Observing Left-Right Symmetry in Cosmic Microwave Background

Based on PRD102(2020)3,035025

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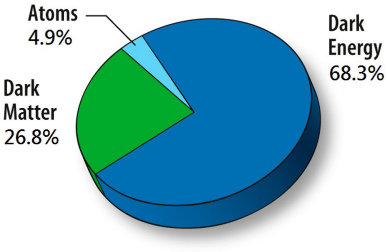
Cosmology in Colombia:2020
International Conference (Online)

Motivations



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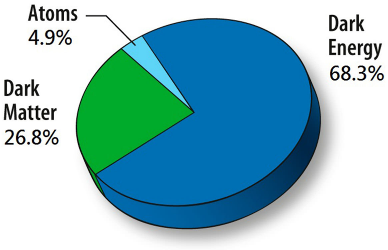

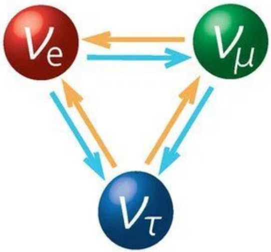

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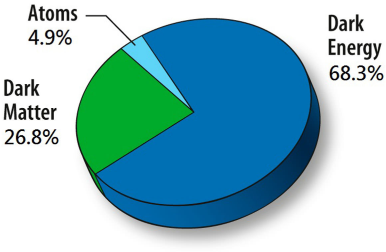

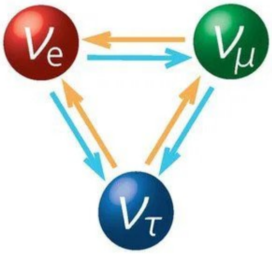

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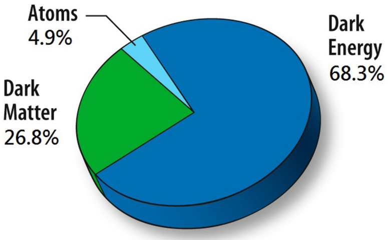
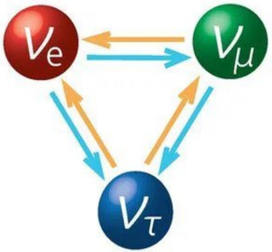




$\longrightarrow$ ΔN_{eff}

What is $\mathrm{N_{eff}}$?

- The relativistic energy density can be expressed as

$$\rho = \frac{\pi^2}{30} \left[\sum_{i=bosons} g_i T_i^4 + \frac{7}{8} \sum_{i=fermions} g_i T_i^4\right]$$

- SM neutrinos decouples from the thermal bath about 2 MeV and then its temperature falls as a^{-1}.
- $\mathrm{T} < 0.5\,\mathrm{MeV}$, the electrons and positrons have gone away and the photon and neutrino temperatures are no longer identical.

$$\rho = \frac{\pi^2}{30} \left[2 + \frac{7}{8} \times 2\, N_\nu \left(\frac{T_\nu}{T_\gamma}\right)^4\right] T_\gamma^4$$

3.046

Mangano et al. (PLB534(2002)8)

Mangano et al. (NPB729(2005)221)

Dirac Neutrinos and $\mathrm{N_{eff}}$

- Will it contribute to the $\mathrm{N_{eff}}$?
  - Dirac neutrino contains two more light degrees of freedom than a Majorana neutrino.
- The total relativistic energy density below 0.5 MeV,

$$\begin{aligned}\rho &= \frac{\pi^2}{30}\left[2\,T_\gamma^4 + \frac{7}{8}\times 2\,N_{\nu_L}\,T_{\nu_L}^4 + \frac{7}{8}\times 2\,N_{\nu_R}\,T_{\nu_R}^4\right] \\ &= \frac{\pi^2}{30}\left[2\,T_\gamma^4 + \frac{7}{8}\times 2\left\{N_{\nu_L} + N_{\nu_R}\frac{T_{\nu_R}^4}{T_{\nu_L}^4}\right\}\frac{T_{\nu_L}^4}{T_\gamma^4}\right]T_\gamma^4\end{aligned}$$

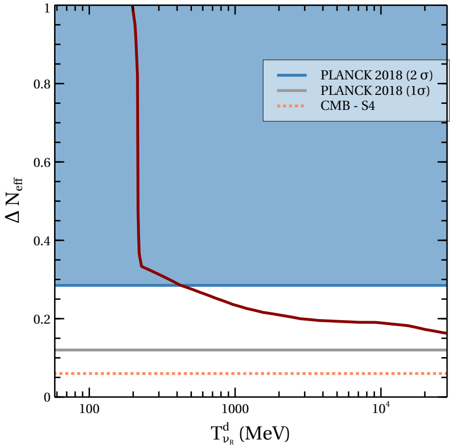
- To know the temperature of ν_R,
  - Temperature scales throughout as a^{-1}
  - The total entropy of the universe have to be conserved.

Dirac Neutrinos and ΔN_{eff}

$$\Delta N_{eff} = N_{eff} - N_{eff}^{SM} = N_{\nu_R}\left(\frac{T_{\nu_R}}{T_{\nu_L}}\right)^4 = N_{\nu_R}\left(\frac{g\left(T_{\nu_L}^{dec}\right)}{g\left(T_{\nu_R}^{dec}\right)}\right)^{\frac{4}{3}}$$

$N_{eff} = 2.99^{+0.34}_{-0.33}$
$\Delta N_{eff} \leq 0.285$

1807.06209



Dirac Neutrinos and $\Delta N_{\rm eff}$

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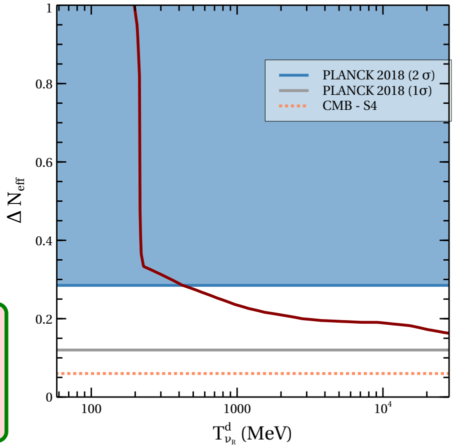
$$\Gamma_{\nu_R}\left(T_{\nu_R}^{\rm dec}\right) = H\left(T_{\nu_R}^{\rm dec}\right)$$

$$n_{\nu_R}(T)\langle\sigma(\overline{\nu_R}\,\nu_R \to \bar{f}\,f)v\rangle$$



Dirac ν and Dark Matter in LRSM

- Left-right symmetric models (LRSMs) have been one of the most popular beyond the standard model (BSM) frameworks studied in the literature.

PRD10,275(1974), PRD11,566(1975), PRD11,2558(1975)

- The inclusion of RHNs become automatic which put the left- and right-handed fermions on equal footing.
- Scalar structure of the model can make sure the Dirac nature of the neutrinos.
- Right handed neutrino can be thermalised via interaction with $\mathrm{W_R}$ and $\mathrm{Z_R}$.
- To realise the DM in DLRSM, we have introduced a pair of fermion quintuplet.
- Fermion quintuplet was not just a choice but the minimal stable multiplet.

TABLE I. Fermionic fields of the present model including the SM fermions.

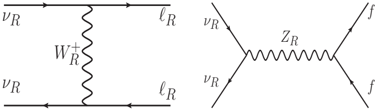
Particles	$SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
$Q_L = \binom{u_L}{d_L}$	$(3, 2, 1, \frac{1}{3})$
$Q_R = \binom{u_R}{d_R}$	$(3, 1, 2, \frac{1}{3})$
$\ell_L = \binom{\nu_L}{e_L}$	$(1, 2, 1, -1)$
$\ell_R = \binom{\nu_R}{e_R}$	$(1, 1, 2, -1)$

TABLE II. Scalar fields and their corresponding charges under all the symmetry groups.

Particles	$SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$
$\Phi = \begin{pmatrix} \phi^0 & \phi'^+ \\ \phi^- & \phi'^0 \end{pmatrix}$	(1,2,2,0)
χ_L	(1,2,1,1)
χ_R	(1,1,2,1)

Observing LRSM in CMB

- The processes responsible for the thermalising of right-handed neutrinos are



- We consider negligible mixing between left and right sector gauge bosons.
- Important parameters are $\mathrm{M_{W_R}}$, $\mathrm{M_{Z_R}}$, $\mathrm{g_R}$ and , $\mathrm{g_{BL}}$. Two of them are independent.

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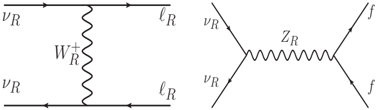
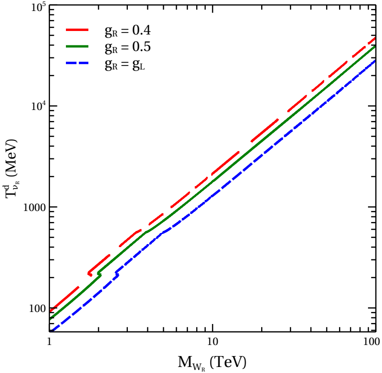


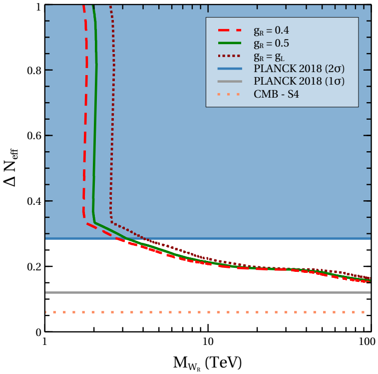


- We consider negligible mixing between left and right sector gauge bosons.
- Important parameters are $\mathrm{M_{W_R}}$, $\mathrm{M_{Z_R}}$, $\mathrm{g_R}$ and, $\mathrm{g_{BL}}$. Two of them are independent.
- The $\mathrm{T^{dec}_{\nu_R}}$ rises for lower values of gauge coupling as well as higher values of $\mathrm{W_R}$ mass.

Observing LRSM in CMB

Dependence on model parameters!!

- One can see that the contribution to the ΔN_{eff} decreases with increasing M_{W_R}.
- Clearly, the Planck 2018 bound at 2σ C.L. itself rules out a W_R mass below 4.06 TeV with gauge coupling $g_R = g_L$.
- CMB-S4 and PLANCK 2018 bound at 1σ C.L. can rule out a much larger parameter space out of reach of present direct search experiments.



Observing LRSM in CMB

Dependence on model parameters!!

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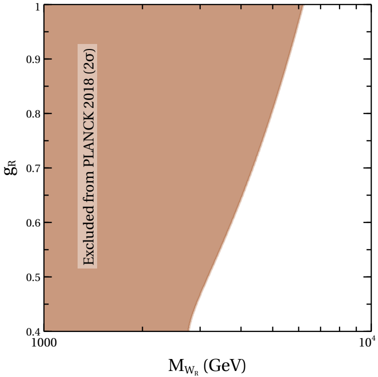
- CMB-S4 and PLANCK 2018 bound at 1σ C.L. can rule out a much larger parameter space out of reach of present direct search experiments
- Final parameter space in the $g_R - M_{W_R}$ plan can be shown as



Dark Matter in DLRM

- The minimal DLRM discussed above does not have a stable DM candidate.
- One can minimally extend the model by including additional scalar or fermionic multiplets in the spirit of the minimal dark matter scenario.

Cirelli et. al. NPB753,178(2006)
Heeck et. al. PRL115,121804(2015)

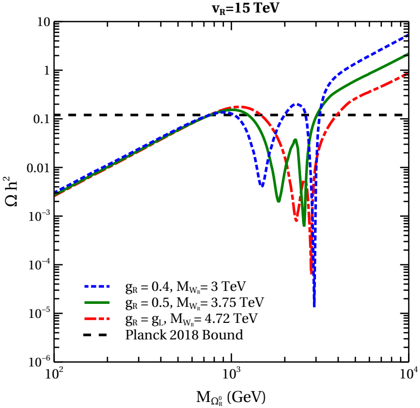
Heeck et al. JCAP03(2016)021

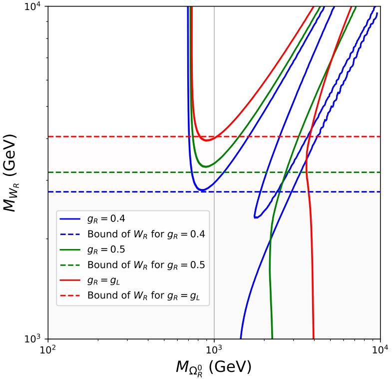
- We have introduced a real fermion quintuplet of $\mathrm{B-L}$ charge 0 and the relevant gauge interactions can be written as

$$\mathcal{L}_{\Omega_R} \supset -s_W s_M g_R Q \overline{\Omega_R^Q} Z_L^\mu \gamma_\mu \Omega_R^Q + c_M g_R Q \overline{\Omega_R^Q} Z_R^\mu \gamma_\mu \Omega_R^Q + c_W s_M g_R Q \overline{\Omega_R^Q} A^\mu \gamma_\mu \Omega_R^Q + \frac{g_R}{\sqrt{2}} \left(c_Q \overline{\Omega_R^{Q+1}} W_R^\mu \gamma_\mu \Omega_R^Q + \mathrm{h.c.} \right)$$

Dark Matter in LRSM

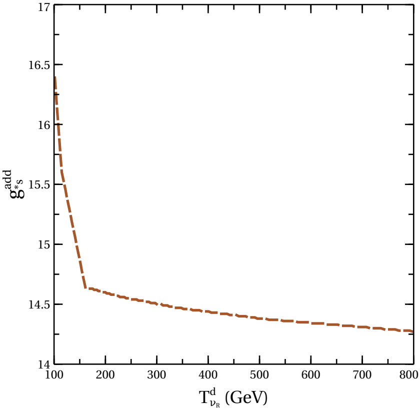
- We have shown the role of the same two parameters g_R, M_{W_R} in the context of DM.
- The relic density can only be satisfied in the resonance regions corresponding to W_R and Z_R masses.
- We also apply the corresponding bounds on the W_R mass from ΔN_{eff} bound.

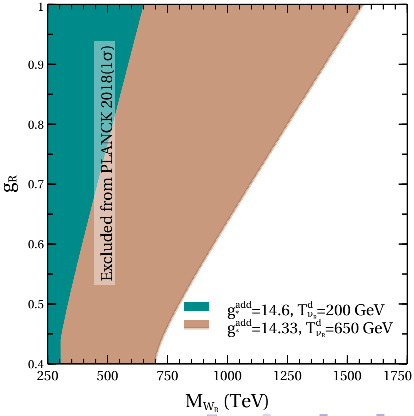




One Comment

- The 1σ bound on $\Delta N_{\rm eff}$ rules out all the parameter space of interest, if we consider the contributions from ν_R only.
- However, if there are more relativistic degrees of freedom, one can satisfy the bound.





Conclusions

- We consider the possibility of probing the left-right symmetric model (LRSM) via the cosmic microwave background (CMB).
- We adopt the minimal LRSM with Higgs doublets, also known as the doublet left-right model (DLRM).
- Because of the Dirac nature of light neutrinos, there exist additional relativistic degrees of freedom.
- Thermalization of those DOFs in the early Universe by virtue of their gauge interactions can constrain the model from Planck 2018 bound.
- We also study the consequence of these constraints on dark matter in the DLRM by considering a right-handed real fermion quintuplet to be the dominant dark matter component in the Universe.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and
Healthy


Thank
you!