Colored Scotogenic.

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Focus on: arXiv:1803.08528 [PRD]
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SM-like $B-L$ model

Field	$\mathrm{U}(1)_{B-L}$
L	-1
H	0
$(\nu_R)_i^\dagger$	ν_i

If $\nu_i \neq 0$

- No neutrino masses.
- No DM,

SM+ν_R with exotic $B-L$ charges is equivalent to SM

six massless neutrinos instead of three

Seesaw mechanism

For Dirac neutrino masses: we require to introduce at least one SM-singlet heavy Dirac fermión (Weyl fermion notation)

$$\mathcal{L} = i\,(\psi_L)^\dagger\,\overline{\sigma}^\mu \partial_\mu \psi_L - m\,(\psi_R)^\dagger\,\psi_L + \text{h.c}\,. \tag{1}$$

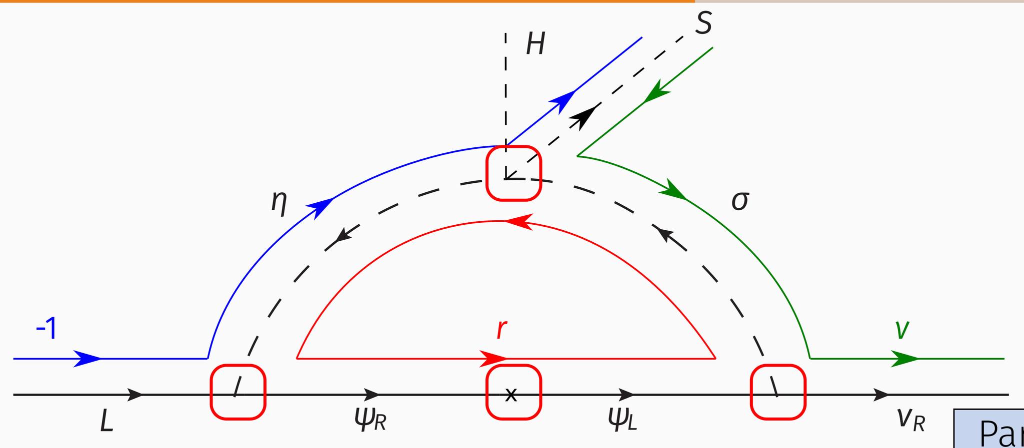
The required $\mathrm{U}(1)$ symmetry is identified with $B-L$

Field	$\mathrm{U}(1)_{B-L}$
L	-1
H	0
$(\nu_R)_i^\dagger$	ν_i
$(\psi_R)^\dagger$	r
ψ_L	$-r$

if we impose $\mathrm{U}(1)_{B-L}$ to be local:

	$(\nu_R)_1^\dagger$	$(\nu_R)_2^\dagger$	$(\nu_R)_3^\dagger$
$\mathrm{U}(1)_{B-L}$	$+4$	$+4$	-5
$\mathrm{U}(1)_{B-L}$	-6	$+\frac{10}{3}$	$+\frac{17}{3}$

Exotic $(\nu_R)^\dagger$ with $\nu \neq -1$, and vector-like Dirac fermion with $r \neq 1$



Soft breaking term induced:

$$\mathcal{L} \supset \kappa \sigma \eta^\dagger H\,,$$

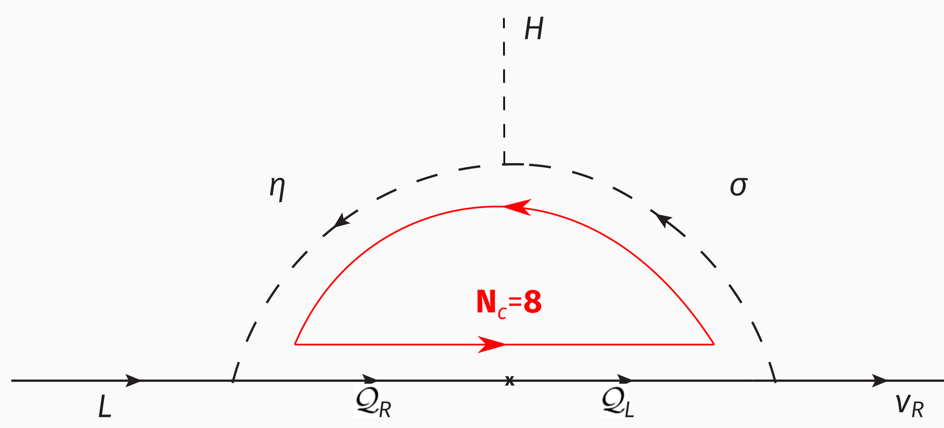
where $\kappa = \lambda \langle S \rangle$.

$$-1+\eta = -r$$
$$-r = -r$$
$$-r = -\nu + \sigma$$
$$\sigma = \eta + s$$

$N_c = 1$.

Particles	$\mathrm{U}(1)_{B-L}$	$(\mathrm{SU}(3)_c, \mathrm{SU}(2)_L)_Y$
L_i	-1	$(1,2)_{-1/2}$
H	0	$(1,2)_{1/2}$
$(\nu_{Ri})^\dagger$	ν	$(1,1)_0$
ψ_L	$-r$	$(N_c,1)_0$
$(\psi_R)^\dagger$	r	$(N_c,1)_0$
σ_a	$\nu-r$	$(N_c,1)_0$
η_a	$1-r$	$(N_c,2)_{1/2}$
S	$\nu-1$	$(N_c,2)_{1/2}$

The model: *colored scotogenic*



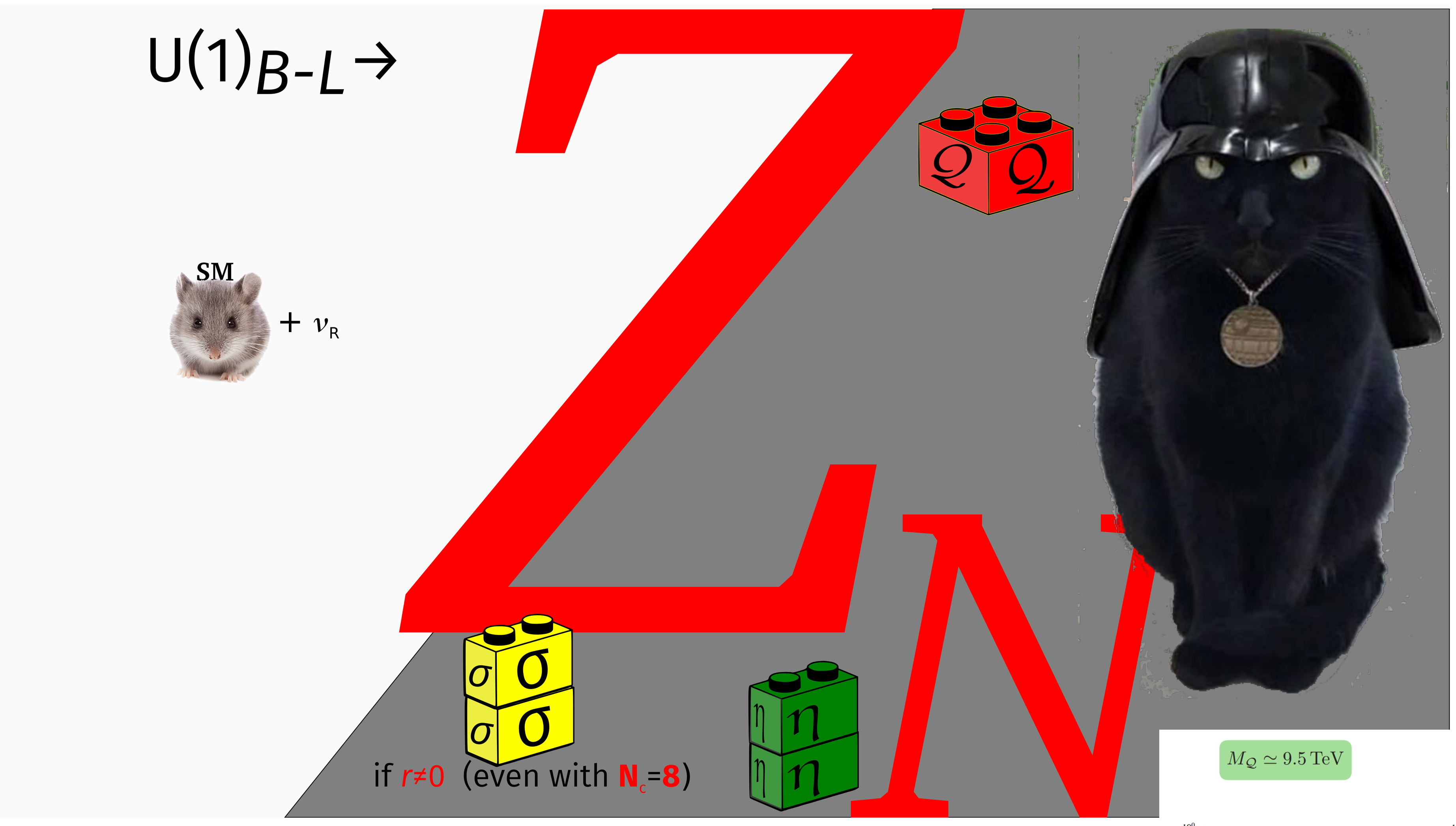
$$-1+\eta = -r$$
$$-r = -r$$
$$-r = -\nu + \sigma$$
$$\sigma = \eta + s$$

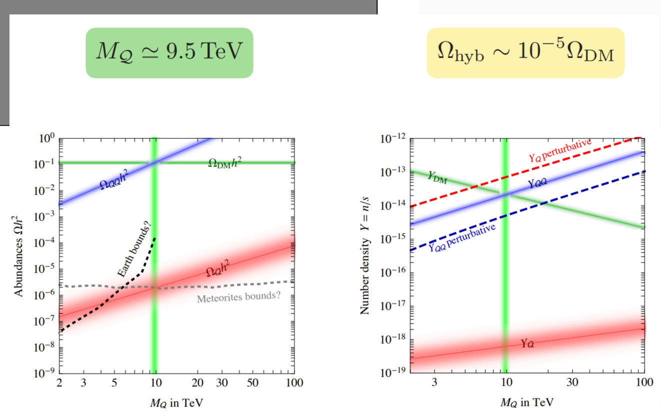
$N_c = 8$.

Particles	$\mathrm{U}(1)_{B-L}$	$(\mathrm{SU}(3)_c, \mathrm{SU}(2)_L)_Y$
L_i	-1	$(1,2)_{-1/2}$
H	0	$(1,2)_{1/2}$
$(\nu_{Ri})^\dagger$	ν	$(1,1)_0$
$\mathcal{Q}_L$	$-r$	$(N_c,1)_0$
$(\mathcal{Q}_R)^\dagger$	r	$(N_c,1)_0$
σ_a	$\nu-r$	$(N_c,1)_0$
η_a	$1-r$	$(N_c,2)_{1/2}$

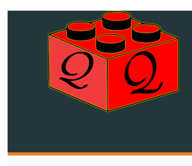
To have at least a rank 2 neutrino mass matrix we need:
At least two sets of scalars η_a, σ_a

$$\mathcal{L} \supset \left[M_{\mathcal{Q}}\,(\mathcal{Q}_R)^\dagger\,\mathcal{Q}_L + h_i^a\,(\mathcal{Q}_R)^\dagger\,\widetilde{\eta}_a^\dagger L_i + y_i^a \overline{\nu_{Ri}}\,\sigma_a^* \mathcal{Q}_L + \text{h.c} \right] + \kappa^{ab}\,\sigma_a \eta_b^\dagger H + \ldots$$



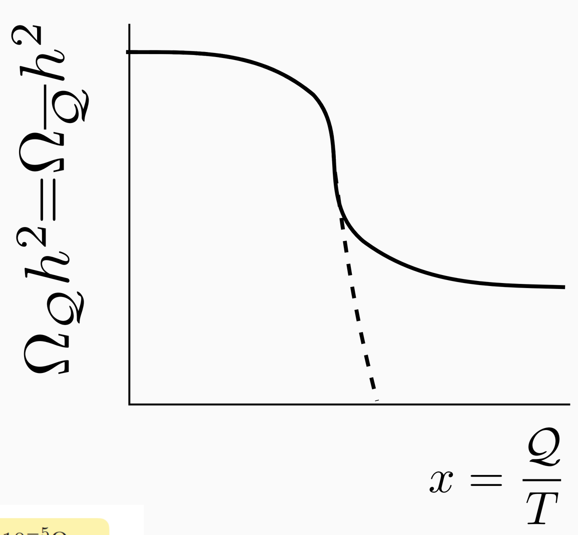


Colored dark matter: De Luca , Mitridate, Redi, Smirnov & Strumia, arXiv:1801.01135



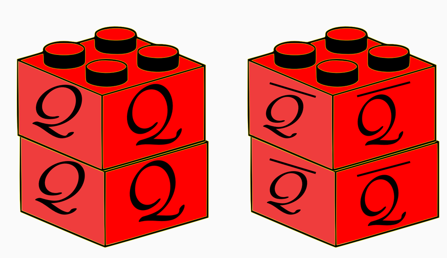
(Switch to Dirac fermions)
Because $\mathcal{Q}$ is a Dirac fermion, $\mathcal{Q}\mathcal{Q}$ is also stable

$$\mathcal{Q}\mathcal{Q} \not\to g\,, \qquad \overline{\mathcal{Q}\mathcal{Q}} \not\to g\,.$$



Step one

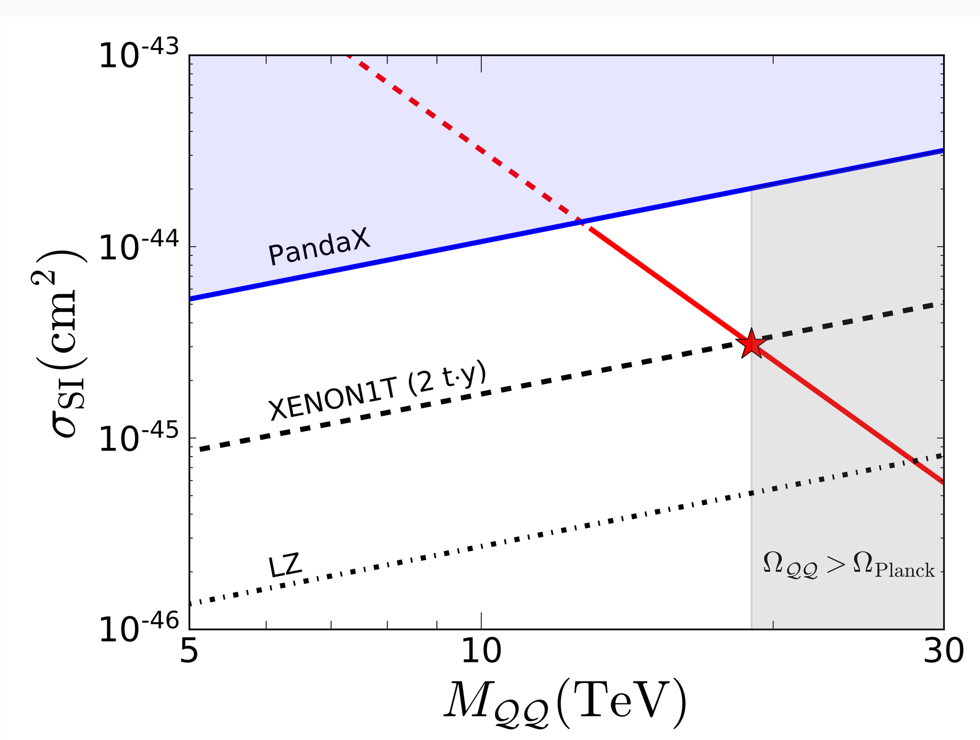
$\mathcal{Q}$-onlyum



Step two

From: http://bit.ly/Mitridate_53d_53rd_Rencontres_de_Moriond

Direct detection & Collider Physics



Long lived hadrons

$$p + p \longrightarrow \mathcal{Q} + \overline{\mathcal{Q}}$$
$$\Downarrow$$
$$\mathcal{Q} \to \mathcal{Q}g \qquad \mathcal{Q} \to \mathcal{Q}q\bar{q}$$

$\sqrt{s} = 65$ TeV needed to discover
$M_{\mathcal{Q}} = 9.5$ TeV.

Conclusions

Standard Model with right-handed neutrinos of exotic $B-L$ charges

Dirac neutrino masses and DM

- Spontaneously broken $U(1)_{B-L}$ generates a radiative Dirac Type-I seesaw.
- A remnant symmetry makes the lightest field circulating the loop stable and good dark matter candidate.
- If color is also circulating the loop, the colored dark matter scenario can be realized

DM is made of two color octets with mass around 9.5 TeV

- For standard cosmology:
  - A single point to be discovered in Direct Detection.
  - Crosscheck at future colliders possible.