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Constraints on variation in α and m_e from WMAP 7-year data

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ABSTRACT

Aims. We update the constraints on the time variation of the fine structure constant α and the electron mass m_e, using the latest CMB data, including the 7-yr release of WMAP.
Methods. We made statistical analyses of the variation of each one of the constants and of their joint variation, together with the basic set of cosmological parameters. We used a modified version of CAMB and COSMOMC to account for these possible variations.
Results. We present bounds on the variation of the constants for different data sets, and show how results depend on them. When using the latest CMB data plus the power spectrum from Sloan Digital Sky Survey LRG, we find that $\alpha/\alpha_0 = 0.986 \pm 0.007$ at 1-σ level, when the 6 basic cosmological parameters were fitted, and only variation in α was allowed. The constraints in the case of variation of both constants are $\alpha/\alpha_0 = 0.986 \pm 0.009$ and $m_e/m_{e0} = 0.999 \pm 0.035$. In the case of only variation in m_e, the bound is $m_e/m_{e0} = 0.964 \pm 0.025$.

Key words. Cosmology: cosmic background radiation; Cosmology: cosmological parameters; Cosmology: early Universe

1. Introduction

The variation of fundamental constants over cosmological time scales is a prediction of theories that attempt to unify the four interactions in nature, like string derived field theories, related brane-world theories and Kaluza-Klein theories (see Uzan (2003) and references therein). Many observational and experimental efforts have been made to put constraints on such variations. Most of the reported data are consistent with null variation of fundamental constants. Although there have been recent claims for time variation of the fine structure constant (α) and of the proton to electron mass ratio ($\mu = \frac{m_p}{m_e}$) (Murphy et al. 2003; Reinhold et al. 2006), independent analyses of similar data give null results (Srianand et al. 2004; King et al. 2008; Thompson et al. 2009; Malec et al. 2010). On the other hand, a recent analysis of ammonia spectra in the Milky Way suggests a spatial variation of μ (Molaro et al. 2009; Levshakov et al. 2009).

Unifying theories predict variation of all coupling constants, being all variations related in general to the rolling of a scalar field. Therefore, the relationship between variations of coupling constants depends on the unifying model. In this paper we adopt a phenomenological approach and analyse the possible variation of α and/or m_e at the time of the formation of neutral hydrogen without assuming any theoretical model. Nakashima et al. (2010) have considered also the variation in the proton mass (m_p). This quantity affects mainly the baryon mass density and the baryon number density. Their results confirm the strong degeneracy with the baryon density. Therefore, we will not consider the variation in m_p in this work.

Cosmic microwave background radiation (CMB) is one of the most powerful tools to study the early universe and in particular, to put bounds on possible variations in the fundamental constants between early times and the present. Changing α or m_e at recombination affects the differential optical depth of the photons due to Thompson scattering, changing therefore Thompson scattering cross section and the ionization fraction. The signatures on the CMB angular power spectrum due to varying fundamental constants are similar to those produced by changes in the cosmological parameters, i.e. changes in the relative amplitudes of the Doppler peaks and a shift in their positions. Moreover, an increment in α or m_e decreases the high-ℓ diffusion damping, which is due to the finite thickness of the last-scattering surface, and thus, increases the power on very small scales (Kaplinghat et al. 1999; Hannestad 1999).

Recent analysis of CMB data (earlier than the WMAP seven-year release) including a possible variation in α have been performed by Scóccola et al. (2008, 2009); Menegoni et al. (2009); Nakashima et al. (2010); Martins et al. (2010), and including a possible variation in m_e have been performed by Scóccola et al. (2008, 2009); Nakashima et al. (2010).

In our previous works, we have also analyzed the dependence of the updated recombination scenario (that includes the recombination of helium, and was implemented in RECFAST following Wong et al. (2008)) on α and m_e, and

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show that these dependencies are not relevant for WMAP data.

In this paper we adopt a phenomenological approach and analyse the possible variation in α and/or m_e without assuming any theoretical model. We use WMAP seven-year release, together with other recent CMB data. We also combine CMB data with other cosmological data sets: i) the power spectrum of the Sloan Digital Sky Survery DR7 LRG, ii) a recent constraint of the Hubble constant H_0 with data from the Hubble Space Telescope. In section 2 we describe the method and data sets we used in the statistical analysis. We present and discuss our results in section 3. We conclude in section 4.

2. Statistical Analysis

We performed our statistical analysis by exploring the parameter space with Monte Carlo Markov chains generated with the CosmoMC code (Lewis & Bridle 2002) which uses the Boltzmann code CAMB (Lewis et al. 2000) and RECFAST to compute the CMB power spectra. We modified them in order to include the possible variation in α and m_e at recombination.

We use data from the WMAP 7-year temperature and temperature-polarization power spectrum (Larson et al. 2010), and other CMB experiments such as CBI (Readhead et al. 2004), ACBAR (Kuo et al. 2004), BOOMERANG (Piacentini et al. 2006; Jones et al. 2006), BICEP (Chiang et al. 2009) and QUAD (Brown et al. 2009). In order to reduce degeneracies of the cosmological parameters, we combine the CMB data sets with other cosmological data: i) the power spectrum of the Sloan Digital Sky Survey LRG (Reid et al. 2009) and ii) the recent constraint on the Hubble constant, $H_0 = 74.2 \pm 3.6$ km s^{-1} Mpc^{-1}, presented by Riess et al. (2009). We did not consider supernovae type I data, because these data (see Kowalski et al. (2008) for example) are obtained assuming that the constants have their present values at the time corresponding to the observing redshift. However, if at high redshift α has a value different than the present one, the light curves of the SNs could be affected by these variations. Since there is no agreement in the scientific community about the claimed variations at redshifts $0.22 < z < 3$, and the supernovae data set includes data at redshifts $0.001 < z < 1.4$, we decided not to include this data set in our analysis.

We have considered a spatially-flat cosmological model with adiabatic density fluctuations, and the following parameters:

$$P = \left(\Omega_b h^2, \Omega_{CDM} h^2, \Theta, \tau, \frac{\alpha}{\alpha_0}, \frac{m_e}{m_{e0}}, n_s, A_s\right)$$

where $\Omega_b h^2$ is the baryon density and $\Omega_{CDM} h^2$ is the dark matter density, both in units of the critical density; Θ gives the ratio of the co-moving sound horizon at decoupling to the angular diameter distance to the surface of last scattering (and is related to the Huble constant H_0); τ is the reionization optical depth; n_s the scalar spectral index; and A_s is the amplitude of the density fluctuations.

We have performed statistical analyses using the data mentioned above and considering variation of only one constant (α or m_e) and variation of both constants. We present our results in the next section.

3. Results and Discussion

Results for the variation of the constants in the case when only one constant is allowed to vary are shown in Table 1 and for the case when both are allowed to vary, are presented in Table 2. The obtained values are consistent with no variation of α or m_e at recombination. The obtained errors are at the same percent level than those obtained by Scóccola et al. (2008, 2009); Menegoni et al. (2009); Martins et al. (2010) using WMAP-5 year release. The parameter space has higher dimension when both constants are allowed to vary. Therefore, limits on α and m_e are more stringent in the case were only one constant is allowed to vary. Results for the cosmological parameters have similar values for all of the analyses. Therefore, we only report the values obtained in the case where both α and m_e were allowed to vary and the data from CMB and the power spectrum of the SDSS DR7 were considered (see Table 3). The mean values and errors for the cosmological parameters are in agreement within 1-σ with those obtained by the WMAP collaboration (Larson et al. 2010) with no variation of fundamental constants.

Table 1. Mean values and 1-σ errors for the analysis with variation of only α, and only m_e.

Data set	α/α_0	m_e/m_{e0}
all CMB	$0.987^{+0.010}_{-0.009}$	$0.983^{+0.067}_{-0.066}$
all CMB + H_0	$0.998^{+0.006}_{-0.007}$	$1.012^{+0.017}_{-0.018}$
all CMB + Sloan $P(k)$	0.986 ± 0.007	0.964 ± 0.025

Table 2. Mean values and 1-σ errors for the analysis with the joint variation of α and m_e.

Data set	α/α_0	m_e/m_{e0}
all CMB	0.986 ± 0.010	$1.015^{+0.075}_{-0.074}$
all CMB + H_0	0.986 ± 0.010	1.044 ± 0.029
all CMB + Sloan $P(k)$	0.986 ± 0.009	0.999 ± 0.035

In Fig. 1 we show the 68% and 95% c.l. constraints for α/α_0 versus H_0, for the analysis of the variation of α alone. The results correspond to different data sets: all the CMB data alone; all the CMB data plus the H_0 prior taken from Riess et al. (2009); and all the CMB data plus the power spectrum from Sloan Digital Sky Survery DR7 LRG (Reid et al. 2009). The large degeneracy between α/α_0 and H_0 from CMB data is reduced when another data set is added. However, since the value of H_0 obtained from the extra data sets are different, the obtained constraint on α/α_0 depends strongly on the data chosen for the analysis. Nevertheless, the results are consistent within 1-σ.

In Fig. 2 we present the constraints for α/α_0 versus τ and in Fig. 3 we present the constraints for α/α_0 versus $\Omega_b h^2$. There are degeneracies among these parameters. The contours change because of the different mean value of α/α_0 obtained with different data sets.

Table 3. Mean values and 1σ errors for the cosmological parameters using all CMB data and the SDSS DR7 power spectrum. H_0 is in units of km s^{-1} Mpc^{-1}.

parameter	all CMB + SDSS
$\Omega_b h^2$	$0.02195^{+0.00067}_{-0.00068}$
$\Omega_{CDM} h^2$	$0.1070^{+0.0065}_{-0.0065}$
τ	$0.087^{+0.006}_{-0.007}$
n_s	$0.971^{+0.013}_{-0.013}$
A_s	$3.097^{+0.035}_{-0.036}$
H_0	$64.3^{+4.3}_{-4.4}$

Fig. 1. 68% and 95% c.l. constraints for α/α_0 versus H_0, for the analysis of the variation of α alone. Results from different data sets.

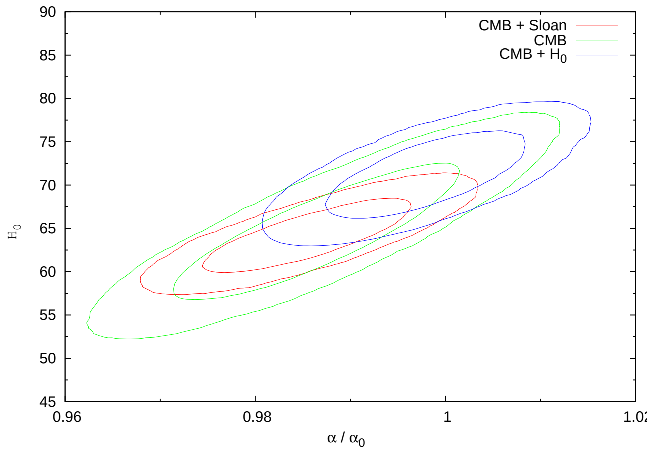
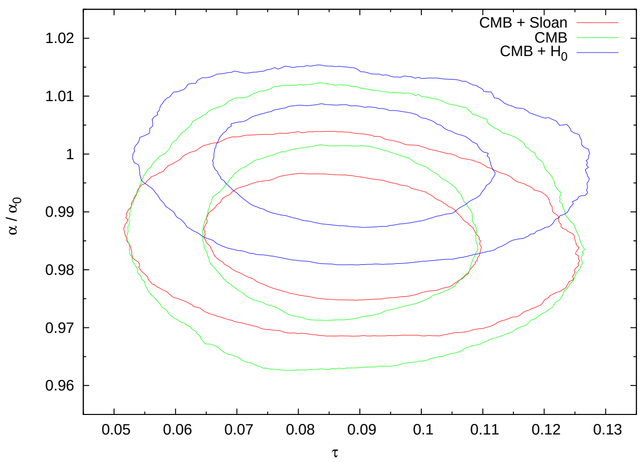
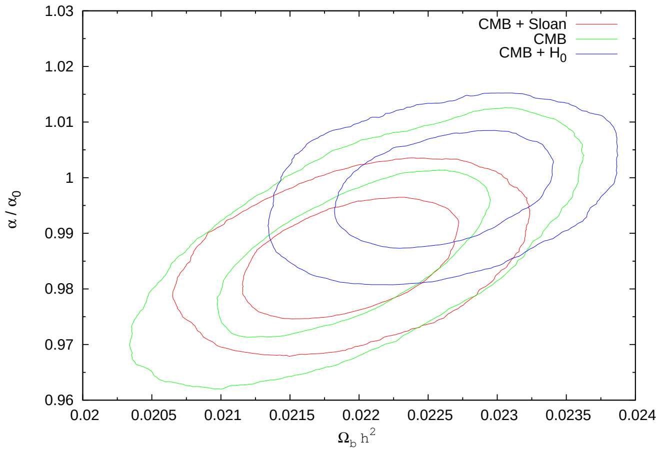


Fig. 2. 68% and 95% c.l. constraints for α/α_0 versus τ, for the analysis of the variation of α alone. Results from different data sets.



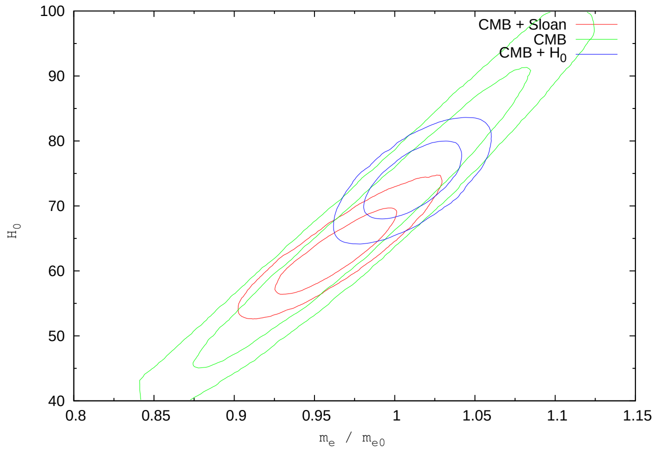
In Fig. 4 we present the result for the case where only m_e was allowed to vary. The degeneracy between m_e/m_{e0} and

Fig. 3. 68% and 95% c.l. constraints for α/α_0 versus $\Omega_b h^2$, for the analysis of the variation of α alone. Results from different data sets.



H_0 is larger than between α/α_0 and H_0, making impossible to find reliable constraints using CMB data alone. When another data set is added, the bounds result tighter, but the mean value for m_e/m_{e0} depends strongly on which data set was added. Results are marginally consistent at 1-σ.

Fig. 4. 68% and 95% c.l. constraints for m_e/m_{e0} versus H_0, for the analysis of the variation of m_e alone. Results from different data sets.



The constraints on m_e/m_{e0} versus τ are shown in Fig. 5, and on m_e/m_{e0} versus $\Omega_b h^2$ are shown in Fig. 6. In both cases, the results depend on the data set added to CMB data in the statistical analysis.

In Fig. 7 we show the posterior distribution for α/α_0 and $m_e/(m_e)_0$, for the case of joint variation of these quantities, marginalized over the cosmological parameters. The results correspond to different data sets. The difference in the contours is mainly due to the large degeneracy of m_e and H_0, and the different H_0 values derived from the Sloan power spectrum and from the H_0 prior. We see that the

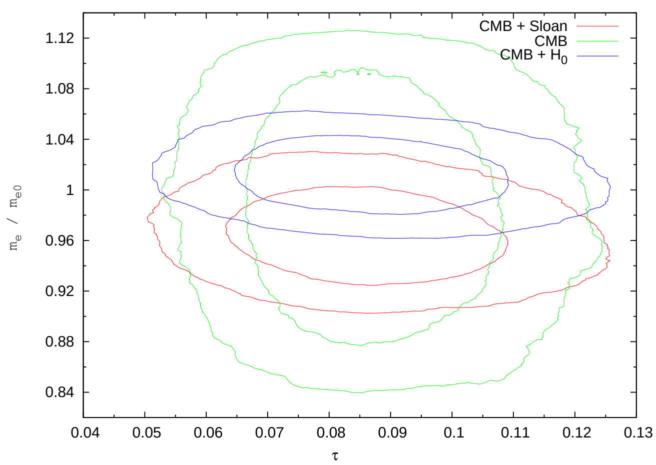


Fig. 5. 68% and 95% c.l. constraints for m_e/m_{e0} versus τ, for the analysis of the variation of m_e alone. Results from different data sets.

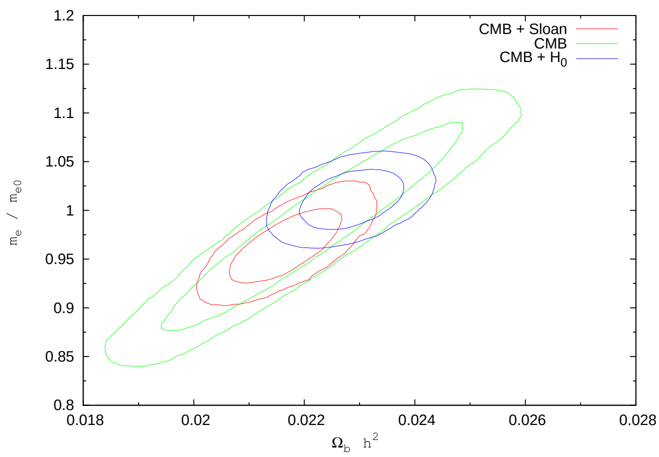


Fig. 6. 68% and 95% c.l. constraints for m_e/m_{e0} versus $\Omega_b h^2$, for the analysis of the variation of m_e alone. Results from different data sets.

mean value of m_e is more affected than the mean value of α. These results can also be seen in Table 2.

A variation of α or m_e affects the recombination scenario (see Scóccola et al. (2009) for example). As a consequence, the angular diameter distance at recombination is modified if any of these constants varies. This results in a change in the Doppler peak positions and heights (see Kaplinghat et al. (1999) for example). This explains the degeneracy between α and m_e shown in Fig. 7 and confirmed by the correlation coefficient. On the other hand, the degeneracy between α or m_e with the baryon mass density or the Hubble constant can be explained since these effects are similar to a change in the cosmological parameters.

4. Conclusions

In this paper we have updated the constraints on the time variation of the fine structure constant α and the electron

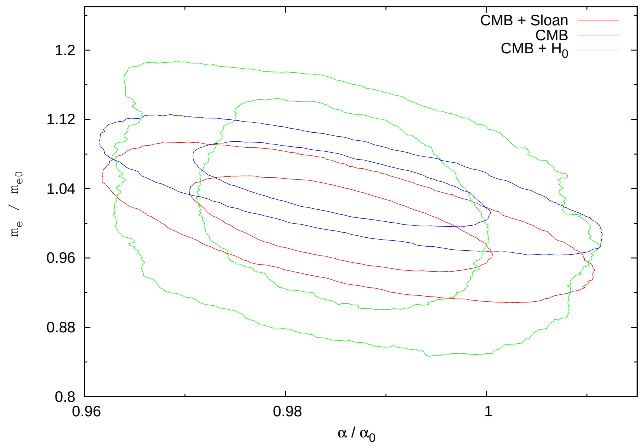


Fig. 7. 68% and 95% c.l. constraints for the joint variation of α and m_e from different data sets.

mass m_e during recombination epoch, using the latest CMB data, including the 7-yr release of WMAP. We perform several statistical analyses adding two different data sets; the H_0 prior taken from Riess et al. (2009); and the power spectrum from Sloan Digital Sky Survery DR7 LRG (Reid et al. 2009). The bounds on the variation of the constants are tighter than previous results because of the higher precision of the new data used in this work.

Our results show no variation of the constants at recombination time. We also emphasize that the constraints depend strongly on which data set we choose in the analysis, due to the large degeneracy between α or m_e and H_0. Yet, the results are consistent within 1-σ.

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