WIMP DM & γ-ray observations

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From recent various experimental & theoretical observations, the WIMP dark matter seems to be a fermionic particle which carries the weak isospin. This fact indicates that DM search using γ-ray observations will be the most important one!!!

WIMP DM & direct detections

~ WIMP (Weakly interacting massive particle) hypothesis ~

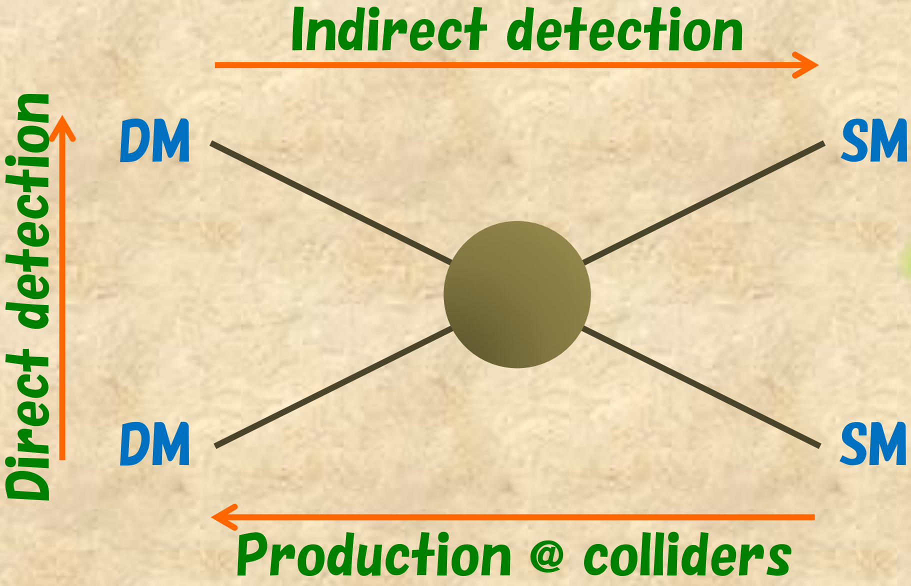
DM is a neutral and stable particle whose mass is O(0.1 - 1)TeV!

It is consistent with DM cosmology.

- Why is DM weakly interacting?
- Why is DM cold in present Univ.?
- Why is abundance $\Omega_{DM}h^2 \sim 0.1$?

It is consistent with Particle Phys.

BSM for EWSB often predicts WIMP candidate. Its mass and the scale of the EWSB can have the same origin!



Indirect detections put a limit as $\sigma v < 1 - 10$ pb·c.

Collider experiments (LHC) put a limit as $\sigma < 1 - 10$ fb.

Direct detections put a limit stringently as s < 1 - 10 zb!

WIMP DM & direct detections

Direct detection experiments put stringent limits on the WIMP scattering off a nuclei, so that those already give an important implication to its property.

When WIMP has DM-DM-h coupling of O(1), current limits already ruled out it.

Scalar and Vector WIMP have a dimension 4 interaction inducing the O(1) coupling.

Fermionic WIMP has the O(1) coupling when its state is given by the mixing of different weak-isospin states.

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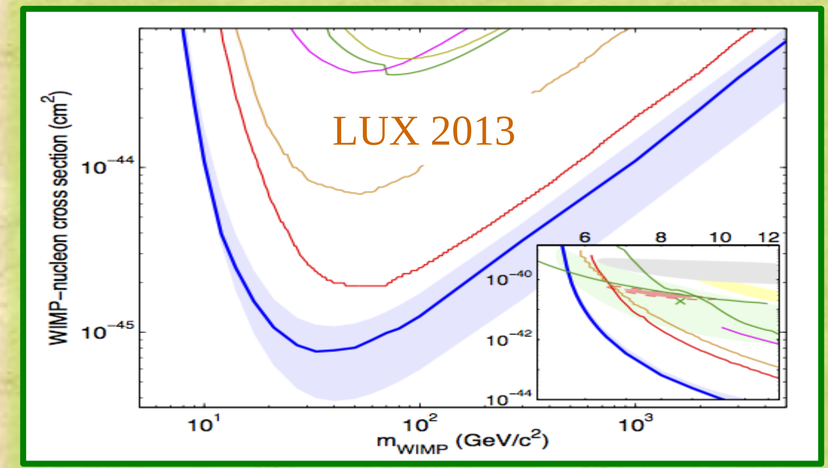
The coupling is suppressed for Fermionic WIMP close to a weak-isospin eigenstate.



Fermionic WIMPs

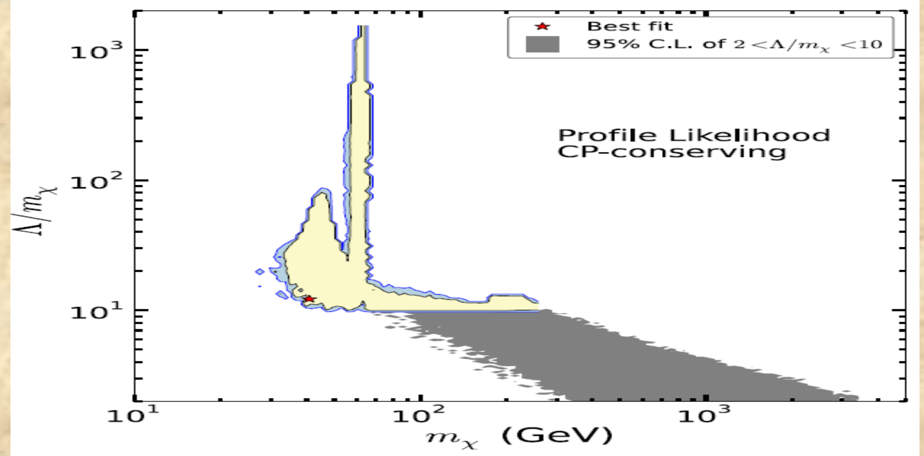
Scientific name	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	Examples
Singlet fermion	1	1	0	Bino
Doublet fermion	1	2	½	Higgsino
Triplet fermion 1	1	3	0	Wino
Triplet fermion 2	1	3	1	
…	…	…	…	…

Fermionic WIMP (weak-isospin singlet)

The singlet WIMIP does not have any renormalizable interactions coupling to SM particles directly.

Additional new particles with their masses of $O(m_{WIMP})$ must exist. →

Or m_{WIMP} must be tuned enough. →



[S. M., S. Mukhopadhyay, Y-L. Tsai, 1405.1859]

Fermionic WIMPs

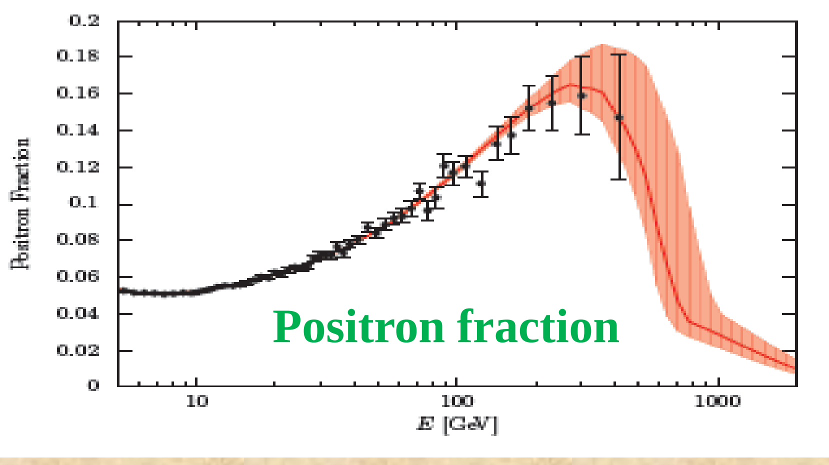
Fermionic WIMP (weak-isospin non-singlet)

The non-singlet WIMIP always has renormalizable interactions coupling to SM particles directly, the $SU(2)_L$ gauge interactions. Thermal relics are consistent with the PLANCK result when its mass is 1-3TeV. [Hisano, S.M., et.al., PLB, 2007]

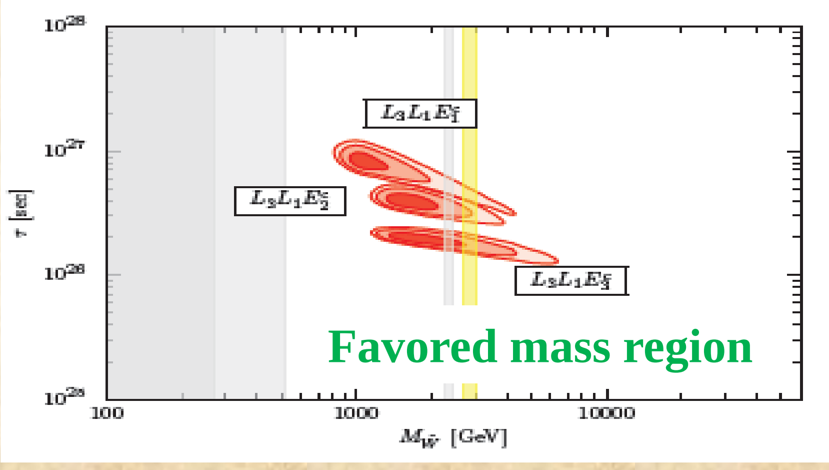
Is the WIMP relevant to AMS-02 anomaly?

The WIMIP is not necessarily to be absolute stable and it may decay into SM particles via e.g. GUT suppressed interactions. [Ibe, S.M., Shirai, Yanagida, 2014]

$$L_{int} = (1/\Lambda_{GUT})^2\, \chi LLE^c \rightarrow \tau \sim 10^{-27}\, (1\mathrm{TeV}/m)^5\, (\Lambda_{GUT}/10^{16}\,\mathrm{GeV})^4\ [s]$$



Positron fraction



Favored mass region

Fermionic WIMPs

The non-singlet WIMP is theoretically favored

The minimal SUSY breaking model

MSSM SUGRA interaction / No-singlets → **~~SUSY~~**

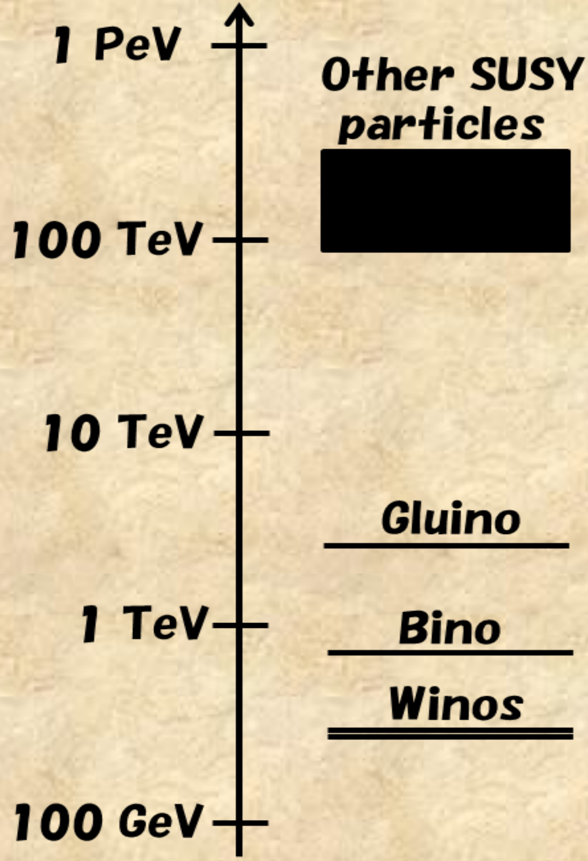
Pure Gravity Mediation Model

[Ibe, Yanagida, Moroi, PLB, 2007]

Merits obtained from the model

- Higgs mass of 125 GeV
- DM candidate exist
- GUT unification works
- Leptogenesis works
- No Flavor/CP problems
- No gravitino problem
- No Plonyi problem

Split-type SUSY Spectrum



The LSP is the neutral wino, namely $SU(2)_L$-triplet Majorana fermion!

$SU(2)_L$ non-singlet fermionic WIMPs

DM mass: m_χ ~ 1-3TeV & Scattering cross section $\sigma_{SI}(\chi N)$ ~ 10^{-11}pb.

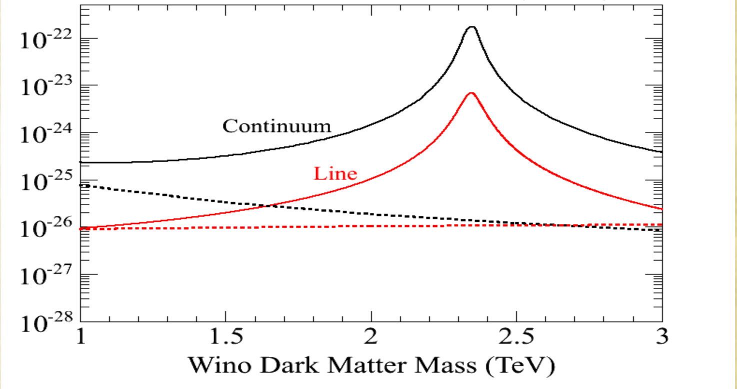
Continuum & line γ-rays from the WIMP

- Wino annihilates mainly into W bosons, and W-decay produces continuum γ.
- Thanks to the existence of charged wino, wino annihilates also into line γ.

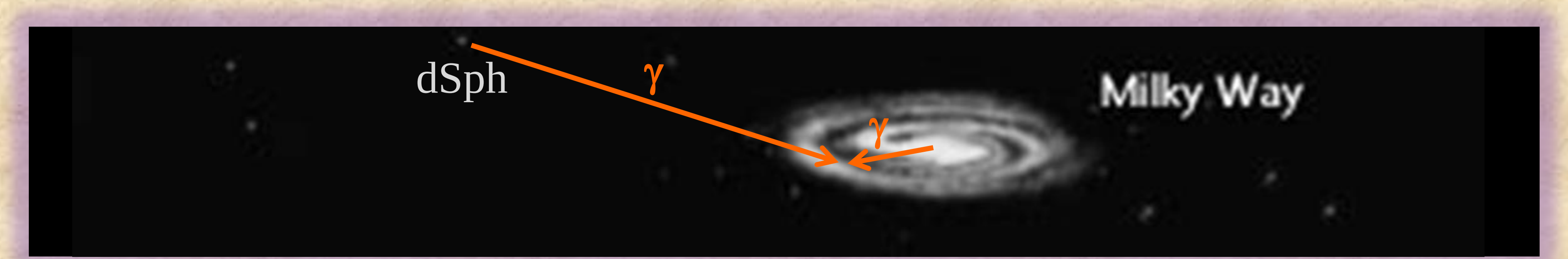
Sommerfeld effect of Wino annihilation

When the wino mass is heavier than O(1)TeV, annihilation cross sections of all channels are significantly boosted by the Sommerfeld enhancement. [Hisano, S.M. Nojiri, PRL, 2004]

The effect can be understood by the effect of long range forces (exchanging W, Z, γ) which modify the initial wino wave functions.



γ-ray observations of the WIMP



dSph: Continuum γ-ray obs. at satellite born experiments (Fermi-LAT, etc.)

G.C. : Line γ-ray obs. at air Cherenkov type experiments (H.E.S.S., CTA, etc.)

	Time	dSph data
Present	4yrs	Only CL. dSphs
Near future	10yrs	CL. & UF. dSphs
Future	25yrs	Updated data

In addition to continuing dSph obs., it is important to upgrade stellar kinematical data of dSphs!

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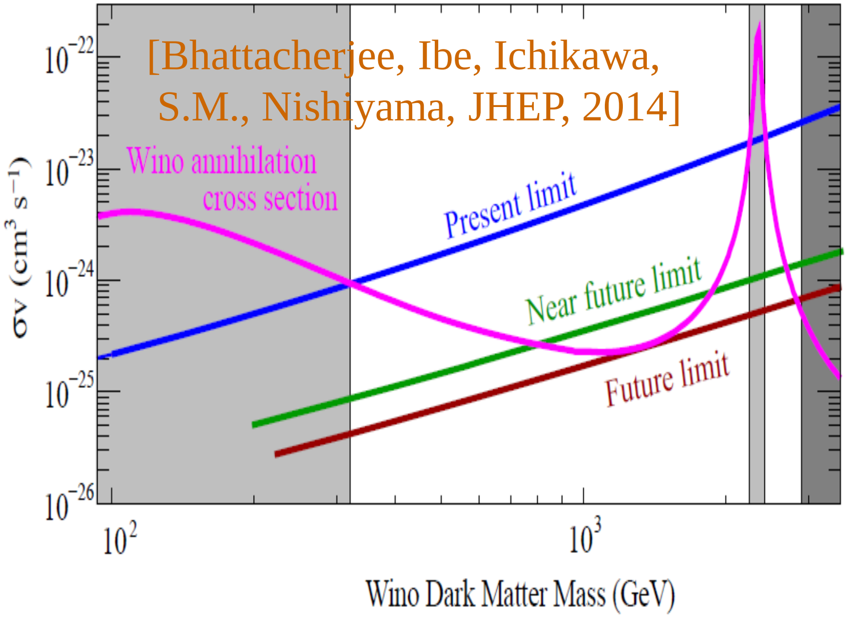
PFS of the SuMIRe project!

[Ibe, Ichikawa, Ishigaki, S.M., Sugai]



[Bhattacherjee, Ibe, Ichikawa, S.M., Nishiyama, JHEP, 2014]

Summary

- 様々なスピン及び量子数を持つWIMP暗黒物質候補の中で、弱アイソスピンを持つフェルミオン暗黒物質が現在とても注目されている。
- このWIMP暗黒物質は、その質量が1－3TeV当たりと予言され。また対消滅過程がSommerfeld効果により増大し、ガンマ線の連続スペクトル及び線スペクトルを強い強度で放出する。
- そのため衛星実験(Fermi-LAT)や空気チェレンコフ実験(H.E.S.S.やCTA等)を用いた矮小楕円体銀河(dSphs)や銀河中心(G.C.)の観測は、最も有効な暗黒物質の検出方法である。

EFT for the singlet WIMP

$$\mathcal{L}_{\mathrm{F}_0} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{2}\bar{\chi}\left(i\not{\partial} - M_\chi\right)\chi + \sum_{n,i}\frac{c_i^{(n)}}{\Lambda^{n-4}}\mathcal{O}_i^{(n)}$$

$$\mathcal{O}_S^{(5)} = (\bar{\chi}\chi)|H|^2,$$

~~$\mathcal{O}_{PS}^{(5)} = i(\bar{\chi}\gamma_5\chi)|H|^2$~~, **CPV**

$$\mathcal{O}_H^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(H^\dagger i\overleftrightarrow{D_\mu}H),$$

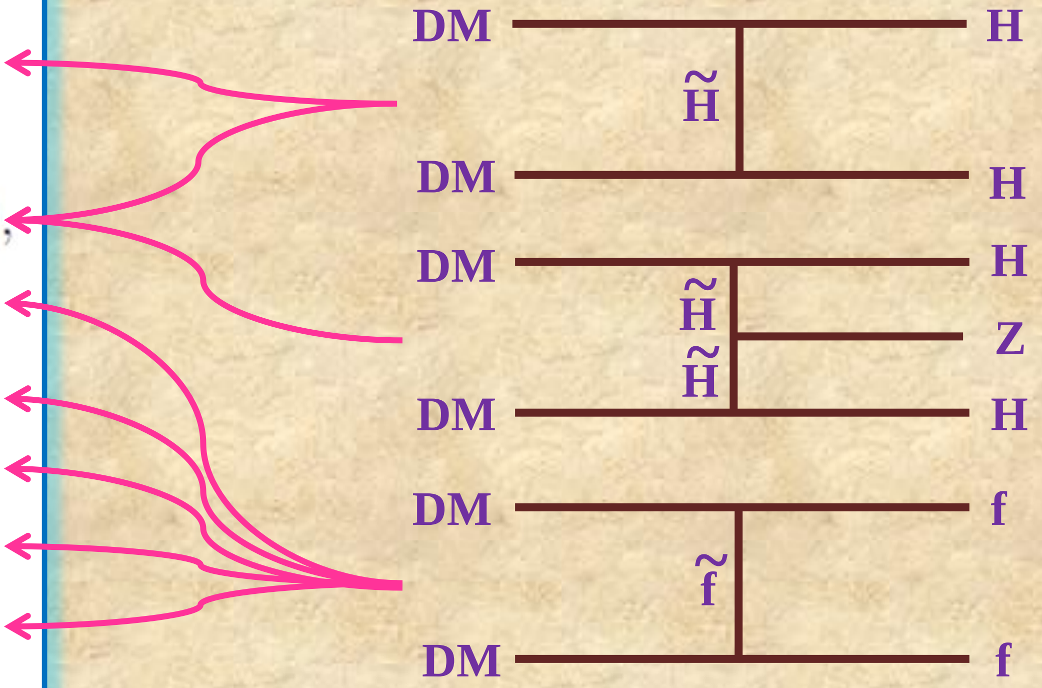
$$\mathcal{O}_Q^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{Q}\gamma_\mu Q),$$

$$\mathcal{O}_U^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{U}\gamma_\mu U)$$

$$\mathcal{O}_D^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{D}\gamma_\mu D)$$

$$\mathcal{O}_L^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{L}\gamma_\mu L)$$

$$\mathcal{O}_E^{(6)} = (\bar{\chi}\gamma^\mu\gamma_5\chi)(\bar{E}\gamma_\mu E)$$



- Only the mass dimension 5 operator $\mathcal{O}_{PS}$ breaks the CP-symmetry.
- Flavor blindness is assumed for each 4-Fermi (mass dimension 6) operators.
- The regions of the cutoff $\Lambda > 10m_{DM}$ and $10m_{DM} > \Lambda > 2m_{DM}$ are considered.