A Testable Scenario for Asymmetric Dark Matter from Leptogenesis

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Abstract

- Minimal Co-genesis setup: decay of lightest heavy Majorana neutrino N_1 generate both the baryon asymmetry and DM abundance; complex Yukawa couplings with a hierarchical structure enhance CP violation while supporting a low-scale seesaw at $\mathcal{O}(2\ \text{TeV})$.
- Testable DM signals: annihilation extension allows spin-independent scattering within reach of DM direct detection experiments for $m_\chi \gtrsim 10$ GeV, and motivates searches in the "neutrino fog" for light DM $m_\chi \lesssim 10$ GeV

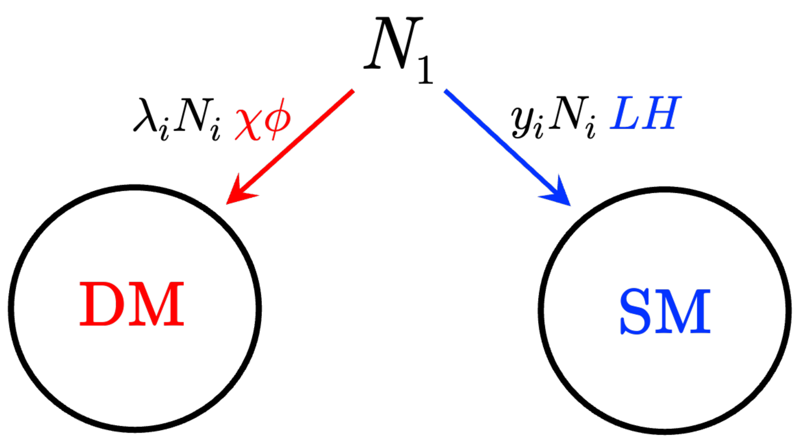
Co-genesis Overview

χ is the dark matter candidate, ϕ is a complex singlet scalar, N_i is the right-handed neutrino (RHN) from See-Saw Type I, where i =1,2,3. L and H are the Lepton and Higgs doublets.

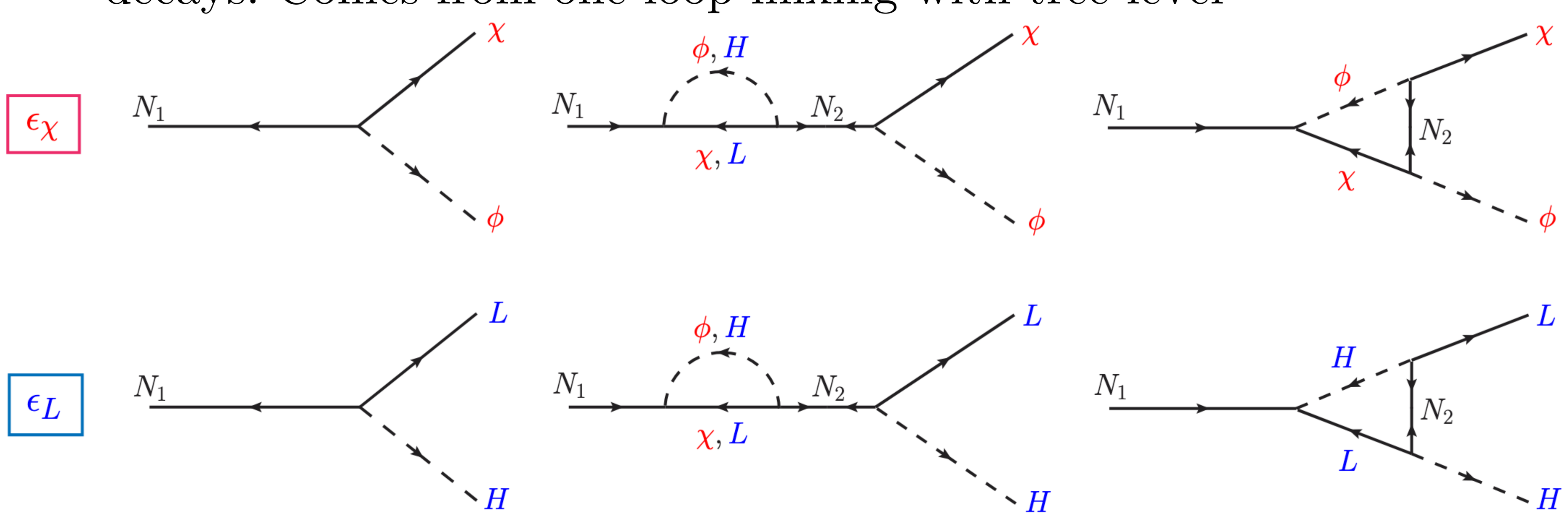
Fields		SU(2)	U(1)$_Y$
Fermions	N_i	1	0
	χ	1	0
	L	2	-1
Scalars	ϕ	1	0
	H	2	1

$$-\mathcal{L} \supset M_i \overline{N}_i^c N_i + \lambda_i N_i\, \chi\phi + y_{i\alpha}\, N_i\, L_\alpha H + h.c.$$

- The model was proposed by A. Falkowski et al.[1]
- They showed that for $\frac{\Gamma_{N_j}}{\Gamma_{N_1}} \simeq \frac{M_{N_j}}{M_{N_1}}$, then $M_{N_1} \gtrsim 10^9$ GeV
- DM stability requires $m_\chi < m_\phi < M_{N_1}$
- With unsuppressed washout can't obtain stable DM below this
- We explore the case where $\frac{\Gamma_{N_j}}{\Gamma_{N_1}} \gg \frac{M_{N_j}}{M_{N_1}}$ (j =2,3 for 2,3 RHN's)
- Find that the energy scale can be much lower



- We have asymmetry generated in both the visible sector (SM) and the dark sector (DM) simultaneously from just N_1 CP violating decays. Comes from one loop mixing with tree level[2]



$$\epsilon_L \simeq \frac{M_1}{M_2}\frac{\text{Im}\left[3(y^\dagger y)_{12}^2 + (y^\dagger y)_{12}\,\lambda_1^*\lambda_2\right]}{8\pi(2\,(y^\dagger y)_{11} + |\lambda_1|^2)} \qquad \epsilon_\chi \simeq \frac{M_1}{M_2}\frac{\text{Im}\left[(\lambda_1^*\lambda_2)^2 + (y^\dagger y)_{12}\,\lambda_1^*\lambda_2\right]}{8\pi(2\,(y^\dagger y)_{11} + |\lambda_1|^2)}$$

Boltzmann equation

Give relevant terms in Boltzmann equations.

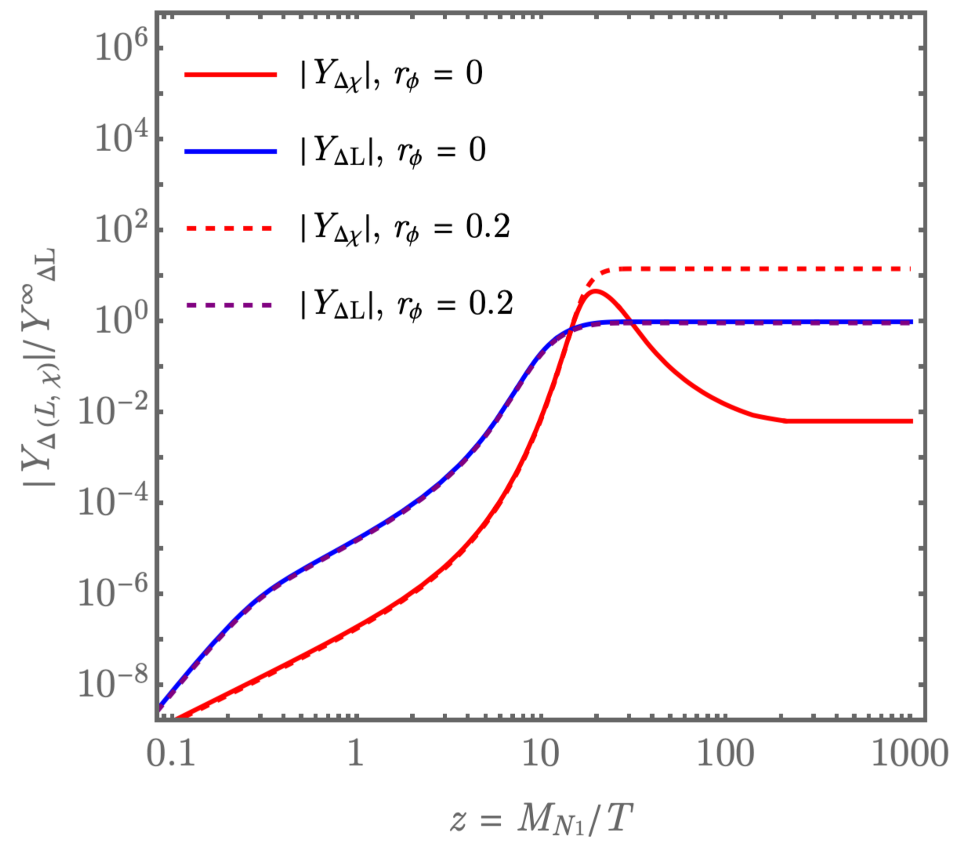
$$\frac{dY_{N_i}}{dz_1} = -\frac{\Gamma_{N_i}}{H_1} z_1 \frac{K_1(z_i)}{K_2(z_i)}\,(Y_{N_i} - Y_{N_i}^{eq})$$

$$\frac{dY_{\Delta\chi}}{dz_1} = \frac{\Gamma_{N_1}}{H_1}\epsilon_\chi\, z_1 \frac{K_1(z_i)}{K_2(z_i)}(Y_{N_i} - Y_{N_i}^{eq}) - \frac{\Gamma_{N_2}}{H_1}(2\,\text{Br}_\chi^2\, I_W(z_2)\, Y_{\Delta\chi})$$

$$\frac{dY_{\Delta L}}{dz_1} = \frac{\Gamma_{N_1}}{H_1}\epsilon_L\, z_1 \frac{K_1(z_i)}{K_2(z_i)}\,(Y_{N_i} - Y_{N_i}^{eq}) - \frac{\Gamma_{N_2}}{H_1}\text{Br}_L\text{Br}_\chi(I_{T_+}(z_2)(Y_{\Delta L} + Y_{\Delta\chi}))$$

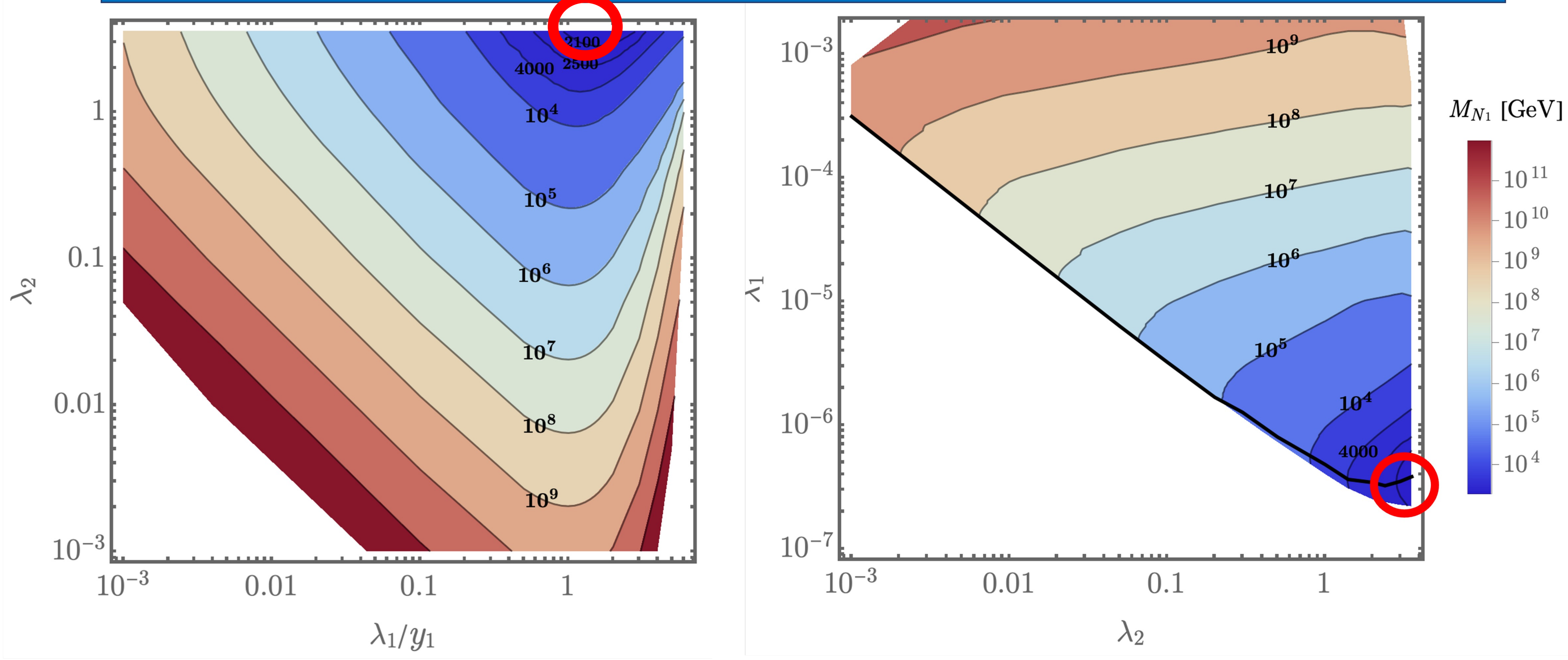
- Small couplings result in large thermal departure but small ϵ
- Large couplings result in small thermal departure but large ϵ
- A Hierarchy in $\lambda_1 \ll \lambda_2$ allows Large departure in N_1 with large $\epsilon_{L,\chi}$ from the mixing from the λ_2 coupling

Washout suppression



- For negligible χ and ϕ masses, DM is only stable when $M_{N_1} > 10^6$ GeV
- $m_\phi \lesssim M_{N_1}$, washout of DM is suppressed which allows for stable DM when $M_{N_1} \simeq \mathcal{O}(2\ \text{TeV})$
- $r_\phi = m_\phi / M_{N_1}$

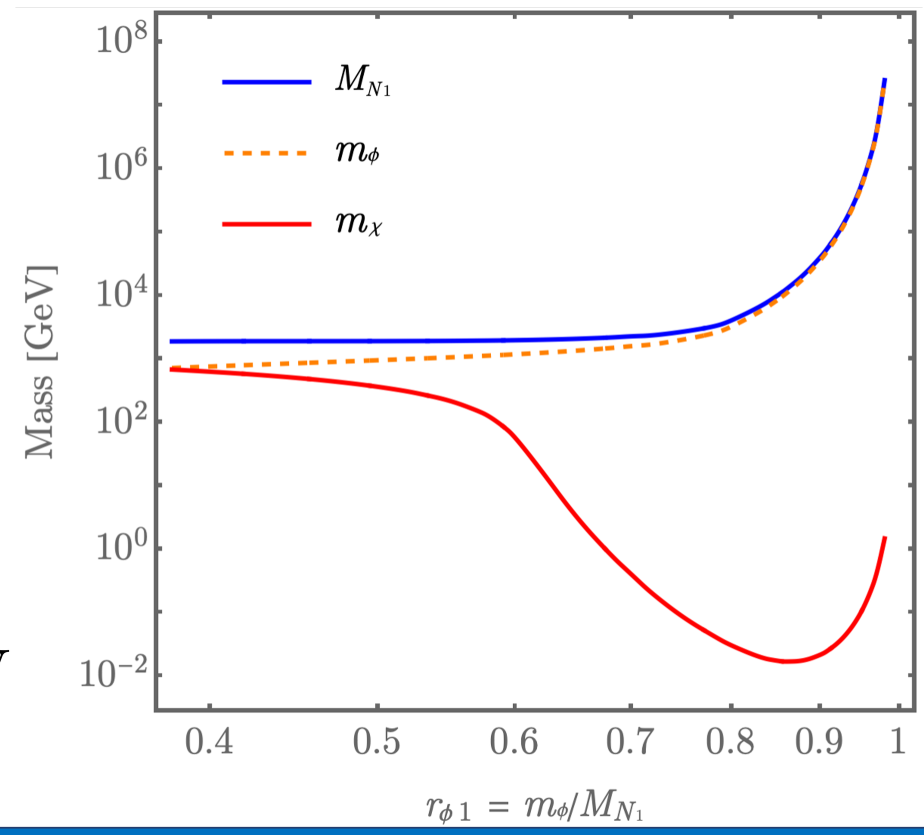
Optimal parameters



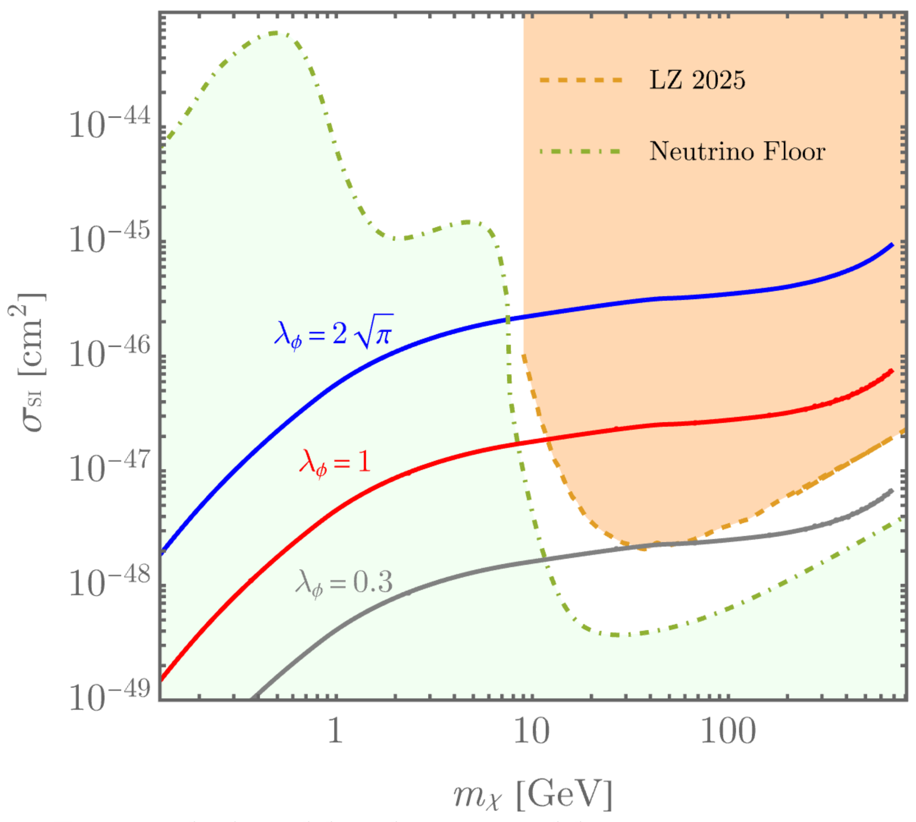
Minimal mass of N_1 as function of λ_1 and λ_2 to produce the observed Baryon asymmetry and DM relic abundance

DM mass range

- Large ϕ mass supresses lepton asymmetry,
- Small ϕ mass increases washout of DM requiring larger DM mass to compensate
- DM stability requires $m_\chi < m_\phi$
- 10^{-2} GeV $\lesssim m_\chi \lesssim 10^3$ GeV



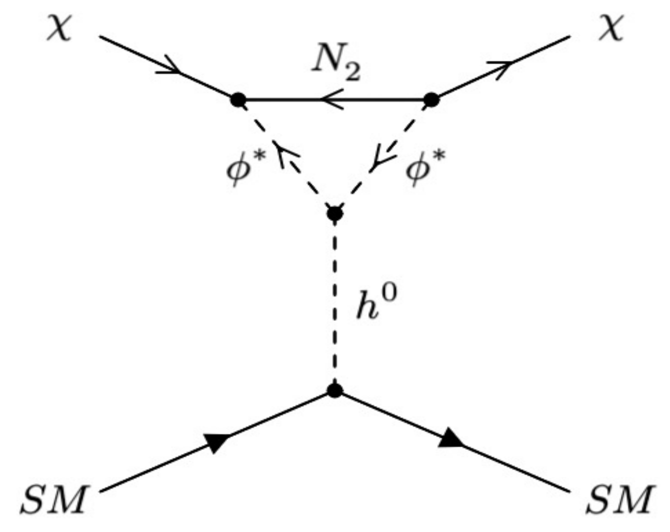
Observational Prospects



Region below blue line possible parameter space, orange shaded region ruled out, green shaded is neutrino fog

$\mathcal{L} \supset \lambda_\phi\ \phi^*\phi\ H^\dagger H$ will generate after EWSB: $\mathcal{L} \supset \lambda_\phi v\ h^0\ \phi^*\phi$

Leads to spin independent direct detection (for $M_{N_1} \simeq 2$ TeV)



UV complete scattering for direct detection

Conclusion

- Have low energy Leptogenesis ($M_{N_1} \simeq$ 2 TeV) with asymmetric dark matter
- Testable parameter space if Higgs couples to ϕ for certain parameters

References

[1] Falkowski A, Ruderman JT, Volansky T. Asymmetric dark matter from leptogenesis. Journal of High Energy Physics. 2011 May;2011(5):1-32.
[2] A. Falkowski, *Asymmetric dark matter and leptogenesis*, talk (slides), Theoretical Particle and Astroparticle Physics Seminar, Max Planck Institute for Nuclear Physics (MPIK), Heidelberg (18 Apr 2011)