Hunting dark matter in TeV region by VHE gamma-ray

ICRR, University of Tokyo
Tomohiro Inada

The workshop
"The extreme Universe viewed in very-high-energy gamma rays 2018"
La Palma, 12/10/2018

Hunting TeV dark matter in the Galactic Center with VHE gamma-rays in the northern hemisphere

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Motivation

Dark Matter Search

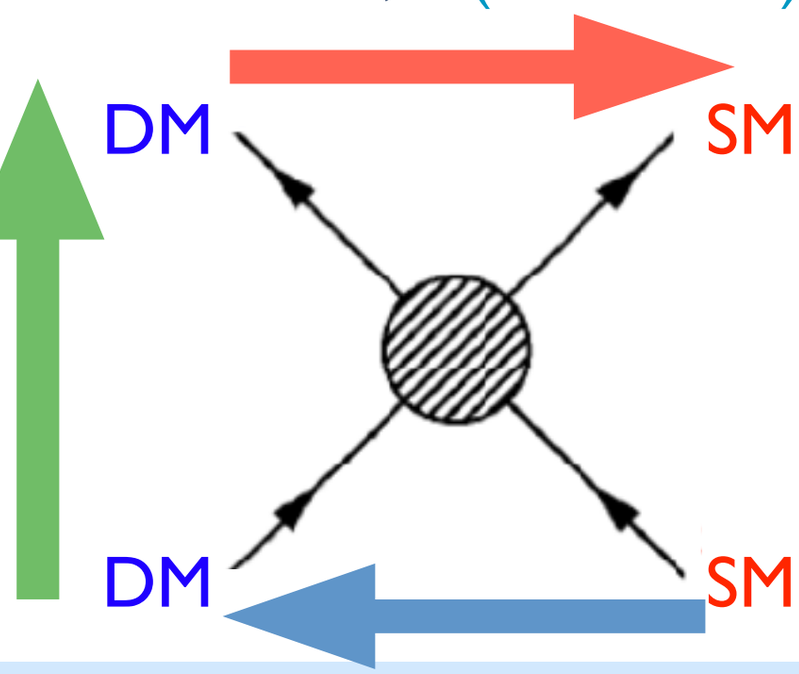
★ Dark matter dominates ~23% of mass-energy of the universe.

★ Good candidate : Weakly Interactive Massive Particle, WIMP

★ "WIMP Miracle" : expects DM mass, O(GeV - TeV) range

Direct Search

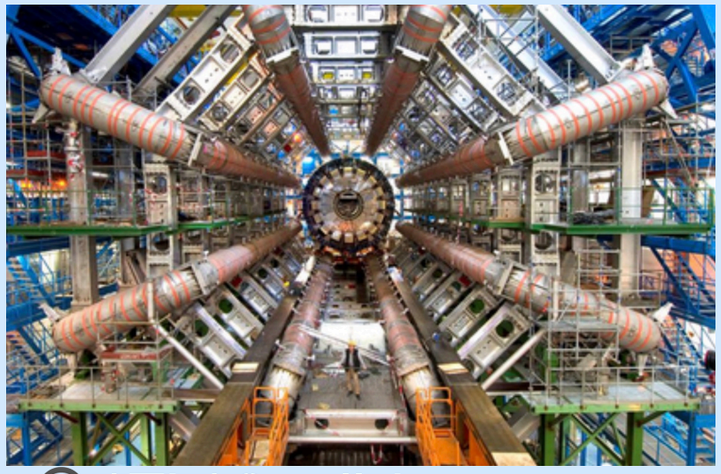
©XENON collaboration



Indirect Search

©Fermi collaboration

Production at Collider



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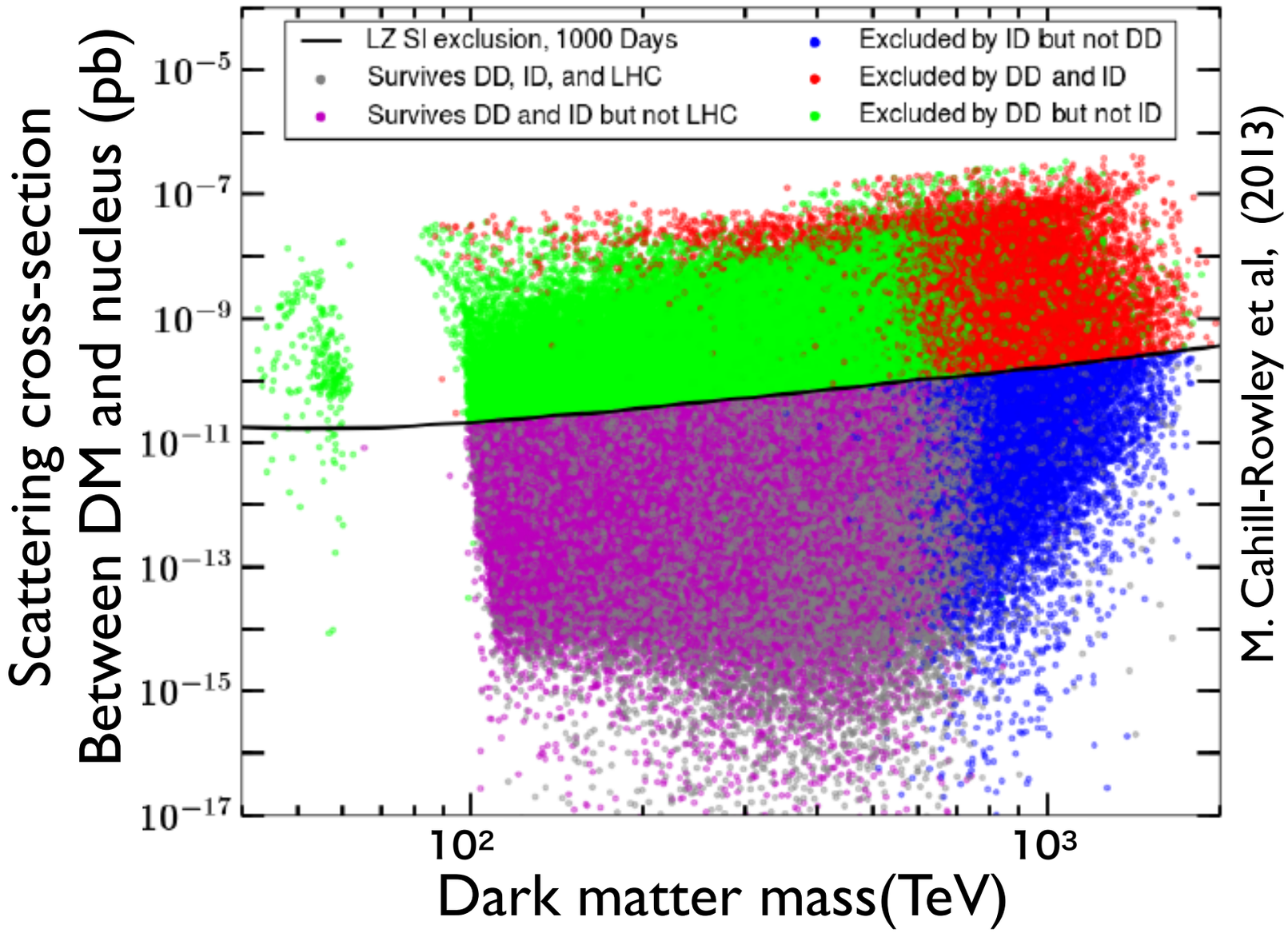
Many experiments are trying, but no evidence for detection yet…

Where is a “next frontier”?

pMSSM model parameter space

(phenomenological minimum supersymmetric model)



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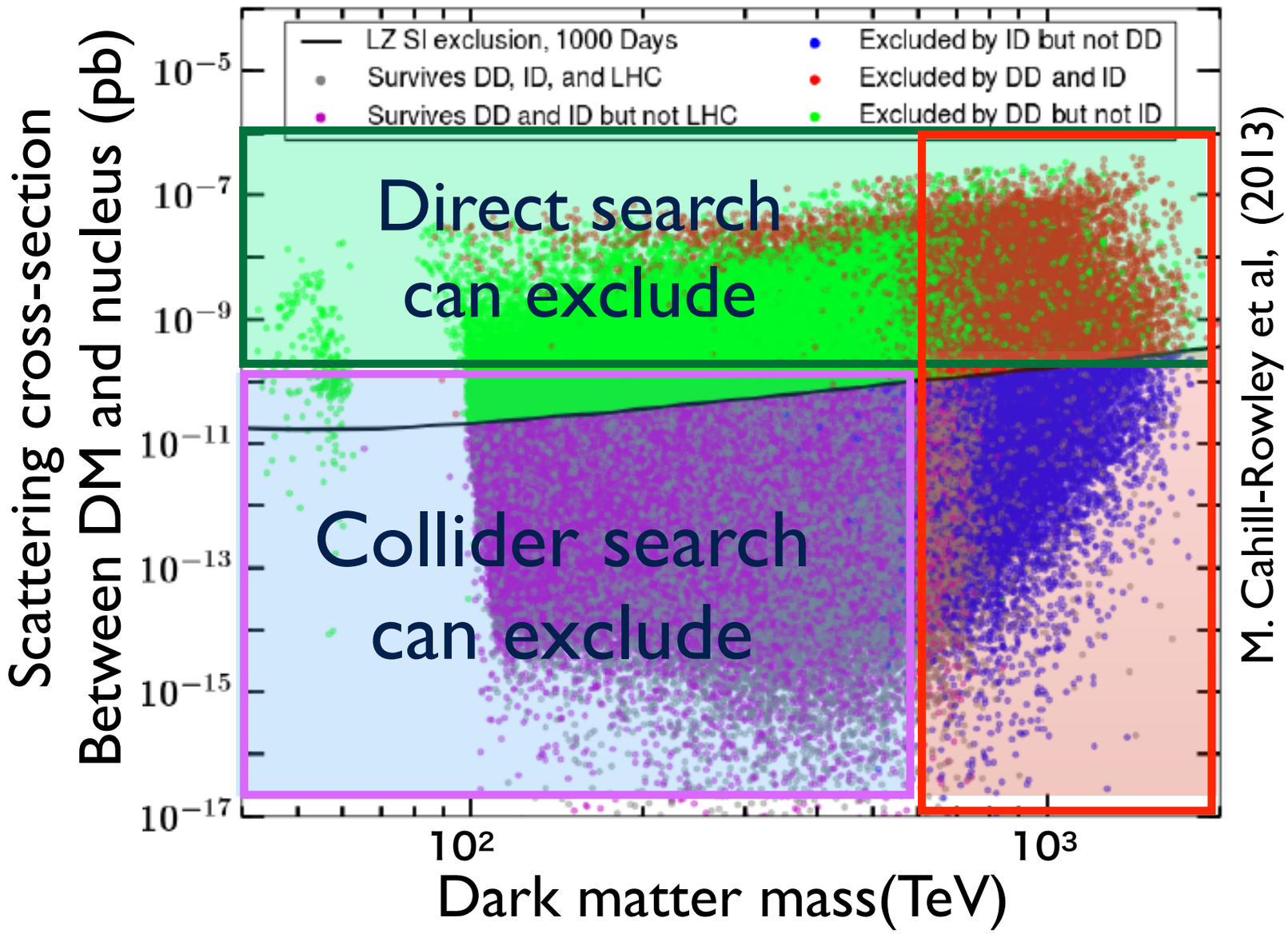


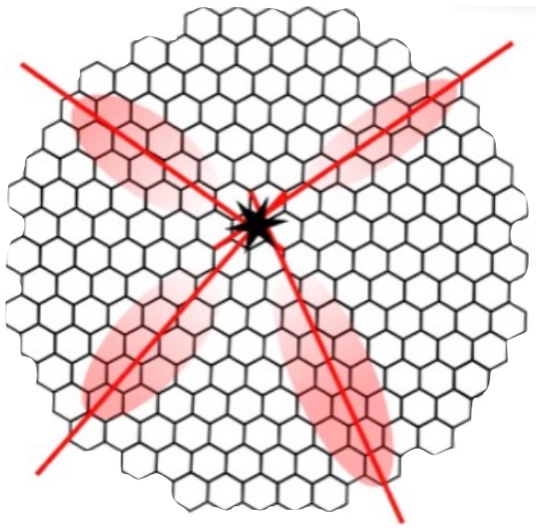
A. DM in the TeV range by indirect search

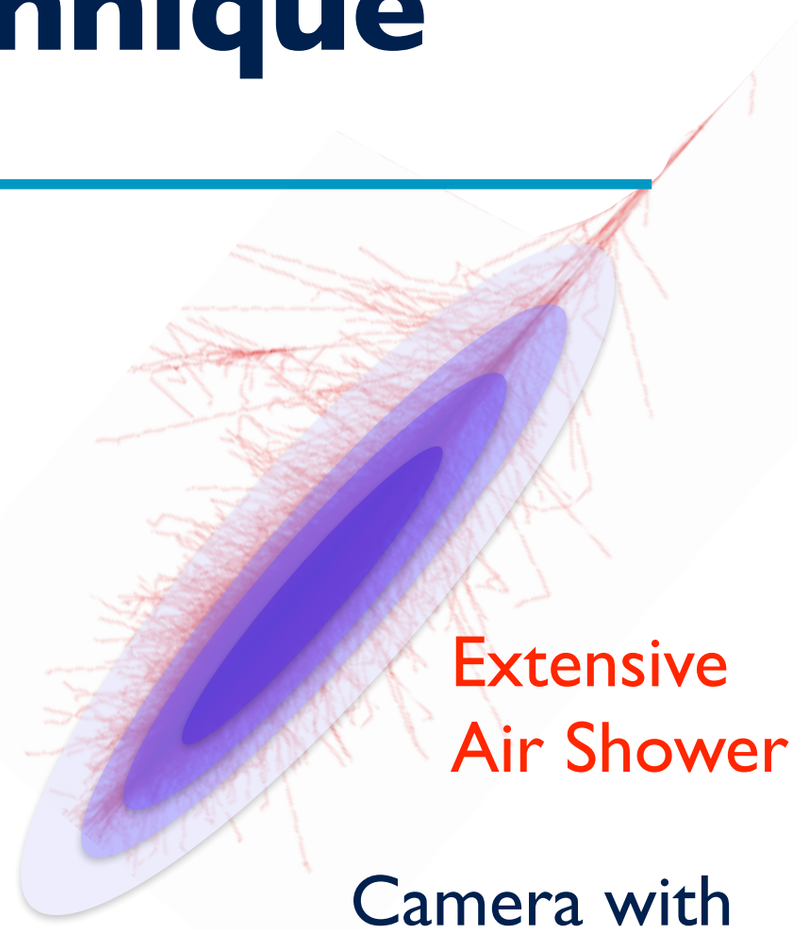
DM search
by Cherenkov telescope

Imaging Cherenkov Technique

★Image intensity
➔ Energy of primary
★Image orientation
➔ Direction of primary
★Image shape
➔ Kind of primary

Reconstructed direction of primary particle





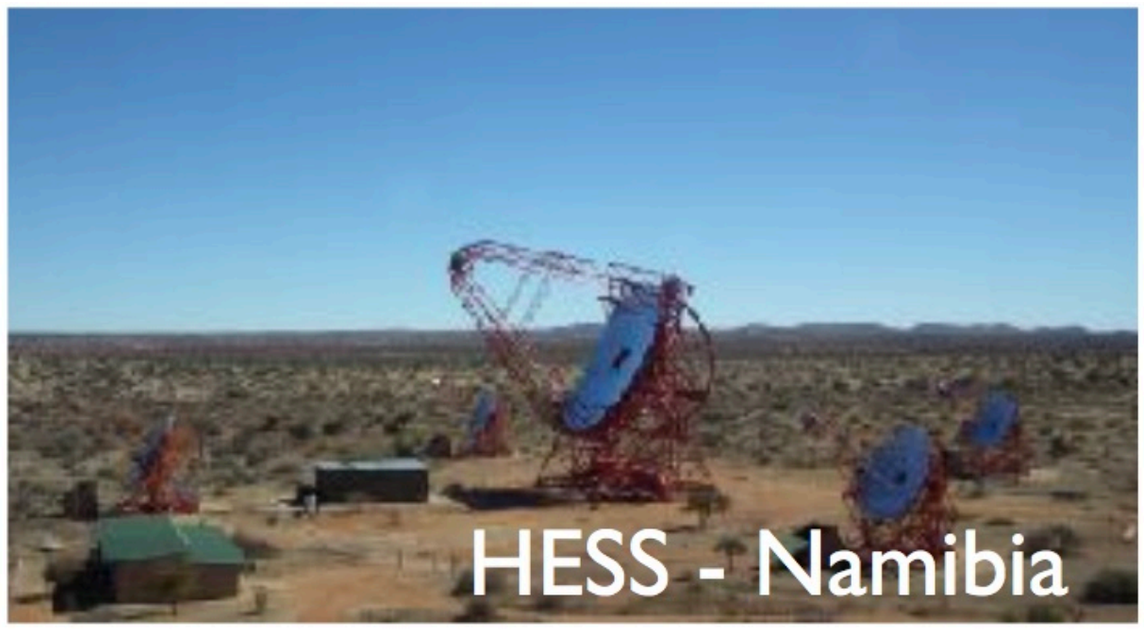
Extensive Air Shower

Camera with PMT pixel

Air Shower Image with Cherenkov telescopes

Current Cherenkov Telescopes

- Effective area : $10^4 \sim 10^5$ m^2
- Energy range : O(100) GeV - O(100)TeV
- Energy resolution : between ~10% and ~20%
- Angular resolution : ~0.06 deg @ 1TeV
- FoV : 3 ~ 5 deg
- Stereoscopic system : 2 - 5 telescopes



Why VHE gamma-ray ?

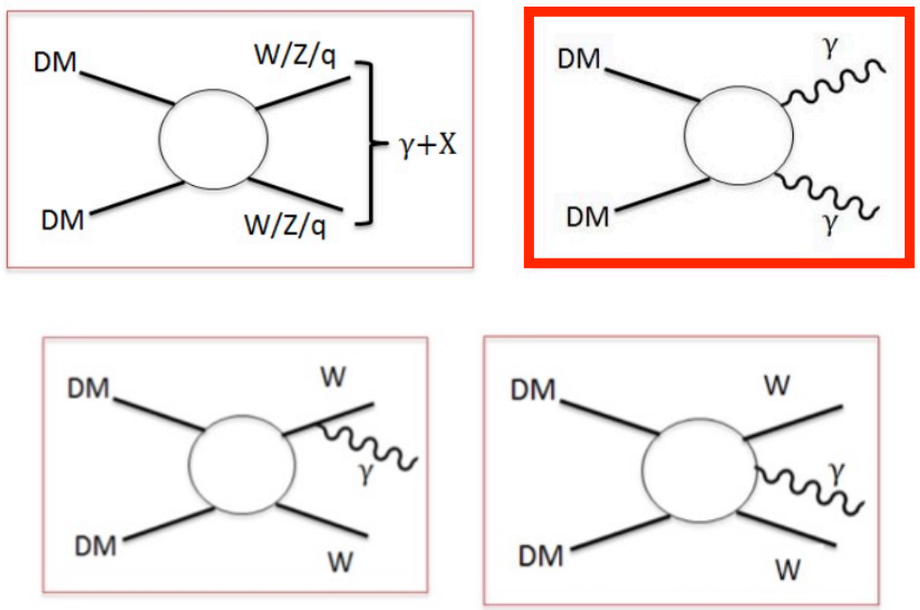
★DM annihilating into gamma-rays

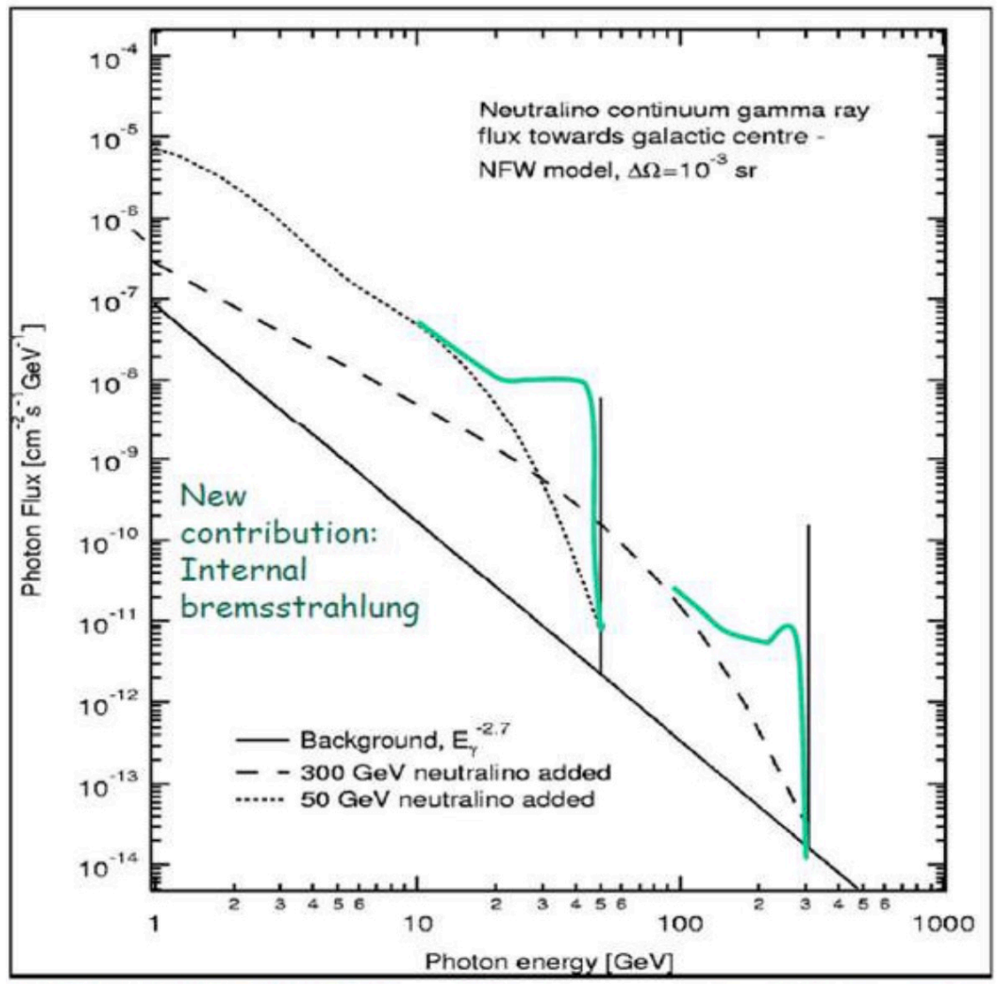
★ Point back to the source

★ Can determine DM abundance and distribution in the universe

★ Characteristics spectral features

★ Can identify the characteristics of particle, mass, cross-section/lifetime



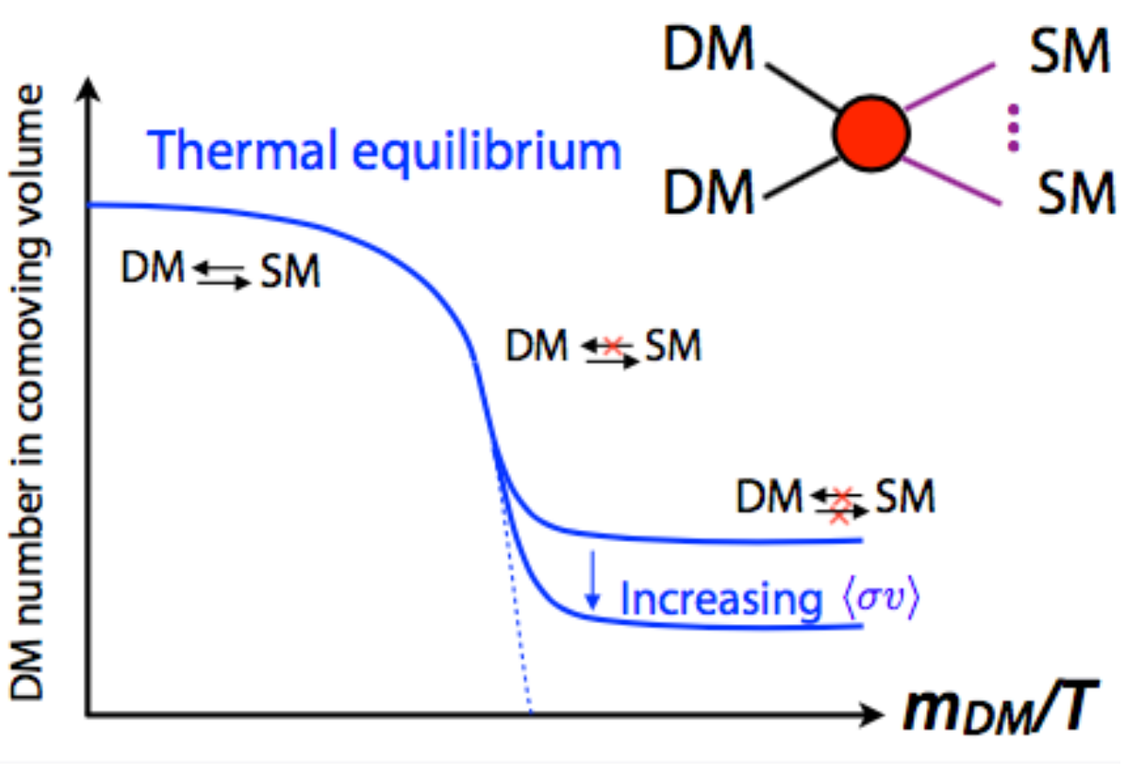


★**Focus on line search !**

★Line emission easily distinguishable from astrophysical and cosmic-rays backgrounds

Benchmark for DM line search

◆Test of DM production via thermal freeze-out



- DM is in thermal equilibrium
- DM is diluted by the cosmic expansion
- DM cannot find each other and stop annihilating
- DM number in comoving volume is frozen
- The expected relic abundance is:

$$\Omega h^2 \simeq \frac{3 \times 10^{-27}\,\mathrm{cm}^3\,\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

- Correct dark matter abundance, $\Omega_{DM}h^2 \sim 0.1$

$$\langle \sigma v \rangle = \langle \sigma v_{\tau\tau} \rangle + \langle \sigma v_{bb} \rangle + \langle \sigma v_{\gamma\gamma} \rangle \cdots$$

$$\langle \sigma v \rangle \simeq 3 \times 10^{-26}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$$

◆DMDM -> γγ is suppressed by factor α^2.

Several models suggest σv increases by quantum effects (Sommerfeld enhancement)

$$\langle \sigma v_{\gamma\gamma} \rangle \leq 10^{-32}\ \mathrm{cm}^{-3}\mathrm{s}^{-1} \xrightarrow{\text{increase}} \langle \sigma v_{\gamma\gamma} \rangle \leq 10^{-28}\ \mathrm{cm}^{-3}\mathrm{s}^{-1}$$

In detail, J. Hisano, et al, L. Bergstrom et al, etc…

Gamma ray Flux from DM

Gamma ray flux

$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{d\Phi^{\rm PP}}{dE} \times J(\Delta\Omega).$$

Particle physics term
in case of annihilation

$$\frac{d\Phi^{\rm PP}}{dE} = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann}v\rangle}{2m_\chi^2}\frac{dN}{dE}$$

Astrophysical term

$$J_{\rm ann}(\Delta\Omega) = \int_{\Delta\Omega}\int_{los}\rho^2(l,\Omega)dld\Omega.$$

$M\chi$: Mass of DM particle
$\langle\sigma_{ann}\, v\rangle$: cross-section times velocity
dN/dE : differential gamma-ray yield per annihilation

ρ : dark matter density
ΔΩ : solid angle
l : line of sight

In case of line search, spectral shape is delta function at $M\chi$

$$\frac{dN}{dE} = 2\delta(E - m_\chi)$$

Depends on the given source, on DM distribution and on the instrument

Observational targets

★Condition to choose targets for DM search

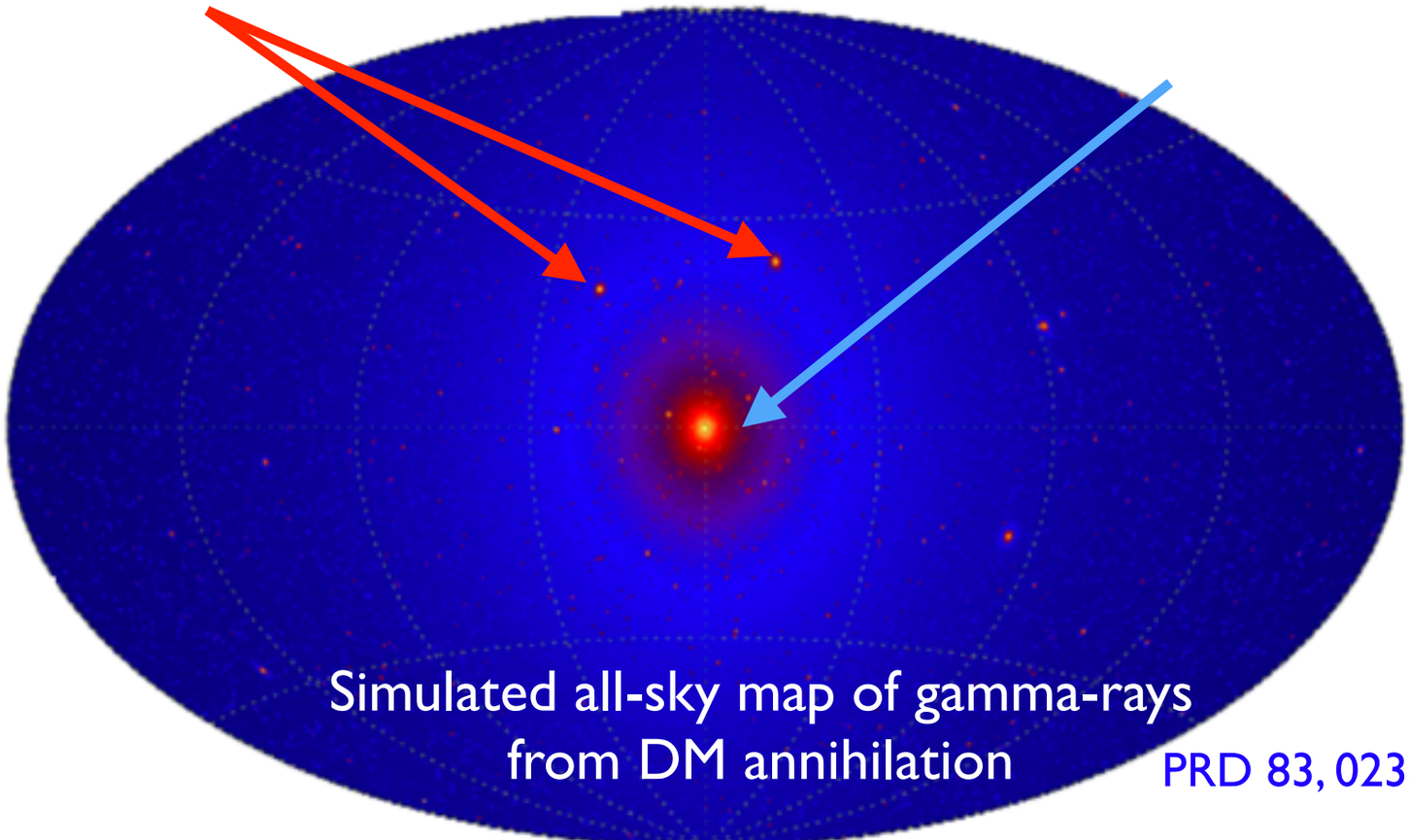
- Maximize the quantity of DM signal (close distance and large DM density)

★Dwarf-Sph galaxies

- Galaxy satellites of the Milky Way
  - Close (approximately 100 kpc from GC)
- High J-Factor : 10^{18} - 10^{19} GeV^2/cm^5
- Much less astrophysical background
- "Point-like" source

★Galactic Center

- Proximity (~8 kpc)
- Highest J-Factor : ~ 10^{20}-10^{21} GeV^2/cm^5
- High astrophysical background and source confusion.
- Extended source



Simulated all-sky map of gamma-rays from DM annihilation

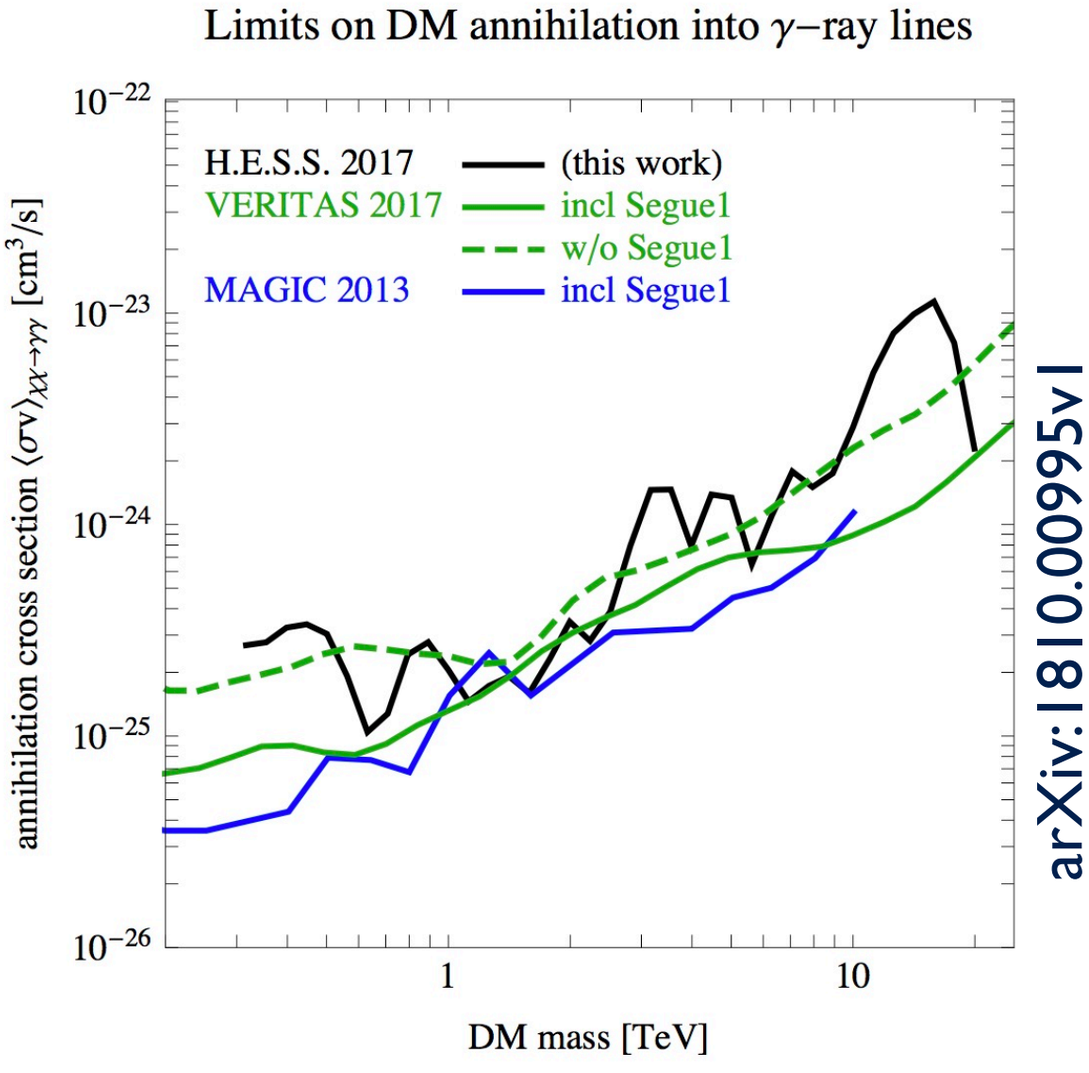
PRD 83, 023518 (2011)

Observed targets

★Most popular targets
- ◆dwarf-Sph galaxies
- ◆Galactic Centre region

Deep observation by IACT (recently published)

Source	Telescope	Year	T[h]	$\log_{10} J$ [GeV²/cm⁵]
Fornax	HESS	2010	6.0	17.72
Coma Berenices	HESS	2010-2013	10.9	19.52
Sculptor	HESS	2008	11.8	18.36
Carina	HESS	2008-2010	22.9	17.86
Sagittarius	HESS	2006-2012	85.5	18.34
Segue 1	VERITAS	2007-2013	92.0	19.04
Ursa Minor	VERITAS	2007-2013	60.4	18.9
Draco	VERITAS	2007-2013	49.8	18.8
Boötes	VERITAS	2007-2013	14.0	18.2
Segue 1	MAGIC	2010-2013	160	19.04
Ursa Major II	MAGIC	2014-2016	100	19.04
GC halo	HESS	2004-2014	254	20.92



Ref : PRD 95, 082001 (2017), arXiv:1810.00995v1,
JCAP 02 (2014) 008, JCAP03(2018)009, PRL120, 201101 (2018)
PRL 120, 201101 (2018)

Many telescopes are observing dwarf-sph galaxies.
But from a point of view about DM search in G.C.,
results are published **only by H.E.S.S.**

Galactic Centre

★Current Status

- Galactic Centre in GeV - TeV range is occupied by H.E.S.S…
- because of good observability
  - Zenith angle ~ 20 [deg] (average)
  - Observation time : 254 h (10 years)

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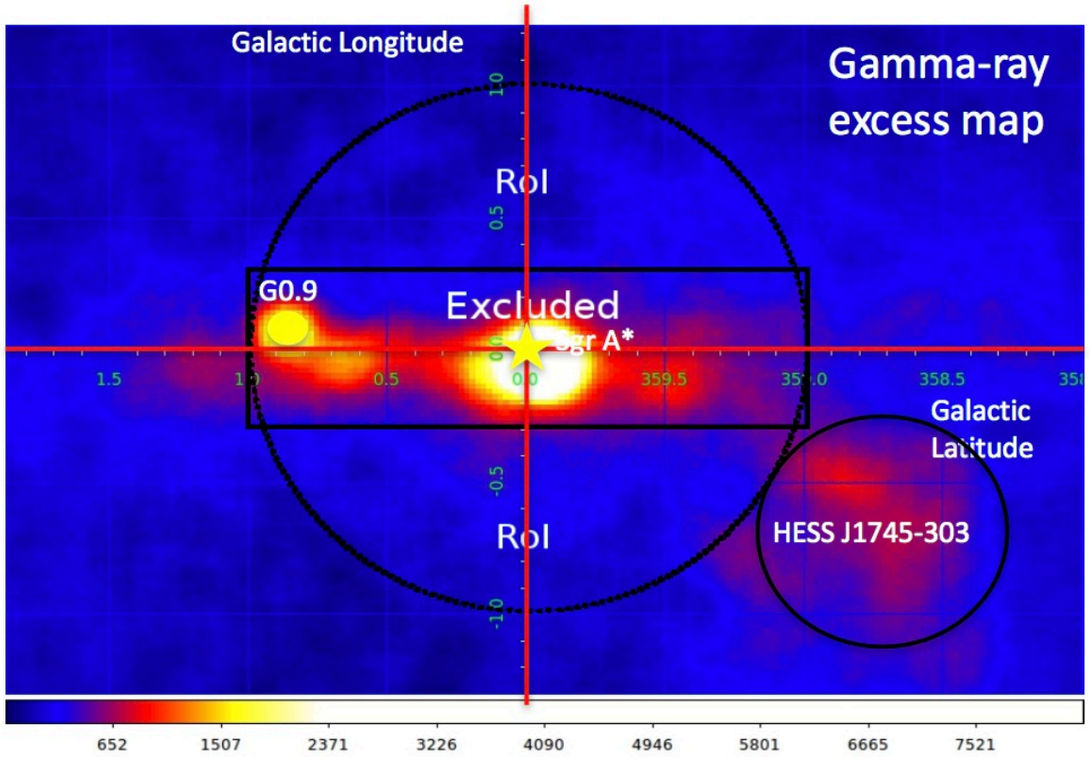

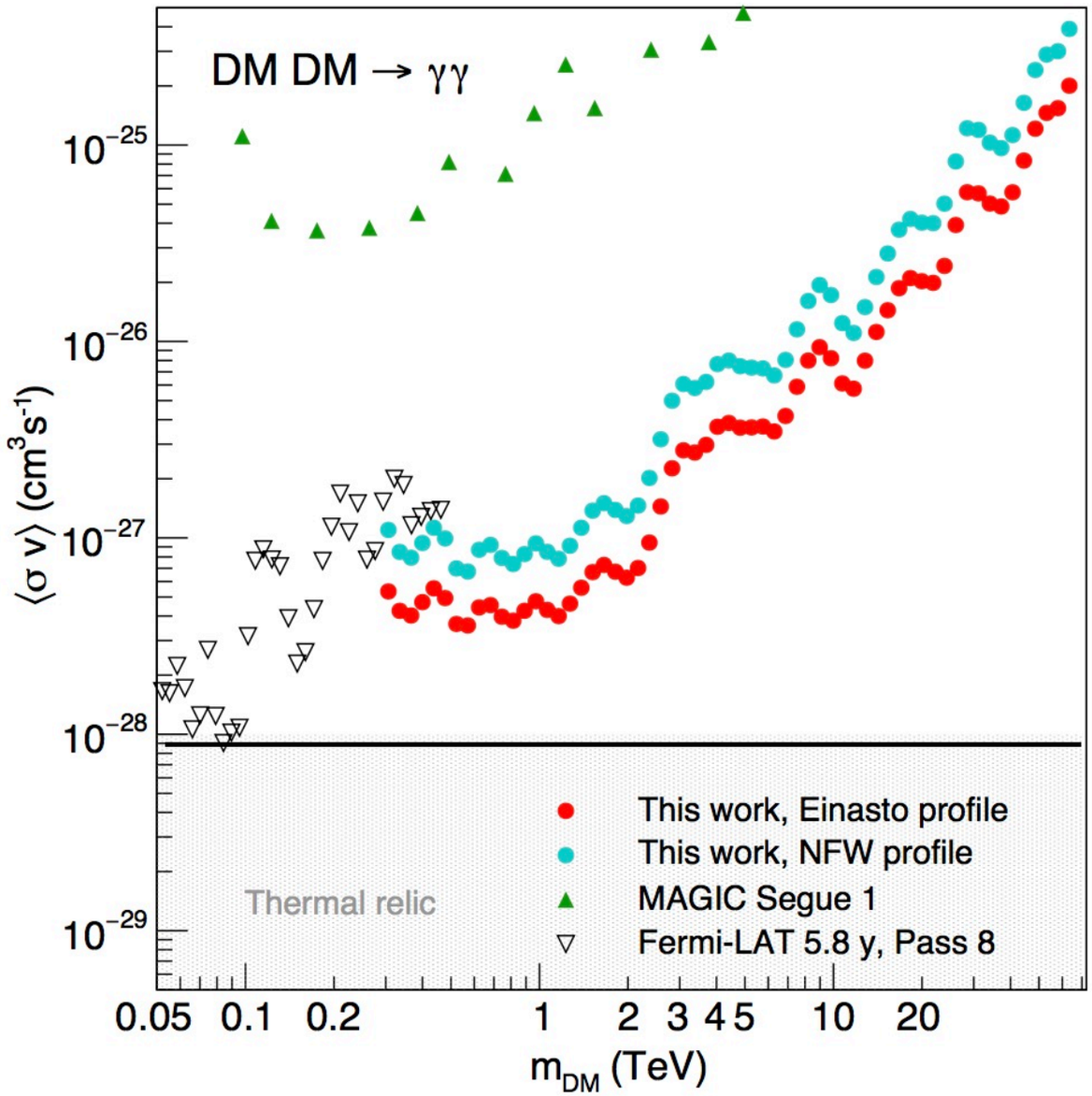

GeV range is excellent!
But what about the TeV range…?
The limit is getting worse rapidly.

PRL 120, 201101 (2018)

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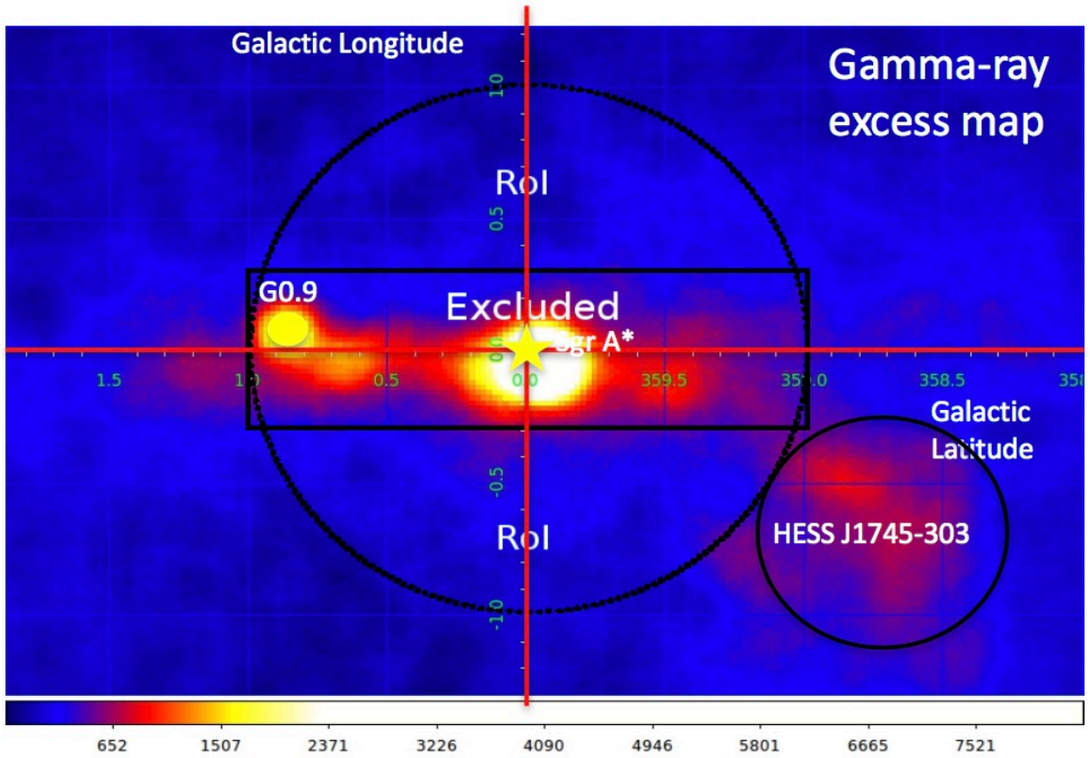

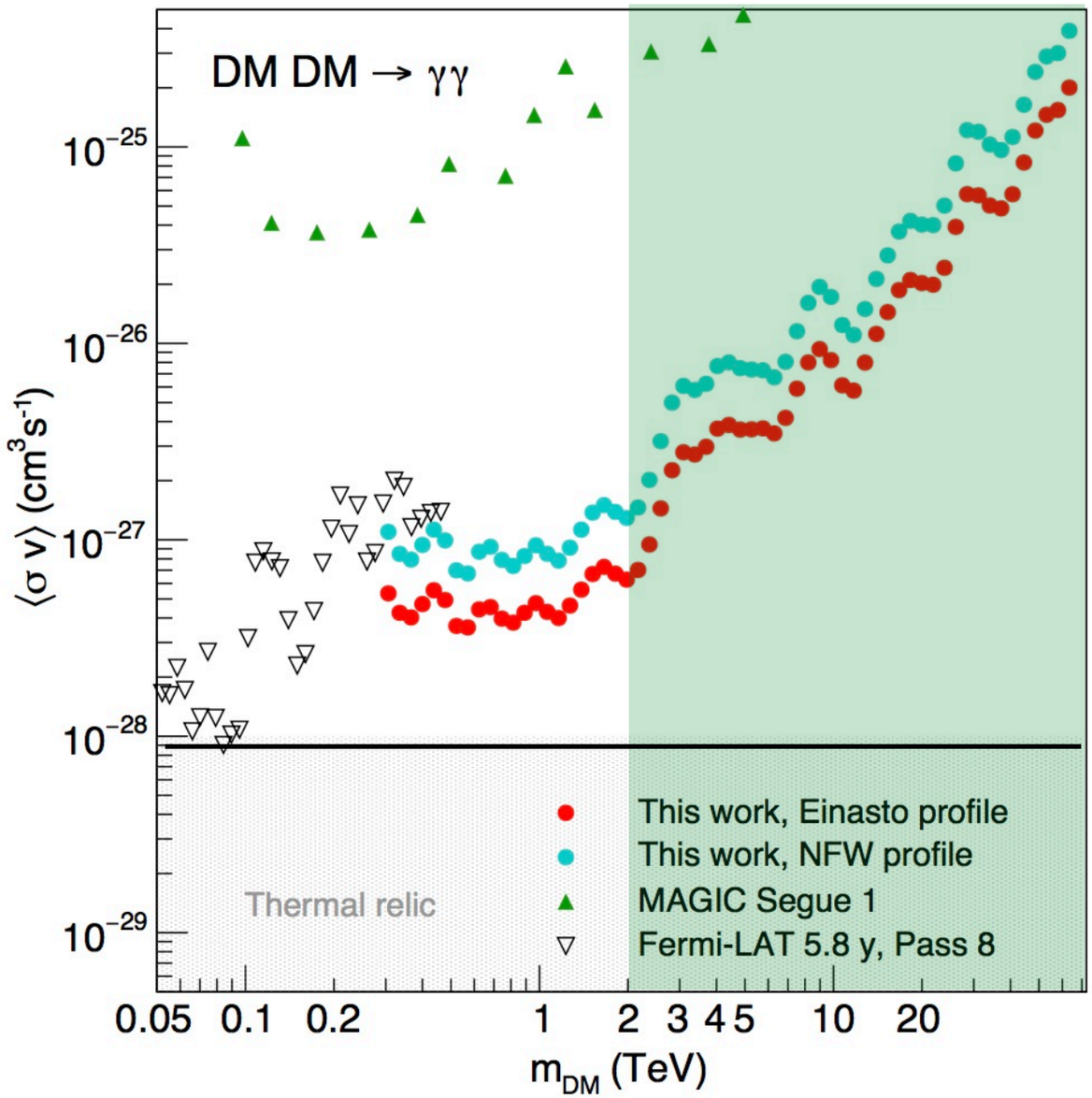

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What is the situation for MAGIC?

- **G.C observation in La Palma.**
  - Zenith Angle : **~60** [deg] (High Zenith, HZ)

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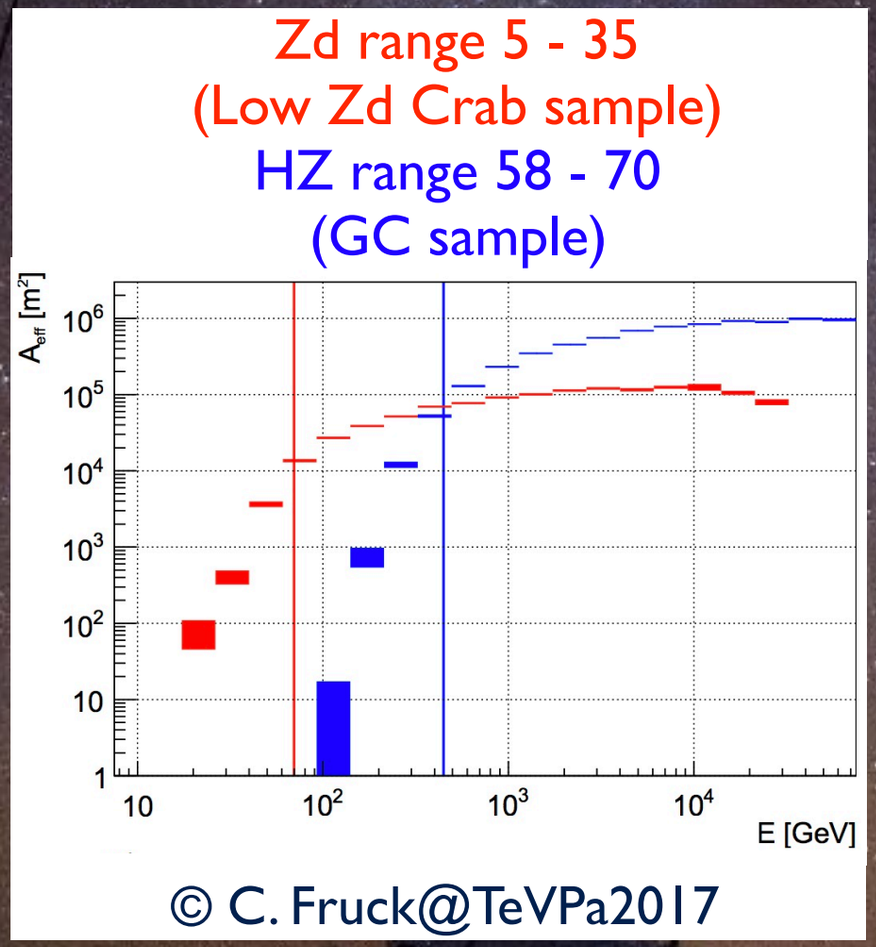


- **Merit and demerit HZ observation**
  - **Effective area : increasing**
    - **by factor ~10 in TeV range**
  - **Threshold : increasing**
    - **~ 500GeV (MAGIC case)**

OK, I have to dismiss GeV range…, but what is the situation in TeV range???

Observability of G.C. from La Palma

Let's estimate observation time to be competitive with H.E.S.S !!

Gamma-rays rate from DM

$$N^{\gamma}_{\mathrm{DM}} = \frac{1}{4\pi}\frac{<\sigma v>}{2m^2_{DM}}\int \frac{dN}{dE'}R(E,E')T_{obs}A_{eff}(E)dE' \times J(\Delta)$$

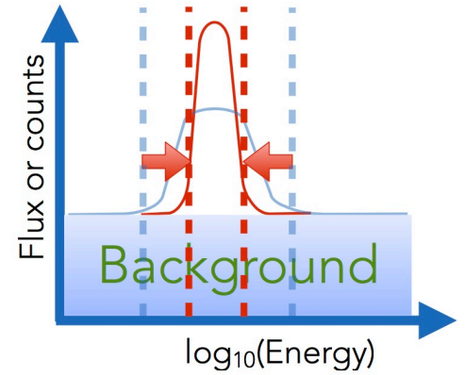
Realistic values

- R(E, E') : Energy Resolution
  - HESS : ~ 10 %
  - MAGIC : ~ 15 % in HZ observation
    - Recently ΔE/E of MAGIC is improved very well by K. Ishio(MPP) *ref. DPG 2018*
    - T_{obs} : observation time
  - HESS : 254 h
  - MAGIC : ??? h
- Aeff : effective area
  - MAGIC / HESS ~ 10

Significance calculation

MAGIC case

- R(E, E') : factor 1.5 worse
- Aeff : factor 10 is better.



$$\sqrt{\frac{10}{1.5}} \times S = \frac{N_s \times 10}{\sqrt{N_b \times 1.5 \times 10}}$$

$$2.58 \times S = \frac{T_{HESS}}{T_{MAGIC}}$$

$$T_{MAGIC} \sim 100\ hours$$

Looks not so bad ???

Future Prospect

- Problems to be solved
  - Systematics from atmosphere by High Zenith observation.
    - Ld : 16 - 20%, Hz : 20 - 30% for absolute energy scale in MAGIC
      - cf : J. Aleksic et al. (2012), C.Fruck Ph.D thesis(2015)
    - LIDAR of MAGIC can correct the energy bias in event by event
      - ref. C.Fruck Ph.D theis(2015)
    - It can reduce the effect by atmosphere, estimation in detail is needed.
  - Astrophysical background in G.C. region.
    - Assume the simple background model or just comparison between ON and OFF while observing far points from galactic plane like H.E.S.S.
- But once we establish the method in MAGIC, we can do with CTA-LSTs !
  - We will have “the fast pass” to reach TeV DM.
- Science in G.C. region is fruitful, in any case, it is worth observing!!

Summary

- Many experiments are trying to search DM, but not detected yet.
- TeV region is next frontier for DM search.
- Cherenkov telescope are very strong tools to search DM in TeV range.
  - It has a chance to detect DM or finally "kill" the WIMP paradigm.

- Most popular targets
  - dwarf spheroidal galaxies :
    - low background & high DM density. many telescopes are observing.
  - Galactic Center :
    - High background & Very high DM density.
    - So far, results about DM search are published only by H.E.S.S.

- Strong tool for northern site : High zenith observation.
  - MAGIC is possibly competitive with H.E.S.S. in TeV range
  - We can get "fast pass" to reach TeV DM.

- Stay tuned!!

Back

Up