

# Self-interacting dark matter and cosmology of a light scalar mediator

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## Introduction

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- Motivation: Small-scale structure problems (missing satellite, core-cusp, too big to fail) and observations of galaxy clusters (Abell 3827, Abell 520).
- If interpreted as evidences of DM self-interactions these imply DM self-interaction strength  $\sigma/m \sim 0.1 - 1\text{cm}^2/\text{g}$ .
- Model: Fermionic dark matter  $\psi$ , self-interactions mediated by a scalar  $S$ .

## Model

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- Extend the SM scalar sector with a real singlet  $s$ ,

$$\mathcal{L} \ni \mu_1 s \phi^2 + \lambda_p s^2 \phi^2.$$

- The mass eigenstates are

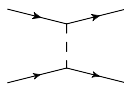
$$H = h \cos \beta + s \sin \beta, \quad S = -h \sin \beta + s \cos \beta,$$

- $m_H = 126 \text{ GeV}$ .
- The dark matter candidate is a SM singlet fermion  $\psi$ :

$$\mathcal{L}_{\text{DM}} = \bar{\psi}(i\not{\partial} - m_\psi)\psi + g_s s \bar{\psi}\psi.$$

## Self-interaction

### Scattering from a Yukawa potential



self-interaction

$$V(r) = -\frac{\cos^2\beta g_s^2}{4\pi r} e^{-m_S r}.$$

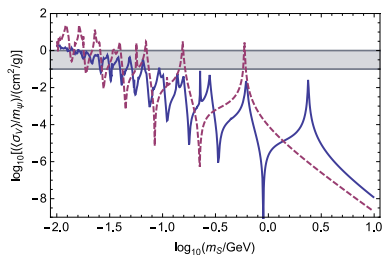
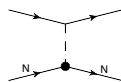


Figure : Solid line:  $m_{\phi} = 400$  GeV, dashed line:  $m_{\phi} = 100$  GeV.

$\implies$   $S$  has to be light,  $m_S \lesssim 1$  GeV.

## Direct detection constraint



direct detection

$$\sigma_{\text{SI}} \sim \frac{g_s^2 \sin^2 \beta \cos^2 \beta}{m_S^4}.$$

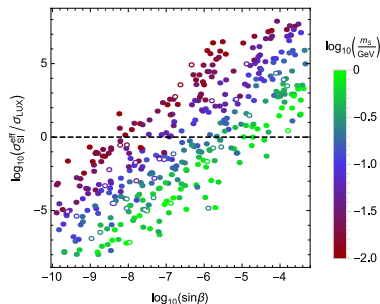
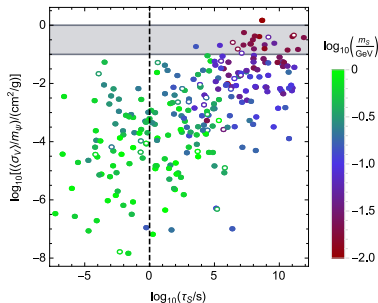
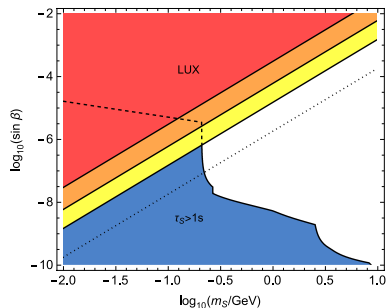


Figure :  $\Omega_\psi h^2 / 0.12 > 0.8$

$\implies \sin\beta$  has to be small,  $\sin\beta \lesssim 10^{-5}$ .

## BBN

$m_S \lesssim 1 \text{ GeV}$  and  $\sin \beta \lesssim 10^{-5} \implies$  lifetime of  $S$  is long. Successful BBN requires  $\tau_S < 1\text{s}$ .



## Extension

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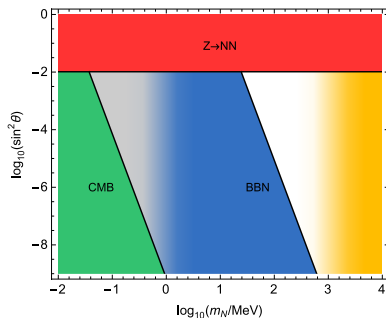
Introduce a light sterile neutrino  $N$  which couples to  $S$ ,  $\mathcal{L}_{SNN} = y_N S N \bar{N}$ , and mixes with the SM neutrinos mixing angle  $\sin \theta$ .

- lifetime of  $S$  is less than 0.1sec if  $y_N \gtrsim 2 \times 10^{-11} (\text{GeV}/m_N)^{1/2}$
- also  $\tau_N$  less than 0.1sec  $\implies m_N (\sin \theta)^{2/5} > 10 \text{MeV}$

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- If  $N$  is light and decouples before QCD phase transition, it's effect on BBN is insignificant.



## Conclusions

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- For the self-interactions to be sufficiently strong, the mediator  $S$  has to be light.
- Since  $S$  mediates also dark matter-nucleon scattering, its coupling to SM fermions has to be very small.
- The BBN sets an upper limit on lifetime of  $S$  and excludes the region where  $\sigma/m \sim 0.1 - 1\text{cm}^2/\text{g}$ .
- The problems of a long-lived mediator  $S$  be alleviated with a sterile neutrino  $N$ , but the BBN gives stringent constraints on the mass and the mixing of  $N$ .