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Indirect Direction of TeV-Scale Dark Matter with MAGIC/LST

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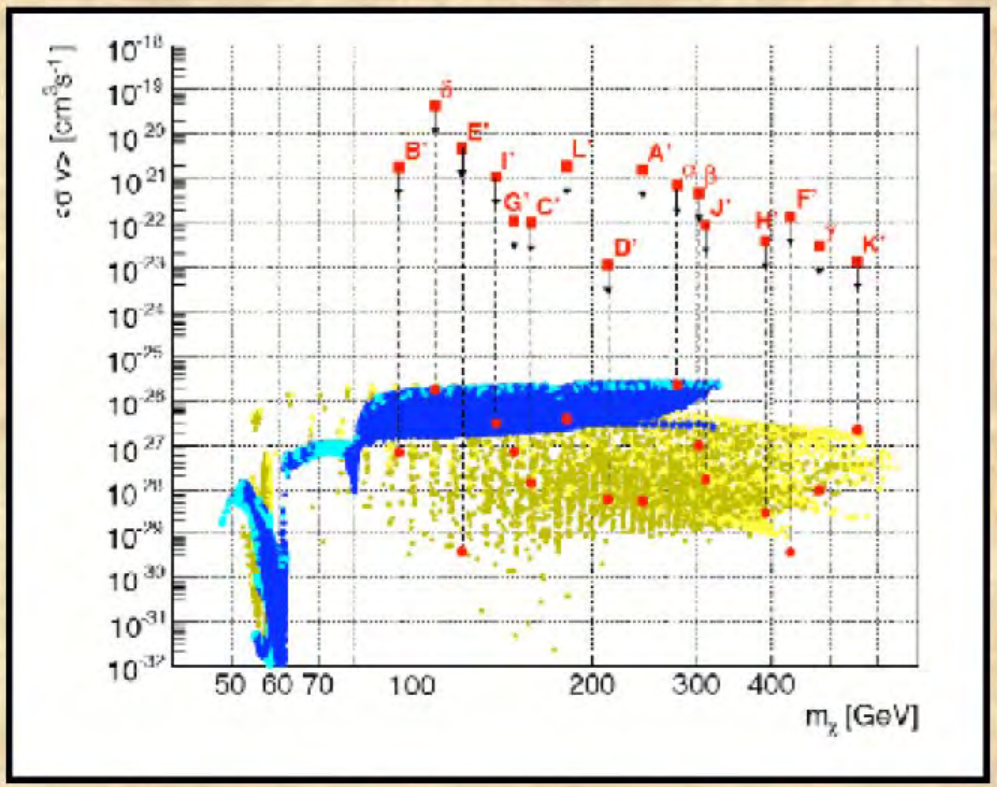
MAGIC Collaboration Meeting Würzburg 2002

A brief history from MAGIC to FACT and LST

- MAGIC-I, 17m IACT, ORM, La Palma: in operation since 2004
- MAGIC-II twin-IACT MAGIC-II: in operation since 2009
- FACT (Si-PM Camera): with ETH Zürich and TU Dortmund, in operation since 2011 (Adrian Biland)
- LST-I: commissioning since 2018
- LST-II-IV: in construction
- More LSTs for CTA-South in Chile
- Thanks to Masahiro Teshima and the LST Collaboration, the telescope LST-array on ORM La Palma will soon be the world-leading facility for northern hemisphere TeV-scale DM indirect detection

MAGIC targets

- Galactic Center
  (Albert et al. ApJ 2006)
- Dwarf galaxies
  - Draco (Albert et al. ApJ 2008)
  - Wilman 1 (Aliu et al. ApJ 2009)
  - Segue 1 (subm.)
- Unidentified gamma-ray sources
- Clusters of galaxies
  - Virgo (M87) (Albert et al. ApJ 2008, Acciari et al. Sci 2009, Aleksic et al. in prep.)
  - Perseus (NGC1275, IC310) (Aleksic et al. ApJ 2010)



Upper limits for mSUGRA benchmark models (Battaglia et al.) for Draco

KM, Colloquium Stockholm (2010)

Probing DMA with M87

Source of high-energy emission

- SSC from AGN jet
- Cosmic rays in ICM
- WIMP annihilation, boosted by sub-halo clumping

$$\frac{d\Phi_\gamma}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{m_\chi^2}\frac{1}{2}\frac{dN_\gamma}{dE}\int_{l.o.s.}\rho^2 ds$$

„prompt" (mainly pion decay)

Characteristics

- Highly variable
  → nonthermal models
- Steep spectrum, extended
- Prompt & secondary emission
  → double-hump signature

$$j_{IC}(E_\gamma, r) = \int dE \left(\frac{dn_{e^-}}{dE} + \frac{dn_{e^-}}{dE}\right) P_{IC}(E_\gamma, E)$$

inverse-Compton from secondary e^+/e^-

KM, Colloquium, Stockholm (2010)

Gamma rays from the Dark Matter halo of M87

- Klypin et al. code
- 3 10^{14} solar masses; 9 million particles
- „Virgo Cluster“ constrained simulation

$$P_f(k) = T^2(k)\ P_i(k)$$

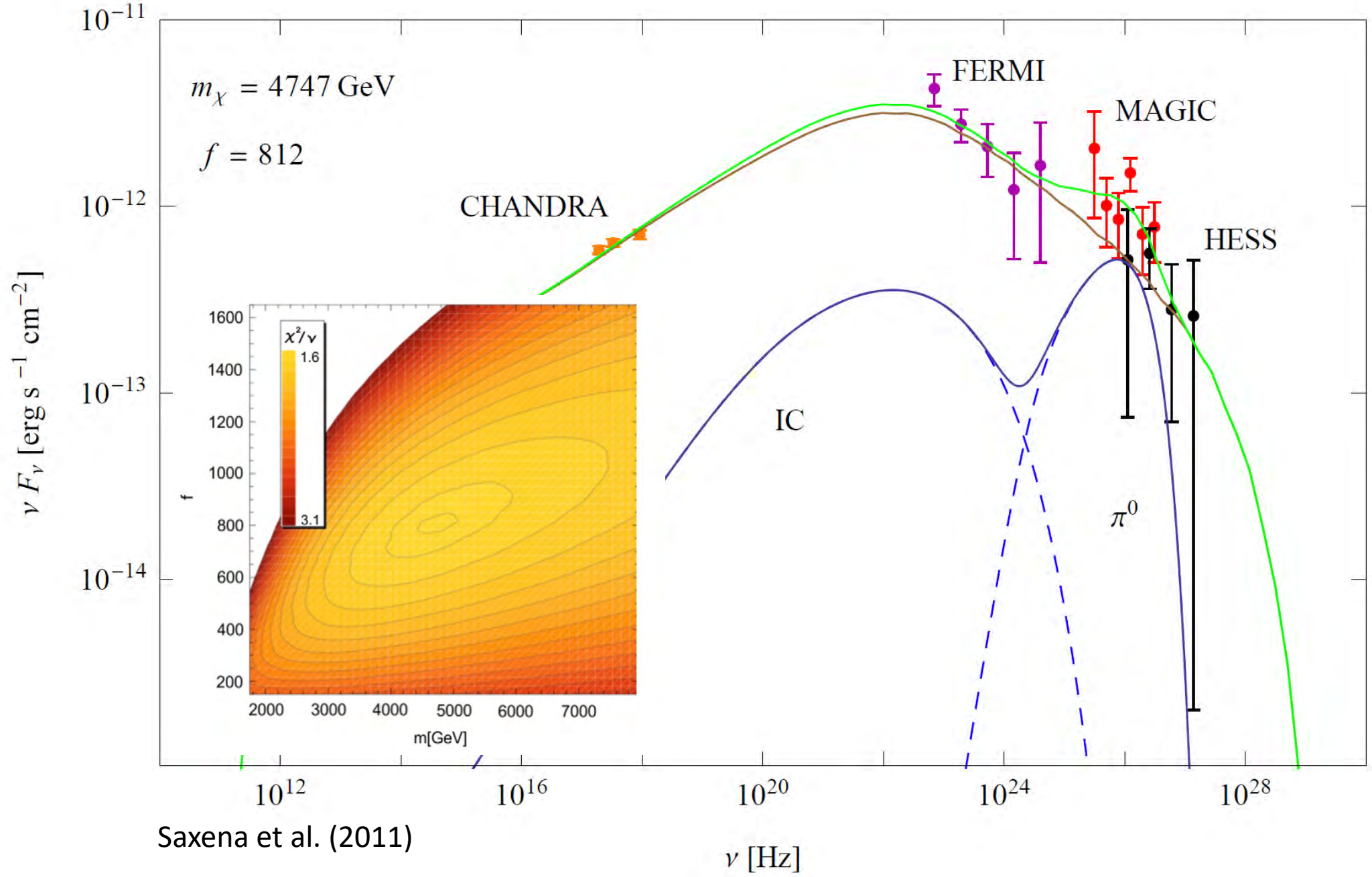
Transfer function describes modification of power spectrum of DM halos determined by the free-streaming scale at the time of radiation-matter equality

D. Elsaesser, S. Gottloeber, A. Khalathyan and M. Steinmetz

Linear growth phase: clumping down to 10^{-6} solar masses (Green et al. 2004) which cannot be numerically resolved.

Theoretical prediction of boost factor in nonlinear phase out of reach:

Tidal interactions and baryonic feedback during the entire assembly history of the halo are relevant.



Saxena et al. (2011)

Chandra

Highly sensitive X-ray telescopes could probe background-free „stripped“ clusters of galaxies like the bullet cluster for masses well below 1 TeV to find IC photons

Astrophysical back-/foreground:

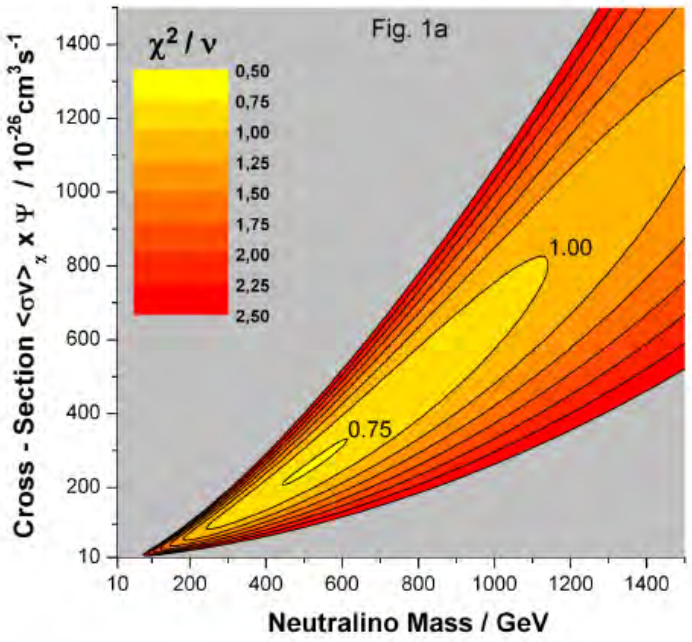
- Faint AGN
- Faint Galactic sources
- Cosmic Rays in the ISM
- Cosmic Rays in the ICM
- Cosmic rays in supercluster medium

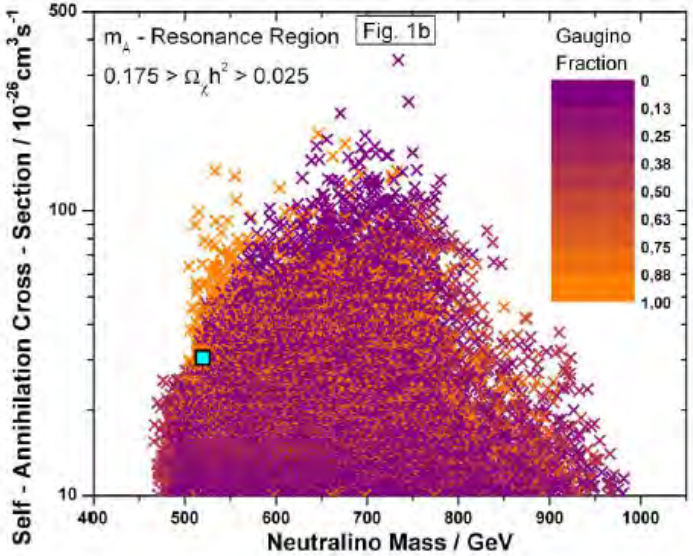
DM back-/foreground:

- Galactic DM subhalos
- Extragalactic distribution

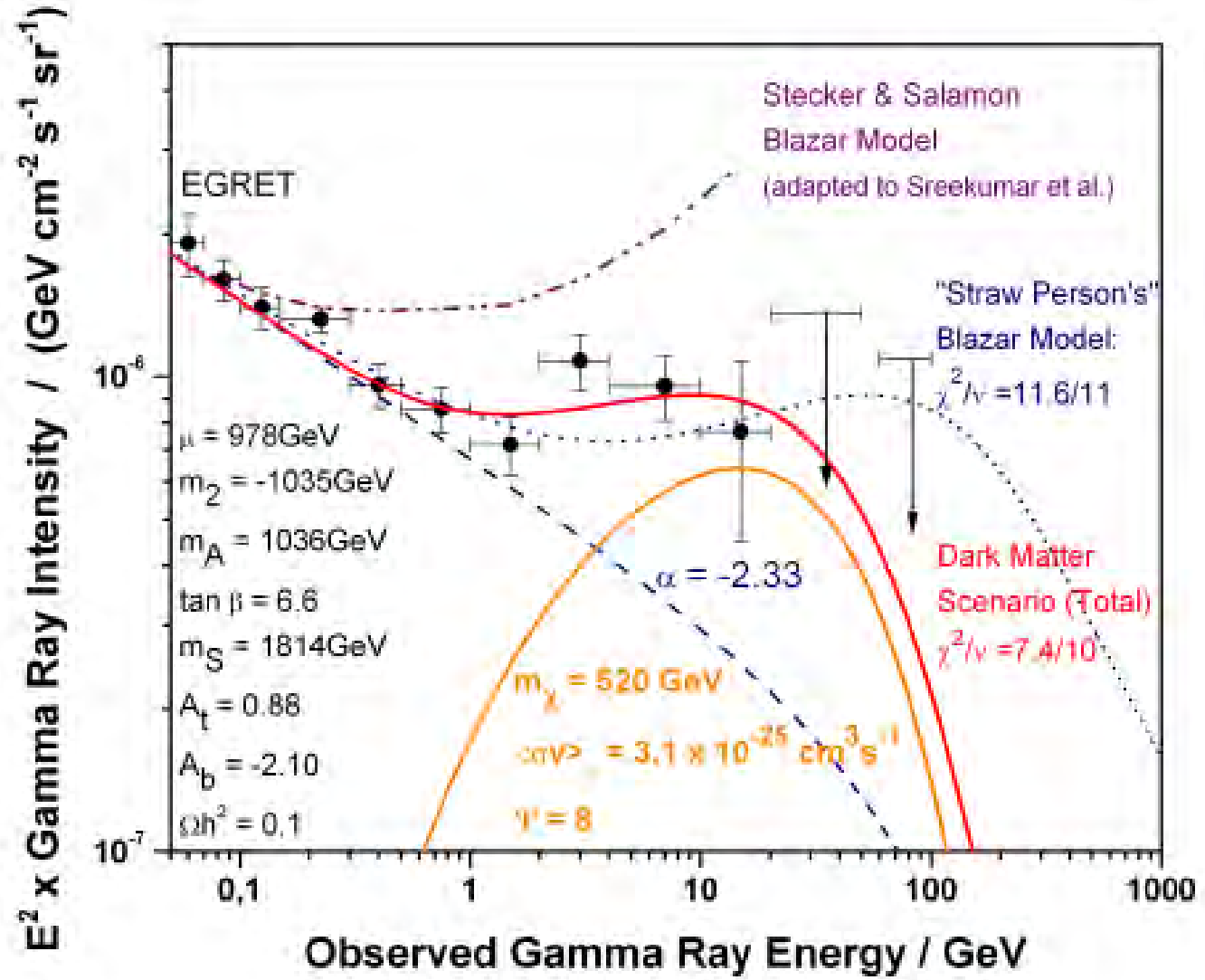
→ Anisotropy from supergalactic plane ~ ca. 10% of the isotropic background emission due to DMA (Elsässer & KM, Aph, 2004)

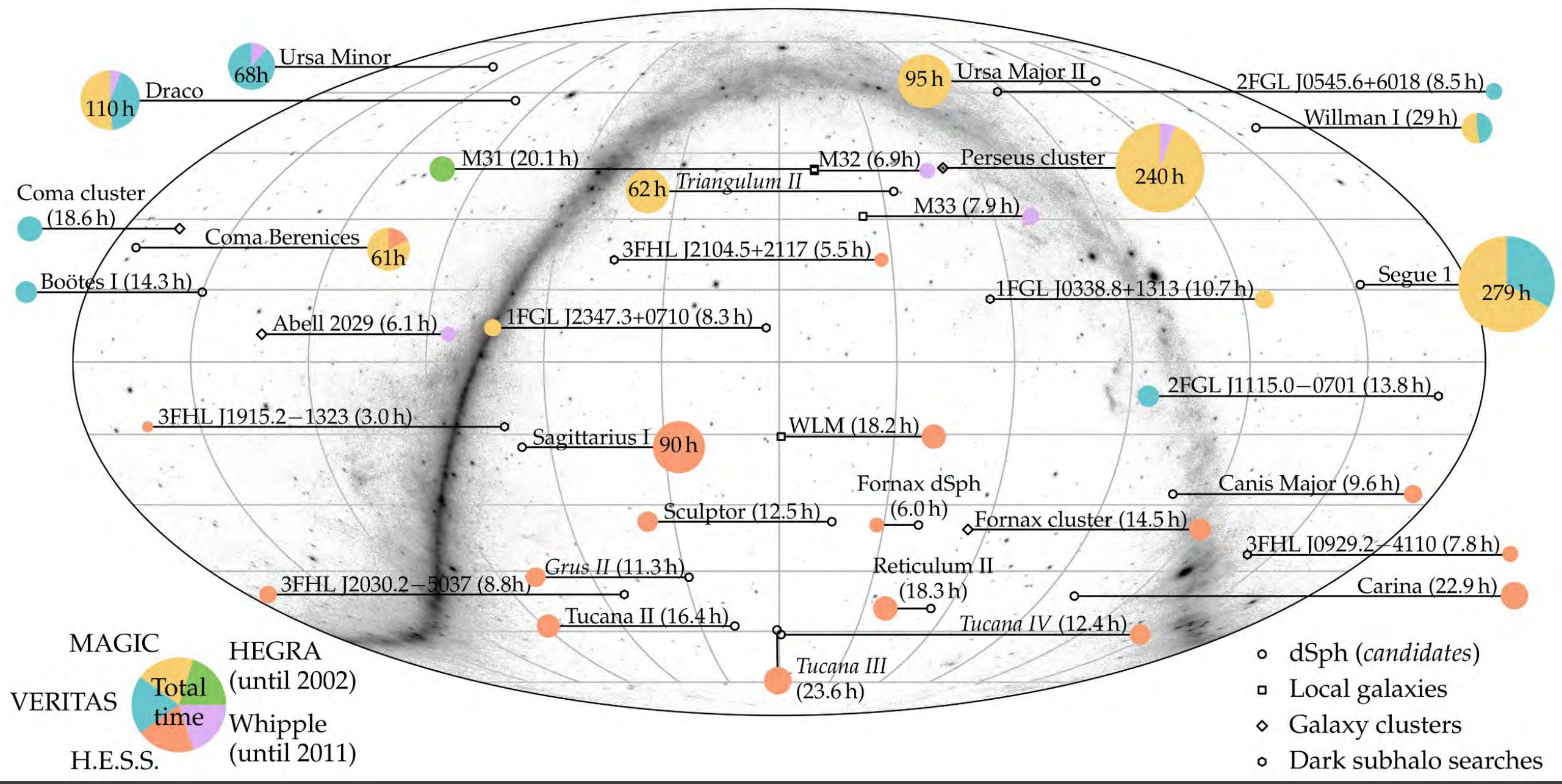
→ Fermi-LAT & COSI





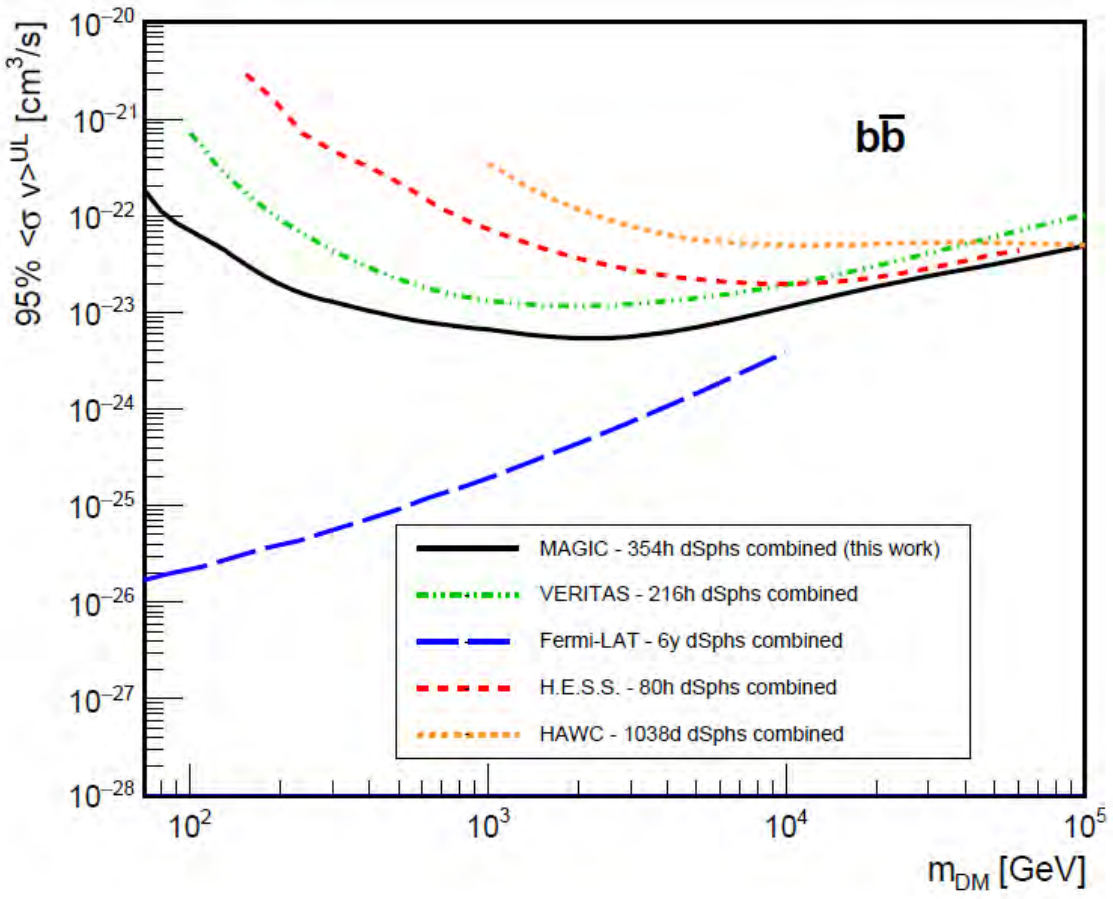
Elsässer & KM, Phys. Rev. Lett. (2005)

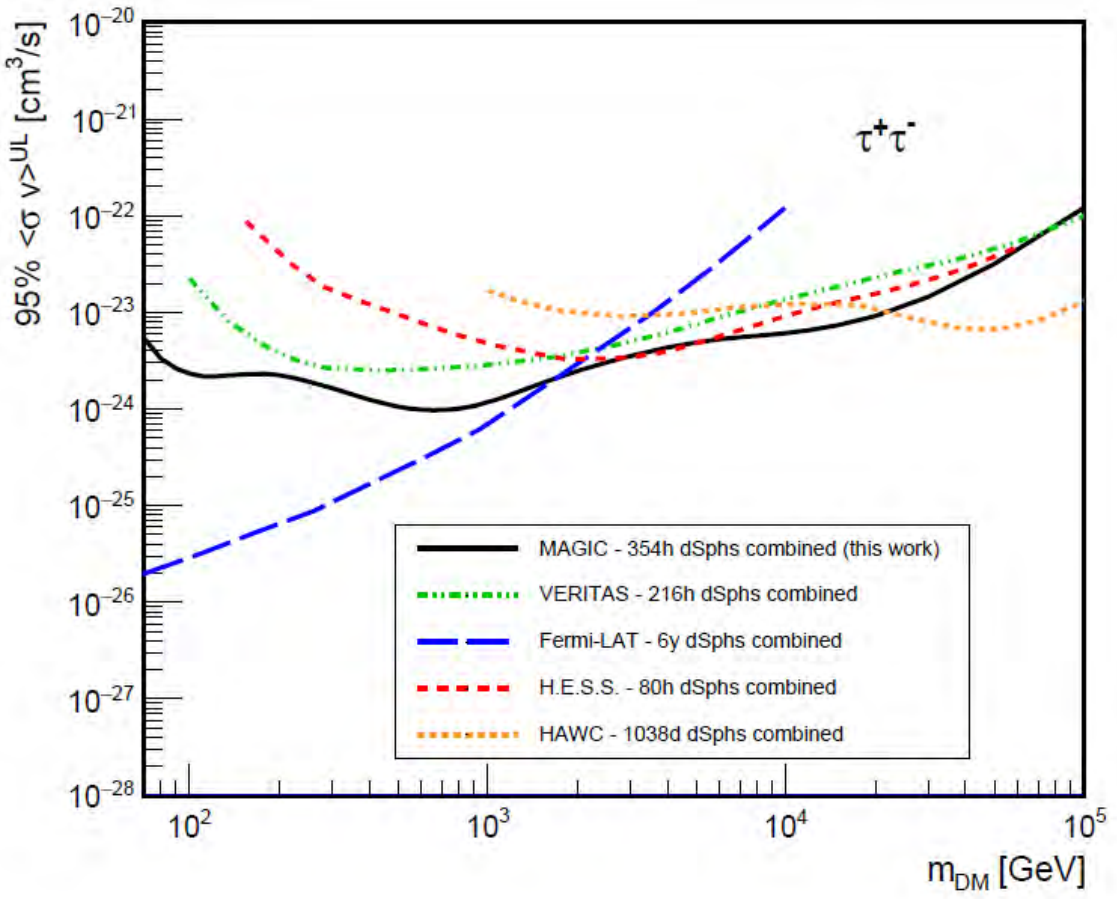




Hütten & Kerszberg (2022)

Acciari et al. (2022): Combined searches for dark matter in dwarf spheroidal galaxies observed with the MAGIC telescopes, including new data from Coma Berenices and Draco

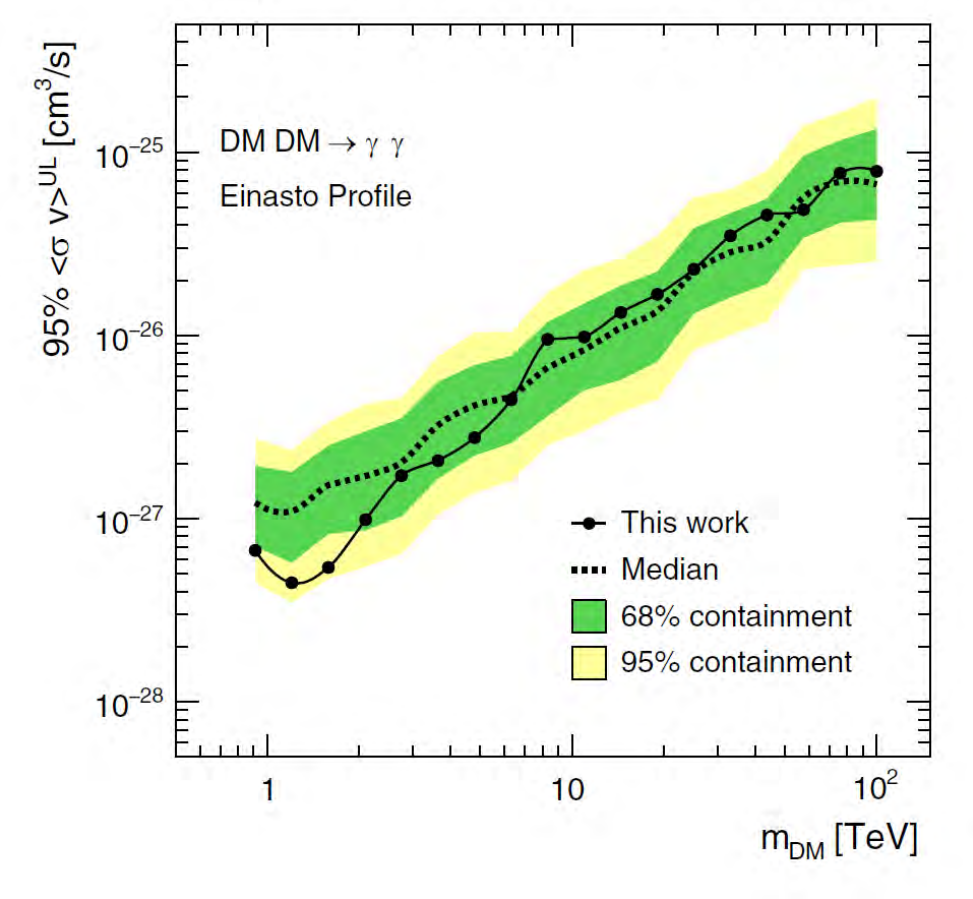


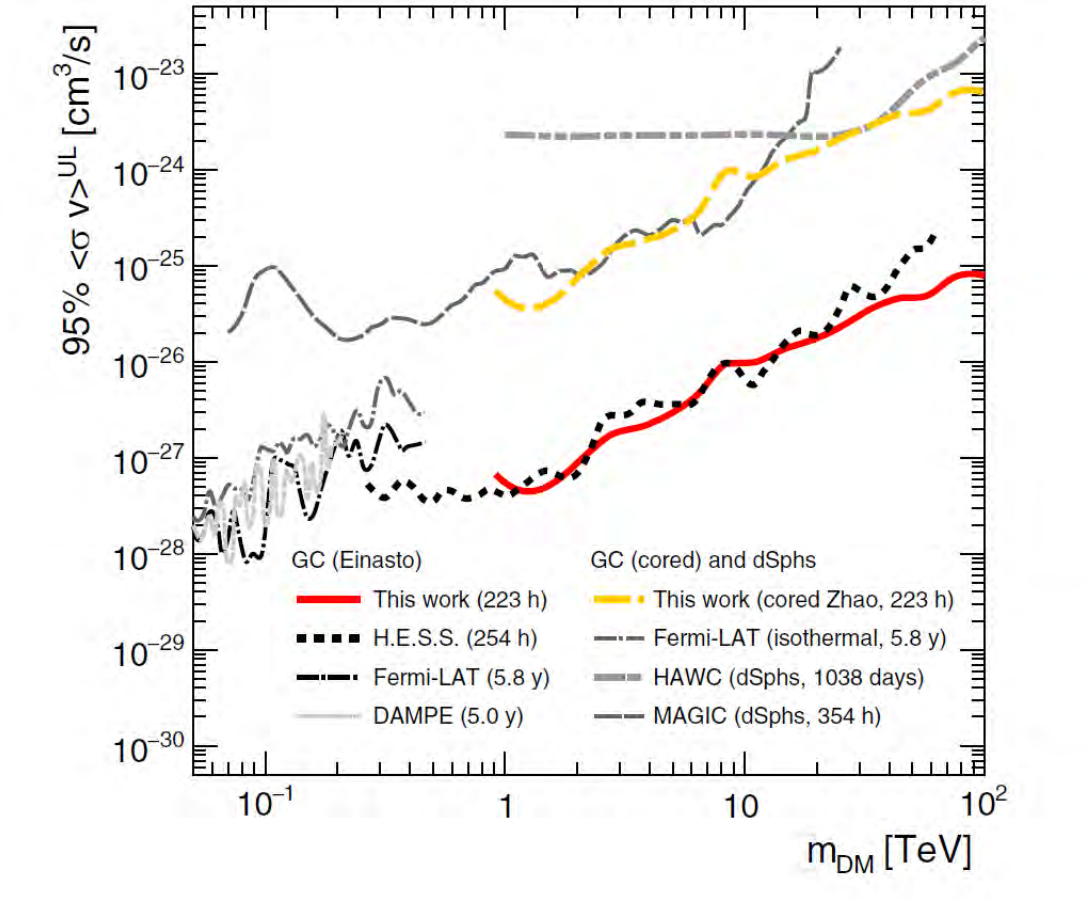


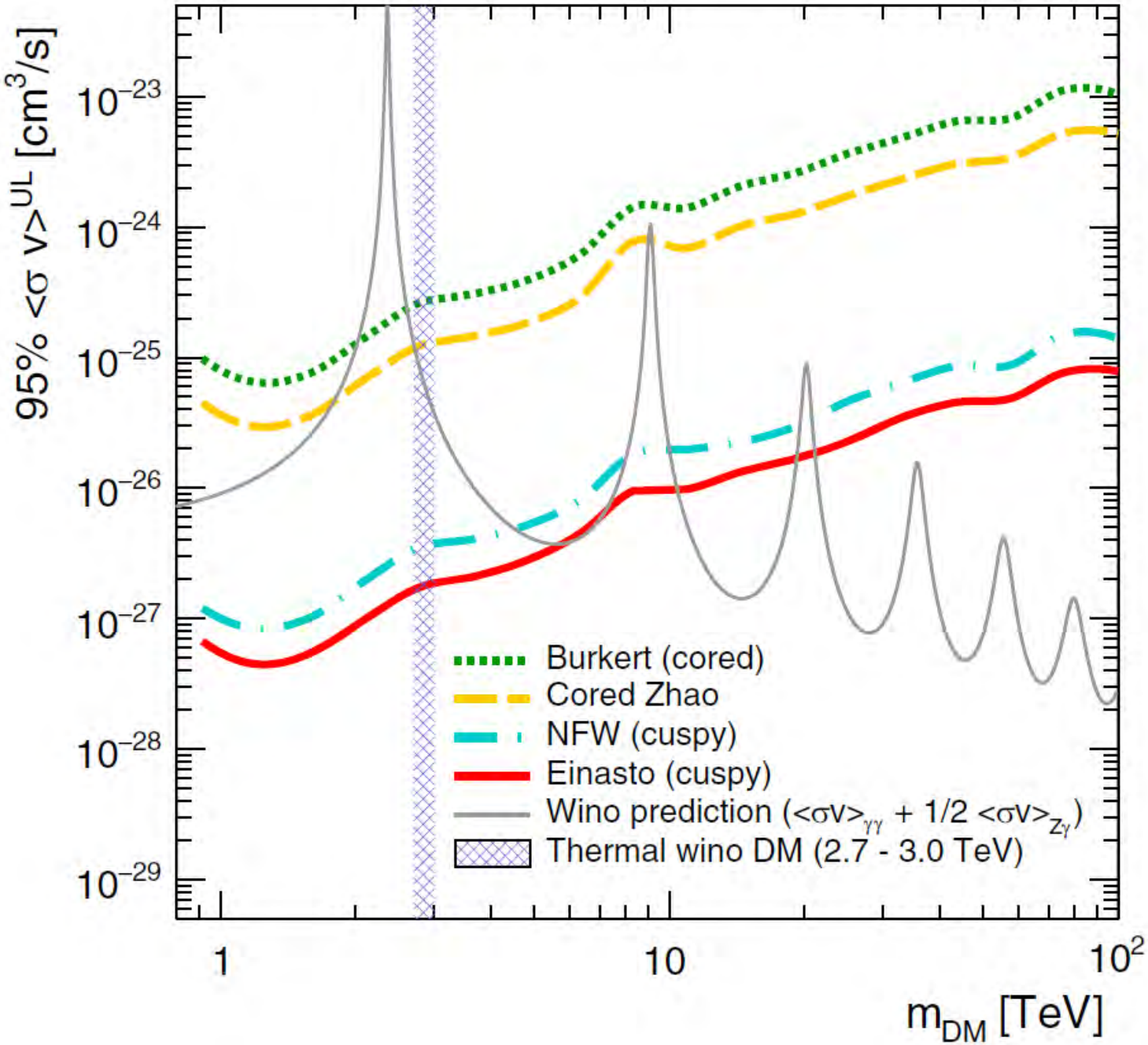
Galactic Center HZA observations with MAGIC

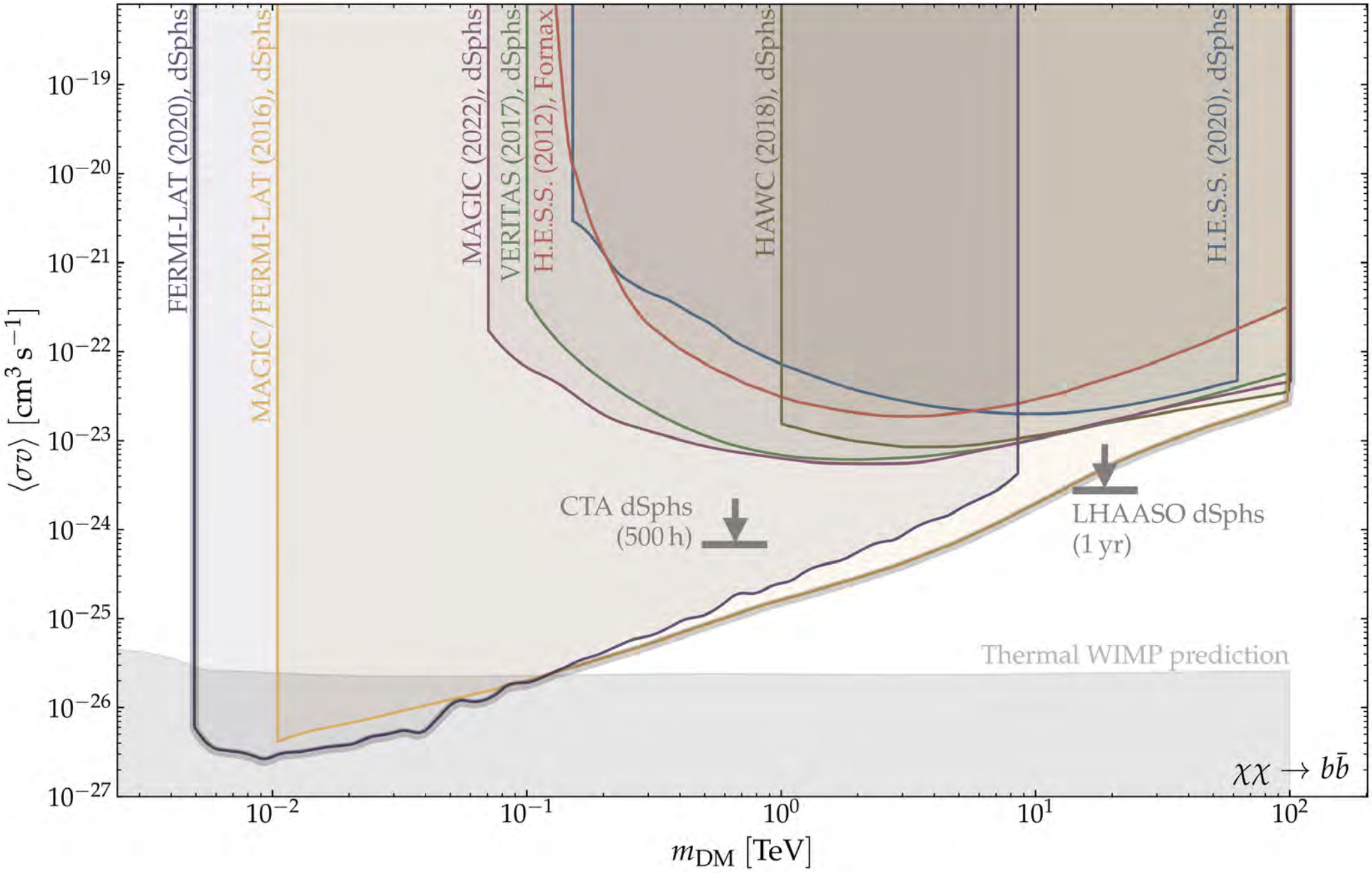
Abe et al. , PRL 130, 061002 (2023): “Search for Gamma-Ray Spectral Lines from Dark Matter Annihilation up to 100 TeV toward the Galactic Center with MAGIC”.

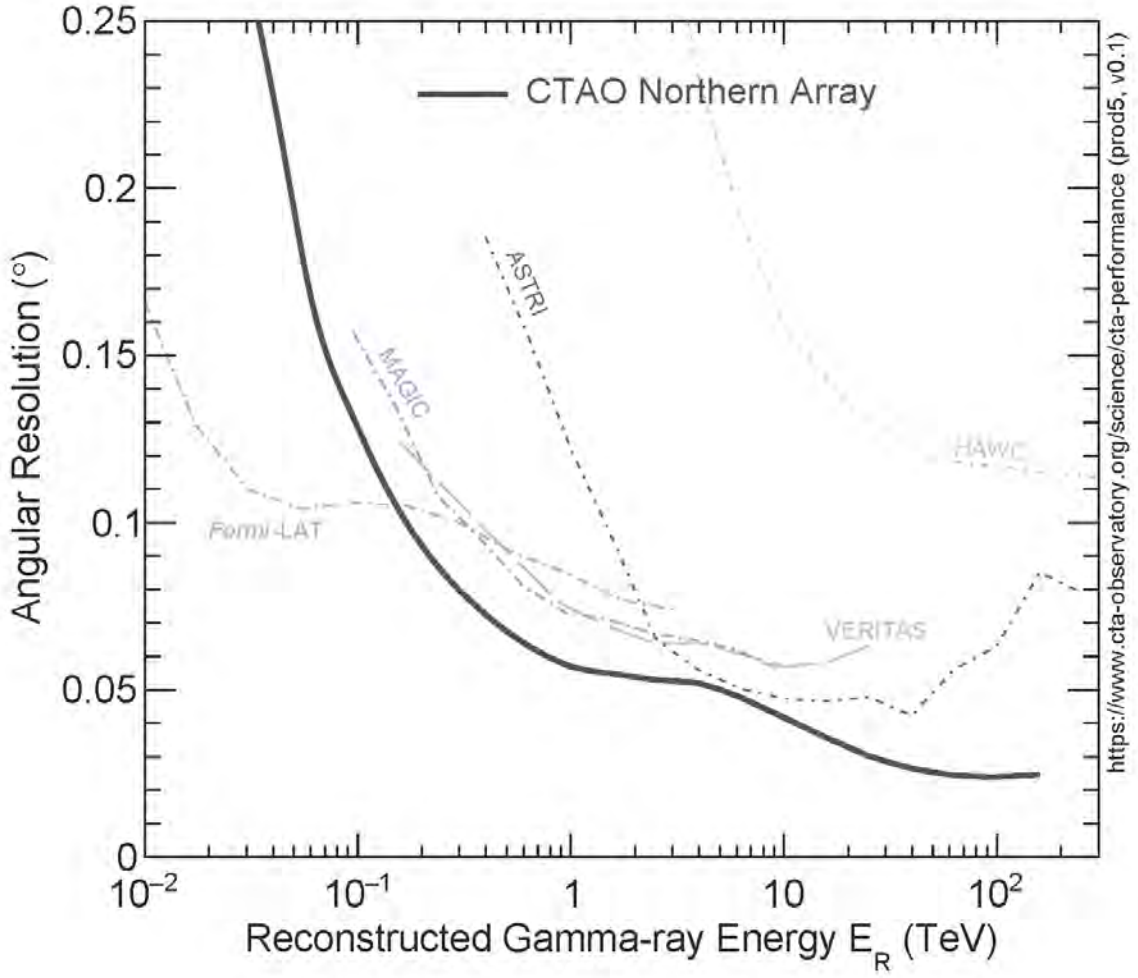
Sliding window line search…

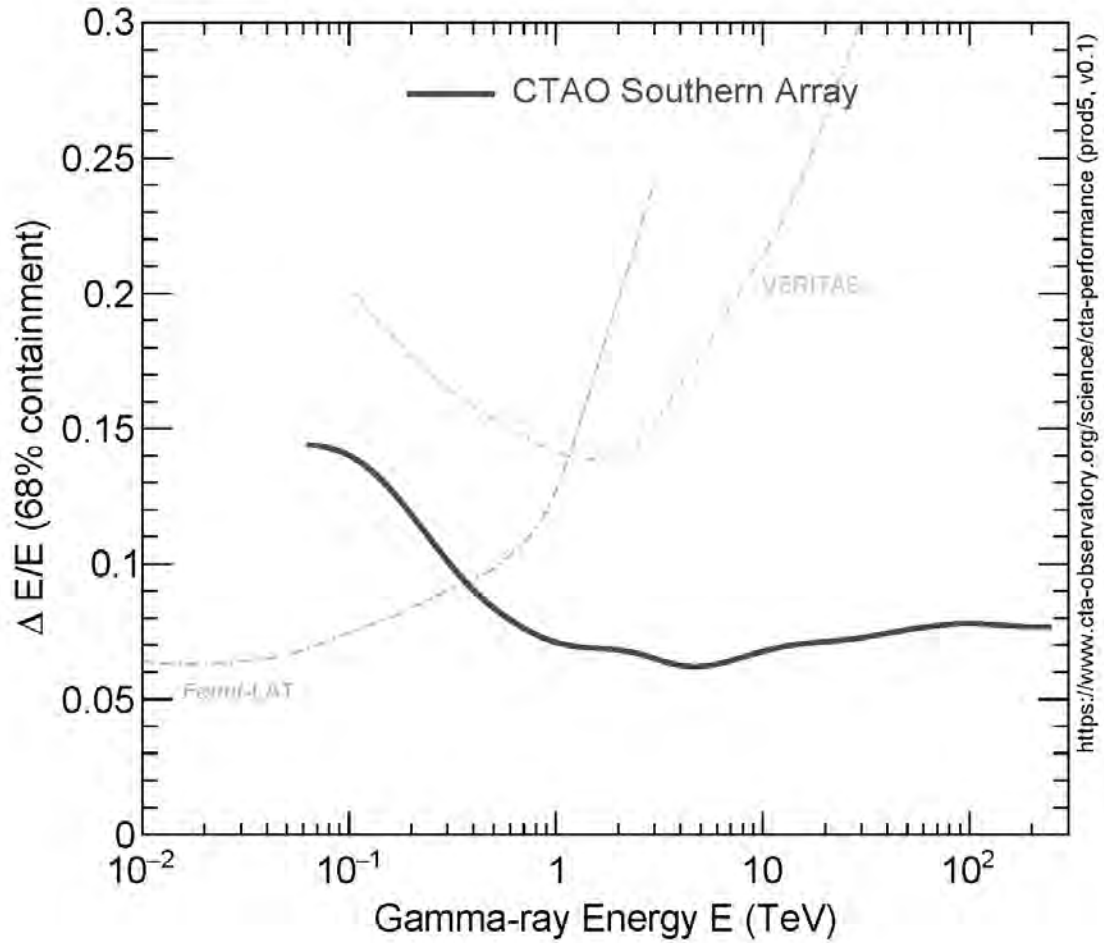


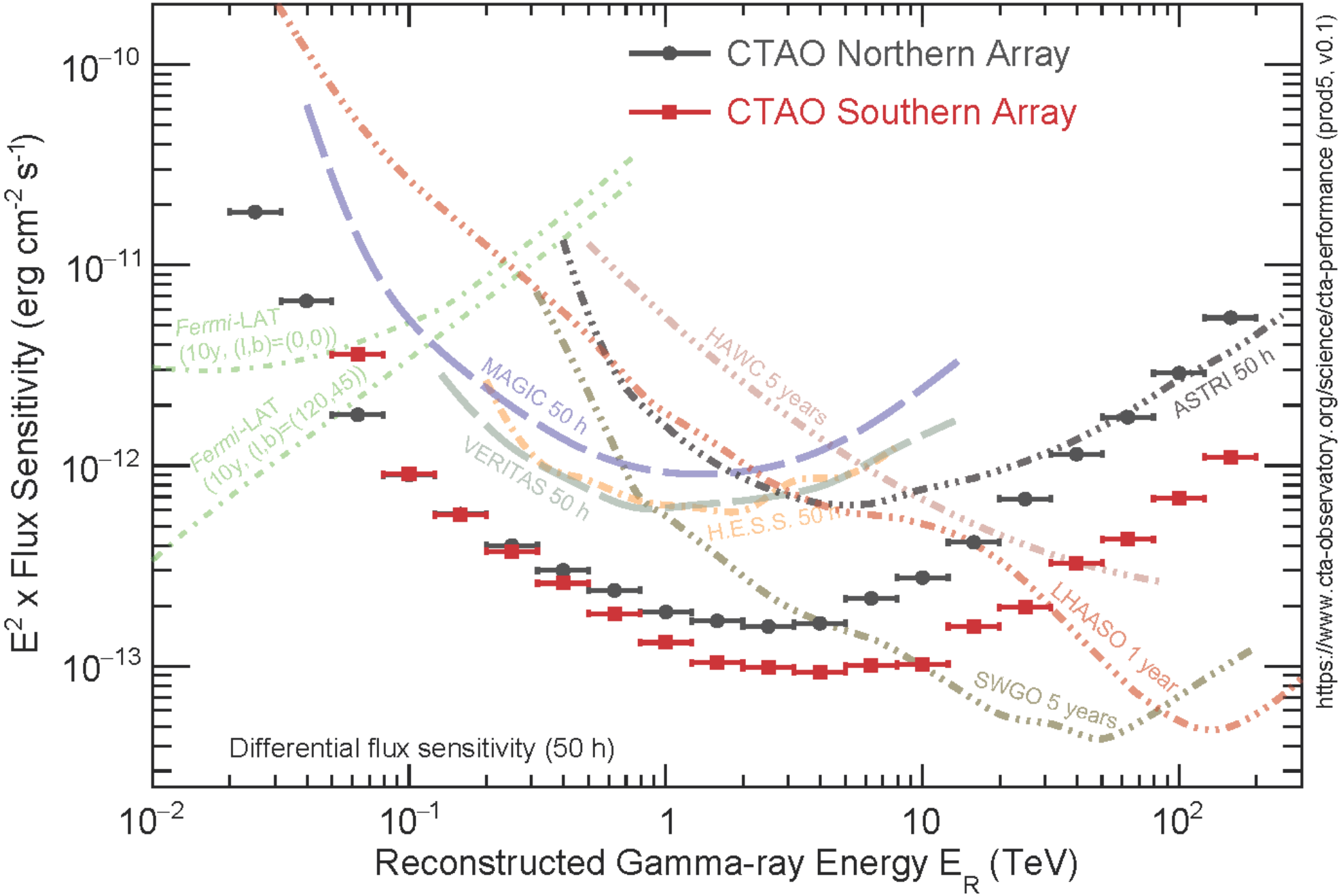


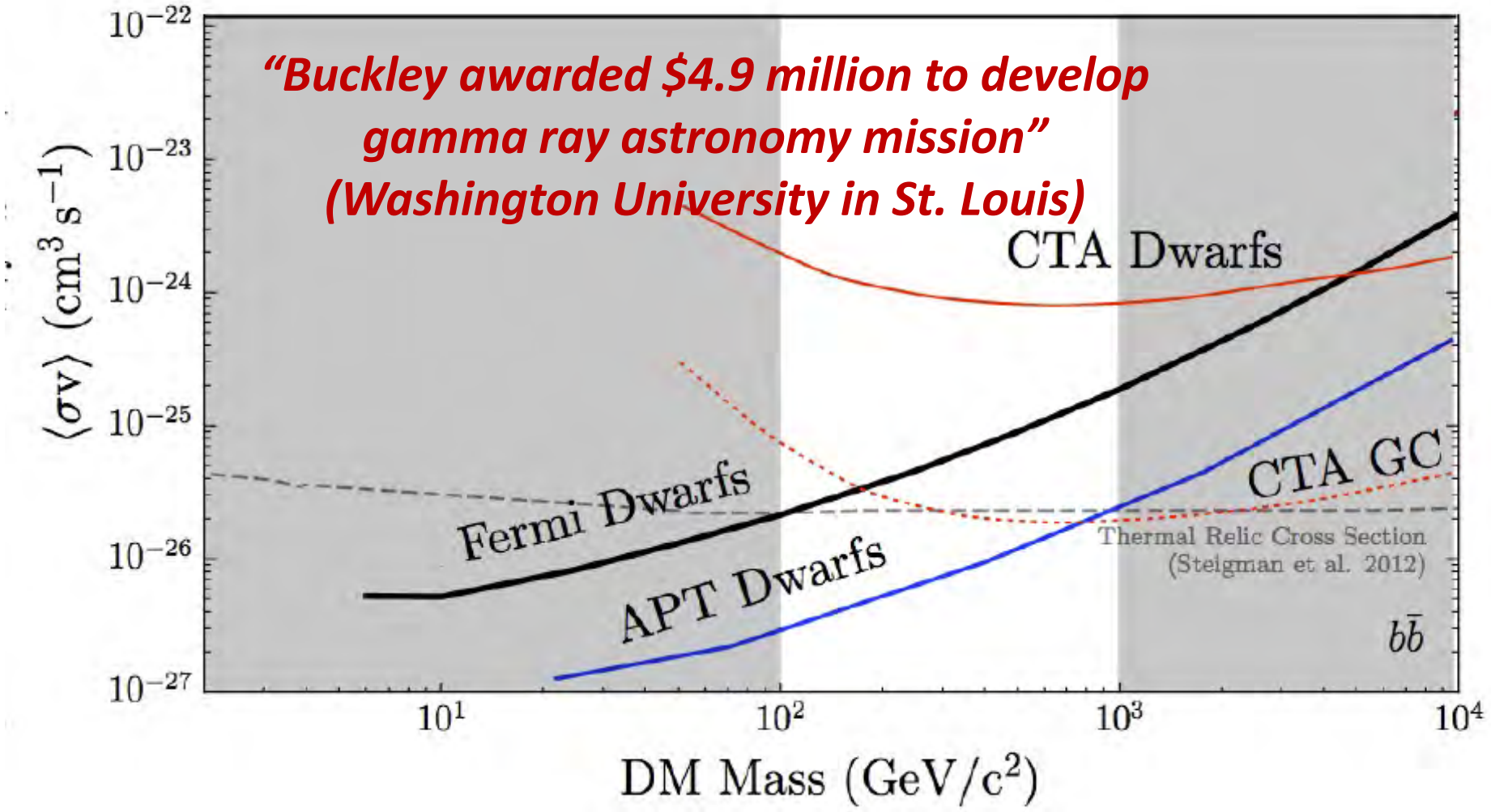

95% <σ v>^UL [cm^3/s]
10^−23
10^−24
10^−25
10^−26
10^−27
10^−28
10^−29
1
10
10^2
m_DM [TeV]
Burkert (cored)
Cored Zhao
NFW (cuspy)
Einasto (cuspy)
Wino prediction (<σv>_γγ + 1/2 <σv>_Zγ)
Thermal wino DM (2.7 - 3.0 TeV)


FERMI-LAT (2020), dSphs
MAGIC/FERMI-LAT (2016), dSphs
MAGIC (2022), dSphs
VERITAS (2017), dSphs
H.E.S.S. (2012), Fornax
HAWC (2018), dSphs
H.E.S.S. (2020), dSphs
CTA dSphs
(500 h)
LHAASO dSphs
(1 yr)
Thermal WIMP prediction
$\chi\chi \to b\bar{b}$
$\langle \sigma v \rangle$ [cm^3 s^{-1}]
$m_{\rm DM}$ [TeV]
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}


CTAO Northern Array
Angular Resolution (°)
Reconstructed Gamma-ray Energy E_R (TeV)
0.25
0.2
0.15
0.1
0.05
0
10^{-2}
10^{-1}
1
10
10^2
ASTRI
MAGIC
HAWC
Fermi-LAT
VERITAS
https://www.cta-observatory.org/science/cta-performance (prod5, v0.1)


CTAO Southern Array
Δ E/E (68% containment)
Gamma-ray Energy E (TeV)
0.3
0.25
0.2
0.15
0.1
0.05
0
10^{-2}
10^{-1}
1
10
10^2
VERITAS
Fermi-LAT
https://www.cta-observatory.org/science/cta-performance (prod5, v0.1)


CTAO Northern Array
CTAO Southern Array
Fermi-LAT (10y, (l,b)=(0,0))
Fermi-LAT (10y, (l,b)=(120,45))
MAGIC 50 h
VERITAS 50 h
HAWC 5 years
H.E.S.S. 50 h
ASTRI 50 h
LHAASO 1 year
SWGO 5 years
Differential flux sensitivity (50 h)
E² x Flux Sensitivity (erg cm⁻² s⁻¹)
Reconstructed Gamma-ray Energy E_R (TeV)
https://www.cta-observatory.org/science/cta-performance (prod5, v0.1)



Buckley et al., APT Proposal (2020)

Prospects for the next 5 years:

Improved performance of LST-array

New hints from LHC upgrade

COSI fills sensitivity gap for IC detection