The weak-charged WIMP

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The weak-charged WIMP, Majorana fermion with a weak charge one, is a very attractive dark matter candidate.

1. Motivation for the weak-charged WIMP
2. Future prospect to search for the WIMP

Dark matter ansatzes

Particle dark matter

Mass

10^{-22} eV

10^{19} GeV

10^{40} g

$\lambda = 2\pi/mv <$ Gal. size

$\lambda = 2\pi/m \sim 2m/M_{pl}^2$

$m <$ Gal. mass

Experimental/Observational anomalies

Dark matter ansatzes:

Sterile ν
ADM
Axion
WIMP
SIMP
FIMP
Fuzzy DM
pBH

Motivations from new physics models

Phenomenological test of each ansatz. (Present S. & Future P)

WIMP ansatz

"Dark matter is a massive, stable and electrically neutral particle, and was in a thermal equilibrium with SM particles in the early universe."

There are many types of WIMP, depending on those quantum numbers.

→ Classification of WIMP in terms of its spin and isospin!

After its spin fixed,

WIMP

Singlet-like	Weak-charged	Mixed
Unexplored well. Good motivation?	Vert attractive!!! (The triplet WIMP)	being excluded by direct detections.

Weak-charged WIMP (Triplet WIMP)

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{T}\left(\not{D} - M_T\right)T$$

[Z_2 symmetry imposed]

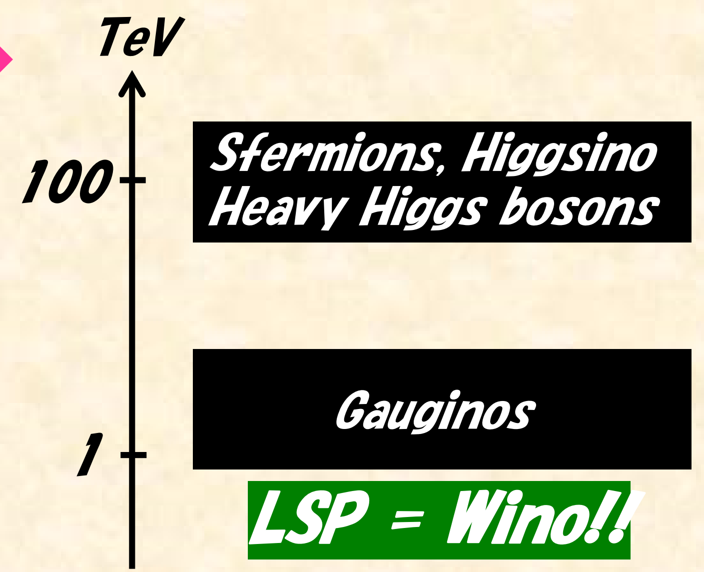
Physics is governed by $SU(2)_L$
One new physics parameter M_T

Theoretical ··· *AMSB* [L. Randall, R. Sundrum & G. Giudice, M. Luty, H. Murayama, R. Rattazzi, 1998]

It is know to be the simplest SUSY breaking model consistent with cosmology!

MSSM --- *Simplest mediation* / *w/o singlet →* --- ~~SUSY~~

- ✓ *Wino (the triplet WIMP) is the LSP.*
- ✓ *Its mass is predicted to be 3TeV!*
  [Hisano, S. M., Nagai, Saito, Senami, 2006]
- ✓ *m_{LSP} is O(1)TeV → M_{SUSY} is O(100)TeV.*
- ✓ *Hiss mass is predicted to be 125GeV.*
- ✓ *Avoid serious SUSY flavor problems.*
- ✓ *Free from any cosmological problems.*



[N. Arkani-Hamed, S. Dimopoulos, 2004]
[M. Ibe, T. Moroi, T. T. Yanagida, 2006]

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Physics is governed by $SU(2)_L$
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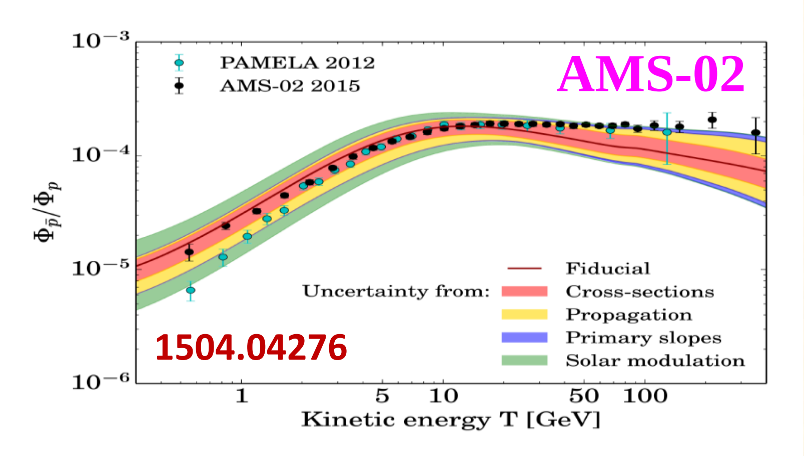
Phenomenological … (Anti-proton flux)/(proton flux) observed at AMS-02.

It is consistent with BG, but there is a trend of the deviation at E > 100GeV.



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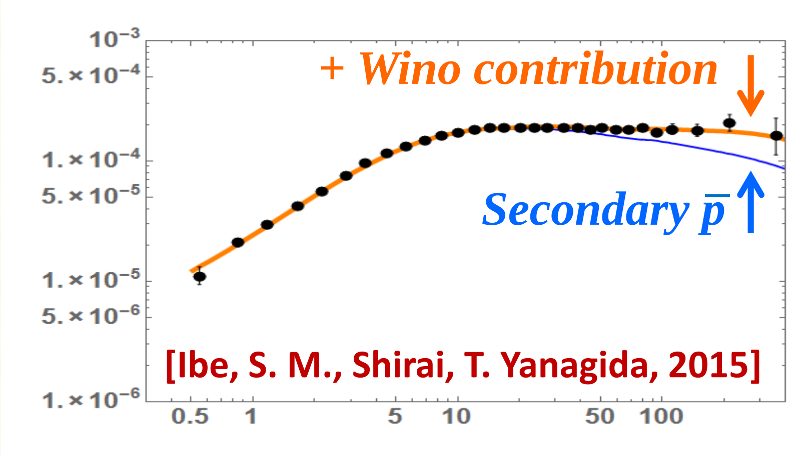
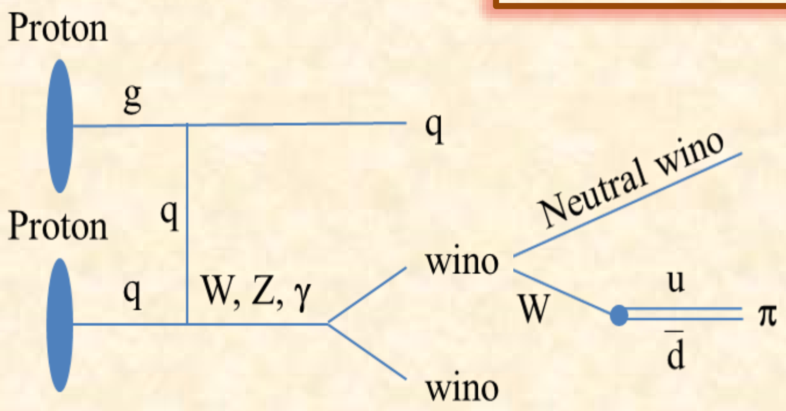


If we include the Triplet WIMP contribution, the fitting becomes better.
(There is no new physics parameters we can vary, for m_T = 3TeV.)

How we can test the triplet WIMP?

Search @ Collider experiments



Disappearing charged track search

Current limit (13TeV LHC)

→ m_T < 460GeV

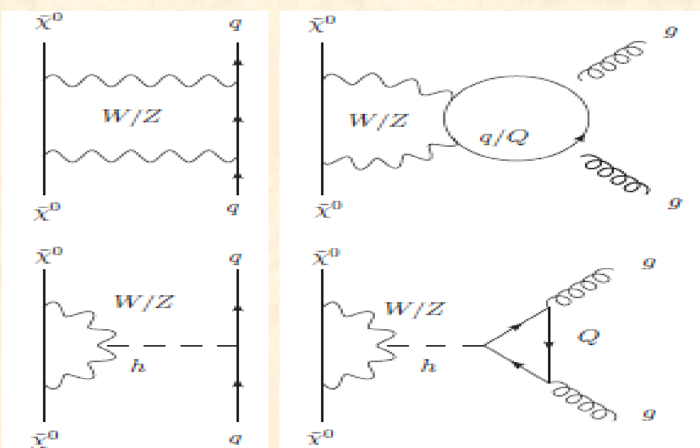
Future-expected limit (HL-LHC)

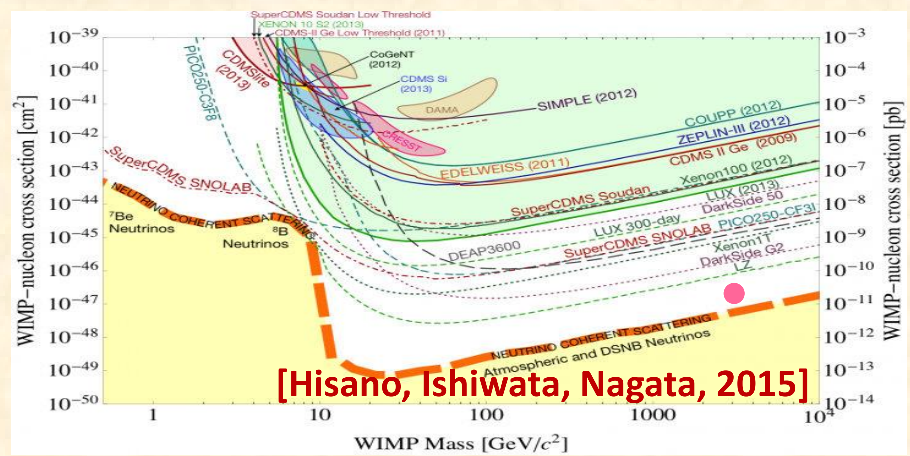
→ m_T < 800GeV

Future-expected limit (100TeV pp)

→ m_T < 3TeV

Search @ Direct detections





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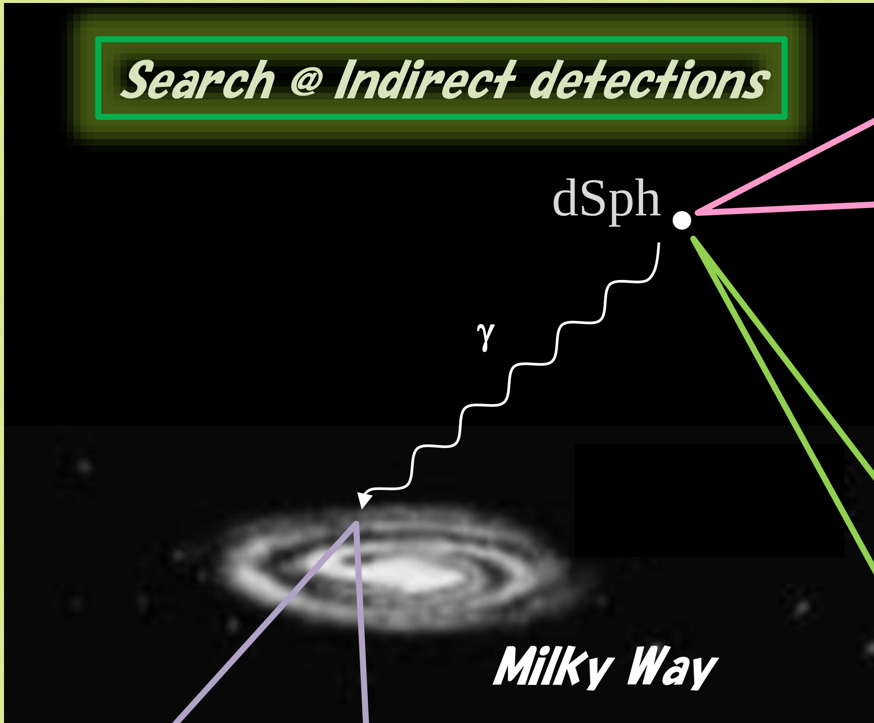

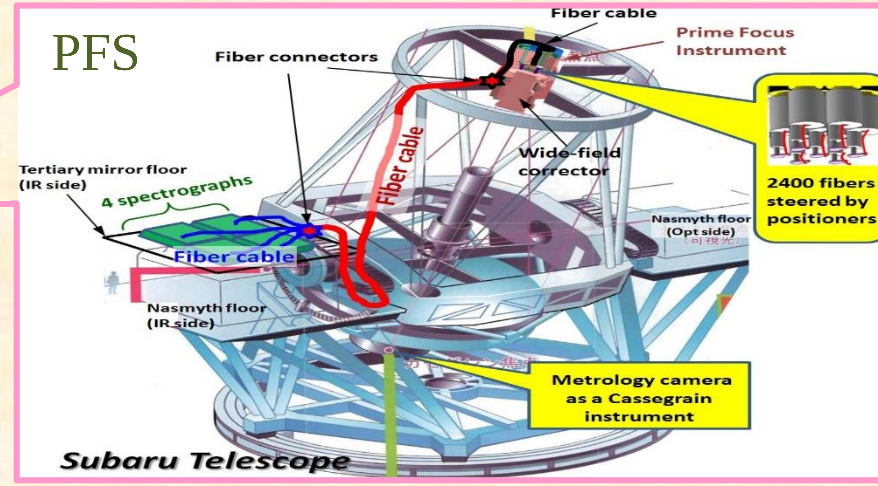

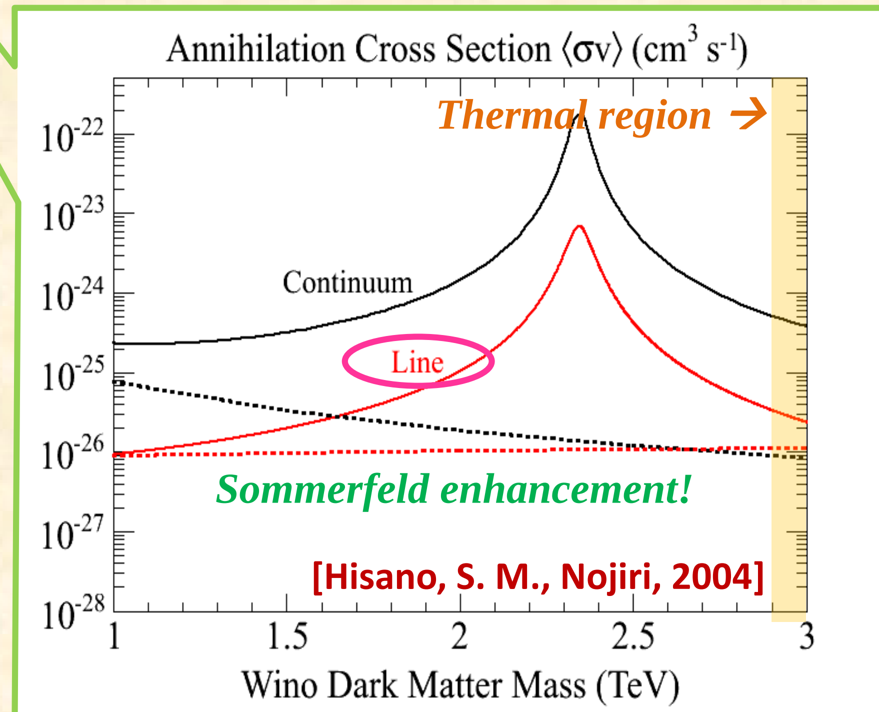

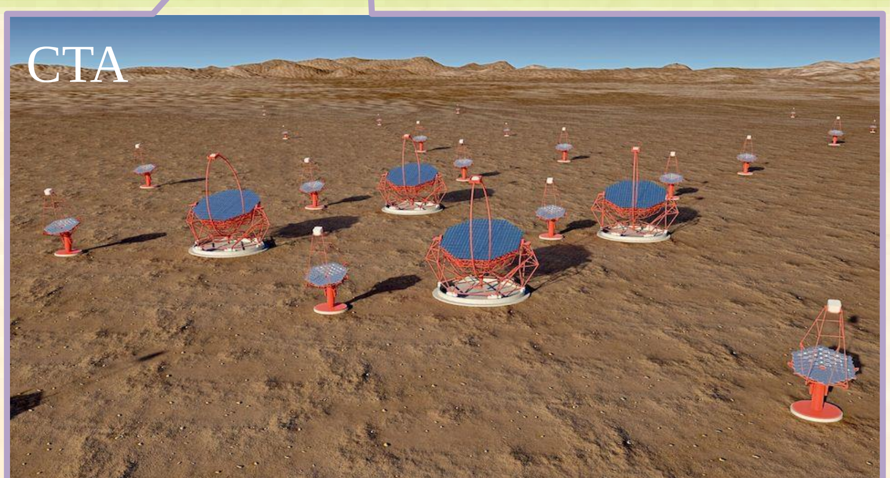

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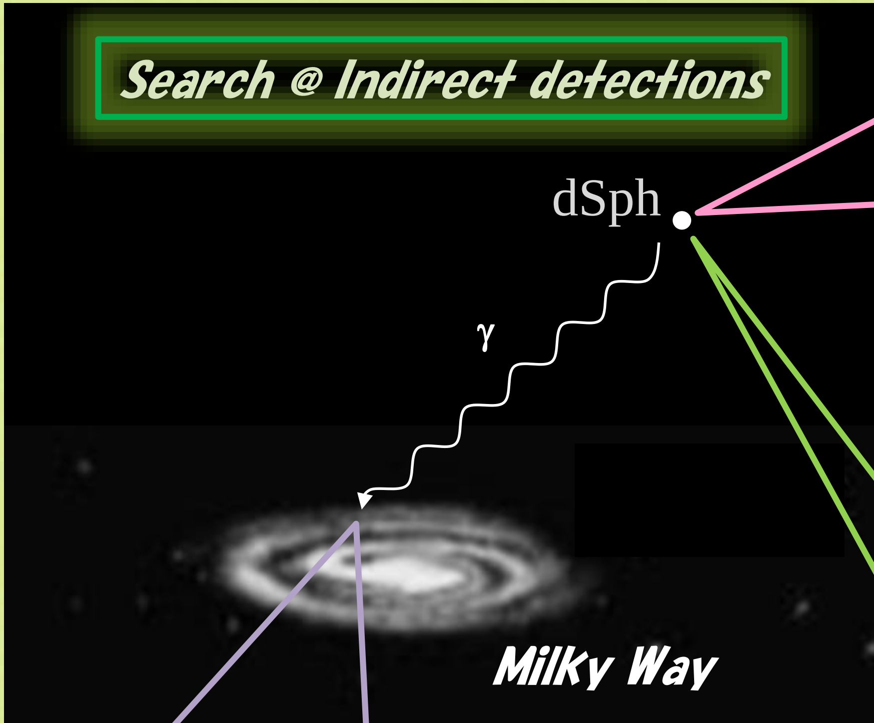

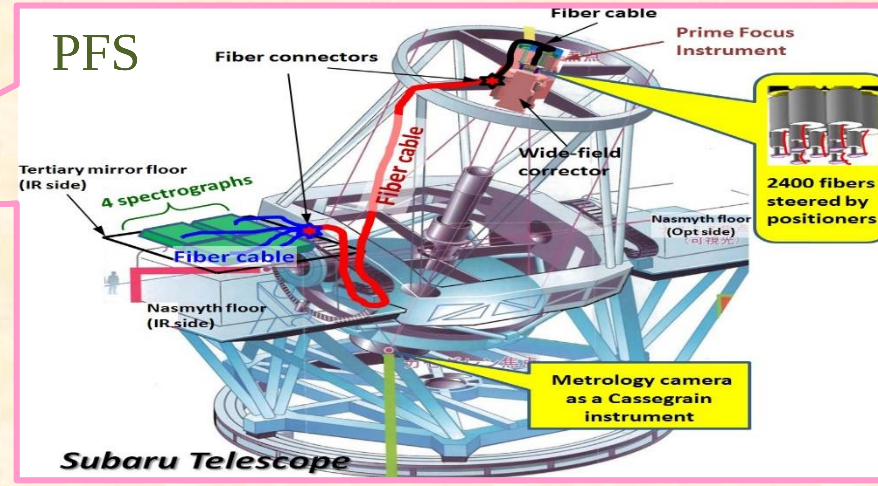

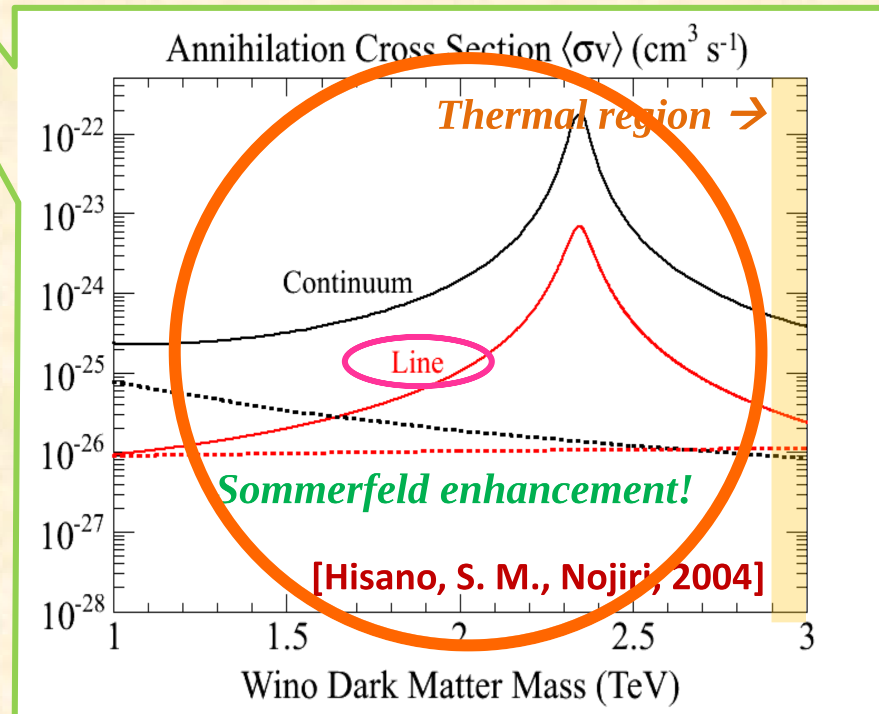

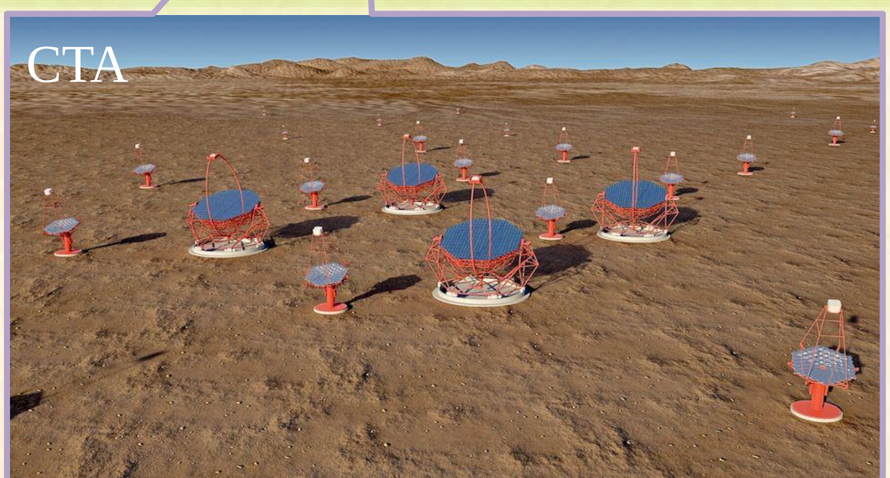

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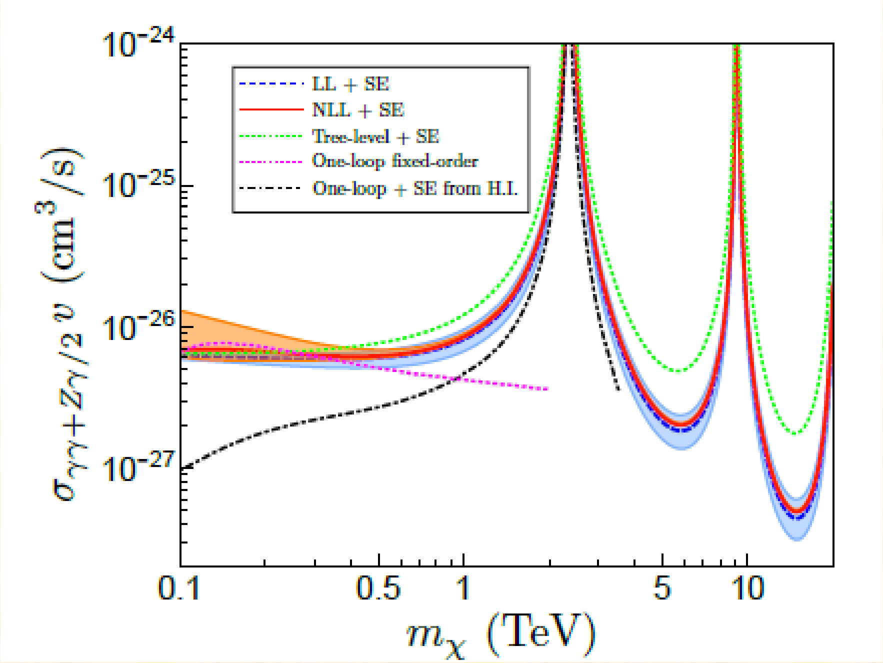

Non-perturbative Sommerfeld Effect (SE) [J. Hisano, S.M., M. Nojiri, 2004]

SE + Perturbative one-loop correction [A. Hryczuk, R. Iengo, 2013]

SE + Perturbative Sudakov logarithms (LL & NLL)
[M. Bauer, T. Cohen, Ri. Hill, M. Solon, 2014; G. Ovanesyan, T. Slatyer, I. Stewart, 2014]

SE + NL + NLL + Inclusive effects
[M. Baumgart, I. Rothstein, V. Vaidya, 2015; G. Ovanesyan, N. Rodd, T. Slatyer, I. Stewart, 2016]

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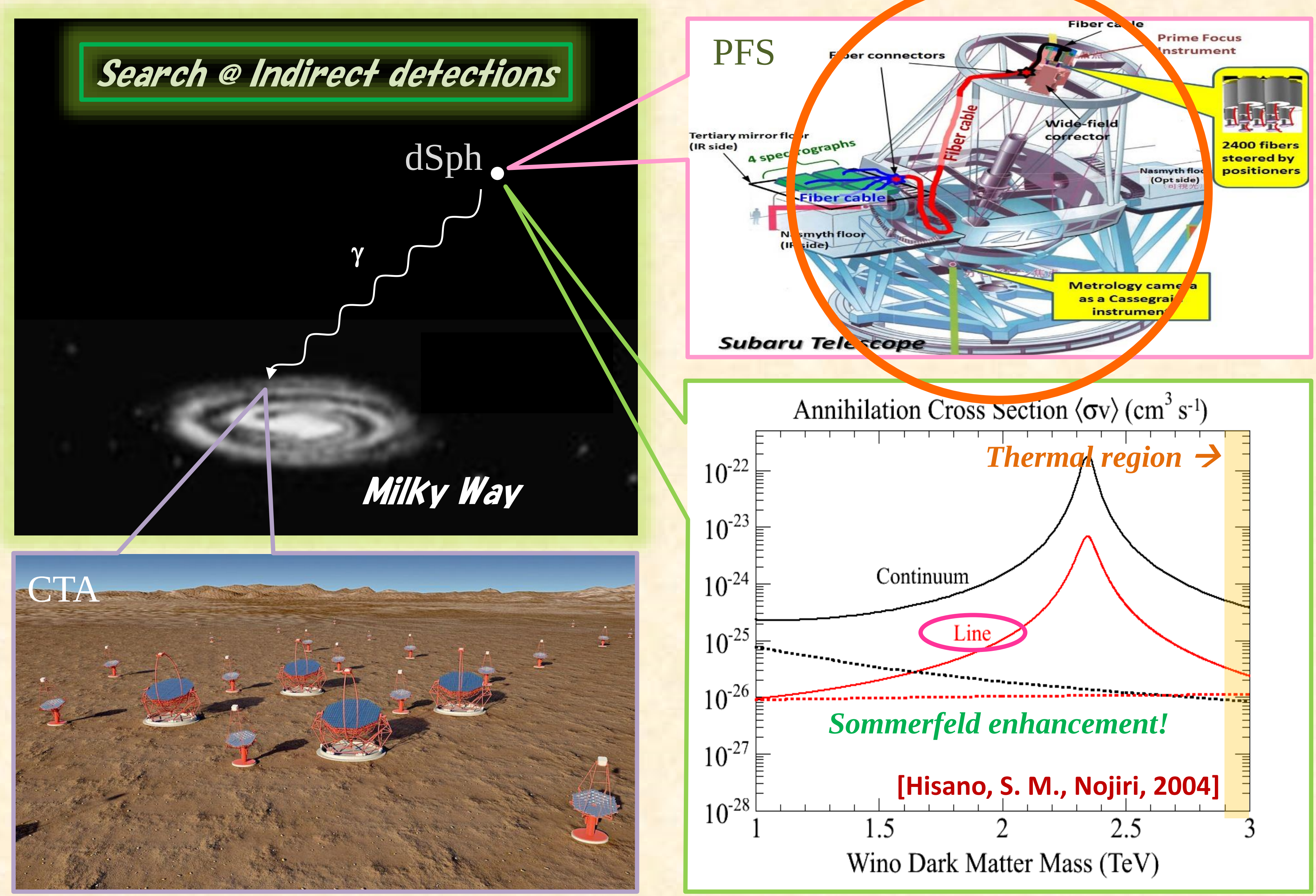

How we can test the triplet WIMP?

Theory side

Collisionless Boltzmann eq.

⇓

Jean's equation derived.

Distribution of member stars [$f(x, v)$ of the member stars]

⇓

DM mass distribution [$\rho(x)$]

Bayesian analysis ⟷

Observation side

Astrophysical observations

Photometric data:
Locations of the member stars, etc. are obtained.

Spectroscopy data:
Velocity of the member stars, etc. are obtained.

DM profile $\rho(x)$ obtained. → **J-factor** is evaluated as the pdf of the analysis.

Systematic errors associated with the J-factor determination

- ✔ The systematic error coming from the non-spherical nature of dSphs.
- ✔ The systematic error coming from the contamination of foreground stars.
- ✔ The systematic error coming from binaries composed of member stars.
- ✔ The systematic error coming from asymmetry of velocity dissipations.

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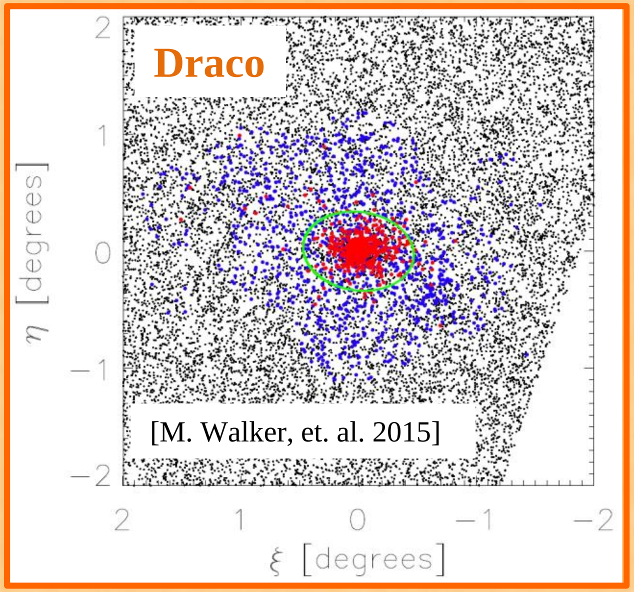

Several ways to deal with the contamination:

1. Cut-based identification of member stars, which is used for the most of UF dSphs.
2. EM method to put a membership probability, which is currently used for CL dSphs.
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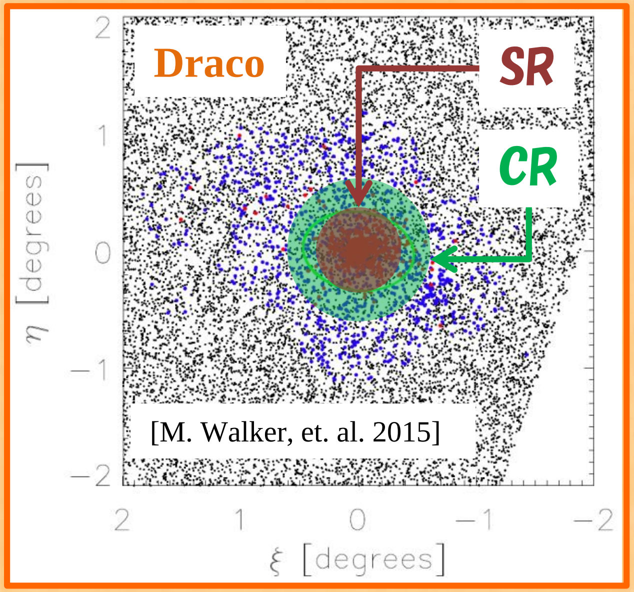

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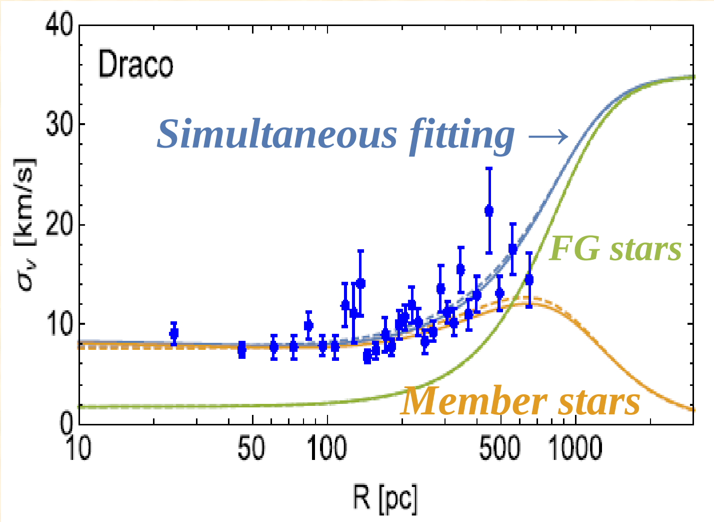

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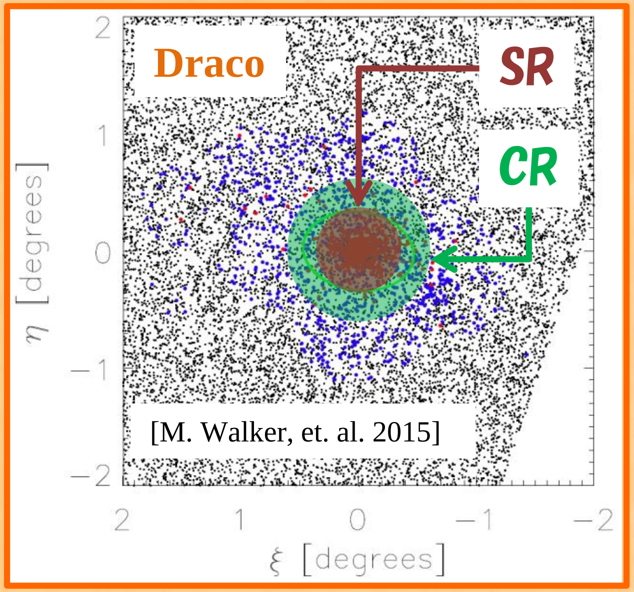

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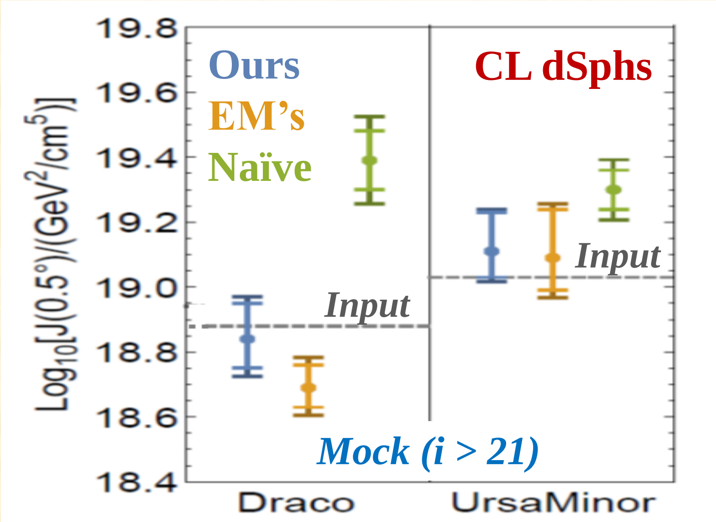

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- ✓ *EM method also reproduces the input, though some systematic errors remain.*
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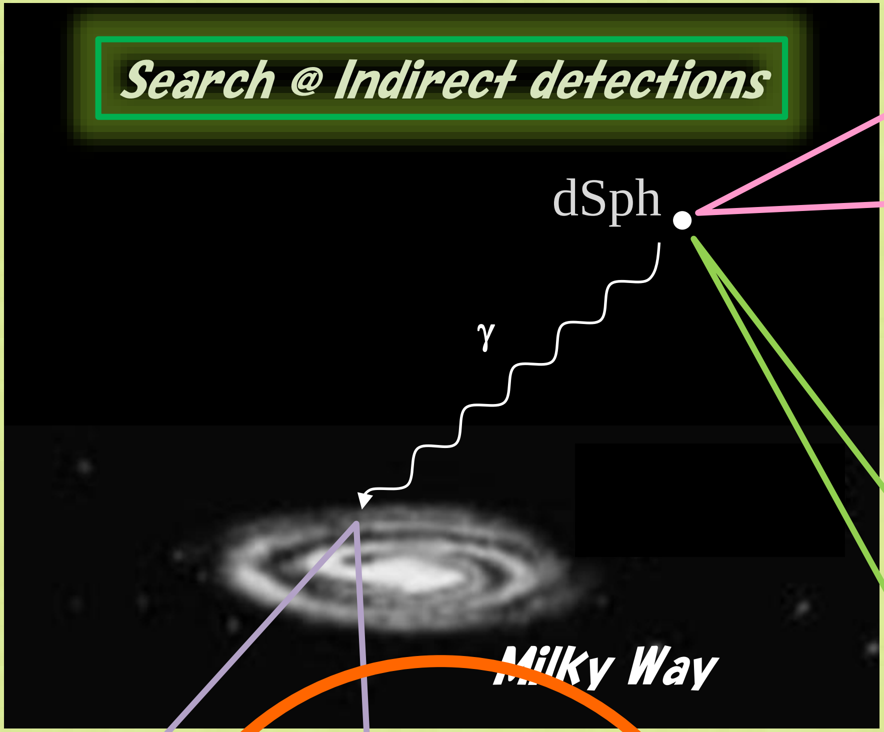
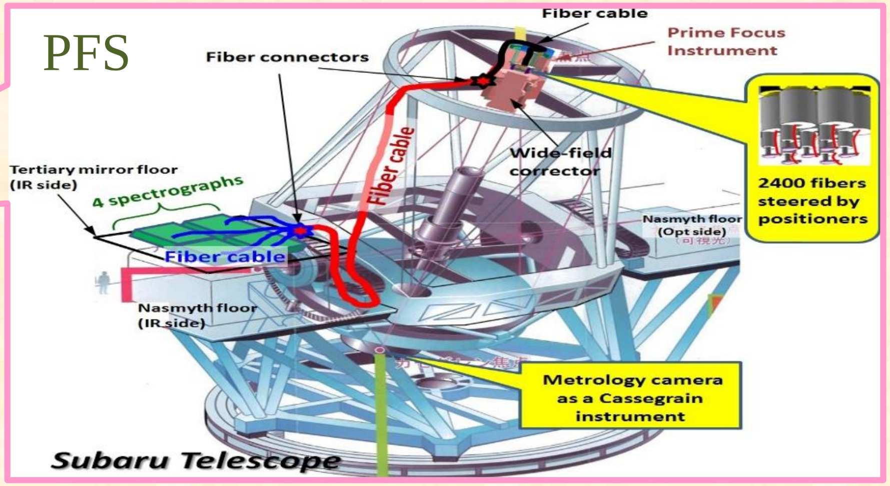
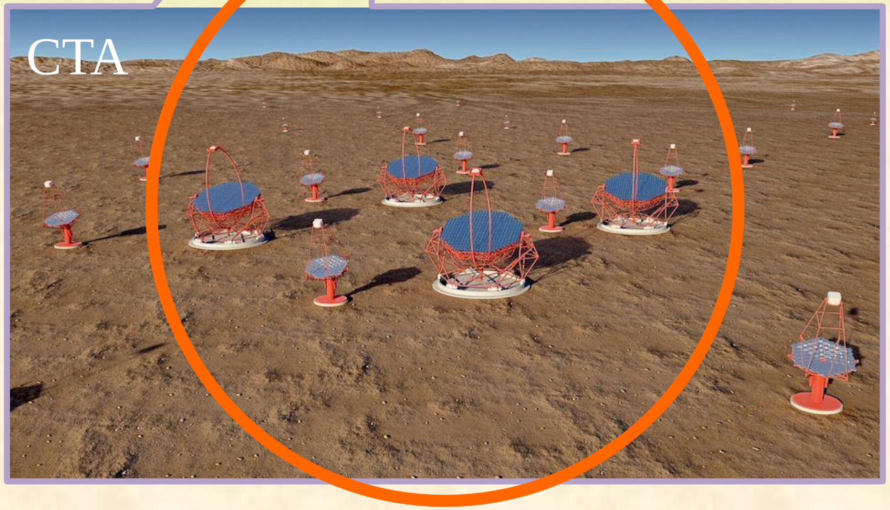
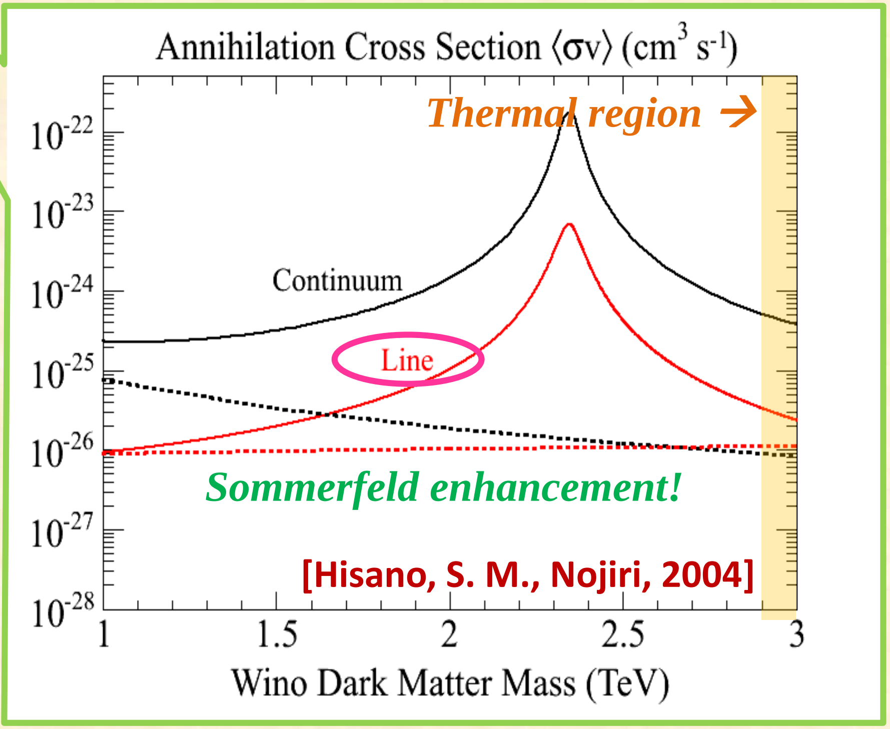








How we can test the triplet WIMP?

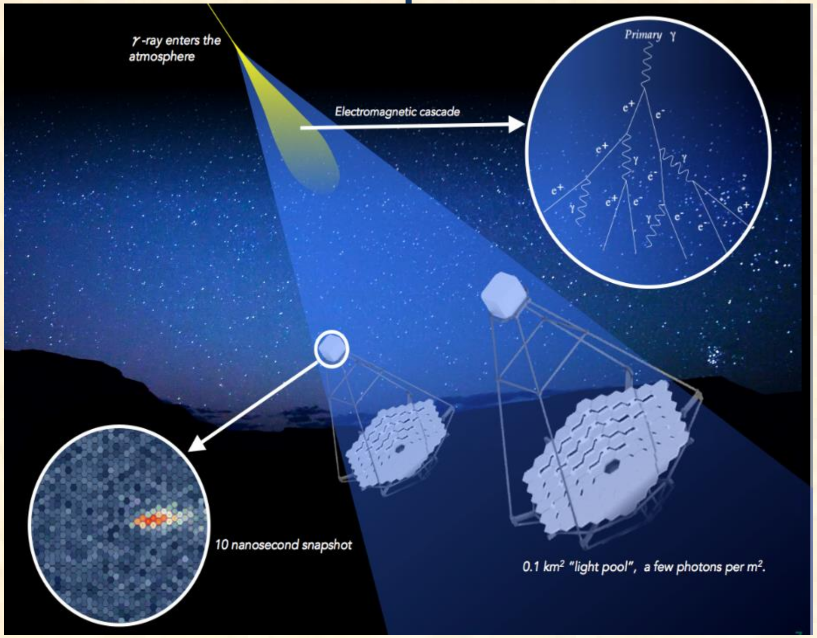
$$\Phi(E,\Delta\Omega) = \left[\frac{\langle\sigma v\rangle}{8\pi m_{DM}^2}\sum_f b_f \frac{dN_\gamma}{dE}\right] \times J_{\Delta\Omega}$$

$$J_{\Delta\Omega} = \int_{\Delta\Omega}\int_{\mathrm{l.o.s}} d\ell d\Omega\, \rho^2(\ell,\Omega)$$

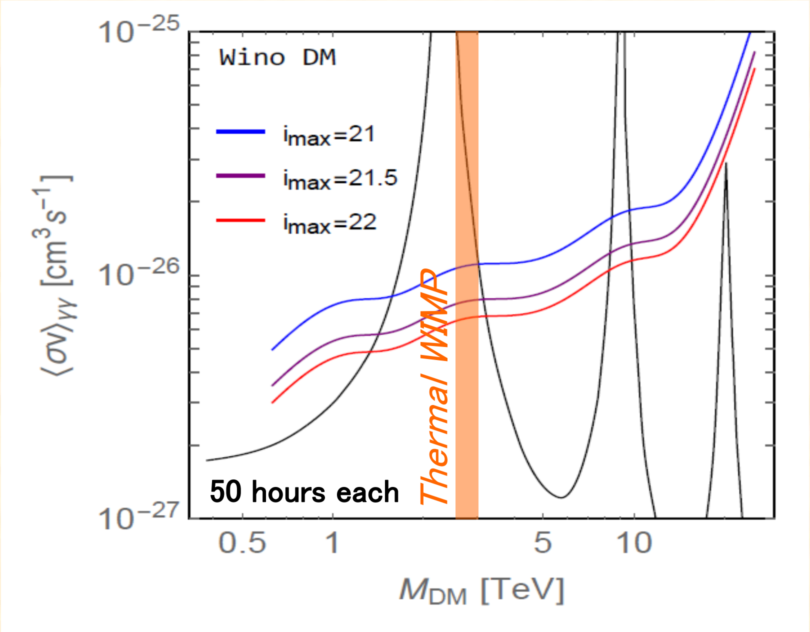
Theoretical calculation in particle physics.

Observing the motion of dSph member stars.

CTA observation



Sensitivity (UMaII+CB+Seg1+UMaI)



Summary

- The WIMP which has weak charge one attracts many attentions after the Higgs discovery. Only indirect dark matter detections allow us to detect it in near future, for it has O(1)TeV mass.
- Among various indirect dark matter detections, the observation of gamma-rays from dSphs are the most robust one to detect the signal of, or to put a constraint on the TeV scale WIMP.
- It is important to predict the signal flux for this purpose, and it requires the careful estimation of J-factors involving the treatment of FG star contamination and the DM & stellar non-sphericity, etc. Future spectroscopic measurements such as the PFS in the SuMIRe project will play a very important role!

Backup (Triplet-like Fermion WIMP)

Field Theory Lagrangian of WIMP

$$\mathcal{L} = \mathcal{L}_{SM} + \bar{T}\left(i\gamma^\mu D_\mu - \mathrm{M_T}\right)T$$

↓

Non-relativistic expansion and introducing a 'composite' field describing WIMP 2-body states.

↓

The Schrodinger eq. is obtained as EOM of the composite field.

$$[-\nabla^2/m + V(r)]\psi(r) = 0$$

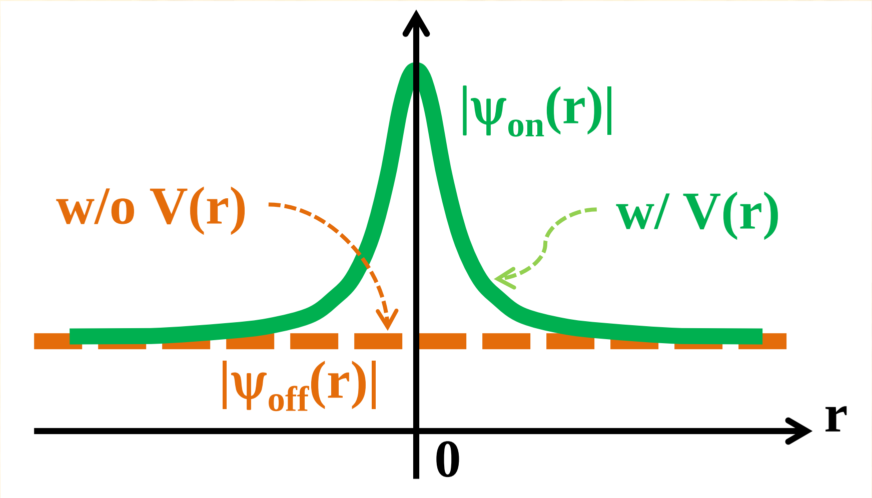
↓

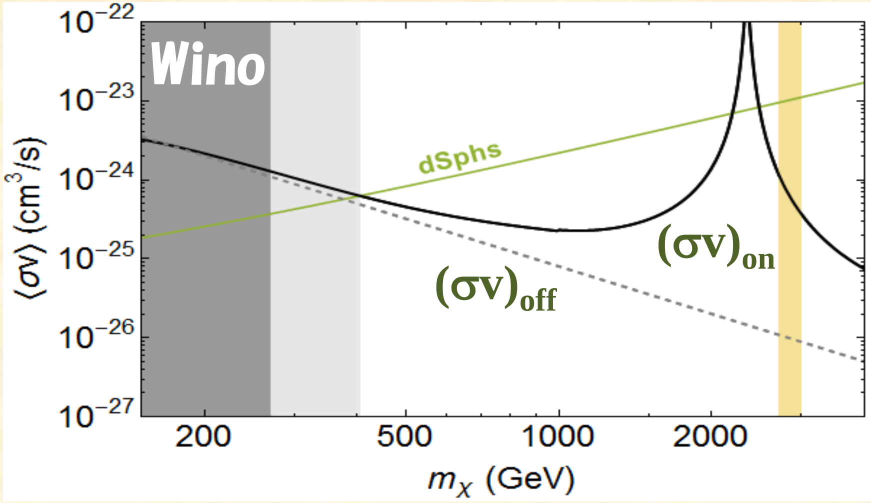
WIMP Annihilation cross section is obtained by the formula:

$$(\sigma v)_{on} = (|\psi_{on}(0)|^2/|\psi_{off}(0)|^2)\ (\sigma v)_{off}$$

↓

Weak long-range force increase the wave function at origin, for it acts as a attractive force!!!





[J. Hisano, S. M., M. Nagai, M. Nojiri, O. Saito, M. Senami, 2004-2007.]

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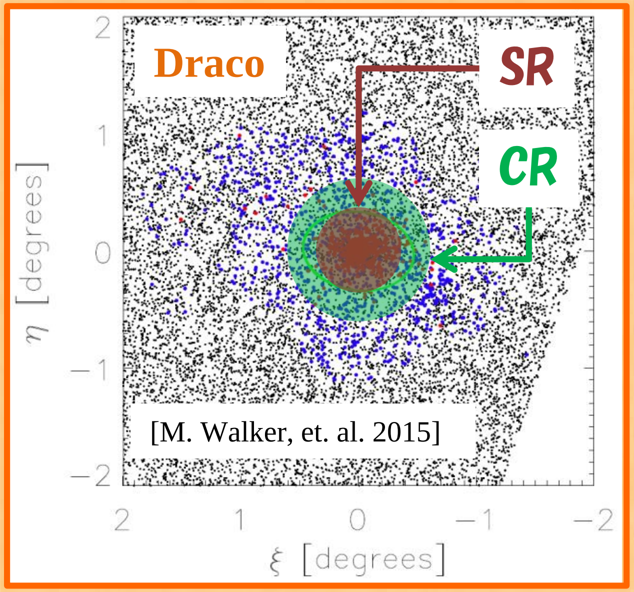

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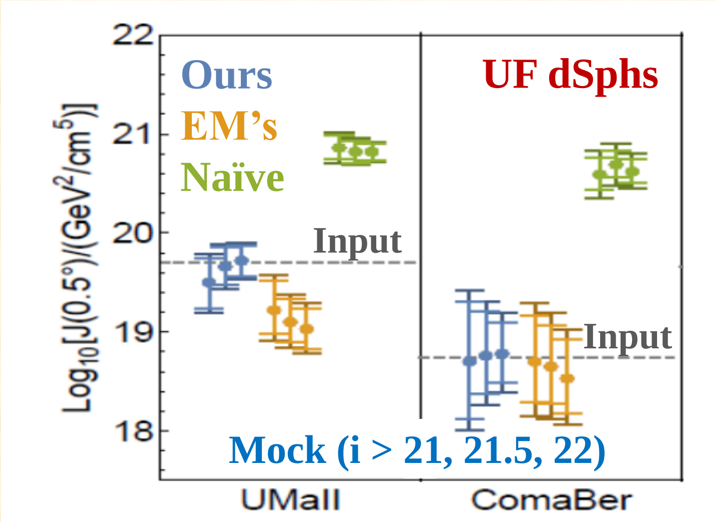

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