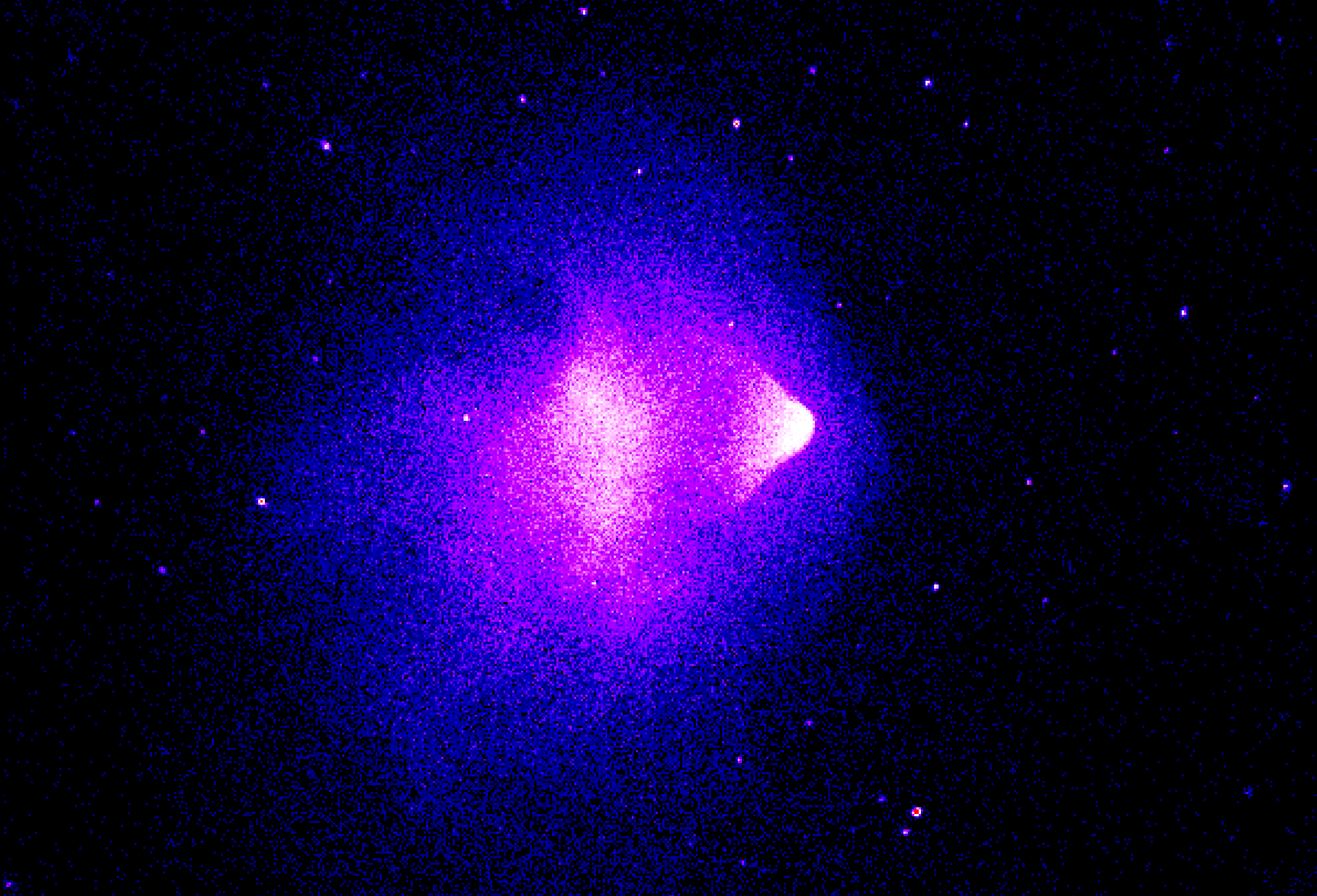
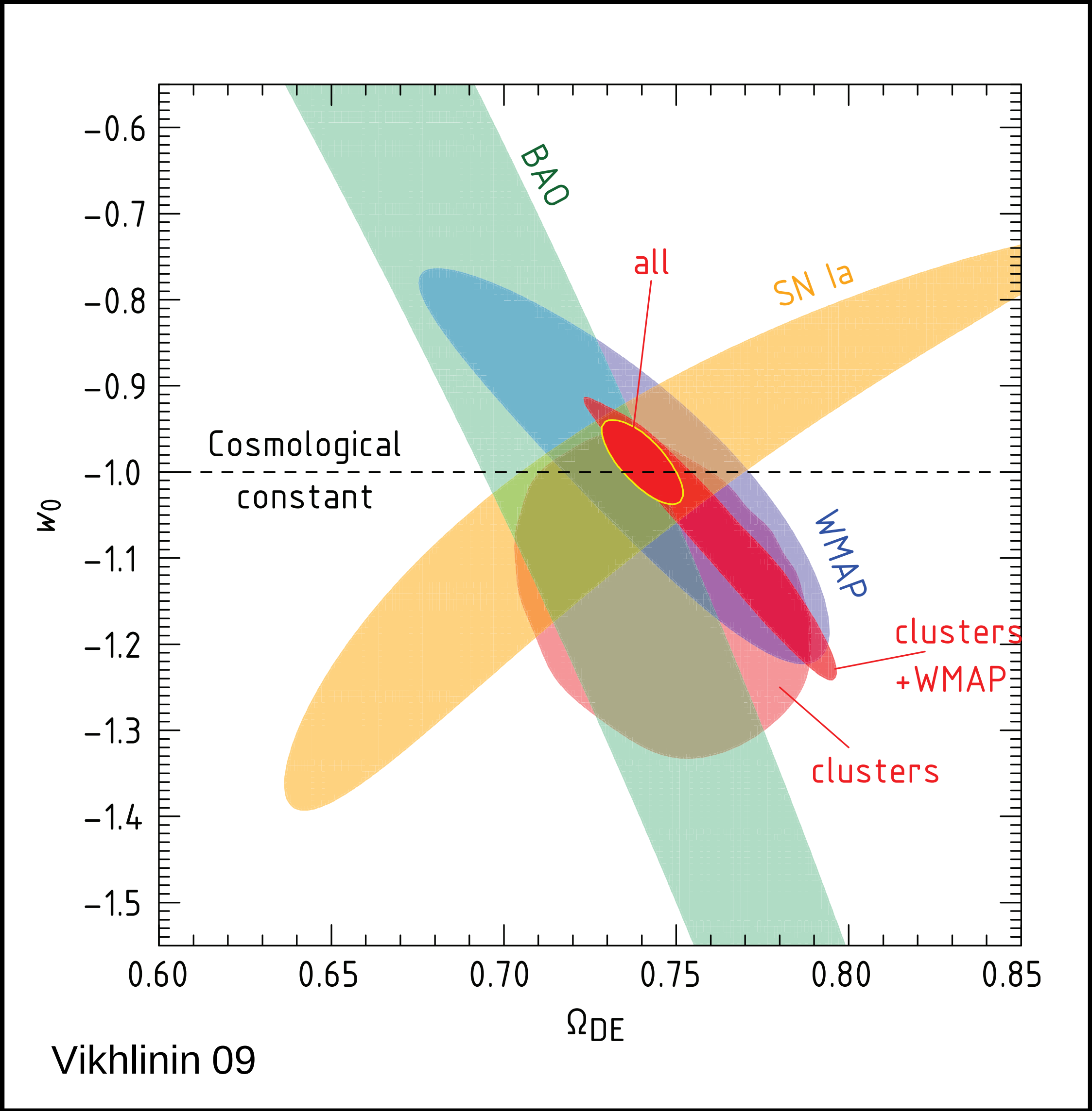
Shocks and cold fronts in galaxy clusters



Maxim Markevitch (NASA GSFC)

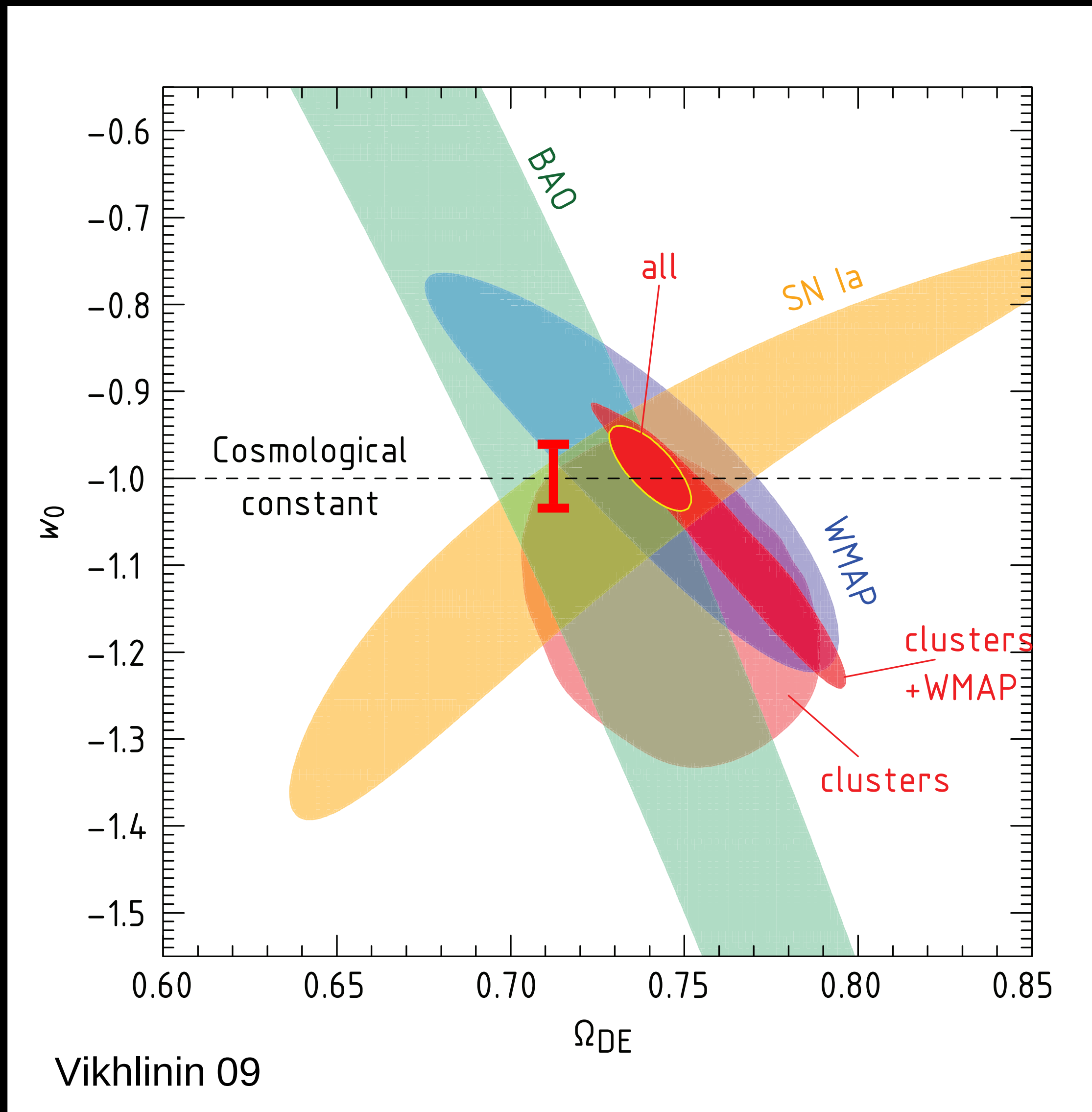
Milan, October 2012

Cluster precision cosmology



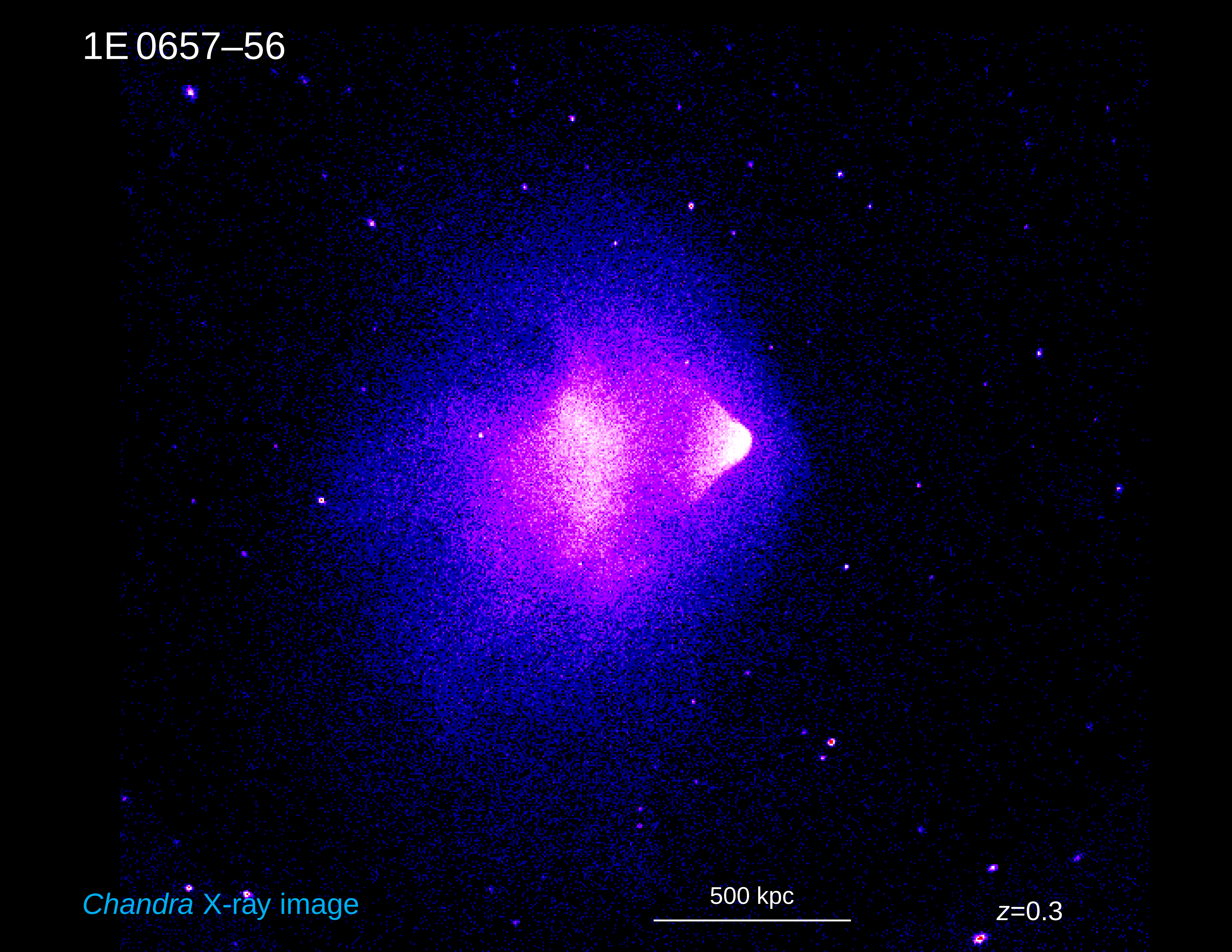
Cluster precision cosmology

only as precise as our knowledge of cluster physics



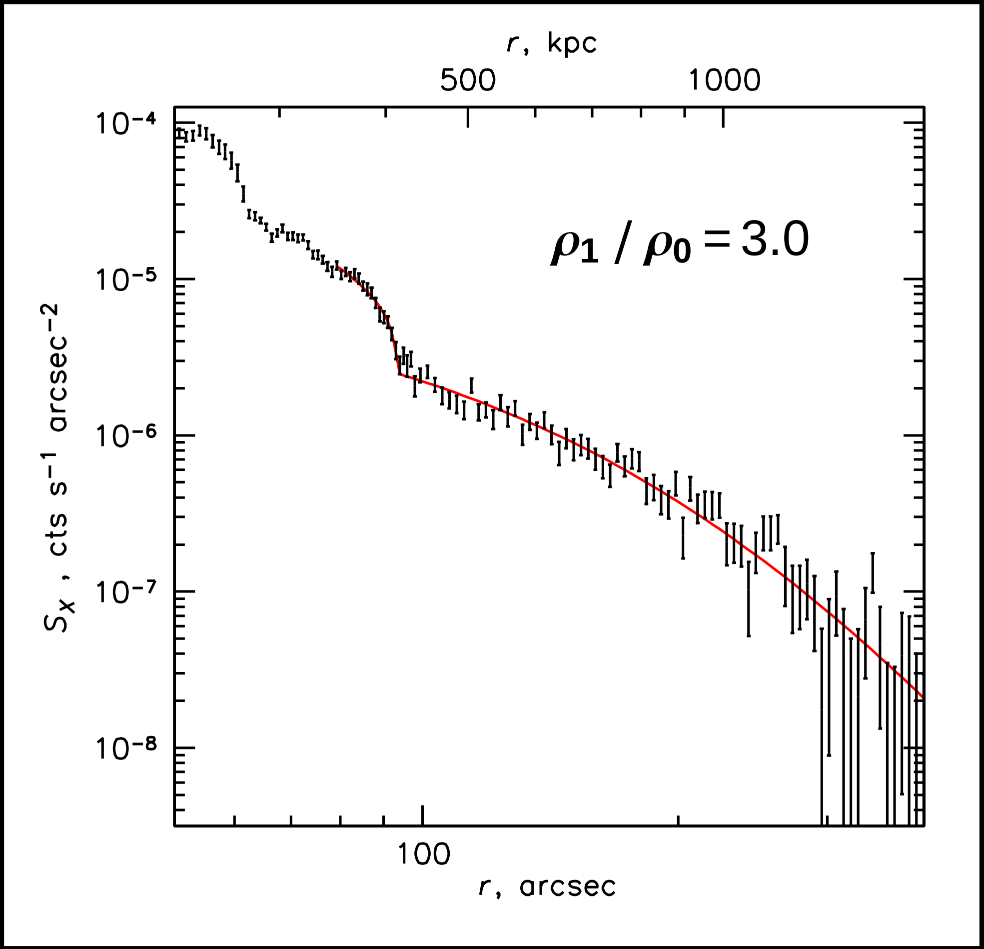
±10% mass error

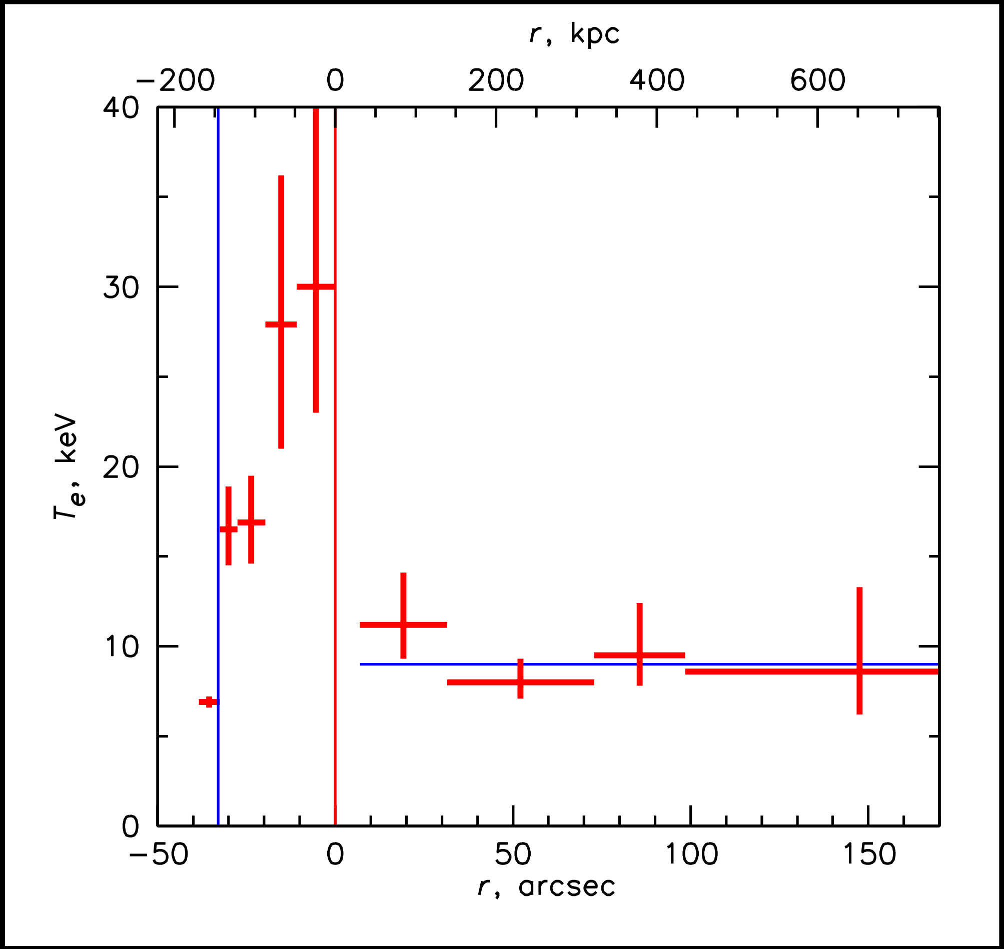
Cluster physics from shock fronts



Chandra X-ray image

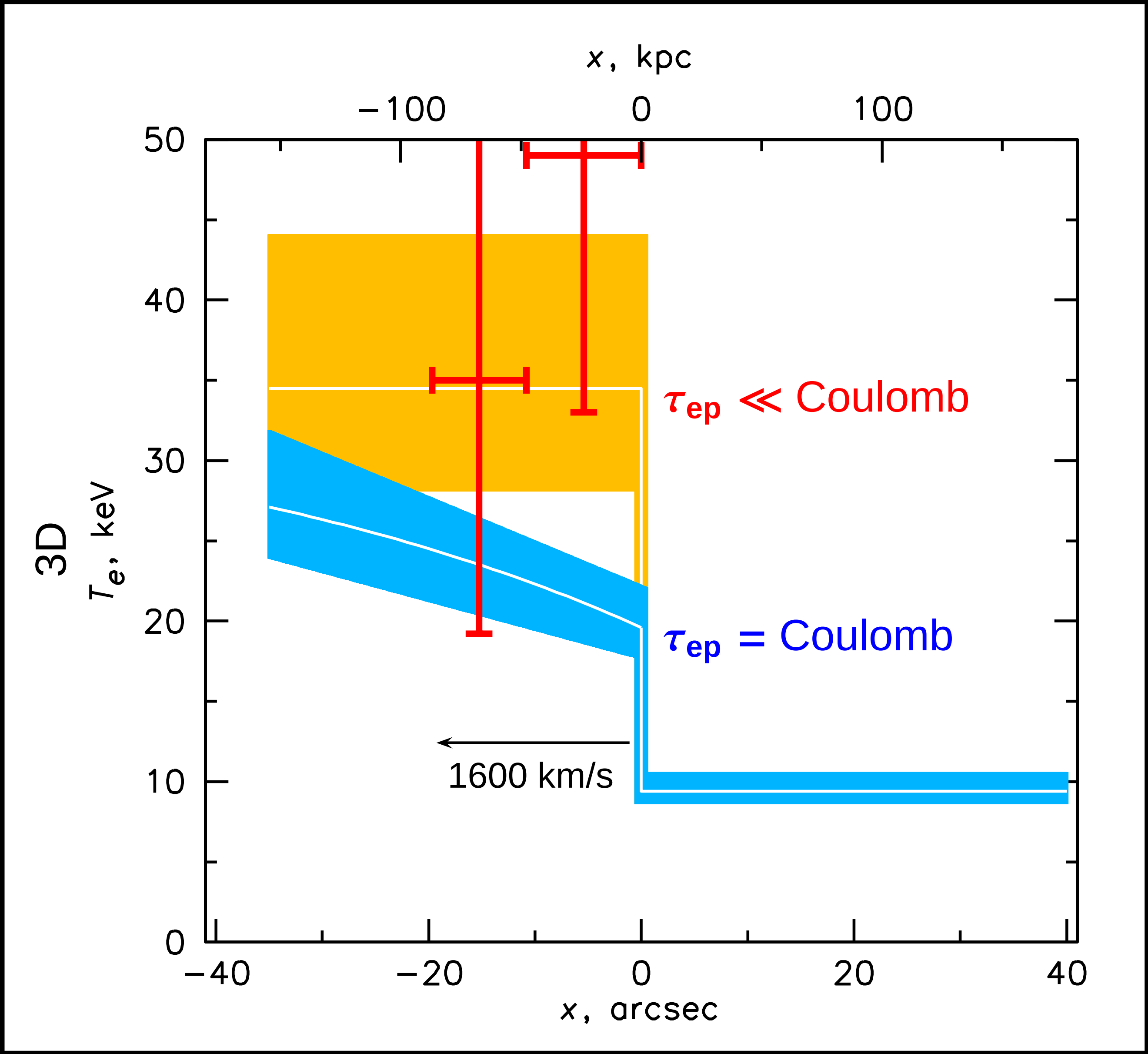
1E0657–56: bullet and shock front





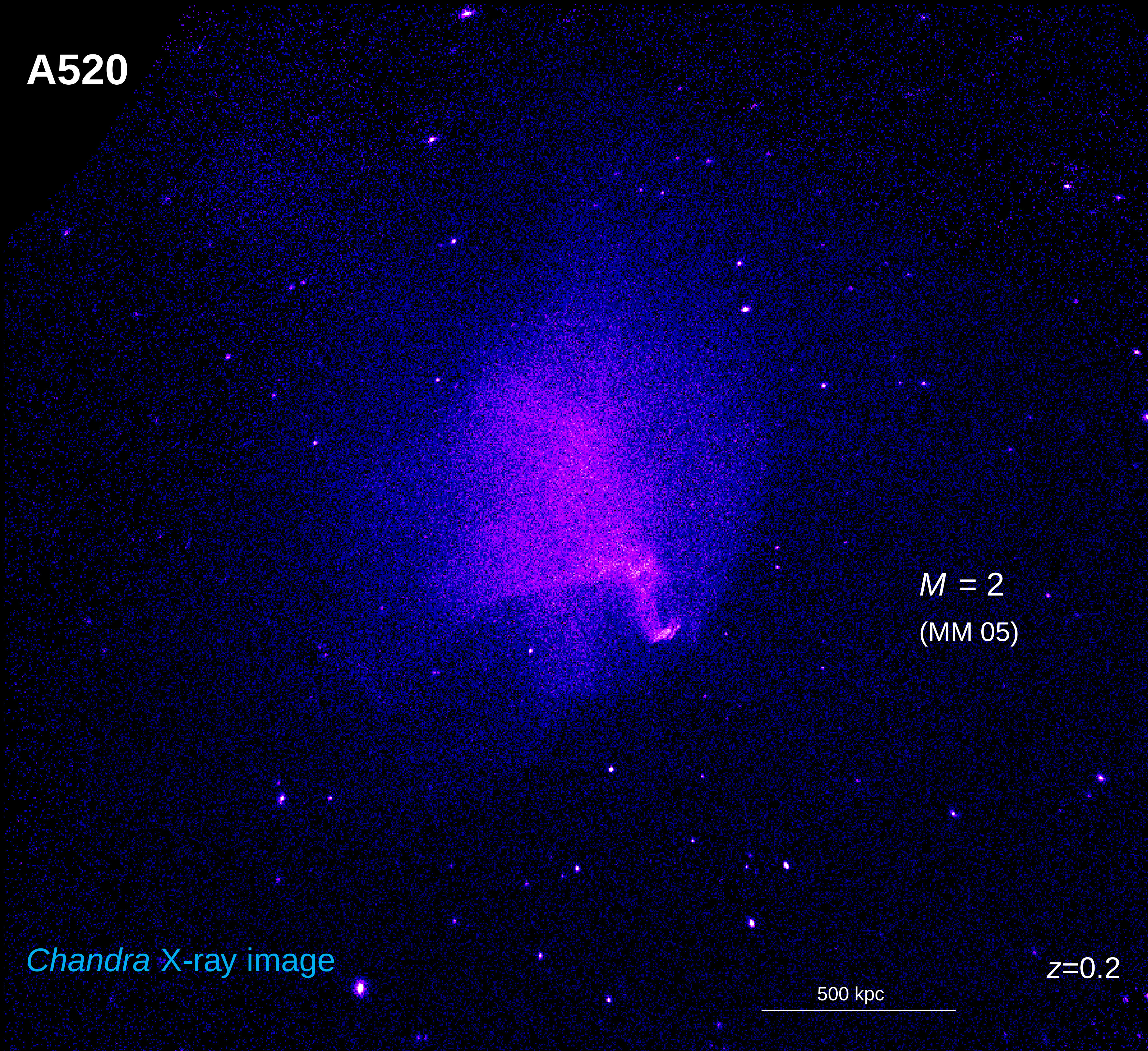
$M = 3.0 \pm 0.4$, shock $v = 4700$ km/s

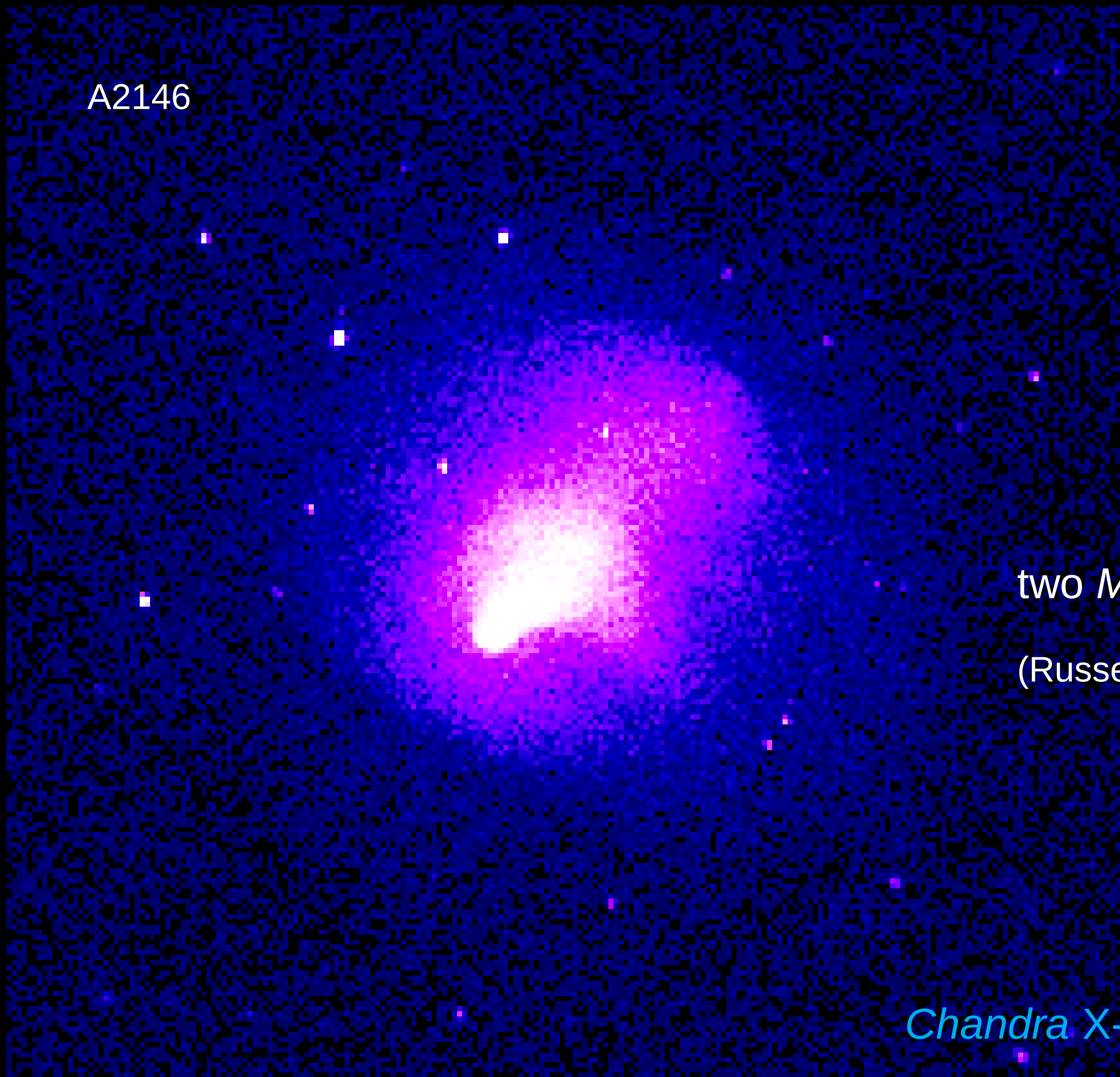
1E 0657 shock: electron-proton equilibration timescale



MM 06

- 95% confidence: τ_{ep} ≪ Coulomb
  (or electrons are heated right at shock)


A520
M = 2
(MM 05)
Chandra X-ray image
500 kpc
z=0.2



two $M \sim 2$ shocks

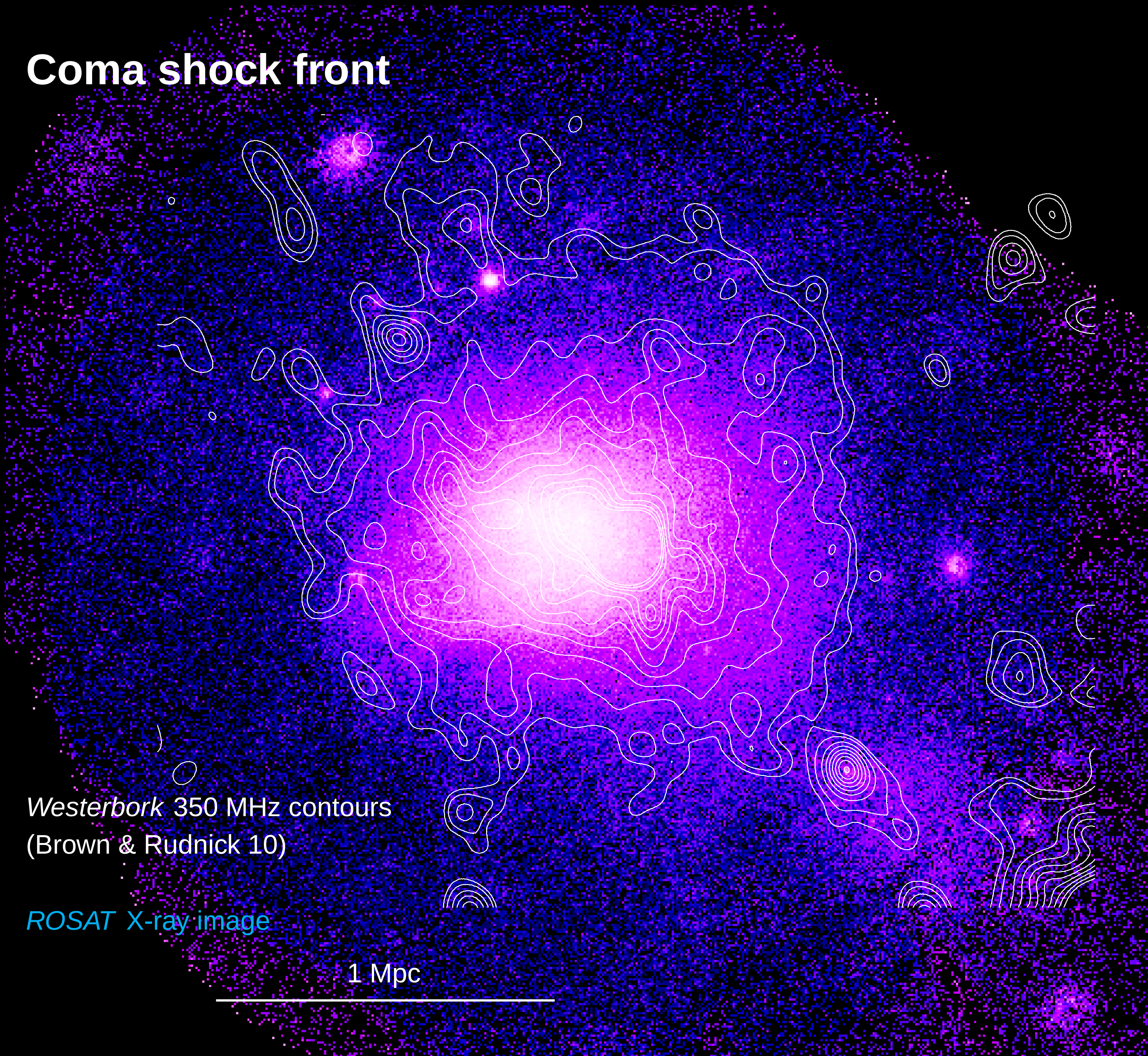
(Russell et al. 10, 12)

Chandra X-ray image

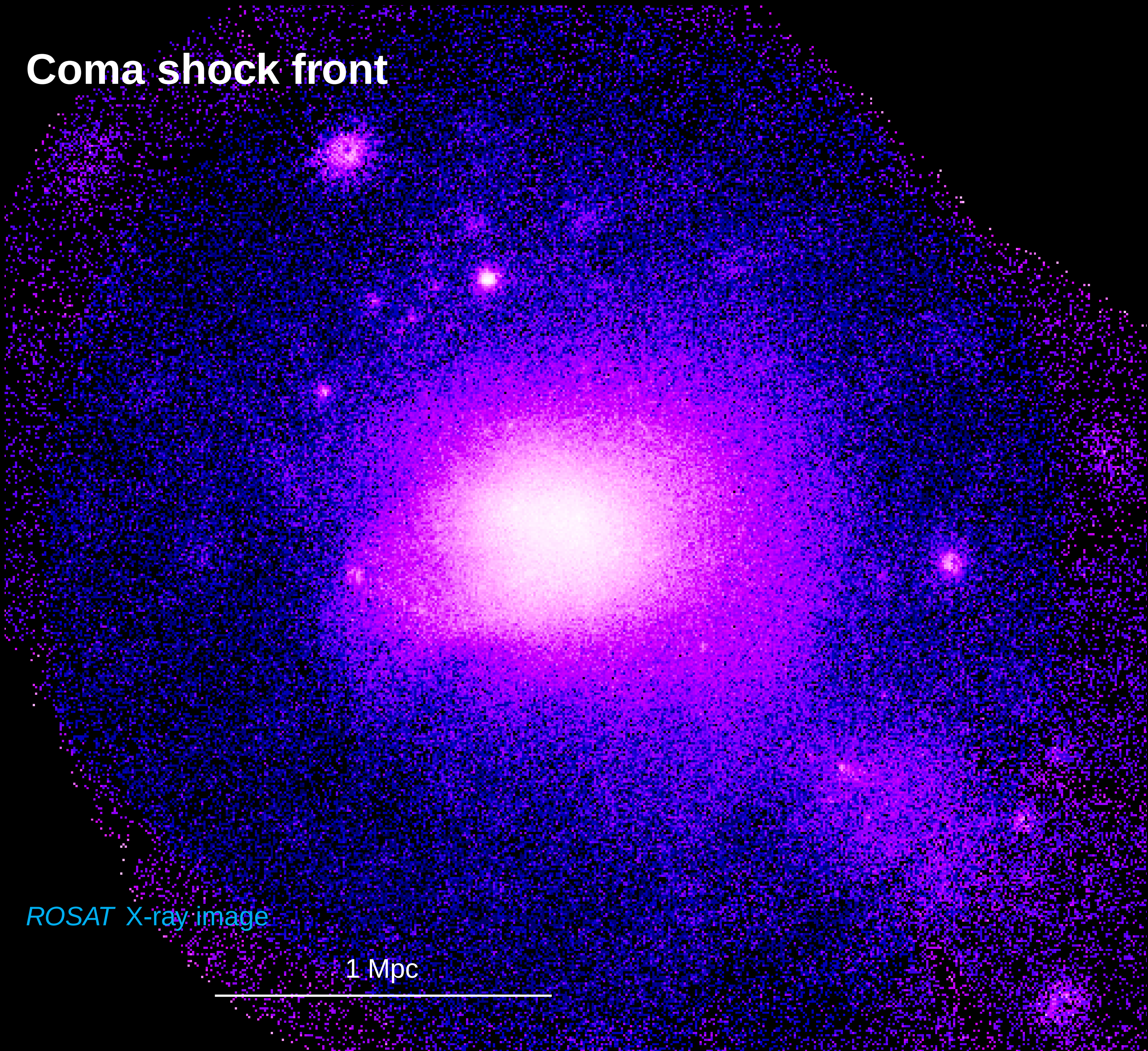
z=0.23

Shocks and relativistic electrons in clusters

Coma shock front



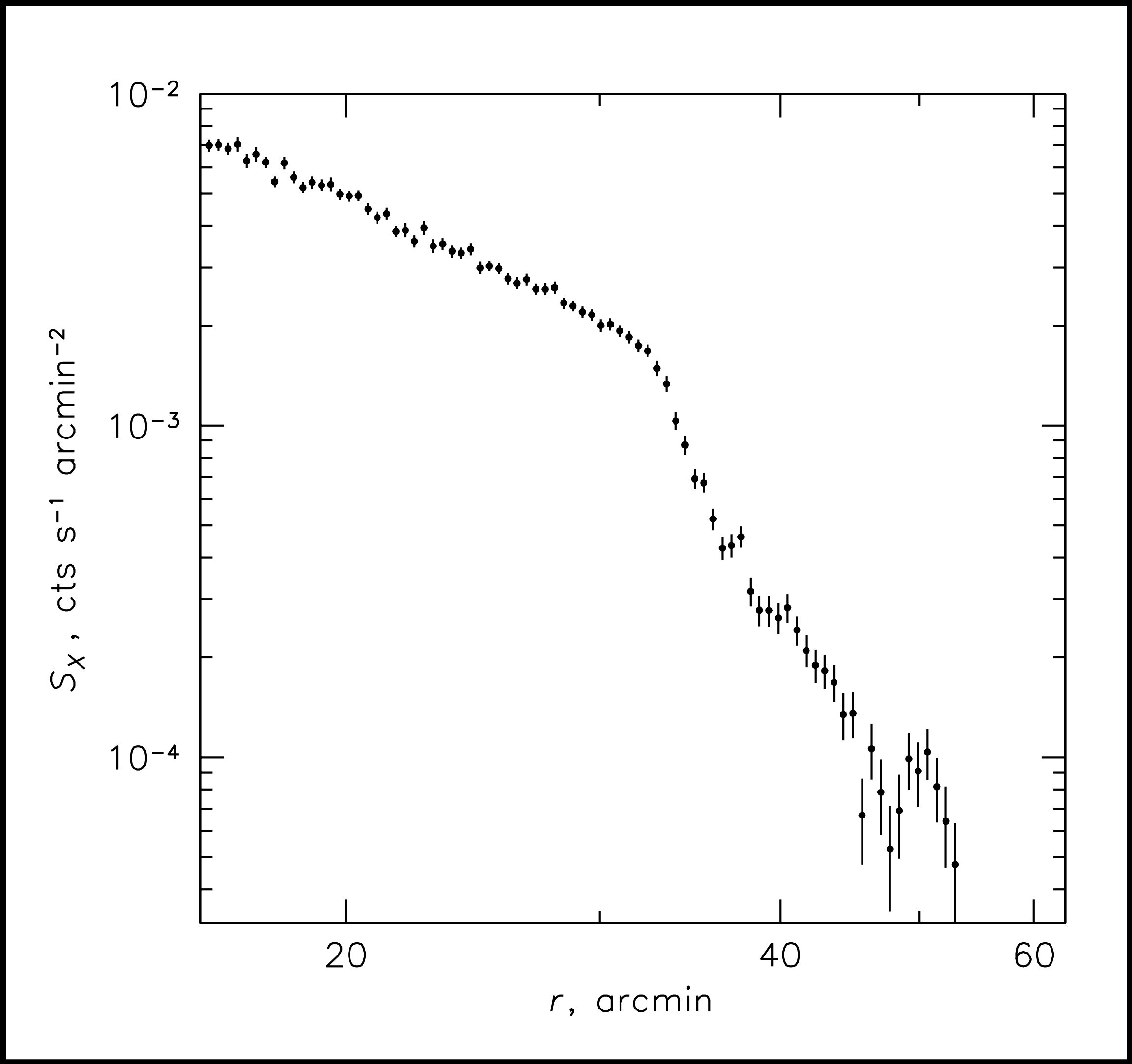
Coma shock front



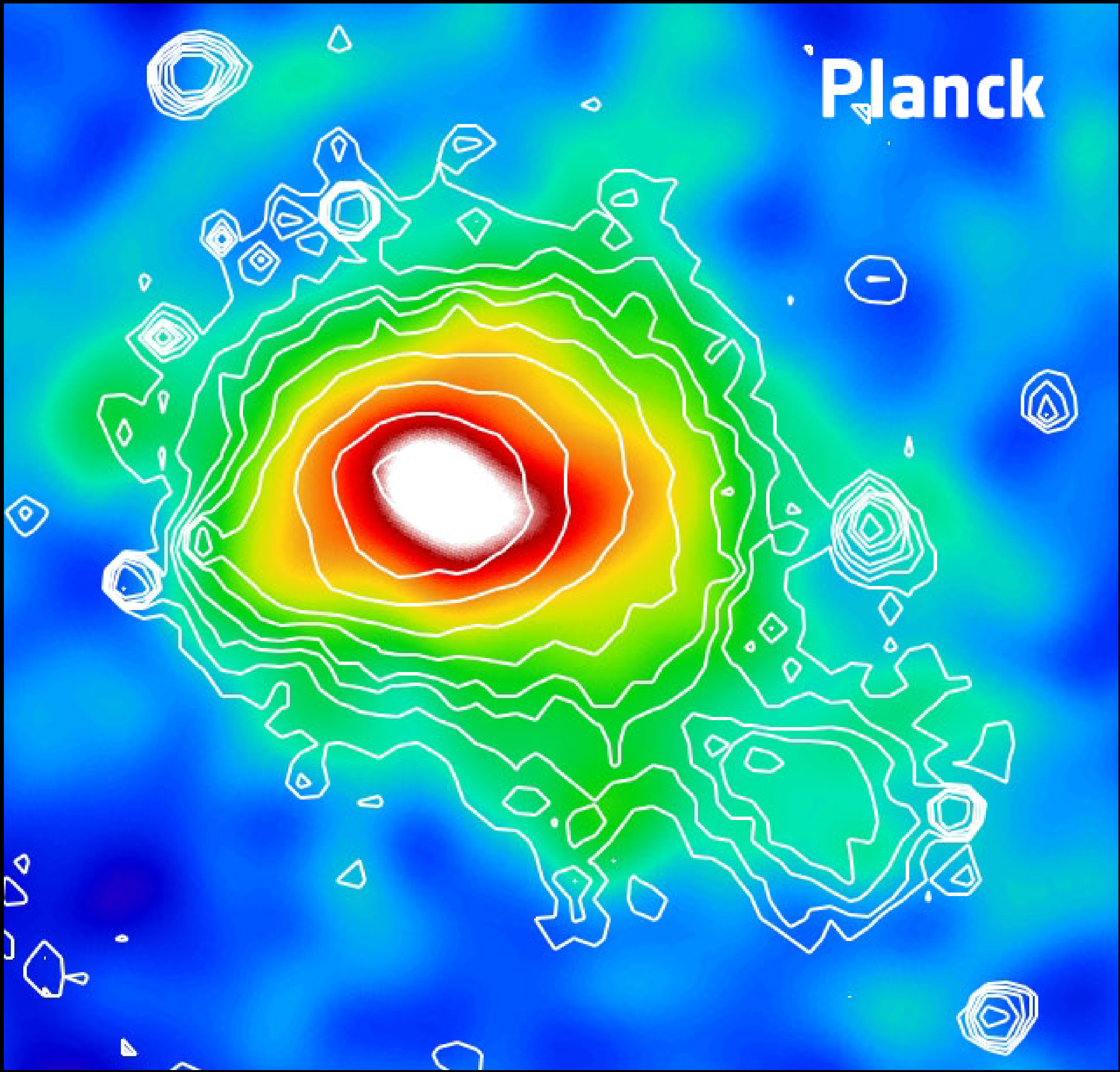
ROSAT X-ray image

Coma shock front

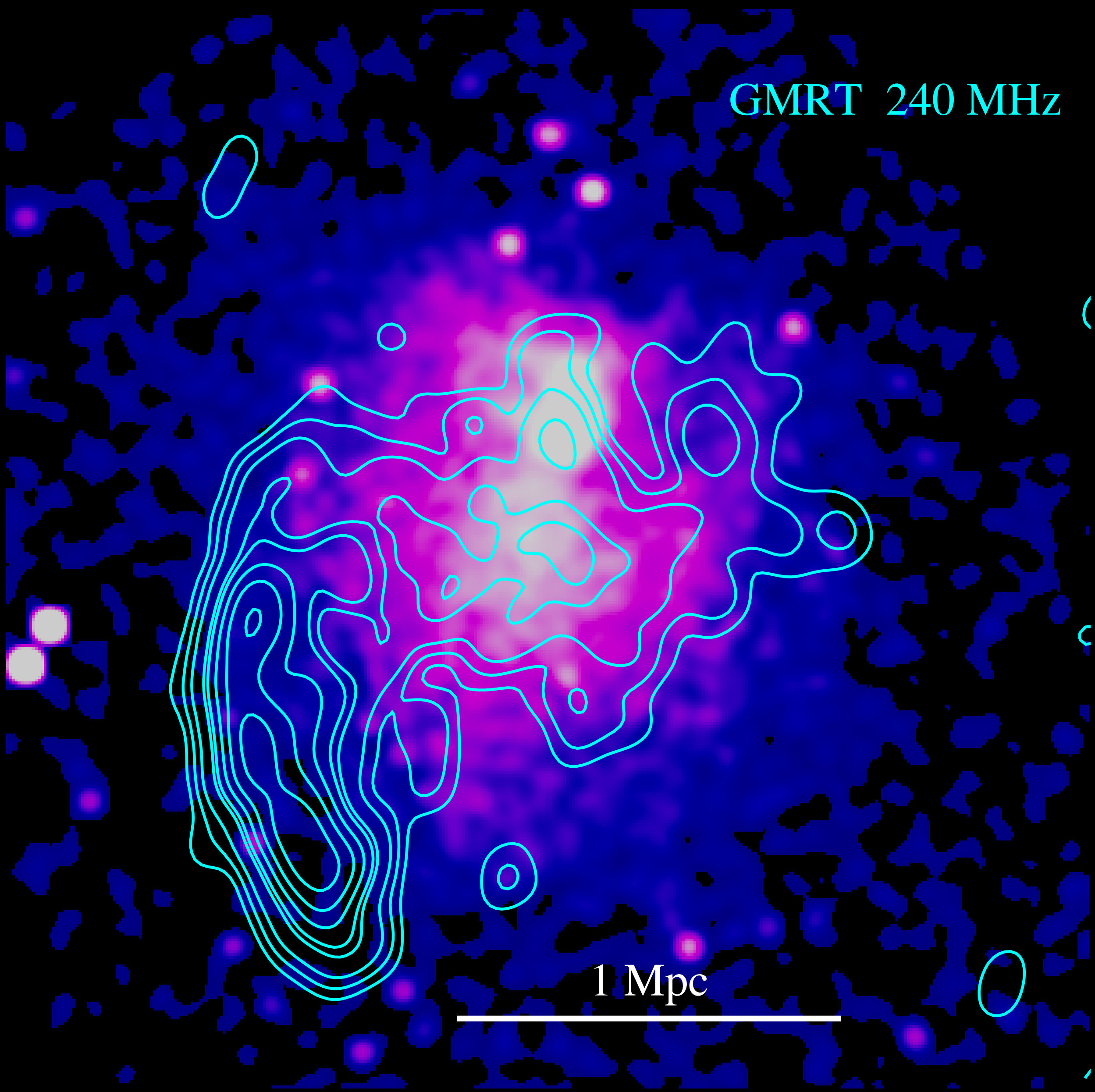
ROSAT brightness profile across X-ray edge



Coma shock front



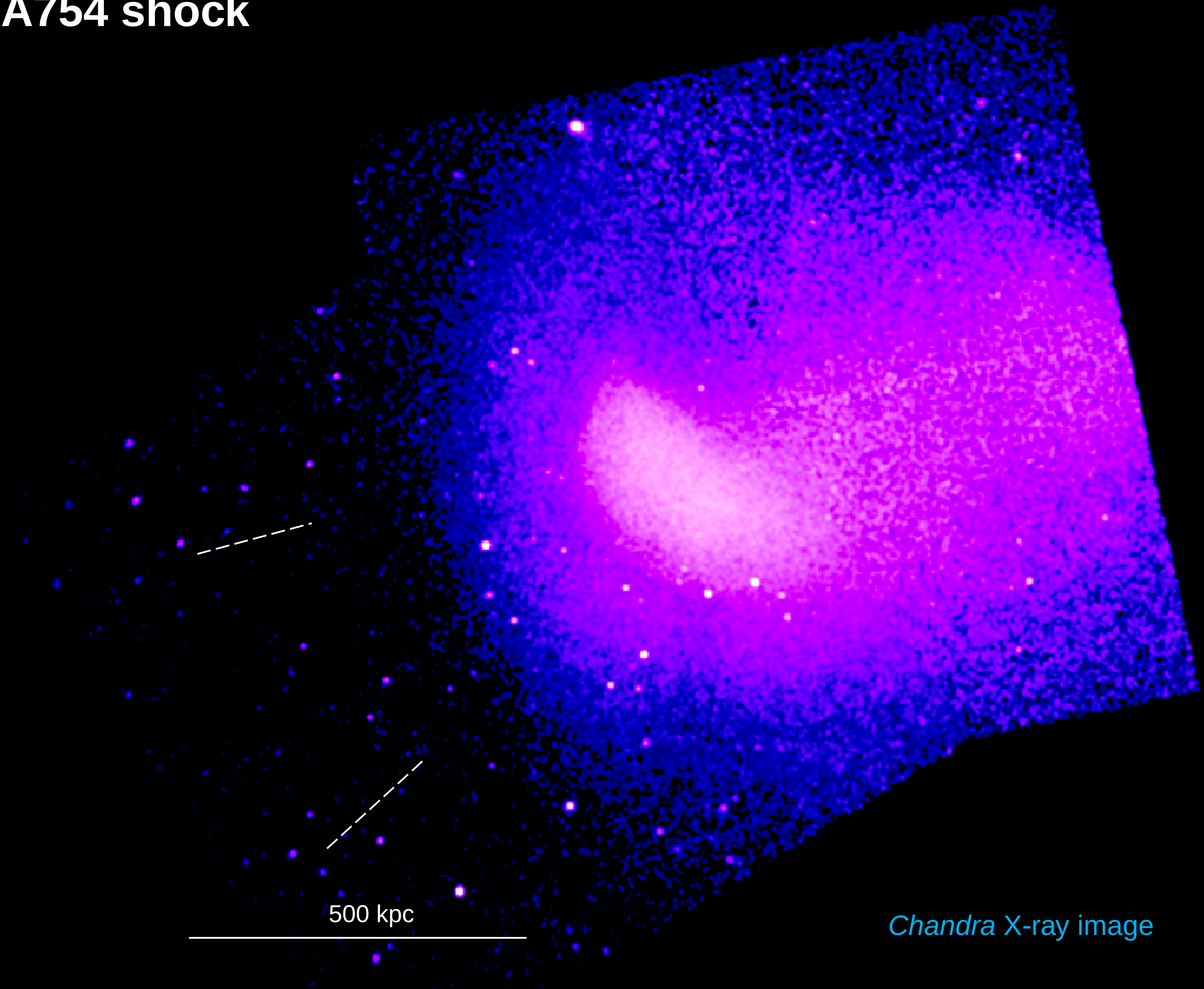
A521 shock



Chandra X-ray image

Brunetti et al. 08

A754 shock



Fermi I acceleration at cluster shocks?

A754:

X-ray shock with $M = 1.6 \pm 0.15$ → post-shock radio slope $\alpha = 2.3$ (2.0–2.8)

(assuming Fermi-I acceleration); observed: $\alpha^{1.4}_{330} = 2.0$ (Macario et al. 10)

A521:

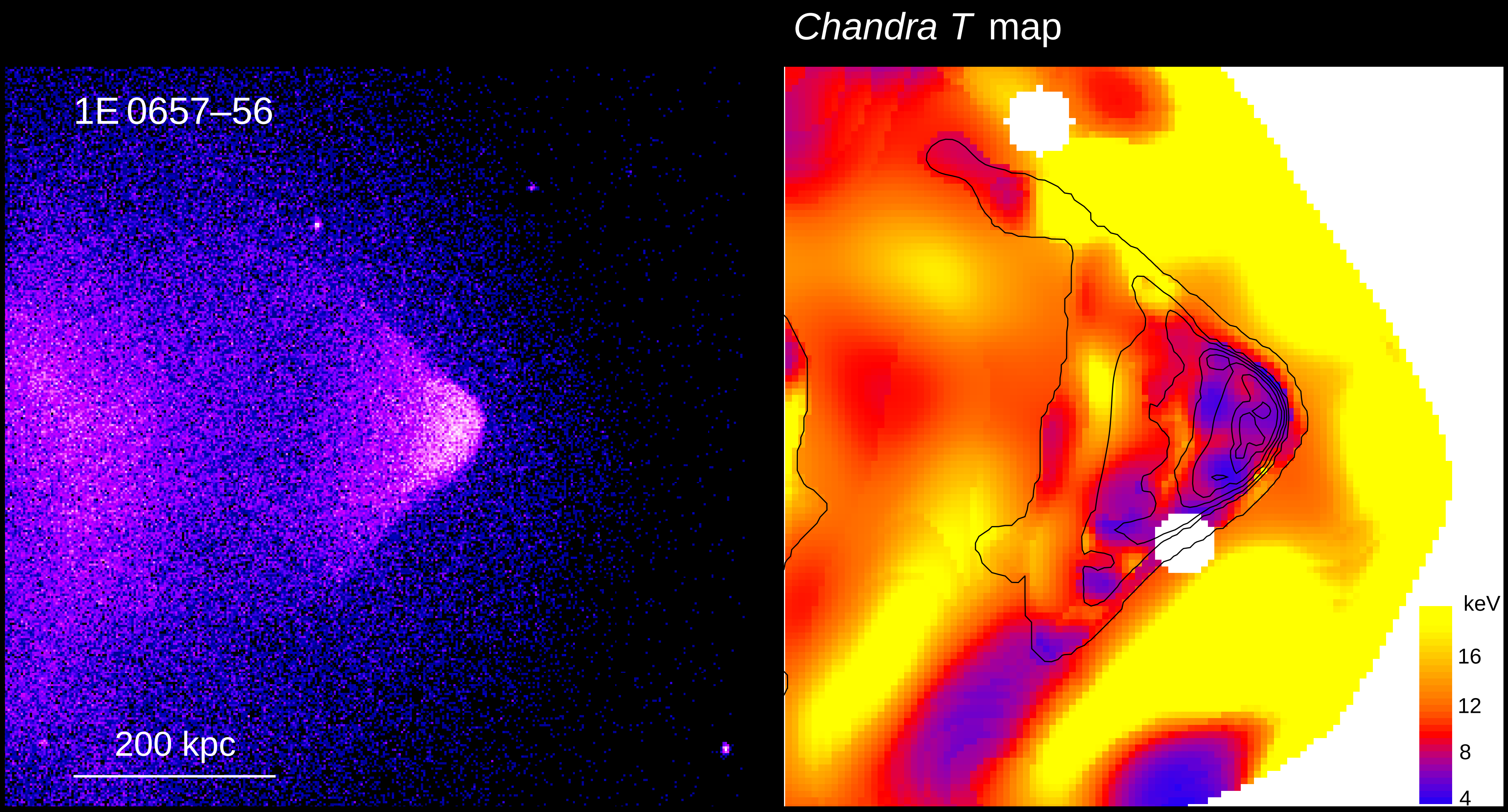
Radio spectral slope → $M = 2.3$

observed in X-rays: $M = 2.1^{+0.5}_{-0.9}$ (Bourdin et al. 12)

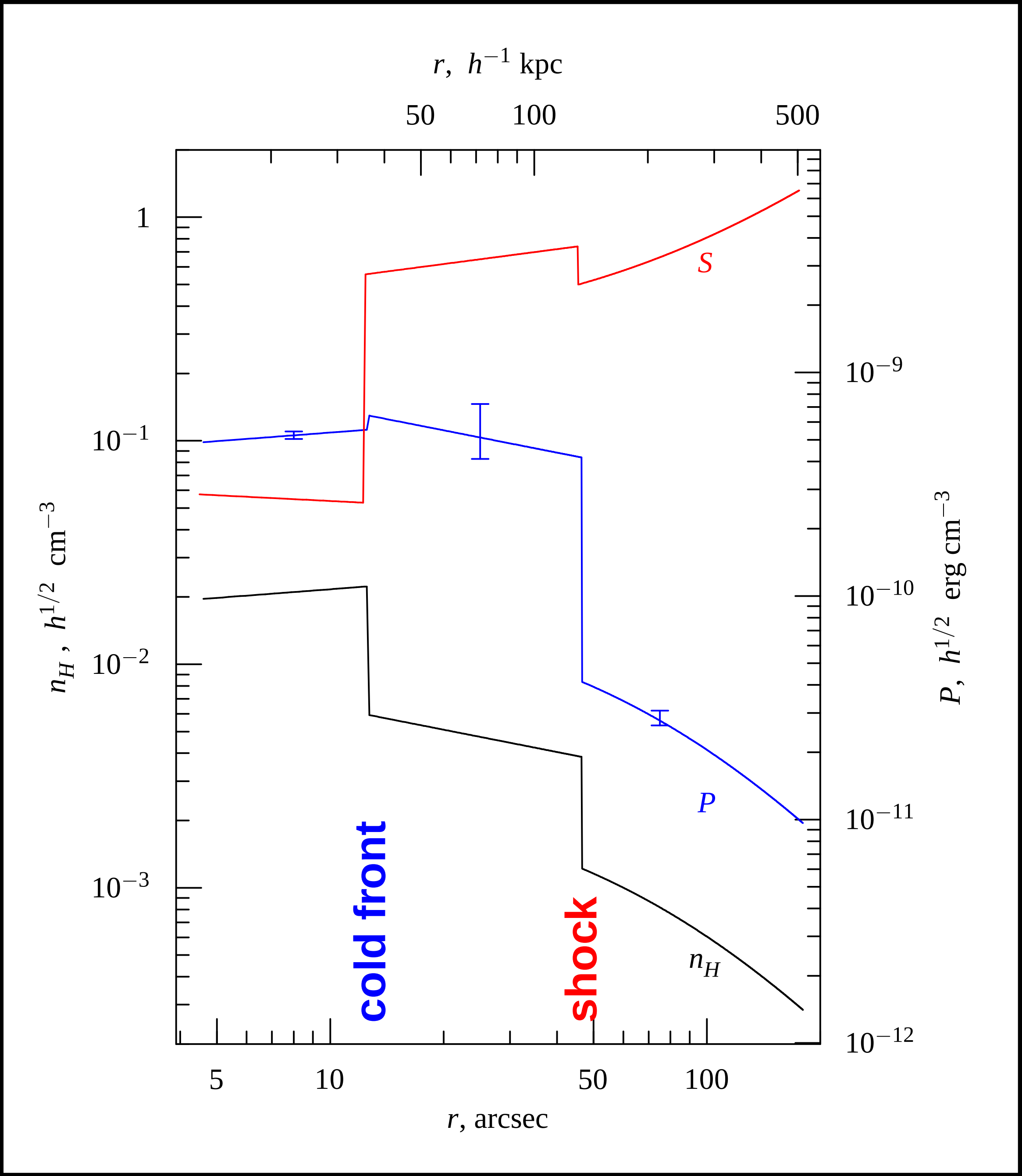
- First direct evidence of cosmic ray acceleration by cluster shocks

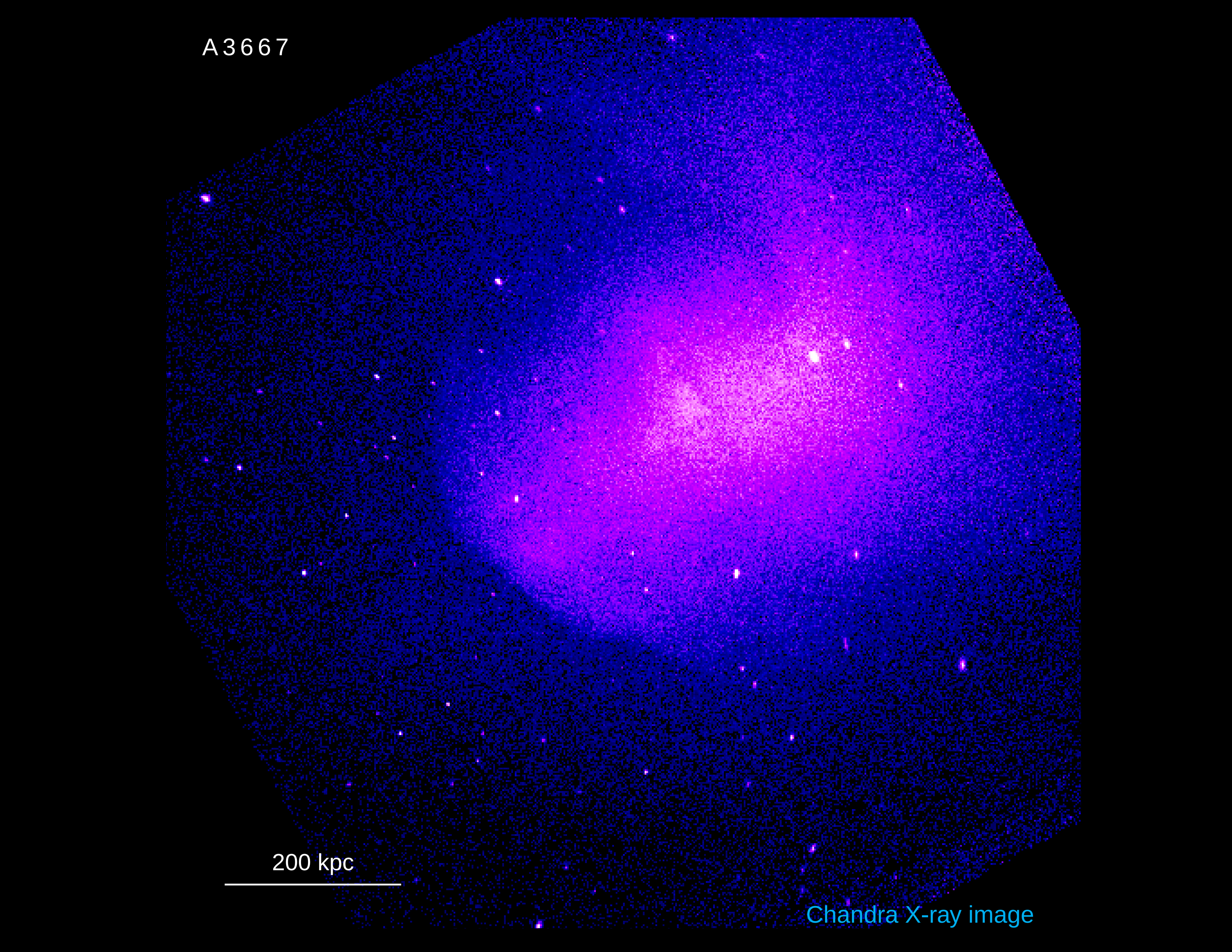
  (more likely, re-acceleration)

Cold fronts

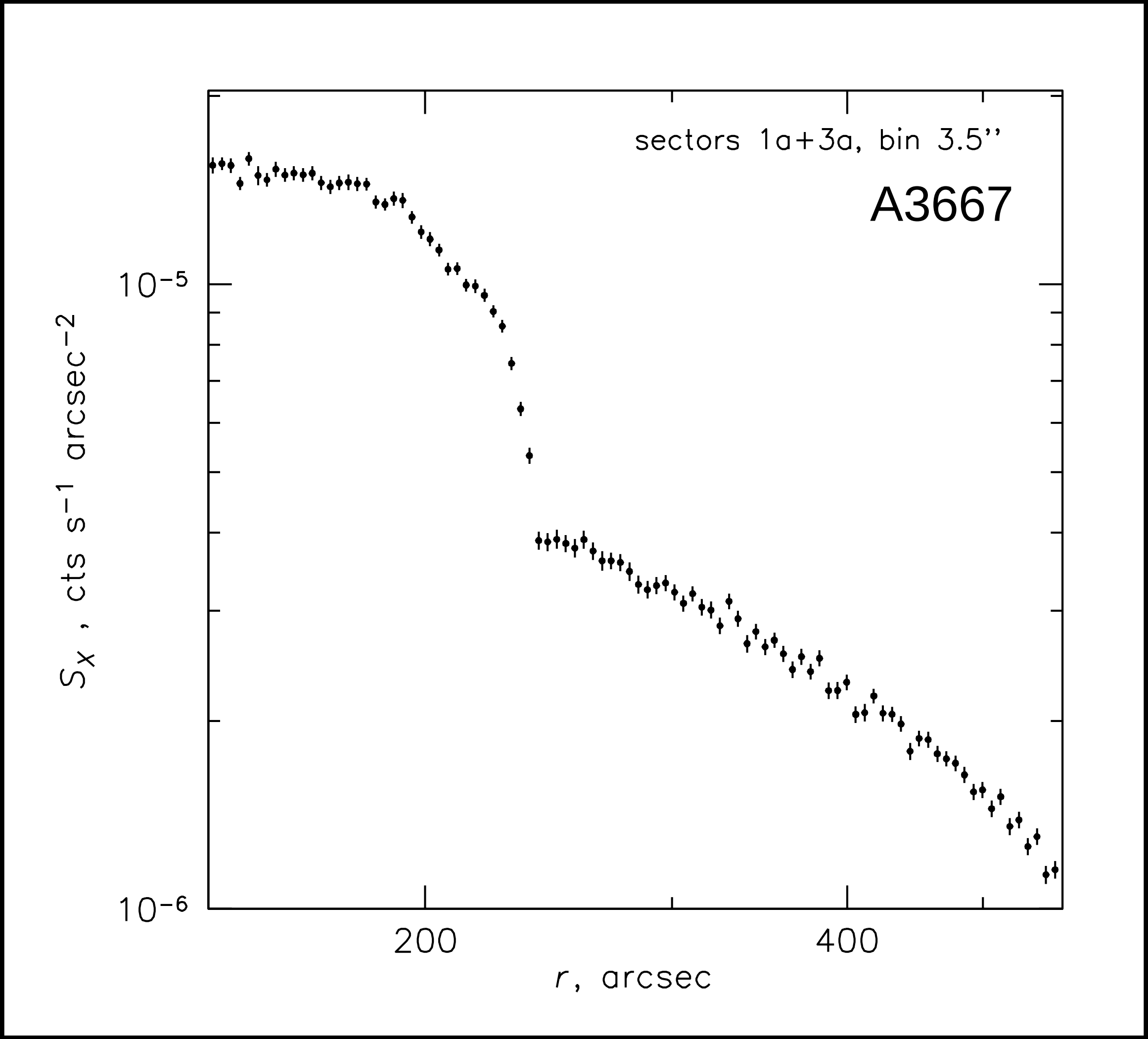

1E 0657–56
200 kpc
Chandra T map
keV
16
12
8
4

Shock and cold front profiles in 1E 0657




A3667
200 kpc
Chandra X-ray image

Cold fronts — diffusion and conduction barriers

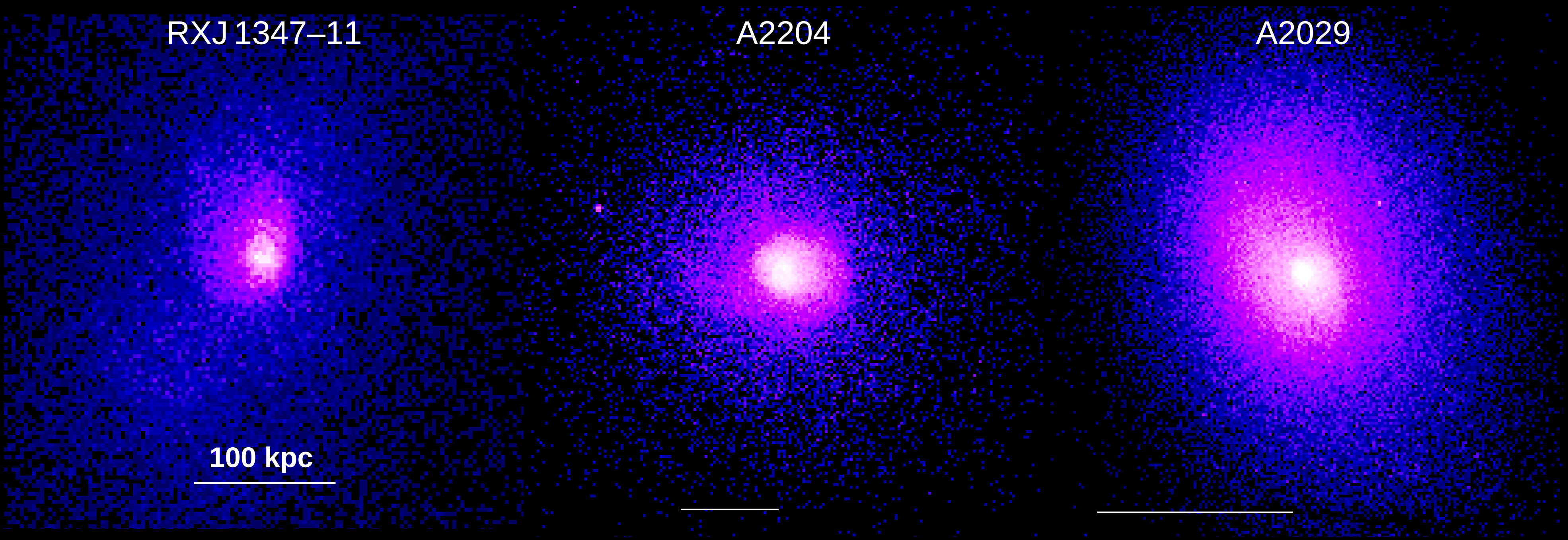


Width of density jump $d < 4$ kpc $< \lambda_e$ (Coulomb) $\approx$ 10–15 kpc

→ diffusion across front is suppressed (magnetic barriers)

Vikhlinin et al. 01, M & V 07

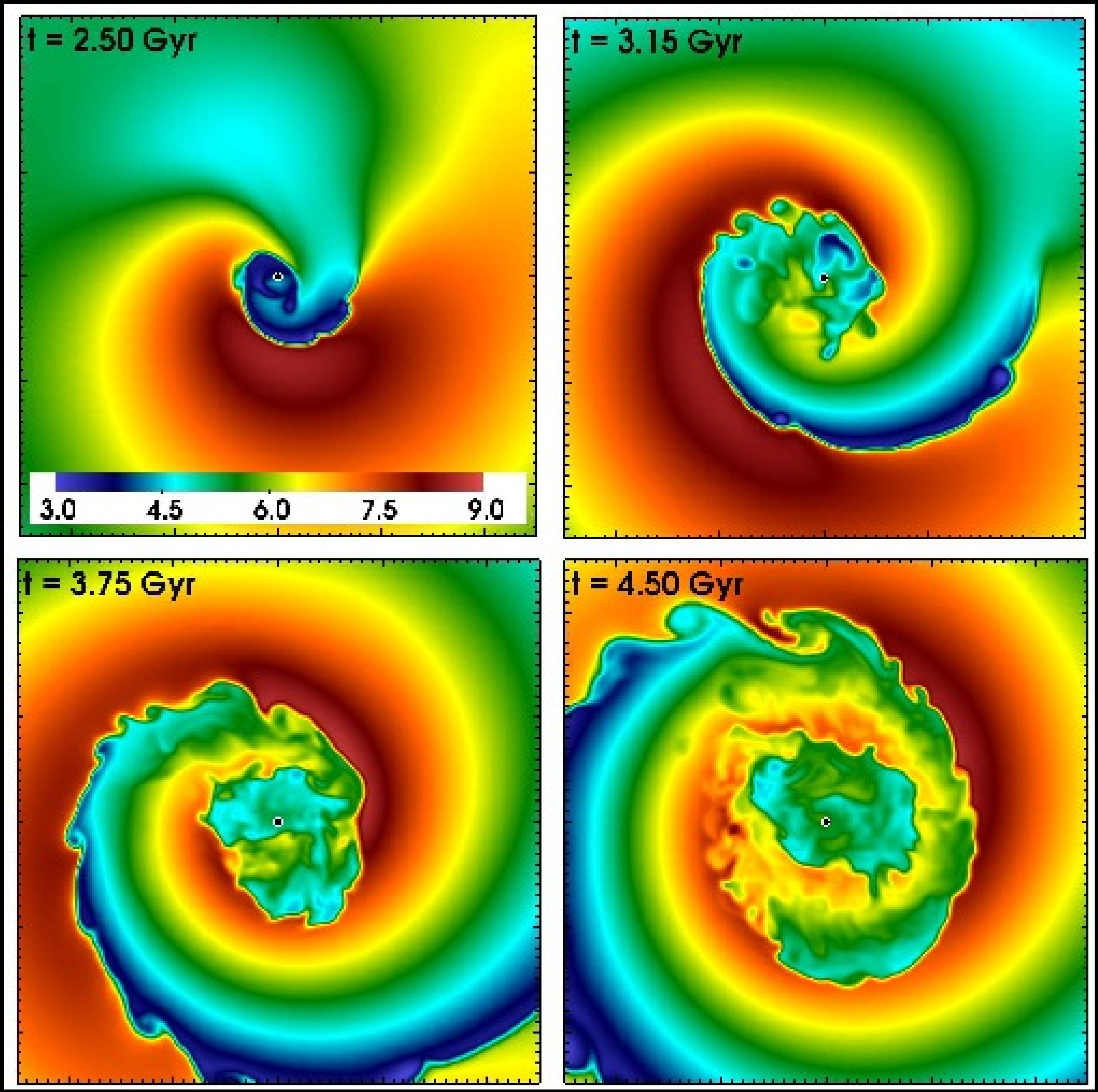
Cold fronts in cool cores



Long-lived “sloshing” from past disturbances (Ascasibar & Markevitch 06)

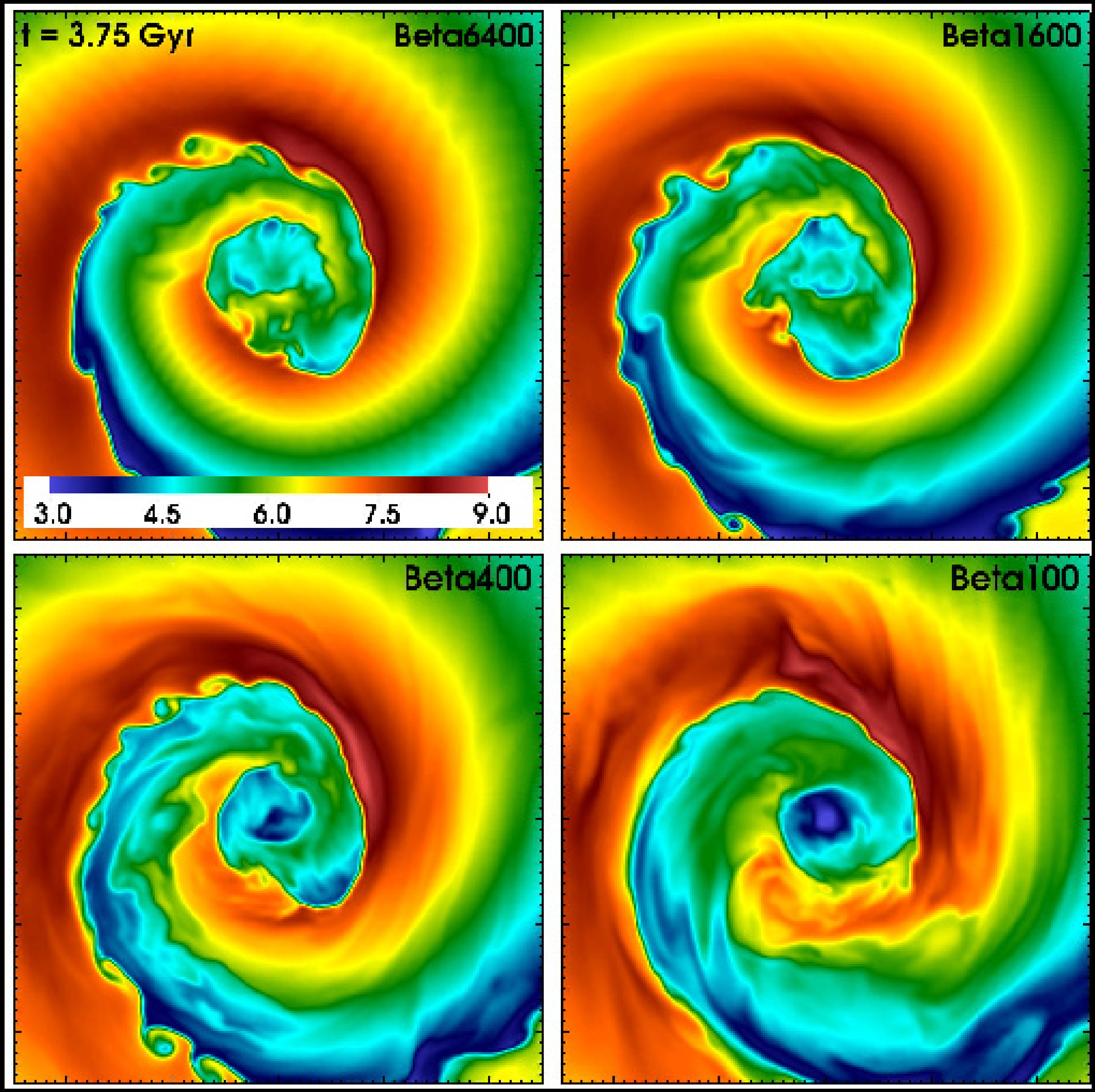
Cool dense gas sloshing in the central potential minimum

Core sloshing: gas *T* maps

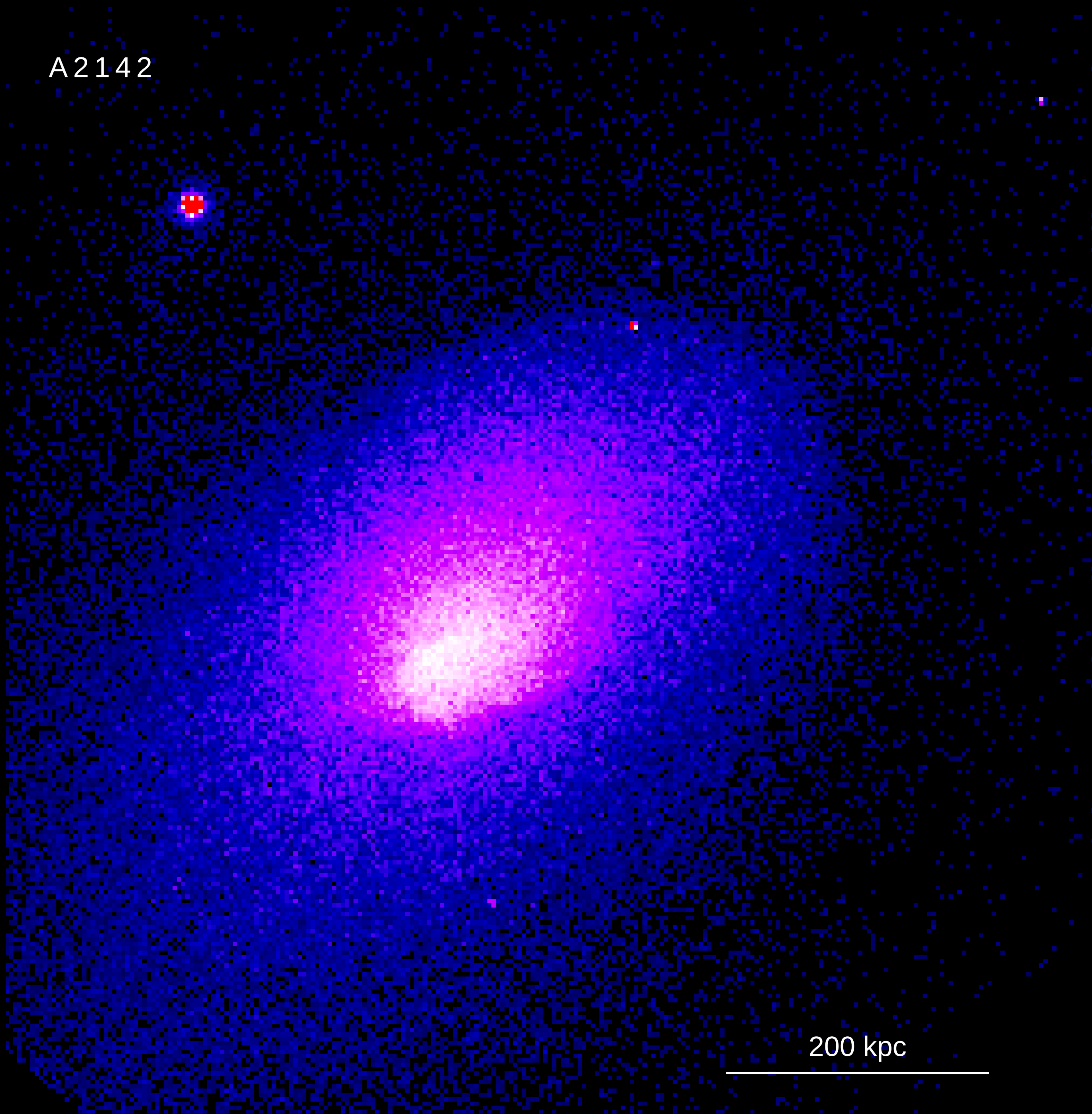


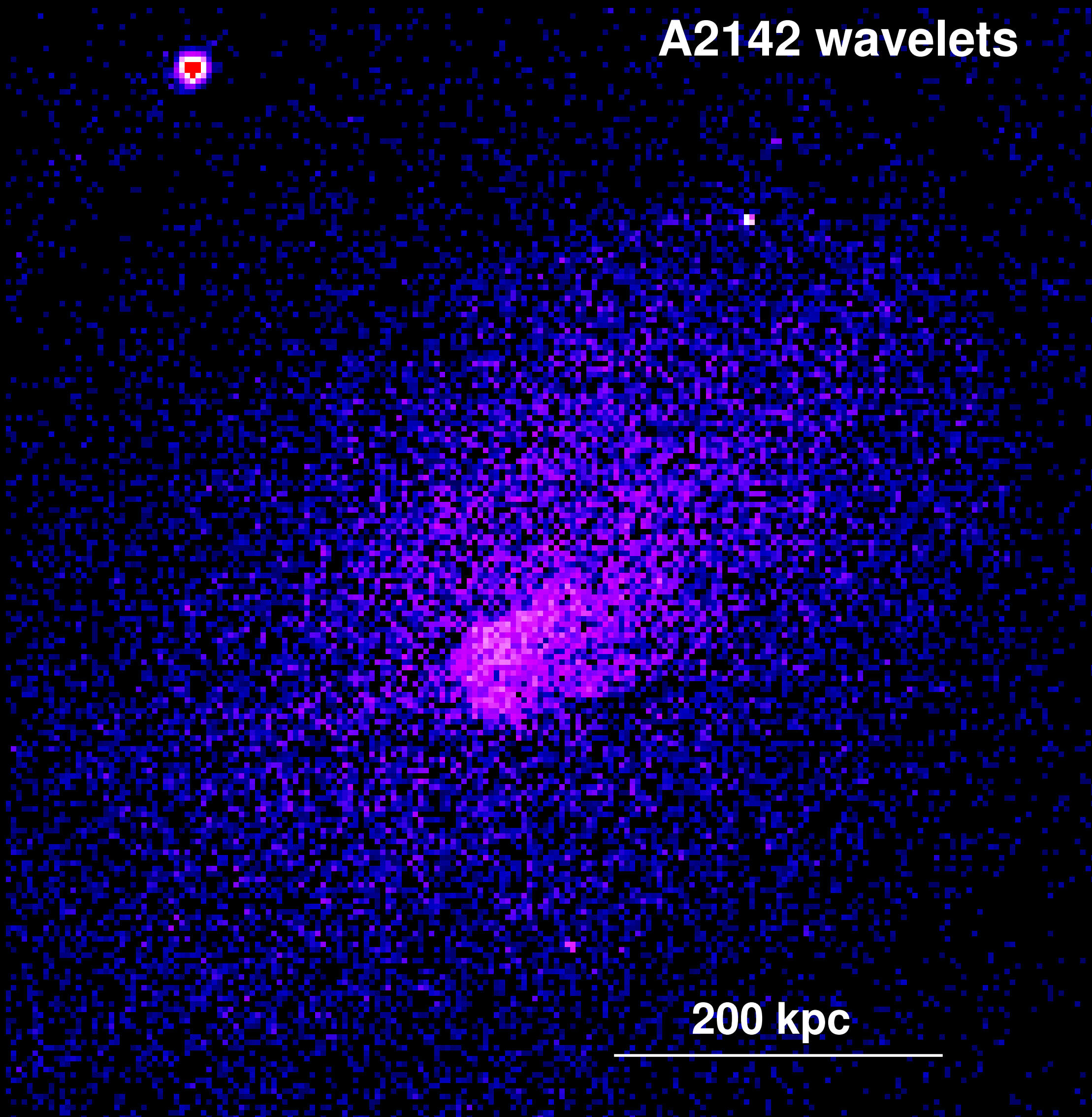
ZuHone 11 (FLASH, resolution 2 kpc, no magnetic field)

Core sloshing: *B* suppresses instabilities

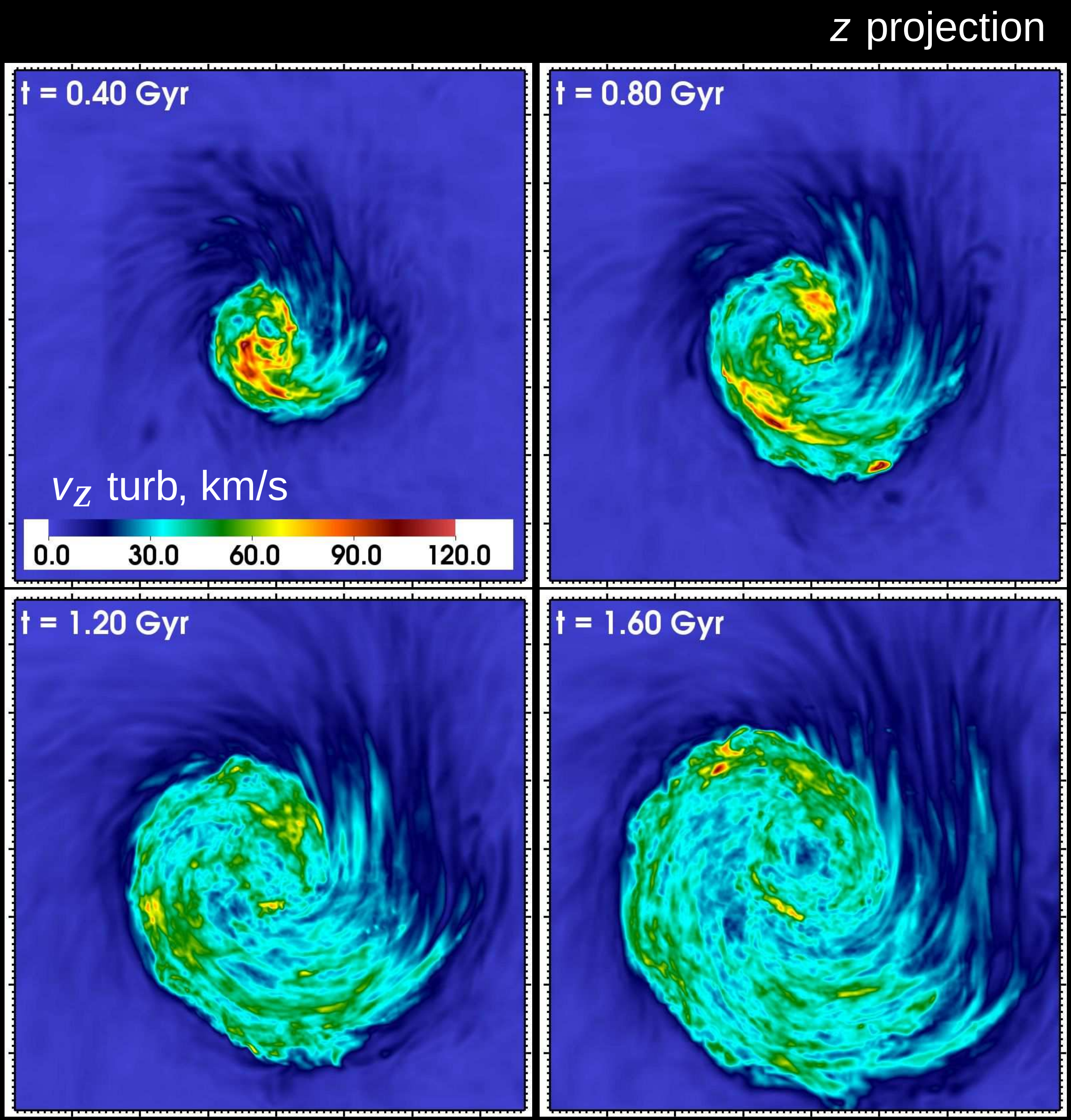


ZuHone 11 (FLASH, MHD, resolution 2 kpc)


A2142
200 kpc

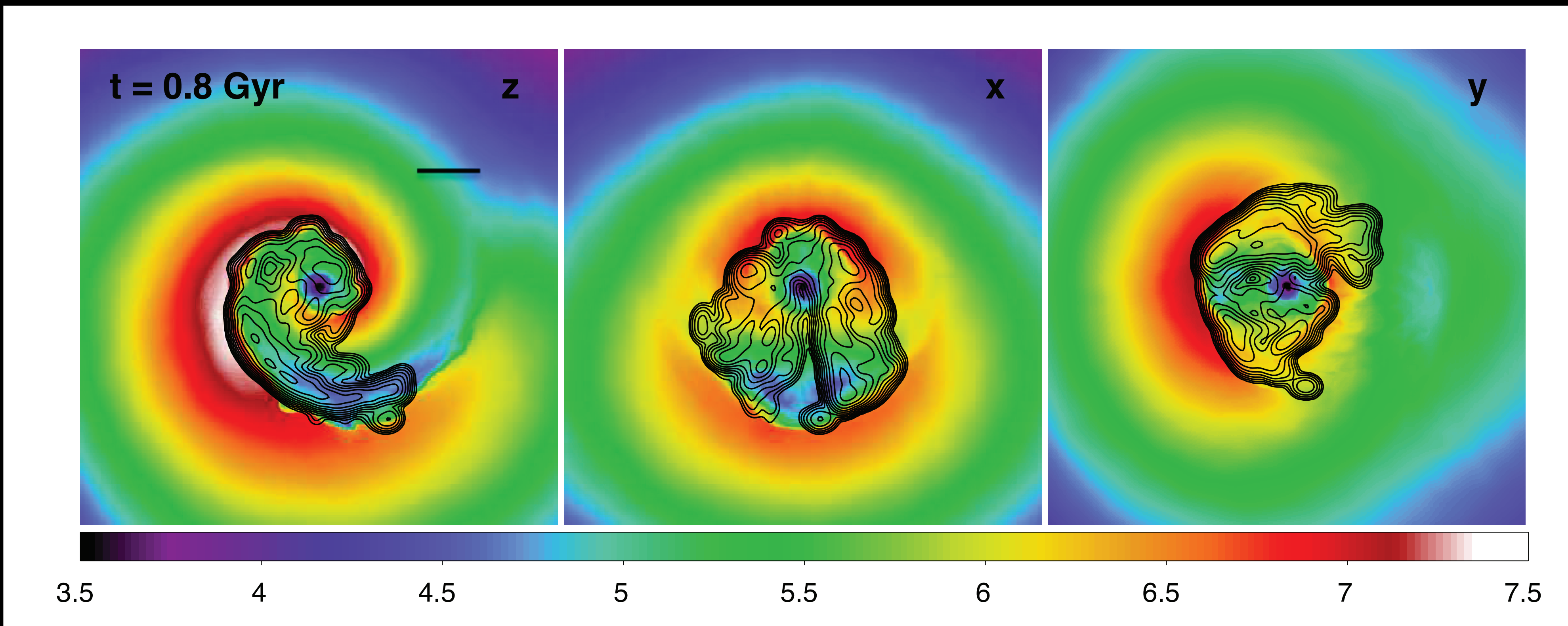

A2142 wavelets
200 kpc

Core sloshing: turbulence



ZuHone 12 (FLASH, MHD, resolution 1 kpc)

Core sloshing: synchrotron radio emission

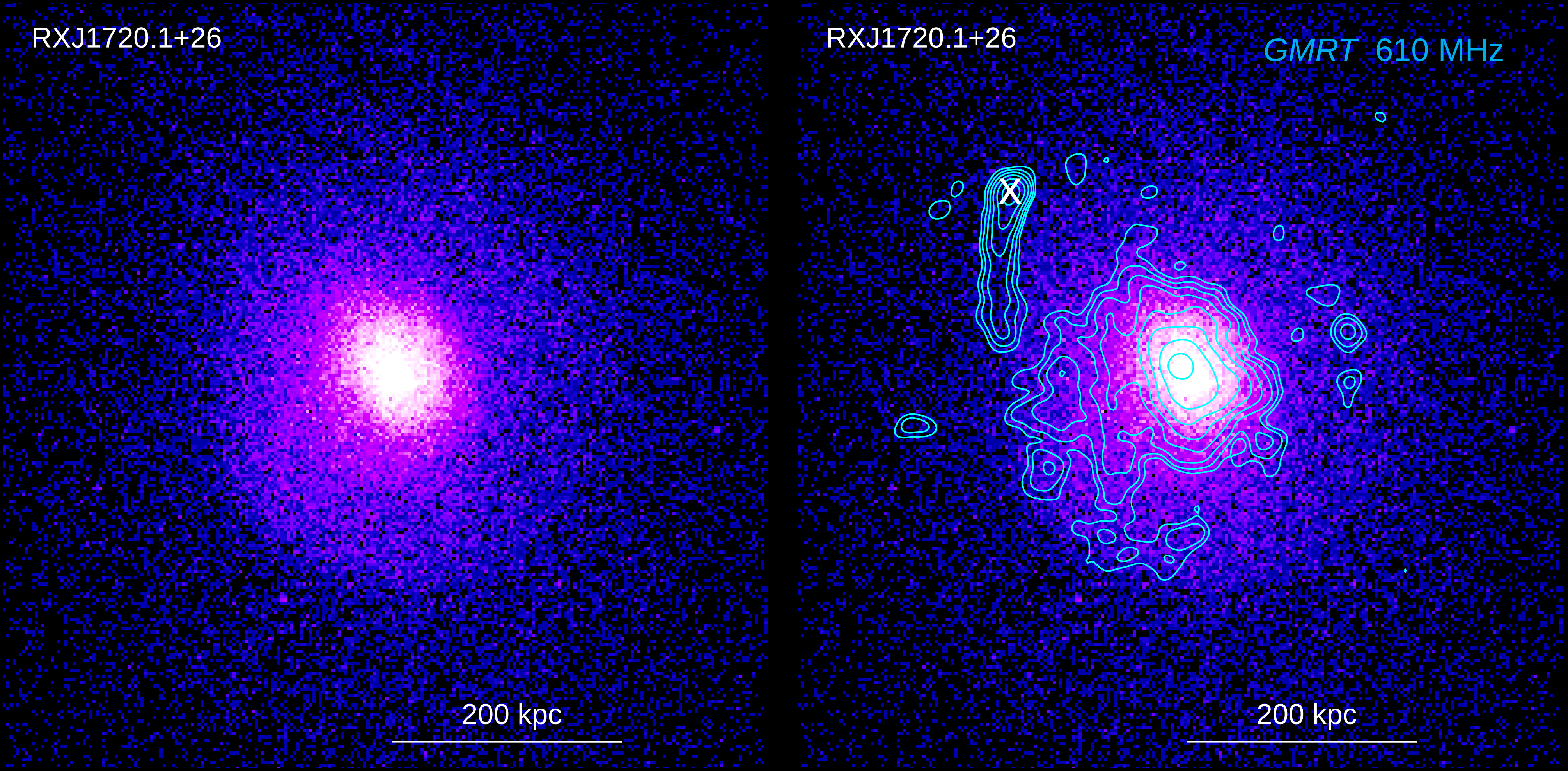


T, keV

contours: radio brightness

ZuHone 12

Radio minihalos in cluster cores



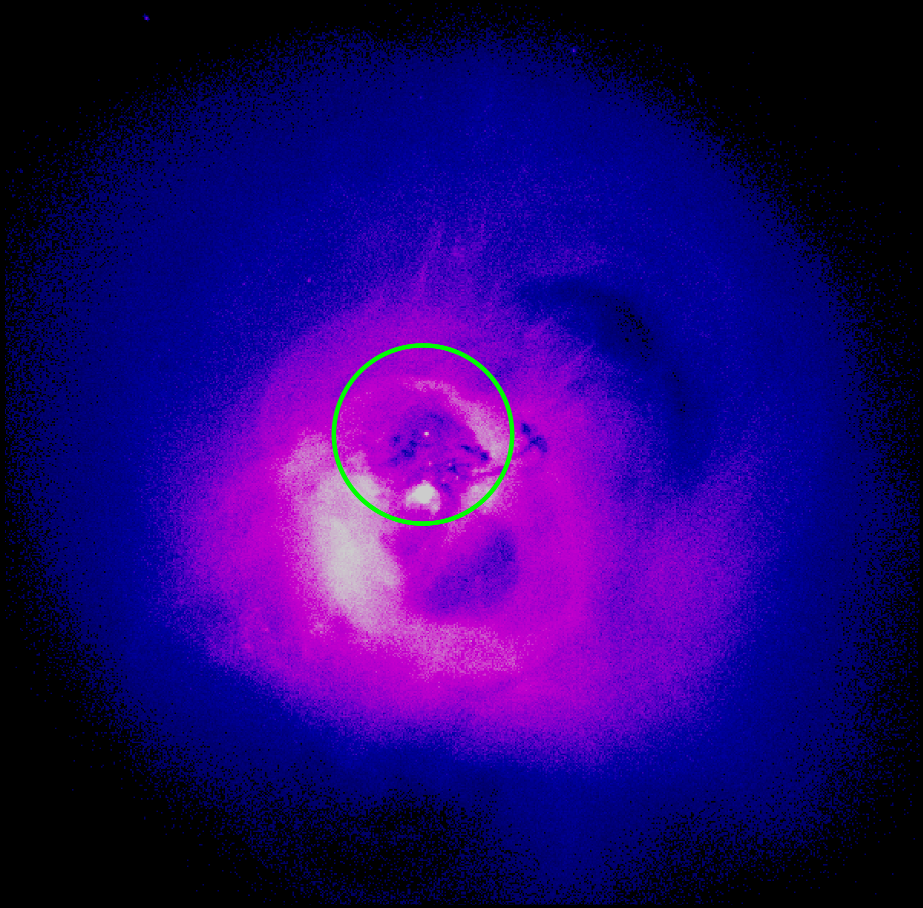
Mazzotta & Giacintucci 08; Giacintucci 12

- Simulation reproduces minihalo geometry and radio spectrum

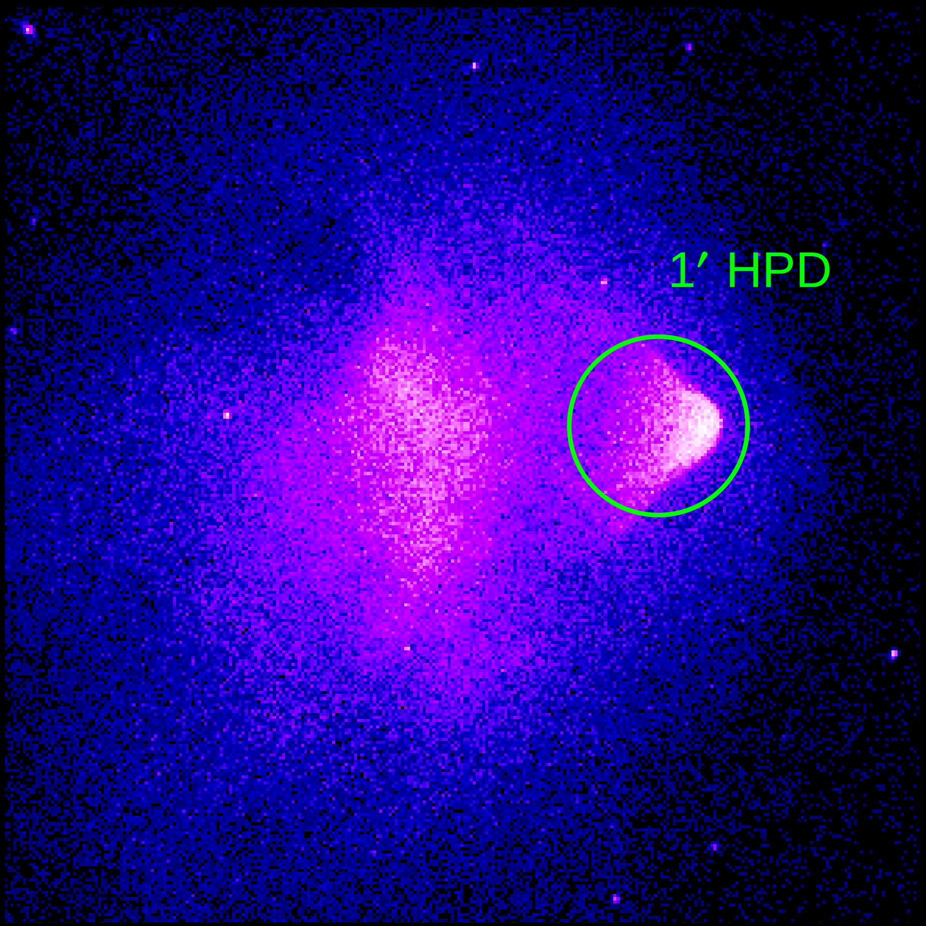
Next 50 years?

Cluster dynamics

Perseus



1E 0657–56



Chandra X-ray images

- Need calorimeter with *Chandra* angular resolution

Relativistic matter in clusters