Structure of the ICM and its evolution with redshift: Status from X-ray observations

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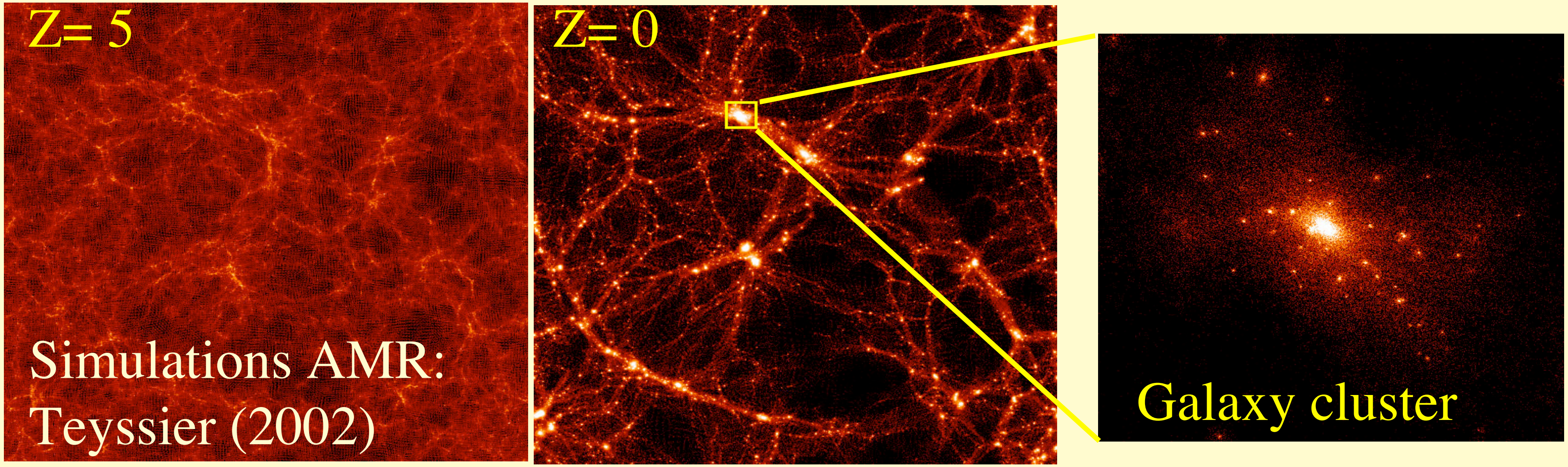


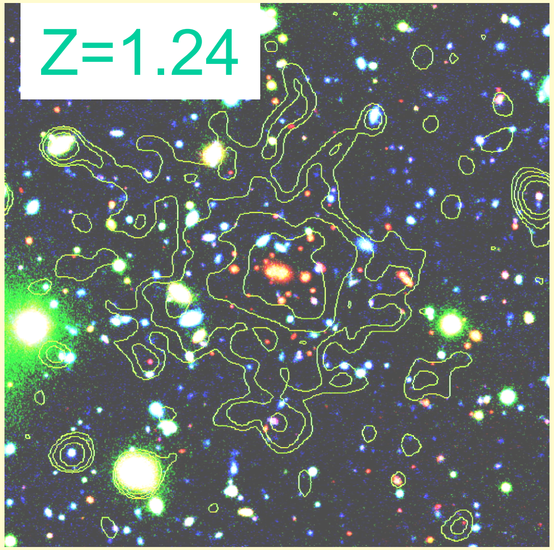
- Primordial fluctuations (DM) that growth under the influence of gravity
==> the cosmic ' web ': Voids, Filaments, Blobs : The clusters of galaxies

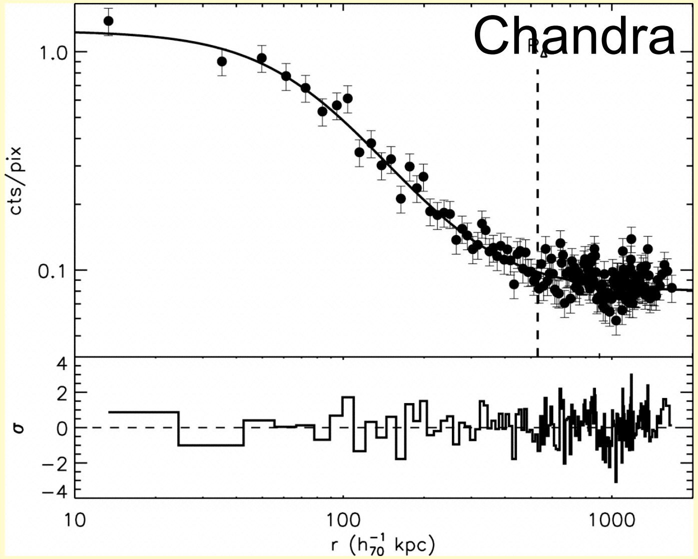
- Hierarchical clustering:
clusters: forming/growing since z~2 *till now* by merger/accretion along LS filaments

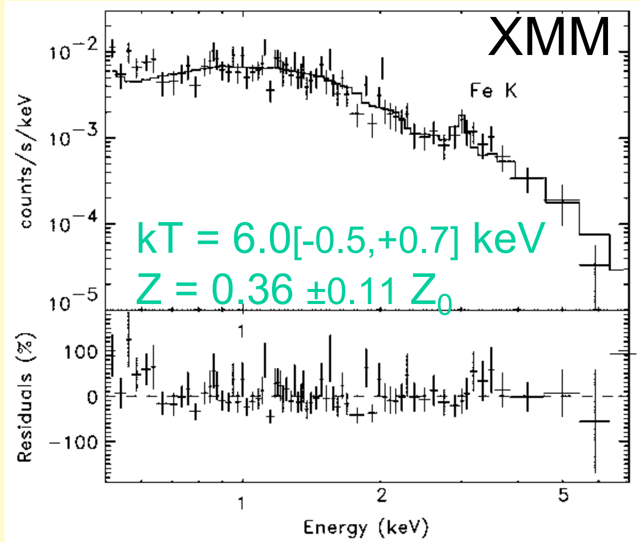
- The cluster population is an evolving population
stat prop. vs z => test of structure formation scenario *(Dark Matter and Gas)*
and can be used to constrain the cosmological parameters

The XMM/Chandra capabilities
for highz cluster studies

Basic properties up to high z







Rosati et al., 04

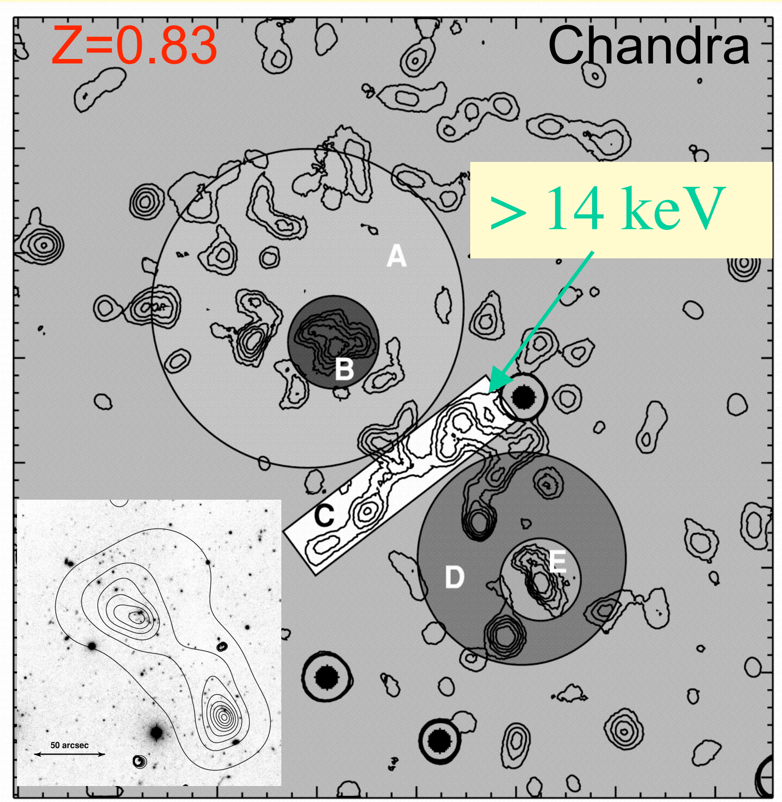
Morphology

Gas density: n_{gas} (r)

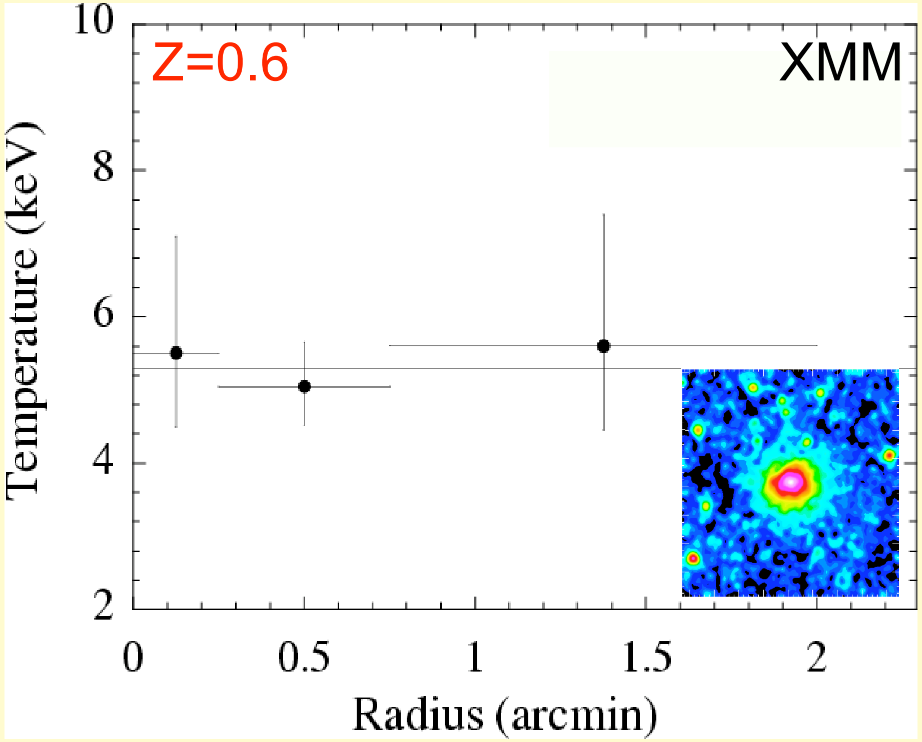
Temperature, Z

=> L_x, M_{gas}, M_{tot} , S down to flux at ROSAT detection limit

Crude kT structure for brightest clusters



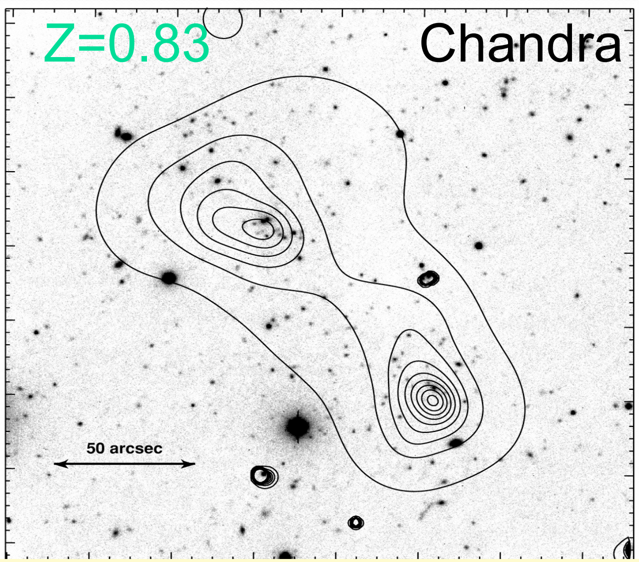
RXJ0152.7-1357 *Maughan et al 03*



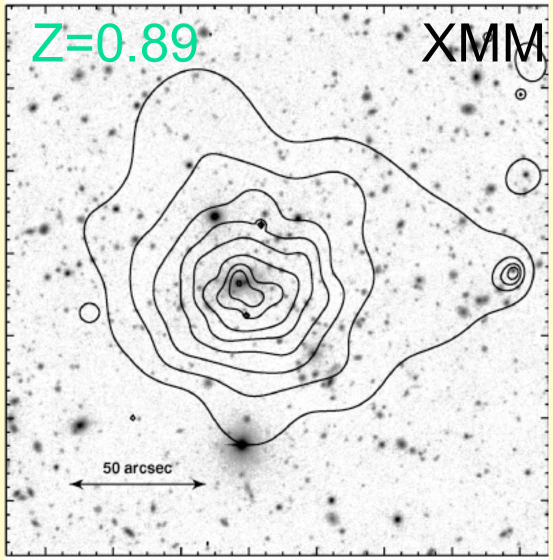
RXJ1120.1+4318 *Arnaud et al,02*

Distant cluster dynamical state

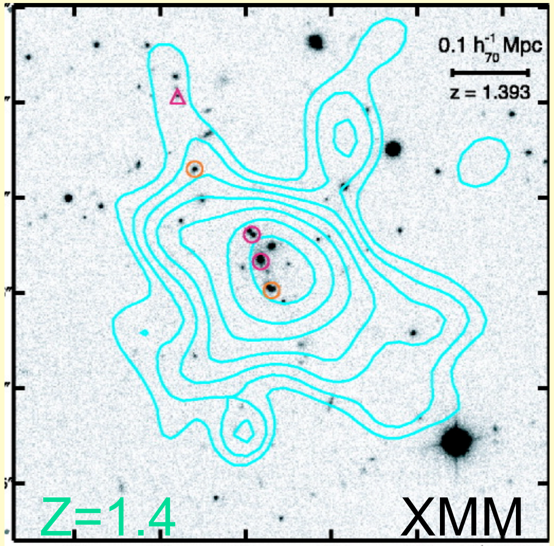
A variety of clusters



Maughan et al 03



Maughan et al 04



Mullis et al 05

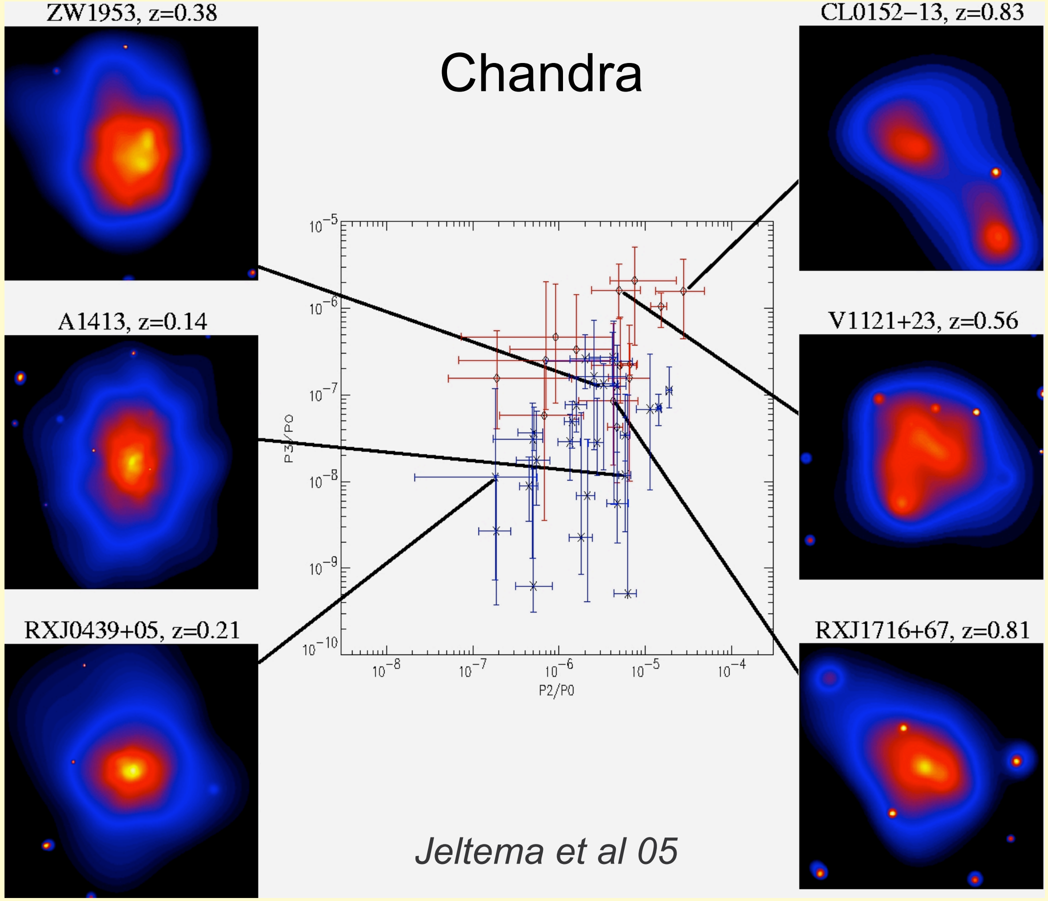
∃: mergers

massive relaxed cluster

kT=11± 1 keV

clusters up to z=1.4

Evolution of (sub)structures



High z (> 0.5) clusters:

more substructures
dynamically younger

as expected in
hierarchical scenario

The evolution of scaling properties

Canonical model of cluster formation

Dark matter

⇒ virialized' M(z) : fixed density contrast

$3\,M/4\pi R^3 = \Delta\,\rho_c(z) \qquad \Delta \sim 200$

⇒ universal profile

Gas

evolving in the DM gravitational potential

⇒ universal profile

⇒ $f_{gas} = cst$

⇒ close to HE

$kT = \beta\,GM/R$

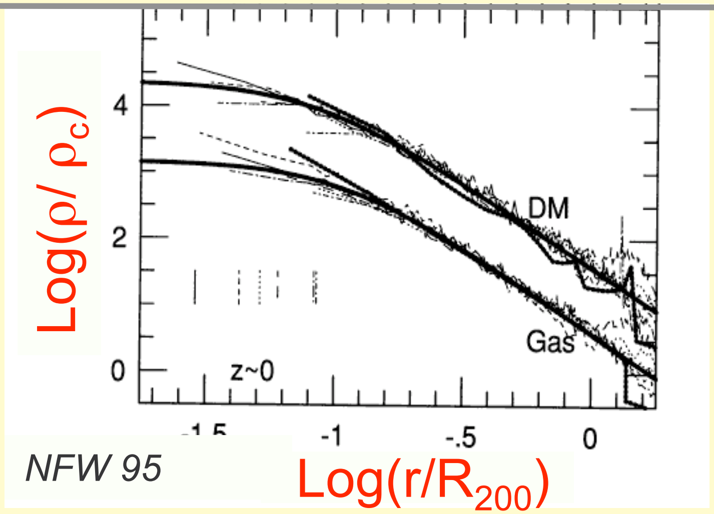
Self Similarity of the cluster population

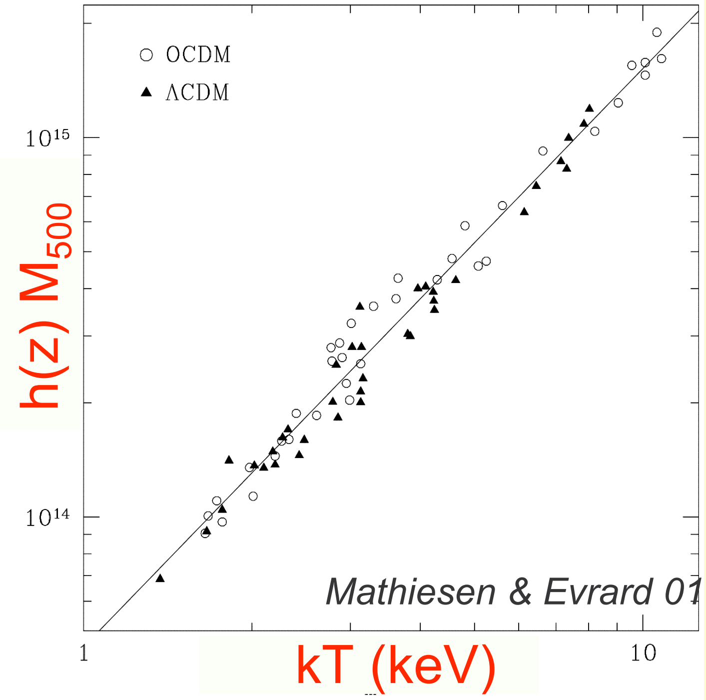
⇒ universal profiles

⇒ simple scaling laws: $Q = A(z)T^{\alpha}$

⇒ evolution via $\rho_c(z) \,\alpha\, h^2(z)$

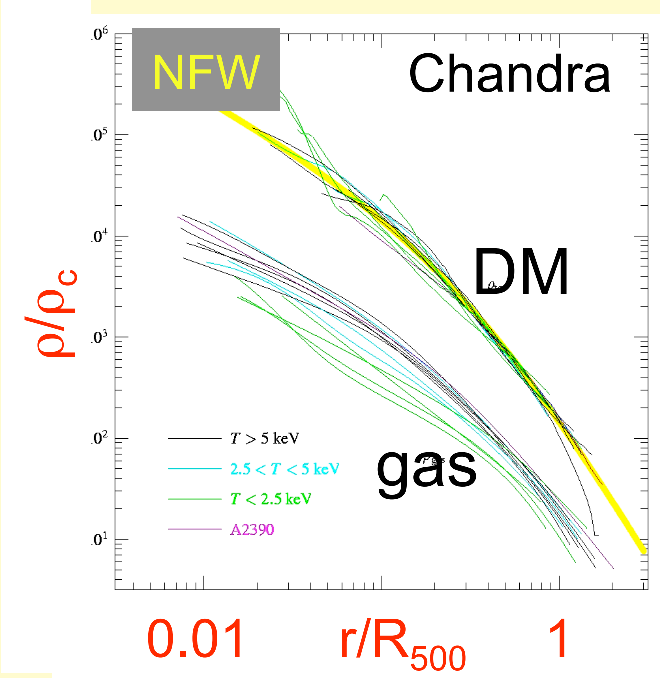
e.g: $M \,\alpha\, h^{-1}(z)\,T^{3/2}$; $L_X \,\alpha\, h(z)\,T^2$



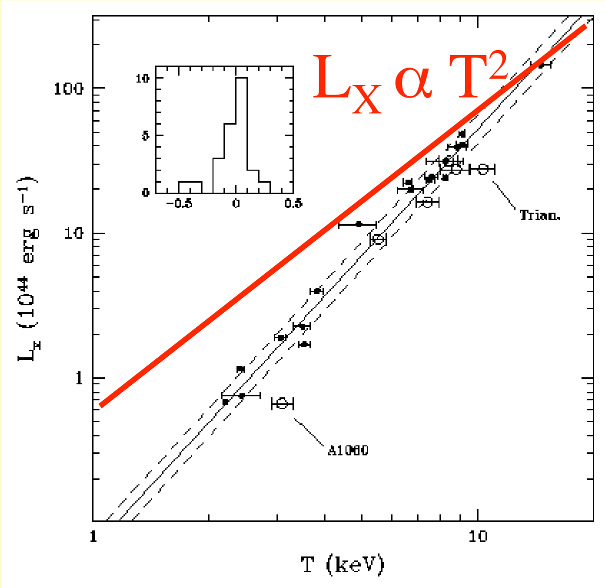


The observed local cluster population

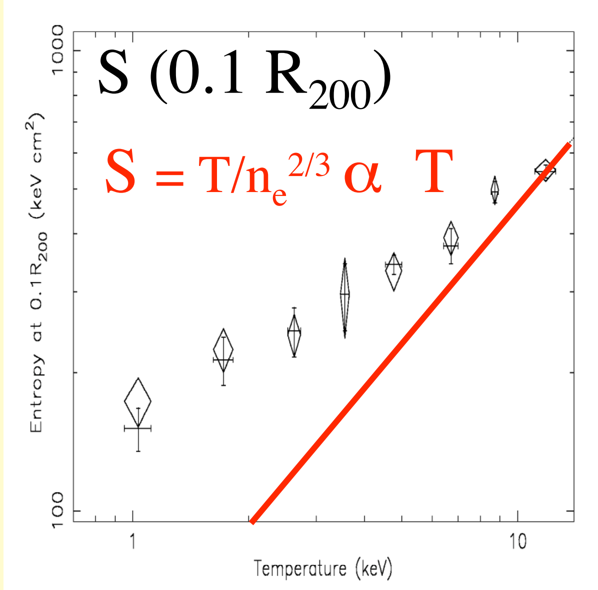
See G. Pratt talk



Vikhlinin et al, 05; see also:
Pratt & MA, 03,05; Pointecouteau et al,05



Arnaud & Evrard, 99



Ponman et al, 03; see also
Pratt et al,05

Self-similarity

Scaling laws not as expected

Entropy excess

DM: validity of the modeling of CDM collapse

Gas: importance of non gravitat. processes: cooling and/or AGN/SN heating ?

Some trivialities about studying evolution

• Interest:

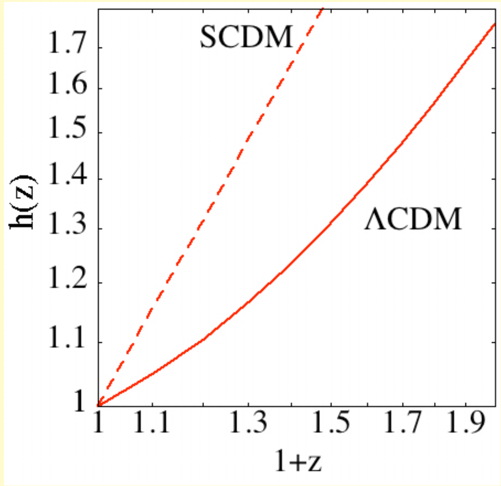
understand physics of structure formation

empirical laws when using clusters for cosmology

• Obs and prediction depend on cosmology (Ω, Λ)

• Expected evolution is not large

30% at z=0.5 for ΛCDM; precision essential



• Requires:

⇒ reference theoretical model

obs via def of $R_v(z)$; obs. vs theory

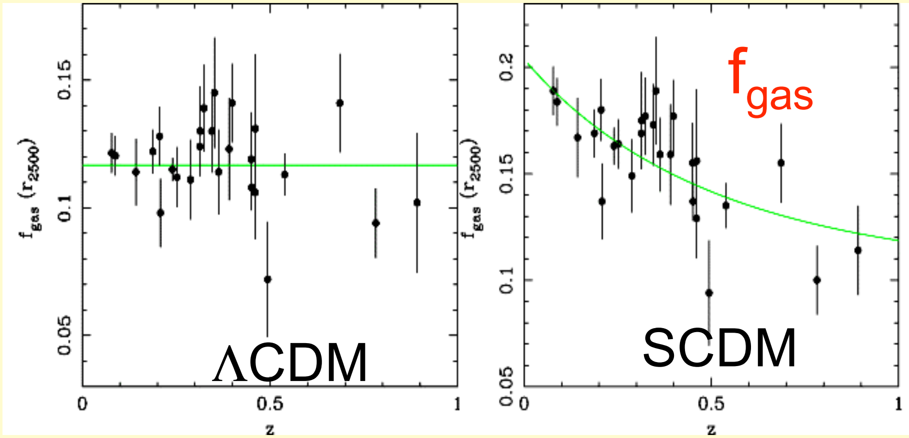
⇒ (precise) local scaling properties

⇒ compare apples with apples

use consistent cluster (sub)samples

extract 'same' quantities

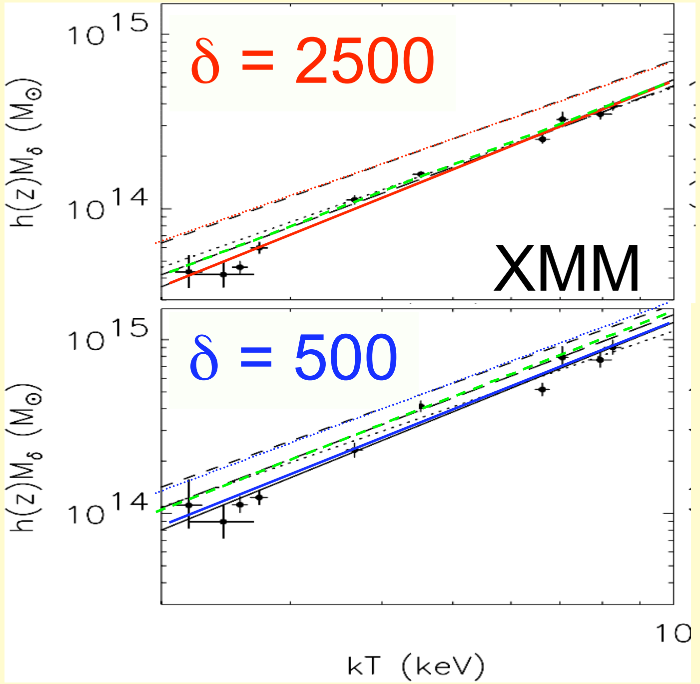
beware of systematic errors when using different instruments



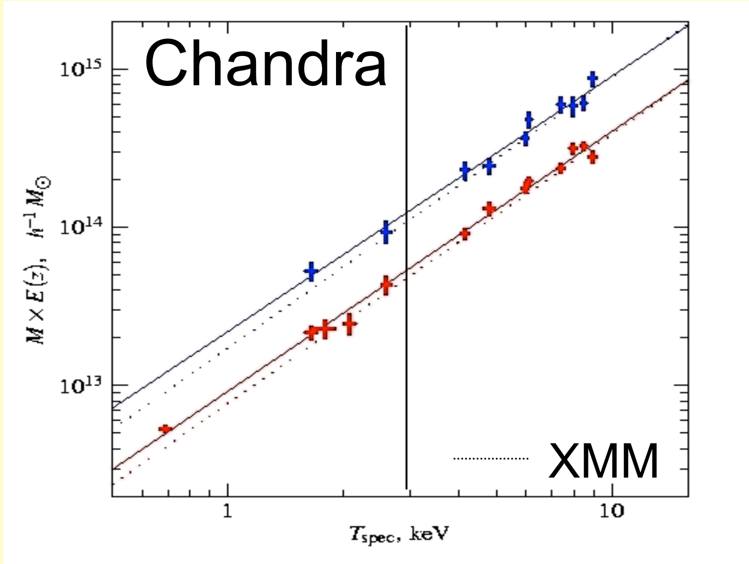
Allen et al, 04

Many sources of confusion and systematic errors ……

Evolution of the M-T relation (1)



Arnaud,Pointecouteau & Pratt,05



Vikhlinin et al, 05, astro-ph/0507092

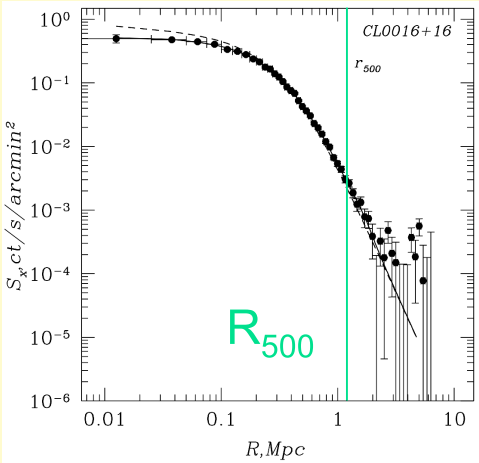
relaxed clusters

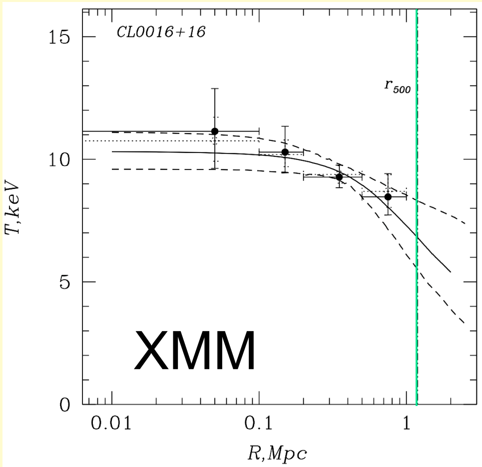
Precise converging calibration of the *local* M-T relation

- M(r) from the HE equation with kT profile => consistent estimate of R_δ and M_δ
- effect on non-grav. physics: normalisation offset ; α = 1.5±0.1 (T>3.5 keV) α ~ 1.7 (T>2 keV)

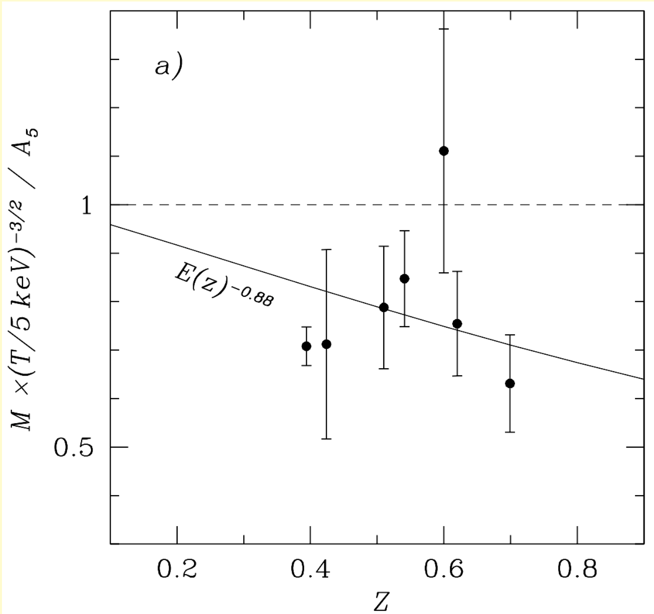
😐 Some discrepancies with previous ROSAT/ASCA studies (*see Arnaud et al, 05*)

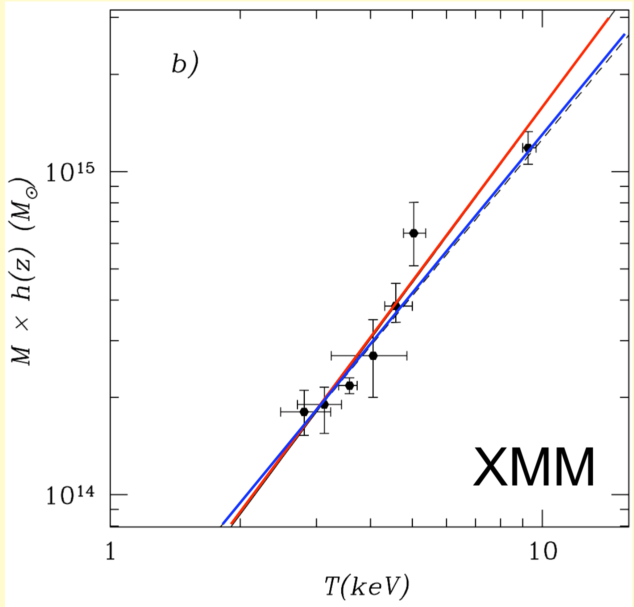
Evolution of the M-T relation (2)





Kotov & Vikhlinin, astro-ph/0504233



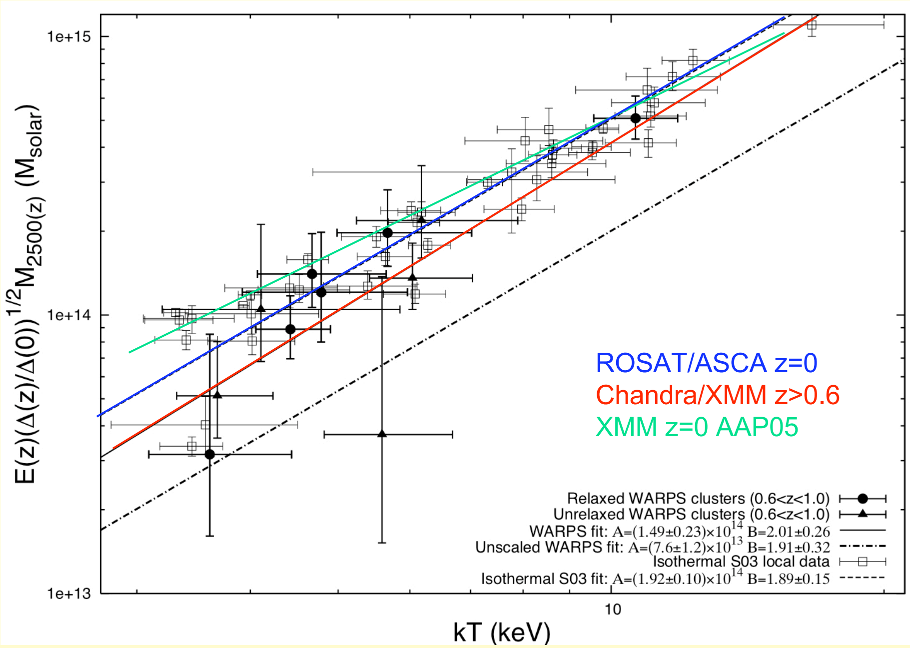


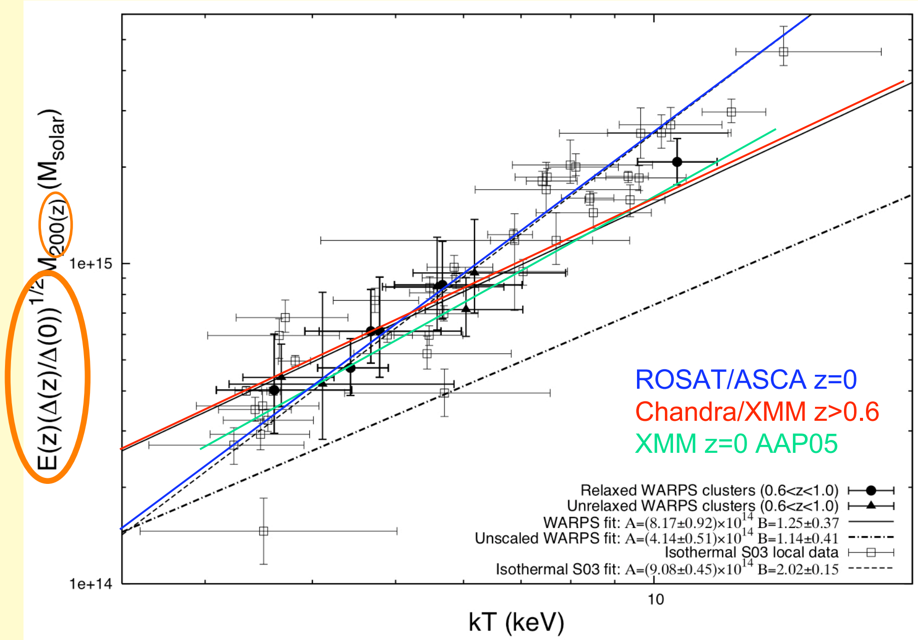
- Local M-T from Chandra ~ XMM
- High z (0.4 -0.7) relaxed cluster sample
- Mass and <T> from XMM resolved kT profiles as at z=0

Evolution as expected

$M_{500} = h(z)^{0.81\pm0.21}\ T^{3/2}$

Evolution of the M-T relation (3)





Maughan et al, 05, astro-ph/0503455

- There is evolution
- Consistent with expected

☺ Larger unbiased (0.6<z< 1; ~ local) sample

☹ M_Δ assuming isothermality; HE valid?

😐 Different definition for M_Δ

See also Ettori et al, 04

Some technalities (1)

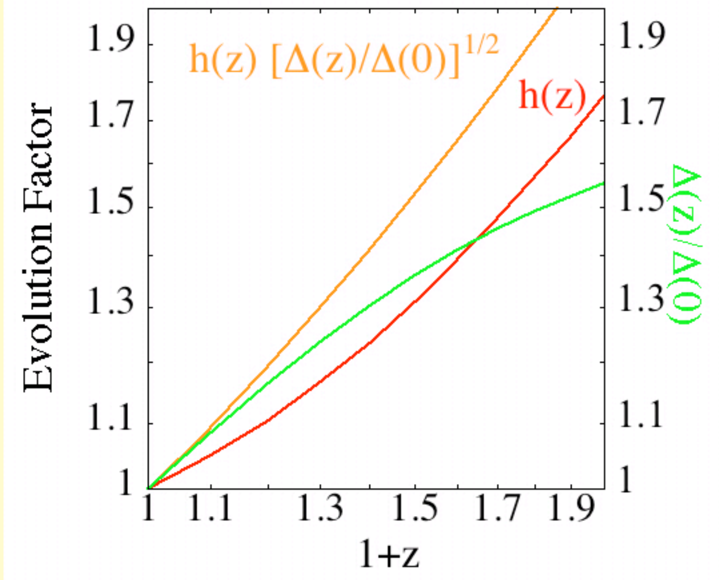
- Multiple definition of 'virial' radius in literature

$$3\,M_v/4\pi R_v^3 \;=\; <\rho>_v = \Delta_v\, \rho_c(z)$$

1a) Δ_v fixed ~ 200 Numerical simulations
1b) $\Delta_v(z) = 18\pi^2 + 82\,x - 39\,x^2$; $x = \Omega_m(z) - 1$

Spherical collapse of top-hat perturbation

Equivalent in SCDM: $\Delta_v(z) = \Delta = 18\pi^2 = 178 \sim 200$
NOT in ΛCDM: $\Delta_v(0) = 110$; increases with z



2) For more confusion, use of
- $\Delta > \Delta_v$ with $\Delta(0)$ = 2500, 500, 200 …
- mean contrast : $<\rho> = \Delta\,\rho_m(z) = \Delta\,\Omega_m(z)\,\rho_c(z)$
- fixed physical radius ….

- Non trivial effect
  - global quantities via extraction region
  - 'expected' evolution factor : h(z) ➡ $h(z)\,[\Delta(z)/\Delta(0)]^{1/2}$

IF self-similarity in $r/R_{\Delta(z)}$ rather than in r/R_Δ

Some technalities (2)

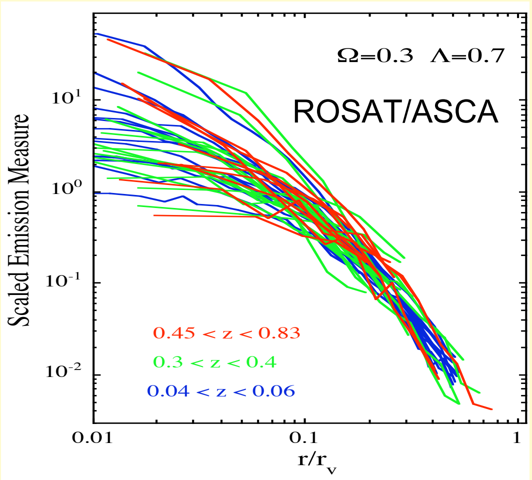
Impact on the evolution of the M-T relation

$$M(r) = -\frac{kT\ r}{G\mu m_p}\left[\frac{d\log n_e}{d\log r} + \frac{d\log T}{d\log r}\right]$$

⬇

$$h(z)\Delta_z^{1/2}\, M_{\Delta_z} = A\ \overline{T}^{3/2}$$

$$A \propto \left[\frac{T}{\overline{T}}\right]^{3/2} \left[-\frac{d\log n_e}{d\log r} - \frac{d\log T}{d\log r}\right] \qquad \text{evaluated at } R_{\Delta_z}$$



Arnaud et al, 02

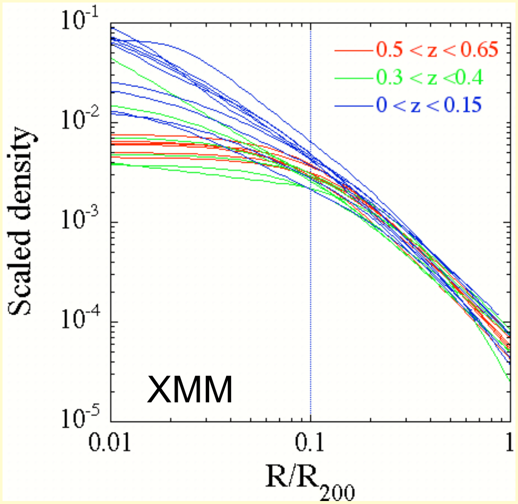
Probe universality of ICM *structure*

⇒Isothermal mass: A = β at large r (Δ = 200, 500)

std evolution for both def if non-evolving β

⇒Non-isothermal mass:

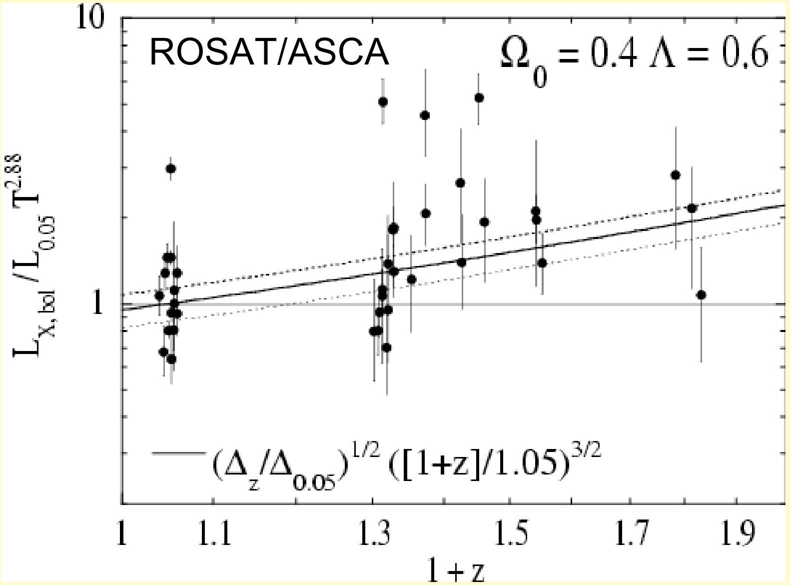
same if non evolving kT power-law shape



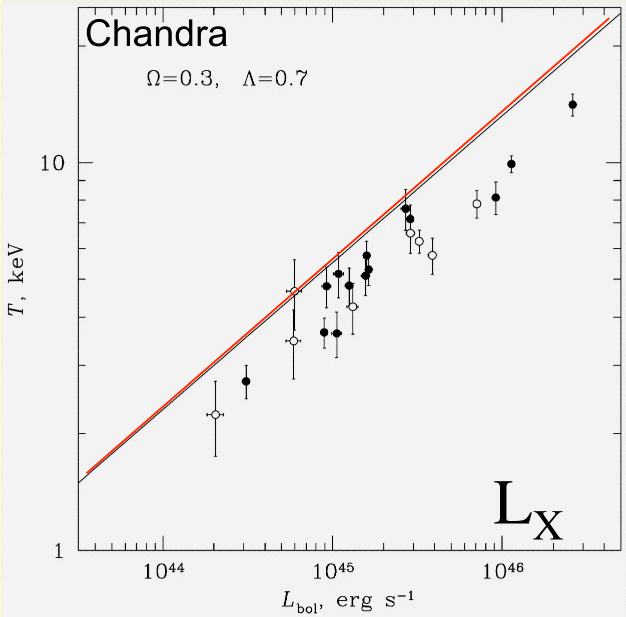
MA from misc data

Std evolution indt of M_Δ definition not surprising …

The evolution of the L_x -T relation (1)



Arnaud et al, 02
Also Novicki et al,03

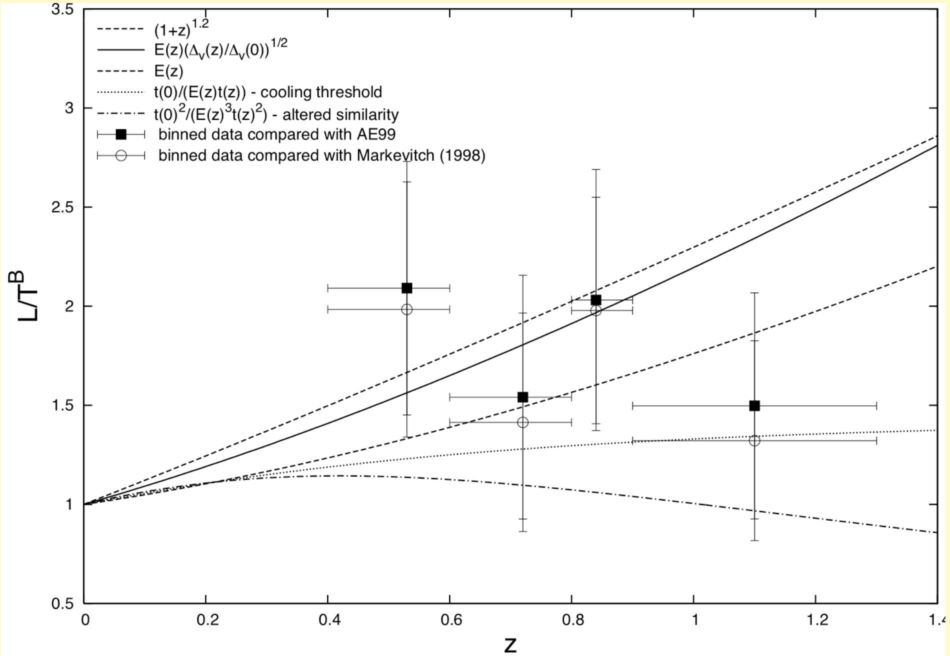


Vikhlinin et al, 02

The L_x-T relation does evolve *for a ΛCDM cosmology*

Whether it is consistent with expectations is uncertain

The evolution of the L_x -T relation (2)



Maughan et al, 05

In ΛCDM:

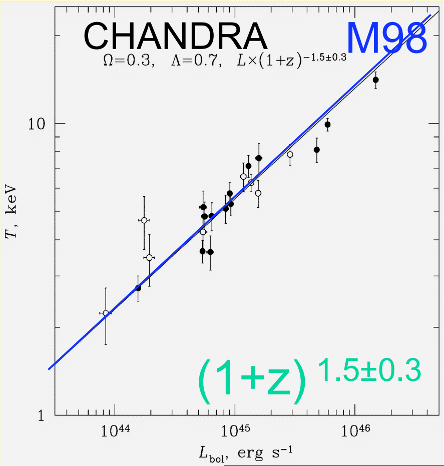
- Larger evolution of A(z) expected for Δ(z)
- effect on L_{bol} via integration region: minor
- $A(z) \neq (1+z)^{\alpha}$ but $h(z)\,\Delta(z)^{1/2} \sim (1+z)^{1.2}$
  $h(z) \sim (1+z)^{0.6\text{-}0.9}$

Caveats $L_{bol} = A(z)\,T^{\alpha}$

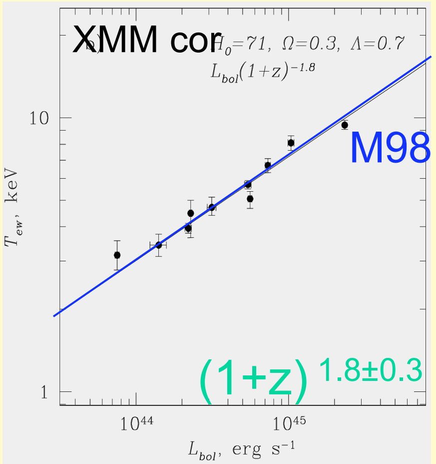
- CF correction
  local reference:
  Markevitch 98: CF corrected
  Arnaud & Evrard 99: weak CF cluster
- Instrument cross-calibration
  10% on kT => 30% on A(z) $\cong$ h(0.5)
- Parametrisation of A(z)
  and reference 'self-similar' model

The evolution of the L_x -T relation (3)

Vikhlinin et al 02

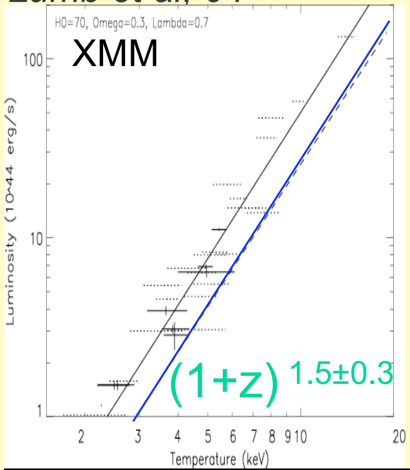


Kotov & Vikhlinin 05



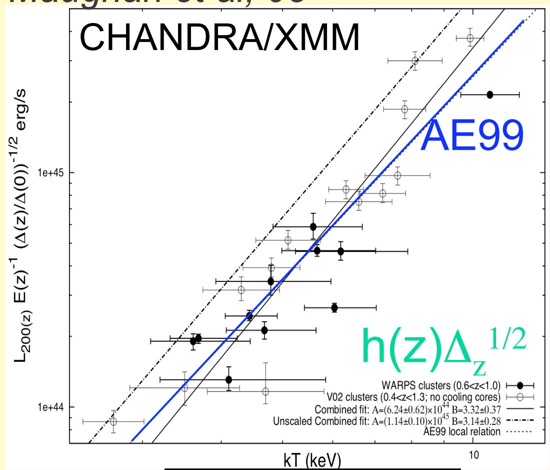
R fixed; CF corrected

Lumb et al, 04



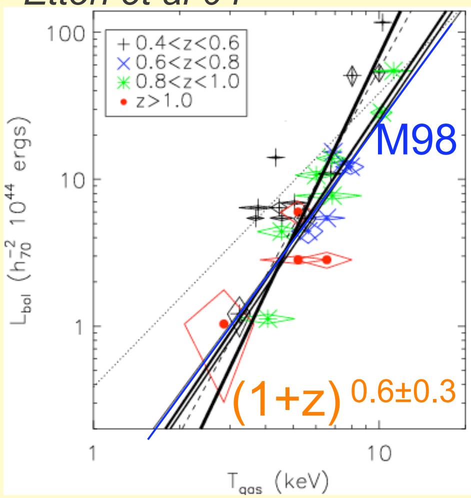
R_{200}; CF corrected

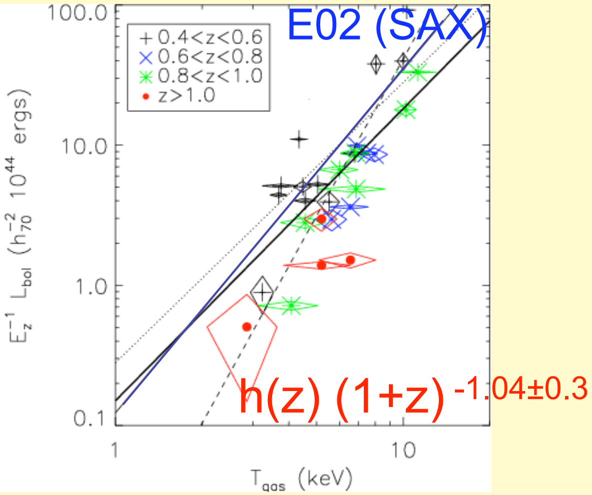
Maughan et al, 05



$R_{200(z)}$; no CF

Ettori et al 04





$R'_{500(z)}$; no CF correction

More than h(z)

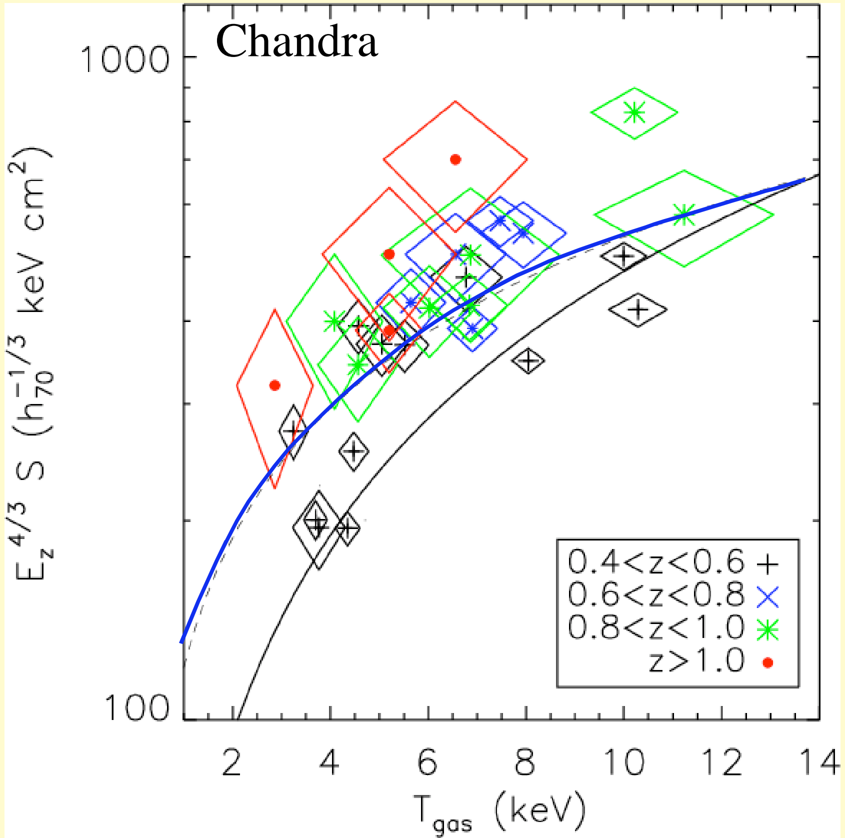
or

as h(z)

or

less than h(z)

And the entropy evolution ?



Ettori et al, 04

may be higher than expected:

$h(z)^{4/3}$ S -T = $(1+z)^{0.3\pm0.08}$ (z>0.6)

Caveats:

- Large scatter
- Strongly depends on radius: S α r thus on definition $R'_{200(z)}$

Conclusions

With XMM and Chandra

- we can probe the evolution up to high z (>1) down to ROSAT detection limit
- Evolution of substructures qualitatively consistent with hierarchical model
- Start to constrain the evolution of scaling properties

The overall picture provided by this study of the evolution of the cluster scaling relations is that within the statistical limits of the current data, the evolution of galaxy clusters out to $z \approx 1$ is described well by the self-similar model. The

Maughan et al, 05

and systematic uncertainties…..

For future progress:

- avoid confusion and agree on a reference 'pure grav.' model….
- minimize systematic uncertainties: large unbiased samples (at z=0 and high z) studied with same instrument and methods

………….more when on going LP fully analysed