Leptophilic Z' model: Perturbative effects in the CMB spectrum

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Leptophilic models with new Z' gauge bosons can play a critical role in new physics effects. Neutrino experiments takes advantage on nucleus scattering to measure featuring events of this new neutral currents. Here, we study some effects of a particular $L_\mu - L_\tau$ leptophilic model in the early

MODEL BUILDING

Under the leptophilic symmetry $L_\mu - L_\tau$ with an abelian group $U(1)_{Z'}$ extending the SM, the interactions of the Z'-gauge boson with leptons and neutrinos are given by

$$\mathcal{L} \supset g' Z'_\alpha \Big[(\bar{\mu}\gamma^\alpha \mu) - (\bar{\tau}\gamma^\alpha \tau) + (\bar{\nu}_\mu \gamma^\alpha P_L \nu_\mu) - (\bar{\nu}_\tau \gamma^\alpha P_L \nu_\tau) + \sum_{i=1}^{n_{even}} \bar{N}_i \gamma^\alpha P_R N_i \Big]$$

Scope of this extended gauge sector

- We have extended the leptonic sector with an even number of massive right-handed neutrinos (in principle, they don't interfere in the active neutrinos oscillations).
- New massive neutrinos can be either Dirac or Majorana. The even number for right-handed neutrinos is a consequence of chiral anomalies cancelation.
- In particular considering only equations with new massive RH neutrinos, the right-handed and left-handed fermions charges satisfy:

$$\sum_\alpha \Big[2(Q^{\rm L}_\alpha)^3 - (Q^{\rm R}_\alpha)^3 \Big] - \sum_{\rm N} Q^3_{\rm N} = 0 \quad {\rm U}(1)^3_{Z'},$$

$$\sum_\alpha \Big[2Q^{\rm L}_\alpha - Q^{\rm R}_\alpha \Big] - \sum_{\rm N} Q_{\rm N} = 0 \quad \textbf{Gauge-Gravity}$$

- With $Q_\mu = 1, Q_\tau = -1, Q_{N,Odd} = 1$ and $Q_{N,Even} = -1$.
- Z' mass can be obtained via the Stueckelberg mechanism, where the new Higgs excitation has been integrated out.
- Z' impacts the cross-section and the events generated by trident mechanisms $\nu_\mu X \to \nu_\mu l^+ l^- X$, i.e., or the lepton-antilepton pairs $l^+ l^-$ production via the scattering of a neutrino off a heavy nucleus.
- Sensitivities for beam-dump experiments as DUNE show an excellent opportunity to measure the trident events of these novel neutral currents [1].
- The regions where tridents take place are compatible at 1σ and 2σ C.L. with scenarios allowed by muon anomalous magnetic moment $(g-2)_\mu$.

THERMALIZATION IN THE EARLY UNIVERSE

- Z' boson allows new neutrinos to appear in the primordial plasma through dynamical thermalized interactions originated from massless SM fermions. The thermally averaged rate between right-handed neutrinos and ultrarelativistic SM fermions f via s-channel Z' exchange ($\Gamma_{Z'}$ is the mass width) can be calculated as in [2]. We have found the following features:
- Considering the Hubble rate, the most efficient temperatures for this processes are located around $T_c \sim M_{Z'}/4$ and can be considered as a characteristic decoupling temperature
- Maximum for thermal production rate is independent of Dirac or Majorana nature for Heavy neutrinos.
- Rate in the low temperature regime scales as g'^4/M'^4_z , while in the intermediate regime it behaves like $g'^2 M^2_{Z'}/T$

Regimen	Thermal rate scales as	Ratio	Limit
Region I: $T << M_{Z'}$	g'^4/M'^4_z	$M_{Z'}/\text{TeV}/g'$	> 8.5
Region II: $T \sim M_{Z'}/4$	$g'^2 M'^2_Z/T$	$g'/\sqrt{M_{Z'}/\text{TeV}}$	$> 7.4 \times 10^{-8}$

Table I: Lower values for coupling and Z' mass ratios using the Planck constraint $\Delta N_{eff} < 0.23$ at 95%, using TT, TE, EE+lowE

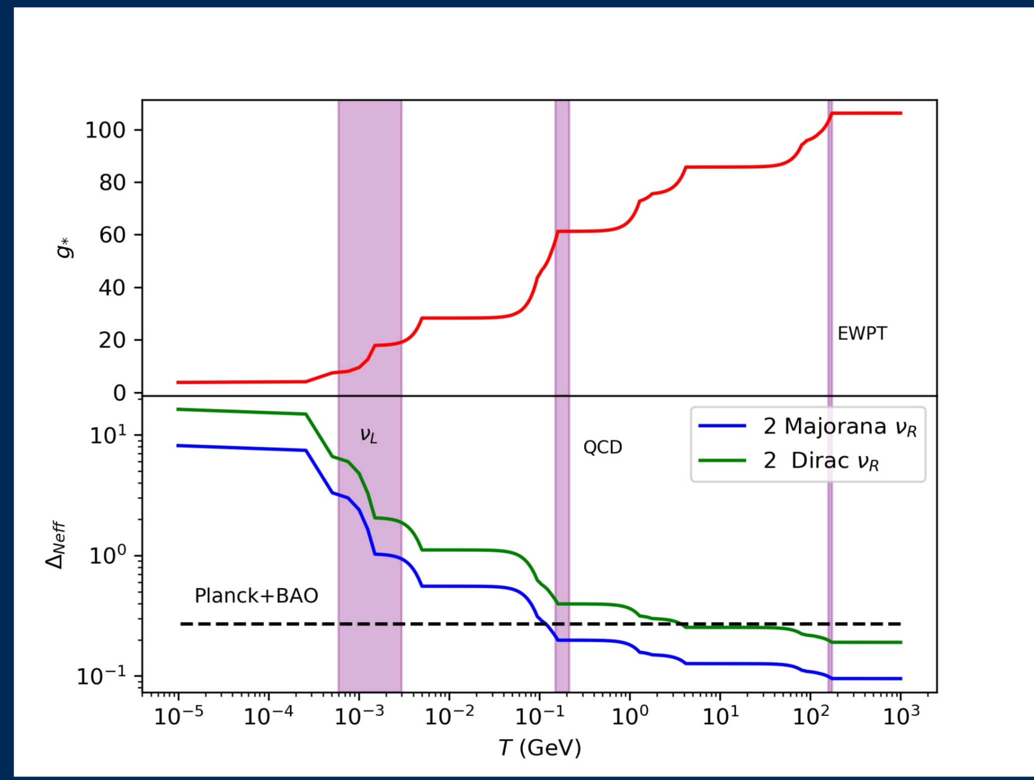
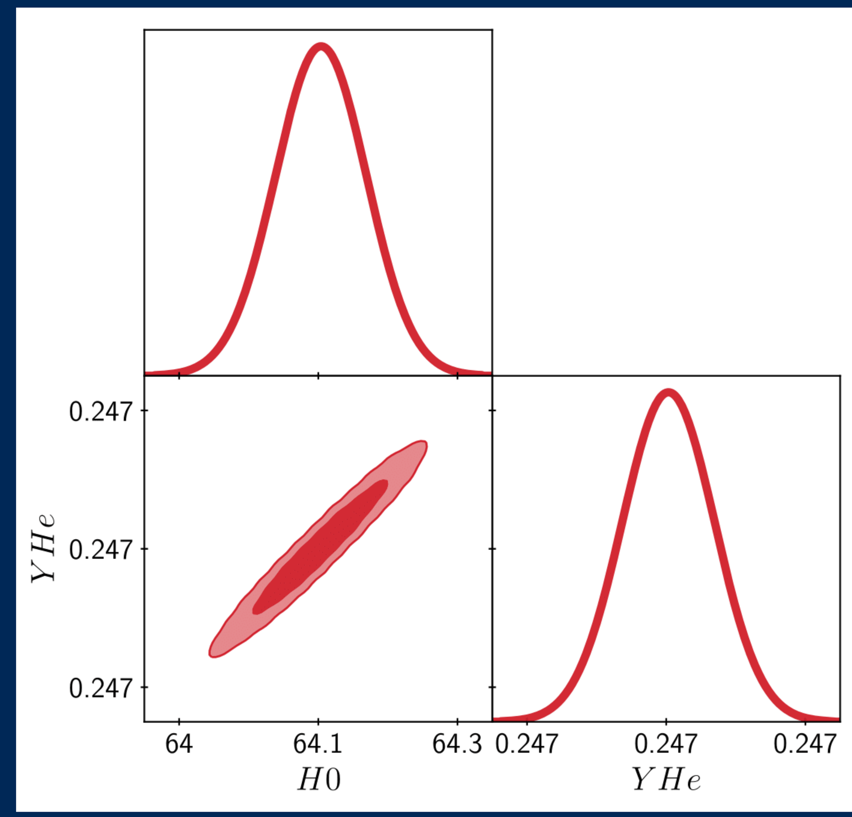


Figure 1: (Top) Effective degrees of freedom and (Bottom) ΔN_{eff} as a function of temperature for a variable number of right handed neutrinos.

The effective degrees of freedom g^* for the universe are, primarily, a function of the universe temperature. When thermalized, a particle contributes to this number, the effect ceases when temperature reaches values below its effective mass, at this point the particle will decouple from the plasma.The Standard Model predictions differ from the measured value of degrees of freedom for the early universe temperature. This discrepancy may carry information about new physics. The dashed line in Figure 1 bottom represent the Planck+BAO [3] ability to detect differences above a certain ΔN_{eff}. These calculations allow us to obtain ΔN_{eff} for two Majorana or Dirac particles.
Since N_{eff} changes the transfer function, it is also expected to observe these effects in LSST quantities such as weak lensing, a direct prove for neutrino masses, that might be extended to N_{eff}.



Parameter	ΛCDM	$\nu_{s1,s2}$+ΛCDM	$\nu_{s1,s2}+Z'$+ΛCDM
$H0$	$64.138^{+0.088}_{-0.090}$	$64.911^{+0.082}_{-0.092}$	$65.091^{+0.086}_{-0.087}$
YHe	$0.246667^{+0.000027}_{-0.000028}$	$0.249503^{+0.000026}_{-0.000029}$	$0.250177^{+0.000027}_{-0.000028}$

Figure 2: Two Sterile neutrinos+Z'-Boson+Base-ΛCDM model constraints from Planck results using TT,TE,EE+lowE. Contours contain 68% and 95% of the probability [4].
Table II. Constraints at 95% C.L. on cosmological parameters from PlanckTT,TE,EE+lowE when the base-ΛCDM model is extended by adding two sterile neutrinos $\nu_{s1,s2}$ and the Z'-Boson.

To observe the effect of the new sterile neutrinos and the Z'- boson in the standard cosmological scenario, we have constrained the Hubble parameter H0 and the primordial helium abundance YHe from the Planck TT,TE,EE+lowE data. The results are shown in Figure 2 and its comparison with ΛCDM is found in Table II. As we expected, H0 enhances due to the dark radiation density driven by the neutrinos.

In the limit of massless ν_R and Z' all the contributions to the particle content in the universe will be condensed only in the parameter N_{eff} . Using the estimation of $\Delta N_{eff} \approx 0{,}21$ for a new leptophilic neutral gauge boson in the parameter region we have been studying, found by [5], and the ΔN_{eff} obtained in Figure 1 for 2 Majorana and Dirac Neutrinos we can look at how the temperature power spectrum of the CMB will change with respect to the ΛCDM model.
Besides modifying N_{eff} we also adjust the Hubble parameter h and the Cold Dark Matter content Ω_{CDM} to keep background effects such as the equality redshifts unaltered [6].
It is also possible to compare the ratio for the ΛCDM model as shown in Figure 3 top. In the silk damping zone, the ratio between this coefficients blows away and it cannot be enterely due to neutrino perturbation effects. To unmask these effects we adjust the primordial helium fraction Y_{He} as in [7]. The green lines in Figure 3(top) take into account this correction.

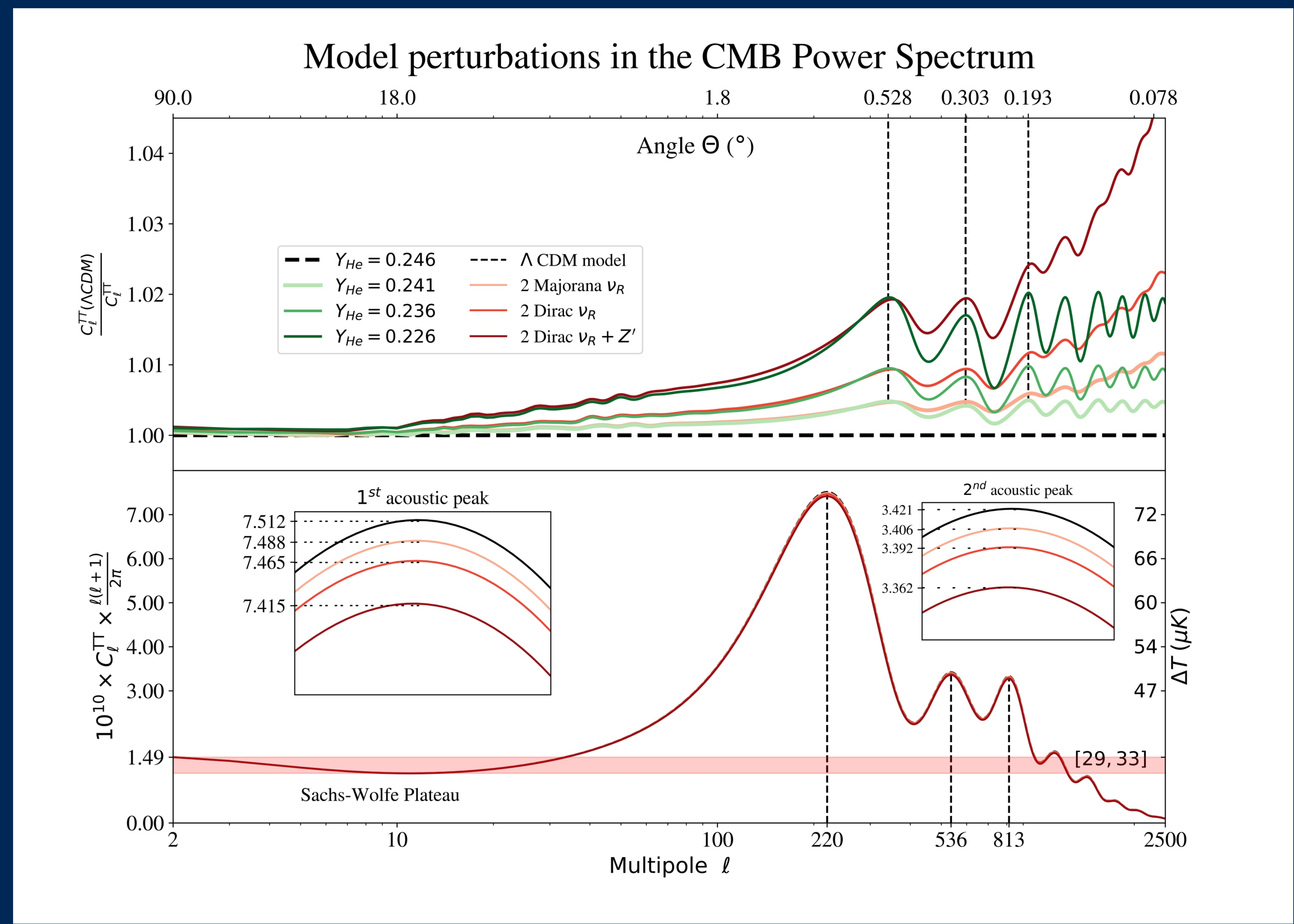


Figure 3: Temperature power spectrum for a $U(1)_{L\mu-L\tau}$ Z' boson with 2 right-handed neutrinos [8]

All the peak locations match, showing that our model does not modify the redshifts of equality or the sound horizon at decoupling.
In the massless limit, the Sachs-Wolfe Plateau remains between 29 and 33 μK, this reflects that the new particle content is not interacting gravitationally with the other species.
The amplitude of the acoustic peaks lowers with our model because we are enhancing the dark matter component, therefore there will be less radiation to eject pressure on the γ-baryon fluid.
In all cases rarefraction modes are around 3% higher than the compression peaks indicating that the radiation content is higher than the baryonic content in the universe. Moreover, it allows us to conclude that even though the individual amplitudes of these peaks vary when introducing our model, the net force in the fluid, summing the positive term from the radiation pressure and the negative term from gravity will remain the same.

CONCLUSIONS AND REMARKS

- Adding mass to these right-handed neutrinos and the new gauge boson would leave imprints in the low multipole region, corresponding to the gravitational effects that will have these new massive species. However, it is difficult to determine by the temperature power spectrum any of these effects, due to the high cosmic variance in this regime.
- Changes to N_{eff} could explain deviations between future precise measurements of the CMB from the ΛCDM predictions in the dark matter content and the hubble parameter.
- Our leptophilic model with 2 Dirac ν_R will be probably ruled out because the deviation ΔN_{eff} predicted is already greater than the current uncertanty in N_{eff} . However, the model with 2 Majorana ν_R appears to be possible and measurable when including a new Z' boson. We also note that, based on [5], this model becomes a strong candidate to adress the Hubble tension problem.
- The strongest signatures of our model in the CMB temperature power spectrum are predicted to deviate up to 2 % from the ΛCDM spectrum in the angular scales of approximately 0.528°, 0.303° and 0.193°.
- Future work is needed to calculate ΔN_{eff} for the boson proposed in this model, studying the massive regime of the new particle content, comparing these results to other cosmological frameworks such as the hot dark energy model and more.

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