The Cluster Conendrum

Cosmological Framework

- H_0 measurements
- Supernovae
- CMB
- Clusters
- BBN
- Lensing

} **Concordance Model!**

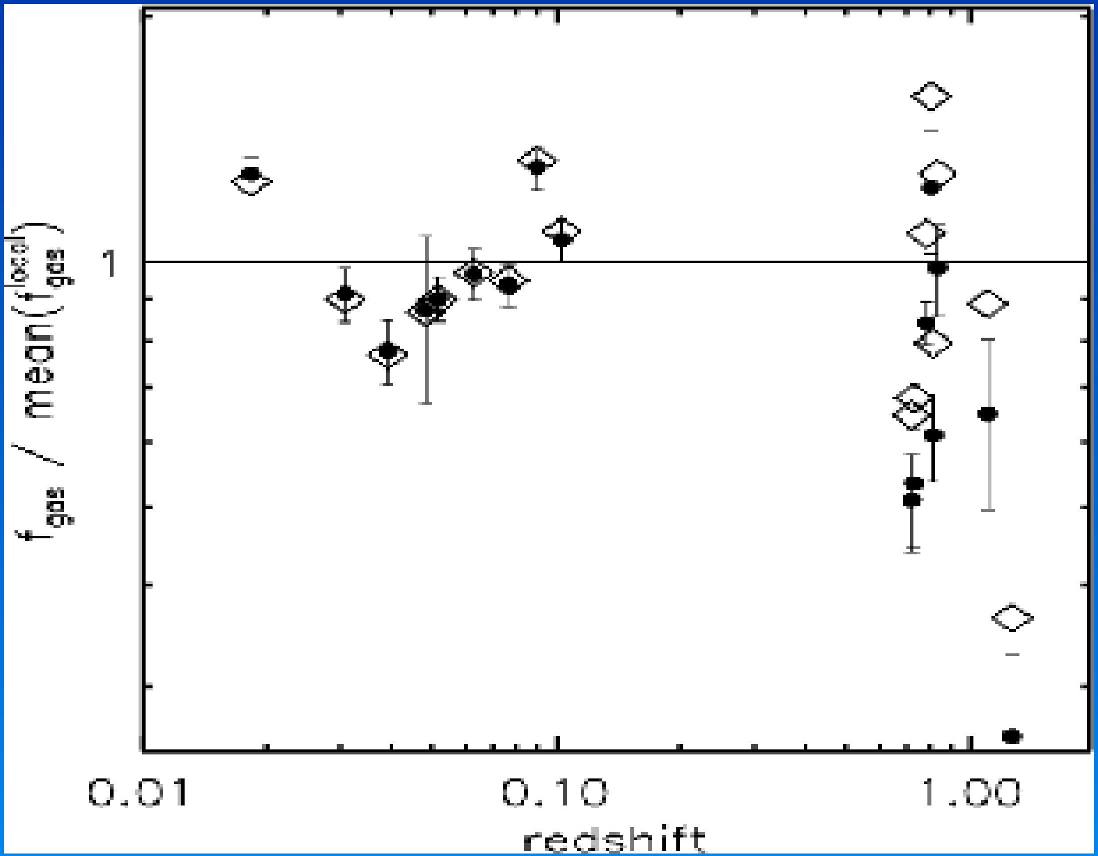
$H_0 \approx 70$ km/s/Mpc $\Omega_\lambda \approx 0.7$ $\Omega_m \approx 0.3$

Ω_m

From X-ray Clusters

Baryon Fraction evolution

Baryon Fraction (non)evolution as a test of Ω_m



Chandra

Scaling relations of (X-ray) clusters

Basic principle:

Two clusters at two different epochs z_1 and z_2 with different masses M_1 and M_2 should be identical once densities and sizes are scaled properly

Scaling argument for Clusters:

Clusters are geometrically identical

With virial radius-mass relation

$$M = \frac{4\pi}{3}\rho_0(1+z)^3(1+\Delta)R_V^3$$

i.e.

$$R_V = \sqrt[3]{\frac{3M}{4\pi\rho_0(1+\Delta)}}\frac{1}{1+z}$$

Mass-temperature relation:

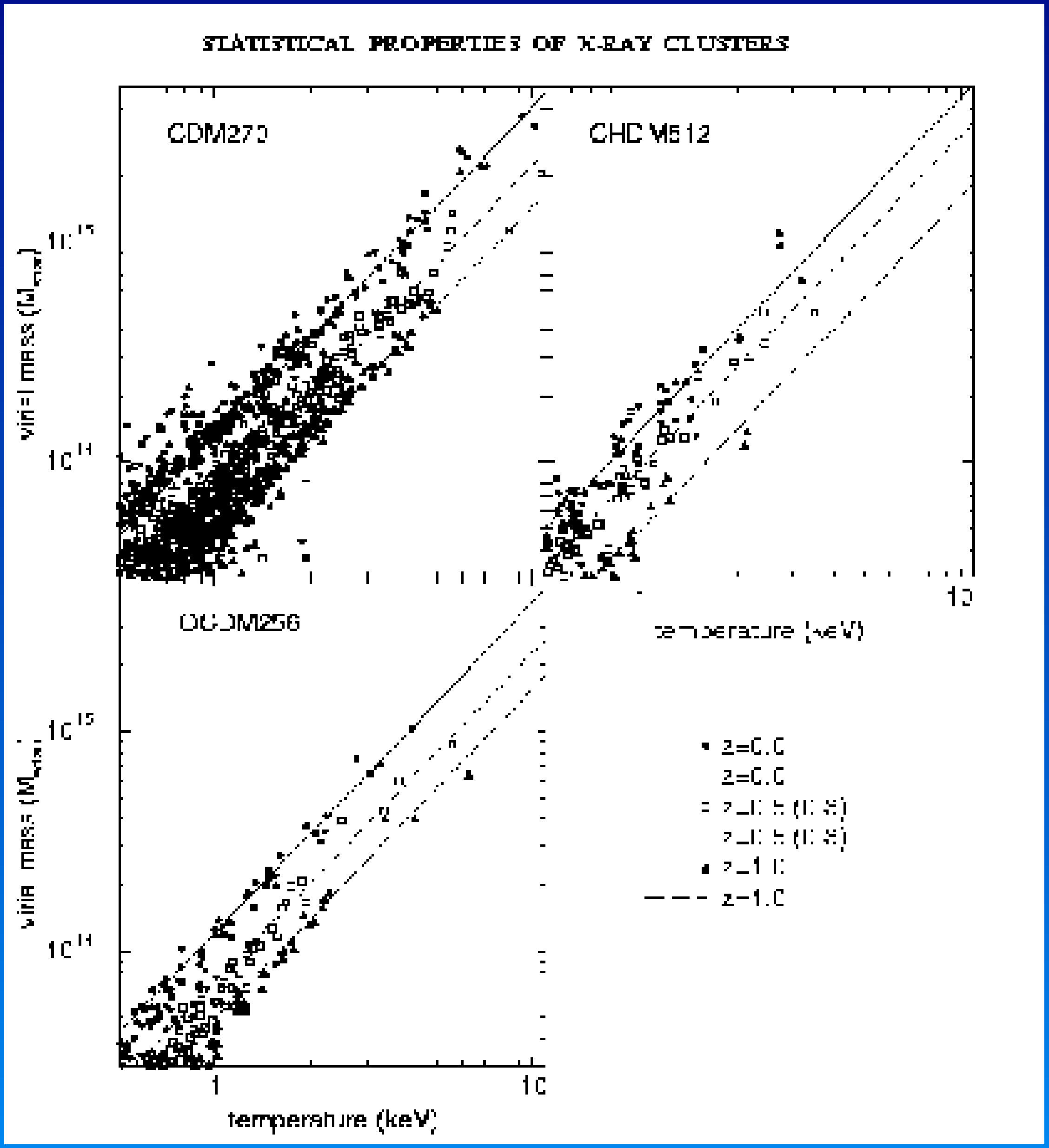
$$T \propto GM/r$$

whatever you do with gravity...

$$T_x \simeq A_{TM}\, M^{2/3}\, (1+z)\ \mathrm{keV}$$

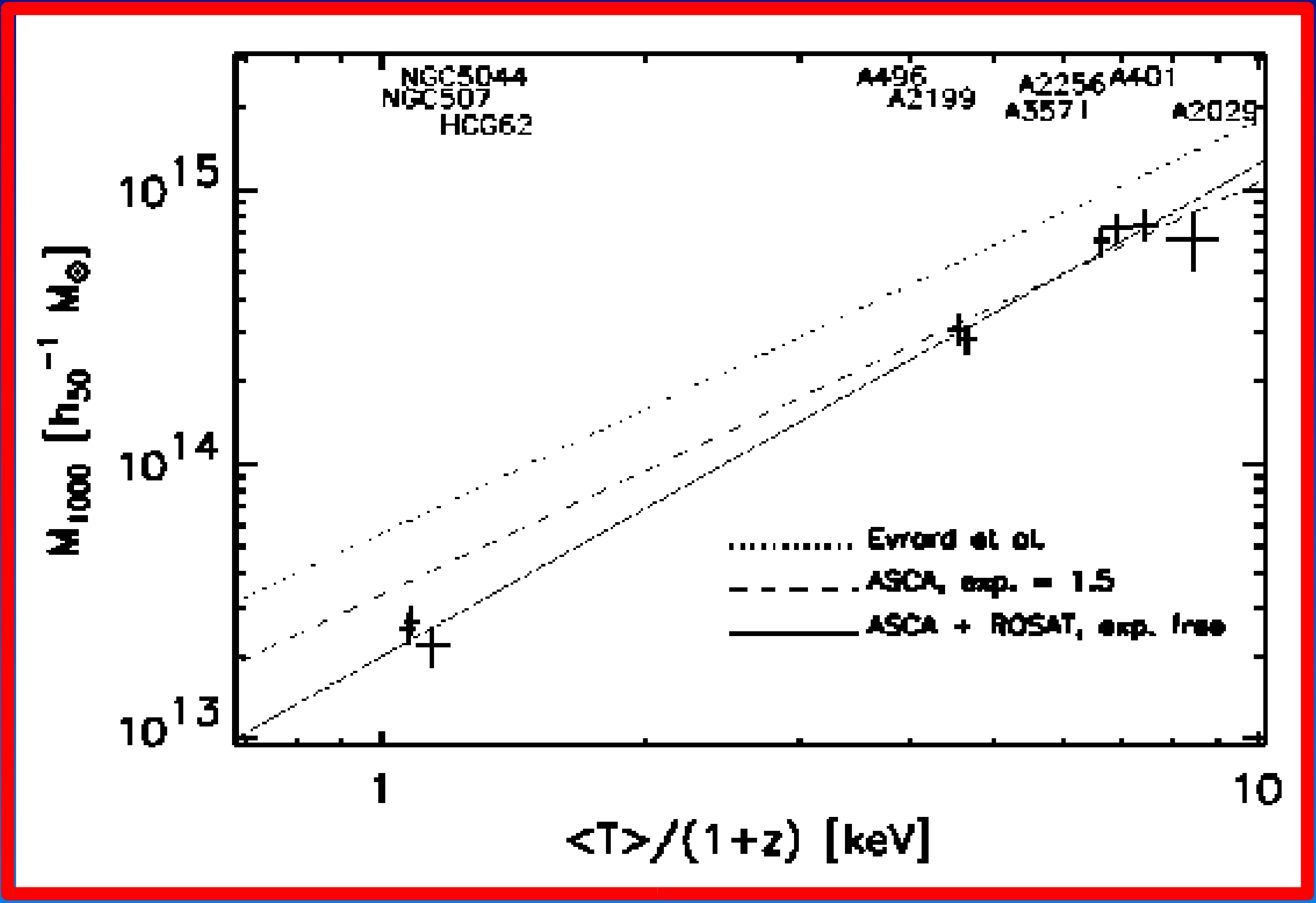
Hydrostatic equilibrium equation

Numerical simulations, Bryan & Norman, 1998



Bryan & Norman (ApJ 495 80 1998)

« Temperature-mass diagram » :



Nevalainen, Markevitch & Forman, 2000

Mass-Luminosity Relation :

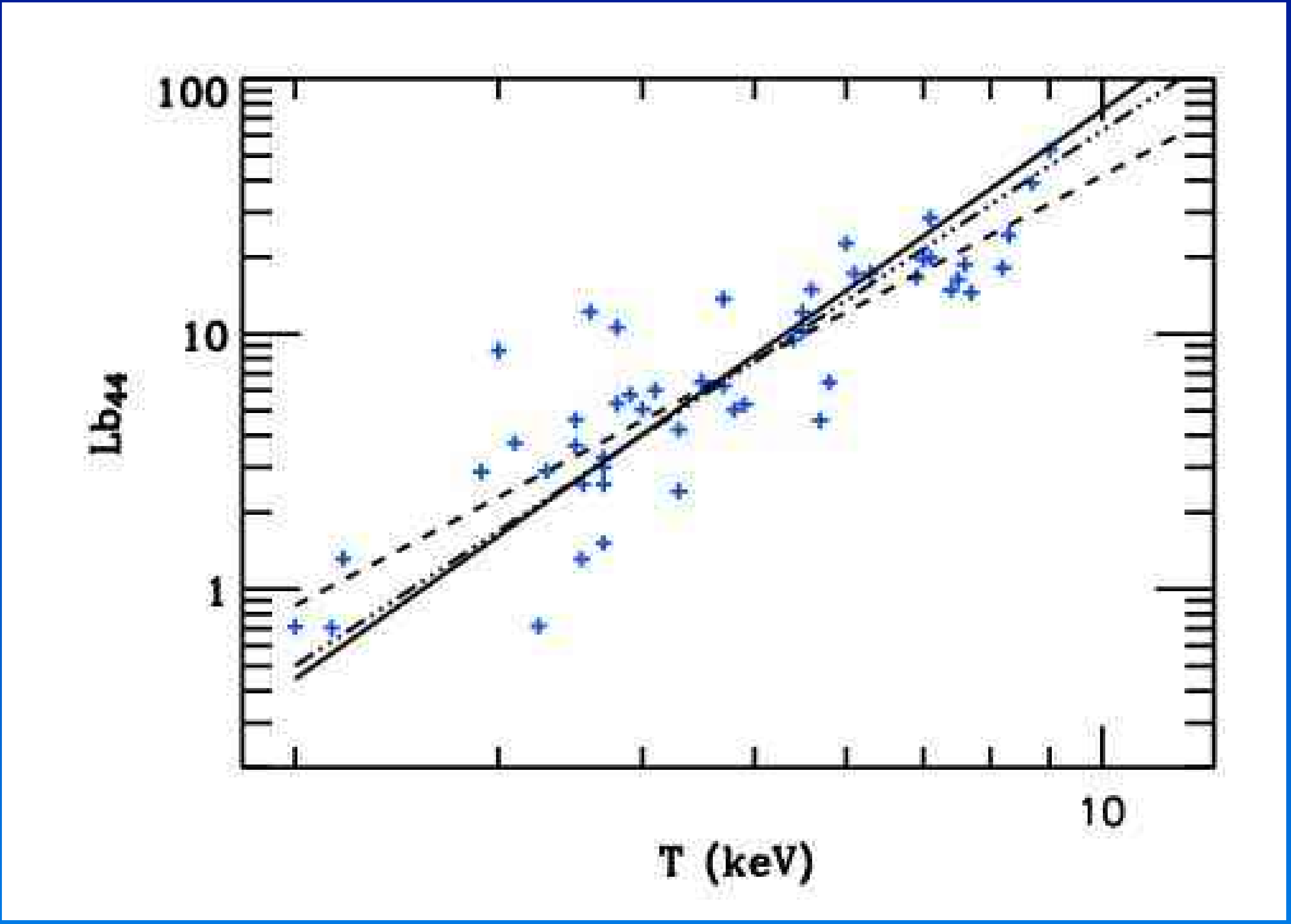
$$L_x \propto n^2 T^{1/2} V$$

...

$$L_x \simeq B\, M^{4/3}\, \Omega^{1/6} \Delta^{7/3} (1+z)^{3.5}$$

$$L_x \propto T^{2}\, \Delta^{1/2} (1+z)^{1.5}$$

Observed Temperature -Luminosity Relation



$$L_x \propto T_x^{\sim 3}$$

Conclusion at that point is that

Clusters are not self similar!

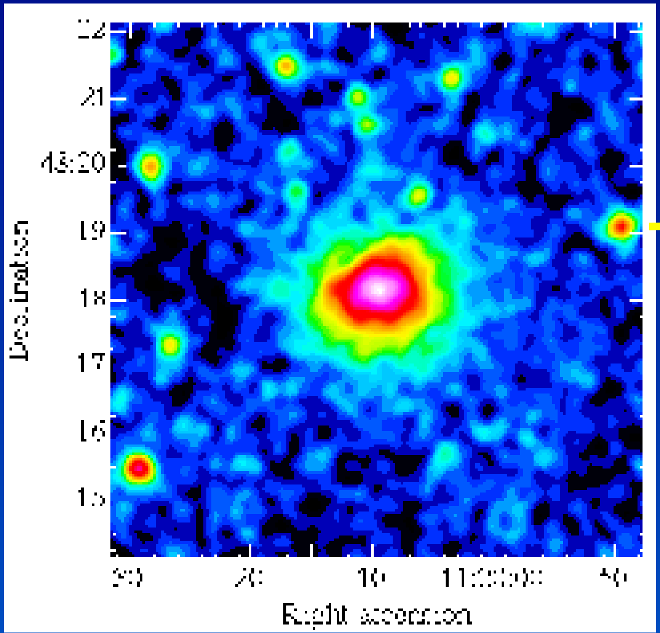
However...

Ω_m

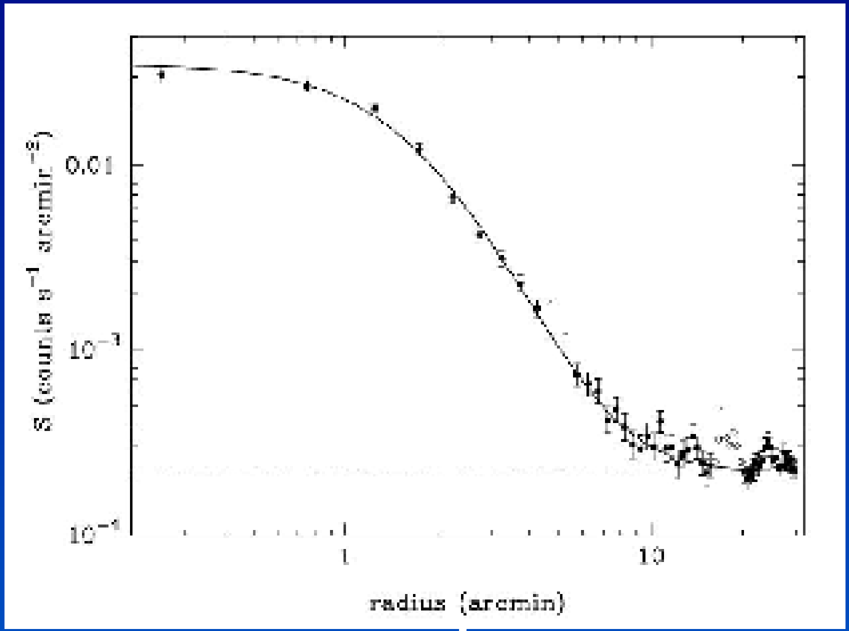
From X-ray Clusters

Baryon Fraction

What do you do with a cluster?

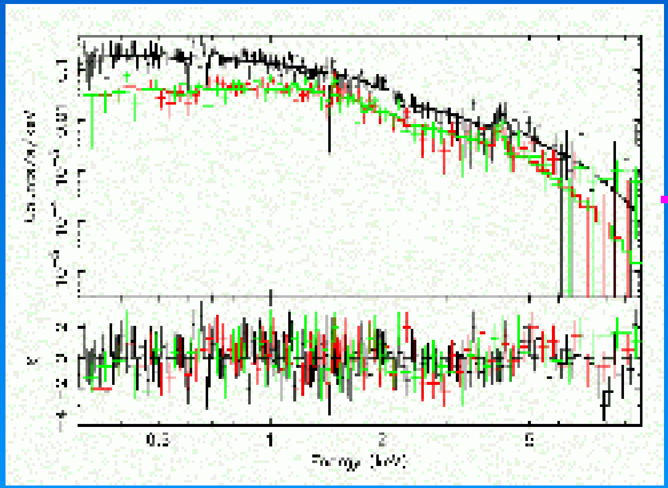


Fit

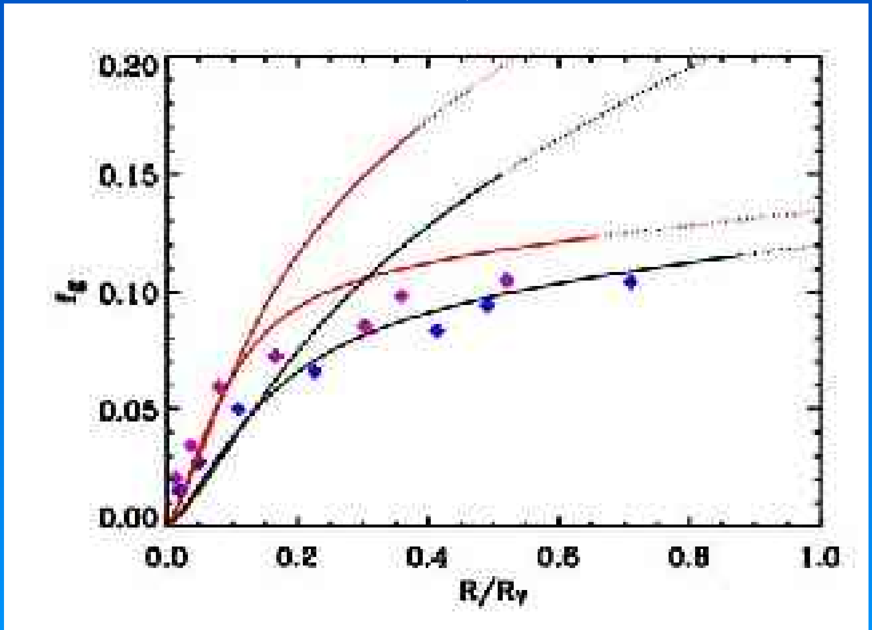


Gas mass $M_g(r)$

X-ray spectrum



M(r)



Method :

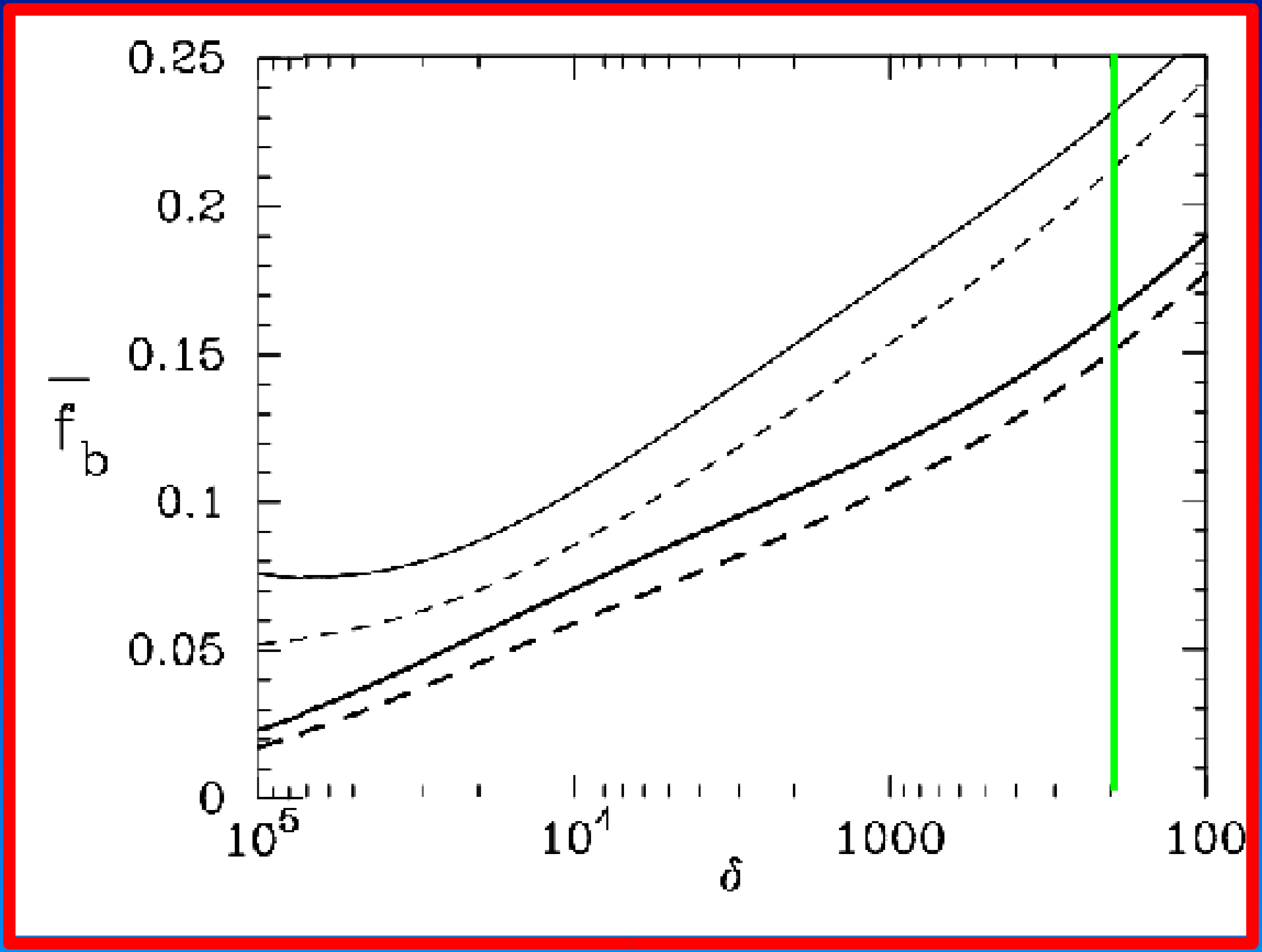
Ratio : $f_b = M_b/M_t$

Observations $\Rightarrow M_g, \; T_x \Rightarrow M_t$

i.e. : $f_b \approx 15.\text{-}20.\; h_{50}^{-3/2}\,\%$

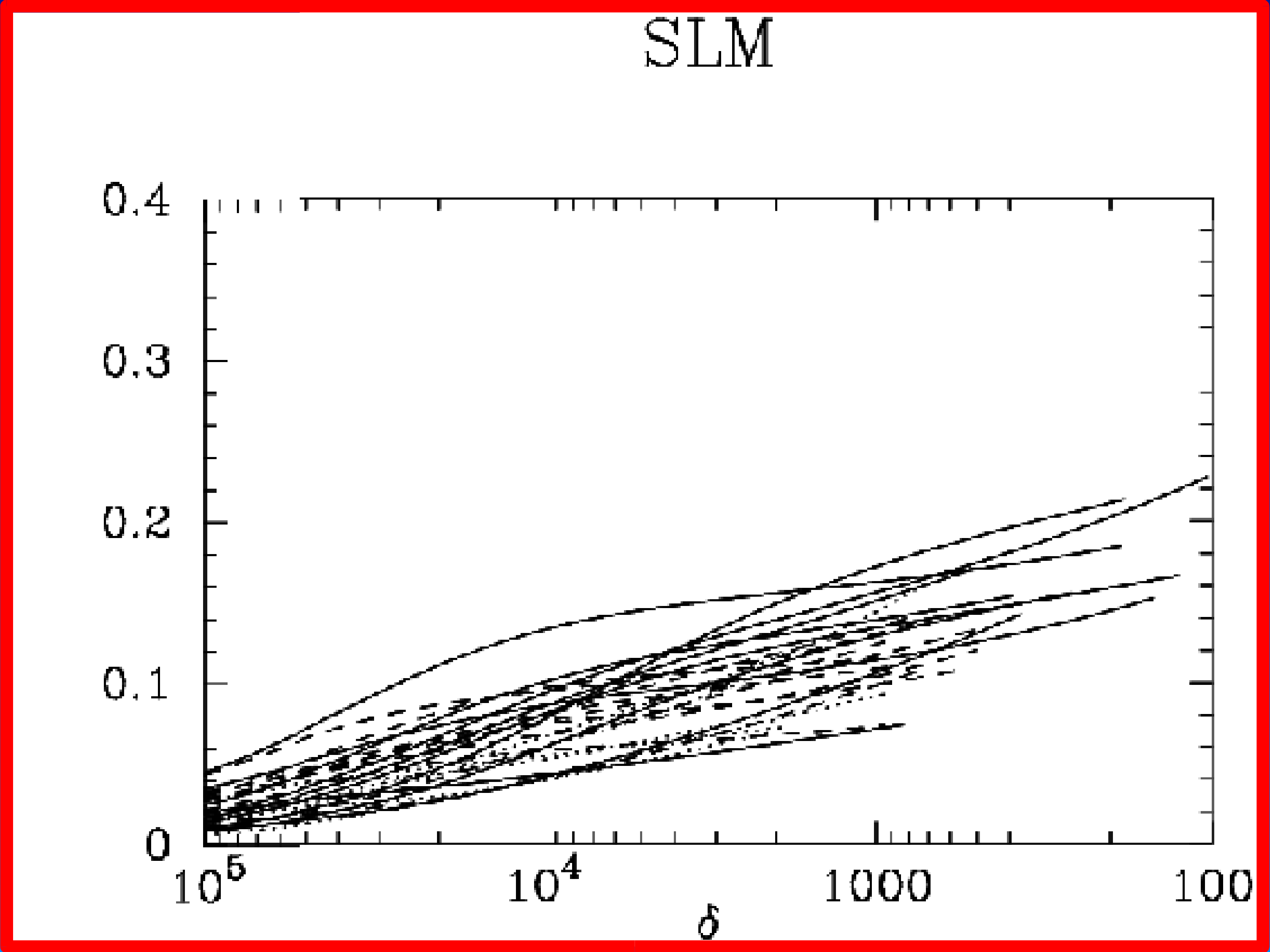
Cosmology : $f_b = \Omega_{bbn}/\Omega_0$

Average baryon fraction :



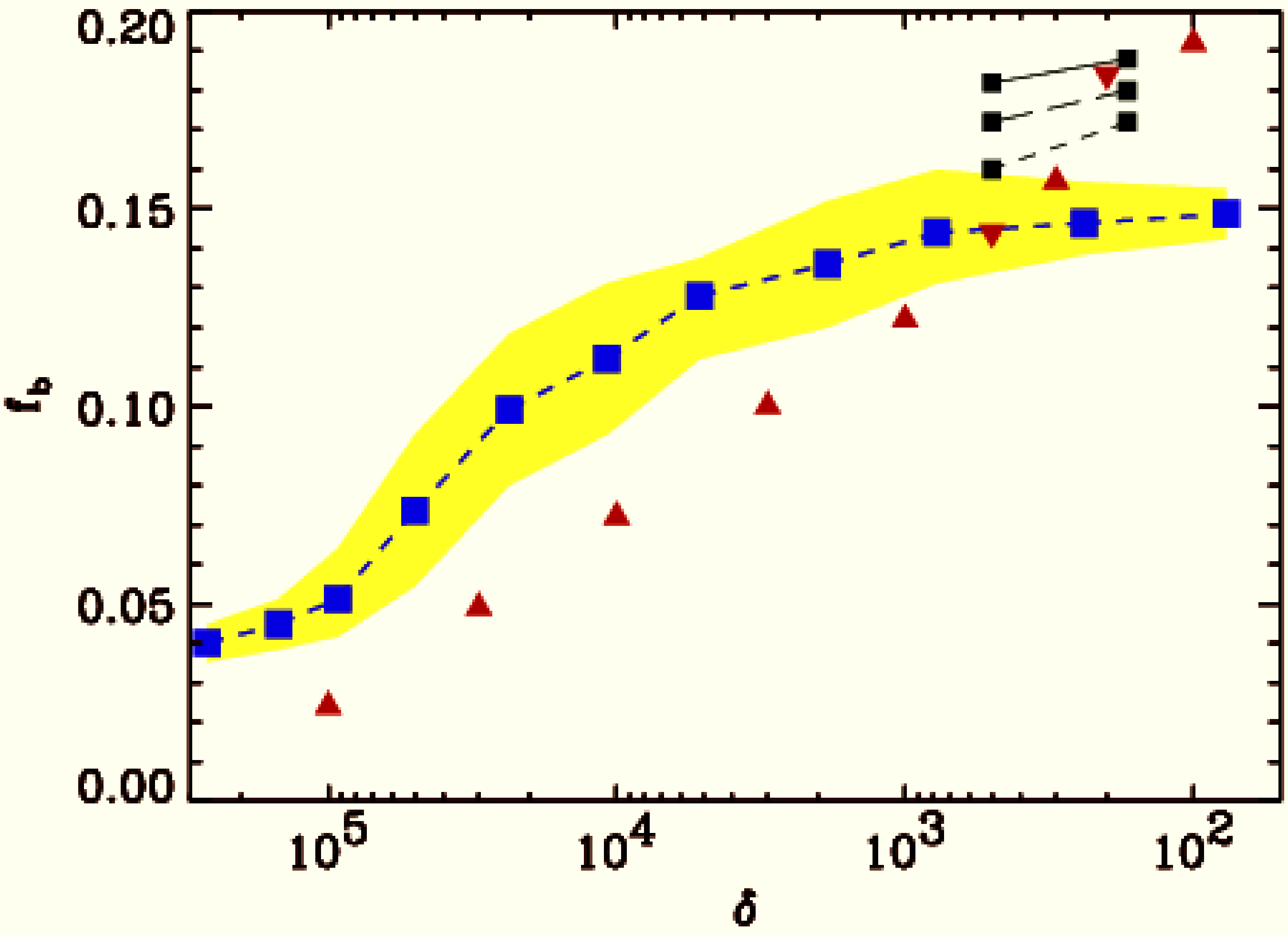
Roussel et al, 2000

Scaling of baryon fractions :



Roussel et al, 2000

Comparison with simulations:

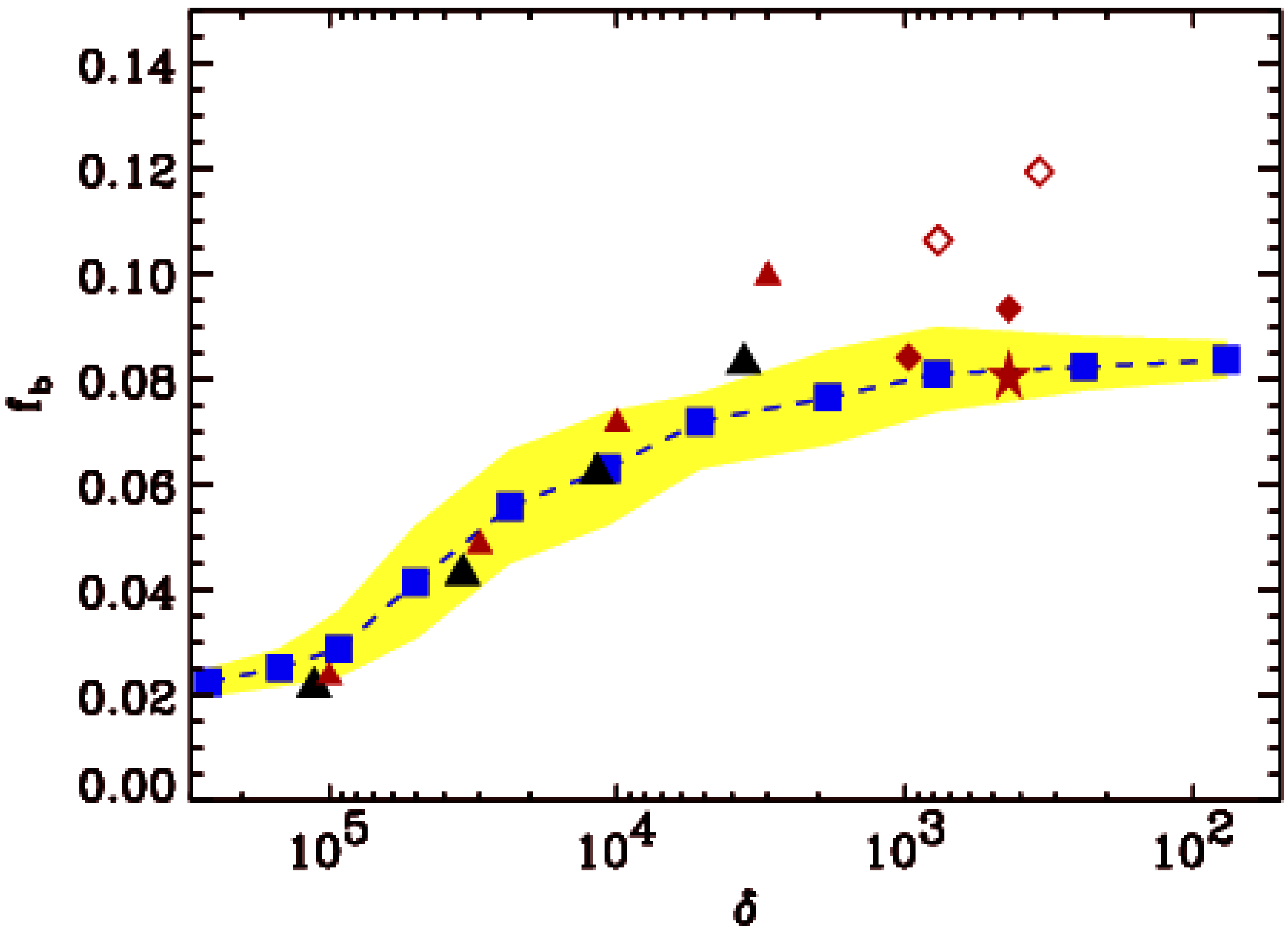


Sadat & Blanchard, 2001

Three correcting factors :

- ♦ Mass estimator
- ♦ Clumping of the gas
- ♦ Outer emission

Actual comparison :



Sadat & Blanchard, 2001

Conclusion :

➔ **baryon fraction favors low Ω_m :**

➔ **however outer region of clusters not so well known...**

➔ **a baryon fraction of the order of $10.\ h_{50}^{-3/2}$ % or less could be consistent with data...**

XMM

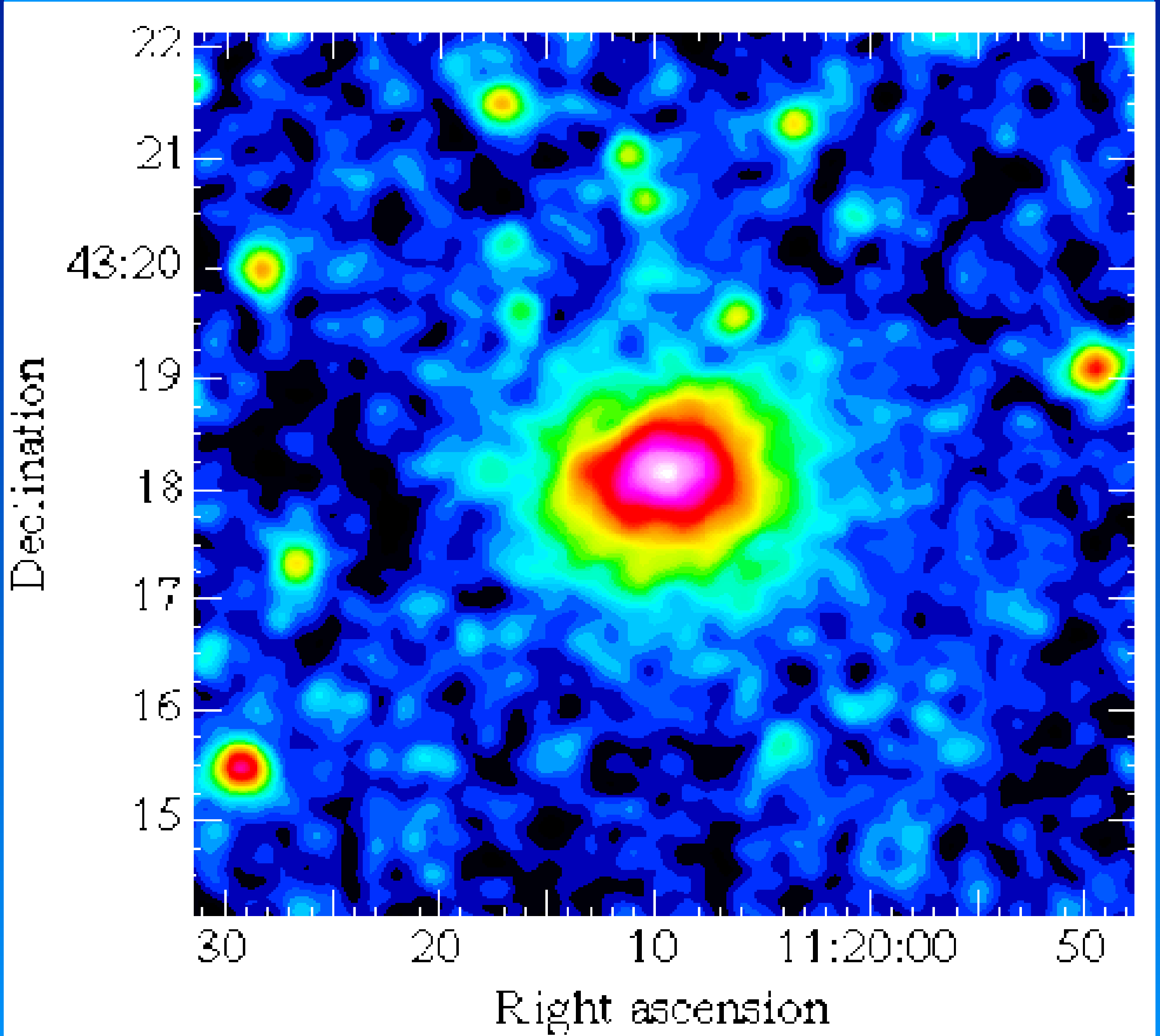
Ω-Project

X-ray properties of distant SHARC clusters for Cosmology

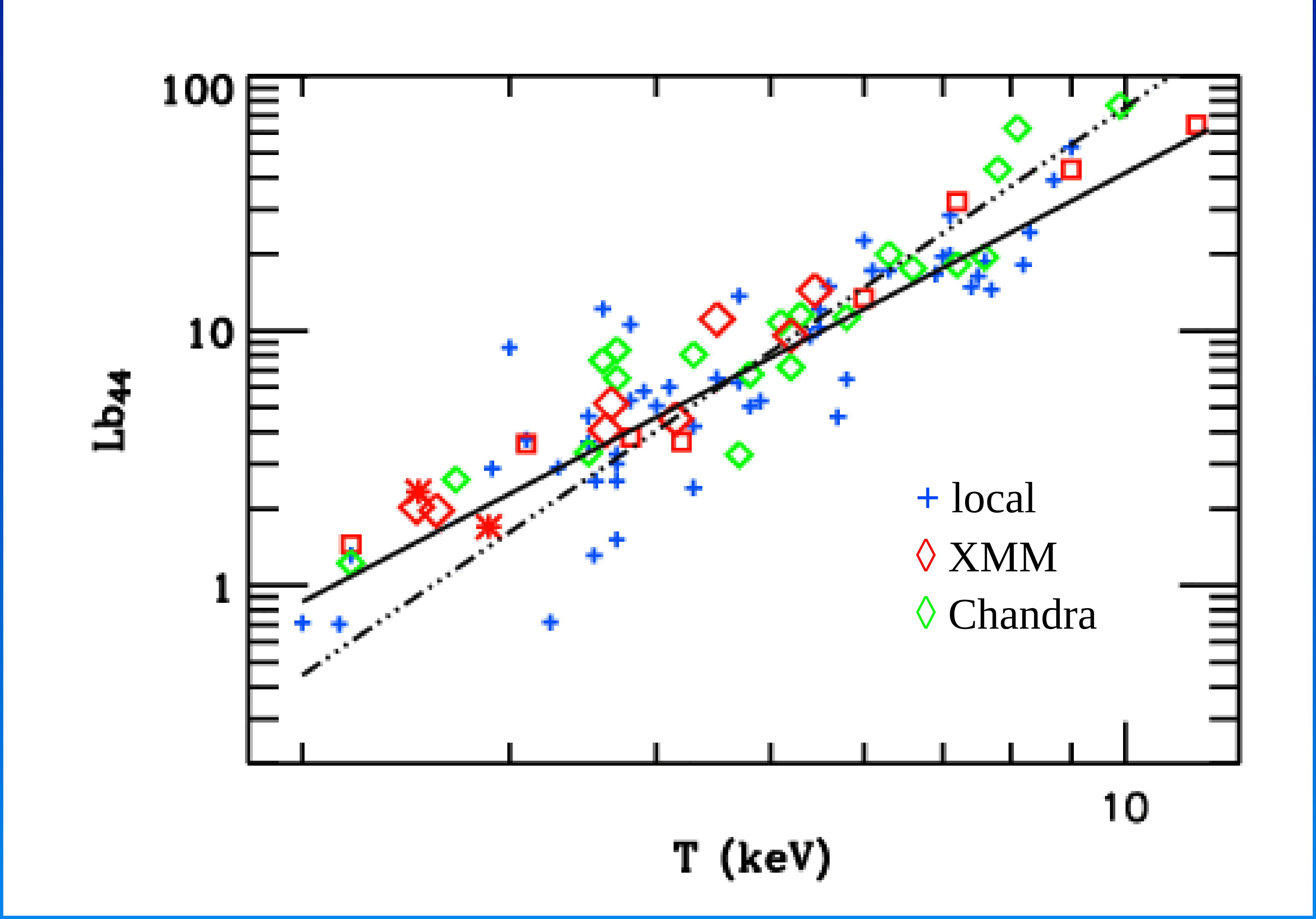
Z ≈ 0.6

XMM

RXJ1120



XMM Lx-Tx evolution



Conclusion on evolution:

- remarkable convergence

$$Lx/Tx)_z = Lx/Tx)_{z=0}(1+z)^{\beta}$$

with $\beta = 0.65 \pm 0.28$

D.Lumb et al., 2003

in full agreement with ASCA (Sadat et al., 1998; Novicki et al., 2003;...), Chandra (Vikhlinin et al, 2002), new XMM analysis (Kotov & Vikhlinin, 2005)

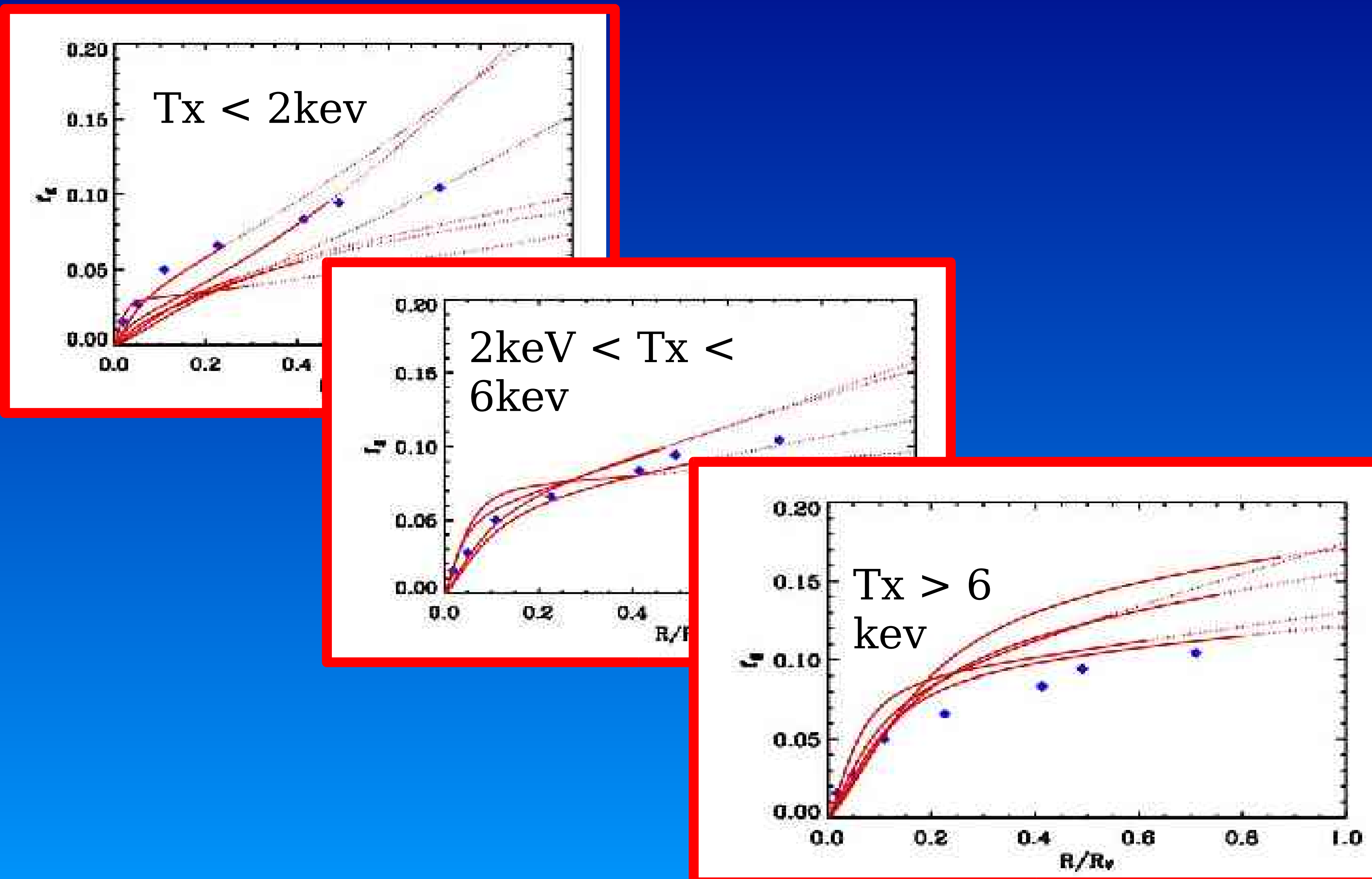
Ω_m

From X-ray Clusters

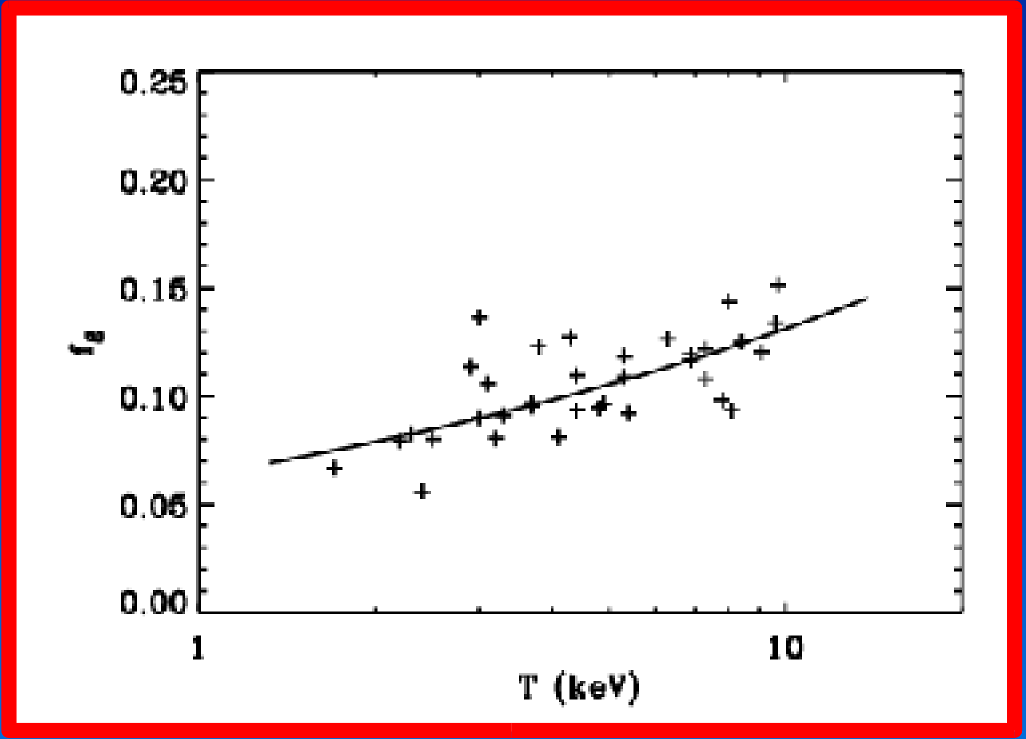
Baryon Fraction evolution in the XMM Ω-project

(Sadat et al., 2005, A&A)

Baryon Fraction @ z = 0

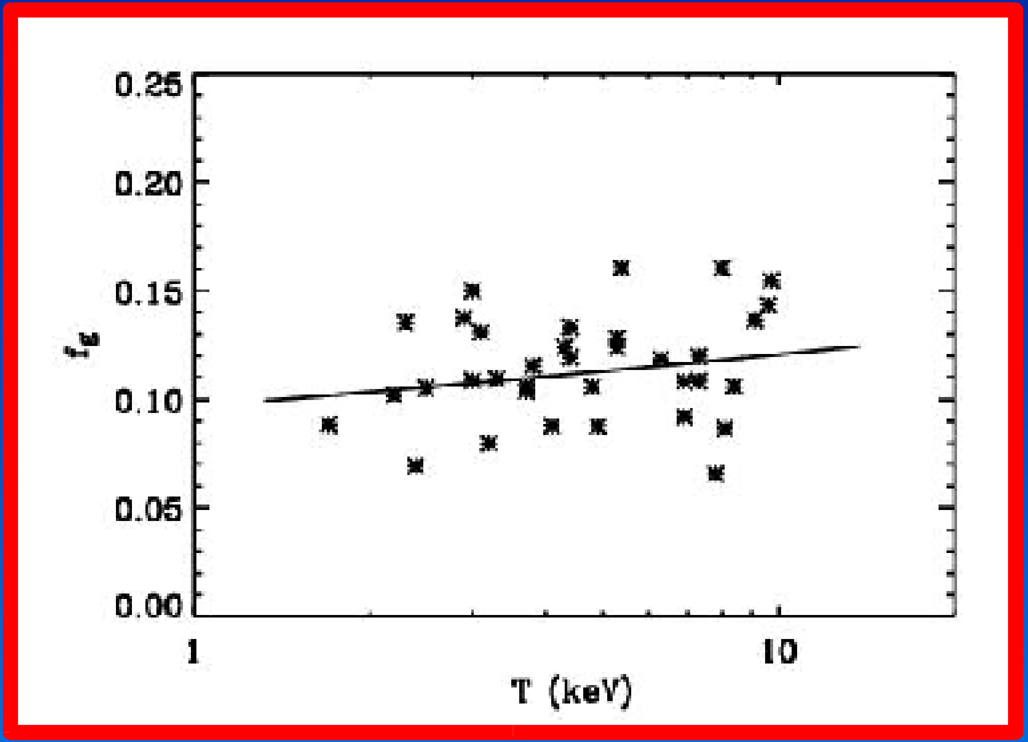


Baryon Fraction @ z = 0



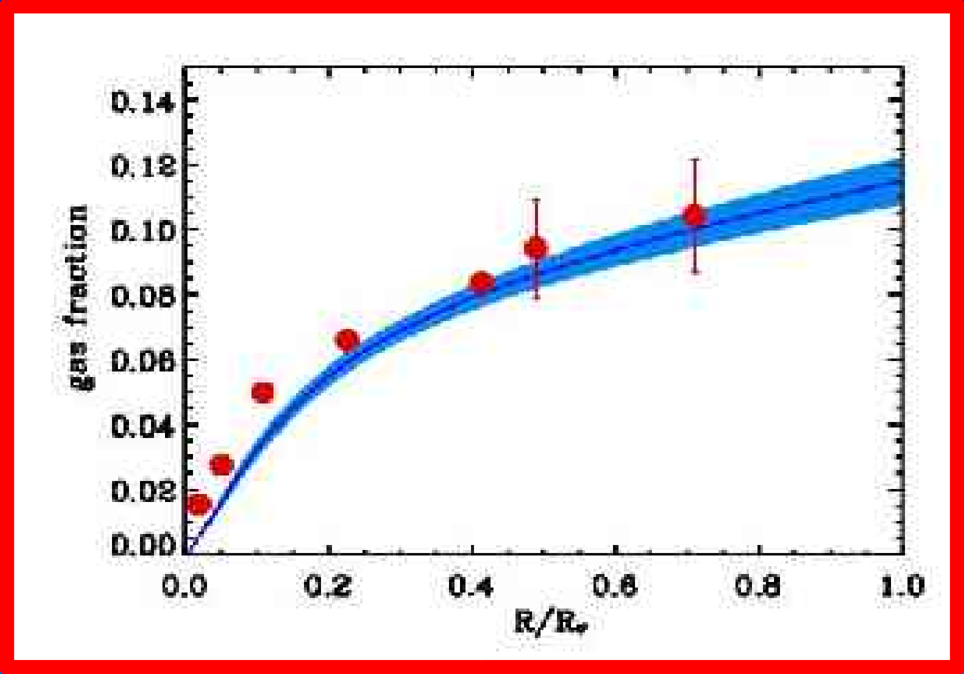
R_{2000} in Vikhlinin, Forman, Jones 1999 (~35-45% Rv)

Baryon Fraction @ z = 0



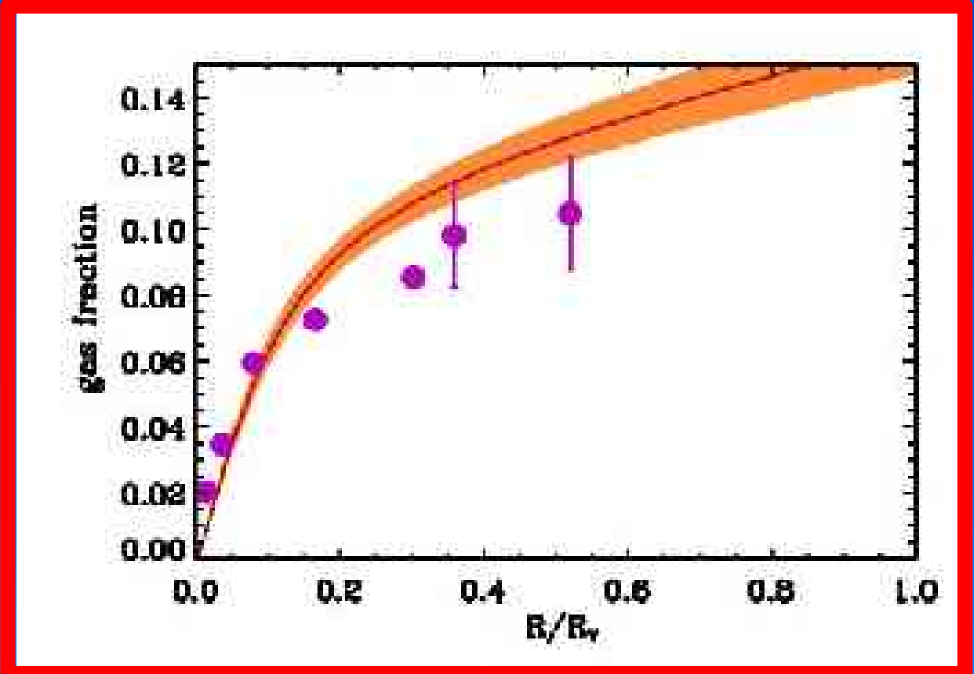
R_v in Vikhlinin, Forman, Jones 1999

Baryon Fraction @ z = 0.6



Internal structure

is complex...

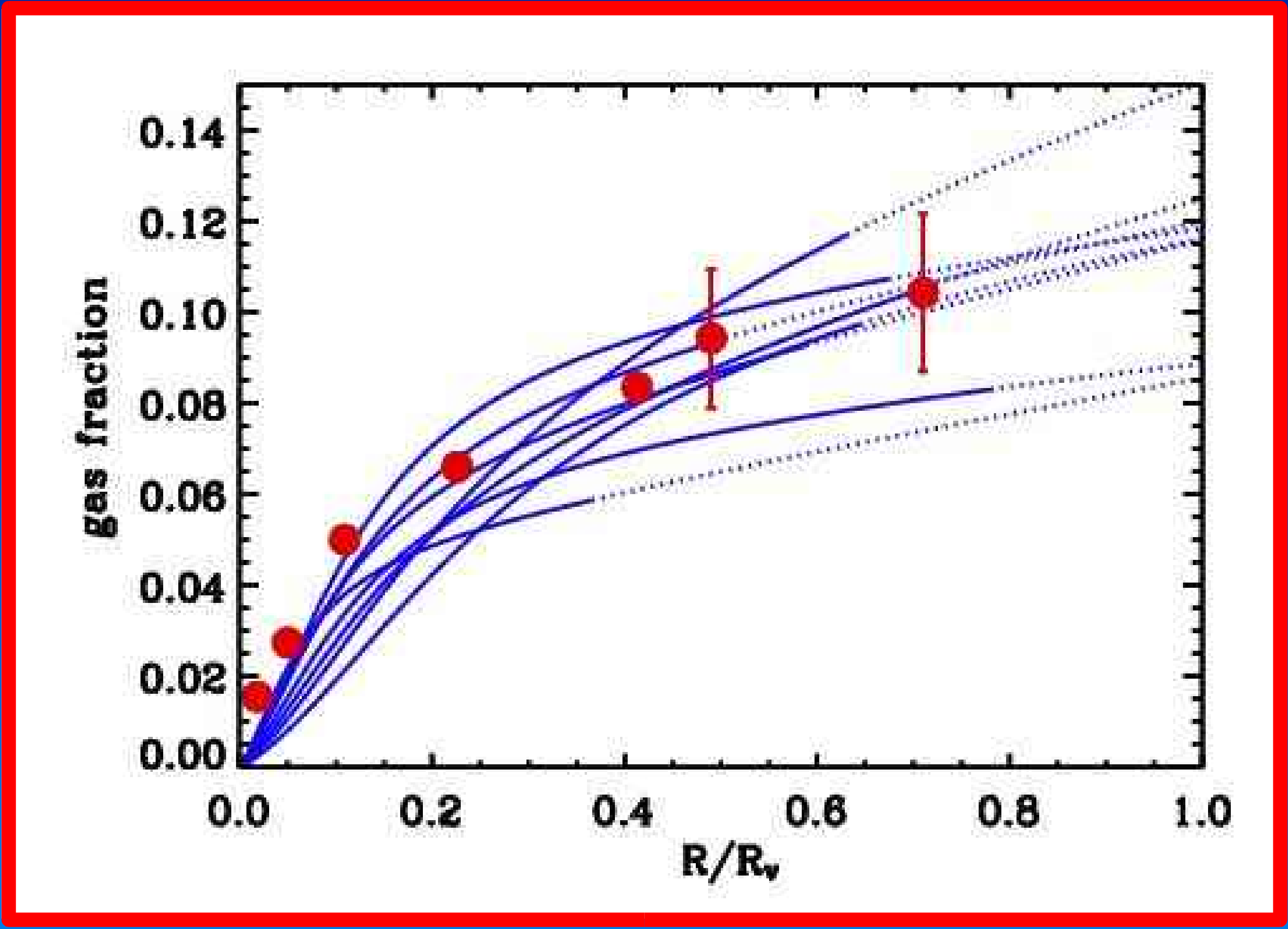


Conclusion at that point is that

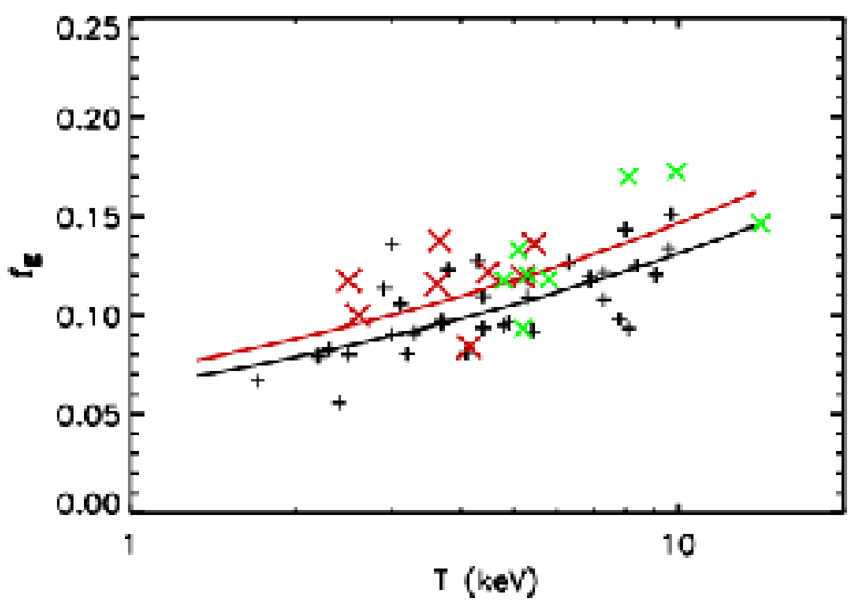
Clusters are not self similar!

However...

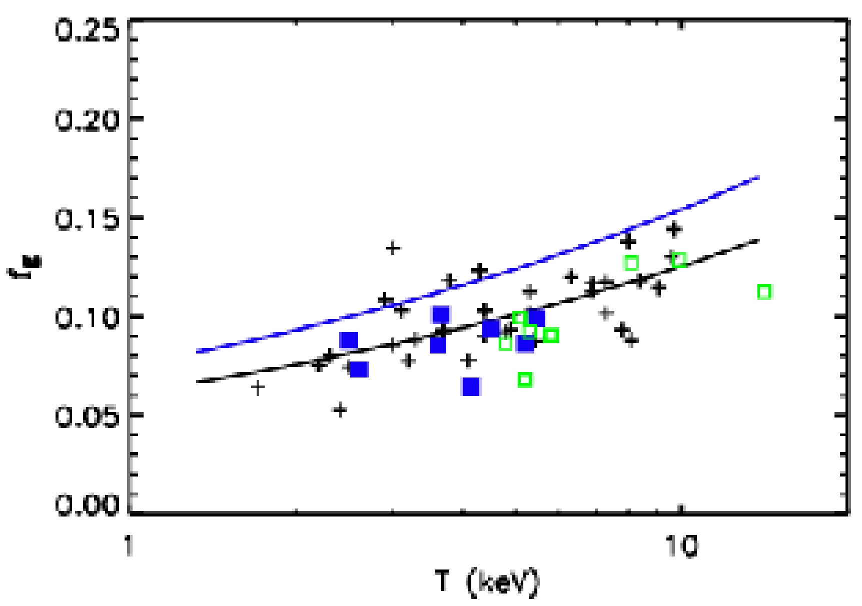
Baryon Fraction @ z = 0.6



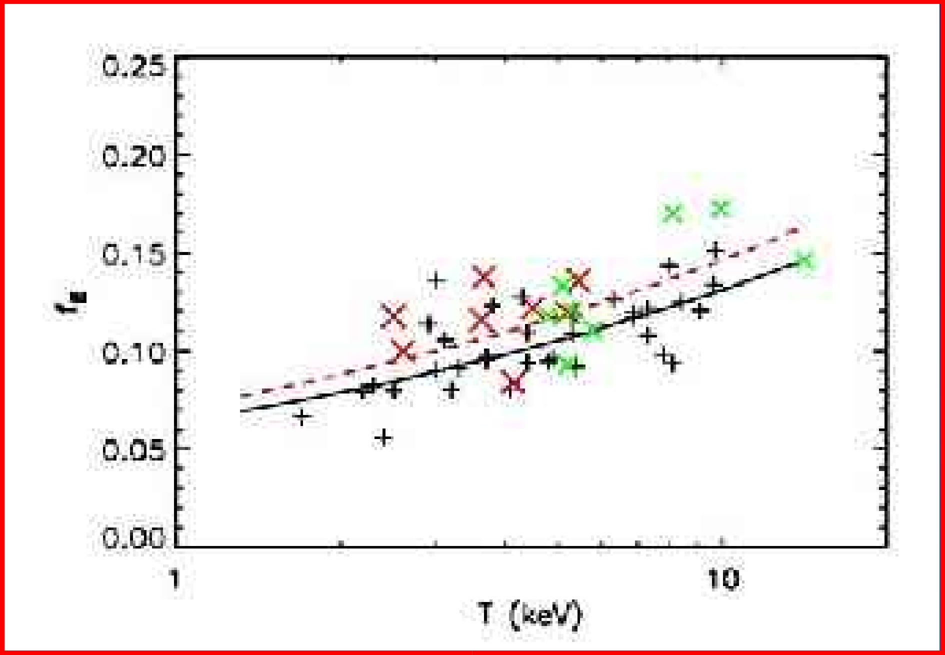
Baryon Fraction @ z = 0.6



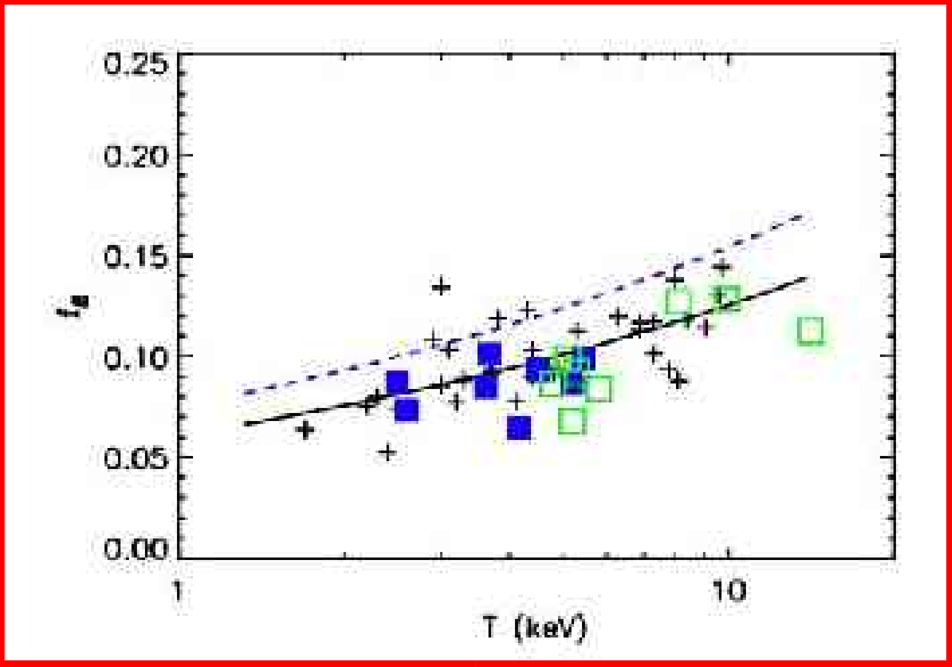
$\Delta = 2000$



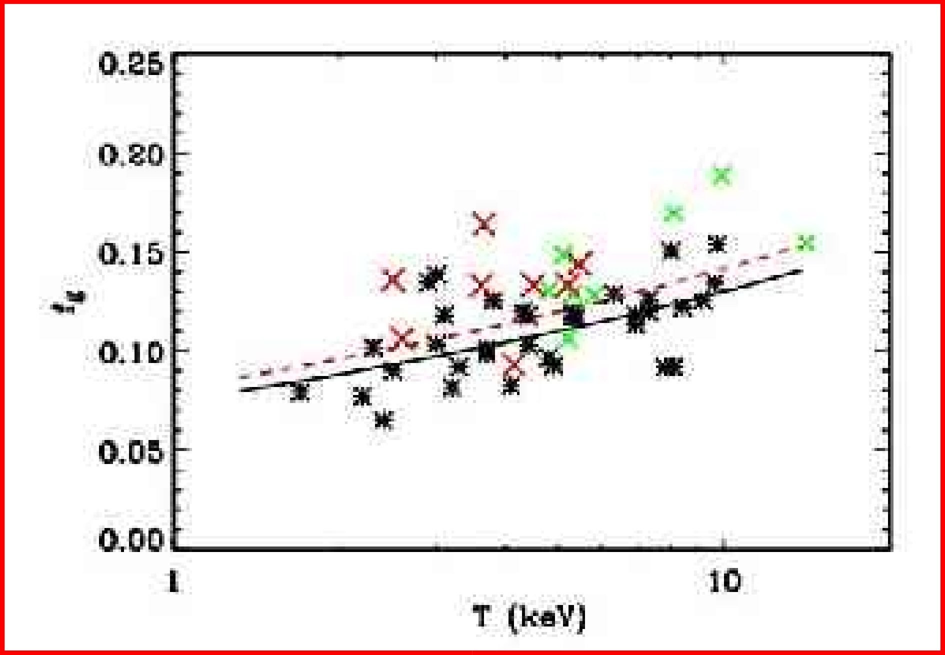
Baryon Fraction @ z = 0.6



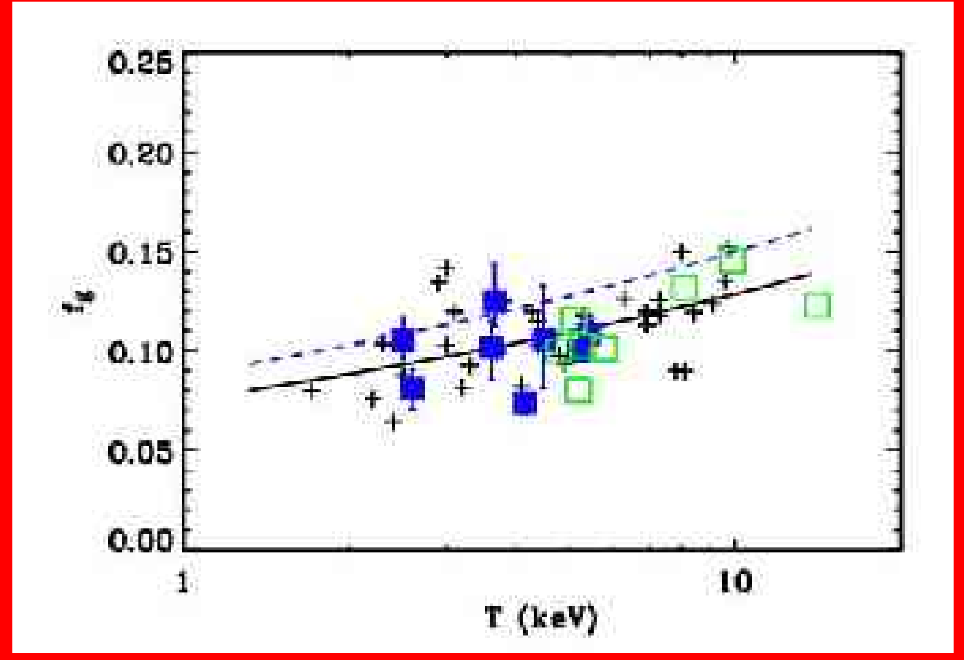
$\Delta = 2000$



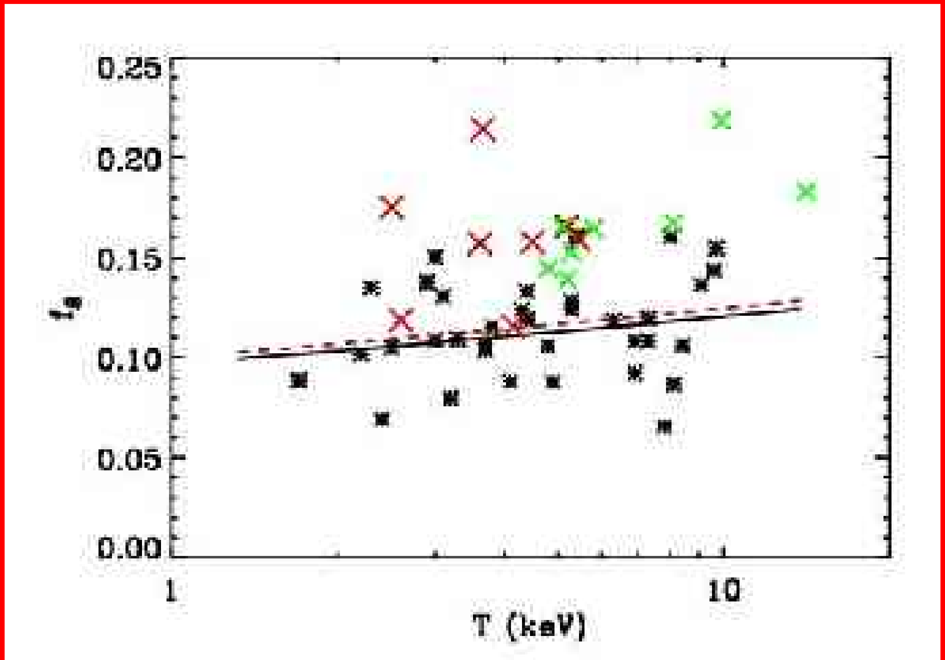
Baryon Fraction @ z = 0.6

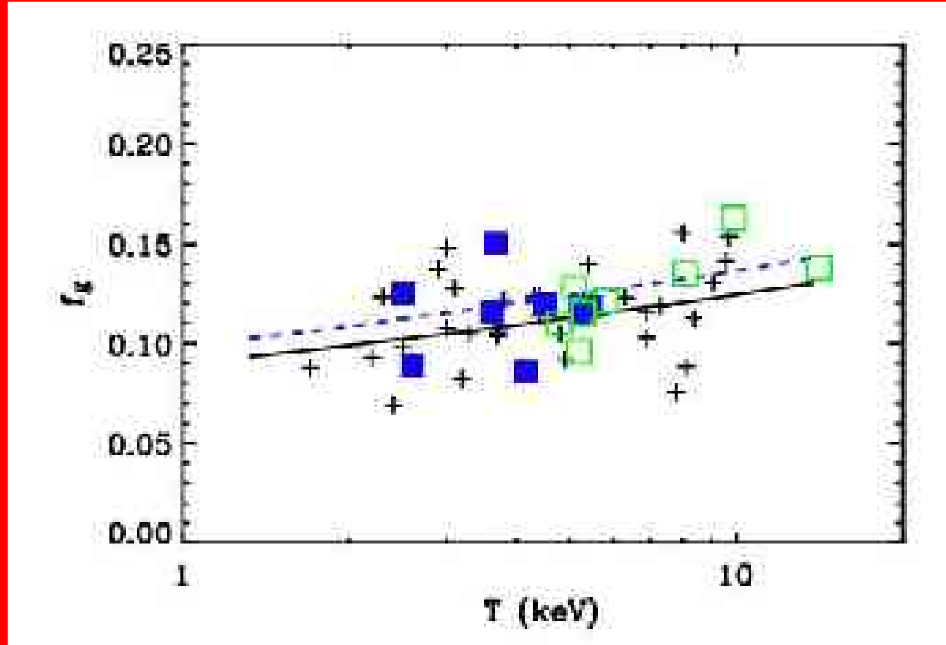


$\Delta = 1000$



Baryon Fraction @ z = 0.6

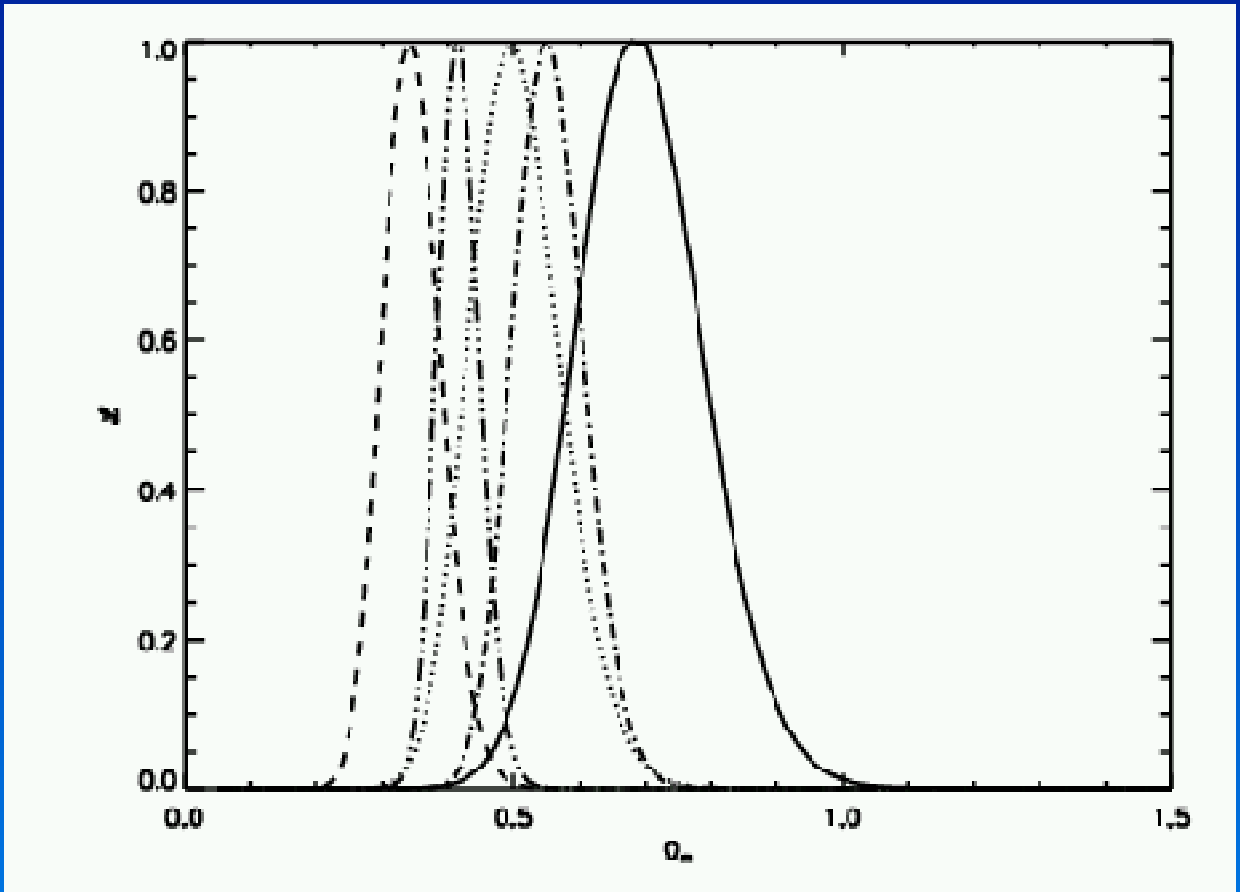




Δ_v

... favors high Ω_m !

Likelihood analysis:



(Ferramacho et al., 2006, submitted)

Theory of the mass function

Basics

Matter = random field:

$$\rho(x) = \overline{\rho}(1 + \delta(x))$$

δ mathematically ill-behaved...

1. The field is smoothed = ρ is convolved:

$$\tilde{\delta} = \delta * W_R$$

with a window function:

$$\int W_R(u)du = 1$$

the smoothed field:

$$\tilde{\delta}(x) = \int \delta(x+u)W_R(u)du$$

Variance of the field :

$$\overline{\tilde{\delta}^2(x)} = \sigma^2(R)$$

Ex: top-hat window:

$$W_R(u) = 1/V \quad \text{for} \quad |u| < R$$
$$W_R(u) = 0. \quad \text{for} \quad |u| \geq R$$

Mass associated:

$$M(R) = \frac{4\pi}{3} R^3 \overline{\rho}$$

2. Nonlinear model

- linear overdensity $\tilde{\delta}(x) \sim 1$

Ex: spherical model $\delta_{NL}(z, \Omega_m, \Omega_\lambda ...)$

3. Mass function:

- trivially (!): dV will be in an object with mass > M if included in a NL fluctuation of $\tilde{\delta}_R$ with radius > R

$$\int_M^{+\infty} m n(m) dm = \overline{\rho} \int \mathcal{F}_\delta(\delta) s(\delta) d\delta \sim \overline{\rho} \int_{\delta_{NL}}^{+\infty} \mathcal{F}_\delta(\delta) d\delta$$

or (sharp threshold):

$$\int_{M}^{+\infty} m n(m) dm = \overline{\rho} \int_{\delta_{NL}}^{+\infty} \mathcal{F}_{\delta}(\delta) d\delta = \overline{\rho} \int_{\nu_{NL}}^{+\infty} \mathcal{F}(\nu) d\nu$$

with:

$\delta = \nu\sigma(R) = \nu\sigma(M)$ **and** $\nu_{NL} = \dfrac{\delta_{NL}}{\sigma(M)}$

and just take the derivative...

the mass function:

$$N(M) = -\frac{\rho}{M^2\sigma(M)}\delta_{NL}\frac{\ln\sigma}{\ln M}\mathcal{F}(\nu_{NL})$$

normalization condition:

$$\frac{1}{\bar{\rho}}\int_0^{+\infty} mn(m)dm = \int_0^{+\infty}\mathcal{F}(\nu)d\nu = 1$$

Press and Schechter (1974) used:

$$\mathcal{F}(\nu) = \sqrt{\frac{2}{\pi}} \exp(-\frac{\nu^2}{2})$$

major recent improvements:

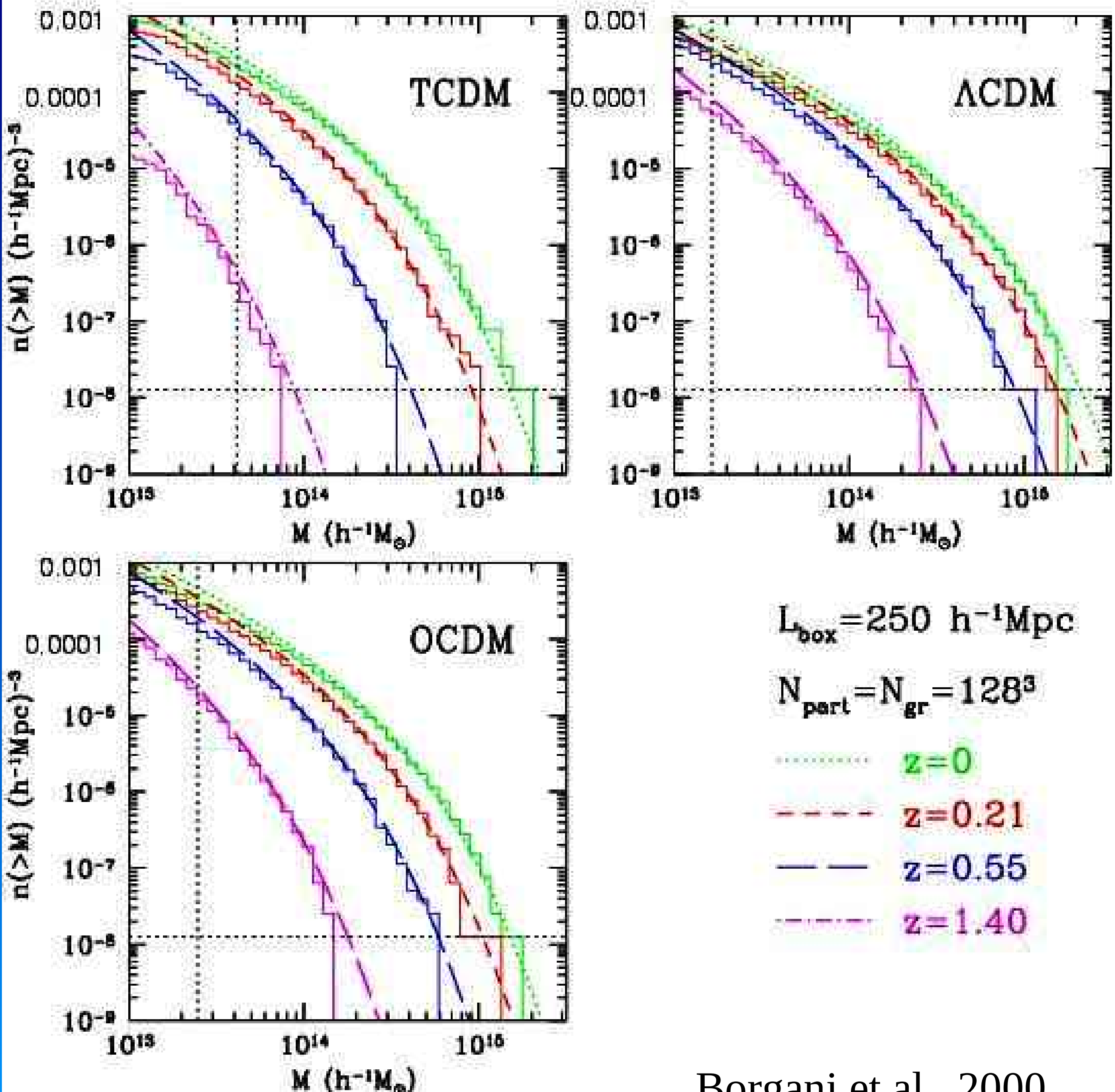
$$\mathcal{F}(\nu) = \sqrt{\frac{2A}{\pi}} C \exp(-0.5 A\nu^2)(1. + (1./(A\nu)^2)^Q)$$

with $A = 0.707 \; C = 0.3222 \; Q = 0.3$

Sheth, Mo, Tormen 2001 MNRAS, 323 1

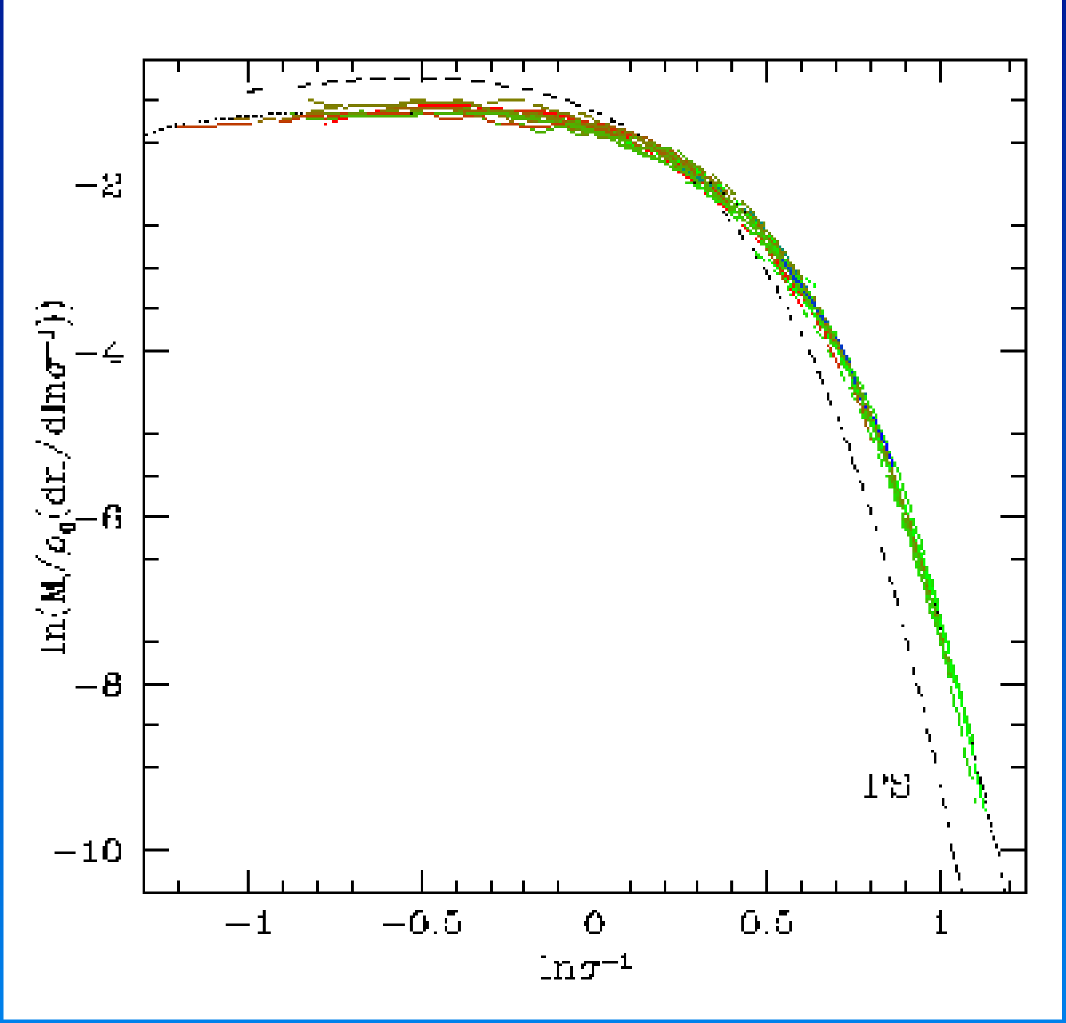
TESTING THE E

MASS FUNCTION



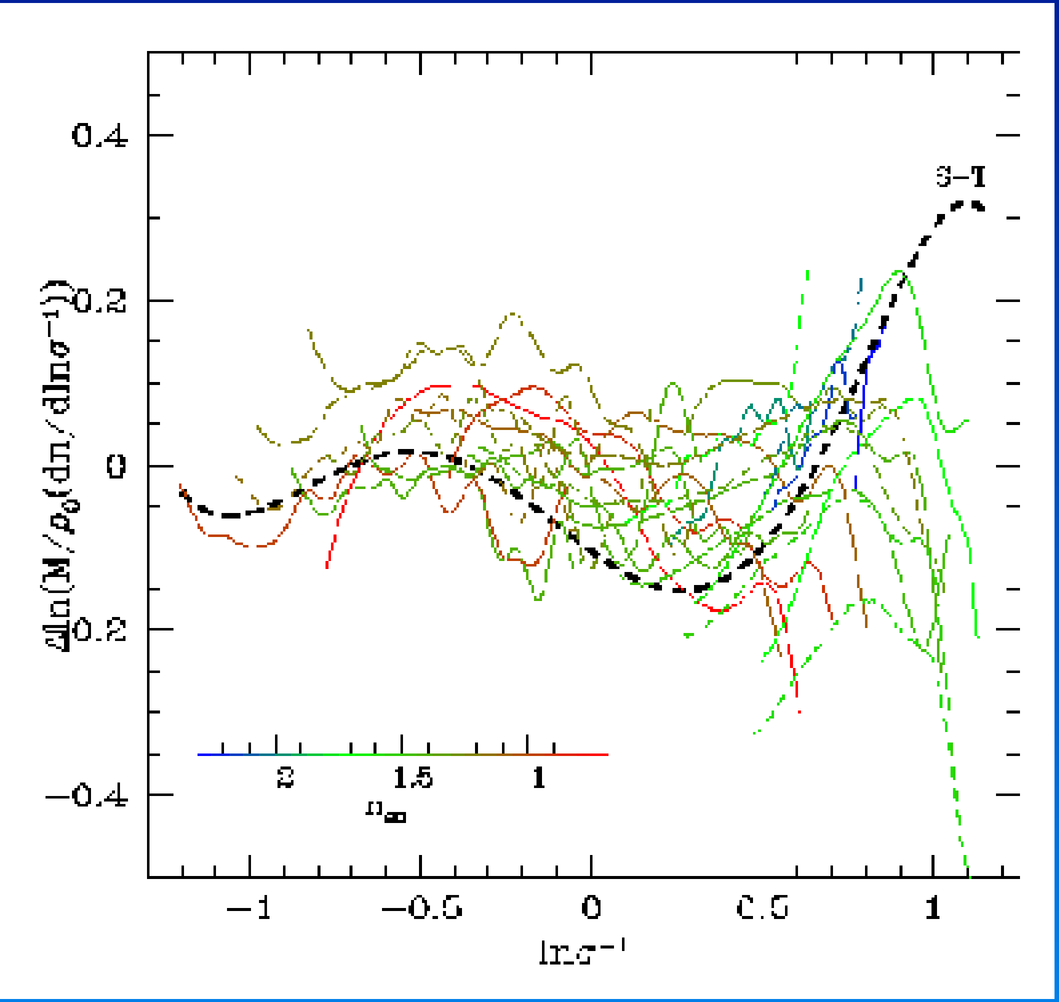
Borgani et al., 2000

Checking N(M)



Jenkins et al., 2001 MNRAS, 321, 372

Checking N(M) (2)

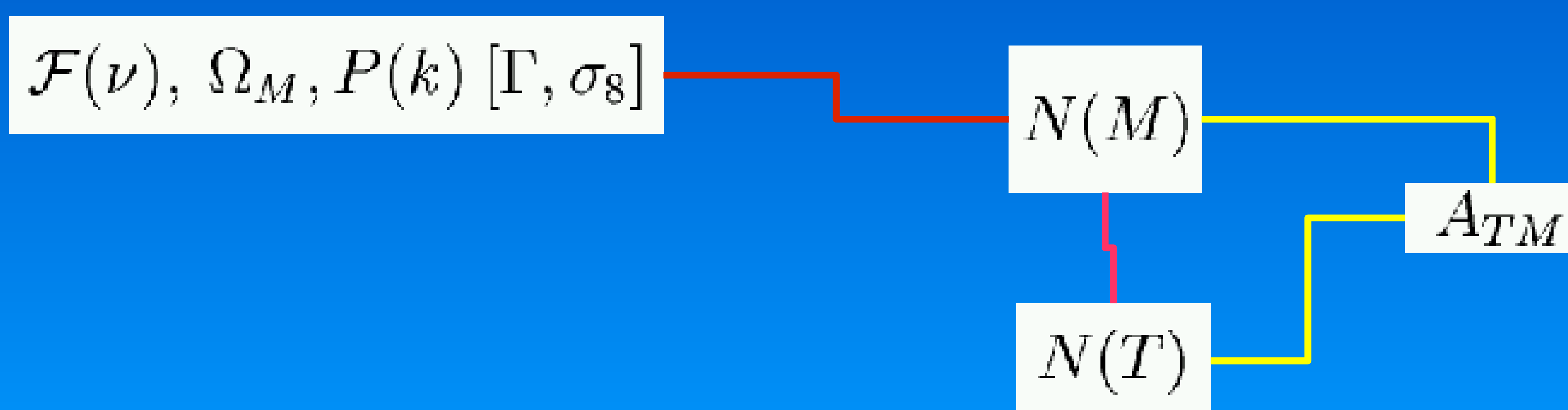


Jenkins et al., 2001 MNRAS, 321, 372

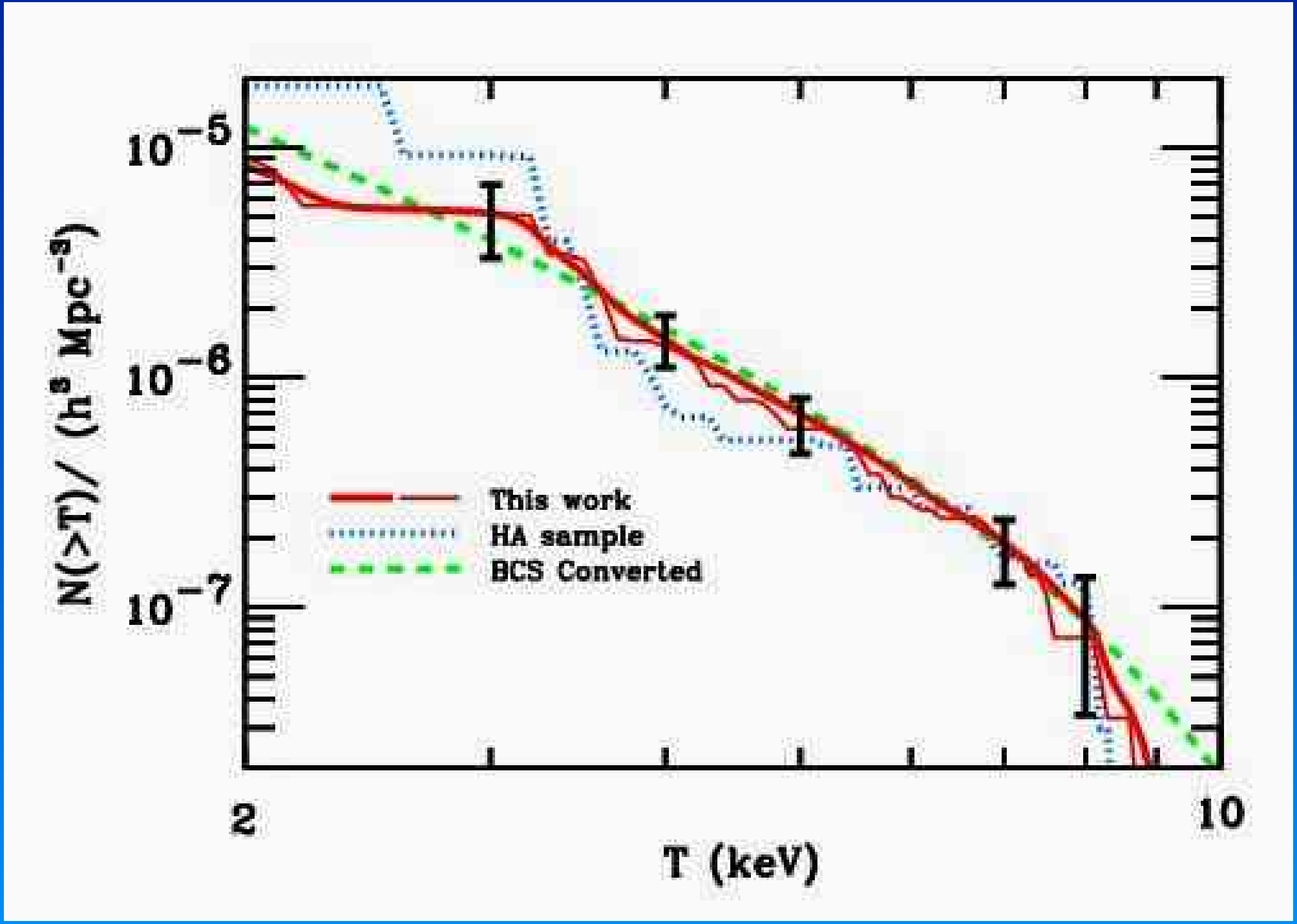
Conclusion

Reliable description
of the mass function in
numerical simulations...

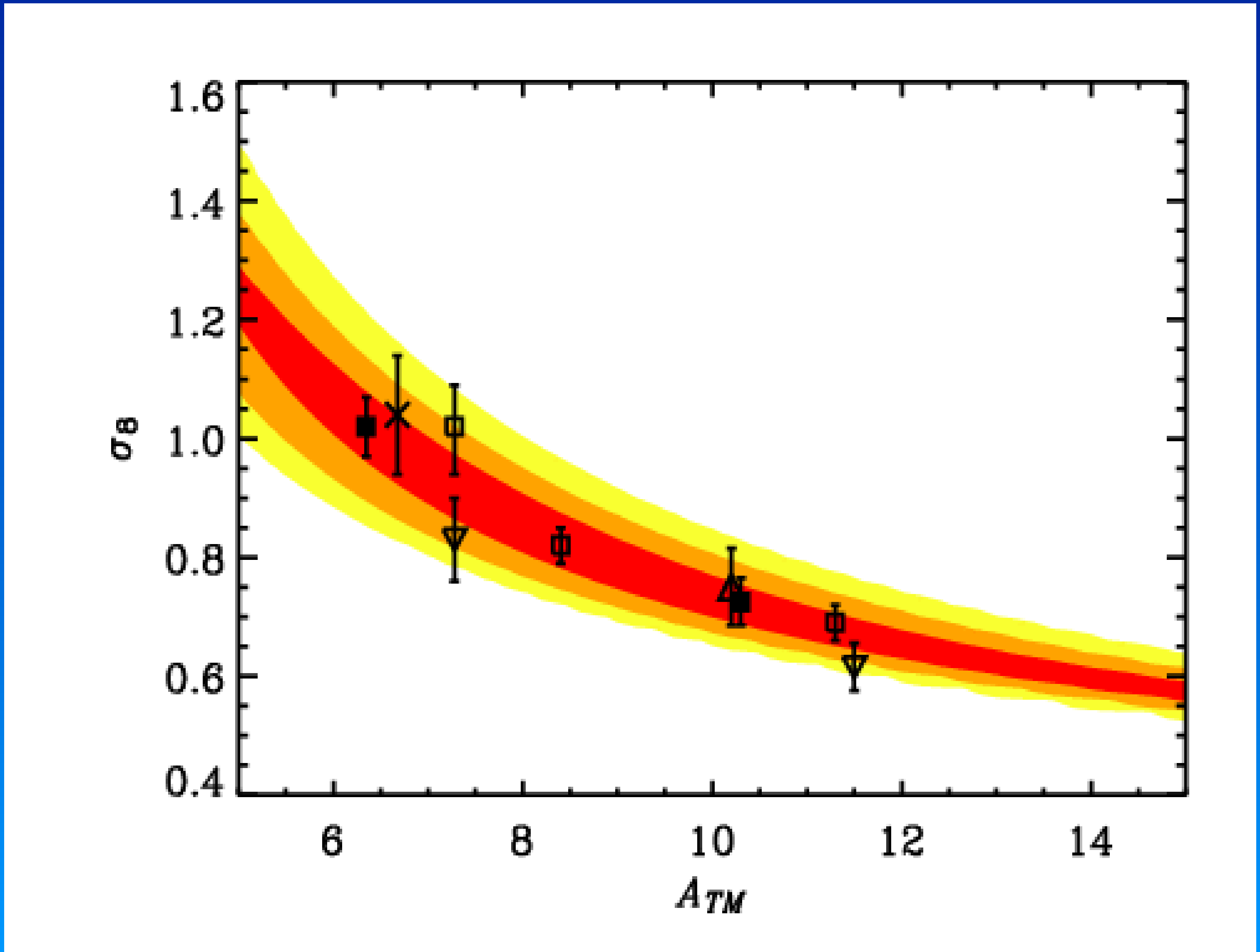
σ_8 from X-ray clusters:



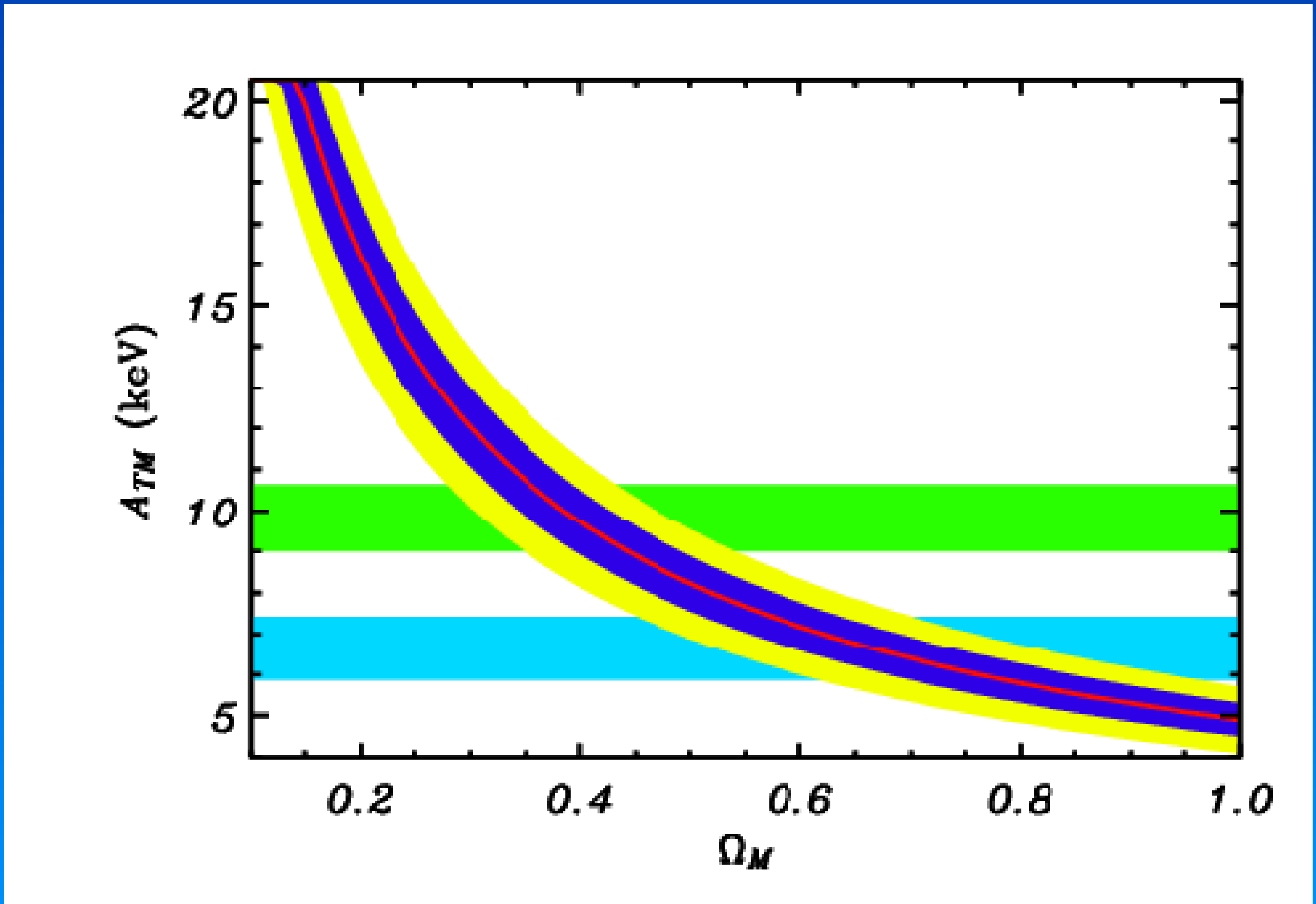
A revised estimation of the local N(T)



σ_8 from X-ray clusters:

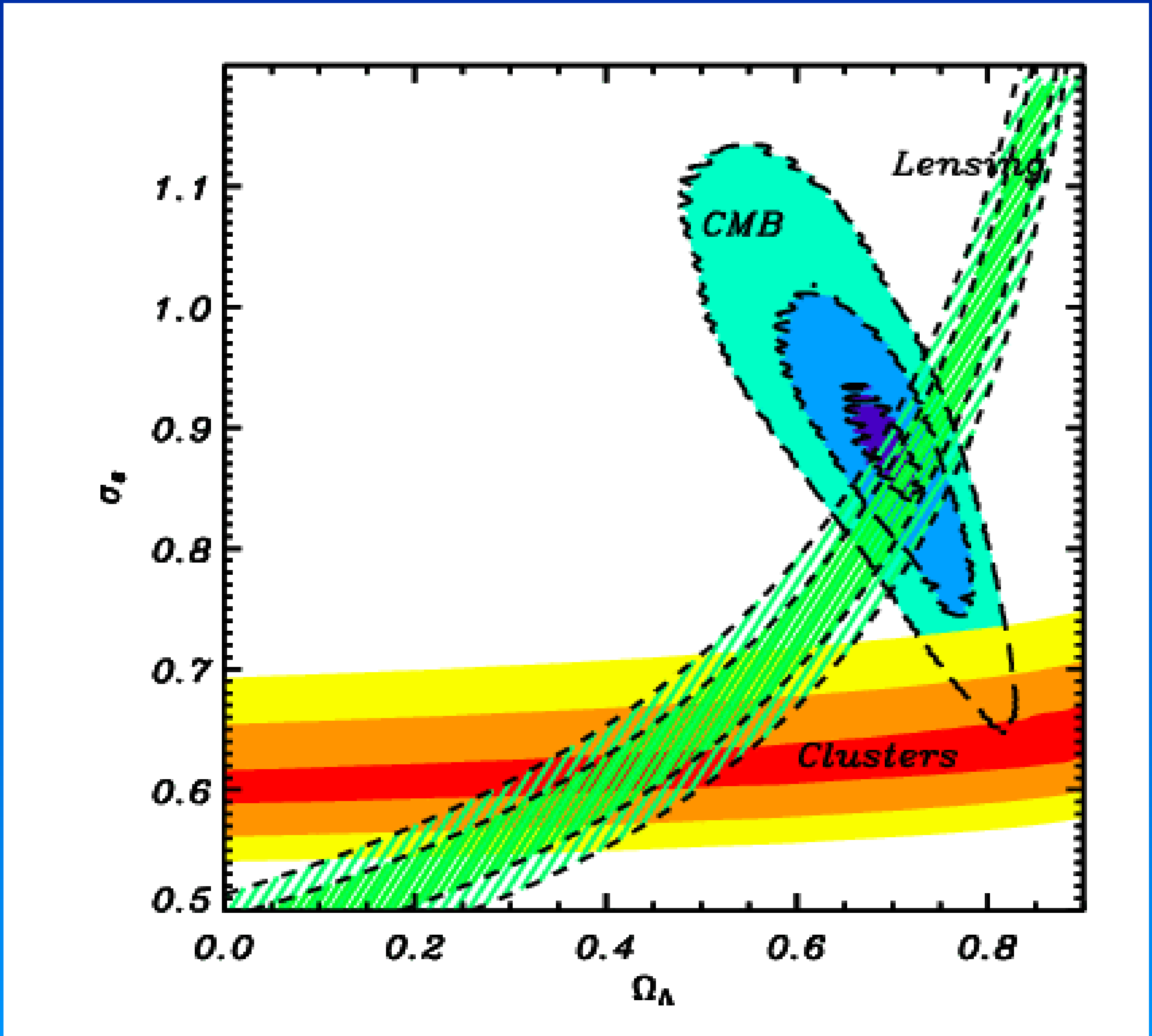


Self-consistent baryon fraction



σ_8 all together:

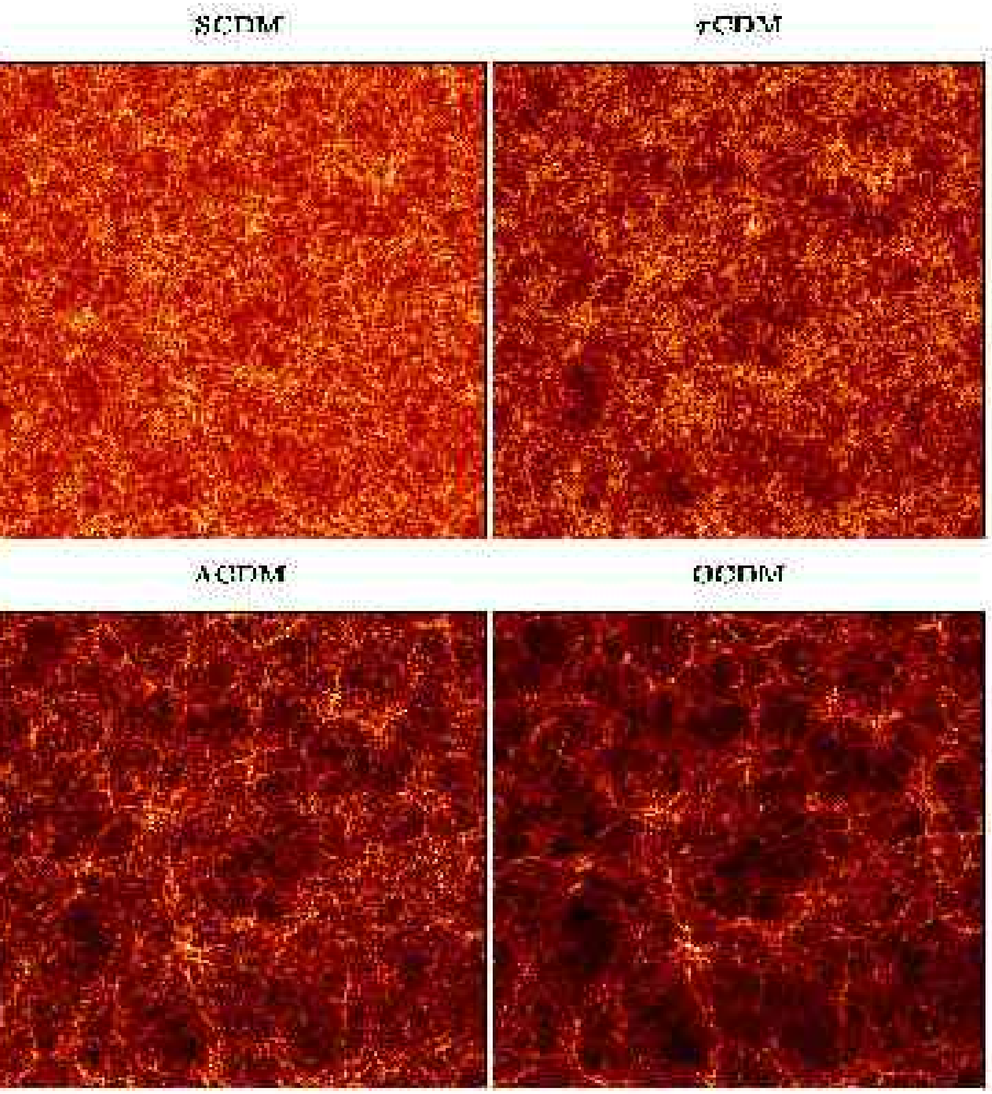
Blanchard & Douspis 2004

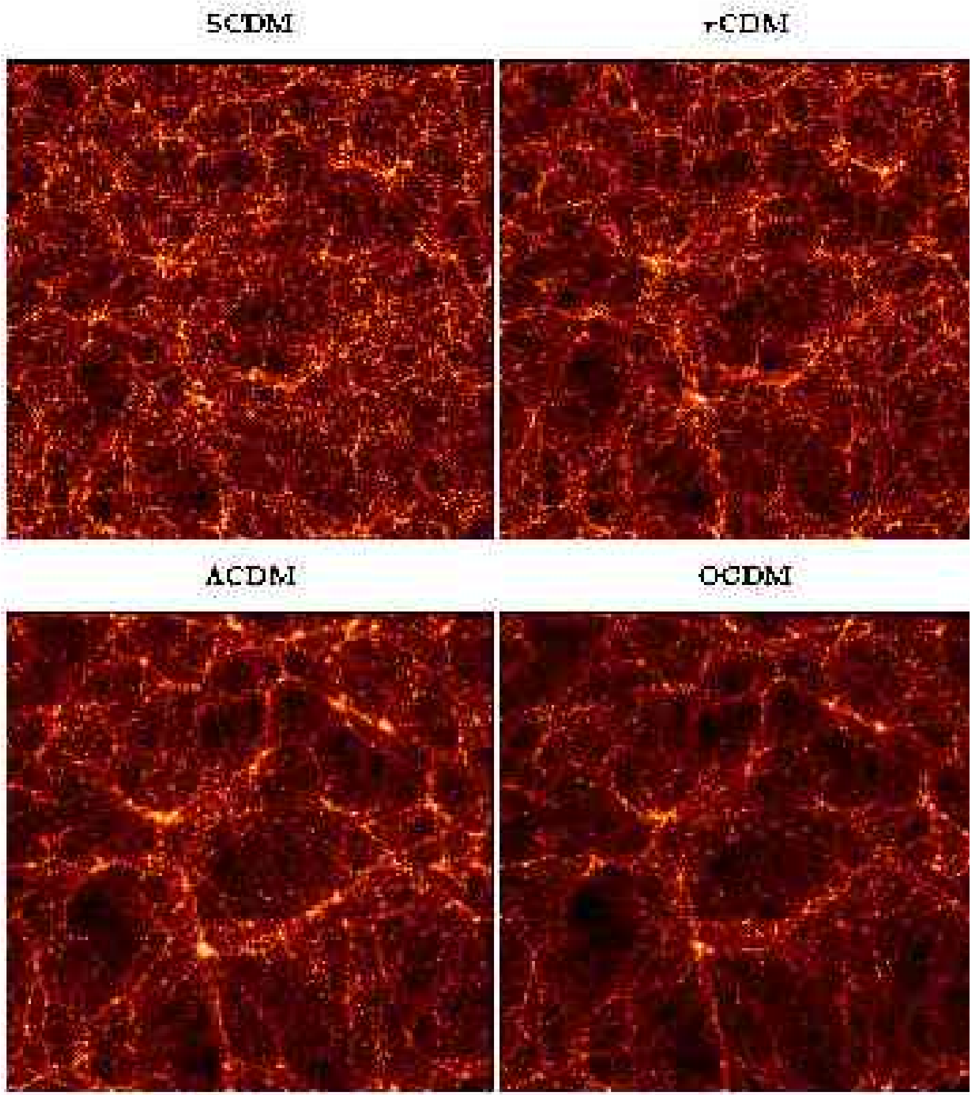


Ω_m

From X-ray Clusters

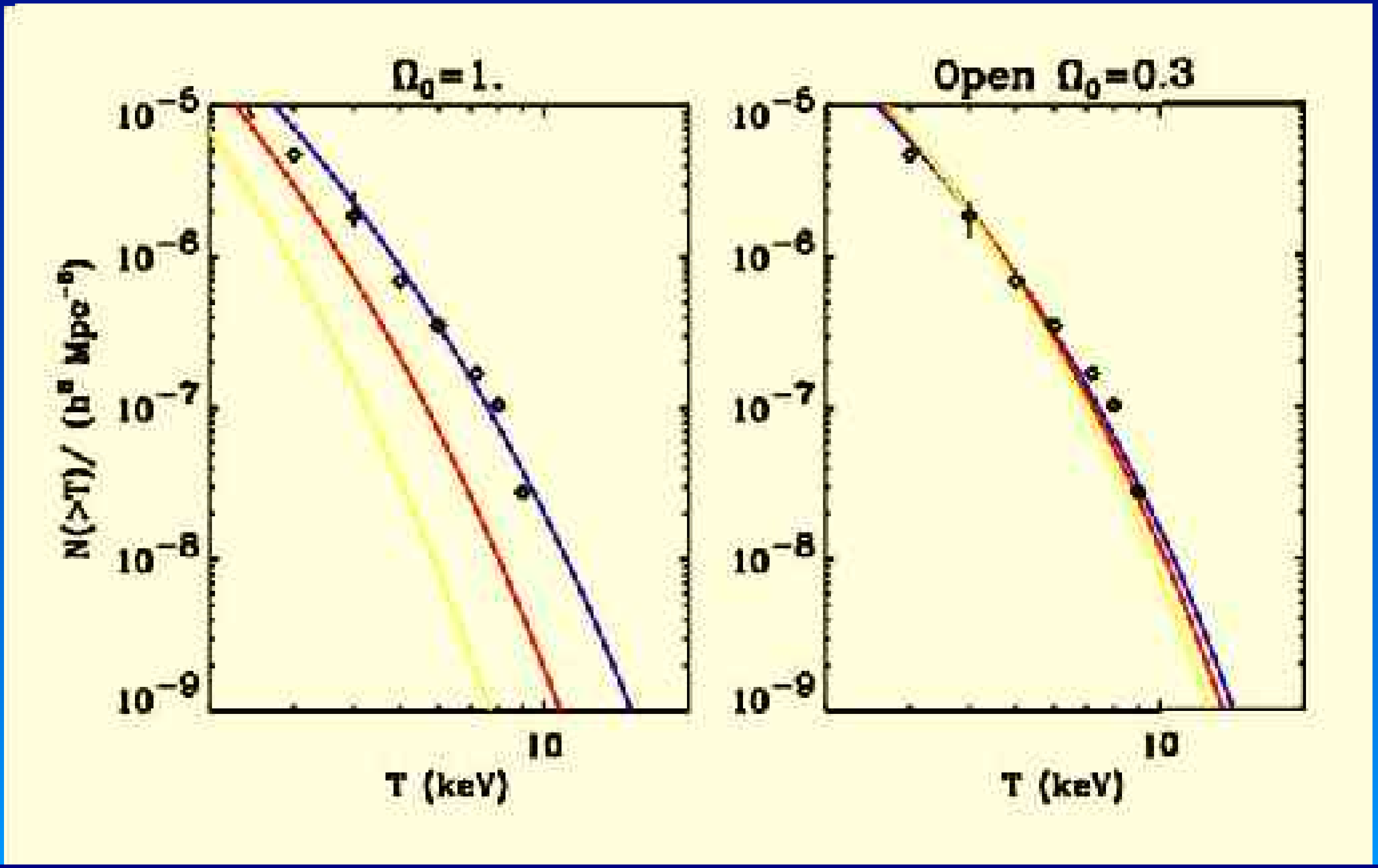
Number evolution





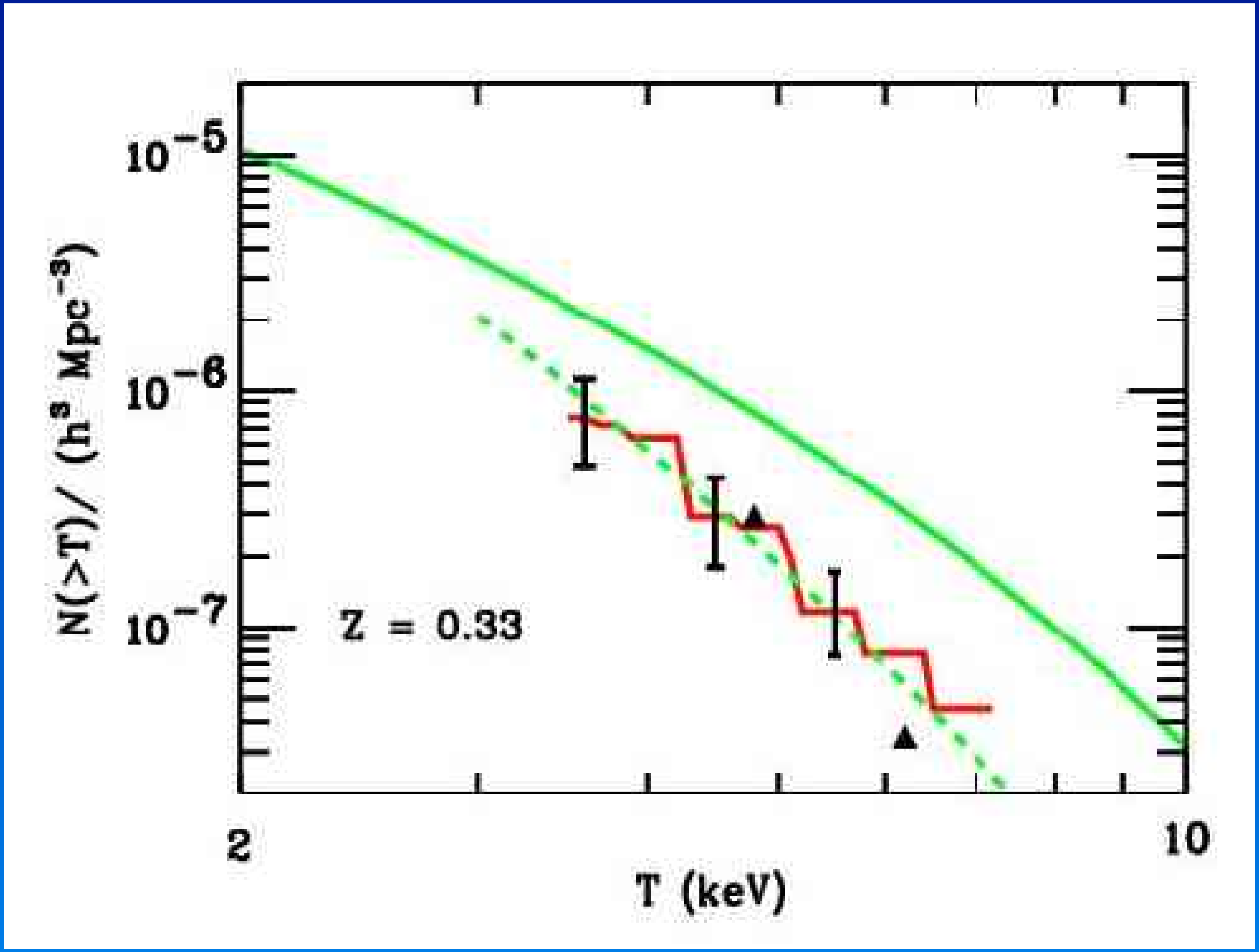
VIRGO simulations

Principle



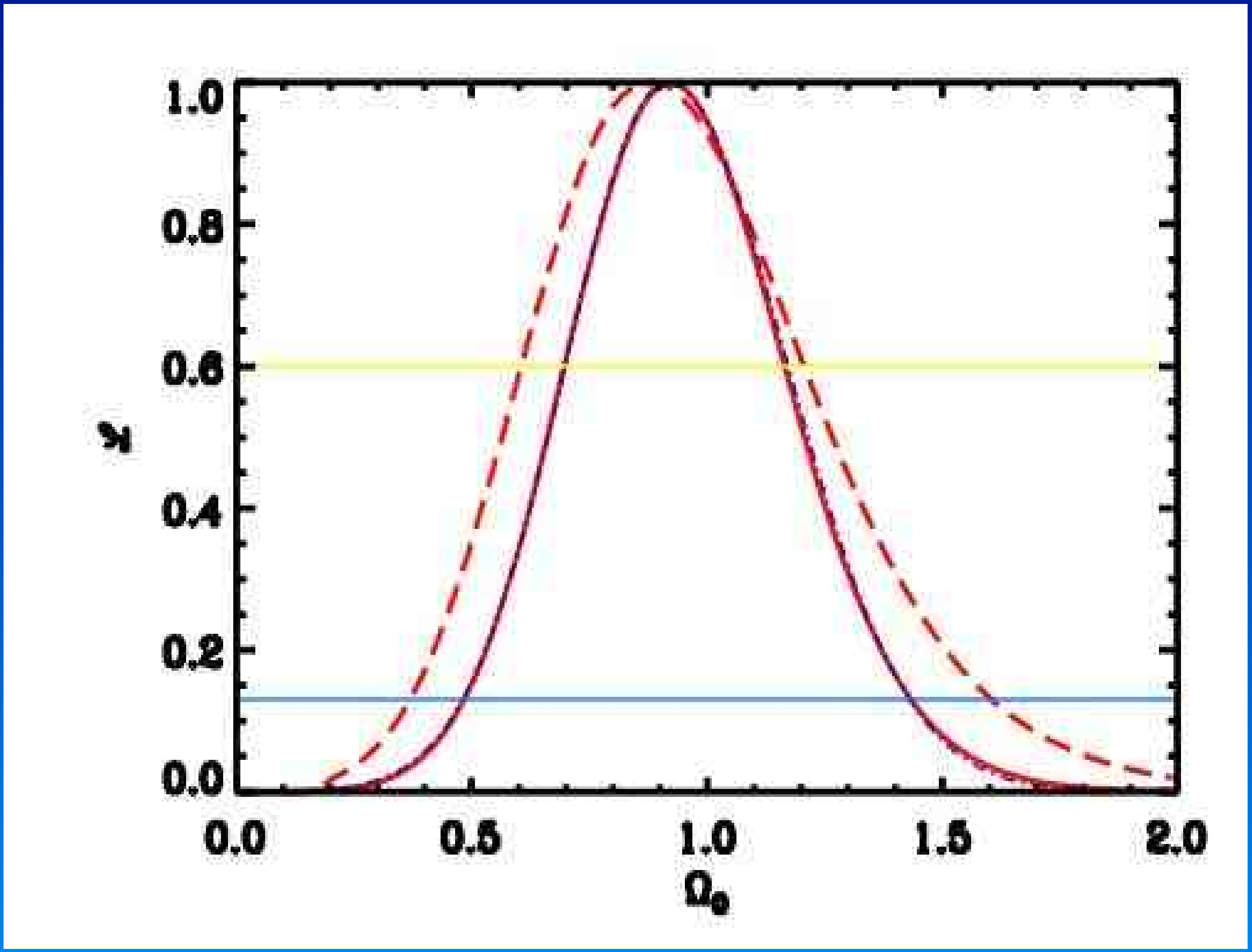
Oukbir, Blanchard, 1992, A&A, 26, L212

Estimated N(T) at z ≈ 0.33



Using Henri's sample (1997)

Likelihood on Ω_m



Blanchard et al (2000)

Ω_m From X-ray Clusters

Vauclair et al, 2003
A&A 412, L37

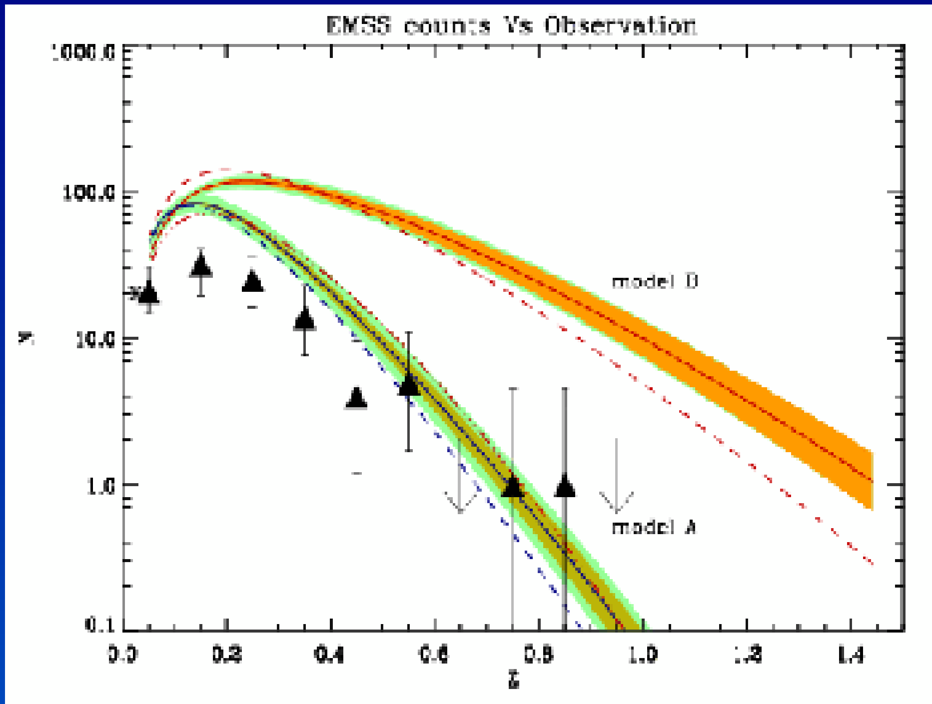
Number counts:

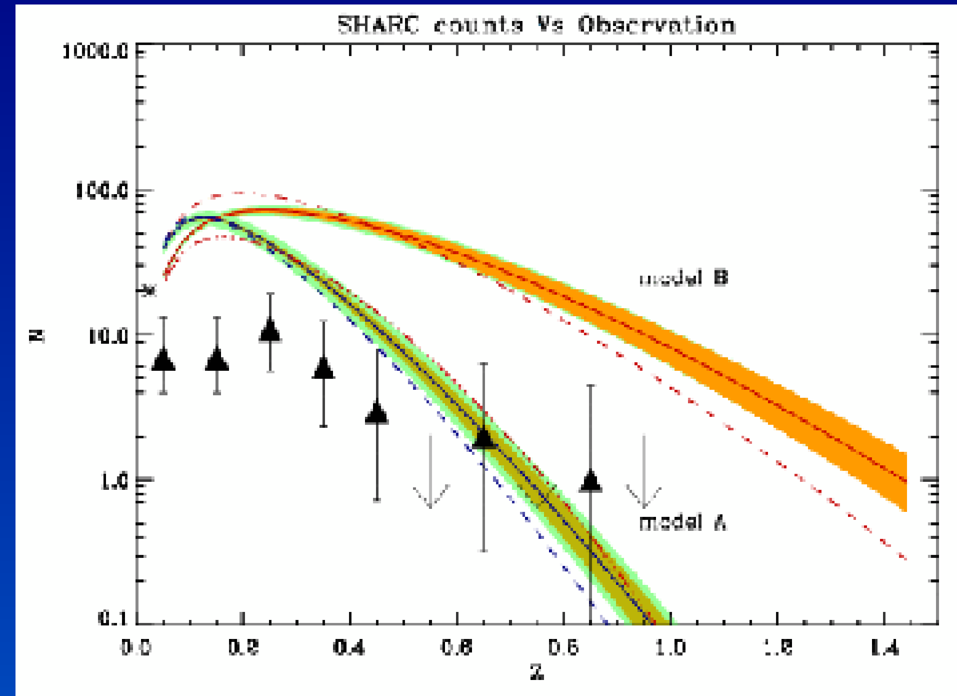
~300 clusters with
z > 0.3

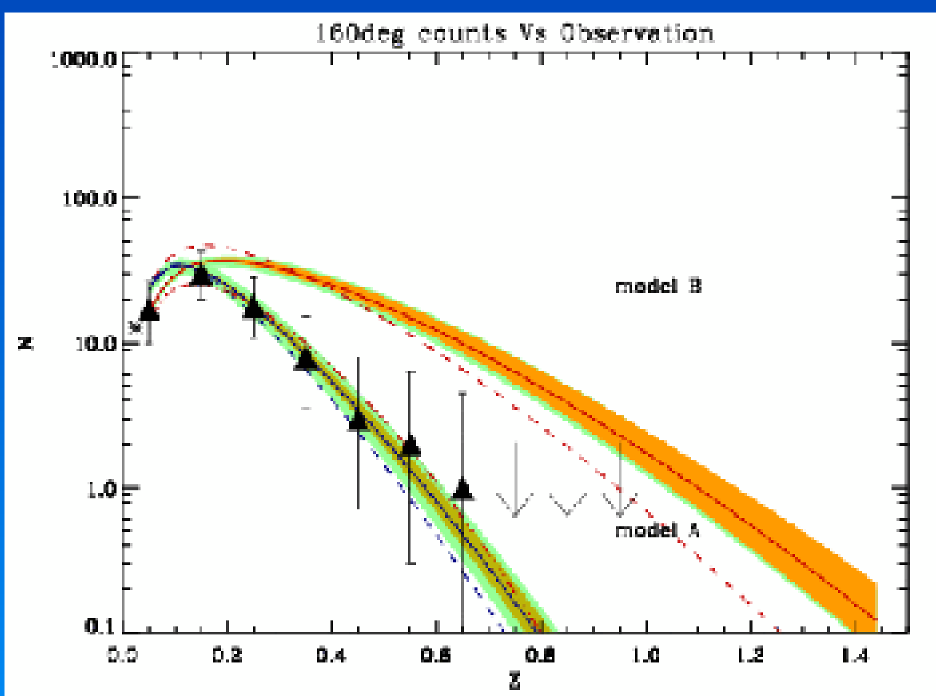
Method:

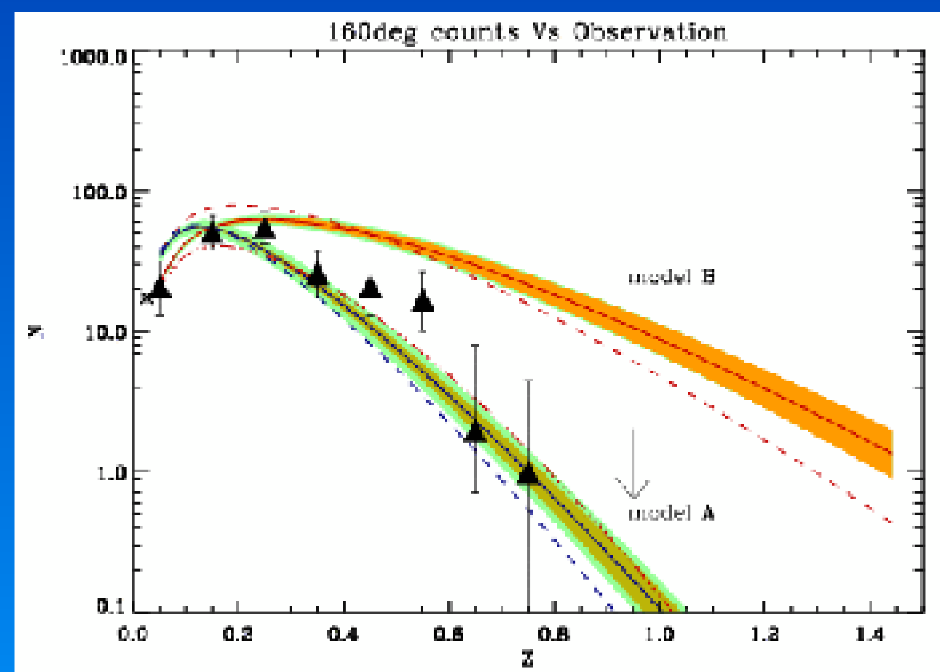
$$f_x \rightarrow L_x \rightarrow s, T_x$$

$$N(>f_x) = \int_0^{+\infty}\int_0^{+\infty} s(T,z)N(T,z)dTdV(z)$$
$$>\sim \int_0^{+\infty} N(>T(z))dV(z)$$


EMSS counts Vs Observation
1000.0
100.0
10.0
1.0
0.1
N
model B
model A
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Z


SHARC counts Vs Observation
1000.0
100.0
10.0
1.0
0.1
N
model B
model A
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Z


160deg counts Vs Observation
1000.0
100.0
10.0
1.0
0.1
N
model B
model A
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Z


160deg counts Vs Observation
1000.0
100.0
10.0
1.0
0.1
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model A
0.0
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0.6
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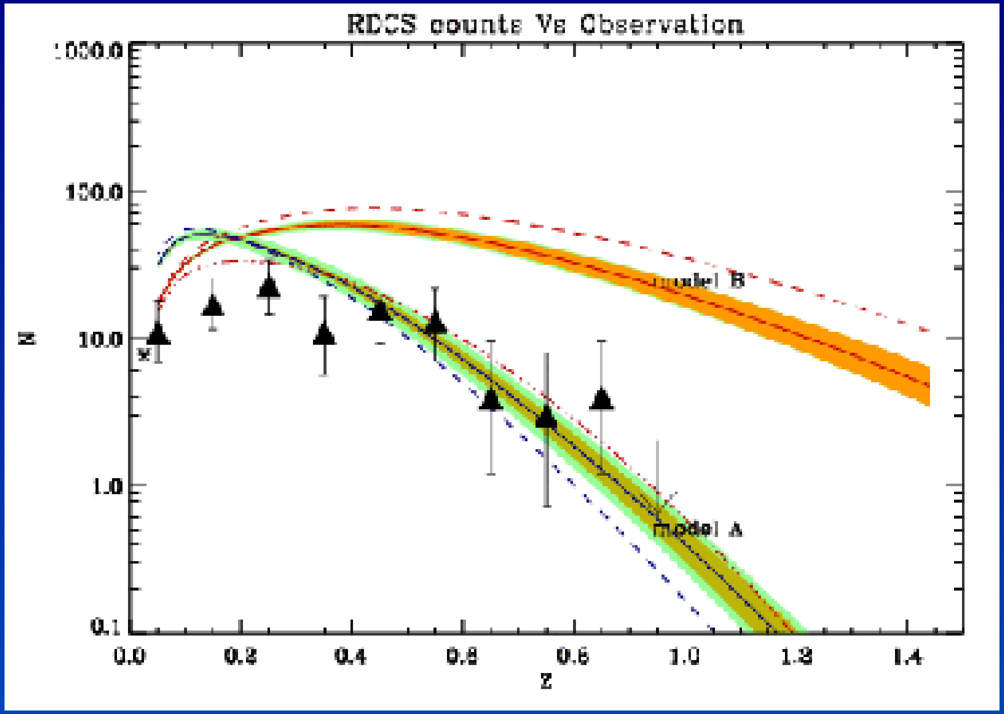
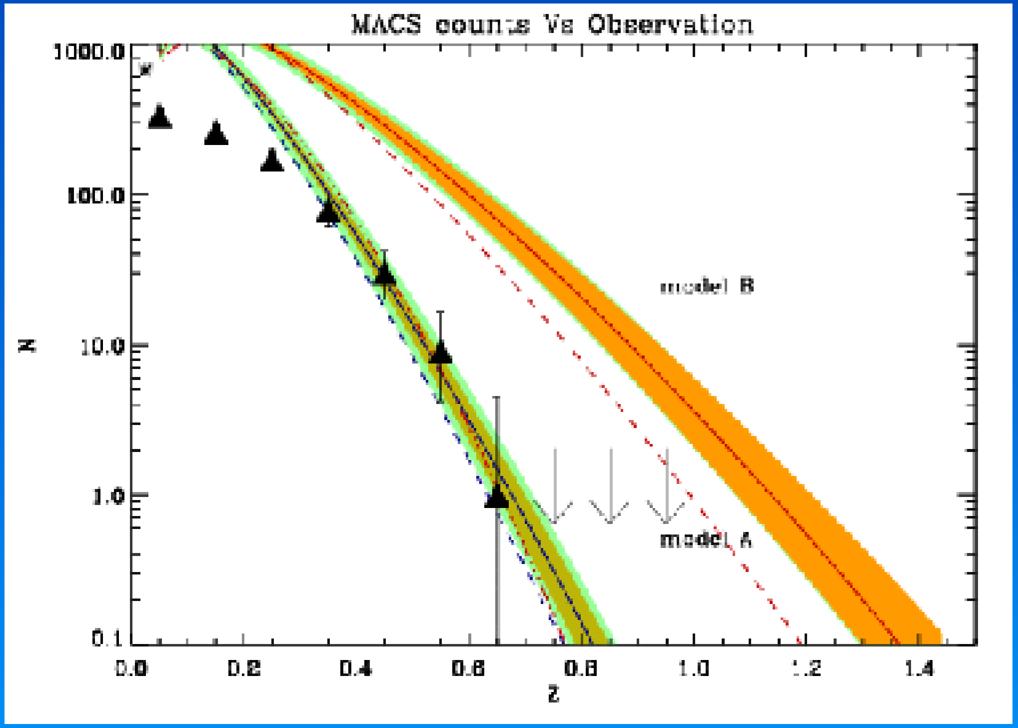
1.0
1.2
1.4
Z

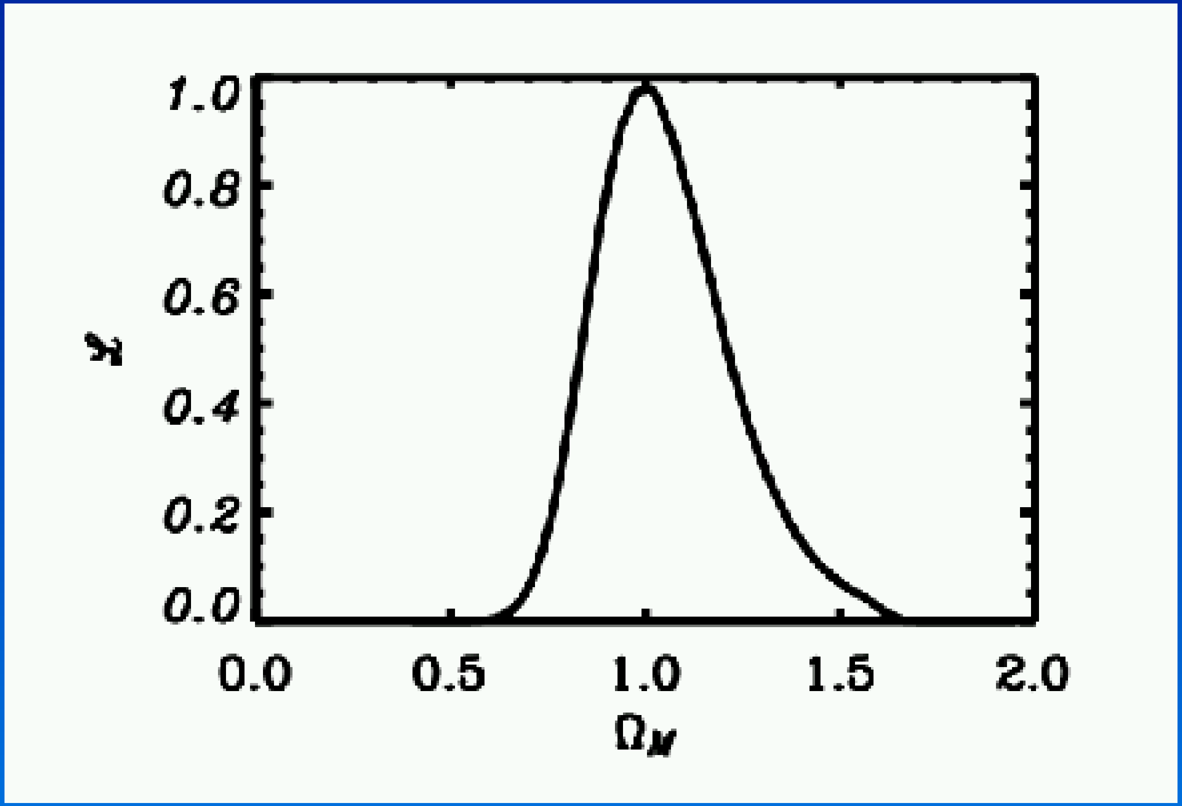


RDCS: 50 deg²
fx ≈ 3. 10^{-14} erg/s/cm²

MACS: 22 000 deg²
fx ≈ 10^{-12} erg/s/cm²



Likelihood analysis:



(Vauclair S., 2004)

$\Omega_m = 0.99 \pm 0.15 \pm 0.15$

Conclusions ?

- **Strong Evolution in the abundance of x-ray clusters appears from all existing surveys in a very consistent way.**
- **This provides a strong argument in favor of a high matter density... ☺**
- **Consistent with f_b evolution ... ☺**

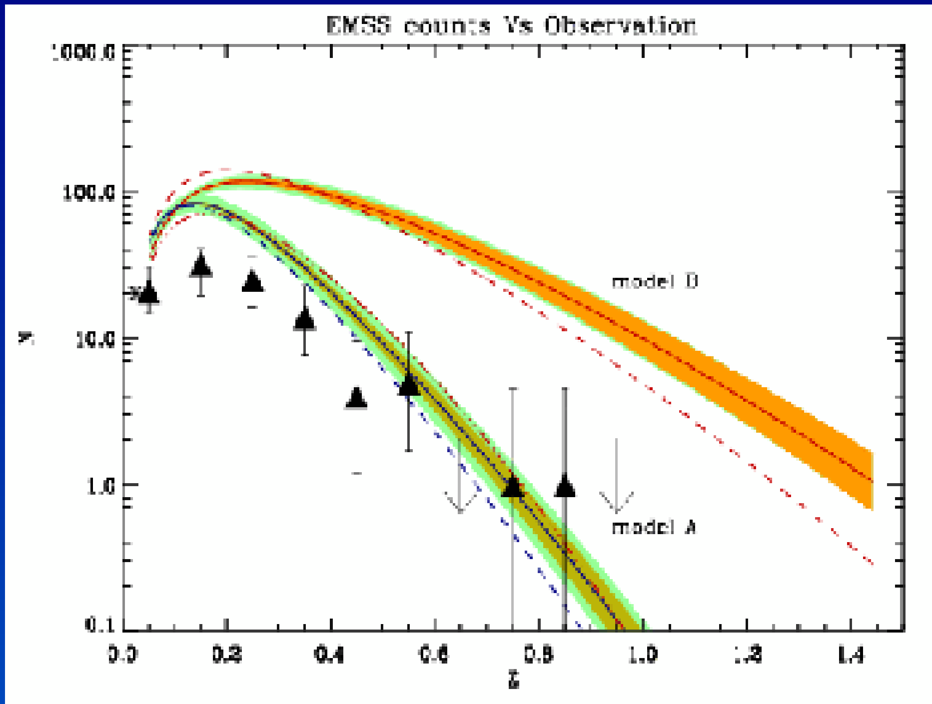
Yet an other degeneracy?

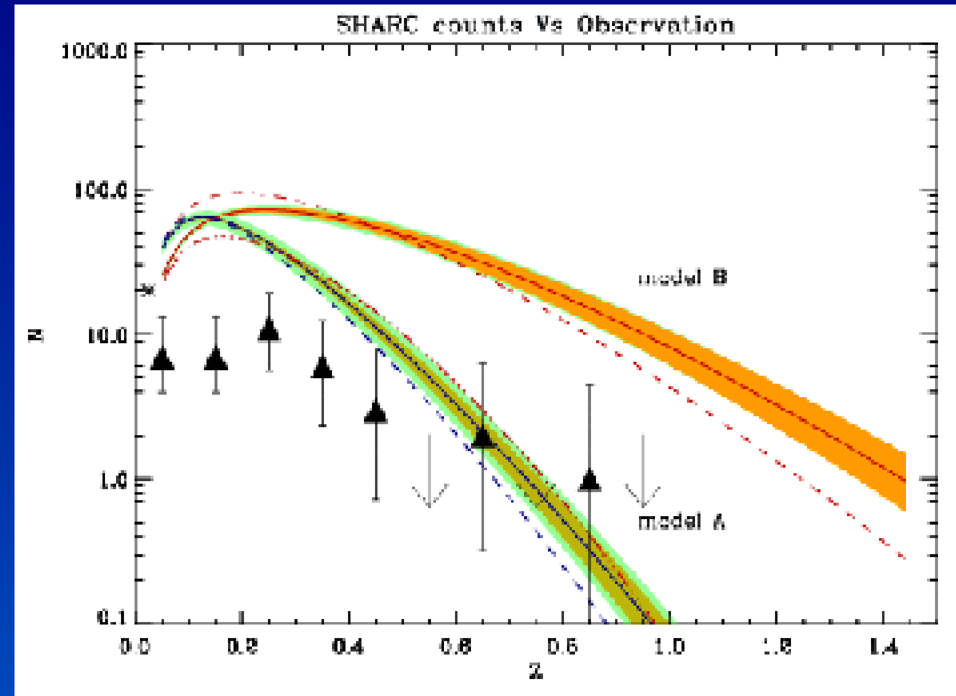
Kill the Mass-Temperature Relation :

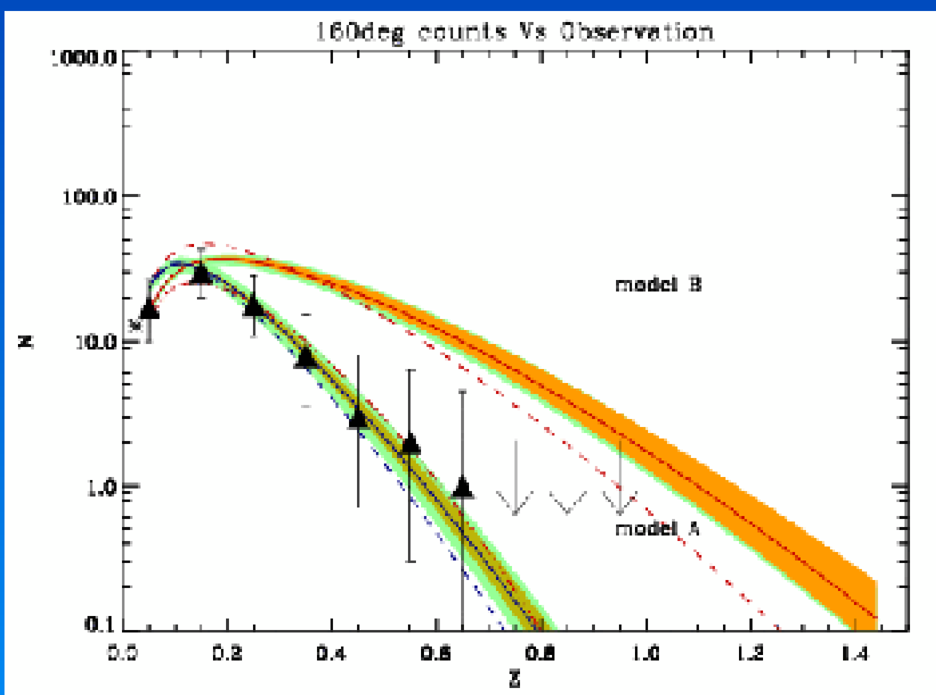
$$T \propto GM/r + \ldots \propto GM/r\,/(1+z)$$

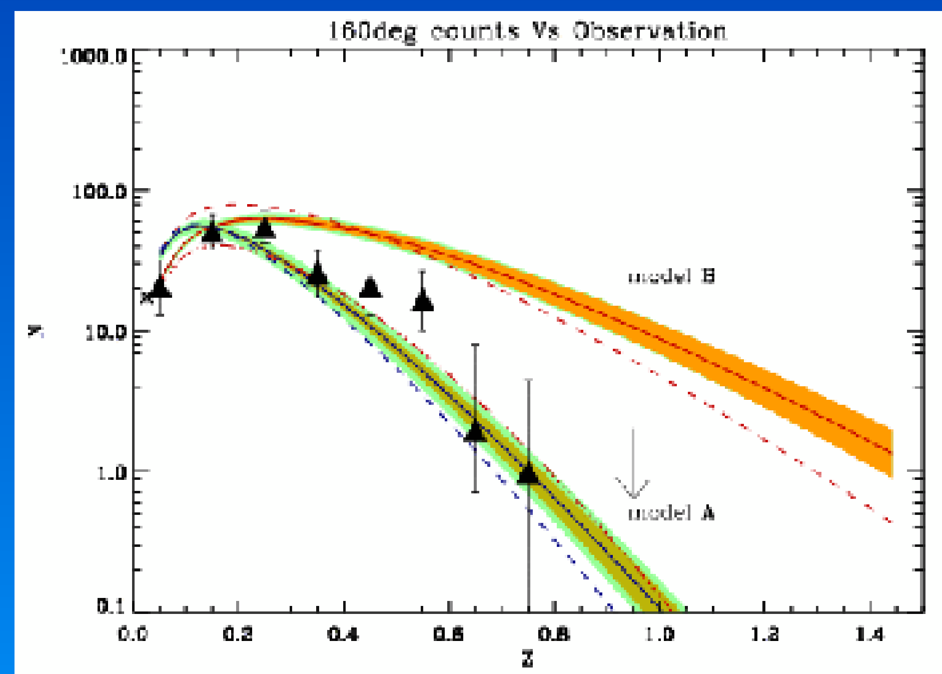
i.e. ~ forget gravity...

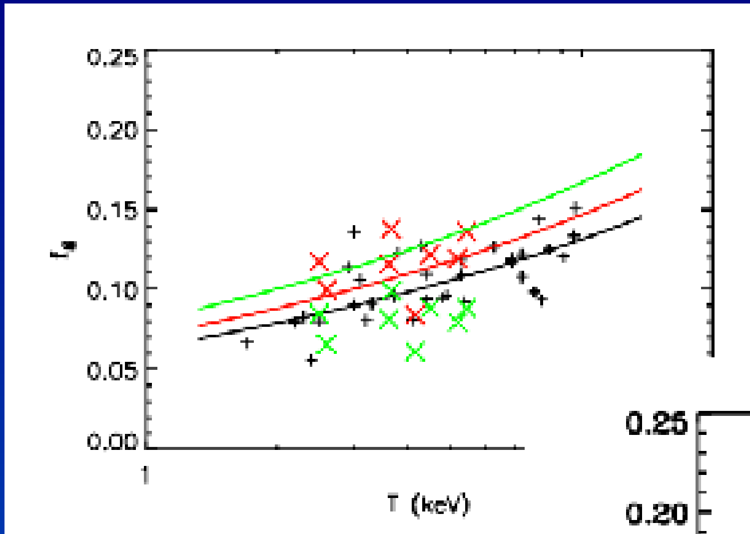
$$T_x \propto M^{2/3}$$

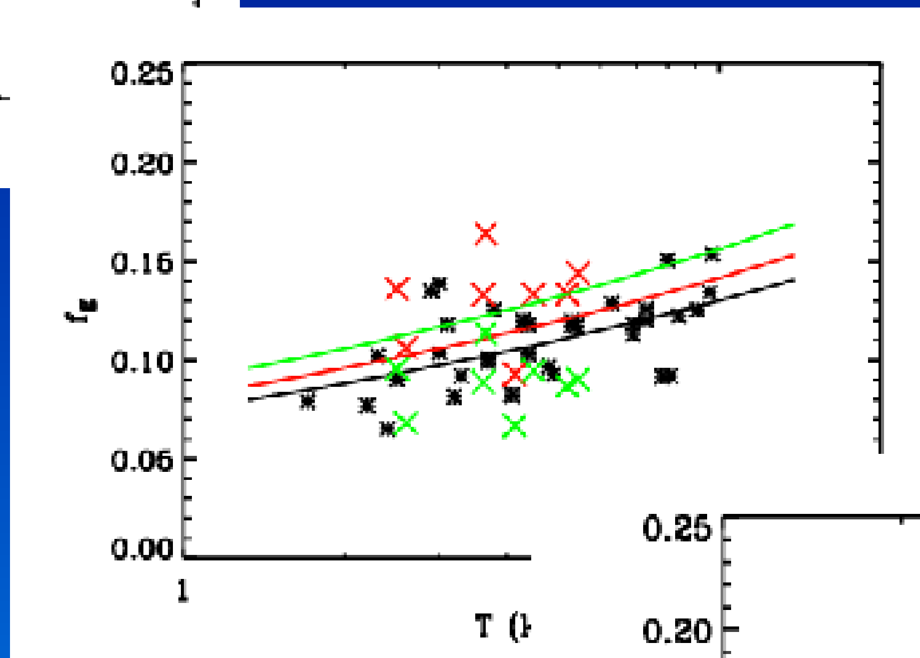

EMSS counts Vs Observation
N
Z
model B
model A
1000.0
100.0
10.0
1.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

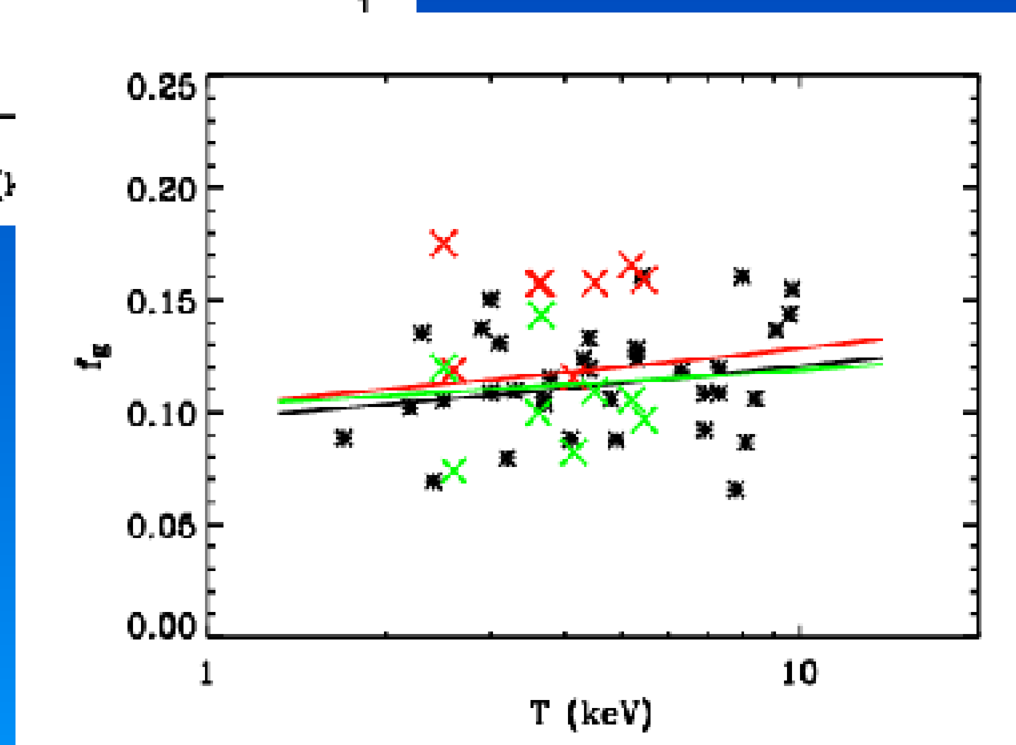

SHARC counts Vs Observation
N
Z
model B
model A
1000.0
100.0
10.0
1.0
0.1


160deg counts Vs Observation
N
Z
model B
model A
1000.0
100.0
10.0
1.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


160deg counts Vs Observation
N
Z
model B
model A
1000.0
100.0
10.0
1.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4







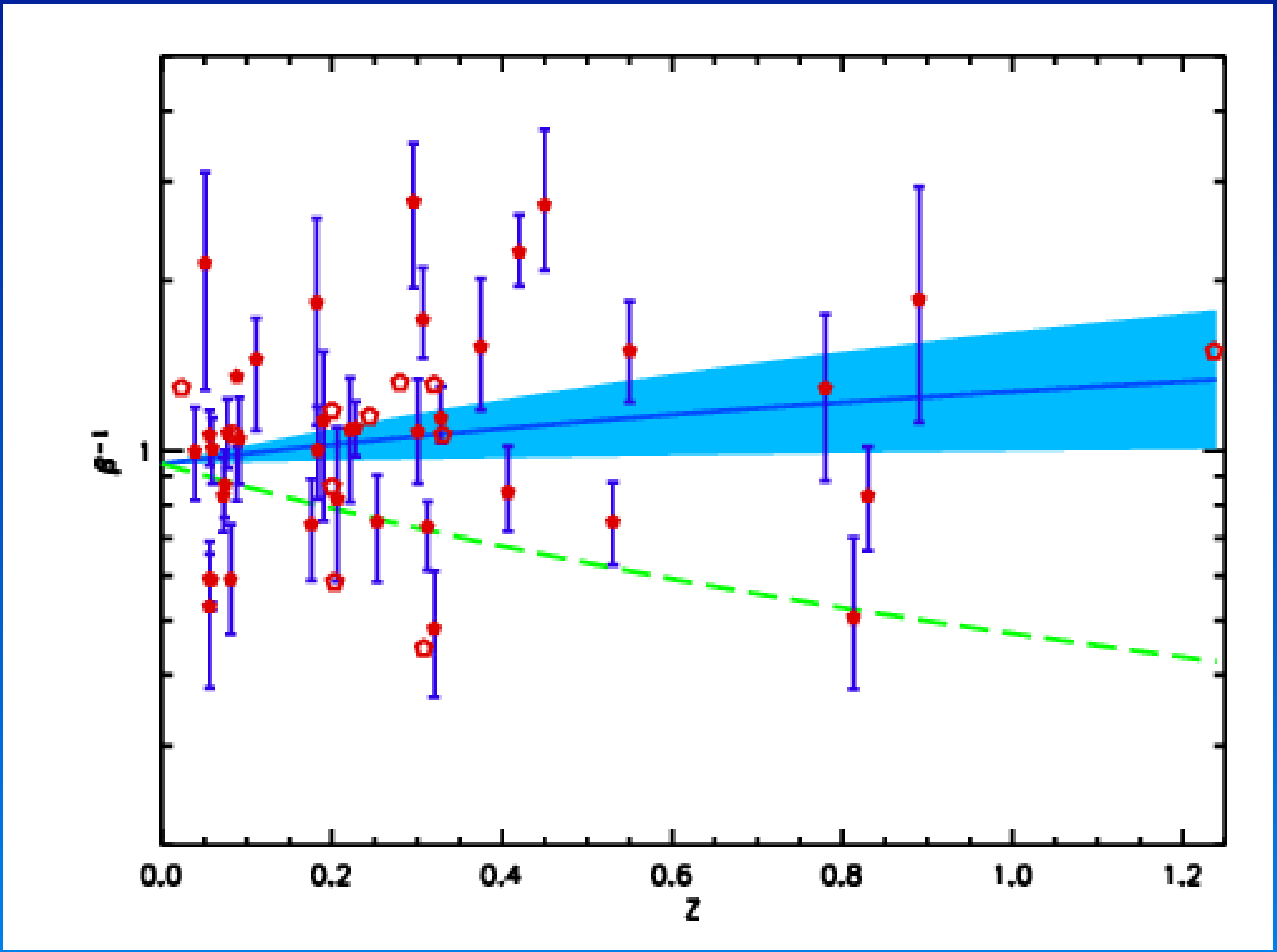
Concordance works !

Breaking the degenracy...

$T \propto GM/r\,/(1+z) \propto \sigma^2/(1+z)$

- **Testable... i.e.**

$\beta^{-1} \propto T/\sigma^2 \propto 1/(1+z)$



0.0
0.2
0.4
0.6
0.8
1.0
1.2
Z
1
β^{-1}

Conclusion:

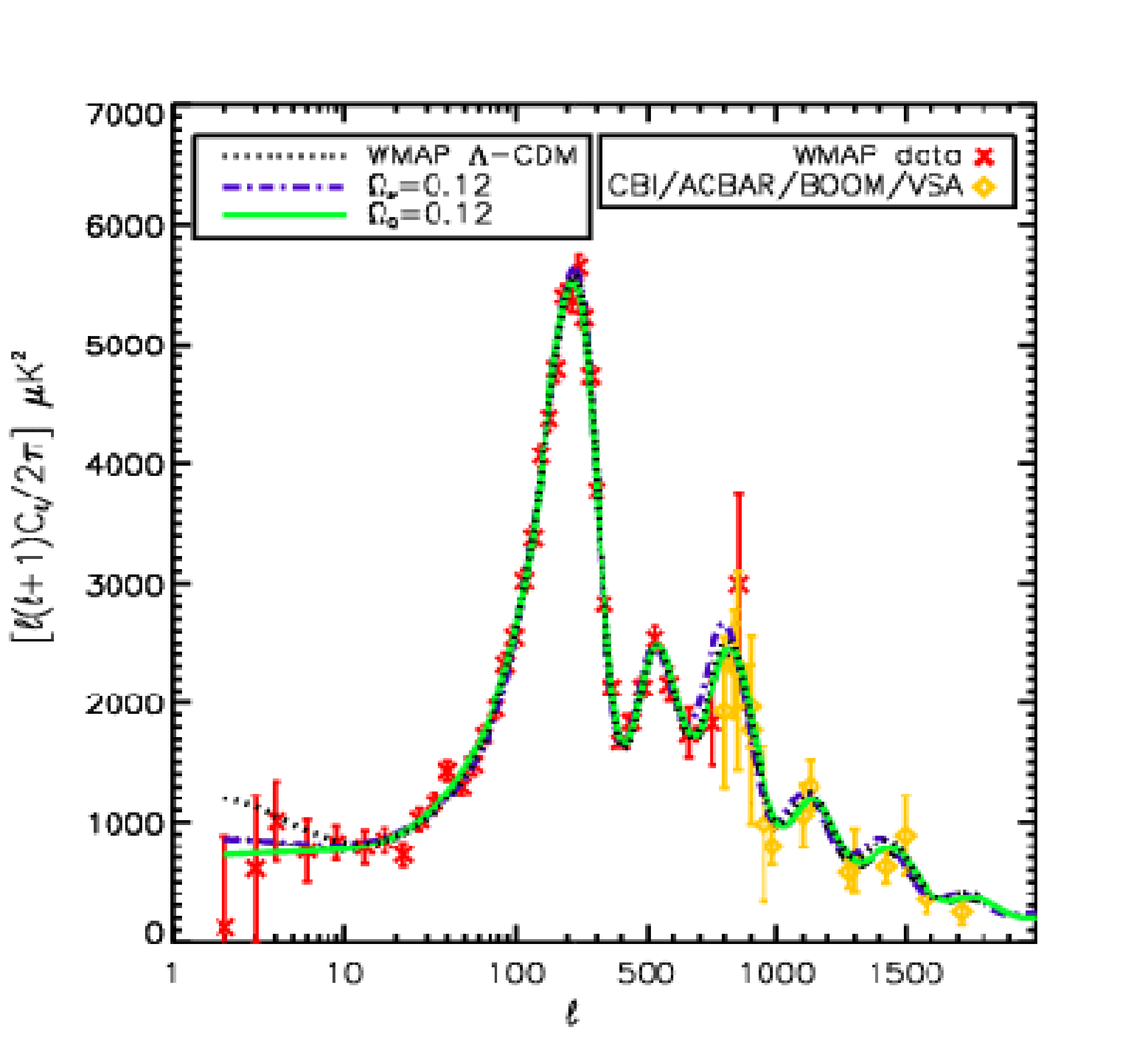
- **Strong Evolution in the abundance of x-ray clusters appears from all existing surveys in a very consistent way.**
- **This provides a strong argument in favor of a high matter density... ☺**
- **Consistent with f_b evolution ... ☺**
- **Consistent with f_b amplitude ... ☺**

An Einstein-de Sitter universe, why not?

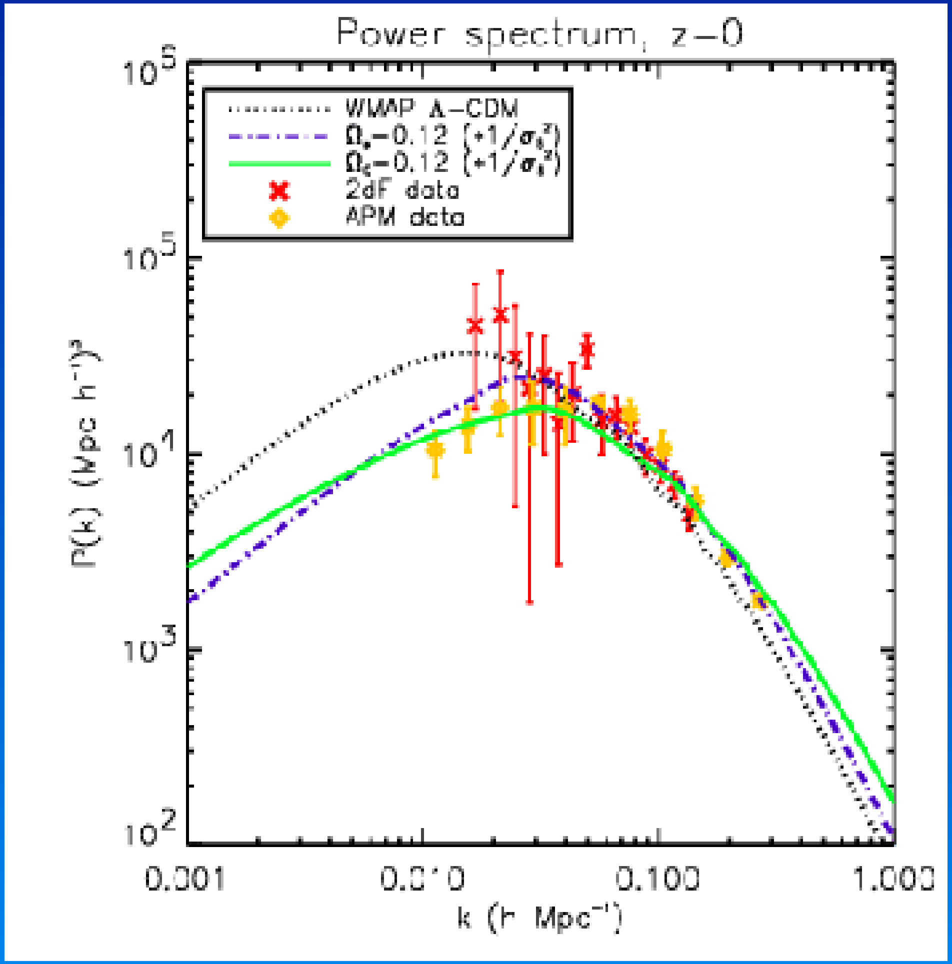
An Einstein-de Sitter universe,

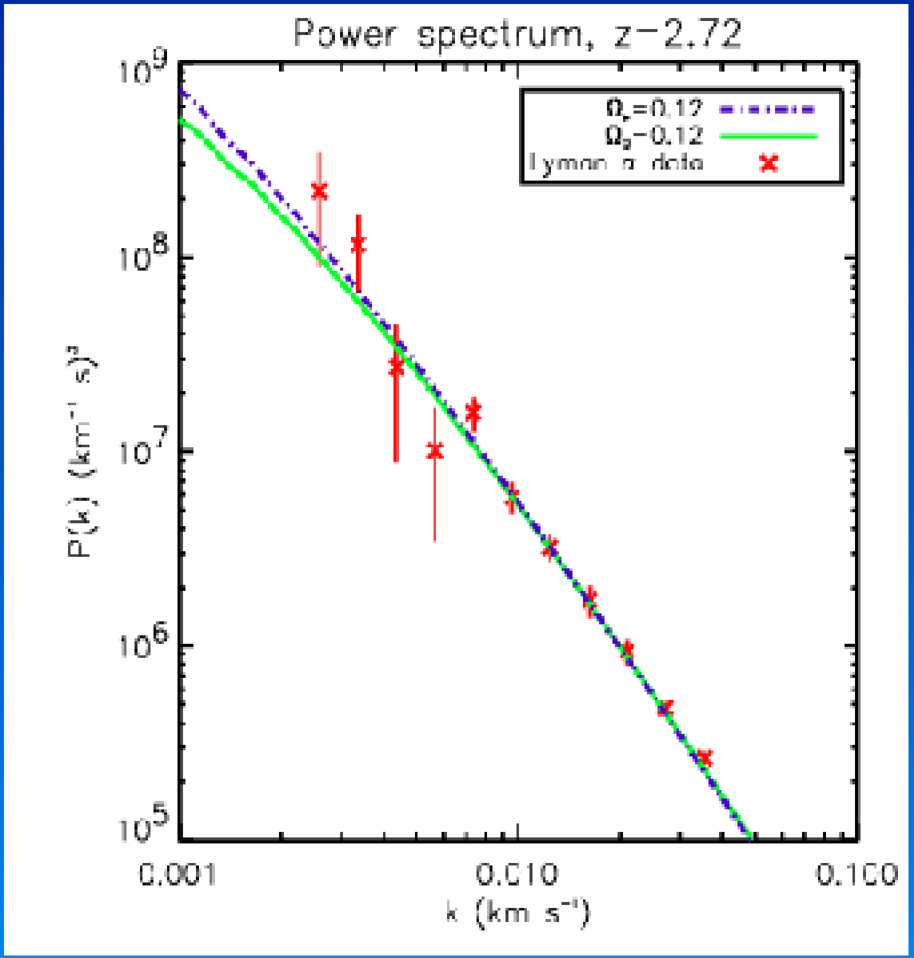
why not ???

C.M.B.



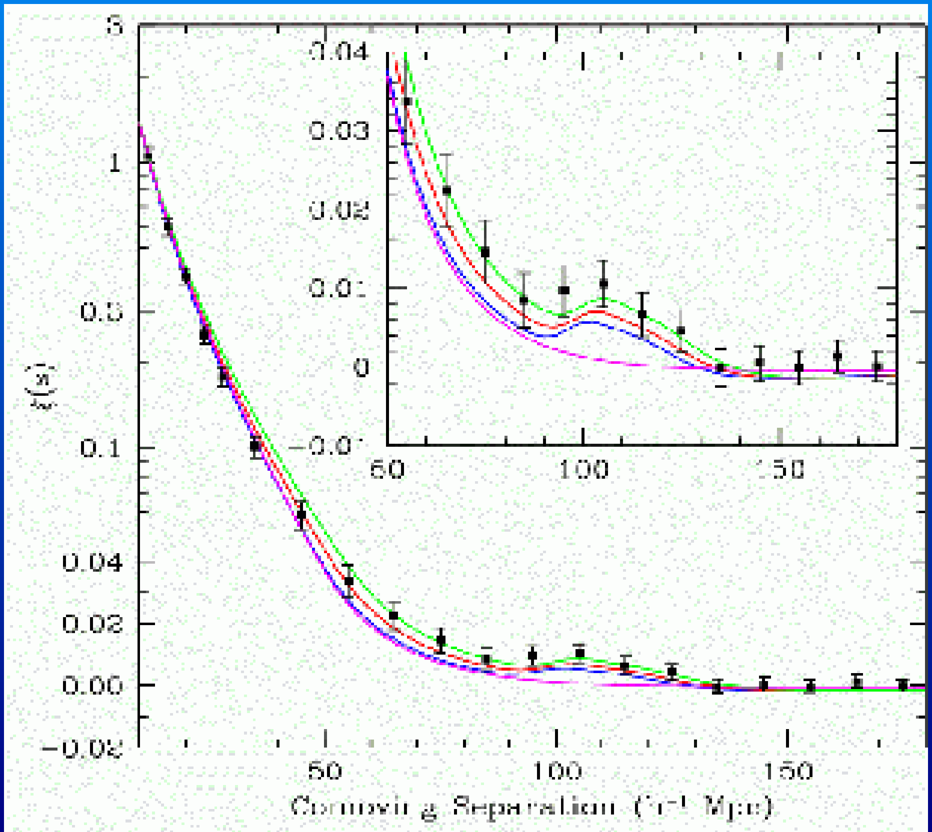
Blanchard, Douspis, Rowan-Robinson, Sarkar 2003


Power spectrum, z=0
WMAP Λ-CDM
2dF data
APM data
P(k) (Mpc h⁻¹)³
k (h Mpc⁻¹)
0.001
0.010
0.100
1.000

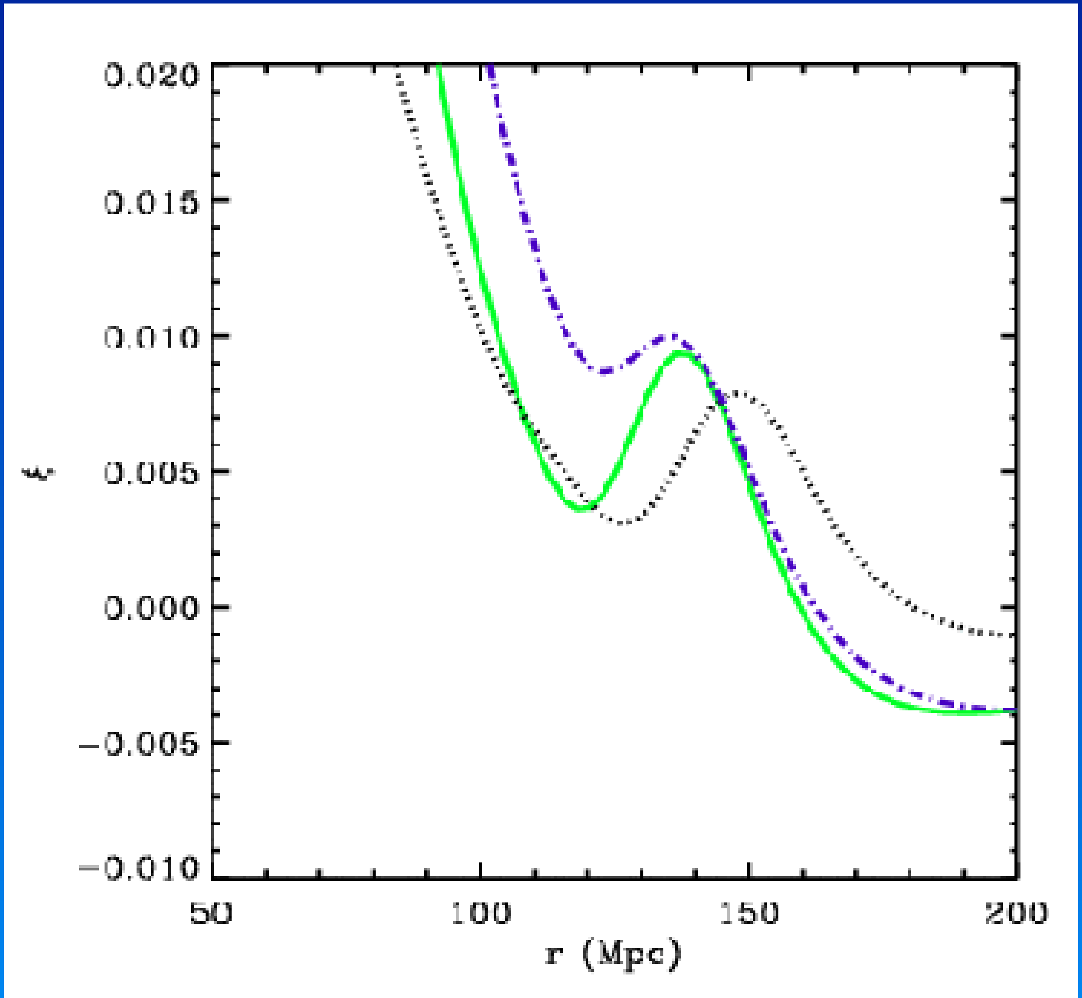

Power spectrum, z=2.72
Lyman α data
P(k) (km⁻¹ s)³
k (km s⁻¹)
0.001
0.010
0.100

LSS correlation

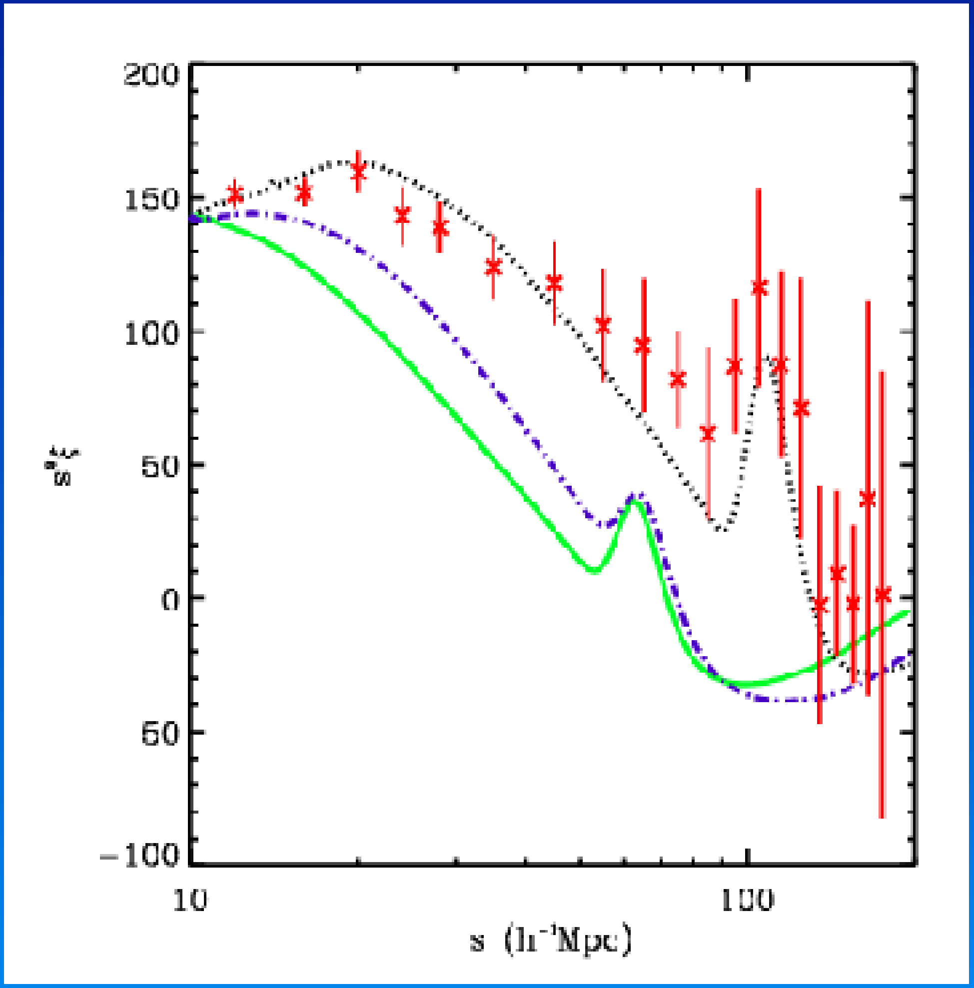
SLOAN red galaxies



Acoustic peak ?



Blanchard, Douspis, Rowan-Robinson, Sarkar 2005



Blanchard, Douspis, Rowan-Robinson, Sarkar 2005

Conclusion

- Clusters do not fit well in the concordance model

  i.e. favoring an Einstein de Sitter ...

  - SLOAN LSS excludes EdS However

- Troubles from clusters ?