Current & Future constraints on Wino Dark Matter from indirect detection of dSphs

Koji Ichikawa

with

B. Bhattacherjee (IPMU), M. Ibe (IPMU & ICRR),
S. Matsumoto (IPMU) and K. Nishiyama (IPMU)

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KAVLI IPMU

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Outline

- Introduction
  - Indirect Detection
  - Dwarf Spheroidal Galaxies
  - Case Study: Wino DM
- Analysis
  - Signal Flux
  - Background Flux
  - Detector Capabilities
- Result
  - Future Sensitivity Line
- Summary

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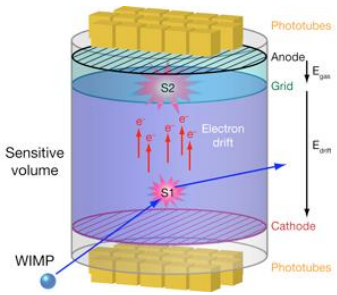
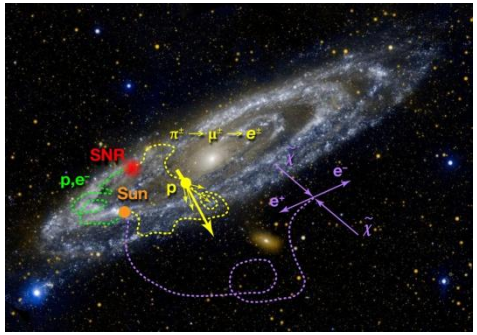
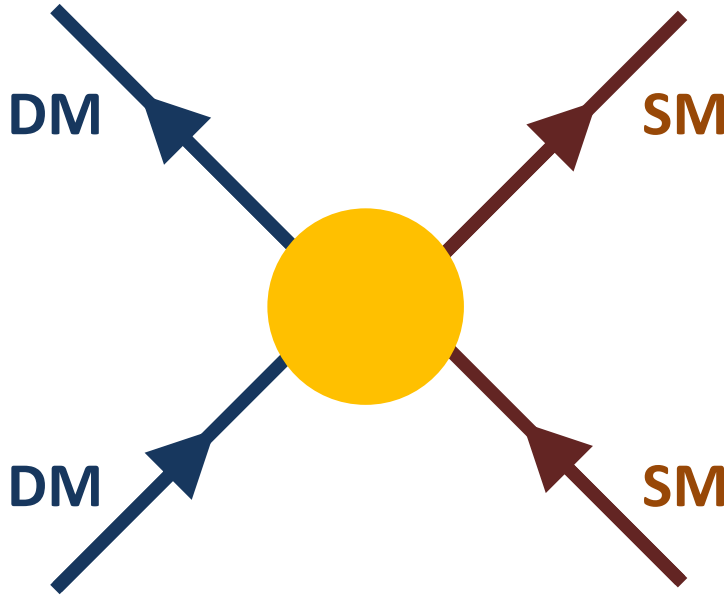
Dark Matter Search



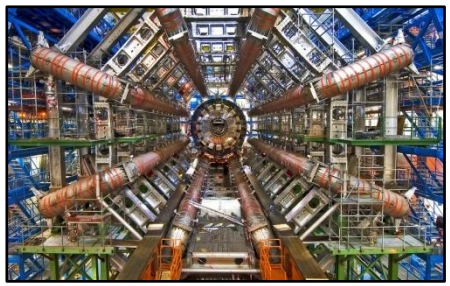
Direct Detection

Indirect Detection

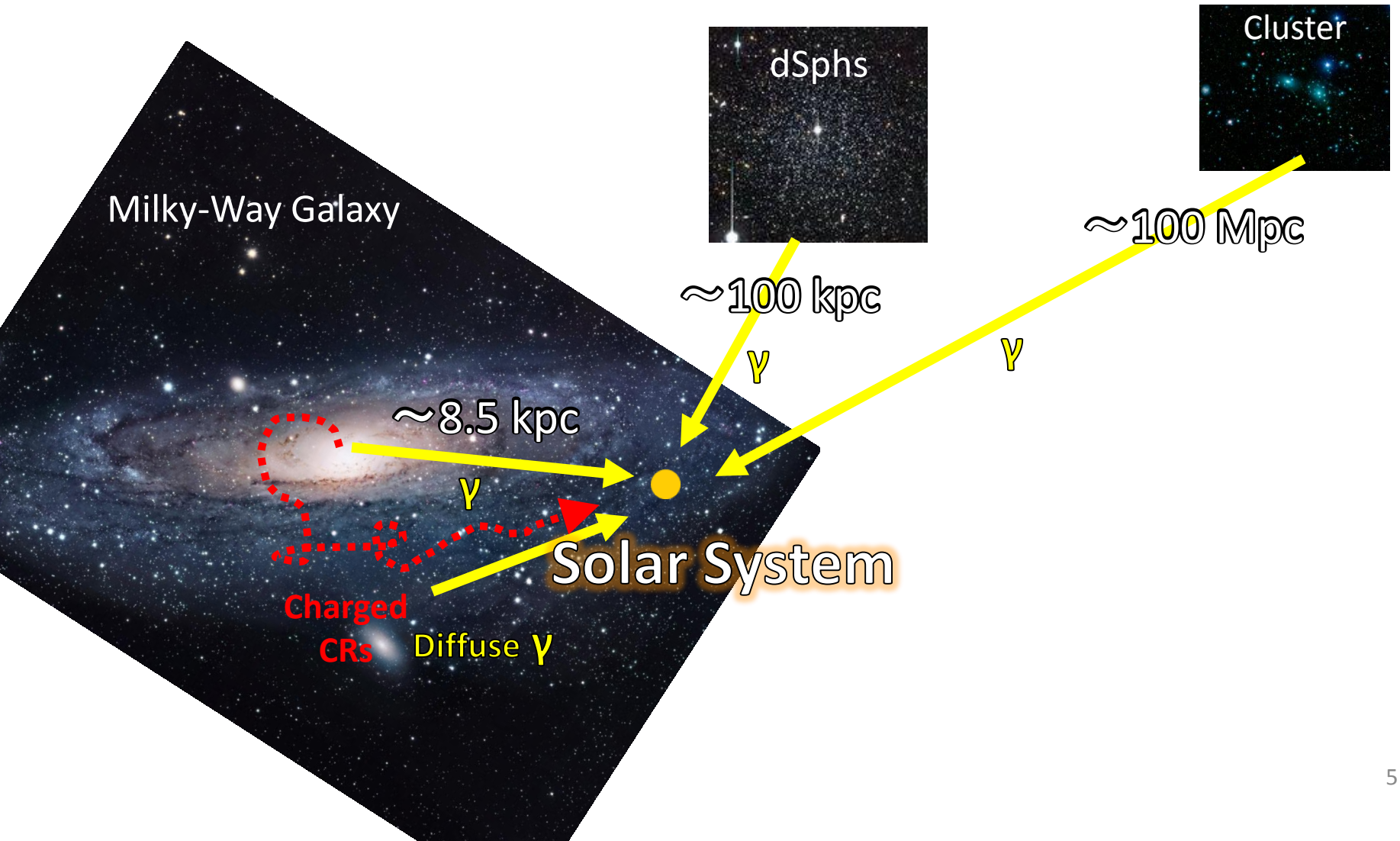




Collider Production



Signal Target



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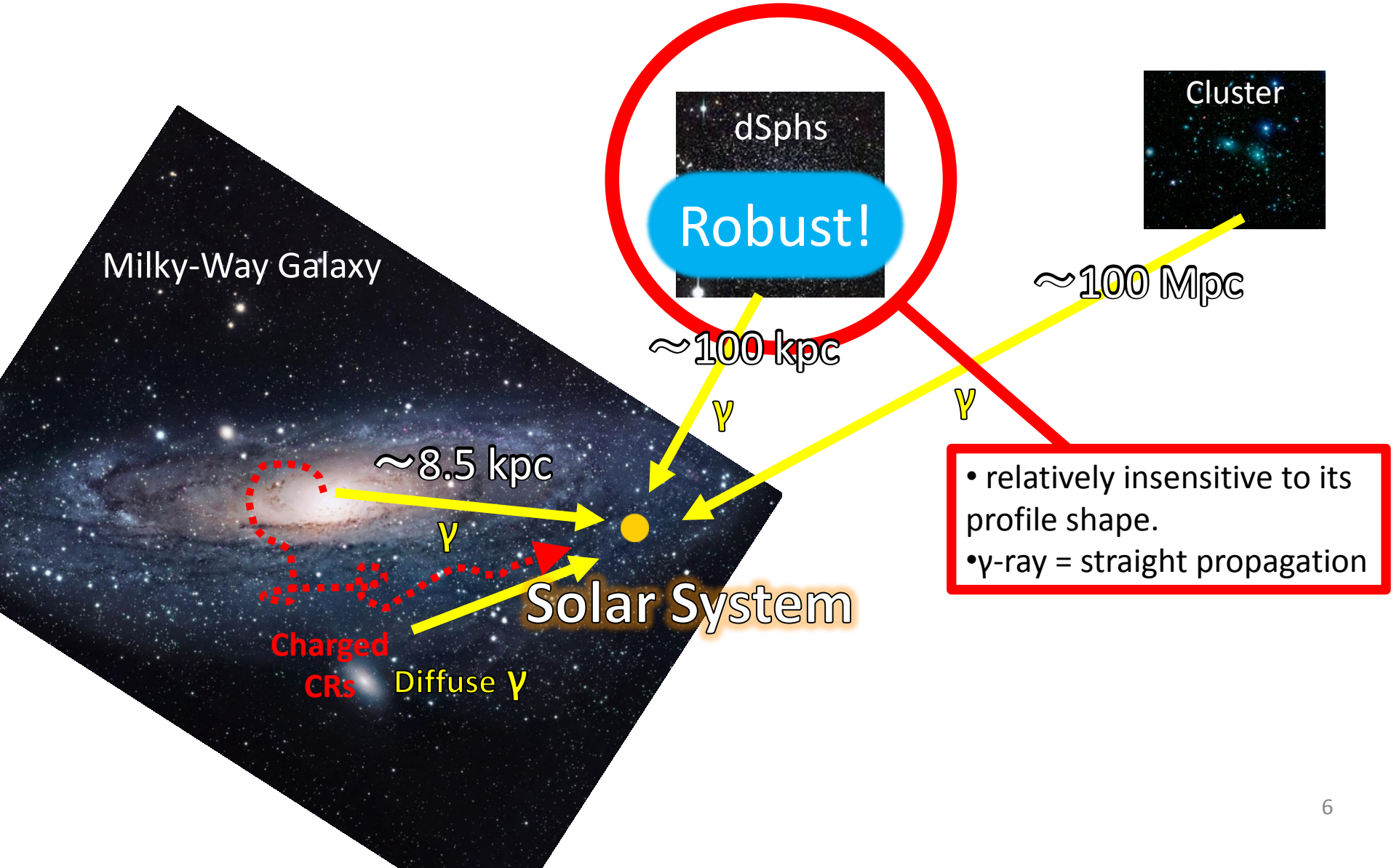
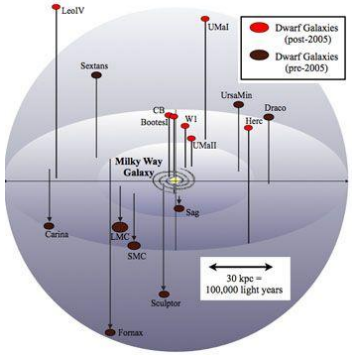


Dwarf spheroidal galaxies

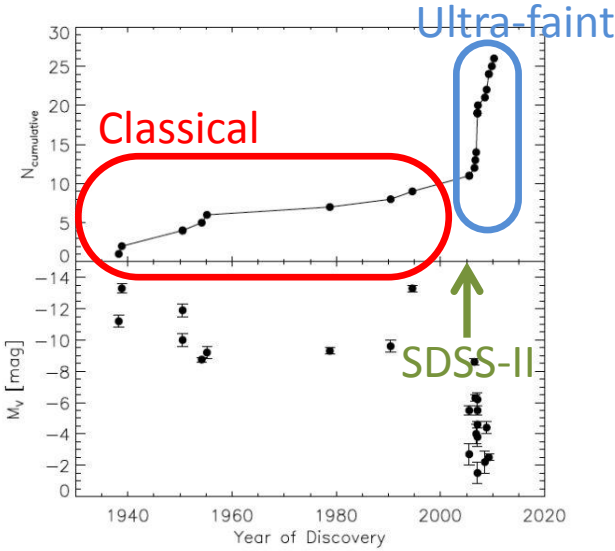
dSphs:

1. Neighbor galaxies: 10~100kpc
2. Large Mass to Luminosity ratio = **DM rich**
3. Fewer gas containment



	Classical	Ultra-faint
#dSphs	8	>20
M/L ($M_\odot/L_\odot$)	10-100	100-1000
Distance (kpc)	60-250	10-60
#Obs Stars	150-2500	20-100
Characteristics	Brighter, farther	Darker, closer

See, e.g. Wolf et al (2010)



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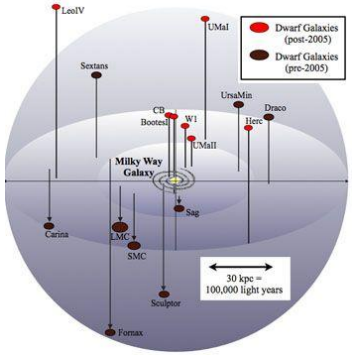

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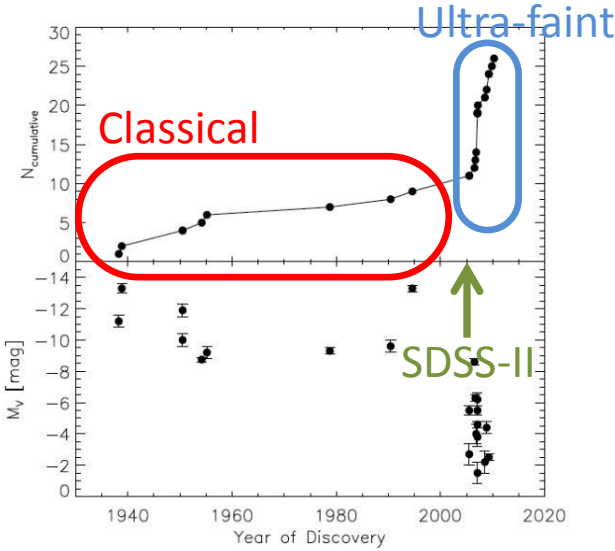


Case Study: Wino DM

SUSY

- Higgs UV divergence
- Dark matter candidates
- Gauge Unification

A. **Higgs Radiative Correction**
B. **DM Relic Abundance**

Heavy sfermion + (relatively) light DM seems to be favored…

AMSB → **Wino DM**

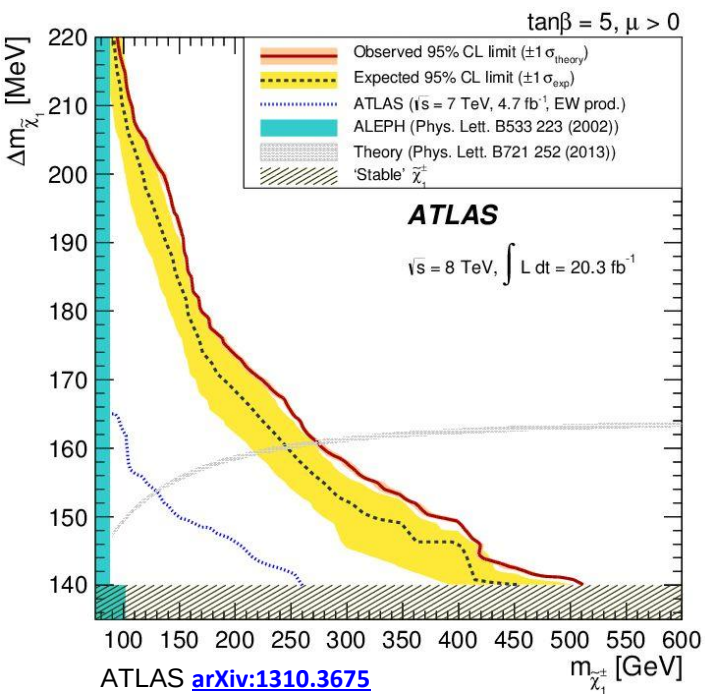
Wino DM: Current observational limit

- Collider: LHC bound
- DM relic abundance
- Astro: γ-ray observation from the milky way satellite galaxies

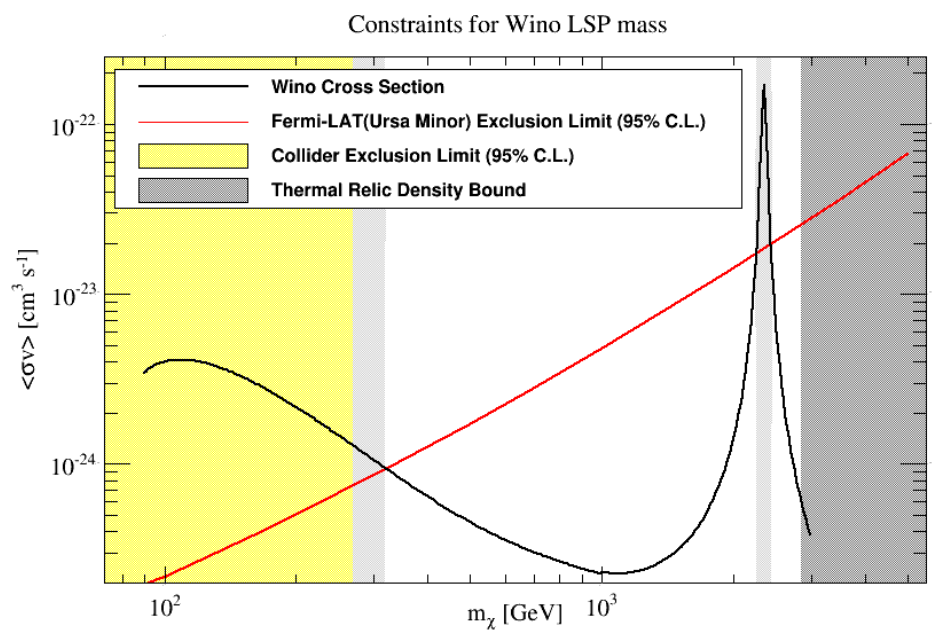
$M_{Wino} \geq 270\,\mathrm{GeV}$ (ATLAS 95% C.L)

$M_{Wino} \leq 2.9\,\mathrm{TeV}$ (M. Ibe, et al, PLB709, 2012)

$M_{Wino} \geq 320\,\mathrm{GeV}$ (Fermi-LAT 95% C.L)

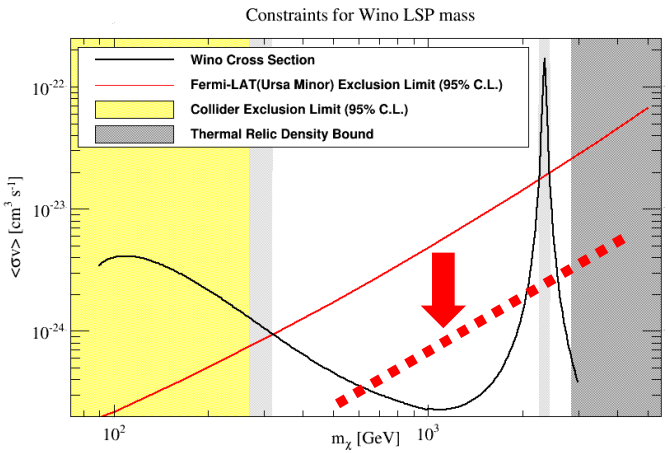


ATLAS arXiv:1310.3675



Data: Fermi-LAT arXiv:1310.0828

Questions…



?

1.

What will the future exclusion region be like?

2.

What should we do to improve the sensitivity line efficiently?

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Observed Events

Signal: $$S_{ai} = t_{\rm obs} \times \int_{\Delta E_i} dE\, \mathcal{F}_a^{(\rm S)}(E, \Delta\Omega_i)\, A_{\rm eff}(E)$$

Background: $$B_{ai} = t_{\rm obs} \times \int_{\Delta E_i} dE\, \mathcal{F}_a^{(\rm B)}(E, \Delta\Omega_i)\, A_{\rm eff}(E)$$

a: dSph
i: Energy Bin

Energy Bin

ROI

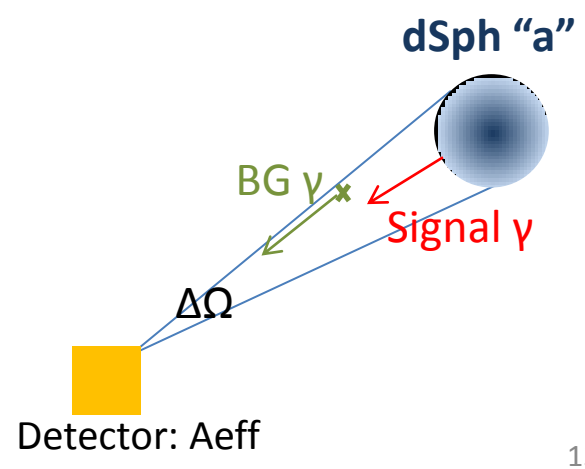
Effective Area

Signal Flux: $F^{(S)}$

Particle Factor
Astrophysical Factor

BG Flux: $F^{(B)}$

Galactic Diffuse
Isotropic Diffuse
Point-like Source



Signal Flux

$$\Phi(E,\Delta\Omega) = \left[\frac{\langle\sigma v\rangle}{8\pi m_{\tilde{w}}^2}\sum_f \mathrm{Br}(\tilde{w}^0\tilde{w}^0 \to f)\left(\frac{dN_\gamma}{dE}\right)_f\right]\left[\int_{\Delta\Omega} d\Omega \int_{l.o.s.} dl\, \rho^2(l,\Omega)\right]$$

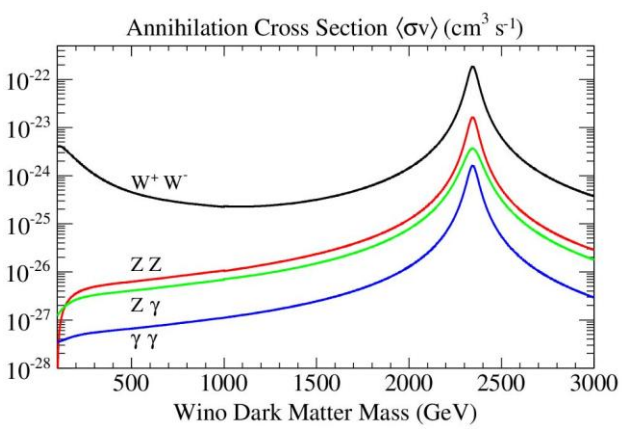
Particle Physics Factor

$f = WW, ZZ, \gamma\gamma, Z\gamma$ Error: 1-10 % level

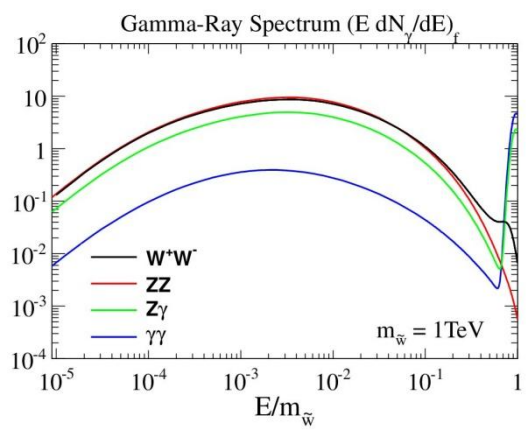
Astrophysics Factor (J-factor)

Large uncertainty:
Next Slide

$$J \simeq \frac{1}{D^2}\int_{\mathrm{Vol}} r^2\rho^2(r)\mathrm{d}r$$



Hryczuk and Iengo (2012)



Cirelli et al (2012)

Astrophysical Factor

DM Density profile

$$\rho(r) = \rho_s \left(r/r_s\right)^{-\gamma} \left[1 + \left(r/r_s\right)^{\alpha}\right]^{(\gamma-\beta)/\alpha}$$

$\rho_s (r/r_s)^{-1}(1+r/r_s)^{-2}$ Cusp

$\rho_s (1+r/r_s)^{-1}(1+r/r_s)^{-2}$ Cored

Stellar Density Profile: v(r)

Annisotropy β

Jeans equation for stars

$$\frac{1}{\nu}\frac{d}{dr}(\nu \bar{v_r^2}) + 2\frac{\beta(r)\bar{v_r^2}}{r} = -\frac{GM(r)}{r^2}$$

$\sigma^{2\,(\mathrm{Theory})}_{\mathrm{l.o.s}}$ ⟷ $\sigma^{2\,(\mathrm{obs})}_{\mathrm{l.o.s}}$

Fit

		long. (deg.)	lat. (deg.)	dist. (kpc)	α_s (deg.)	$\log_{10}[J(0.5°)/(\mathrm{GeV}^2\mathrm{cm}^{-5}\mathrm{sr})]$
Classical: Well-determined	Draco	86.4	34.7	76	$0.25^{+0.15}_{-0.09}$	18.8 ± 0.16
	Ursa Min.	105.0	44.8	76	$0.32^{+0.18}_{-0.12}$	18.8 ± 0.19
	Sculptor	287.5	-83.2	86	$0.25^{+0.25}_{-0.13}$	18.6 ± 0.18
	Sextans	243.5	42.3	86	$0.13^{+0.07}_{-0.05}$	18.4 ± 0.27
Ultra-faint: Not well-determined. Prior dependence	Segue 1	220.5	50.4	23	$0.40^{+0.86}_{-0.27}$	19.5 ± 0.29
	Ursa Maj. II	152.5	37.4	32	$0.32^{+0.48}_{-0.19}$	19.3 ± 0.28
	Willman 1	158.6	56.8	38	$0.25^{+0.54}_{-0.17}$	19.1 ± 0.31
	Coma B.	241.9	83.6	44	$0.25^{+0.54}_{-0.17}$	19.0 ± 0.25

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Background Flux

1. Galactic Diffuse

CR + ISM, Brems of CRe, IC (CRe + Interstellar radiation field)

→ Simulation (e.g. GALPROP) with ISM, ISRF, Large Scale Structure.

2. Isotropic Diffuse

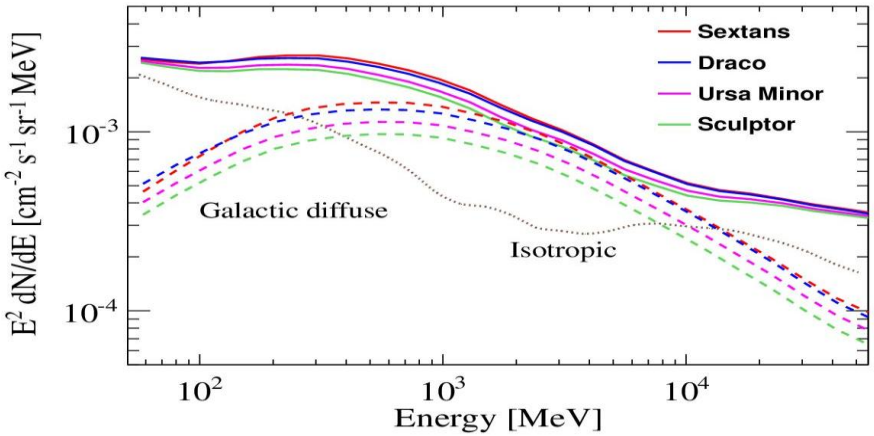
AGN, Starburst, γ-Ray burst, unknown sources

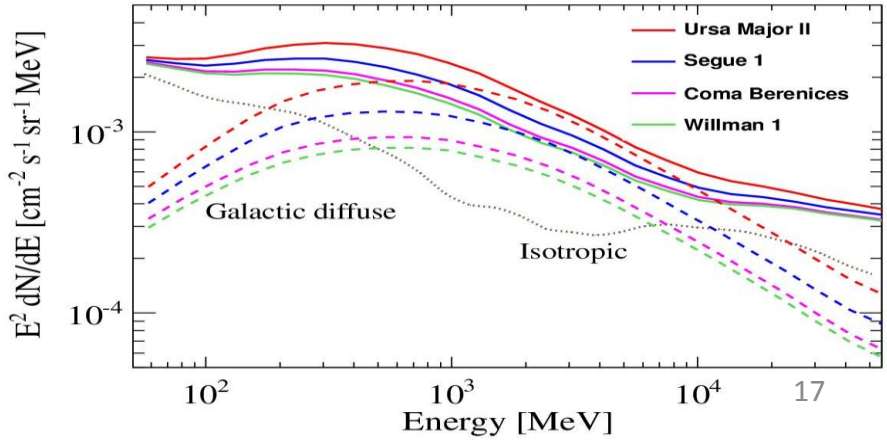
→ Evaluated from $|b| > 30^{o}$ sky data

3. Point-like Source

AGN, SNR, Pulsars, Unidentified

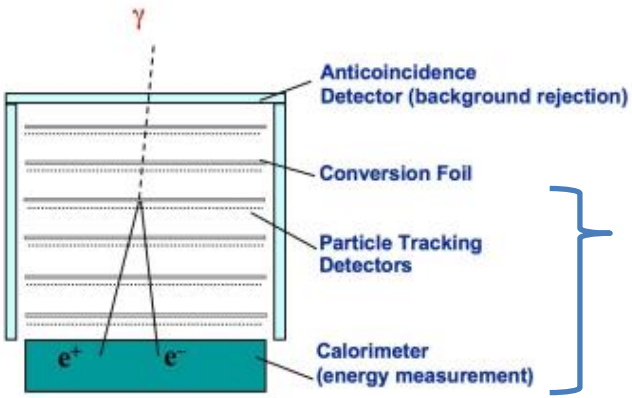
→ Mask/Model



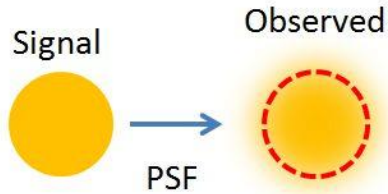


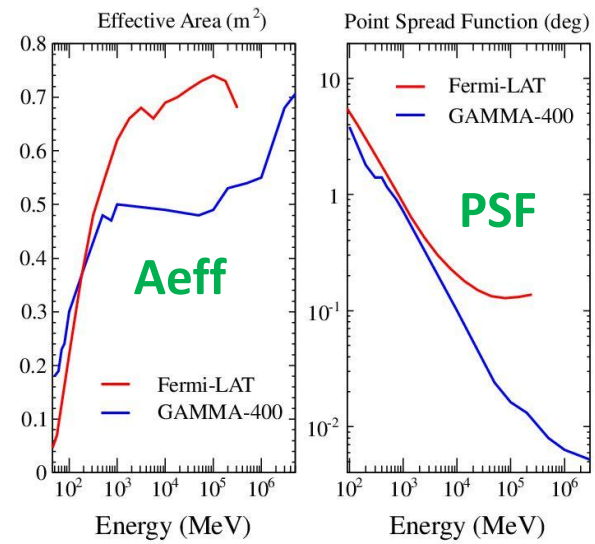
Detector Capabilities

Satellite- type Obs



Direction Reconstruction

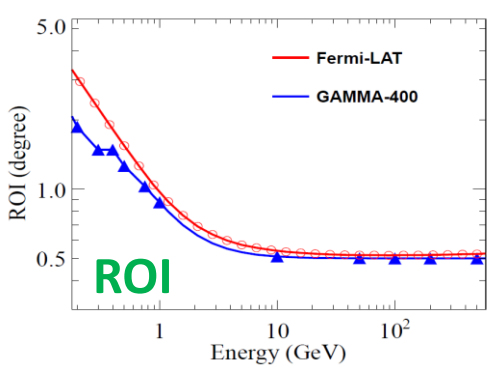


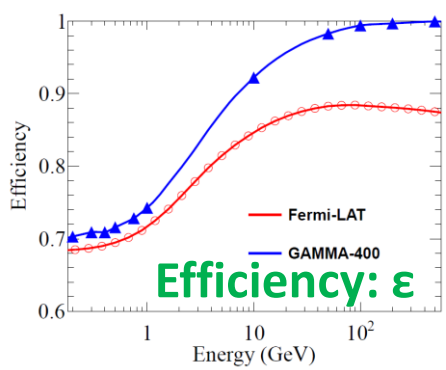


ROI: $\Delta\Omega_i = 2\pi(1 - \cos\alpha_i)$

$$\alpha_i = [(0.5^\circ)^2 + \psi_{68}^2(E_i)]^{1/2}$$

Typical dSphs Size PSF (68 % containment angle)





Signal Flux

$$\mathcal{F}_a^{(S)}(E, \Delta\Omega_i) = \epsilon(\Delta\Omega_i)\,\Phi_a(E, \Delta\Omega_i)$$

PSF effect -> efficiency ε

Background Flux

$$\mathcal{F}_a^{(B)}(E, \Delta\Omega_i) = \Delta\Omega_i\,(d\Phi_a^B(E)/d\Omega)$$

Large ΔΩ -> Large Background

Sensitivity Line

Profile Likelihood

J-factor error is included

$$\mathcal{L}[\langle\sigma v\rangle, \{J_a\}] \equiv \prod_{a,i} \frac{P\left(N_{ai}; S_{ai}[\langle\sigma v\rangle, J_a] + B_{ai}\right)}{P\left(N_{ai}; N_{ai}\right)} G\left(J_a; \log_{10} J_a^{(\mathrm{obs})}, \delta(\log_{10} J_a^{(\mathrm{obs})})\right)$$

P(N:λ): Poisson
G(x: μ, σ): Log Gaussian
N_{ai}: Observed Events

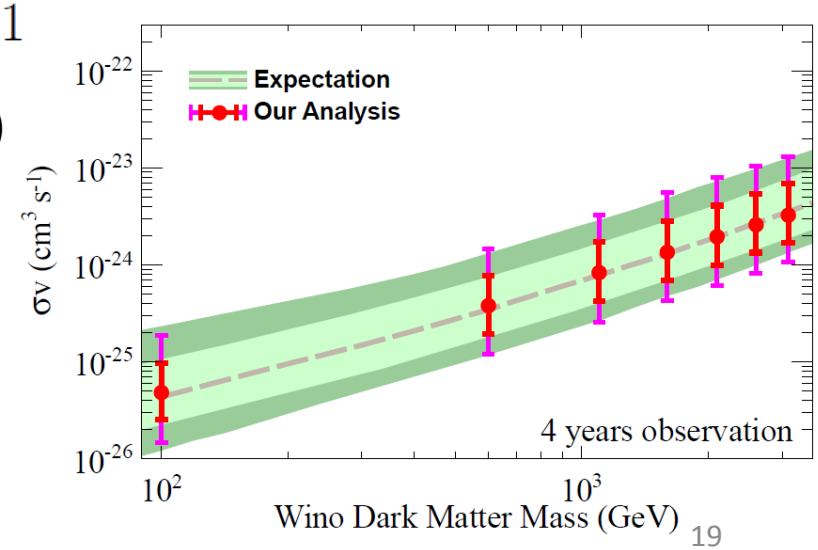
Test (95% C.L)

$$-2\ln\mathcal{L}(\langle\sigma v\rangle, \{J_{\min}\}) + 2\ln\mathcal{L}(0, \{J_{\min}\}) = 2.71$$

2000 Pseudo Experiments for N_{ai} ($\{N^{(1)}_{ai}, N^{(2)}_{ai}, N^{(3)}_{ai}\ldots\}$)
(Poisson with the mean of B_{ai})

Each $N^{(i)}_{ai} \rightarrow \langle\sigma v\rangle^{(i)}$

Right Figure:
Mean and 68 (95) % band
for the set $\{\langle\sigma v\rangle^{(1)}, \langle\sigma v\rangle^{(2)}, \langle\sigma v\rangle^{(3)}, \ldots\}$



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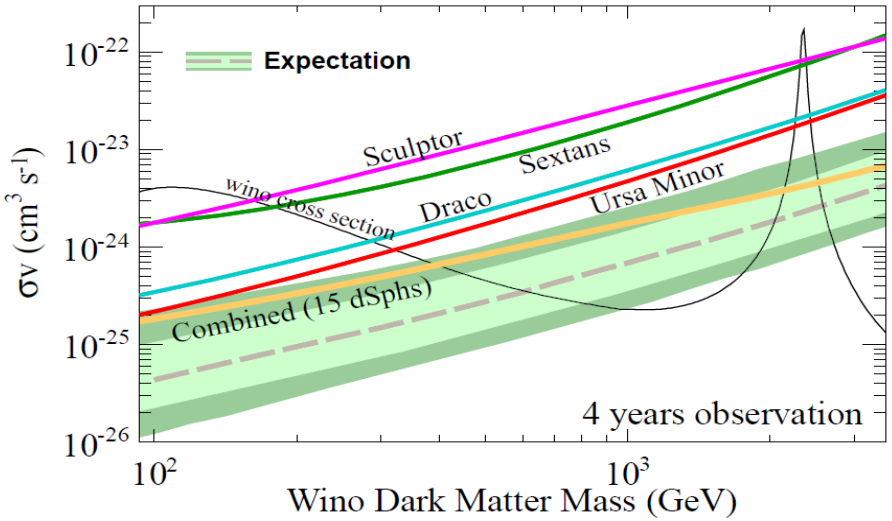
Current Limit



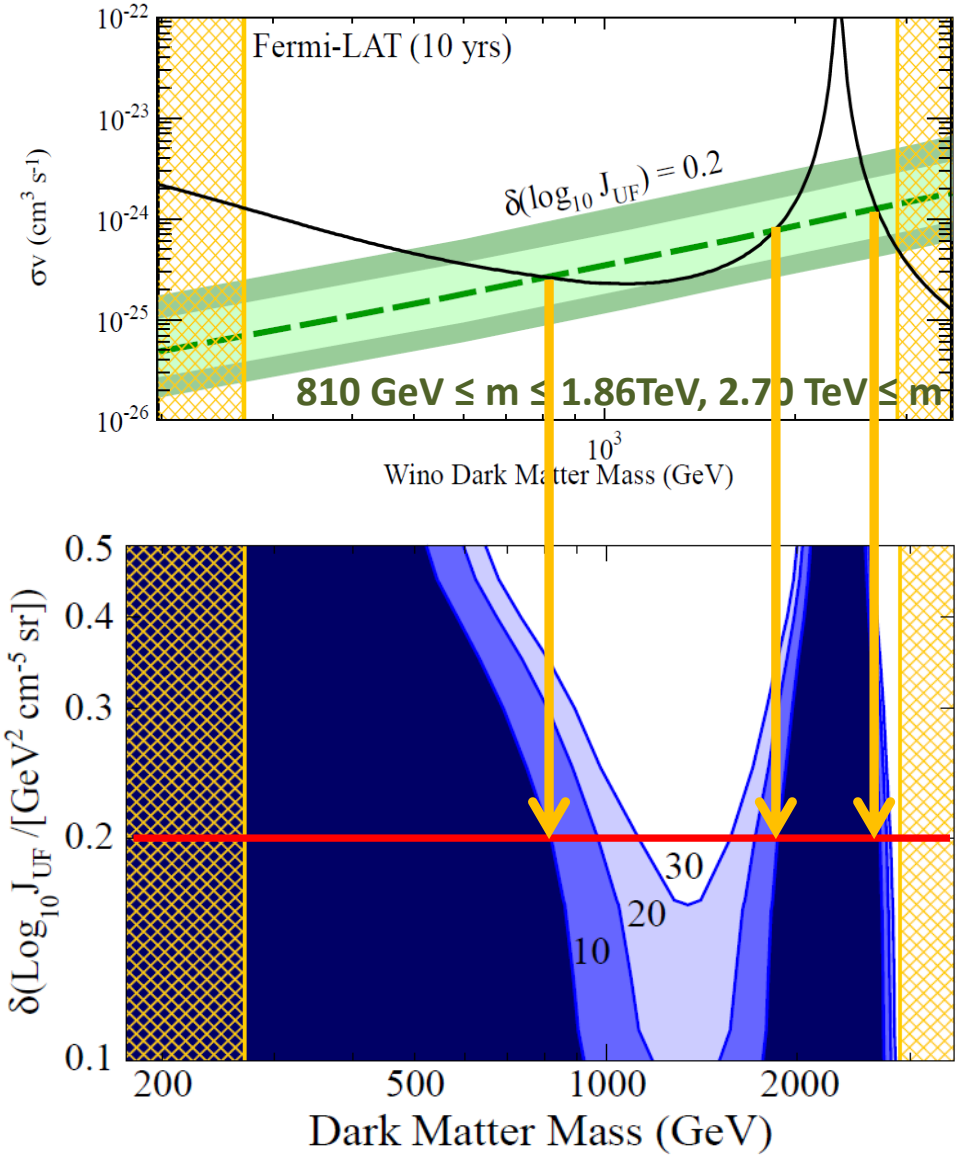
Ursa Minor

320 GeV ≤ m ≤ 2.25TeV and 2.43 TeV ≤ m

Combined (15 dSphs) <- Aggressive

390 GeV ≤ m ≤ 2.14TeV and 2.53 TeV ≤ m

Future Prospects



Summary

- Indirect detection is essential for the heavy DM search.
- Gamma-ray observation of dSph can give robust constraints on the DM annihilation cross section.
- Investigation of Ultra-faint's stellar kinematics dramatically affects the sensitivity lines.

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