Dark Sector Mass Relations from RG Focusing

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May 6, 2014

BASED ON: hep-ph/1309.4447 with Aaron Pierce [Phys. Rev. D88 (2013) 095009]

Stop me if you've heard this one

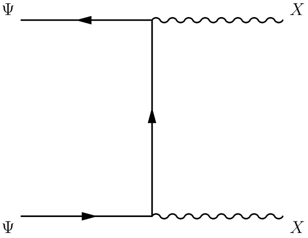
A simple WIMP model...

New $\mathrm{U}(1)_X$ group, charged fermion and kinetic mixing

$$\mathcal{L} \supset i\overline{\Psi}\gamma^{\mu}(\partial_{\mu} + ig_X(q_L P_L - q_R P_R)X_{\mu})\Psi - \frac{\sin\epsilon}{2}F_X^{\mu\nu}F_{Y\,\mu\nu}$$

Neutral gauge bosons: γ, Z, Z'

$m_X \lesssim m_{\mathrm{DM}}$



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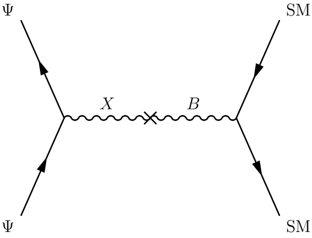
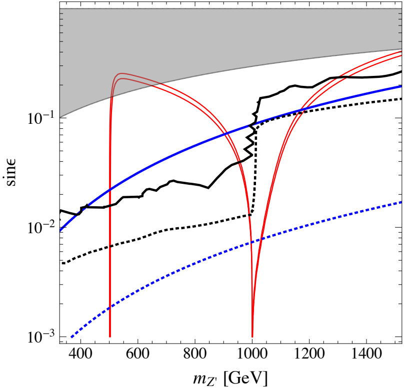


$m_{\rm DM} = 500$ GeV, $q_L = \frac{5}{4}, q_R = -\frac{1}{4}$



Current constraints (solid)

- Planck 2013 (red)
  $\Omega_{\rm DM} h^2 = 0.1199 \pm 5 \times 0.0027$
- LUX (blue)
- LHC (CMS-PAS-EXO-12-061 – black)

Projected constraints (dashed)

- XENON1T (blue)
- LHC (14 TeV, 300 $\rm fb^{-1}$ – black)

$\Rightarrow m_{\rm DM} \approx m_{Z'}$ (near threshold) or $m_{\rm DM} \approx \frac{m_{Z'}}{2}$ (near resonance).

See also: Mambrini, hep-ph/1104.4799

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Maybe renormalization group (RG) running somehow *drives* the masses to the required values. In other words, parameters take on some (unrelated) values in UV and are attracted towards specific ratios in IR.

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SM example: predicting m_h, m_t and mass relations using IR fixed points

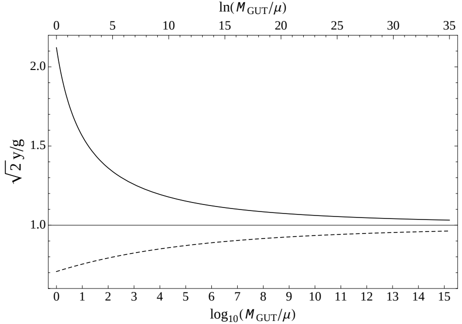
Pendleton & Ross (1981), Hill (1981), Wetterich (1987), Schrempp & Schrempp (1993)

Higgs mechanism: $m_f \propto yV, m_X \propto g_X V \Rightarrow \frac{m_f}{m_X} \propto \frac{y}{g_X}$

$$(4\pi)^2 \frac{dg}{dt} = bg^3, \qquad (4\pi)^2 \frac{dy}{dt} = y(cy^2 - kg^2)$$

IR-attractive ratio!

$$\frac{d}{dt} \ln\left(\frac{y}{g}\right) = 0 \quad \Rightarrow \quad \left(\frac{y}{g}\right)_{IR} = \pm\sqrt{\frac{k+b}{c}}$$



For $c = 5, b = 1, k = \frac{3}{2}$, with $g_{GUT} = 2$

- $y_{GUT} = 3$ (solid)
- $y_{GUT} = 1$ (dashed)

A Realistic Near-Threshold Model

Kinetic mixing model with Higgs field (charge normalized to $q_\Phi = -1$)

$$\mathcal{L} \supset |D_\mu \Phi|^2 = |(\partial_\mu - i g_X X_\mu)\Phi|^2$$

DM: $\chi_\pm, \eta_\pm$ LH Weyl fermions with $X = \pm q, \pm(1-q)$, respectively.

$$\mathcal{L} \supset -y_+ \Phi \chi_+ \eta_+ - y_- \Phi^* \chi_- \eta_- + \text{h.c.}$$

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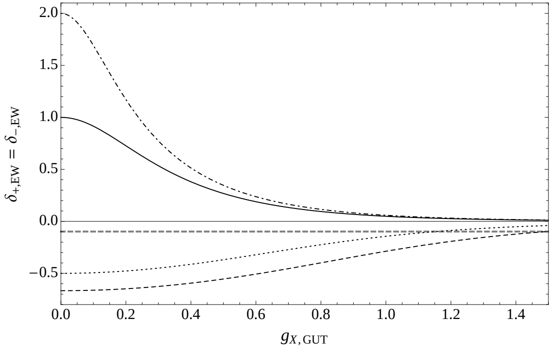
For $\langle \Phi \rangle = \frac{V}{\sqrt{2}}$, $m_X = g_X V$ and $m_\pm = \frac{y_\pm V}{\sqrt{2}}$.

$$\left.\frac{m_+}{m_-}\right|_0 = \left.\frac{y_+}{y_-}\right|_0 = 1, \quad \left.\frac{m_\pm}{m_X}\right|_0 = \left.\frac{y_\pm}{\sqrt{2} g_X}\right|_0 = \frac{1}{3}\sqrt{\frac{13}{2}(q^2 + (1-q)^2) + 1}.$$

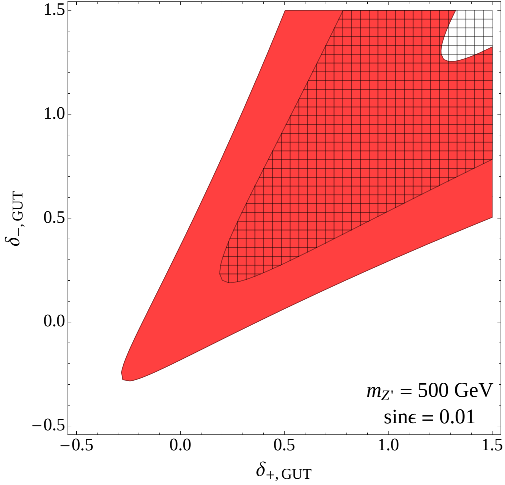
$$\boxed{q = \frac{5}{4} \Rightarrow \left.\frac{m_\pm}{m_X}\right|_0 \approx 1.1}$$

Parameterize $\frac{y_\pm}{g_X} = \left(\frac{y_\pm}{g_X}\right)_0 (1 + \delta_\pm)$. For $\delta_+ = \delta_-$:

$$\frac{d\delta_\pm}{dt} = \frac{3g_X^2}{(4\pi)^2} \left(\frac{y_\pm}{g_X}\right)_0^2 \delta_\pm(\delta_\pm + 1)(\delta_\pm + 2).$$



$\delta_{\pm,GUT}$	Line
$+2$	dot-dashed
$+1$	solid
$-1/2$	dotted
$-2/3$	dashed

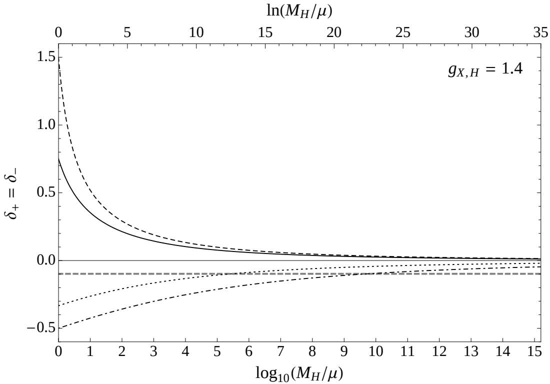


Regions with $\Omega_{\mathrm{DM}} h^2 = 0.1199 \pm 0.0135$ (Planck $\pm 5\sigma$)

- $g_{X,GUT} = 1.2$ (hatched)
- $g_{X,GUT} = 1.4$ (red)

How fast is the focusing?

Assume boundary conditions at some heavy mass threshold $M_H \leq M_{GUT}$



$\delta_{+,H} = \delta_{-,H} = 1.5 \Rightarrow \delta_{\pm} \lesssim 0.05$ by $\mu = 10^{-8} M_H$.

This could work with, e.g., a new threshold at $M_H \approx 10^{11}$ GeV!

Focusing to resonance

Difficult in the minimal model...

For the above model

$$\left.\frac{2m_\pm}{m_X}\right|_0 = \left.\frac{\sqrt{2}y_\pm}{g_X}\right|_0 \geq 1.3 \qquad \left(q = \frac{1}{2}\right)$$

Resonance requires additional Yukawas ⇒ additional states.

Pheno in lieu of DM detection!

Solution: Introduce new states

Add $X_\pm, N_\pm$, LH Weyl fermions with $X = \pm q, \pm(1-q)$ and $Y = \pm 1, \mp 1$,

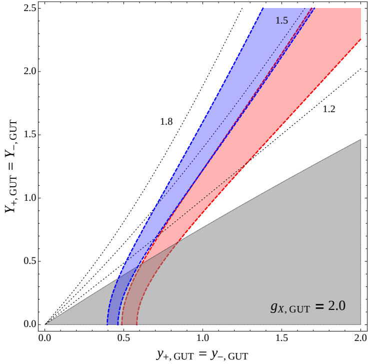
$$\mathcal{L} \supset -Y_+ \Phi X_+ N_+ - Y_- \Phi^* X_- N_- + \text{h.c.}$$

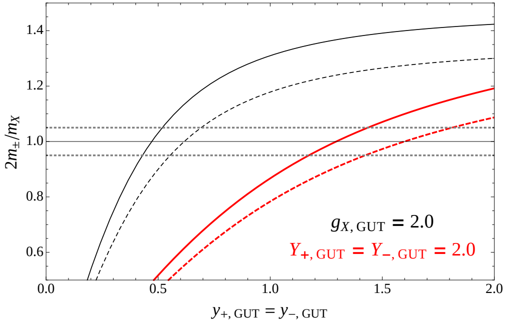
Also, charged scalar $\tilde{e}$ with $Y = -1$. Charged states decay via

$$-\Delta\mathcal{L} = \kappa_+ \tilde{e} X_+ \chi_- + \kappa_- \tilde{e} N_- \eta_+ + \kappa \tilde{e}^\dagger \ell\ell + \text{h.c.},$$

RG-fixed ratios

$$\left.\frac{y_\pm}{g_X}\right|_0 = \sqrt{\frac{17(q^2 + (1-q)^2) + 1 - 36(g_Y/g_X)^2}{15}},$$
$$\left.\frac{Y_\pm}{g_X}\right|_0 = \sqrt{\frac{17(q^2 + (1-q)^2) + 1 + 54(g_Y/g_X)^2}{15}}.$$





Regions exhibiting $2m_{\pm}/m_X \in [0.95, 1.05]$ for

- $q = \frac{3}{4}$ (blue/solid),
- $q = \frac{1}{2}$ (red/dashed).

Dashed contours (left) give $M_{\pm}/m_{\pm}$.

To conclude

Summary

Renormalization group focusing can generate the mass relations required in numerous WIMP DM models.

Desired focusing may require certain charges, couplings or even additional states. Perhaps mass relations hint at specific DM properties or novel dark sector pheno?

Thank you!

Additional Material

RG Focusing: Convergence with $\delta_+ \neq \delta_-$