Simple Theory of Chiral Fermion Dark Matter

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What is the origin of mass of dark matter?

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By hand in many models

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Mass of DM is also determined by condensation ?

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- We assume that the mass of a spin-$\frac{1}{2}$ dark matter is proportional to a VEV of a scalar field
- We constructed a simple model and studied its phenomenology

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$$\mathscr{L} \supset -\cancel{m\bar{\psi}}\psi - y\bar{\psi}\psi\phi$$

forbidden by a symmetry

$$\langle \phi \rangle \neq 0$$

DM mass is proportional to a VEV of a scalar field

Let’s forbid the mass term

$$\mathscr{L} \supset -\cancel{m\bar{\psi}\psi} - y\bar{\psi}\psi\phi$$

Let’s forbid this term

- Use a gauge symmetry to forbid mass terms
- mass of vector-like fermions are not forbidden by symmetries…
- Let’s use a chiral fermion

U(1) gauge symmetry does not work

There are gauge anomaly

- At least 5 chiral fermions are required to forbid mass terms with anomaly cancellation
  [hep-ph/0312285, hep-ph/0504198, hep-ph/0510181, 1102.4688, 1605.03610, 1905.13729, 2001.11991, ⋯]

- model becomes complicated⋯

- let's seek other possibilities

SU(2) gauge symmetry

doublet fermion

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triplet fermion

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- No Witten anomaly!
- No mass term!
  - ⋆ $\mathbf{4} \times \mathbf{4} = \mathbf{7} + \mathbf{5} + \mathbf{3} + \mathbf{1}$
  - ⋆ $\mathbf{5}$ and $\mathbf{1}$ are anti-symmetric and are zero

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We use 4-plet fermion!

SU(2) rep. of scalar

3 or 7 is the candidate for scalar that couples to the fermion

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- $\mathbf{4} \times \mathbf{4} = \mathbf{7} + \cancel{\mathbf{5}} + \mathbf{3} + \cancel{\mathbf{1}}$

3 is not a good candidate

- U(1) remains after the SU(2) breaking by $\mathbf{3}$
- a massless gauge boson is predicted, not good for phenomenology
- a 7-plet scalar is only the candidate for us

Model

$SM \times SU(2)_{Dark}$

- an $SU(2)_{Dark}$ 4-plet chiral fermion
- an $SU(2)_{Dark}$ 7-plet scalar

Model

SM x SU(2)$_{\mathrm{Dark}}$

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Distinctive features of the 7-plet

- Discrete symmetries remain after SU(2)$_{\text{Dark}}$ breaking
- In our setup, T′ (double covering of A$_4$) remains
- The irreducible reps. of T′ are $\mathbf{3}, \mathbf{2}, \mathbf{2}', \mathbf{2}'', \mathbf{1}, \mathbf{1}', \mathbf{1}''$
- SM particles are SU(2)$_{\text{Dark}}$ singlet and thus $\mathbf{1}$
- Particles other than $\mathbf{1}$ are DM candidates

Representation of new particles under T'

gauge field

- V_μ^a : SU(2)$_{\text{Dark}}$ gauge fields; $\mathbf{3}$

scalar fields (7 = 3 + 3 + 1)

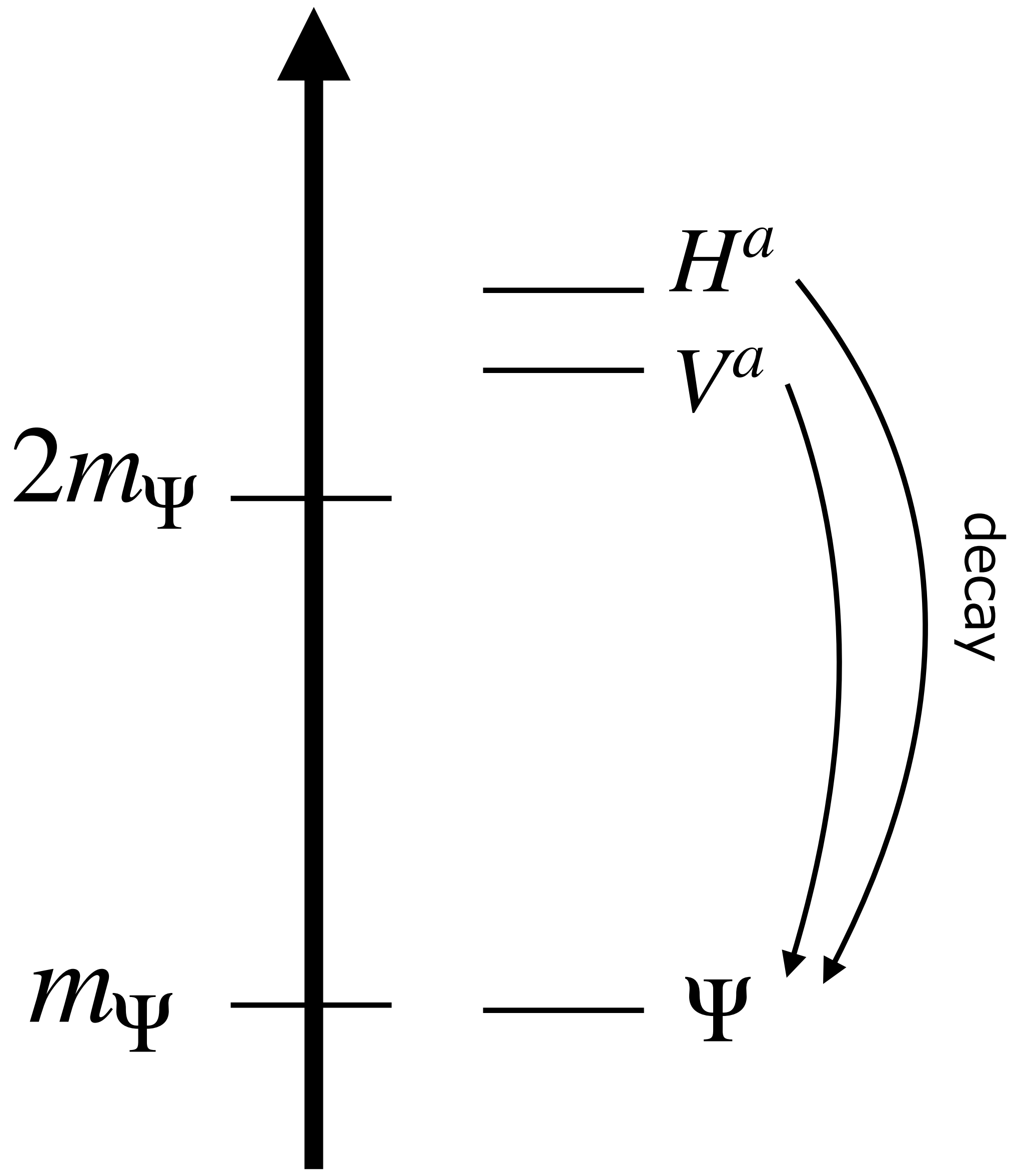
- π^a : would-be Nambu-Goldstone boson; $\mathbf{3}$
- H^a : physical scalars; $\mathbf{3}$
- h' : scalar around the fluctuation of the VEV; $\mathbf{1}$
  - ★ h' mixes with the SM Higgs, and thus phenomenology is similar to the Higgs portal models

fermion fields (4 = 2′ + 2″)

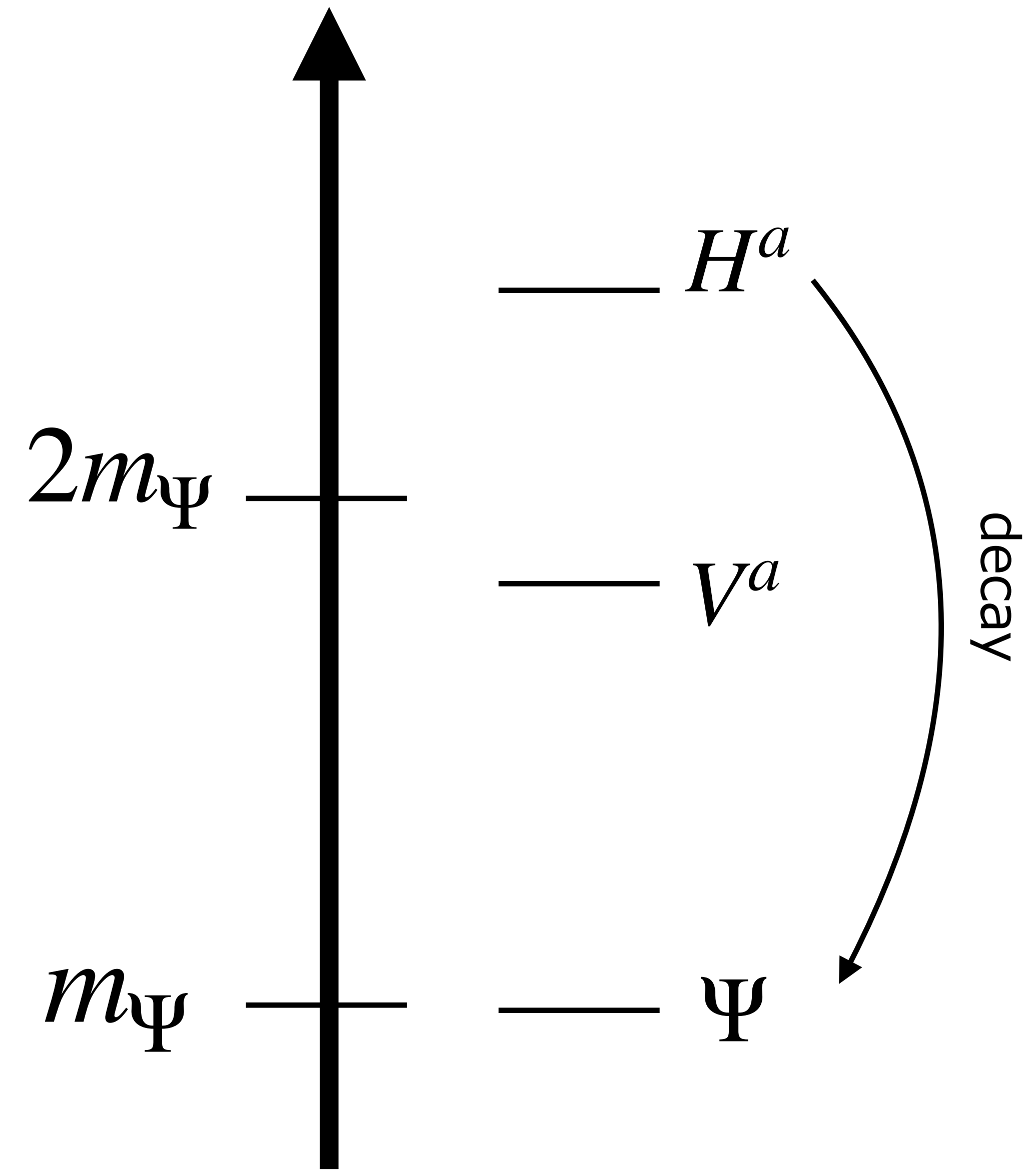
- Ψ : Dirac fermion $\mathbf{2}'$

single or multi-component DM

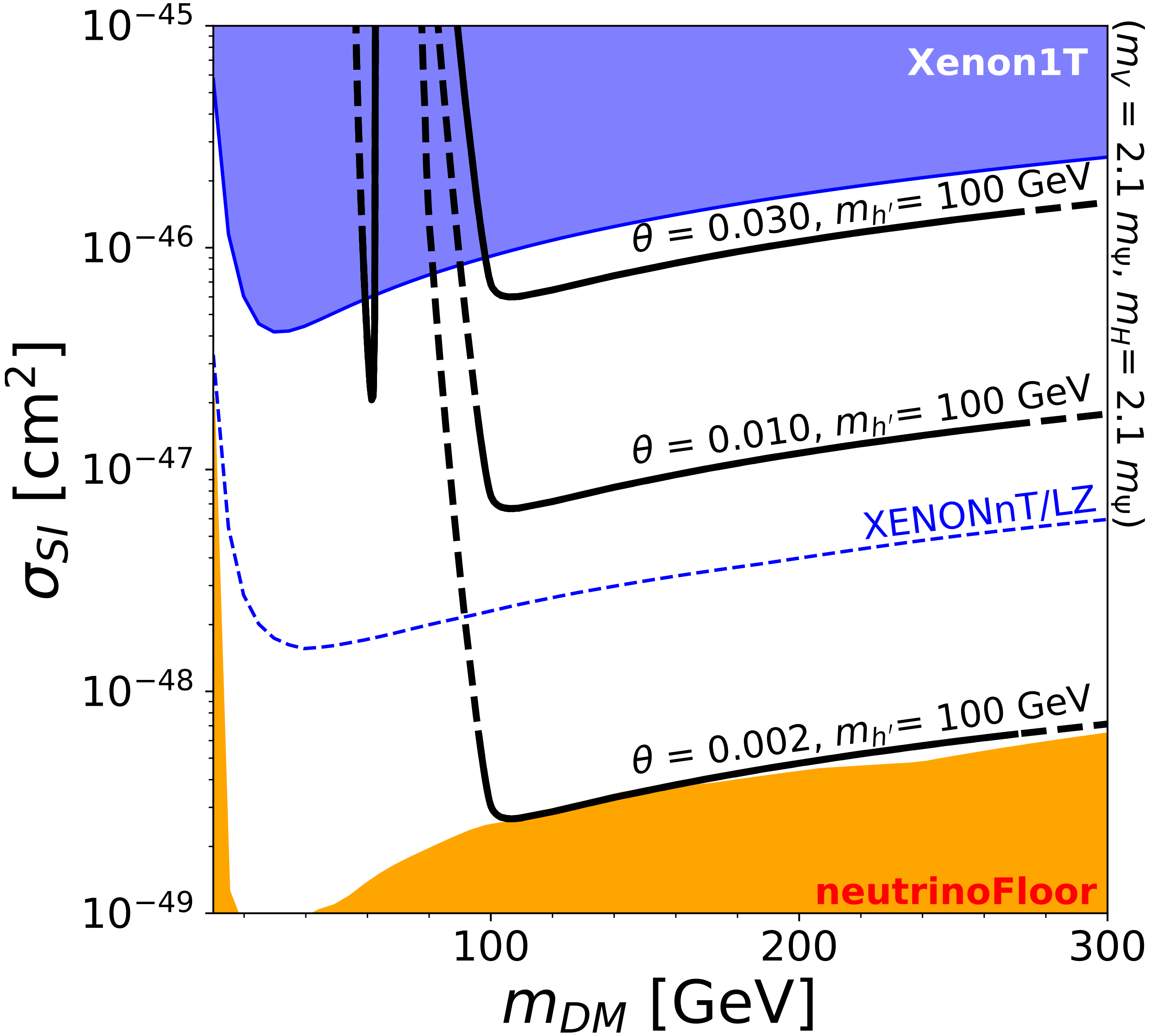
Example for the single-component DM
(only ψ is DM)



Example for the two-component DM
(ψ and V^a are DM)



The result of the case Ψ is the only DM



- $\Omega h^2 = 0.12$ (by choosing the Yukawa coupling)
- we have a chance to see signal near future at XENONnT/LZ
- Dashed curves are exulted by perturbative unitarity of the gauge and Yukawa couplings
  $\rightarrow$ $m_\Psi \lesssim 280$ GeV

Summary

We constructed a DM model where its mass is proportional to the VEV of a scalar field

- $SU(2)_{Dark}$ 4-plet chiral fermion
- $SU(2)_{Dark}$ 7-plet scalar

Distinctive features

- A discrete symmetry T' remains after the $SU(2)_{Dark}$ breaking
- Model can be multi-component DM model depending on the mass spectra

phenomenology (single component case)

- $m_{DM} < 280$ GeV (perturbative unitarity)
- signal is expected at the direct detection exp. in future.