Freezing in with Lepton Flavored Fermions

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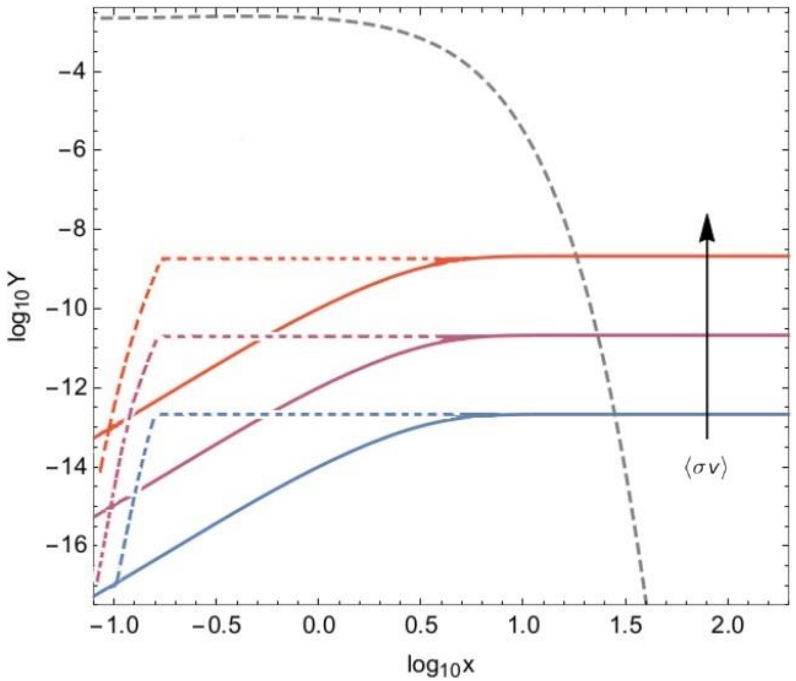
Outline

- Freeze-in and Lepton Flavored Dark Matter
- Minimal Flavor Violation
- Stability analysis
- Model
- Results

Freeze-in & Lepton Flavored Dark Matter

- Freeze-in mechanism
  - Non-thermalized: **small couplings**
  - $SM(SM) \longrightarrow DM, DM$
  - $\Omega h^2 \propto \langle \sigma v \rangle$



  - Small couplings make **detection** difficult

Electron Yukawa

is a *small* parameter in the SM

Lepton Flavored Dark Matter

Minimal model with fermionic dark matter under

Minimal Flavor Violation

leads to photon mediated direct detection process

Light mediator

Minimal Flavor Violation

- Consider the lepton sector of the Standard Model

$$\mathcal{L}_{SM} \supset i\bar{L}\not{D}L + i\bar{e}_R\not{D}e_R + \bar{L}Y_l e_R H$$

$$L\sim\begin{pmatrix} l_e \\ l_\mu \\ l_\tau \end{pmatrix}, \qquad e_R\sim\begin{pmatrix} e_R \\ \mu_R \\ \tau_R \end{pmatrix}$$

- All but the Yukawa term are symmetric under a large Global symmetry

$$G_{LF}\sim SU(3)_L \otimes SU(3)_{e_R}$$

$$L\sim(3,1),\ e_R\sim(1,3)$$

- MFV hypothesis demands that the SM Yukawa matrices be the only sources of flavor breaking. Treats Yukawas as spurions transforming non-trivially under flavor:

$$\bar{L}Y_l e_R H \ \Rightarrow Y_l\sim(3,\bar{3})$$

- Models are constructed by adding flavored particles and constructing operators invariant under G_{LF}

Minimal Flavor Violation: Stability Analysis

Denote the irreducible representation of a SM singlet DM χ under G_{LF}

$$\chi \sim (n_L, m_L)_L \times (n_e, m_e)_{e_R}$$

And write the most general decay operator

$$\mathcal{O}_{decay} = \chi_{L,R} \underbrace{L \dots}_{A} \underbrace{\bar{L} \dots}_{B} \underbrace{e_R \dots}_{C} \underbrace{\bar{e}_R \dots}_{D} \underbrace{Y_l \dots}_{E} \underbrace{Y_l^\dagger \dots}_{F} \mathcal{O}_{weak}$$

Condition for $\mathcal{O}_{decay}$ to be allowed:

$$SU(3)_L : (A - B + E - F + n_L - m_L) \; mod \; 3 = 0$$
$$SU(3)_R : (C - D - E + F + n_E - m_E) \; mod \; 3 = 0$$
$$\Rightarrow (A - B + C - D + n_L - m_L + n_E - m_E) \; mod \; 3 = 0$$

Assume χ has lepton number q_{LN} and demand for lepton number conservation

$$(A - B + C - D + q_{LN}) = 0$$

$$(n_L - m_L + n_E - m_E - q_{LN}) \; mod \; 3 \neq 0$$

Batell et al (2011)
Chen et al (2016)

Lepton flavored DM under MFV

$$(n_L - m_L + n_E - m_E - q_{LN})\ mod\ 3 \neq 0$$

MFV + Lepton number conservation renders specific DM representations automatically stable ***up to all orders***

χ_L	χ_R	q_{LN}	MFV	LNC	$Stable$	$Operators$
(3,1)	(1,3)	−1	✓	✓	✓	$(\bar{\chi}_L \sigma_{\mu\nu} Y_l \chi_R) B^{\mu\nu}, (\bar{\chi}_L \sigma_{\mu\nu} Y_l \gamma_5 \chi_R) B^{\mu\nu}, (\bar{\chi}_L \sigma^{\mu\nu} Y_l \chi_R) H^\dagger H$
(3,1)	(3,1)	−1	✓	✓	✓	$(\bar{\chi}_L \sigma_{\mu\nu} \chi_R) B^{\mu\nu}, (\bar{\chi}_L \sigma_{\mu\nu} \gamma_5 \chi_R) B^{\mu\nu}, (\bar{\chi}_L \sigma^{\mu\nu} \chi_R) H^\dagger H$

Introduce a chiral, fermionic DM transforming nontrivially under flavor group:

$\chi_L \sim (3,1)_{G_{LF}} \sim (\chi_1, \chi_2, \chi_3)_L$, $\chi_R \sim (1,3)_{G_{LF}} \sim (\chi_1, \chi_2, \chi_3)_R$, where $G_{LF} \sim SU(3)_L \otimes SU(3)_{e_R}$

$$\mathcal{L}_{int} \supset \underbrace{\frac{1}{2\Lambda_{MFV}} (\bar{\chi}_L \sigma_{\mu\nu} Y_l \chi_R) B^{\mu\nu}}_{\text{Magnetic dipole moment } (MDM)} + \underbrace{\frac{i}{2\Lambda_{MFV}} (\bar{\chi}_L \sigma_{\mu\nu} \gamma_5 Y_l \chi_R) B^{\mu\nu}}_{\text{Electric dipole moment } (EDM)} + \underbrace{\frac{1}{2\Lambda_{MFV}} (\bar{\chi}_L \sigma^{\mu\nu} Y_l \chi_R) H^\dagger H}_{\text{H−mediated}}$$

and the masses of the DM partners get related by:

$$m_\chi (\bar{\chi}_L Y_l \chi_R) \Rightarrow m_{\chi_1} : m_{\chi_2} : m_{\chi_3} = m_e : m_\mu : m_\tau$$

Flavored DM Freeze-in and Detection

$\chi_L \sim (3,1)_{G_{LF}} \sim (\chi_1, \chi_2, \chi_3)_L, \qquad \chi_R \sim (1,3)_{G_{LF}} \sim (\chi_1, \chi_2, \chi_3)_R$, where $G_{LF} \sim SU(3)_L \otimes SU(3)_{e_R}$

$$\mathcal{L}_{int} \supset \underbrace{\frac{1}{2\Lambda_{MFV}}(\bar{\chi}_L \sigma_{\mu\nu} Y_l \chi_R) B^{\mu\nu}}_{\text{Magnetic dipole moment }(MDM)} + \underbrace{\frac{i}{2\Lambda_{MFV}}(\bar{\chi}_L \sigma_{\mu\nu} \gamma_5 Y_l \chi_R) B^{\mu\nu}}_{\text{Electric dipole moment }(EDM)} + \underbrace{\frac{1}{2\Lambda_{MFV}}(\bar{\chi}_L Y_l \chi_R) H^\dagger H}_{\text{H-mediated}}$$

and the masses of the DM partners get related by:

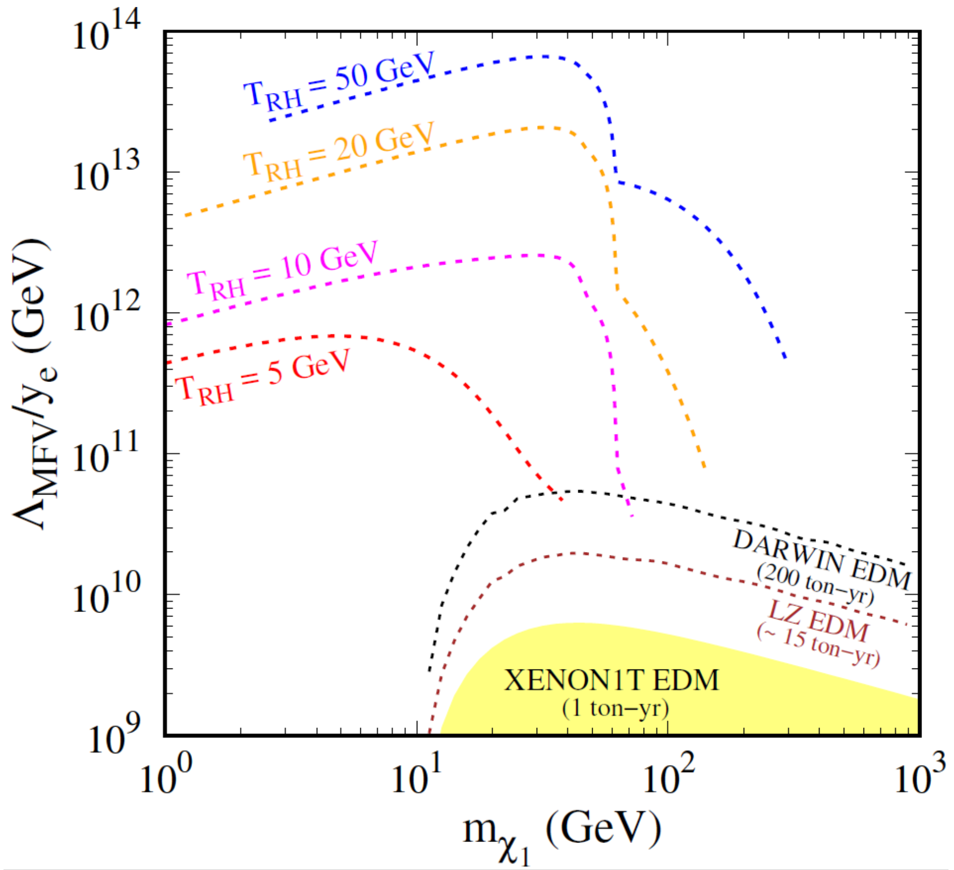
$$m_\chi(\bar{\chi}_L Y_l \chi_R) \Rightarrow m_{\chi_1} : m_{\chi_2} : m_{\chi_3} = m_e : m_\mu : m_\tau$$

- Higgs mediated term ⇒ IR freeze-in
- Dipole moment like terms ⇒ UV freeze-in (sensitive to reheating temperature)
- Electric dipole moment like operator lead to direct detection signals enhanced by $1/v^2 E_R$ giving the strongest constraints

Results: $G_{LF} \sim SU(3)_L \otimes SU(3)_{e_R}$

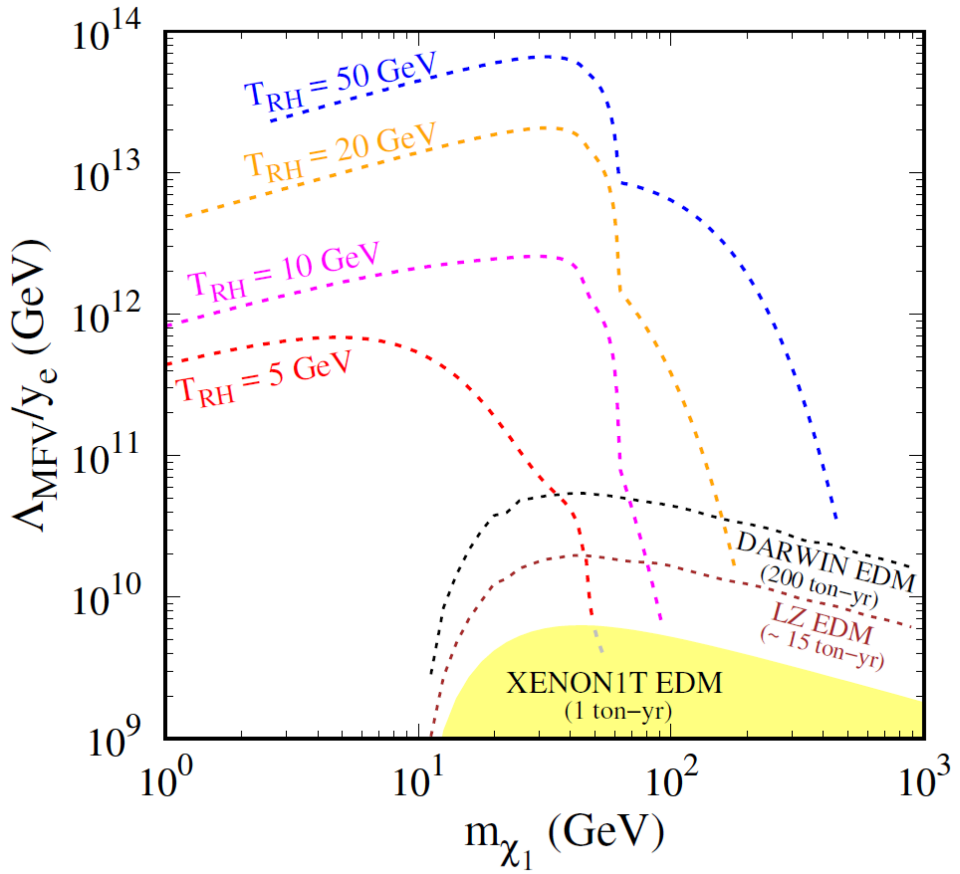
$\chi_L \sim (3,1), \chi_R \sim (1,3)$

- Conditions:
  - $\Lambda_{MFV} > T_{RH}$
  - $m_{\chi_1}, m_{\chi_2}, m_{\chi_3} < \Lambda_{MFV}$
  - The lightest DM partner χ_1 also has the smallest coupling, form the complete relic abundance ($m_{\chi_2} \gg T_{RH}$)
- Future direct detection experiments will probe parts of the parameter space



Results: $G_{LF} \sim SU(2)_L \otimes SU(2)_{e_R}$ $\chi_L \sim (2,1), \chi_R \sim (1,2)$

- Conditions:
  - $\Lambda_{MFV} > T_{RH}$
  - $m_{\chi_1}, m_{\chi_2} < \Lambda_{MFV}$
  - The lightest DM partner χ_1 also has the smallest coupling, and forms the complete relic abundance ($m_{\chi_2} \gg T_{RH}$)
- XENON1T already rules out parts of the parameter space with future experiments probing it more extensively.



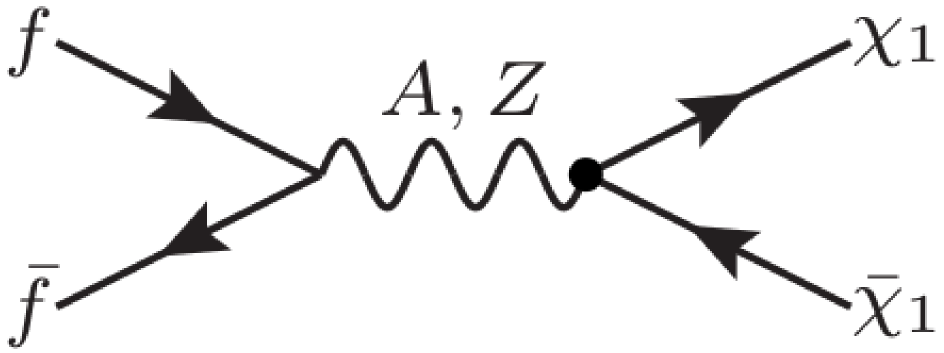
Summary

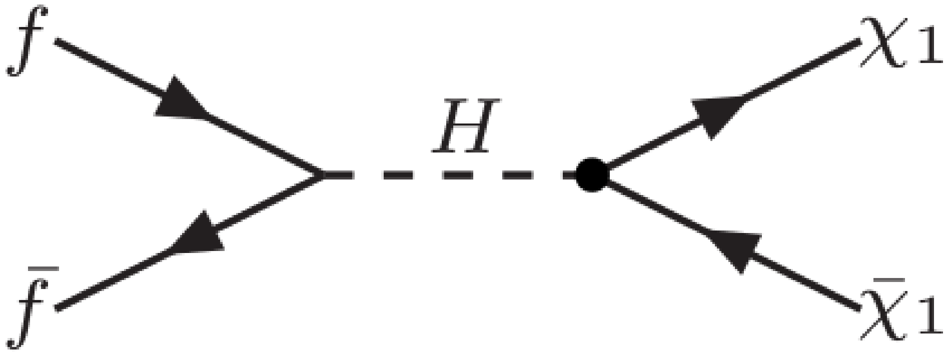
- We consider a lepton flavored dark matter particles in the paradigm of Minimal Flavor Violation to motivate a small coupling for freeze-in production of dark matter
- Lepton number conservation in conjunction with MFV leads to stability at cosmological scales
- We show with the example of a model that such a stable particle can reproduce the observed relic density through freeze-in
- And we get viable freeze-in models that can be probed in present/ future direct detection experiments

Thank you!

Back-up

For relic density:





For direct detection: