Constraints on fundamental physics from CMB data and galaxy clustering

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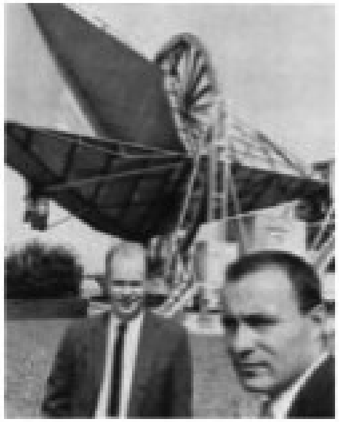
Outline

- **Theory:**
  - **Introduction to the Standard Cosmological model**
  - **CMB and Standard Recombination**
  - **Dark energy +Dark Matter**
- **Results**
  - **How we can deal with these problems?**
  - **Constraints from future experiments.**
- **Conclusions**

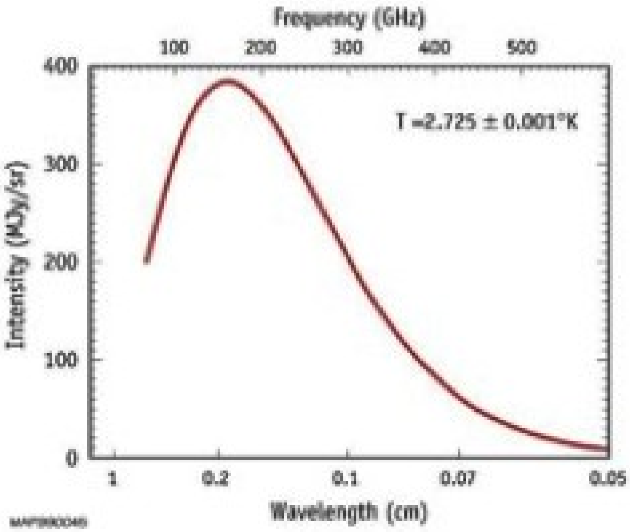
The Cosmic Microwave Background

Discovered by Penzias and Wilson in 1964.



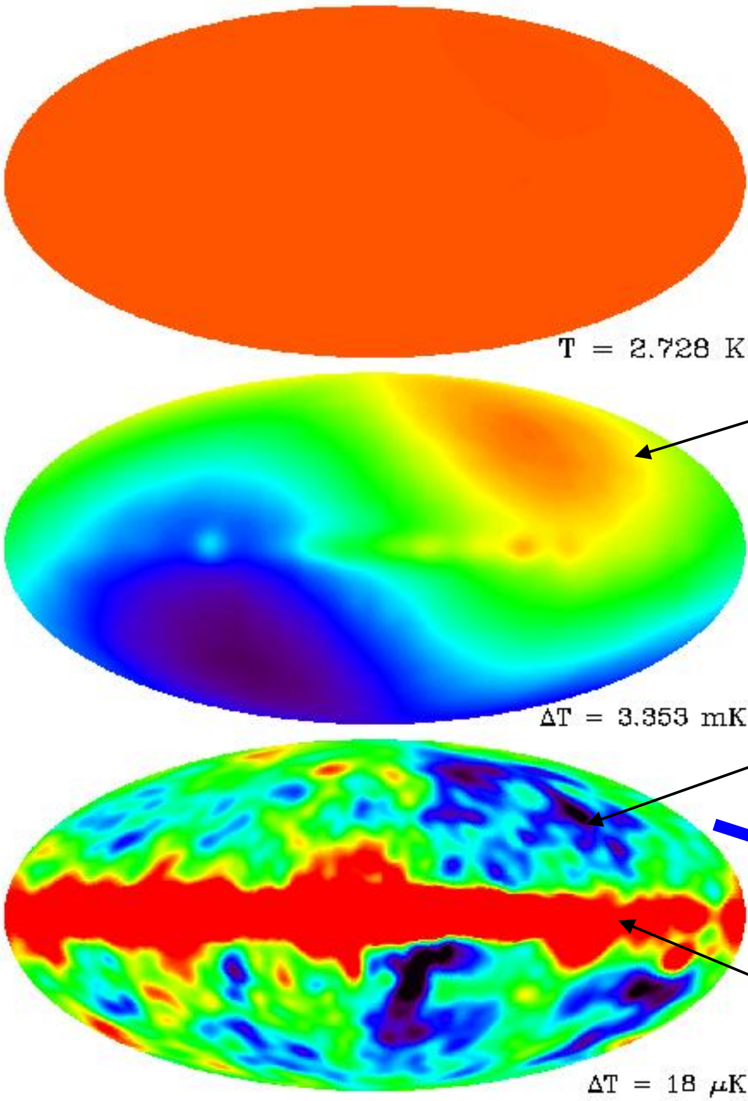
It is an image of the universe at the time of recombination (near baryon-photons decoupling), when the universe was just a few thousand years old (z~1000).

The CMB frequency spectrum is a perfect blackbody at T=2.73 K: this is an outstanding confirmation of the hot big bang model.



The Microwave Sky

COBE

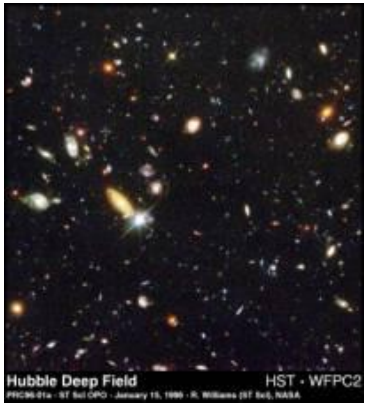


Uniform...

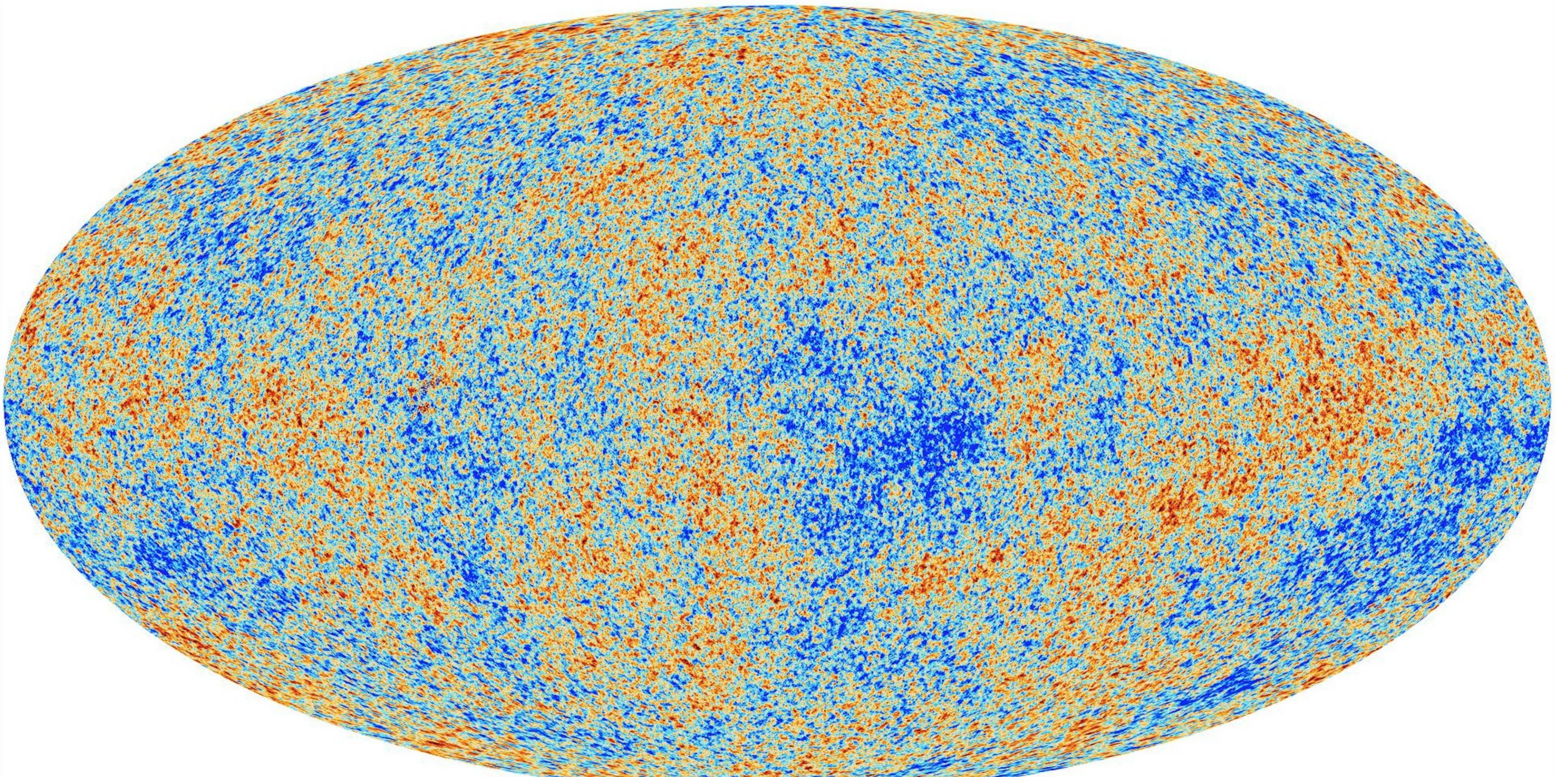
Dipole...

Imprint left by primordial tiny density inhomogeneities (z~1000)..

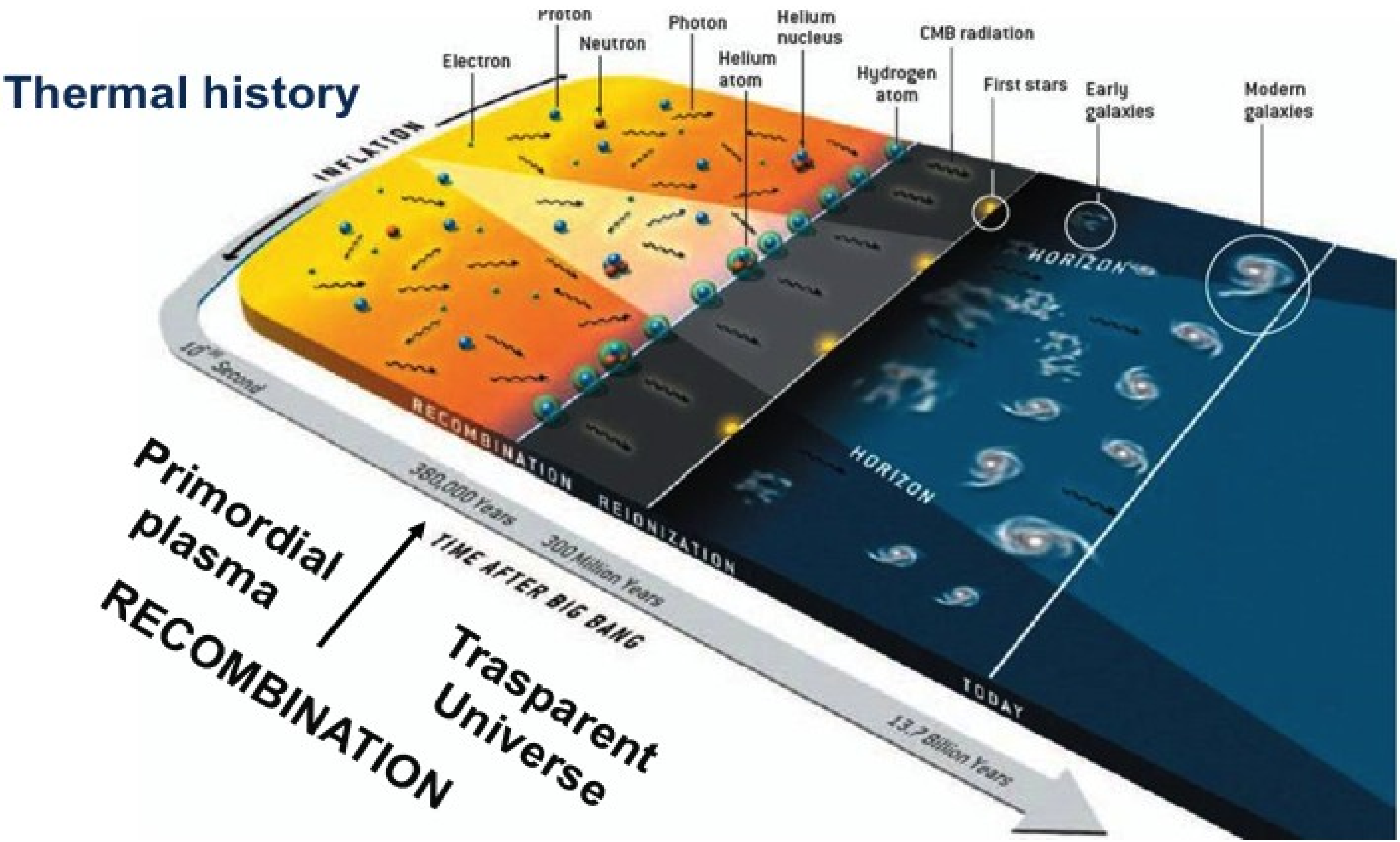
Galaxy (z=0)



Planck 2013 results. I. Overview of products and scientific results (Astronomy & Astrophysics Volume 571, November 2014)



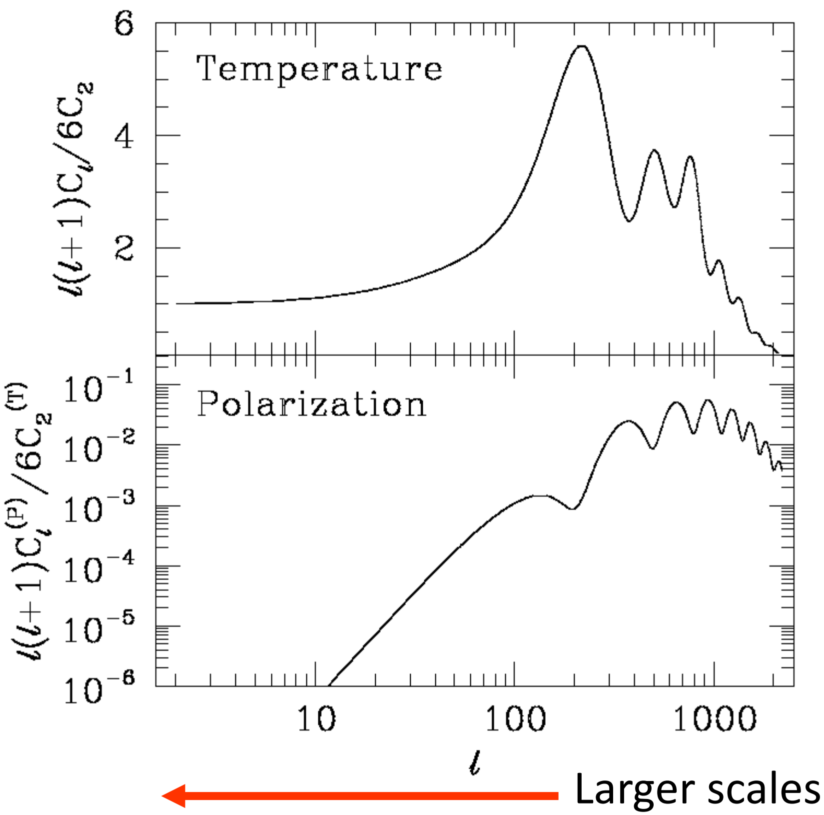
Why we use CMB anisotropies ?



The CMB Angular Power Spectrum

The main reason of this success relies on the existance of a highly predictable theoretical model that describes the CMB anisotropies.
The most important theoretical prediction is the CMB anisotropy angular power spectrum.
i.e. you consider a two point correlation function
For the anisotropies in the sky, you expand
the correlation function in Legendre polinomials
(i.e. there is non azimuthal dependence for
The anisotropies) and the model predict
a value of the Legendre coefficient in function
of the order l as in figure.

Small l's correspond to large angular scales,
while large l's correspond to small angular scales.



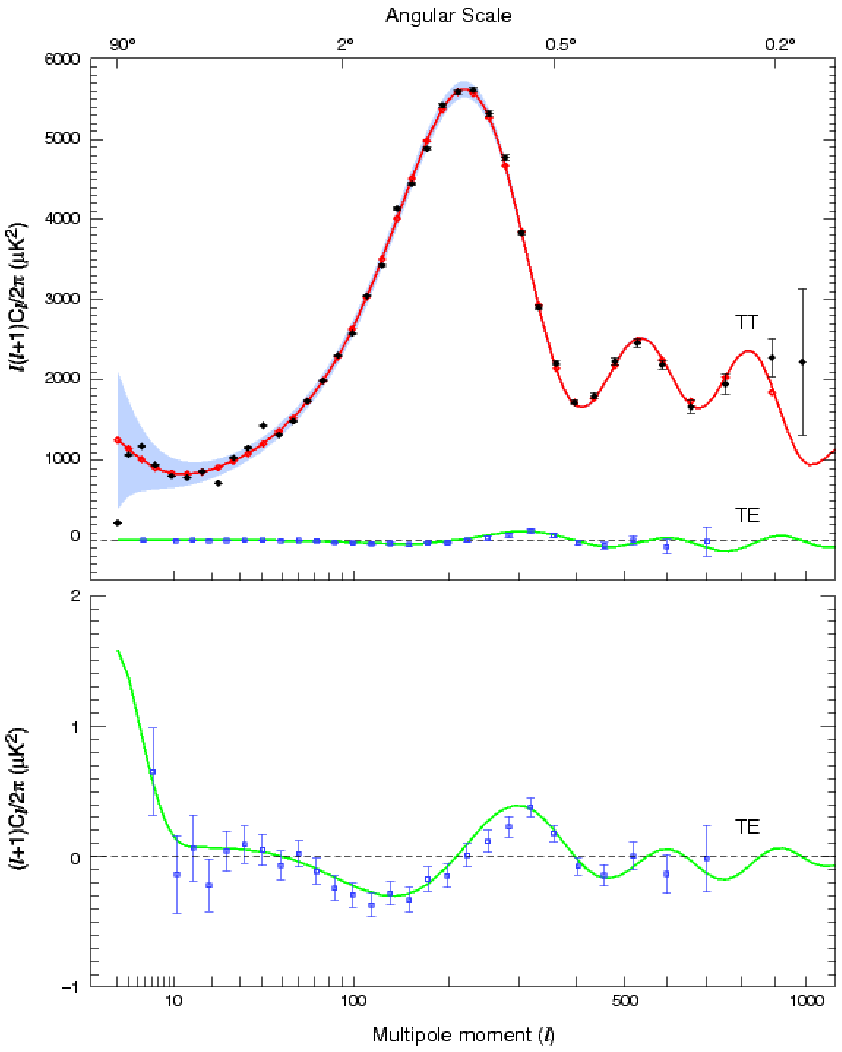
We can correlate not only temperature but also polarization.

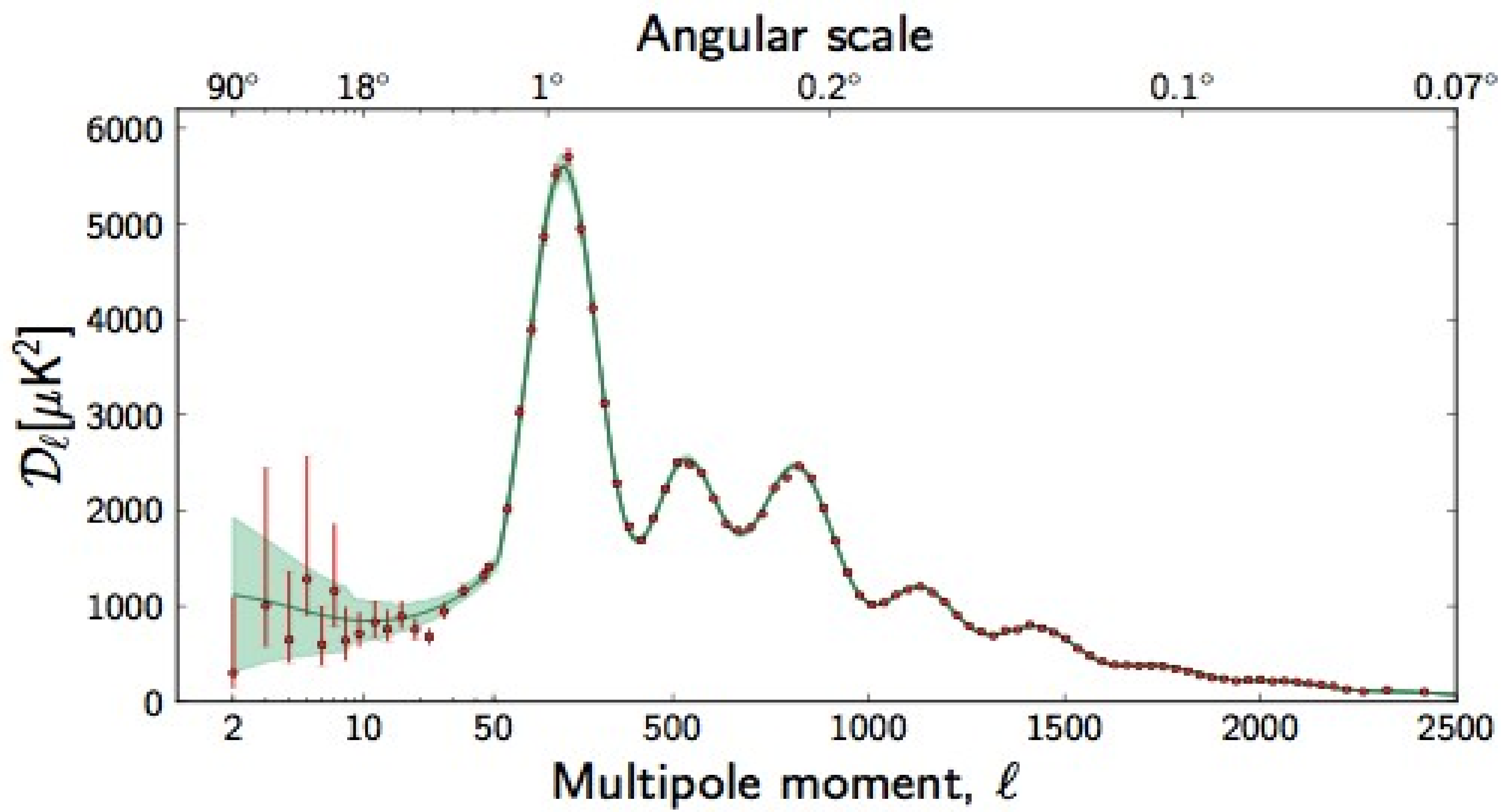
$$\left\langle \frac{\Delta T}{T}(\vec{\gamma}_1)\frac{\Delta T}{T}(\vec{\gamma}_2)\right\rangle = \frac{1}{2\pi}\sum_\ell (2\ell+1)C_\ell P_\ell(\vec{\gamma}_1\cdot\vec{\gamma}_2)$$

WMAP

Theory and Experimental data are in spectacular agreement !

We can use the CMB data to constrain the parameter of the model !





Planck collaboration [2013 Submitted to A&A]
arXiv:1303.5075

Physical Processes that Induce CMB Fluctuations

The primary anisotropies of CMB are induced by three principal mechanisms:

- **Gravity (Sachs-Wolfe effect, regions with high density produce big gravitational redshift)**
- **Adiabatic density perturbations (regions with more photons are hotter)**
- **Doppler Effect (peculiar velocity of electrons on last scattering surface)**

The anisotropies in temperature are modulated by the visibility function which is defined as the probability density that a photon is last scattered at redshift z:

$$\frac{\Delta T}{T}(\vec{n}) \doteq \int_0^\infty \left[g(z) \left(\Psi + \Theta_0 + \vec{n}\cdot\vec{\mathrm{v}}_{\mathrm{b}} \right) \right] dz \qquad \boxed{\alpha}$$

Gravity

Adiabatic

Doppler

Visibility function and fine structure constant

$$g(\eta) = \dot{\tau}\ e^{-\tau}$$

Rate of Scattering

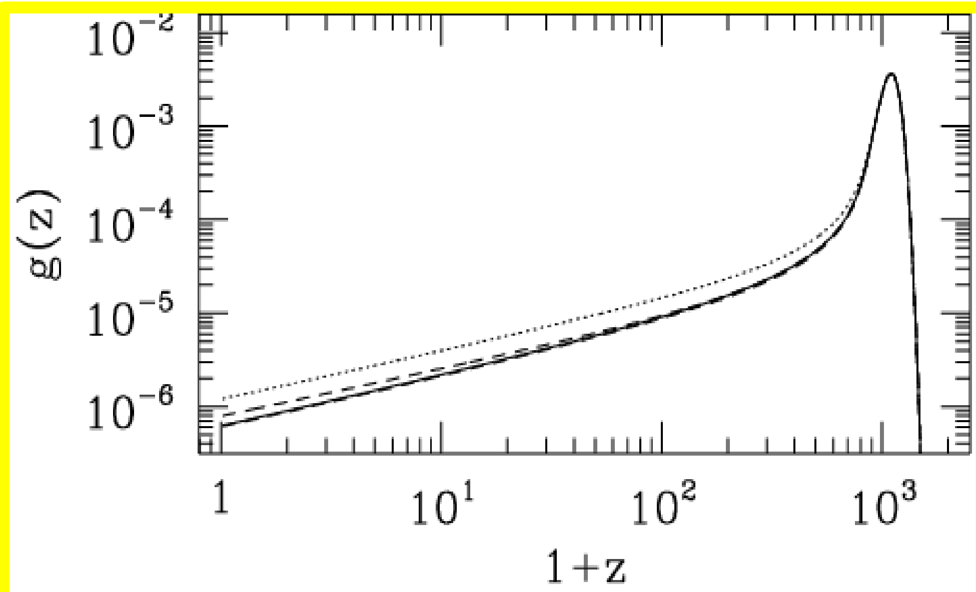
$$\dot{\tau}(\eta) = n_e\, x_e\, a\sigma_T$$

Optical depth

$$\tau(\eta) = \int_{\eta}^{\eta_0} d\eta'\, n_e\, x_e\, a\sigma_T$$

$$x_e = \frac{n_e}{n_e + n_H}$$

We can see that the visibility function is peaked at the Epoch of Recombination.



Thomson scattering cross section

$$\sigma_T = \frac{8\pi}{3} \frac{\hbar^2}{m_e^2 c^2} \alpha^2$$

Recombination: standard Model

Direct Recombination

NO net recombination

$$H_{1s} + \gamma \leftrightarrow H^{+} + e^{-}$$

Decay to 2 photons from 2s levels metastable

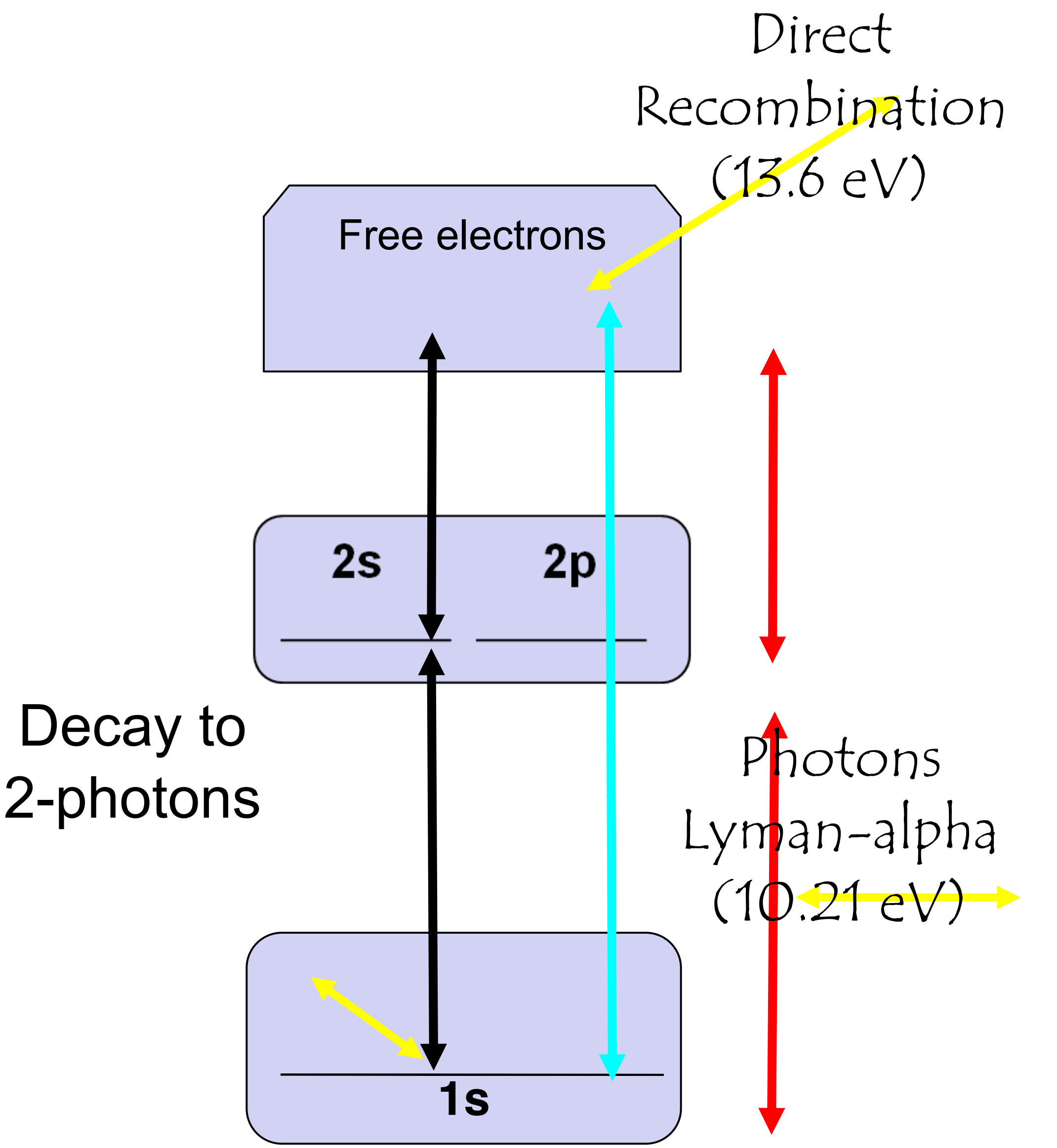
$$H^{+} + e^{-} \leftrightarrow H_{2s} + \gamma$$

$$H_{2s} \leftrightarrow H_{1s} + 2\gamma$$

Cosmological redshift of **Lyman alpha's photons**

$$H^{+} + e^{-} \leftrightarrow H_{2p} + \gamma$$

$$H_{2p} \leftrightarrow H_{1s} + \gamma$$



Evolution of the free electron fraction with time

ionization coefficient

$$\beta_H \equiv R_H \left(\frac{2\pi m_e K_B T}{h^2} \right) e^{-B_2 / K_B T}$$

recombination coefficient

$$R_H \approx \sigma_{nl} f(B_n, T)$$

cross section of ionization

$$\sigma_{nl} \propto \alpha^{-1} m_e^{-2} f(h\nu / B_1)$$

$$\frac{dx_e}{dt} = C_H \left[\beta_H (1 - x_e) e^{-\frac{B_1 - B_2}{K_B T}} - R_H n_p x_e^2 \right]$$

$$C_H = \frac{1 + K\Lambda_{2s}(1 - x_e)}{1 + K(\beta_H + \Lambda_{2s})(1 - x_e)}$$

Rate of decay 2s a 1s $\quad \Lambda_{2s} \propto m_e \alpha^8$

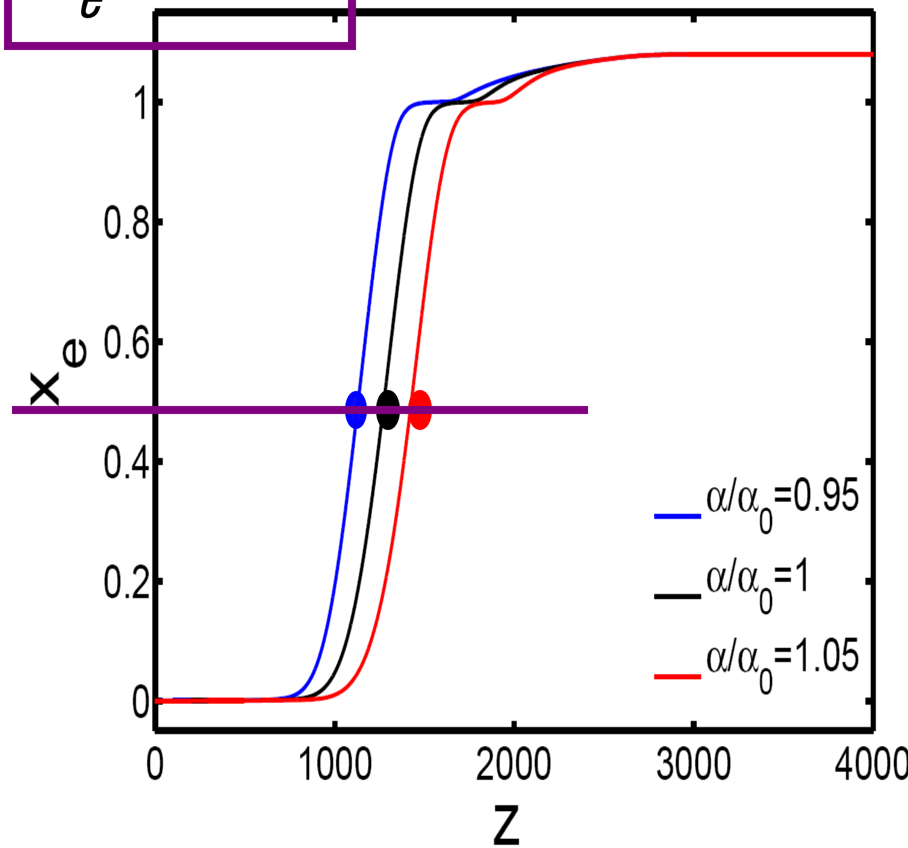
Constant K $\quad K = n_e \lambda^3 / (8\pi H) \propto m_e^{-3} \alpha^{-6}$

Lyman-alpha $\quad \lambda_\alpha = 16\pi\hbar / (3 m_e c \alpha^2)$

Variation of free electron fraction

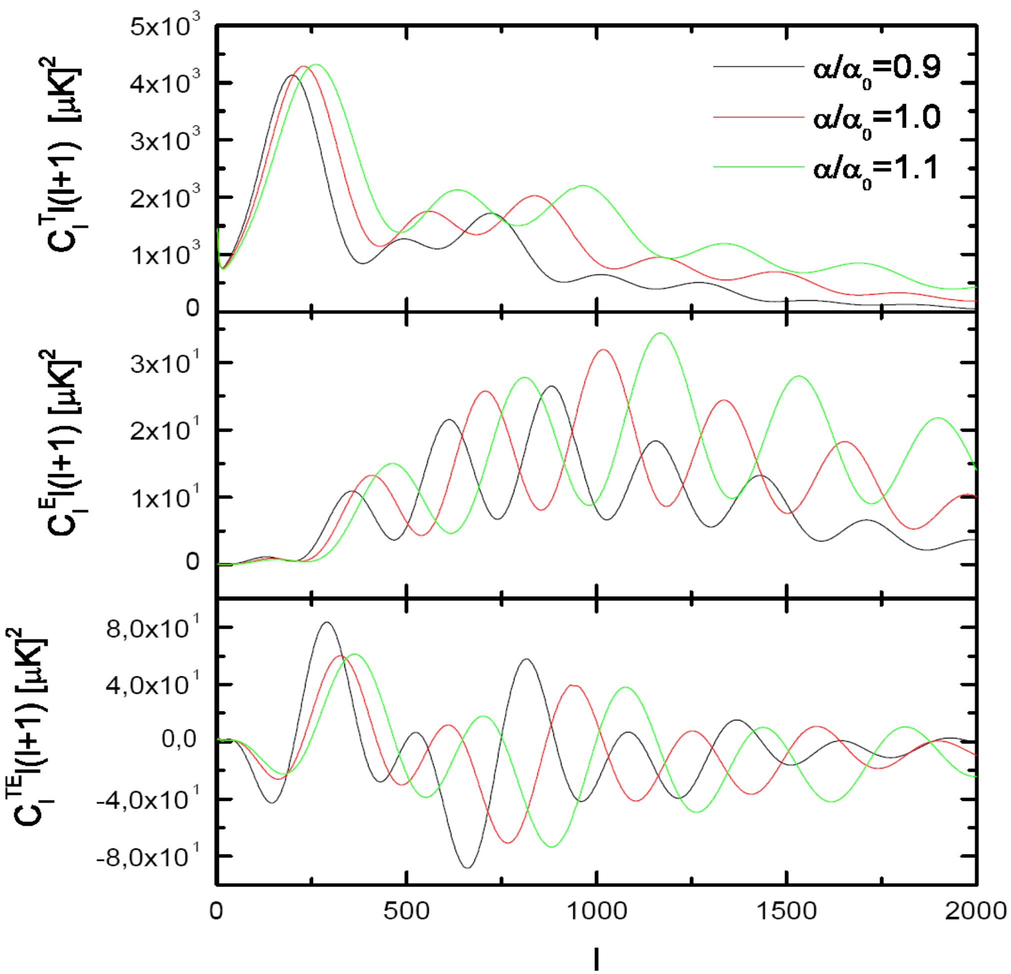
If we plot the free electron fraction versus the redshift, we can notice a different epoch of Recombination for different values of alpha. In particular if the fine structure constant α is smaller than the present value, then the Recombination takes place at smaller z.

$$x_e = 0.5$$



(see e.g. Avelino et al., Phys.Rev.D64:103505,2001)

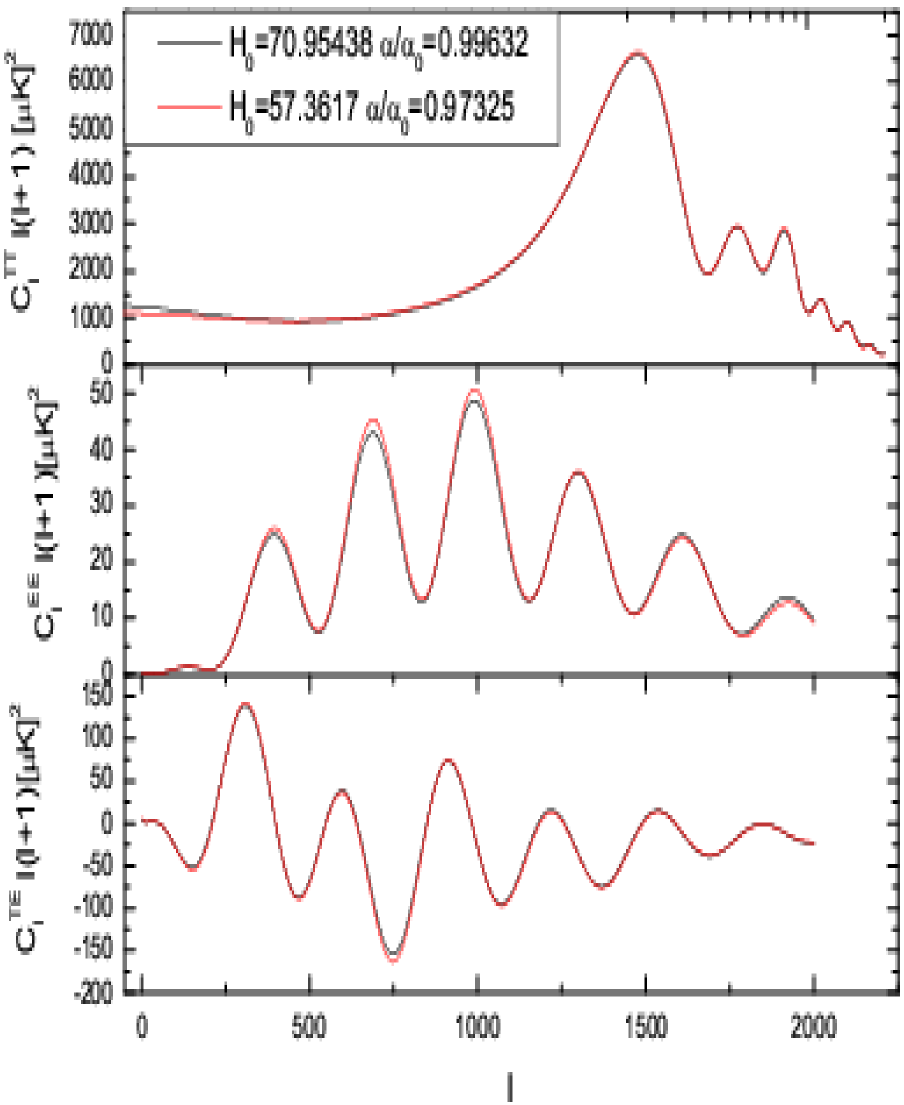
Modifications caused by variations of the fine structure constant



If the fine structure constant is $\alpha / \alpha_0 < 1$ recombination is delayed, the size of the horizon at recombination is larger and as a consequence the peaks of the CMB angular spectrum are shifted at lower l (larger angular scales).

Therefore, we can constrain variations in the fine structure constant at recombination by measuring CMB anisotropies !

Caveat: is not possible to place strong constraints on the fine structure constant by using cmb data alone !



A "cosmic" degeneracy is cleary visible in CMB power spectrum in temperature and polarization between the fine structure constant and the Hubble constant.

The angle that subtends the horizon at recombination is indeed given by:

$$\theta_H \approx c_s H^{-1}(z_r) / d_A(z_r)$$

The horizon size increases by decreasing the fine structure constant but we can compensate this by lowering the Hubble parameter and increasing the angular distance.

New constraints on the variation of the fine structure constant

Menegoni, Galli, Bartlett, Martins, Melchiorri, arXiv:0909.3584v1
Physical Review D *80 081302 (2009)*

We sample the following set of cosmological parameters from WMAP-5 years observations:

Baryonic density	$\Omega_b h^2$
Cold dark matter density	$\Omega_c h^2$
Hubble parameter	H_0
Scalar spectrum index	n_S
Optical depth	τ
Overall normalization of the spectrum	A_s
Variations on the fine structure constant	α / α_0

We also permit variations of the parameter of state w .

We use a method based on Monte Carlo Markov Chain

(the algorithm of Metropolis-Hastings).

The results are given in the form of likelihood probability functions.

We are looking for possible degeneracies between the parameters.

We assume a flat universe.

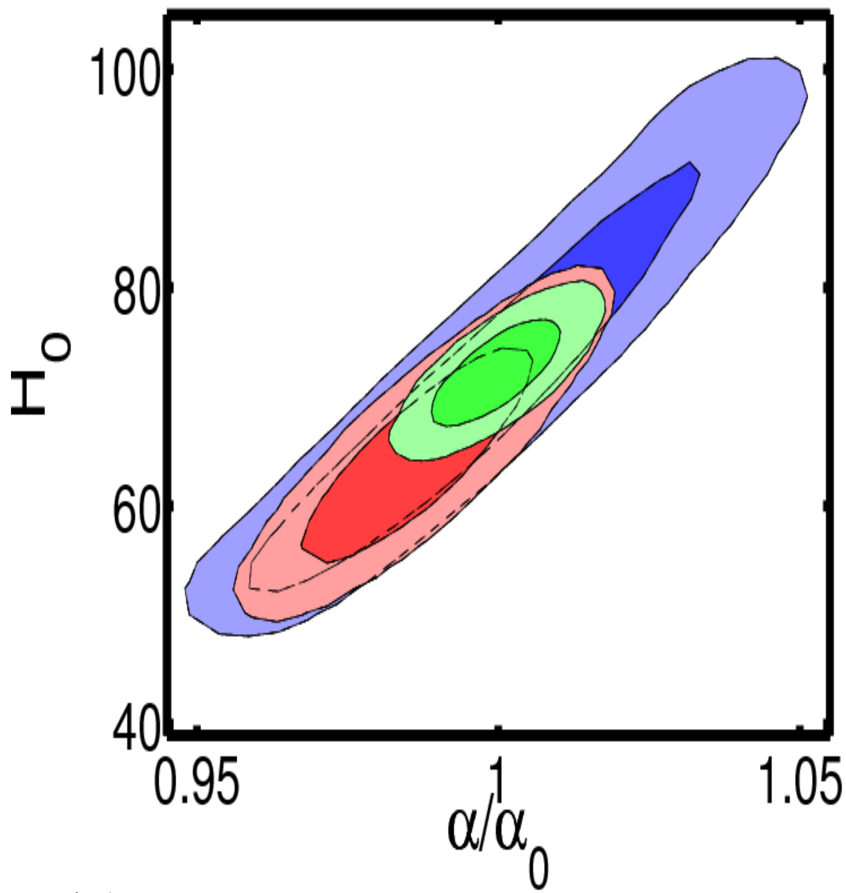
Constraints on the fine structure constant

In this figure we show the 68% and 95% c.l. constraints on the α/α_0 vs Hubble constant for different datasets .

Experiment	α/α_0	68% c.l.	95% c.l.
WMAP-5	0.998	± 0.021	$^{+0.040}_{-0.041}$
All CMB	0.987	± 0.012	± 0.023
All CMB+ HST	1.001	$\boxed{\pm 0.007}$	± 0.014

TABLE I: Limits on α/α_0 from WMAP data only (first row), from a larger set of CMB experiments (second row), and from CMB plus the HST prior on the Hubble constant, $h = 0.748 \pm 0.036$ (third row). We report errors at 68% and 95% confidence level.

$\boxed{\approx 0.7\%}$



Menegoni, Galli, Bartlett, Martins, Melchiorri, arXiv:0909.3584v1
Physical Review D *80 081302 (2009)*

Planck and additional datasets

- Planck data: TT power spectra analyzed with two likelihood codes:
  - l=2-49: from component separation approach.
  - l~49-2500 (depending on frequency): from cross-spectra over the frequency range 100-217 Ghz (Planck Collaboration XV 2013).
- WP data: l=2-23: polarization data from WMAP.
- Additional datasets:
  - BAO: from 4 redshift surveys (SDSS,WiggleZ,BOSS,6dF):
  - HST: prior on H_0:73.8±2.4 Km/s/Mpc (Riess et al 2011)
  - High-l: ACT data at 148Ghz (540<l<9440) and 218 GHz (1540 < l < 9440) from Das 2013, SPT 2000 < l< 10000 (Reichardt et al.2012) (17 additional nuisance parameters needed) .
  - CMB Lensing

Table 11. Constraints on the cosmological parameters of the base ΛCDM model with the addition of a varying fine-structure constant. We quote ±1 σ errors. Note that for *WMAP* there is a strong degeneracy between H_0 and α, which is why the error on α/α_0 is much larger than for *Planck*.

	Planck+WP	*Planck*+WP+BAO	*WMAP*-9
$\Omega_b h^2$	0.02206 ± 0.00028	0.02220 ± 0.00025	0.02309 ± 0.00130
$\Omega_c h^2$	0.1174 ± 0.0030	0.1161 ± 0.0028	0.1148 ± 0.0048
τ	0.095 ± 0.014	0.097 ± 0.014	0.089 ± 0.014
H_0	65.2 ± 1.8	66.7 ± 1.1	73.9 ± 10.9
n_s	0.975 ± 0.012	0.969 ± 0.012	0.973 ± 0.014
$\log(10^{10} A_s)$	3.106 ± 0.029	3.100 ± 0.029	3.090 ± 0.039
α/α_0	0.9936 ± 0.0043	0.9989 ± 0.0037	1.008 ± 0.020

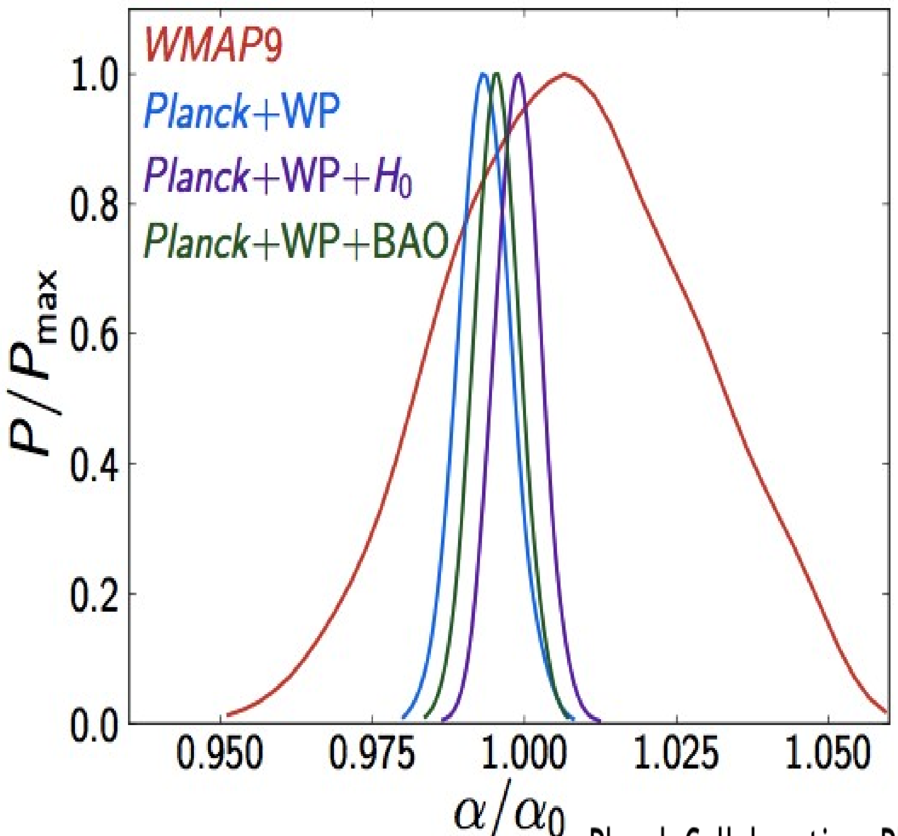


Figure 2. Marginalized posterior distributions of α/α0 for the WMAP-9 (red), Planck+WP (blue), Planck+WP+H0 (purple), and Planck+WP+BAO (green)data combinations.

Planck Collaboration, Planck 2013 results.XVI. Cosmological parameters, arXiv:1303.5076 [astro-ph.CO].

Results from Planck data on α

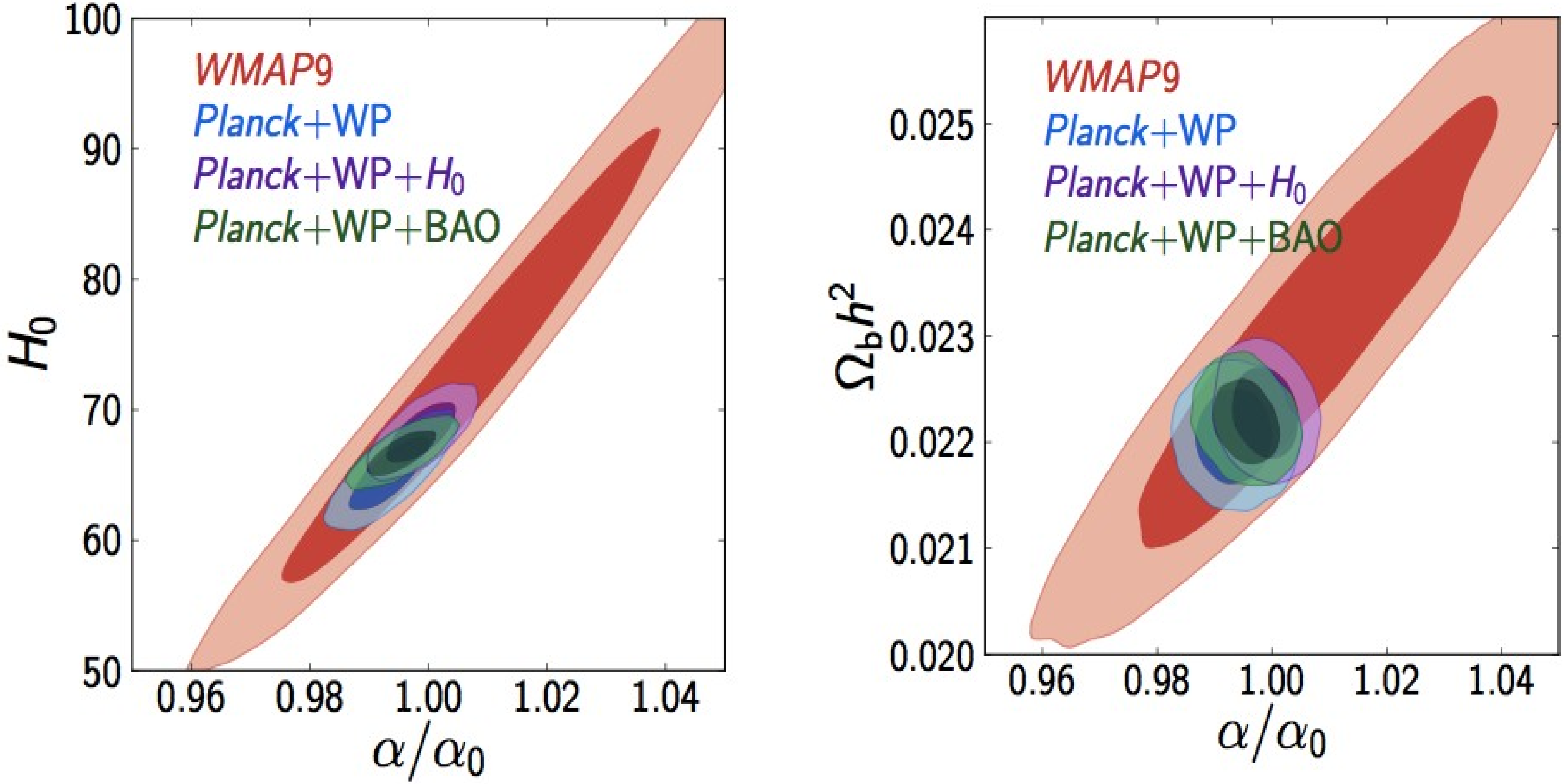
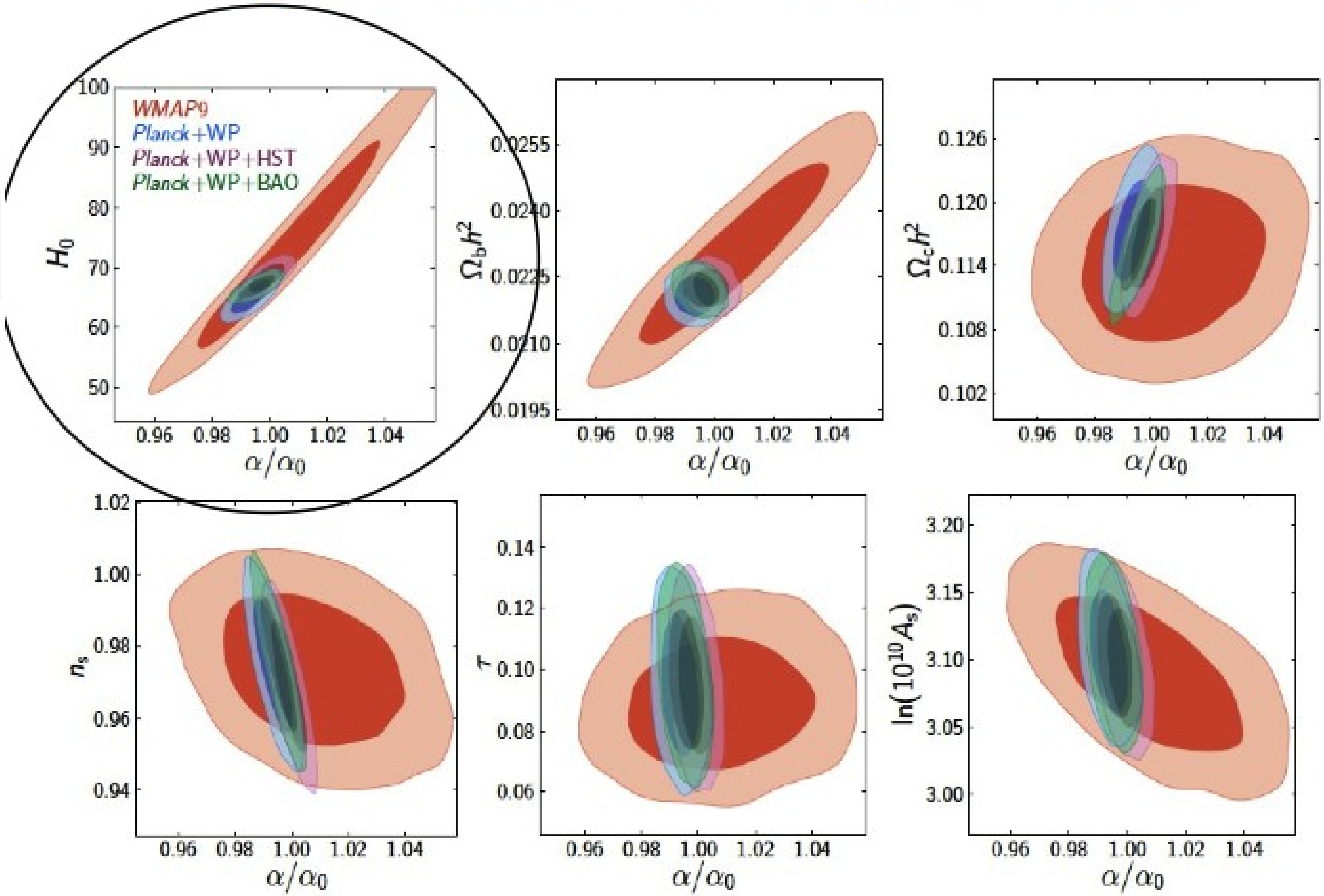


Figure 1. Left: Likelihood contours (68% and 95%) in the α/α_0- H_0 plane for the WMAP-9 (red), Planck+WP (blue), Planck+WP+H0 (purple), and Planck+WP+BAO (green) data combinations Right: As left, but in the α/α_0-$\Omega_b h^2$ plane.

Degeneracies α-other parameters



Observations tell us that our Universe is FLAT and full of an unknown component!!!!

$$H^2 = \frac{8\pi G}{3}\left(\rho_{\mathrm{Matter}} + \rho_{\mathrm{DE}}\right) - \frac{K}{a^2}$$

~ 0

DARK+ORDINARY MATTER

DARK ENERGY

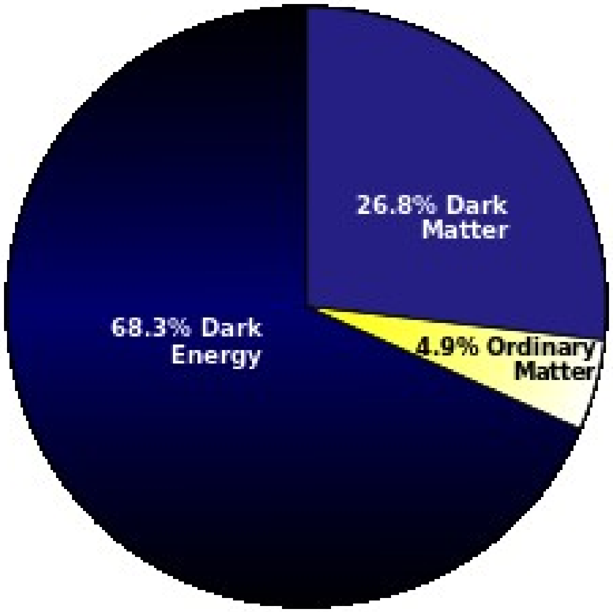
The expansion and the evolution of the universe depends on the energy density: we must specify the content of the universe !!!

ONLY the ~4.9% is baryonic matter!!!

"Planck 2013 results. XVI. Cosmological parameters". Planck Collaboration XVI, Astron. Astroph. Vol. 571, A16, (2014).

DARK ENERGY MODELS

The standard cosmological model is consistent with the current data only if we admits the presence of a dark energy component



The nature of DE is still a big problem in modern cosmology!!!!

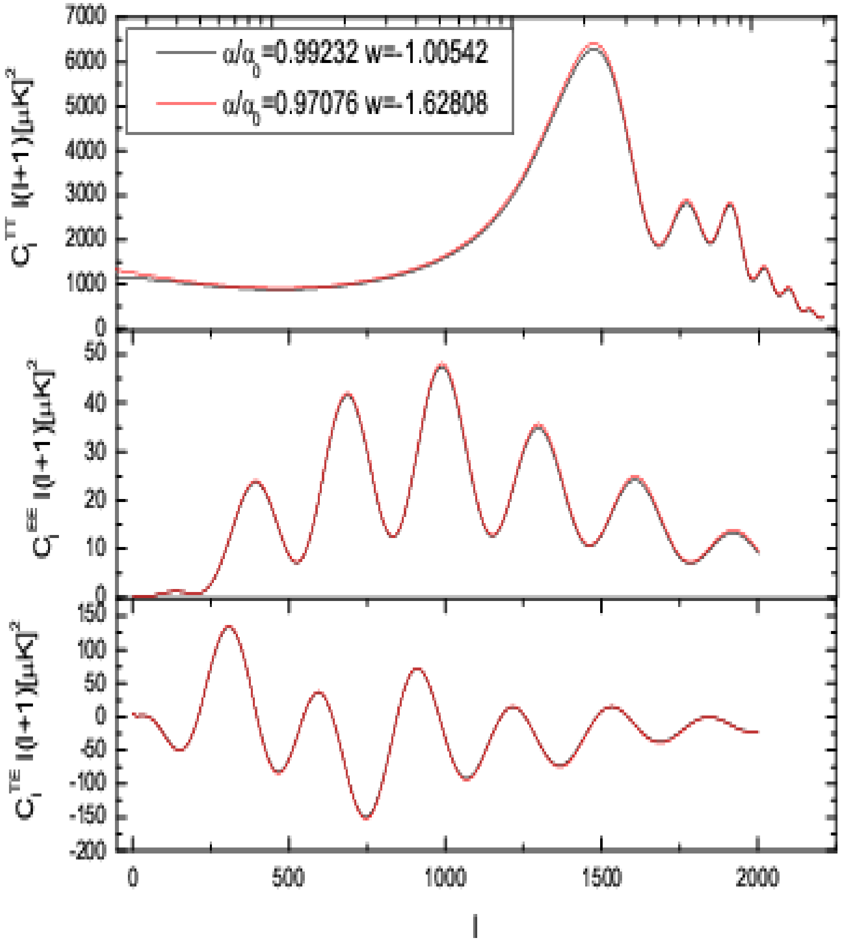
w= -1 OR

w= w(a)

change with time?

- Cosmological constant? Quintessence scalar field?....

The degeneracy between the fine structure constant with the dark energy equation of state w



If we vary the value of w we change the angular distance at the Recombination. Again this is degenerate with changing the sound horizon at recombination varying the fine structure constant.

$$d_A = \frac{cH_0^{-1}}{(1+z)} \int_0^{1100} \frac{dz'}{E(z')}$$

$$E(z) = \left[\Omega_m (1+z)^3 + \Omega_r (1+z)^4 + \Omega_X (1+z)^{[3(1+w)]}\right]^{1/2}$$

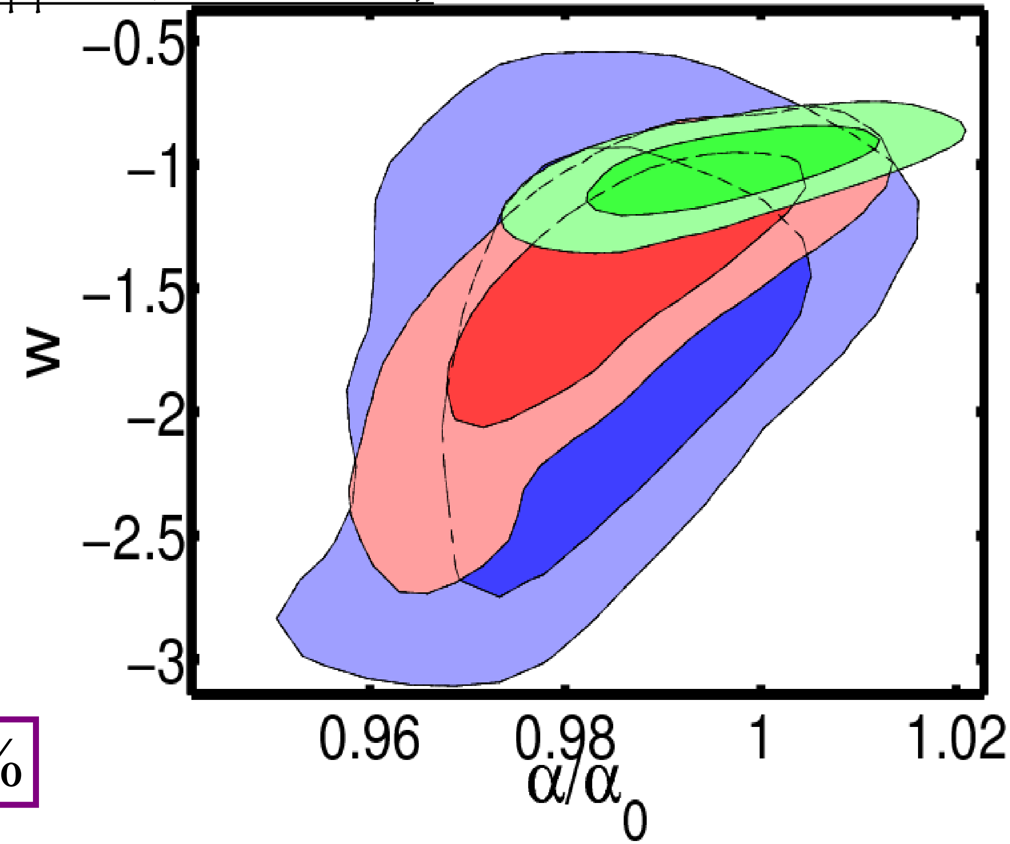
Constraints on the dark energy parameter w

E. Menegoni, S. Pandolfi, S. Galli, M. Lattanzi, A. Melchiorri
(IJMPD, International Journal of Modern Physics D, Volume 19, Issue 04, pp. 507-512 2010)

Datasets	α/α_0	w
CMB	0.983 ± 0.012	-1.74 ± 0.53
CMB+ HST	$0.983 \pm \boxed{0.011}$	-1.52 ± 0.39
CMB+ HST+SN-Ia	$0.996 \pm \boxed{0.009}$	-1.02 ± 0.11

TABLE I: Limits on w and α/α_0 from CMB experiments (first row), from CMB plus the HST prior on the Hubble constant, $h = 0.748 \pm 0.036$ (second row), and from CMB+HST plus luminosity distances of supernovae type Ia from the UNION catalog. We report errors at 68% confidence level.

$\boxed{\approx 0.9\%}$ $\boxed{\approx 1.1\%}$



Varying fine structure constant: (possible) physical motivations

If dark energy is described by a scalar field, this scalar field can be coupled to the electromagnetic sector and change the value of the fine structure constant

In order to have variations of alpha at the Epoch of Recombination we need a scalar field with energy density non-negligible, i.e. **Early dark energy (EDE)**

It's interesting to see what happens to alpha in the case of and EDE component

DARK ENERGY MODELS

LCDM $w = const = -1$

Scalar field $w = w(a) \neq -1$

The dark energy contribution is assumed to be represented by a scalar field whose evolution tracks that of the dominant component of the cosmic fluid at a given time!

$$\Omega_{\rm de}(a) = \frac{\Omega^0_{\rm de} - \Omega_{\rm e}\left(1 - a^{-3w_0}\right)}{\Omega^0_{\rm de} + \Omega^0_m a^{3w_0}} + \Omega_{\rm e}\left(1 - a^{-3w_0}\right)$$

$$w(a) = -\frac{1}{3[1 - \Omega_{\rm de}(a)]}\frac{d\ln\Omega_{\rm de}(a)}{d\ln a} + \frac{a_{eq}}{3(a + a_{eq})}$$

Calabrese, Roland de Putter, Dragan Huterer, Eric V. Linder, Alessandro Melchiorri

Journal-ref: Phys.Rev.D83:023011,2011

We want to deal with a scalar field..

- We add the dark energy perturbations by considering the EDE clustering proprieties through the effective sound speed

$$c_s^2 = \delta p / \delta \rho$$

- The viscosity parameter c_{vis}^2

  describe the presence of anisotropic stress. In the present analysis we assume these clustering parameters as constant with $c_{vis}^2 = 0$

  $c_s^2 = 1$

In any realistic dynamical scalar field scenario, the scalar field should be coupled to the rest of the model, unless one postulates a (yet unknown) symmetry to suppress the coupling. We are presently interested in the coupling between the scalar field and electromagnetism, which we take to be of the form:

$$L_{(\phi F)} = -1/4 B_F(\phi) F_{(\mu\nu)} F^{(\mu\nu)}$$

where the gauge kinetic function is linear:

$$B_F(\phi) = 1 - \zeta \kappa (\phi - \phi_0)$$

ζ **is therefore the relevant coupling, and among other things it is related to the amount of equivalence principle violations. Constraints on this coupling are tight at low redshift; conservatively we have**

$$\zeta < 10^{-3}$$

Constraints on the fine structure constant with early dark energy model

The scalar field could be coupled to other components. In this case is taken in account the coupling between the electromagnetism and the scalar field:

$$\frac{\Delta\alpha}{\alpha_0} \equiv \frac{\alpha - \alpha_0}{\alpha_0} = \zeta k(\phi - \phi_0)$$

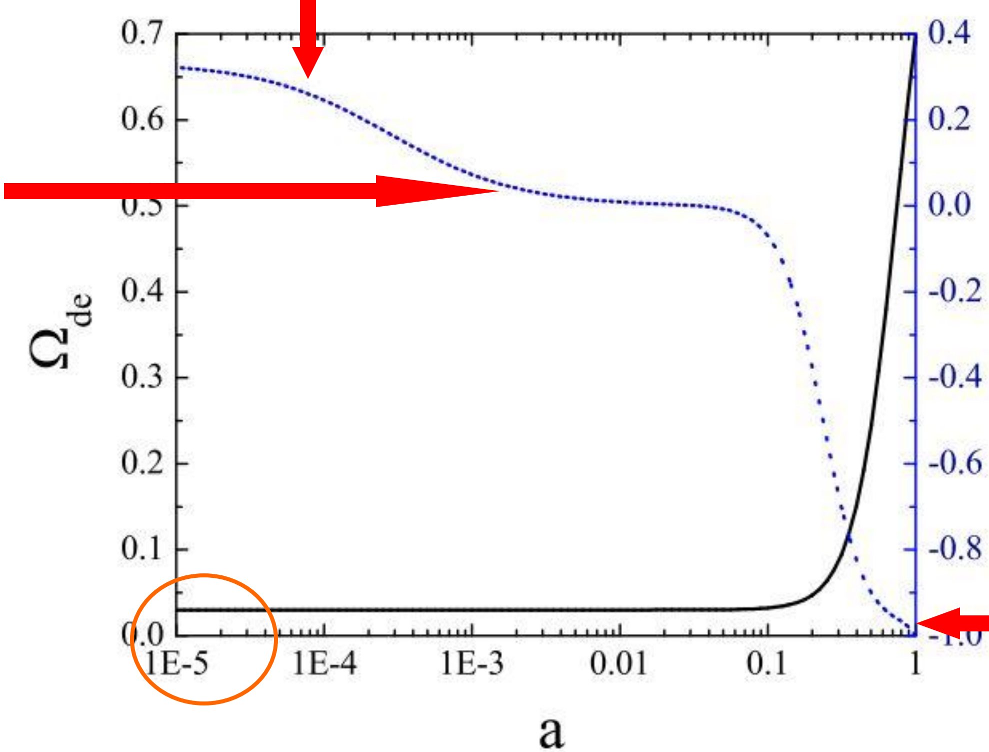
$$\boxed{\alpha/\alpha_0(a) = 1 - \zeta \int_a^{a_0} \sqrt{3\Omega_{de}(a)(1 + w(a))}\, d\ln a}$$

$$w = -1 + \frac{(\kappa\phi')^2}{3\Omega_{de}}$$

Dark Energy model with a EDE constant component in the past

$\approx 1/3$

≈ 0

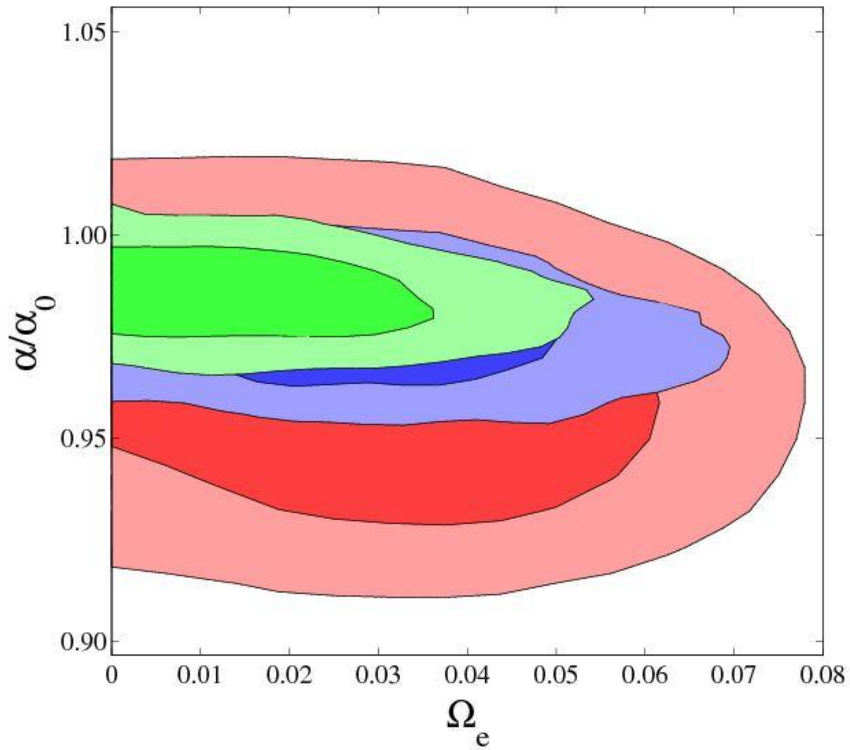


≈ -1

Behaviour of early dark energy model in energy density (solid black line) and equation of state (dotted blue line) as a function of the scalar factor.

$$\Omega_e \approx 0.03$$

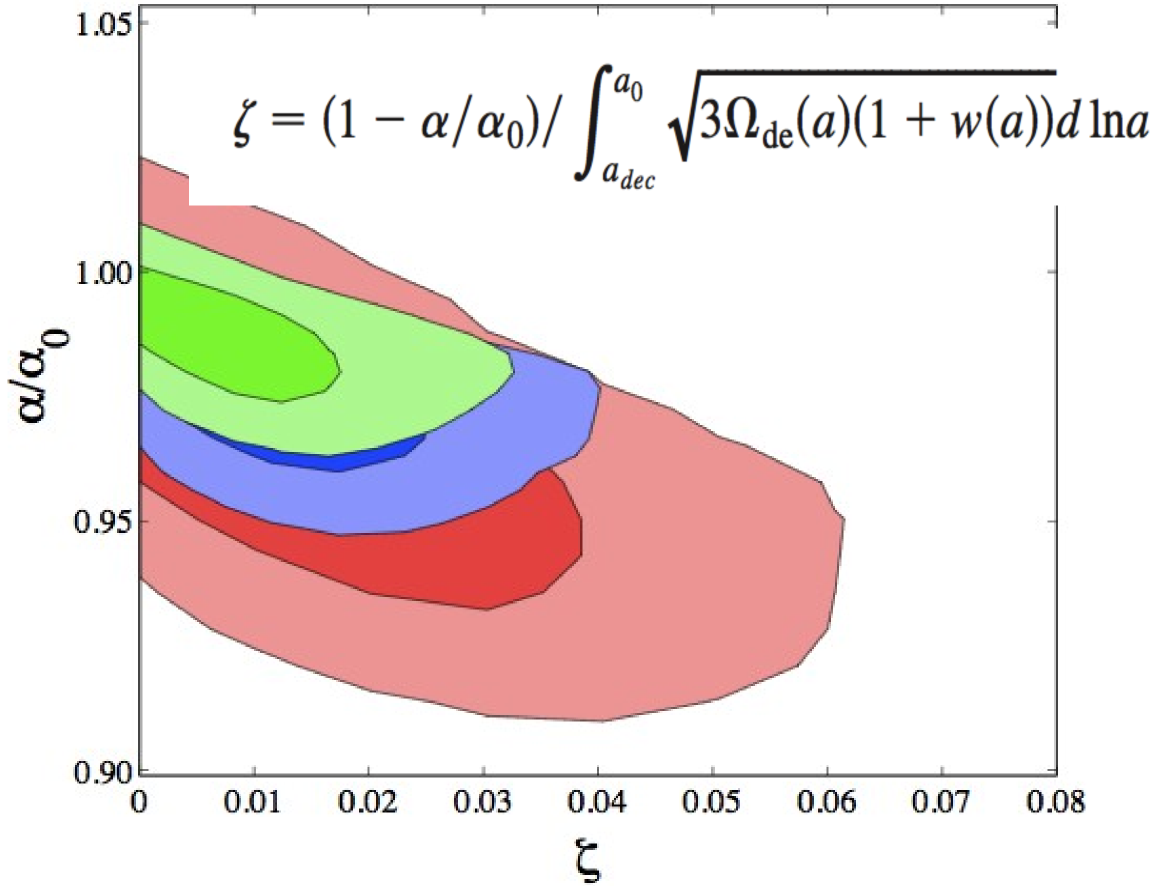
Constraints on the variations of the fine structure constant, EDE density parameter and on coupling



Experiment	α/α_0	Ω_e	ζ
WMAP7+HST	$\boxed{0.963 \pm 0.044}$	< 0.064	< 0.047
WMAP7+ACT+HST	$\boxed{0.977 \pm 0.010}$	< 0.051	< 0.028
WMAP7+ACT+HST+BAO	$\boxed{0.986 \pm 0.014}$	< 0.043	< 0.024

Calabrese, Menegoni, Martins, Melchiorri and Rocha

Phys.Rev.D84:023518,2011



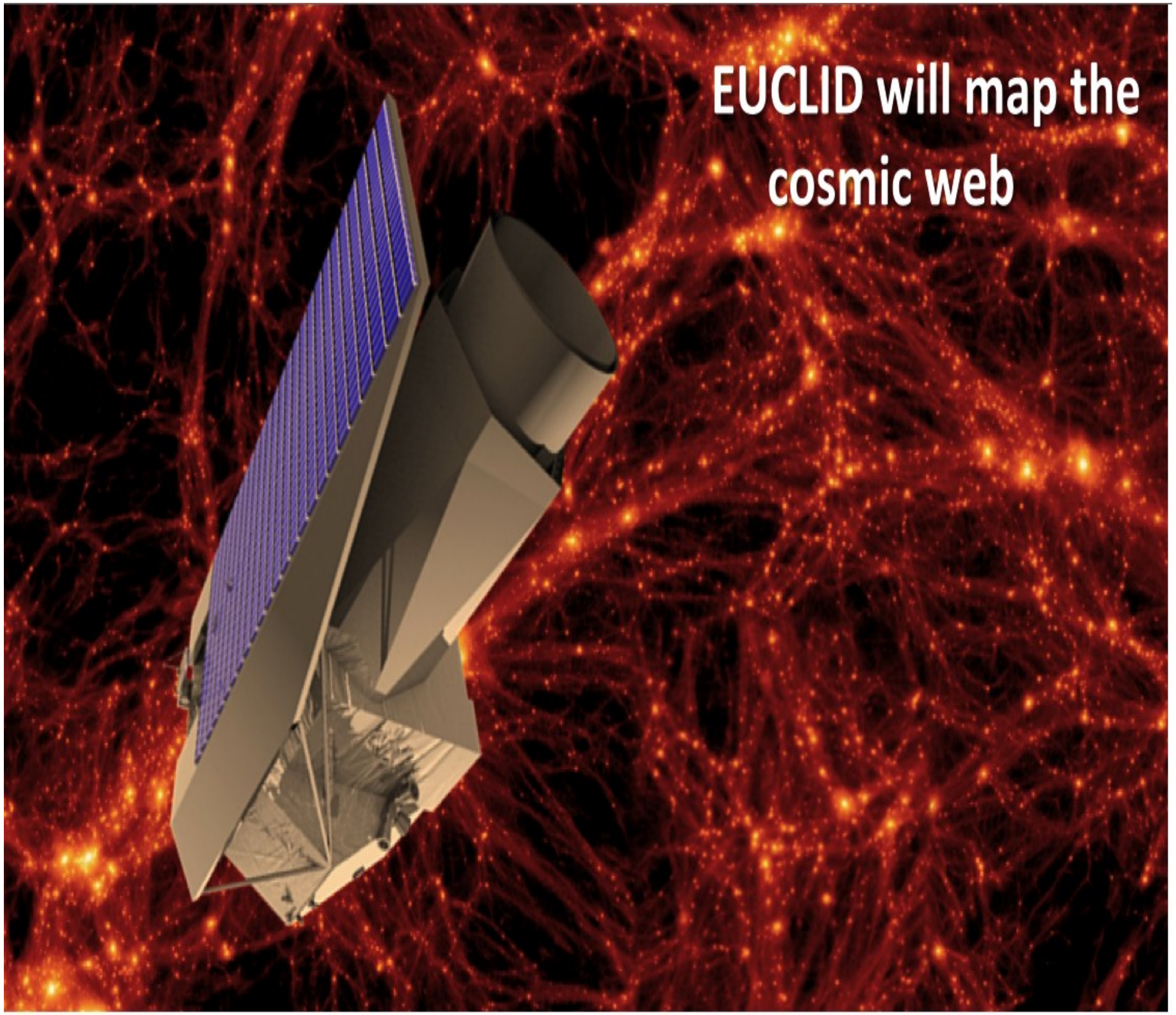
$$\zeta = (1 - \alpha/\alpha_0) / \int_{a_{dec}}^{a_0} \sqrt{3\Omega_{\rm de}(a)(1 + w(a))}\, d\ln a$$

The current constraints are 20 to 40 times weaker than the ones that can be obtained from weak equivalence principle tests..

Our constraints are obtained on completely different scales (cosmological ones as opposed to laboratory ones). So a discrepancy of less than two orders of magnitude is actually impressive!!!! (the Cassini bound effectively on 10^{-4} parsec scales)

TABLE I. Limits at 95% C.L. on α/α_0, Ω_e and the coupling ζ from the MCMC analyses.

Datasets	α/α_0	Ω_e	ζ
WMAP7 + HST	0.963 ± 0.044	<0.064	<0.047
WMAP7 + HST2	0.960 ± 0.040	<0.070	<0.047
WMAP7 + ACT + HST	0.975 ± 0.020	<0.060	<0.031
WMAP7 + ACT + HST + BAO	0.986 ± 0.018	<0.050	<0.025
WMAP7 + ACT + HST2 + BAO	0.986 ± 0.016	<0.050	<0.021



EUCLID will be launched in 2020 to explore **dark energy and dark matter** in order to understand the evolution of the Universe since the Big Bang and, in particular, its present accelerating expansion. Dark matter is invisible to our normal telescopes but acts through gravity to play a vital role in forming galaxies and slowing the expansion of the Universe.

EUCLID+Planck will help in the next future to understand how the structures were originated, and, furthermore to investigate the nature of the dark universe (both matter and energy).

The observed galaxy power spectrum

$$P_{obs}(z,k_r) = \frac{D_{Ar}^2(z)H(z)}{D_A^2(z)H_r(z)} G^2(z) b(k,z)^2 \left(1 + \frac{f}{b(k,z)}\mu^2\right)^2 P_{0r}(k) + P_{shot}(z)$$

Direction cosine within the survey

Shot noise due to the discreteness of the survey

Total galaxy power spectrum:

$$P(z,k) = P_{obs}(z,k)\, e^{k^2\mu^2\sigma_r^2}$$

$$F_{ij} = 2\pi \int_{k_{min}}^{k_{max}} \frac{\partial \log P(k_n)}{\partial \theta_i} \frac{\partial \log P(k_n)}{\partial \theta_j} \cdot V_{eff} \cdot \frac{k^2}{8\pi^3} \cdot dk$$

Effective volume of the survey :

$$V_{eff} = \int \left[\frac{n(\vec{r})\, P(k,\mu)}{n(\vec{r})\, P(k,\mu) + 1}\right]^2 d\vec{r} = \left[\frac{n(\vec{r})\, P(k,\mu)}{n(\vec{r})\, P(k,\mu) + 1}\right]^2 V_{survey}$$

We want to test two models:

Power Law Model:

$$b(z,k) = b_0(z) + b_1(z)\left(\frac{k}{k_1}\right)^n$$

COLE et al. (arXiv:astro-ph/0501174) Model:

$$b(z,k) = b_0(z)\left[\frac{1+Q(z)(k/k_1)^2}{1+A(z)(k/k_1)}\right]^{1/2}$$

Derivatives with respect to the various parameters for the **Power Law** Model:

$$\frac{d\ln P}{db_0}\Big|_{fid} = \frac{2}{b_0^{ref}} - \frac{2f\mu^2}{b_0^{ref}(b_0^{ref}+f\mu^2)}$$

$$\frac{d\ln P}{db_1}\Big|_{fid} = \frac{2}{b_0^{ref}}k^n - \frac{2f\mu^2 k^n}{b_0^{ref}(b_0^{ref}+f\mu^2)}$$

We set $\longrightarrow$ $k_1 = 1$

Derivatives with respect to the various parameters for the "COLE" Model:

$$\frac{d\ln P}{db_0}|_{fid} = \frac{2}{b_0^{ref}} - \frac{2f\mu^2}{b_0^{ref}\left[b_0^{ref}\left(\frac{1+Q_{ref}k^2}{1+A_{ref}k}\right)^{1/2} + f\mu^2\right]}$$

$$\frac{d\ln P}{dQ}|_{fid} = \frac{k^2}{1+Q_{ref}k^2} - \frac{f\mu^2 k^2}{1+Q_{ref}k^2}\frac{1}{f\mu^2 + b_0^{ref}\left[\frac{1+Q_{ref}k^2}{1+A_{ref}k}\right]^{1/2}}$$

Now we an extra parameter!!

with $k_1 = 1$

$$\frac{d\ln P}{dA}|_{fid} = -\frac{k}{1+A_{ref}k} + \frac{f\mu^2 k b_0^{ref}}{[1+A_{ref}k]\left[f\mu^2 + b_0^{ref}\left[\frac{1+Q_{ref}k^2}{1+A_{ref}k}\right]^{1/2}\right]}$$

Fisher Matrix Analysis

The FISHER matrix is defined as

$$L(data\,|\,\overline{p})$$

Likelihood function of a set of parameters given some data

$$F_{ij} \equiv \left\langle -\frac{\partial^2 \ln L}{\partial p_i \partial p_j} \right\rangle_{p_0}$$

Parameters of the fiducial model

The Cramèr-Rao inequality implies that $(F^{-1})_{ii}$ is the smallest variance in the parameter p_i .

The one sigma error for each of parameter is defined:

$$\boxed{\sigma_{p_i} \geq \sqrt{(F^{-1})_{ii}}}$$

z-values	$n_{\rm dens}$
$z = 0.6$	$n_{\rm dens} = 3.56 \times 10^{-3}$
$z = 0.8$	$n_{\rm dens} = 2.42 \times 10^{-3}$
$z = 1.0$	$n_{\rm dens} = 1.81 \times 10^{-3}$
$z = 1.2$	$n_{\rm dens} = 1.44 \times 10^{-3}$
$z = 1.4$	$n_{\rm dens} = 0.99 \times 10^{-3}$
$z = 1.6$	$n_{\rm dens} = 0.55 \times 10^{-3}$
$z = 1.8$	$n_{\rm dens} = 0.29 \times 10^{-3}$
$z = 2.0$	$n_{\rm dens} = 0.15 \times 10^{-3}$

Galaxy density at different redshift values from Euclid Red Book.

Values of the fiducial model:

$$h_0 = 0.7$$
$$\Omega_{m0} = 0.25$$
$$\Omega_{b0} = 0.0445$$
$$\Omega_{\Lambda 0} = 1 - \Omega_{m0}$$
$$\Omega_{de0} = \Omega_{\Lambda 0}$$
$$\Omega_{k0} = 0$$
$$w_0 = -0.95$$
$$w_1 = 0$$

Constraints on a scale-dependent bias from galaxy clustering

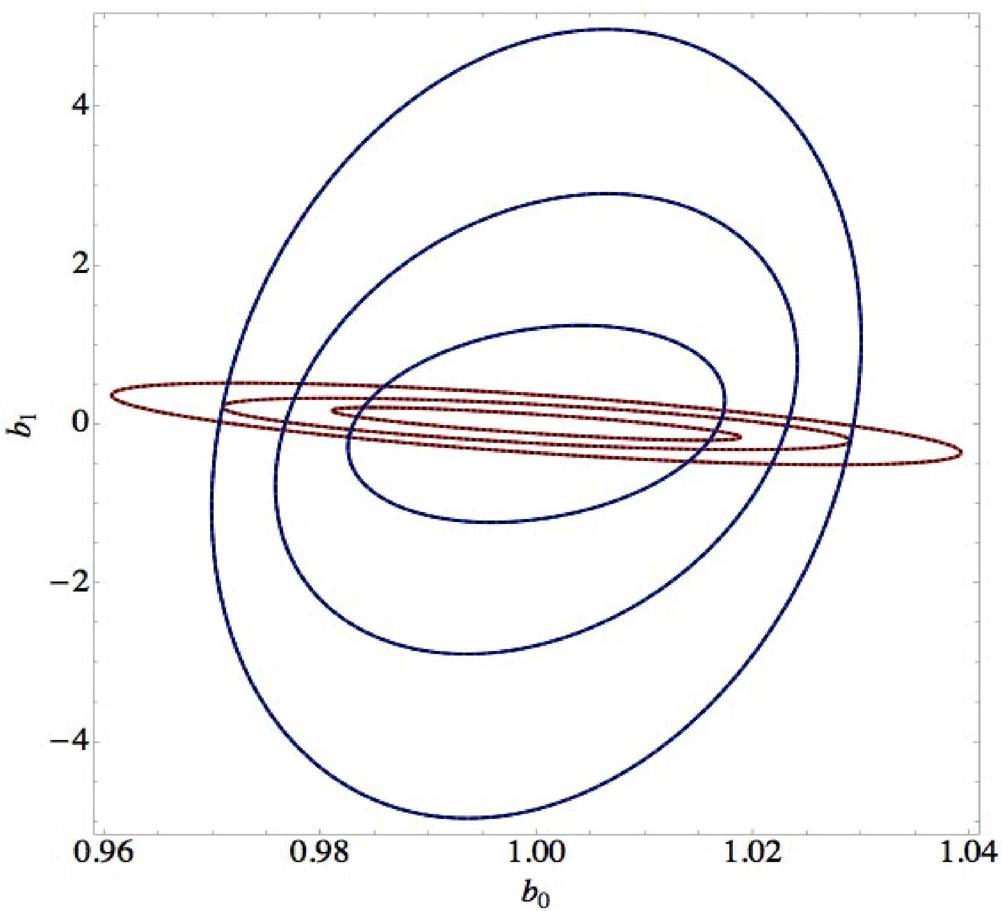
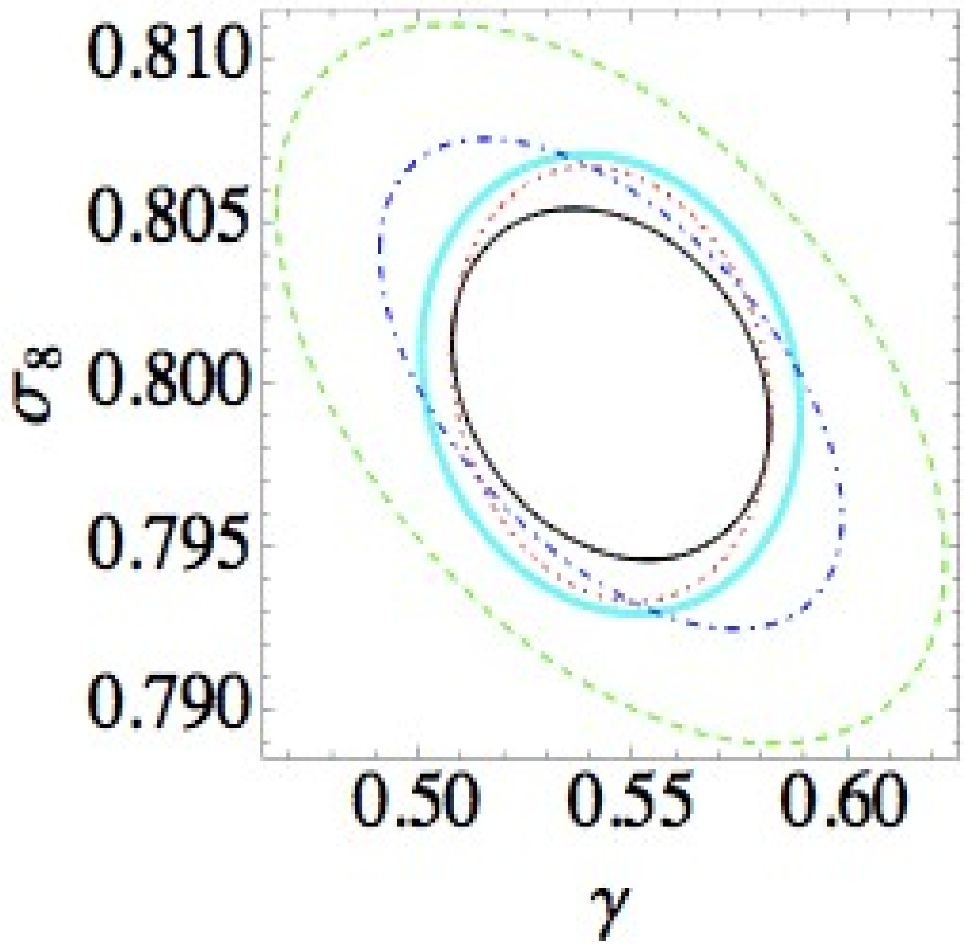


TABLE V: Errors on bias parameters for Type 1 fiducial models.

		FM1-PL				FM1-Q		
	$n = 0$	$n = 1$		$n = 2$				
z	σ_{b_0}	σ_{b_0}	σ_{b_1}	σ_{b_0}	σ_{b_1}	σ_{b_0}	σ_Q	σ_A
0.6	0.007	0.013	0.14	0.0081	1.2	0.017	3.04	0.35
0.8	0.008	0.013	0.13	0.0093	0.97	0.017	2.5	0.32
1.0	0.009	0.013	0.12	0.011	0.86	0.017	2.2	0.31
1.2	0.010	0.014	0.12	0.012	0.82	0.018	2.2	0.31
1.4	0.011	0.014	0.13	0.013	0.91	0.019	2.5	0.34
1.6	0.012	0.016	0.16	0.014	1.2	0.023	3.4	0.42
1.8	0.014	0.019	0.22	0.016	1.9	0.027	5.4	0.59
2.0	0.018	0.026	0.34	0.019	3.3	0.037	9.4	0.97

68% probability contours for the parameters b0 and b1 of the FM1-PL model.The dotted red line is the case with n = 1 while the dashed line in blue shows the case n = 2. The redshift bins are z = 0.6, 1.8, 2.0.



Error	$n=0$	FM1-PL $n=1$	$n=2$	FM1-Q
σ_h	0.036	0.038	0.037	0.039
σ_{Ω_m}	0.015	0.016	0.015	0.016
σ_{Ω_b}	0.0034	0.0036	0.0034	0.0036
σ_{n_s}	0.036	0.042	0.036	0.044
σ_γ	0.024	0.025	0.028	0.029
σ_{σ_8}	0.0036	0.0044	0.0045	0.0047

1-sigma errors on cosmological parameters for Type 1 f ducial models.

68 % probability contours for sigma8 and gamma. Black, continuos: standard scale-independent case, i.e. n = 0. Red, Dotted: FM1-PL with n = 1. Cyan, continuous: FM1-Q. Blue, Dot-Dashed: FM2-PL with n = 1. Green, dashed: FM2-Q.

Table of reference values for b0 and b1

$n_{ref}=1$

$z-values$	b_0	b_1
$z=0.6$	1.0525	0.669
$z=0.8$	1.0385	0.673
$z=1.0$	1.133	0.747
$z=1.2$	1.2175	0.988
$z=1.4$	1.355	1.0935
$z=1.6$	1.4875	1.2205
$z=1.8$	1.614	1.4015
$z=2.0$	1.754	1.4395

$n_{ref}=1.28$

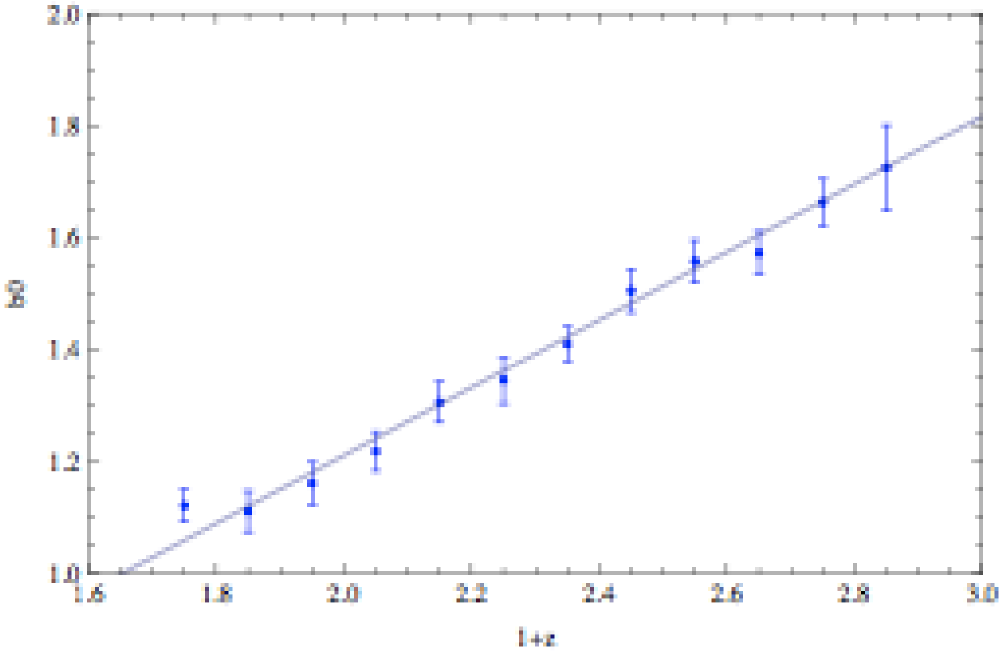
$z-values$	b_0	b_1
$z=0.6$	1.06	0.707
$z=0.8$	1.088	0.663
$z=1.0$	1.191	0.75
$z=1.2$	1.2985	0.9715
$z=1.4$	1.441	1.0635
$z=1.6$	1.5835	1.192
$z=1.8$	1.7195	1.399
$z=2.0$	1.8535	1.495

$n_{ref}=2$

$z-values$	b_0	b_1
$z=0.6$	1.1595	0.6685
$z=0.8$	1.1695	0.6825
$z=1.0$	1.277	0.7865
$z=1.2$	1.41	1.017
$z=1.4$	1.55	1.1235
$z=1.6$	1.706	1.251
$z=1.8$	1.879	1.4365
$z=2.0$	2.011	1.6505

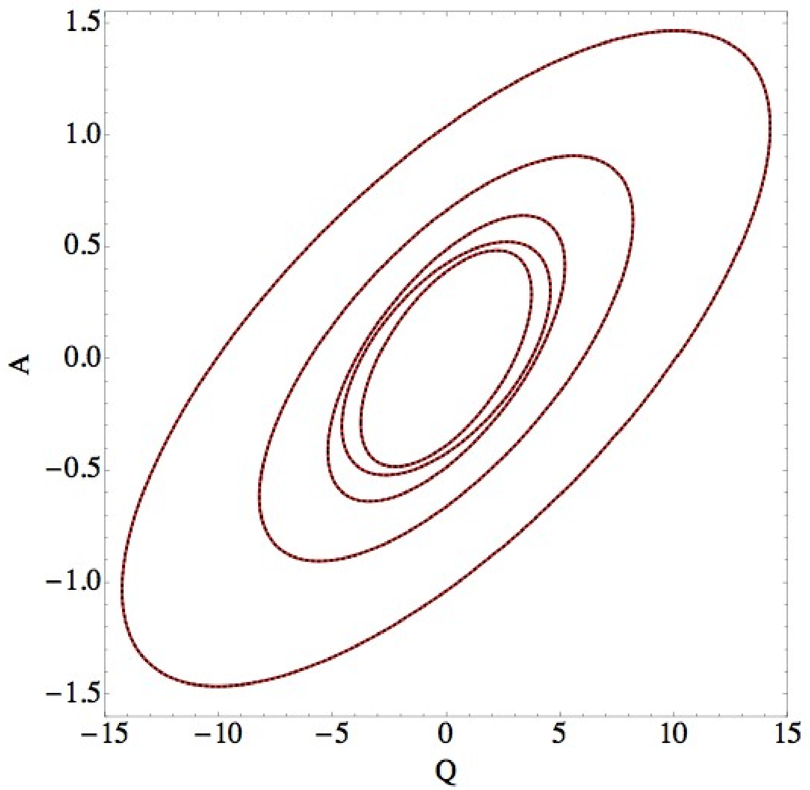
How we choose these values for the bias-parameters?

Fit based on the mock Durham catalogue from Euclid Consortium by Alex Merson

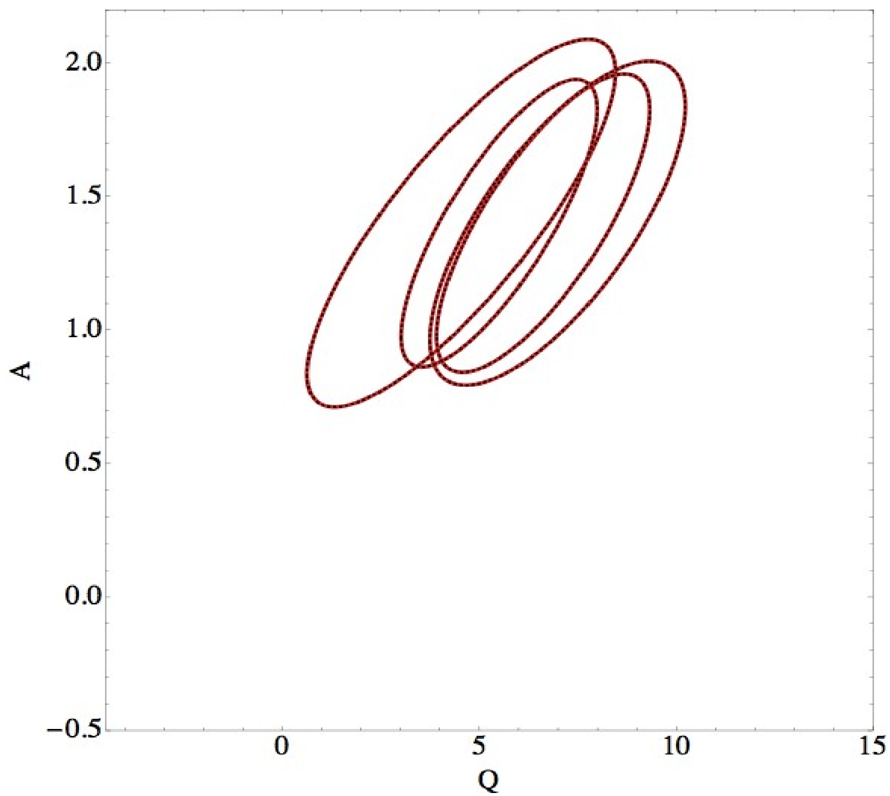


The clustering properties can be different at different values of the redshift...

Martina Corsi (Ph.D student at Roma-3 with Enzo Branchini)

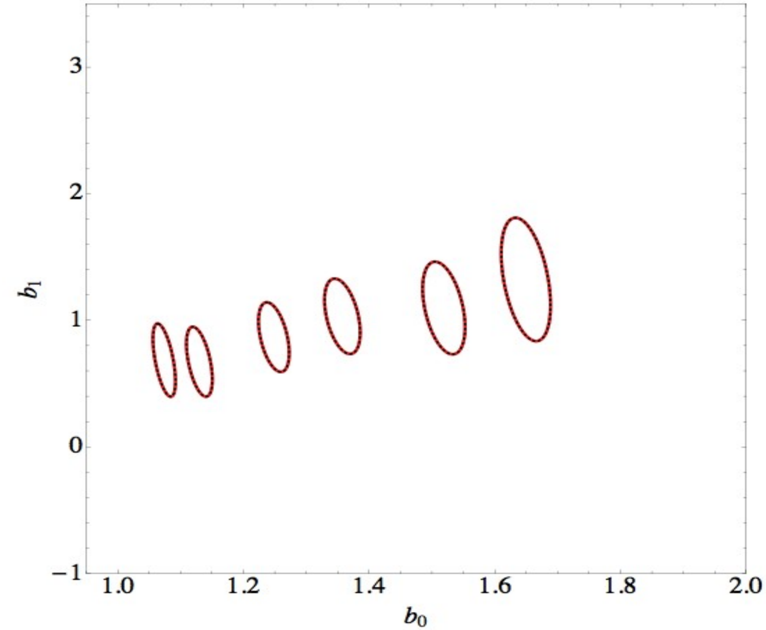


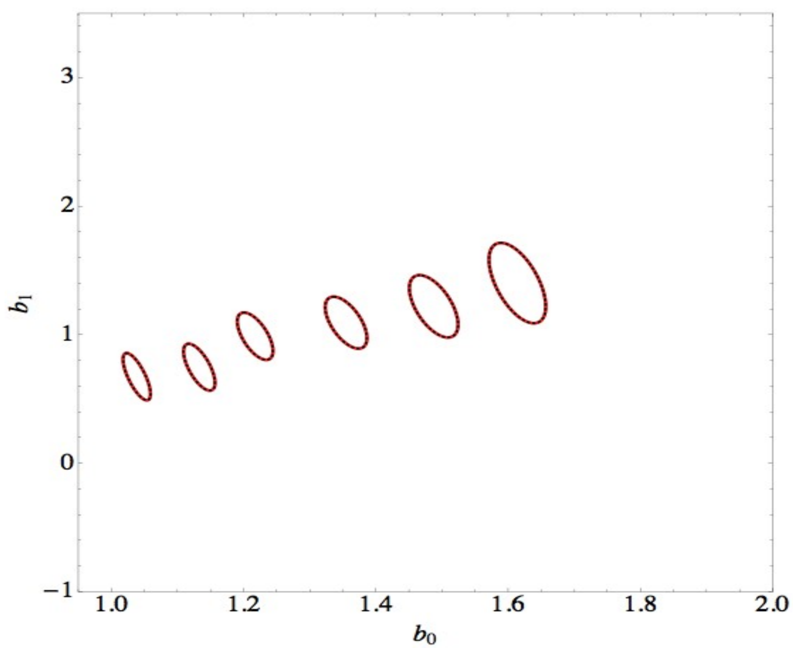
Contours plots for 68 % probability contours for the parameters A and Q of the FM1-Q model. We decided to plot only the bins z = 0.6, 0.8, 1.6, 1.8, 2.0, to improve clarity.

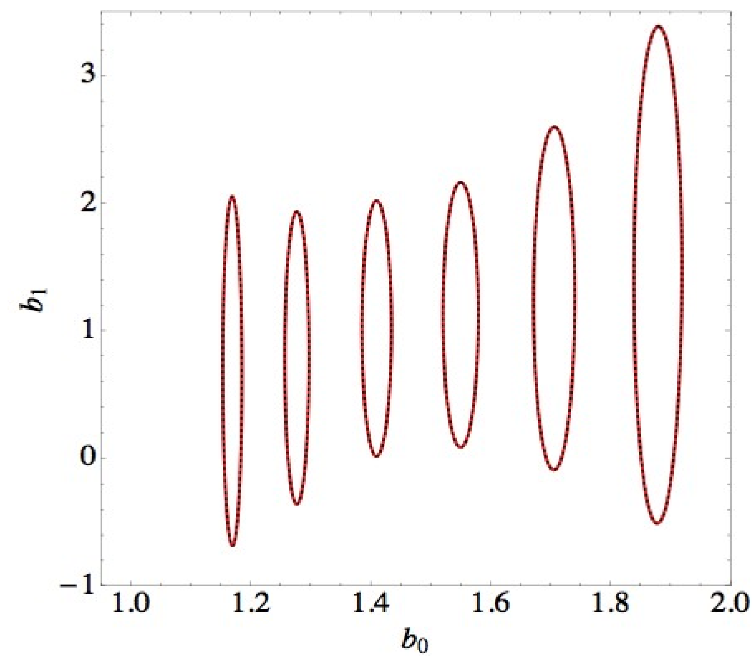


Contours plots for 68 % probability contours for the parameters A and Q of the FM2-Q model. We decided to plot only the bins z = 0.6, 0.8, 1.6, 1.8, 2.0, to improve clarity.

	FM2-PL						FM2-Q		
	$n=1$		$n=1.28$		$n=2$				
z	σ_{b_0}	σ_{b_1}	σ_{b_0}	σ_{b_1}	σ_{b_0}	σ_{b_1}	σ_{b_0}	σ_Q	σ_A
0.8	0.014	0.12	0.012	0.19	0.011	0.91	0.029	2.6	0.46
1.0	0.016	0.12	0.014	0.18	0.013	0.76	0.033	1.9	0.39
1.2	0.018	0.12	0.016	0.18	0.016	0.66	0.039	1.6	0.36
1.4	0.021	0.13	0.019	0.19	0.019	0.69	0.045	1.6	0.34
1.6	0.024	0.16	0.022	0.24	0.023	0.89	0.049	1.8	0.37
1.8	0.028	0.21	0.026	0.32	0.027	1.3	0.056	2.1	0.40







CONCLUSIONS:

- We found a substantial agreement with the present value of the fine structure constant (we constrain variations at max of 2,5% at 1-sigma from WMAP-5 years and less than 0.7% when combined with HST observations).

- Planck data improve the constraints on α/α_0 , with respect to those from WMAP-9 by a factor of about five. Our analysis of Planck data limits any variation in the fine structure constant from $z \approx 10^3$ to present day to be less than approximately 0.4%.

- There is no clear degeneracy between the early dark energy density parameter and the fine structure constant, however we can reach tighter constraints on these quantities from the next experiments.

- The linear bias parameter b0 can be determined within a few %. The relative error is rather insensitive to the hoice of the f ducial and slightly increases with the redshift. As expected, the errors increase with the number of free parameters in the model and therefore is larger in the Q Model than in the Power Law one. The accuracy with which one can estimate the bias parameters that describe the scale dependency depends on the bias model and on the f ducial.