The GeV-scale dark matter with B − L asymmetry

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1. What we know about dark matter (DM)
2. Stability of DM in terms of $U(1)_{B-L}$
3. The GeV-scale dark matter (Asymmetric dark matter)

What we Know about DM

○ Cosmological & Astrophysical observations:

CMB, Circular velocity, Galactic clusters, LSS, Bullet clusters, etc.

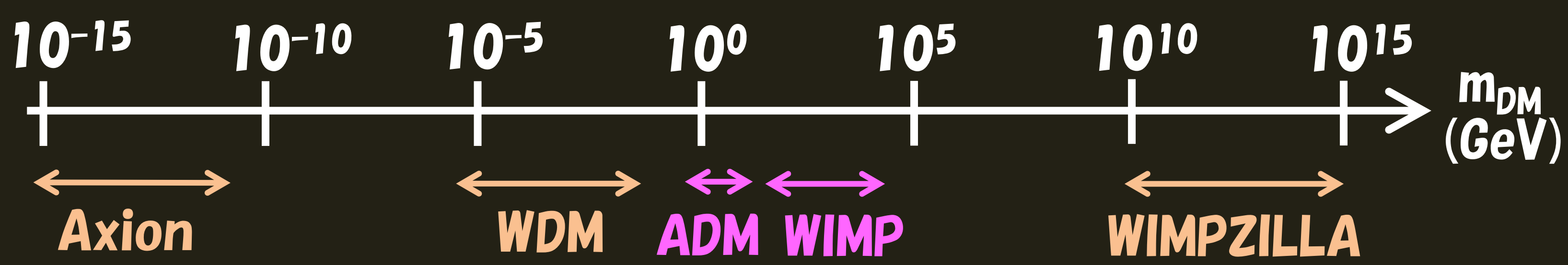
○ Properties

Electrically neutral
Enough stable
Weak interacting
(Non-Baryonic)

○ Status

Cold (Non-relativistic)
$\Omega_{DM} h^2 = 0.110$ ($\rho_{DM} \sim 10^{-6}$ GeV/c.c.)
Distributions in galaxies & clusters
($\rho_{gal} \sim 10^{-1}$ GeV/c.c. & $\rho_{g.c.} \sim 10^{-3}$ GeV/c.c.)

No DM candidates in the SM (Exception: PBH w/ 10^{14-23} kg)



What we Know about DM

○ Interactions of DM w/ 1GeV−1TeV mass are well studied!

Neutral, Stable, Weak int, Non-relativistic, and $\Omega_{DM} h^2 = 0.110$

Several constraints on DM interactions

1. Observing halo shapes of galactic clusters.
   → Elastic scattering of DM should be $\sigma_T < O(1)(m/1\mathrm{GeV})$ mb
2. Direct detections of DM. (Also, LHC experiment)
   → DM & p(n) scattering is $\sigma < 10^{-7}-10^{-8}$pb (m = 10−1000GeV)
3. Indirect detections of DM (γ, anti-p, $e^\pm$, ν)
   → DM annihilation is $\sigma v|_\gamma < 10^{-23}-10^{-25}\mathrm{cm}^3/\mathrm{s}$ (m = 10−1000GeV)
   $\sigma v|_p < 10^{-26}\mathrm{cm}^3/\mathrm{s}$ (m < 30GeV)

Anomalies existing

1. PAMELA/Fermi-LAT anomaly in indirect detections ($e^\pm$).
   → DM with O(1) TeV mass? Or other astrophysical activities?
2. DAMA/CoGeNT anomaly in direct detections
   → DM with 6-8 GeV mass? Or modulating backgrounds?

Stability of DM in terms of $U(1)_{B-L}$

Neutral, Stable, Weak int, Non-relativistic, and $\Omega_{DM} h^2 = 0.110$

○ Many candidates of the symmetry to stabilize DM.

Gauge $U(1)_{B-L}$ broken at some higher scale [$\sim 10^{12}$ GeV]

→ Existence of RH neutrinos → Neutrino masses & Leptogenesis.

○ $U(1)_{B-L}$ is good symmetry at low energy, but not enough for DM.

1. SM ⊃ fermions (B-L charge 1) & bosons (B-L charge 0)
2. $U(1)_{B-L}$ is broken by VEV with B-L charge of two.

○ There is a residual discrete symmetry to stabilize DM.

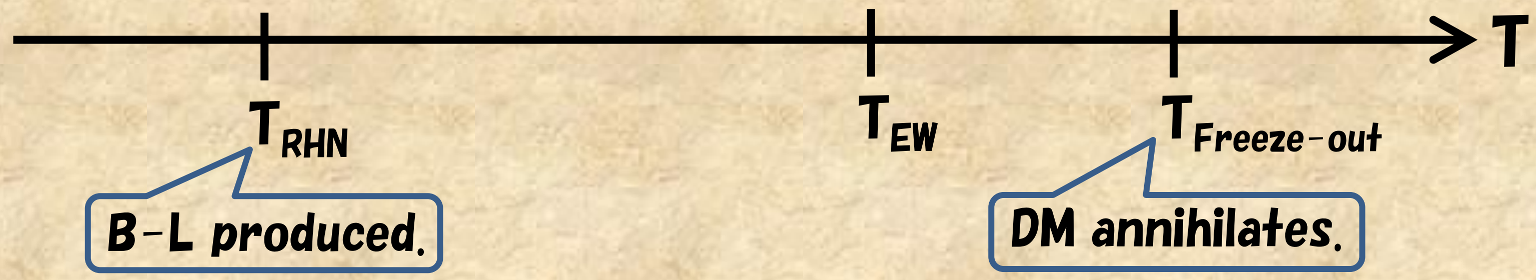
1. New fermion with even (0, 2, 4, …) B-L charge
2. New boson with odd (1, 3, 5, …) B-L charge
3. New particle with fractional (1/2, 2/3, …) B-L charge.

Stability of DM in terms of $U(1)_{B-L}$

~ DM with $Q_{DM} = 0$: the WIMP dark matter ~

This fermionic DM is expected to have a Majorana mass without breaking the $U(1)_{B-L}$. Typical example of the DM is the neutralino.

The simplest thermal history of the (fermionic) dark matter is



○ Several predictions

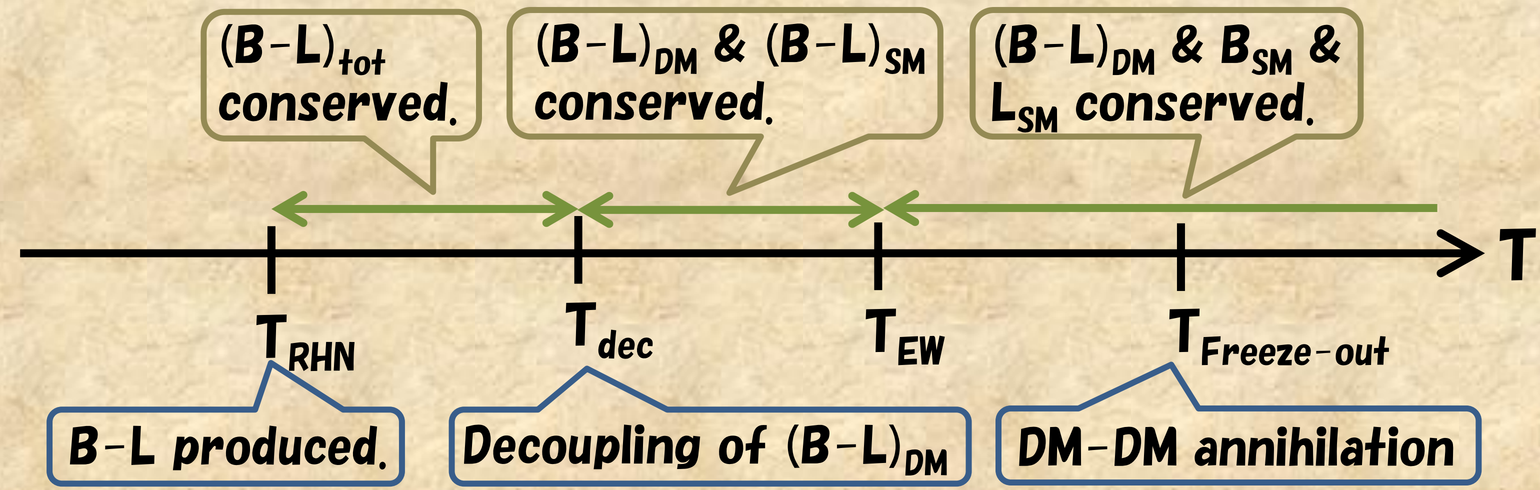
1. Annihilation cross section between DMs is about 1pb.
2. Mass of the dark matter is 10-1000 GeV.
3. The dark matter may have a $SU(2)_L$ charge.
4. The dark matter may be discovered in near future.

Stability of DM in terms of $U(1)_{B-L}$

~ DM with $Q_{DM} \neq 0$: the Asymmetric dark matter ~

D.E.Kaplan, M.A.Luty, K.M.Zurek, (2009)

The simplest thermal history of the dark matter in this case is



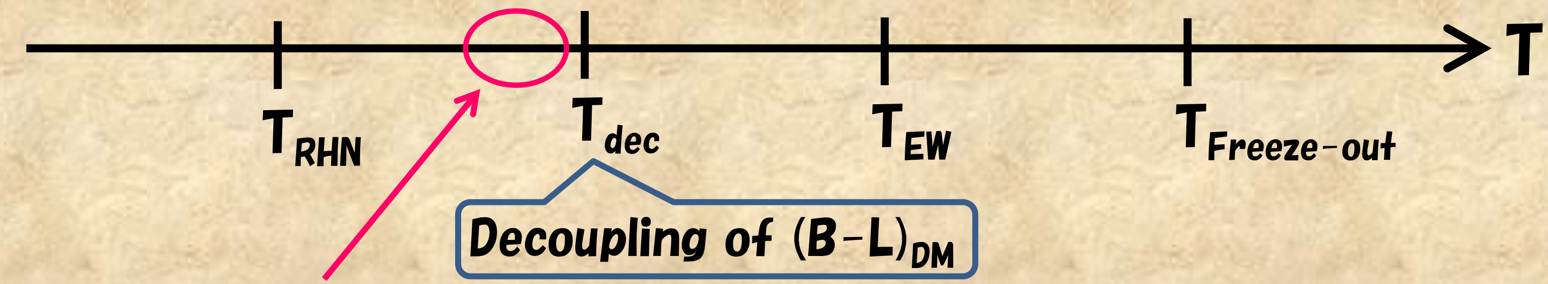
If DM with $Q_{DM} \neq 0$ has a Majorana-type mass, it breaks $U(1)_{B-L}$, which may wash-out B-L asym produced in the early universe.

Since $U(1)_{B-L}$ is broken in the unit of B-L charge of 2, the DM with integer Q_{DM} should have some mechanism to suppress the Majorana-type mass. No problems for DM with fractional Q_{DM}.

The GeV-scale dark matter

○ Several predictions

ADM is much lighter than m_Z for $(B-L)_{DM} \sim B_{SM}$ → Gauge Singlet!



$\mathcal{L}_{\rm int} \simeq \frac{1}{\Lambda^n}\mathcal{O}_{\rm DM}\cdot\mathcal{O}_{\rm SM}$ **e.g.** $\mathcal{L}_{\rm int} = \frac{1}{\Lambda^3}\phi^2(LH)^2$ **or** $\mathcal{L}_{\rm int} = \frac{1}{\Lambda^3}\chi^3\cdot(LH) + {\rm h.c.}$ **etc.**

If DM with $Q_{DM} \neq 0$ has a Majorana-type mass, it breaks $U(1)_{B-L}$, which may wash-out B-L asym produced in the early universe.

1. L_{int} is inv. under SM gauge & $U(1)_{B-L}$.
2. SM & Sphaleron interactions exist.
3. Our universe is electrically neutral.

$$\frac{B_{\rm SM}}{(B\text{–}L)_{\rm DM}} = \frac{15}{97}\frac{66+13n_H}{10+n_H}\frac{1}{Q_{\rm DM}^2}$$

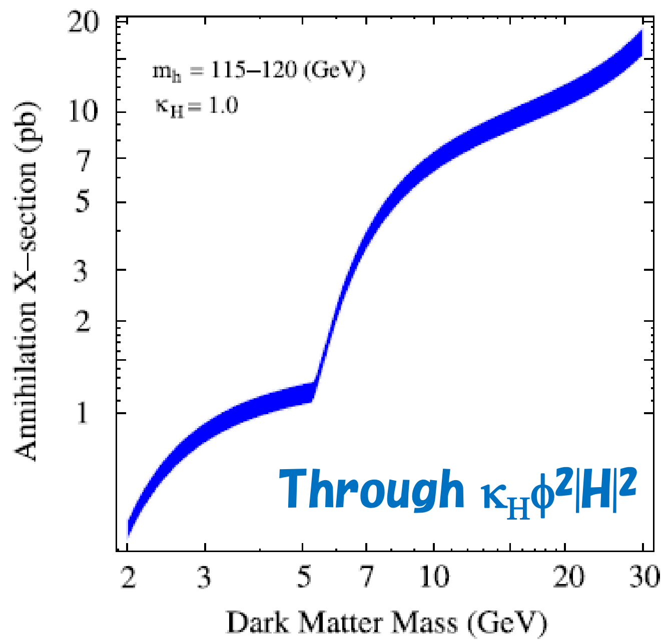
$$m_{\rm DM} = \frac{15}{97}\frac{66+13n_H}{10+n_H}\frac{\Omega_{\rm DM}}{\Omega_b}\frac{m_N}{Q_{\rm DM}} \longrightarrow m_{\rm DM} = (5.0\text{–}5.4)/Q_{\rm DM}\ {\rm GeV}$$

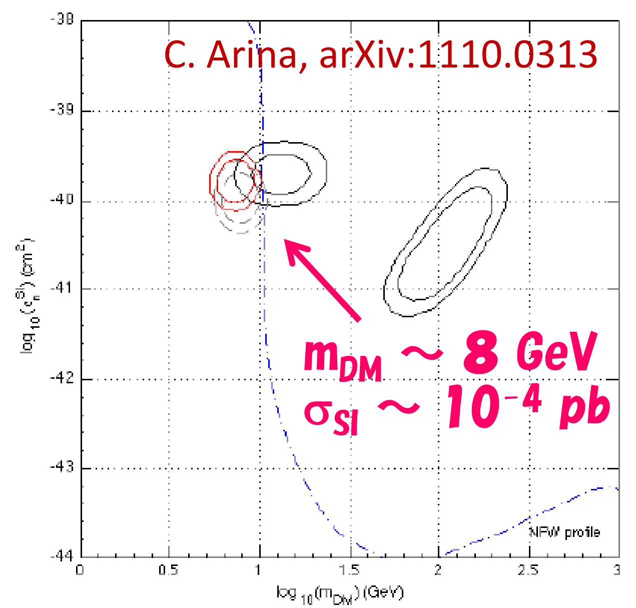
M. Ibe, S. M., T. T. Yanagida, PLB (2012)

The GeV-scale dark matter

~ Example 1: Scalar ADM with $L_{int} = \phi\phi\phi LHLH$ ~

DM mass: $Q_{DM} = 2/3 \rightarrow m_{DM} = 5/Q_{DM} = 7.5$ GeV





$$\sigma_{SI} \simeq \frac{\kappa_S^2}{4\pi m_h^4} \frac{m_n^2}{(m_{DM}+m_n)^2} f_n^2 \simeq 1.03 \times 10^{-4}\ \mathrm{pb} \times \kappa_S^2 \left(\frac{124\mathrm{GeV}}{m_h}\right)^4$$

But, higgs decays invisibly, mainly into DM pair …

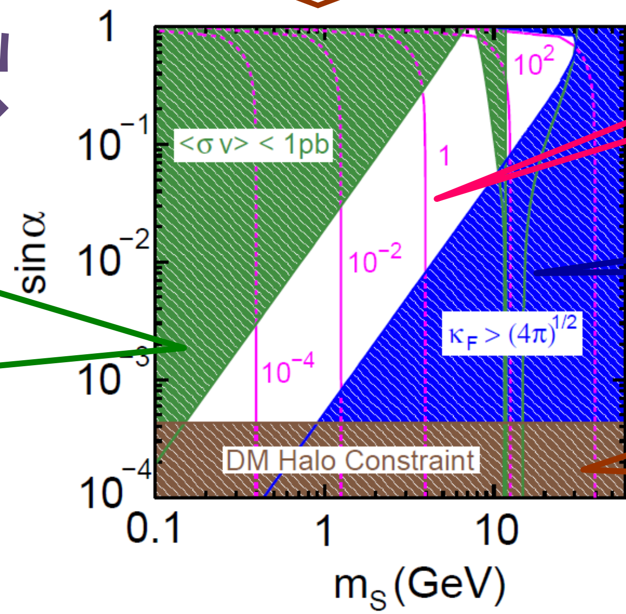
The GeV-scale dark matter

~ Example 2: Fermionic ADM with $L_{int} = \chi\chi\chi\chi\chi LHLHLH$ ~

DM mass: $Q_{DM} = 3/5 \rightarrow m_{DM} = 5/Q_{DM} = 8$ GeV

No renormalizable interaction between the ADM and SM particles.
(Introduction of a scalar light mediator into SM. → $\kappa\chi\chi S$)

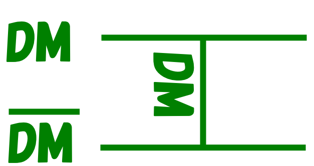
m_{DM} & κ are set so that CoGeNT signal can be explained →



Ratio: $\Gamma_{inv}/\Gamma_{vis}$

Unitarity cond.

DM & anti-DM annihilation



Self-scattering between ADMs.

Higgs decays invisibly or visibly (SM-like)

Summary

- Dark matter (DM) experiments are developed very well and new results **are frequently updated**. Interactions of DM (scatterings & annihilations) are especially well studied when its mass is within 1GeV–1TeV.
- Many dark matter candidates have been proposed so far in various mass ranges. From the viewpoint of DM stability using $U(1)_{B-L}$, **a neutral (Majorana) fermion under $U(1)_{B-L}$** seems to be a good candidate for DM.
- Another interesting candidate is the DM charged under $U(1)_{B-L}$. This DM is nothing but the Asymmetric DM (ADM), and it is possible to definitely predict its mass to be m_{DM} = 5 GeV/Q_{DM}, which is very consistent with that required to explain **CoGeNT anomaly**.