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BBN as Probe of Fundamental Physics

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1. Introduction

The primordial Universe provides a laboratory to probe fundamental physics at high energies. Relics from those early epochs, such as the light elements synthesized during primordial Big Bang Nucleosynthesis (BBN) (Burles et al., 2001; Eidelman et al., 2004; Olive et al., 2000; Wagoner et al., 1967) when the Universe was only a few minutes old, and the Cosmic Microwave Background (CMB) photons, last scattered when the protons and electrons recombined some 400 thousand years later, represent powerful probes of the high energy phenomena pointing beyond the standard models of cosmology, particle physics and general relativity (Boesgaard & Steigman, 1985; Steigman et al., 1977; Steigman, 2007).

During its earlier evolution the Universe was hot and dense. The combination of high temperature and density ensures that collision rates are very high during early epochs, guaranteeing that all particles were in equilibrium at sufficiently early times. As the Universe expands and cools, interaction rates decline and, depending on the strength of their interactions, different particles depart from equilibrium at different epochs.

At a temperature of few MeV, the neutrino interaction rates become lower than the Hubble expansion rate, decoupling from the CMB photons and $e^{\pm}$ pairs present at that time. However, electron neutrinos (and antineutrinos) continue to interact with the baryons through the weak interactions until the Universe where few seconds old and the temperature has dropped below MeV. The interactions among neutrons, protons and $e^{\pm}$ continue to influence the ratio of neutron to proton number densities, tracking its equilibrium value. After electrons, neutrons and protons combine to form neutral atoms at recombination, the CMB photons propagate freely. This occurs when the Universe is some 400 thousand years old. The relic photons from this epoch redshifted to the currently observed CMB black body temperature $T_{cmb} = 2.725$ K.

Predictions of the abundances of the light elements as D,^{3}He, ^{4}He and ^{7}Li synthesized at the BBN epoch are in good agreement with the primordial abundances inferred from observational data, which validates the Standard Big Bang Nucleosynthesis (SBBN).

The primordial abundances of the relic nuclei produced during SBBN depend on the baryon number density and on the Hubble expansion rate of the Universe. At the same time, the shape and amplitude of the CMB anisotropy angular power spectra at the time of recombination depend on the same parameters. One of the key cosmological tests in understanding the cosmological dynamics between BBN and recombination is the determination of baryon energy density mass fraction, $\Omega_b h^2$, at these two different epochs.

The abundance of baryons, η_{10}, is related to the number density of baryons, n_B, and the number density of CMB photons, n_γ, through: $\eta_{10} = 10^{10}(n_B/n_\gamma)$. The baryon energy density mass fraction influences the growth rate of the density perturbation through its impact on the Hubble expansion rate. It is convenient to express η_{10} in terms of this two parameters as: $\eta_{10} = 274\,\Omega_b h^2$, where h is the reduced Hubble constant at the present time ($h = H_0/100$ km s^{-1} Mpc^{-1}). During expansion of the Universe, n_B and n_γ decrease but remain unchanged in a given comoving volume. Therefore, the value of η_{10} measured at BBN epoch and at recombination epoch should be the same.

Among the nuclides synthesized at the BBN epoch, deuterium is the better indicator of the primordial baryon abundance since no significant amounts of deuterium are synthesized after BBN (Epstein et al., 1976). The measurement of the QSO Absorption Lines Systems (QSOALS) leads to the determination of the primordial deuterium abundance (Pettini et al., 2008) from which the infered baryon abundance is $\eta_{10}(BBN) = 5.80^{+0.27}_{-0.28}$ ($\Omega_b h^2 = 0.0212 \pm 0.0010$).

The analysis of WMAP 7-year data (Komatsu et al., 2009) provides an independent determination of the baryon abundance $\eta_{10}(CMB) = 6.190 \pm 0.145$ ($\Omega_b h^2 0.02260 \pm 0.00053$).

The two independent determinations are in good agreement, differing by only 1.3σ.

BBN also provides powerful constraints on possible deviations from the standard cosmology and on new physics beyond the Standard Model (SM) particle physics (Sarkar, 1996). Many non-SBBN models introduce new free parameters in addition to the baryon energy density parameter. Most of these models assume either non-standard contribution to the total energy density, or a lepton asymmetry. This paper aims to place constraints on parameters of two types of non-SBBN models by using most of the present cosmological data complemented with the BBN predictions on the ^{4}He abundance.

These models include: i) the leptonic asymmetric cosmological models, challenging the standard neutrino sector and ii) the Higgs inflation models, challenging the electroweak sector of the SM of particle physics.

2. Challenging the neutrino physics

The radiation budget of the Universe relies on a strong theoretical prejudice: apart from the CMB photons, the relativistic background would consist of neutrinos and of possible contributions from other relativistic relicts. The main constraints on the radiation energy density come either from the very early Universe, where the radiation was the dominant source of energy, or from the observation of cosmological perturbations which carry the information about the time equality between matter and radiation.

The primordial abundance of the light elements depends also on the radiation energy density at the BBN epoch (energy density of order MeV^4), usually parametrized by the effective number of relativistic neutrino species, N_{eff}. Meanwhile, the number of active neutrino flavors have been fixed by Z^0 boson decay width to $N_\nu = 2.944 \pm 0.012$ (Eidelman et al., 2004), while the combined study of the incomplete neutrino decoupling and the QED corrections indicate that the number of relativistic neutrino species is $N_{eff} = 3.046$ (Mangano et al., 2002). Any departure of N_{eff} from this last value would be due to non-standard neutrino features or to the contribution of other relativistic relics, having as main effect the modification of the competition between the nuclear reaction rates and the Hubble expansion rate. Since the primordial ^{4}He mass fraction, Y_P is largely determined by the neutron to proton ratio, Y_P is quite sensitive to the competition between the weak interaction rates and the expansion rate.

The most natural phenomenological extension of the standard neutrino sector is the consideration of the leptonic asymmetry (Freese et al., 1983; Ruffini et al., 1983; 1988), parametrized by the neutrino degeneracy parameter $\xi_\nu = \mu_\nu / T_{\nu_0}$ [μ_ν is the neutrino chemical potential and T_{ν_0} is the present temperature of the neutrino background, $T_{\nu_0}/T_{\rm cmb} = (4/11)^{1/3}$]. Although the standard model of particle physics predicts the value of leptonic asymmetry of the same order as the value of the baryonic asymmetry, $B \sim 10^{-10}$, there are many particle physics scenarios in which a leptonic asymmetry much larger can be generated (Chu & Cirelli, 2006; Smith et al., 2006).
One of the cosmological implications of a larger leptonic asymmetry is the possibility to generate baryonic asymmetry of the Universe through the sphaleron processes (Buchmuller et al., 2004; Falcone & Tramontano, 2001; Kuzmin et al., 1985). Therefore, distinguishing between a vanishing and non-vanishing ξ_ν at the BBN epoch is a crucial test of the standard assumption that sphaleron effects equilibrating the cosmic lepton and baryon asymmetries.

The measured neutrino mixing parameters implies that neutrinos reach the chemical equilibrium before BBN (Abazajian et al., 2002; Dolgov et al., 2002; Wong, 2002), so that all neutrino flavors are characterized by the same degeneracy parameter, ξ_ν, at this epoch. The most important impact of the leptonic asymmetry on BBN is the shift of the beta equilibrium between protons and neutrons and the increase of the radiation energy density parametrized by:

$$\Delta N_{eff}(\xi_\nu) = 3\left[\frac{30}{7}\left(\frac{\xi_\nu}{\pi}\right)^2 + \frac{15}{7}\left(\frac{\xi_\nu}{\pi}\right)^4\right] . \tag{1}$$

The total extra energy density can be splitted in two distinct uncorrelated contributions, first due to net lepton asymmetry of the neutrino background, $\Delta N_{eff}(\xi_\nu)$, and second due to the extra contributions from other unknown processes, ΔN^{oth}_{eff}:

$$\Delta N_{eff} = \Delta N_{eff}(\xi) + \Delta N^{oth}_{eff} . \tag{2}$$

2.1 Present bounds on lepton asymmetry and radiation energy density

The BBN constraints on N$_{eff}$ have been analyzed by comparing the theoretical predictions and experimental data on the primordial abundances of light elements, by using the baryon abundance derived from the WMAP 3-year CMB temperature and polarization measurements (Hinshaw et al., 2007; Page et al., 2007; Spergel et al., 2007): $\eta_B = 6.14 \times 10^{-10}(1.00 \pm 0.04)$. In particular, the ^{4}He abundance, Y_p, is quite sensitive to the value of N_{eff}. The conservative error analysis of helium abundance, $Y_P = 0.249 \pm 0.009$ (Olive & Skillman, 2004), yielded to $N_{eff} = 3.1^{+1.4}_{-1.2}$ (95% CL) in good agreement with the standard value (Mangano et al., 2007), but still leaving some room for non-standard values.

More stringent error bars of helium abundance , $Y_p = 0.2516 \pm 0.0011$ (Izotov et al., 2007), leaded to $N_{eff} = 3.32^{+0.23}_{-0.24}$ (95% CL) and a degeneracy parameter $-0.04 < \xi_\nu < 0.07$ (68% CL) (Ichikawa et al., 2007; Serpico & Raffelt, 2005).

The CMB anisotropies and LSS matter density fluctuations power spectra carry the signature of the energy density of the Universe at the time of matter-radiation equality (energy density of order eV^4), making possible the measurement of N_{eff} through its effects on the growth of cosmological perturbations. The number of relativistic neutrino species influences the

CMB power spectrum by changing the time of matter-radiation equality that enhances the integrated Sachs-Wolfe effect, leading to a higher first acoustic Doppler peak amplitude. Also, the temperature anisotropy of the neutrino background (the anisotropic stress) acts as an additional source term for the gravitational potential (Hu et al., 1995; Trotta & Melchiorri, 2005), changing the CMB anisotropy power spectrum at the level of $\sim 20\%$.

The delay of the epoch of matter-radiation equality shifts the LSS matter power spectrum turnover position toward larger angular scales, suppressing the power at small scales.

In particular, the non-zero neutrino chemical potential leads to changes in neutrino free-streaming length and neutrino Jeans mass due to the increase of the neutrino velocity dispersion (Ichiki et al., 2007; Lattanzi et al., 2005).

A lower limit to $N_{eff} > 2.3$ (95% CL) was recently obtained from the analysis of the WMAP 5-year (WMAP5) data alone (Dunkley et al., 2009), while the combination of the WMAP5 data with distance information from baryonic acoustic oscillations (BAO), supernovae (SN) and Hubble constant measured by Hubble Space Telescope (HST), leaded to $N_{eff} = 4.4 \pm 1.5$ (68% CL), fully consistent with the standard value (Komatsu et al., 2009).

The bounds on the radiation content of the Universe and neutrino properties obtained from the analysis of the WMAP-5 year CMB measurements complemented with most of the existing CMB and LSS measurements, with self-consistent constraints on the primordial helium abundance from BBN leaded to a mean value (at 68% CL) of the effective number of relativistic neutrino species of $N_{eff} = 3.256^{+0.607}_{-0.641}$ and a neutrino degeneracy parameter of $-0.216 \leq \xi_\nu \leq 0.226$ (Popa & Vasile, 2008).

2.2 New bounds on neutrino properties: BBN and CMB constraints

In this section we revisit the constraints on the lepton asymmetry and radiation energy density by using the latest cosmological and astrophysical measurements: the WMAP 7-year CMB measurements (Komatsu et al., 2011; Larson et al., 2011) complemented with geometric probes from the Type Ia supernovae (SN) distance-redshift relation, the baryon acoustic oscillations (BAO) and the BBN predictions on Y_p.

The SN distance-redshift relation has been studied in detail in the recent unified analysis of the published heterogeneous SN data sets the Union Compilation08 (Kowalski et al., 2008; Riess et al., 2009).

The BAO in the distribution of galaxies are extracted from Two Degree Field Galaxy Redshift Survey (2DFGRS)the Sloan Digital Sky Surveys Data Release 7 (Percival et al., 2010).

The BBN predicted values of Y_P are obtained by using the PArthENoPE code (Pisanti et al., 2008). Starting from nuclear statistical equilibrium conditions, the code determines Y_P as function of $\Omega_b h^2$, ΔN^{oth}_{eff} and ξ_ν.

We use these measurements especially because we are testing models deviating from the standard Friedmann expansion. These datasets properly enables us to account for any shift of the CMB angular diameter distance and of the expansion rate of the universe. Hereafter, we will denote WMAP7+BAO+SNIa+BBN data set as WMAP7+BBN+All. We perform our analysis in the framework of the extended ΛCDM cosmological model described by $6+3$ free parameters:

$$\Theta = \{\underbrace{\Omega_b h^2, \Omega_{dm} h^2, H_0, z_{re}, n_s, A_s,}_{standard} \Omega_\nu h^2, \xi_\nu, \Delta N^{oth}_{eff}\}\,. \tag{3}$$

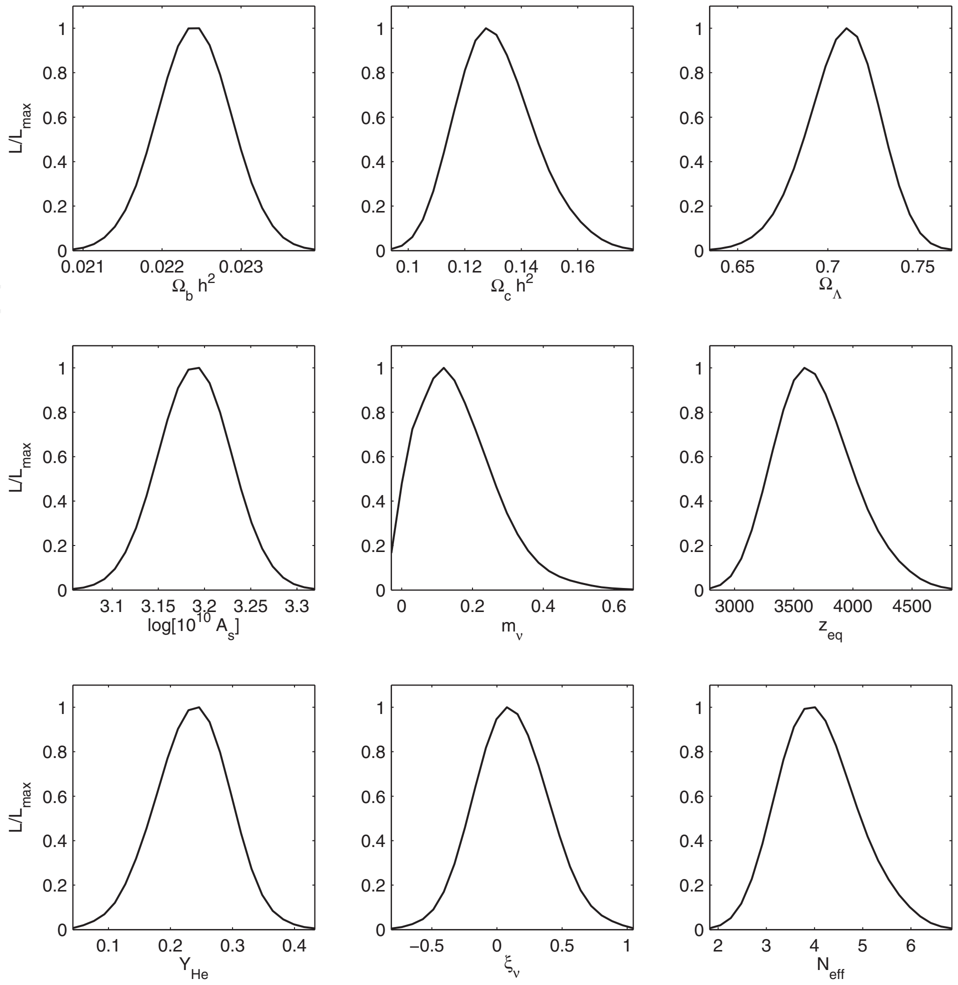

Fig. 1. The marginalized posterior likelihood probability distributions of the main cosmological parameters obtained from the fit of the leptonic asymmetric cosmological models to the WMAP7+BBN+All data set.

Here $\Omega_b h^2$ and $\Omega_{dm} h^2$ are the baryon and cold dark matter energy density parameters, H_0 is the Hubble expansion rate, z_{re} is the redshift of reionization, n_s is the scalar spectral index of the primordial density perturbation power spectrum and A_s is its amplitude at the pivot scale $k_* = 0.002$ hMpc^{-1}. The additional three parameters denote the neutrino energy density $\Omega_\nu h^2$, the neutrino degeneracy parameter ξ_ν and the contribution of extra relativistic degrees of freedom from other unknown processes ΔN^{eff}_{oth}.

The likelihood probabilities are evaluated by using the public packages COSMOMC and CAMB (Lewis et al., 2000; Lewis & S. Briddle, 2002) modified to include the formalism for the leptonic asymmetric cosmological models (Popa & Vasile, 2008).

We assume uniform prior probability on parameters Θ and compute the cumulative distribution function $C(\theta) = \int_{\Theta_{min}}^{\Theta} \mathcal{L}(\Theta) d\Theta / \int_{\Theta_{min}}^{\Theta_{max}} \mathcal{L} d\Theta$, quoting the upper and lower intervals at 68% CL.

Figure 1 presents the marginalized likelihood probabilities of the main cosmological parameters as obtained from the fit of the leptonic asymmetric cosmological models to the WMAP7+BBN+All data set and Figure 2 presents the degeneracies among them.

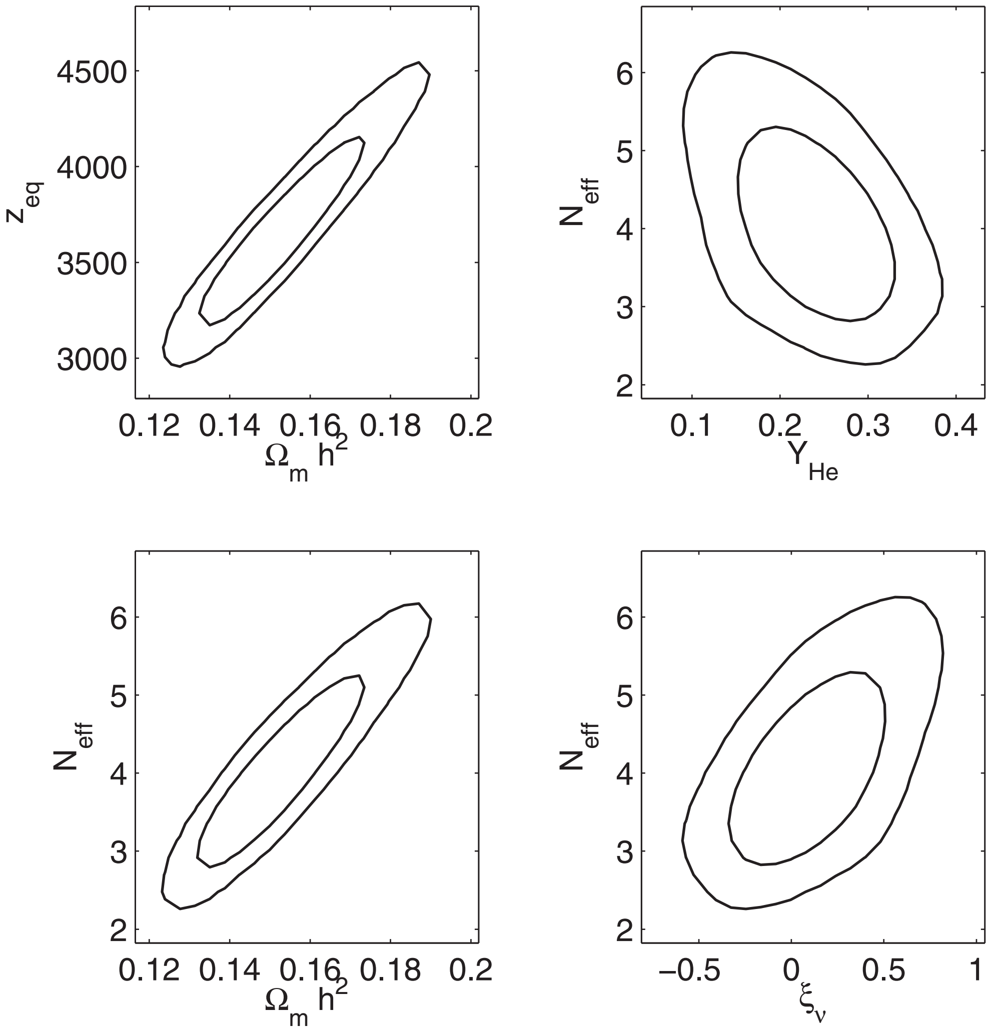

Fig. 2. Two dimensional joint probability distributions (68% and 95% CL) showing the degeneracy between different cosmological parameters as obtained from the fit of the leptonic asymmetric cosmological models to the WMAP7+BBN+All data set.

As neutrinos with eV mass decouple when they are still relativistic ($T_{dec} \sim 2$ MeV), the main effect of including ΔN_{eff} is the change of relativistic energy density. This changes the redshift of matter-radiation equality, z_{eq}, that affects the determination of $\Omega_m h^2$ from CMB measurements because of its linear dependence on N_{eff} (Komatsu et al., 2009):

$$1 + z_{eq} = \frac{\Omega_m h^2}{\Omega_\gamma h^2} \frac{1}{1 + 0.2271 N_{eff}} \,. \tag{4}$$

Here $\Omega_\gamma h^2$=2.469 $\times 10^{-5}$ is the present photon energy density parameter for $T_{cmb} =$ 2.725 K. As a consequence, N_{eff} and $\Omega_m h^2$ are linearly correlated, with the width of degeneracy line given by the uncertainty in the determination of z_{eq}.

In Table 1 we compare the mean values and the absolute errors on the main cosmological parameters obtained from the analysis of WMAP5+BBN+All and WMAP7+BBN+All data sets. For all parameters, except m_ν, we quote the errors at 68% CL. For m_ν we give the upper limits at 95% CL.

Parameter	WMAP5+BBN+All	WMAP7+BBN+All
$\Omega_b h^2$	$0.02246^{+0.00063}_{-0.00072}$	$0.02240^{+0.00022}_{-0.00045}$
$\Omega_{dm} h^2$	$0.1115^{+0.0089}_{-0.0093}$	$0.1135^{+0.0061}_{-0.0084}$
z_{re}	$11.31^{+1.92}_{-2.11}$	$10.96^{+0.59}_{-0.83}$
n_s	0.965 ± 0.018	0.969 ± 0.008
$\ln[10^{10} A_s]$	3.265 ± 0.056	$3.189^{+0.018}_{-0.019}$
m_ν(eV)	≤ 0.535	≤ 0.412
ξ_ν	0.051 ± 0.221	$0.037^{+0.123}_{-0.143}$
ΔN_{eff}	$0.256^{+0.607}_{-0.641}$	$0.209^{+0.332}_{-0.401}$
Y_p	$0.2487^{+0.0451}_{-0.0484}$	$0.2356^{+0.0271}_{-0.0284}$
z_{eq}	3124^{+120}_{-128}	3132^{+64}_{-87}

Table 1. The table shows the mean values and the absolute errors on the main cosmological parameters obtained from the analysis of WMAP5+BBN+All and WMAP7+BBN+All data sets. For all parameters, except m_ν, we quote the errors at 68% CL. For m_ν we give the upper limits at 95% CL.

From the analysis of WMAP7+BBN+All data we find a mean value of $N_{eff} = 3.21^{+0.332}_{-0.401}$, bringing an improvement over the similar result obtained from WMAP5+BBN+ALL data, $N_{eff} = 3.26^{+0.638}_{-0.690}$. We also obtain improved values for ^{4}He mass fraction, $Y_p = 0.2356^{+0.0271}_{-0.0284}$, and neutrino degeneracy parameter, $-0.123 \leq \xi_\nu \leq 0.143$.

We find also a significantly reduced upper limit of the neutrino mass, $m_\nu < 0.412$ eV.

3. Challenging the standard model of particle physics

The primary goal of particle cosmology is to obtain a concordant description of the early evolution of the universe, establishing a testable link between cosmology and particle physics, consistent with both unified field theory and astrophysical and cosmological measurements.

Inflation is the most simple and robust theory able to explain the astrophysical and cosmological observations, providing at the same time self-consistent primordial initial condition mechanisms for the quantum generation of scalar (curvature) and tensor (gravitational waves) perturbations. In the simplest class of inflationary models, inflation is driven by a single scalar field ϕ (or inflaton) with some potential $V(\phi)$ minimally coupled to the Einstein gravity. The perturbations are predicted to be adiabatic, nearly scale-invariant and Gaussian distributed, resulting in an effectively flat universe.

The possibility that the Standard Model (SM) of particle physics with an additional non-minimally coupled term of the Higgs field to the gravitational Ricci scalar can give rise to inflation have been recently investigated by a number of authors (Barvinsky et al., 2008; Bezrukov & Shaposhnikov, 2008; Bezrukov et al., 2009; De Simone et al., 2009). This scenario is based on the observation that the problem of the very small value of Higgs quadratic coupling required by the CMB anisotropy data can be solved if the Higgs inflaton has a large coupling to gravity. The resultant Higgs inflaton effective potential in the inflationary domain

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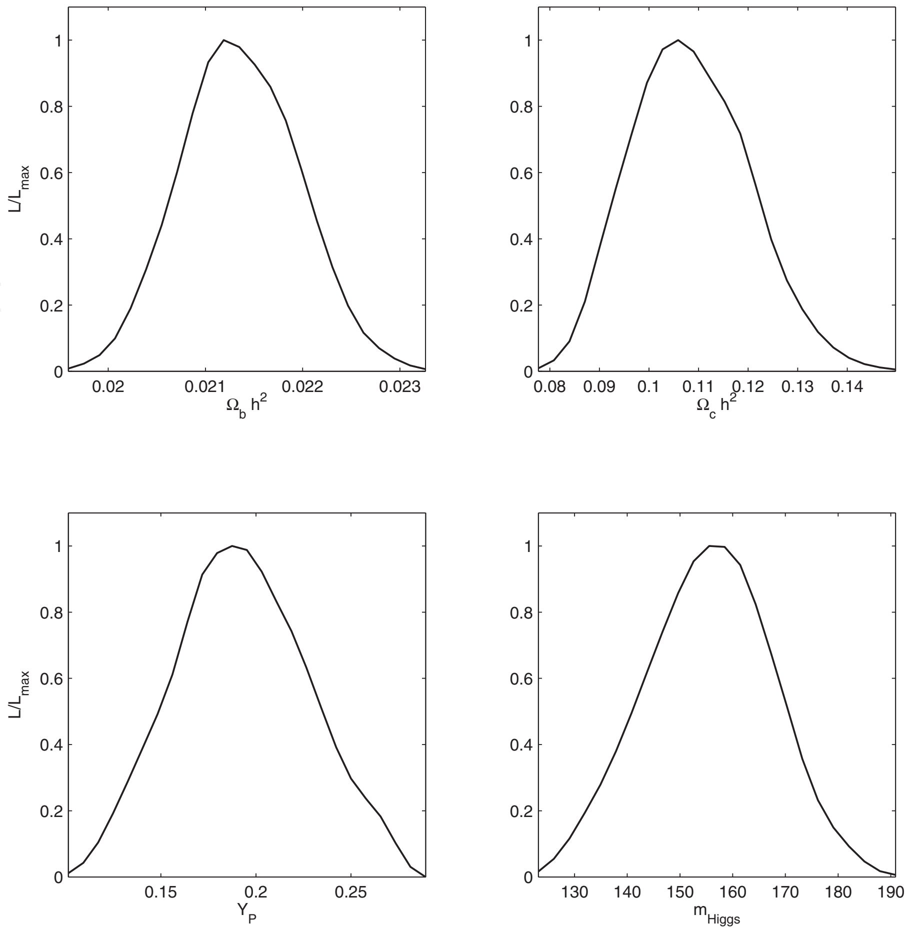

Fig. 3. The marginalized posterior likelihood probability distributions of the main cosmological parameters obtained from the fit of the Higgs inflation model to the WMAP7+BBN+All data set.

is effectively flat and can result in successful inflation for values of non-minimally coupling constant $\xi \sim 10^3 - 10^4$, allowing for cosmological values for Higgs boson mass in a window in which the Higgs vacuum expectation value $< v >= 246.22$ GeV is the minimum of the inflationary potential (Espinosa et al., 2008). The fluctuations of the electroweak vacuum expectation value might change the dynamics of the Higgs field during inflation, leading to modification of the main inflationary parameters and of the Higgs boson mass.

3.1 BBN and the Higgs vacuum expectation value

A modification of the Higgs vacuum expectation value during BBN leads to variations of the the neutron-proton mass difference, Δm_{np}, the Fermi constant, G_F, the deuterium binding energy, ϵ_D, and the electron mass, m_e.

The ^{4}He abundance is very sensitive to the parameters that fixed the neutron-to-proton ratio. In thermal equilibrium, this ratio is given by:

$$\frac{Y_n}{Y_p} = e^{-\Delta m_{np}/T} , \tag{5}$$

where Y_n and Y_p are the neutron and proton abundances and T is the temperature in MeV. The neutron-proton mass difference is affected by a change in the Higgs vacuum expectation value according to (Bergstrom et al., 1999):

$$\frac{\delta \Delta m_{np}}{\Delta m_{np}} = 1.587 \, \frac{\Delta < v >}{< v >} \, . \tag{6}$$

An increase in the Higgs vacuum expectation value $< v >$ leads to an increase in Δm_{np}. This produces a smaller neutron-to-proton equilibrium ratio and a smaller abundance of ^{4}He (Yoo & Scherrer, 2003). On the other hand, a larger Higgs vacuum expectation value during BBN results in: i) a smaller value of the Fermi coupling constant, $G_F = 1/\sqrt{2} < v >^2$, leading to earlier freeze-out of the weak reactions and producing more ^{4}He; ii) an increase in the electron mass, m_e, and a decrease of the weak reaction rates, producing also more ^{4}He (Landau et al., 2008).

The dependence of the deuterium binding energy, ϵ_D, on the Higgs vacuum expectation value is extremely model dependent and can be approximated as (Yoo & Scherrer, 2003):

$$\frac{\Delta \epsilon_D}{(\epsilon_D)_0} \simeq \kappa \frac{\Delta < v >}{< v >_0} \; , \tag{7}$$

where κ is a model dependent constant (e.g. $\kappa \simeq -6.230$ for a Reid potential). An increase in the Higgs vacuum expectation value results in a decrease in the deuterium binding energy, leading to a smaller initial deuterium abundance (Landau et al., 2008):

$$Y_d = \frac{Y_n Y_p e^{11.605 \epsilon_D / T_9}}{0.471 \, T_9^{3/2}} \, , \tag{8}$$

where T_9 is the temperature in units of 10^9K, and ϵ_D is in MeV. The production of ^{4}He begins later, leading to a smaller helium abundance and an increase in the deuterium abundance (Yoo & Scherrer, 2003).

The electron mass is proportional to the Higgs vacuum expectation value:

$$\frac{\Delta m_e}{m_e} = \frac{\Delta < v >}{< v >} \, . \tag{9}$$

A value of electron mass during BBN different from the present one translates into changes of electron and positron energy densities, leading to modifications of the Hubble expansion rate. Also, an increase of the electron mass during BBN slowers the neutron-proton intreaction rates, leading to a higher ^{4}He abundance. It is important to note that the modification of the primordial abundances due to the changes of the weak interaction rates are dominant over those due to the changes in the Hubble expansion rate (Yoo & Scherrer, 2003).

3.2 Bounds on the Higgs boson properties and the inflationary parameters: BBN and CMB constraints

For a robust interpretation of upcoming high precision temperature and polarization CMB anisotropies (Mandolesi et al., 2010), it is imperative to understand how the inflationary dynamics of a non-minimally coupled Higgs scalar field (ξ-inflation) may affect the degeneracy of the inflationary observables, the determination of the Higgs boson mass and of the vacuum expectation value.

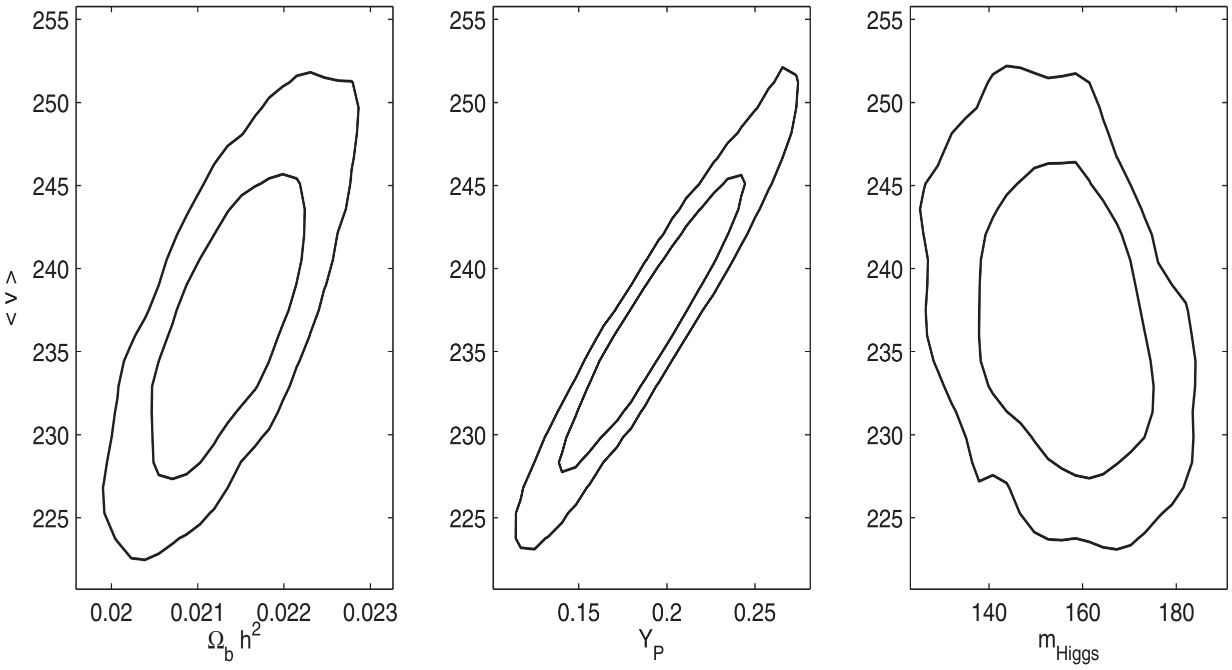

Fig. 4. Two dimensional joint probability distributions (68% and 95% CL) showing the degeneracy between different cosmological parameters as obtained from the fit of Higgs inflation model to the WMAP7+BBN+All data set.

Model Parameter	Standard Inflation	Higgs Inflation
$100\Omega_b h^2$	2.259±0.054	2.257±0.051
$\Omega_c h^2$	0.113±0.003	0.114±0.003
τ	0.088±0.015	0.086±0.013
θ_s	1.038±0.002	1.037±0.002
Y_P	0.245±0.014	0.247±0.091
m_{Higgs}(GeV)	-	155.372±3.851
$< v >$ (GeV)	-	243.131±5.912

Table 2. The mean values from the posterior distributions of the parameters obtained from the fit of the standard inflation model and Higgs inflation model with m_{Top}=171.3 GeV to the WMAP7+BBN+All dataset. The errors are quoted at 68% CL. All parameters are computed at the Hubble radius crossing k_*=0.002 Mpc^{-1}.

We place bounds on these parameters by using WMAP7+BBN+All data set, in the context of the non-minimally coupled Higgs inflaton field with gravity.

We obtain the CMB temperature anisotropy and polarization power spectra by integrating the coupled Friedmann equation and equation of motion of the Higgs scalar field with respect to the conformal time (Popa & Caramete, 2010; Popa, 2011).

The quantum corrections due to the interaction effects of the SM particles with Higgs boson through quantum loops modify Higgs potential from its classical expression. We consider the quantum corrections to the Higgs potential by including in the computation the running of the different coupling constants: the SU(2) × SU(1) gauge couplings $\{g', g\}$, the $SU(3)$ strong coupling g_s, the top Yukawa coupling y_t, and the Higgs quadratic coupling λ (Espinosa et al., 2008).

At the top quark mass scale m_{Top}, the Higgs quadratic coupling $\lambda(0)$ and the top Yukawa coupling $y_t(0)$ are determined by the corresponding Higgs boson and top quark pole masses and the vacuum expectation value $< v >$:

$$\lambda(0) = \frac{m^2_{Higgs}}{2 < v >^2}\left[1 + 2\Delta_H(m_{Higgs})\right], \qquad y_t(0) = \frac{\sqrt{2}m_{Top}}{< v >}\left[1 + \Delta_T(m_{Top})\right], \quad (10)$$

where $\Delta_H(m_{Higgs})$ and $\Delta_T(m_{Top})$ are the corrections to Higgs and top quark mass respectively.

The likelihood probabilities are evaluated by using the public packages CosmoMC and CAMB (Lewis et al., 2000; Lewis & S. Briddle, 2002) modified to include the formalisms for the SM Higgs driven ξ-inflation.

Our fiducial model is the ΛCDM cosmological model described by the following set of parameters receiving uniform priors:

$$\Theta = \{\Omega_b h^2\,,\ \Omega_c h^2\,,\ \theta_s\,,\ \tau\,,\ m_{Higgs}\,,\ < v >\ \} \qquad (11)$$

where: $\Omega_b h^2$ is the physical baryon density, $\Omega_c h^2$ is the physical dark matter density, θ_s is the ratio of the sound horizon distance to the angular diameter distance, τ is the reionization optical depth, m_{Higgs} is the Higgs boson pole mass, $< v >$ is the Higgs vacuum expectation value. As in the previous case, we use the PArthENoPE code (Pisanti et al., 2008) to obtain the ^{4}He mass fraction as function of $\Omega_b h^2$ and $< v >$.

Figure 3 presents the marginalized posterior likelihood probability distributions of the main cosmological parameters and Figure 4 presents the two-dimensional joint probability distributions showing the degeneracy in the planes $< v >$ - $\Omega_b h^2$, $< v >$ - Y_P and $< v >$ - m_{Higgs}, as obtained from the fit of the Higgs ξ-inflation model to the WMAP7+BBN+All data set.

Table 2 presents the mean values from the posterior distributions of the parameters obtained from the fit of the standard inflation model and Higgs inflation model with m_{Top}=171.3 GeV to the WMAP7+BBN+All dataset. The errors are quoted at 68% CL.

From this analysis we obtain the vacuum expectation value and the Higgs boson mass in the limits expected from the collider experiments, while the cosmological parameters are compatible to the standard inflation scenario (Popa & Caramete, 2009).

4. Acknowledgments

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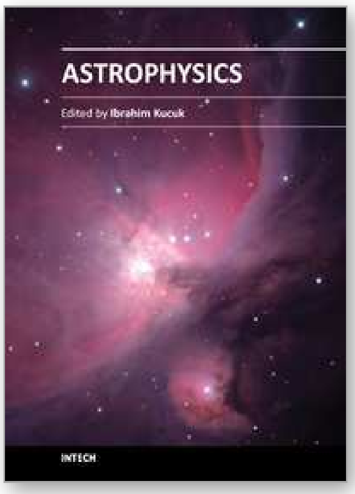

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