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Baryon asymmetry, lepton number violation and asymmetric dark matter

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M. T. Frandsen, C. Hagedorn, WCH, E. Molinaro, H. Päs, arXiv:1801.09314

Outline

- L-violation responsible for $0\nu\beta\beta$ decay and wash-out on L and B
- Connection to asymmetric dark matter (ADM)
- Conclusions

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Upper bound on baryogenesis scale from neutrino masses

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We examine the constraints on baryogenesis if anomalous weak baryon violation is in thermal equilibrium at high temperatures. If neutrinos have Majorana masses, there is an upper bound on the scale of baryogenesis: $T_0 \leqslant 10^{12}\,\mathrm{GeV}(1\,\mathrm{eV}/m_\nu)^2$, where m_ν is the mass of the *lightest* neutrino, and no baryon number is generated at temperatures below T_0.

Chemical potential equilibrium

$$-\mu_q+\mu_H+\mu_{d_R}=0\ ,\quad -\mu_q-\mu_H+\mu_{u_R}=0\ ,\quad -\mu_\ell+\mu_H+\mu_{e_R}=0\ ,$$
$$3\,(3\,\mu_q+\mu_\ell)=0\ ,\quad \mu_q+2\mu_{u_R}-\mu_{d_R}-\mu_\ell-\mu_{e_R}+\frac{2}{3}\mu_H=0\ ,$$

All chemical potentials vanish after ΔL=2 kicks in !

$$\mu_\ell+\mu_H=0$$

$$n_\gamma HT\frac{d\eta_L}{dT}=c_D\frac{T^{2D-4}}{\Lambda_D^{2D-8}}\eta_L$$

$\eta_L=n_L/n_\gamma$

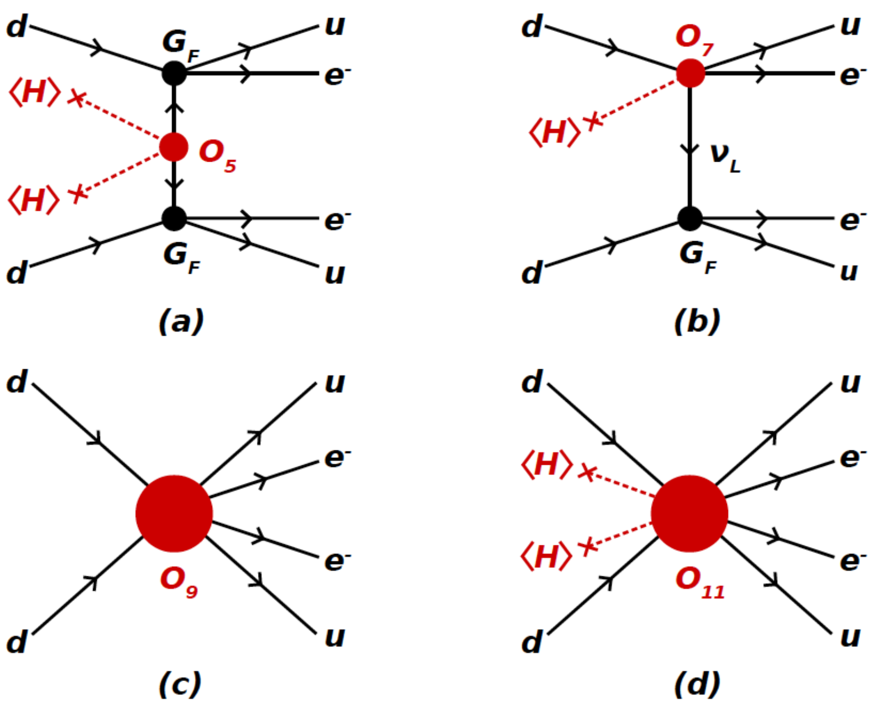
$n_\gamma\approx 2T^3/\pi^2$

$H\approx 1.66\sqrt{g_*}T^2/\Lambda_{\rm Pl}$

g_* (≈ 107 in the SM)

$\Lambda_{\rm Pl}=1.2\times 10^{19}$ GeV

Lepton Number Violation (LNV) Operators



- We single out operators which contribute $0\nu\beta\beta$ with short- and long-range interactions.

$$\mathcal{O}_5 = \frac{1}{\Lambda}(L^i L^j) H^k H^l \epsilon_{ik}\epsilon_{jl},$$

$$\mathcal{O}_7 = \frac{1}{\Lambda^3}(L^i d^c)(\bar{e^c}\bar{u^c}) H^j \epsilon_{ij},$$

$$\mathcal{O}_9 = \frac{1}{\Lambda^5}(L^i L^j)(\bar{Q}_i \bar{u^c})(\bar{Q}_j \bar{u^c}),$$

$$\mathcal{O}_{11} = \frac{1}{\Lambda^7}(L^i L^j)(Q_k d^c)(Q_l d^c) H_m \bar{H}_i \epsilon_{jk}\epsilon_{lm},$$

FIG. 1: Contributions to $0\nu\beta\beta$ decay generated by the operators in Eq. (2) in terms of effective vertices, point-like at the nuclear Fermi momentum scale.

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Lepton Flavor Violation (LFV)

- Since we only study wash-out effects resulting from the $0\nu\beta\beta$ operators, only e-lepton asymmetry will be eliminated.
- In order to washout other flavor asymmetries, one would need LFV operators together with the $0\nu\beta\beta$ operators.
- We study $\ell_i \to \ell_j + \gamma$ and $\ell_i \to \ell_j$ conversion

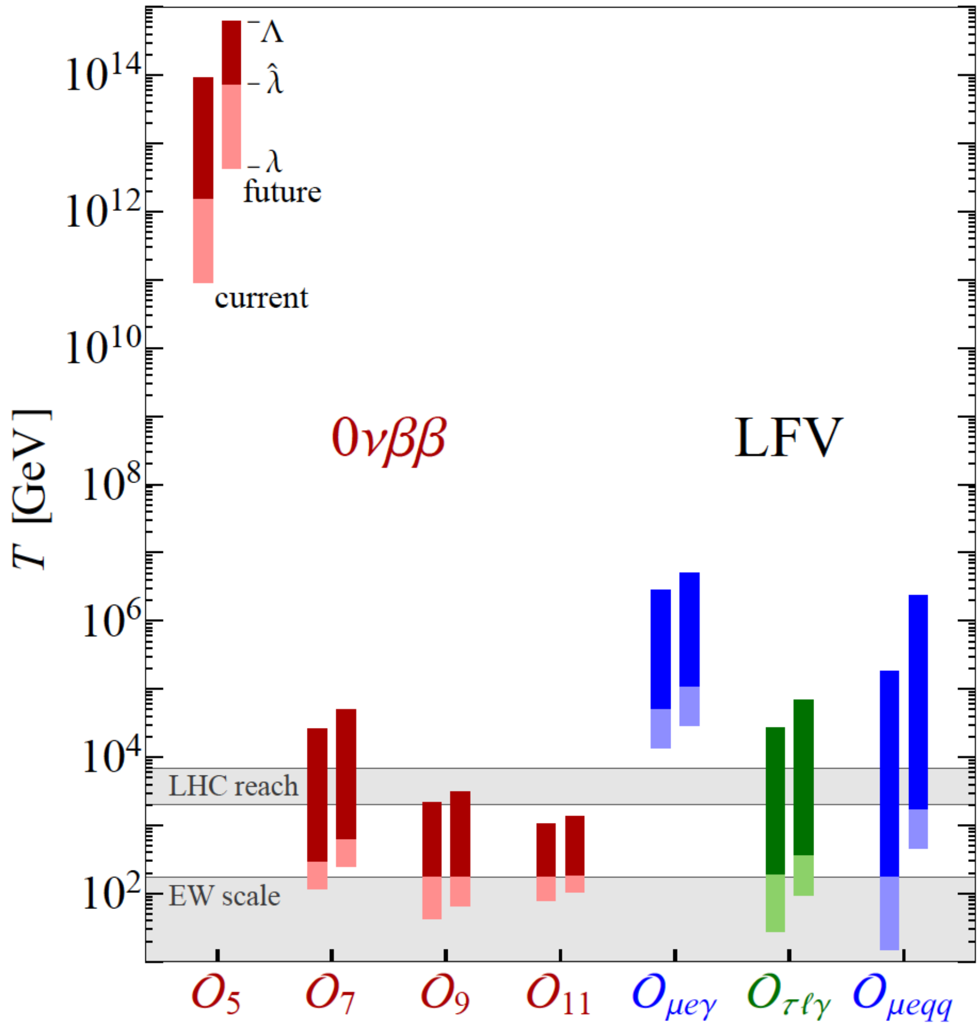
$$\mathcal{O}_{\ell\ell\gamma} = \mathcal{C}_{\ell\ell\gamma} \bar{L}_\ell \sigma^{\mu\nu} \bar{\ell}^c H F_{\mu\nu}$$

$$\mathcal{O}_{\ell\ell qq} = \mathcal{C}_{\ell\ell qq} (\bar{\ell}\, \Pi_1 \ell)(\bar{q}\, \Pi_2 q)$$

Π : Lorentz structures

$$\mathcal{C}_{\ell\ell\gamma} = \frac{e g^3}{16\pi^2 \Lambda^2_{\ell\ell\gamma}}, \quad \mathcal{C}_{\ell\ell qq} = \frac{g^2}{\Lambda^2_{\ell\ell qq}},$$

Results



- From $0\nu\beta\beta$, one can not differentiate O_9 and O_{11} from O_5
- However, O_9 and O_{11} can be probed at the LHC

$$\mathcal{O}_5 = \frac{1}{\Lambda}(L^i L^j)H^k H^l \epsilon_{ik}\epsilon_{jl},$$

$$\mathcal{O}_7 = \frac{1}{\Lambda^3}(L^i d^c)(\bar{e^c}\bar{u^c})H^j \epsilon_{ij},$$

$$\mathcal{O}_9 = \frac{1}{\Lambda^5}(L^i L^j)(\bar{Q}_i \bar{u^c})(\bar{Q}_j \bar{u^c}),$$

$$\mathcal{O}_{11} = \frac{1}{\Lambda^7}(L^i L^j)(Q_k d^c)(Q_l d^c)H_m \bar{H}_i \epsilon_{jk}\epsilon_{lm},$$

Caveats

- $0\nu\beta\beta$ decays only probe the electron flavor, so LFV is needed to wash out asymmetries stored in μ and τ flavors

- To carry out the analysis in a model-independent way, we assume no correlation between the generation mechanism and washout

- The existence of a decoupled sector can protect asymmetries from washout in the visible sectors (Phys. Lett. B207, 210 (1988) and 1309.4770)

Can ADM save world?

$$-\mu_q + \mu_H + \mu_{d_R} = 0 \ , \quad -\mu_q - \mu_H + \mu_{u_R} = 0 \ , \quad -\mu_\ell + \mu_H + \mu_{e_R} = 0 \ ,$$

$$3\,(3\,\mu_q + \mu_\ell) = 0 \ , \quad \mu_q + 2\mu_{u_R} - \mu_{d_R} - \mu_\ell - \mu_{e_R} + \frac{2}{3}\mu_H = 0 \ ,$$

All chemical potentials vanish after ΔL=2 kicks in !

$$\mu_\ell + \mu_H = 0$$

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Baryogenesis, sphalerons, and the cogeneration of dark matter

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Processes involving the electroweak anomaly can erase completely a primordial baryon and lepton asymmetry if $B-L=0$. This has led to the search for plausible mechanisms for weak-scale baryogenesis, or for the generation of a primordial $B-L$ asymmetry. Here it is emphasized that if another quantum number conserved up to anomalies is present electroweak anomaly processes would not necessarily erase a primordial baryon asymmetry even if $B-L=0$. Moreover, an asymmetry in the new quantum number that is comparable to the baryon asymmetry is generated concomitantly due to the electroweak anomaly. This asymmetry could be the origin of dark matter.

$$\alpha B+\beta L+\gamma X=0 \quad \Longrightarrow \quad B=L=-\left[\frac{\gamma}{\alpha+\beta}\right]X\neq 0$$

Can ADM save world?

$$-\mu_q + \mu_H + \mu_{d_R} = 0\ , \quad -\mu_q - \mu_H + \mu_{u_R} = 0\ , \quad -\mu_\ell + \mu_H + \mu_{e_R} = 0\ ,$$

$$\cancel{3\,(3\,\mu_q + \mu_\ell) = 0}, \quad \mu_q + 2\mu_{u_R} - \mu_{d_R} - \mu_\ell - \mu_{e_R} + \frac{2}{3}\mu_H = 0\ ,$$

$$\mu_\ell + \mu_H = 0\ ,$$

If particles in the dark sector are also charged under $SU(2)_L$, then the sphalerons can transfer symmetry between B, L and X (dark charge) => Asymmetric DM

$$3\,(3\,\mu_q + \mu_\ell) + n_X \mu_X = 0,$$

Can ADM save world?

$$-\mu_q + \mu_H + \mu_{d_R} = 0 \ , \ \ -\mu_q - \mu_H + \mu_{u_R} = 0 \ , \ \ -\mu_\ell + \mu_H + \mu_{e_R} = 0 \ ,$$

$$3\,(3\,\mu_q + \mu_\ell) = 0 \ , \ \ \mu_q + 2\mu_{u_R} - \mu_{d_R} - \mu_\ell - \mu_{e_R} + \frac{2}{3}\mu_H = 0 \ ,$$

$$\mu_\ell + \mu_H = 0 \, ,$$

If models need an extra asymmetry-transfer interaction, then DM asymmetry will also vanish!

$$X_{\rm DM}^2\,(\ell H)^2 \ , \ \ X_{\rm DM} d_R d_R u_R \ (\text{or } X_{\rm DM}^2 d_R d_R u_R)$$

Can ADM save world?

$$-\mu_q + \mu_H + \mu_{d_R} = 0 \ , \quad -\mu_q - \mu_H + \mu_{u_R} = 0 \ , \quad -\mu_\ell + \mu_H + \mu_{e_R} = 0 \ ,$$

$$3\,(3\,\mu_q + \mu_\ell) = 0 \ , \ \cancel{\mu_q + 2\mu_{u_R} - \mu_{d_R} - \mu_\ell - \mu_{e_R} + \frac{2}{3}\mu_H = 0} \, ,$$

$$\mu_\ell + \mu_H = 0 \, ,$$

- If there exist particles carrying $U(1)_Y$ charge, the hypercharge neutrality condition will be modified

$$\lambda^\alpha_{jk} \ \overline{F}_{Lj} \, S^*_k \, e_{R\alpha}$$

$$3\,\mu_q + 6\,\mu_{u_R} - 3\,\mu_{d_R} - 3\,\mu_\ell - 3\,\mu_{e_R} + 2\,\mu_H - 2\,n_{F\,(S)}\,\mu_{F\,(S)} = 0$$

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Conclusions

- Observation of LNV via 0vbb decay or at colliders together with LFV can falsify high-scale baryogenesis/leptogenesis

- In certain ADM models, the existence of DM can *revive* high-scale baryon or lepton asymmetry generation mechanisms and realize the connection of the baryon and DM density