Neutrinophilic Self-interacting Dark Matter

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We focus on MeV scale DM

Reason

- EW scale DM has not been discovered.

- Experiments for MeV scale gamma ray and neutrinos are going to start.

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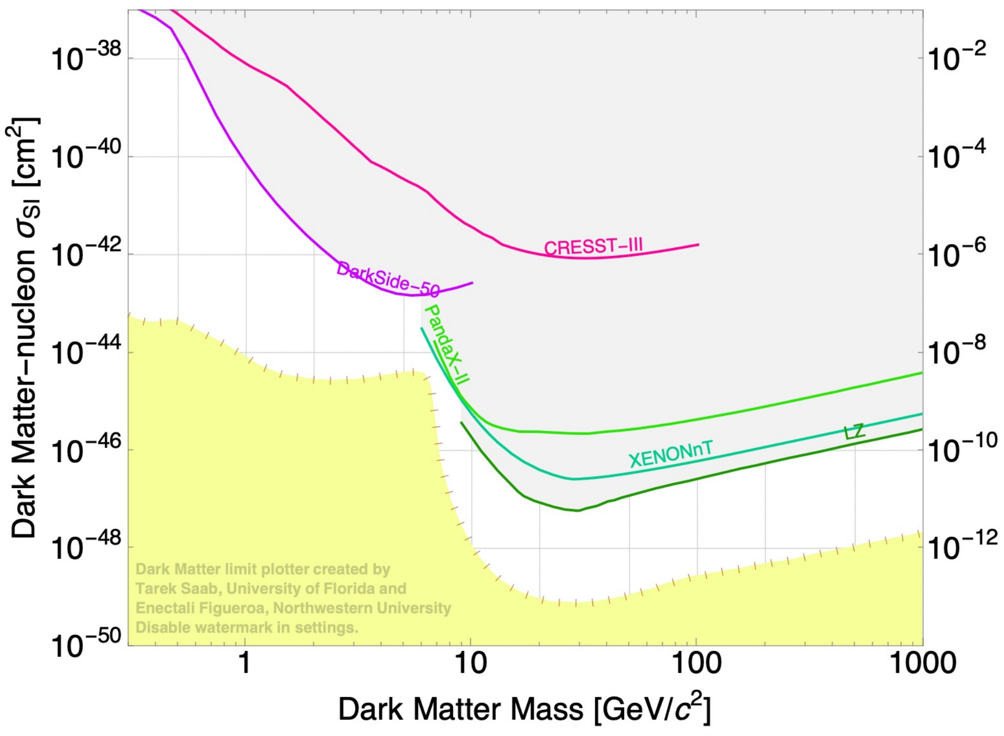
The best time to consider this DM !

Advantages of MeV DM

1. Produced by freeze-out mechanism yet.

2. Direct detection constraint becomes weaker.

3. It has potential to explain the core-cusp problem.

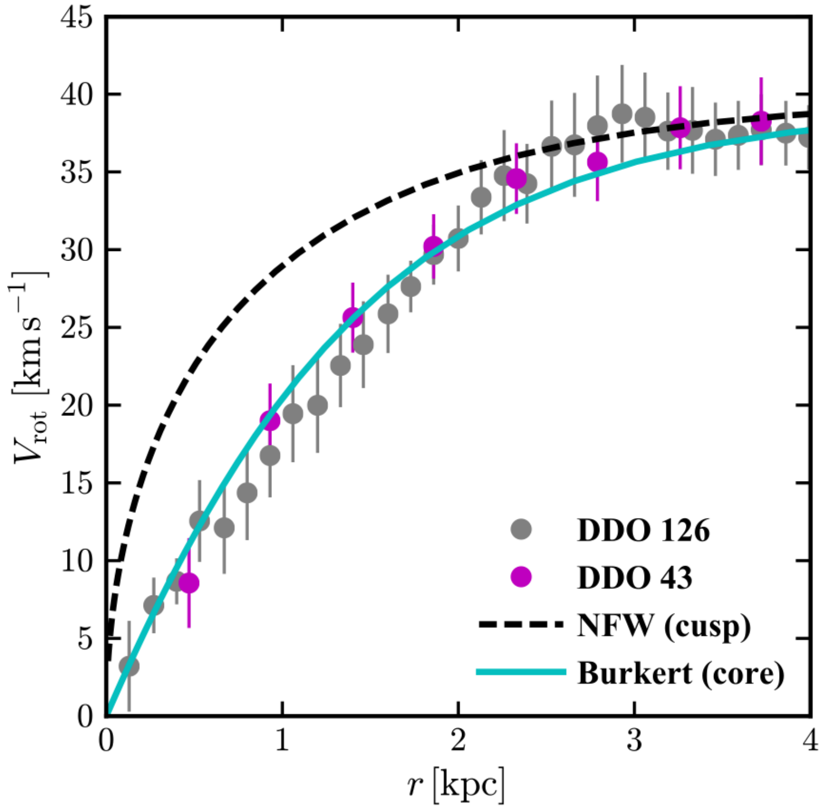


Core-cusp problem

Some observations showed DM density in the center of galaxies is lower than the NFW profile.

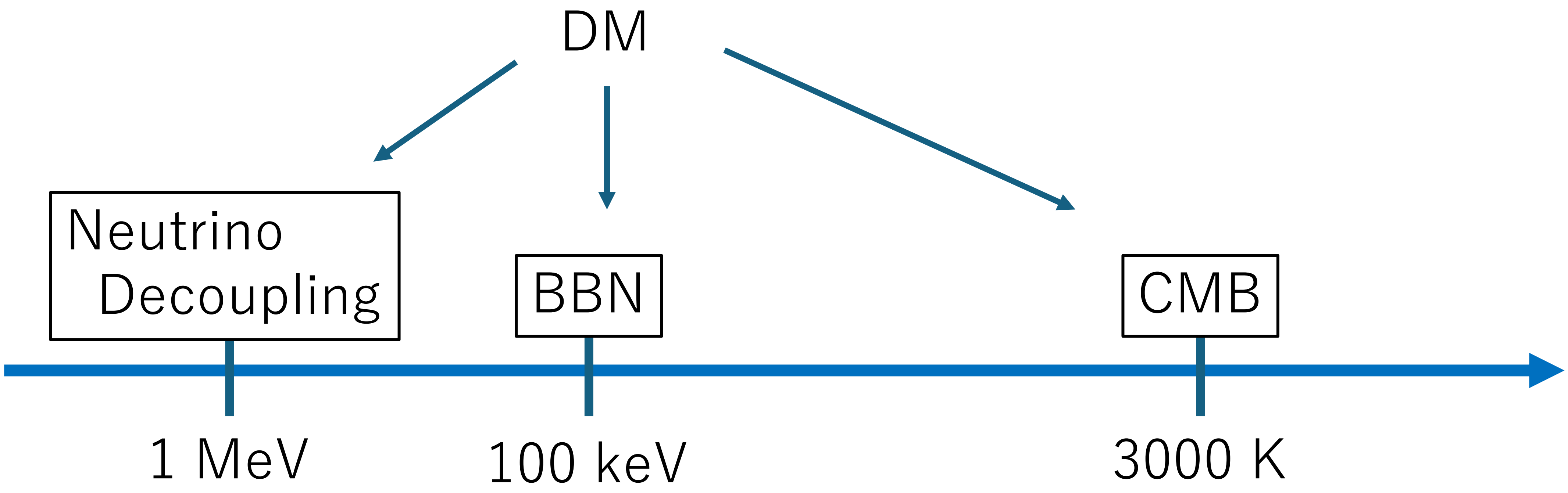
One solution : DM self-scattering.

For the enough self-scattering, MeV scale mass is preferred.



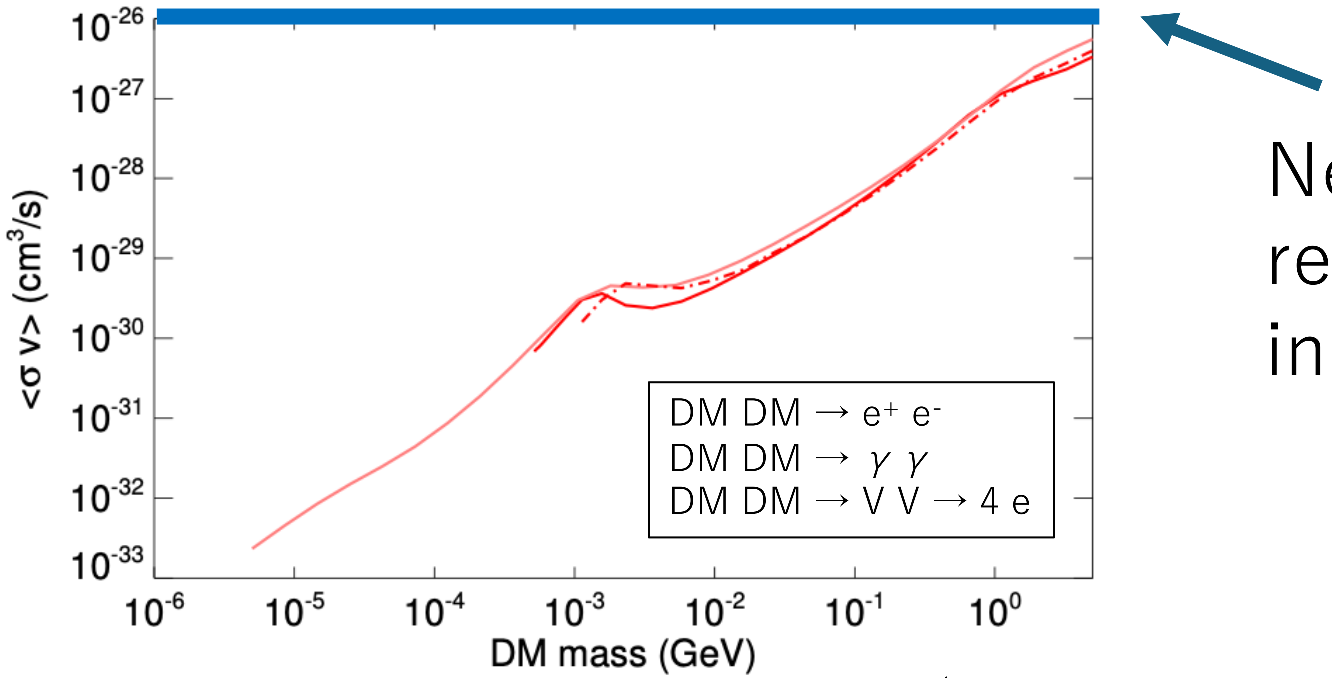
(J. S. Bullock. et al. Ann.Rev.Astron.Astrophys. 55 (2017))

Problems of MeV scale DM



Light DM is more constrained by these observations

Upper bound on DM annihilation from CMB



Needed cross section to realize the present density in s-wave.

(T. R. Slatyer. Phys.Rev.D 93 (2016))

⇒ We must suppress DM annihilation to electrons and photon.

How to avoid CMB constraint

- Assume the different thermal history.
- Annihilation rate depends on velocity.
- DM annihilate to only harmless particles.

Model

- We introduce $U(1)_{B\text{-}L}$ gauge boson (Z') and scalar DM(ϕ).

$$\mathscr{L}_{BSM} \supset -\frac{1}{4}Z'_{\mu\nu}Z'^{\mu\nu} - \frac{\sin\chi}{2}Z'_{\mu\nu}B^{\mu\nu}$$
$$-\sum_f \bar{f}_{SM}\gamma^\mu(Y_f g_1 B_\mu + g_2 W^a_\mu \tau^a + z_f g_{B-L} Z'_\mu) f_{SM}$$
$$+|(\partial_\mu + i z_{DM} g_{B-L} Z'_\mu)\phi|^2 - m^2_{DM}|\phi|^2 - \frac{\lambda}{4}|\phi|^4$$

Diagonalize to mass basis

$$-\sum_f (z_f g_{B-L} - Q_f g_1 c_W^2 \chi) Z'_\mu \bar{f}_{SM}\gamma^\mu f_{SM} \quad (m_{Z'} \ll m_Z, \quad \chi \ll 1)$$

Z' coupling to SM fermion

Suppose $g_{B-L} \sim g_1 c_W^2 \chi$,

$$g_{B-L} Z'_\mu \bar{\nu} \gamma^\mu \nu + \frac{1}{3} g_{B-L} Z'_\mu \bar{u} \gamma^\mu u - \frac{2}{3} g_{B-L} Z'_\mu \bar{d} \gamma^\mu d + (g_{B-L} - g_1 c_W^2 \chi) Z'_\mu \bar{e} \gamma^\mu e$$

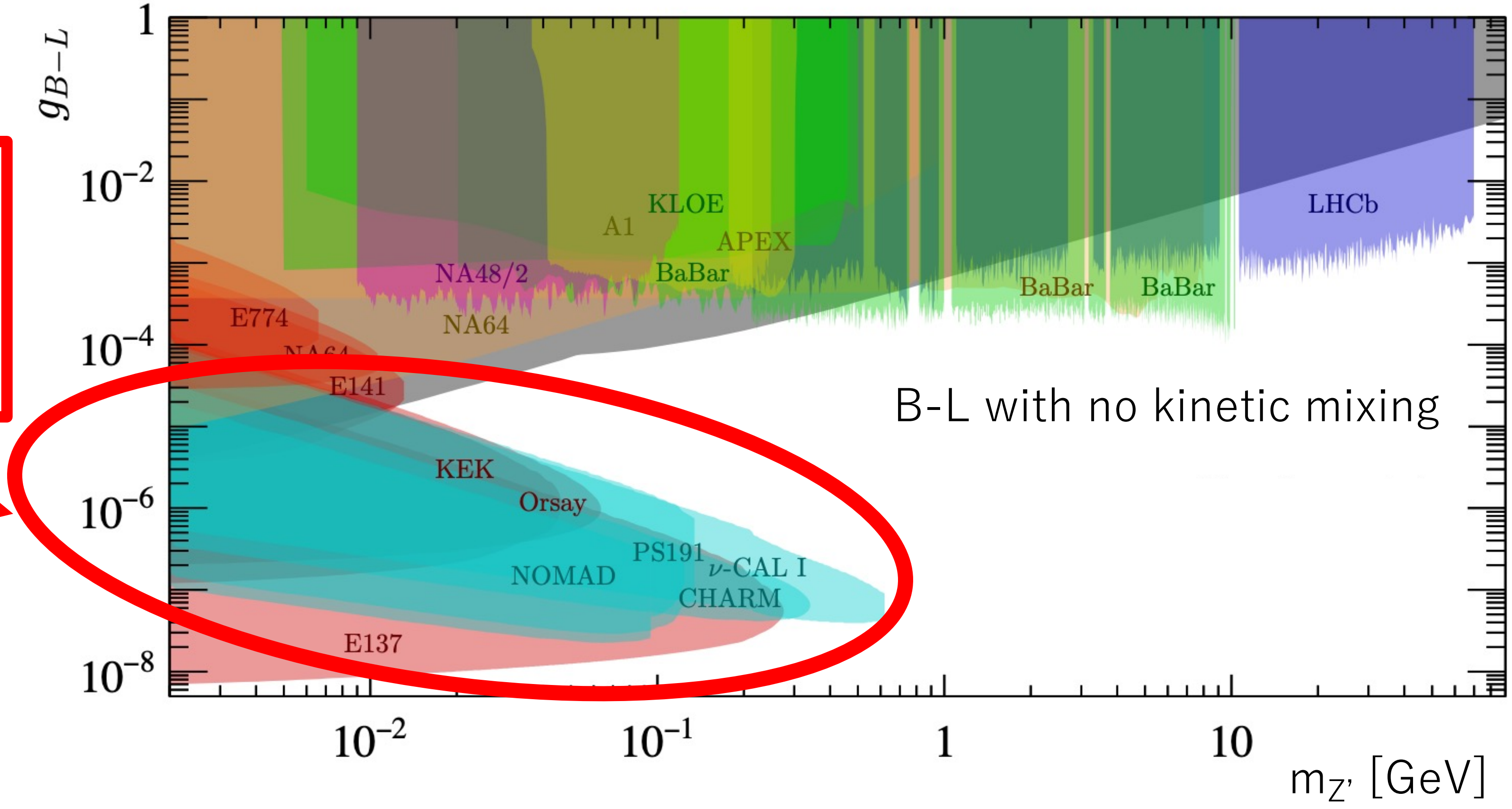
DM annihilate to mainly neutrinos.

The CMB constraint becomes weaker!

Collider constraint

(P. Ilten. et al. JHEP 06 (2018))

Use the assumption of Z' -> e^+e^-
(We can't use)



Collider constraint becomes also weaker in our model

✔Direct detection

✔Collider experiment

・DM self-scattering

・DM density

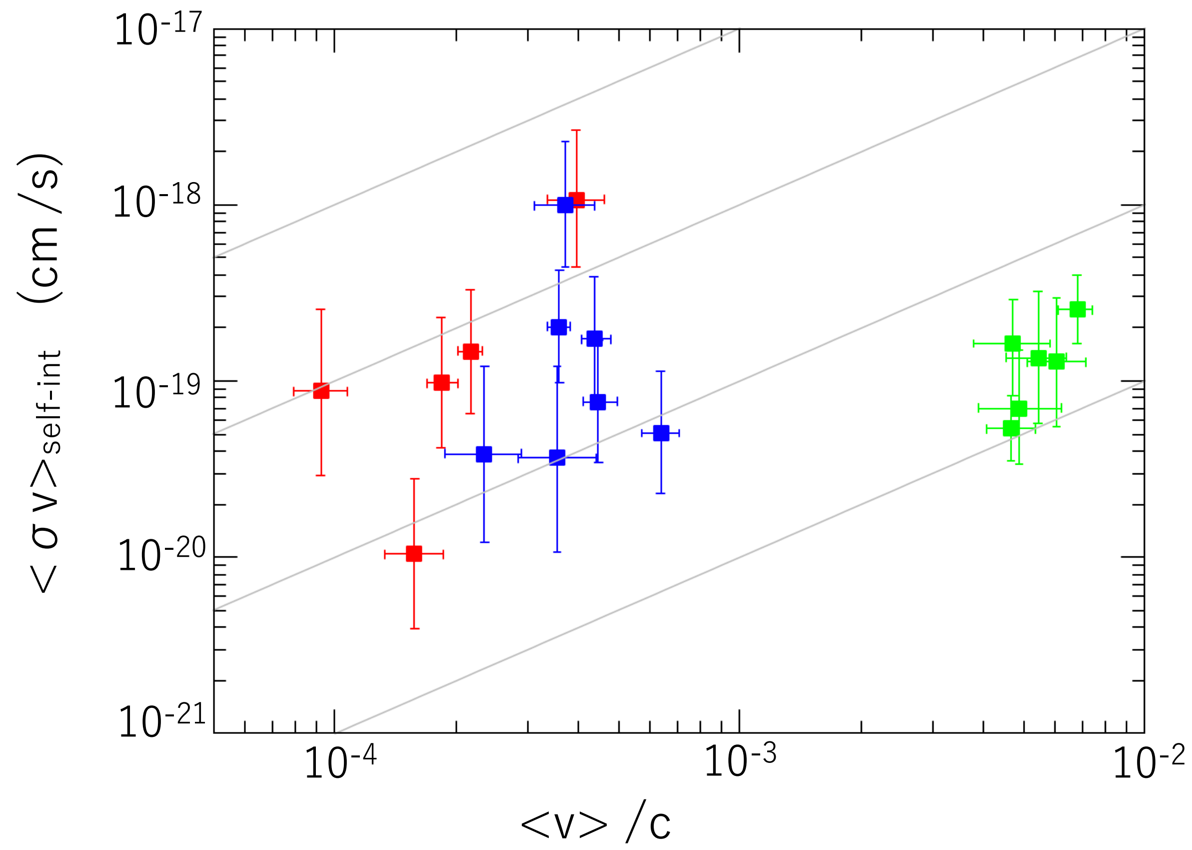
・Indirect detection

・Cosmological constraint

We will see that one parameter set which satisfies these constraints exists.

← In process

Self-scattering dependence on velocity

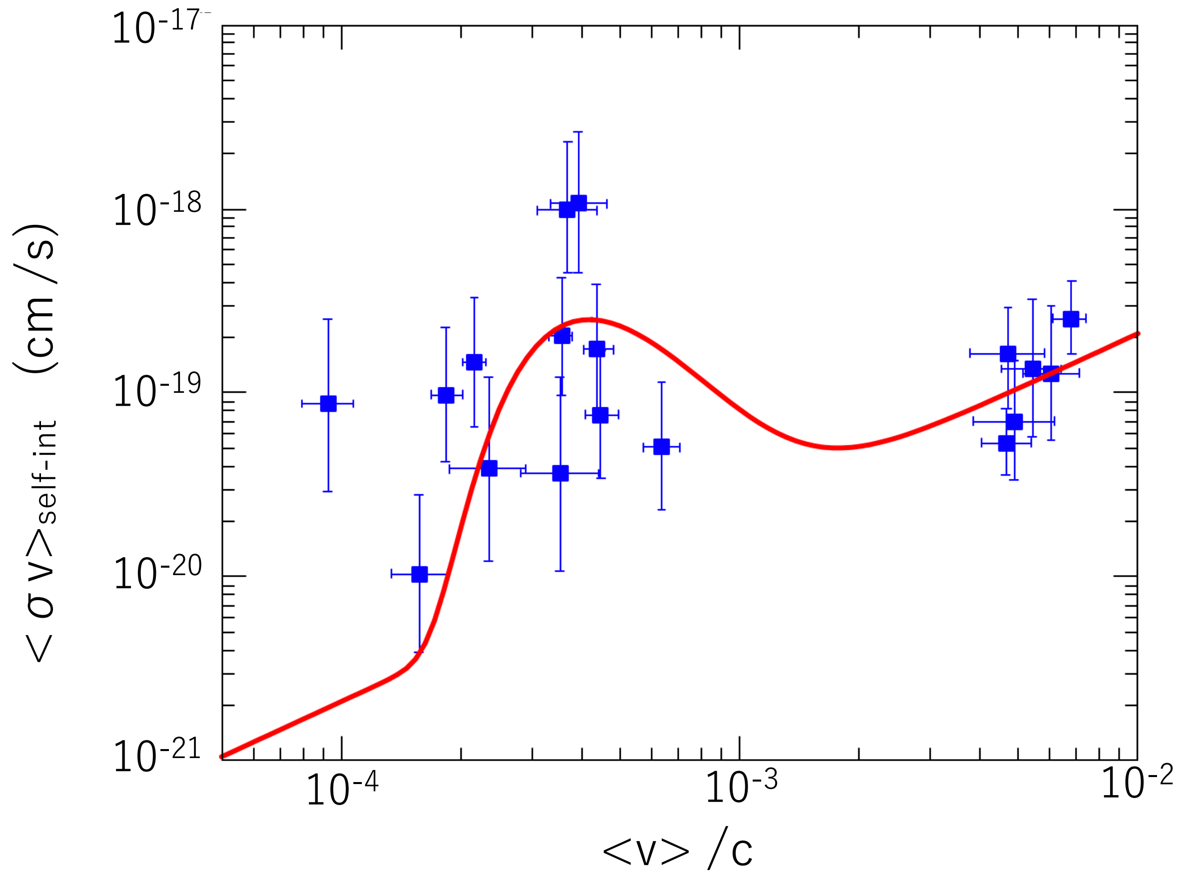


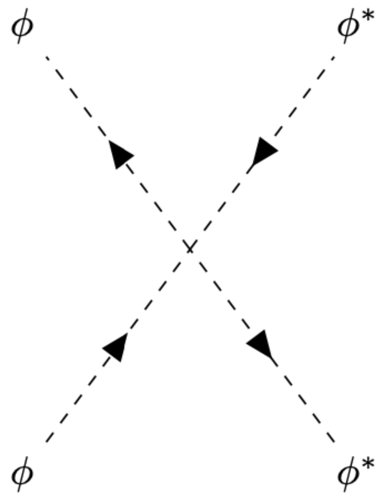
- dwarf galaxy
- low surface brightness galaxy
- galaxy cluster

(M. Kaplinghat. et al. Phys.Rev.Lett. 116 (2016)))

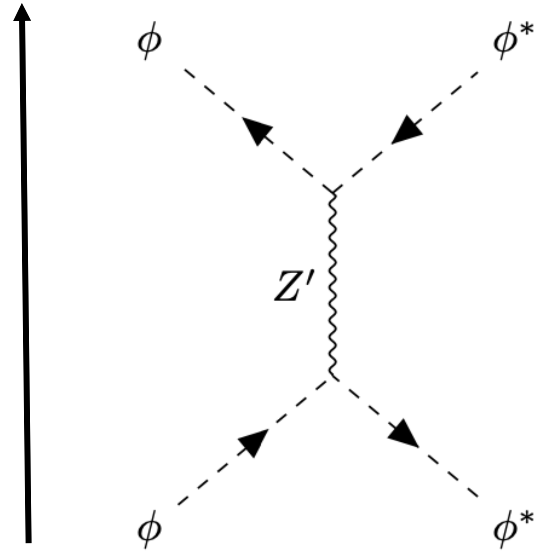
Resonant self-interaction of DM

(X. Chu. et al. Phys.Rev.Lett. 122 (2019))





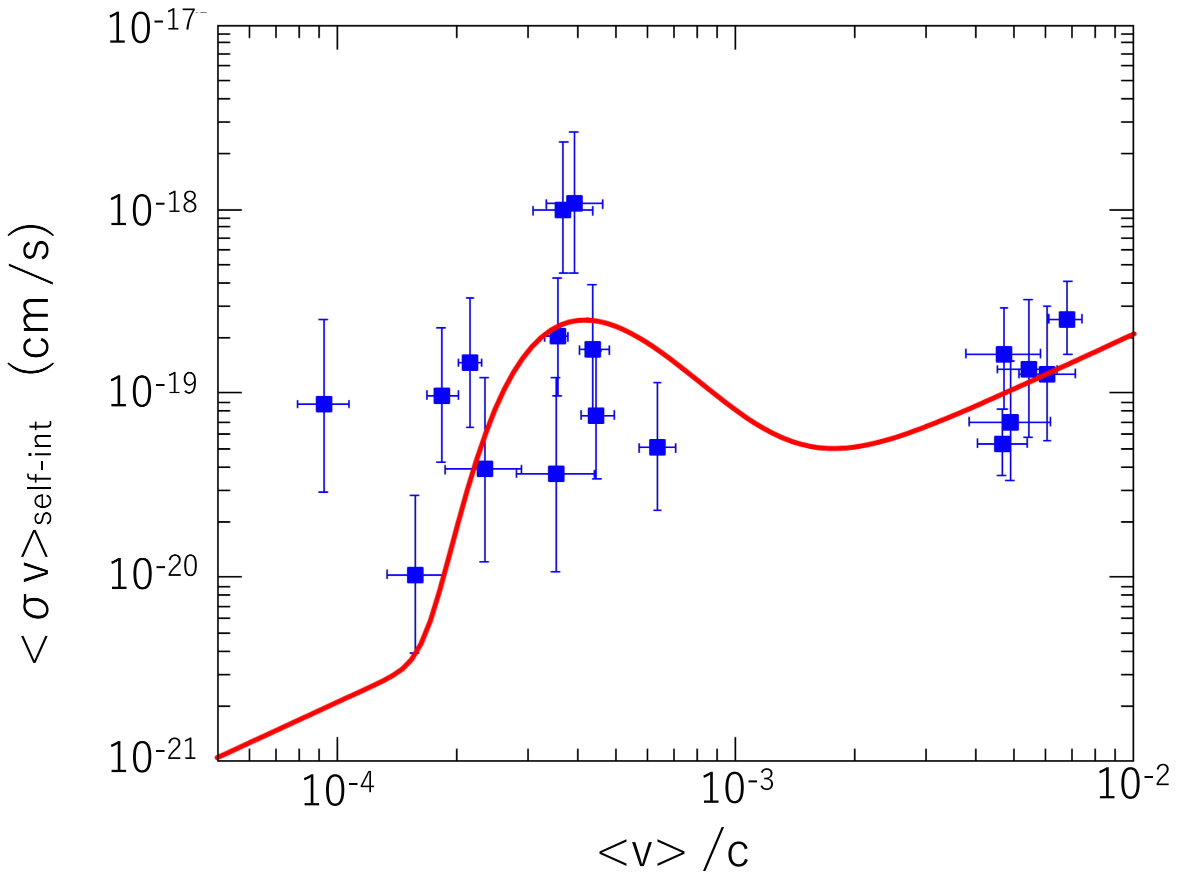
Liner with <v>



Resonance

To explain the peak of cross section, the resonance is favored.

Parameter set we use



<u>Parameter set</u>

- λ : 0.11
- $g_{B\text{-}L}$: 6.1×10^{-11}
- z_{DM} : 1.6×10^{7}
- m_{DM} : 4.0 MeV
- $m_{Z'}$: $2\, m_{DM} + 1/4\, m_{DM}\, v_R^2$
- v_R : 4.5×10^{-4} c

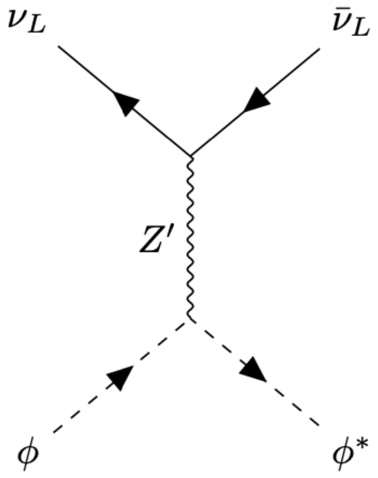
We will confirm this parameter set satisfies the other constraints.

Constraint from relic density

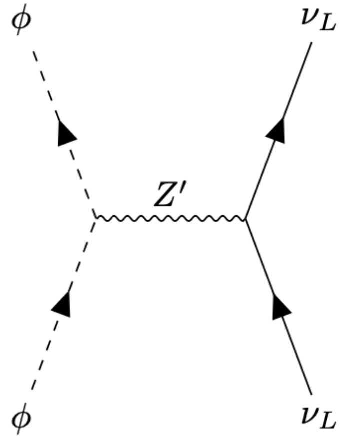
We consider the s-channel resonance process.

Scattering cross section with SM particle is much smaller than DM annihilation one.

DM has the different temperature from SM one during chemical decoupling.

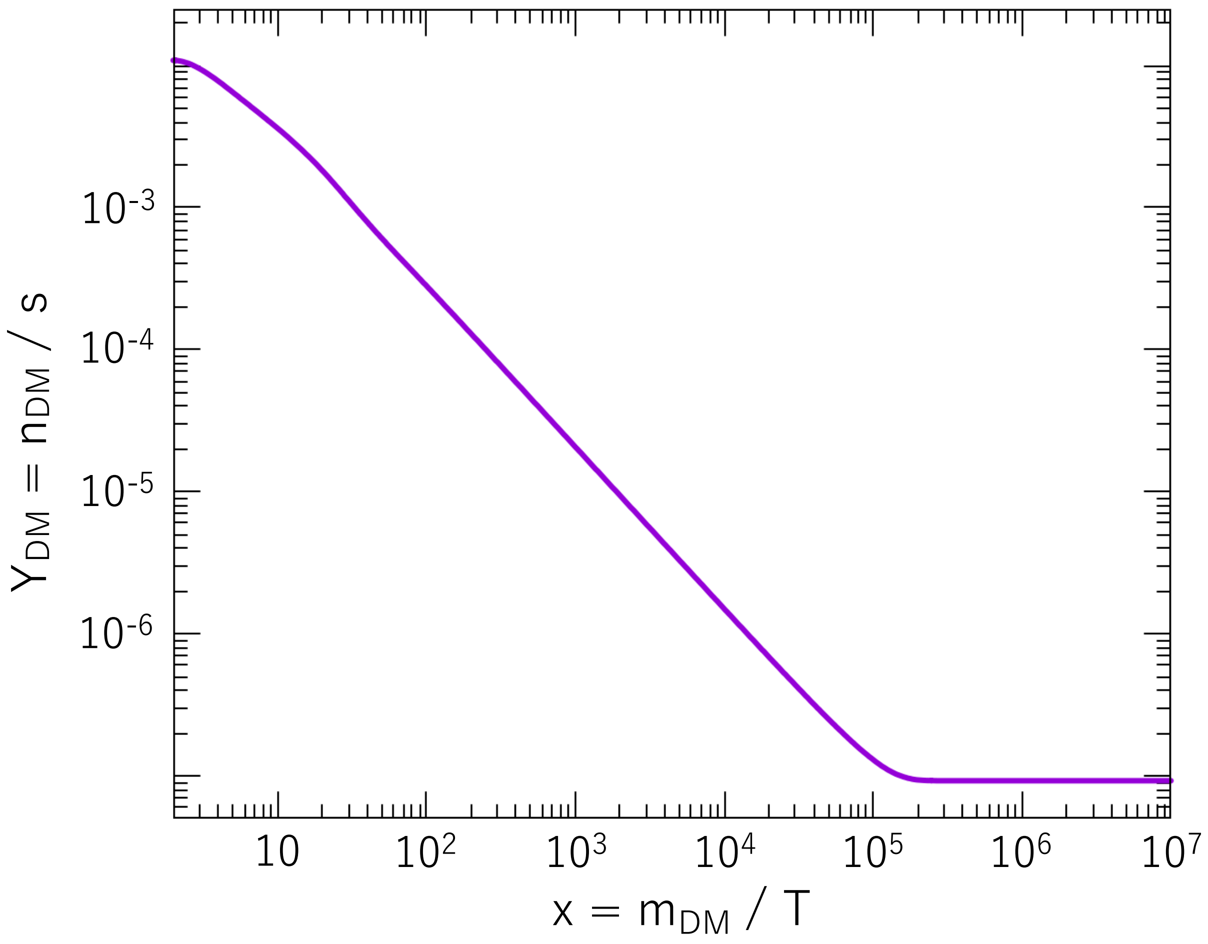


Annihilation



Scattering

DM density during freeze out

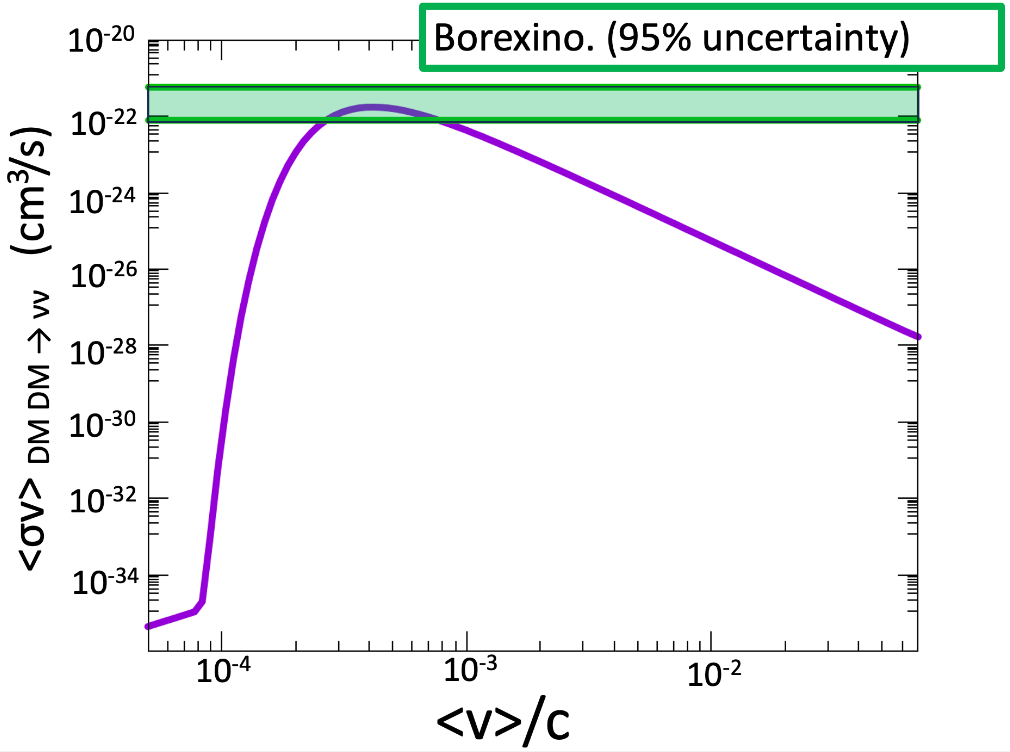


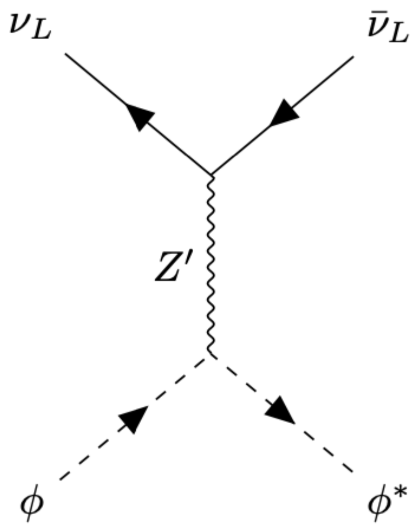
$\Omega_{DM}\, h^2$ becomes 0.1!

・s-channel resonance makes annihilation rate larger when T decreases.

Indirect detection (neutrino)

DM annihilation to neutrino pair





Neutrinos from DM annihilation can be detected in the near future.

Constraint from cosmological observation

The existence of the MeV scale DM can affect the neutrino decoupling (effective number of neutrinos : N_{eff}).

Lower bound of m_{DM} (in s-wave) is

(M. Escudero . JCAP 02 (2019))

- 6.0 MeV (e : ν = 1 : 10^6) ($\Delta N_{eff} > 0$)
- 2.6 MeV (e : ν = 1 : 10^4) (mediator)
- 12.9 MeV (e : ν = 10^6 : 1) ($\Delta N_{eff} < 0$)

Our parameter set (m_{DM} = 4 MeV) seems to survive.

Constraint from cosmological observation

However, in our model, chemical decoupling starts at T ~ 2 MeV.

↓

The amount of DM becomes larger, and it's expected that N_{eff} is more sensitive than usual.

However, we have already confirmed that there is another parameter set in which m_{DM} is 10 MeV.

→ It is likely that this model is promising candidate.

Summary

・With a simple $U(1)_{B\text{-}L}$ extension, we constructed a model where MeV scale DM interact mainly harmless particles.

・This model can be produced by the freeze-out mechanism and solve the core-cusp problem evading the present constraint　(except for N_{eff}).

・Search for valid parameter region is the left work.