Dark matter from a complex scalar singlet and the role of its discrete symmetries

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Introduction:

We consider a model where dark matter (DM) emerges from a complex scalar field, $S = \rho + \theta\, i$, charged under a U(1) global symmetry.
This is the simplest model beyond having the SM plus a real scalar singlet, which is too restrained.

From the U(1) the following sym. breaking (SB) terms develops:

- **Spontaneously SB** (SSB) [v_s] avoids being over-restrained and from suffer instability problems.
- **Explicit SB** gives mass to the Goldstone boson (θ) allowing it to be a DM candidate.

Explicit SB develops from the subset of discrete symmetries of the kinetic term:

$$Z_2: \quad S \to -S \qquad Z_3: \quad S \to e^{i2\pi/3}\, S$$
$$Z_4: \quad S \to i\, S \qquad DCP: \quad S \to S^*$$

DCP can be identified with a "dark" CP and it is the only **remaining sym.** after SSB. An easy long-lived particle means preserving a discrete symmetry and DCP needs for all the couplings to be real.

Objectives:

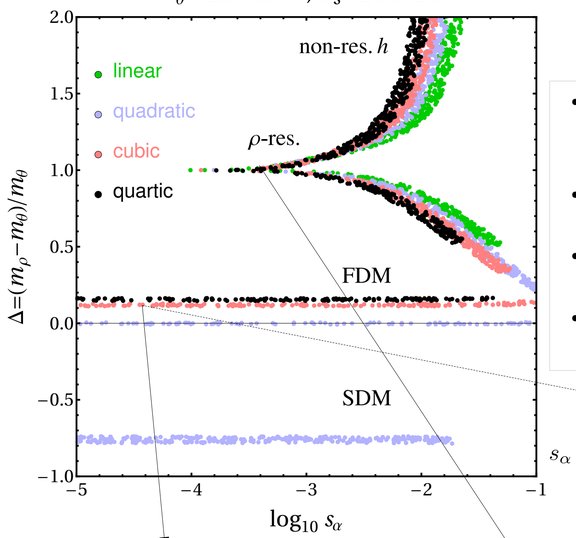
Consider the following minimal models (MM) containing one single SB term which satisfies different discrete sym. (except V_1) and find if they lead to different subsets in the parameter space for a DM.

$$V_1 = \frac{1}{2}\mu^3 S + h.c.; \quad V_{Z_2} = \frac{1}{2}\mu_S^2 S^2 + h.c.$$
$$V_{Z_3} = \frac{1}{2}\mu_3 S^3 + h.c.; \quad V_{Z_4} = \frac{1}{2}\lambda_4 S^4 + h.c.$$

Results:

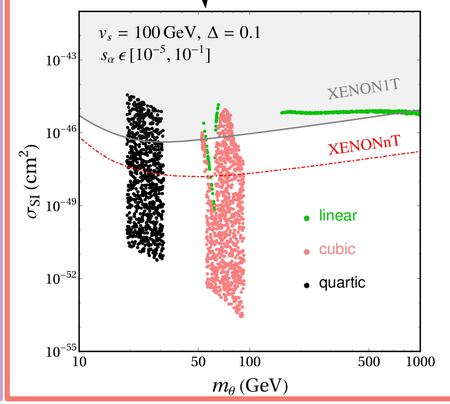
In the Early Universe, S is in thermal equilibrium with SM until the interactions become insufficient and it **freezes-out**. The right relic abundance is reached in:

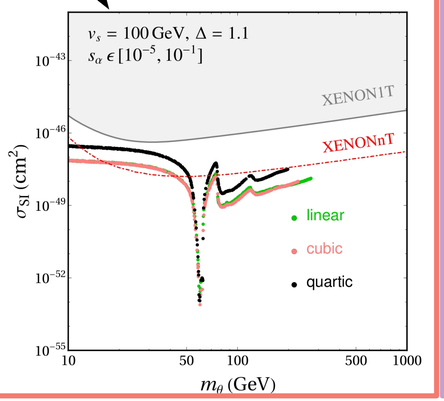
m_θ=130 GeV, v_s=100 GeV



- Resonance with the other scalars (res).
- Secluded DM (SDM).
- Forbidden DM (FDM).
- Non-resonance (non-res).

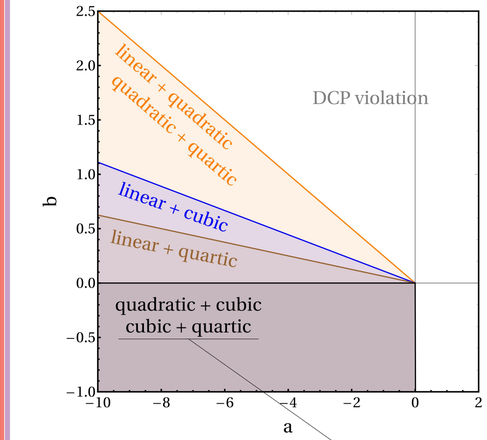
s_α : mixing angle





Conclusion → MM are only distinguished in the FDM and SDM scenarios.

Beyond the minimal models:

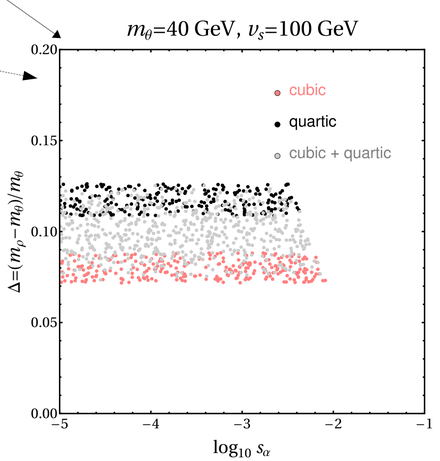


Two real SB terms may lead to **SSB of the DCP sym.** Consider as the general potential:

$$V_{SB} = \left(aS^n + bS^{n'}\right)$$

In the colored regions the vacuum preserves DCP.

m_θ=40 GeV, v_s=100 GeV



Combining pairs of MMs only expands the allowed region in between them.

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