

# Cosmological constraints on variations of the fine structure constant at the epoch of recombination

E Menegoni<sup>1</sup>, S Galli<sup>2,3</sup>, M Archidiacono<sup>4</sup>, E Calabrese<sup>5</sup> and A Melchiorri<sup>6</sup>

<sup>1</sup>The Institut für Theoretische Physik, University of Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany.

<sup>2</sup>Institut d'Astrophysique de Paris, UMR-7095 du CNRS, Universite' Pierre et Marie Curie, 98 bis bd Arago, 75014 Paris, France.

<sup>3</sup>Sorbonne Universite's, Institut Lagrange de Paris, 98 bis bd Arago, 75014 Paris, France

<sup>4</sup>Department of Physics and Astronomy University of Aarhus, DK-8000 Aarhus C, Denmark.

<sup>5</sup>Sub-department of Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH, UK.

<sup>6</sup>Dipartimento di Fisica, Universita' La Sapienza, P. le A. Moro 2, 00185 Roma, Italy.

E-mail: e.menegoni@thphys.uni-heidelberg.de

**Abstract.** In this brief work we investigate any possible variation of the fine structure constant at the epoch of recombination. The recent measurements of the Cosmic Microwave Background anisotropies at arcminute angular scales performed by the ACT and SPT experiments are probing the damping regime of Cosmic Microwave Background fluctuations. We study the role of a mechanism that could affect the shape of the Cosmic Microwave Background angular fluctuations at those scales, namely a change in the recombination process through variations in the fine structure constant  $\alpha$ .

## 1. Introduction

The recent observations from Cosmic Microwave Background (CMB hereafter) satellite, balloon-borne and ground based experiments ([1]-[4]), galaxy redshift surveys [5] and luminosity distance measurements, have fully confirmed the theoretical predictions of the standard  $\Lambda$ CDM cosmological model. This not only allows to place stringent constraints on the parameters of the model but can be fruitfully used to constrain non standard physics at the fundamental level. The  $\Lambda$ CDM model assumes the validity of General Relativity on cosmological scales, as well as the physics of the standard model of particle physics. One possible extension, which may have motivations in fundamental physics, is to consider variations of dimensionless constants [6, 7]. Possible changes in the recombination process have been investigated by several authors. Another possible mechanism is based on the hypothesis of a change in the fundamental constants of nature, specifically the fine structure constant,  $\alpha$  ([8]-[11]).

In this framework, an interesting discrepancy with the expectations of the standard model has recently been discovered in the small CMB scale measurements of the ACT [2] and SPT [4] experiments. The effective number of relativistic degrees of freedom  $N_{eff}$  (for a review on  $N_{eff}$  see [12]) has been reported as higher (at more than two standard deviations) than the expected standard value of  $N_{eff} = 3.046$  (the little deviation from  $N_{eff} = 3$  takes into account effects



from the non-instantaneous neutrino decoupling from the primordial photon-baryon plasma, see for more details [13]). This discrepancy has been confirmed by several recent analyses of the ACT and SPT datasets (see e.g. [14]-[20]). We analyse this issue by obtaining constraints in the framework of a non-standard recombination process, in which variations of the fine structure constant are permitted.

## 2. Method and Analysis

The analysis method we adopted is based on the publicly available Monte Carlo Markov Chain package `cosmomc` [21] with a convergence diagnostic done through the Gelman and Rubin statistic. A COSMOMC analysis [21] was performed combining the following CMB datasets: WMAP7 [1], ACT [2], ACBAR [3], SPT [4]: we analyzed datasets out to  $l_{\max} = 3000$ , and we include also information on dark matter clustering by using the SDSS-DR7 luminous red galaxy sample [5]. We impose a prior on the Hubble parameter based on the last Hubble Space Telescope observations [22].

We sample the following six-dimensional standard cosmological parameters, adopting flat priors on them: the baryon and cold dark matter densities  $\Omega_b h^2$  and  $\Omega_c h^2$ , the Hubble constant  $H_0$ , the optical depth to reionization  $\tau$ , the scalar spectral index  $n_s$ , and the overall normalization of the spectrum  $A_S$  [23]. In order to perform this analysis, we consider purely adiabatic initial conditions and we impose spatial flatness. The variations in the fine structure constant  $\alpha/\alpha_0$  where  $\alpha_0$  is the current, local, value are implemented in the code by modifying the RECFAST recombination subroutine ([24] -[27]) following the procedure described in [28].

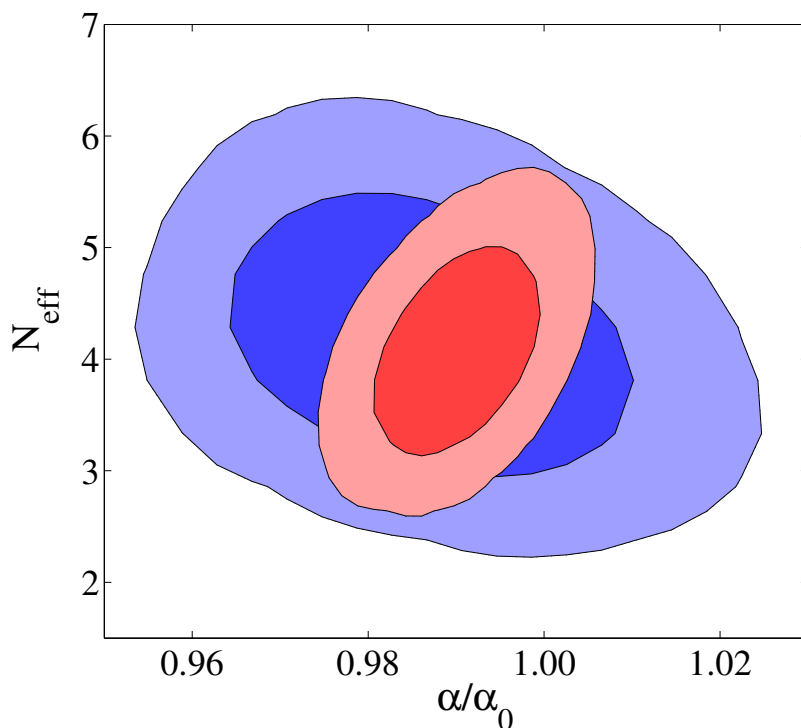
**Table 1.** In the table are reported the results for the three analyses described in the text by using a MCMC estimation of the cosmological parameters from the dataset described in the Analysis section. Upper bounds at 95% c.l. are reported for foregrounds parameters [23].

<i>Parameter</i>	$\alpha/\alpha_0$	$\alpha/\alpha_0 + N_{eff}$	$\alpha/\alpha_0 + N_{eff} + Y_p$
$\Omega_b h^2$	$0.0218 \pm 0.0004$	$0.0224 \pm 0.0005$	$0.0223 \pm 0.0007$
$\Omega_c h^2$	$0.1144 \pm 0.0034$	$0.1302 \pm 0.0095$	$0.1303 \pm 0.0094$
$\tau$	$0.086 \pm 0.014$	$0.088 \pm 0.015$	$0.088 \pm 0.016$
$H_0$	$68.9 \pm 1.4$	$71.52 \pm 2.0$	$71.8 \pm 2.1$
$\alpha/\alpha_0$	$0.984 \pm 0.005$	$0.99 \pm 0.006$	$0.987 \pm 0.014$
$n_s$	$0.976 \pm 0.013$	$0.991 \pm 0.015$	$0.992 \pm 0.016$
$\log[10^{10} A_s]$	$3.193 \pm 0.037$	$3.169 \pm 0.04$	$3.167 \pm 0.042$
$A_{SZ}$	$< 2.$	$< 2.$	$< 2.$
$A_C$	$< 16.$	$< 15.8$	$< 14.8$
$A_P$	$< 24.7$	$< 24.9$	$< 22.4$
$\Omega_\Lambda$	$0.7137 \pm 0.007$	$0.702 \pm 0.0094$	$0.704 \pm 0.013$
$Age/Gyr$	$13.76 \pm 0.24$	$13.18 \pm 0.38$	$13.15 \pm 0.37$
$\Omega_m$	$0.2863 \pm 0.007$	$0.298 \pm 0.0094$	$0.296 \pm 0.013$
$\sigma_8$	$0.836 \pm 0.023$	$0.862 \pm 0.028$	$0.859 \pm 0.034$
$z_{re}$	$10.7 \pm 1.2$	$11. \pm 1.3$	$11. \pm 1.3$
$N_{eff}$	—	$4.10^{+0.24}_{-0.29}$	$4.19^{+0.31}_{-0.35}$
$Y_p$	—	—	$0.215 \pm 0.096$
$\chi^2_{min}$	7600.2	7596.8	7596.5

Also variations in the effective number of relativistic degrees of freedom  $N_{eff}$  and the

primordial Helium abundance  $Y_p$ , otherwise fixed at the values  $N_{eff} = 3.046$  and  $Y_p = 0.24$ , are included. Since we are varying also the Helium abundance, we considered variations in  $\alpha$  also in the process of Helium recombination. A  $\sim 5\%$  change of  $\alpha$  for Helium recombination changes the CMB angular spectra by less than  $0.5\%$  up to  $l = 1500$ . We focus on constraining the variations of the fine structure constant at the epoch of Recombination and we fixed the fine structure constant to the local standard value  $\alpha = \alpha_0$  in the epoch of reionization [23].

The dataset considered prefers a value of  $\alpha/\alpha_0$  smaller than unity at more than two standard deviations when both the  $N_{eff}$  and  $Y_p$  are kept fixed at their standard values as shown in the table 1. This result was to be expected since is clearly driven by data preference for larger values of  $N_{eff}$ . Allowing for variations in  $N_{eff}$  significantly shifts the best fit value for  $\alpha/\alpha_0$ , causing it to be now consistent with the standard value.



**Figure 1.** Likelihood contour plot for  $\alpha/\alpha_0$  vs  $N_{eff}$  at 68% c.l. and 95% c.l. in the case of  $Y_p = 0.24$  (red smaller contours) and  $Y_p$  allowed to vary (blue larger contours).

Allowing for variation in the fine structure constant enlarges the error bars on  $N_{eff}$  of about  $\sim 30\%$  but does not shift the best fit value towards the standard result. The largest effect on  $\alpha$  comes however when also the helium abundance  $Y_p$  is let free to vary: the errors on  $\alpha$  are almost doubled [23].

We can better understand the impact of  $Y_p$  on the determination of  $\alpha/\alpha_0$  by looking at figure 1, where we plot the 2-D likelihood contours in the  $\alpha/\alpha_0$ - $N_{eff}$  plane in the cases of  $Y_p = 0.24$  and free  $Y_p$ . In the case in which we keep the helium abundance fixed there is a clear but moderate degeneracy between  $\alpha/\alpha_0$  and  $N_{eff}$ , this is because when  $N_{eff}$  is increased the Hubble parameter at recombination increases. By decreasing the free electron density at recombination we recover the damping scale at the same value fixed by observations [23].

The degeneracy changes direction by varying the Helium abundance, in fact, a larger value for  $Y_p$  produces a large free electron fraction at recombination and a smaller value for  $N_{eff}$  is needed to keep the damping scale small. On the other hand a large value for  $Y_p$  needs large values for  $\alpha$ . So now small values of  $N_{eff}$  are more compatible with observations when  $\alpha$  is larger.

The other cosmological parameters are effected in different ways when we let vary the value of  $N_{eff}$  and Helium abundance  $Y_p$ : in particular the value of the "standard" matter is a little bit larger (both  $\Omega_b h^2$  and  $\Omega_c h^2$  see table [1]) respect to the case in which  $N_{eff}$  and  $Y_p$  are kept fixed, and the value of  $\Omega_\Lambda$  is smaller (table [1]), furthermore, the recombination process happens at higher value of the redshift  $z_{re}$ , meaning that the formation of neutral hydrogen is accelerated respect to the standard case.

### 3. Conclusions

We presented new constraints on variation of the fine structure constant using the recent CMB anisotropy measurements from the ACT and SPT experiments, combined with other cosmological datasets. Assuming the standard three active neutrino framework and a primordial Helium abundance of  $Y_p = 0.24$  the current data favours a lower value for the fine structure constant at more than two standard deviations with  $\alpha/\alpha_0 = 0.984 \pm 0.005$ . When the number of relativistic degrees of freedom is let to vary freely, the standard value is consistent with the data considered, while varying the primordial Helium abundance further enlarges the error bars.

The recent Planck data delivered on March 2013 shows an improvement on the constraints on the variations of the fine structure constant by a factor of about five if compared with those from WMAP-9 data. The analysis of Planck data limits any variation in the fine structure constant from the epoch of recombination to the present day to be less than approximately 0.4% (for more details see [29]).

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