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Exploring the relic neutrinos properties with CMB, HST and galaxy clusters

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Outline

1. Introduction and Motivation
2. Theoretical framework
   2.1. Cosmic Neutrino Background (CNB)
   2.2. Models and data analysis
   2.3. Results
3. Summary and conclusions

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Introduction and motivation

1.The existence of a cosmic neutrino background (CNB), or also called relic neutrinos, is a consenquence of the thermal history of the universe where the neutrinos become to stream freely at $k_B T \sim$ MeV.

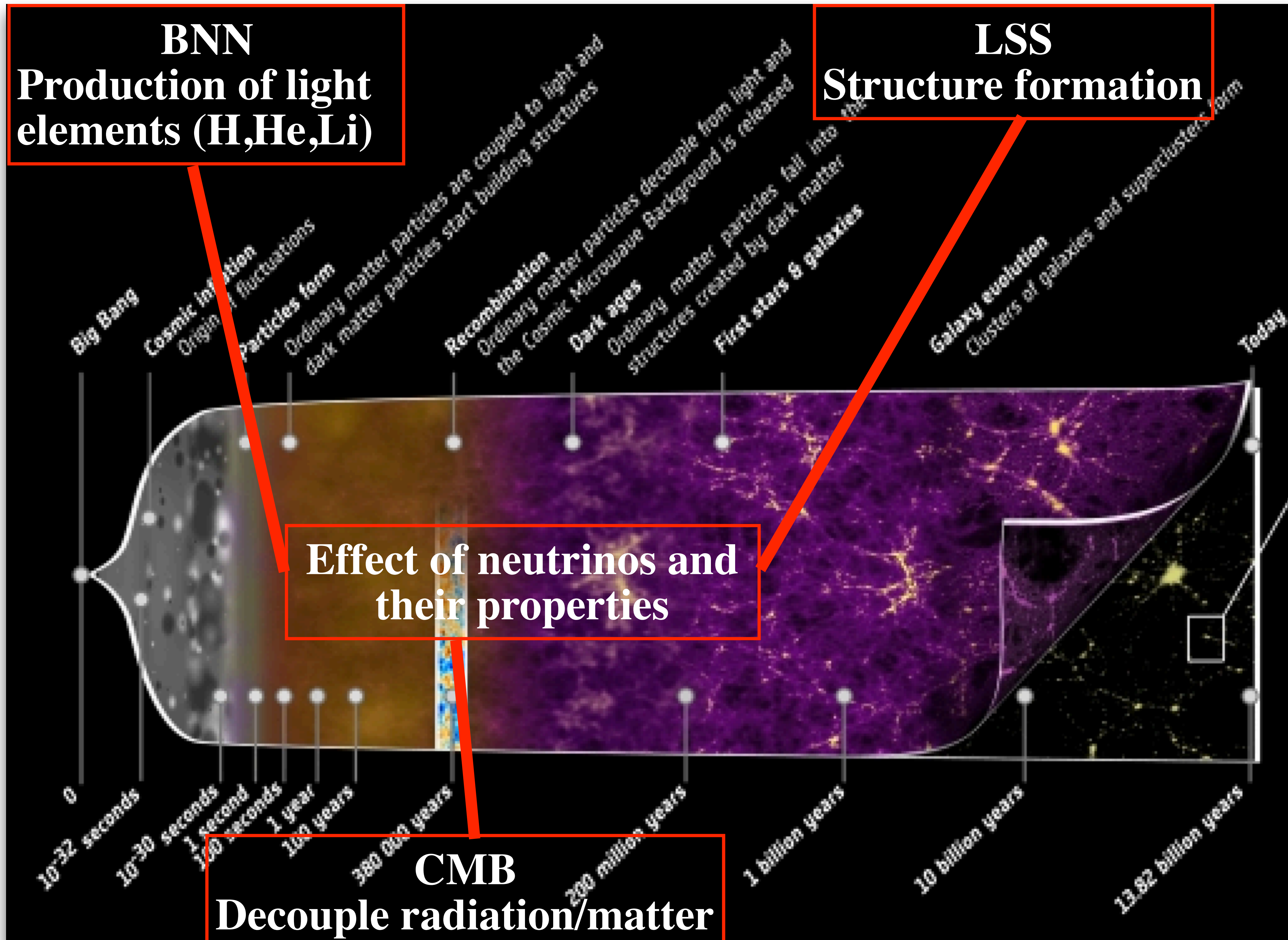
2.Unlike the cosmic microwave background (CMB), the CNB not was yet been detected directly and such direct detection proves to be difficult Betts et al. (2013). (1.9 ºK ≈ 0.00017 eV)

3.Recently the authors in Follin et al. (2015) interpreted data about damping of acoustic oscillations of the CMB, shows a detection of the temporal phase shift generated by neutrino perturbations.

4.The properties the massive neutrinos play an important role on the dynamics of the universe inferring direct changes on important cosmological sources and consequently in the determination of cosmological parameters (see Dol- gov (2002); Lesgourgues & Pastor (2006); Abazajian et al. (2015) for review).

5.The effects of the relic neutrinos on the CMB and LSS are only gravitational, since they are decoupled (free streaming particles) at the time of recombination.

Introduction and motivation



Introduction and motivation

Implications

1. Particle physics: Physics beyond the standard model.

2. Cosmology: Neutrinos are the second most abundant particle in the universe and thus can affect different epochs in cosmic history.

Open questions

1. What is the hierarchical ordering of neutrino mass?

2. What is the absolute mass scale of neutrinos?

3. What is the nature of the neutrino? Dirac or Majorana?

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Cosmic Neutrino Background (CvB)

The standard parameters that characterize these effects on cosmological sources are the effective number of species $N_{\rm eff}$ and the total neutrino mass $\sum m_\nu$.

Planck team Ade et al. (2016) within the ΛCDM + $\sum m_\nu$ model has constrained $\sum m_\nu < 0.194$ eV (from CMB alone), and $N_{\rm eff} = 3.04 \pm 0.33$ at 95% CL. The value of $N_{\rm eff}$ via theoretical calculations is well determined within of the standard model $N_{\rm eff} = 3.046$ Lesgourgues et al. (2013).

The evidence of any positive deviation from this value can be a signal that the radiation content of the Universe is not only due to photons and neutrinos, but also to some extra relativistic relics called in the literature of dark radiation and parameterized by $\Delta N_{\rm eff} = N_{\rm eff} - 3.046$.

CvB and basic equations

Friedmann equation

$$E^2(a,\Omega_i) = \Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_X e^{3\int_a^1 \frac{da'}{a'}(1+w(a'))}$$

Radiation density + relativistic neutrinos

$$\rho_r = (\rho_\gamma + \rho_\nu) = \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right)\rho_\gamma,$$

$$N_{\rm eff} = 3.046$$

—> Effective number of relativistic species

$$\Delta N_{\rm eff}^{\xi_\nu} = \frac{60}{7}\left(\frac{\xi_\nu}{\pi}\right)^2 + \frac{30}{7}\left(\frac{\xi_\nu}{\pi}\right)^4$$

$$\xi_\nu = \mu_\nu / T_{\nu 0}$$

—> Lepton asymmetry

Chemical potential

$$T_{\nu 0} \approx 1.9K$$

Current temperature CvB

$$\mu_\nu = 0$$

—> Majorana particles
Neutrinos = Antineutrinos

$$\mu_\nu \neq 0$$

—> Dirac particles
Neutrinos ≠ Antineutrinos

Any excess in N_{eff} can be due to:

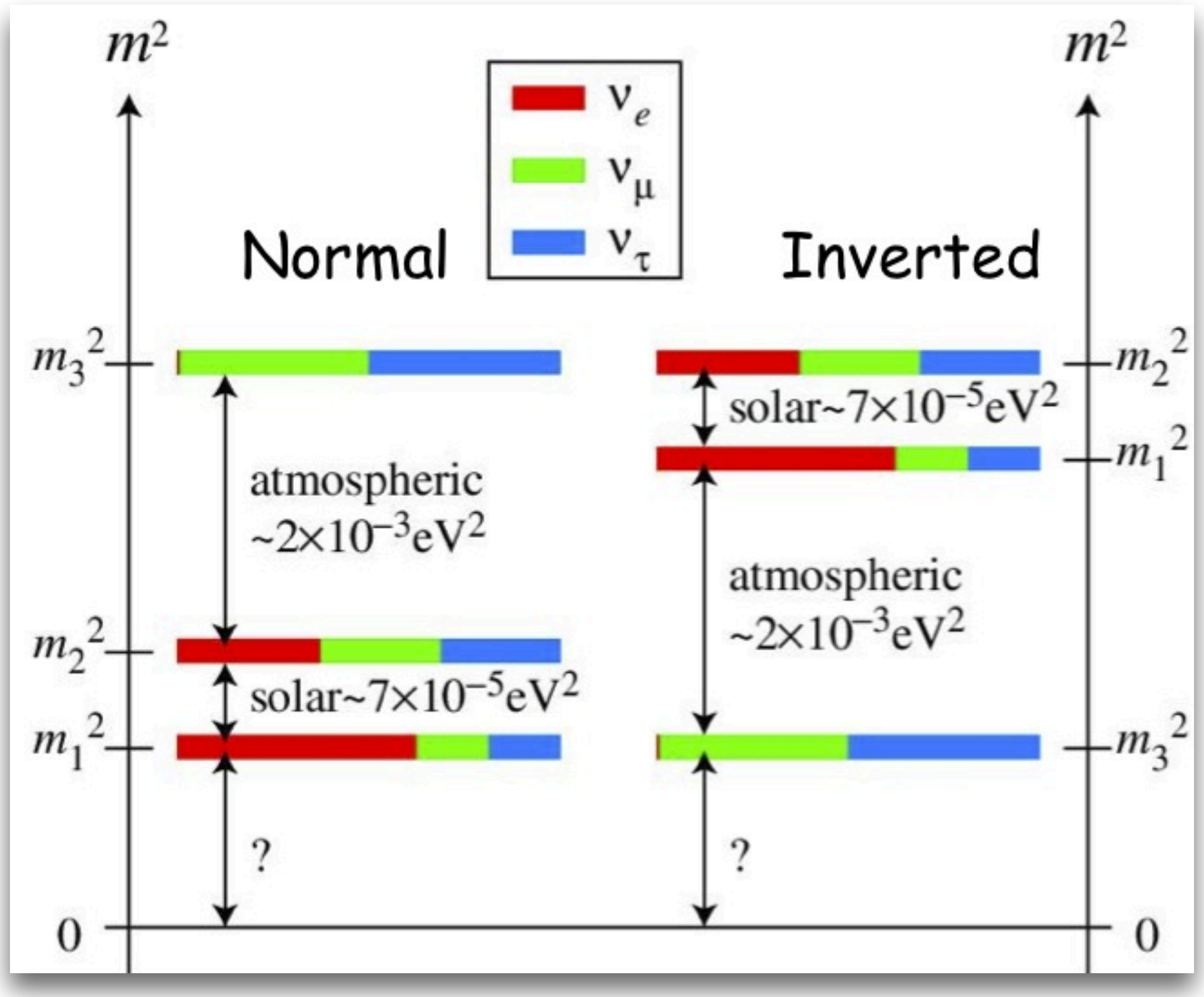
- Primordial Grav Waves (PGWs)
- Sterile neutrino
- Goldstone boson
- Lepton asymmetry (Matter/antimatter)
- Dark radiation (X17 boson, Recently detected), New Force in nature…?

CvB and basic equations

Friedmann equation

$$E^2(a,\Omega_i) = \Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_X e^{3\int_a^1 \frac{da'}{a'}(1+w(a'))}$$

Matter energy density + non relativistic neutrinos



$$\rho_{\nu_i} + \rho_{\bar{\nu}_i} = T_\nu^4 \int \frac{d^3q}{2(\pi)^3} E_{\nu_i}(f_{\nu_i}(q) + f_{\bar{\nu}_i}(q))$$

Fermi-Dirac phase space distribution

$$f_{\nu_i}(q) = \frac{1}{e^{E_{\nu_i}/T_\nu - \xi_\nu} + 1}, f_{\bar{\nu}_i}(q) = \frac{1}{e^{E_{\bar{\nu}_i}/T_\nu + \xi_{\bar{\nu}}} + 1},$$

$$E_{\nu_i}^2 = q^2 + a^2 m_{\nu_i}$$

—> Neutrino mass

$$\Omega_M = \Omega_{\rm CDM} + \Omega_b + \Omega_\nu$$

$$\Omega_\nu = \frac{\Sigma_i m_{\nu_i}}{93.14\ h^2 \mathrm{eV}}$$

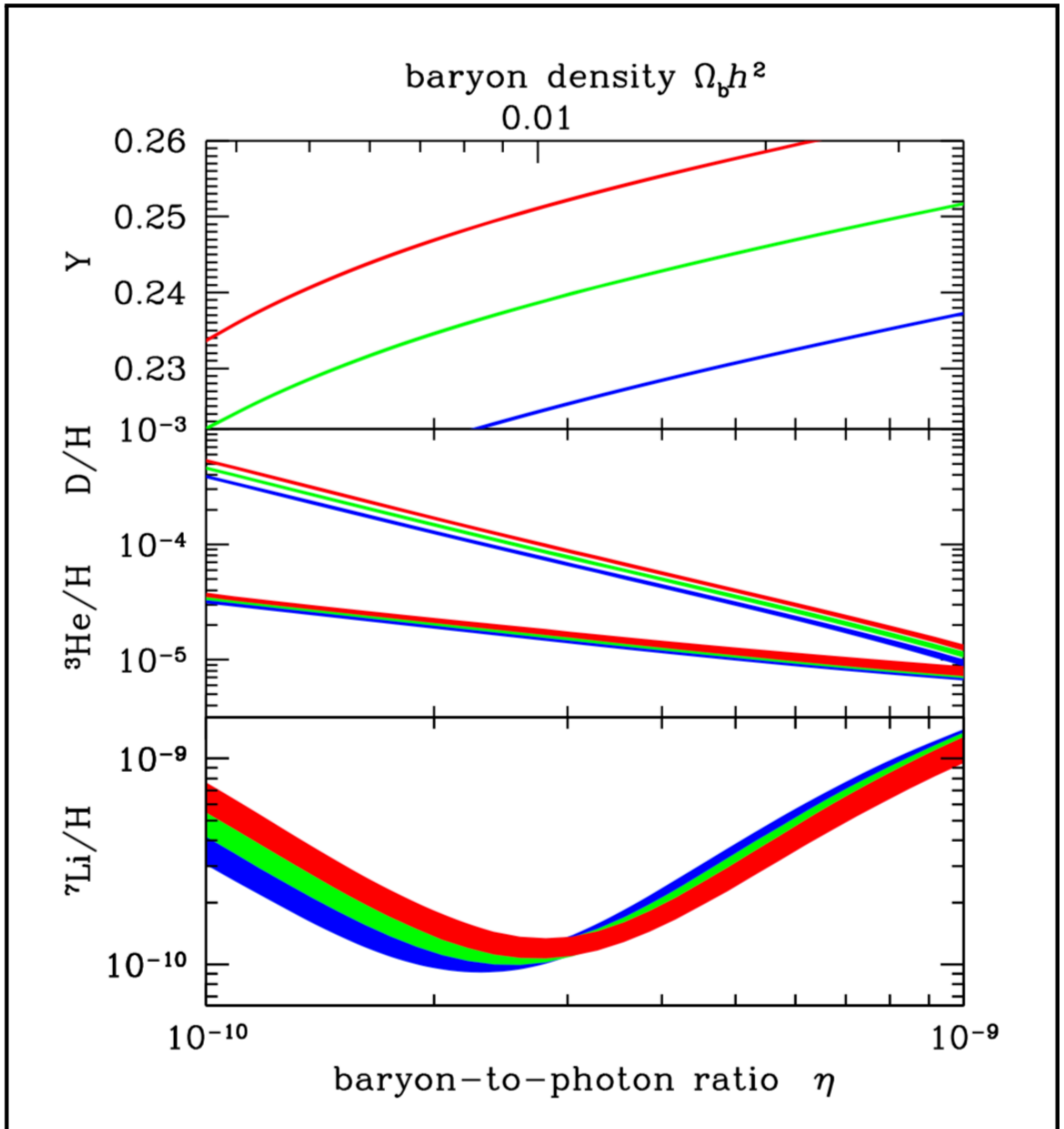
$$\Sigma m_\nu < 0.12\ \mathrm{eV}$$

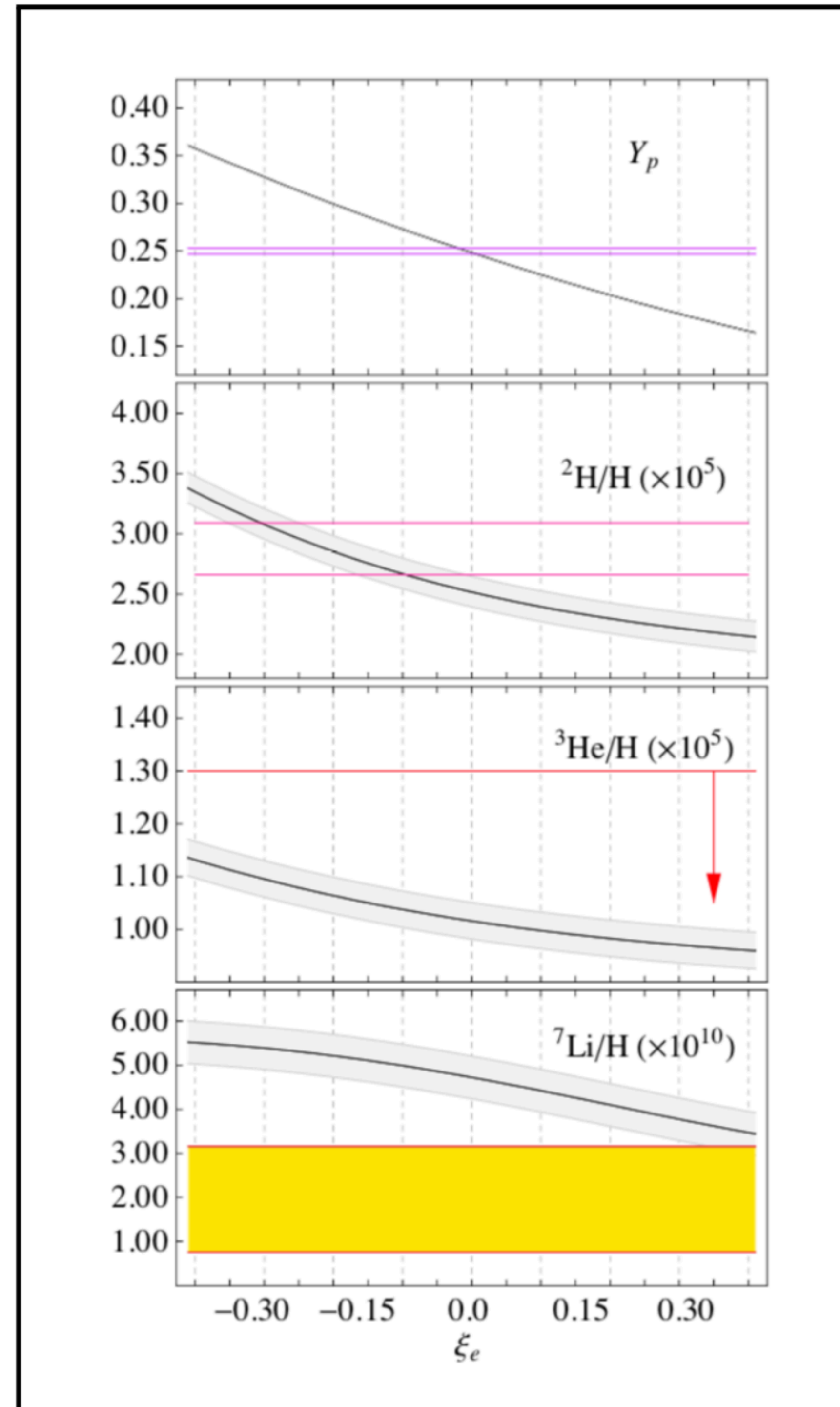
CvB and Big Bang Nucleosynthesis (BBN)

$N_{eff} = 4$

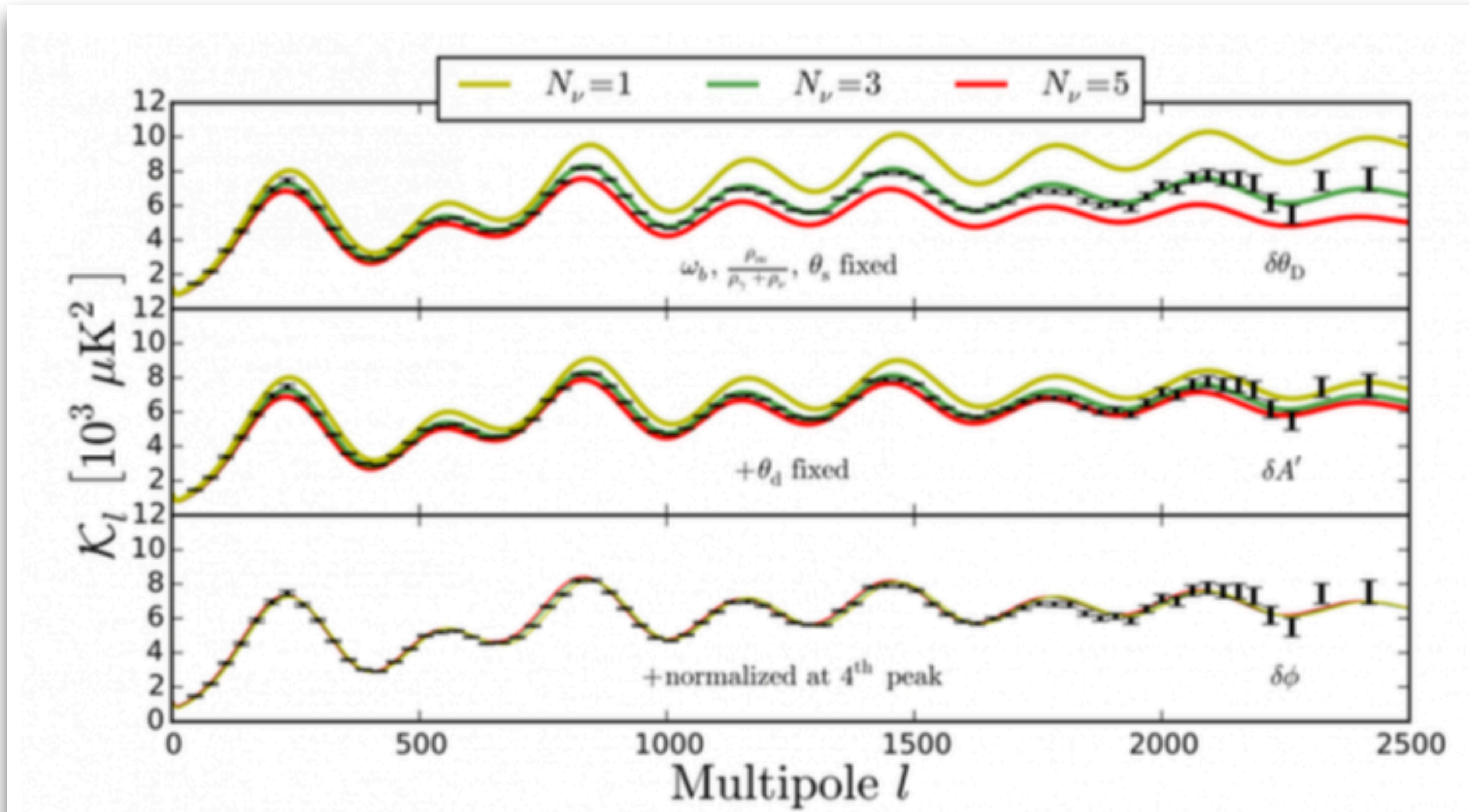
$N_{eff} = 3$

$N_{eff} = 2$



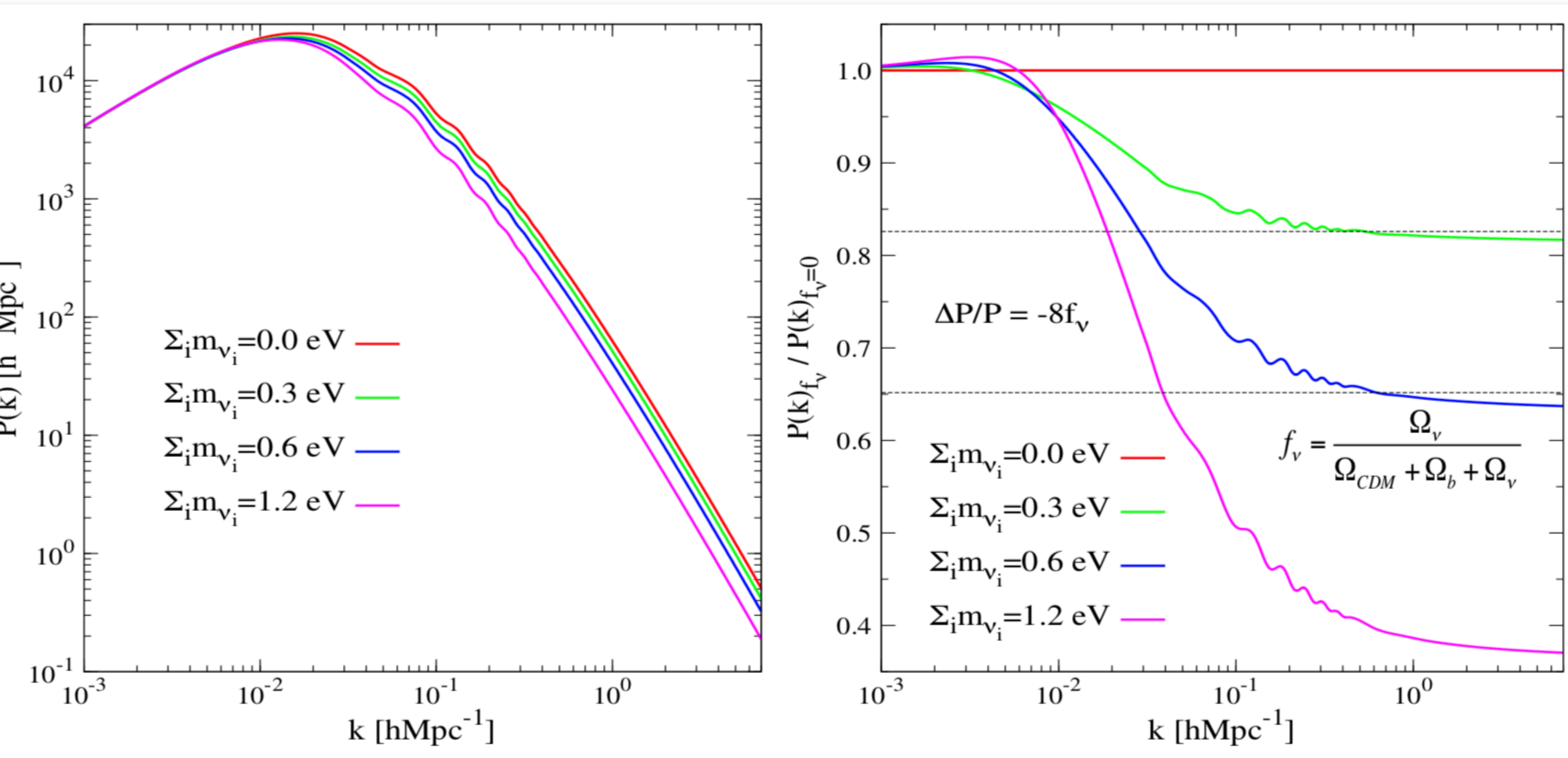


CνB and Cosmic Microwave Background (CMB)



Follin et al. (2015)

CvB and Large Scale Structure (LSS)



Outline

Models and data analysis

We consider two different models. First, let us take ΛCDM + $N_{\rm eff} + \sum m_\nu + c^2_{\rm eff} + c^2_{\rm vis} + \xi$ (**Model I**). Then, we take a particular case of the model I when $c^2_{\rm eff} = c^2_{\rm vis} = 1/3$, i.e., ΛCDM + $N_{\rm eff} + \sum m_\nu + \xi$ (**Model II**).

Sound speed parameter

Viscosity parameter

Parameterizes the anisotropic stress

The evolution of standard neutrinos (non-interacting free-streaming neutrinos) is obtained for

Any deviation of this valúes can represent interactions with others relativistic particles

Models and data analysis

1. **CMB:** We consider a conservative data set from Planck 2015 comprised of the likelihoods of temperature power spectrum (TT), low-polarisation and lensing reconstruction.

2. **BAO:** The BAO measurements from the Six Degree Field Galaxy Survey (6dF) Beutler et al. (2011), the Main Galaxy Sample of Data Release 7 of Sloan Digital Sky Survey (SDSS-MGS) Ross et al. (2015), the LOWZ and CMASS galaxy samples of the Baryon Oscillation Spectroscopic Survey (BOSS-LOWZ and BOSS-CMASS, respectively) Anderson et al. (2014), and the distribution of the LymanForest in BOSS (BOSS-Ly) Font-Ribera et al. (2014).

3. **HST:** We also include the new local value of H_0 as measured by Riess et al. (2016) with a 2.4 % determination, which yields $H_0 = 73.02 \pm 1.79$ km/s/Mpc.

4. **GC:** The measurements from the abundance of galaxy clusters (GC) are a powerful probe of the growth of cosmic structures. The cosmological information enclosed in the cluster abundance is efficiently parameterized by $S_8 = \sigma_8(\Omega_m/\alpha)$^$\beta$, where σ_8 is the linear amplitude of fluuctuations on 8 Mpc/h and α, β are the fiducial value adopted in each survey analysis.

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Results

We use the publicly available CLASS (Blas et al. 2011) and Monte Python (Audren et al. 2013) codes.

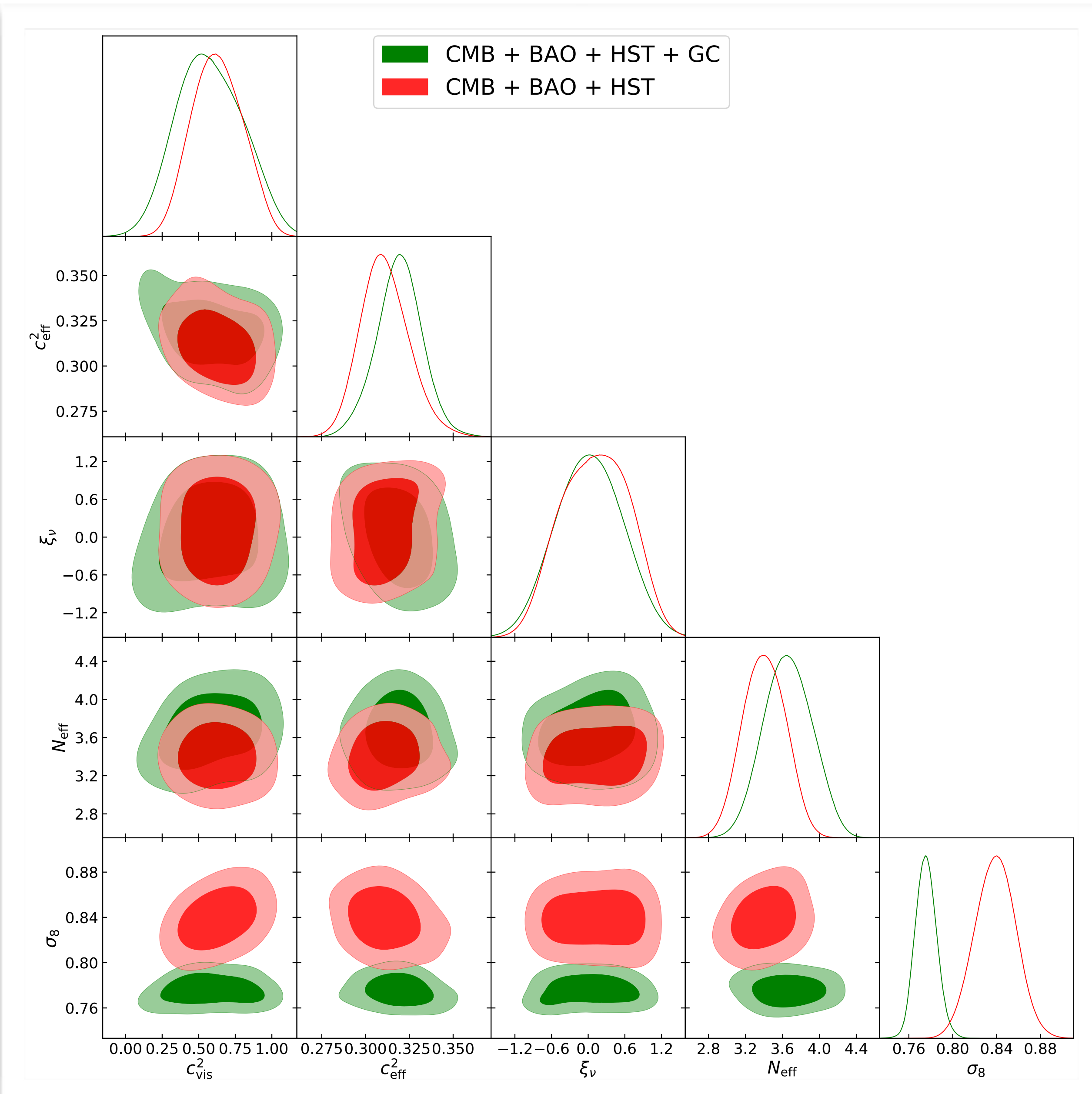

Table 2. Constraints at 68% CL and 95% CL on some parameters of the model I using two distinct data set. The parameter H_0 is in the units of km s^{-1} Mpc^{-1} and $\sum m_\nu$ is in units of eV.

Parameter	CMB + BAO + H_0	CMB + BAO + H_0 + GC
$\sum m_\nu$	$< 0.24\,(< 0.36)$	$< 0.64\,(< 0.81)$
$c^2_{\rm vis}$	$0.63^{+0.17+0.32}_{-0.17-0.32}$	$0.58^{+0.22+0.40}_{-0.25-0.40}$
$c^2_{\rm eff}$	$0.311^{+0.012+0.028}_{-0.015-0.027}$	$0.319^{+0.013+0.024}_{-0.013-0.027}$
ξ	$0.1^{+0.54+1.0}_{-0.54-1.0}$	$0.02^{+0.50+0.90}_{-0.50-0.85}$
$N_{\rm eff}$	$3.41^{+0.23+0.43}_{-0.23-0.42}$	$3.66^{+0.26+0.48}_{+0.26-0.49}$
Ω_Λ	$0.706^{+0.008+0.016}_{-0.008-0.016}$	$0.706^{+0.008+0.015}_{-0.008-0.015}$
Y_{He}	$0.2523^{+0.0029+0.0054}_{-0.0029-0.0056}$	$0.2557^{+0.0032+0.0059}_{-0.0032-0.0063}$
H_0	$69.8^{1.3+2.5}_{1.3-2.5}$	$70.7^{+1.2+2.4}_{-1.2-2.2}$
σ_8	$0.839^{+0.018+0.036}_{-0.018-0.037}$	$0.776^{+0.010+0.019}_{-0.010-0.019}$

Figure 1. One-dimensional marginalized distribution and 68% CL and 95% CL regions for some selected parameters of the model I.

Results

We use the publicly available CLASS (Blas et al. 2011) and Monte Python (Audren et al. 2013) codes.

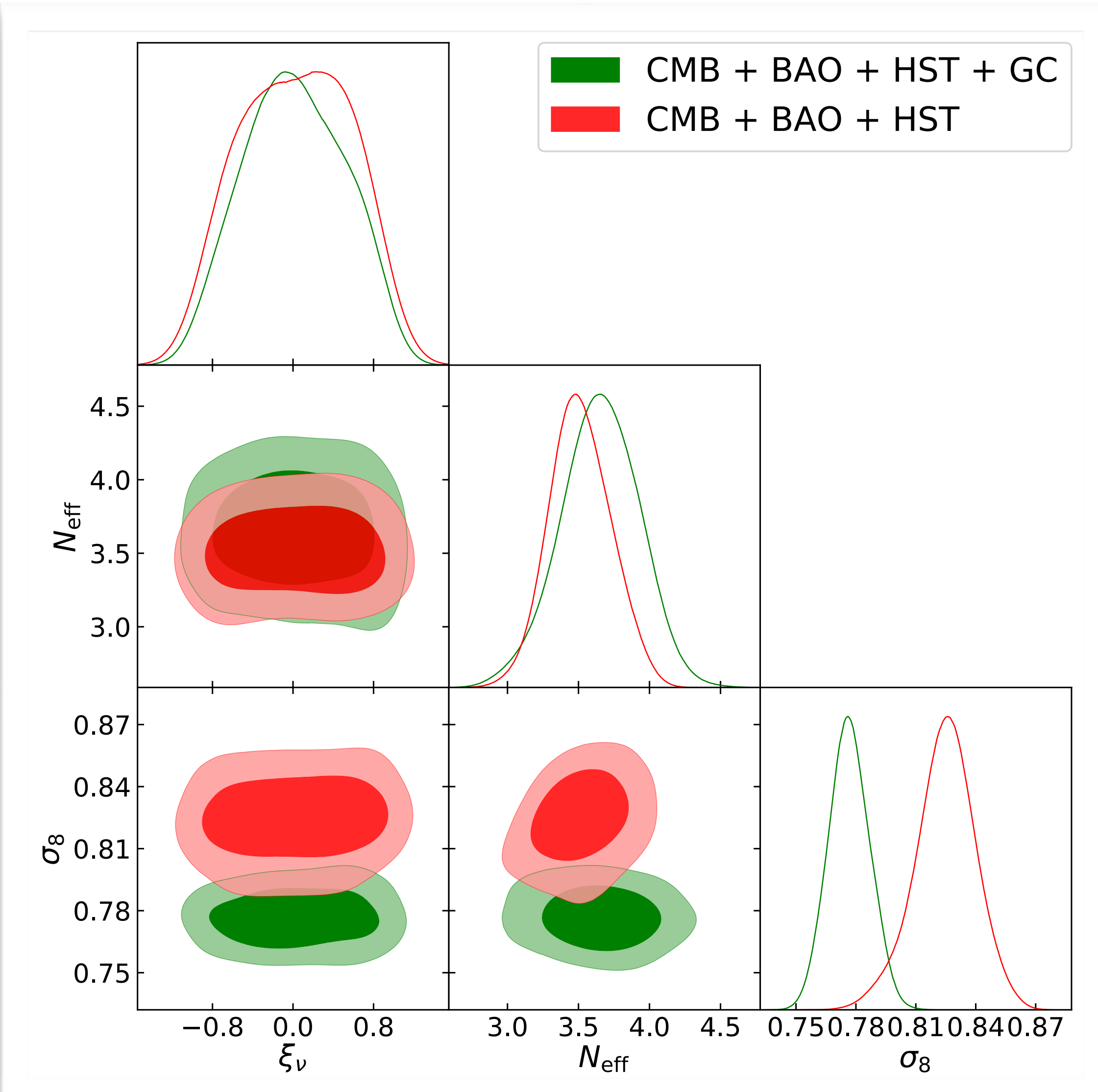

Table 3. Constraints at 68% CL and 95% CL on some parameters of the model II using two distinct data set. The parameter H_0 is in the units of km s^{-1} Mpc^{-1} and $\sum m_\nu$ is in units of eV.

Parameter	CMB + BAO + H_0	CMB + BAO + H_0 + GC
$\sum m_\nu$	$< 0.18\,(< 0.30)$	$< 0.52\,(< 0.64)$
ξ	$0.05^{+0.56+0.97}_{-0.56-0.99}$	$-0.02^{+0.51+0.92}_{-0.51-0.89}$
$N_{\rm eff}$	$3.49^{+0.21\,+0.44}_{-0.23\,-0.42}$	$3.65^{+0.28\,+0.57}_{-0.28\,-0.60}$
Ω_Λ	$0.703^{+0.009+0.015}_{-0.008-0.016}$	$0.706^{+0.008+0.015}_{-0.008-0.016}$
Y_{He}	$0.2537^{+0.0028+0.0056}_{-0.0028-0.0056}$	$0.2557^{+0.0038+0.0071}_{-0.0032-0.0077}$
H_0	$70.5^{+1.3+2.7}_{-1.3-2.6}$	$71.2^{+1.4+2.6}_{-1.4-2.7}$
σ_8	$0.823^{+0.016+0.030}_{+0.014-0.032}$	$0.777^{+0.010+0.020}_{-0.010-0.019}$

Figure 2. One-dimensional marginalized distribution and 68% CL and 95% CL regions for some selected parameters of the model II

Results

We use the publicly available CLASS (Blas et al. 2011) and Monte Python (Audren et al. 2013) codes.

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Probing the properties of relic neutrinos using the cosmic microwave background, the *Hubble Space Telescope* and galaxy clusters

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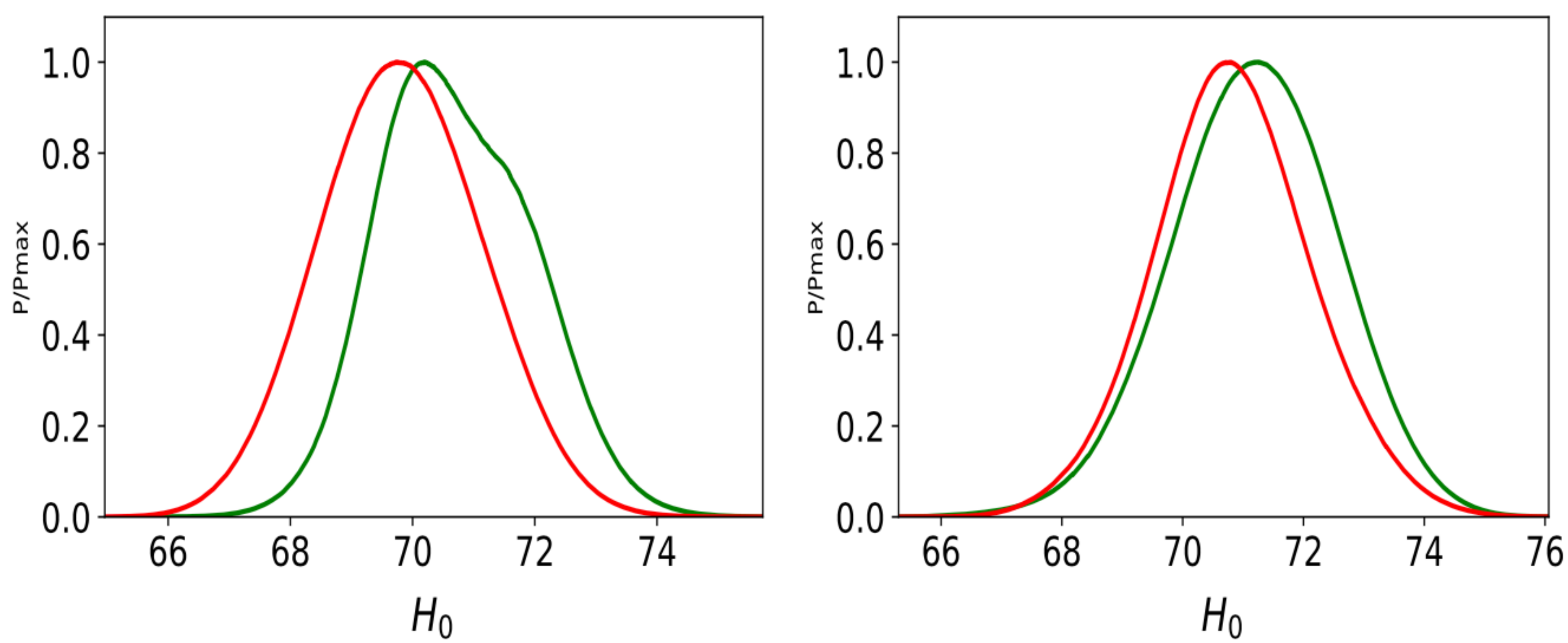


Figure 3. The likelihoods of the parameter H_0 for model I (left panel) and model II (right panel), in red (CMB + BAO + HST) and green (CMB + BAO + HST + GC).

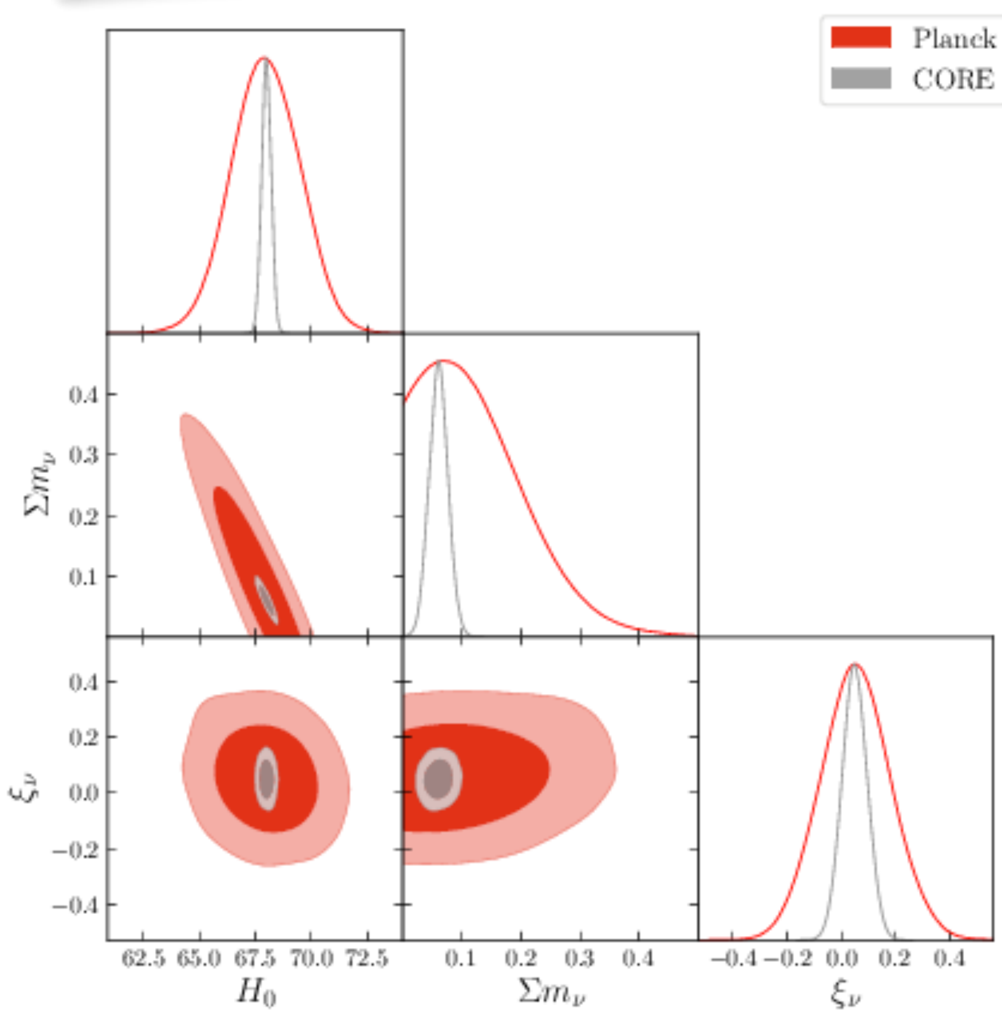
Results

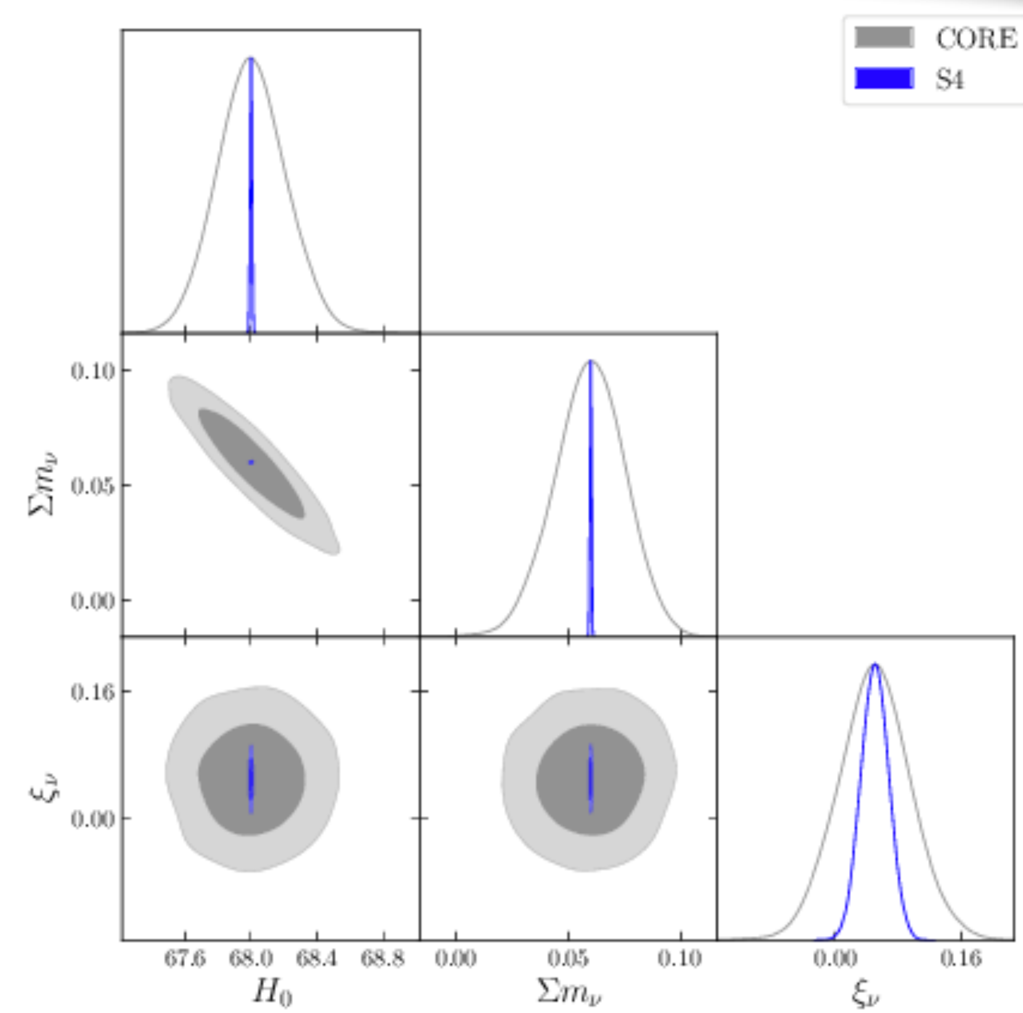
Forecast on lepton asymmetry from future CMB experiments

Alexander Bonilla (Juiz de Fora U.), Rafael C. Nunes (Sao Jose, INPE), Everton M.C. Abreu (Rio de Janeiro Federal U. & Juiz de Fora U. & UFRJ, Rio de Janeiro)

Oct 15, 2018 - 6 pages

- **Mon.Not.Roy.Astron.Soc. 485 (2019) no.2, 2486-2491**
- (2019-05-11)
- DOI: 10.1093/mnras/stz524
- e-Print: arXiv:1810.06356 [astro-ph.CO] | PDF





Results

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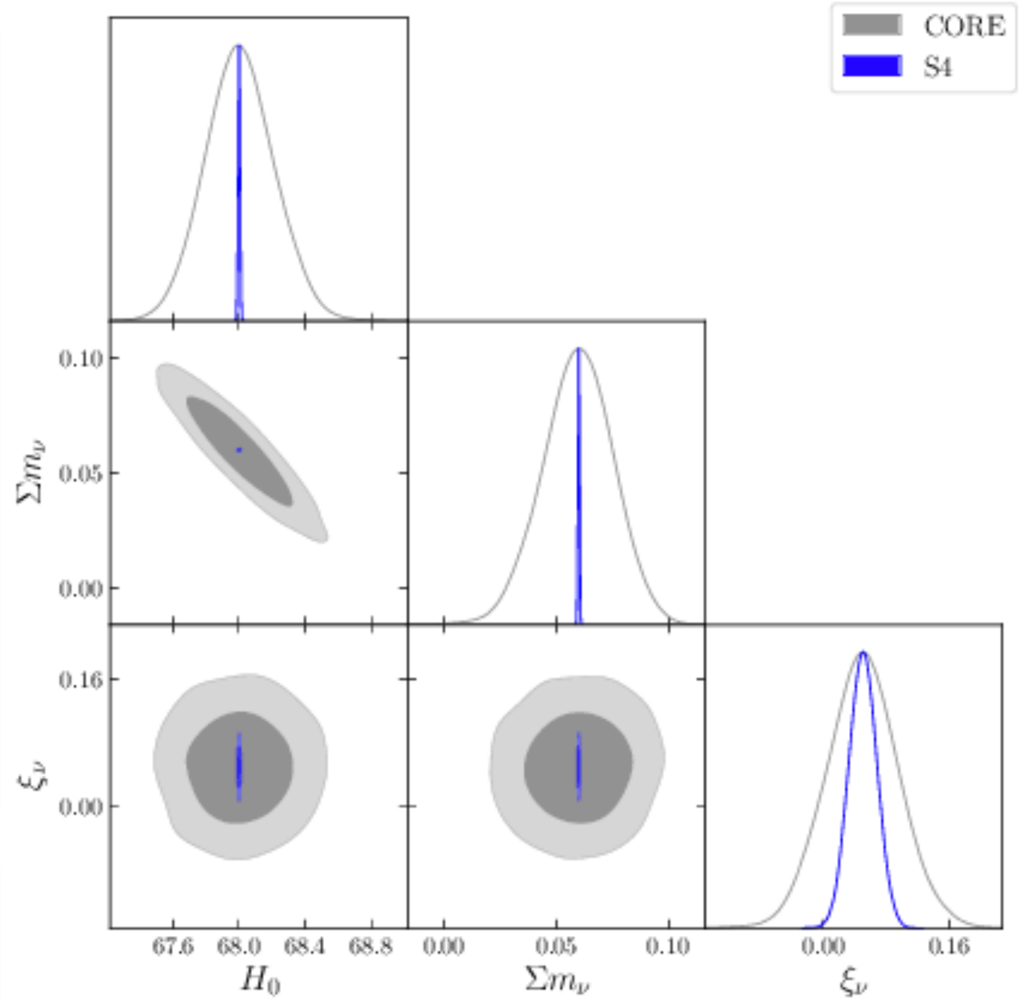
Parameter	Fiducial value	σ(CORE)	σ(S4)
$10^2\omega_b$	2.22	0.000057	0.00012
ω_{cdm}	0.11919	0.00037	0.0000093
H_0	68.0	0.32	0.0088
$\ln 10^{10} A_s$	3.0753	0.0056	0.0035
n_s	0.96229	0.0022	0.0054
$\tau_{\rm reio}$	0.055	0.0028	0.00025
$\sum m_\nu$	0.06	0.024	0.00053
ξ_ν	0.05	0.071	0.027

Table 2. Summary of the observational constraints from both CORE and S4 experiments. The notation σ(CORE) and σ(S4), represents the 68 % CL estimation on the fiducial values.



Following the Planck collaboration, we fix the mass ordering of the active neutrinos to the normal hierarchy with the minimum masses allowed by oscillation experiments, i.e., $\sum m_\nu = 0.06$ eV.

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Summary and conclusions

- With CMB-S4, we find $\xi_\nu = 0.05 \pm 0.027$ (± 0.043) at 68 % CL (95 % CL). These constraints can rule out the null hypothesis up to 2σ CL on ξ_ν. In this perspective the neutrinos can be Dirac particles against the null hypothesis and no Majorana.
- For neutrino mass scale, we find $0.021 < \sum m_\nu \lesssim 0.1$ eV and $0.05913 < \sum m_\nu \lesssim 0.061$ eV at 95 % CL for CORE and S4, respectively, thus, unfavorable to inverted hierarchy scheme mass in both cases.
- We note that $\Delta N_{\rm eff}^{\xi_\nu} = 0.002 \pm 0.019$ (± 0.030) for Planck $\Delta N_{\rm eff}^{\xi_\nu} = 0.0022 \pm 0.0083$ (± 0.013), CORE and $\Delta N_{\rm eff}^{\xi_\nu} = 0.0022 \pm 0.0045$ (± 0.0059) S4..

End…?Any collaboration will be welcome…!

ufjf

CAPES

CNPq
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