Dark energy : Myth or Reality ?

Alain Blanchard

Annecy, May 17, 2011

Classical Cosmology

Standard Cosmological model:

Homogenous (on large scale) $\rightarrow$ RW metric:

$$ds^2 = -c^2dt^2 + R(t)^2[r^2(d\theta^2 + \sin^2\theta d\phi^2) + \frac{dr^2}{1-kr^2}]$$

General Relativity gives the dynamics $\rightarrow R(t)$

Observable quantity $\frac{\lambda_o}{\lambda_s} = \frac{R_o}{R_s} = 1+z$

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Testing the models

Geometry:

From the light geodesic equation:

$$c^2 dt^2 - R^2(t)\frac{dr^2}{1-kr^2} = 0$$

General Mattig relation:

$$\int_{t_S}^{t_0} \frac{cdt}{R(t)} = \int_0^{r_S} \frac{dr}{(1-kr^2)^{1/2}} = S_k^{-1}(r_S)$$

with:

$$S_k(u) = \begin{cases} \sin(u) & \text{if } k = +1 \\ u & \text{if } k = 0 \\ \sinh(u) & \text{if } k = -1 \end{cases}$$

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Geometrical tests

Most cosmological tests rely on a combination of $r(z)$ and $R(t)$

Angular distance:

$$\theta = \frac{d}{D_{\rm ang}}$$

with

$$D_{\rm ang} = R(t_S)r$$

Luminosity distance $l = \frac{L}{4\pi D^2}$

$$\begin{aligned} D_{\rm lum} &= R(t_0)\ r\ (1+z) \\ &= R(t_S)\ r\ (1+z)^2 \\ &= D_{\rm ang}\ (1+z)^2 \end{aligned}$$

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Up to $z \sim 2$ i.e.$t(z) \sim 3$ Gyr

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Distant SNIa

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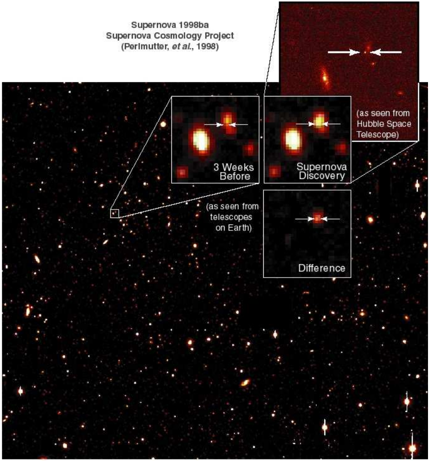
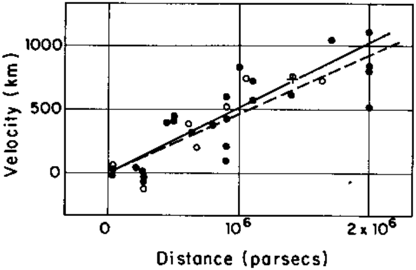


SNIa Hubble diagramm



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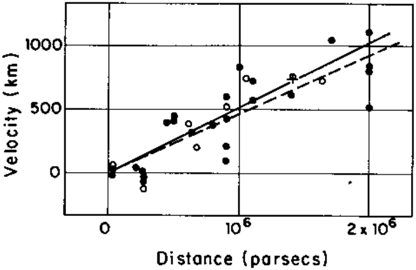

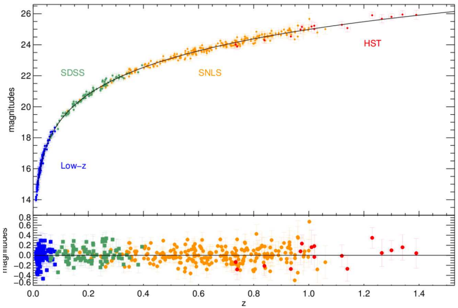

Acceleration!!

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So that the gravity strength is repulsive and proportional to R

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Distant SNIa Hubble diagramm

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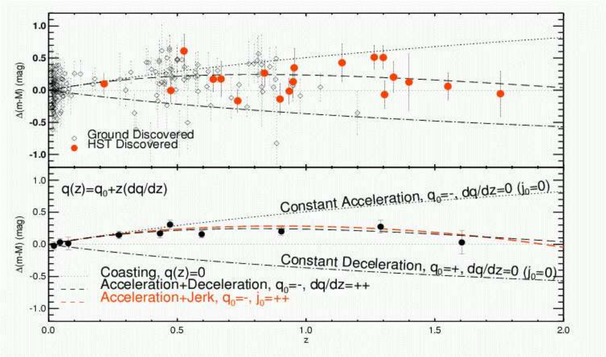

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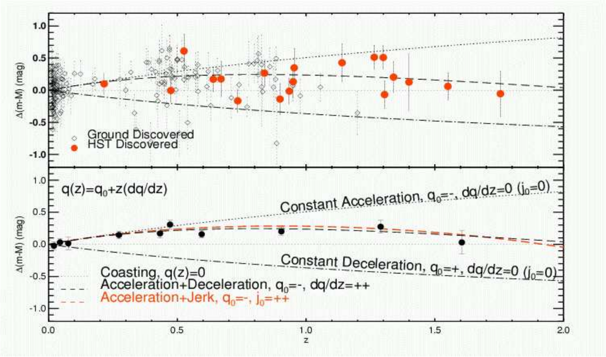

→ Acceleration+decceleration!!

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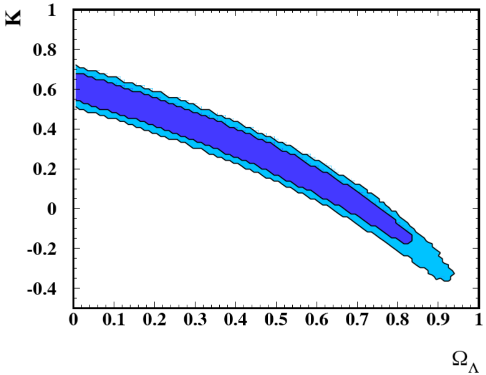

L. Ferramacho, A. Blanchard, Y. Zolnierowski (2009)

Cosmic microwave radiation fluctuations

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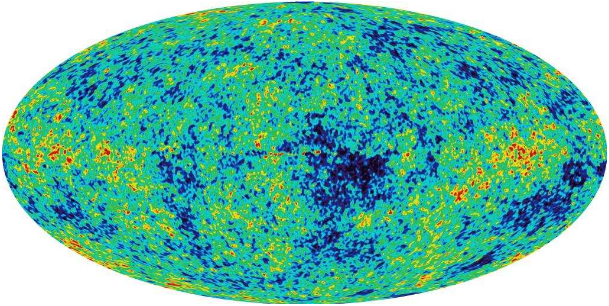
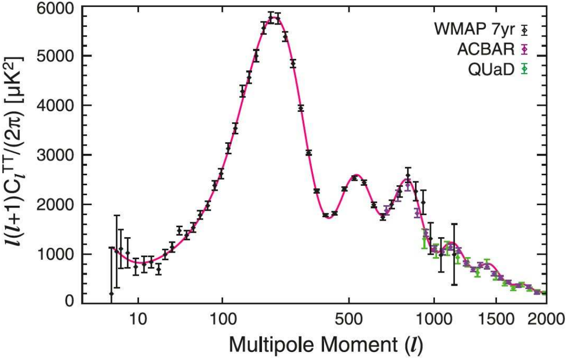


WMAP 1, 3, 5, 7,...

Cosmic microwave radiation fluctuations



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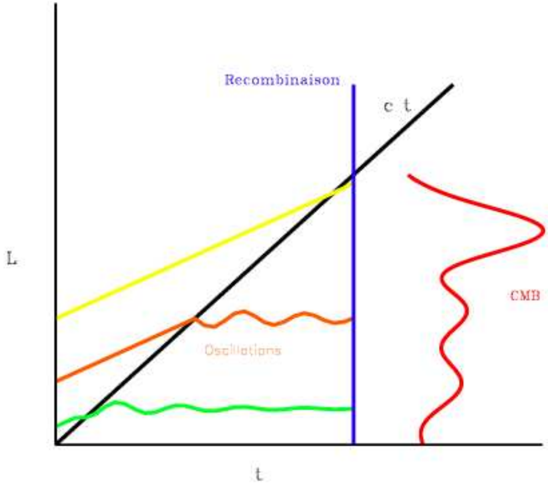

Cosmic microwave radiation fluctuations

Essentially geometric:

$z_{lss} \approx 1090$

Angular distance to the CMB is the key parameter, combined with the accoustic scale r_S corresponding to the sound horizon at ls:

$$l_A = \frac{D_{ang}(z_{lss})}{r_S}$$

The shift parameter:

$$R = \sqrt{\Omega_m H_0^2} D_{ang}(z_{lss}) = 1.710 \pm 0.019$$

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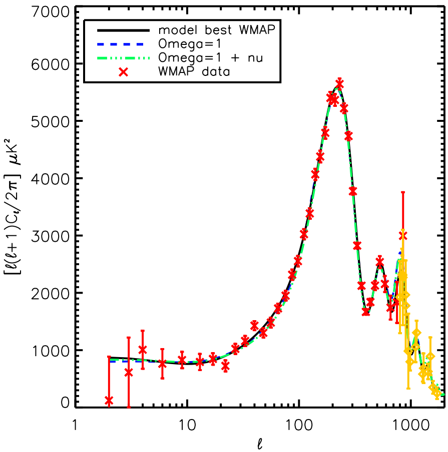

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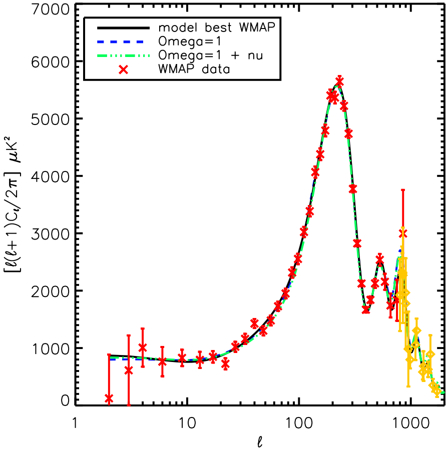

Degeneracy in parameters allows to reproduce the C_l

Blanchard et al., 2003

Conlusion (at this point)

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Neither SNIa nor CMB strongly require acceleration!

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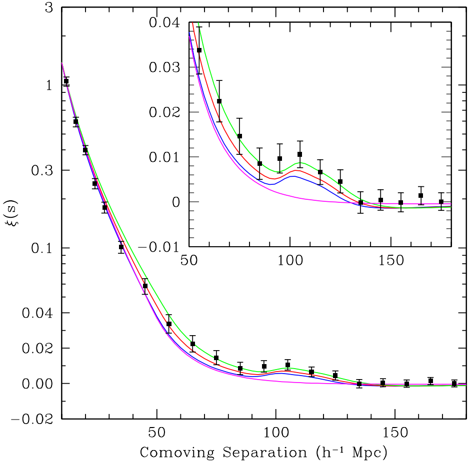

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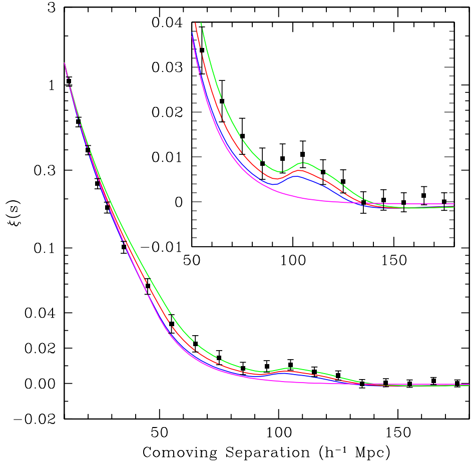

This was a prediction of ΛCDM

Trensverse dilatation

The scale appears along the line of sight and trensverse to the line of sight:

$$D(z) = \left[(1+z)^2 D_{ang}^2 \frac{cz}{H(z)}\right]^{1/3}$$

From the SDSS LRG:

$$D(0.35) \sim 0.469 \pm 0.019$$

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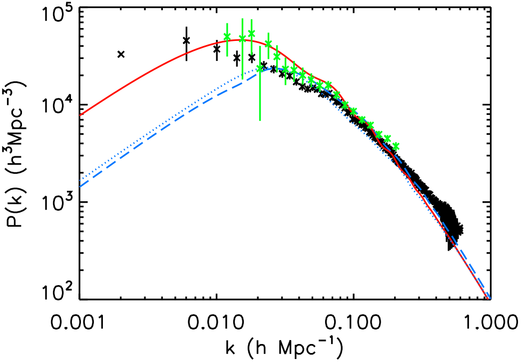

Standard Cosmological model: ΛCDM

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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

L. Ferramacho, A. Blanchard, Y. Zolnierowski (2009)

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$\Omega_c h^2$	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

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Possible origins:

The Einstein Cosmological constant...

Vaccum energy density:
Nerst-Weinberg argument:

$$\rho_v \sim \int^{k_c} k d^3\mathbf{k} \propto k_c^4 \approx 10^{121} \rho_{obs}$$

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Inhomogeneities

Non linear effect of GR

Standard model: background + linear perturbations

Non linear effects could contribute to the background

However $\delta h^2 \sim 10^{-10}$

Lemaître-Tolman-Bondi models.

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A new component with like a scalar field such that :

$$P \sim -\rho$$

quintessence, ...

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ΛCDM has been predictive and successful!

The situation will improve with the next generation of experiments (BigBOSS, LSST, Euclid, Wfirst, ...)

A fundamentaly new step is to test GR on large scale.

Measuring growth rate of structures: testing GR

Evidence for the Fifth Element, Astrophysical status of Dark Energy, 2010, Blanchard, A., *A&A Rev.*, **18**, 595.

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