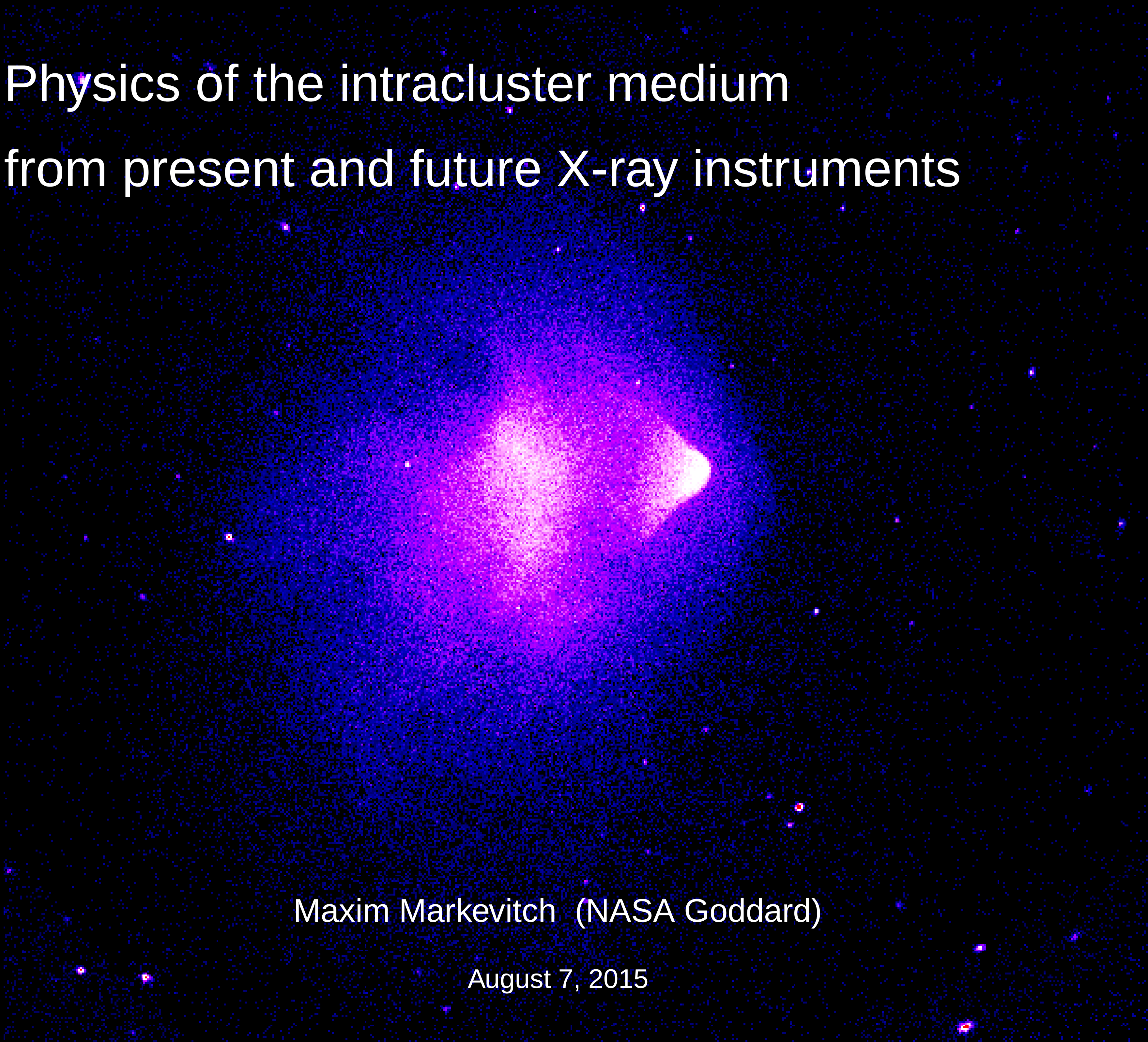
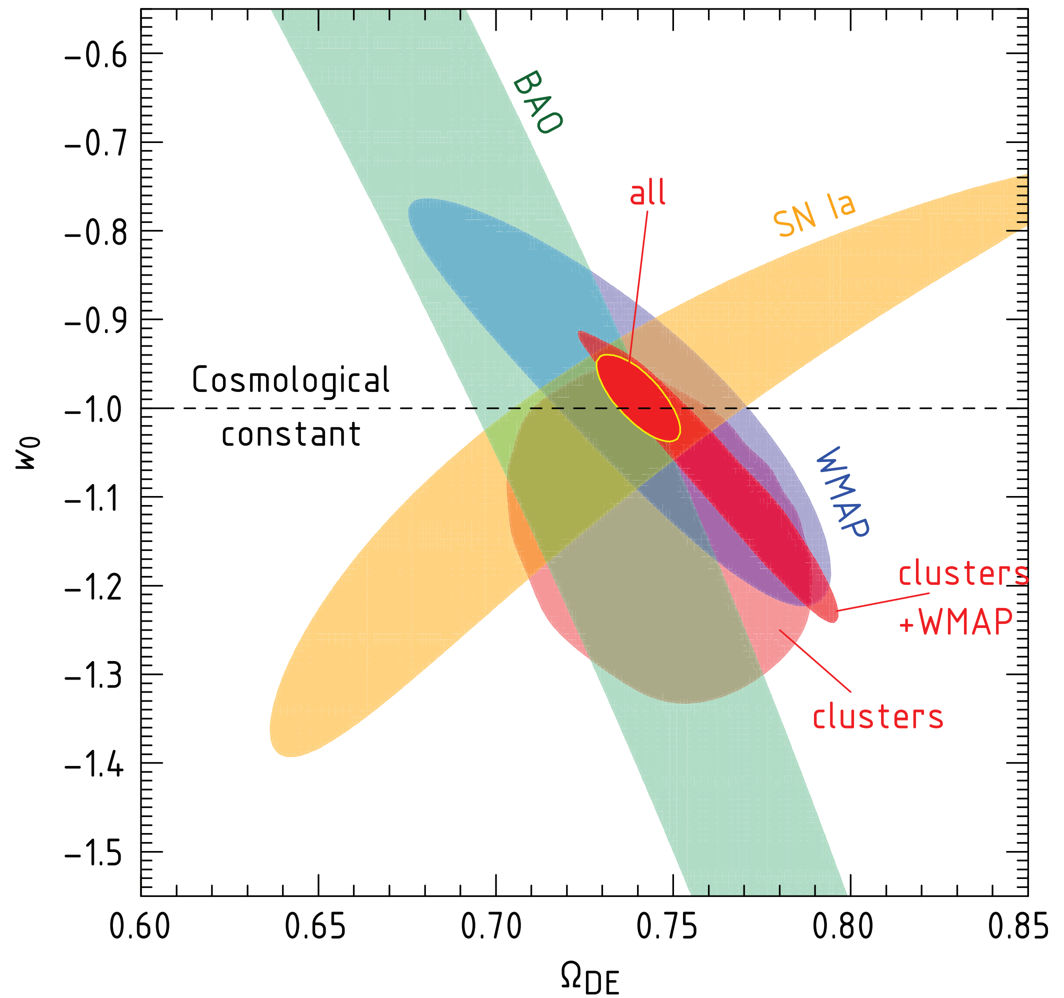
Physics of the intracluster medium from present and future X-ray instruments



Maxim Markevitch (NASA Goddard)

August 7, 2015

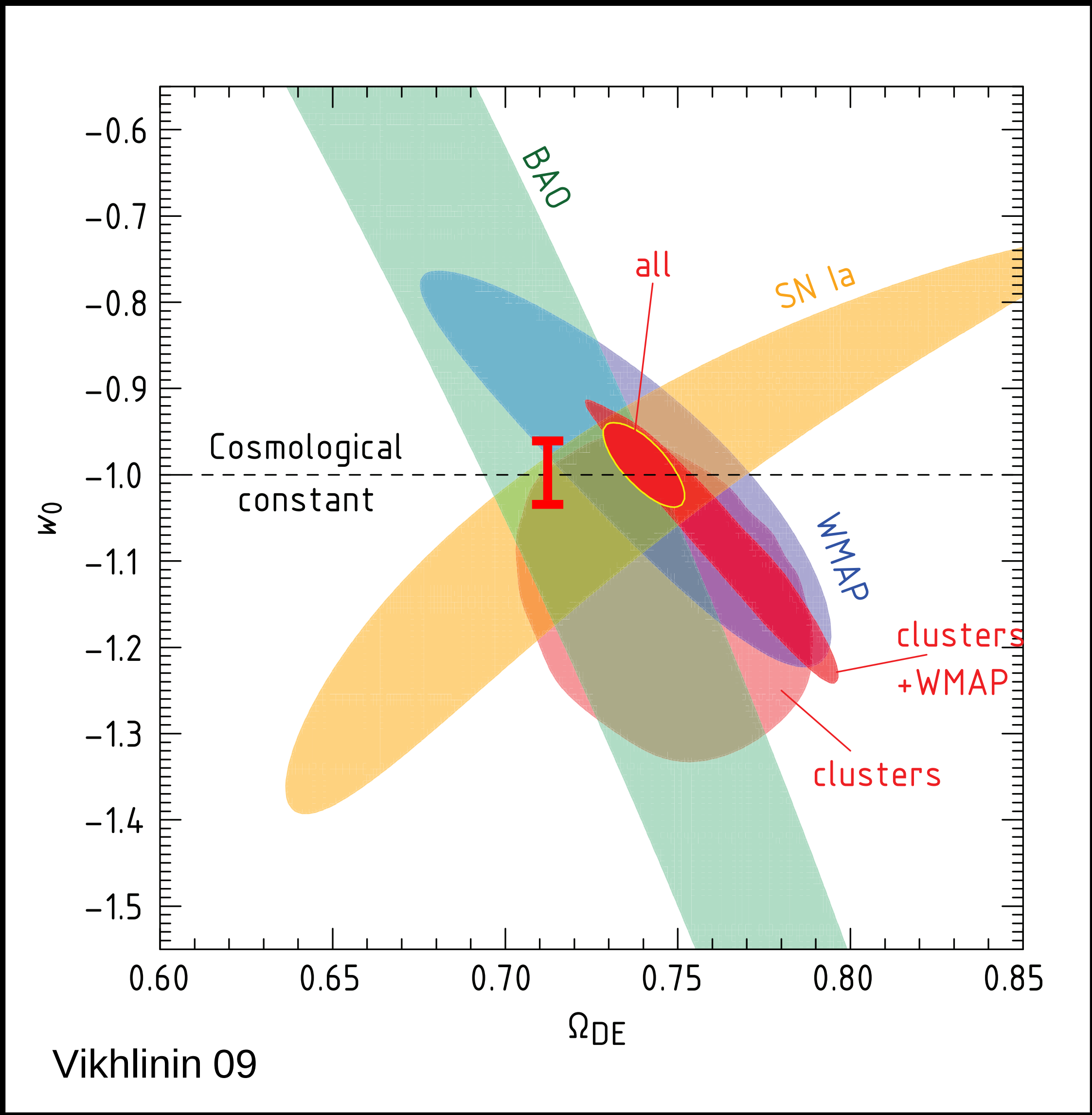
Cluster precision cosmology



Vikhlinin 09

Cluster precision cosmology

only as precise as our knowledge of cluster physics



±10% mass error

“Nuisance parameters”

AGN and star formation feedback — *Chandra* bubbles, shocks around them

Radiative cooling — match simulations with observed density profiles;
high-res *XMM* RGS and *Astro-H* spectra

ICM clumpiness (related to cooling) *Chandra* ultra-deep observations

Turbulence, bulk motions — *Astro-H* details in this talk

Thermal conduction — *T* maps, profiles details in this talk

Viscosity — cold front stability

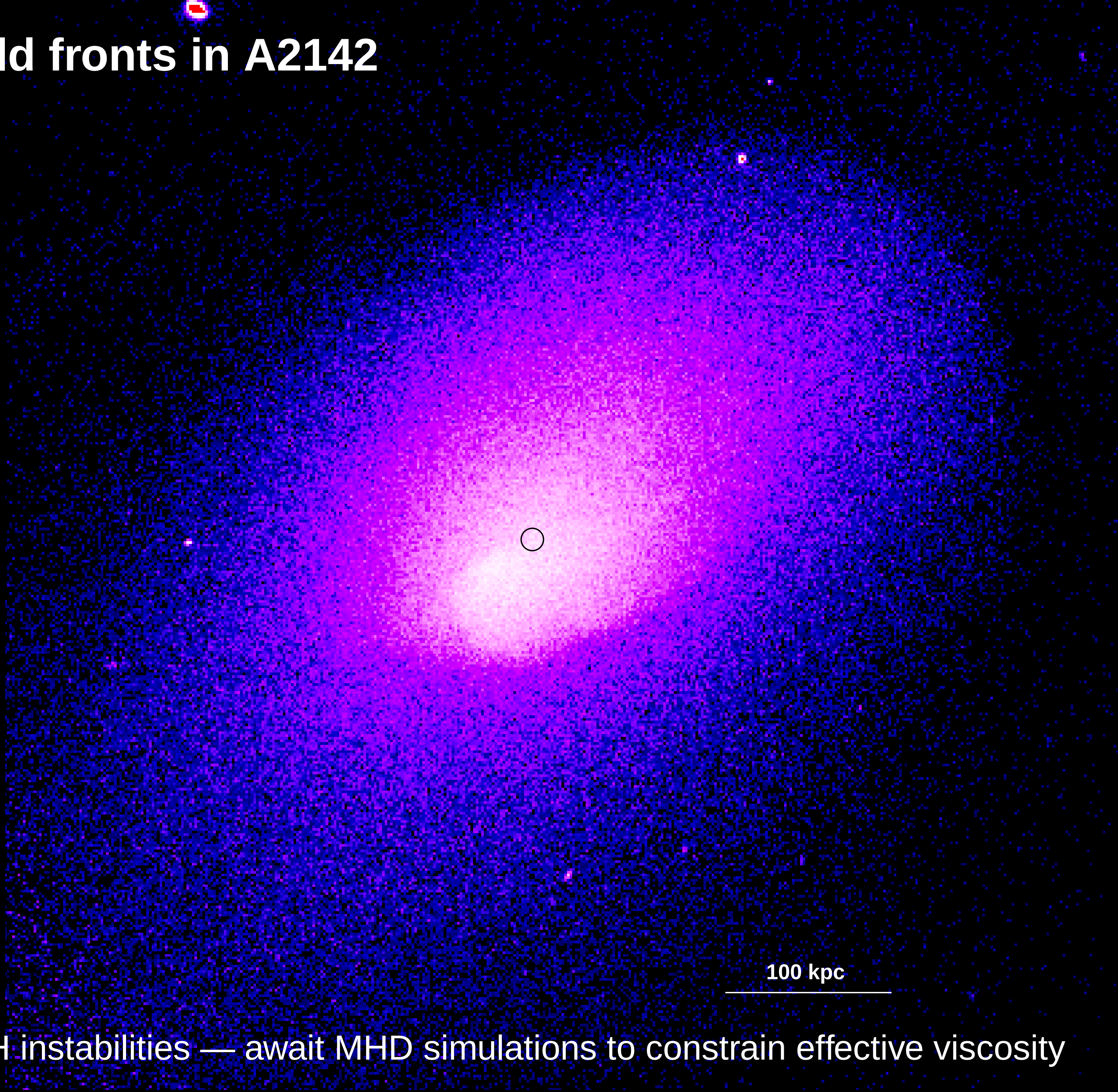
Electron-ion non-equipartition — shock fronts

Magnetic fields, cosmic ray electrons (mostly radio) match radio with X-ray

Cosmic ray protons — *Fermi* upper limit

Helium abundance — SZ / X-ray

Cold fronts in A2142



- KH instabilities — await MHD simulations to constrain effective viscosity

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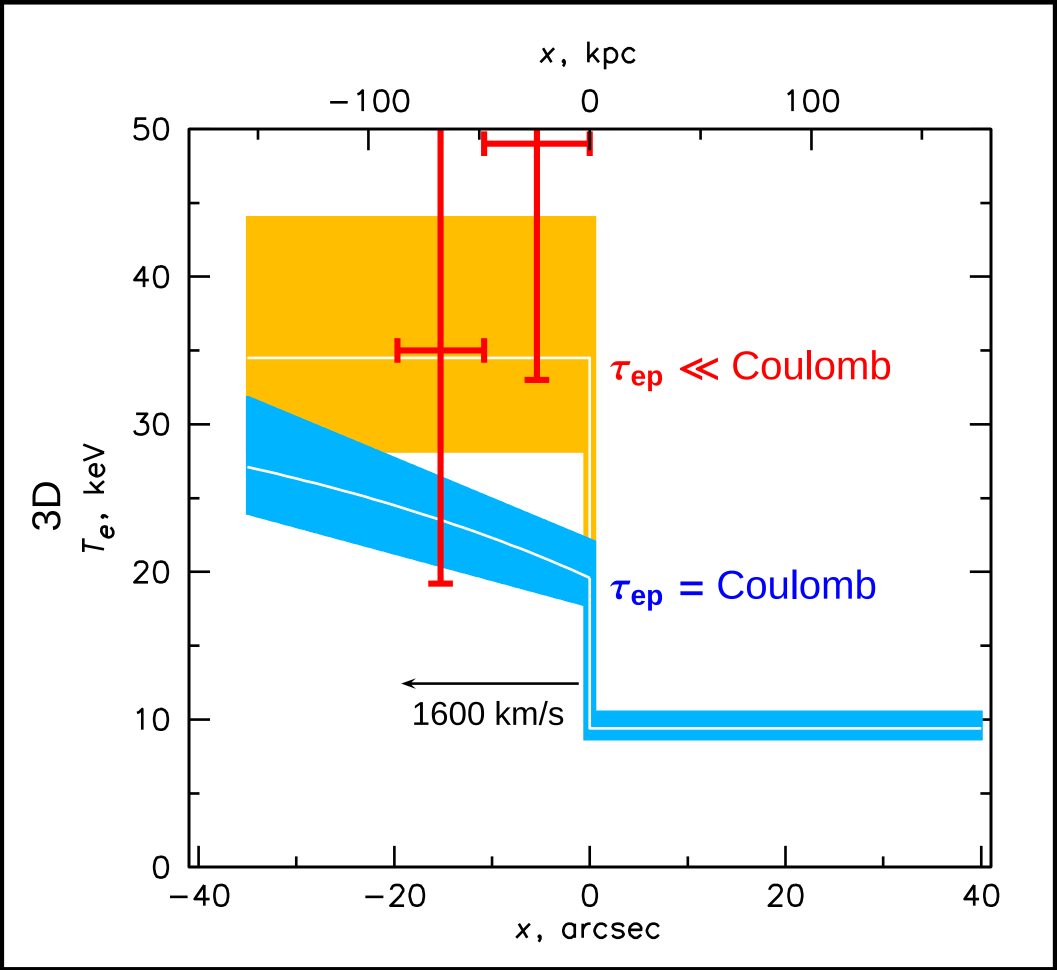
Electron-proton equilibration timescale from shock fronts

Bullet cluster shock



MM 06

- 95% confidence: $\tau_{ep} \ll$ Coulomb

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Refreshments
#SKA
www.skatelescope.org
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SKA
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"Nuisance parameters"

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New constraints on large-scale heat conduction

(B. Russel 2014 PhD thesis; Russell, MM, ZuHone in prep.)

Observational constraints on ICM conductivity so far

- Conduction across cold fronts must be strongly suppressed (Ettori & Fabian 2000, ...)

- Stripped tails of infalling groups survive → strong suppression (Eckert et al. 14)

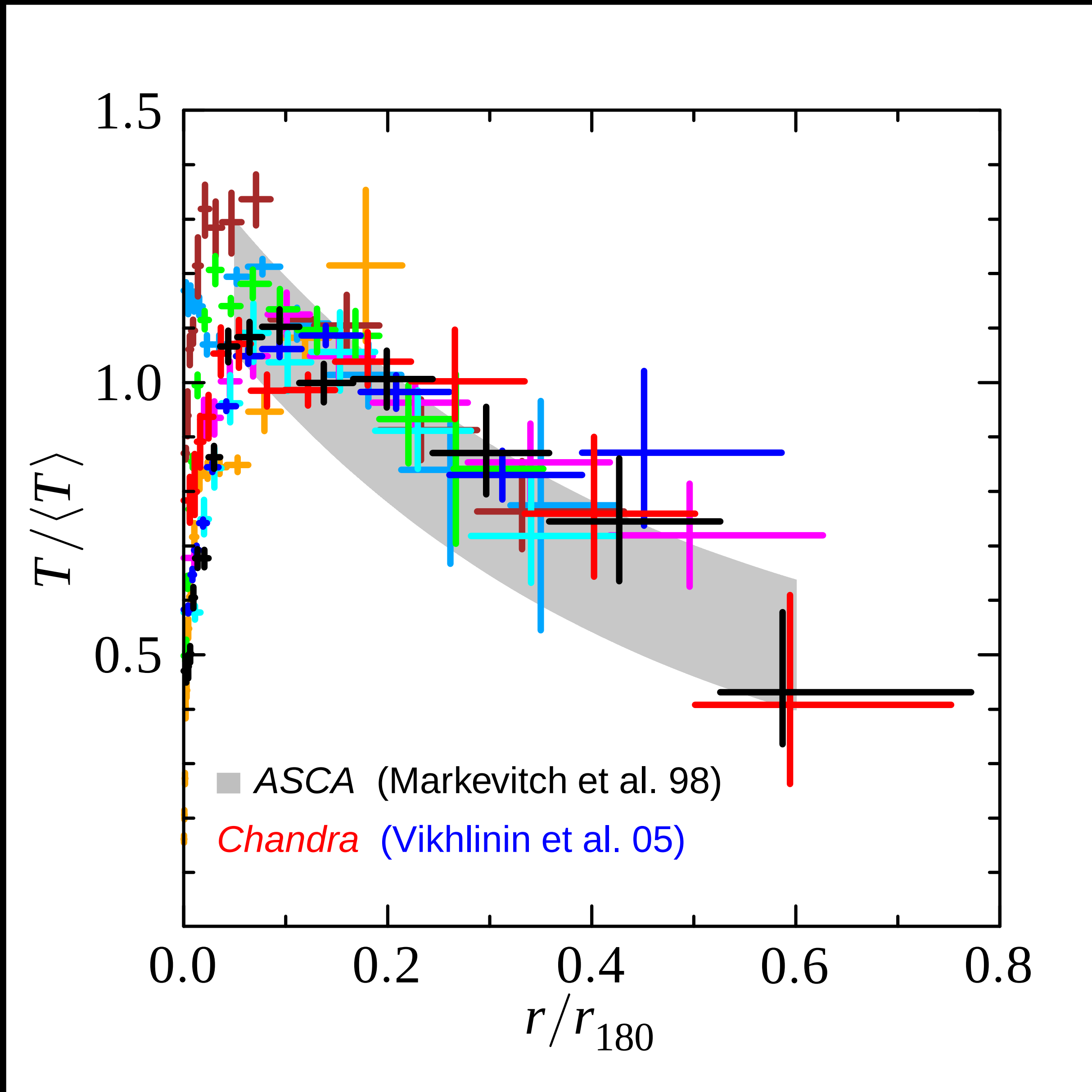
— both can be explained by magnetic draping

- Small-scale temperature structure in mergers, e.g., A754 →
  suppressed by ×10 – 40 (Markevitch et al. 03)

— can be a selection effect (pick thermally isolated regions)

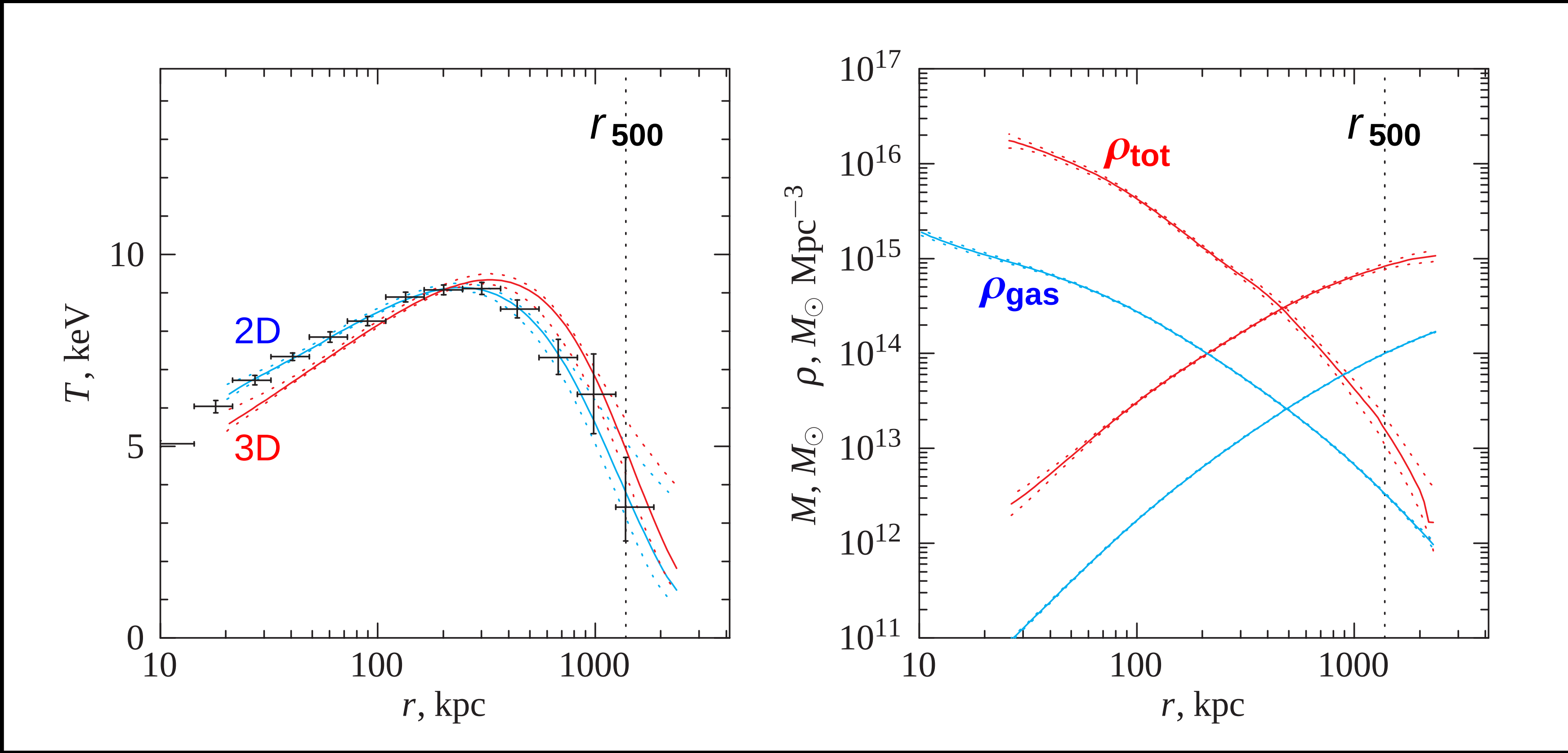
Cluster-wide, large-scale thermal conduction?

Cluster temperature profiles — radial decline



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

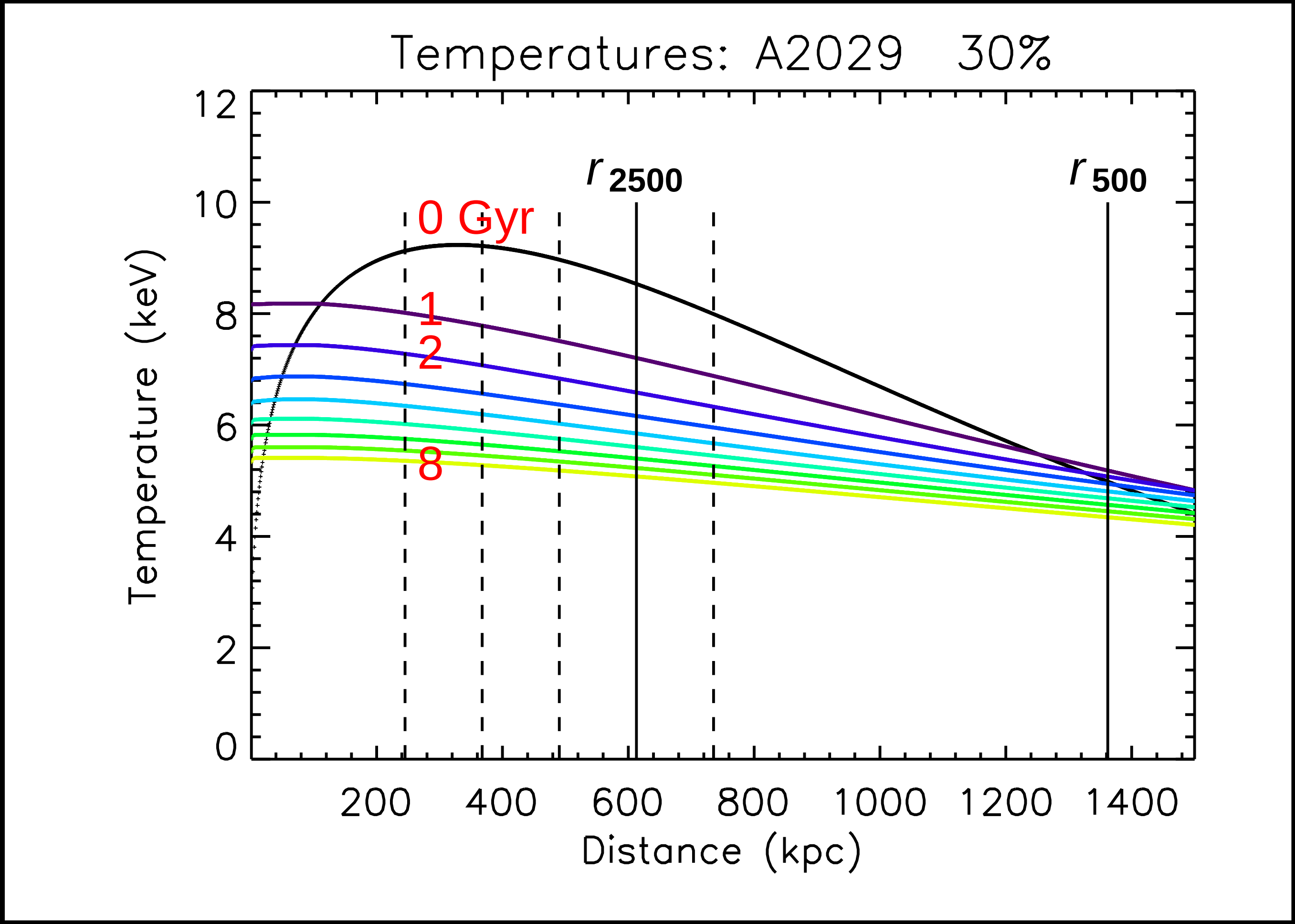
A2029, a prototypical hot relaxed cluster



Vikhlinin et al. 06

If the cluster were a solid body ...

no cooling, 0.3 Spitzer isotropic conduction

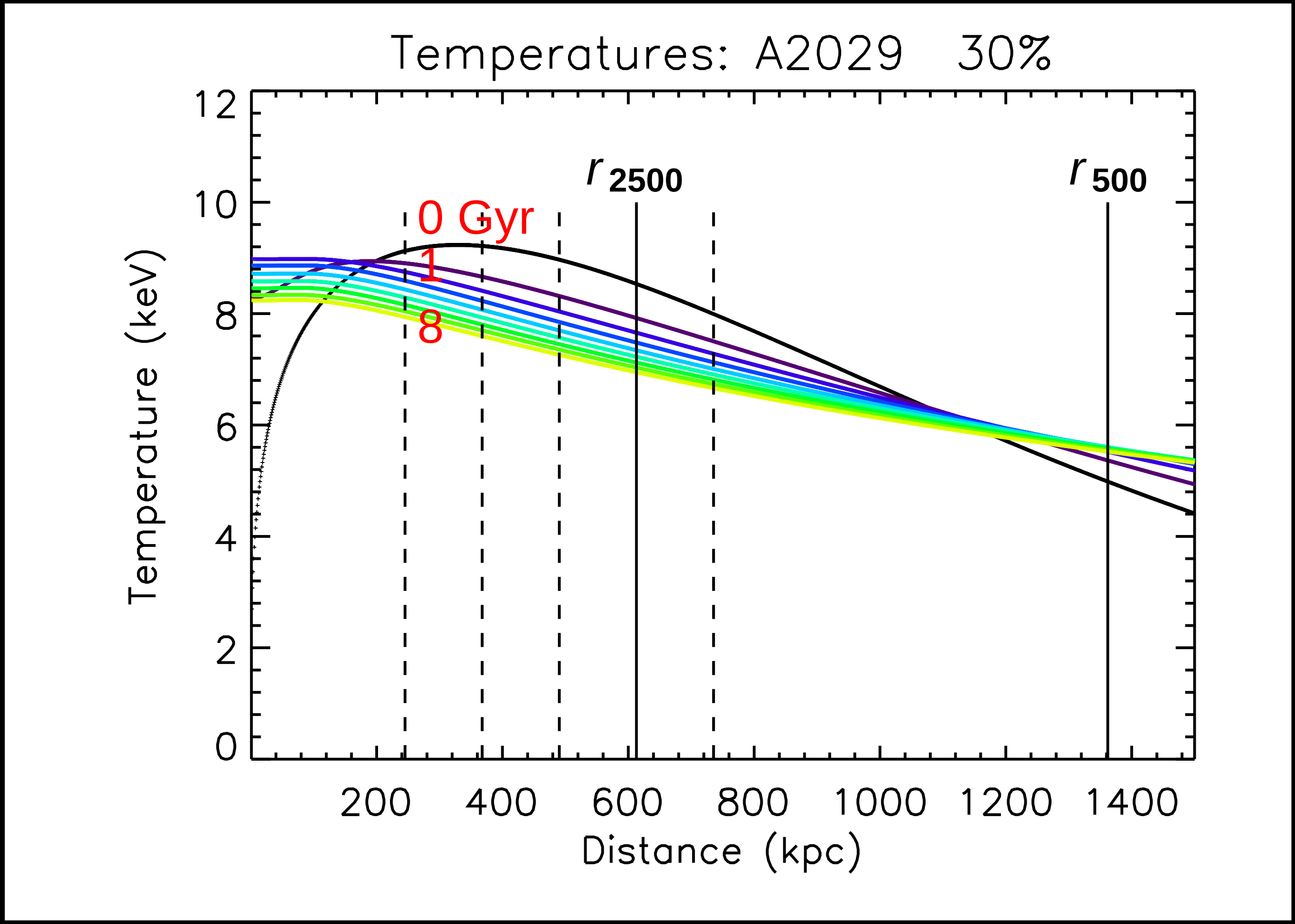


B. Russell 14

- conduction erases T gradient

If the cluster is hydrostatic ...

no cooling, 0.3 Spitzer isotropic conduction, allow gas redistribution



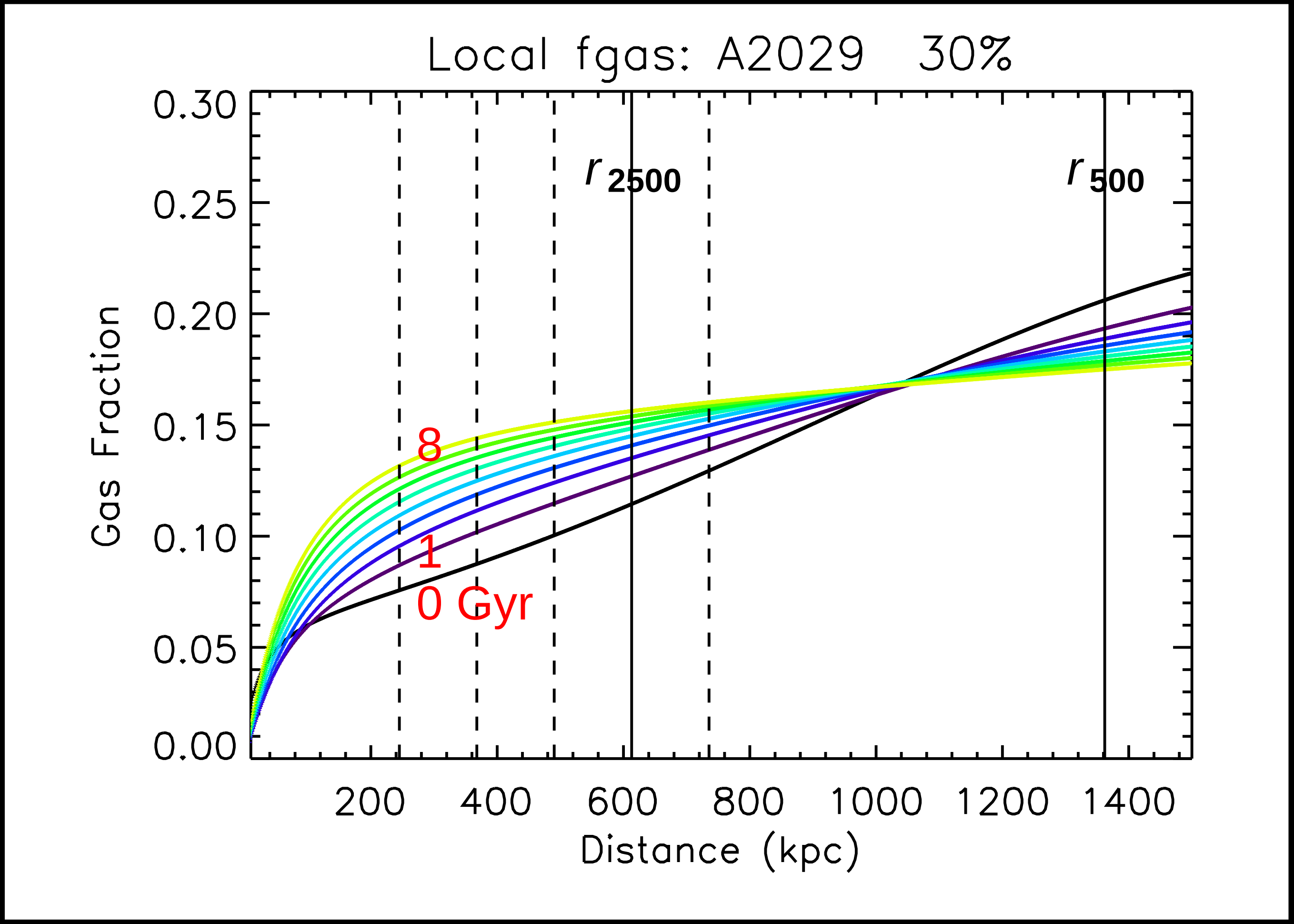
B. Russell 14

- T gradient maintained because of cluster compression

(result very similar to McCourt 13)

Evolution of gas density profile

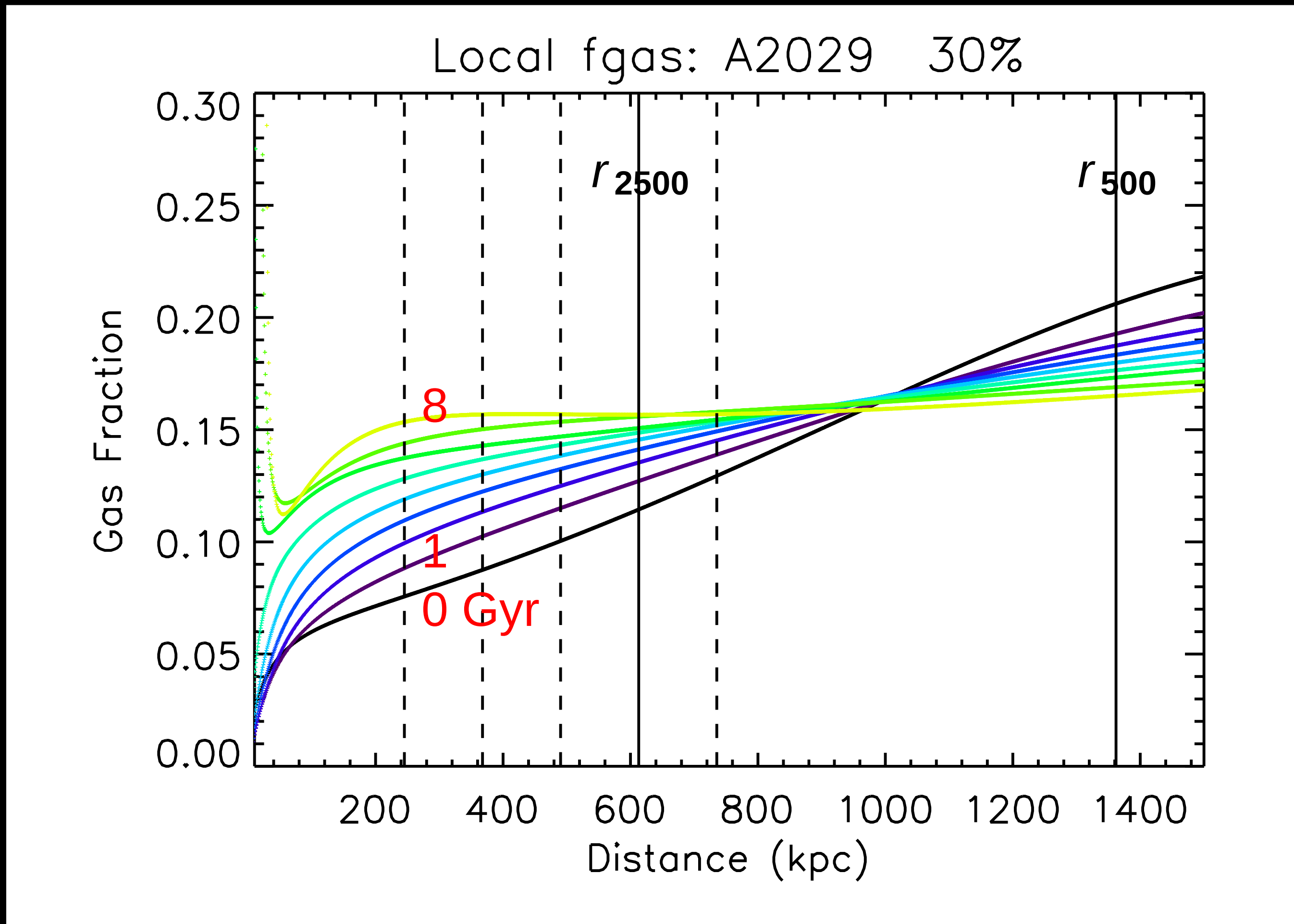
no cooling, 0.3 Spitzer isotropic conduction



B. Russell 14

Evolution of gas density profile

cooling, 0.3 Spitzer isotropic conduction

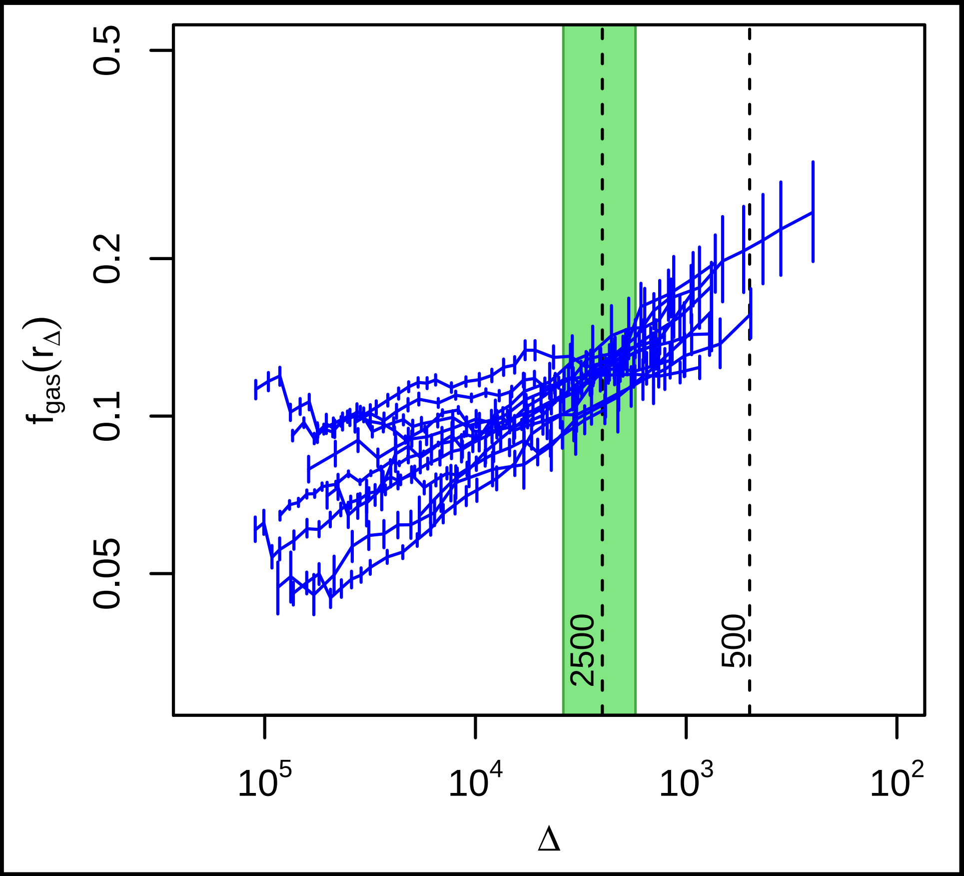


B. Russell 14

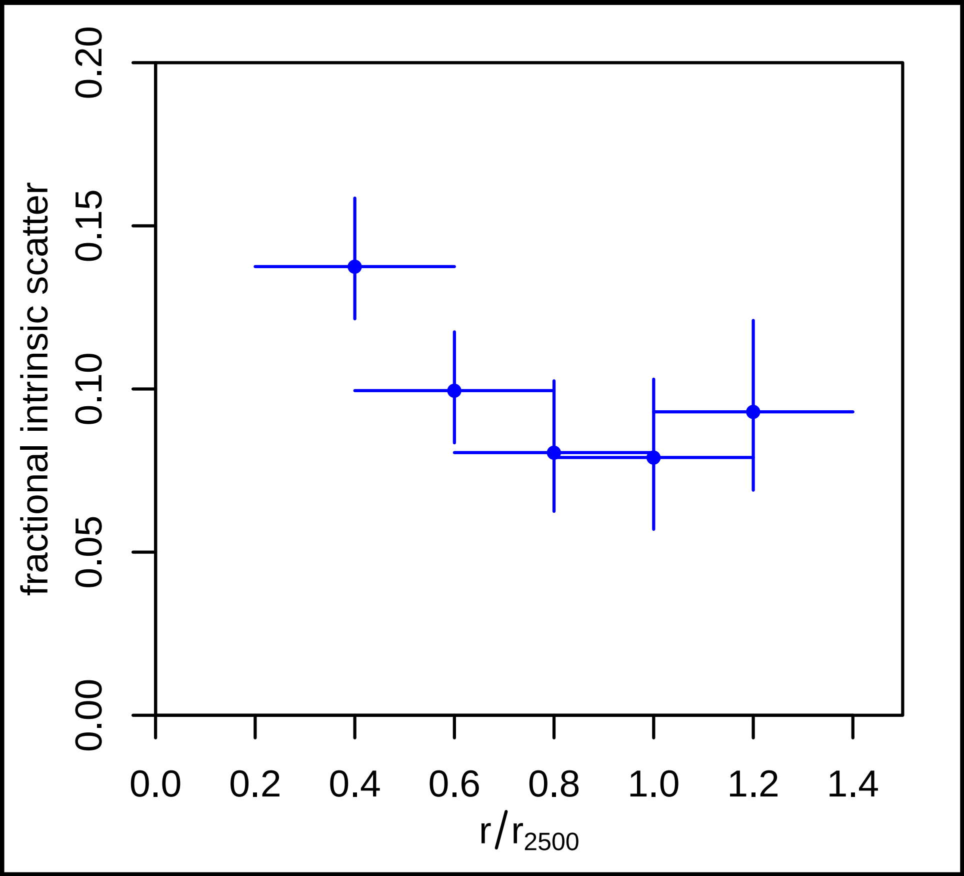
- for $r > 0.5\, r_{2500}$, result doesn't depend on details of heating and feedback in cool core

Observed differential f_{gas} profiles in hot relaxed clusters

T > 5 keV, z < 0.25 relaxed clusters



• very low scatter!



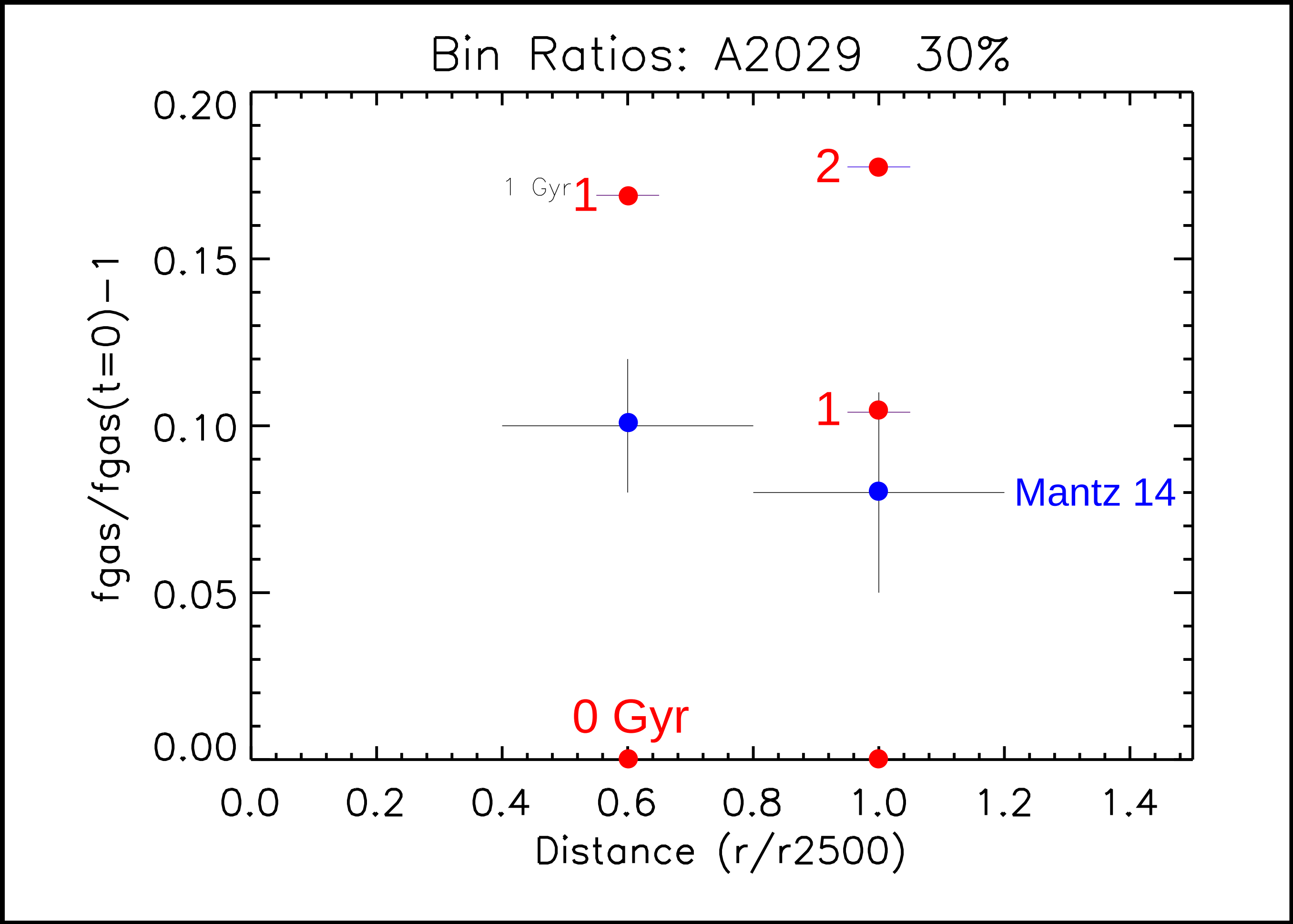
Mantz et al. 14

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

- If $\kappa \neq 0$, clusters of different age should have different $f_{\mathbf{gas}}$
  = scatter in the sample

Evolution of differential f_{gas} profile with conduction

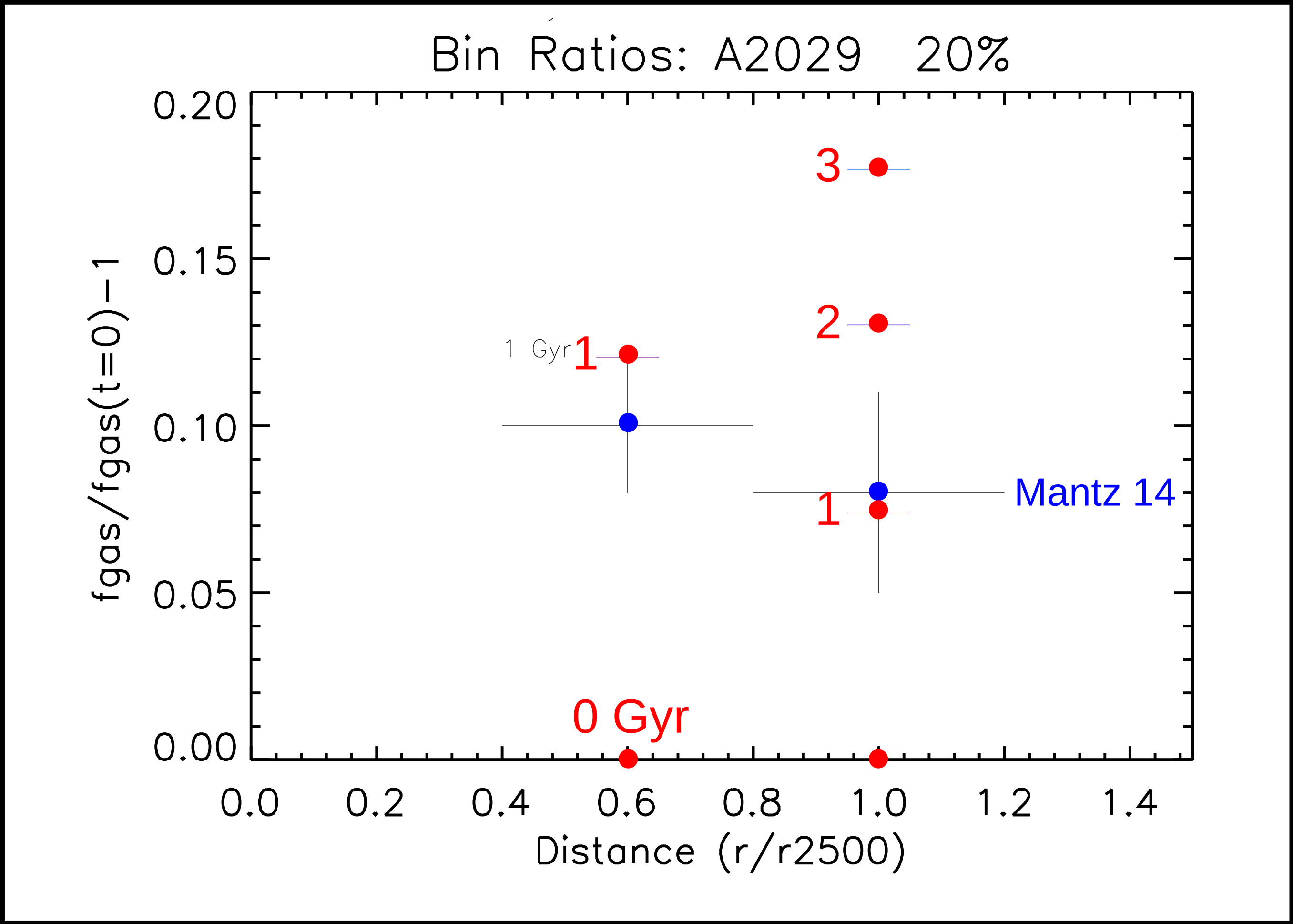
30% Spitzer



B. Russell 14

Evolution of differential f_{gas} profile with conduction

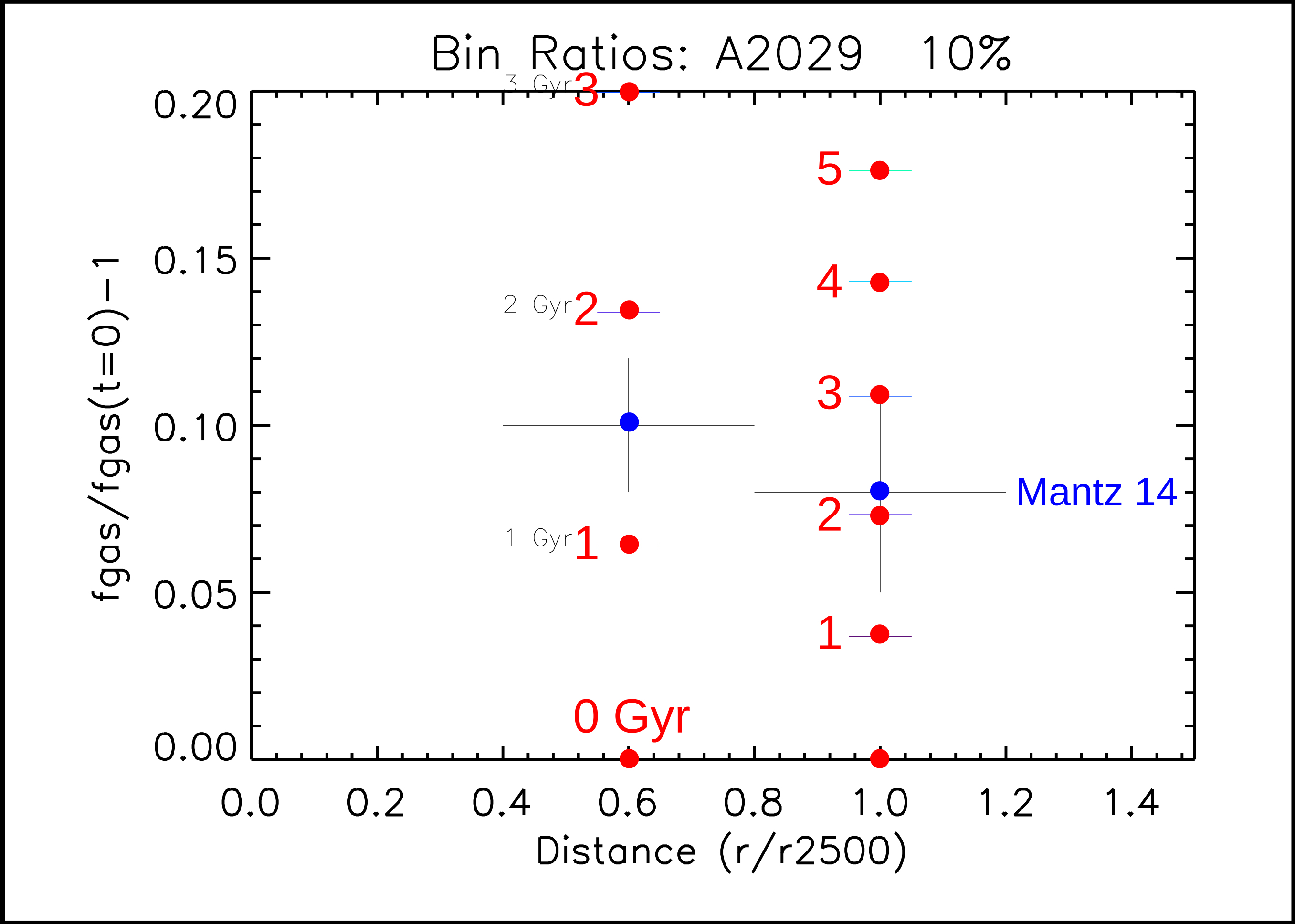
20% Spitzer



B. Russell 14

Evolution of differential f_{gas} profile with conduction

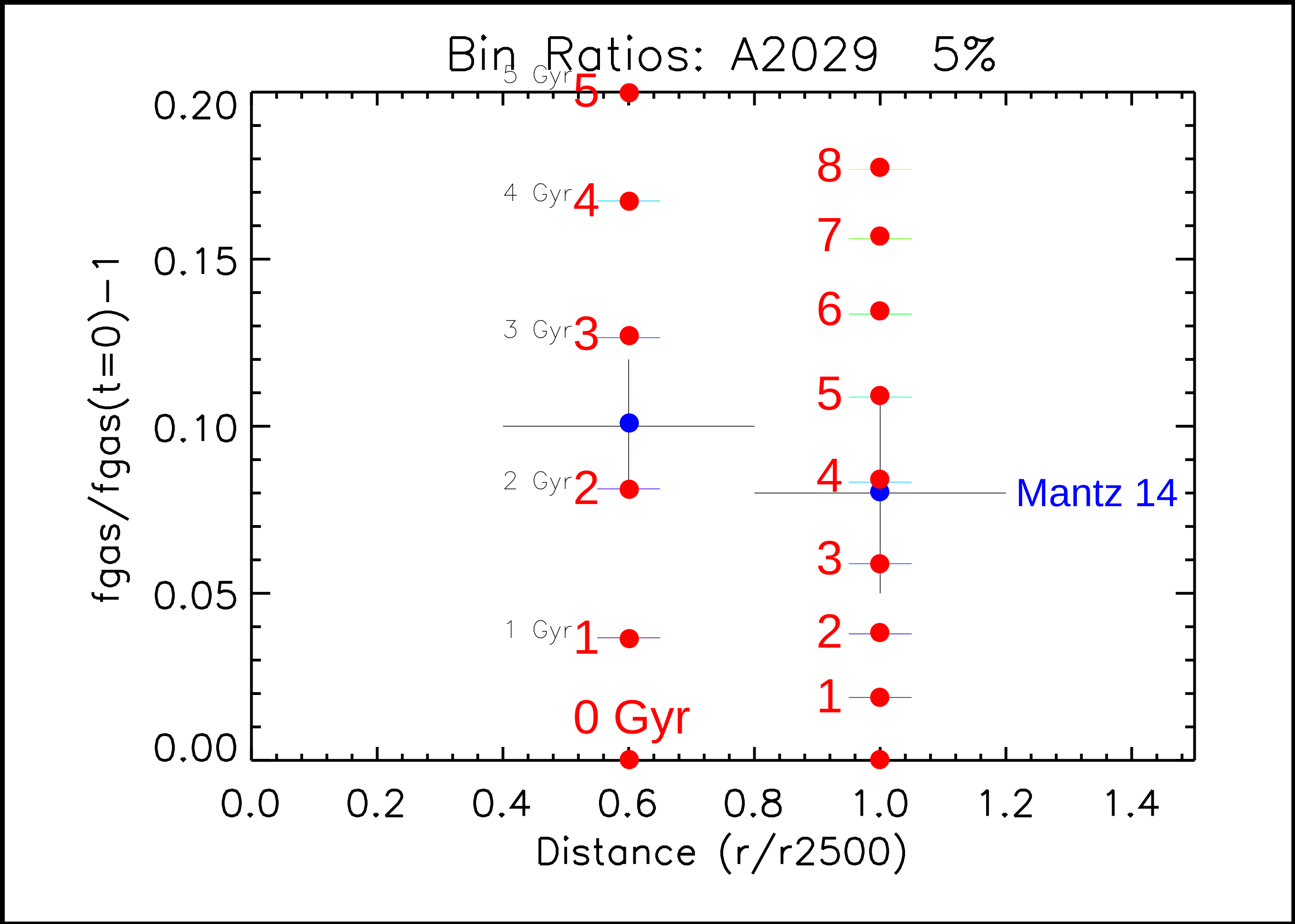
10% Spitzer



B. Russell 14

Evolution of differential $f_{\rm gas}$ profile with conduction

5% Spitzer



B. Russell 14

Conclusions on conduction

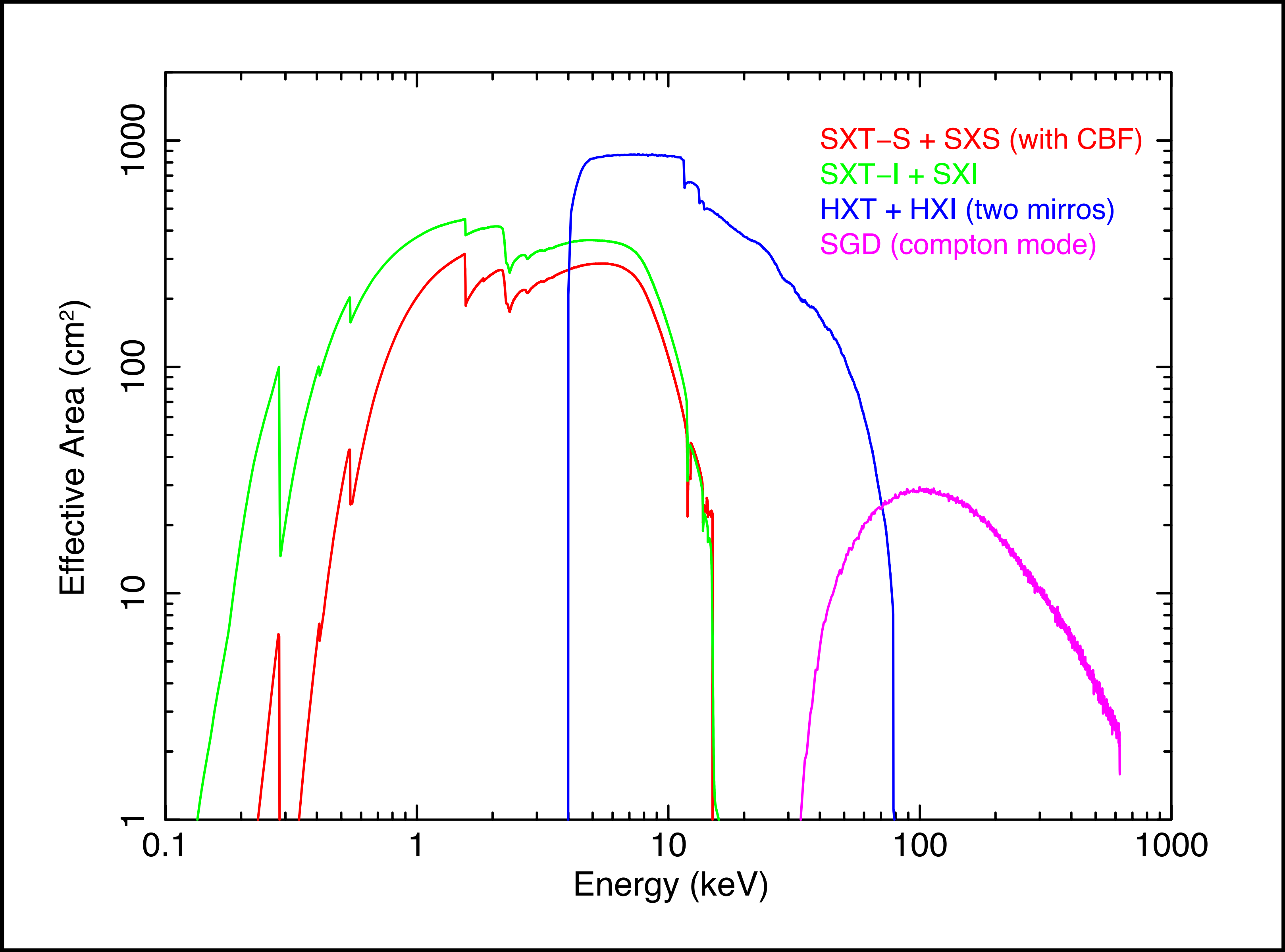
- Under simple assumptions, $\kappa > 5 - 10\%$ Spitzer (in the cluster radial direction) contradicts the observed lack of scatter in f_{gas} at $r \sim r_{2500}$ in hot, relaxed clusters

- Cosmological simulations including heat conduction and the relaxed cluster selection as in Mantz 14 may place stronger constraints

ICM turbulence (direct measurements)

X-RAY OBSERVATORY
ASTRO-H

Astro-H instruments

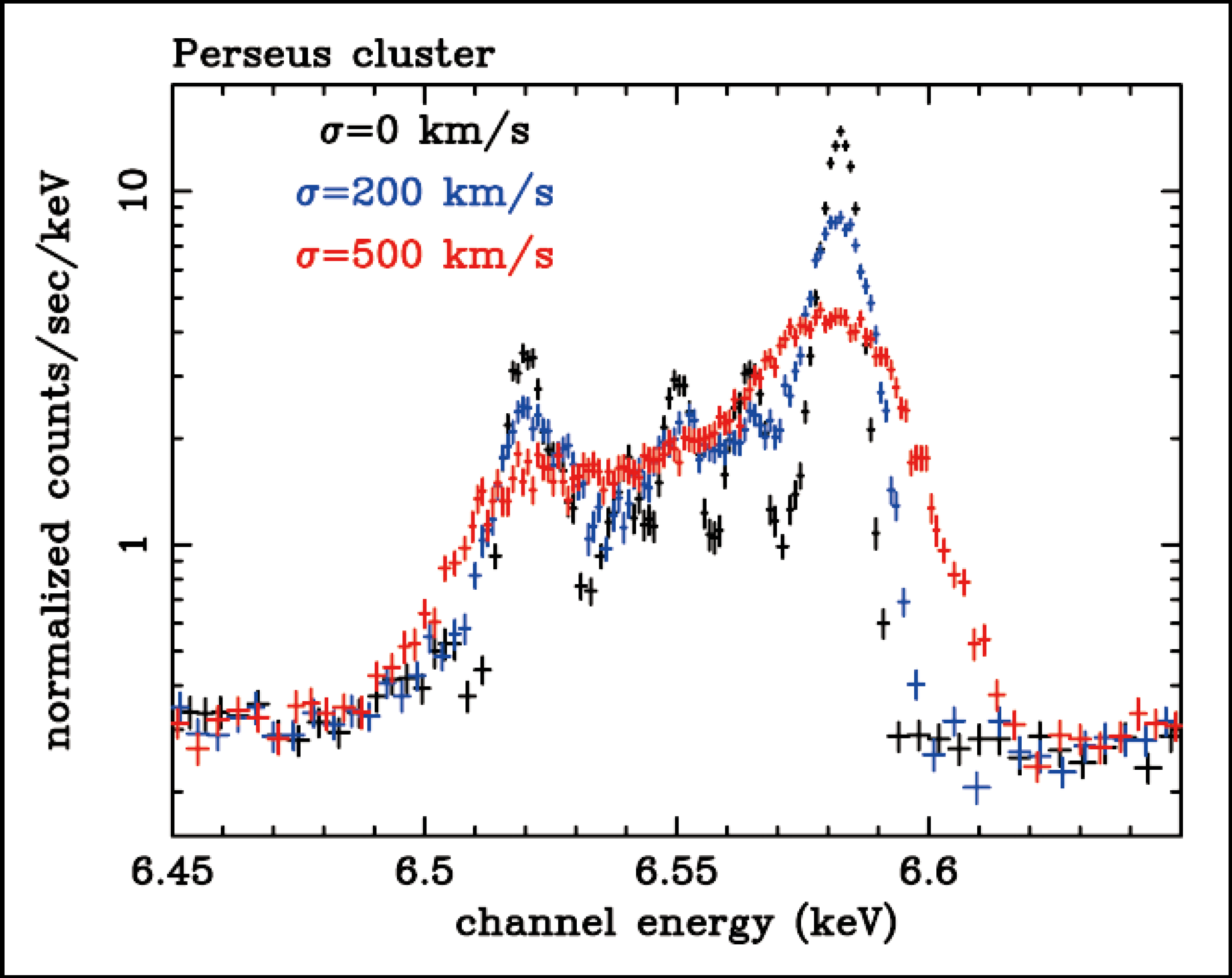


Astro-H instruments (relevant for clusters)

	Soft X-ray Spectrometer (SXS)	Soft X-ray Imager (SXI)	Hard X-ray Imager (HXI)
Detector technology	microcalorimeter	CCD	Si / CdTe cross-strips
Effective area	210 cm² at 6 keV	300 cm² at 30 keV	360 cm² at 6 keV
Energy range	0.4 – 12 keV	0.3 – 12 keV	5 – 80 keV
Energy resolution, FWHM	**5 eV**	< 200 eV	2 keV
Angular resolution, HPD	1.2′	1.2′	1.7′
FOV	3′ × 3′ (6×6 pixel array)	38′ × 38′	9′ × 9′

Can resolve turbulently broadened Fe line:

5 eV resolution at E = 6.5 keV $\rightarrow$ σ_{LOS} = 100 km/s

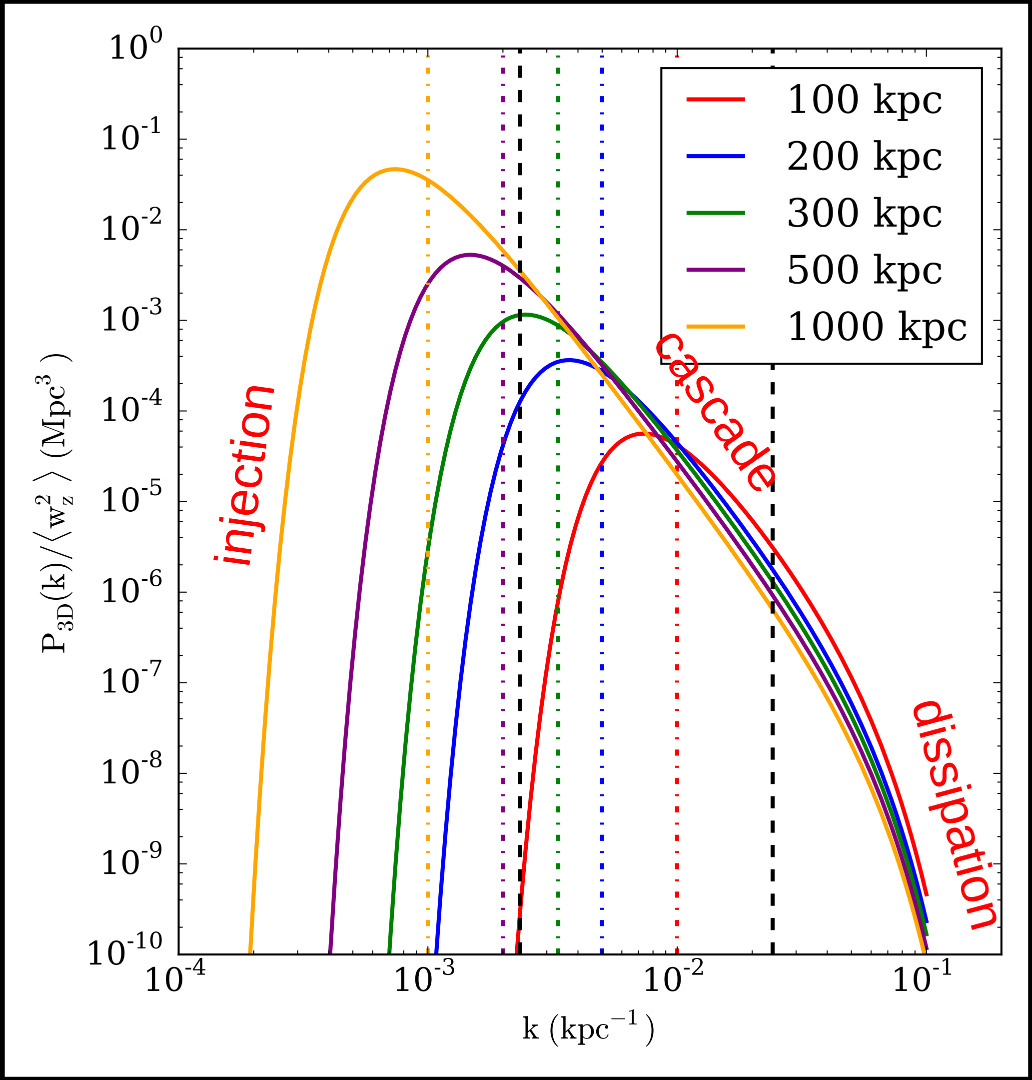


100 ks simulation of Perseus core (expected exposure much longer)

Likely early cluster projects (*Astro-H* White Paper, arxiv:1412.1176)

- Perseus core: turbulence, bulk motions, rare elements, 3.5 keV line
- Centaurus: line-rich cool core, cooling gas *EM* distribution
- M87: velocity of SW arm
- A2029, the most relaxed cluster: constrain turbulence at r_{2500} to $\sigma_{LOS} < 150$ km/s ($\sim$2% of thermal pressure)
- Power spectrum of turbulence in Coma

Power spectrum of turbulence



- Dissipation scale, power-law slope → plasma microphysics (can't measure)
- Injection scale + normalization (can measure) → (a) energy flow down the cascade, (b) diffusion and mixing rate (for metals, entropy, cosmic rays, ...)

Coma is the best cluster to study turbulence

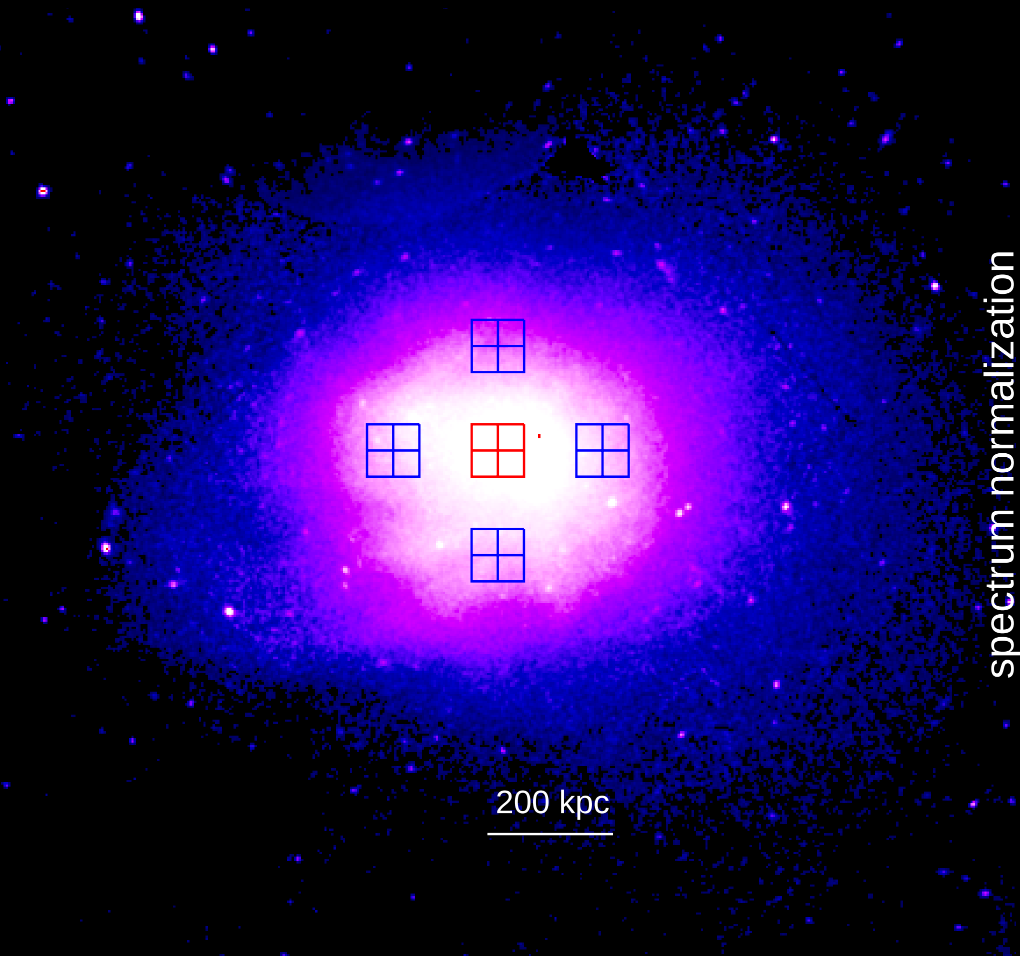
A simple system:

- No cooling flow, a big flat core → turbulence should develop in an isotropic, textbook fashion on all scales
- No central AGN → turbulence is driven only by cluster mergers

A well-studied radio halo — can estimate efficiency of turbulent acceleration of cosmic rays

Expected constraints on power spectrum

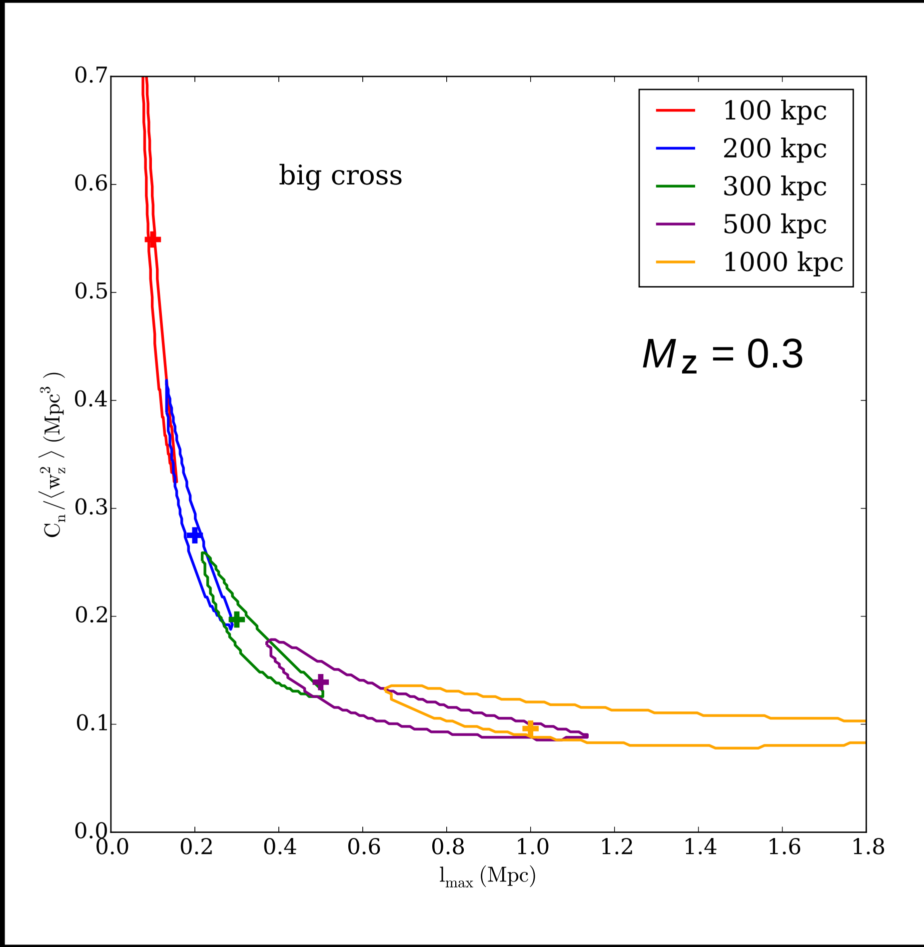
- fit line width and "structure function"
  (average velocity difference as a function of angular separation)



ZuHone et al. 15

5× 100 ks pointings

spectrum normalization



injection scale

but ... with 5 eV resolution for the first time, expect surprises