Observing Left-Right Symmetry in the Cosmic Microwave Background

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Objective

- We consider the possibility of probing left-right symmetric model (LRSM) from Planck 2018 bound on the effective relativistic degrees of freedom.
- We adopt the minimal LRSM with Higgs doublets, also known as the doublet left-right model (DLRM), where all fermions including the neutrinos acquire masses only via their couplings to the Higgs bidoublet.
- Due to the Dirac nature of light neutrinos, there exist additional relativistic degrees of freedom which can thermalise in the early universe by virtue of their gauge interactions corresponding to the right sector.
- We have extended the discussion by introducing the fermion quituplate as a stable Dark matter candidate and constrained the parameter space.

$\Delta N_{\rm eff}$ in DLRM

- Recent 2018 data from the cosmic microwave background (CMB) measurement by the Planck satellite suggests that the effective degrees of freedom for neutrinos as

$$N_{\rm eff} = 2.99^{+0.34}_{-0.33} \tag{1}$$

at 2σ CL including baryon acoustic oscillation (BAO) data.
- At 1σ CL it becomes more stringent to $N_{\rm eff} = 2.99 \pm 0.17$.
- The contribution of ν_R to the relativistic degrees of freedom can be estimated as

$$\Delta \rm N_{eff} = N_{eff} - N_{eff}^{SM} = N_{\nu_R}\left(\frac{g_{*s}\left(T^{dec}_{\nu_L}\right)}{g_{*s}\left(T^{dec}_{\nu_R}\right)}\right)^{\frac{4}{3}} \tag{2}$$

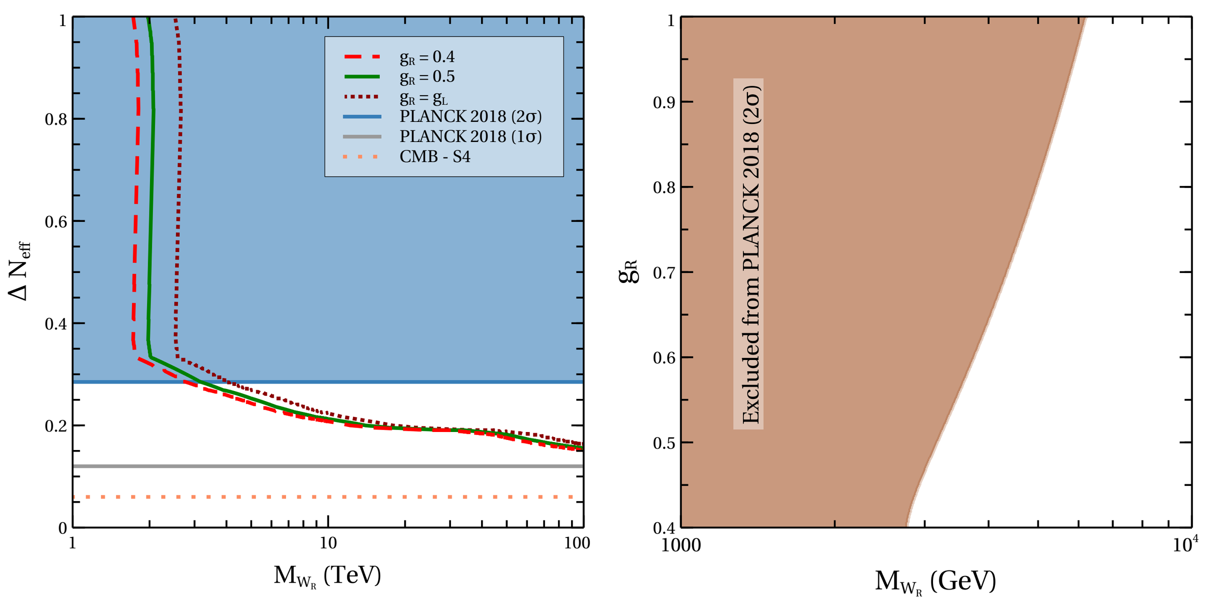

Figura 1: Left panel: $\Delta N_{\rm eff}$ as a function of W_R mass. Right panel: Parameter space in $g_R - M_{W_R}$ plane from Planck 2018 2σ constraints on $N_{\rm eff}$.

- We first calculate the decoupling temperature of right handed neutrinos from the thermal bath for different values of W_R, Z_R mass and gauge coupling g_R.
- We show the variation of decoupling temperature as well as other physical quantities only in terms of W_R mass because of the fact that Z_R mass typically depends upon W_R mass and is heavier than it, similar to Z and W masses of the SM.
- We show the contribution to $\Delta N_{\rm eff}$ in the left panel of figure 1 as functions of W_R mass for three different values of g_R.
- Along with the Planck 2018 bound mentioned earlier, we also show the CMB-S4 sensitivity as well as the Planck 2018 1σ limit while the latter is same as SPT-3G sensitivity.
- In the right panel of figure 1, we show the final parameter space in $g_R - M_{W_R}$ plane after applying Planck 2018 2σ constraints in figure.

Dark Matter in DLRM

- The data from Planck experiment which restricts the effective relativistic degrees of freedom in our universe also reveal that more than 26**%** of present universe's energy density is composed of a non-luminous and non-baryonic form of matter, known as **dark matter**.
- In the pure left-right symmetric setup, one has to introduce a pair of left and right handed fermion quintuplets (Ω_L, Ω_R) having same mass. In DLRM, quintuplet is the lowest dimension fermion representation which gives naturally stable DM.
- Since we are discussing a general scenario with $g_L \neq g_R$, we consider the left fermion quintuplet to be very heavy and decoupled from the low energy phenomenology.

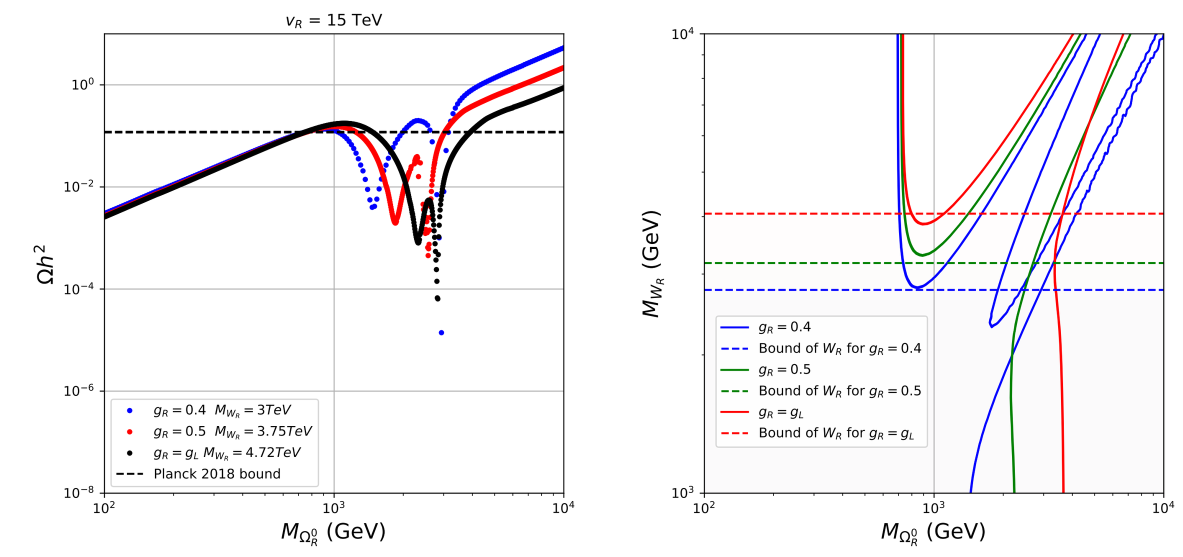

Figura 2: Left panel: DM relic as a function of DM mass for different benchmark combinations of (g_R, M_{W_R}), Right panel: Parameter space satisfying relic abundance criteria of right handed fermion quintuplet dark matter in DLRM. The shaded regions are ruled out by Planck 2018 bound on $\Delta N_{\rm eff}$ at 2σ for respective values of g_R.

- While all the components of fermion multiplet have same tree level masses, at radiative level, there arises a mass splitting between charged (with Q) and neutral components.
- Multiple allowed values of DM mass for a fixed W_R mass are arising due to annihilation and coannihilations of $\Omega^0_R, \Omega^{\pm}_R, \Omega^{\pm}_R\pm$ mediated by W_R, Z_R bosons where Z_R is slightly heavier than W_R.
- We scan the parameter space of W_R, Ω^0_R masses and show the region satisfying correct DM relic in right panel plot of figure 2.
- We also apply the corresponding bounds on W_R mass from Planck constraints on $\Delta N_{\rm eff}$ at 2σ CL as horizontal shaded lines so that the region below the respective lines are disallowed.

Discussions and Conclusions

- It is clear from figure 1 that Planck 2018 bound at 2σ CL itself rules out W_R mass below 4.06 TeV with gauge coupling $g_R = g_L$.
- On the other hand, future probe will be able to either confirm or rule out the model, even for very high W_R masses, out of reach of direct search experiments.
- A large part of the DM parameter space specially for $g_R = g_L$ gets ruled out by $\Delta N_{\rm eff}$ bounds.
- In view of more stringent Planck 2018 1σ which rules out all the parameter space with three ν_R to be contributing to the relativistic degrees of freedom (DOF) below the scale of left-right symmetry breaking.

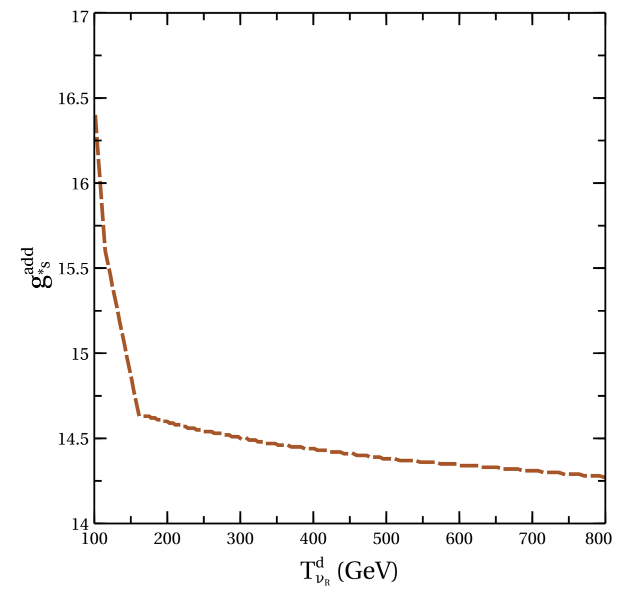

Figura 3: Additional relativistic degrees of freedom required to bring $N_{\rm eff}$ within Planck 2018 1σ bound $N_{\rm eff} = 2.99 \pm 0.17$.

- We show the required additional DOF in left panel of figure 8 as a function of right handed neutrino decoupling temperature. All the points on the dashed line in left panel of figure 3 gives rise to $\Delta N_{\rm eff}$=0.12 so that the points below this line are ruled out.
- These DOF can arise from DLRM with right handed fermion quintuplet DM. The scalar bidoublet, the pair of Higgs doublets, right handed fermion quintuplet DM, can have 19 additional DOF in DLRM.

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