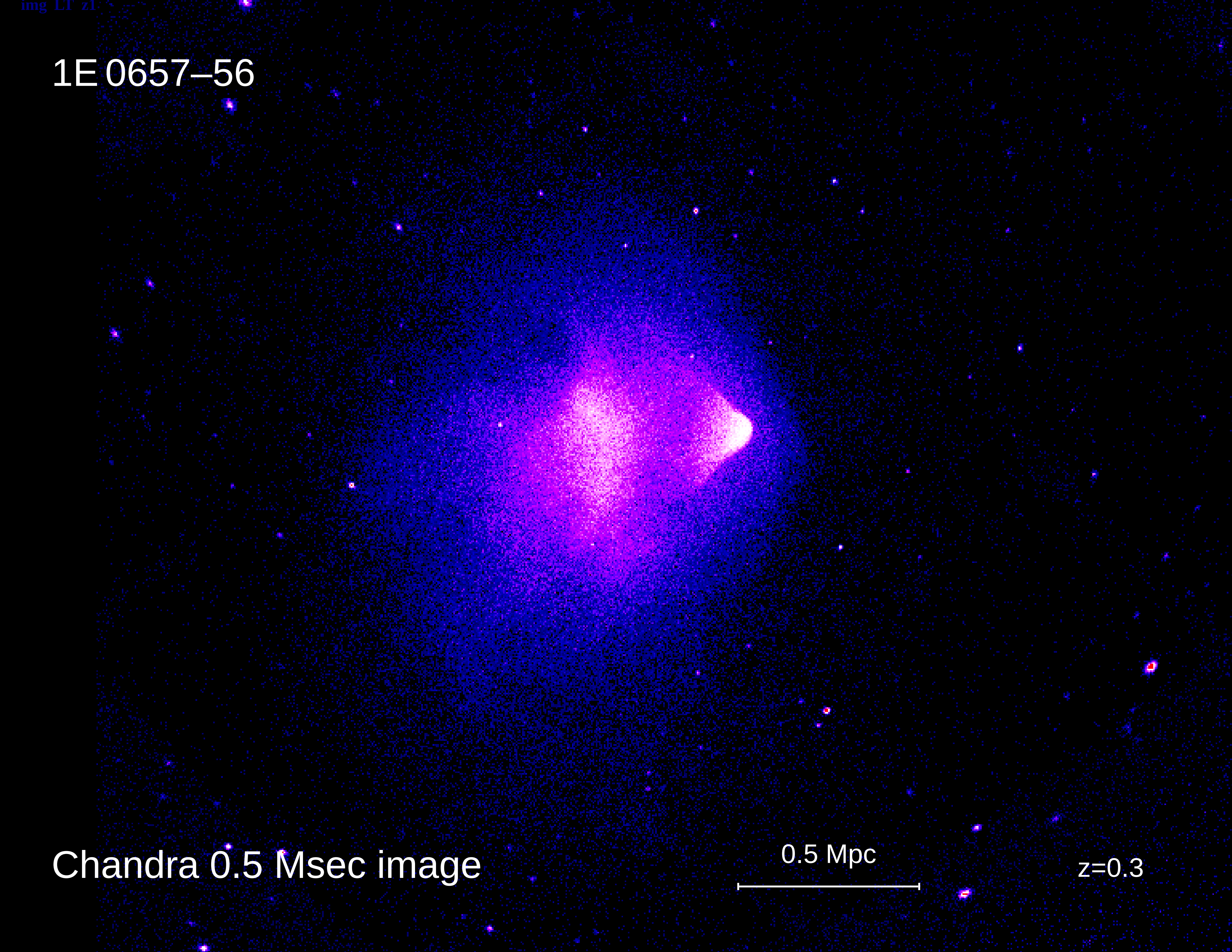
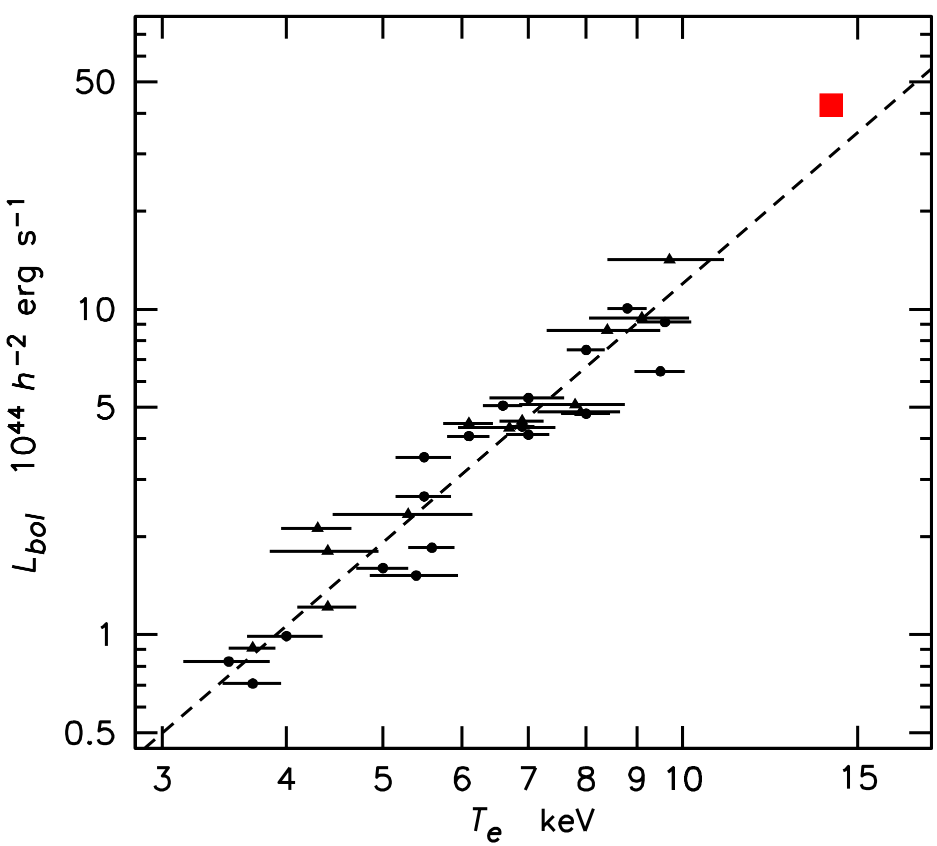
Constraints on physics of gas and dark matter from cluster mergers

Maxim Markevitch (SAO)

November 2005


1E 0657–56
Chandra 0.5 Msec image
0.5 Mpc
z=0.3

An overheated cluster



From $M - T$ relation:

T = 14 keV: M ~ 2.5 $M_{\rm lens}$

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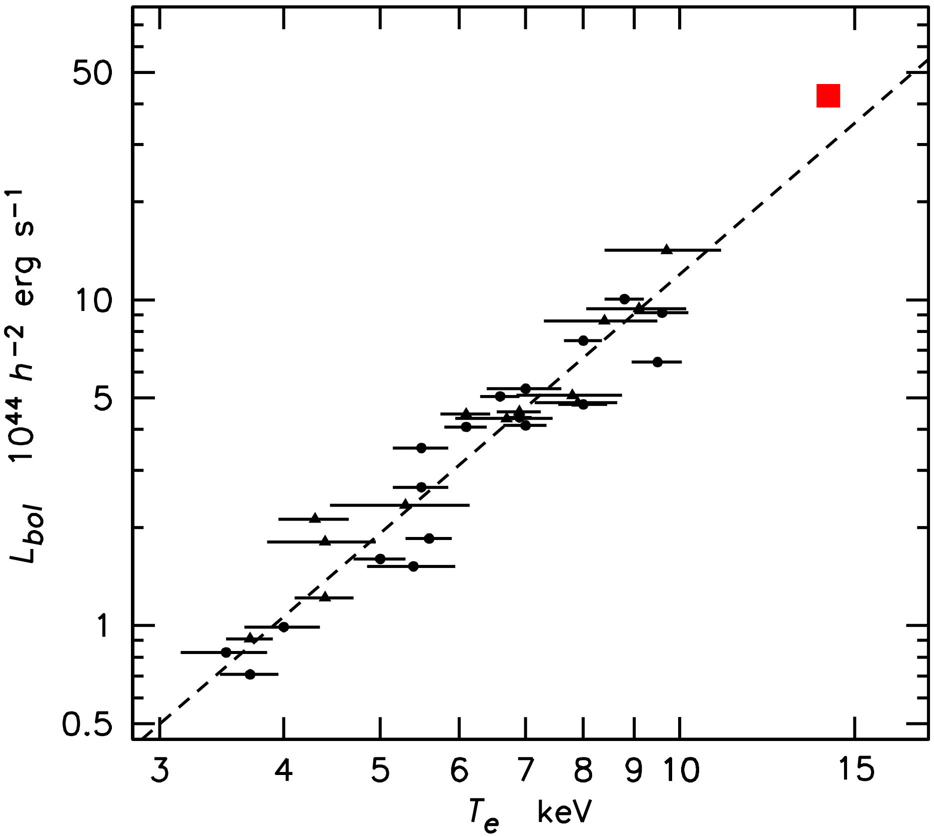

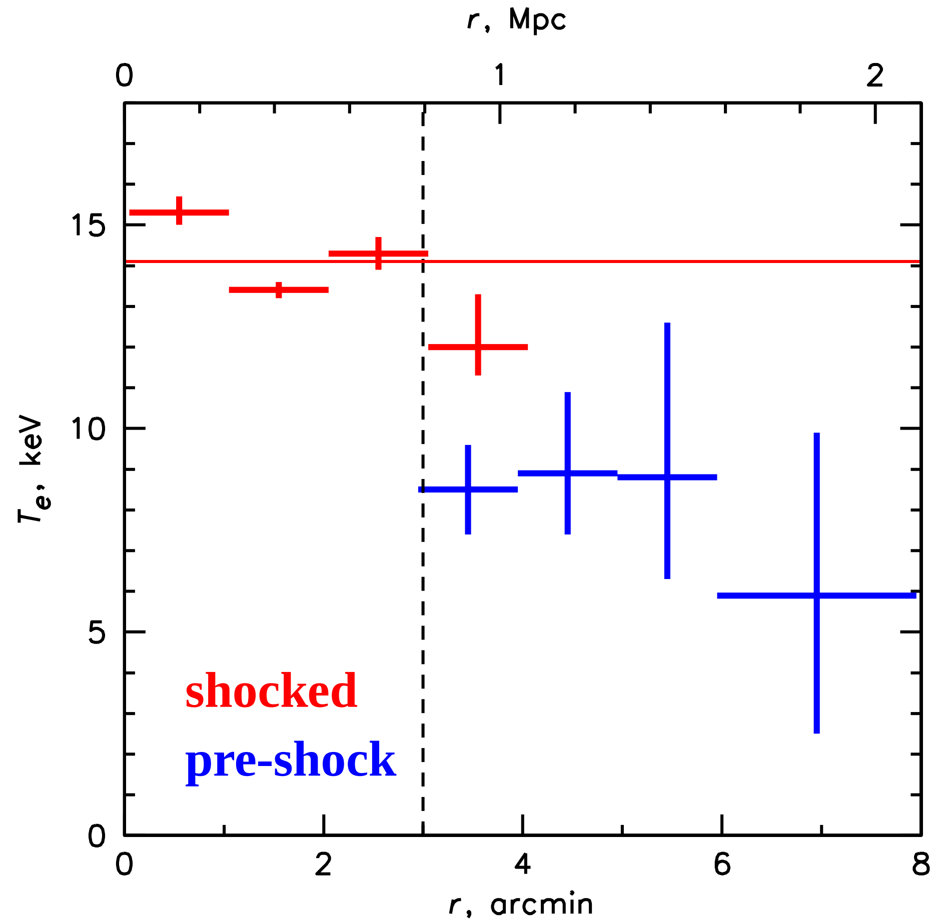

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Too hot by × 1.4–1.5 ?

(simulations: Randall & Sarazin; Rowley)

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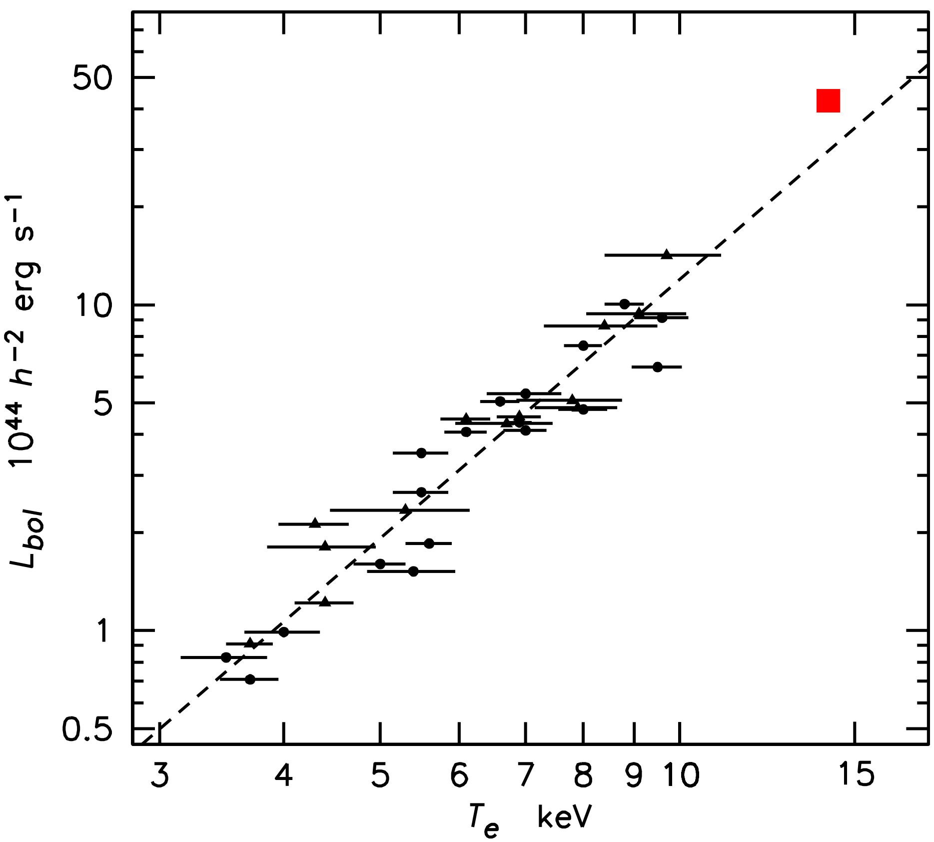
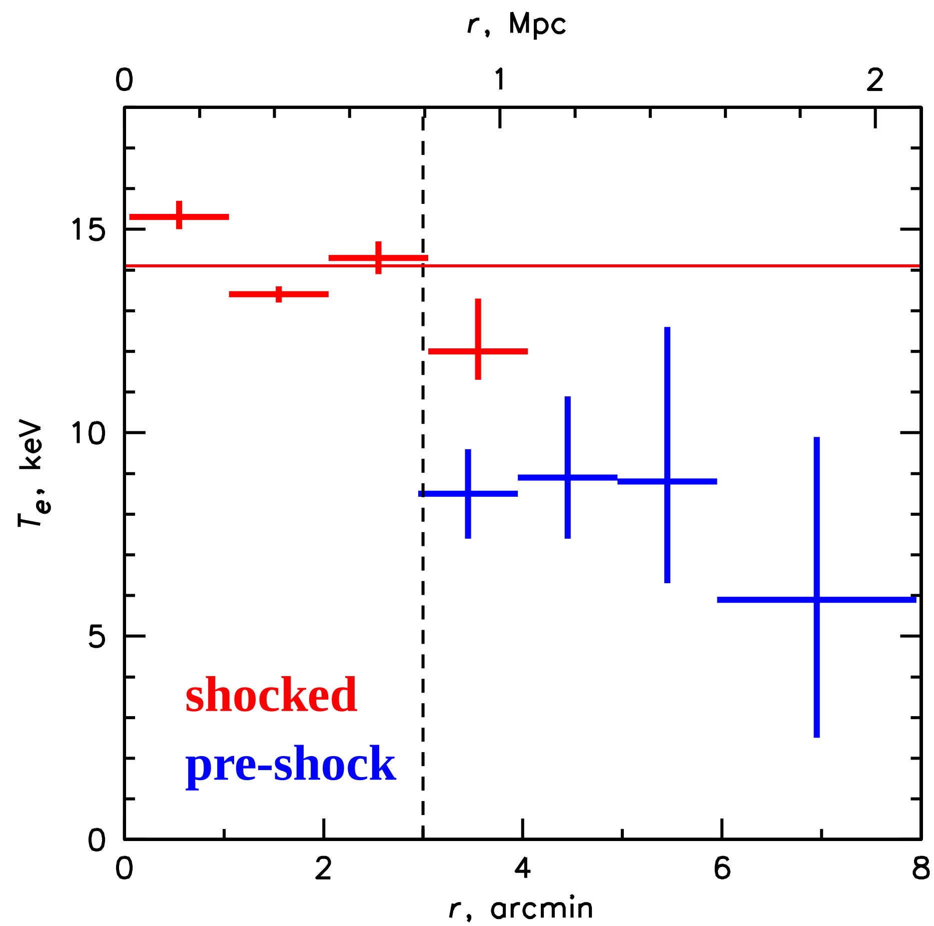




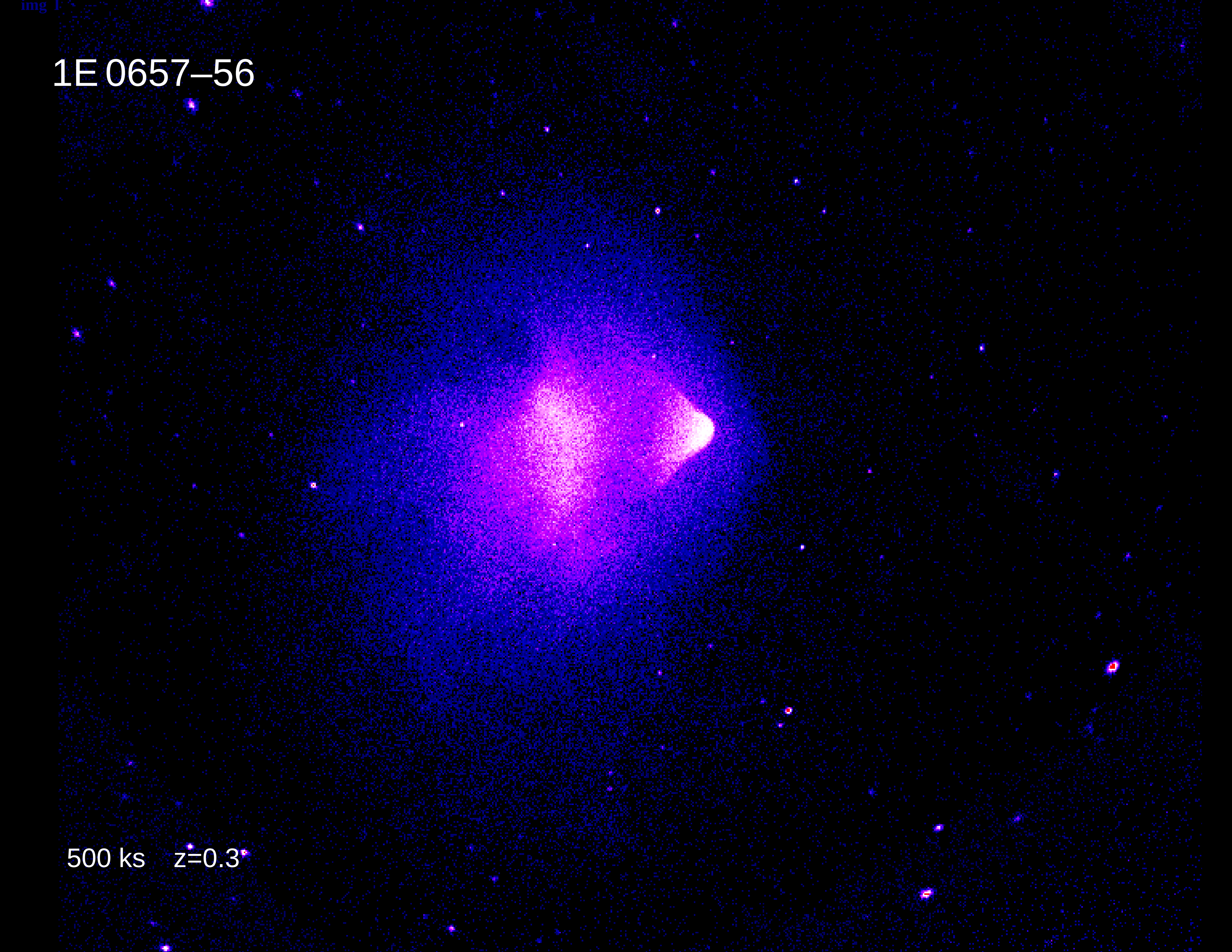
From $M - T$ relation:

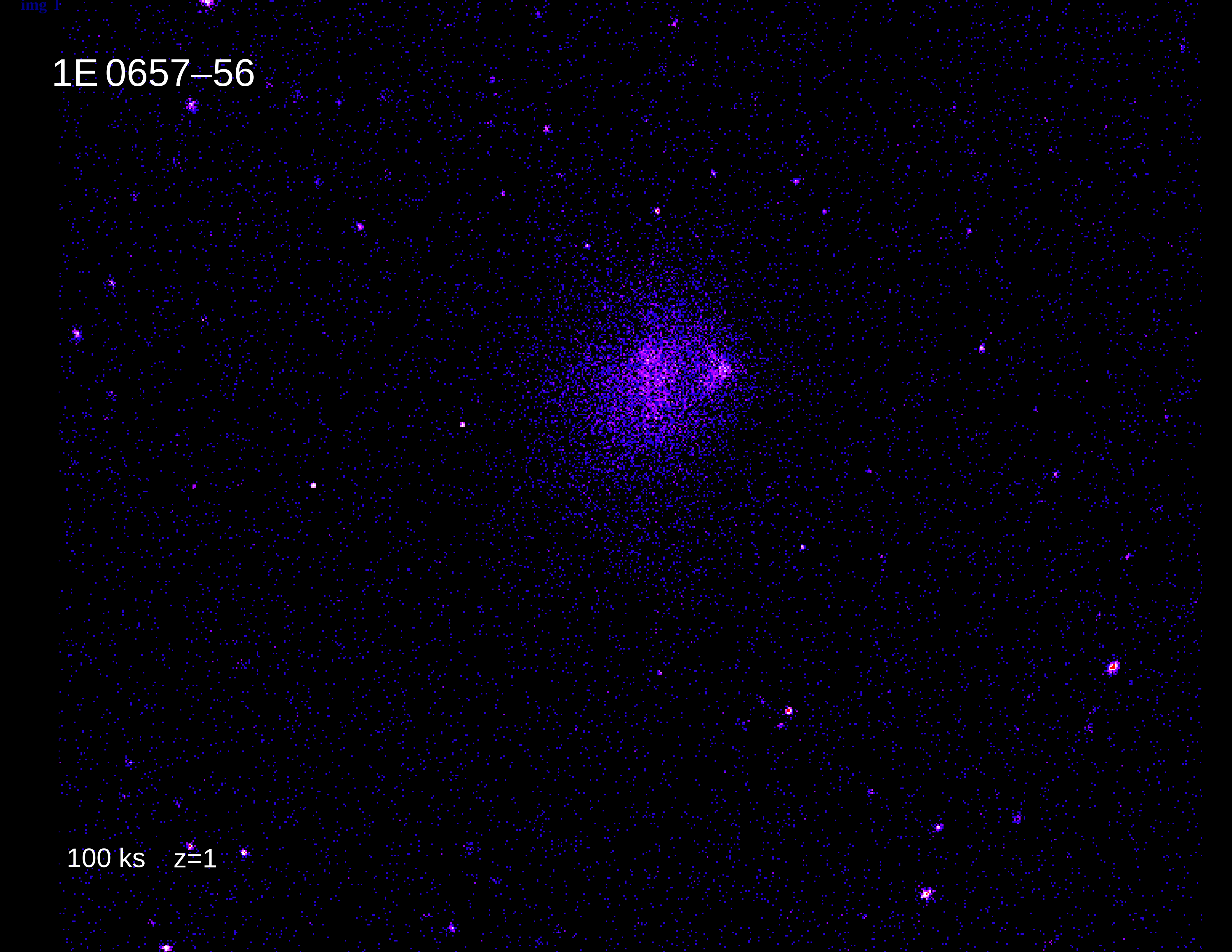
$T = 14$ keV: $M \sim 2.5\, M_{\mathrm{lens}}$

$T = 10$ keV: $M \sim 1.5\, M_{\mathrm{lens}}$

Too hot by × 1.4–1.5 ?

(simulations: Randall & Sarazin; Rowley)

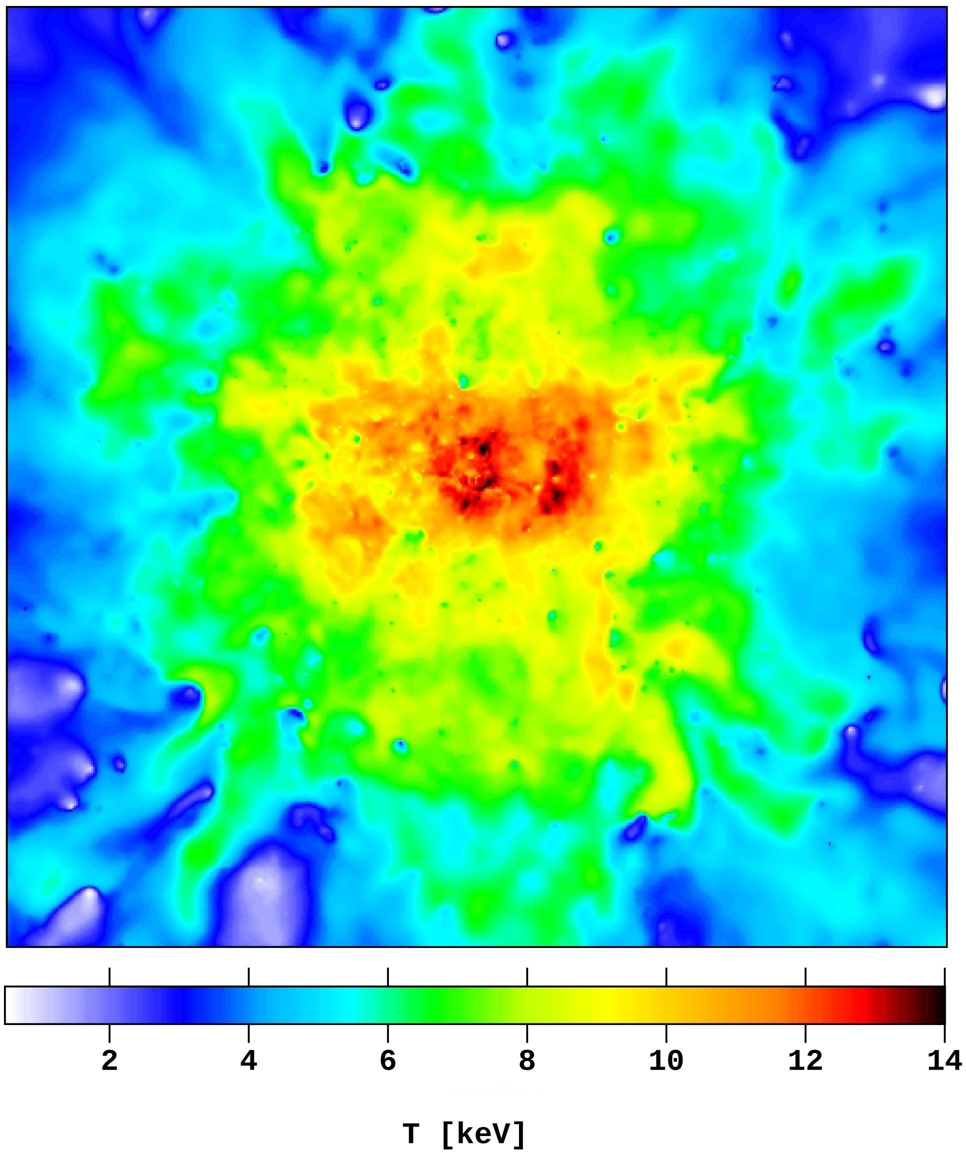

1E 0657–56
500 ks z=0.3


1E 0657–56
100 ks
z=1

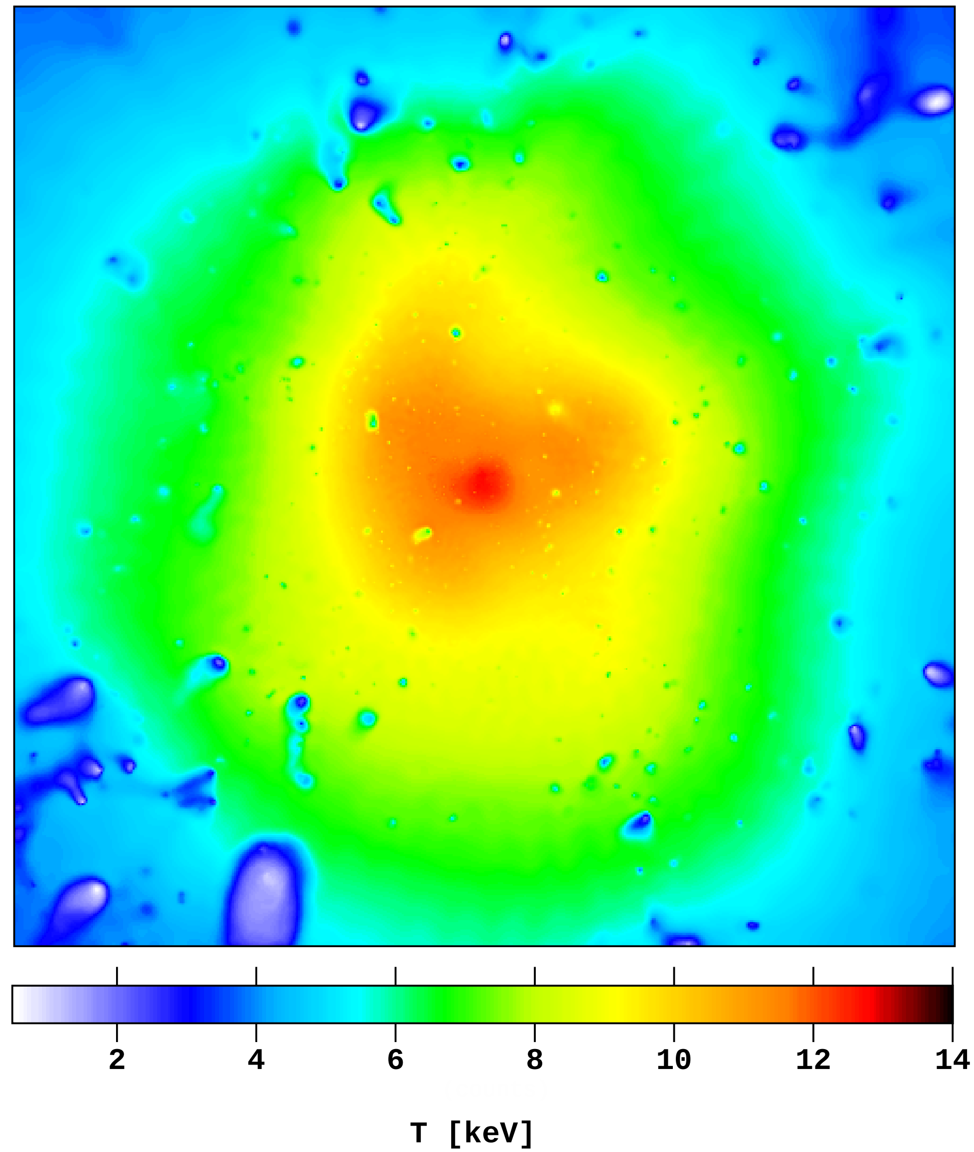
Thermal conduction

Thermal conduction: simulations

no conduction

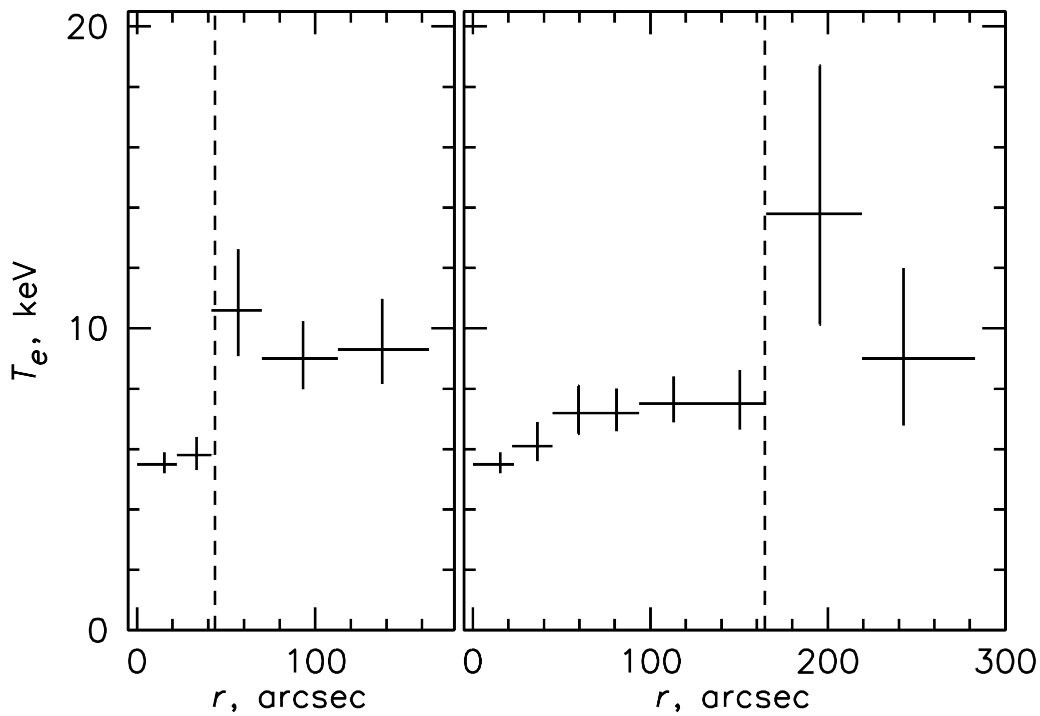


1/3 Spitzer



Dolag et al. (2004)

Thermal conduction: observations

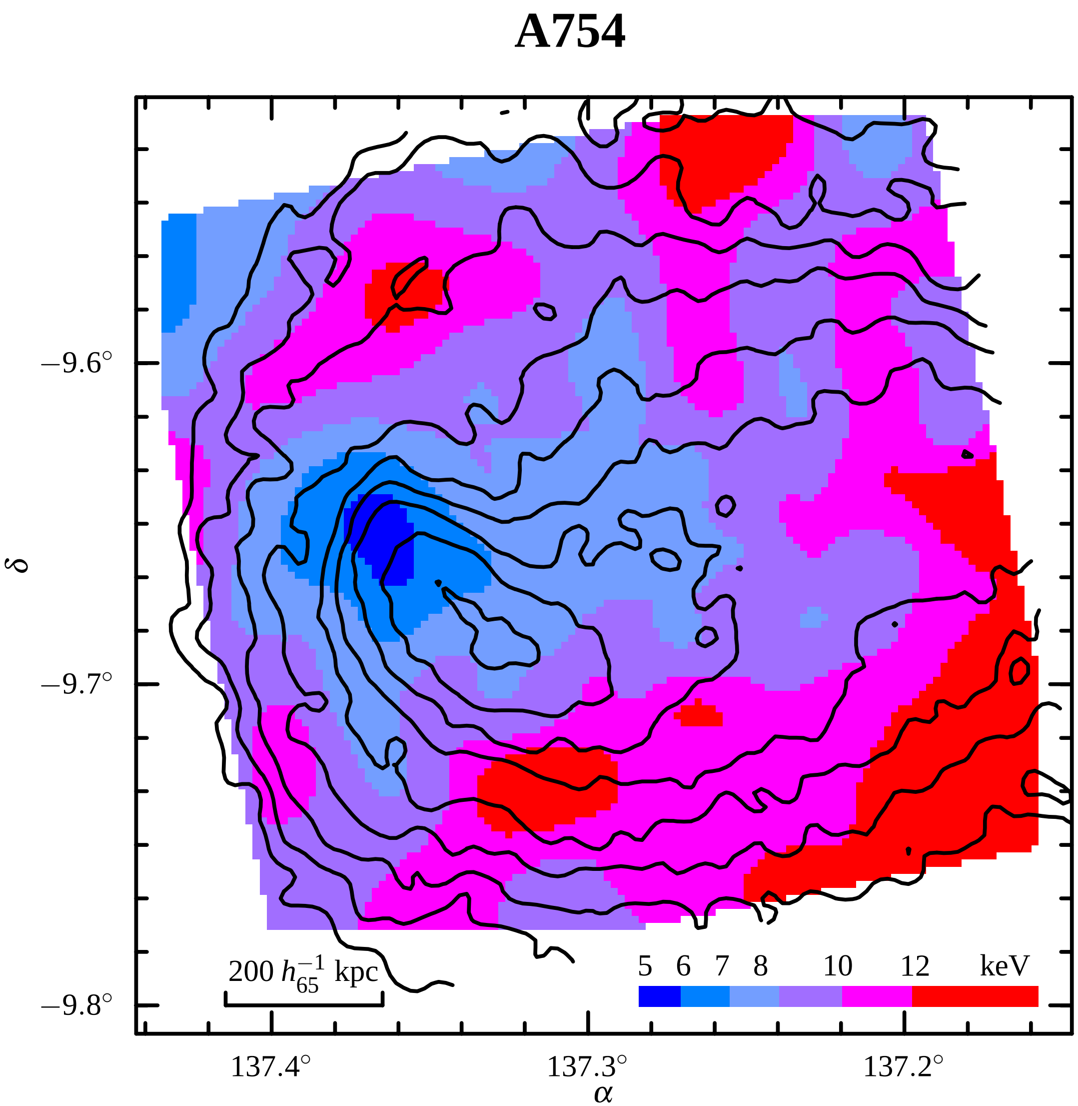


Cold fronts in A2142

- **Conduction and diffusion across fronts are suppressed**

  (Ettori & Fabian 2000; Vikhlinin et al. 2001)

Thermal conduction in the bulk of the gas



Chandra T 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:

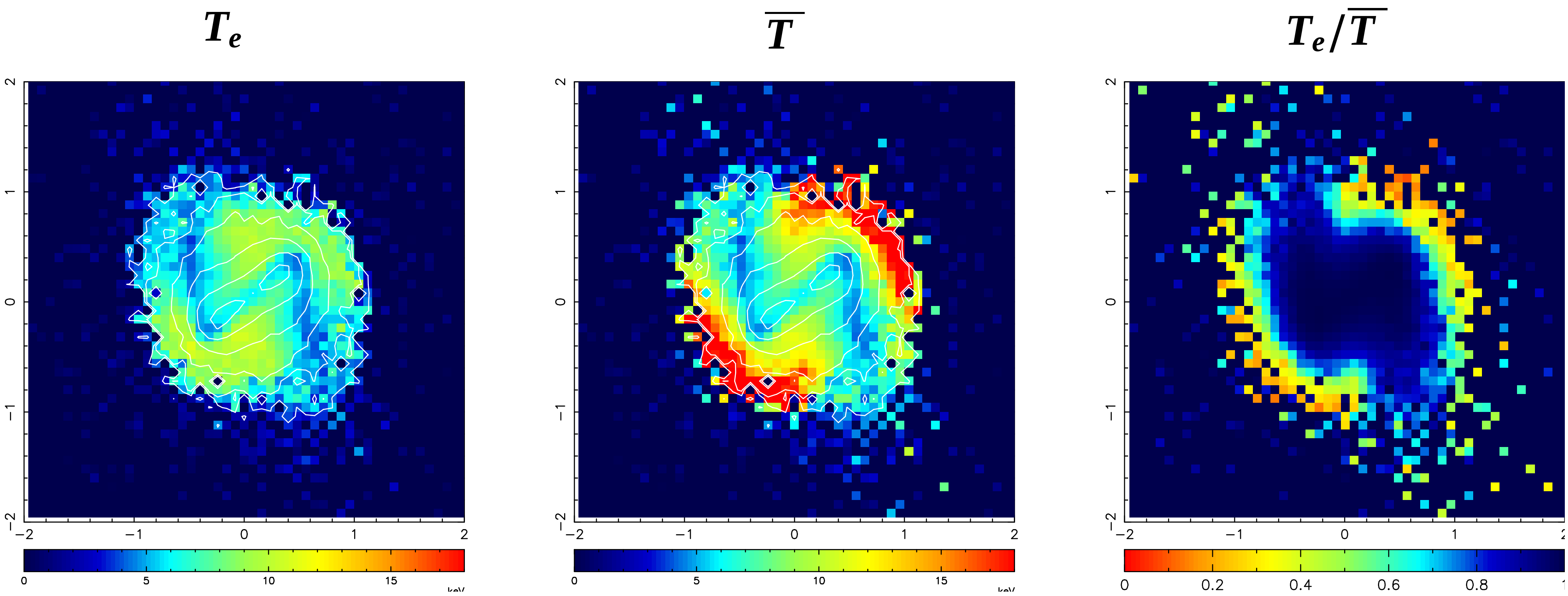
$$t_{\rm age} \sim \frac{L}{c_s} \sim 5 \times 10^8 \text{ yr}$$

Conduction suppressed by factor

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

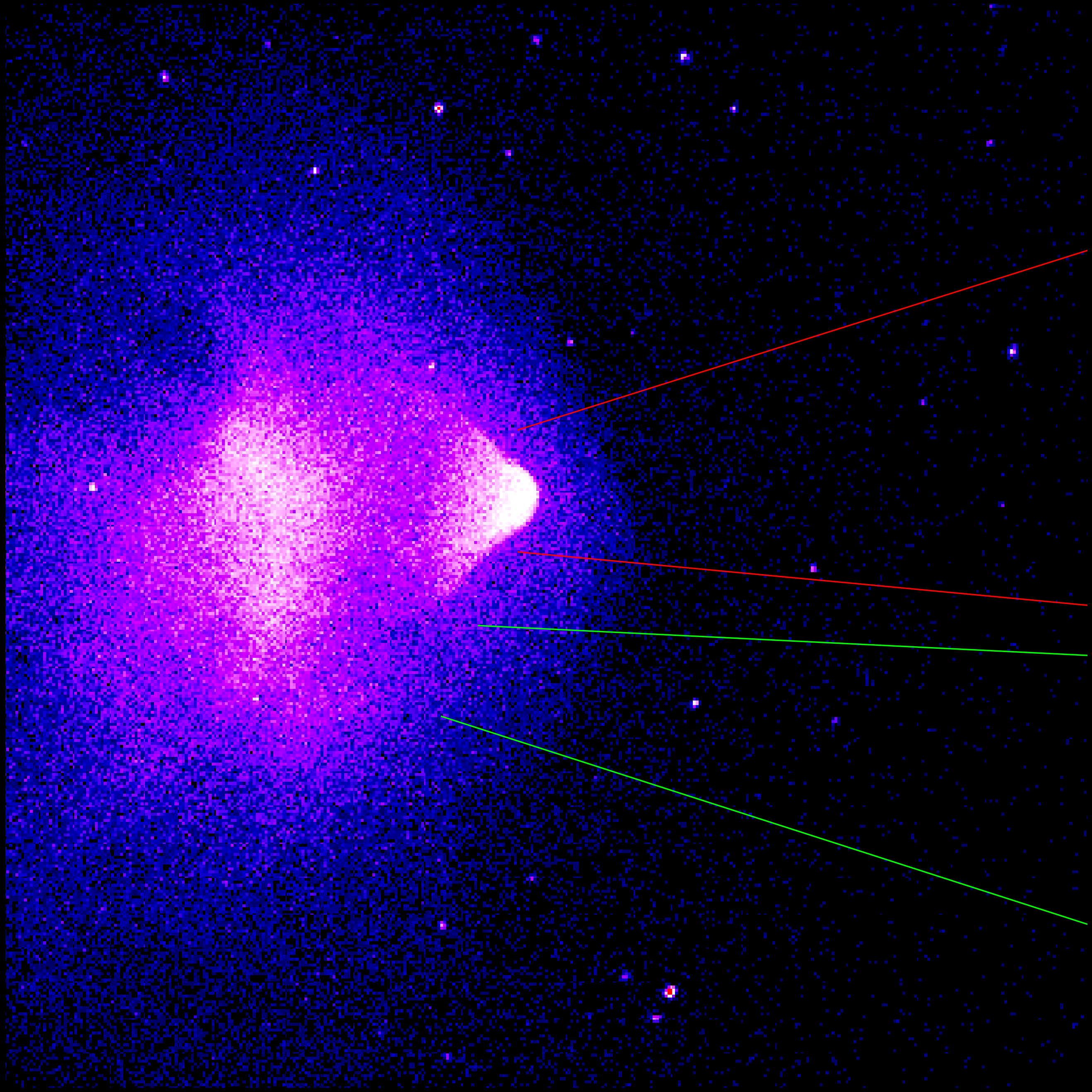
Electron-ion equilibrium

Electron-ion nonequilibrium: simulations

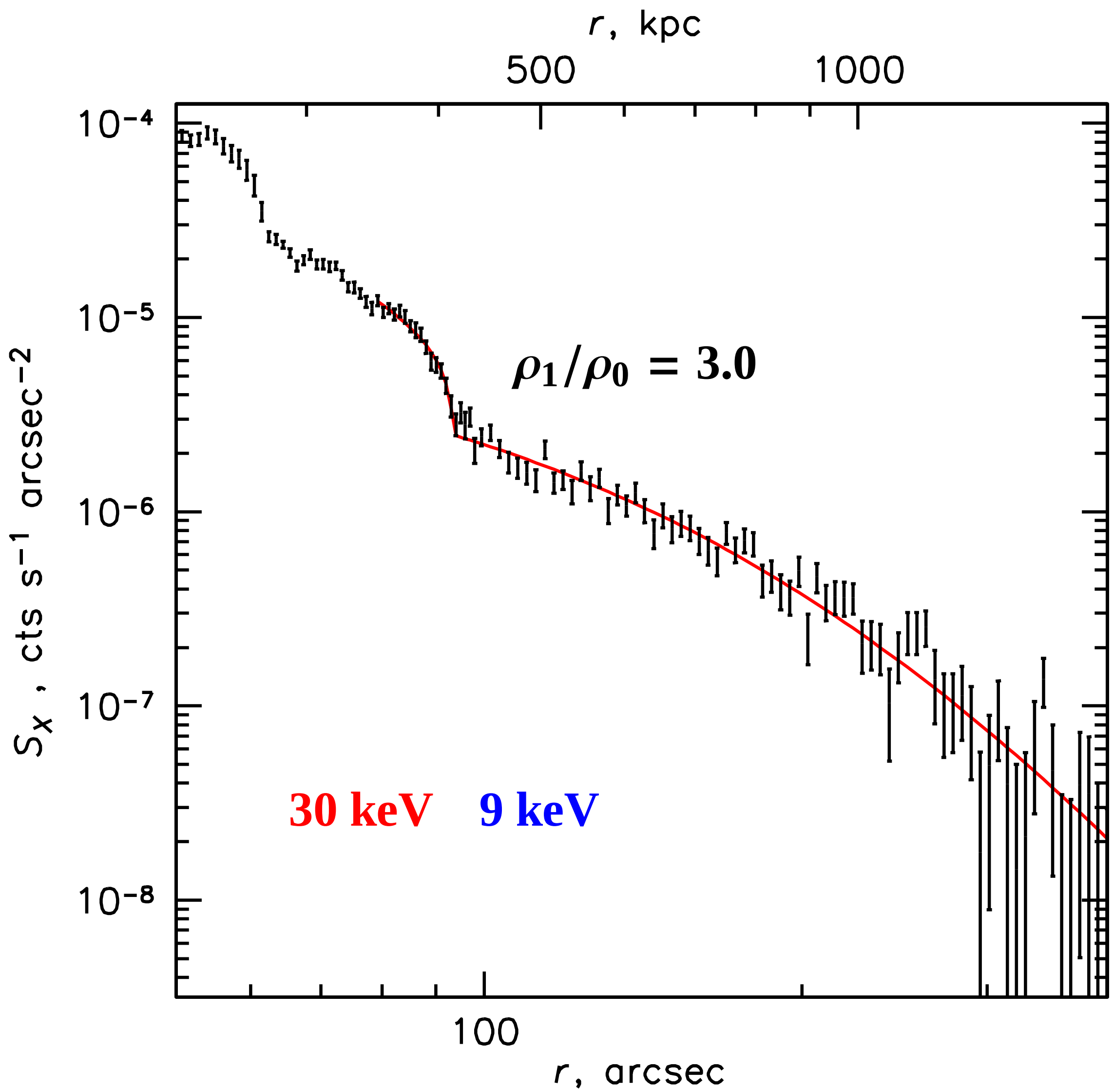


Spitzer τ_{ei} (Takizawa 1999)

1E 0657–56



Nose sector of the front



M = 3.0 ± 0.4, shock v = 4700 km s^{-1}, post-shock v = 1600 km s^{-1}

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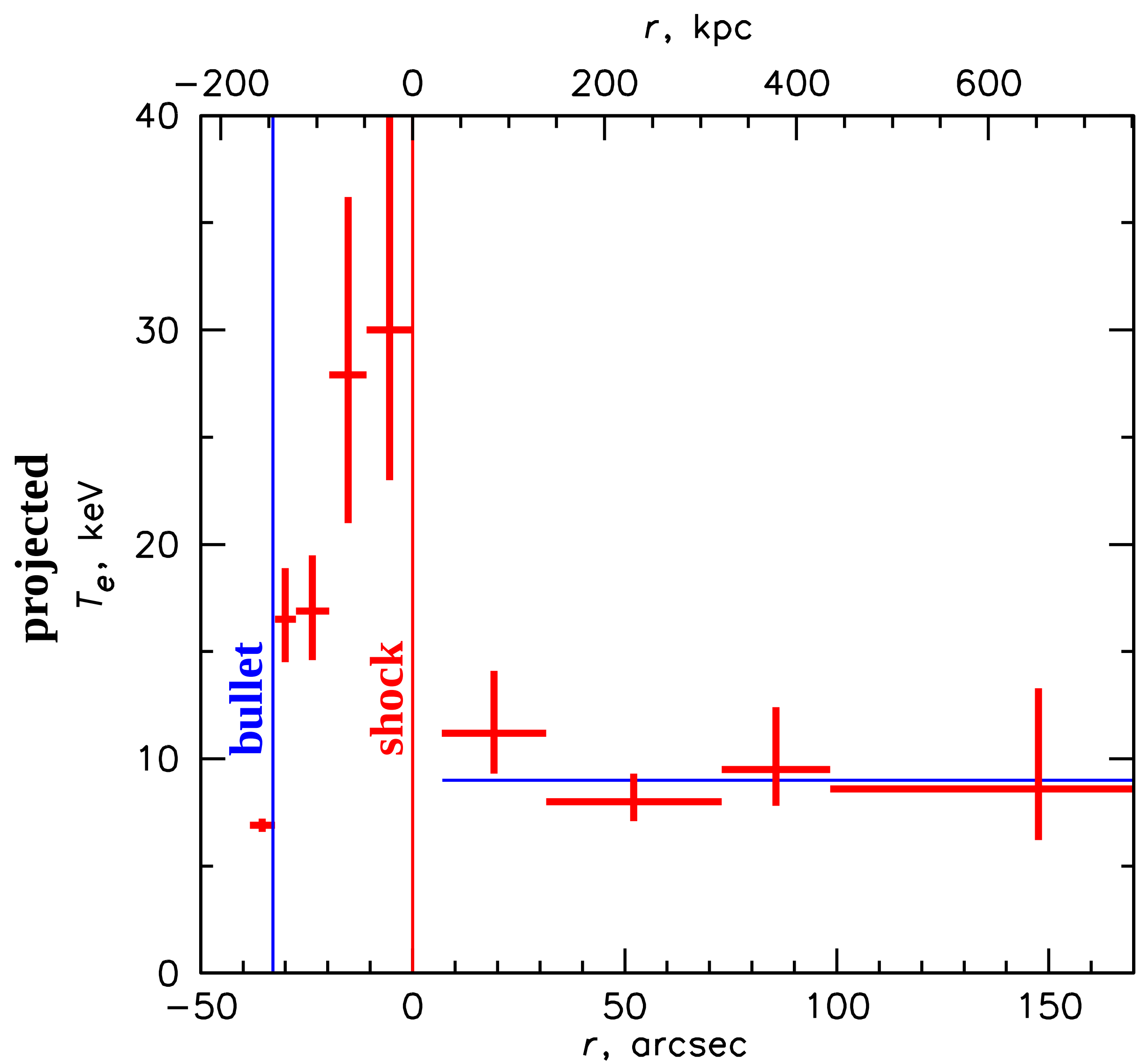

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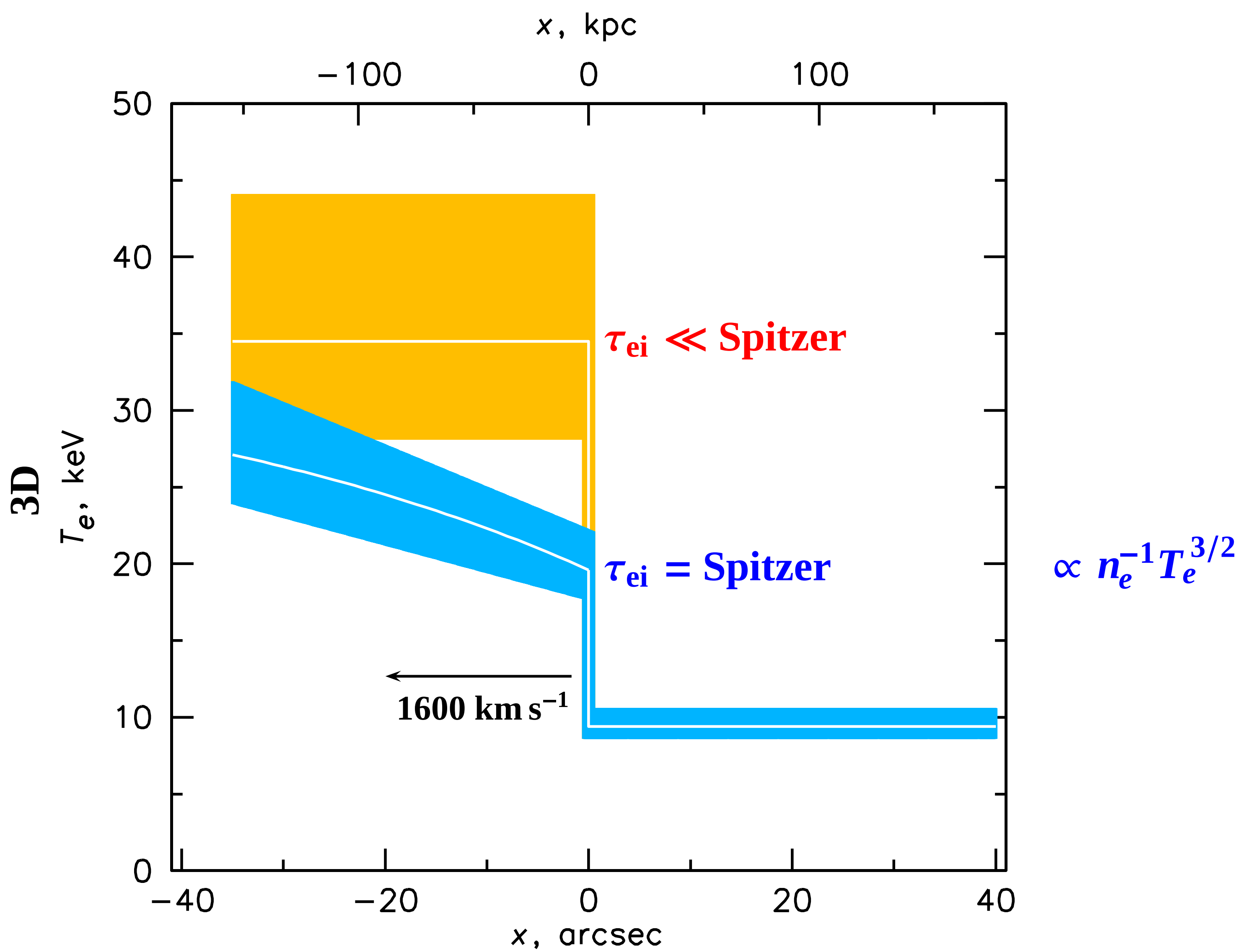

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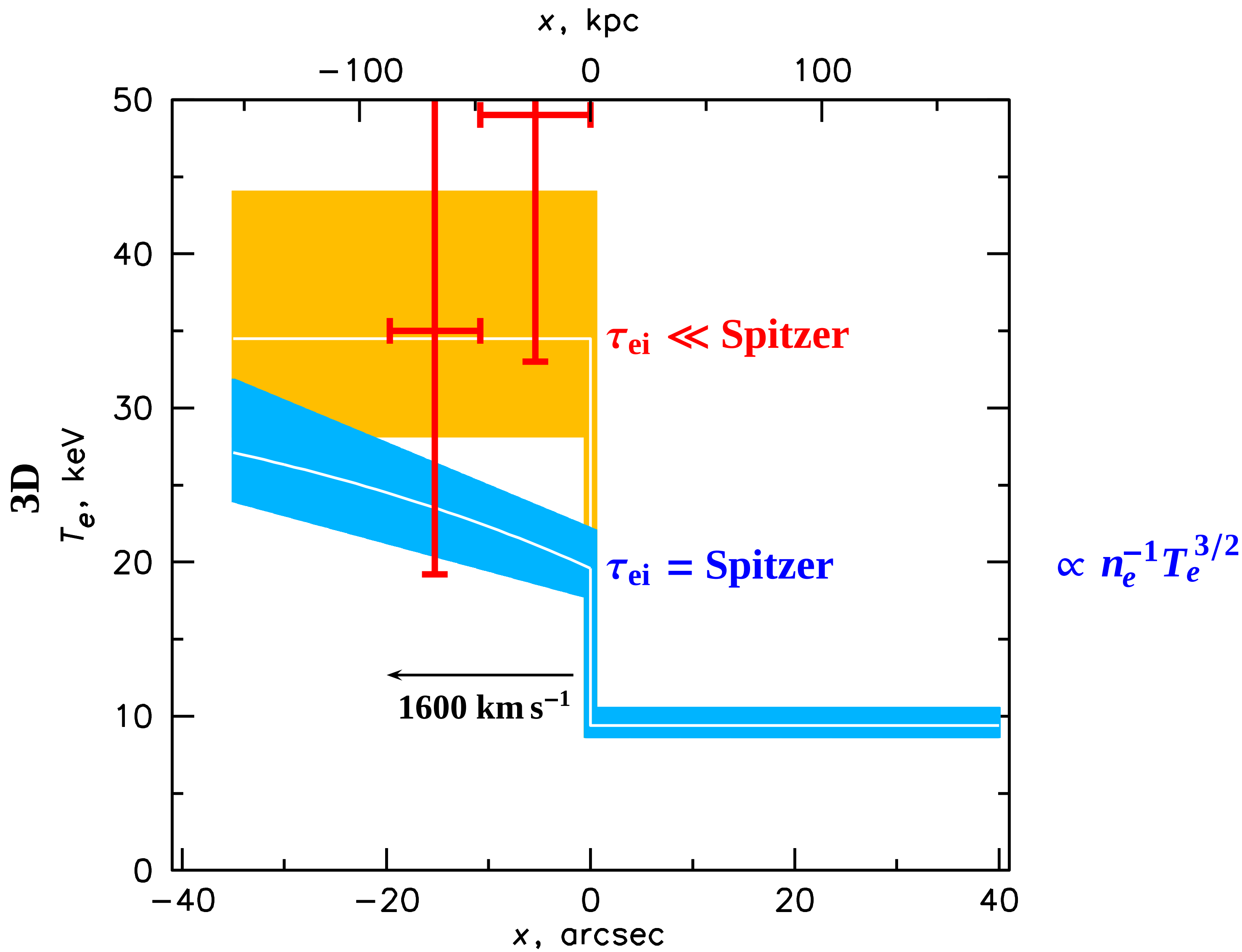
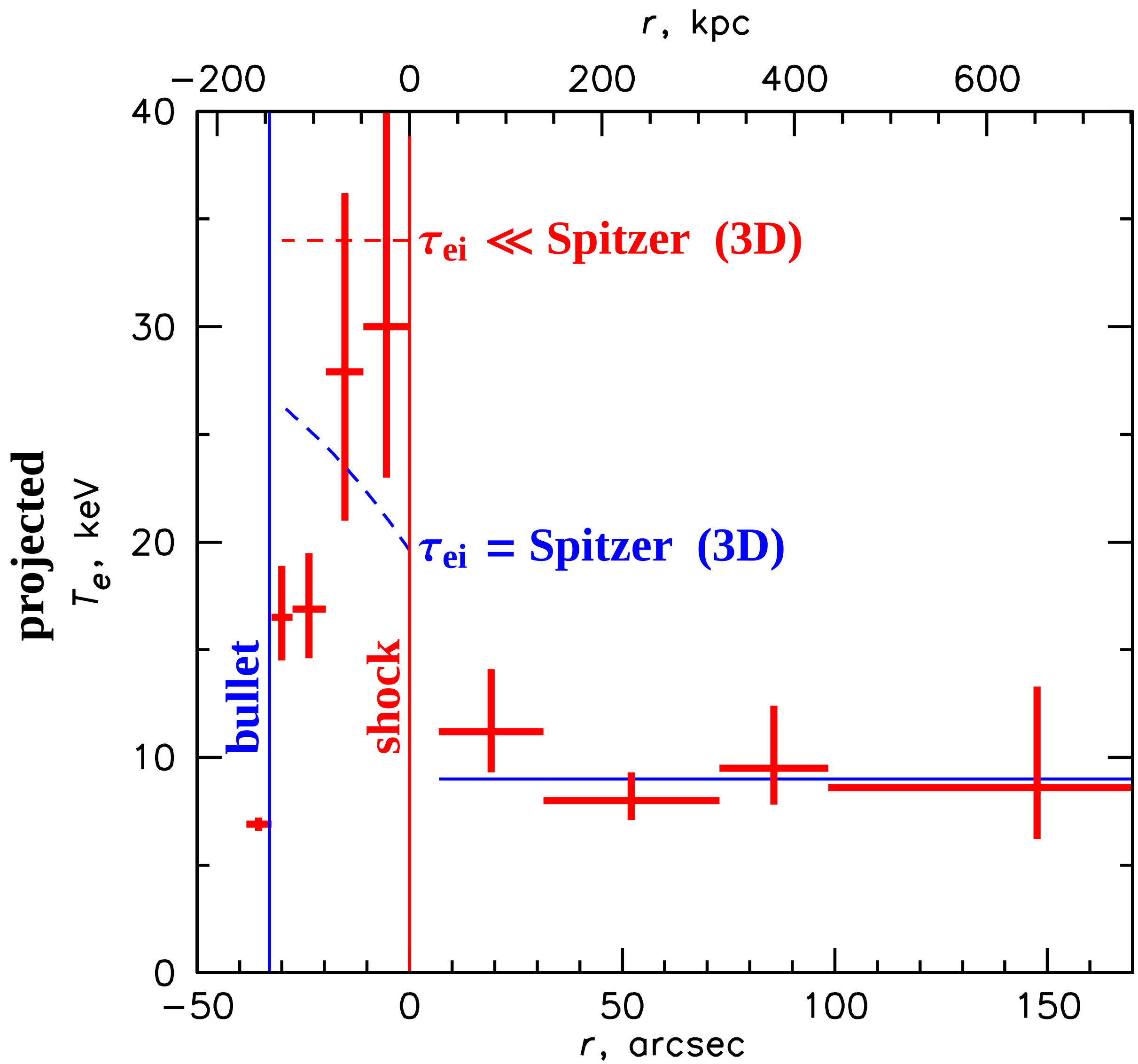
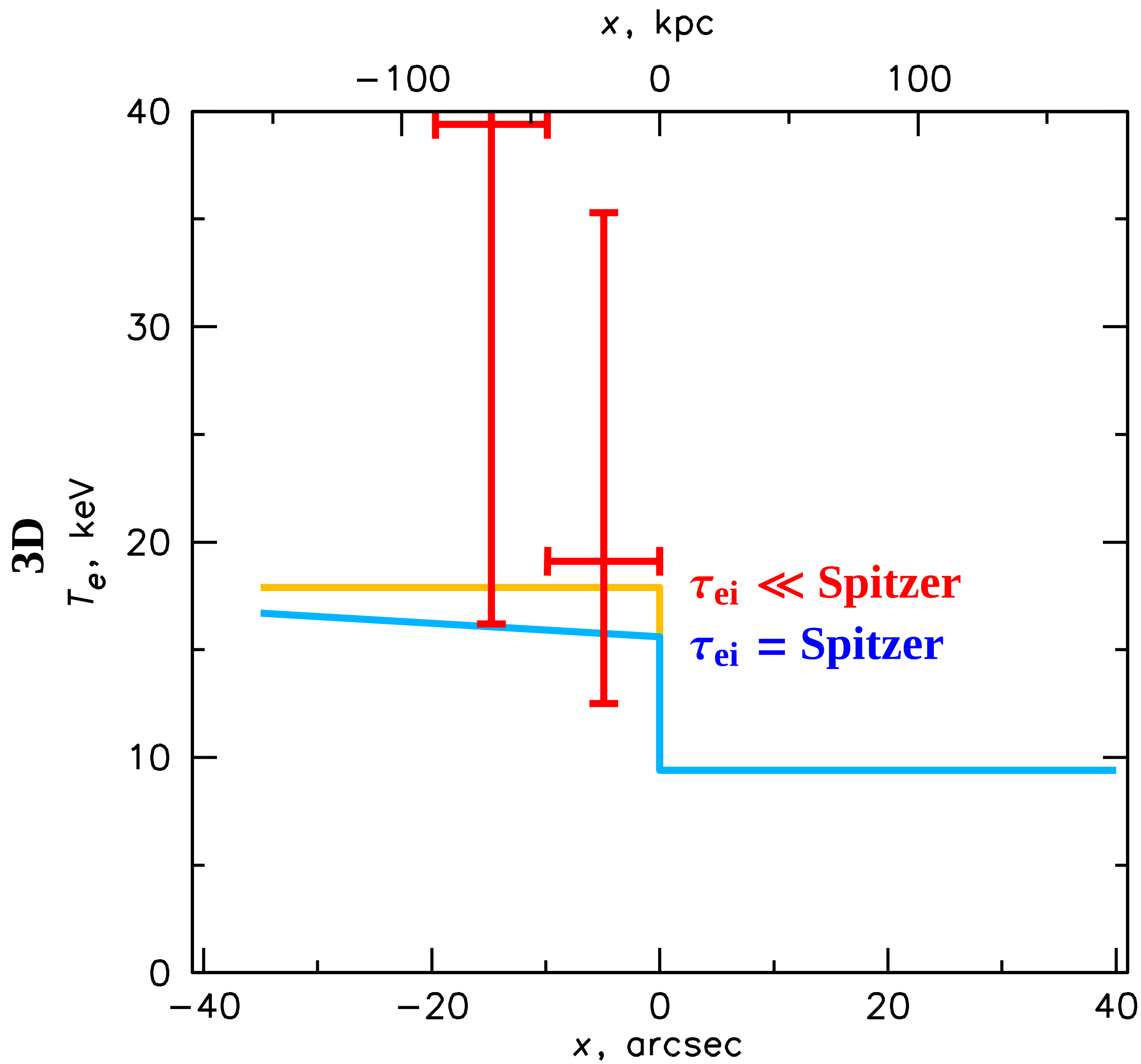


- **95% confidence:** $\tau_{ei} \ll$ **Spitzer**

Nose sector of the front

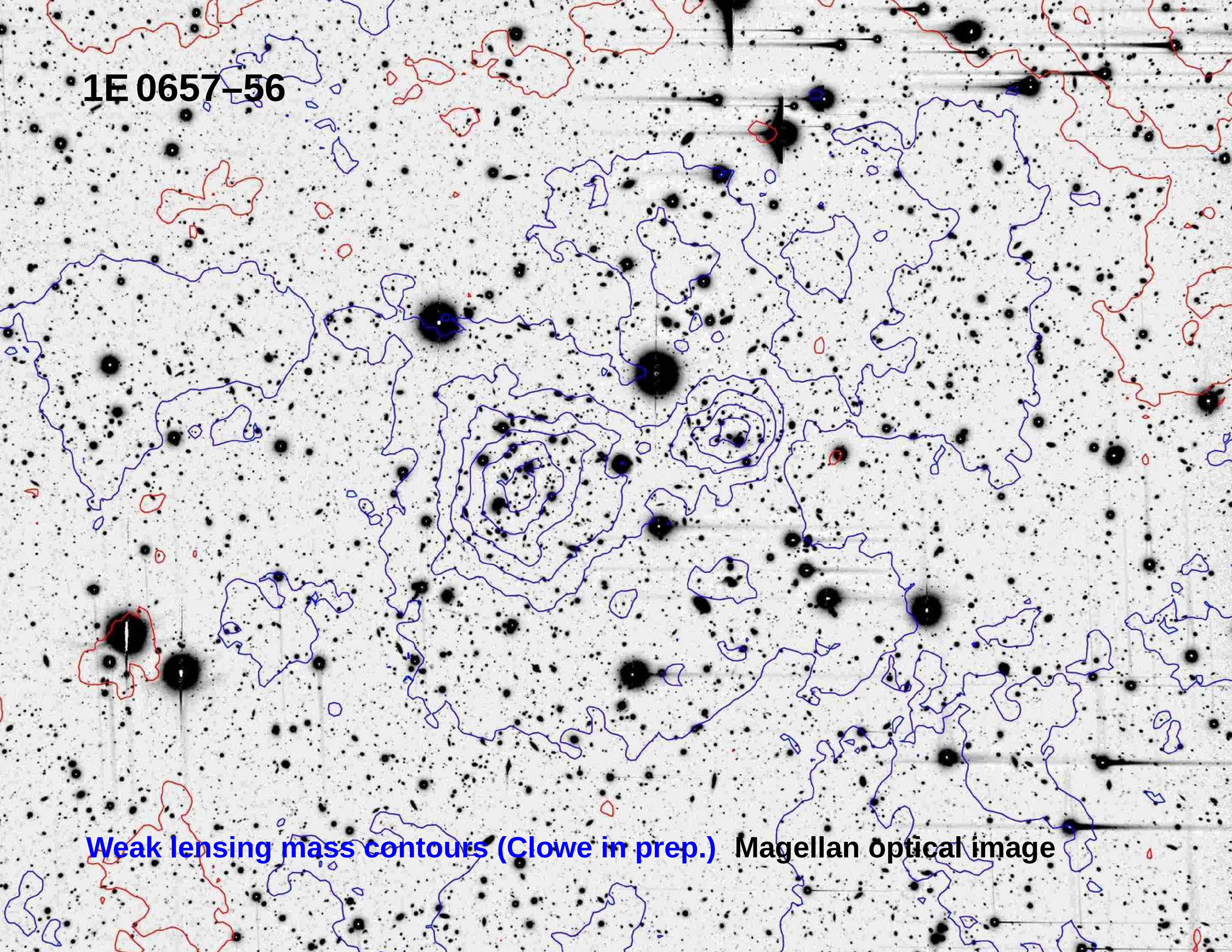


Oblique sector of the front (M = 1.9)

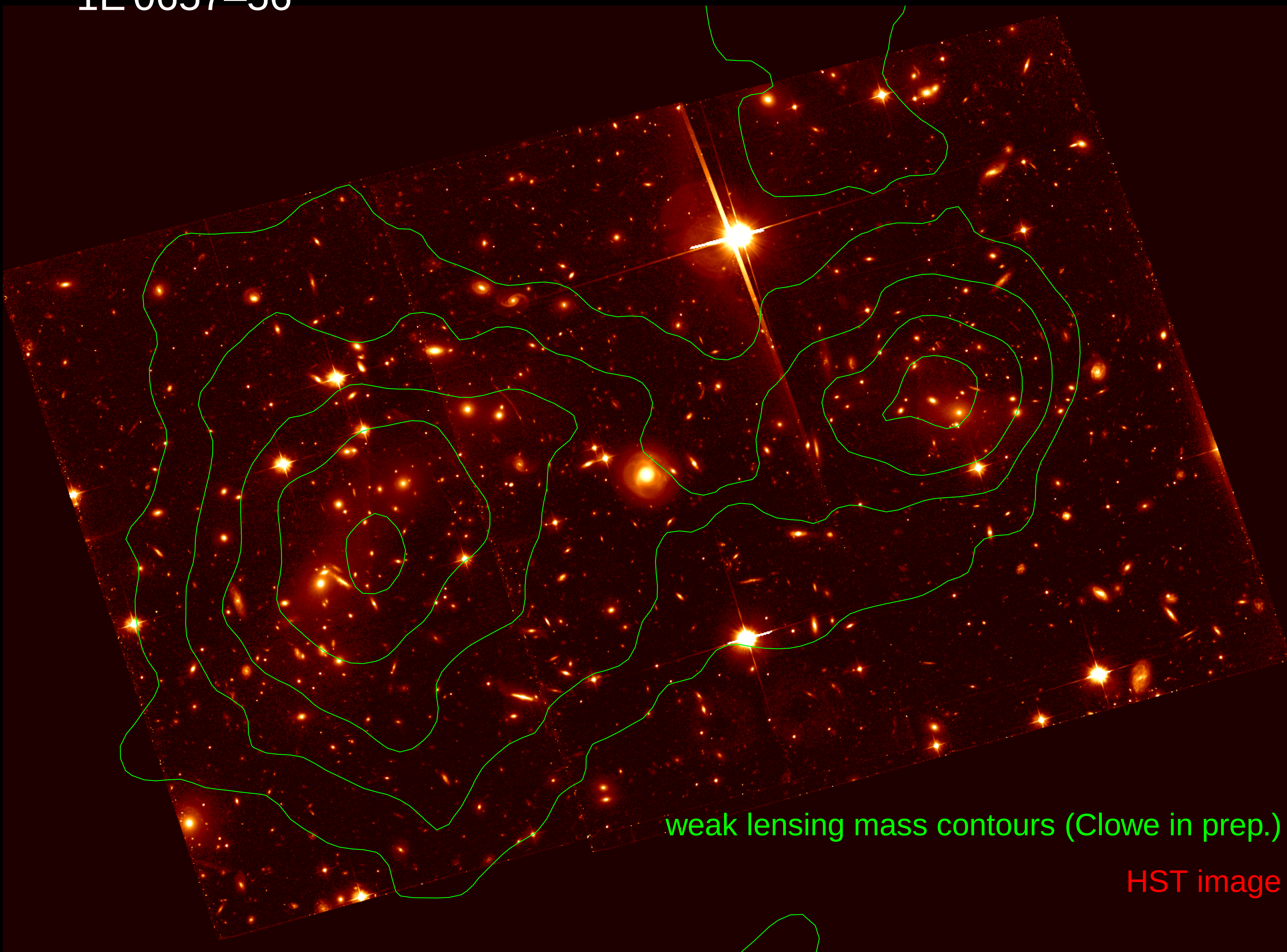


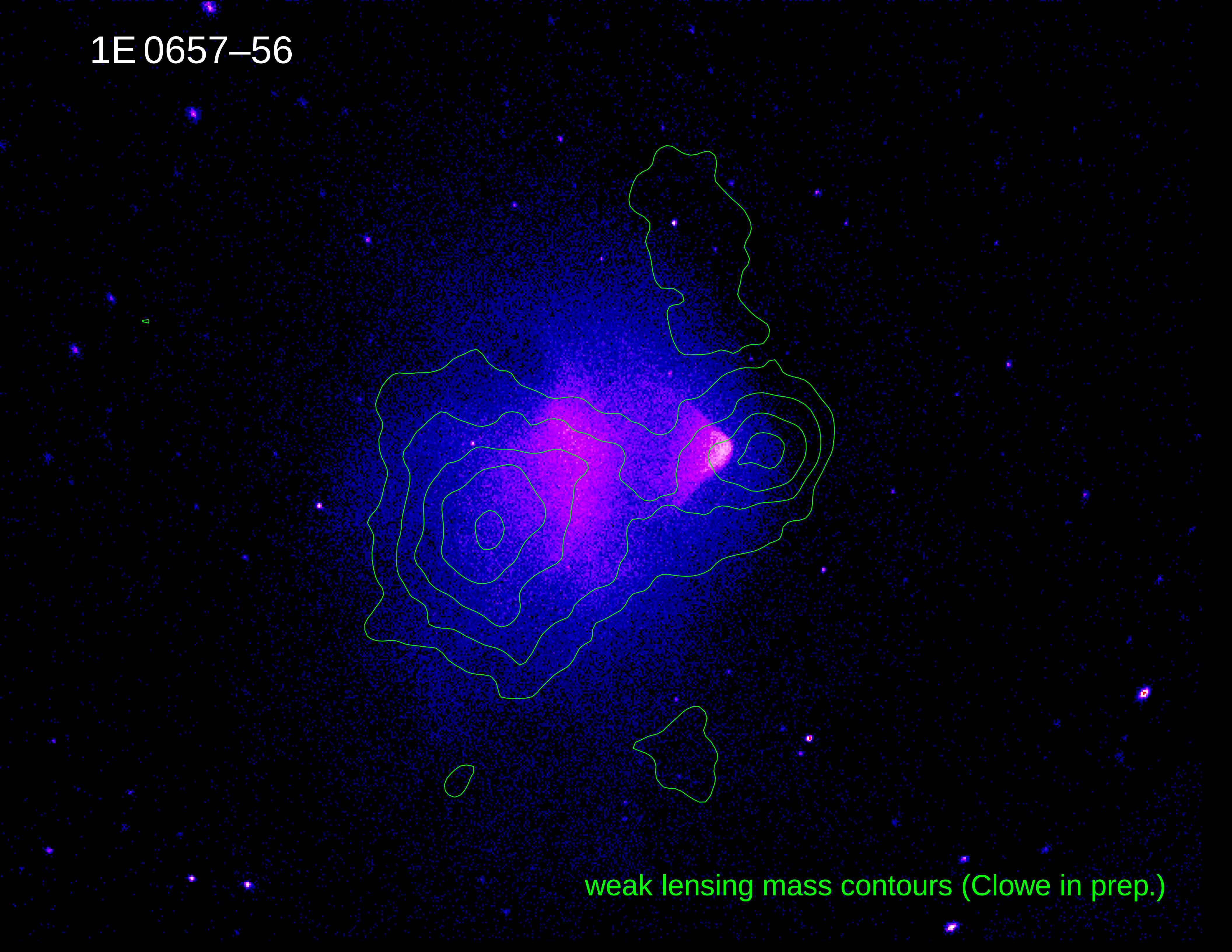
Constraints on dark matter

(does it even exist?)


1E 0657–56
Weak lensing mass contours (Clowe in prep.)
Magellan optical image

1E 0657–56




1E 0657–56
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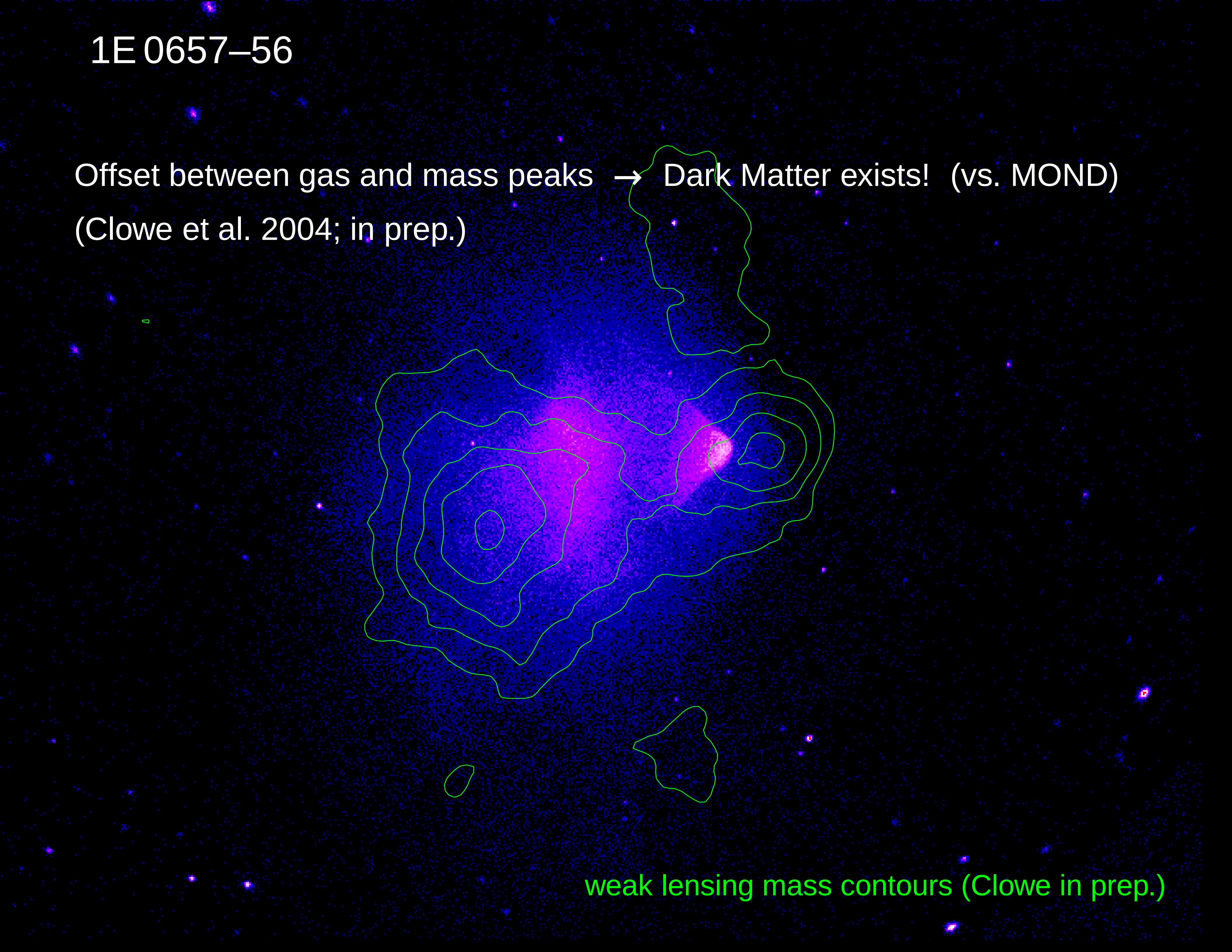
1E 0657–56

Offset between gas and mass peaks → Dark Matter exists! (vs. MOND)

(Clowe et al. 2004; in prep.)



Direct constraint on Dark Matter self-interaction cross-section

Observational evidence:

1. **Offset between gas and dark matter clump**
2. **No offset between dark matter and galaxies**
3. **Subcluster's M/L ratio close to universal**
4. **Subcluster's velocity not less than free-fall velocity**
5. **Ram pressure on gas bullet is balanced by grav. force of dark matter clump**

The best constraint comes from method 3 (Markevitch et al. 2004):

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

2005: new lensing data, method 2 can improve limit by $\times 2-3$ (S. Randall in prep.)

SIDM with $\sigma/m \sim 0.5 - 5\ \mathrm{cm^2\,g^{-1}}$ was proposed to explain problems in standard CDM:

- **Absence of central cusps in dwarf galaxies**
- **Too many surviving small-mass subhalos within large halos**

(Spergel & Steinhardt 2000; Davé et al. 2001)

Some other astrophysical constraints as low as $\sigma/m < 0.1\ \mathrm{cm^2\,g^{-1}}$

(e.g., Arabadjis et al. 2001; Hennawi & Ostriker 2002; Miralda-Escudé 2002)

- **Our limit is the most direct and model-independent**

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Caveat: all limits valid for isotropic scattering:

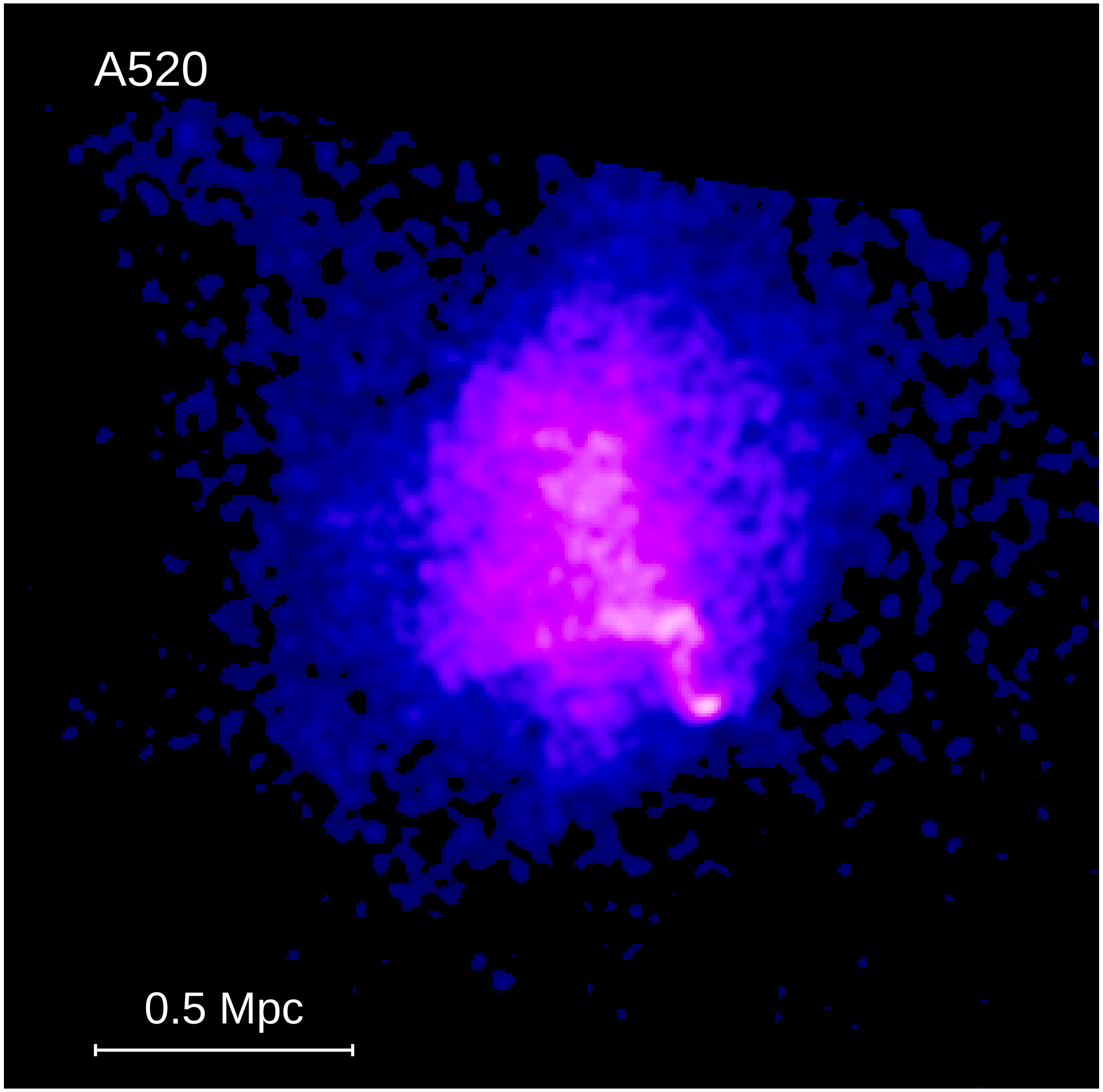
$$\frac{m\,v\,r}{\hbar} \ll 1, \qquad \left(\frac{mc^2}{1\ \mathrm{GeV}}\right)^{3/2}\left(\frac{v}{2400\ \mathrm{km/s}}\right)\left(\frac{\sigma/m}{50\ \mathrm{cm^2/g}}\right)^{1/2} \ll 1$$

Other dynamically important ingredients

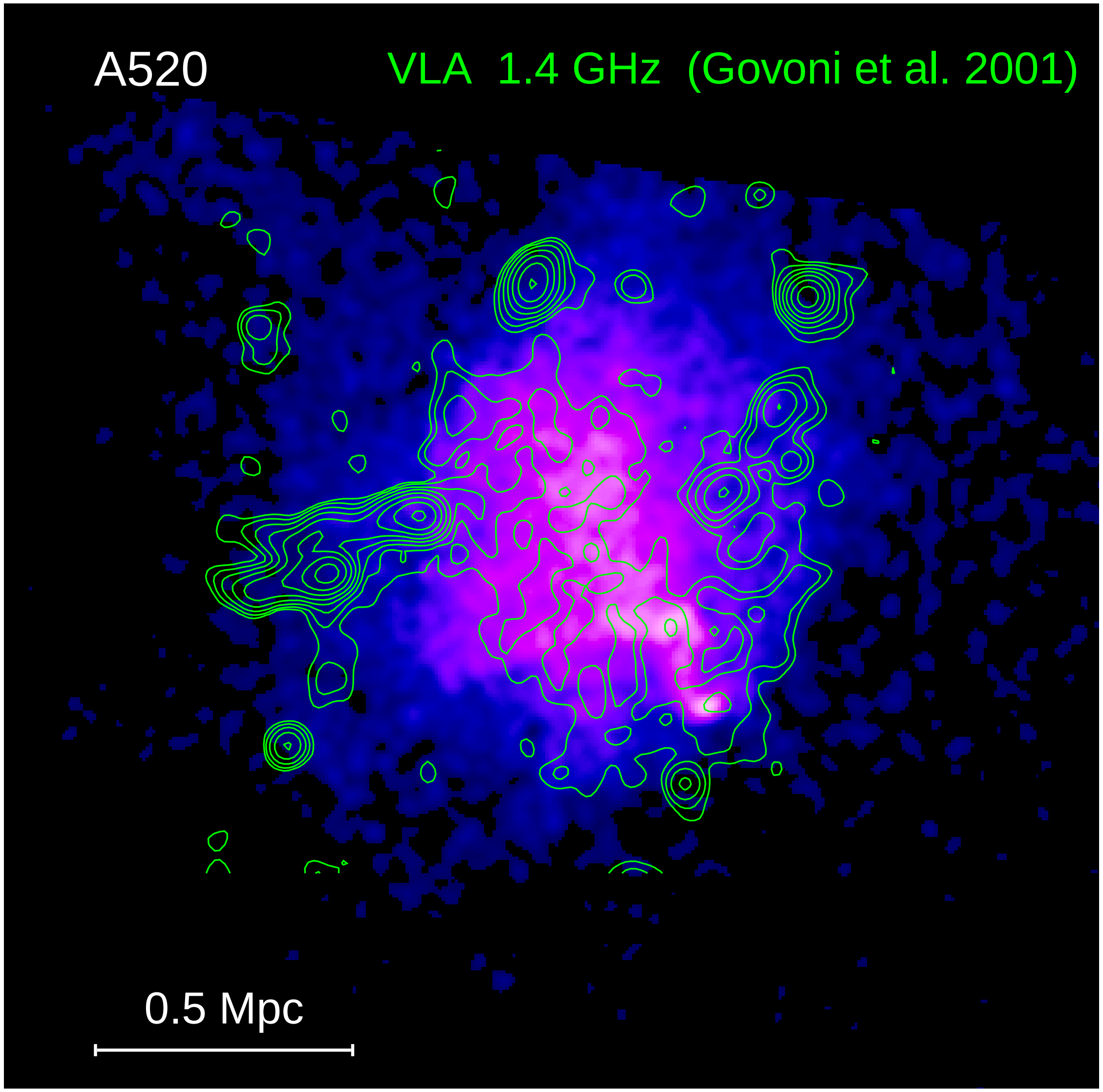
(magnetic fields, cosmic rays) ?

Cluster radio halos

- **Synchrotron radiation from $\gamma \sim 10^4$ electrons**
- **Electrons accelerated in cluster mergers — by shocks or turbulence**
- **Very short lifetime ($10^7 - 10^8$ yr)**



Markevitch et al. (2005)



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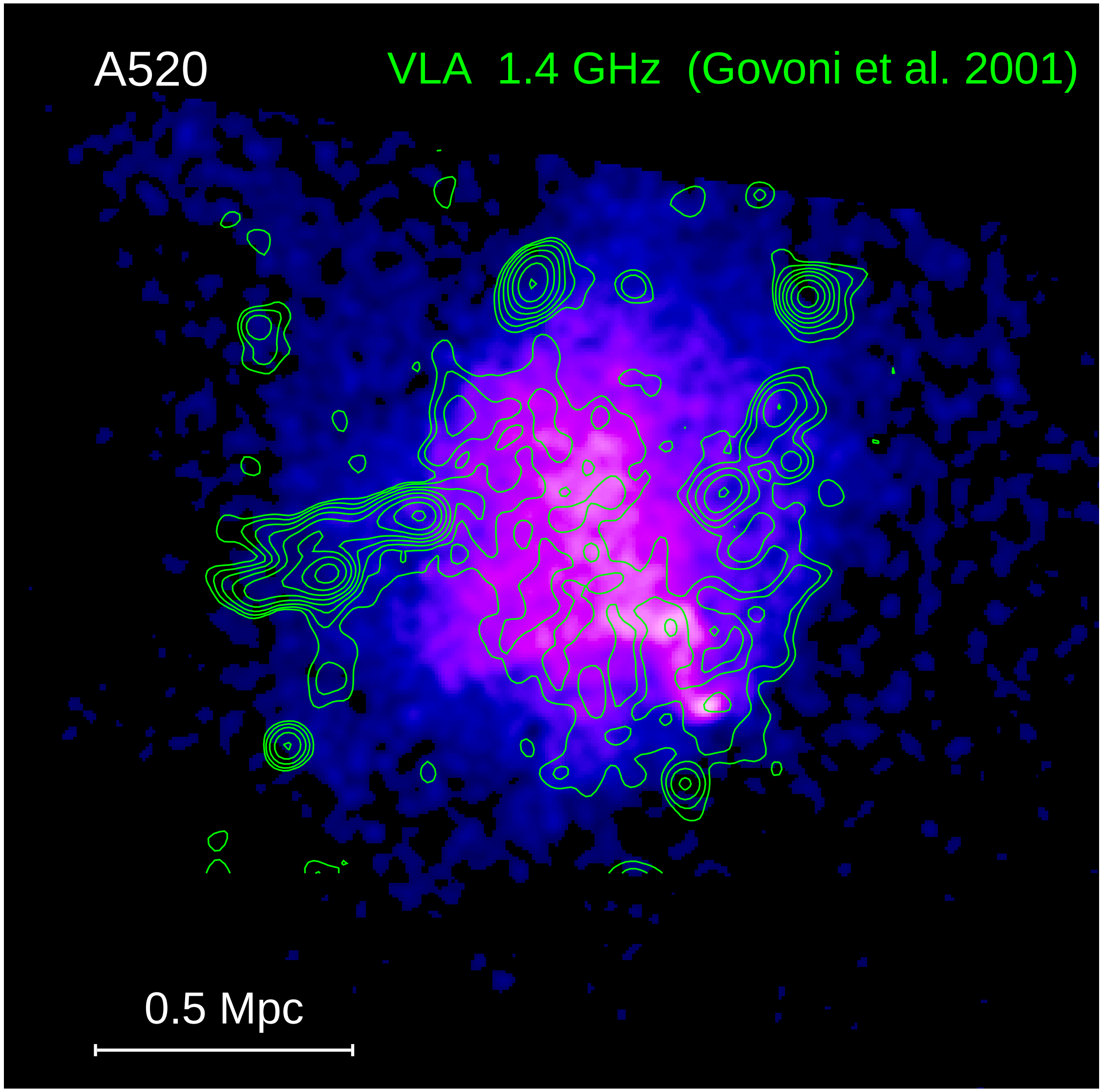


Radio edge:

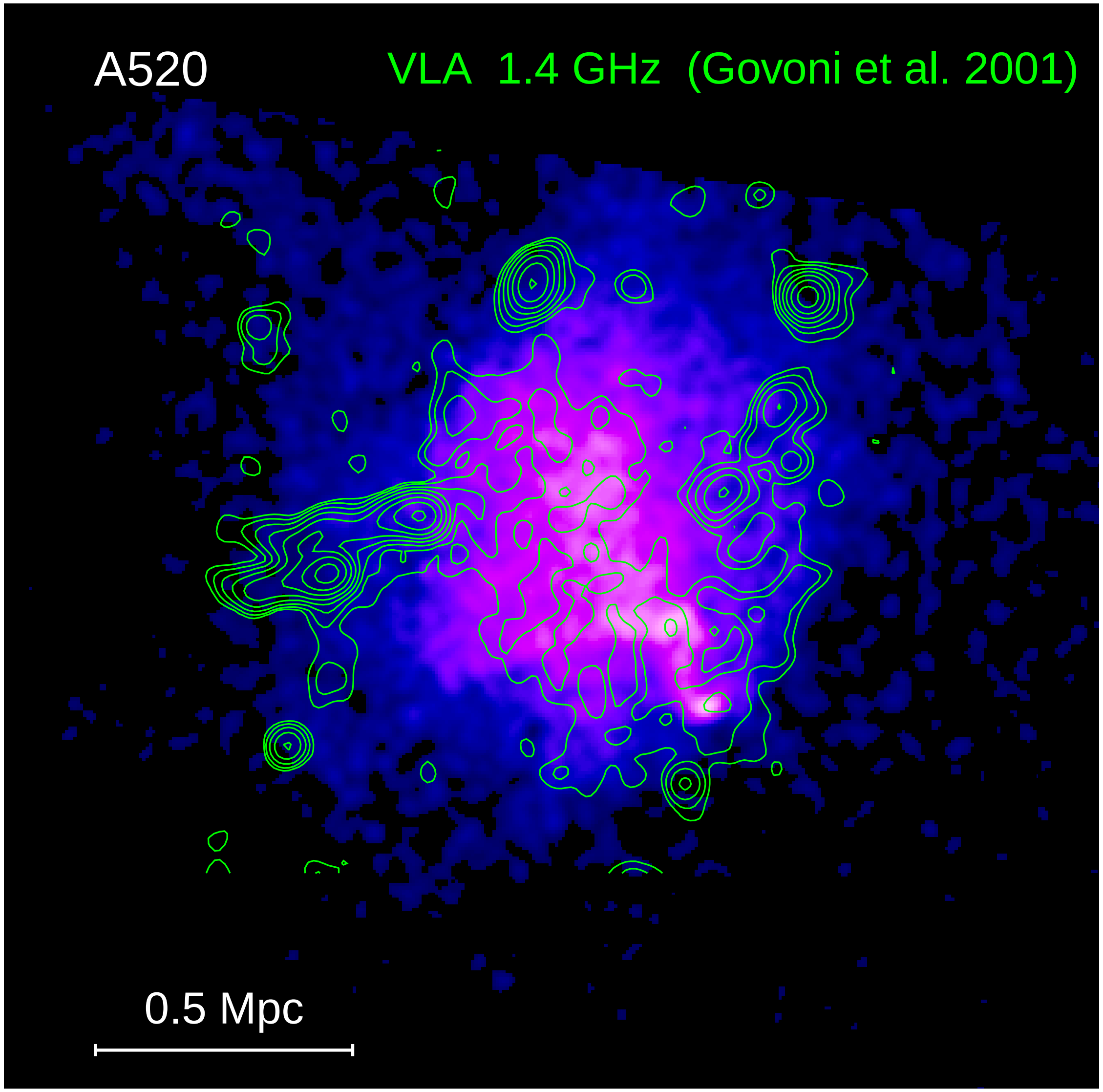
Fermi acceleration at shock?

→ $I_\nu \propto \nu^{-1.2}$

Compression of fossil electrons?

→ Pre-shock radio emission (10–20 times fainter)

Markevitch et al. (2005)



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Electron lifetime depends on *B*

→ From width of halo edge, and gas post-shock velocity, can measure *B* in 0.1 – 3 μG range

Summary

- **Mergers overheat clusters**
  need thorough exclusion from high z samples to avoid errors

- **Thermal conduction suppressed by factor $>$ 10 in bulk of ICM,**
  more across cold fronts

- **Electron-proton equilibration in ICM is faster than Spitzer (2σ result)**

- **Dark matter exists!**

- **DM self-interaction cross-section $\sigma/m < 1\ \mathrm{cm}^2\,\mathrm{g}^{-1}$ — to be improved soon**

- **In future, can use bow shocks for measuring B**
  and studying cosmic ray acceleration mechanism

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