Accidental Dark Matter in gauge theories

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Scalar gauge theory and gauge/Higgs dualities

Consider a scalar field $\mathcal{S}$ in the fundamental representation of a gauge group $\mathcal{G} = \{\mathrm{SU}(N), \mathrm{SO}(N), \mathrm{Sp}(N)\}$ and connected to the SM via the Higgs portal

$$\mathscr{L} = \mathscr{L}_{\rm SM} - \frac{1}{4}\mathcal{G}^A_{\mu\nu}\mathcal{G}^{A\mu\nu} + |\mathcal{D}_\mu \mathcal{S}|^2 - V_{\mathcal{S}} \qquad V_{\mathcal{S}} = -M_{\mathcal{S}}^2|\mathcal{S}|^2 + \lambda_{\mathcal{S}}|\mathcal{S}|^4 - \lambda_{HS}|H|^2|\mathcal{S}|^2$$

The model admits two apparently different phases: *Higgs* (if $\mathcal{S}$ has a non-trivial vev) and *condensed* (or *confined*, if scalar condensates form).

Higgs phase	$\langle \mathcal{S} \rangle$	$\mathcal{G} \to \mathcal{H}$
Condensed phase	$\langle \mathcal{S}^\dagger \mathcal{S} \rangle$	$\mathcal{G}$ confines

We claim a *duality* among the two phases based on the one-to-one mapping of the asymptotic states and the accidental symmetries

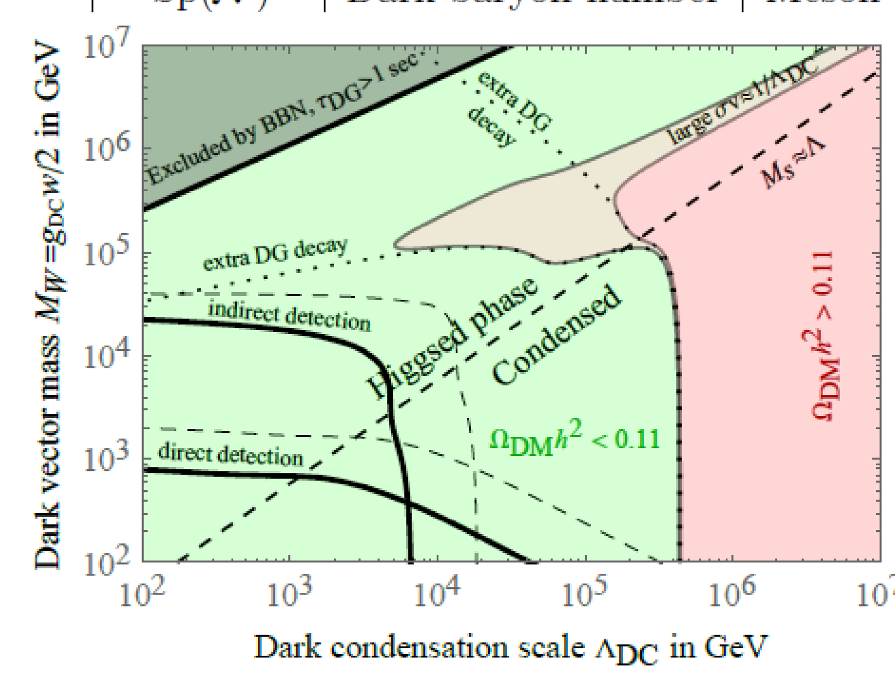
Group	Higgs phase	Condensed phase
$\mathrm{SU}(\mathcal{N}) \to \mathrm{SU}(\mathcal{N}-1)$	s $\mathcal{Z}_\mu$ $\epsilon_{\mathcal{N}-1}\mathcal{W}^{\mathcal{N}-1}$ $\mathcal{A}\mathcal{A}$ $d\mathcal{A}\mathcal{A}\mathcal{A}$	$\mathcal{S}^\dagger\mathcal{S}$ $\mathcal{S}^\dagger\mathcal{D}_\mu\mathcal{S}$ $\epsilon_{\mathcal{N}}\mathcal{S}^{\mathcal{N}}$ $\mathcal{G}\mathcal{G}$ $d\mathcal{G}\mathcal{G}\mathcal{G}$
$\mathrm{SO}(\mathcal{N}) \to \mathrm{SO}(\mathcal{N}-1)$	s $\epsilon_{\mathcal{N}-1}\mathcal{A}\ldots\mathcal{A}$ (for odd $\mathcal{N}$) $\epsilon_{\mathcal{N}-1}\mathcal{W}\mathcal{A}\ldots\mathcal{A}$ (for even $\mathcal{N}$) $\mathcal{A}\mathcal{A}$	$\mathcal{S}^T\mathcal{S}$ $\epsilon_{\mathcal{N}}\mathcal{S}\mathcal{G}\ldots\mathcal{G}$ (for odd $\mathcal{N}$) $\epsilon_{\mathcal{N}}\mathcal{G}\ldots\mathcal{G}$ (for even $\mathcal{N}$) $\mathcal{G}\mathcal{G}$
$\mathrm{Sp}(\mathcal{N}) \to \mathrm{Sp}(\mathcal{N}-2)$	$s, \mathcal{X}^\dagger\mathcal{X}$ $\mathcal{Z}_\mu, \mathcal{X}^\dagger\mathcal{D}_\mu\mathcal{X}$ $\mathcal{W}_\mu, \mathcal{X}^T\gamma_{\mathcal{N}-2}\mathcal{D}_\mu\mathcal{X}$ $\mathcal{A}\mathcal{A}$	$\mathcal{S}^\dagger\mathcal{S}$ $\mathcal{S}^\dagger\mathcal{D}_\mu\mathcal{S}$ $\mathcal{S}^T\gamma_{\mathcal{N}}\mathcal{D}_\mu\mathcal{S}$ $\mathcal{G}\mathcal{G}$

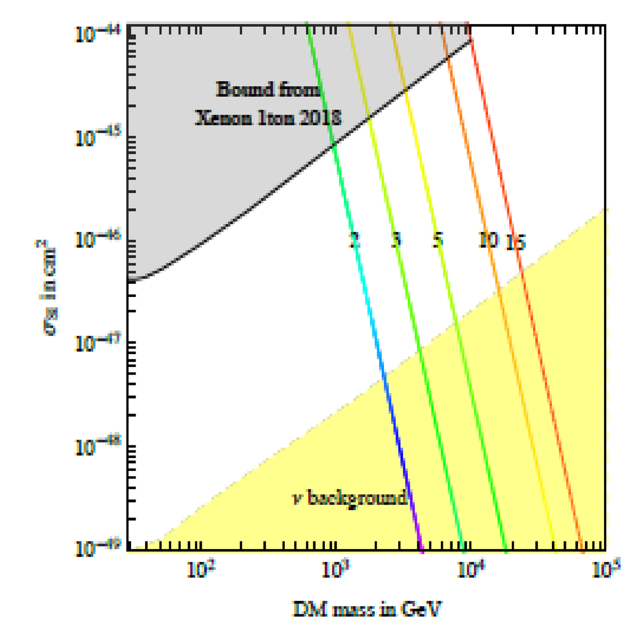
Dark matter from scalar gauge theories

For each choice of $\mathcal{G}$ the model is invariant under a set of *accidental* symmetries (global $\mathrm{U}(1)$, discrete Z_2 group parities and charge conjugations)

This gives rise to *automatically stable* DM candidates with thermal abundance

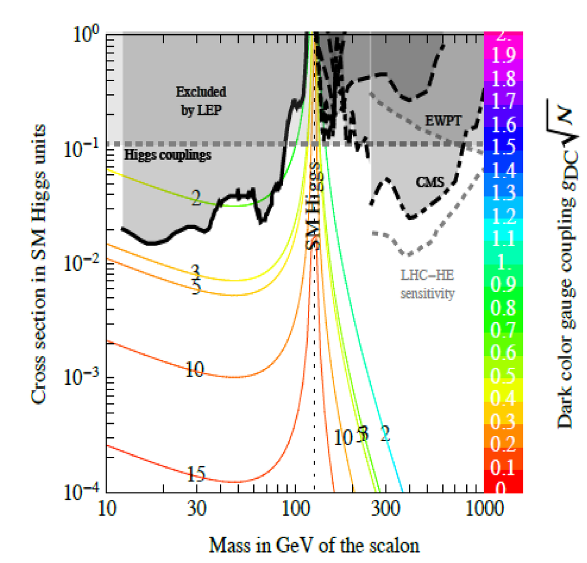
Group	Global symmetry	DM candidate	DM Annihilation
$\mathrm{SU}(\mathcal{N})$	Dark baryon number	Baryon $\epsilon\mathcal{S}^{\mathcal{N}} \cong \mathcal{W}^n$	Bohr-like – $1/\Lambda^2_{\rm DC}$
	Charge conjugation	Glue-balls $d\mathcal{G}\mathcal{G}\mathcal{G} \cong d\mathcal{A}\mathcal{A}\mathcal{A}$	$1/\Lambda^2_{\rm DC}$
$\mathrm{SO}(\mathcal{N}_{\rm even})$	O-parity	1-ball $\epsilon\mathcal{G}^{\mathcal{N}/2} \cong \mathcal{W}\mathcal{A}^{(n-1)/2}$	$1/\Lambda^2_{\rm DC}$
$\mathrm{SO}(\mathcal{N}_{\rm odd})$	O-parity	0-ball $\epsilon\mathcal{S}\mathcal{G}^{(\mathcal{N}-1)/2} \cong \mathcal{A}^{n/2}$	$1/\Lambda^2_{\rm DC}$
$\mathrm{Sp}(\mathcal{N})$	Dark baryon number	Meson $\mathcal{S}\gamma\mathcal{S} \cong \mathcal{W}, \mathcal{X}\mathcal{X}$	Perturbative





Direct detection signals through λ_{HS}

$$\sigma_{\rm SI} \approx (\mathcal{N}-1)^2 \frac{m_N^4 f^2 v^2 \lambda_H \lambda_{HS}}{2\pi M_h^4 M_s^4} g^2_{\rm DC}$$



The model predicts a light scalar which mixes with the SM Higgs boson and could be produced at future colliders

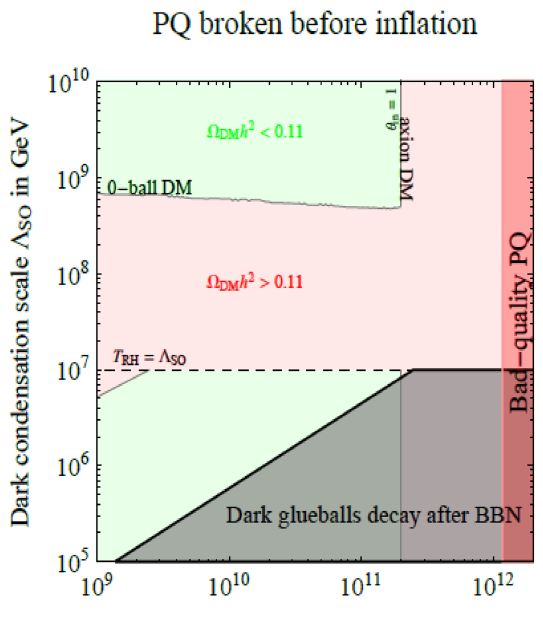
Axion quality from gauge dynamics

- $\mathrm{SU}(N)$ gauge group with a scalar in the symmetric representation + heavy fermions provide an accidental $\mathrm{U}(1)_{\rm PQ}$ symmetry;

Field	Lorentz	Gauge symmetries				Global accidental symmetries		
name	spin	$\mathrm{U}(1)_Y$	$\mathrm{SU}(2)_L$	$\mathrm{SU}(3)_c$	$\mathrm{SU}(\mathcal{N})$	$\mathrm{U}(1)_{\rm PQ}$	$\mathrm{U}(1)_{\mathcal{Q}}$	$\mathrm{U}(1)_{\mathcal{L}}$
$\mathcal{S}$	0	0	1	1	$\mathcal{N}\mathcal{N}$	+1	0	0
$\mathcal{Q}_L$	1/2	$+Y_{\mathcal{Q}}$	1	3	$\mathcal{N}$	+1/2	+1	0
$\mathcal{Q}_R$	1/2	$-Y_{\mathcal{Q}}$	1	$\bar{3}$	$\mathcal{N}$	+1/2	−1	0
$\mathcal{L}_L^{1,2,3}$	1/2	$+Y_{\mathcal{L}}$	1	1	$\bar{\mathcal{N}}$	−1/2	0	+1
$\mathcal{L}_R^{1,2,3}$	1/2	$-Y_{\mathcal{L}}$	1	1	$\bar{\mathcal{N}}$	−1/2	0	−1

- $\mathrm{U}(1)_{\rm PQ}$ is automatically preserved by higher-order operators up to dimension $N \to$ high-quality Peccei-Quinn symmetry;
- $\mathrm{SU}(N) \otimes \mathrm{U}(1)_{\rm PQ} \to \mathrm{SO}(N)$ by scalar vev at f_a

PQ broken before inflation

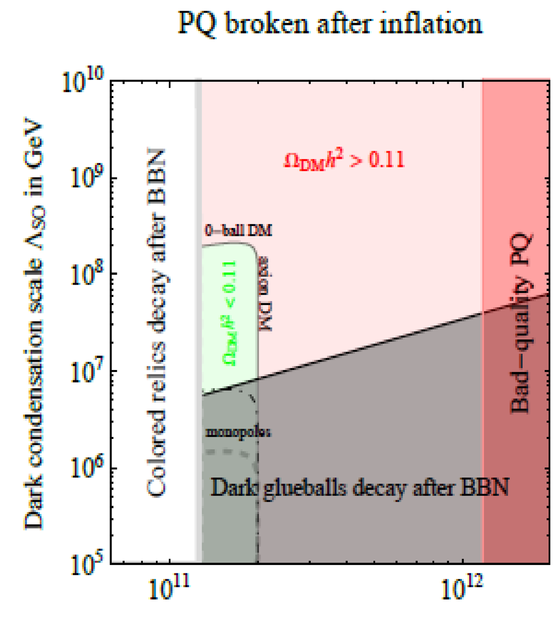


axion DM

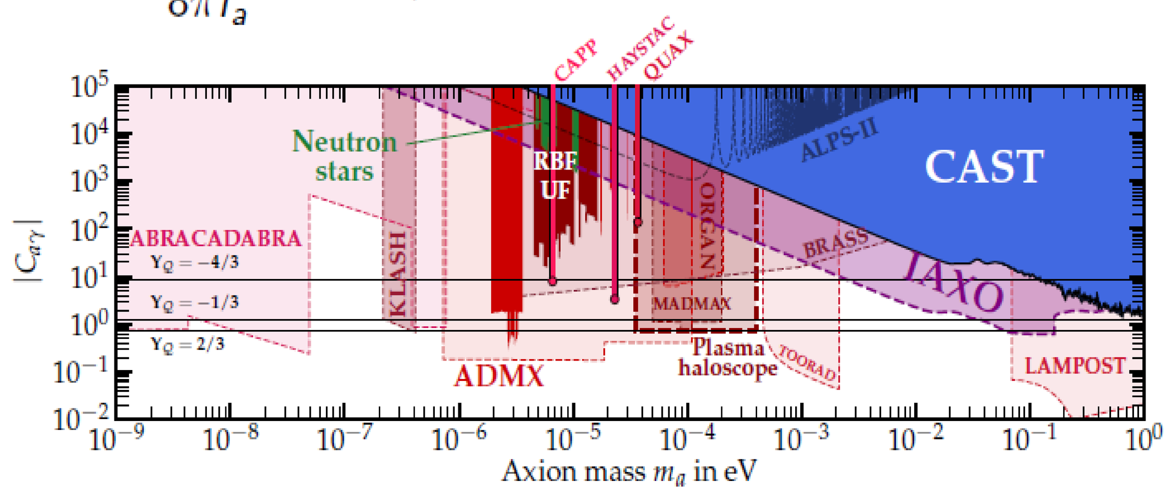
$$\frac{\Omega_a h^2}{0.12} \approx \theta^2_{\rm in}\left(\frac{f_a}{2.0\times 10^{11}\,\mathrm{GeV}}\right)^{7/6}$$

Thermal bound states with $\langle\sigma v\rangle \sim 1/\Lambda^2_{\rm SO}$ diluted by late decays of dark glueballs

PQ broken after inflation



$$\mathcal{L}_{\rm eff} = \frac{\alpha_{\rm em} C_{a\gamma}}{8\pi f_a} a F^{\mu\nu}\tilde{F}_{\mu\nu} \qquad C_{a\gamma} = 6(Y^2_{\mathcal{Q}} - Y^2_{\mathcal{L}}) - 1.92(4)$$



Gravitational vector Dark Matter

Dark sector = pure gauge theory $\mathcal{G} = \{\mathrm{SU}(N), \mathrm{SO}(N)\}$ connected to the SM through gravity.

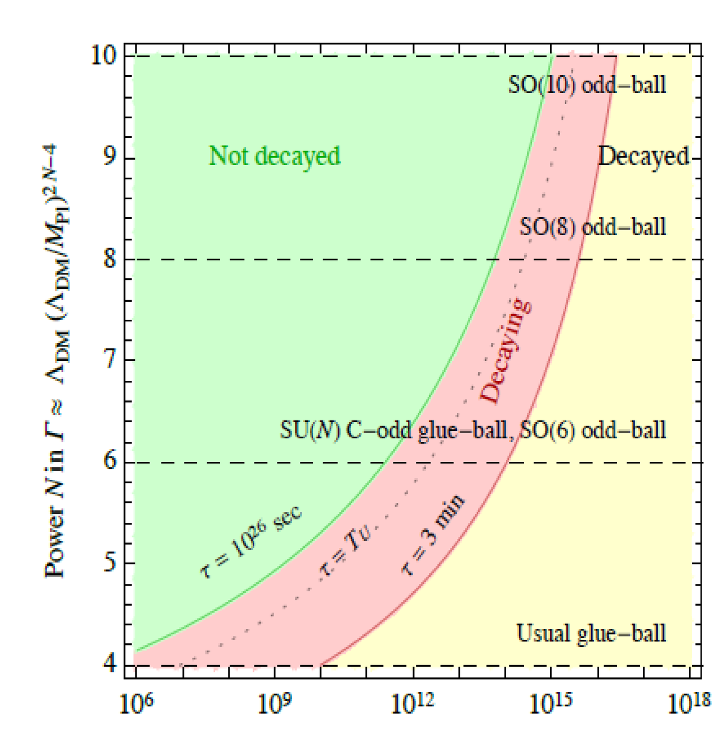
$$S = \int d^4x\sqrt{|\det g|}\left[-\frac{1}{2}\bar{M}^2_{\rm Pl}R + \mathscr{L}_{\rm SM} + \mathscr{L}_{\rm DM} + \mathscr{L}_{\rm NRO}\right] \qquad \mathscr{L}_{\rm DM} = -\frac{1}{4}G^a_{\mu\nu}G^{\mu\nu a} + \theta_{\rm DM}\frac{g^2_{\rm DM}}{32\pi^2}G^a_{\mu\nu}\tilde{G}^{\mu\nu a}$$

Accidental Z_2 group parity (*O-parity*) if $\mathcal{G} = \mathrm{SO}(N)$

$$\mathcal{G}_{ij} \to (-1)^{\delta_{1i}+\delta_{1j}}\mathcal{G}_{ij}$$

The theory confines at $T_{\rm dark} \approx \Lambda_{\rm DM}$

- Ordinary glue-balls $\mathrm{Tr}[\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu}]$: long-lived if $M_{\rm DG} < 100$ TeV
- $\mathrm{SU}(N)$ glue-balls $d^{abc}\mathcal{G}^a\mathcal{G}^b\mathcal{G}^c$ odd under charge conjugation
- $\mathrm{SO}(N)$ glue-balls odd under SO group parity (odd-balls) $\epsilon_N\mathcal{G}\cdots\mathcal{G}$: long lived if $M_{OB} \lesssim 10^{14}$ GeV



Freeze-in production of dark vectors via graviton exchange followed by hadronization (and possibly self-thermalization)

Gravitational vector DM SO(10)