The fifth Element: Astrophysical status of dark energy

A&A Review (to appear soon)

Alain Blanchard, LATT, Toulouse

August 6, 2010

Historical remarks: Λ

Introduction by Einstein...

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Introduction by Einstein... after Newtonien considerations!

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$$\Lambda \equiv \mathrm{Vacuum}$$

Λ as the contribution from Vacuum

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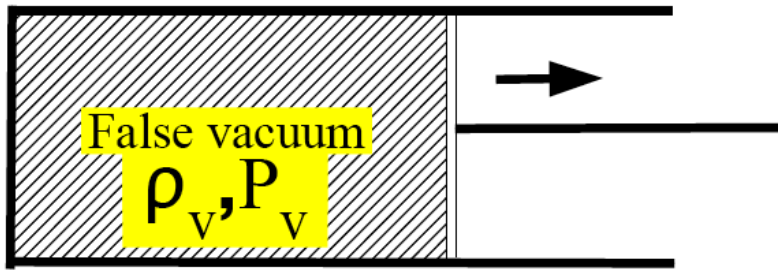

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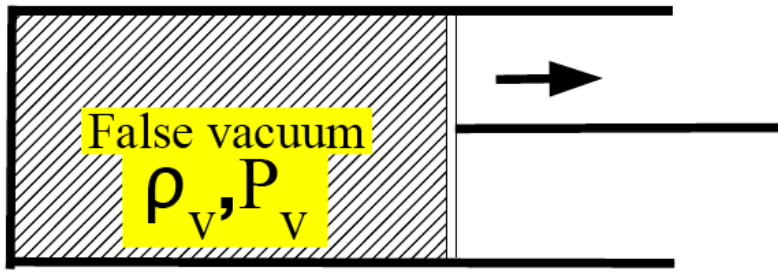

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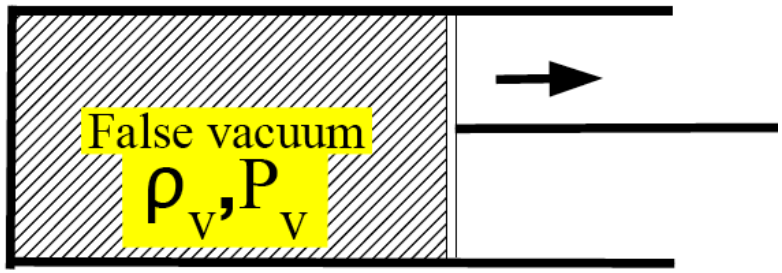

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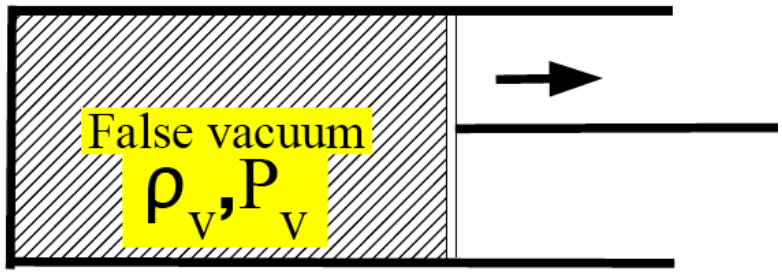

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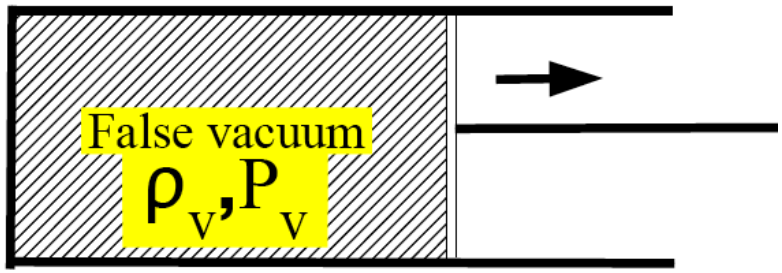

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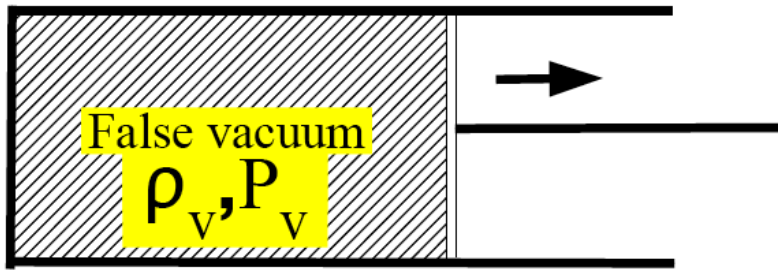

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i.e.

$$w = -1$$

Hubble diagramm

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Hubble 1929...

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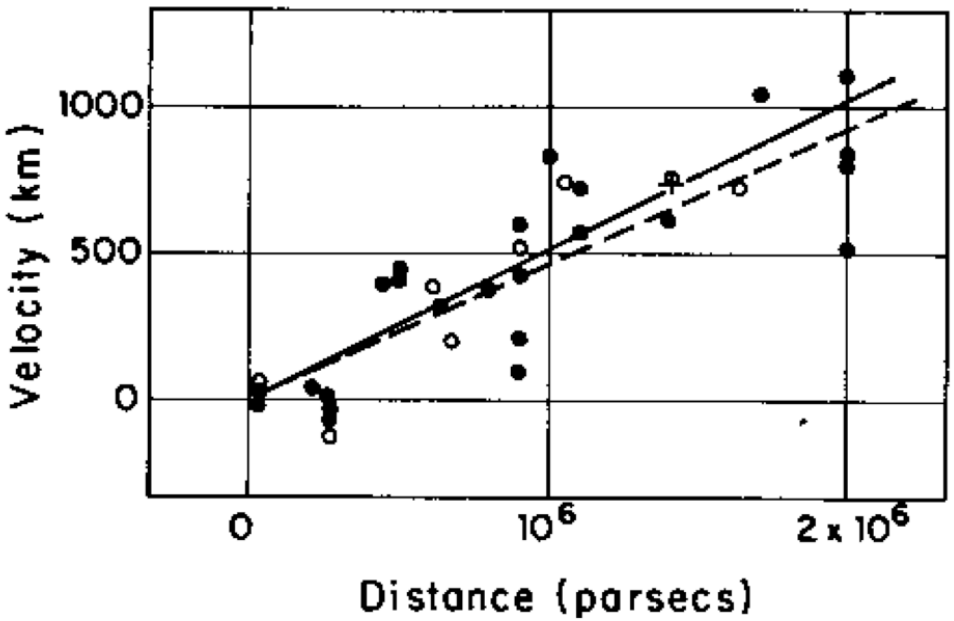

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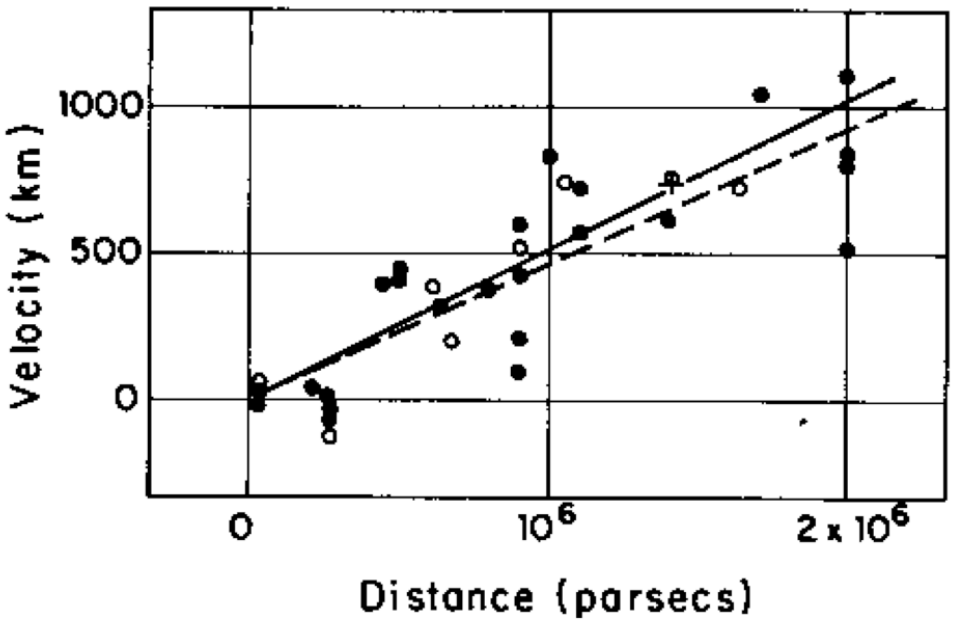

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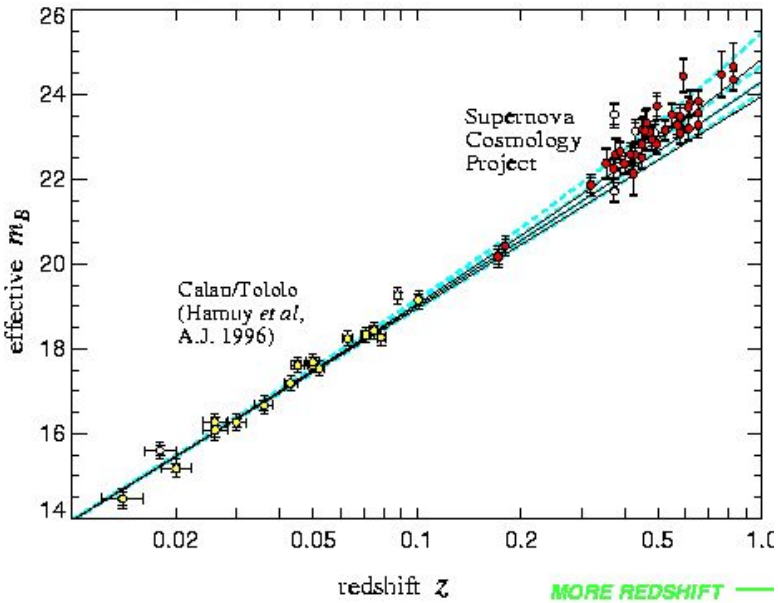

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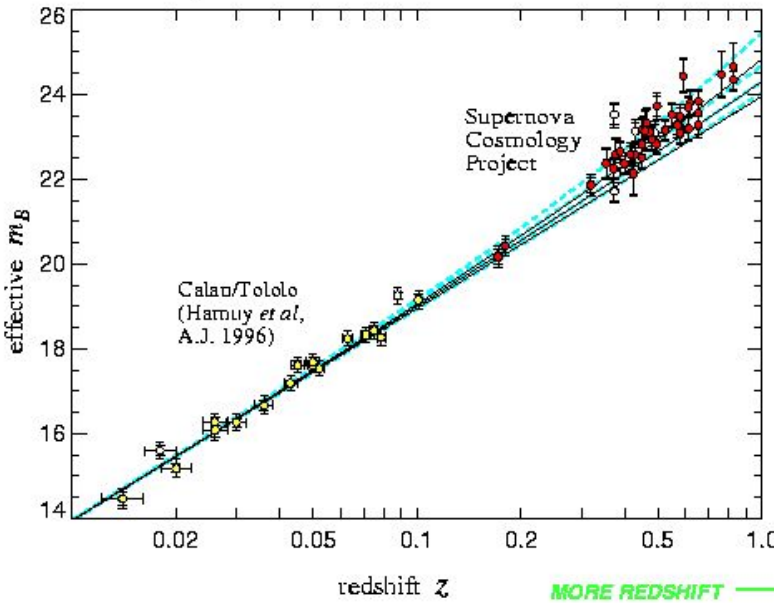

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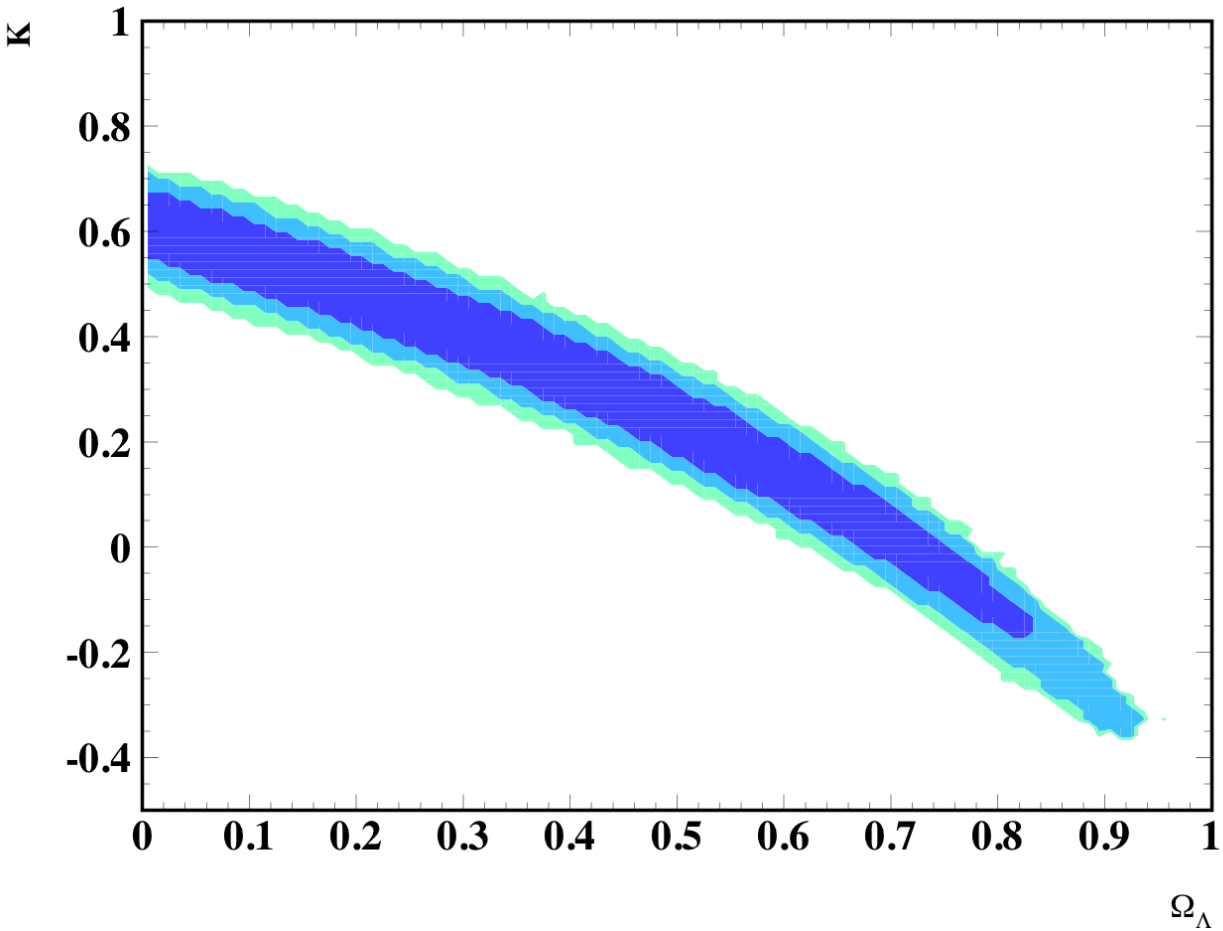

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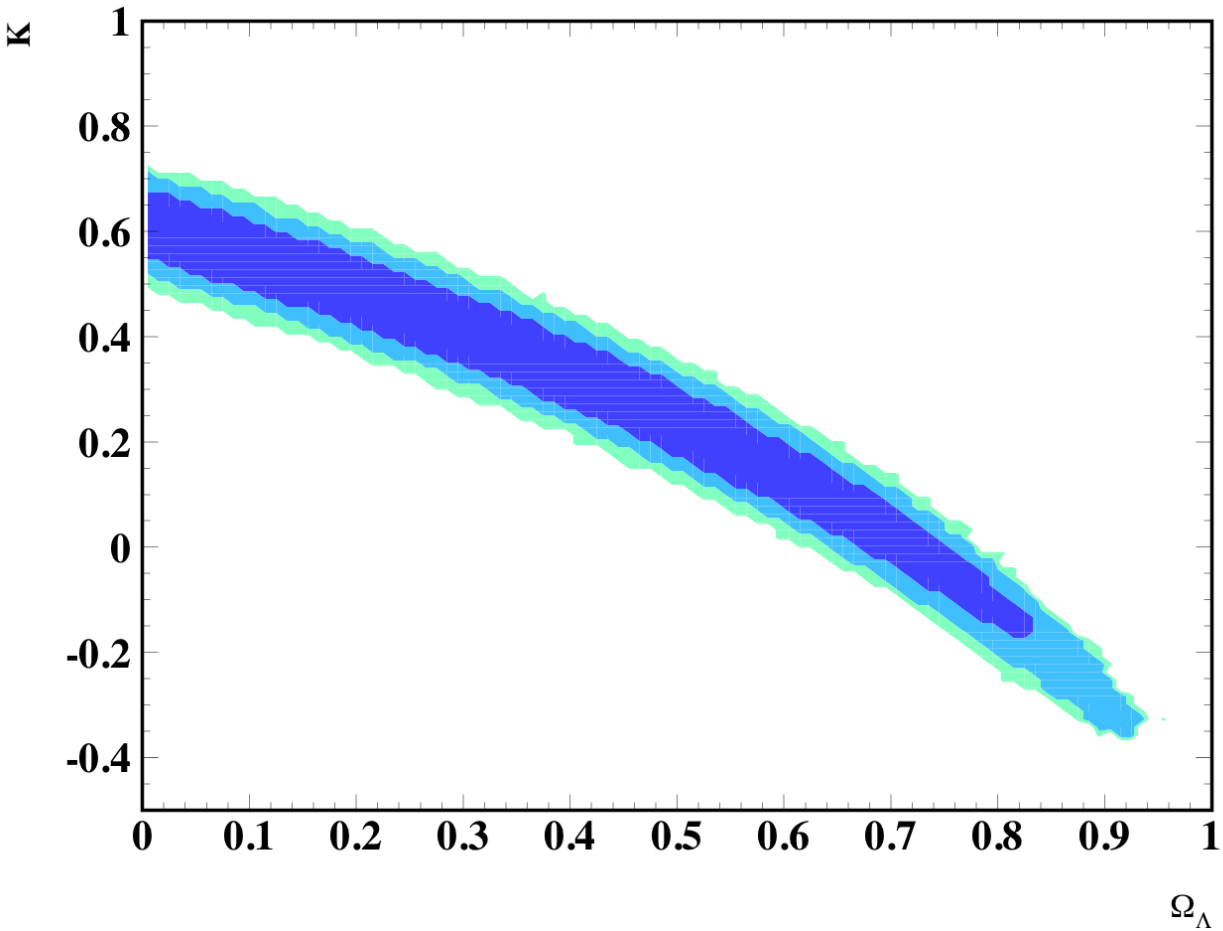

Degeneracy with cosmological constant!

Clusters ?

M/L argument: $\rho_M = \rho_L \times M/L$

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Controversial...

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Optical, SZ, weak lensing are alternatives encoding the same information.

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A (potential) probe of $D(t)$ (sensitive to Ω_m)

sensitive to σ_8 but degeneracy with calibration of the $M - T$ relation.

Clusters Mass-temperature relation

connection to the observable quantities:

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connection to the observable quantities:

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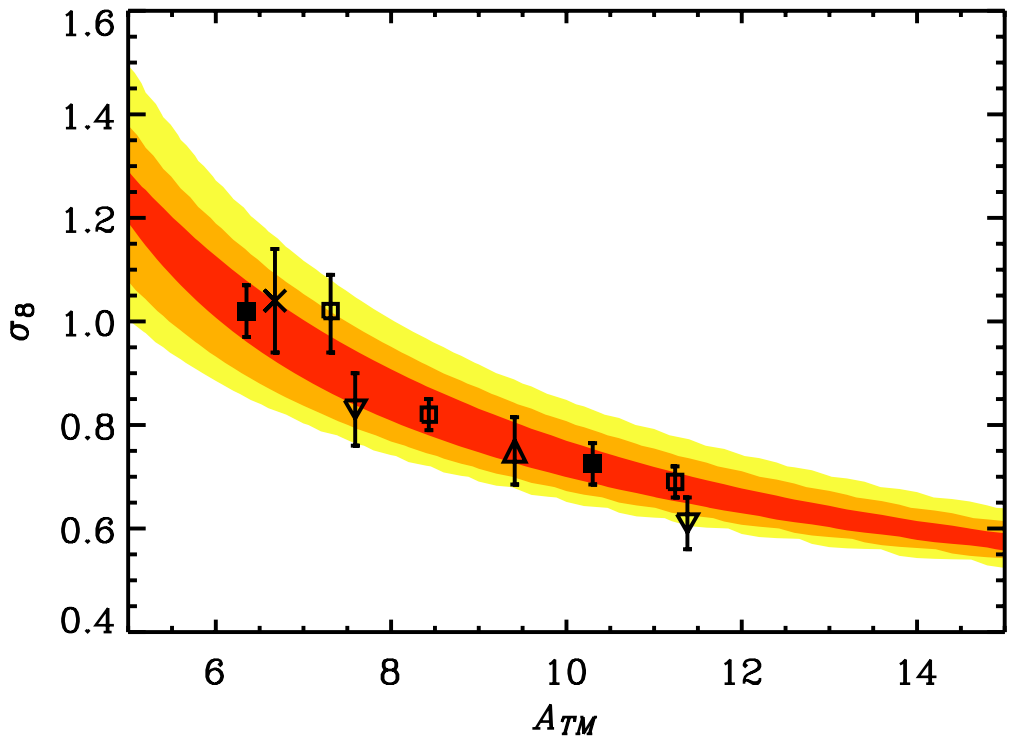
use observed $N(T)$

$\sigma_8 - A_{TM}$

$\Omega_m = 0.3$



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evolution of the abundance of clusters is inconsistent with standard scaling in Λ CDM... (controversial).

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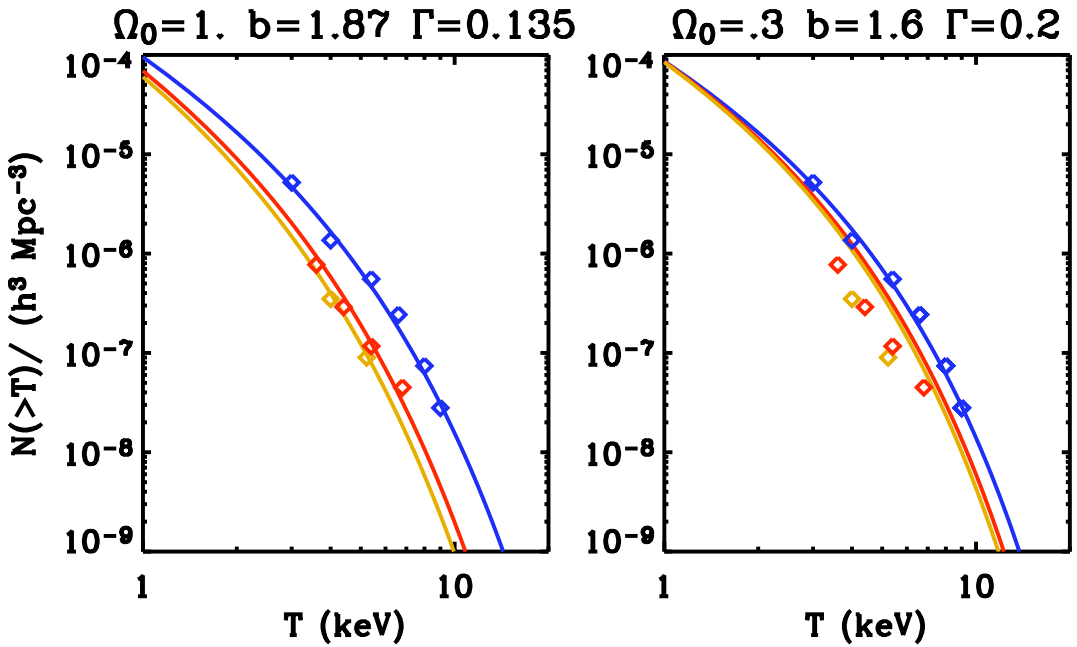
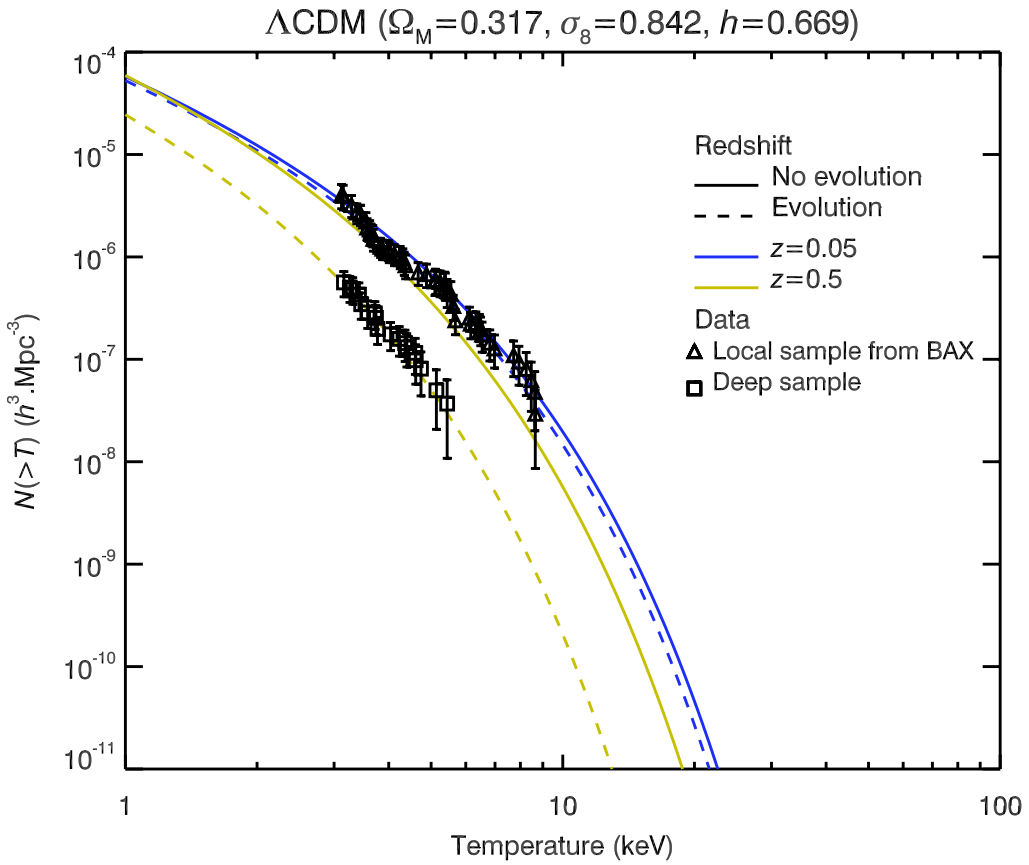


Clusters abundance evolution: 2010

Delsart, Blanchard & Barbosa, 2010



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CMB

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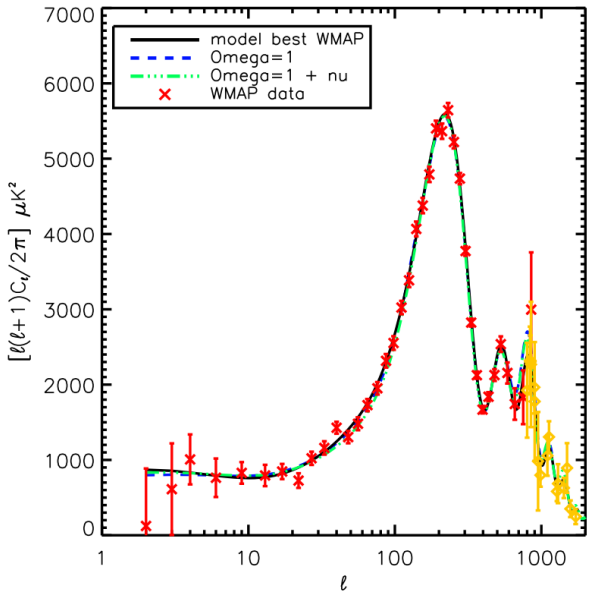
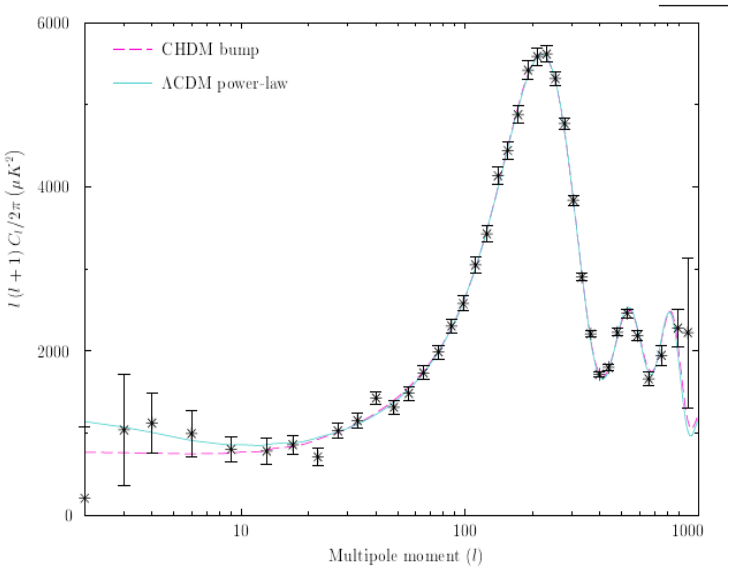


Blanchard et al. 2003



Hunt & Sarkar 2007

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meaning ΛCDM is not to be regarded as a crazy model...

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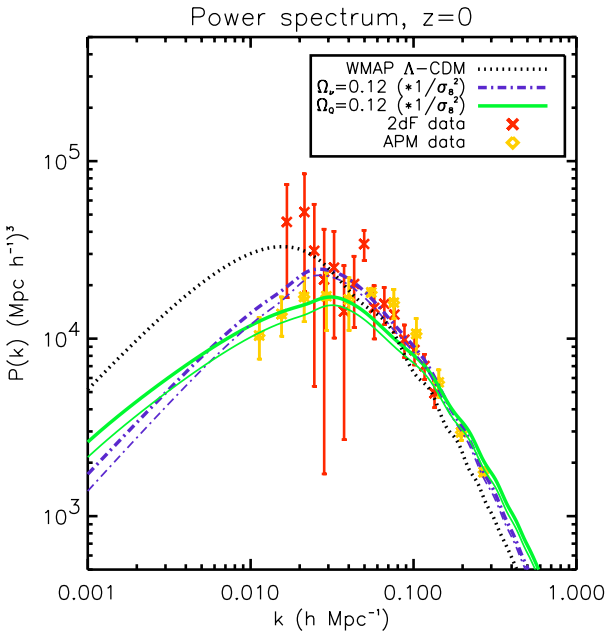

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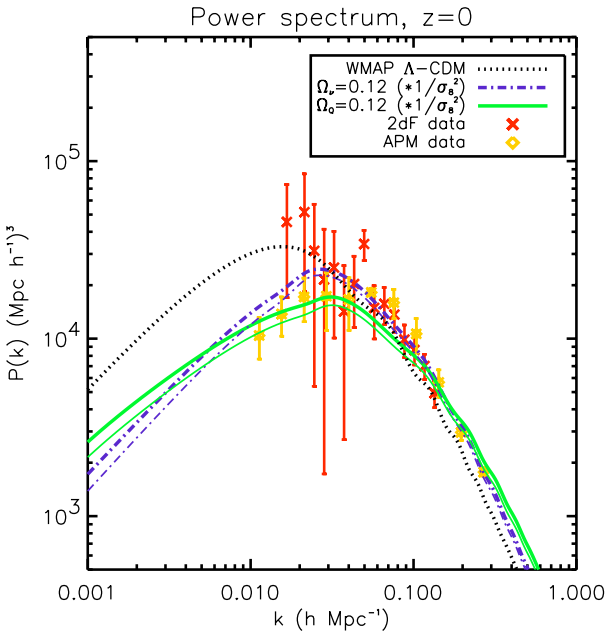

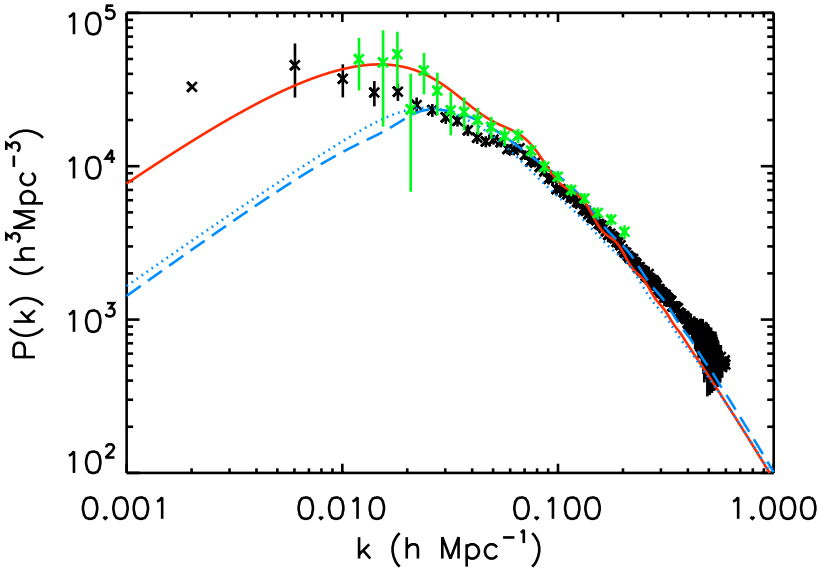

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Serious and non-trivial question in GR:

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would many local Schwarzschild metrics glue together to get FLRW models?

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LTB Models

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+ CMB spectrum + SZ from clusters + ...

Precision Cosmology

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parameter	ΛCDM	oΛCDM	wCDM	owCDM	owCDM+SN
Ω_m	0.289 ± 0.019	0.309 ± 0.025	0.328 ± 0.037	0.306 ± 0.050	0.312 ± 0.022
H_0	69.4 ± 1.6	66.0 ± 2.7	64.3 ± 4.1	$66.7^{+5.9}_{-5.6}$	65.6 ± 2.5
$D_V(0.35)$	1349 ± 23	1415 ± 49	1398 ± 45	1424 ± 49	1418 ± 49
$r_s/D_V(0.35)$	0.1125 ± 0.0023	0.1084 ± 0.0034	0.1094 ± 0.0032	$0.1078^{+0.0033}_{-0.0034}$	0.1081 ± 0.0034
Ω_k	-	$-0.0114^{+0.0076}_{-0.0077}$	-	-0.009 ± 0.012	-0.0109 ± 0.0088
w	-	-	-0.79 ± 0.15	-1.06 ± 0.38	-0.99 ± 0.11
Ω_Λ	0.711 ± 0.019	0.703 ± 0.021	0.672 ± 0.037	$0.703^{+0.057}_{-0.058}$	0.699 ± 0.020
Age (Gyr)	13.73 ± 0.13	14.25 ± 0.37	13.87 ± 0.17	14.27 ± 0.52	14.24 ± 0.40
$\Omega_{\rm tot}$	-	$1.0114^{+0.0077}_{-0.0076}$	-	1.009 ± 0.012	1.0109 ± 0.0088
$100\Omega_b h^2$	2.272 ± 0.058	2.274 ± 0.059	$2.293^{+0.062}_{-0.063}$	$2.279^{+0.066}_{-0.065}$	$2.276^{+0.060}_{-0.059}$
$\Omega_c h^2$	$0.1161^{+0.0039}_{-0.0038}$	0.1110 ± 0.0052	$0.1112^{+0.0056}_{-0.0057}$	$0.1103^{+0.0055}_{-0.0054}$	$0.1110^{+0.0051}_{-0.0052}$
τ	0.084 ± 0.016	0.089 ± 0.017	0.088 ± 0.017	0.088 ± 0.017	0.088 ± 0.017
n_s	0.961 ± 0.013	0.962 ± 0.014	0.969 ± 0.015	0.965 ± 0.016	0.964 ± 0.014
$\ln(10^{10} A_{05})$	$3.080^{+0.036}_{-0.037}$	3.068 ± 0.040	$3.071^{+0.040}_{-0.039}$	3.064 ± 0.041	3.068 ± 0.039
σ_8	0.824 ± 0.025	0.796 ± 0.032	0.735 ± 0.073	0.79 ± 0.11	$0.790^{+0.045}_{-0.046}$

Reid et al. 2009

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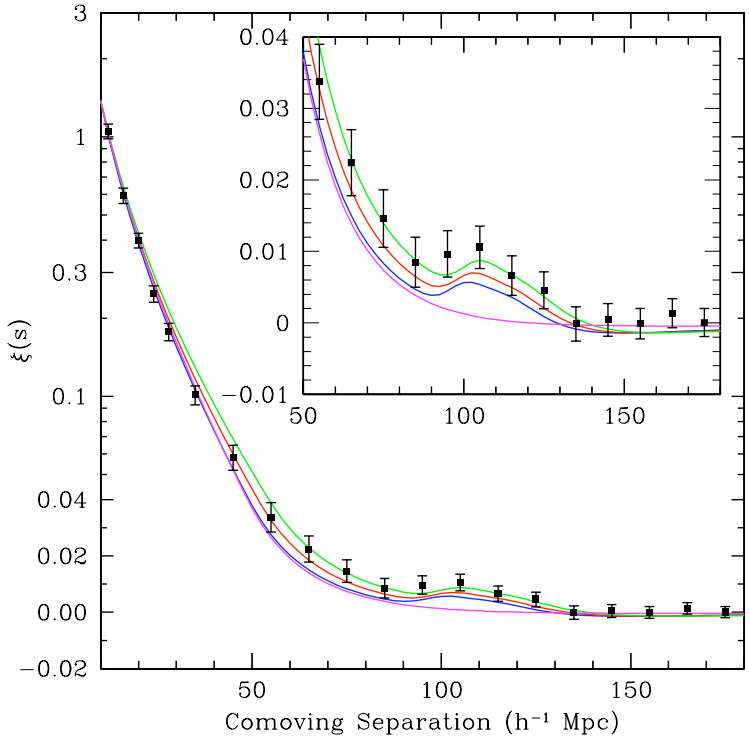

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Parameter	Vanilla	Vanilla + Ω_k	Vanilla + w	Vanilla + Ω_k + w
$\Omega_b h^2$	0.0228 ± 0.0006	0.0227 ± 0.0005	0.0227 ± 0.0006	0.0226 ± 0.0006
$\Omega_c h^2$	0.110 ± 0.004	0.109 ± 0.005	0.113 ± 0.005	0.111 ± 0.005
θ	1.042 ± 0.003	1.042 ± 0.003	1.042 ± 0.003	1.042 ± 0.003
τ	0.088 ± 0.017	0.087 ± 0.017	0.085 ± 0.017	0.085 ± 0.016
n_s	0.968 ± 0.013	0.965 ± 0.013	0.963 ± 0.014	0.960 ± 0.014
$log(10^{10} A_s)$	3.07 ± 0.04	3.06 ± 0.04	3.07 ± 0.04	3.06 ± 0.04
Ω_k	0	-0.002 ± 0.007	0	-0.017 ± 0.013
w	-1	-1	-1.112 ± 0.148	-1.33 ± 0.242
K	-0.042 ± 0.042	-0.035 ± 0.042	-0.105 ± 0.091	-0.133 ± 0.077
Ω_Λ	0.747 ± 0.017	0.745 ± 0.020	0.756 ± 0.022	0.744 ± 0.022
Age	13.6 ± 0.1	13.7 ± 0.4	13.6 ± 0.1	14.5 ± 0.7
Ω_m	0.253 ± 0.017	0.257 ± 0.025	0.244 ± 0.022	0.272 ± 0.029
σ_8	0.801 ± 0.026	0.794 ± 0.029	0.846 ± 0.068	0.867 ± 0.060
z_{re}	11.1 ± 1.5	11.0 ± 1.4	10.9 ± 1.5	10.8 ± 1.4
h	0.725 ± 0.017	0.720 ± 0.036	0.748 ± 0.038	0.703 ± 0.042

Ferramacho et al. 2009

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We need something in the gravitational sector ...