Indirect Detection of the Minimal Dark Matter Quintuplet

KEK Theory Meeting on Particle Physics Phenomenology

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In collaboration with

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Based on
arXiv:2507.17607

IN SUPREMÆ DIGNITATIS
1343
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Sezione di Pisa

Outline

- Introduction
- Minimal Dark Matter (MDM)
- Indirect probes of minimal dark matter
- Statistical Analysis
- Conclusion

Minimal Dark Matter [Cirelli et al. 2005]

MDM is a model that extends the field content of the standard model by **only one** extra electroweak, $SU(2)_L$, multiplet $(\ldots, \chi^+, \chi_0, \chi^-, \ldots)$.

REQUIREMENTS

1. **NEUTRALITY** → Moreover, DM candidate must be neutral! So, the lightest component has to be neutral.
2. **STABILITY** → DM must be stable! So, it better be the lightest component of the multiplet!
3. **INTERACTIONS** → At renormalizable level, DM interactions with SM must be of the gauge type.
4. **NOT EXCLUDED** → It needs to have minimal interactions with SM at the tree level.

Minimal Dark Matter [Cirelli et al. 2005]

At the Renormalizable level, the Lagrangian for a minimal dark matter is:

$$\mathcal{L}_s = \frac{1}{2}(D_\mu \chi)^2 - \frac{1}{2}M_\chi^2 \chi^2 - \frac{\lambda_H}{2}\chi^2 |H|^2 - \frac{\lambda_\chi}{4}\chi^4,$$
$$\mathcal{L}_f = \frac{1}{2}\chi \left(i\bar{\sigma}^\mu D_\mu - M_\chi\right)\chi,$$

In general, Minimal Dark Matter multiplet has three free parameters: multiplicity (n), hypercharge (Y), and bare mass (m). On top of that it can be:

spin	Representation	multiplicity	hypercharge
☐ fermion	☐ Real	☐ even	☐ zero
☐ scalar	☐ Complex	☐ odd	☐ nonzero

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$$\mathcal{L}_f = \frac{1}{2}\chi \, (\ldots$$

Scalars are prone to constraints due to the existence of Higgs portal in their Lagrangian.

In general, Minimal Dark … are

mass (m). On top of that it …

spin	Representation	multiplicity	hypercharge
☑ fermion	☐ Majorana	☐ even	☐ zero
☐ scalar	☐ Dirac	☐ odd	☐ nonzero

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Minimal Dark Matter [Cirelli et al. 2005]

At the Renormalizable level, the Lagrangian for a minimal dark matter is:

$$\ldots \lambda_H \ldots {}^2|H|^2 - \frac{\lambda_\chi}{4}\chi^4,$$

Dirac fermionic multiplets ruin the minimality requirement by doubling the number of degrees of freedom in the model.

In genera[…] […]ree free parameters: multiplicity (n), hypercharge (Y), and bare mass (m). On top of that it can be:

spin	representation	multiplicity	hypercharge
☑ fermion	☑ Majorana	☐ even	☐ zero
☐ scalar	☐ Dirac	☐ odd	☐ nonzero

See Bottaro et al. 2205.04486 for more on complex WIMPs

Minimal Dark Matter [Cirelli et al. 2005]

At the Renormalizable level, the Lagrangian for a … dark

$$\ldots \frac{\lambda_\chi}{4}\chi^4,$$

Odd

$(1, n)_Y$

$\ldots$
χ^+
χ_0
χ^-
$\ldots$

Odd multiplets naturally do not couple to the Z boson at tree level.

In … plicity (n), hypercharge (Y), and bare mass (m). O…

spin	representation	multiplicity	hypercharge
☑ fermion	☑ Majorana	☐ even	☐ zero
☐ scalar	☐ Dirac	☑ odd	☐ nonzero

Minimal Dark Matter [Cirelli et al. 2005]

At the Renormalizable level, the Lagrangian for a dark

e.g. [Cheng et al. 1998]
[Feng et al. 1999]
[Ghergetta et al. 1999]
[Ibe et al. 2012], …

$(\mathbf{1}, \mathbf{n})_{\mathbf{0}}$

$\cdots$
χ^{+}
χ_0
χ^{-}
$\cdots$

$\Delta m = 167(4) MeV$

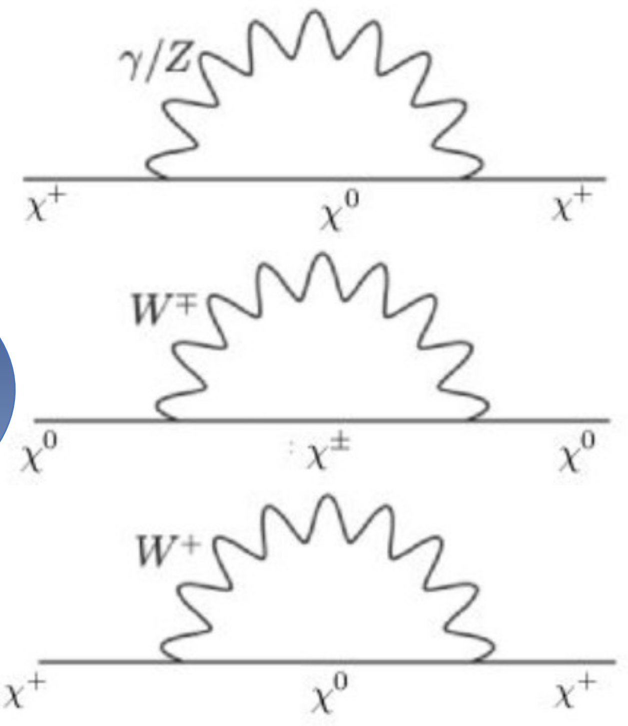
Choosing zero hypercharge multiplets, the neutral one naturally becomes the lightest!

λ

4

In … plicity (n), h

mass (m). O…



spin		representation		multiplicity		hypercharge	
☑	fermion	☑	Majorana	☐	even	☑	zero
☐	scalar	☐	Dirac	☑	odd	☐	nonzero

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Minimal Dark Matter Quintuplet (5-plt)

- So far, we have argued that **Majorana**, **fermionic** MDM candidate with **odd** multiplicity and **zero** hypercharge can be a good dark matter candidate.

But, we can do more…

- Among all Majorana fermionic multiplets with zero hypercharge, the quintuplet's (5-plt) stability is guaranteed by accidental symmetry i.e. there are no operators that can promote decay.

- Fixing the multiplicity and the hypercharge, the only free parameter left in the model is **THE MASS**, and the mass can be fixed by DM relic abundance.

SO, MINIMAL DARK MATTER IS FULLY PREDICTIVE!

Quantum numbers			DM can	DD	Stable?
$SU(2)_L$	$U(1)_Y$	Spin	decay into	bound?	
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 …	S	–	×	√

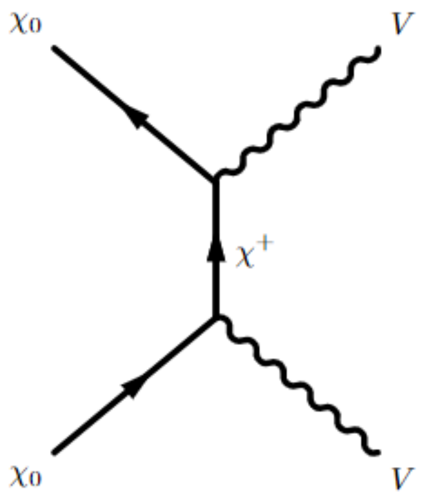
[Cirelli et al. 2005]

Relic Abundance and Boltzmann Equation

In the early universe, for $T > M_\chi$, the tree-level 2 to 2 co-annihilations control the abundance of MDM quintuplet:

$$\frac{dY}{dx} = -\frac{s(x)}{xH(x)} \langle \sigma v \rangle \left(1 - \frac{x}{3g_*(x)} \frac{dg_*(x)}{dx} \right) \left(Y^2(x) - Y_{eq}(x) \right)$$

WHICH CROSS-SECTION?



$$\langle \sigma v \rangle_0 = \frac{\pi \alpha_2^2 (2n^4 + 17n^2 - 19)}{16 g_\chi M_\chi^2}$$

$$\mathbf{M_{DM} = 4.6\ TeV}$$

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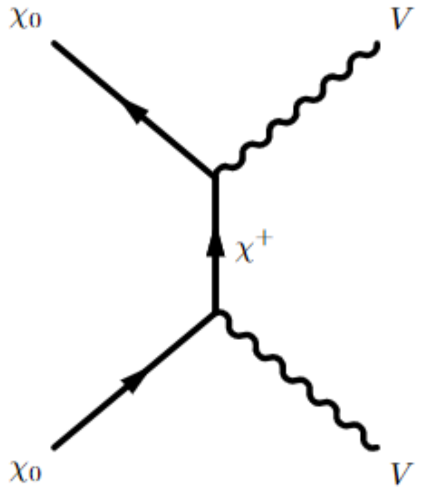

$$\langle \sigma v \rangle_0 = \frac{\pi \alpha_2^2 (2n^4 + 17n^2 - 19)}{16 g_\chi M_\chi^2}$$

INACCURATE

$$\mathbf{M_{DM} = 4.6\ TeV}$$

Non-perturbative non-relativistic effects

1. Sommerfeld Enhancement

This is just the enhancement in the scattering (annihilation) cross-section due to the presence of a long-range potential.

Solving the Schrodinger eq. in the presence of the potential:

$$-\frac{\nabla^2\psi}{M_\chi} + V\psi = E\psi \quad \Longrightarrow \quad \begin{cases} \langle\sigma v\rangle_0 \to \langle\sigma v\rangle = S(x)\langle\sigma v\rangle_0; \\ S(x) = \dfrac{|\psi(0)|^2}{|\psi^{(0)}(0)|^2} = |\psi(0)|^2 \end{cases}$$

Non-perturbative non-relativistic effects

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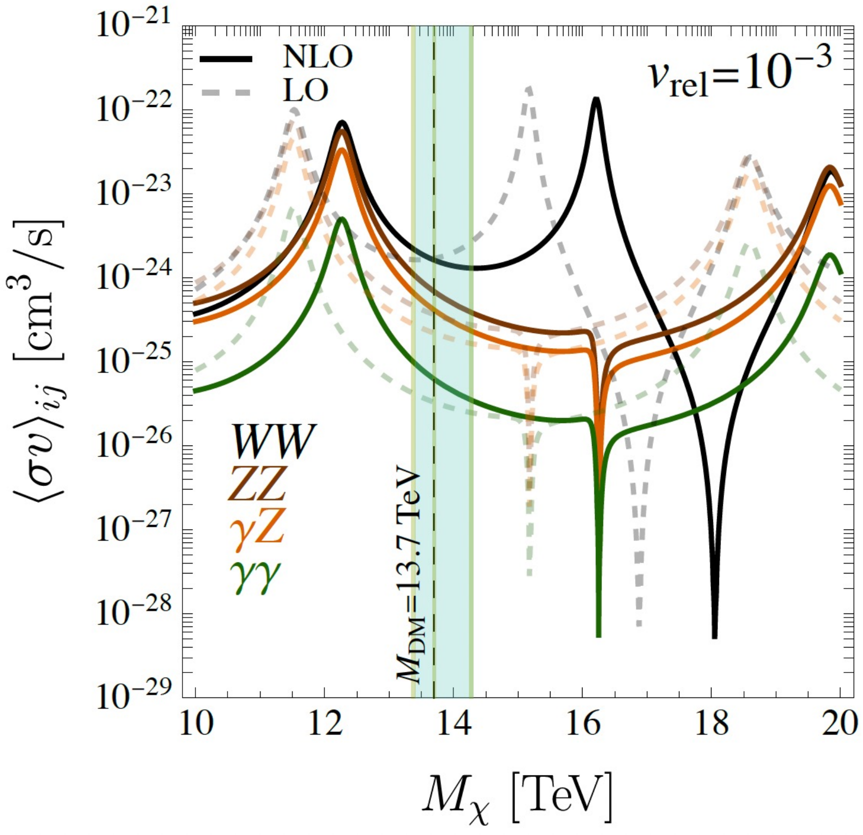
This is just the enhancement in the scattering (annihilation) cross-section due to the presence of a long-range potential.

$$\begin{cases} \langle \sigma v \rangle_0 \to \langle \sigma v \rangle = S(x) \langle \sigma v \rangle_0; \\ S = \dfrac{2\pi\alpha_{\rm eff}}{v_{\rm rel}} \cdot \dfrac{\sinh\left(\dfrac{\pi M_\chi v_{\rm rel}}{\kappa M_V}\right)}{\cosh\left(\dfrac{\pi M_\chi v_{\rm rel}}{\kappa M_V}\right) - \cosh\left(\dfrac{\pi M_\chi v_{\rm rel}}{\kappa M_V}\sqrt{1 - \dfrac{4\alpha_{\rm eff}\kappa M_V}{M_\chi v_{\rm rel}^2}}\right)} \end{cases}$$

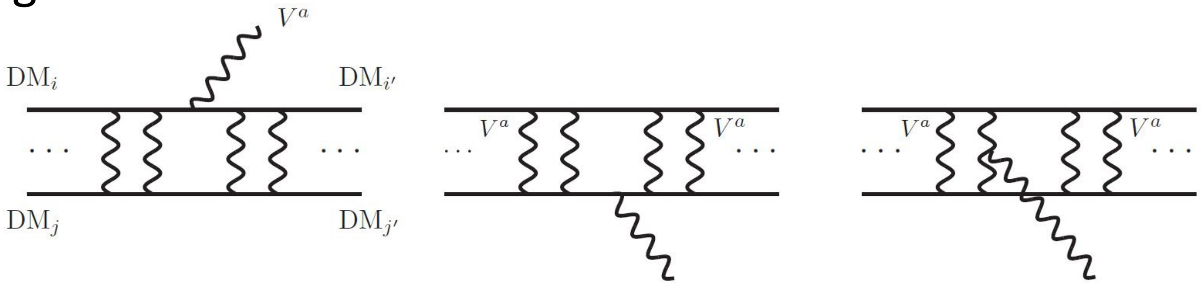


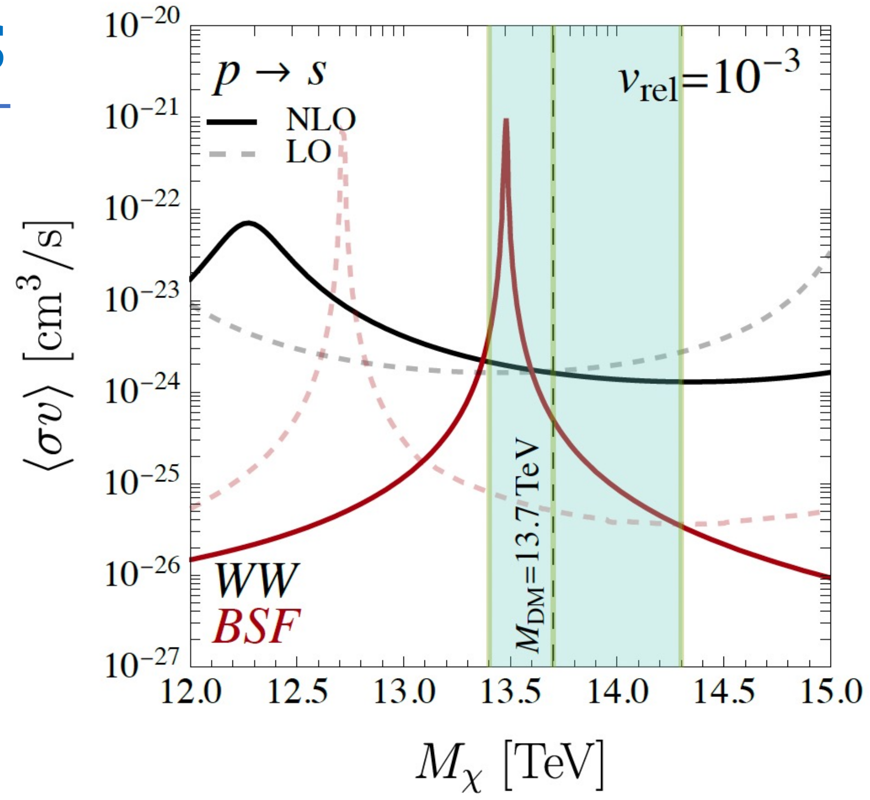
[Aghaie et al. 2025]

Non-perturbative non-relativistic effects

1. Sommerfeld Enhancement
2. Bound State Formation (BSF)

Particle-Antiparticle pair bind into a wimponium bound state emitting a gauge boson.





Eventually, these bound states annihilate into SM that enhances the annihilation cross section.

$$S(x) = S_{som}(x) + \left[\frac{\langle \sigma v \rangle_0}{\langle \sigma_I v \rangle} + \frac{g_\chi^2 \langle \sigma v \rangle_0 M_\chi^3}{2 g_I \Gamma_{ann}} \left(\frac{1}{4\pi x} \right)^{\frac{3}{2}} e^{-x E_{B_I}/M_\chi} \right]^{-1}$$

[Mitridate et al. 2017]

Non-perturbative non-relativistic effects

1. Sommerfeld Enhancement
2. Bound State Formation (BSF)

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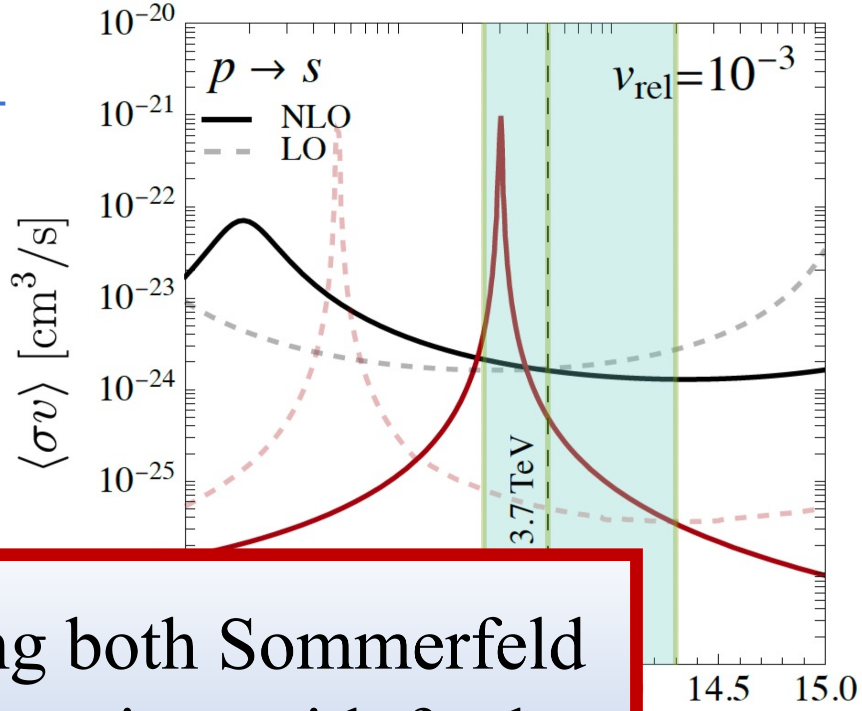


Eventu

Eventually, Solving the Boltzmann eq. including both Sommerfeld enhancement and BSF in the annihilation cross section, with further refinement of the theory uncertainty, we fix MDM 5plt mass to be

$$\boldsymbol{M_{5plt} = 13.7\,^{+0.6}_{-0.3}\ TeV}$$

[Aghaie et al. 2025]

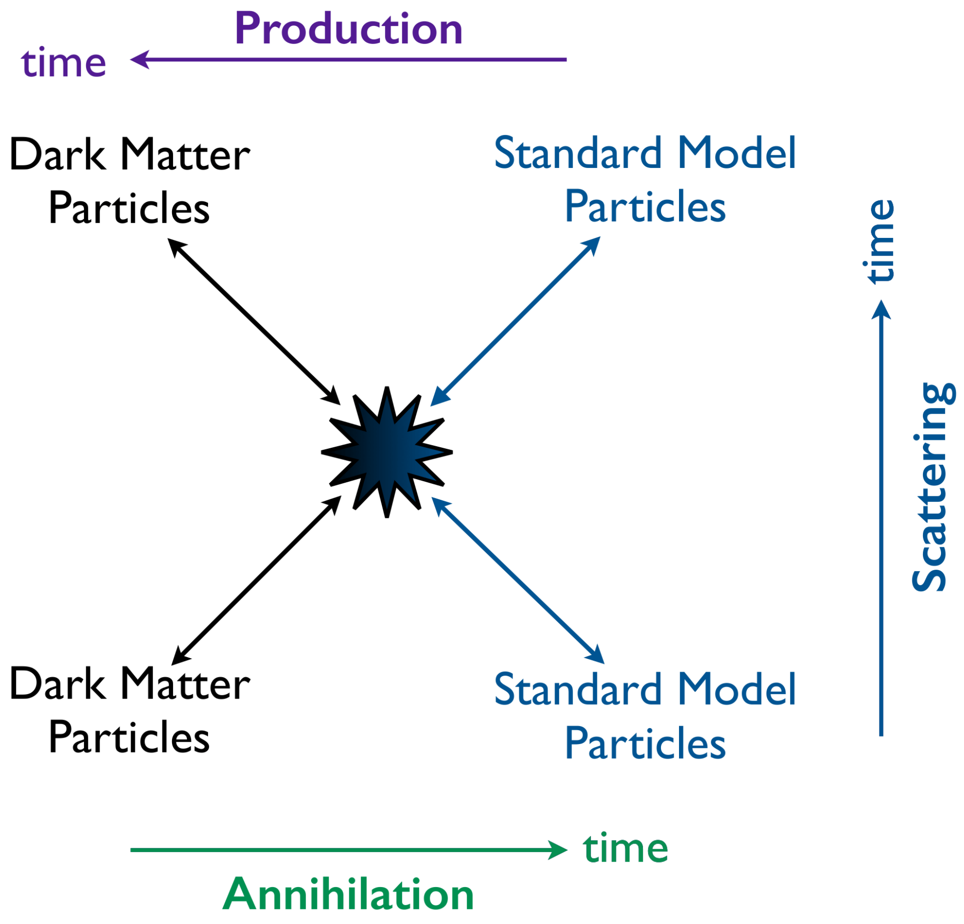
$$S(x) \quad S_{som}(x) \quad \left[\langle \sigma_I v \rangle \quad 2 g_I \Gamma_{ann} \quad (4\pi x) \right]^{-1}$$

[Mitridate et al. 2017]

Probing Minimal Dark Matter

Detection of minimal dark matter quintuplet

- Production @ Colliders
- Direct Detection
- Indirect Searches



Detection of minimal dark matter quintuplet

- Production @ Colliders

- Direct Detection

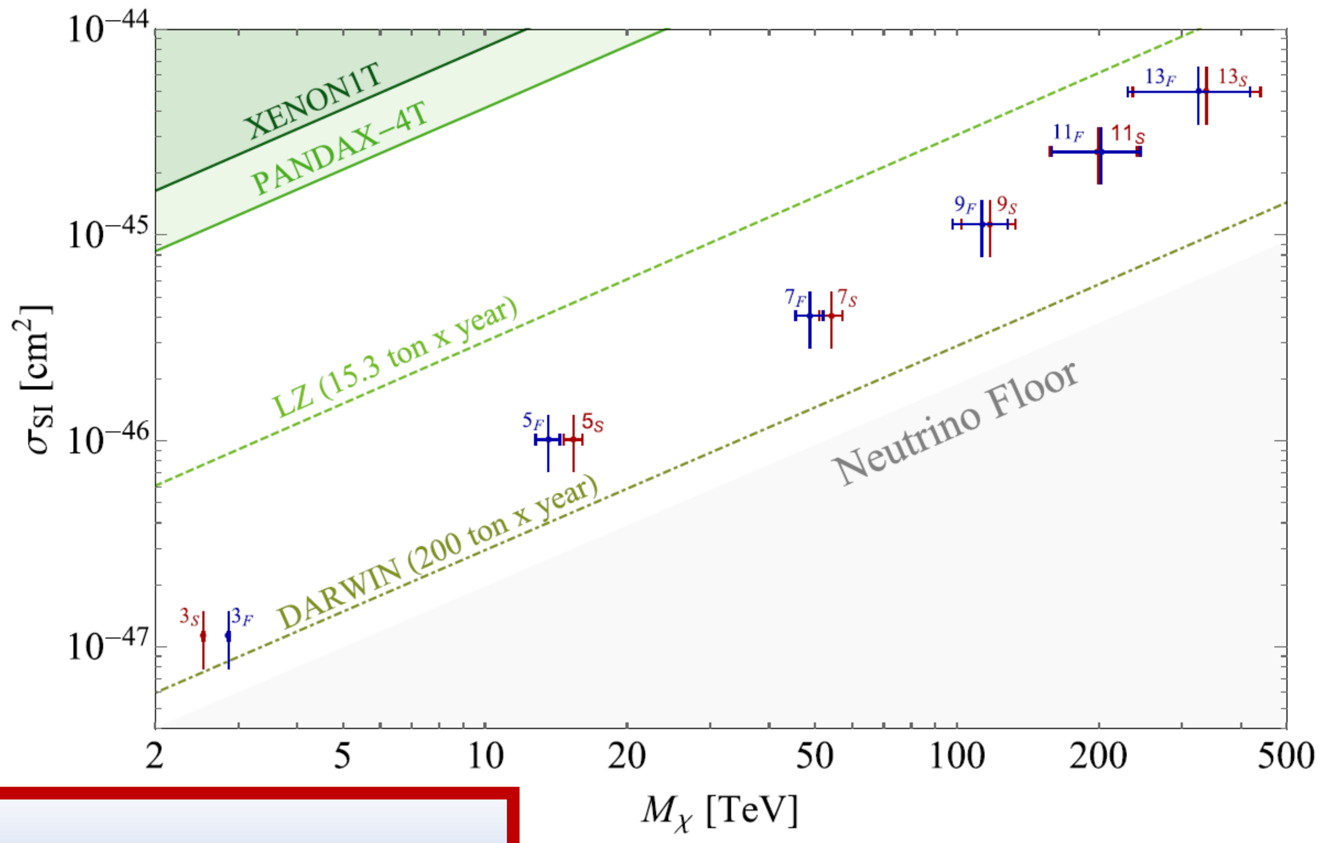
- Indirect Searches

Hadron colliders can not produce particles in this mass range any time soon. So,

- Not possible @ LHC ~ DM Masses $\mathcal{O}$ (200 GeV)
- Even out of reach of FCC with COM energy of 100 TeV. [Sala et al. 2014]
- Muon Collider (in 50 years ???) [Bottaro et al. 2021]

Detection of minimal dark matter quintuplet

- Production @ Colliders ✗
- Direct Detection
- Indirect Detection



[Bottaro et al. 2021]

All multiplets are above the neutrino floor, yet not reachable by any of the current experiments.

Detection of minimal dark matter quintuplet

- Production @ Colliders
- Direct Detection
- Indirect Detection

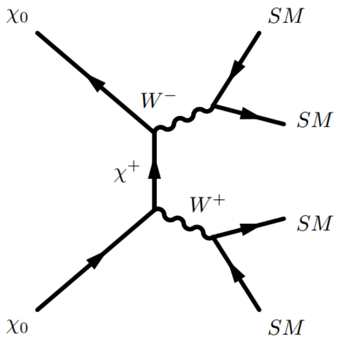
Ironically, Indirect detection is the most direct way to look for MDM candidates.

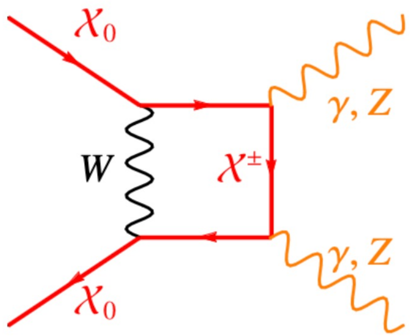
Indirect Detection of MDM Quintuplet

Annihilation channels for MDM Quintuplet

- at tree level*: DM annihilates into W^+, W^-
- at loop level : DM annihilates into $\gamma\gamma, \gamma Z, ZZ$
- through BSF: DM annihilates into $\bar{f}f\ V, \bar{h}h\ V$;

$V = \{W, Z, \gamma\}$



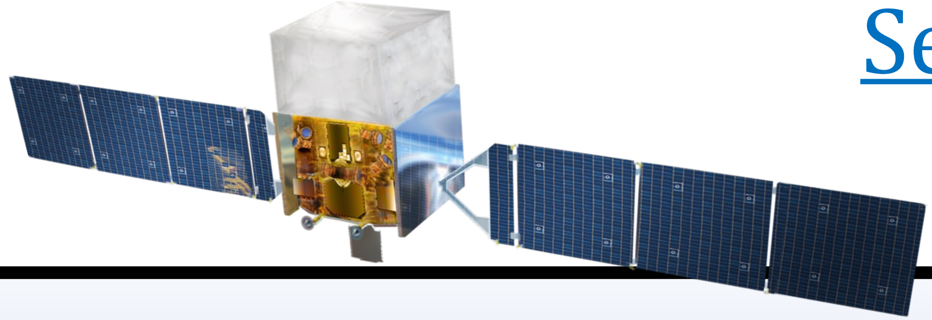


ANNIHILATION SIGNATURES

The γ-ray line associated with DM annihilation (at E = 13.7 TeV)

The γ-ray line associated with Bound State Formation (at E_b = 72 GeV)

The γ-ray continuum generated by the decay of SM gauge bosons.



Search Strategy

Line + Continuum Analysis

BSF line (E = 72 GeV)

BS → ff γ + BS → hh γ

Target: Galactic Center
(highest J-factor)

Line Analysis

Direct Annihilation line (E = 13.7 TeV)

$\chi\chi \rightarrow \gamma Z$ + $\chi\chi \rightarrow \gamma\gamma$

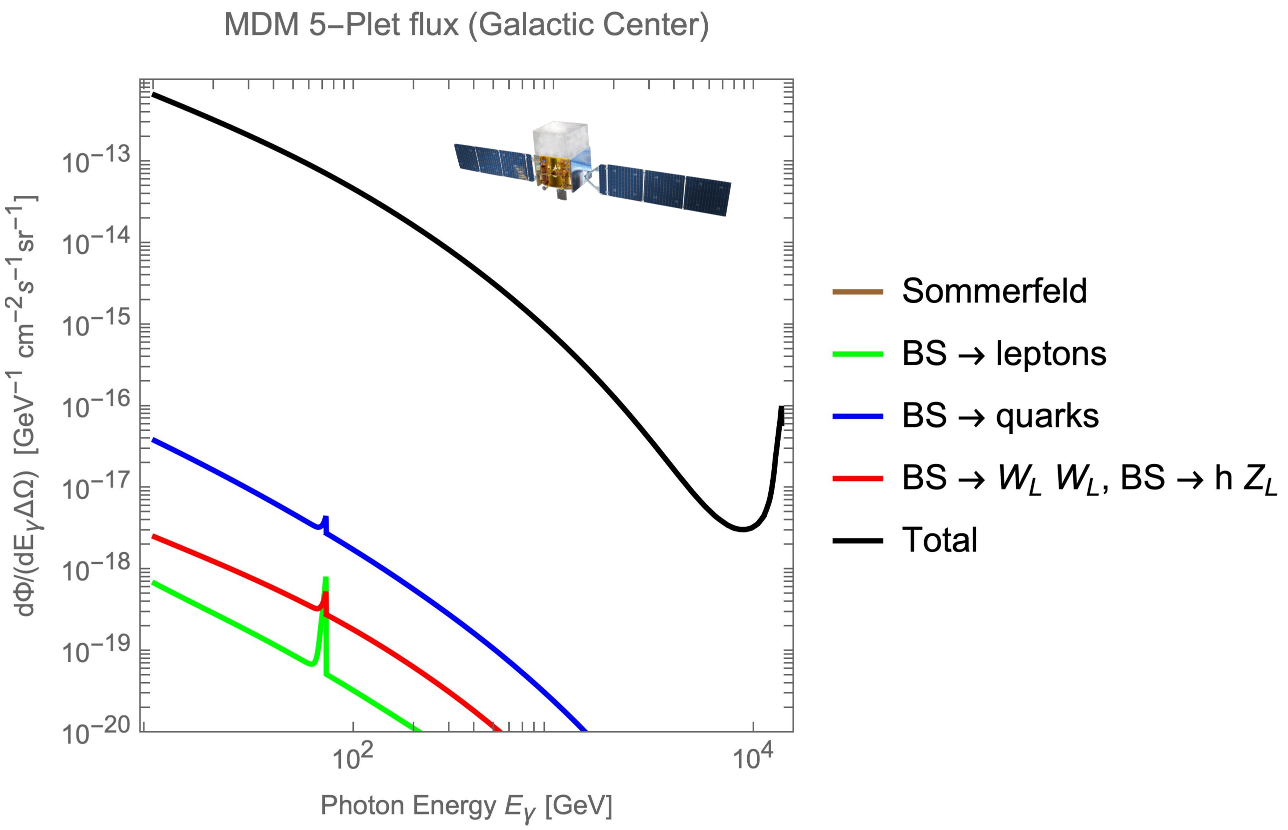
Target: dwarf Spheroidal Galaxies
(Lowest Astrophysical Background)

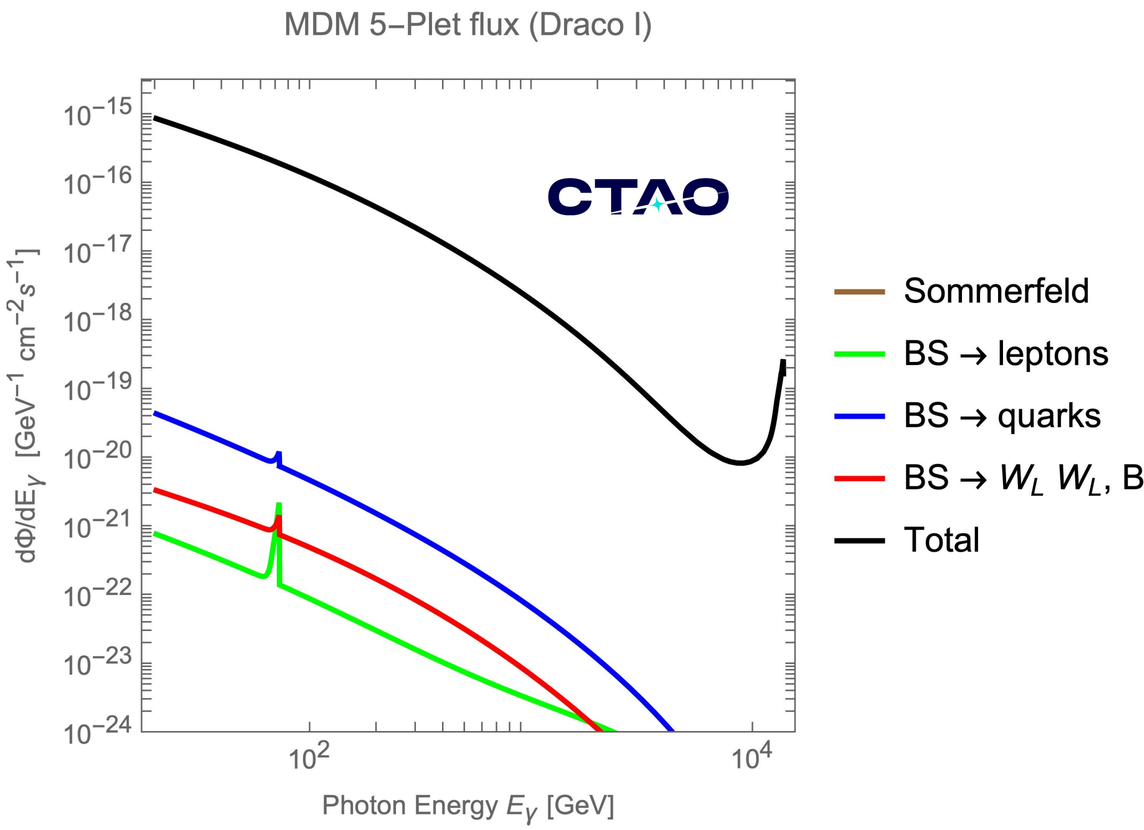
Target	**Inner Galaxy**	**dSph (Northern hemisphere)**			
	RoI16 (Einasto)	Dra I [51]	Wil 1 [51]	CBe [51]	UMajII [52]
$\log_{10} J$ [GeV^2/cm^5]	23.0	$18.7^{+0.3}_{-0.1}$	$19.1^{+0.6}_{-0.5}$	$19.5^{+0.9}_{-0.7}$	$19.44^{+0.41}_{-0.39}$

DM flux

The differential gamma-ray flux produced in the annihilation of pairs of Majorana DM particles, coming from a particular angular direction $d\Omega$, is given by:

$$\frac{d\Phi_\gamma}{d\Omega dE_\gamma} = \frac{1}{8\pi M_{DM}^2} J(\theta) \sum_f \langle \sigma v \rangle_f \frac{dN^f}{dE_\gamma}$$

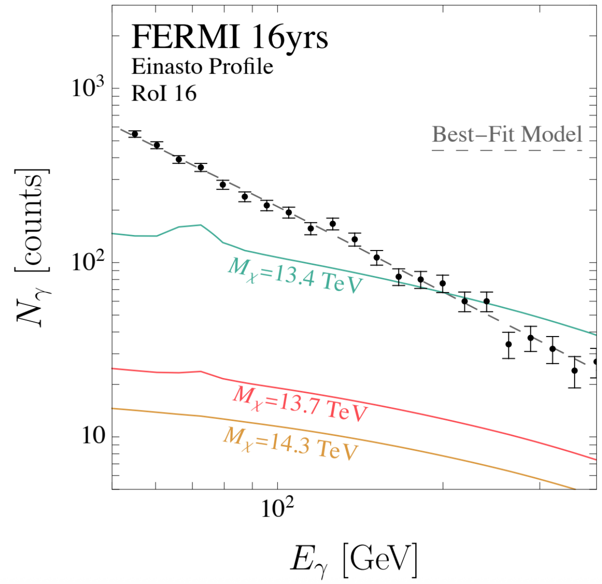




Number of Events

The next step is to convolve the computed flux with the characteristics of the Telescope to get the rate of incoming photons we can expect from each source.

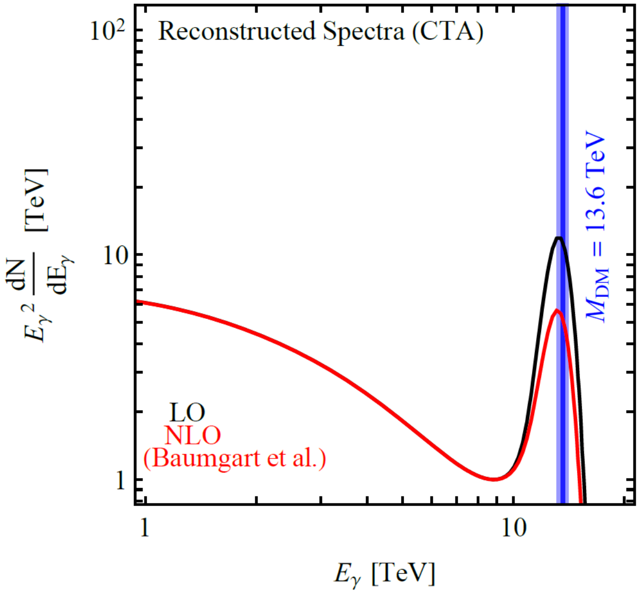
$$N^i_{\rm DM,\,bkg} = {\rm DRM}^i_j \int_{E_j}^{E_{j+1}} {\rm dE}_\gamma \frac{{\rm d}\Phi^{\rm RoI}_{\rm DM,\ bkg}({\rm E}_\gamma)}{{\rm dE}_\gamma} \mathcal{E}^{\rm RoI}({\rm E}_\gamma)$$



CTAO

$$N^i_{\rm DM} = T_{\rm obs} \int_{E_i}^{E_{i+1}} dE' \, \frac{d\Gamma_{\rm DM}(E')}{dE'},$$

$$\frac{d\Gamma_{\rm DM}(E')}{dE'} = \int_0^{M_\chi} dE_\gamma \frac{d\Phi_{\rm DM}(E_\gamma)}{dE_\gamma} \mathcal{A}(E_\gamma) R(E_\gamma, E')$$



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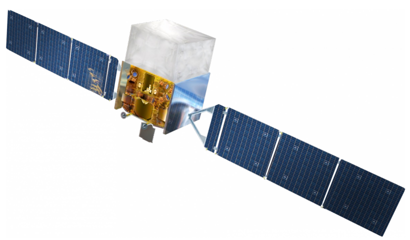
Statistical Analysis – Fermi-LAT



For a fixed DM mass, we build a joint Poissonian likelihood over all the energy bins in the fiducial window

$$\mathcal{L}(\kappa, A_{\rm iso}, A_{\rm diff}) = \prod_{i=1}^{\mathcal{N}} \frac{(N^i_{\rm th}(\kappa, A_{\rm iso}, A_{\rm diff}))^{N^i_{\rm obs}}}{N^i_{\rm obs}!} e^{-N^i_{\rm th}(\kappa, A_{\rm iso}, A_{\rm diff})}$$

with

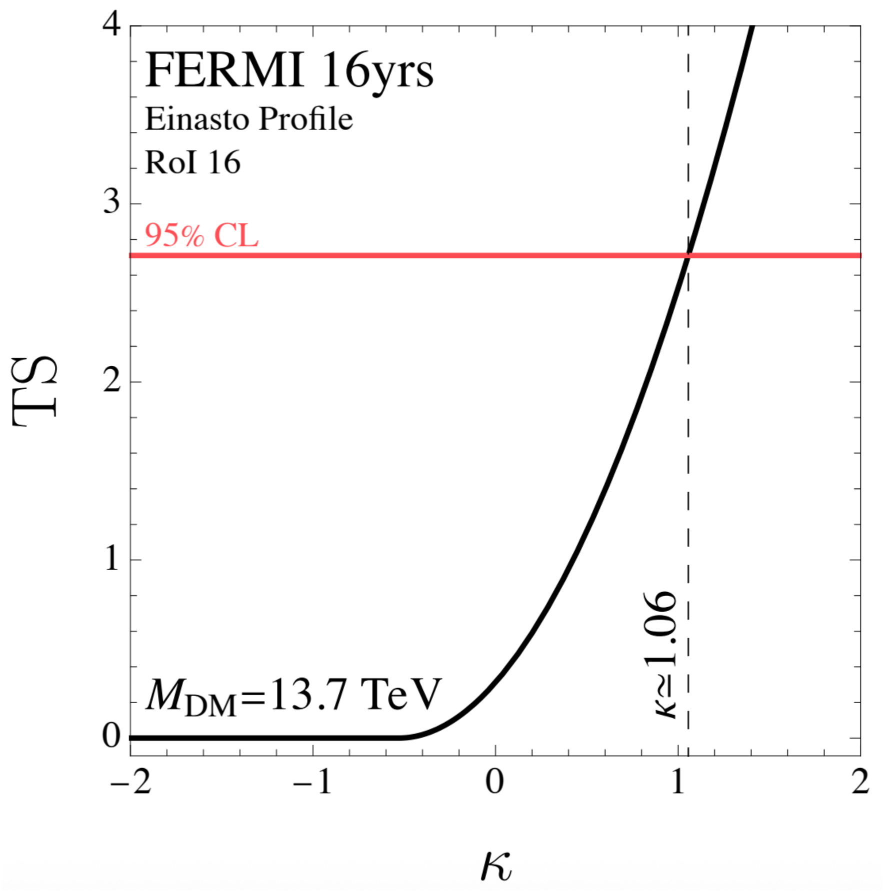
$$N^i_{\rm th} \equiv \kappa\, N^i_{\rm DM} + A_{\rm iso} N^i_{\rm iso} + A_{\rm diff} N^i_{\rm diff}$$

At first step, we marginalize this likelihood function over all three free parameters to compute their best fit values. Then we define Test Statistic as follows:

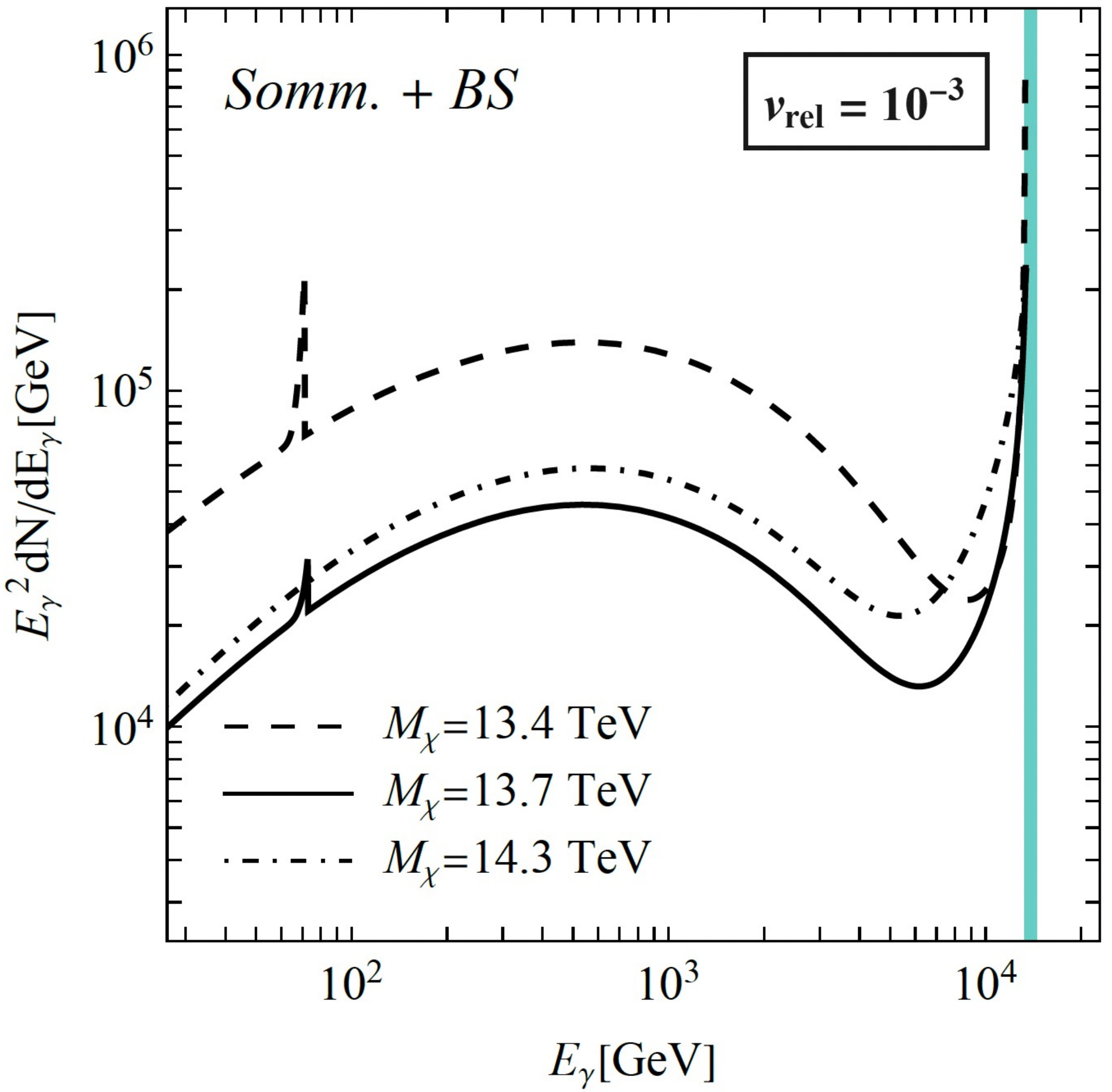
$$\mathrm{TS}(\kappa) = 2 \log \left[\frac{\max_{\kappa, A_{\rm iso}, A_{\rm diff}} \mathcal{L}(\kappa, A_{\rm iso}, A_{\rm diff})}{\max_{A_{\rm iso}, A_{\rm diff}} \mathcal{L}(\kappa, A_{\rm iso}, A_{\rm diff})} \right]$$

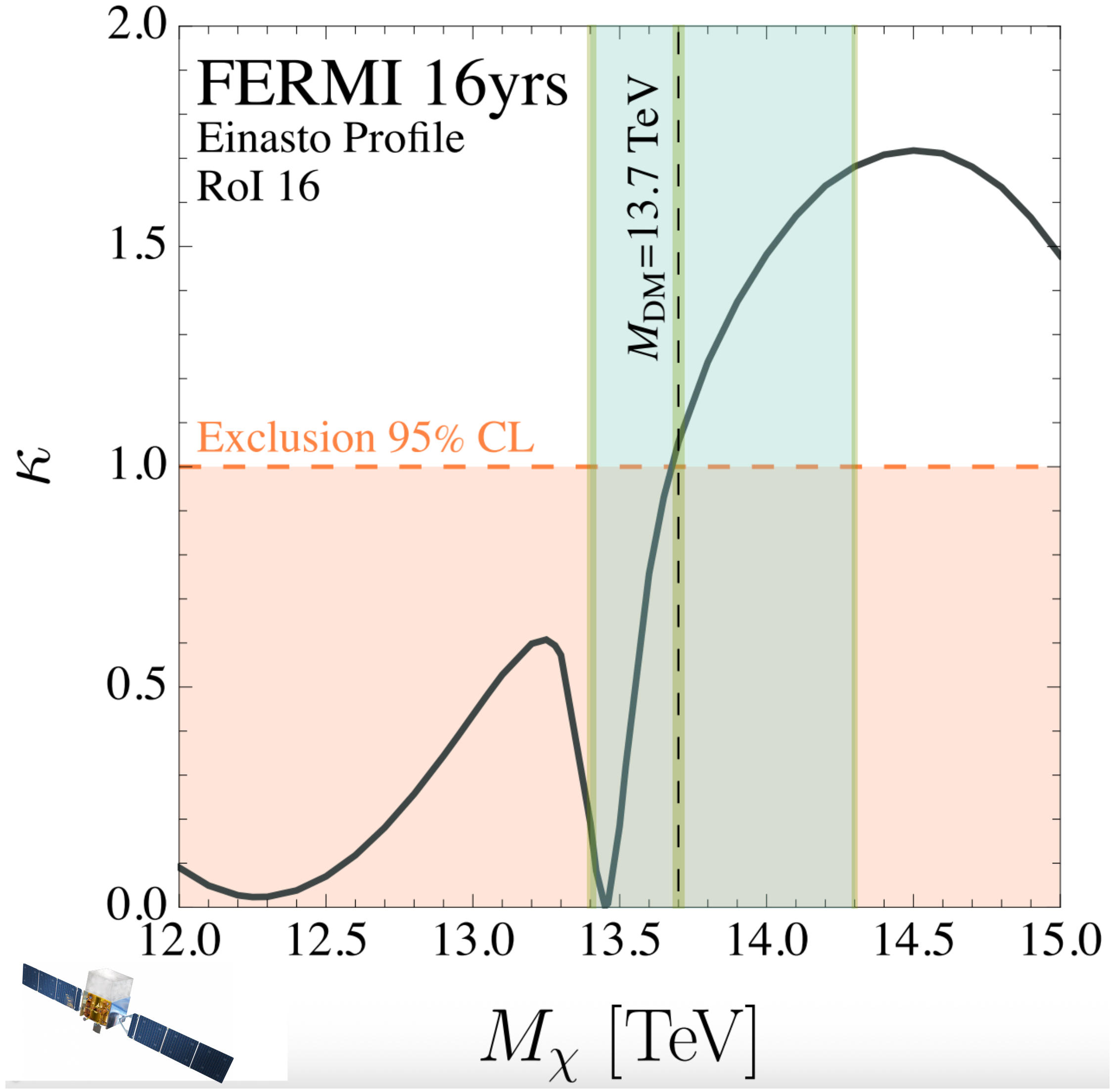
Since TS follows an asymptotic χ^2 distribution with one degree of freedom, we can use Wilks' theorem to determine the one-sided 95% CL upper limit on κ by requiring $\mathrm{TS}(\kappa) \simeq 2.71$.

Then, since there are no free parameters in MDM, we use TS(k) = 2.71 to normalize the cross section and determine the cross section ruled out by the current data.



Results – Fermi-LAT





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Statistical Analysis – CTAO

Again, we start by building a joint Poissonian likelihood

$$\mathcal{L}(T_{\rm obs}) = \prod_{i=1}^{\mathcal{N}} \frac{N^i_{\rm th}(T_{\rm obs})^{N^i_{\rm obs}(T_{\rm obs})}}{N^i_{\rm obs}(T_{\rm obs})!} e^{-N^i_{\rm th}(T_{\rm obs})}$$

with
$$N^i_{\rm th}(T_{\rm obs}) = N^i_{\rm DM}(T_{\rm obs}) + N^i_{\rm bkg}(T_{\rm obs})$$
$$N^i_{\rm obs} = N^i_{\rm bkg}(T_{\rm obs})$$

we treat the J-factor as a nuisance parameter and marginalize over it

$$\mathcal{L}^J = \frac{1}{\ln(10) J_{\rm obs}} \mathcal{G}(\log_{10} J | \log_{10} J_{\rm obs})$$

Then we define our full Likelihood function as

$$\mathcal{L}_{sys}(\kappa) = \prod_{i=1}^{\mathcal{N}} \max_J \left[\mathcal{L}_i(T_{\rm obs}) \times \mathcal{L}^J\right]$$

Statistical Analysis – CTAO

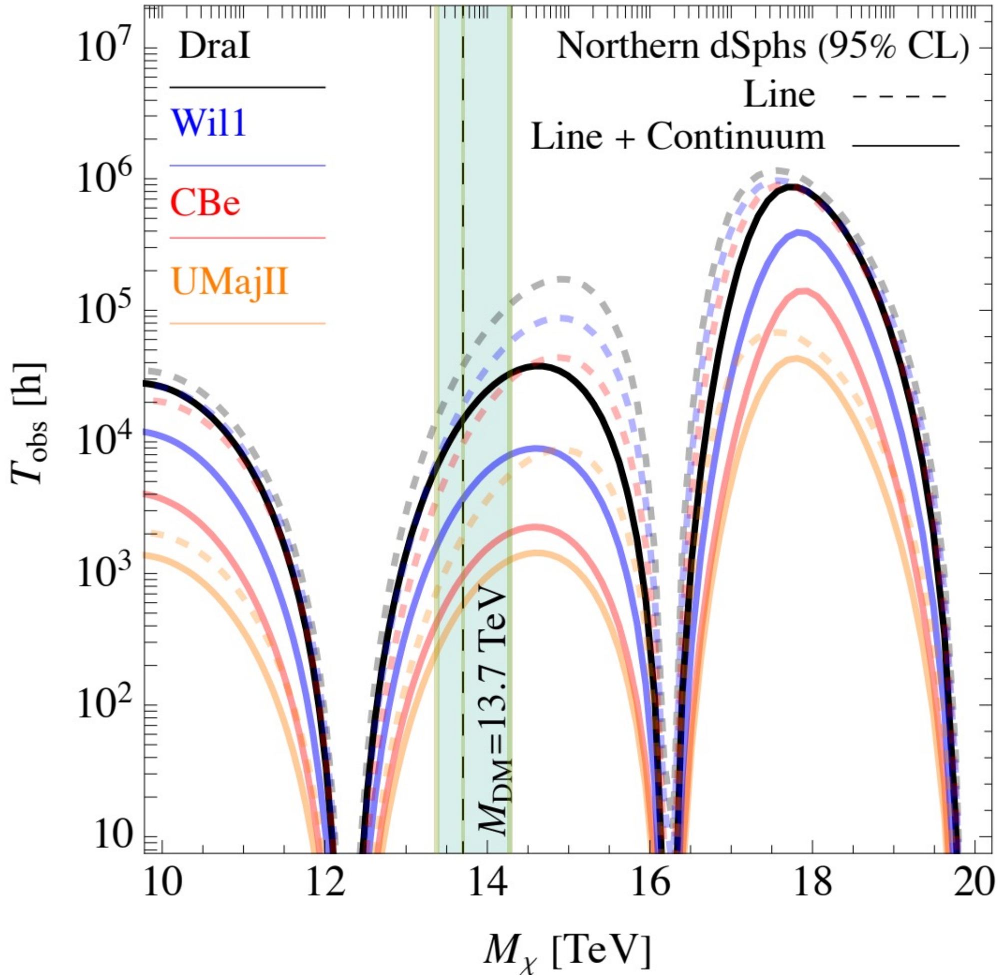
Eventually, we will define TS

$$TS(T_{\rm obs}) = -2\ln\left(\frac{L_{\rm sys}(T_{\rm obs})}{L^0_{\rm sys}(T_{\rm obs})}\right)$$

Here, the L0 is just the null hypothesis.

And we use TS (Tobs) = 2.71 to extract the observation time required for CTAO to become sensitive to the MDM 5plet signal.

WITH 600 HOURS OF OBSERVATION OF URSA MAJOR II , WE MIGHT BE ABLE TO SAY THE FINAL WORD ON MDM 5PLT



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Take away…

- DM is the most compelling hint towards the physics beyond standard model.
- WIMPs are one of the most motivated families of DM candidates.
- Due to a number of null results, the interest in WIMPs is diminishing, yet WIMPs and minimal dark matter in particular are not excluded, yet!
- Due to the large mass of MDM candidates, non-relativistic, non-perturbative phenomena like Sommerfeld enhancement and bound state formation must be included.
- The gamma-ray line associated with bound state formation opens up new direction in ID.
- Astrophysical targets like the Galactic center, dSph galaxies, and galaxy clusters can provide a complementary search for MDM.
- Next decade might shed light on the fate of MDM candidates.

Thank You!

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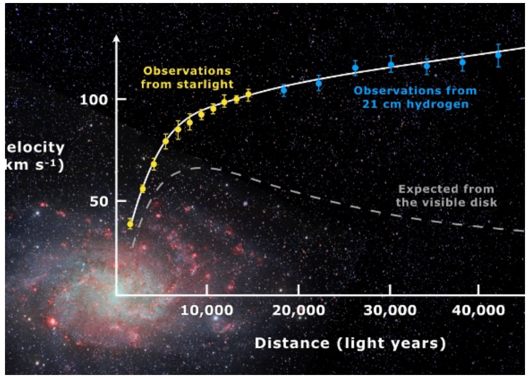
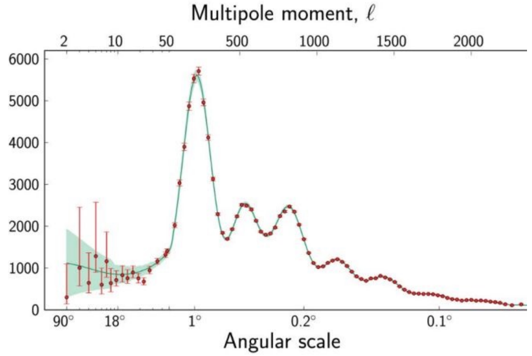
Dark Matter Exists!





- the velocity dispersion of galaxies within galaxy clusters
- Galactic Rotation Curves
- Gravitational lensing
- Large-Scale Structure
- Structure Formation
- Bullet Cluster

&

❖ Cosmic Microwave Background (CMB)

WIMPs and Thermal Freeze Out

As the name perfectly captures, WIMPs are:

1. **Weakly Interacting:** interact via weak nuclear force (no EM or strong interactions)
2. **Massive:** in the GeV – TeV range.

At high enough temperatures, WIMPs were in thermal eq. with SM plasma, i.e.

$$\chi\chi \leftrightarrow \text{SM SM}$$

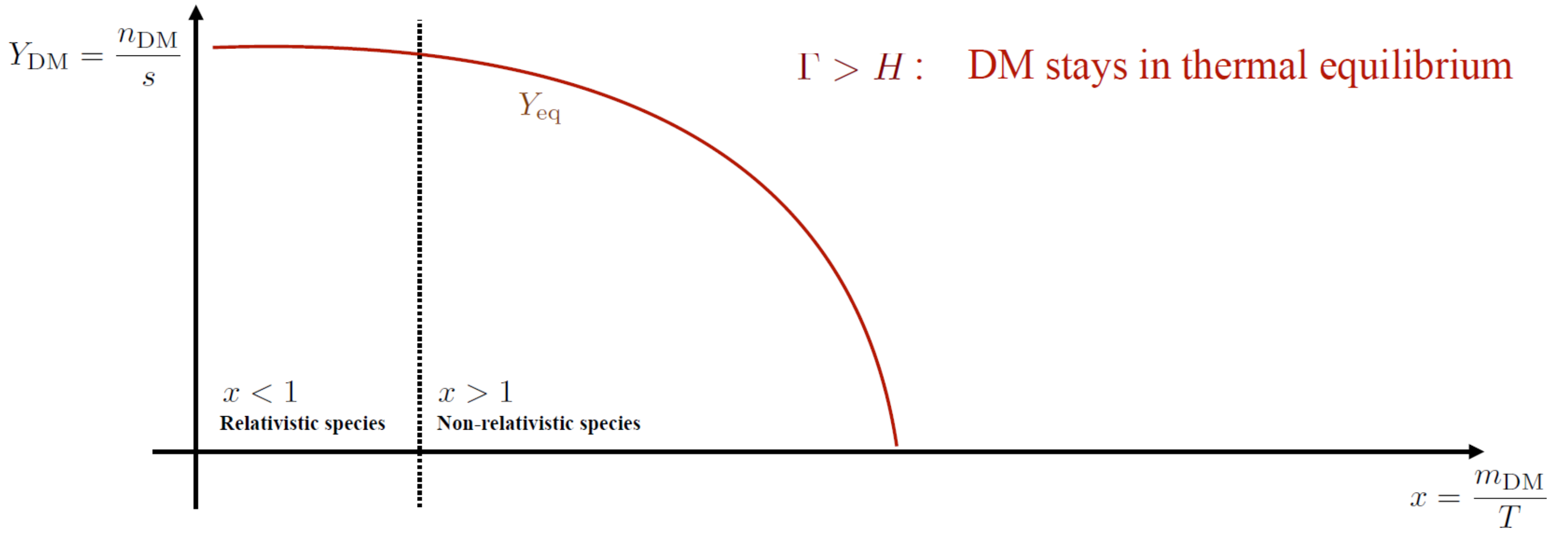
As the universe expands, the temperature decreases and when $T < m_\chi$

$$\chi\chi \rightarrow \text{SM SM}$$

If DM annihilation stays efficient,

$$\Gamma = n_\chi \langle \sigma v \rangle > H(T)$$

DM annihilates completely!



WIMPs and Thermal Freeze Out

As the name perfectly captures, WIMPs are:

1. **Weakly Interacting:** interact via weak nuclear force (no EM or strong interactions)
2. **Massive:** in the GeV – TeV range.

At high enough temperatures, WIMPs were in thermal eq. with SM plasma, i.e.

$$\chi\chi \leftrightarrow \text{SM SM}$$

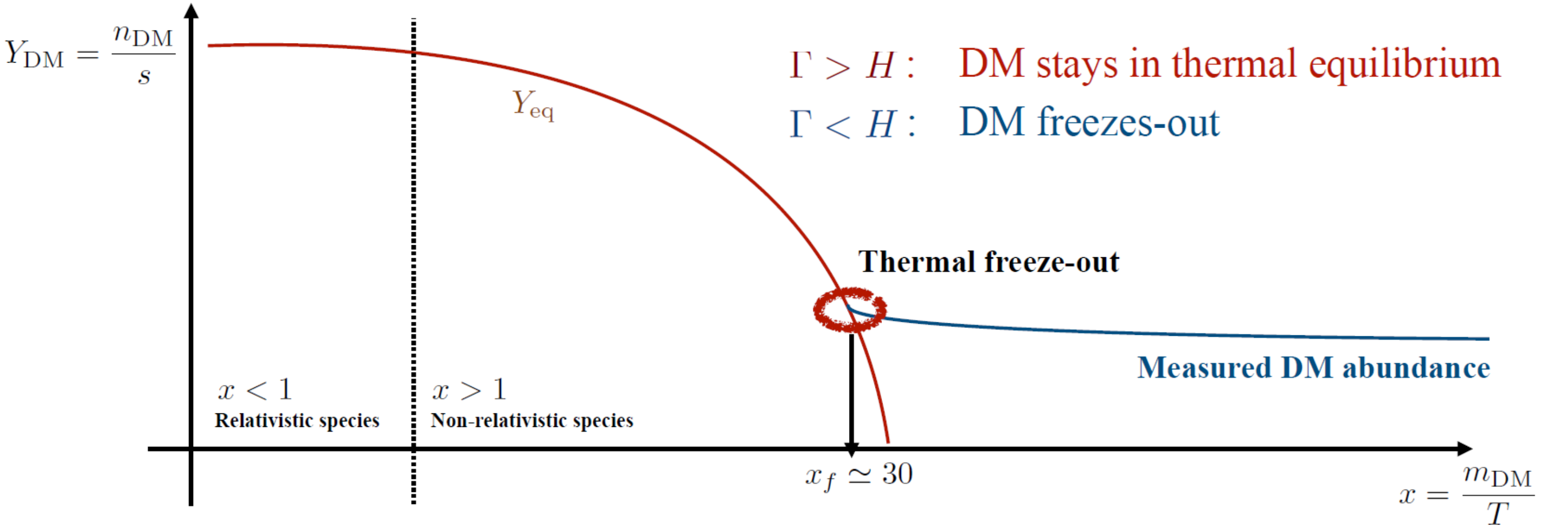
As the universe expands, the temperature decreases and when $\mathrm{T} < m_\chi$

$$\chi\chi \rightarrow \text{SM SM}$$

But if DM ann. x-sec drops,

$$\Gamma = n_\chi \langle\sigma v\rangle < H(T)$$

DM Freeze out!



Boltzmann Equation and the "WIMP Miracle"

The time evolution of the WIMP is determined by the Boltzmann equation,

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma v\rangle(n_\chi^2 - n_{\chi,\mathrm{eq}}^2)$$

In the WIMP scenario this eq. can be solved analytically and interestingly,

$$\Omega_\chi h^2 \propto \langle\sigma v\rangle^{-1}$$

Eventually if we require the WIMP to reproduce the observed relic abundance of the DM today

$$\Omega_\chi h^2 \simeq 0.12 \quad \Longrightarrow \quad \langle\sigma v\rangle \propto \frac{\alpha_w^2}{M_W^2} \sim 3\times10^{-27}\ cm^3/s$$

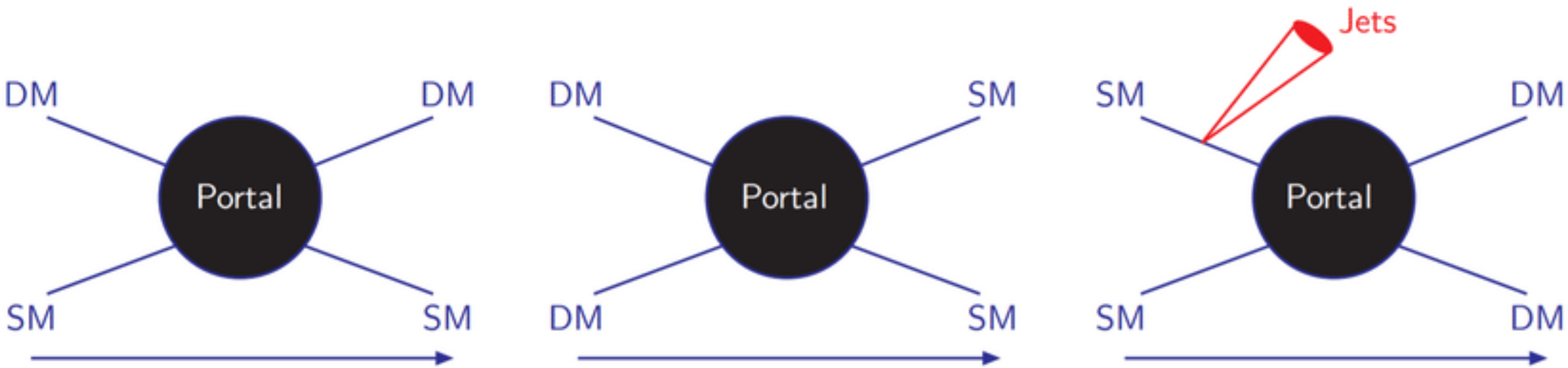
The fact that a thermal relic with a cross section characteristic of the weak interaction gives the right dark matter abundance is called *the WIMP miracle*.

So, Why WIMPs?

1. Natural explanation for relic abundance: The WIMP miracle ties particle physics and cosmology elegantly.

2. Testable predictions: WIMPs could, in principle, interact with SM particles via:
    - Direct detection (scattering off nuclei in underground detectors)
    - Indirect detection (annihilation producing gamma rays, neutrinos, or cosmic rays)
    - Collider production (missing energy signatures at the LHC)

3. Wide theoretical motivation: Many beyond-SM models (e.g. Super Symmetry, Extra dimensions, etc) predict WIMP candidates, making them a robust and well-motivated class of dark matter particles.



(a) Direct Detection (b) Indirect Detection (c) Collider Detection

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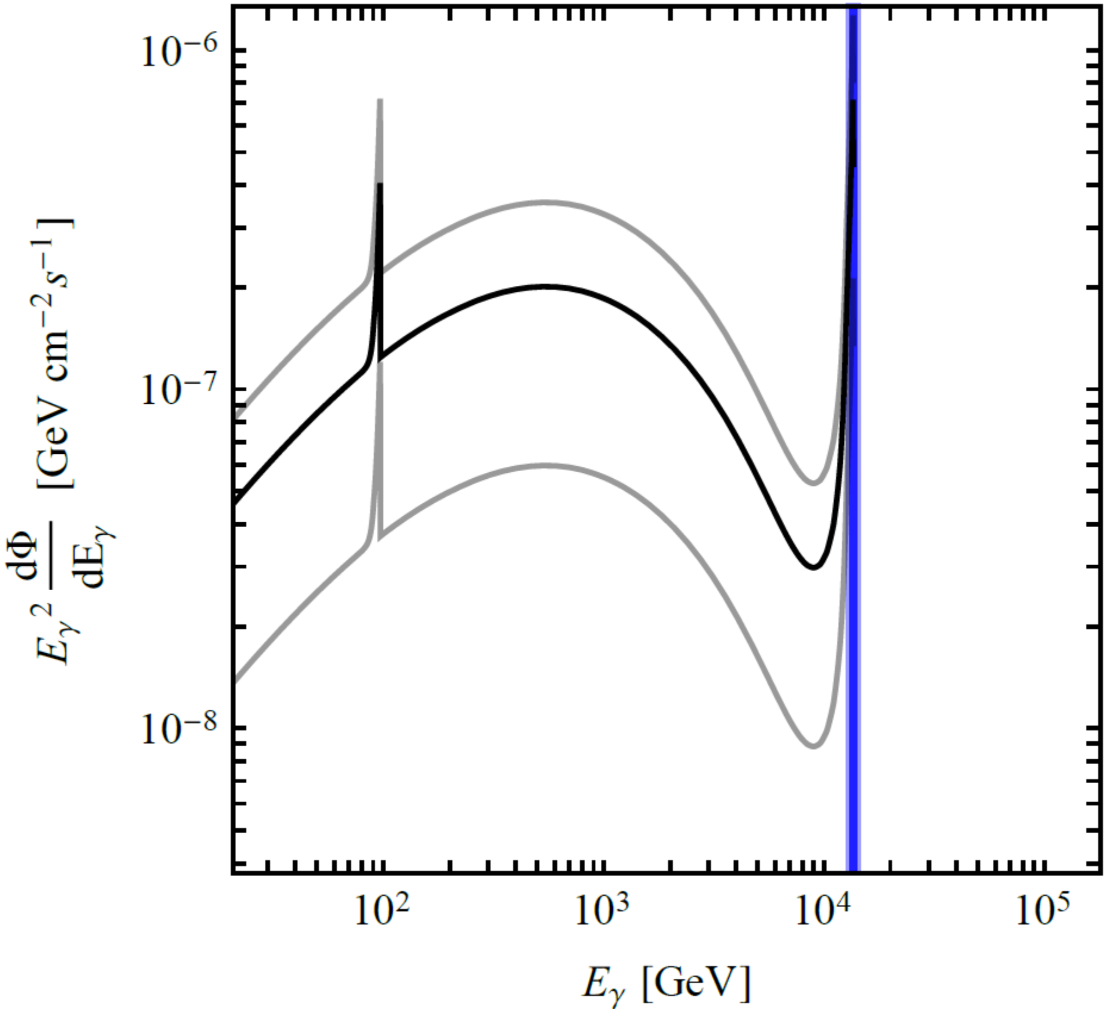
The gamma-ray line associated with BSF(Fermi-LAT)

The BSF gamma-ray line is not as prominent as the one associated with the annihilation. Therefore, at the first step, we look into the galactic center which is reacher in DM.

Different fluxes in the plot are associated with different regions of interest. In the study of Galactic Center we have optimized our evaluation using Likelihood analysis for the size of the ROIs.



Indirect Detection

We select the most promising Dwarf Spheroidal Galaxies for our study

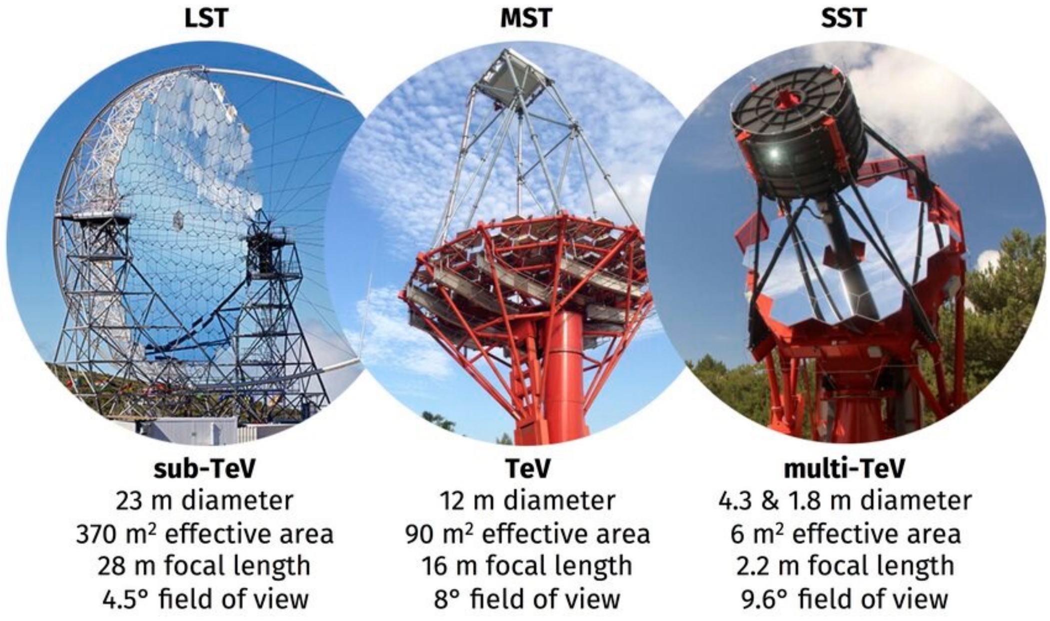
Target	Hemisphere	Distance [kpc]	Angular size [deg] [1]	log10($J_{0.5}$) – s wave [2]	log10($J_{0.5}$) – Sommerfeld [2]
Draco I	N	76	1.30	$18.82^{+0.12}_{-0.12}$	$22.97^{+0.13}_{-0.12}$
Ursa Minor I	N	76	1.37	$18.76^{+0.12}_{-0.11}$	$23.05^{+0.13}_{-0.15}$
Sculptor I	S	86	1.94	$18.58^{+0.05}_{-0.05}$	$22.84^{+0.08}_{-0.07}$
Fornax	S	147	2.61	$18.09^{+0.10}_{-0.10}$	$22.34^{+0.10}_{-0.11}$
Ursa Major II	N	32	0.53	$19.44^{+0.41}_{-0.39}$	$23.66^{+0.33}_{-0.30}$
Willman I	N	38	N/A	$19.36^{+0.52}_{-0.46}$	$23.72^{+0.38}_{-0.38}$
Coma Berenices I	N	44	0.31	$19.01^{+0.36}_{-0.36}$	$23.30^{+0.24}_{-0.24}$
Segue I	N	23	0.35	$19.00^{+0.48}_{-0.68}$	$23.59^{+0.40}_{-0.53}$
Reticulum II	S	30	N/A	$18.94^{+0.38}_{-0.38}$	$23.36^{+0.26}_{-0.25}$
Hydrus I	S	28	N/A	$18.65^{+0.32}_{-0.31}$	$23.14^{+0.23}_{-0.21}$
Ursa Major I	N	97	0.43	$18.33^{+0.28}_{-0.28}$	$22.61^{+0.22}_{-0.22}$
Bootes I	N	66	0.47	$18.19^{+0.30}_{-0.28}$	$22.54^{+0.22}_{-0.21}$

Cherenkov Telescope Array (CTA)

- CTA, the Cherenkov Telescope Array, is the next-generation ground-based instrument for gamma-ray astronomy at very high energies, from some tens of GeV to about 300 TeV.

- It will have up to 118 telescopes on two sites in the North and South – Baseline configuration:
  - -19 in the North, 99 in the South
  - -Largest existing instrument has 5 telescopes

- It is designed and built in a large international collaboration in late 2020, and early 2030.



credit: CTA

Fermi-Large Area Telescope (LAT)

- Satellite gamma-ray telescope
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV
- Key features
  - Huge field of view
    - 30 mins full sky every 3hrs
  - Huge energy range
- Milestones
  - 11 jun 2008 : launch
  - 04 aug 2008 : science ops start
  - 13 aug 2009 : γ data go public
  - 18 feb 2010 : 100B triggers
  - 99.1% uptime from launch, 99.99% from October 2009

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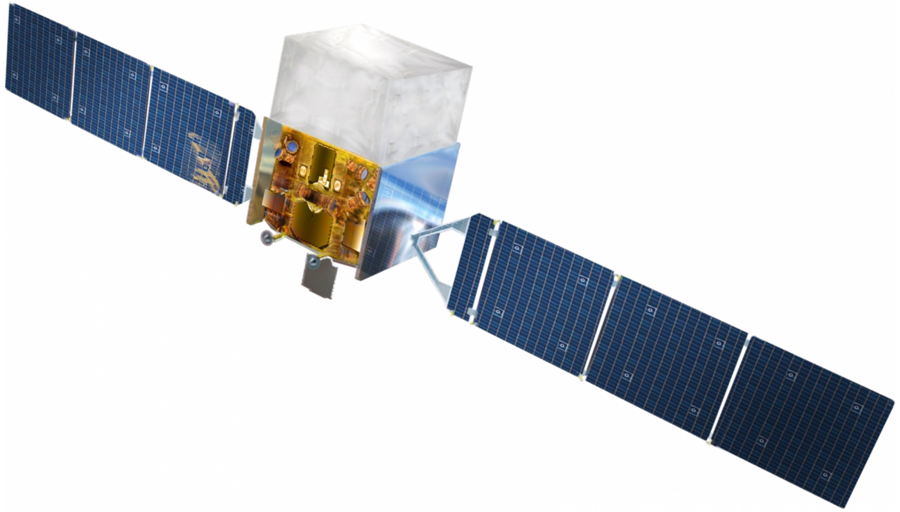


Slide credit: Latronico

Dark Matter Flux [Cirelli et al. 2010]

The differential gamma-ray flux produced in the annihilation of pairs of Majorana DM particles, coming from a particular angular direction $d\Omega$, is given by:

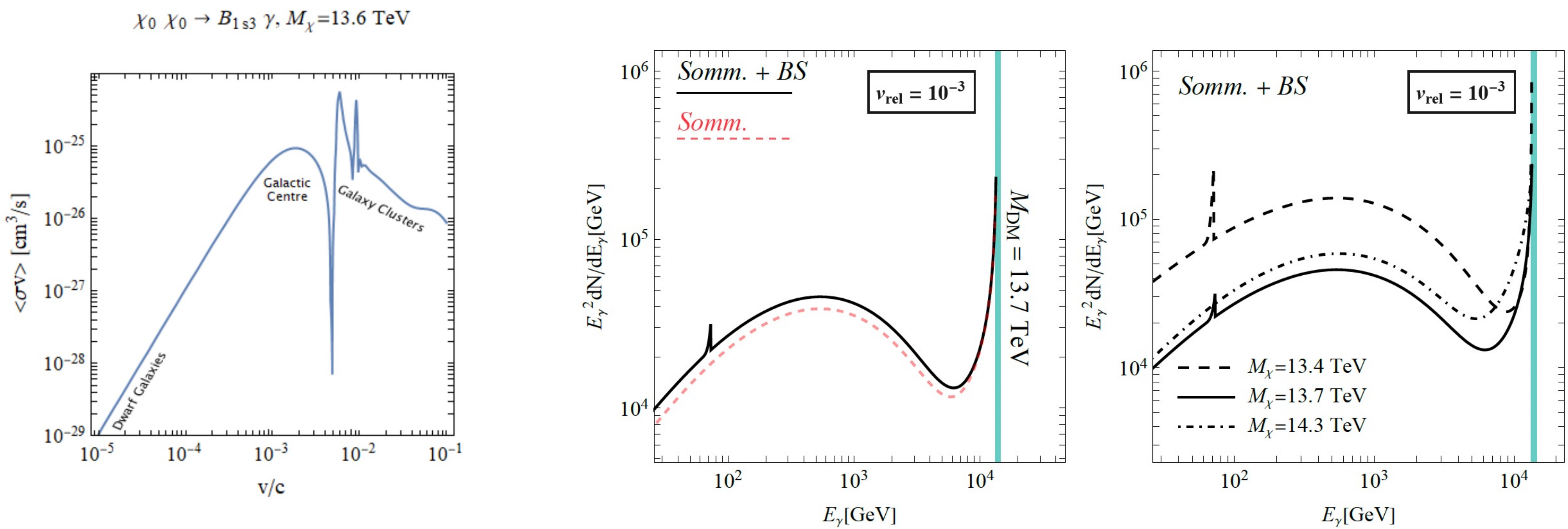
$$\frac{d\Phi_\gamma}{d\Omega dE_\gamma} = \frac{1}{8\pi M_{DM}^2} \underbrace{J(\theta)}_{\text{Astrophysics}} \underbrace{\sum_f \langle\sigma v\rangle_f \frac{dN^f}{dE_\gamma}}_{\text{Particle Physics}}$$

$$J(\theta) = \int_{l.o.s} ds\, \rho(r(s,\theta))^2$$

is literally called the **J-factor** and determines the DM density of a given source. J-factor fully determined by Astrophysics.

$$\sum_f \langle\sigma v\rangle_f \frac{dN^f}{dE_\gamma}$$

is the **photon spectra** and is fully determined by particle physics.



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