Dark Matter from the Vector of SO(10)

in collaboration with S. M. Boucenna, and E. Nardi
Phys. Lett. B755 (2016) 168, arXiv:1511.02524

CHALMERS
UNIVERSITY OF TECHNOLOGY

Martin B. Krauss

12th International Workshop
Dark Side of the Universe

Bergen, Norway

July 28, 2016

Motivation

Colorless, electrically neutral and *weakly interacting* particles in the GeV-TeV range well suited to reproduce DM energy density if ***stable on cosmological timescales***.

Enforcing DM staibility:

- R-Parity (SUSY)
- Kaluza-Klein Parity
- T-parity (littlest Higgs)
- $\mathbb{Z}_2$, in scotogenic model, inert doublet model, etc.

Breaking GUT symmetries $\quad\rightarrow\quad$ remnant unbroken $\mathbb{Z}_2$ parity

$SO(10)$ unifies SM fermions with N_R into $\mathbf{16}$ irrep., allows for gauge coupling unification and proton stability, free from gauge anomalies.

The $SO(10)$ framework I

Breaking $SO(10)$ exclusively with vev in tensor representations

$\rightarrow$ unbroken $\mathbb{Z}_2$ remains

[Kibble, Lazarides, Shafi (1982)]

Stable particles in $SO(10)$ representations

Fermions: $\mathbf{10}, \mathbf{45}, \mathbf{54}, \mathbf{120}, \mathbf{126}, \mathbf{210}, \mathbf{210'}$,

Bosons: $\mathbf{16}, \mathbf{144}$.

see, e.g., [Kadastik, Kannike, Raidal (2009); Kadastik, Kannike, Raidal (2010)]
[Frigerio, Hambye (2010)]
[Mambrini, Nagata, Olive, Quevillon, Zheng (2015); Nagata, Olive, Zheng (2015)]

So far, special attention to $\mathbf{16}$ and $\mathbf{45}$ $\rightarrow$ contain SM singlets (no DD)

Here: DM in fermionic $\mathbf{10}$

SO(10) breaking:

$$SO(10) \xrightarrow{\langle \mathbf{45}_H \rangle} 3_C 2_L 2_R 1_{B-L}$$
$$\xrightarrow{\langle \overline{\mathbf{126}} \rangle} 3_C 2_L 1_Y \otimes \mathbb{Z}_2$$
$$\xrightarrow{\langle \mathbf{10}_H \rangle} 3_C 1_Q \otimes \mathbb{Z}_2$$

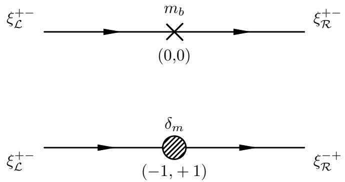
DM in $SU(2)_L \otimes SU(2)_R$ bidoublet:

$$\xi_{\mathcal{L},\mathcal{R}} = \begin{pmatrix} \xi^{+-}_{\mathcal{L},\mathcal{R}} & \xi^{++}_{\mathcal{L},\mathcal{R}} \\ \xi^{--}_{\mathcal{L},\mathcal{R}} & \xi^{-+}_{\mathcal{L},\mathcal{R}} \end{pmatrix}$$

Dark Matter mass

Two possible Dirac mass terms:

- $m_b \propto \langle \mathbf{45} \rangle$, conserves L-R symmetry
- δ_m, transforms as $\langle \mathbf{54} \rangle$, breaks L-R and EW symmetries

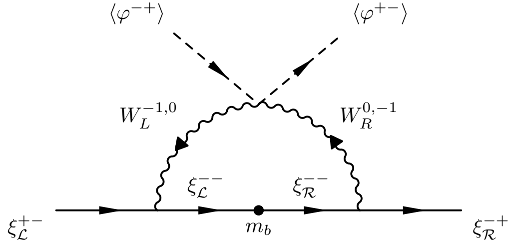


In our model:
No $\mathbf{54}$, but DM couples to Higgs bidoublet via loop ($\mathbf{10} \times \mathbf{10} \supset \mathbf{54}$)

Mass splitting

Loop induced mass-splitting

$$\delta_m \propto v_u v_d \frac{m_b}{M_{W_R}^2}$$



$\Rightarrow$ Two non-degenerate Dirac fermions χ_l and χ_h with mass

$$m_{h,l} = m_b \pm \delta_m$$

Direct detection constraints

Couplings of $\chi_{l,h}$ to neutral gauge bosons **off-diagonal**:

Vectorlike neutral current

$$J_\mu^{\text{nc}} = \frac{1}{2}\overline{\chi_h}\gamma_\mu\chi_l + \text{h.c.}$$

Mass splitting $2\delta_m$ between the light and heavy neutral state, χ_l and χ_h is $\gtrsim$ 200 keV
$\Rightarrow$ DD is kinematically suppressed.

Large enough splitting $\rightarrow$ upper bound on M_{W_R}

$$M_{W_R} \lesssim 25\left(\frac{m_b}{1\text{TeV}}\right)^{1/2}\text{TeV}$$

Relic Density I

Mass splittings irrelevant for DM relic density:
$\rightarrow$ Assume two degenerate $SU(2)_L$ doublets at thermal freeze-out

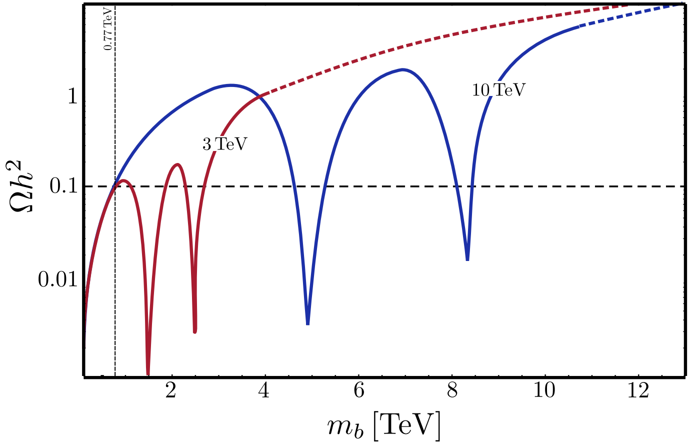
Relic density

$$\Omega_{\text{DM}} h^2 \approx 0.1 \left(\frac{m_{\text{DM}}}{\frac{1}{\sqrt{2}} \cdot 1.1\text{TeV}} \right)^2$$

c.f. Minimal Dark Matter [Cirelli, Fornengo, Strumia (2006)]

- Annihilation via $Z_L \rightarrow$ correct relic density for $m_b = 0.77\,\text{TeV}$
- Additional resonant annihilation via W_R and Z_R

Relic Density II



DM searches

Indirect Detection

- No diagonal coupling to $Z_{L,R}$
- Leading annihilation channel into $W_L W_L$ and $Z_L Z_L$
  (via t-channel exchange of $\chi^{\pm}$ and χ_h)
- For $\chi_l \bar{\chi}_l \to W_L W_L$ we can estimate $\langle \sigma_W |v| \rangle \sim 3 \times 10^{-28} \, (2\,\mathrm{TeV}/m_l)^2 \ \mathrm{cm}^3/\mathrm{s}$
- Even with non-relativistic Sommerfeld corrections well below current limits
  ($\langle \sigma_W |\mathrm{v}| \rangle \lesssim (10^{-25} - 10^{-24})\,\mathrm{cm}^3/\mathrm{s}$ for the mass range $1\,\mathrm{TeV} < m_l < 4\,\mathrm{TeV}$)

Collider Searches

- Most sensitive searches from monojet searches ($pp \to \chi_a \chi_b j$)
- Large background from Z, W + jets
- Searches for quasi-degenerate Higgsino-like DM $\to$ reach of $m_l \sim 250$ GeV
  (relic density $\Rightarrow m_l \sim 0.77$ TeV)

Asymmetric component

- DM carries hypercharge $\rightarrow$ can distinguish particles from anti-particles
- χ in chemical equilibrium with SM particles $\rightarrow$ acquires asymmetry

(c.f. Minimal Asymmetric Dark Matter [Boucenna, MBK, Nardi (2015)])

- Asymmetric contribution to relic density significant?
- In the MADM $SU(2)_L$ doublet asymmetry negligible

HERE:

- Tree-level asymmetry transfer via W_R
- Resonant annihilation of symmetric component
- ...

Still small asymmetric contribution expected, maybe except close to Z_R resonance.

Summary & Conclusions

- Remnant $\mathbb{Z}_2$ from $SO(10)$ breaking stabilizes DM
- Minimal scalar sector $\mathbf{45} + \overline{\mathbf{126}} + \mathbf{10}$
- DM in minimal $\mathbf{10}$ irrep. viable
- Mass-splitting via loop with W_R
- Light stable Dirac fermion χ_l as DM
- Non-diagonal coupling to $Z_L \rightarrow$ evades DD
- Upper limit on M_{W_R}