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# Baryon Asymmetry, Dark Matter & Neutrino Mass via Exotic Multiplets

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*Some related references*: Cai et al., JHEP 1112 054 (2011) [arXiv:1108.0969 [hep-ph]]
Kumericki et al., JHEP 1207 039 (2012) [arXiv:1204.6597 [hep-ph]]
Kumericki et al., PRD 86 013006 (2012) [arXiv:1204.6599 [hep-ph]]

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the subscripts $\alpha$ , $\beta$ denote the many independent ways to contract the components

e.g. $\phi^\dagger\phi\chi^\dagger\chi$ : $\underbrace{\underline{2}^*\otimes\underline{2}}_{\underline{1}+\underline{3}}\otimes\underbrace{\underline{6}^*\otimes\underline{6}}_{\underline{1}+\underline{3}+\cdots}$ or $\underbrace{\underline{2}\otimes\underline{6}}_{\underline{5}+\underline{7}}\otimes\underbrace{\underline{2}^*\otimes\underline{6}^*}_{\underline{5}^*+\underline{7}^*}$ or $\underbrace{\underline{2}\otimes\underline{6}^*}_{\underline{5}^*+\underline{7}^*}\otimes\underbrace{\underline{2}^*\otimes\underline{6}}_{\underline{5}+\underline{7}}$ .

however, only a subset of these are truly independent.

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- $\mu_\phi$ , $\mu_\chi$ , $\lambda_\phi$ , $\lambda_{\chi\alpha}$ , … must be such that VEV $\boldsymbol{\langle\chi\rangle = 0}$

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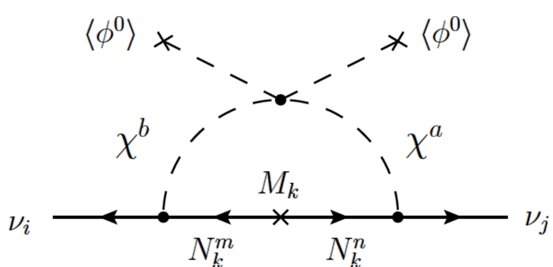

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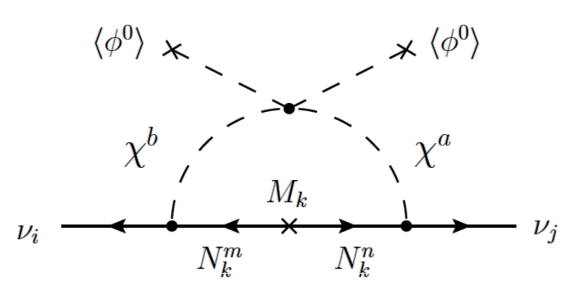


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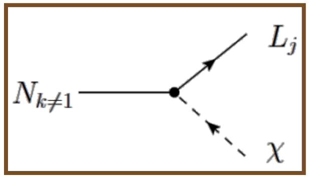


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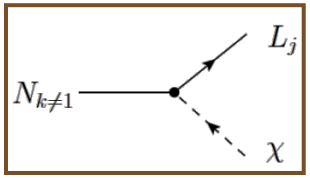


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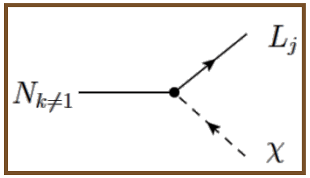


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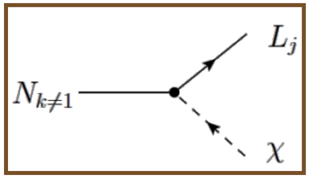


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- So, the challenge is to demonstrate that there exists a **parameter space** where all three problems can be addressed consistently.

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The **key parameters** in the model at a glance:

$$\mathbf{M_1} \quad , \quad \mathbf{M_2} \quad , \quad \mathbf{M_3} \quad , \quad \mathbf{M_\chi} \quad , \quad \boldsymbol{h_{jk}} \quad , \quad \boldsymbol{\lambda'_{\phi\chi}}$$

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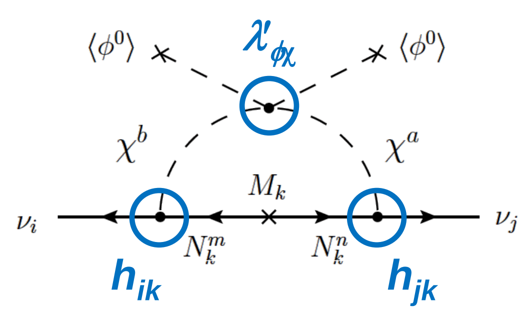

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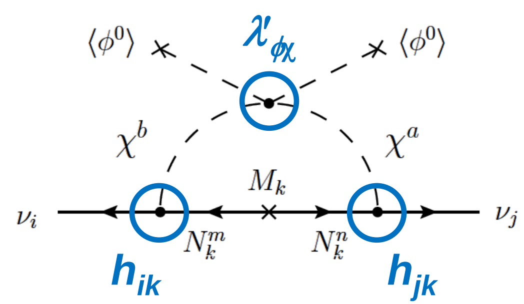
The $M_1$ scale is dictated by the constraints from DM (e.g. **relic density**):

$\boxed{M_1 \gtrsim 10 \text{ TeV}}$

(co)annihilation of $N_k$'s mediated by SM gauge bosons assumed [Cirelli et al., New J. Phys. 11,105005 (09)]



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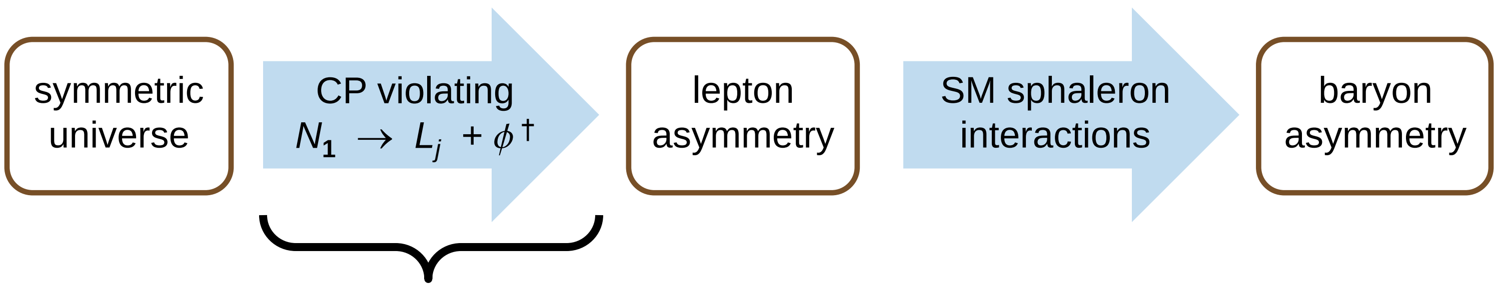


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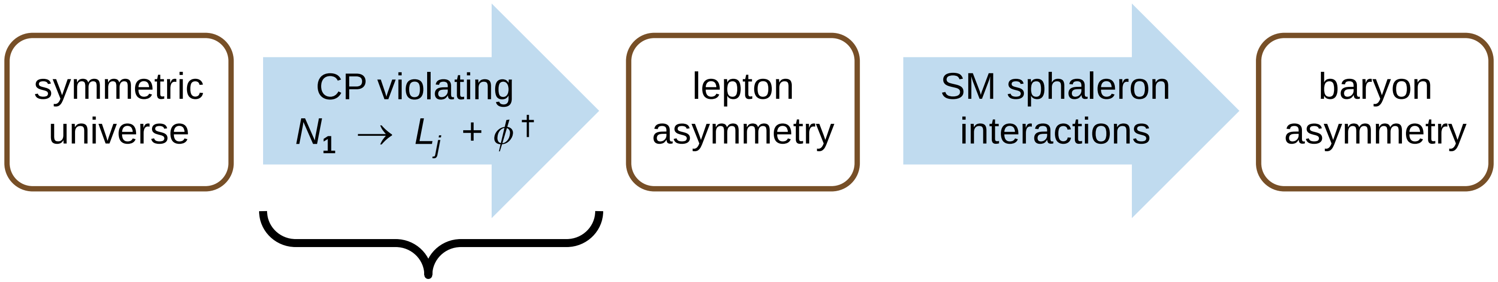


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<u>NB</u>: the decay of $\chi$ will NOT generate any lepton asymmetry since there is only **one** type of 6-plet scalar in the model $\Rightarrow$ vanishing absorptive part for the interference term with one-loop correction graphs.

# Flavored vs. Un-flavored $N_2$-Leptogenesis

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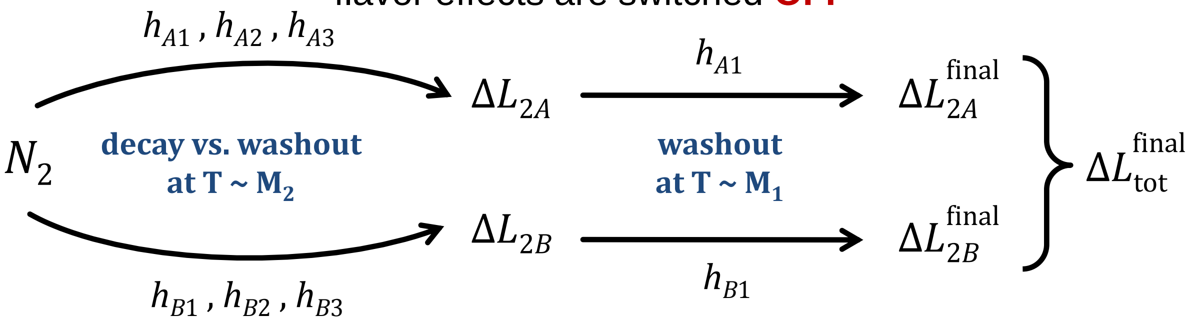
Schematic visualization of how flavor effects can make a difference

flavor effects are switched **OFF**



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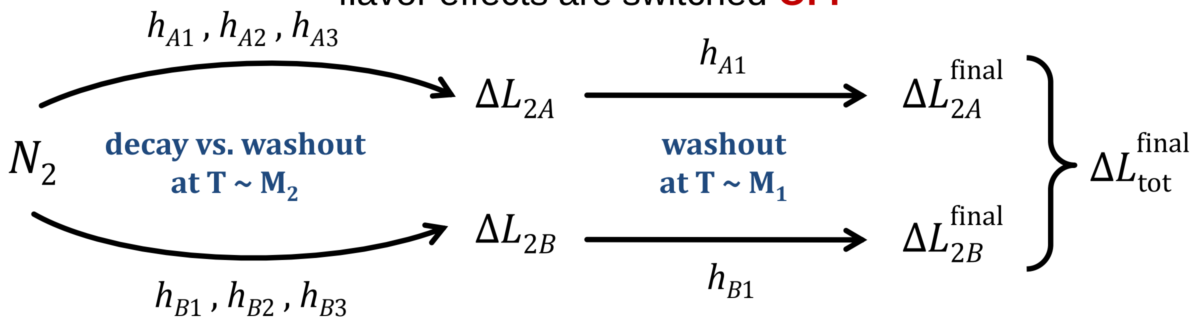


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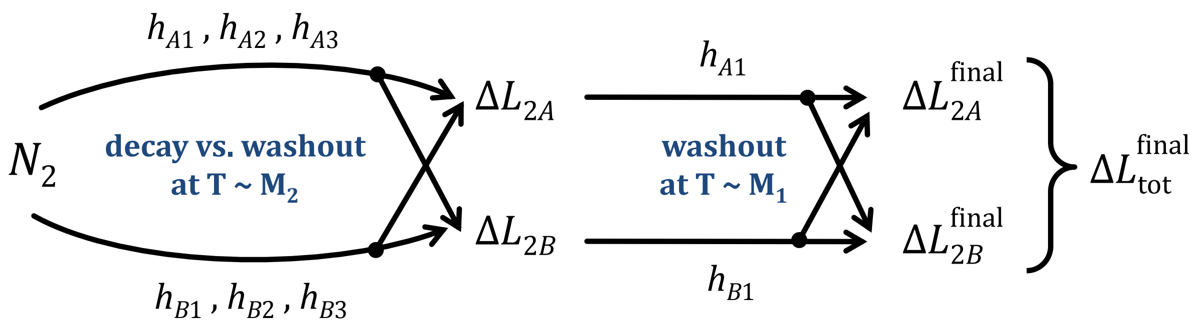


- The interdependence of parameters is <u>less</u> restrictive when flavor effects is **ON**. So, it becomes **possible** to find a set that can generate enough $\Delta L$.

# 5-plet $N_2$-Leptogenesis with flavors

Recall that we require the mass relation:-

$$\mathbf{M_1 < M_\chi < M_2 < M_3}$$

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where $z = M_2 / T$.

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CP asymmetry
from $N_2$ decays

where $z$ = $M_2$ / T.

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decay term

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washout term
(dominated by inverse decays)

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where $z$ = $M_2$ / T.

tree-level
flavor projector

$$\boxed{P^0_{2j} = \frac{h^*_{j2} h_{j2}}{(h^\dagger h)_{22}}}$$

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**non-diagonal** flavor coupling matrix
(this leads to a coupled system)

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$$\frac{d\mathcal{N}_{\Delta_j}}{dx} = -P_{\chi j}^0 W_\chi \sum_{i=e,\mu,\tau} C_{ji}^{f=3} \mathcal{N}_{\Delta_j} \ , \qquad j = e,\mu,\tau \ , \qquad x = M_\chi/T \quad \text{with} \quad P_{\chi j}^0 \equiv \overline{P}_{\chi j}^0 = \frac{h_{j1}^* h_{j1}}{(h^\dagger h)_{11}}$$

- observe that for this stage, there is no contribution from decays.

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- It turns out that for successful $N_2$-leptogenesis, the total lepton asymmetry should originate mainly from decays in the **tau** flavor [Bertuzzo et al., 11; Antusch et al.,12].

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- The resultant set of Yukawa's, $h_{jk}$ , must be checked for consistency with known **neutrino data** by calculating their effects on the 1-loop neutrino diagram.

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$$\left.\begin{array}{c} h_{e1} = 1.23 + 0.359i\ , \quad h_{e2} = 0.104 - 0.329i\ , \quad h_{e3} = -0.344 + 0.263i\ , \\ h_{\mu 1} = 1.71 - 1.02i\ , \quad h_{\mu 2} = -0.304 - 0.468i\ , \quad h_{\mu 3} = -3.76 + 0.367i\ , \\ h_{\tau 1} = 1.07 \times 10^{-5}\ , \quad h_{\tau 2} = 8.88 \times 10^{-3}\ , \quad h_{\tau 3} = 5.34\ . \end{array}\right\} \quad \eta_B \simeq 6 \times 10^{-10}$$

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$\lambda'_{\phi\chi} = 1$ to keep Yukawa's size perturbative, while $K_{z\tau} \simeq 2$ , $K_{x\tau} \simeq 0.01$ .

$$
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For the **quasi-degenerate** light neutrino spectrum and with $m_1 \simeq 0.16$ eV

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$$h_{e1} = 3.25 - 1.91i\,, \quad h_{e2} = 0.541 + 0.895i\,, \quad h_{e3} = -0.090 - 0.128i\,,$$
$$h_{\mu 1} = 1.972 + 3.23i\,, \quad h_{\mu 2} = -0.916 + 0.543i\,, \quad h_{\mu 3} = 0.040 - 0.078i\,,$$
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These will give $\eta_B \simeq$ **$4.3 \times 10^{-11}$** which is the least favored case.

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- We have demonstrated that there is a parameter space in this model where a consistent solution to all three problems can be obtained.