Higgs Portal Leptogenesis

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Work with A. Ritz, paper in preparation

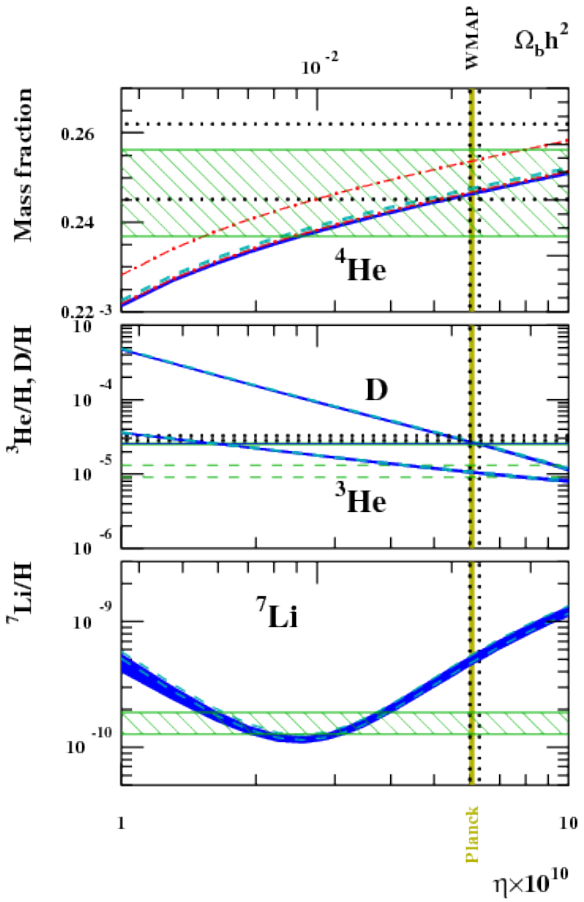
1 The matter/antimatter question

2 Standard Leptogenesis

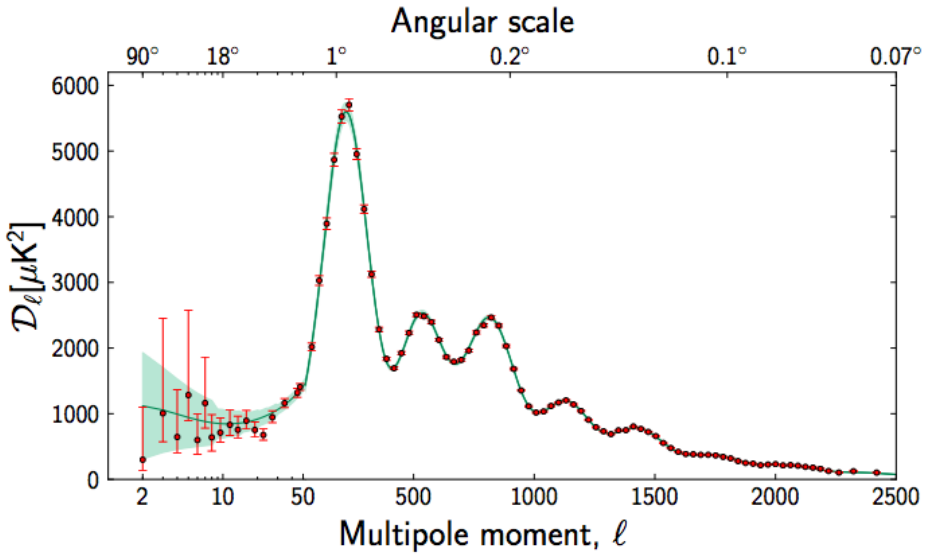
3 Hidden Sector

4 Higgs Portal Leptogenesis

Baryon Asymmetry of the Universe



[A. Coc et al. '14]



[Planck '13]

$$\eta_B = \frac{n_B}{n_\gamma} \sim (6.04 \pm 0.09) \cdot 10^{-10}$$

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Standard Leptogenesis [Luty '91]

$$-\mathcal{L} = \underbrace{\lambda_{ji} N_i L_j \cdot H}_{\text{CP-violation}} + \underbrace{M_i N_i N_i}_{\text{Lepton violation}} + h.c$$

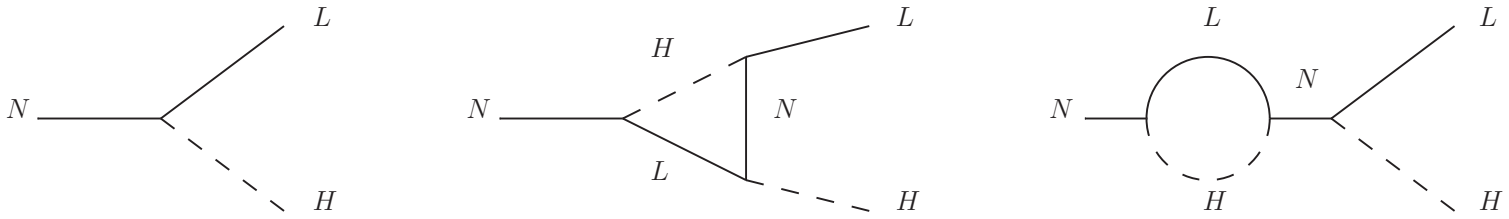
1. Populate leptons: $N \to LH + N \to \overline{LH}$,
2. Lepton over anti-leptons: $N \to LH > N \to \overline{LH}$,
3. Slow reaction rates: $\Gamma_N < H(T)$,
4. Sphalerons: $\eta_L \to \eta_B$

✓Sakharov's conditions [Sakharov '67]

✓See-saw

$$m_\nu \sim \frac{|\lambda|^2 v^2}{M} \sim 10^{-11}\text{GeV}$$

Standard Leptogenesis



CP-asymmetry [Davidson et al. '02]

$$\epsilon_1 \sim \frac{\mathrm{Im}\{(\lambda^\dagger\lambda)^2\}}{8\pi(\lambda^\dagger\lambda)}\mathcal{F}\left(\frac{M_2}{M_1}\right) \xrightarrow[\text{Hierarchical}]{\text{See-saw}} |\epsilon_1| \lesssim \frac{3m_\nu}{8\pi v^2}M_1$$

Boltzmann equations [Buchmuller et al. '04]

$$Y_1' = -D_1(Y_1 - Y_1^{eq}) \quad , \quad Y_{L-\bar{L}}' = \epsilon_1 D_1(Y_1 - Y_1^{eq}) - W_{ID_1}Y_{L-\bar{L}}$$

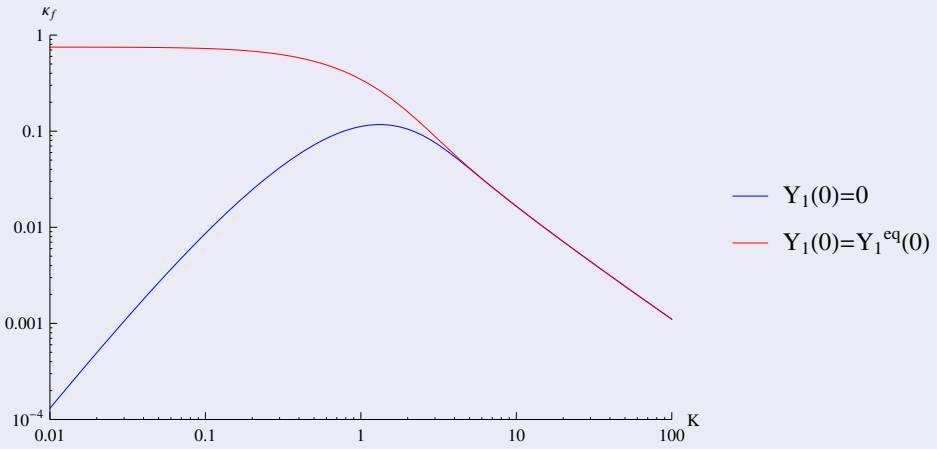
Standard Leptogenesis

Efficiency : $Y^f_{L-\bar{L}} \sim \epsilon_1 \kappa^f_1$

D.I. bound : $\epsilon_1 \lesssim \frac{3 m_\nu}{8\pi v^2} M_1$

Sphalerons : $Y^f_{L-\bar{L}} \sim 2\eta_B$

[Harvey & Turner '90]



Efficiency factor

$$\kappa^f_1 < 1 \quad , \quad \epsilon_1 > 10^{-9} \quad , \quad M_1 > 10^8 \text{GeV}$$

- Large scale
- No opening to Dark sector

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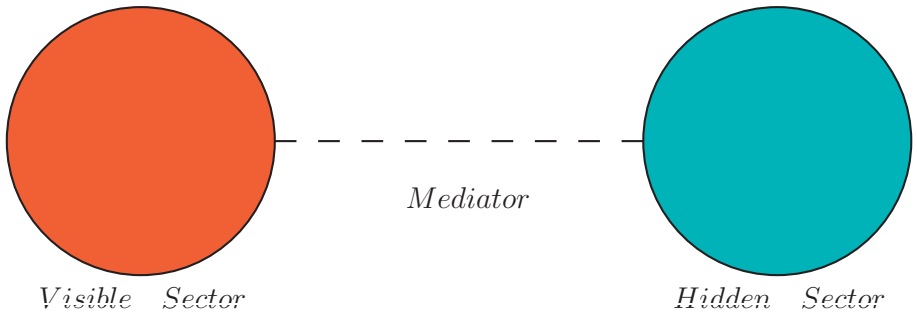
Include a Hidden Sector



- Visible Sector: SM
- Hidden Sector: e.g. DM
- Mediator: S, A_μ, ψ

SM-HS Effective interactions: Portals

$$\mathcal{L} = \sum_{n_1,n_2} \frac{\mathcal{O}_{SM}^{n_1}\mathcal{O}_{HS}^{n_2}}{\Lambda^{n_1+n_2-4}} \quad , \quad \text{Renormalisable:} \quad n_1 + n_2 \leq 4$$

Higgs and Neutrino portals

- $\mathcal{L}_{Higgs} = \beta S H^\dagger H + \gamma S^2 H^\dagger H$
- $\mathcal{L}_{SNN} = \alpha_{ij} S N_i N_j \ , \ \langle S \rangle = 0$

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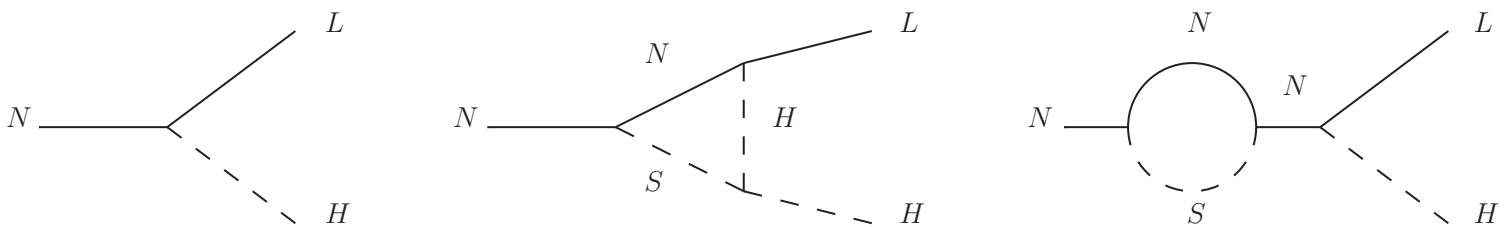
Higgs Portal Leptogenesis

$$-\mathcal{L} = \underbrace{\alpha_{ij} N_i N_j S + \beta S H^\dagger H + \gamma H^\dagger H S^2}_{\text{Hidden sector}} + \underbrace{\lambda_{ij} N_i H \cdot L_j + M_i N_i N_i}_{\text{Standard sector}}$$

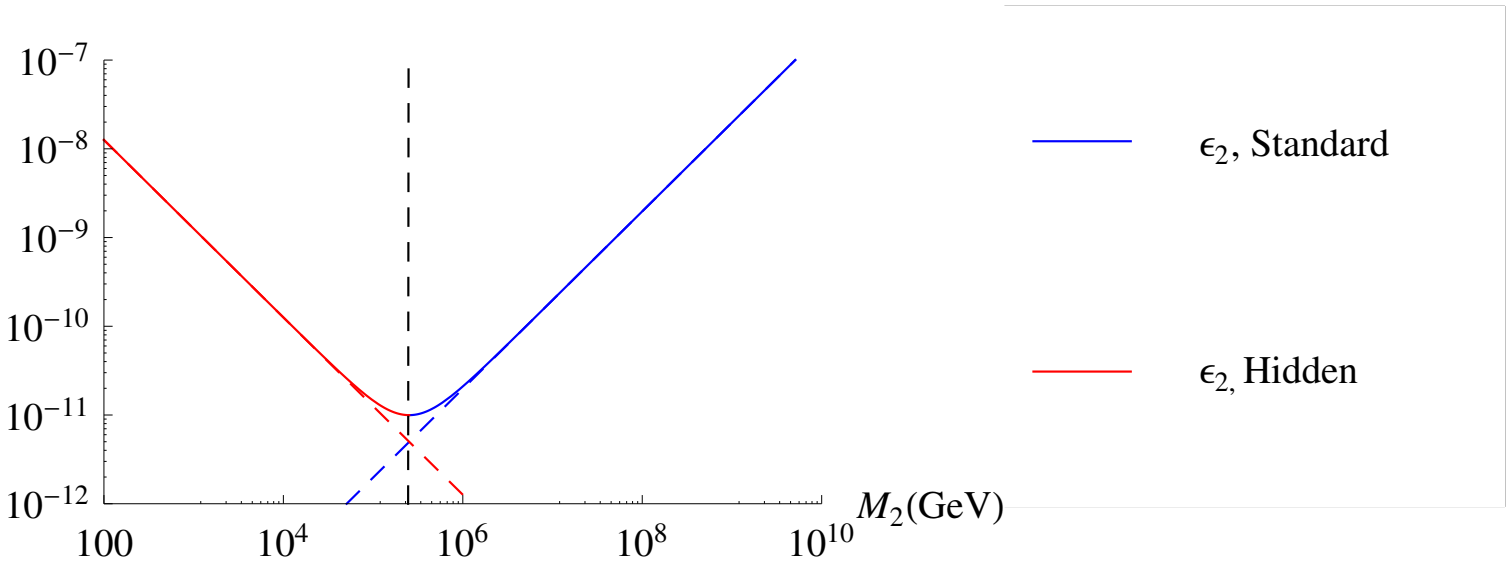
New CP-asymmetry channels



CP-asymmetries

$$|\epsilon_1| \sim \frac{3 m_\nu}{8\pi v^2} M_1 \quad , \quad |\epsilon_2| \sim \frac{3 m_\nu}{16\pi v^2} M_2 + \frac{\alpha\beta}{8\pi M_2}\sqrt{\frac{M_1}{M_2}} + \frac{\alpha^2}{16\pi}\sqrt{\frac{M_1}{M_2}}$$

Low Scale CP-asymmetry



Hidden CP-asymmetry dominates

$$M_2^2 < \frac{2v^2}{3m_\nu}\alpha\beta\sqrt{\frac{M_1}{M_2}}$$

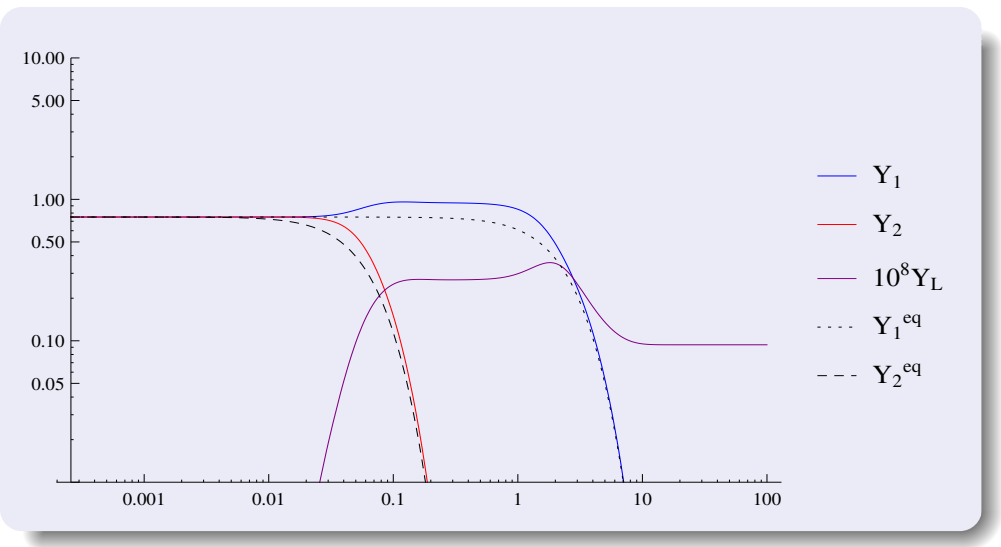
Standard CP-asymmetry dominates

$$M_2^2 > \frac{2v^2}{3m_\nu}\alpha\beta\sqrt{\frac{M_1}{M_2}}$$

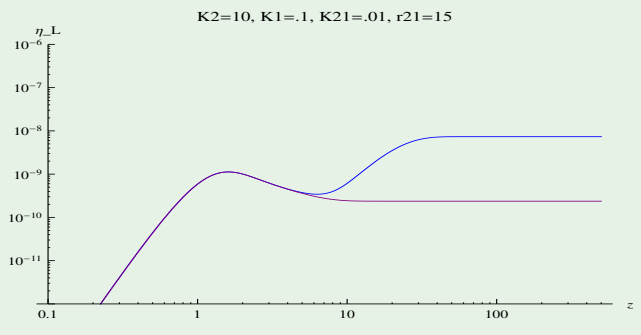
$$Y_2' = -\left(Y_2 - Y_2^{eq}\right)\left(D_2 + D_{2\leftrightarrow 1}\right) + D_{2\leftrightarrow 1}\left(Y_1 - Y_1^{eq}\right)\frac{Y_2^{eq}}{Y_1^{eq}}$$

$$Y_1' = -\left(Y_1 - Y_1^{eq}\right)\left(\frac{D_1}{\sqrt{r_{21}}} + D_{2\leftrightarrow 1}\frac{Y_2^{eq}}{Y_1^{eq}}\right) + D_{2\leftrightarrow 1}\left(Y_2 - Y_2^{eq}\right)$$

$$Y'_{L-\bar{L}} = \sum_{i=1,2}\left[\epsilon_i D_i\left(Y_i - Y_i^{eq}\right) - Y_{L-\bar{L}}W_i\right]\frac{M_i}{M_1}$$

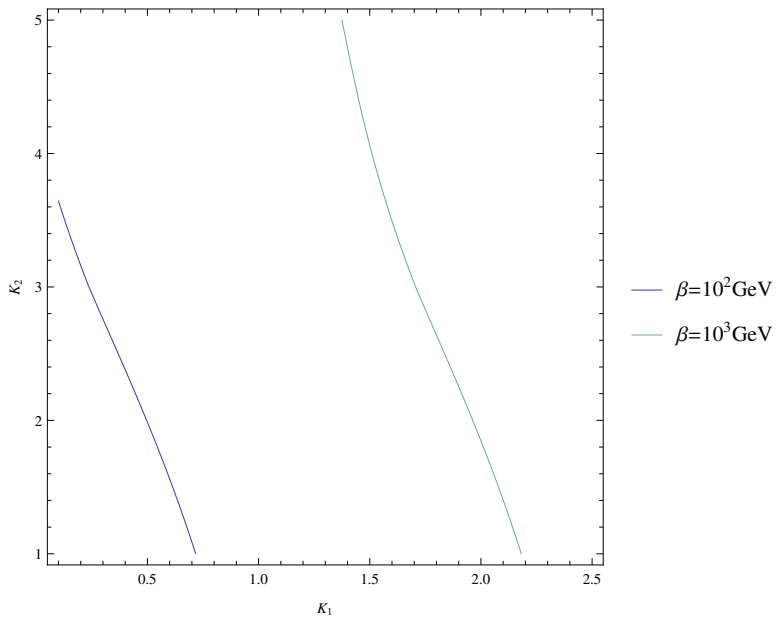


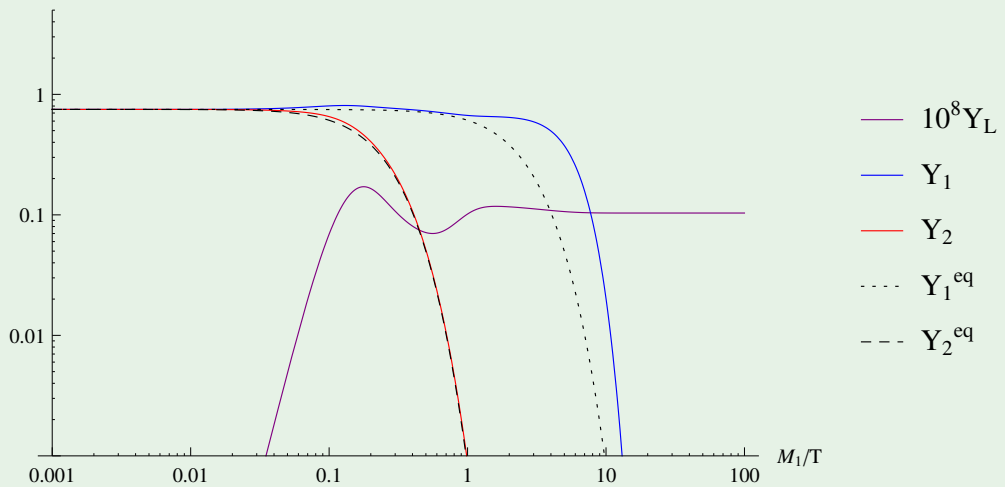
$$Y^f_{L-\bar{L}} \sim Y^{(1)}_{L-\bar{L}} + Y^{(2)}_{L-\bar{L}}$$



Low Scale Example

$$M_2 = 10^3\text{GeV} \quad , \quad M_1 = 10^2\text{GeV} \quad , \quad \epsilon_1 \sim 10^{-15} \quad , \quad \epsilon_2 \sim 10^{-8}$$





$$m_{\nu_i} \sim K_i \cdot 10^{-12}\text{GeV}$$
$$\lambda_i^2 \sim 8\pi K_i \frac{M_i}{10^{12}\text{GeV}}$$

- $m_{\nu_1} \sim 10^{-13}\text{GeV}, m_{\nu_2} \sim 10^{-11}\text{GeV}$
- $\alpha \sim 10^{-6}, \beta = 200\text{GeV}$

Conclusions

Open Leptogenesis to Dark Sector

- Higgs Portal: $\beta HHS + \alpha NNS$
- CP-asymmetry: $\epsilon \propto \beta / M$

Low mass scale CP-asymmetry

- $M_2 < M_2^{crit} \quad \rightarrow \quad |\epsilon_2| \propto \alpha\beta / M_2$

2-level Leptogenesis models

- $Y^f_{L-\overline{L}} \sim Y^{(1)}_{L-\overline{L}} + Y^{(2)}_{L-\overline{L}}$

Viable low scale models

- $M_1 \sim M_2 \sim 10^3 \text{GeV}$