Flavor and Dark Matter

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Standard Model:

A story of success

- $SU(3) \times SU(2) \times U(1)$ gauge symmetry describes all observed interactions in Nature.
- Electroweak symmetry breaking stablished after Higgs discovery in 2012.
- LHC results agree with the model predictions.
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But... $\Rightarrow$ Several open question remain in SM

We still **need** new physics!!!

Flavor Problem

All Observed *Flavour transitions* can be accomodated in Yukawa couplings:

$$\mathcal{L}_Y = H\ \bar{Q}_i\ Y^d_{ij}\ d_j + H^*\ \bar{Q}_i\ Y^u_{ij}\ u_j$$

But... $\Rightarrow$ a) what is the origin of the Yukawa structures??
b) why is there a CP-violating phase in CKM??
c) why couplings are so different???

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c) why couplings are so different???

Dark Matter

Required by rotational velocity of galaxies, Cosmic Microwave Background, etc.

But... $\Rightarrow$ No massive, stable and weakly interacting candidate present in SM.

Dark matter

- Dark matter masses from sub-eV to TeV (or micro black holes).
- Observed DM abundance requires weak couplings through freeze-out, with masses $\mathcal{O}(\Lambda_{EW})$: WIMPs.
- Weaker couplings and lighter masses possible through freeze-in mechanism: FIMPs
- Must be stable or long-lived at cosmological scales.

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$\Longrightarrow$ Additional unbroken symmetry **needed** for DM stability.

Flavour symmetries

- Very different elements in Yukawa matrices: $y_t \simeq 1$, $y_u \simeq 10^{-5}$
- Expect couplings in a "fundamental" theory $\mathcal{O}(1)$
- Small couplings generated as function of small vevs or loops.
- Froggatt-Nielsen mechanism and flavour symmetry to understand small Yukawa elements.

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$\Longrightarrow$ Can a single symmetry explain flavor and stabilize DM ??

Example $U(1)_{\text{fl}}$

- SM fermion with flavour charges:

$$\begin{pmatrix} a_{Q_1} & a_{Q_2} & a_{Q_3} \\ a_{u_1} & a_{u_2} & a_{u_3} \\ a_{d_1} & a_{d_2} & a_{d_3} \\ a_{L_1} & a_{L_2} & a_{L_3} \\ a_{e_1} & a_{e_2} & a_{e_3} \end{pmatrix} = \begin{pmatrix} 4 & 2 & 0 \\ 4 & 2 & 0 \\ 4 & 3 & 3 \\ 4 & 3 & 3 \\ 4 & 2 & 0 \end{pmatrix} .$$

flavon S of charge -1

Dark sector fermion charged under $U(1)_{fl}$ with charge 15/2

$$\mathcal{L}_{\mathrm{DM}} = \frac{1}{2}\overline{\chi}\left(i\gamma^{\mu}\partial_{\mu}\right)\chi - y_{\chi}\left(\frac{S}{\Lambda}\right)^{2n-1} S\,\overline{\chi^{c}}\chi + h.c.$$

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$\Longrightarrow$ Stable with small flavor interactions

Coincidence problem

- Dark matter (WIMP) produced via freeze-out of a massive, O(TeV), stable particle with weak couplings.

- Baryon density produced via baryo/leptogenesis in presence of CP violation, baryon number violation and out of equilibrium processes.

- Nevertheless, measured values for baryon and dark matter densities surprisingly similar:

$$\frac{\Omega_{DM} h_0^2}{\Omega_B h_0^2} = 4.99 \pm 0.20$$

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Can baryonic and dark-matter have a common origin???

$\Longrightarrow$ Asymmetric Dark Matter

Asymmetric Dark Matter

- New quantum number of Dark Matter shared by visible matter.

- Asymmetry in this number shared between the two sectors through new (higher dimension op.) interactions.

- After efficient annihilation of symmetric part, asymmetries of comparable size in visible and dark sectors.

- For total baryons asymmetry, B, and dark matter X.

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B and X related through chemical potentials

$$\text{If } \mathrm{B} \simeq \mathrm{X} \quad \Rightarrow \quad m_{\mathrm{DM}} \simeq 5 \text{ GeV}$$

Asymmetric Dark Matter model building

- New dark sector particles with non-vanishing charges to generate observed dark matter.
- New interactions connecting visible and dark sectors.
- Generation of related asymmetries in baryonic and dark sectors.
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But...

Can we do this in a complete model without new *ad hoc* particles and interactions??

Super Asymmetric Dark Matter

– Sfermions share quantum numbers with standard particles and decay to stable dark matter at low temperatures. ✓

– Gaugino interactions connect fermion and sfermions. ✓

– Baryon/lepton asymmetry shared by the two sectors. ✓

– Efficient (s-)particle–anti(s-)particle annihilation to photons through gauge interactions. ✓

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$\Longrightarrow$ Asymmetry in supersymmetric sector washed away by gaugino interactions...

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Supersymmetric leptogenesis with stau (slpeton) NLSP, decaying to gravitino.

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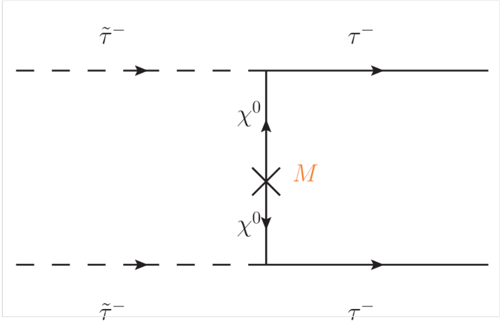
We must require Dirac gaugino masses to avoid washout of the asymmetry in staus.



Can we decouple this porocess with large M_χ??

$$\Gamma(\tilde{\tau}_R + \tilde{\tau}_R \to \tau\tau) \sim \frac{\tilde{m}^3}{z^{3/2}\pi^2} e^{-z} \frac{4\pi\alpha^2}{M^2} \approx H \sim \frac{(100)^{1/2} m_{\tilde{\tau}}^2}{z^2 M_{pl}}$$

with $z = m/T$, so that lepton number transfer from the SM to $\tilde{\tau}_R$s stops at T_b

$$z = \frac{\tilde{m}}{T_b} \approx \ln\left[10^9 \frac{\tilde{m}}{\mathrm{TeV}} \frac{(10\mathrm{TeV})^2}{M^2}\right] \sim 21 + \ln\left[\frac{\tilde{m}}{\mathrm{TeV}} \frac{(10\mathrm{TeV})^2}{M^2}\right]$$

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$$\frac{Y_X - \overline{Y_X}}{Y_x - \overline{Y_x}} \approx \frac{6\sqrt{\pi/2}\, z_b^{3/2} e^{-z_b}}{\pi^2} \quad , \quad z_b = \tilde{m}/T_b$$

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$\Longrightarrow$ No Majorana masses allowed!!

Dirac Asymmetric Dark Matter: to be done...

- Stau decay before nucleosynthesis.

- Low Reheating temperature to avoid gravitino overproduction.

- Allowed Supersymmetric spectrum with $\tilde{\tau}$ NLSP and satisfy LHC bounds.

- Complete calculation of Asymmetry distribution in particles and sparticles through chemical potential...

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