A dark matter candidate as a neutrino model

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- Dark Matter (SM does not include it!)

There are many experimental evidences for dark matter (DM).

Rotation curve of the spiral galaxy

CMB observation by Planck and WMAP

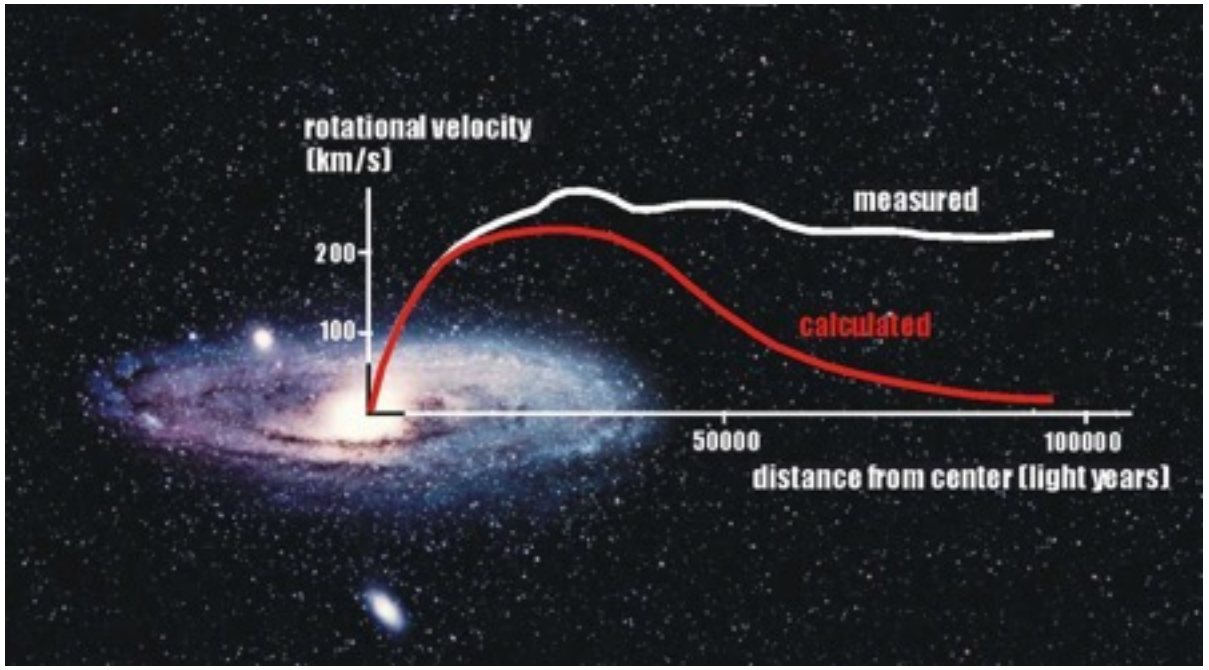
Gravitational lensing

Large scale structure of the universe etc...

- Several models, including DM.

- Summary

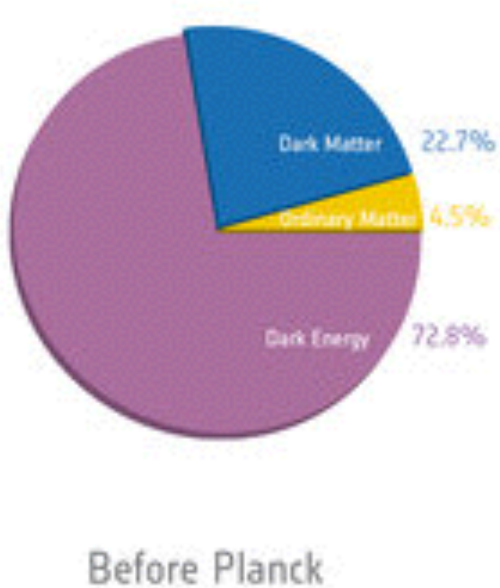
Rotation curve of the spiral galaxy

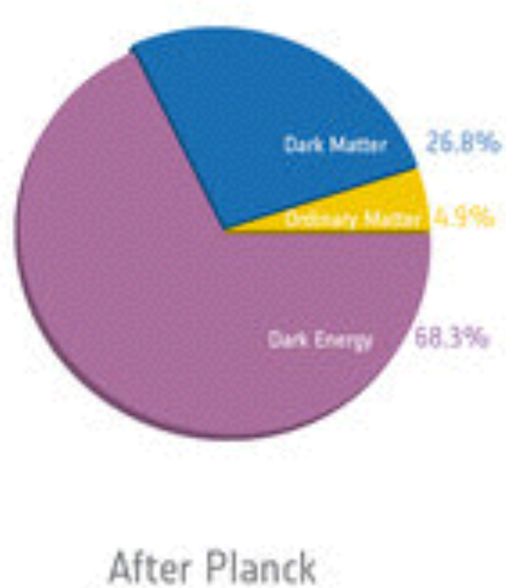


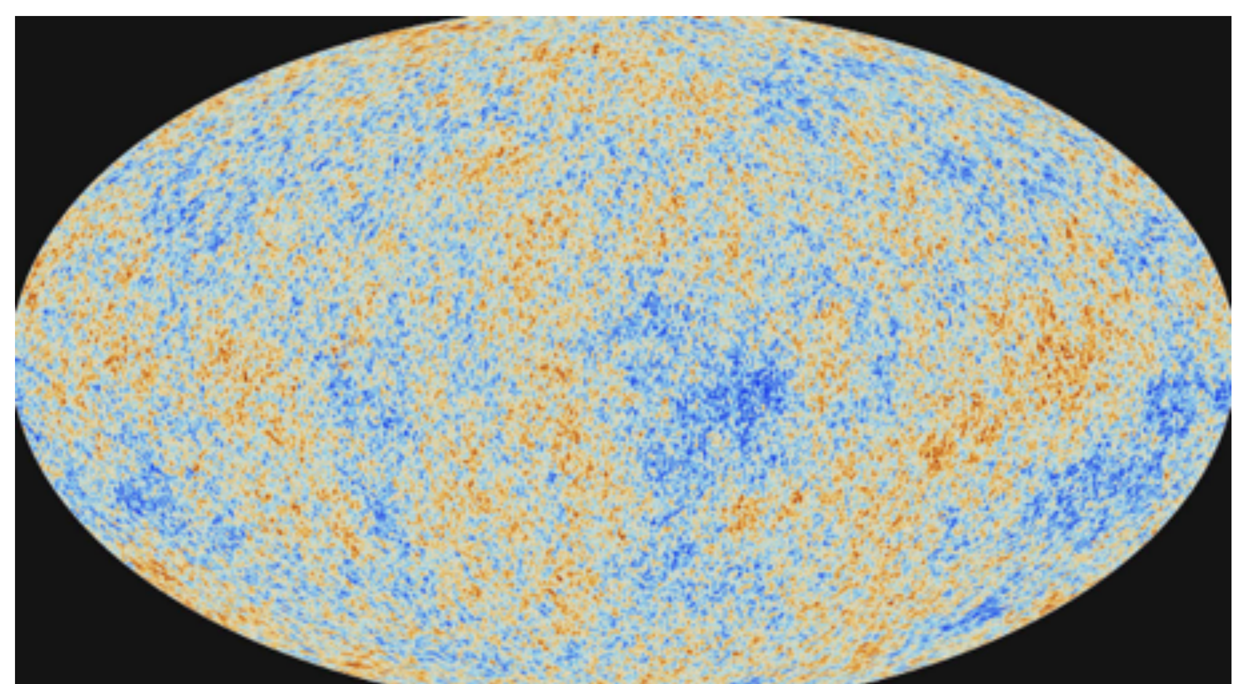
This is the first indirect evidence

$$\frac{1}{2}mv^2 - Gm\frac{M}{r} = E \quad \rightarrow \quad v = \sqrt{\frac{2GM}{r}}, \qquad \therefore \quad v = const. \rightarrow M \propto r$$

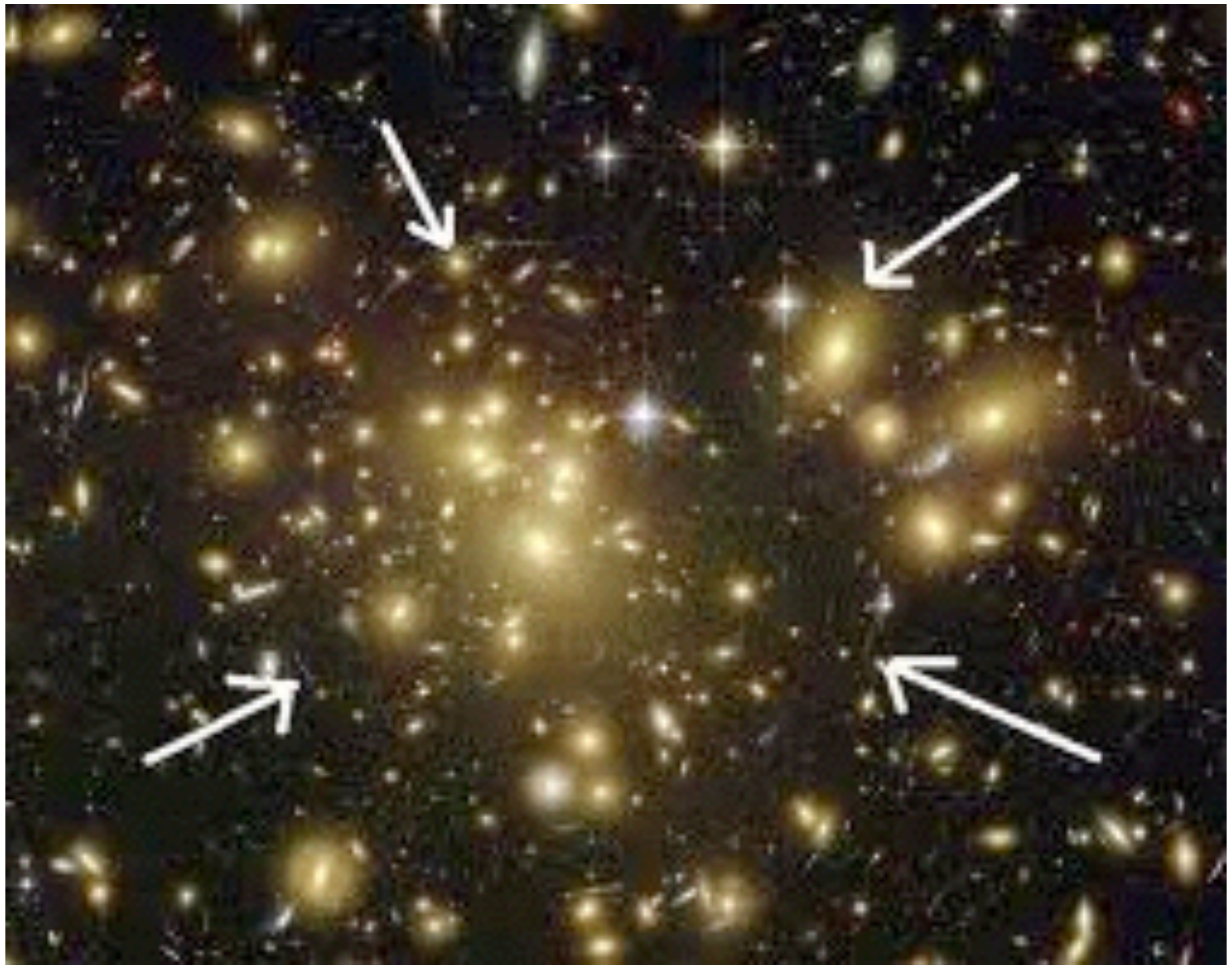
- CMB observation by Planck and WMAP

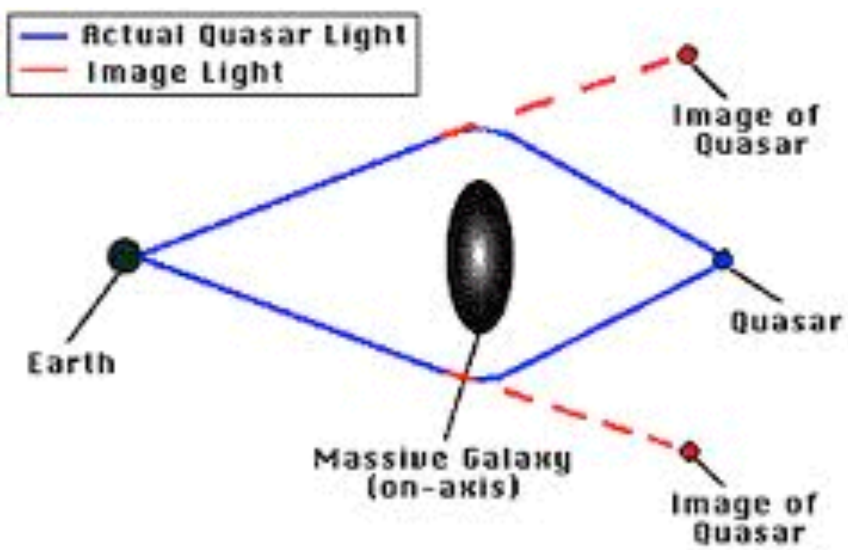




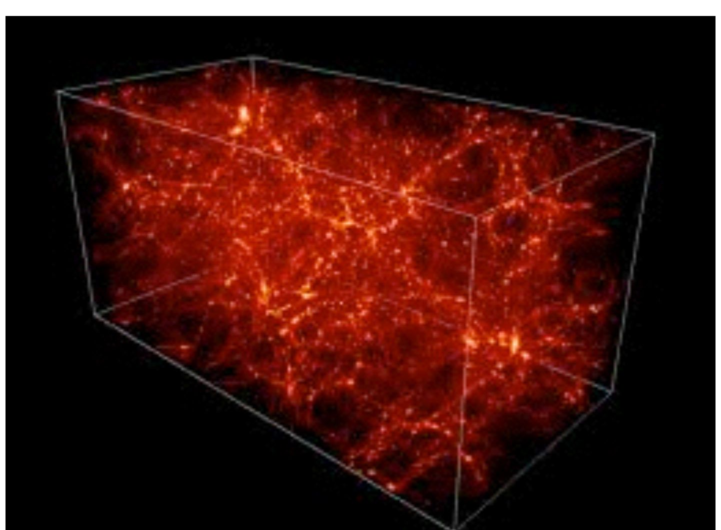


- Gravitational lensing





- Large scale structure of the universe



This large simulation supports the result of Planck!

Nature of dark matter

i)...Zero electric charge,
ii)...Non-relativistic,
iii)...Stable or very long lifetime,
iv)...26.8 % is occupied in the universe,
v)...No color,
vi)...Weak interacting,
vii)...non-baryonic particles (by the observation of MACHO (MAssive Compact Halo Objects))

Question!...How about neutrino???

If 20 eV<m_ν, it would be supported by the simulation of large scale structure of the universe.

viii)...Neutrino cannot be a main component of the dark matter!

Way to detect:

Direct detection(CoGeNT, DAMA, CDMS, KIMS, XENON, CRESST,),

Indirect detection(AMS-02, PAMELA, Fermi-LAT, DAMPE etc.),

Accelerator detections (LHC)…

↓

No significant signals yet!

↓

What we can do is to consider the DM model that can be tested by current experiments!

Models

How to realize a DM model?

↓

How to assure the stability of DM?

↓

Is DM related to the other phenomenologies?

neutrinos, B-physics, etc,⋯

(although not needed⋯)

Representative symmetries to stabilize DM

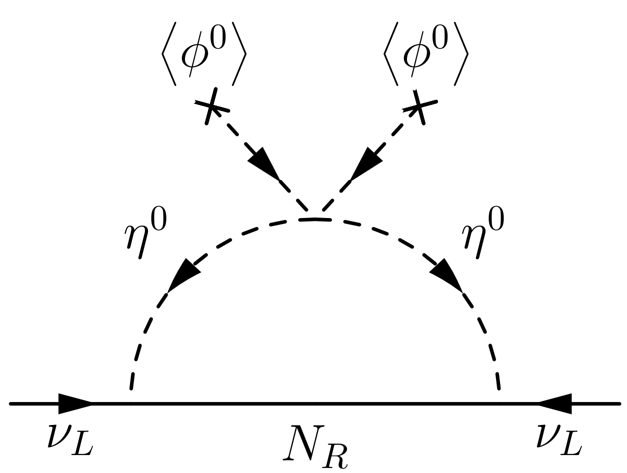
Abelian symmetries… Z_n, U(1),…

Ex.

<u>Verifiable radiative seesaw mechanism of neutrino mass and dark matter</u>
Ernest Ma (UC, Riverside). Jan 2006. 8 pp.
Published in **Phys.Rev. D73 (2006) 077301**

Neutrino masses, dark matter and leptogenesis with B-L gauge symmetry
Chao-Qiang Geng (Shanxi Normal U. & Taiwan, Natl. Tsing Hua U. & NCTS, Hsinchu), Hiroshi Okada (NCTS, Hsinchu). Oct 26, 2017. 7 pp.
Published in **Phys.Dark Univ. 20 (2018) 13-19**

Z_2



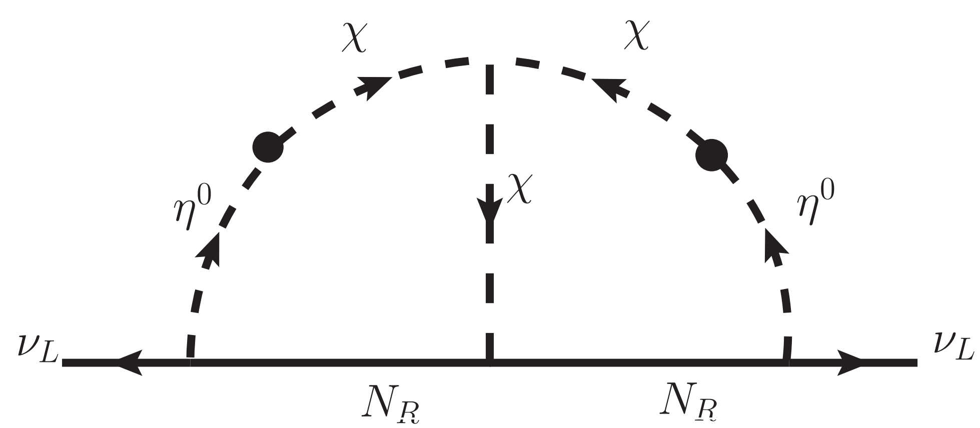
U(1)_(B-L)…(-4,-4,5) for N_R

=>Z_2

Frequently, we can connect neutrino models!

Z_3

Impact of semi-annihilation of Z3 symmetric dark matter with radiative neutrino masses
Mayumi Aoki (Kanazawa U., Inst. Theor. Phys.), Takashi Toma (Durham U., IPPP).
May 22, 2014. 22 pp. Published in **JCAP 1409 (2014) 016**



Flavor dependent U(1)symmetries

$$\prod_{i=1} U(1)_{B_i - L_i}$$

Resoving B-meson anomalies by flavor-dependent gauged symmetries
Chao-Qiang Geng, Hiroshi Okada. Dec 19, 2018. 11 pp.

A model with flavor-dependent gauged
Linping Mu (Shanxi Normal U.), Hiroshi Okada (NCTS, Hsinchu), Chao-Qiang Geng (Shanxi Normal U. & NCTS, Hsinchu & Taiwan, Natl. Tsing Hua U.). Mar 15, 2018. 9 pp.
Published in **Chin.Phys. C42 (2018) no.12, 123106**

=>Neutrino texture prediction and B-anomaly

$U(1)_{\mu-\tau}$

Explaining B->K*ll anomaly by radiatively induced U(1) gauge symmetry
P. Ko (Korea Inst. Advanced Study, Seoul & CQUeST, Seoul), Takaaki Nomura (Korea Inst. Advanced Study, Seoul), Hiroshi Okada (NCTS, Hsinchu). Feb 8, 2017. 6 pp.
Published in **Phys.Rev. D95 (2017) no.11, 111701**

=> B-anomaly

via s-channel diagram via Z’ at one-loop level

U(1)_(yB-xL_x), ($3y=x=x_e+x_\mu+x_\tau$), U(1)_H, etc,

are also applied to the stability of DM,

and these flavor dependent symmetries could

explain indirect detections;

Fermi-LAT, AMS-02, IceCube, DAMPE,…

Non-Abelian symmetries…S_3, D_4, A_4, T_13, …

S_3

Scalar dark matter candidates in a two inert Higgs doublet model
E.C.F.S. Fortes, A.C.B. Machado, J. Montaño, V. Pleitez (Sao Paulo, IFT). Jul 17, 2014. 11 pp.
Published in **J.Phys. G42 (2015) no.10, 105003**

No discussion of neutrinos

D_4

Stability of dark matter from the D4xZ2 flavor group
D. Meloni (Rome III U.), S. Morisi, E. Peinado (Valencia U., IFIC). Apr 2011. 7 pp.
Published in **Phys.Lett. B703 (2011) 281-287**

=> Z_2

A_4

Phenomenology of Dark Matter from A_4 Flavor Symmetry
M.S. Boucenna, M. Hirsch, S. Morisi, E. Peinado, M. Taoso, J.W.F. Valle (Valencia U. & Valencia U., IFIC). Jan 2011. 15 pp.
Published in **JHEP 1105 (2011) 037**

Discrete dark matter
M. Hirsch, S. Morisi, E. Peinado, J.W.F. Valle (Valencia U., IFIC). Jul 2010. 4 pp.
Published in **Phys.Rev. D82 (2010) 116003**

Universally Leptophilic Dark Matter From Non-Abelian Discrete Symmetry
Naoyuki Haba (Osaka U.), Yuji Kajiyama (NICPB, Tallinn), Shigeki Matsumoto (Toyama U.), Hiroshi Okada (British U. in Egypt), Koichi Yoshioka (Kyoto U.). Aug 2010. 14 pp.
Published in **Phys.Lett. B695 (2011) 476-481**

=> Decaying DM

T_13

T(13) Flavor Symmetry and Decaying Dark Matter
Yuji Kajiyama (NICPB, Tallinn & Niigata U.), Hiroshi Okada (British U. in Egypt). Nov 2010. 14 pp.
Published in **Nucl.Phys. B848 (2011) 303-313**

SU(2)_L

Minimal dark matter
Marco Cirelli (Yale U.), Nicolao Fornengo (Turin U. & INFN, Turin), Alessandro Strumia (Pisa U. & INFN, Pisa). Dec 2005. 16 pp.
Published in **Nucl.Phys. B753 (2006) 178-194**
DFTT40-2005, IFUP-TH-2005-34

Quantum numbers $SU(2)_L$	$U(1)_Y$	Spin	DM can decay into	DM mass in TeV	$m_{DM^\pm} - m_{DM}$ in MeV	Events at LHC $\int \mathcal{L}\, dt$ =100/fb	σ_{SI} in 10^{-45} cm^2
2	1/2	0	EL	0.54 ± 0.01	350	$320 \div 510$	0.2
2	1/2	1/2	EH	1.1 ± 0.03	341	$160 \div 330$	0.2
3	0	0	HH^*	2.0 ± 0.05	166	$0.2 \div 1.0$	1.3
3	0	1/2	LH	2.4 ± 0.06	166	$0.8 \div 4.0$	1.3
3	1	0	HH, LL	1.6 ± 0.04	540	$3.0 \div 10$	1.7
3	1	1/2	LH	1.8 ± 0.05	525	$27 \div 90$	1.7
4	1/2	0	HHH^*	2.4 ± 0.06	353	$0.10 \div 0.6$	1.6
4	1/2	1/2	(LHH^*)	2.4 ± 0.06	347	$5.3 \div 25$	1.6
4	3/2	0	HHH	2.9 ± 0.07	729	$0.01 \div 0.10$	7.5
4	3/2	1/2	(LHH)	2.6 ± 0.07	712	$1.7 \div 9.5$	7.5
5	0	0	(HHH^*H^*)	5.0 ± 0.1	166	$\ll 1$	12
5	0	1/2	–	4.4 ± 0.1	166	$\ll 1$	12
7	0	0	–	8.5 ± 0.2	166	$\ll 1$	46

=>5 dim.

Decay can be evaded at renormalizable theory, if fundamental rep. is larger than 3!

Concrete DM models applying SU(2)_L multiplets

One-loop neutrino mass model with SU(2)L multiplet fields
Takaaki Nomura, Hiroshi Okada. Dec 18, 2018. 14 pp.

Quartet fermionic DM with -1/2 hypercharge and neutrino mass is induced at one-loop level

One-loop neutrino mass model without any additional symmetries
Takaaki Nomura (Korea Inst. Advanced Study, Seoul), Hiroshi Okada (APCTP, Pohang). Aug 15, 2018. 12 pp.
KIAS-P18084, APCTP-Pre2018-012
e-Print: **arXiv:1808.05476** **[hep-ph]** | **PDF**

Quintet fermionic DM with 0 hypercharge and neutrino mass is induced at one-loop level

Summary

We discuss how to stabilize the DM candidate, and review several models.

Additional symmetries ((Non-)Abelian continuous(discrete) groups) contribute not only to assure the stability of DM but also to construct/predict the other phenomenologies such as neutrinos, B-physics, etc..

An SU(2)_L multiplet field is also interesting to assure the stability of DM, since no additional symmetries are needed, and several applications are possible.