TeVPa 2023

An indirect search for dark matter with a combined analysis of dwarf spheroidal galaxies from VERITAS

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on behalf of the VERITAS collaboration

National Science Challenge Initiatives
Center for the Gravitational-Wave Universe

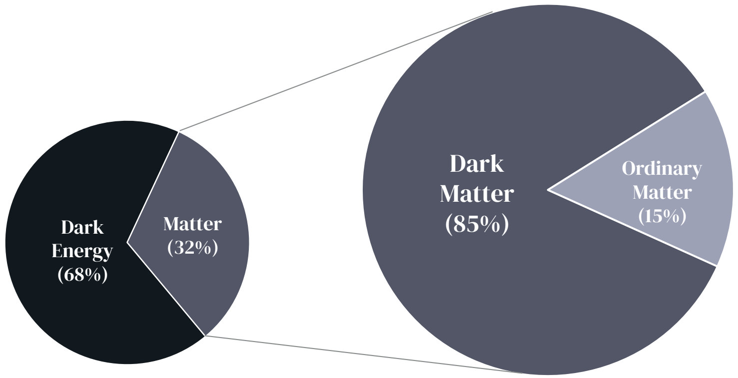
What is Dark Matter (DM)?

A lot of observational evidences

Does not interact with light but does have mass

Forms large clouds or halos around galaxies

About 85% of the matter in the universe



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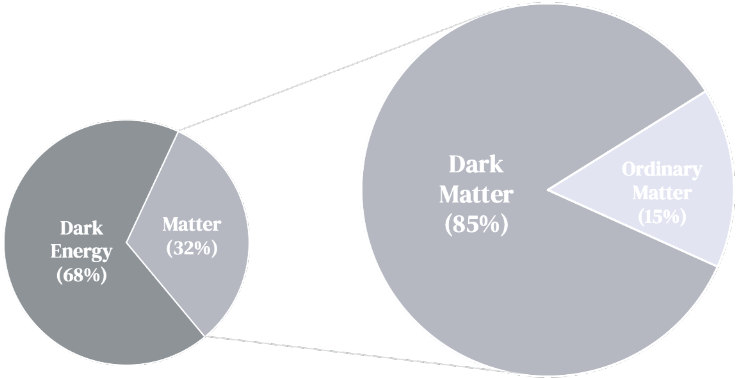


A point-like particle? or a composite particle?

One kind of particles or more than one?

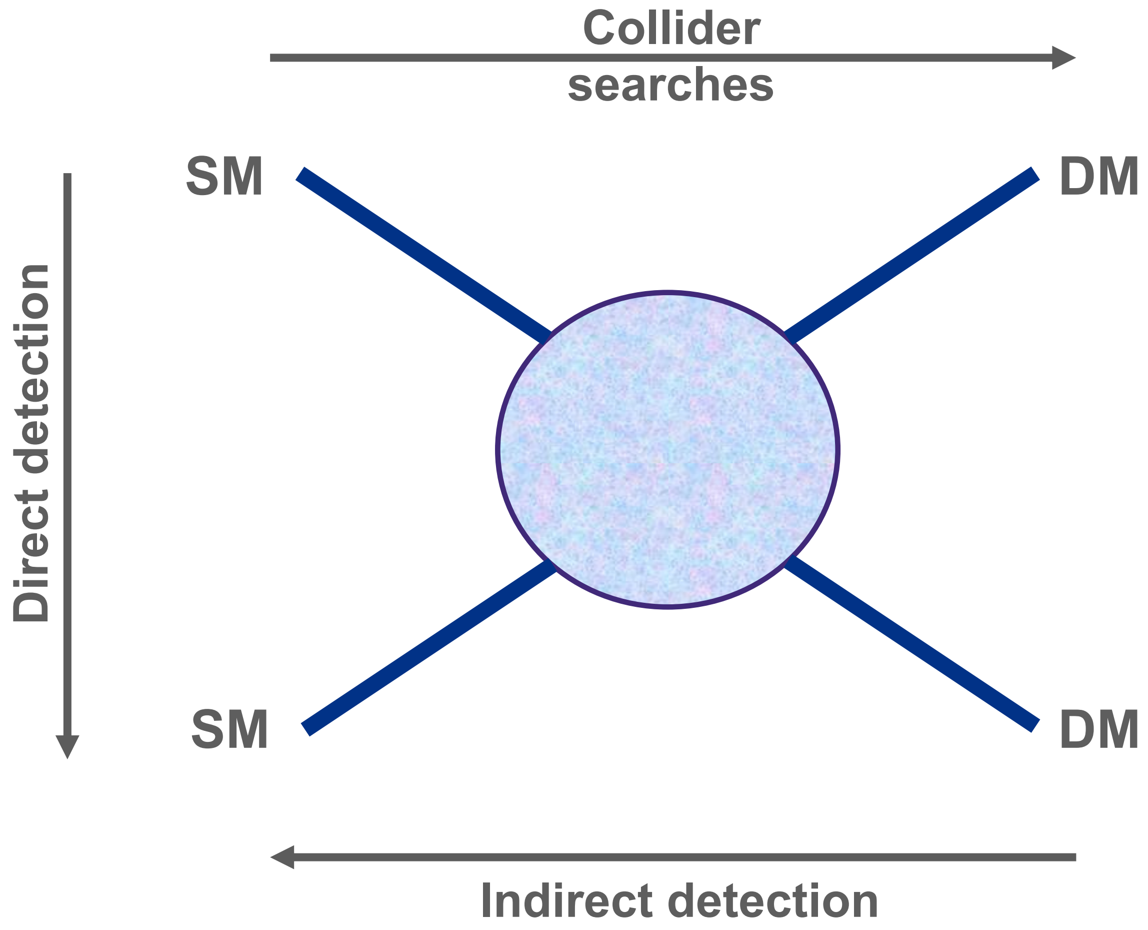
Interacting with Standard Model particles? (weakly, …)

Absolutely stable or not?

Connected to other unsolved problems in the particle physics (like SUSY, CP violation, …)?

and others…

How to study/find DM?



SM: Standard Model particles

Collider: Produce DM particles with high-energy SM particles with particle colliders.

Direct : Measure the recoil of SM particles due to the scattering with DM particles with underground sensitive detectors.

Indirect: **Search for the secondary SM particles from collision and/or decay of DM particles with space- and ground-based telescopes.**

Indirect dark matter search

Search for the secondary SM particles from collision and/or decay of DM particles with space- and ground-based telescopes.

Particle physics to understand the process from DM to SM

+

Astrophysics to guess the amount of DM in the sky or an object

+

Engineering to build telescopes

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi}\frac{<\sigma v>}{\delta m_\chi^2}\frac{dN_\gamma}{dE_\gamma}\int\int \rho^2 ds d\Omega$$

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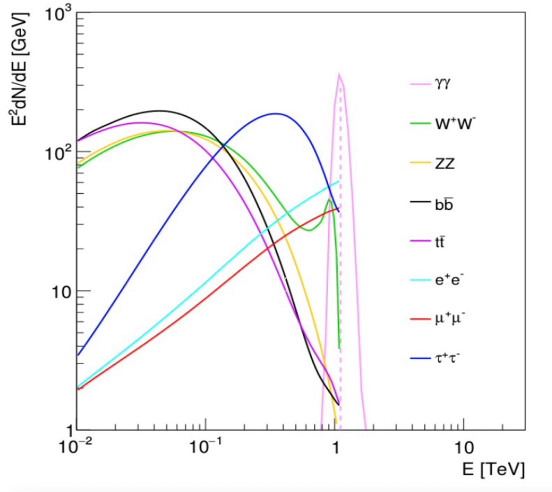

+ **Astrophysics** to guess the amount of DM in the sky or an object

+ **Engineering** to build telescopes

Dark matter specturm

$$\frac{d\Phi_\gamma}{dE_\gamma} = \boxed{\frac{1}{4\pi}\frac{<\sigma v>}{\delta m_\chi^2}\frac{dN_\gamma}{dE_\gamma}} \int\int \rho^2 ds d\Omega$$

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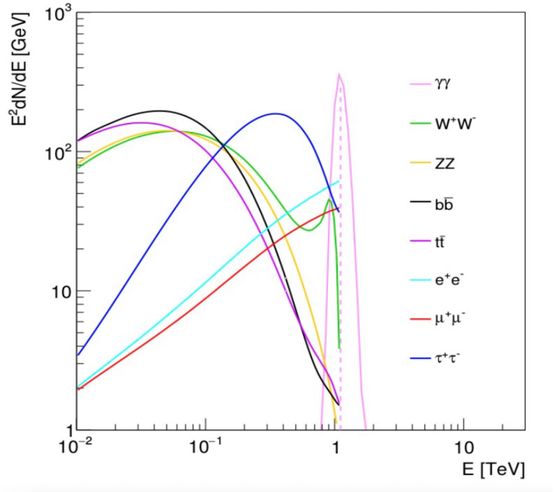

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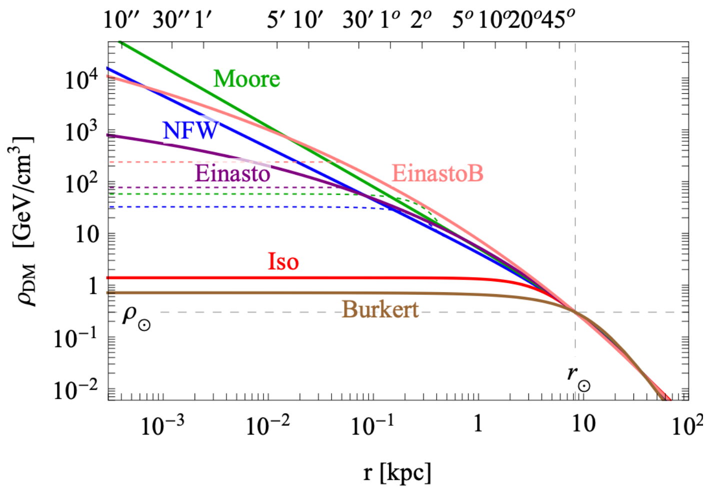

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Engineering to build telescopes

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J factor

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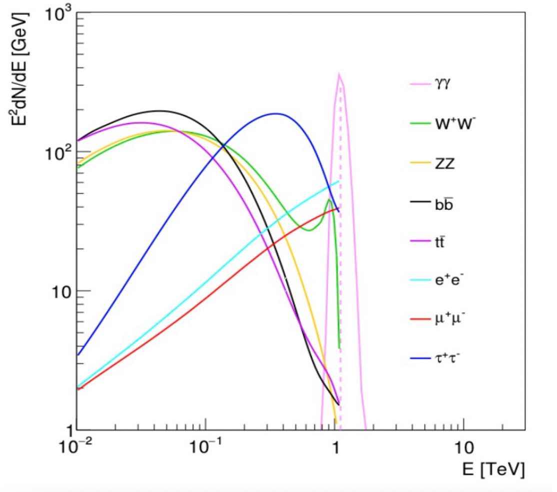

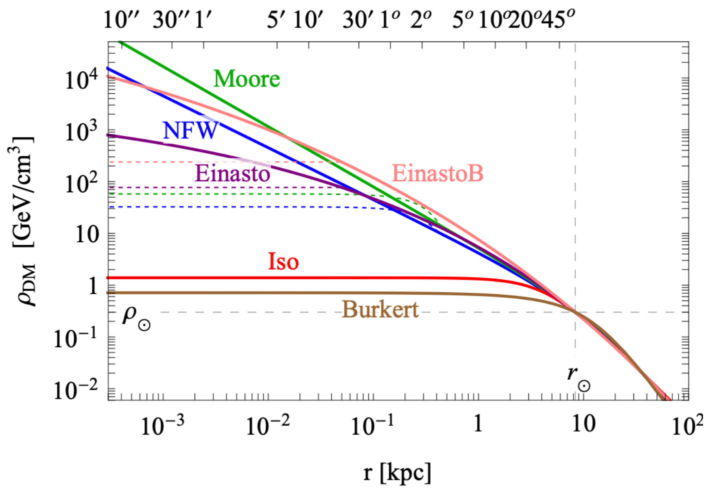

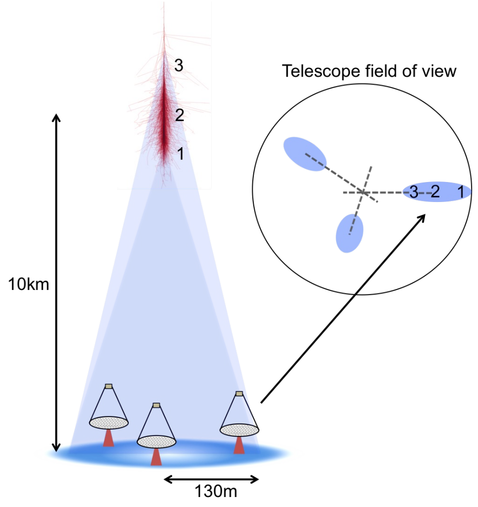

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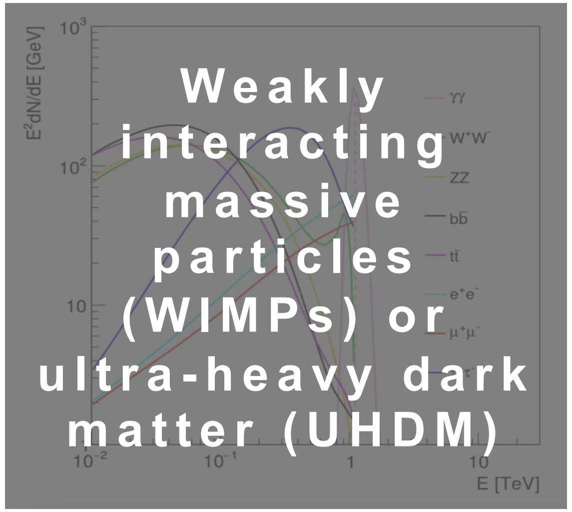

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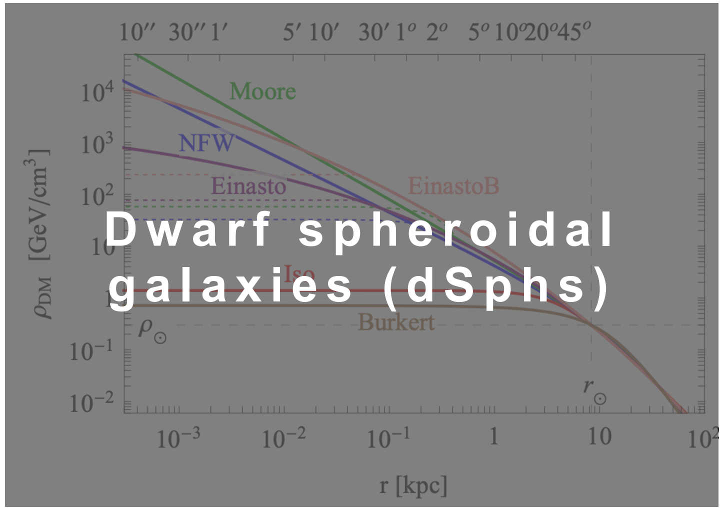

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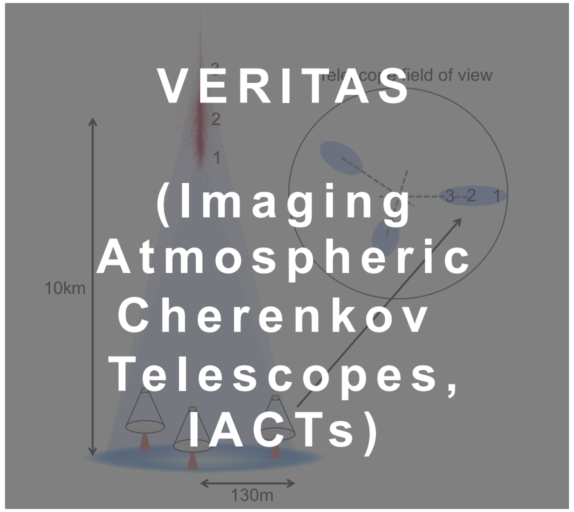


*VERITAS: Very Energetic Radiation Imaging Telescope Array System.

Very Energetic Radiation Imaging Telescope Array System

Four 12m IACTs located in Arizona, US

First light with VERITAS in 2007

Energy range: 85 GeV to > 30 TeV

Field of view: 3.5°

Energy resolution: 15-25%

Angular resolution (68% containment):

<0.1° @ 1 TeV

Point source sensitivity: 1% Crab in ~25h

IACT: Imaging Atmospheric Cherenkov Telescope

VERITAS observation

We have more data from many dSph observations (> 600 hours) with improved methods.

- The previous study (VERITAS+2017, Tak+2023) uses the VERITAS observations from 2007 to 2013 (totally 220 hours).
- The reconstruction pipeline has been updated with the boosted decision trees and other technique.
- The DM density profile has been updated.

Dwarf	N_{ON} [counts]	N_{OFF} [counts]	Exposure [hours]	θ^2 cut [deg^2]	Significance [σ]	$\Phi^{99\%}$ [10^{-12}cm^{-2}s^{-1}]
Böotes	446	2569	13.98	0.02	0.8	1.15
Coma Berenices	1122	6770	39.76	0.012	-0.2	0.82
CVn I	411	2430	9.72	0.02	0.3	1.30
CVn II	335	1822	8.14	0.02	1.6	2.06
Draco II	223	1335	8.02	0.02	0.0	2.08
Hercules I	369	2187	9.46	0.02	0.2	1.48
Leo I	196	1182	5.66	0.02	-0.1	2.39
Leo II	550	3275	11.31	0.02	0.2	1.28
Leo IV	7	65	0.48	0.02	-1.2	4.02
Leo V	33	218	1.38	0.02	-0.5	2.33
Segue 1	3070	18336	126.29	0.012	0.2	0.36
Segue 2	487	3000	12.51	0.012	-0.5	1.07
Sextans I	213	1262	7.45	0.02	0.2	1.29
Triangulum II	751	4870	29.51	0.012	-2.0	0.53
Ursa Major I	358	2073	6.63	0.02	0.6	1.46
Ursa Major II	2266	13855	212.32	0.008	-0.8	0.28
Ursa Minor	2253	13608	135.3	0.012	-0.3	0.39

*** Three deep-exposure dSphs**
: Segue 1, UMa II, and UMi

Updated J profile

Dwarf	$\log_{10} J(0.5^o)$ [GeV^2/cm^5] Ando+20	$\log_{10} J(0.5^o)$ [GeV^2/cm^5] GS+15	ratio
Böotes	$17.77^{+0.23}_{-0.24}$	$18.24^{+0.40}_{-0.37}$	2.95
Coma Berenices	$18.37^{+0.30}_{-0.33}$	$19.02^{+0.37}_{-0.41}$	4.47
CVn I	$17.38^{+0.11}_{-0.11}$	$17.44^{+0.37}_{-0.28}$	1.15
CVn II	$17.19^{+0.37}_{-0.47}$	$17.65^{+0.45}_{-0.43}$	2.88
Hercules I	$16.93^{+0.34}_{-0.39}$	$16.86^{+0.74}_{-0.68}$	0.85
Leo I	$17.70^{+0.07}_{-0.08}$	$17.84^{+0.20}_{-0.16}$	1.38
Leo II	$17.54^{+0.10}_{-0.10}$	$17.97^{+0.20}_{-0.18}$	2.69
Leo IV	$16.56^{+0.57}_{-0.66}$	$16.32^{+1.06}_{-1.69}$	0.58
Leo V	$16.58^{+0.60}_{-0.69}$	$16.37^{+0.94}_{-0.87}$	0.62
Segue 1	$18.91^{+0.39}_{-0.48}$	$19.36^{+0.32}_{-0.35}$	2.82
Segue 2	$17.23^{+0.58}_{-0.99}$	$16.21^{+1.06}_{-0.98}$	0.10
Sextans I	$18.05^{+0.25}_{-0.29}$	$17.92^{+0.35}_{-0.29}$	0.74
Ursa Major I	$18.19^{+0.22}_{-0.25}$	$17.87^{+0.56}_{-0.33}$	0.48
Ursa Major II	$18.79^{+0.36}_{-0.48}$	$19.42^{+0.44}_{-0.42}$	4.27
Ursa Minor	$18.47^{+0.20}_{-0.22}$	$18.95^{+0.26}_{-0.18}$	3.02

GS+15 (Geringer-Sameth et al., 2015) is widely used for the indirect DM search.

We adopt the recent J-factor study by Ando+20, which computes **the J-factor of dSphs with more physically-motivated priors.**

Generally, **GS+15 tends to have much higher J-factors for the DM dense dSphs**, compared to Ando+20.

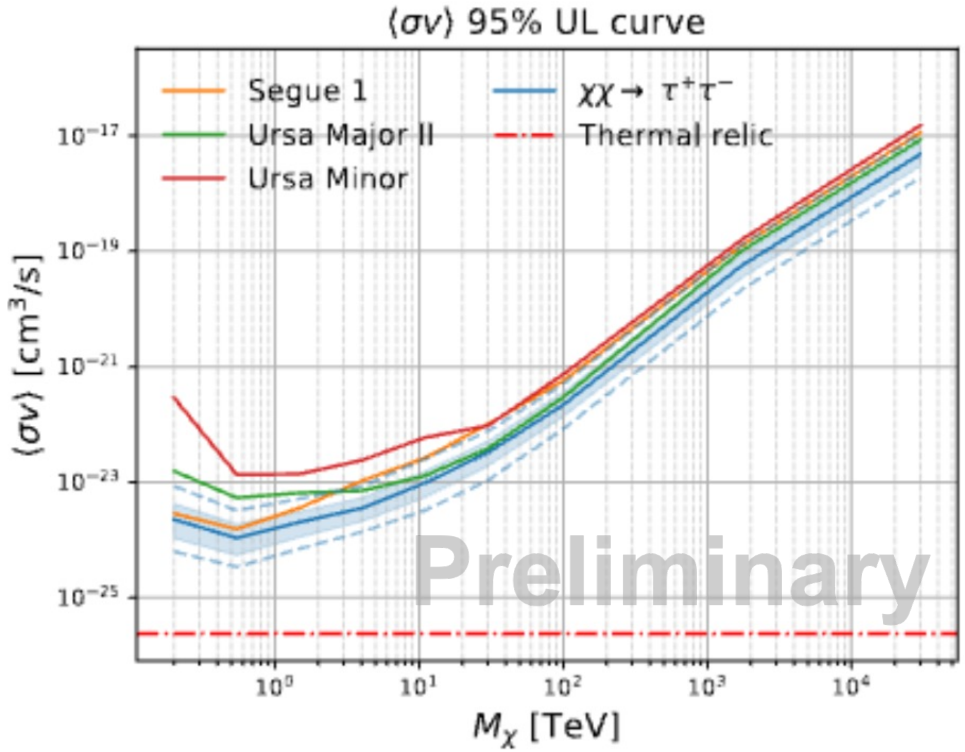
This implies that with the same dataset, **the use of Ando+20 will set a less stringent but more accurate upper limit** on the dark matter cross section.

*** Three deep-exposure dSphs: Segue 1, UMa II, and UMi**

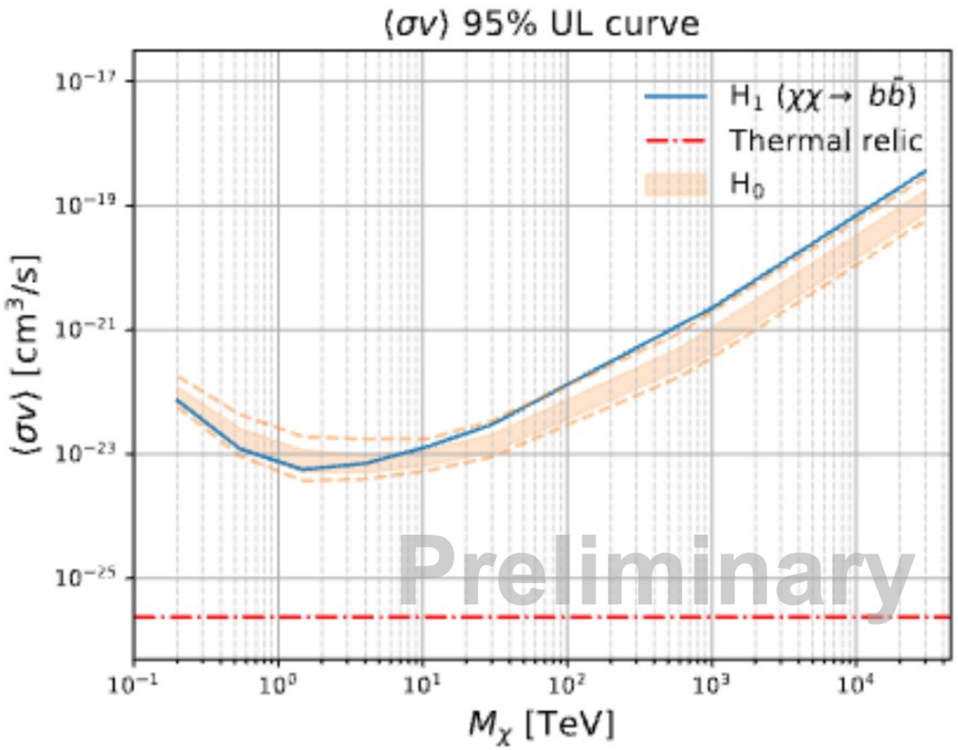
No DM signal has been observed.

We do not see any excess above the expected background level from the target regions.

Combined upper limits from 17 dSphs

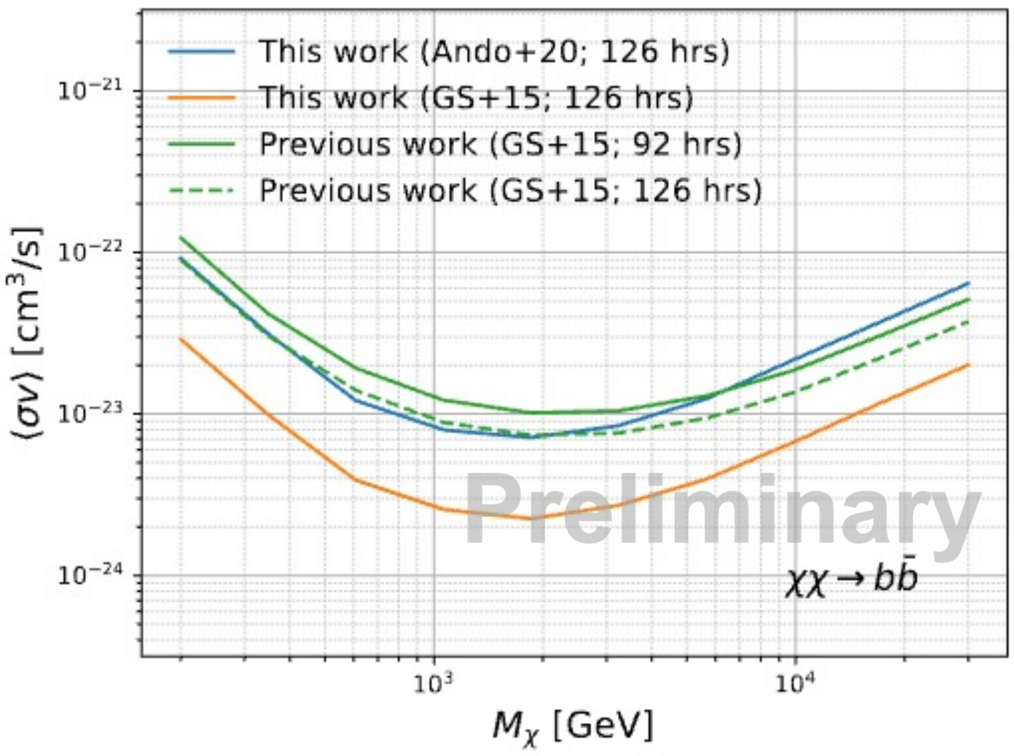


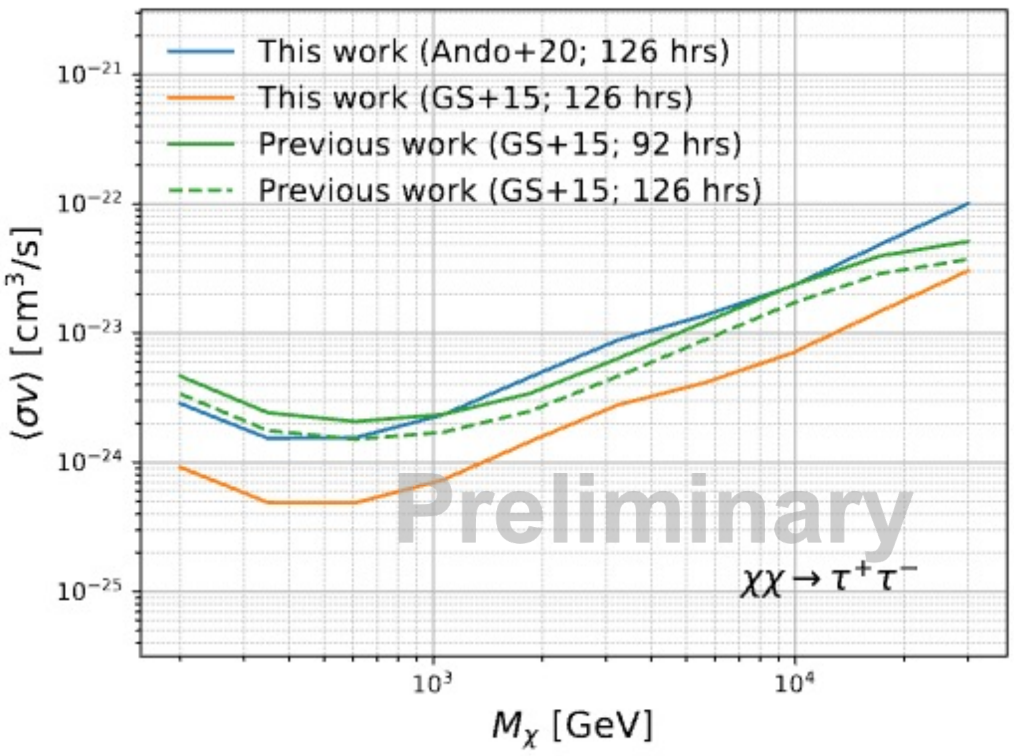
- J-Factor has large effect on results
- Sample J profiles from Ando+20
- 68% and 95% containments from 300 realisations



- Null hypothesis: ULs with background fluctuation
- Random sampling from background events
- Observed ULs are consistent with the null hypothesis

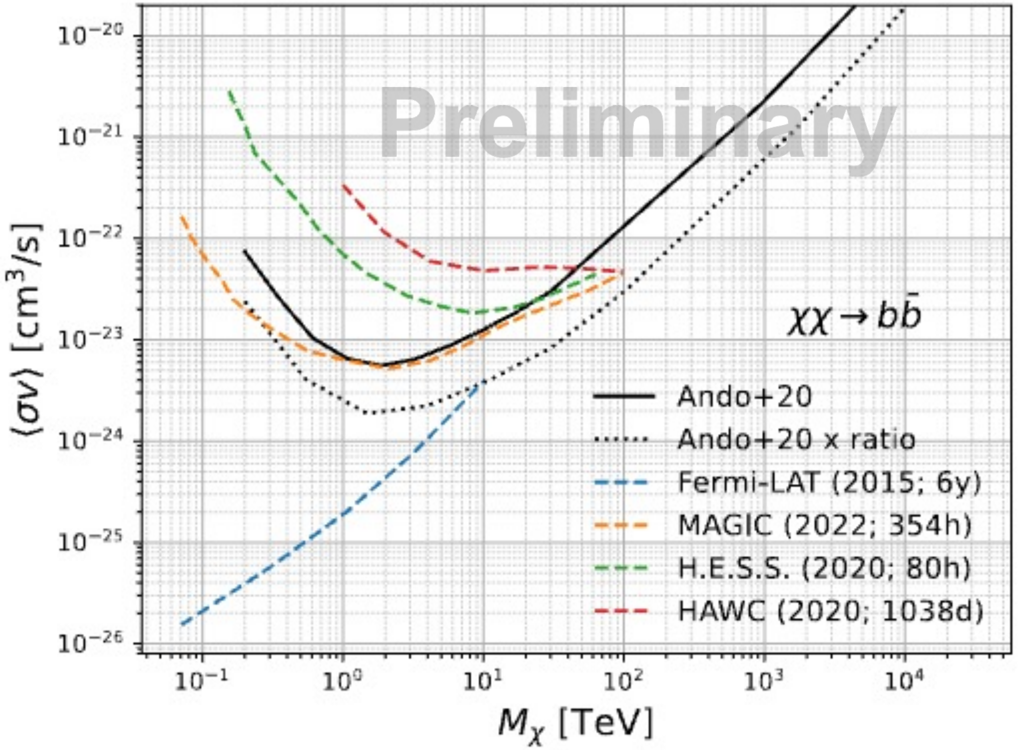
Compare to the previous work

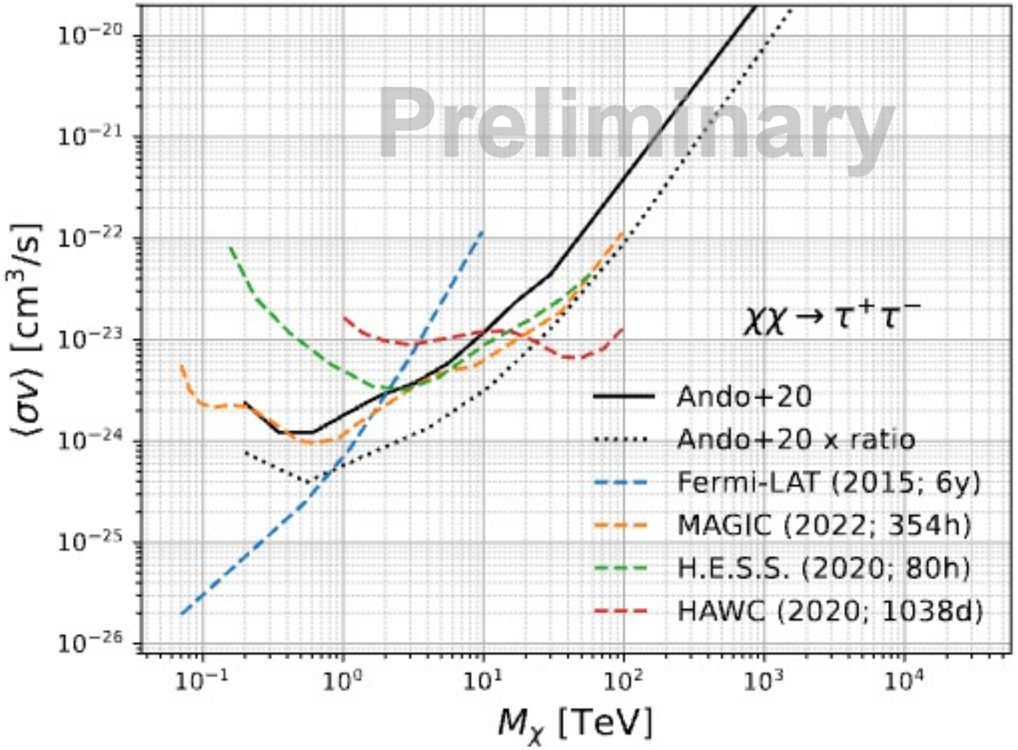




Positive effect: Increased data and improved methods in the data reduction and analysis
Negative effect: Lower (but accurate) DM density

Compare to the other works



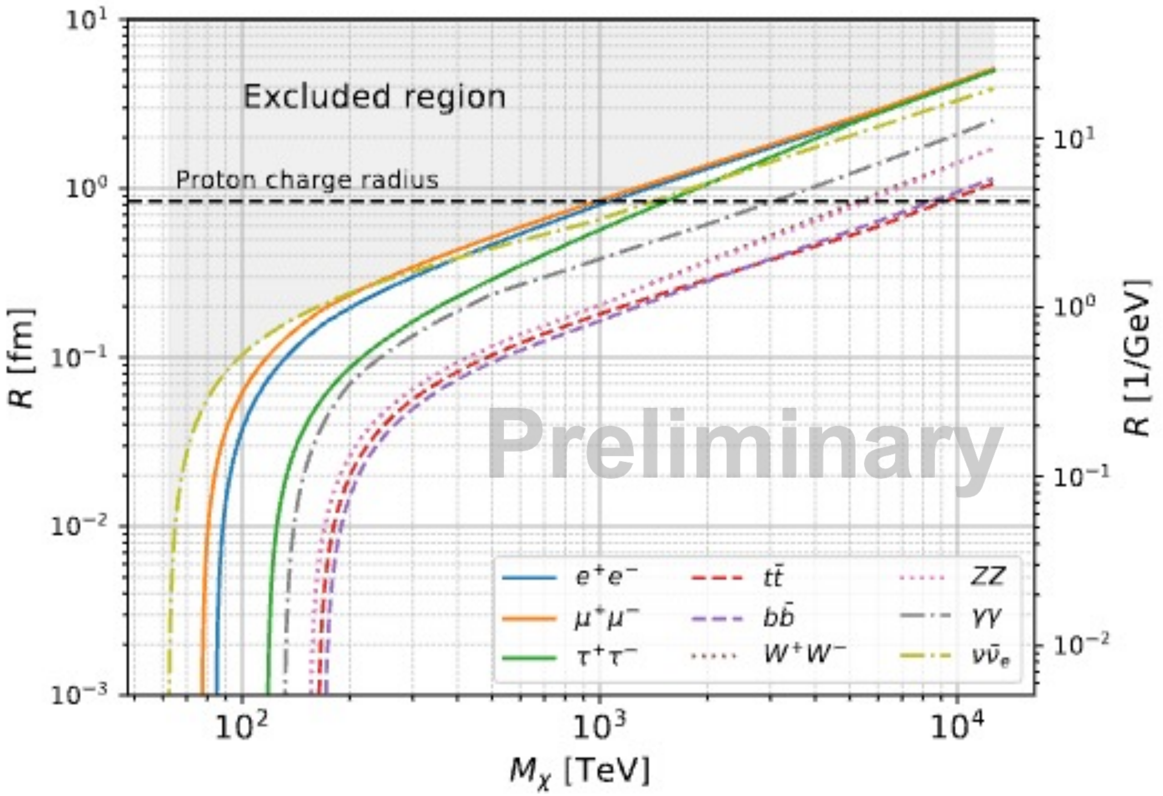


With Ando+20, our work provides a **competitive** result
With GS+15, we expect the **most stringent** result.

UHDM constraint

For the UHDM as a composite particle, we exclude **a certain range of values for the radius** of the composite particle.

If the mass of UHDM is less than 1 PeV, **its radius should be smaller than the proton charge radius**.



Summary

- Indirect searches for dark matter with gamma-ray telescopes are a key part of dark matter search

- For WIMPs and UHDMs (up to 30 PeV), we could not find any evidence of their annihilation signal.

- VERITAS producing competitive limits with state of the art methods

Thank you

Contact

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Link to my orcid