T T2 SumT CF 754sh

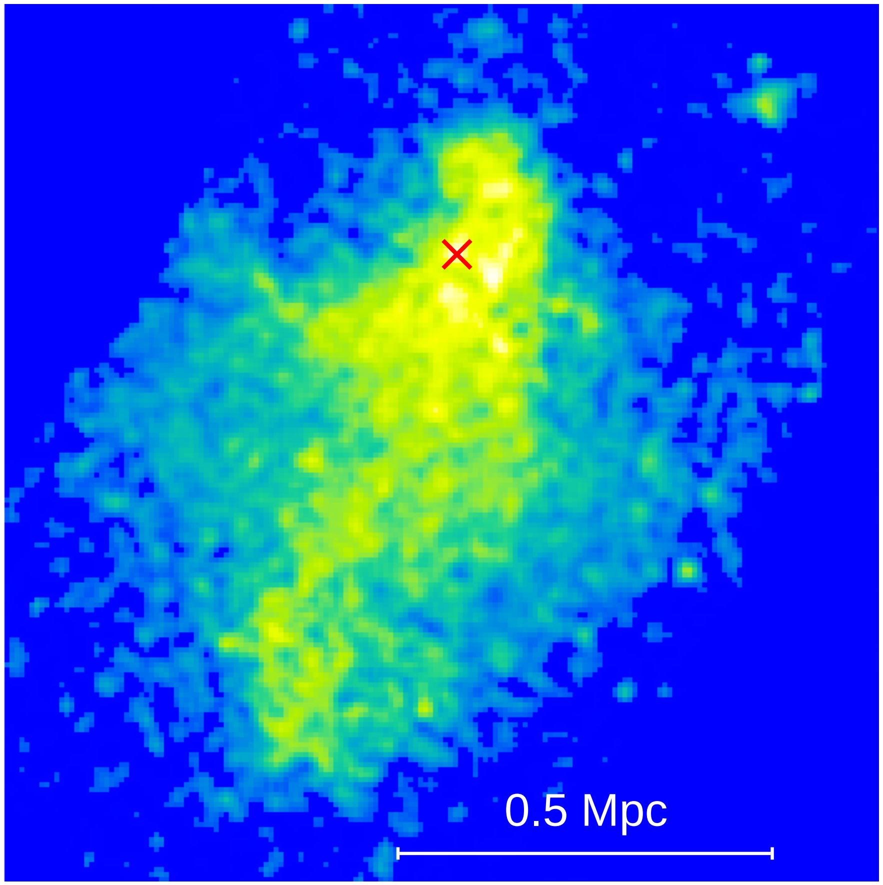


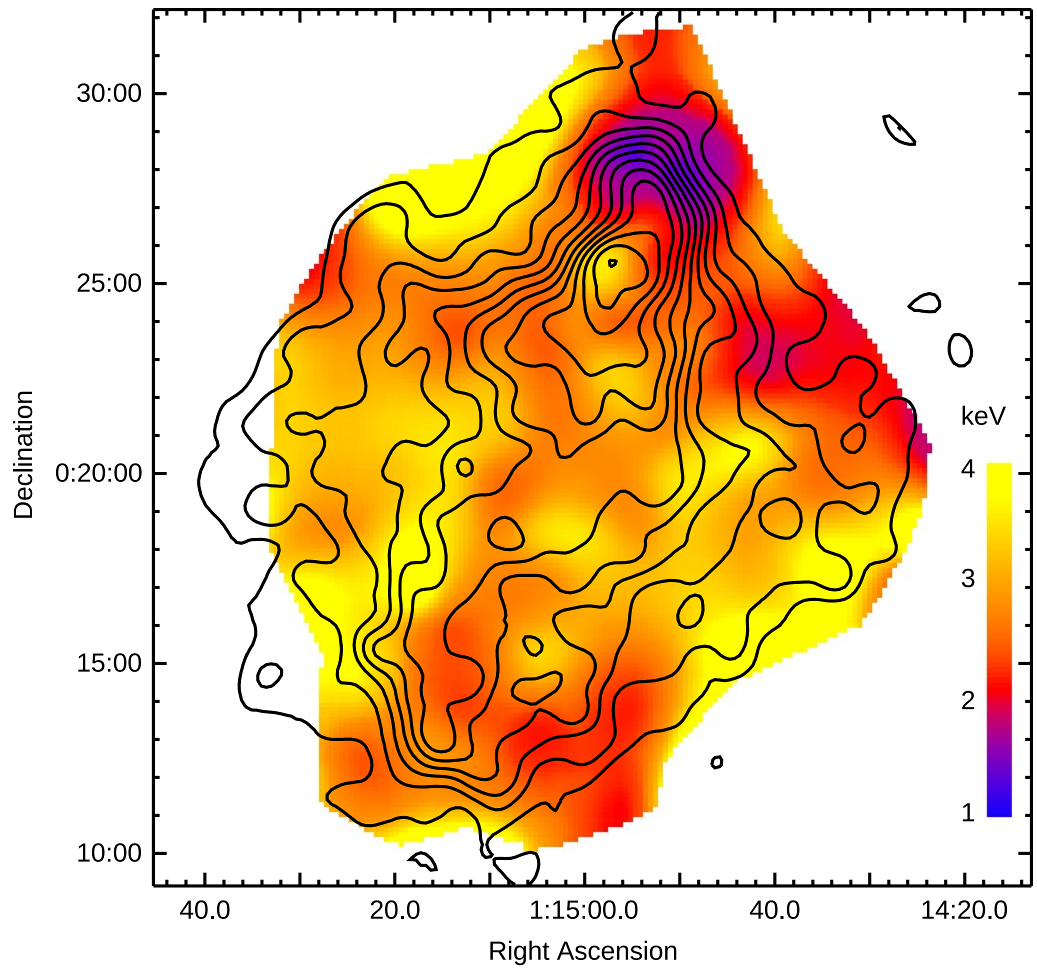
A2218



Chandra map (Govoni et al. 2004)

A168: ram pressure slingshot



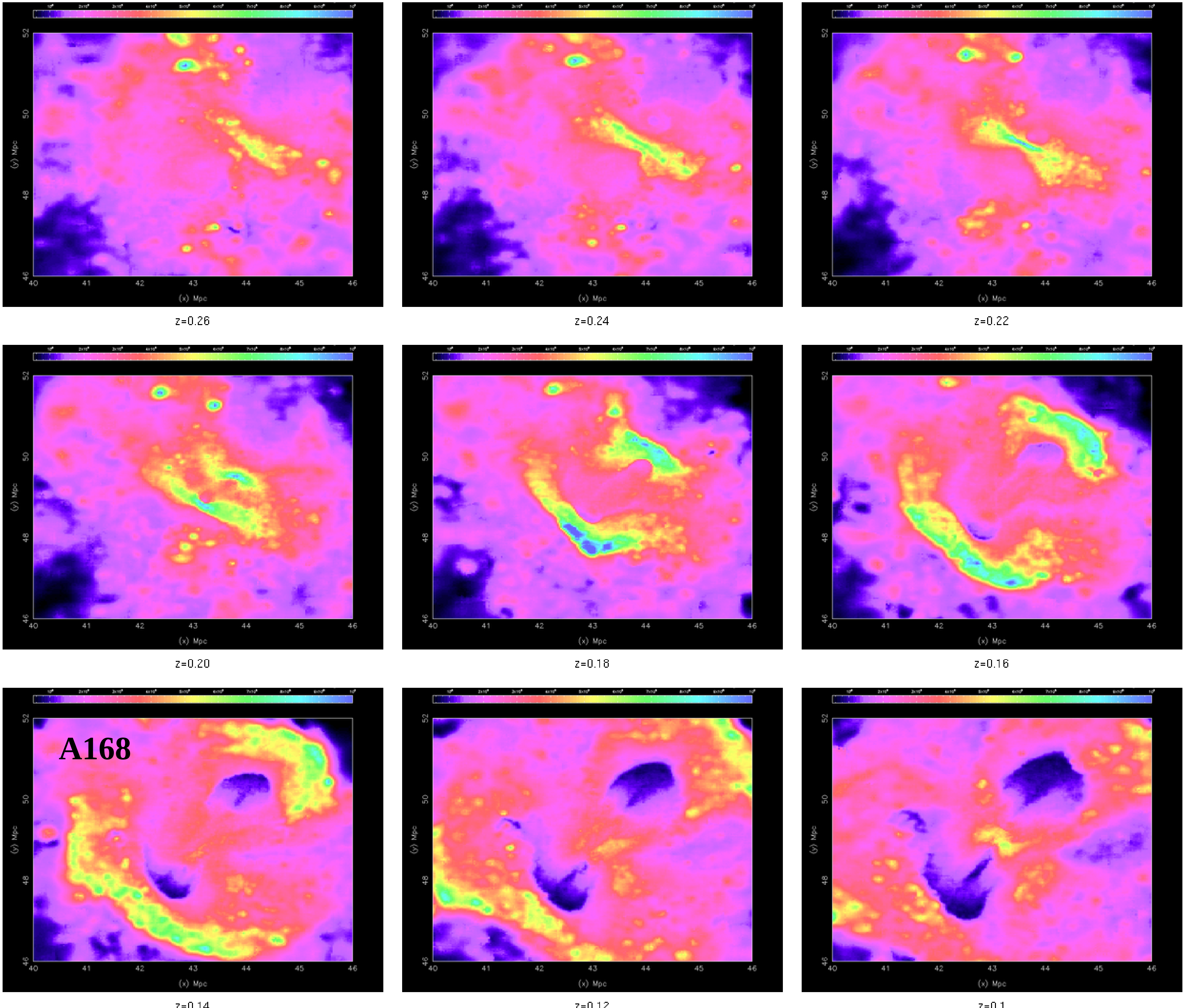


Chandra maps (Hallman & Markevitch 2004)

$M \simeq 0$

Mathis et al. (2003)

T

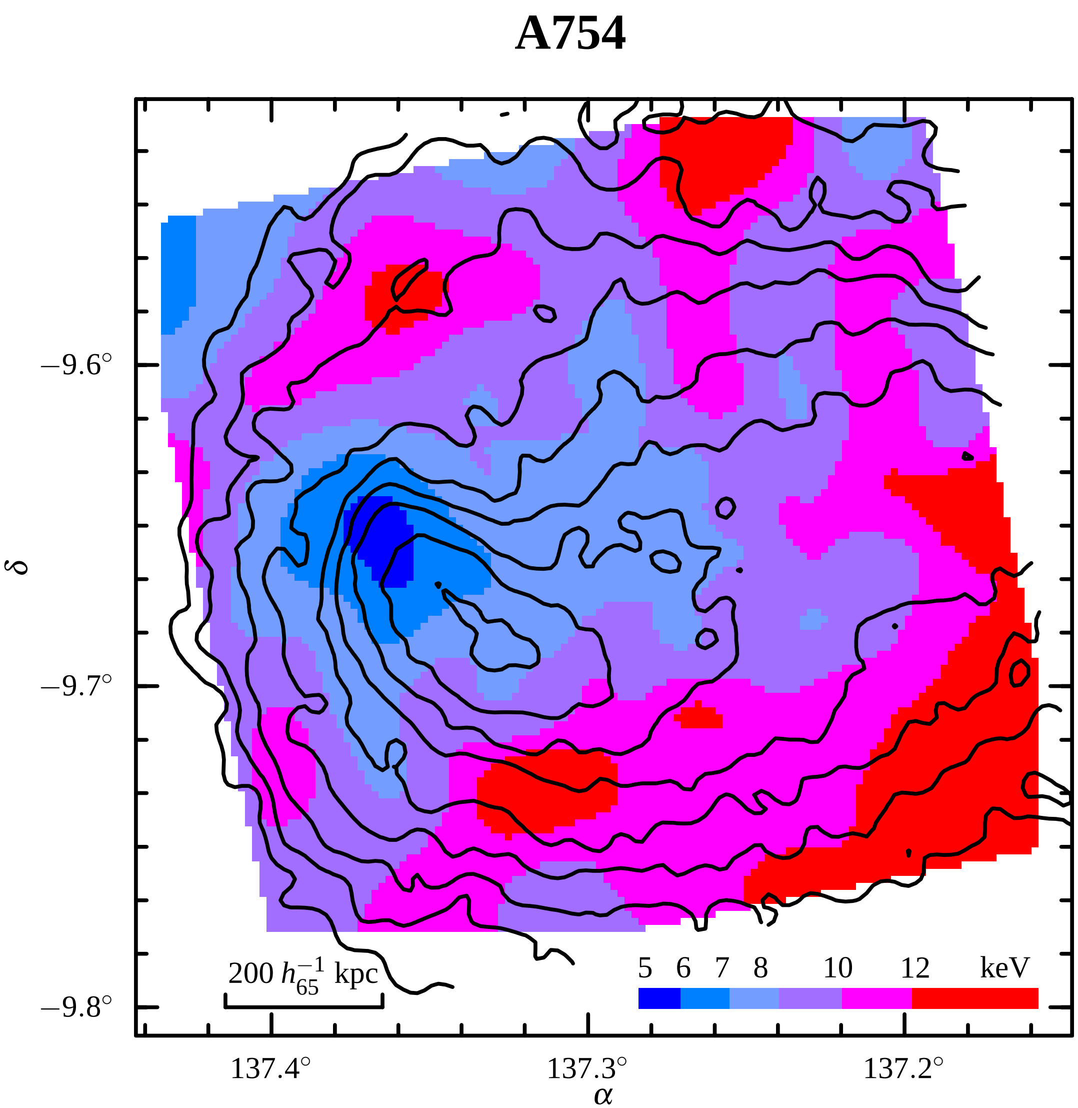


What can we learn about cluster physics?

From cold fronts:

- **Thermal conduction and diffusion across fronts is suppressed (Ettori & Fabian 2000; Vikhlinin et al. 2001)**
- **Stability of cold fronts implies parallel magnetic field layer (Vikhlinin et al. 2001)**

Thermal conduction in the bulk of the gas



Chandra map (Markevitch et al. 2003)

Time for T variations to disappear (for Spitzer $\varkappa$):

$$t_{\rm cond} \sim \frac{k n_e l^2}{\varkappa} \simeq 1.2 \times 10^7 \text{ yr}$$

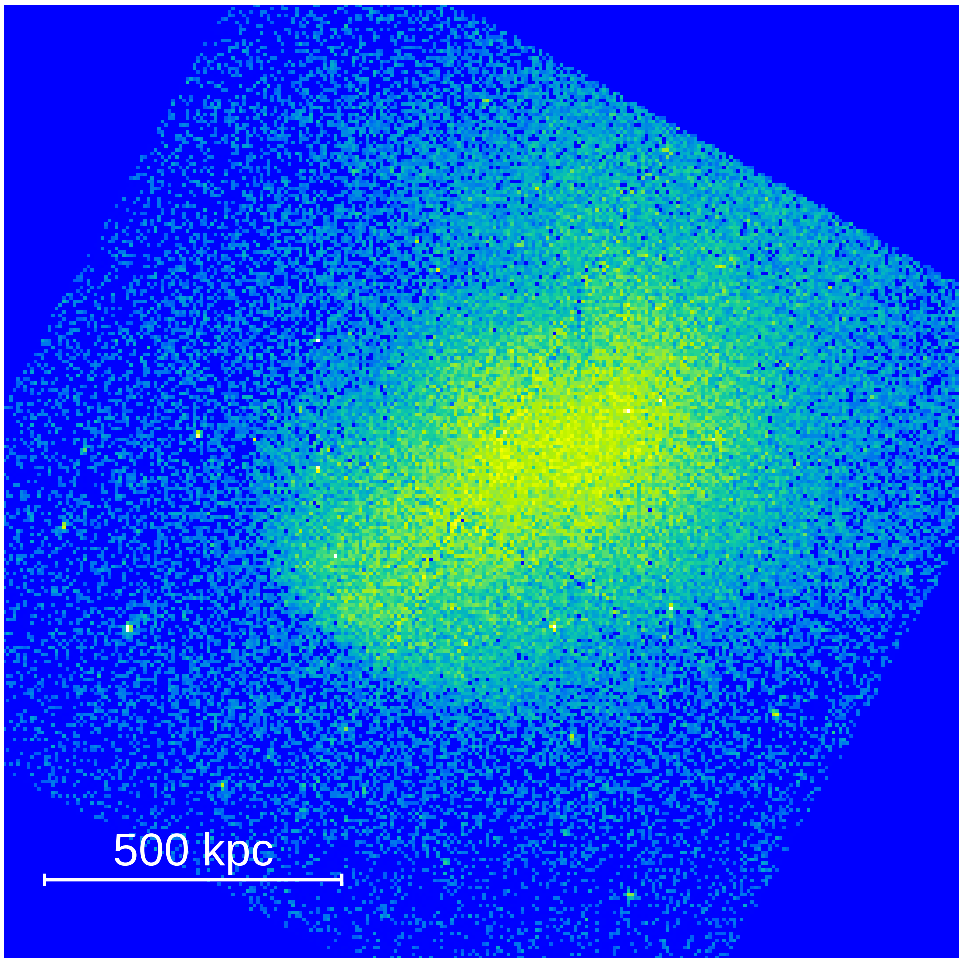
Age of the structure:

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

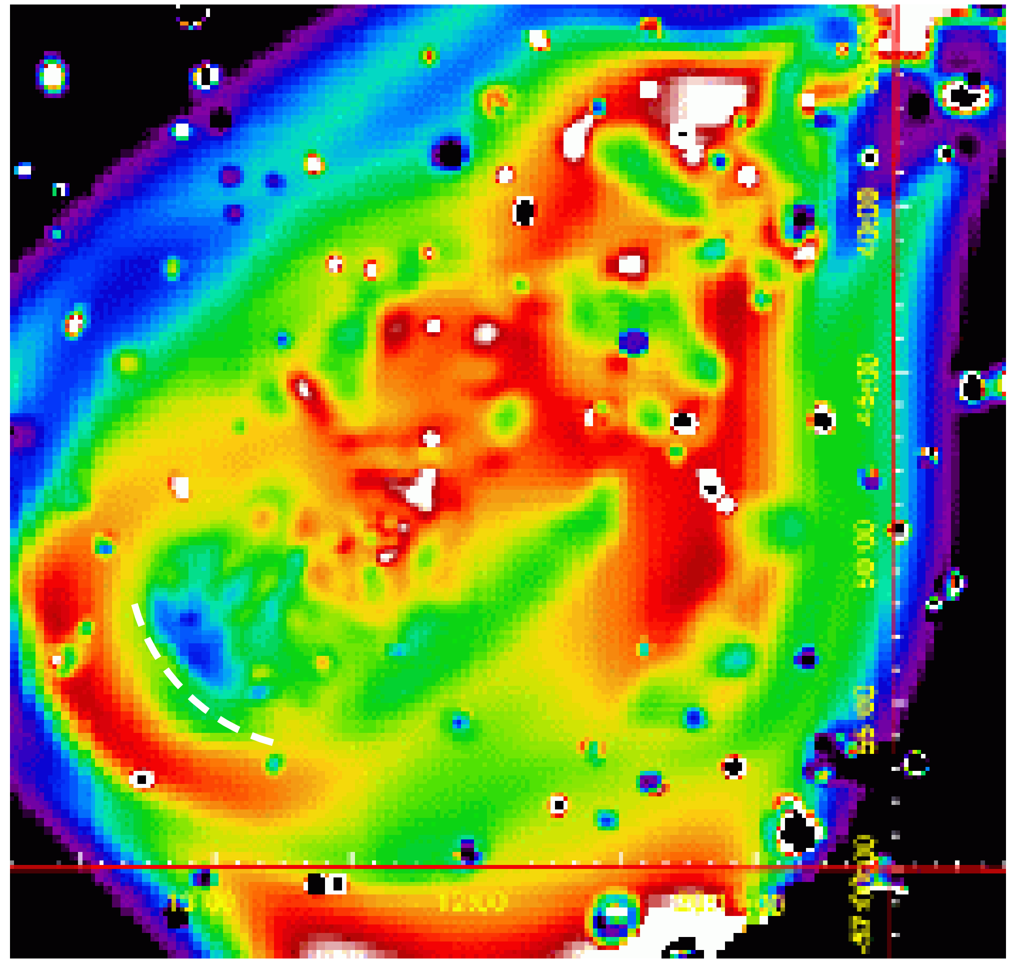
Conduction suppressed by factor

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

A3667, a prototype cold front



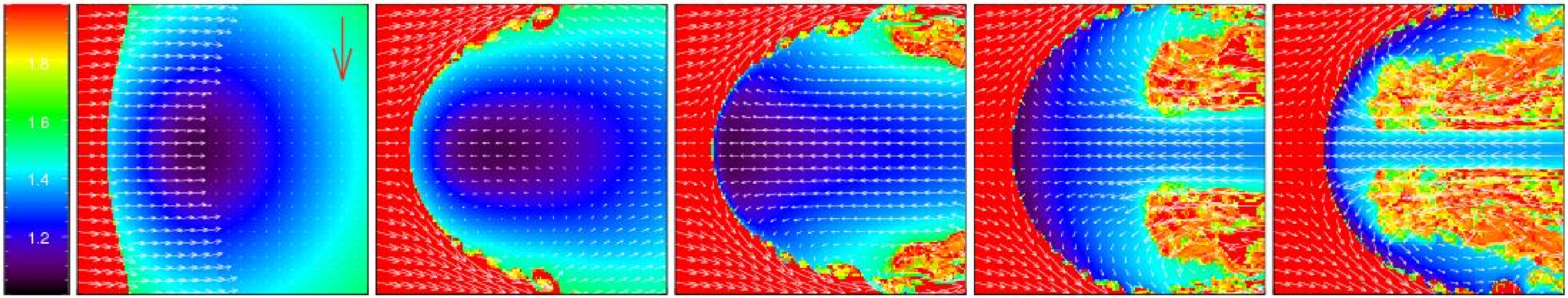
Chandra image: Vikhlinin et al. (2001)

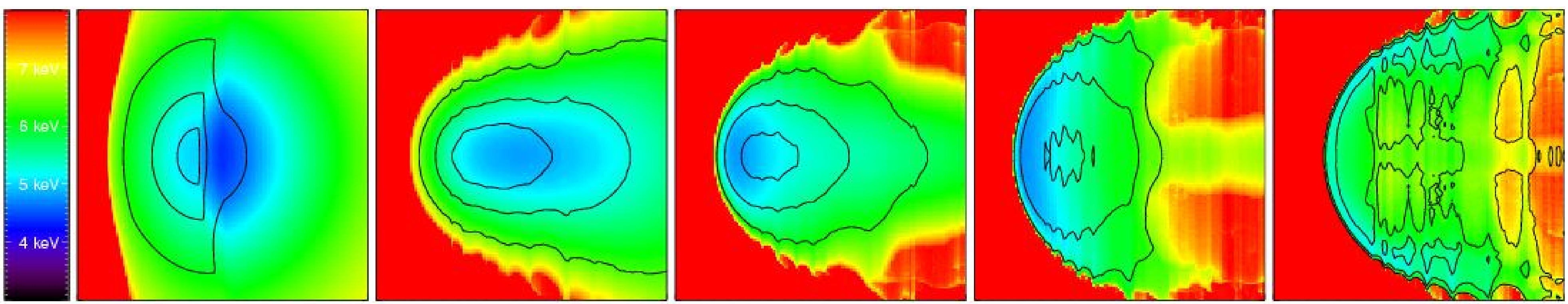


XMM map: Briel, Finoguenov, & Henry (2004)

Cold front simulations

Heinz et al. (2003)

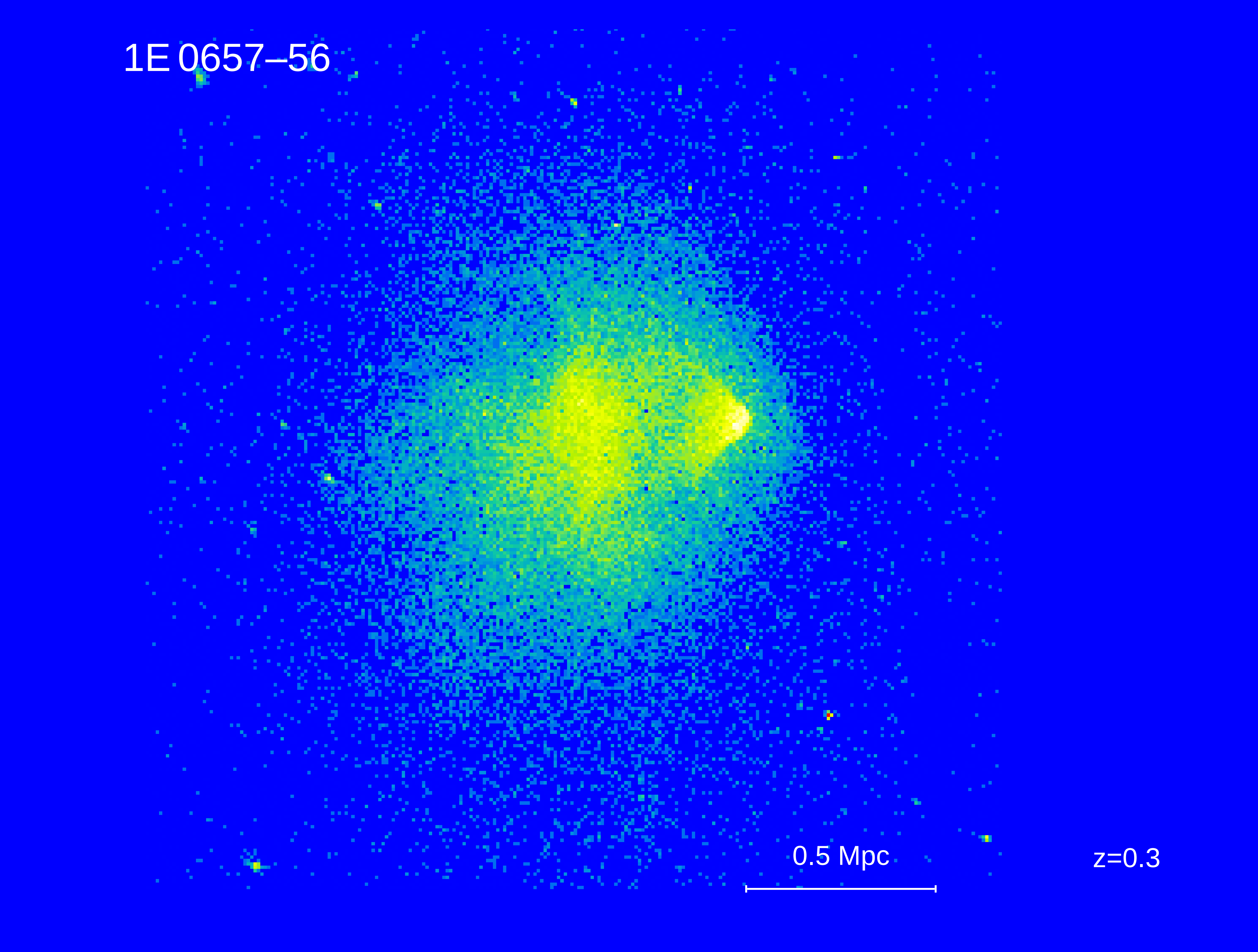




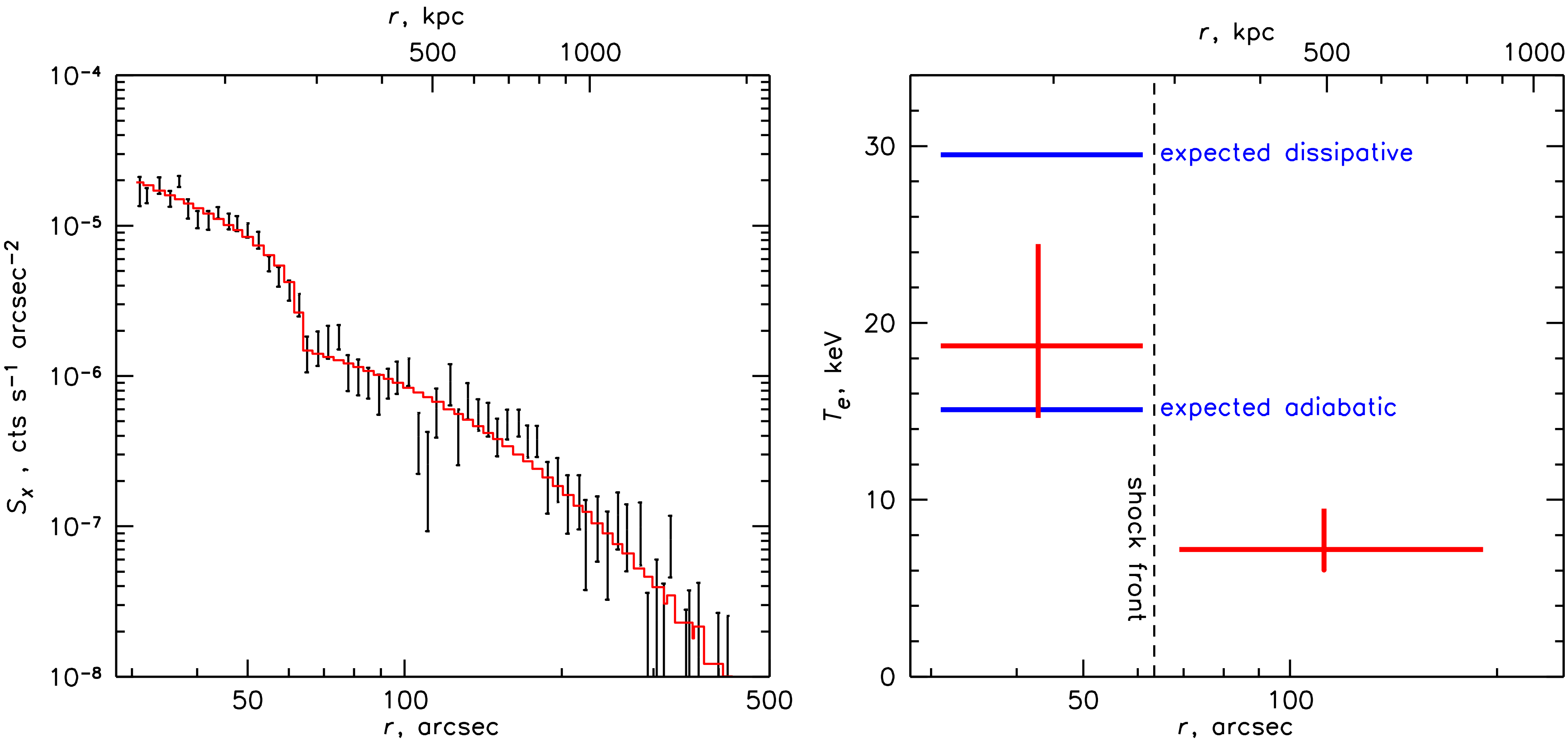
A3667

- **Can put lower limit on gas viscosity?**

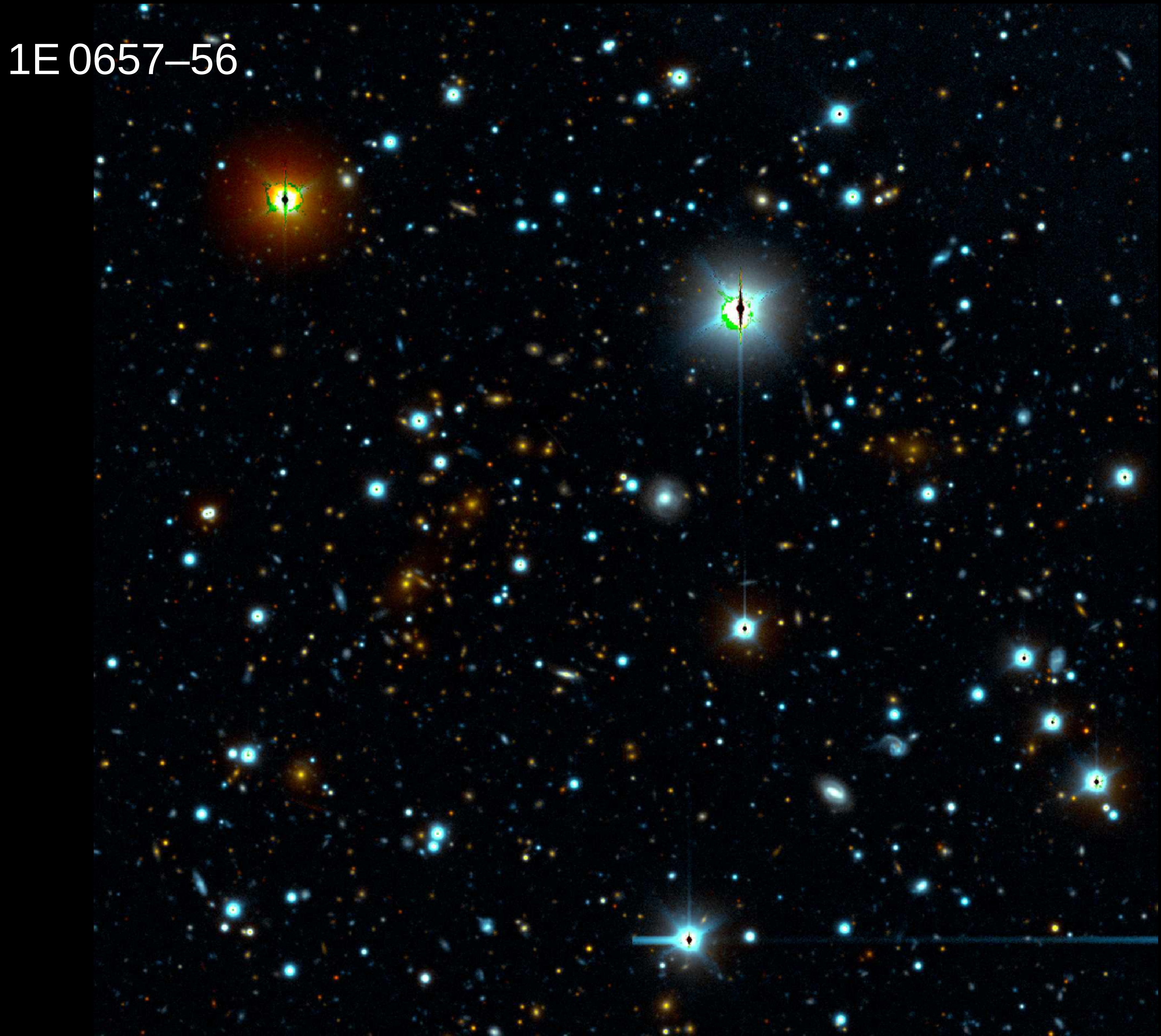
1750 2744 1914 2163 773 2218 168 Mth Cond 754cnd 3667 Hnz Ei Esh Eopt Elen Ecol 520len 520t Ei E-520 Halos Eh Hnoco 520sh Sum T T2 SumT CF 754sh



1E 0657–56: shock front



- **from density jump,** $M = 3.2 \pm 0.7$, **or** $v = 4500\ \mathrm{km\,s^{-1}}$


1E 0657–56

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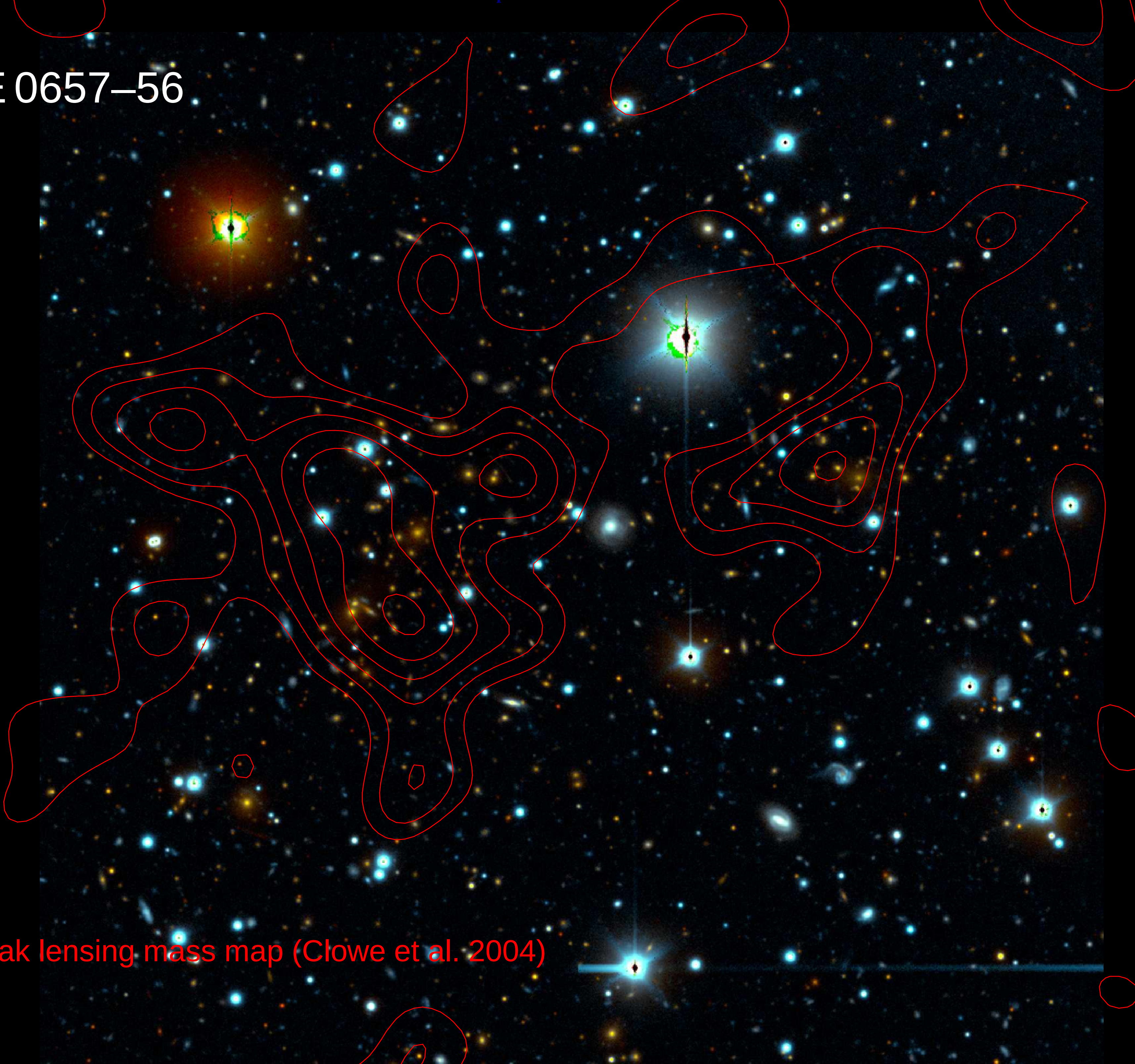
1E 0657–56



Weak lensing mass map (Clowe et al. 2004)

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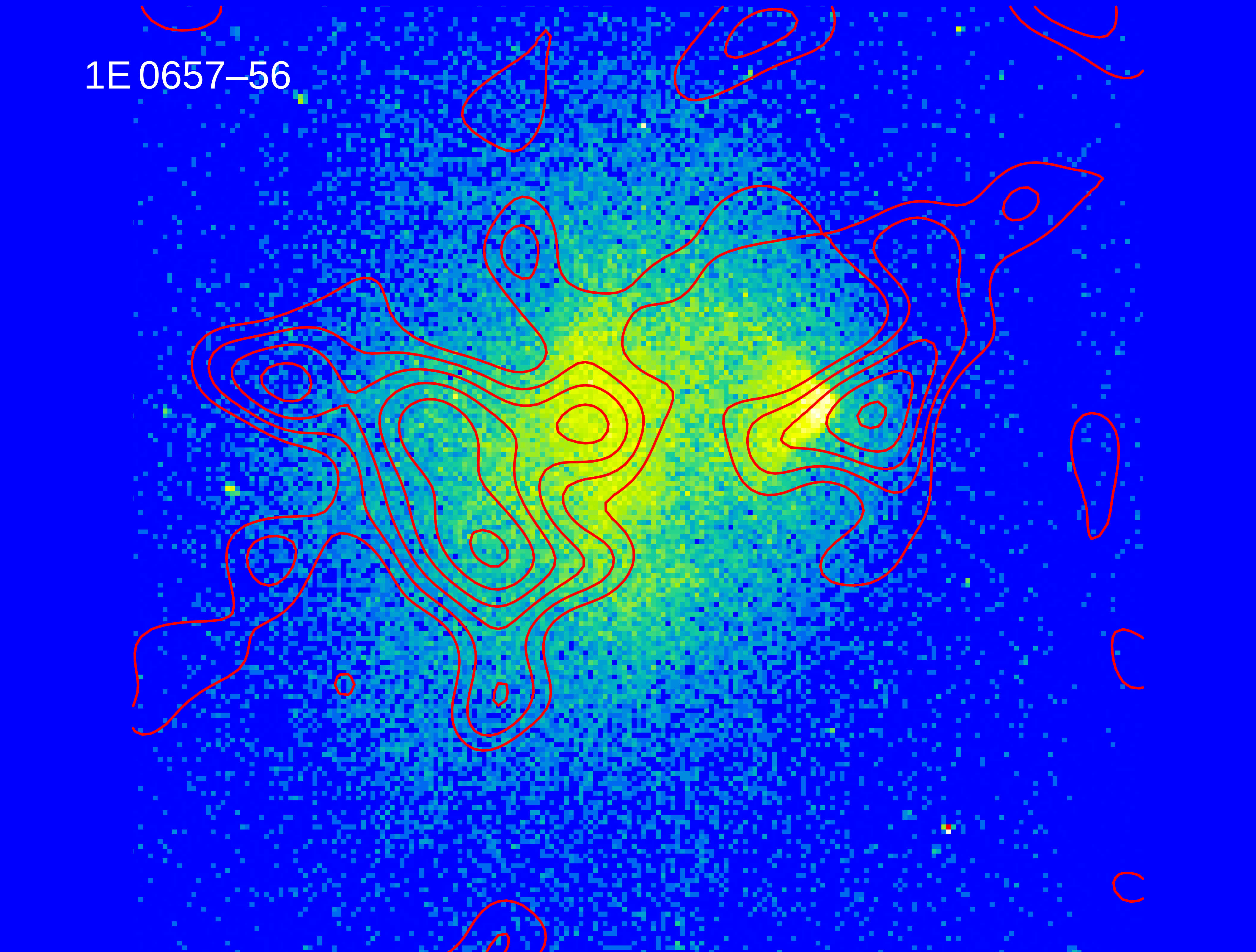

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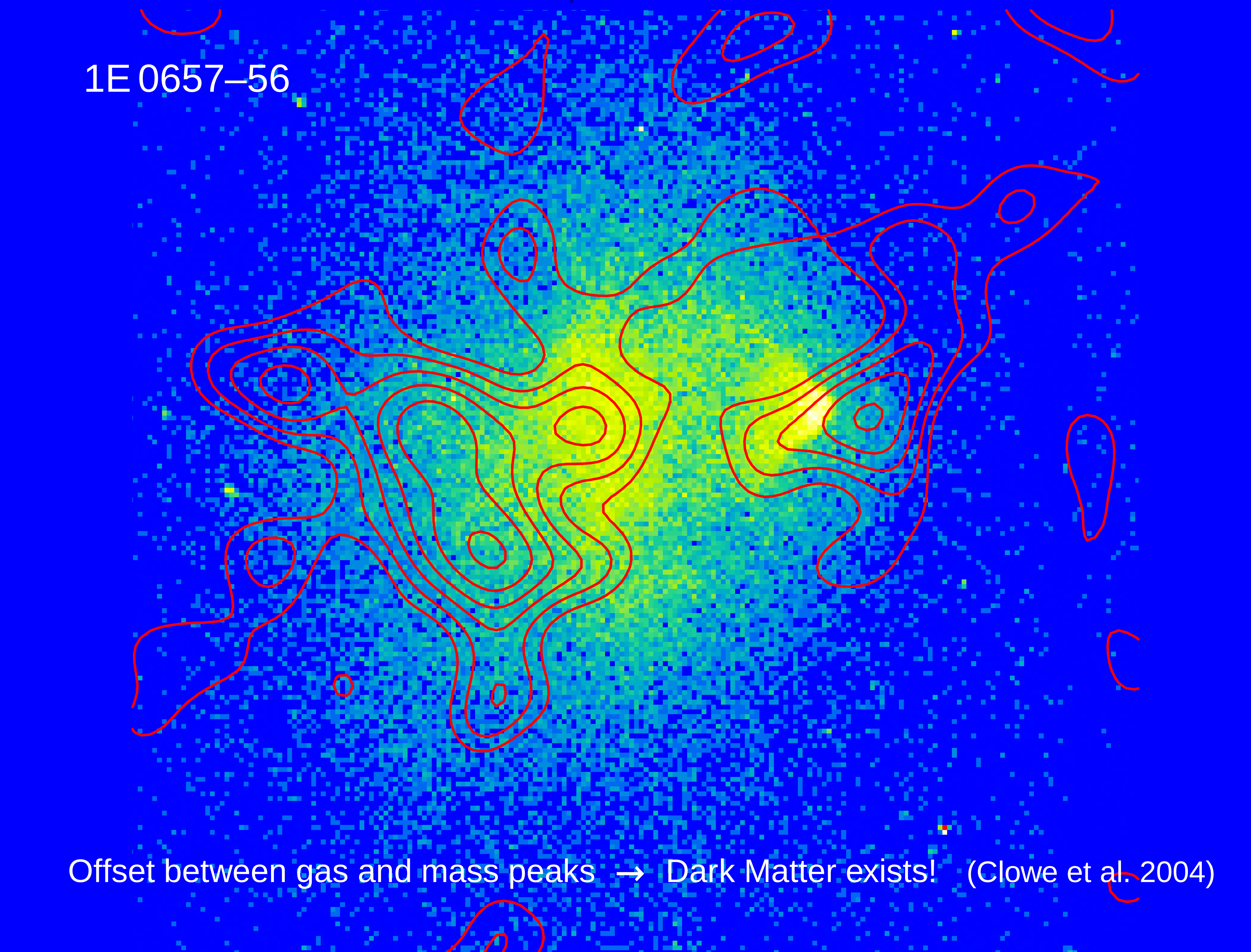


1E 0657–56: Dark Matter self-interaction cross-section

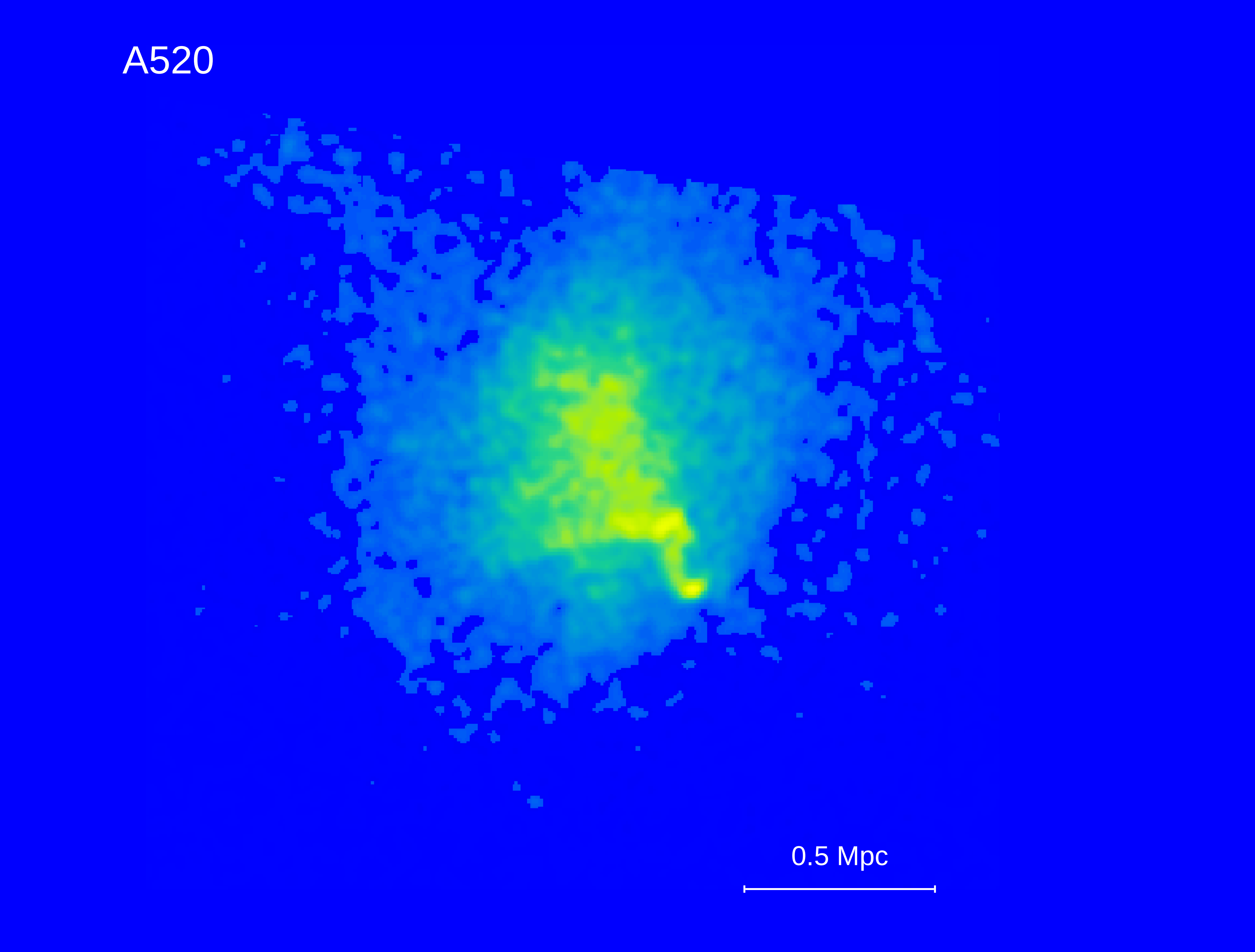
DM collisional cross-section per unit mass can be constrained from

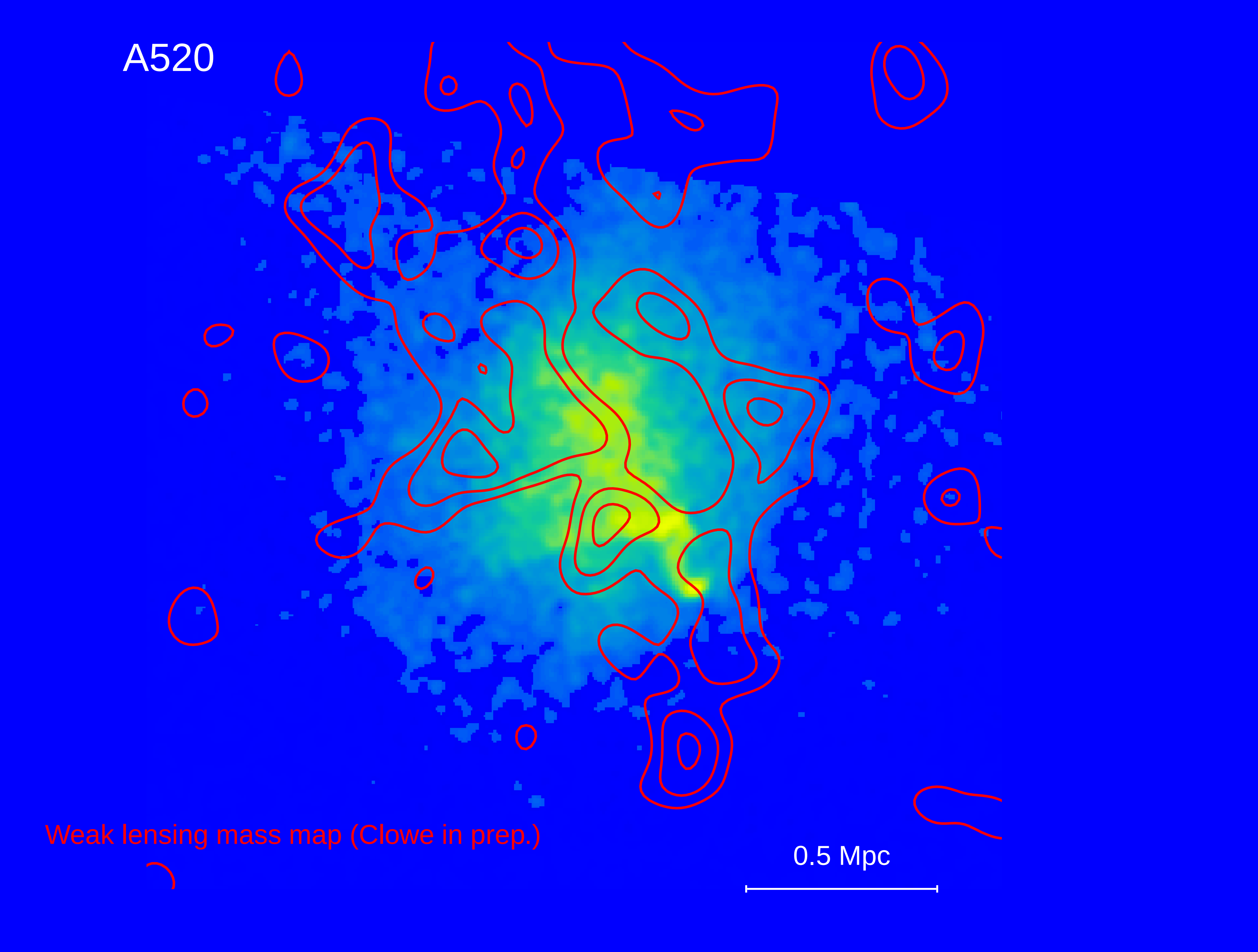
- offset between gas and mass
- no offset (within errors) between mass and galaxies
- large velocity of the subcluster
- consistency of the subcluster's M/L ratio with the universal value

The best (order of magnitude) constraint from these methods is

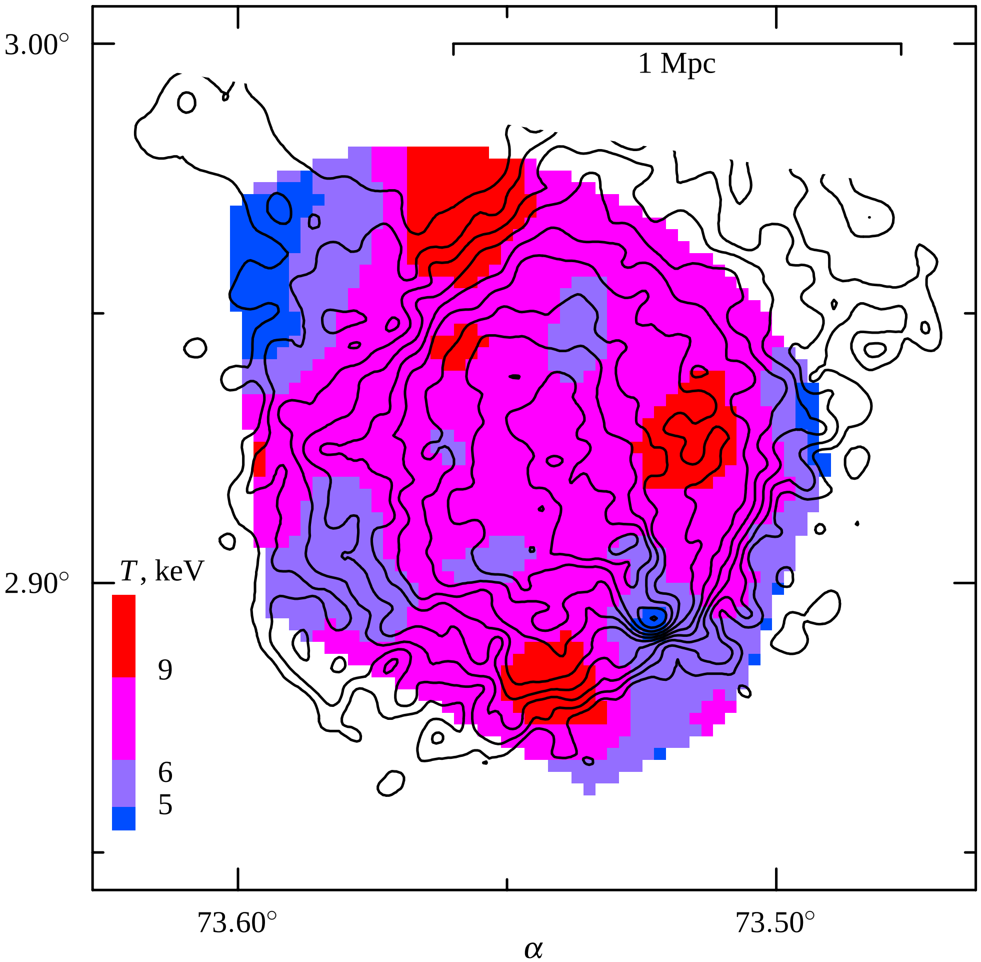
$$\frac{\sigma}{m} < 1 \ \mathrm{cm^2\,g^{-1}}$$

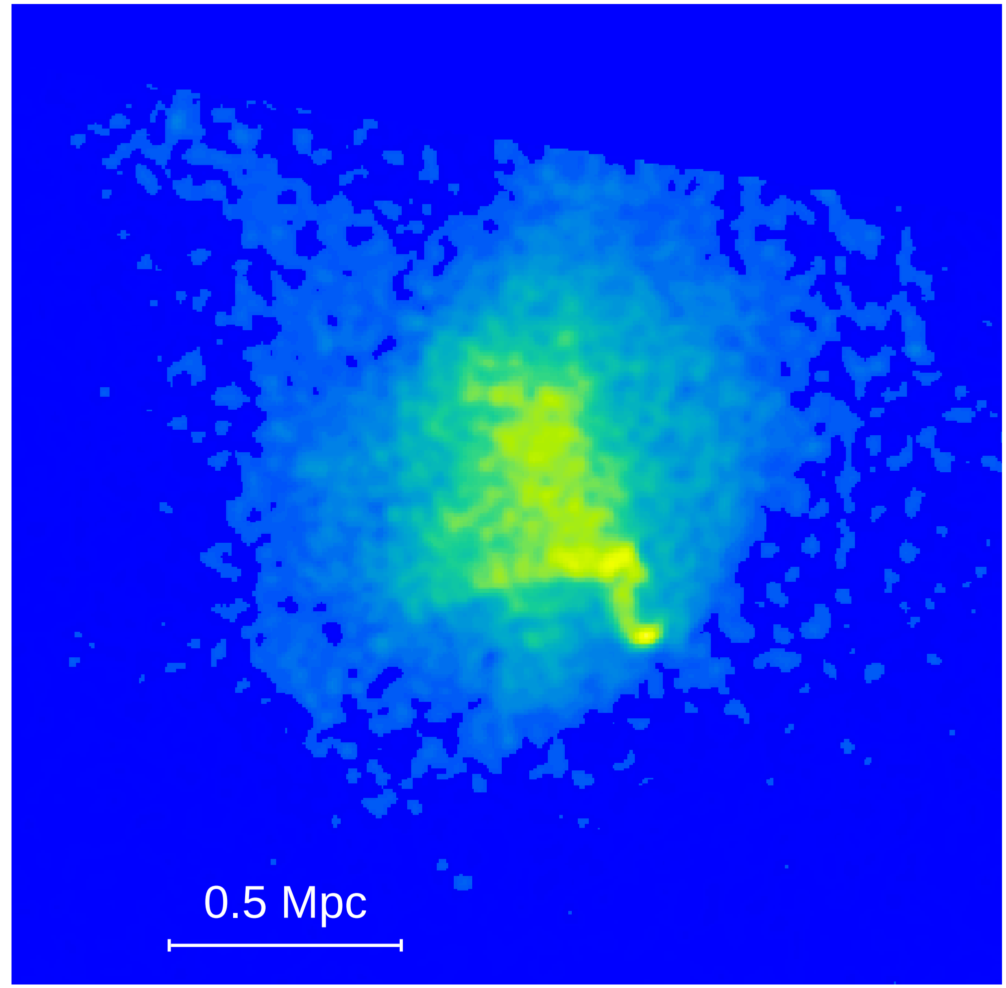
(Markevitch et al. 2004)


A520
0.5 Mpc


A520
Weak lensing mass map (Clowe in prep.)
0.5 Mpc

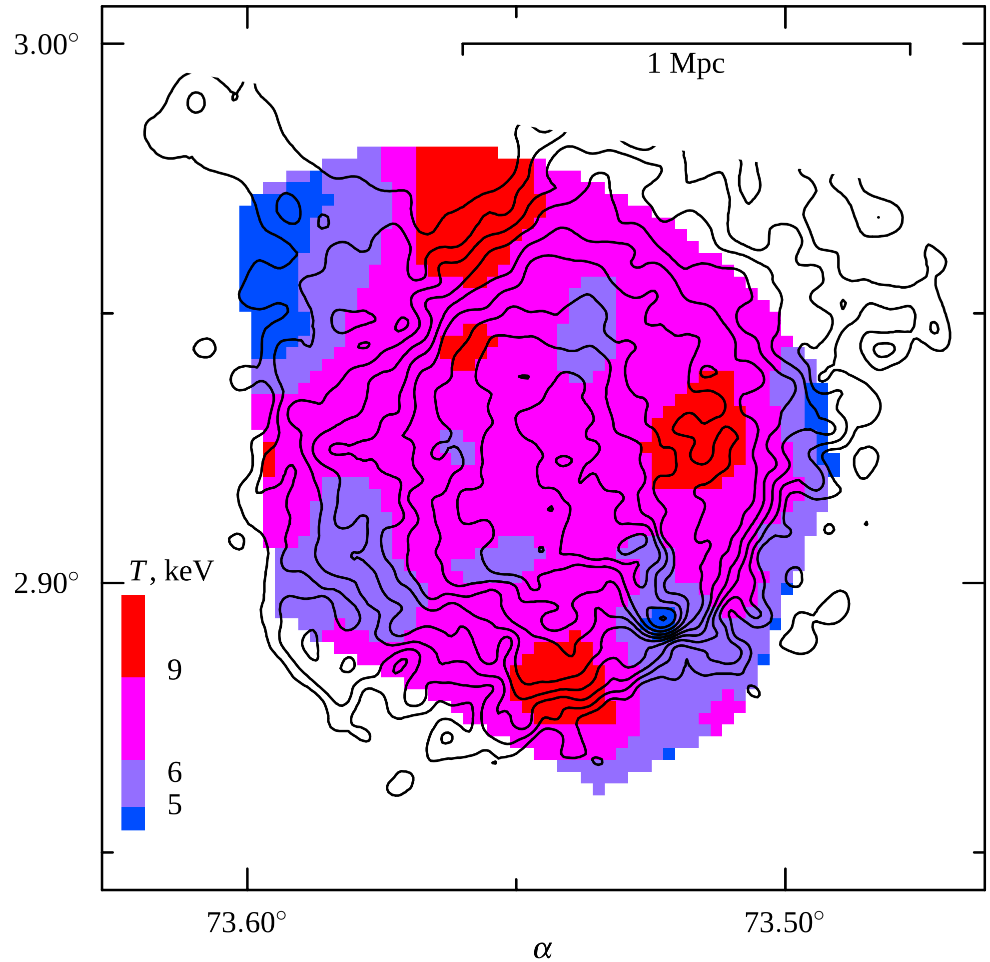
A520

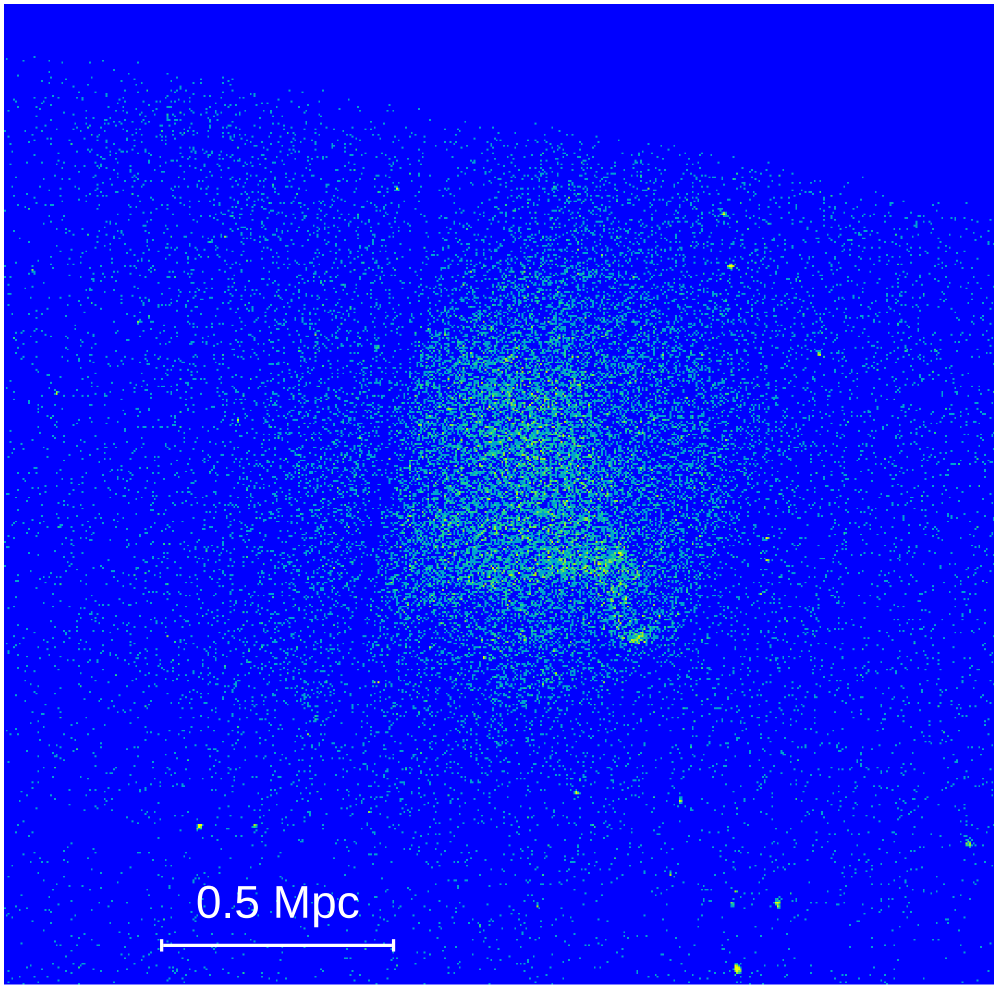




***Chandra* maps (Markevitch et al. in prep.)**

A520





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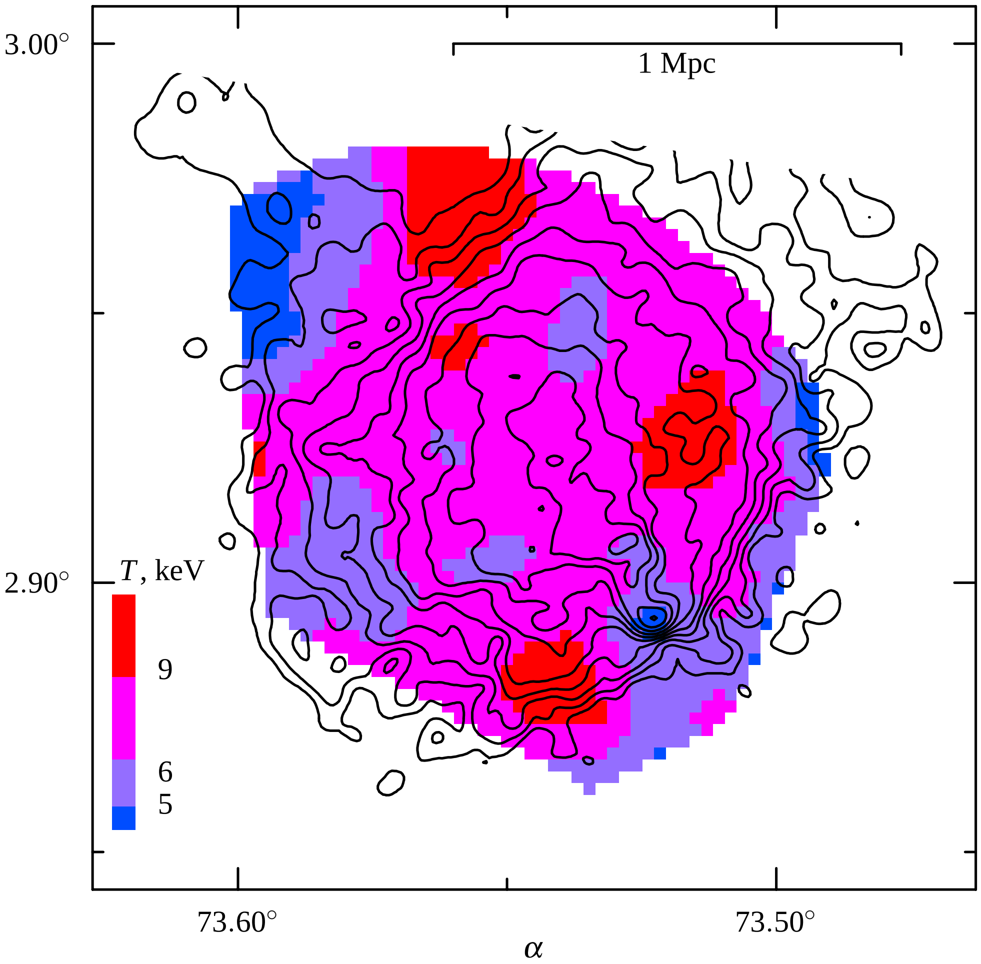
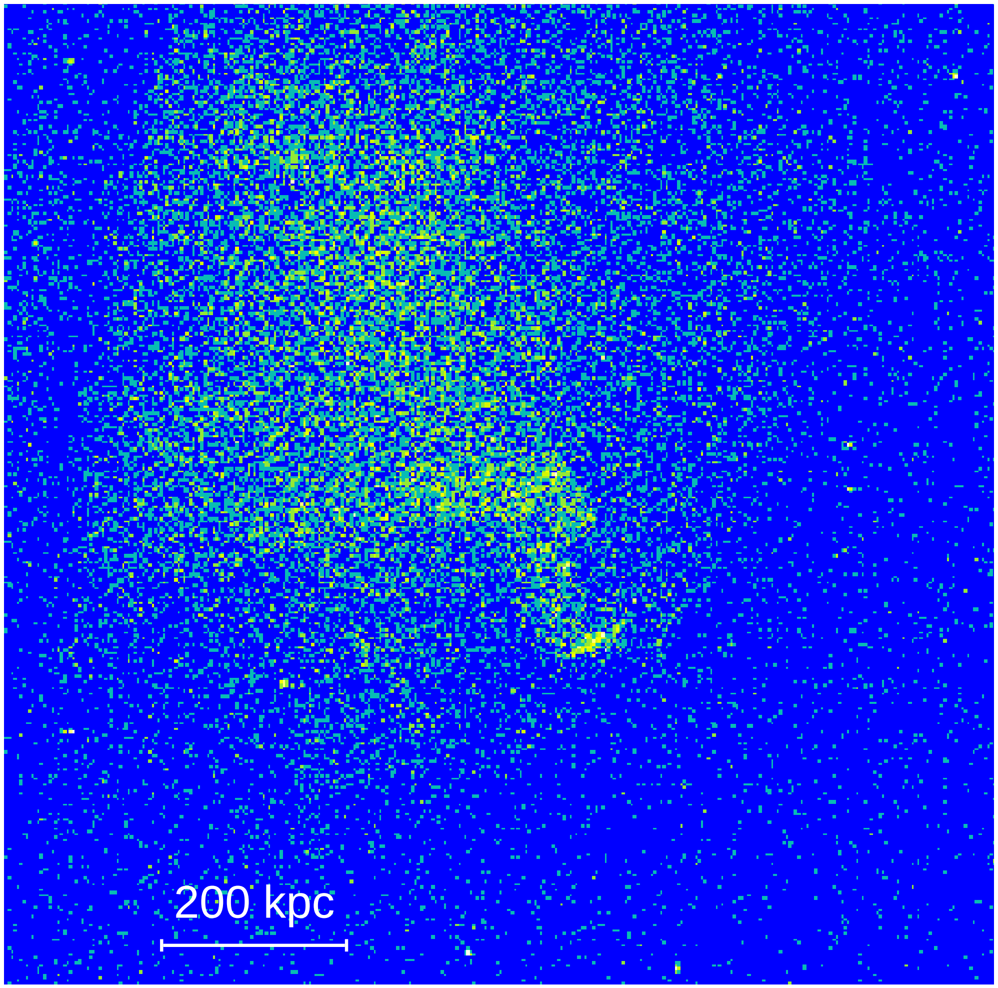
A520





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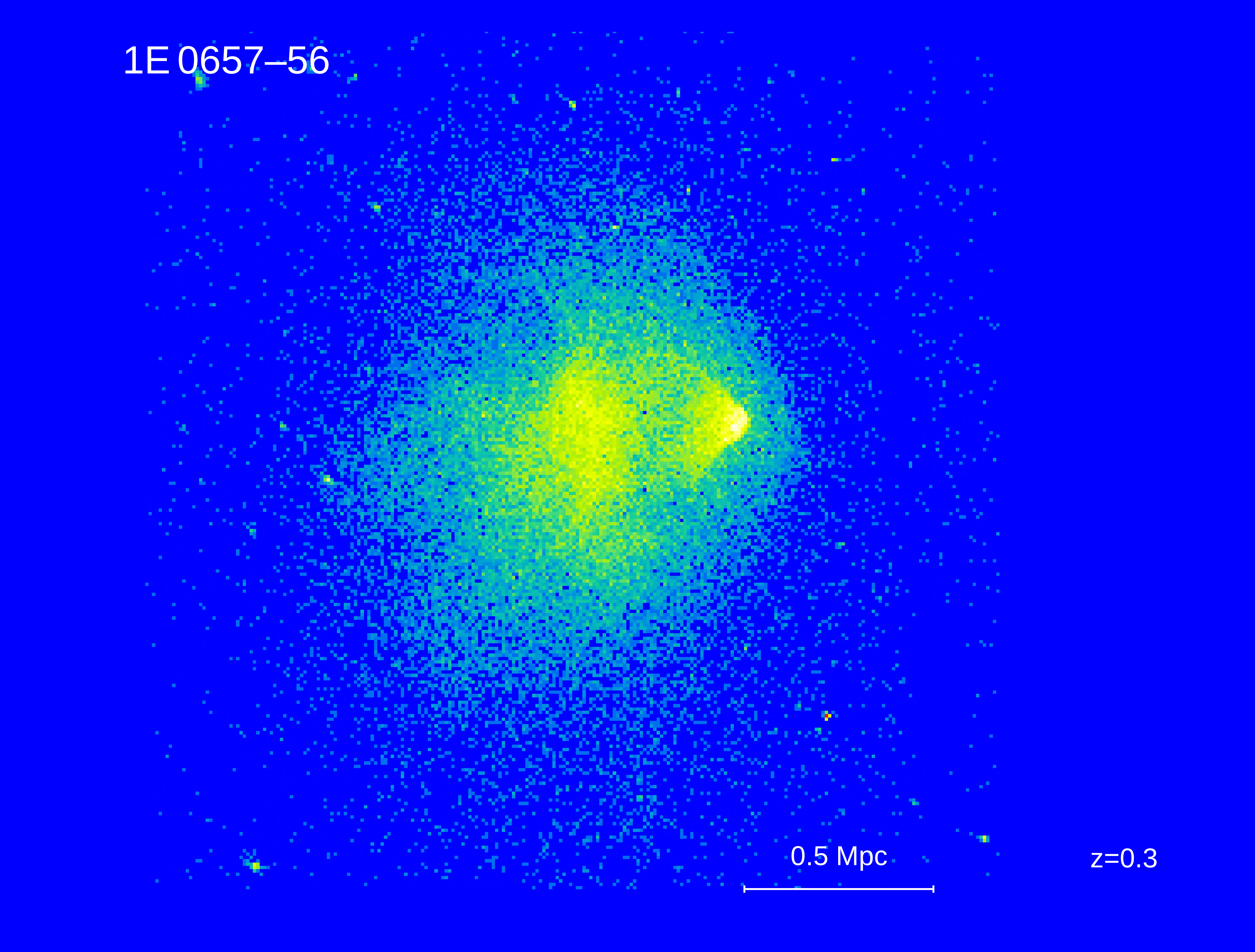
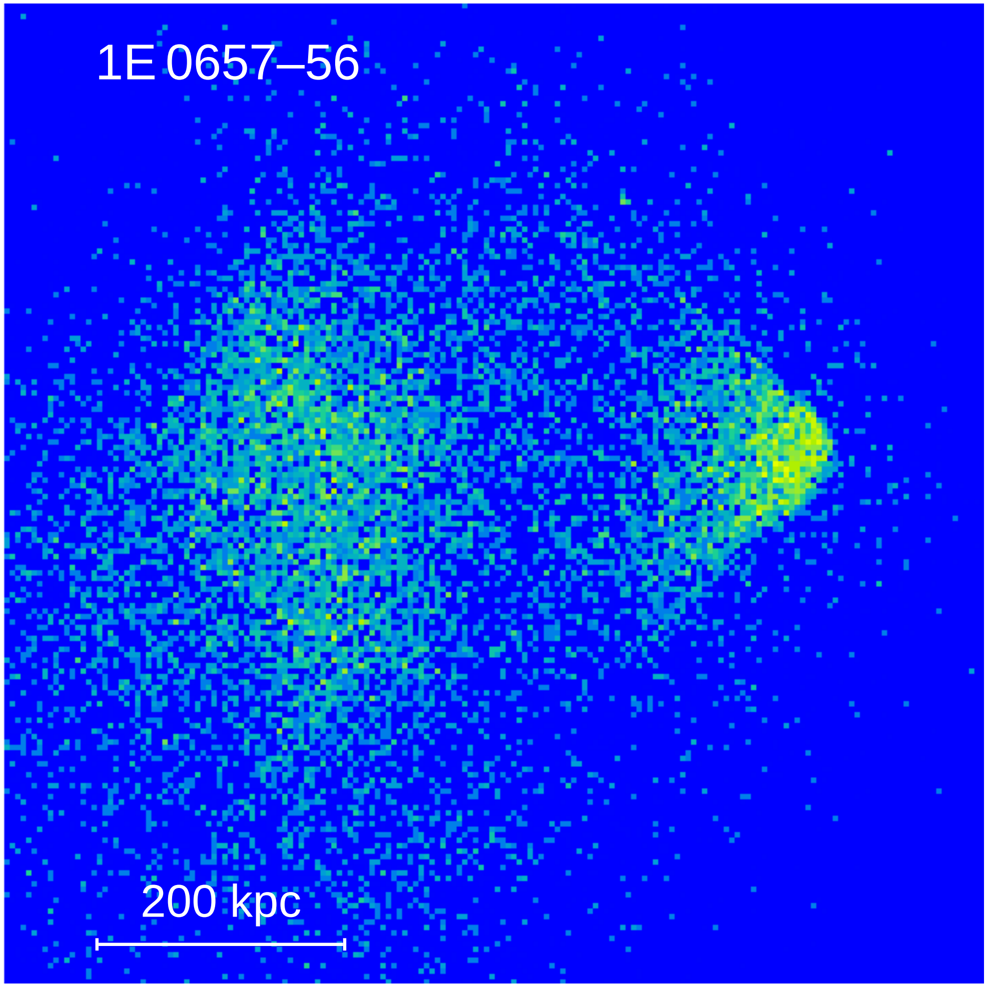
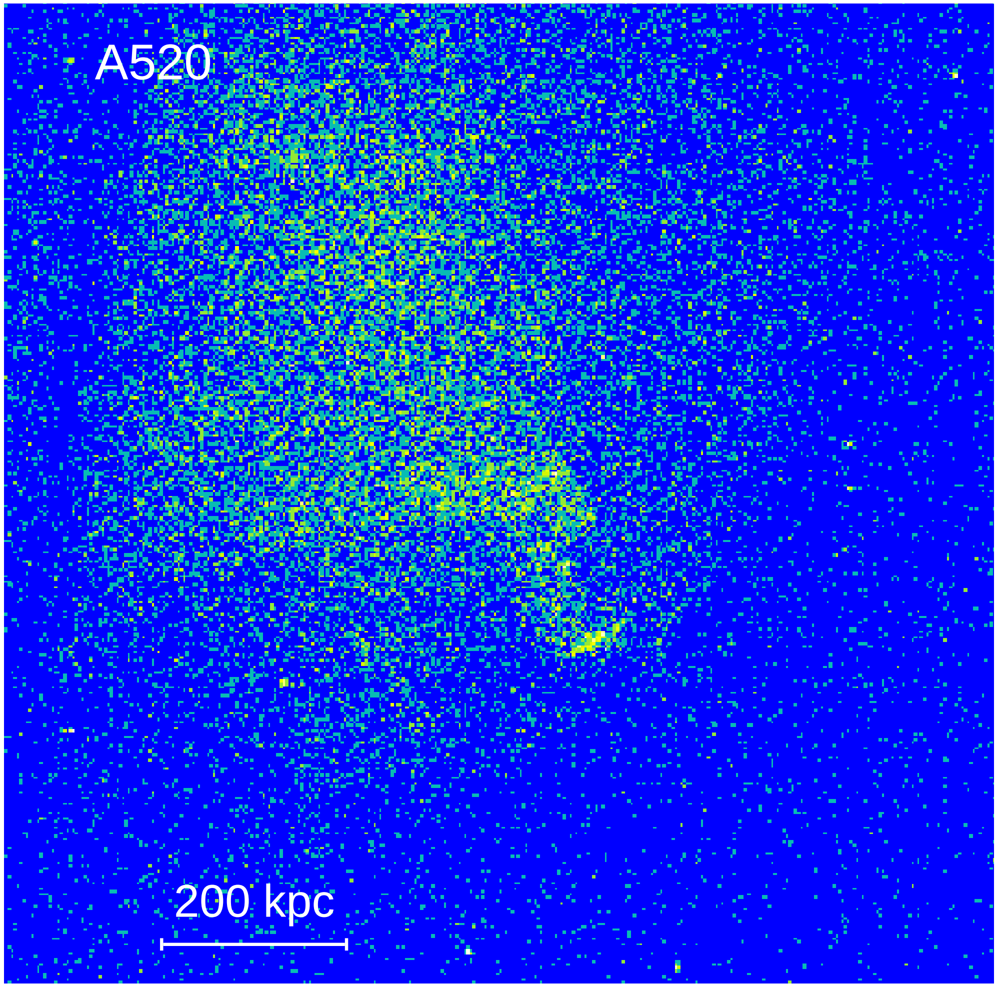


Destruction of a dense core in a high-*M* merger





Cluster radio halos

(from X-ray observer's perspective)

Cluster radio halos

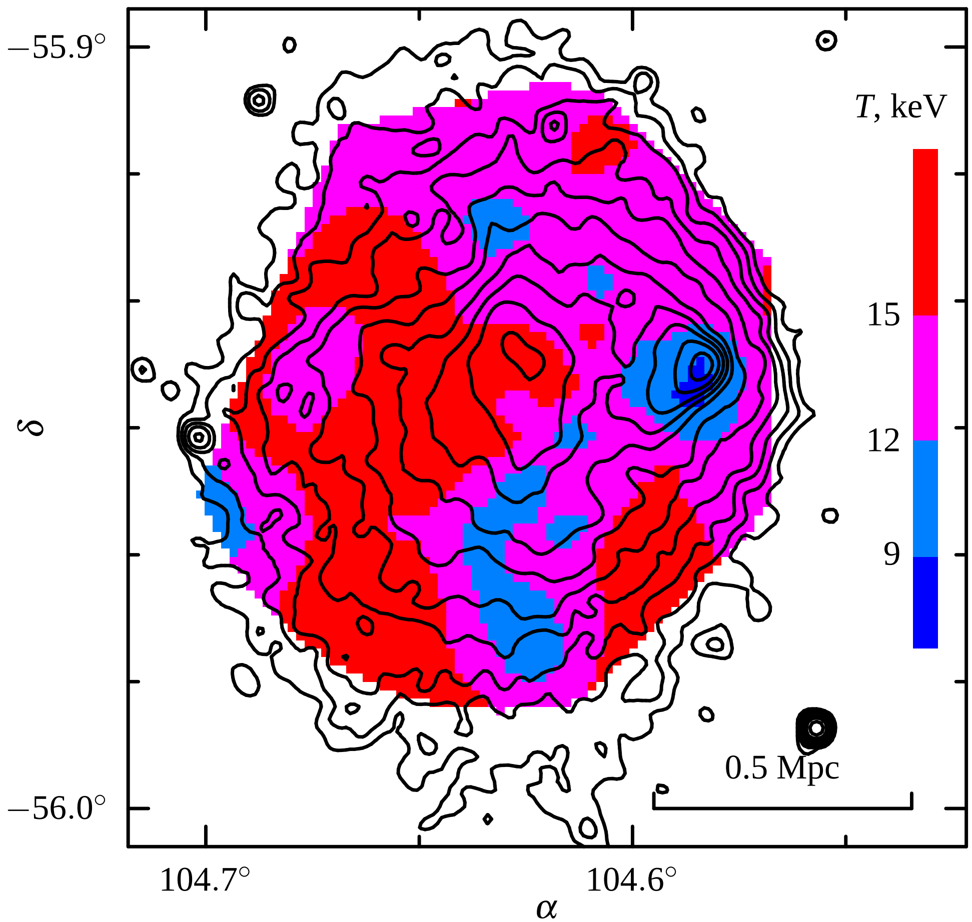
- **Synchrotron radiation from $\gamma \sim 10^4$ electrons**
- **Very short lifetime ($10^7 - 10^8$ yr), yet halos are very extended**
- **Probably generated by cluster mergers — but how exactly (shocks or turbulence)?**

Theoretical arguments against acceleration on shocks with $M < 3 - 5$
(Brunetti 2002; Gabici & Blasi 2003)

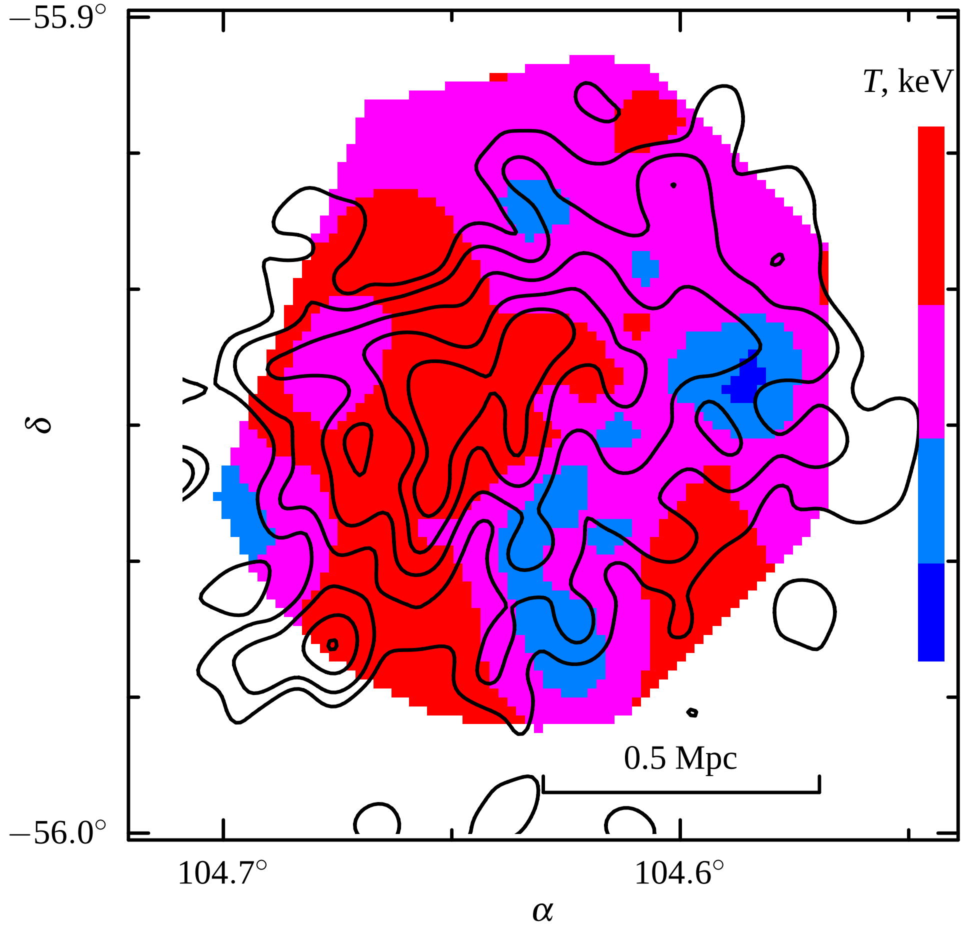
Observations — compare halo brightness with gas temperature maps
(Markevitch & Vikhlinin 2001; Govoni et al. 2004)

1E 0657–56

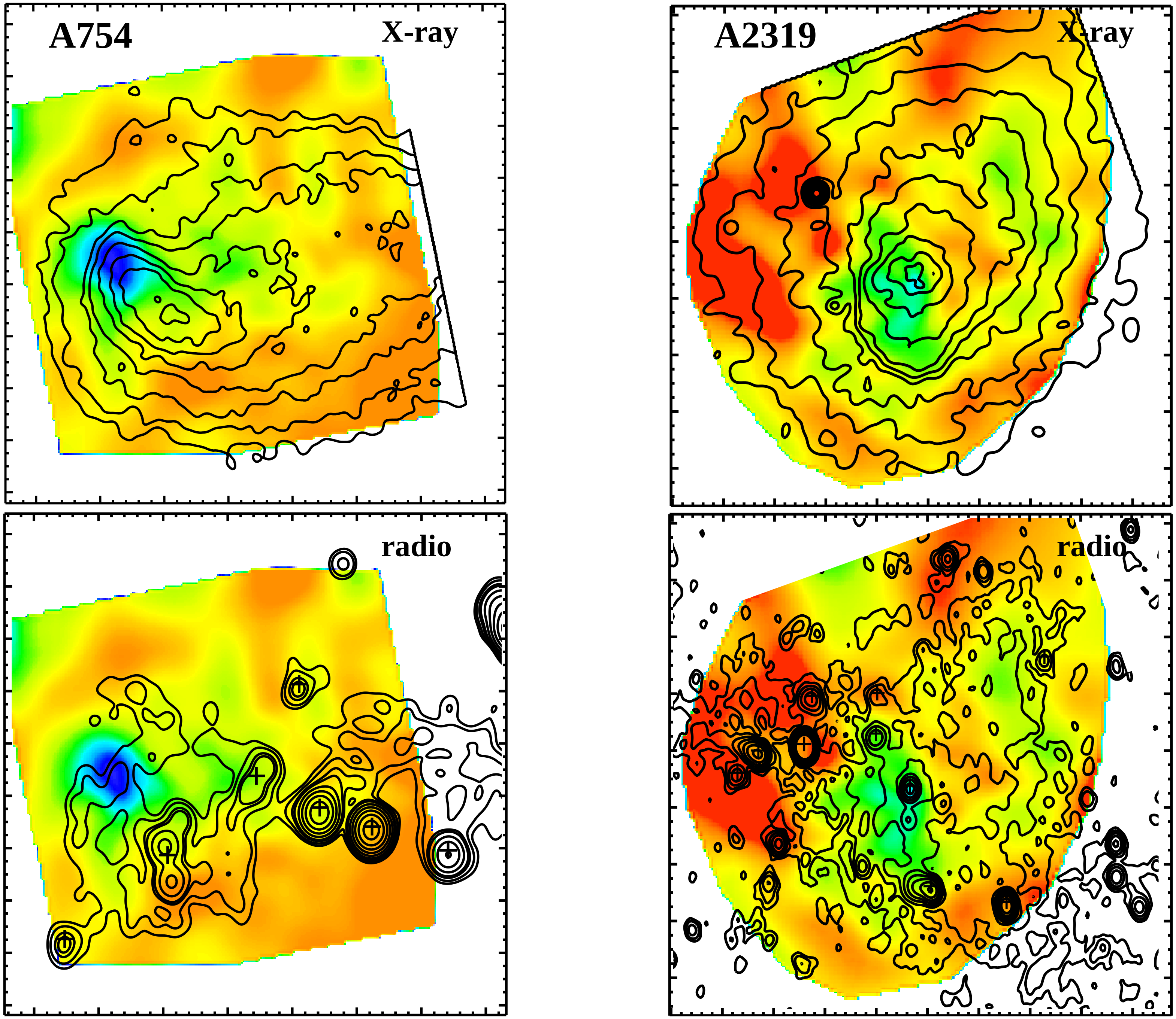
X-ray contours and map (*Chandra*)



radio contours (Liang et al. 2000)

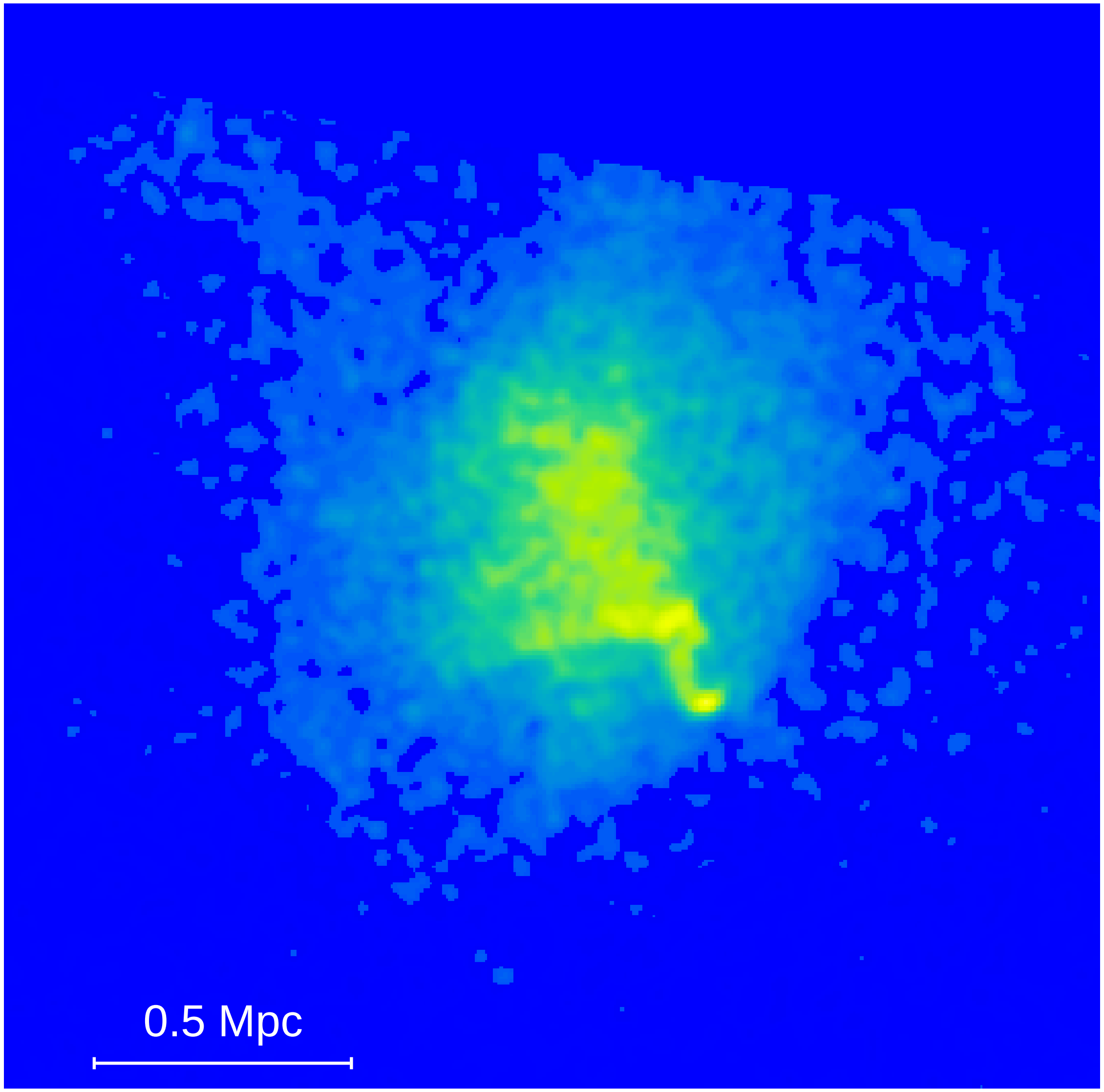


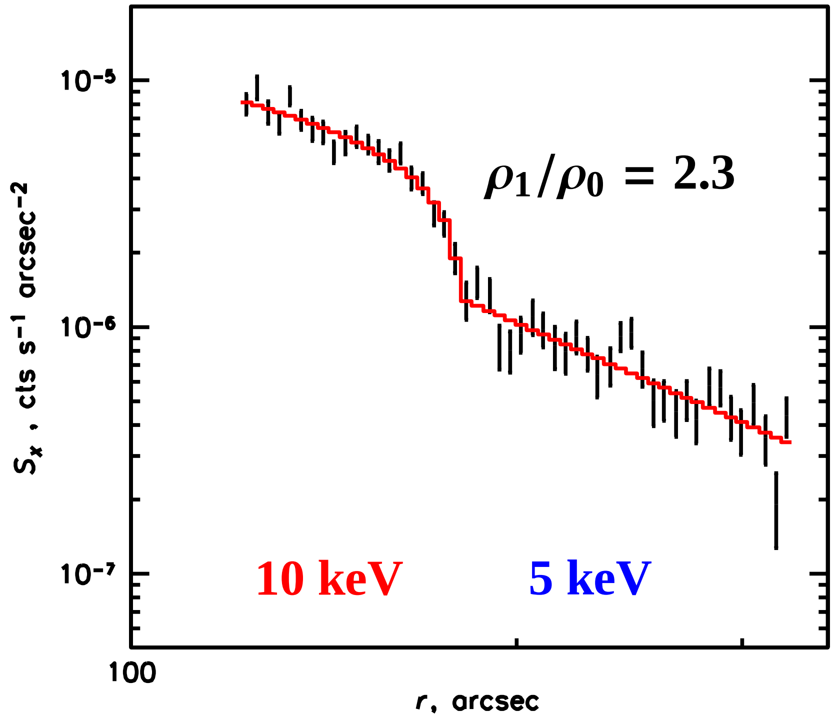
- **Radio brightness correlates with gas temperature — shock acceleration?**



- **Counterexamples — disfavor shock acceleration** (Govoni et al. 2004)

Shock front in A520

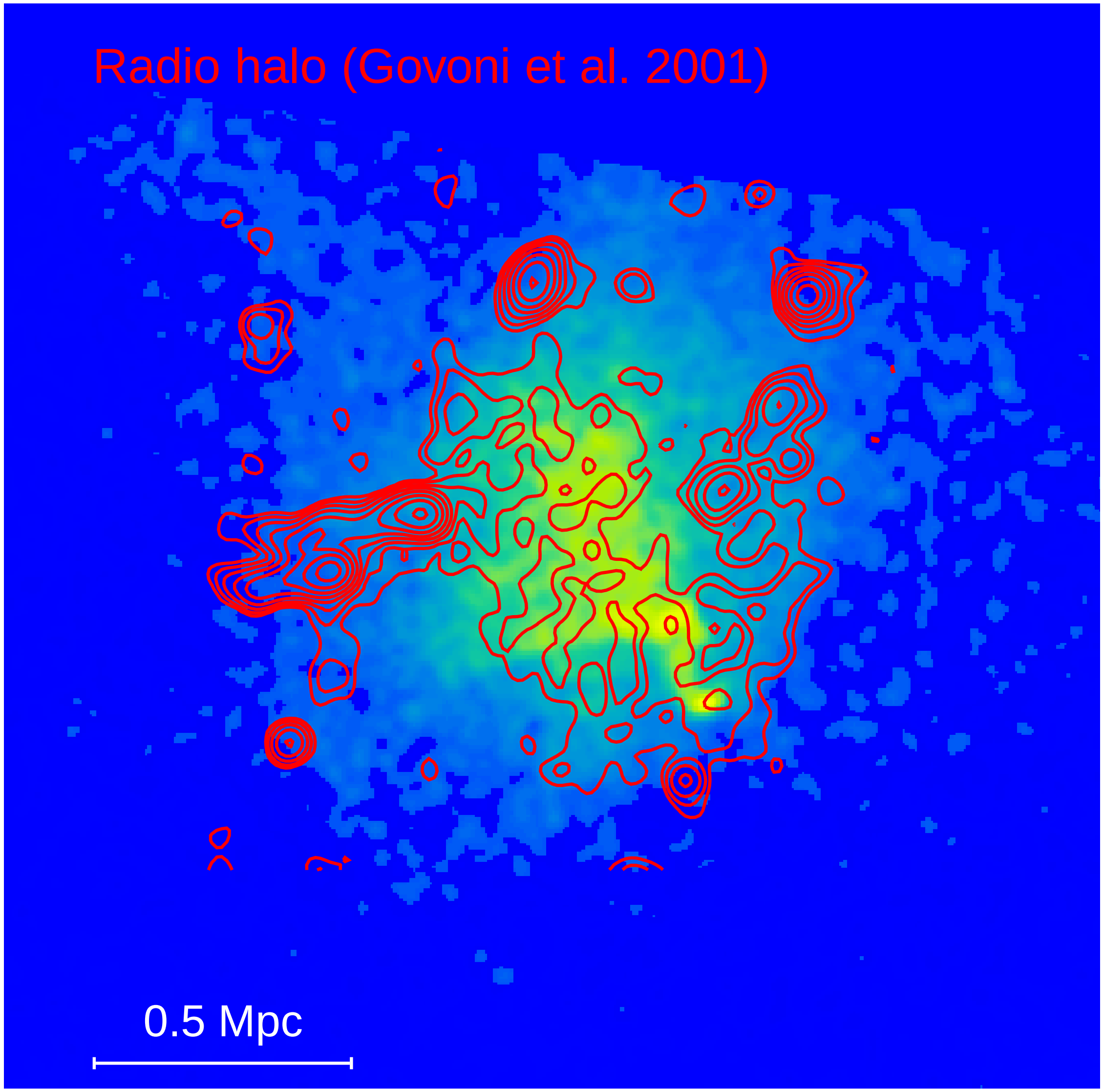


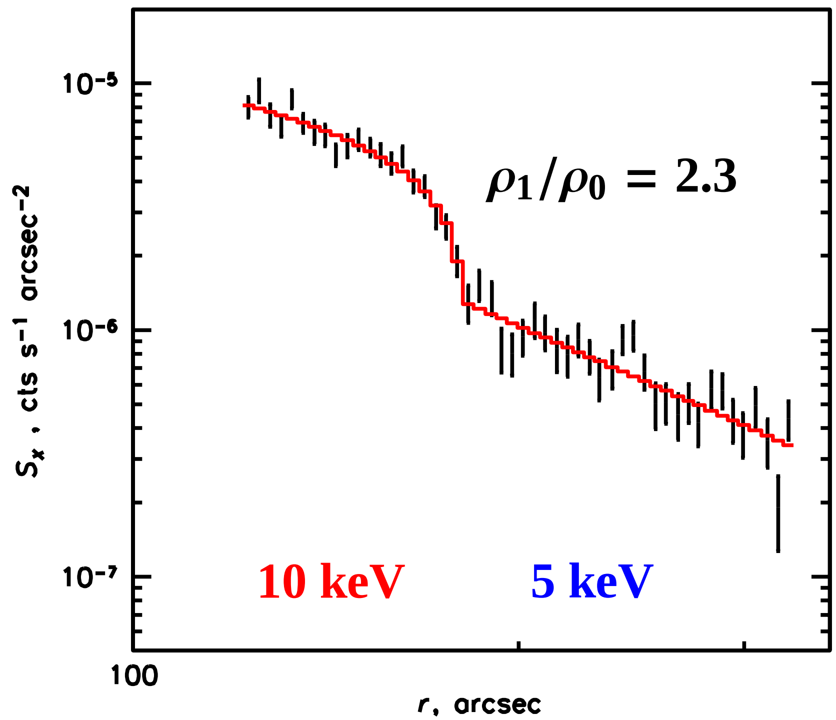


$$M = 2.1^{+0.4}_{-0.3} \quad (90\%)$$

Chandra data (Markevitch et al. in prep.)

Shock front in A520





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Summary

- *Chandra* and *XMM* temperature maps for many clusters — can study dynamic of individual mergers in great detail

- Observe destruction of dense cool cores in mergers at high resolution

- Can use shock fronts, cold fronts and T maps as tools to study cluster physics:

  - upper limit on thermal conductivity (in bulk of gas, $\varkappa < 0.1$ Spitzer at 10 keV)
  - structure and strength of magnetic fields (at cold fronts)
  - independent limit on DM collisional cross section ($\sigma/m < 1\ \mathrm{cm}^2\ \mathrm{g}^{-1}$)

    ... and proof of DM existence!

  - coming soon: test of electron-ion equilibration timescale

- A520 and 1E 0657–56 are the objects to study acceleration on shocks

Radial gas temperature profiles

Radial gas temperature profiles

- **Necessary for total mass derivation:**

$$M_{\rm tot}(r) \propto -r\, T_g(r) \left(\frac{d\, \log T_g}{d\, \log r} + \frac{d\, \log \rho_g}{d\, \log r} \right)$$

- **Measurements difficult and contradictory**

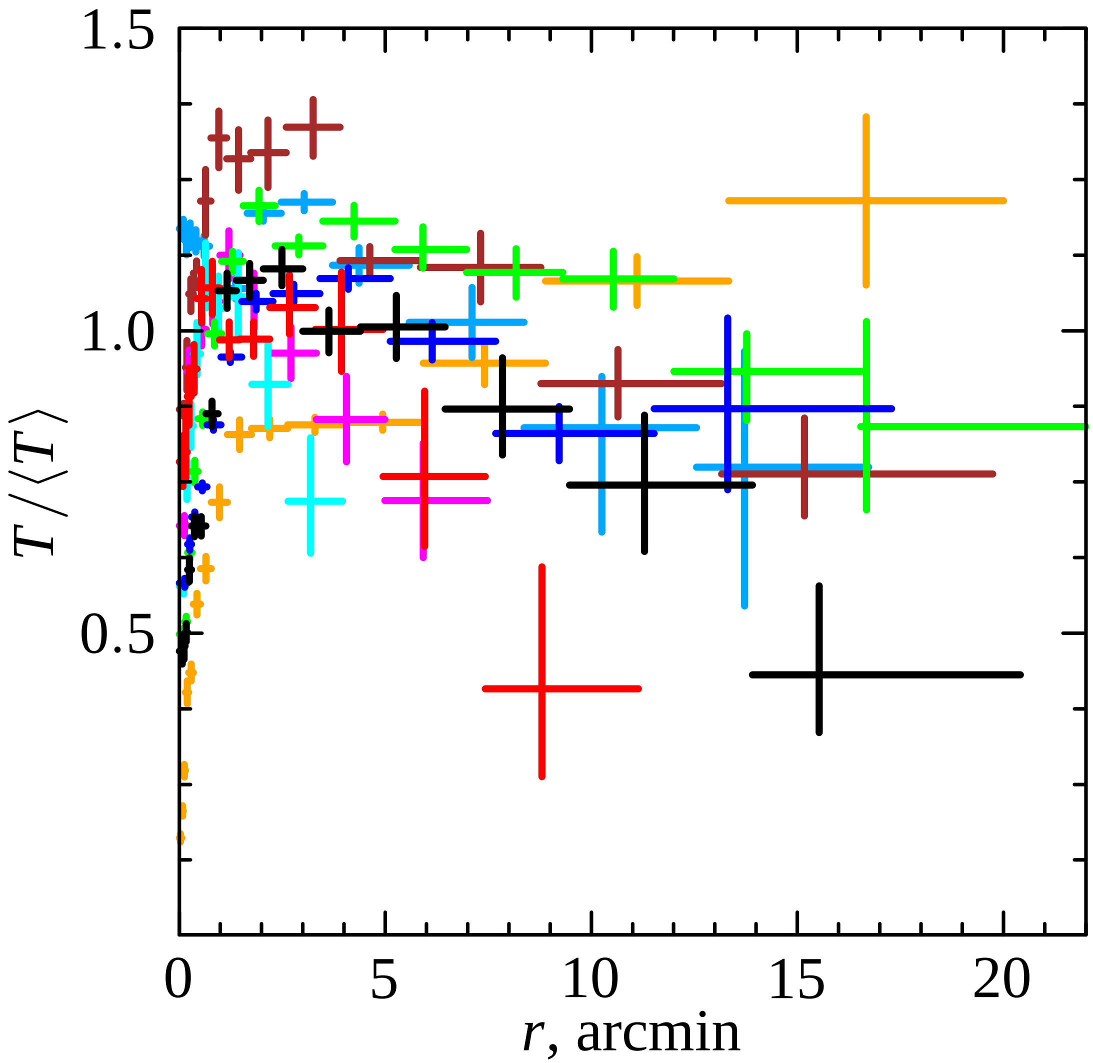
Decline at large *r*:

  - ***ASCA*** **(Markevitch et al. 1996, ...)**
  - ***SAX*** **(De Grandi & Molendi 2001)**

Profiles consistent with isothermal, or vary:

  - ***ASCA*, different method** **(White 2000)**
  - ***SAX*, different method** **(Irwin & Bregman 2000)**
  - **early *XMM* results** **(Arnaud et al., Pratt et al.)**

Temperature profiles from *Chandra*



Nine well-observed nearby clusters with $T = 0.8 - 8$ keV (Vikhlinin et al. in prep.)

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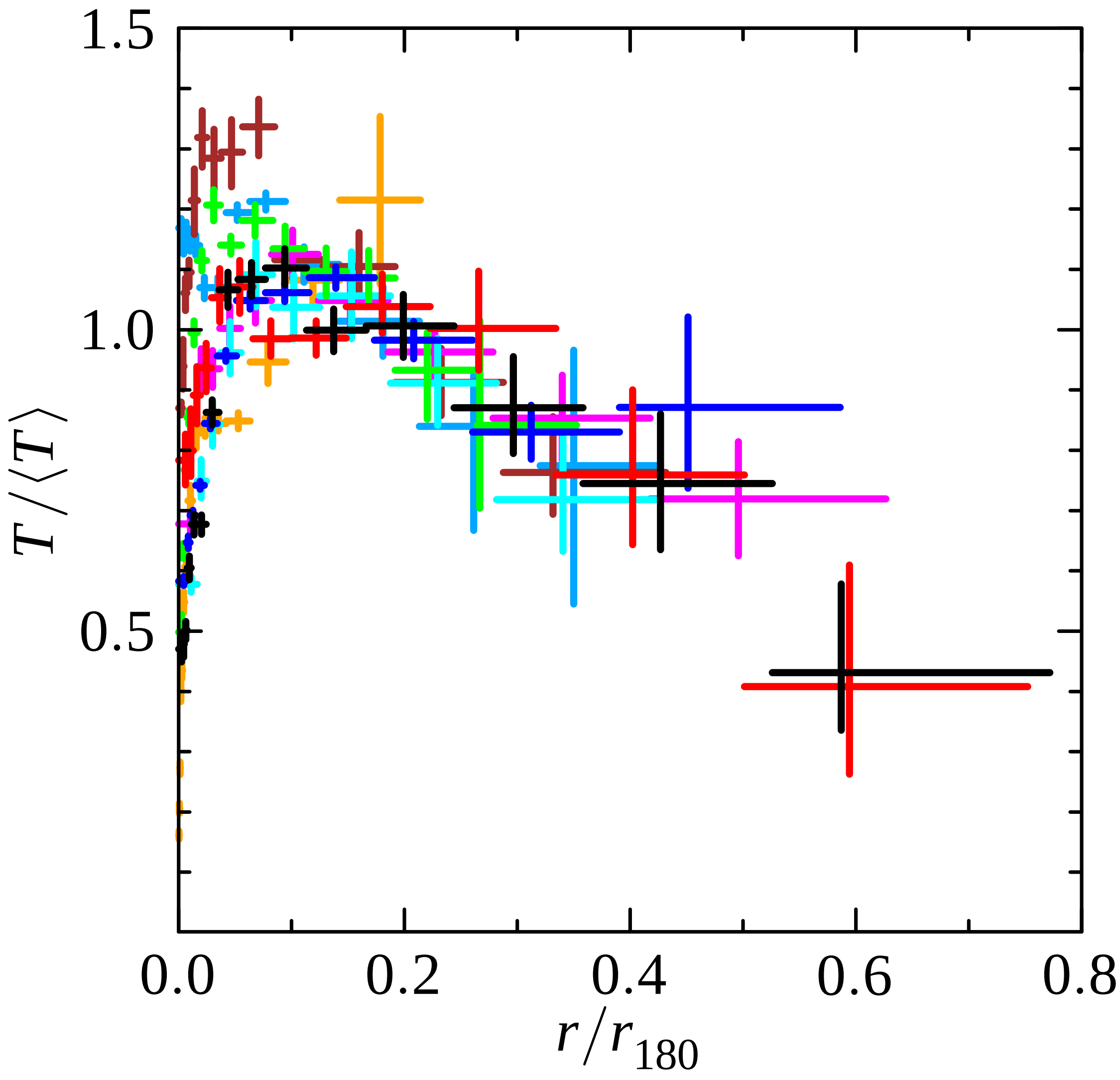

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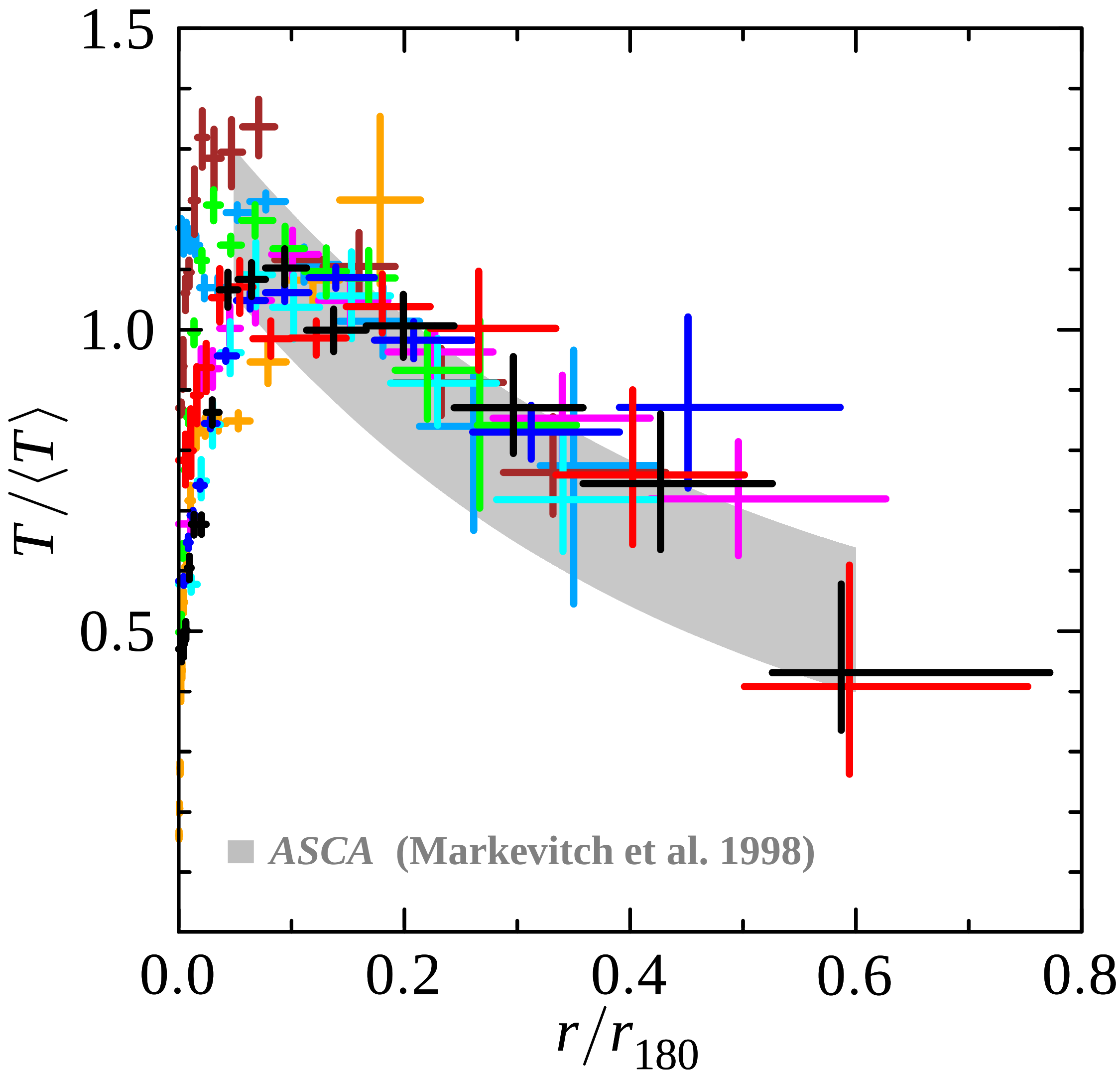

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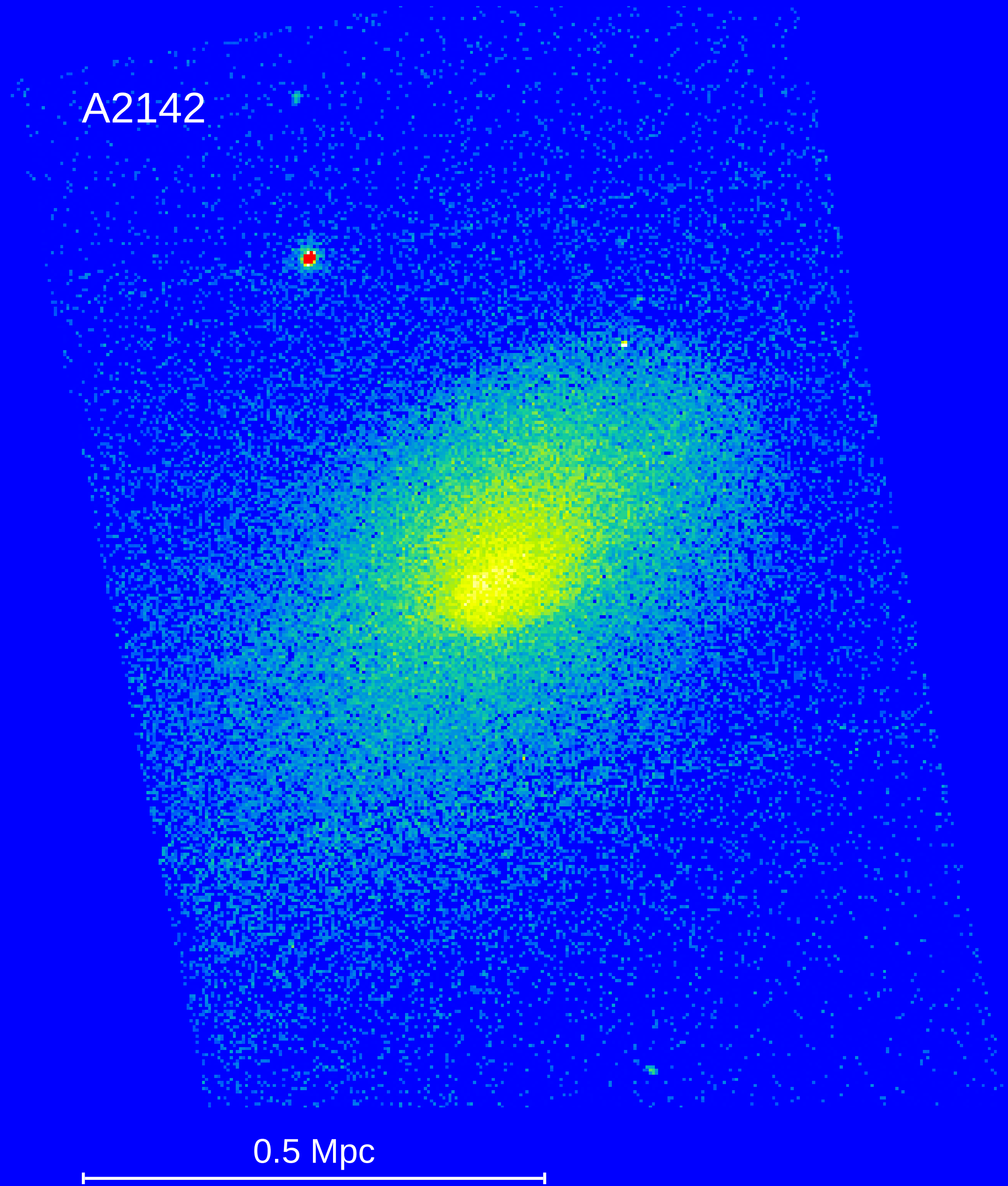
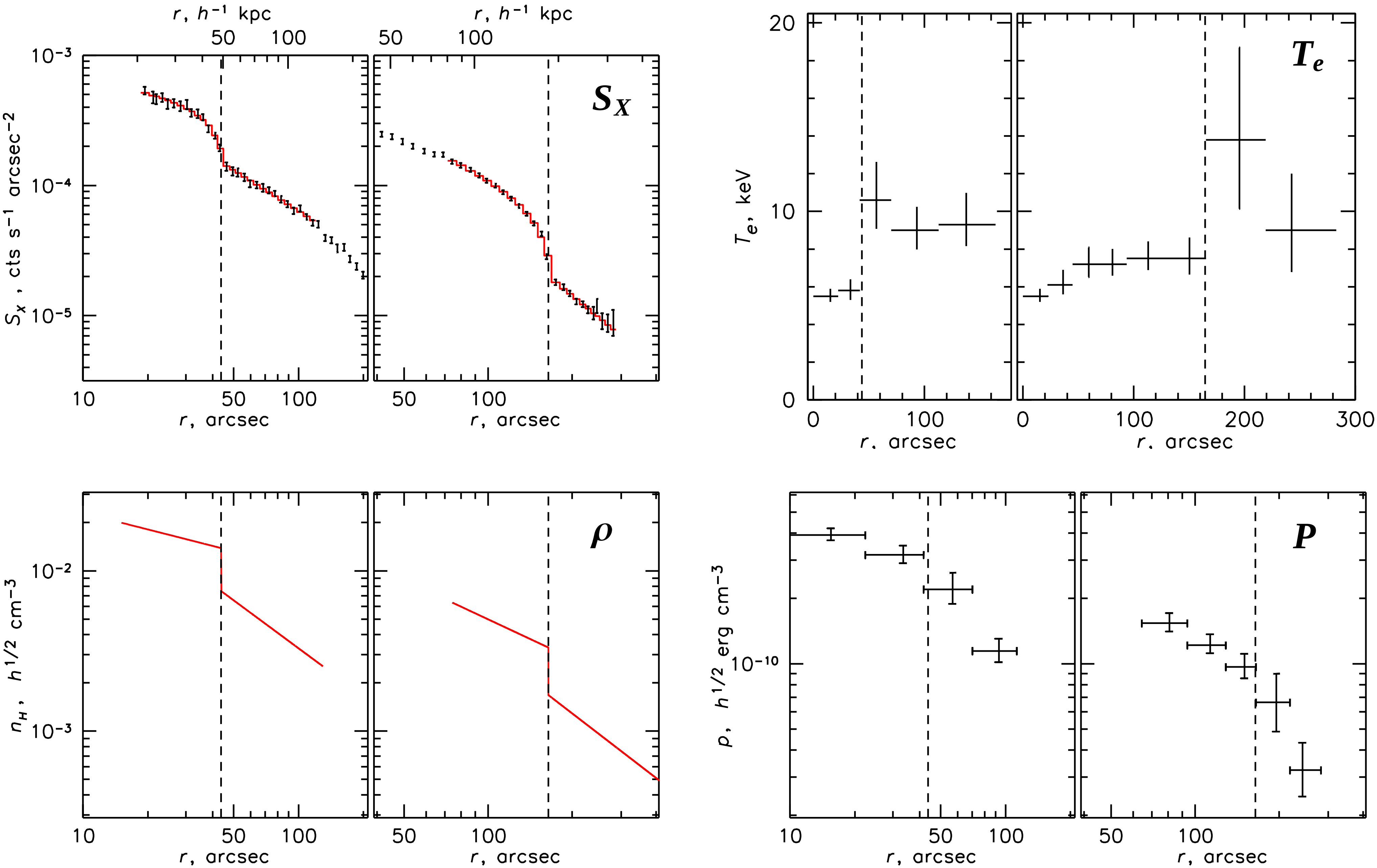
    ... and proof of DM existence!
  - coming soon: test of electron-ion equilibration timescale
- A520 and 1E 0657–56 are the objects to study acceleration on shocks
- Radial T profiles decline by $\times 2$ between $0.1 - 0.6\ r_{180}$

Cold fronts



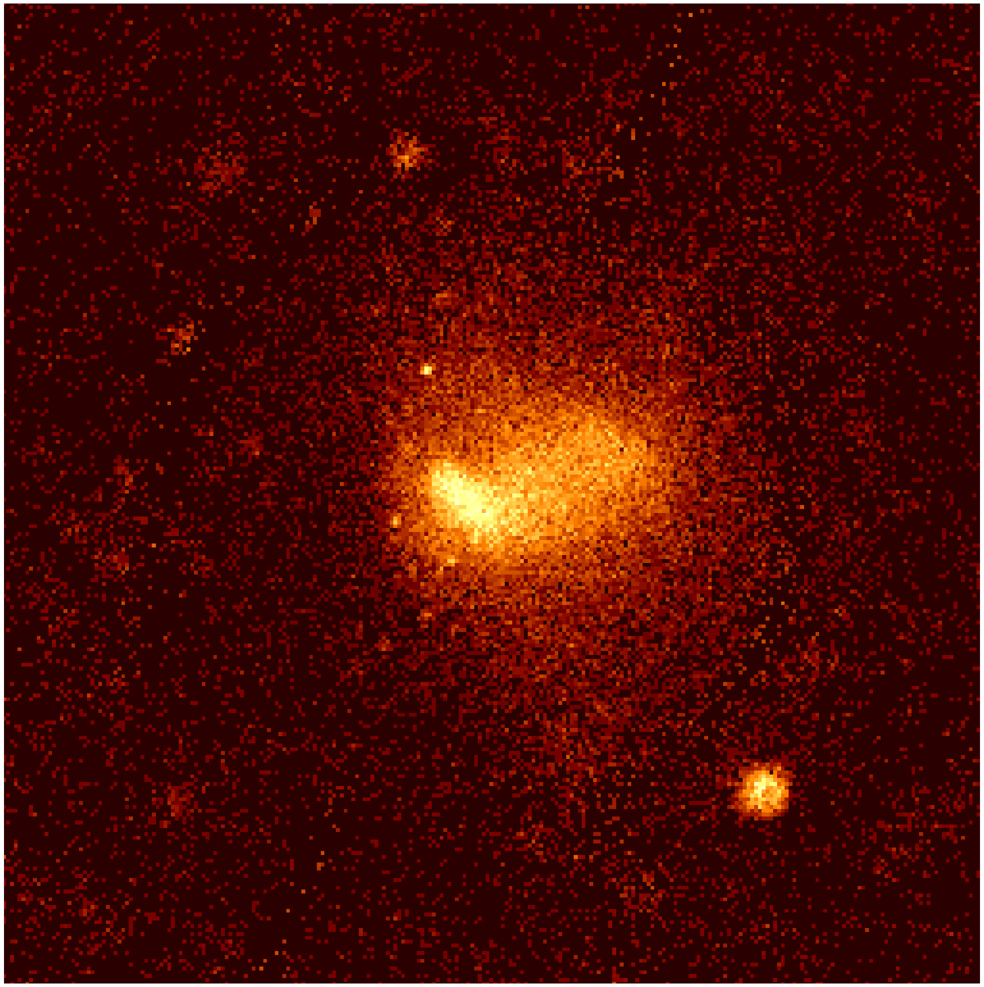
Cold fronts



(Markevitch et al. 2000)

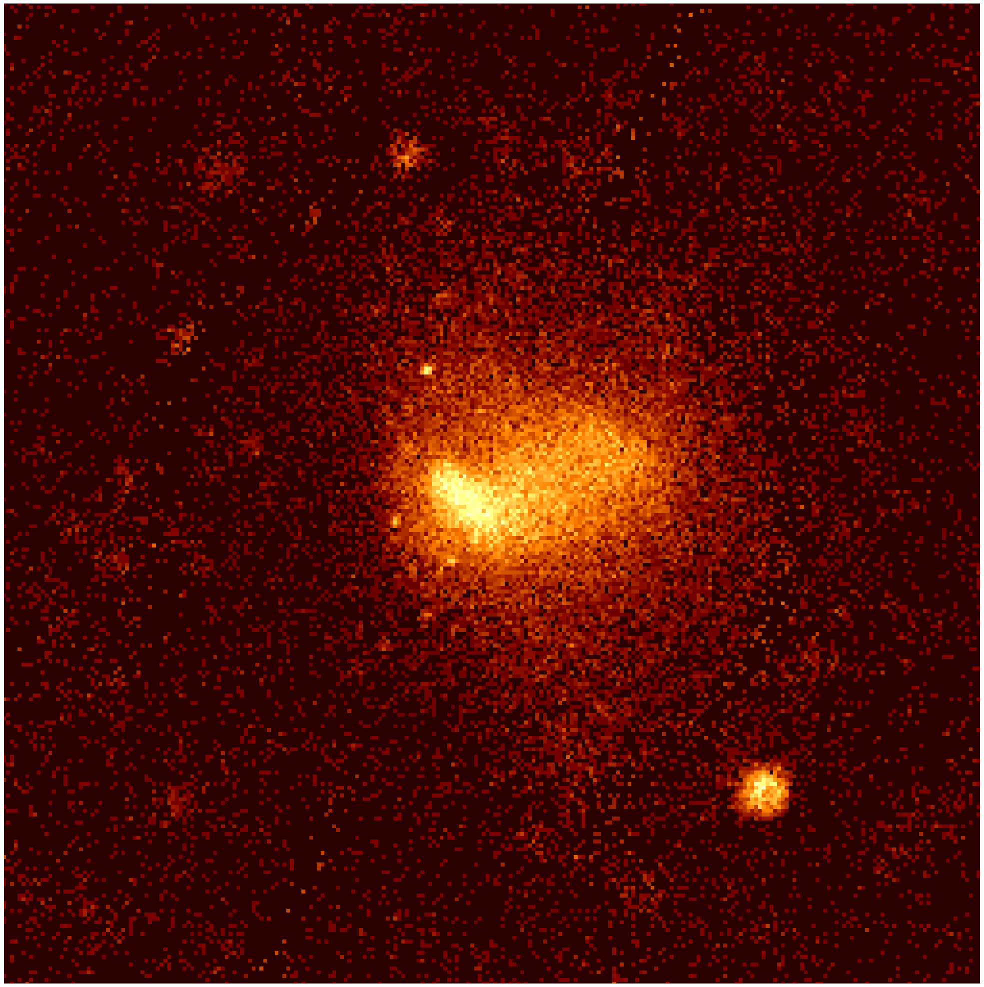
$M \lesssim 1$

A754



***ROSAT* PSPC image (Krivonos et al. 2003)**

A754



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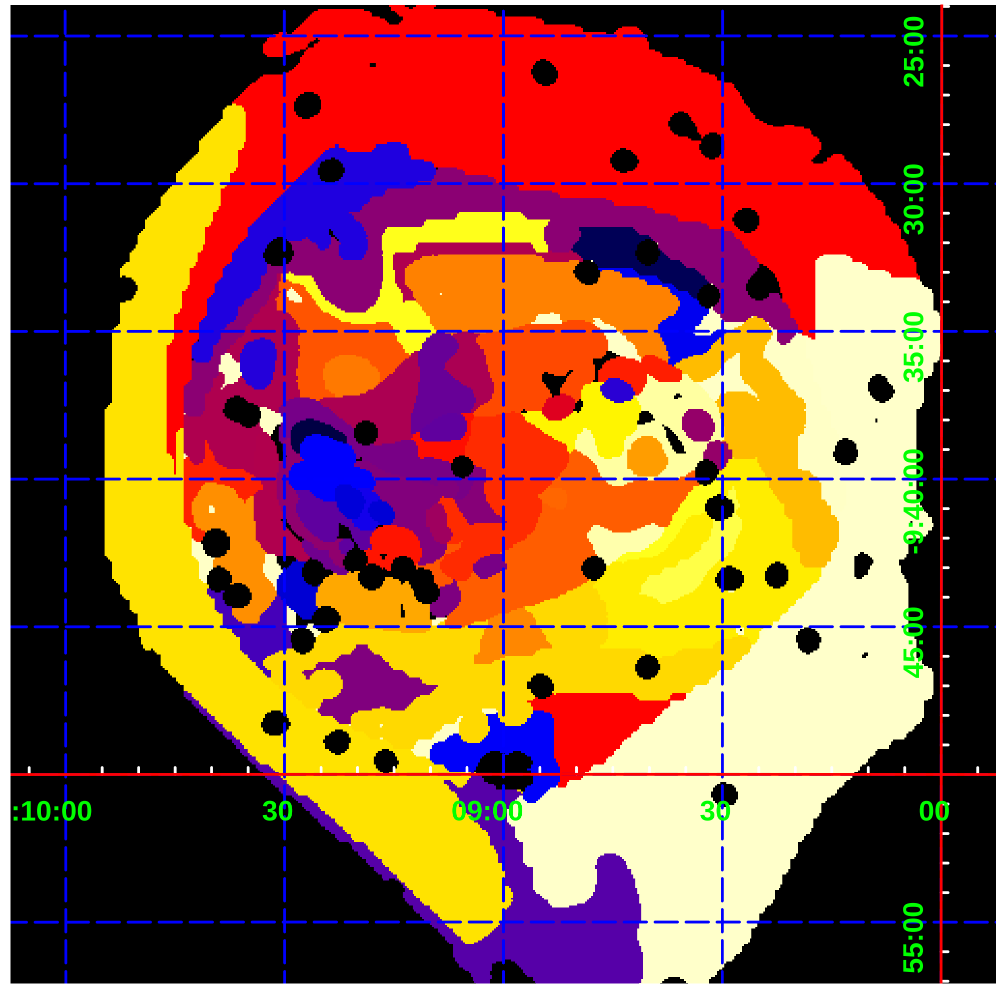

XMM T map (Henry, Finoguenov, & Briel 2004)

- from density jump, $M \simeq 1.5 - 1.7$