La quête du cinquième élément:

les indices astrophysiques en faveur de l'énergie noire

Cargèse2008.

Well Established Results:

- ➔ Universe is expanding!

  (Hubble diagram, SN time scale, CMB at Z > 0)

- ➔ Baryonic content $\Omega_b \approx 0.020\text{-}0.025\, h^{-2}$

- ➔ Dark matter is non-baryonic

- ➔ Power Spectrum is CDM-like ($n \lesssim 1.$, $\Gamma \approx 0.2$)

- ➔ Universe is nearly flat! ($R_c \ll c/H_0$)

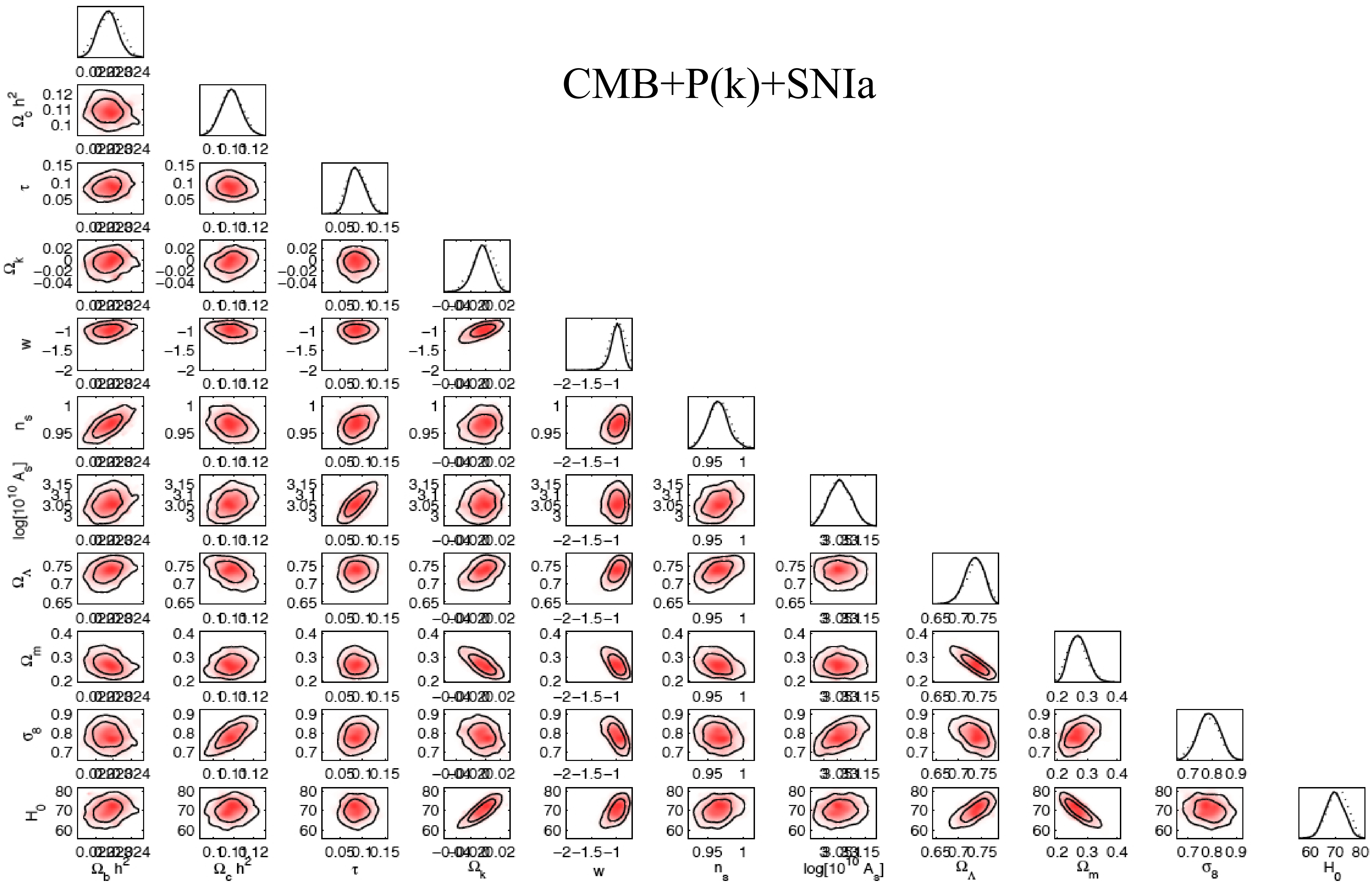
Cosmological Framework

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

} **Concordance Model!**

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

Precision Cosmology...



Precision Cosmology...

Parameter	Vanilla	Vanilla + Ω_k	Vanilla + w	Vanilla + Ω_k + w
$\Omega_b h^2$	0.0227 ± 0.0005	0.0227 ± 0.0006	0.0228 ± 0.0006	0.0227 ± 0.0005
$\Omega_c h^2$	0.112 ± 0.003	0.109 ± 0.005	0.109 ± 0.005	0.109 ± 0.005
θ	1.042 ± 0.003	1.042 ± 0.003	1.042 ± 0.003	1.042 ± 0.003
τ	0.085 ± 0.017	0.088 ± 0.017	0.087 ± 0.017	0.088 ± 0.017
n_s	0.963 ± 0.012	0.964 ± 0.013	0.967 ± 0.014	0.964 ± 0.014
$log(10^{10} A_s)$	3.07 ± 0.04	3.06 ± 0.04	3.06 ± 0.04	3.06 ± 0.04
Ω_k	0	-0.005 ± 0.007	0	-0.005 ± 0.0121
w	-1	-1	-0.965 ± 0.056	-1.003 ± 0.102
Ω_Λ	0.738 ± 0.015	0.735 ± 0.016	0.739 ± 0.014	0.733 ± 0.020
Age	13.7 ± 0.1	13.9 ± 0.4	13.7 ± 0.1	13.9 ± 0.6
Ω_m	0.262 ± 0.015	0.270 ± 0.019	0.261 ± 0.020	0.272 ± 0.029
σ_8	0.806 ± 0.023	0.791 ± 0.030	0.816 ± 0.014	0.788 ± 0.042
z_{re}	10.9 ± 1.4	11.0 ± 1.5	11.0 ± 1.5	11.0 ± 1.4
h	0.716 ± 0.014	0.699 ± 0.028	0.713 ± 0.015	0.698 ± 0.037

Ferramacho, L., B.A., Zolnierowski, Y. (2008)

Typical precision: 2%...

Cosmology...

- Standard cosmology based on proven physics
- Exotic physics advocated for non standard views (tired light, stationary cosmology, ...)
- Early times cosmology: Dark matter, Inflation

- and now dark energy:

$$2\frac{\ddot{R}}{R} = -\frac{8\,\pi\,G}{3}(\rho + 3P/c^2)$$

New exotic physics...

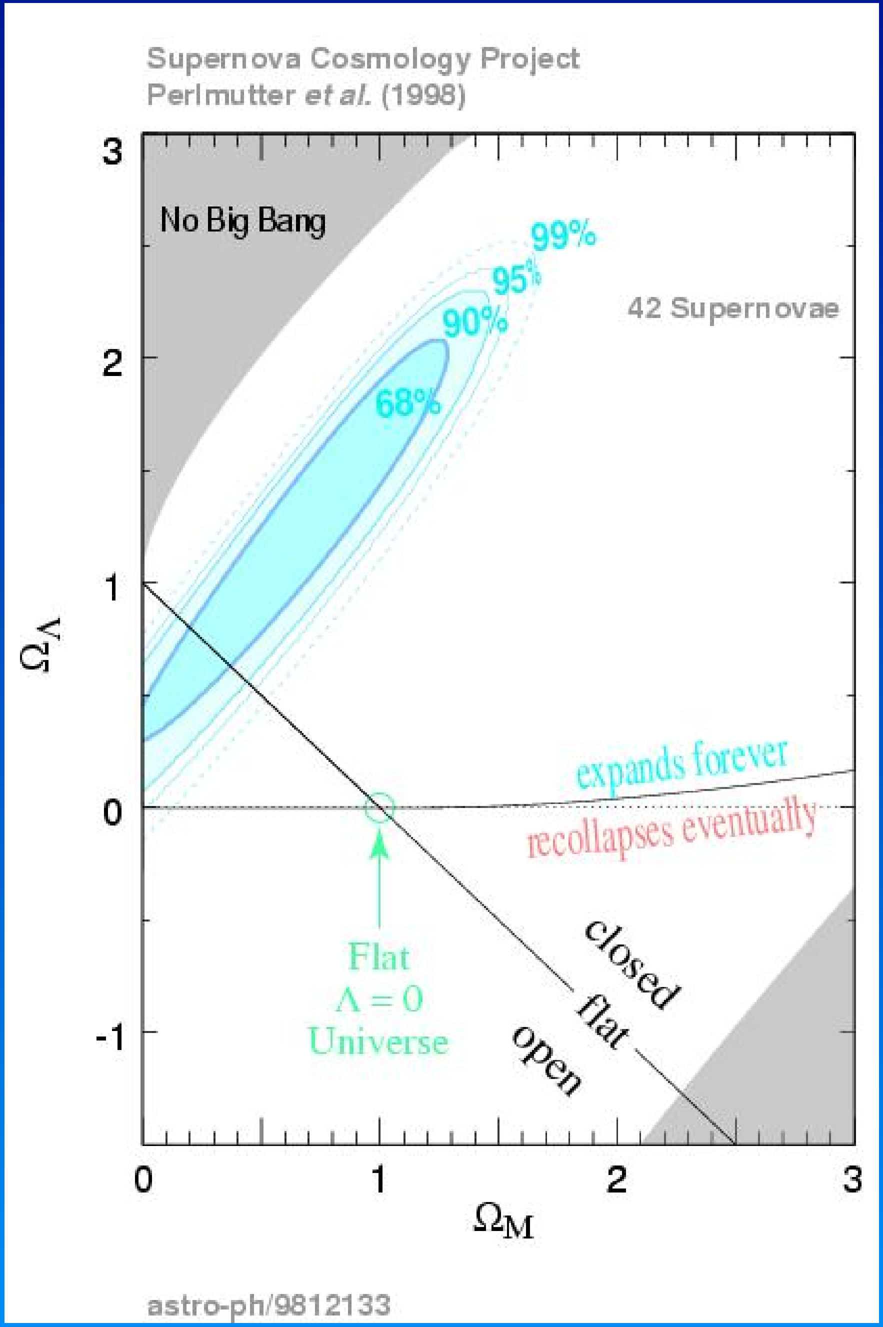
Fundamental questions...

- Are evidences for acceleration secure?

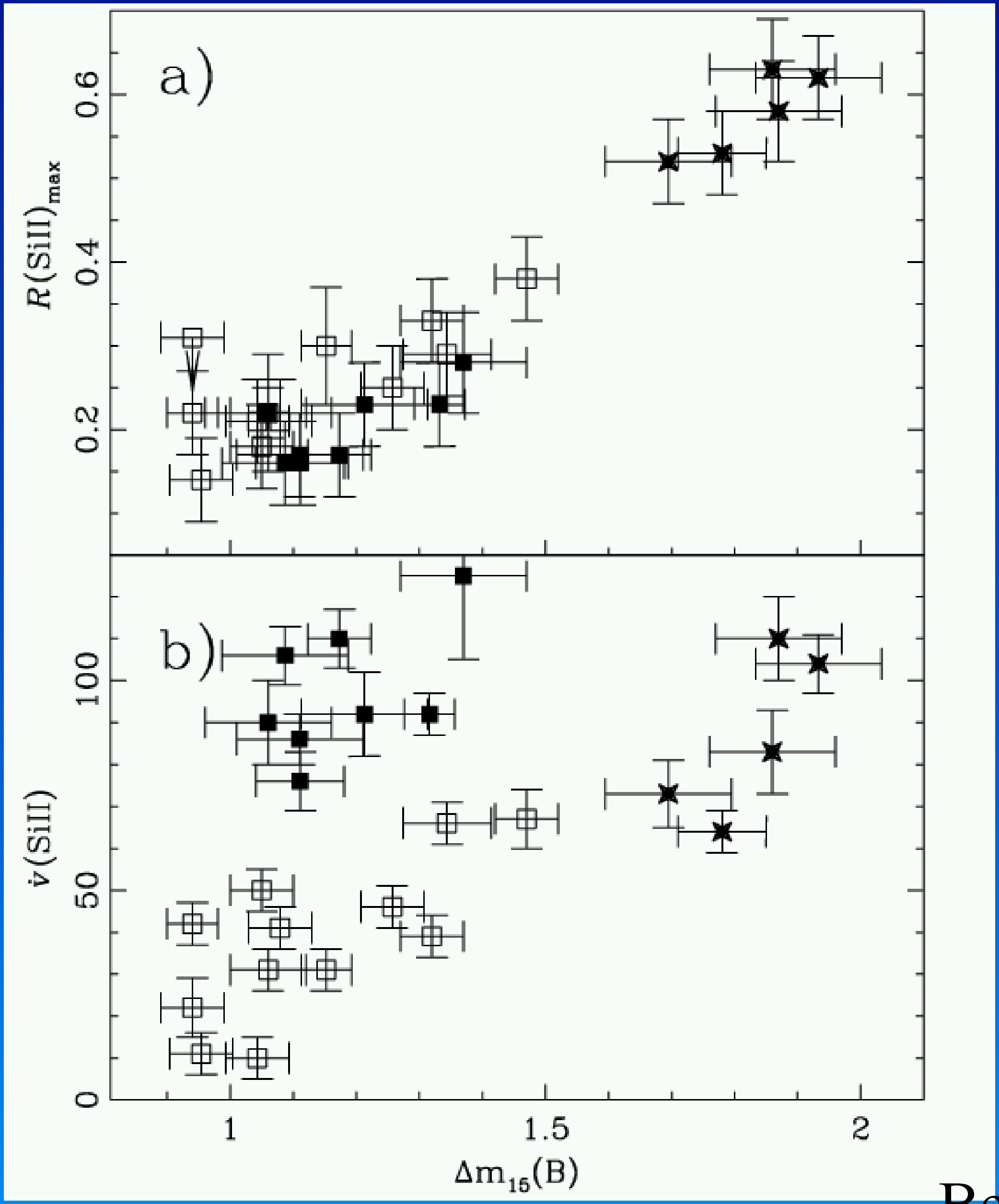
- What are the possible systematics and their impact ?

Only one direct evidence for a accelerating Universe:

Supernovae Hubble diagram

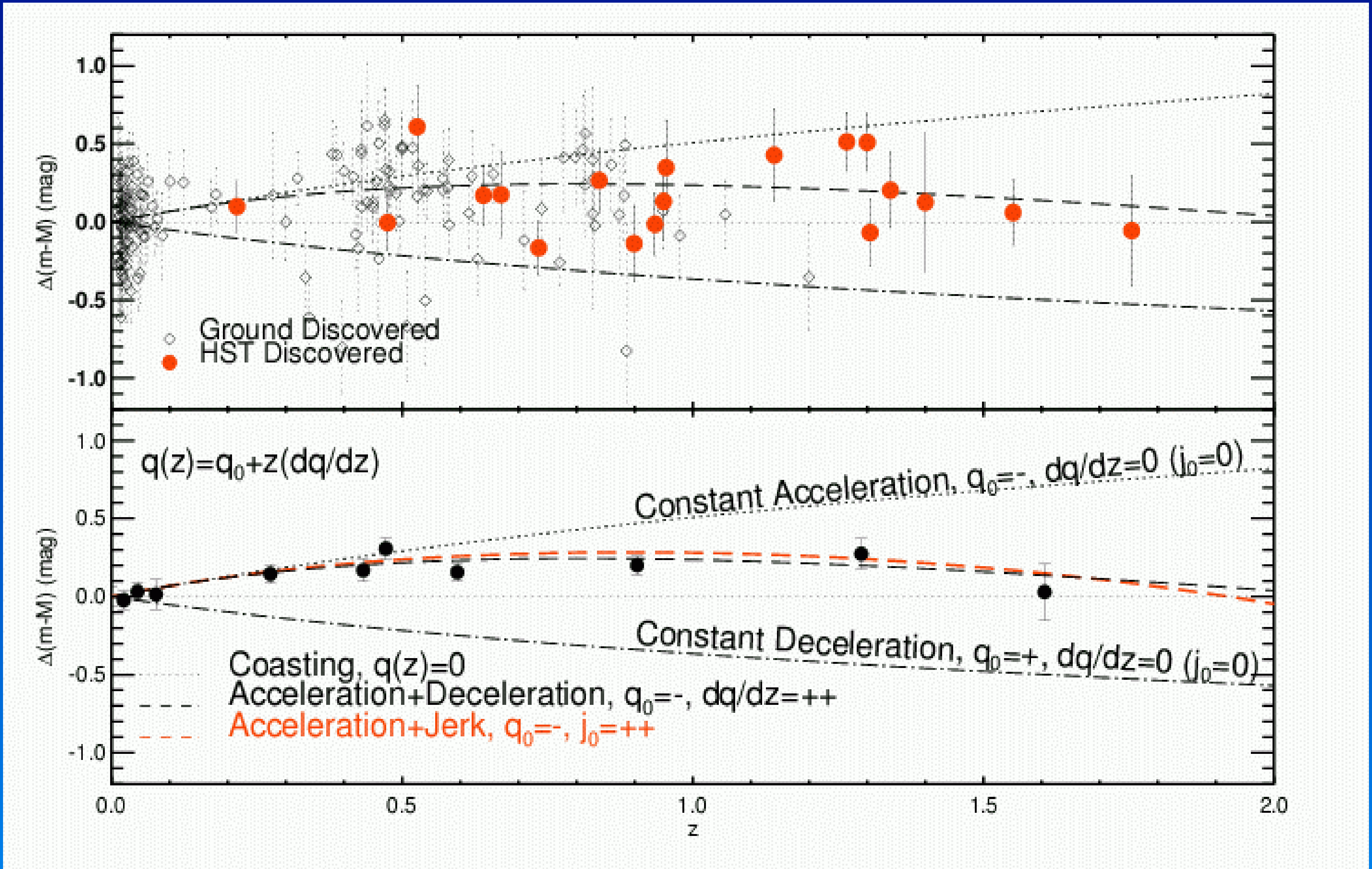


BUT...

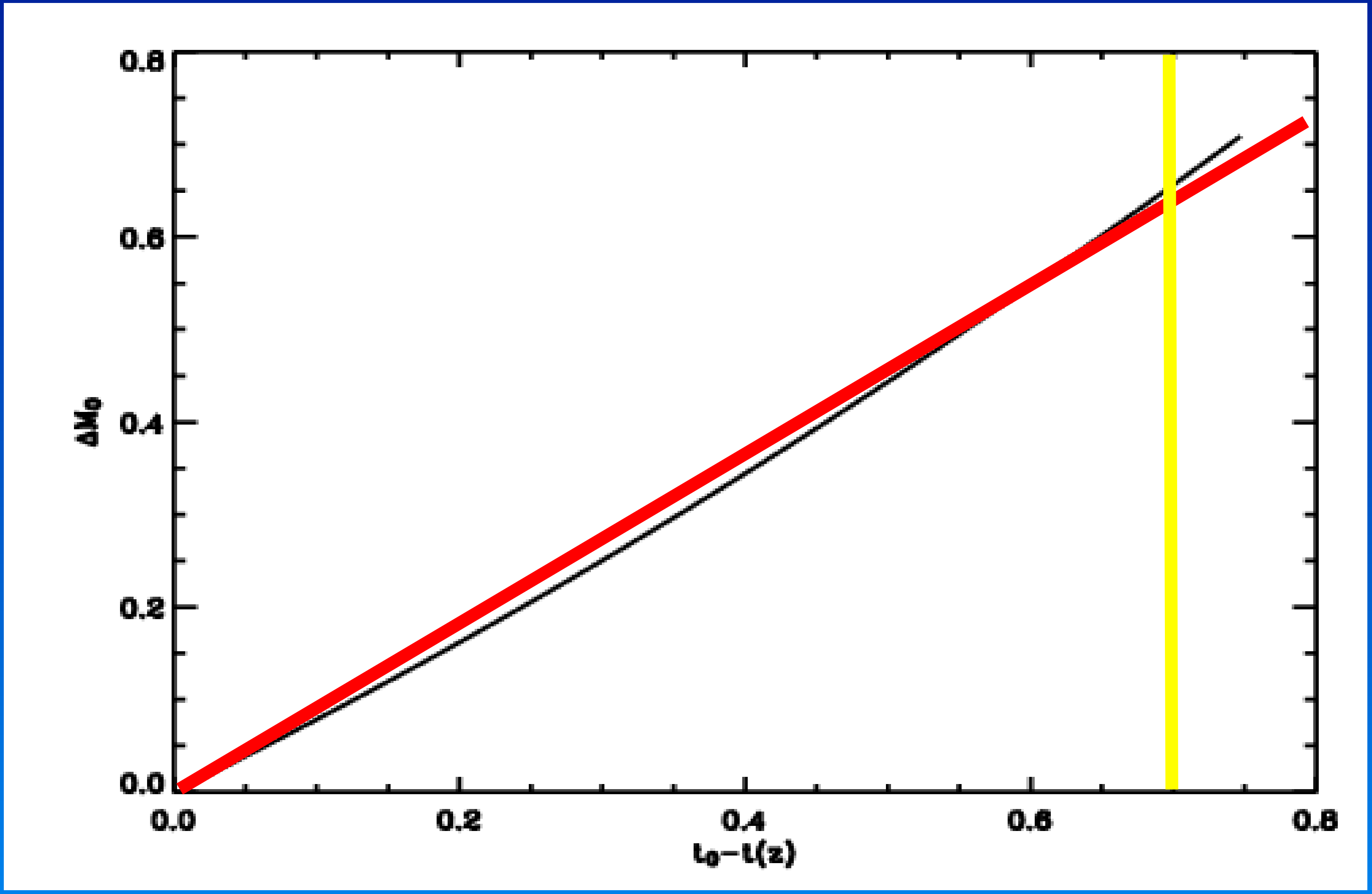


Benetti et al. 2005

Only one direct evidence ...



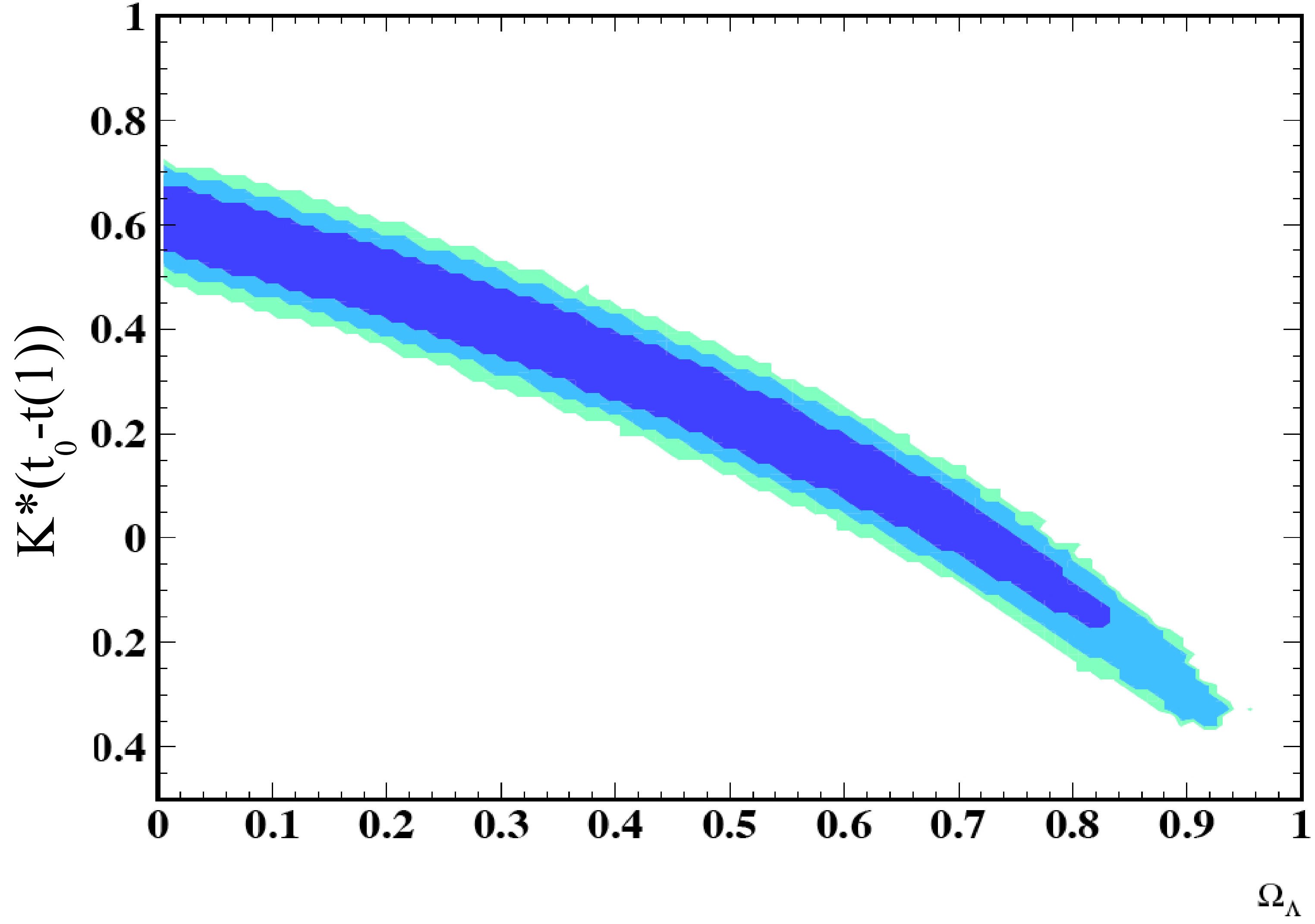
BUT...



Cargèse2008.

BUT...

$$\Delta m(z) = K\,(t_0 - t(z))$$



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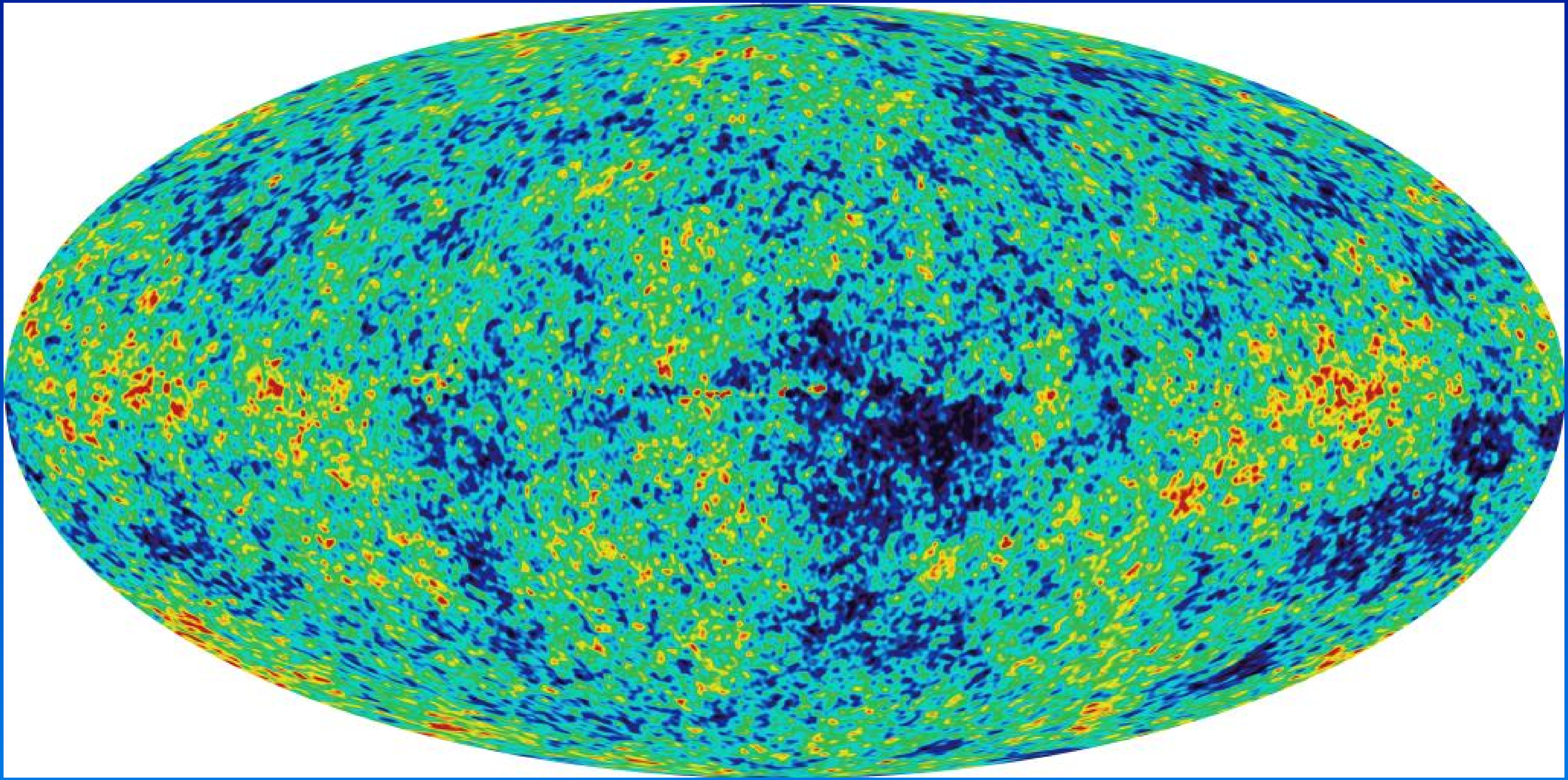
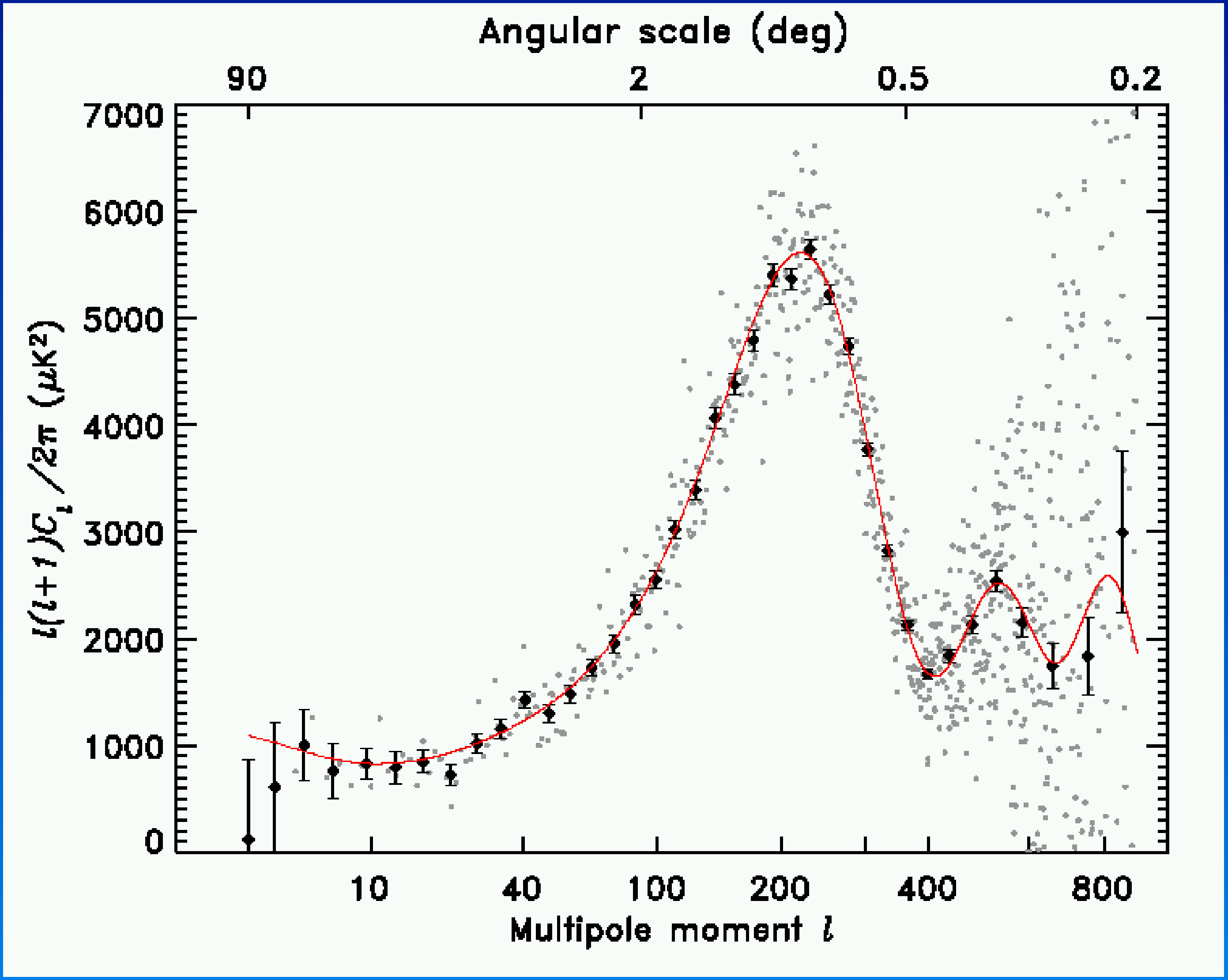
Ferramacho, L., B.A., Zolnierowski, Y. (2008)

CMB



CMB

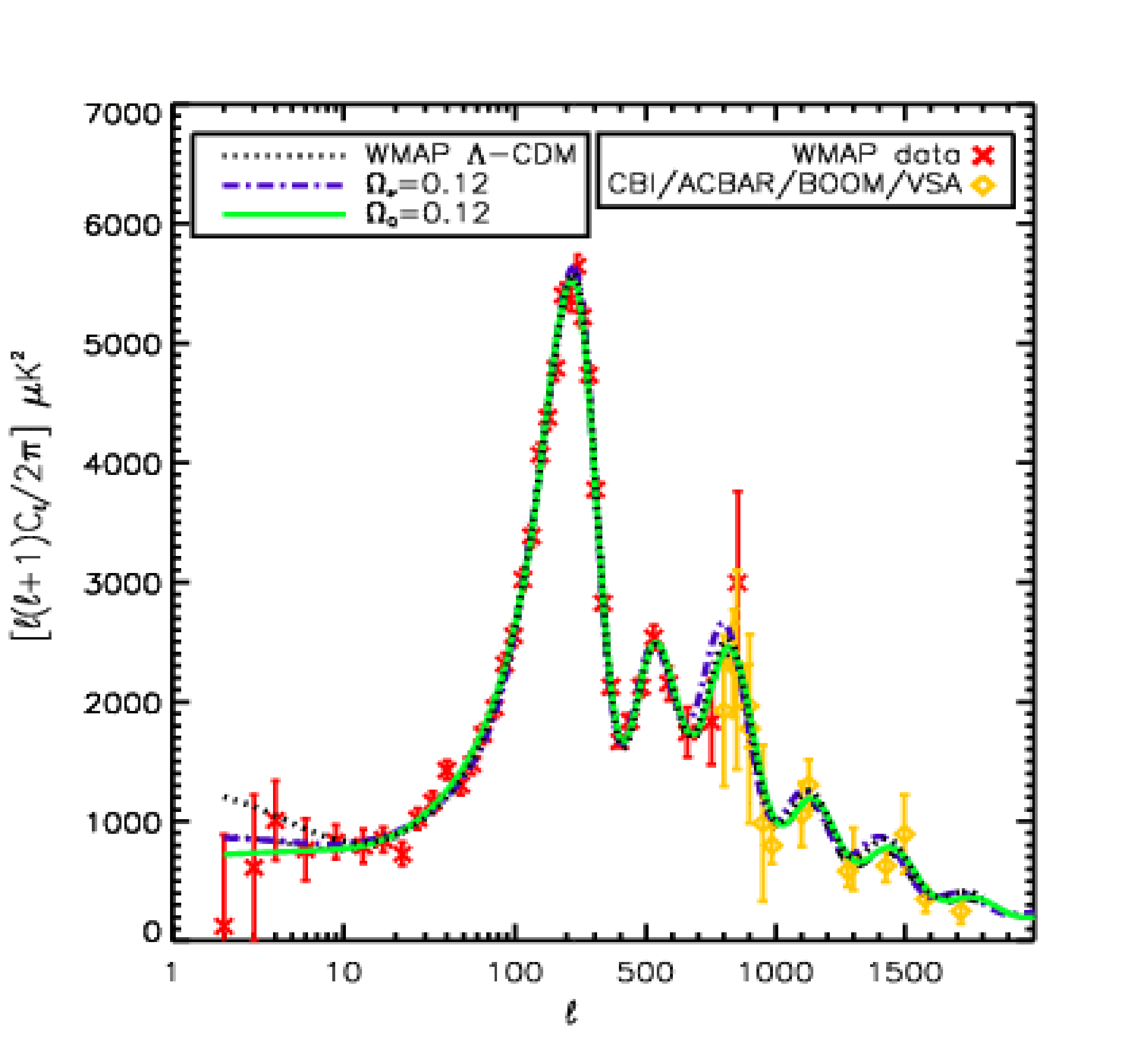


Angular scale (deg)
90
2
0.5
0.2
7000
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
10
40
100
200
400
800
Multipole moment l

Do we actually need Dark Energy ?

Alternative to the Concordance Model:

- No Λ ...
- non power law model
- extra mass components:
  - neutrinos
  - quintessence $w \approx 0$



Blanchard, Douspis, Rowan-Robinson, Sarkar 2003

Ω_m From X-ray Clusters

Do (X-ray) clusters allow precision cosmology?

Data on Clusters

Optical light	⇒ Stellar masses + metals	
	⇒ velocity dispersion	⇒ total mass
	⇒ lensing	⇒ total mass
X-ray light	⇒ imagery	⇒ gas mass
	⇒ spectroscopy	⇒ total mass+ metals
SZ	⇒ pressure	⇒ gas mass

What can you learn in cosmology from

Clusters?

A lot!

Cosmological parameters :

- H_0, Ω_m, (Ω_λ)

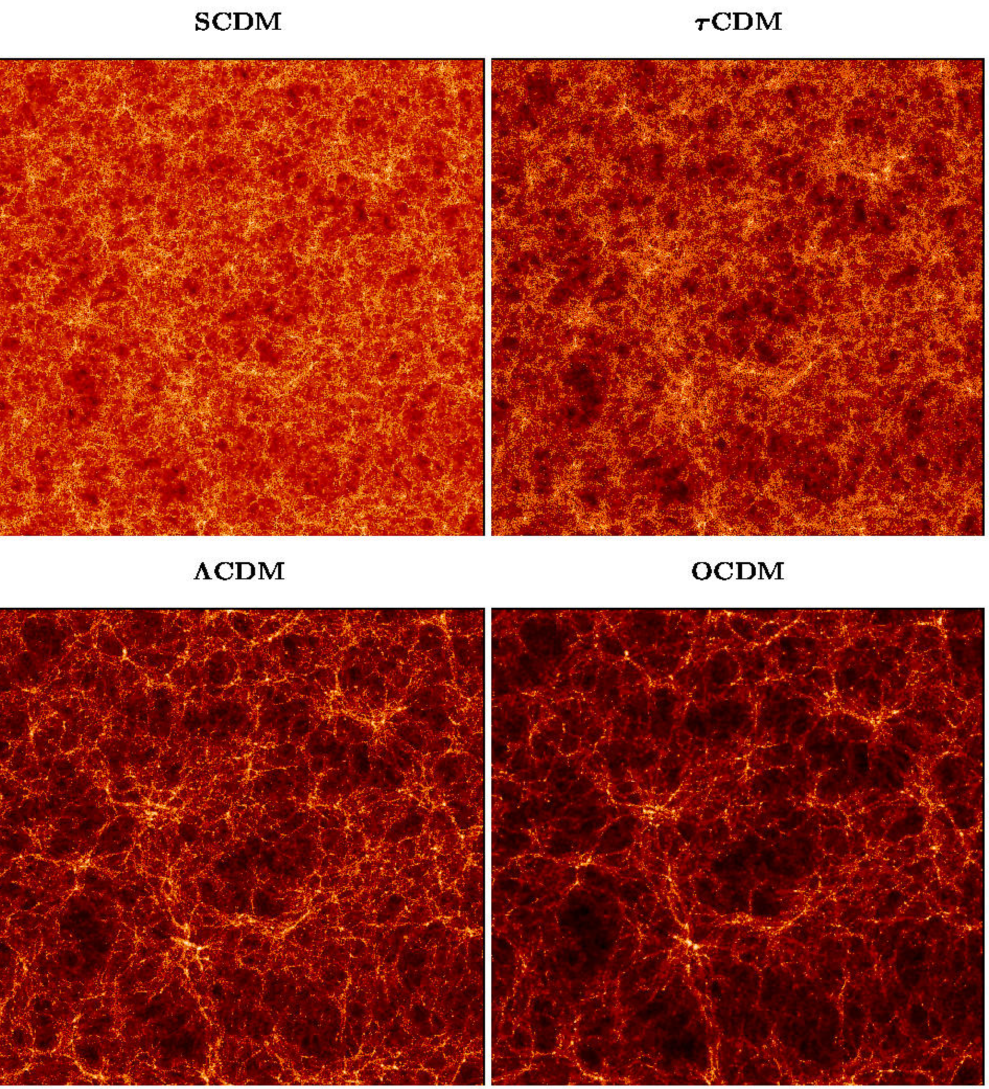
LSS :

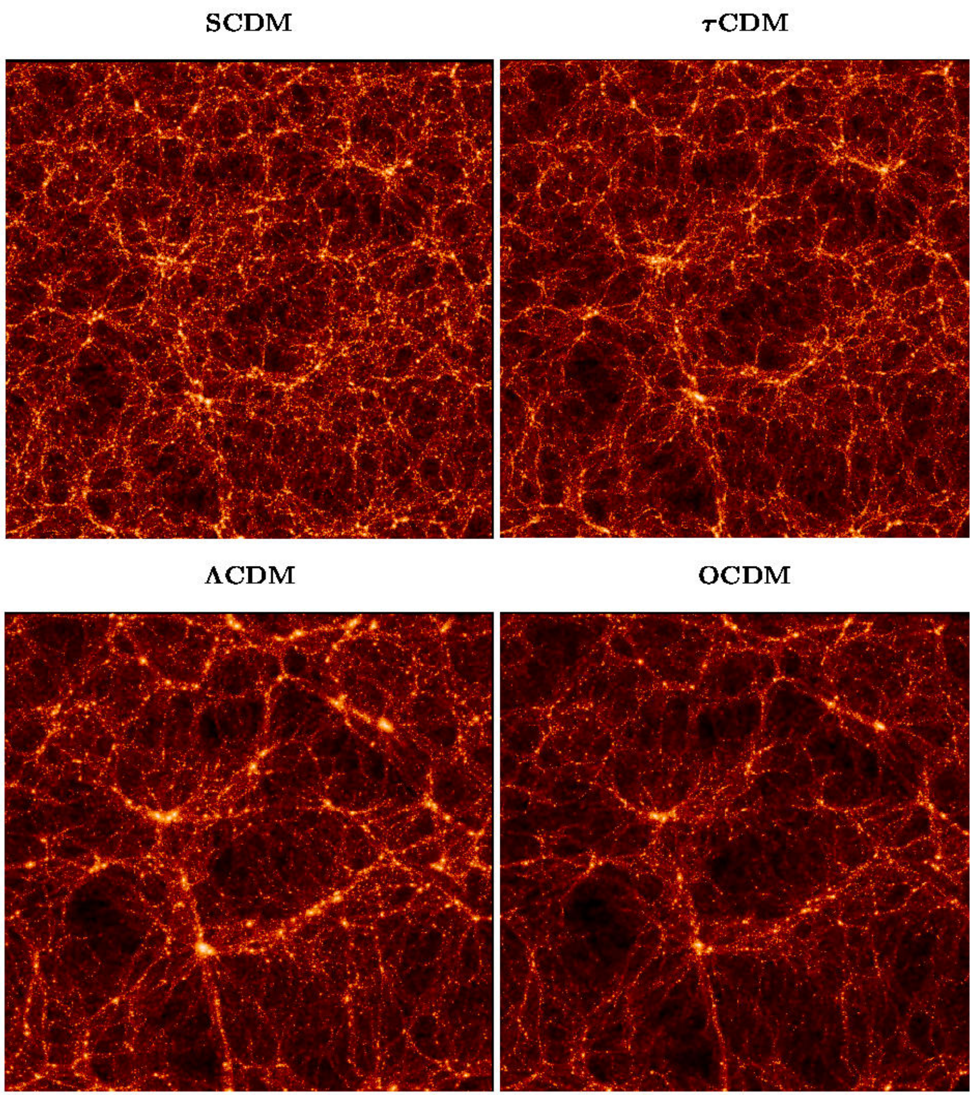
- $P_{cc}(k) \Leftrightarrow \xi_{cc}(r)$, $\xi_{mm}(r)(\Omega_m)$

Insight into structure formation :

- clusters formation...
- physics of the IGM.
- evolution process of galaxies

Clusters as (first) seen by a theorist...





VIRGO simulations

Clusters are not so easy to define...

or any "object"

in numerical simulations

In practice clusters are defined in different ways.

- friend of friend algorithm
- fixed overdensity Δ

Δ:

- fixed value: 180, 200, 1000, 324...
- "virial" value: $18\pi^2 \approx 178$ for $\Omega_m = 1$

otherwise it is a function of Ω_m, Ω_λ...

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.

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

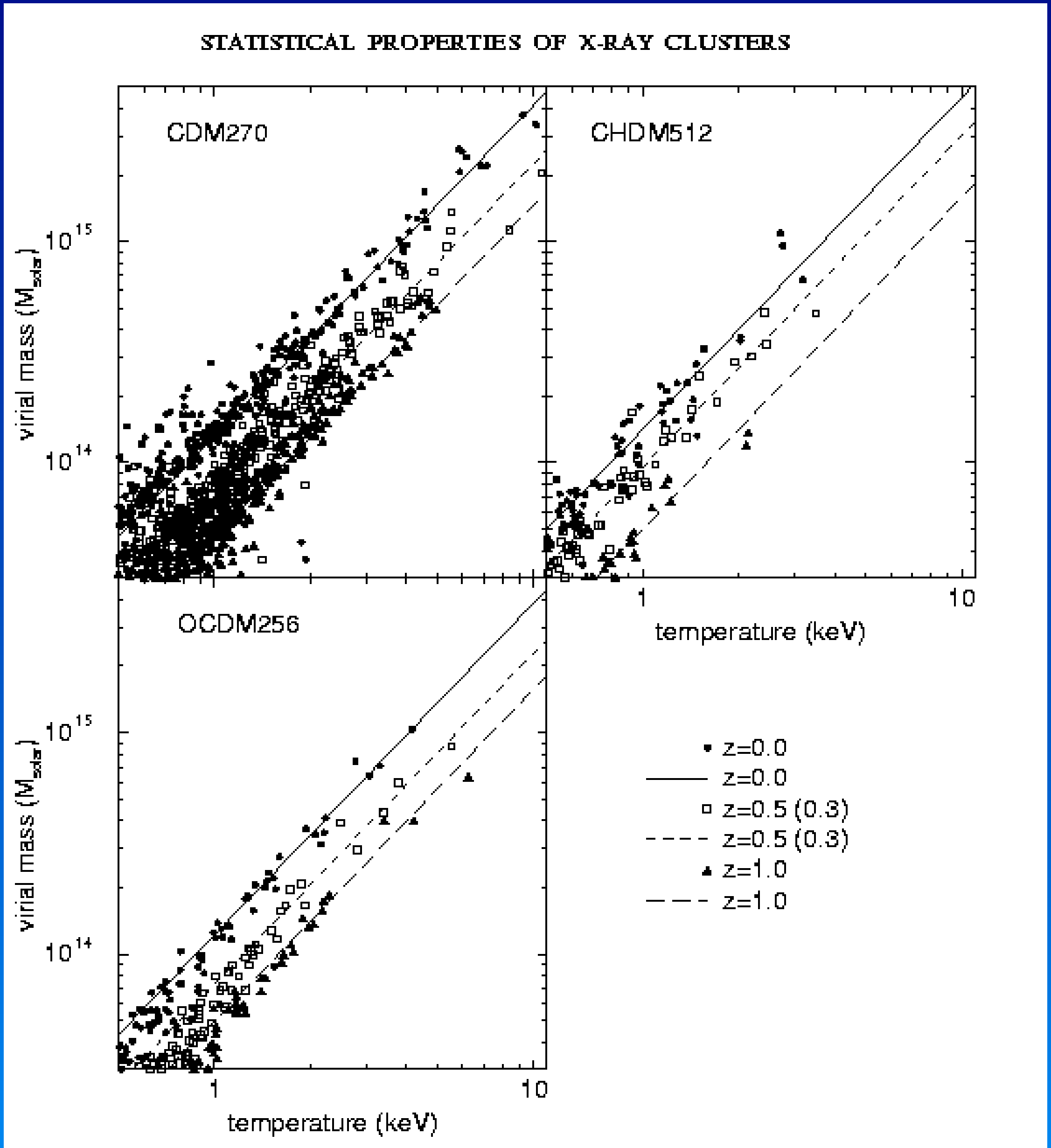
Mass-Temperature Relation :

$T \propto GM/r$

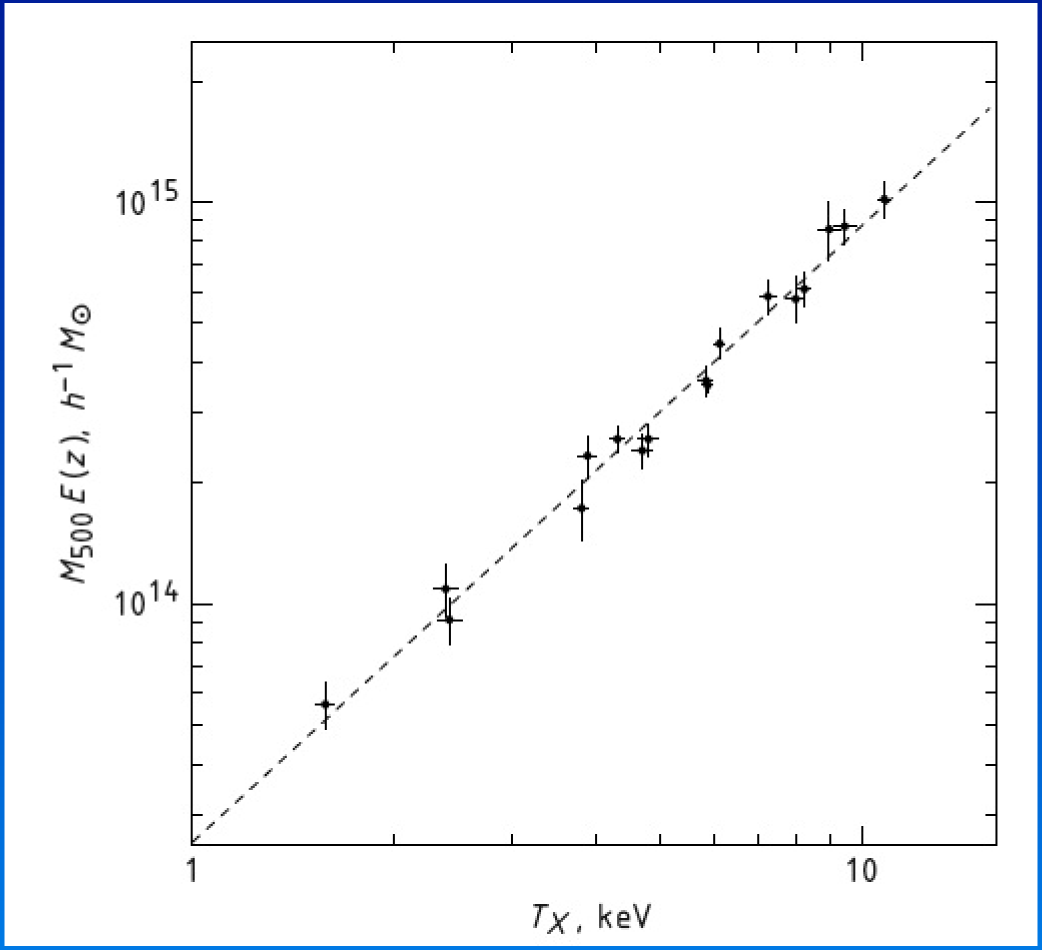
whatever you do with gravity...

$$T_x \simeq A\, M^{2/3} (\Omega\Delta)^{1/3} (1+z)\ \mathrm{keV}$$

Numerical simulations, Bryan & Norman, 1998



Bryan & Norman (ApJ 495 80 1998)



Vikhlinin et al (ApJ 2008)

Critical ingredient: Mass estimates

Mass-temperature estimates relation:

$$T_x \sim 4.\ M^{2/3}\ (1+z)\ \mathrm{keV}$$

Numerical simulations, Bryan & Norman, 1998

Doubt: how good are the mass estimates?

Other techniques:

velocity dispersion, lensing

Mass-Luminosity Relation :

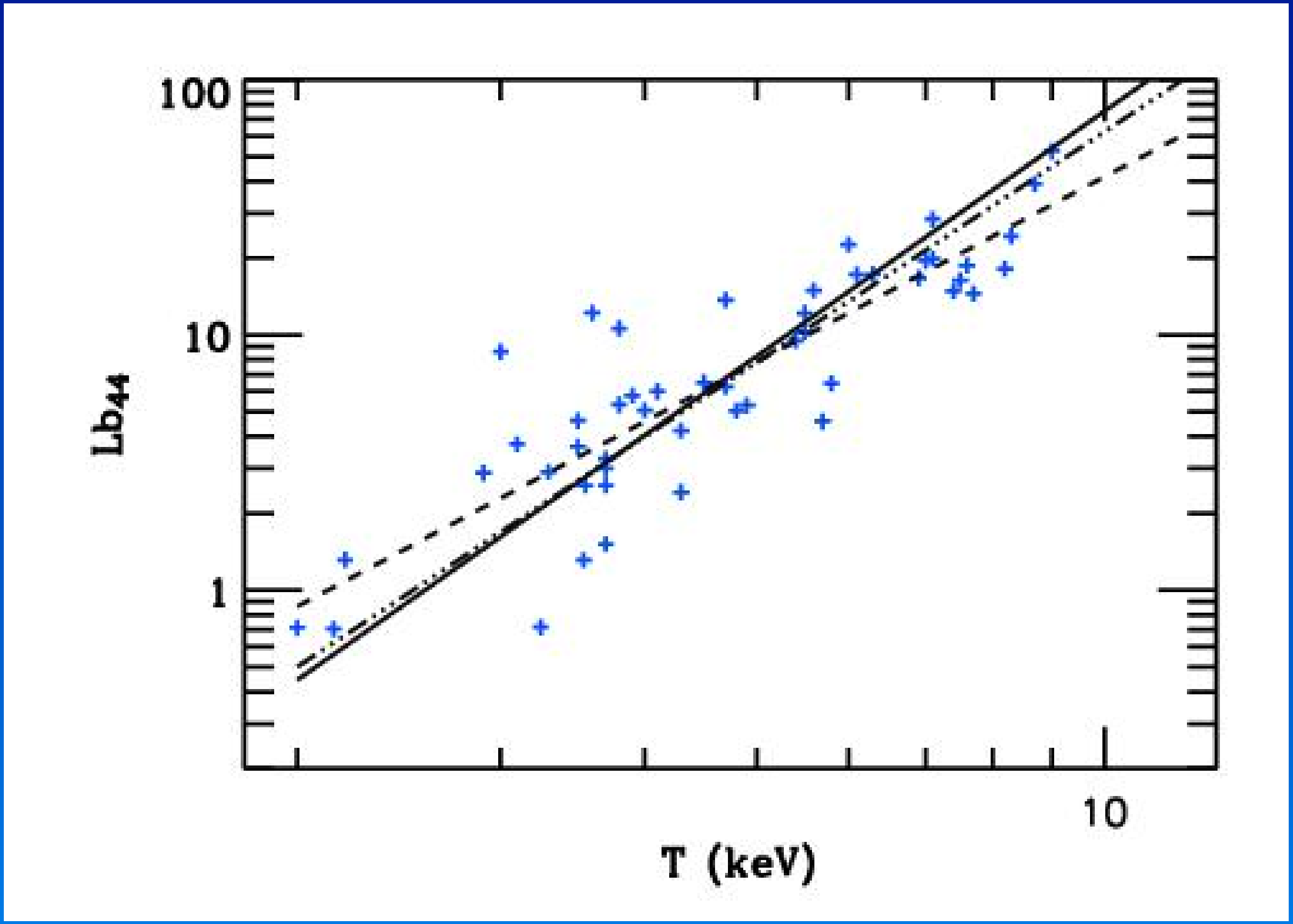
$$L_x \propto n^2 T^{1/2} V$$

...

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

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

Observed Temperature -Luminosity Relation



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

Conclusion at that point is that

Clusters are not self similar!

However...

$$V_c \approx 10^{-5} V_{Universe} \, !$$

$$(\rho_{Cl} \approx 10^{-2} \rho_{Universe})$$