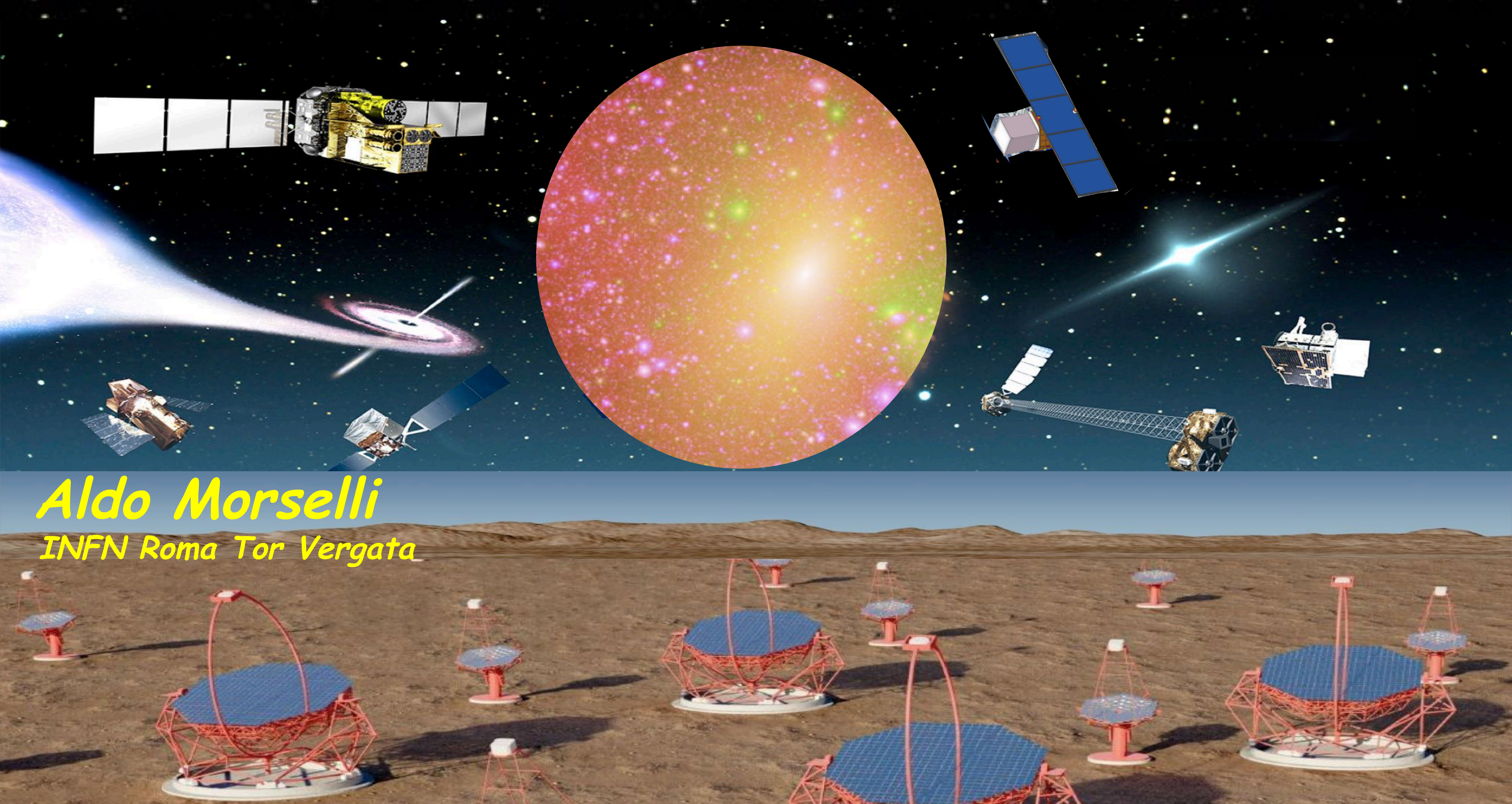
Indirect dark-matter searches with gamma-rays experiments: status and future plans from 300 KeV to 100 TeV



Aldo Morselli

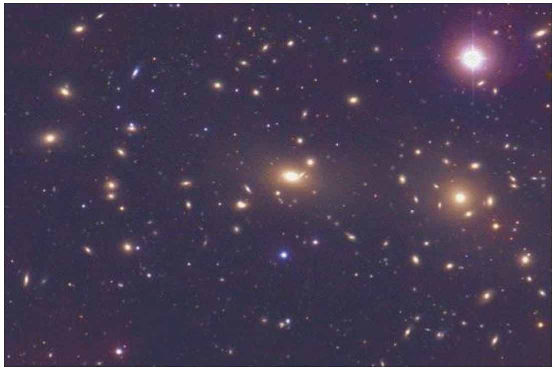
INFN Roma Tor Vergata

17th School and Workshops on Elementary Particle Physics and Gravity

Workshop on the Standard Model and Beyond   Corfu 2 Sept 2017

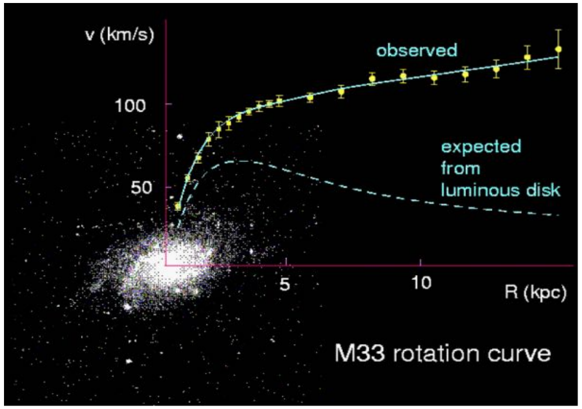
Dark Matter EVIDENCE

In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies.



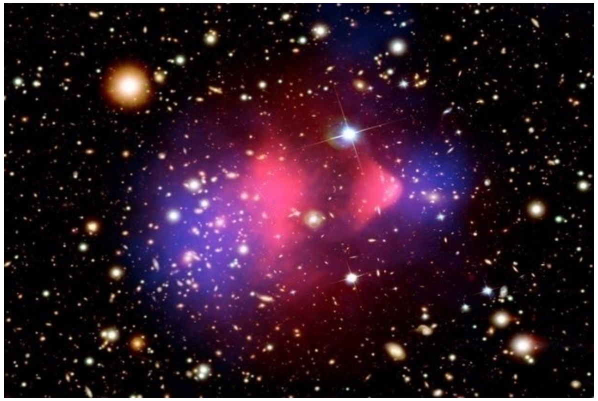
Since then, even more evidence:

Rotation curves of galaxies

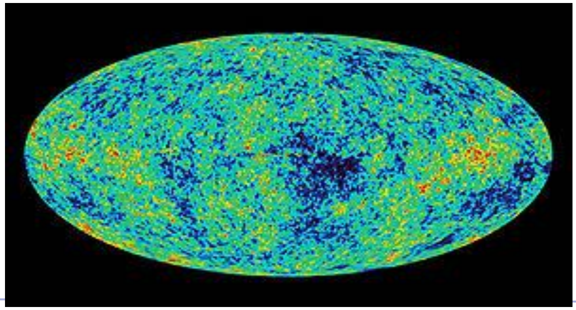


Gravitational lensing

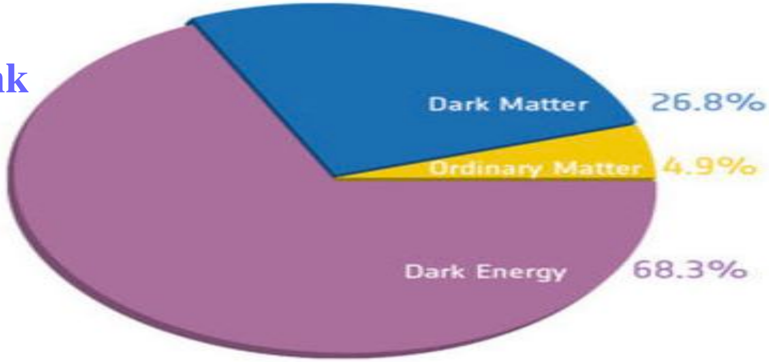
Bullet cluster



Structure formation as deduced from CMB

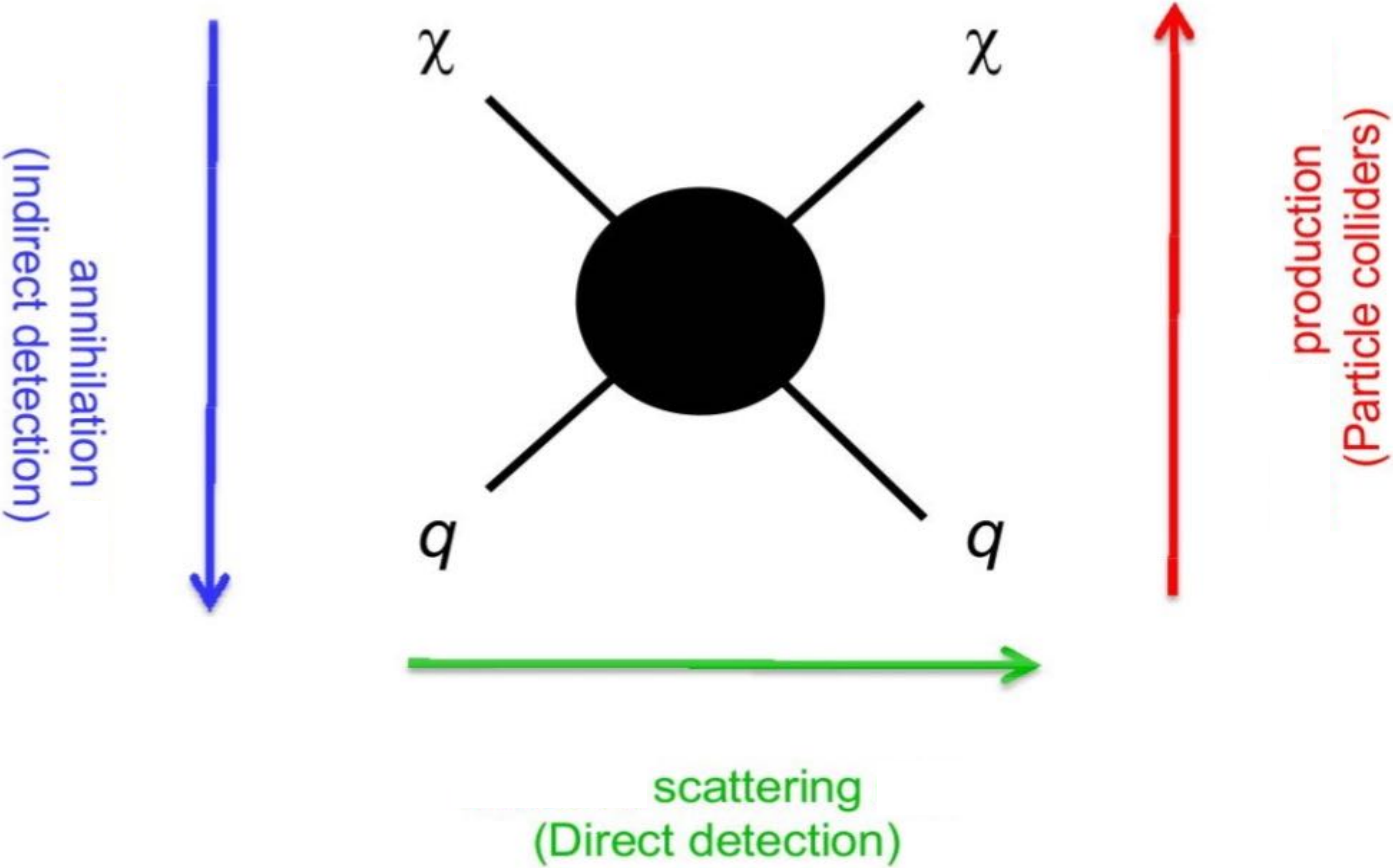


Data by Plank imply:



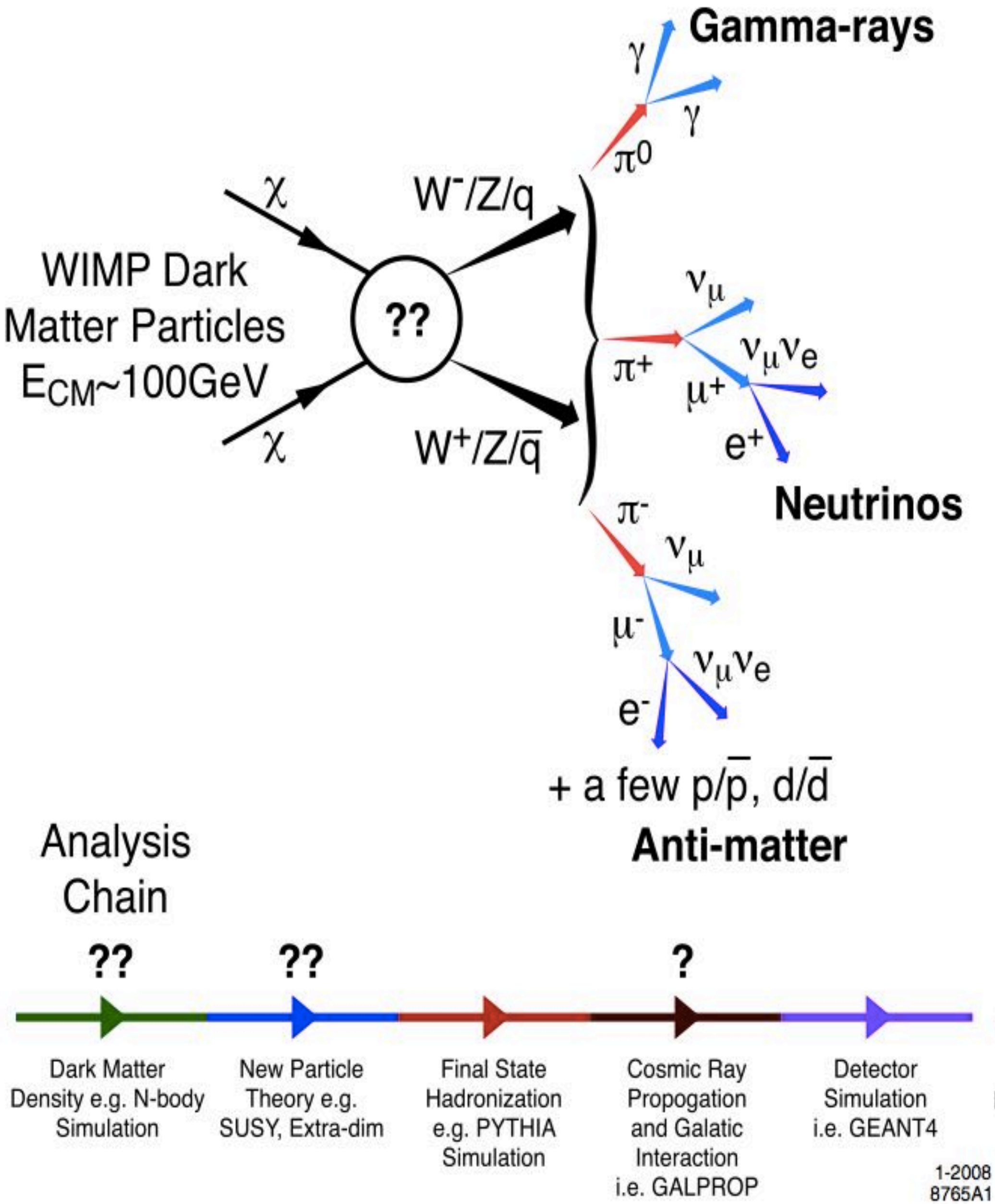
$\Omega_{DM} \approx 26.8\%$

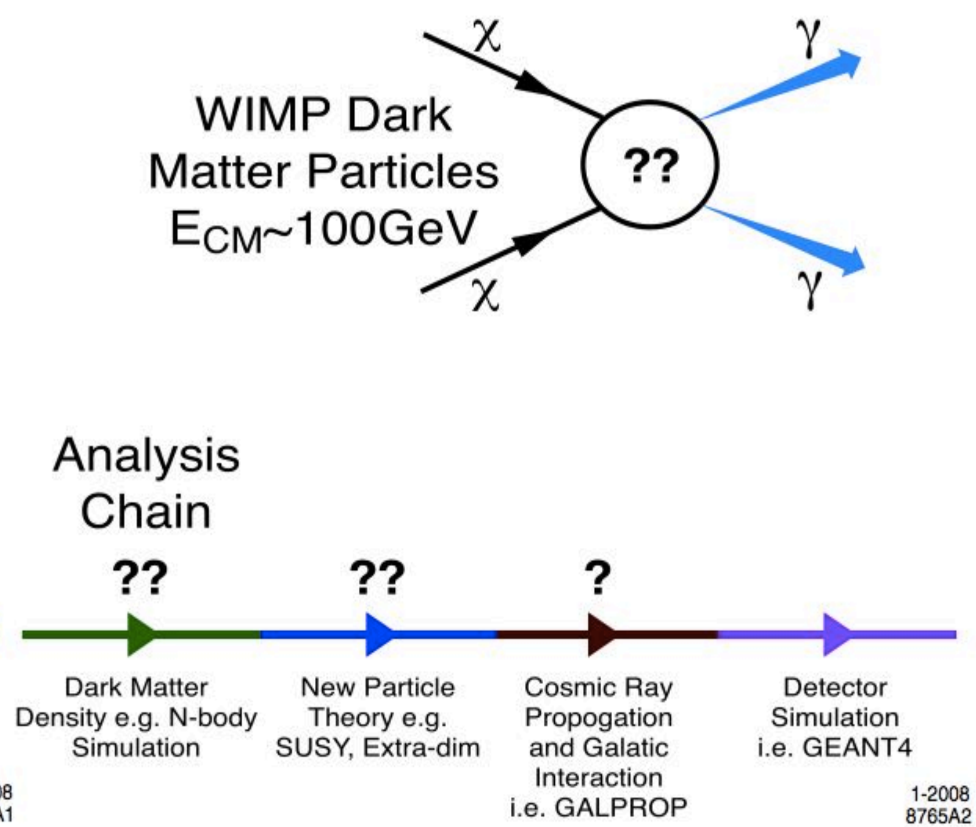
$\Omega_{M} \approx 4.9\%$



χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)

Annihilation channels





Dark Matter Search: Targets and Strategies

Satellites

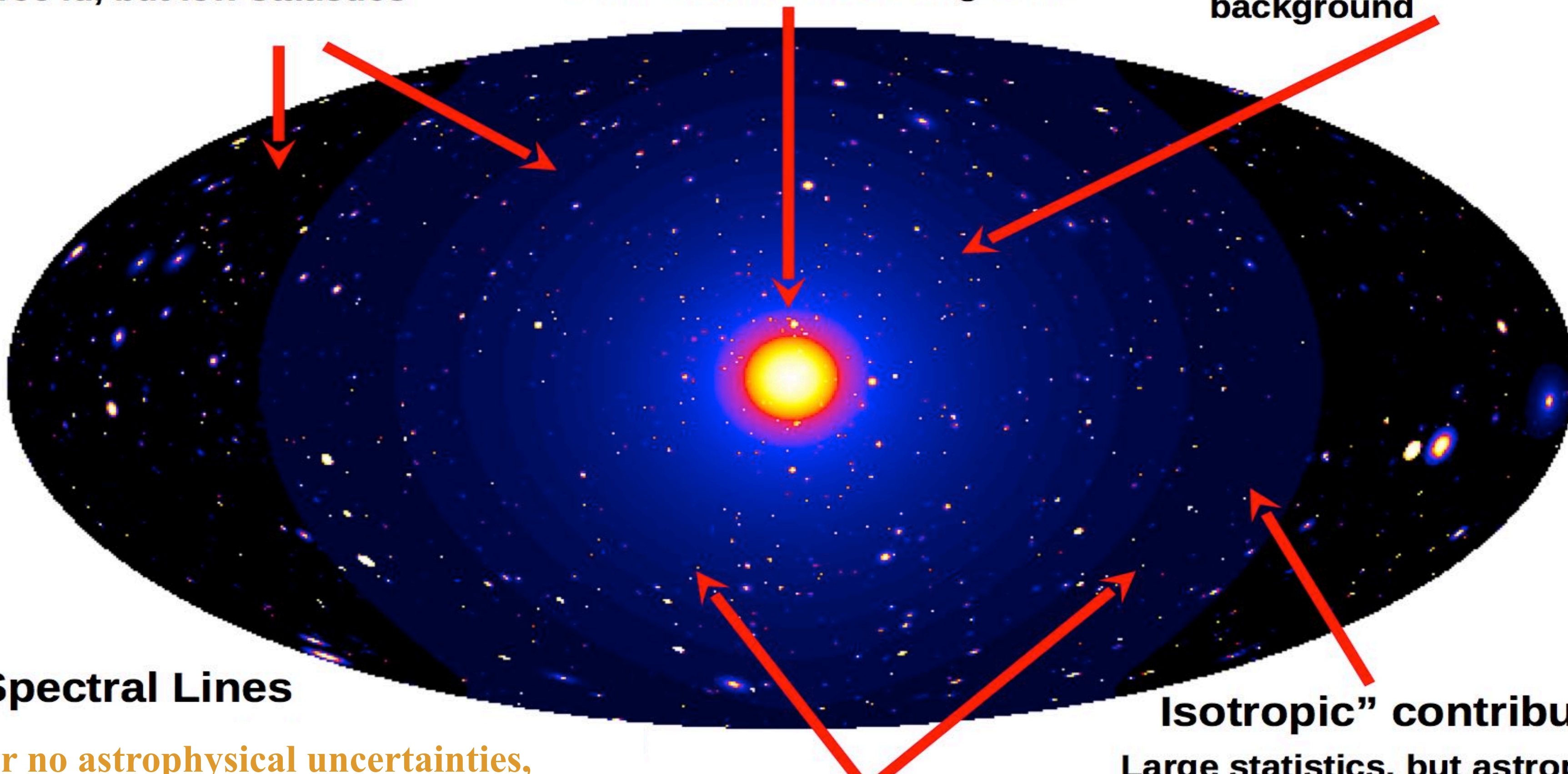
Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

Milky Way Halo

Large statistics, but diffuse background



Spectral Lines

Little or no astrophysical uncertainties, but low sensitivity because of expected small branching ratio

Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

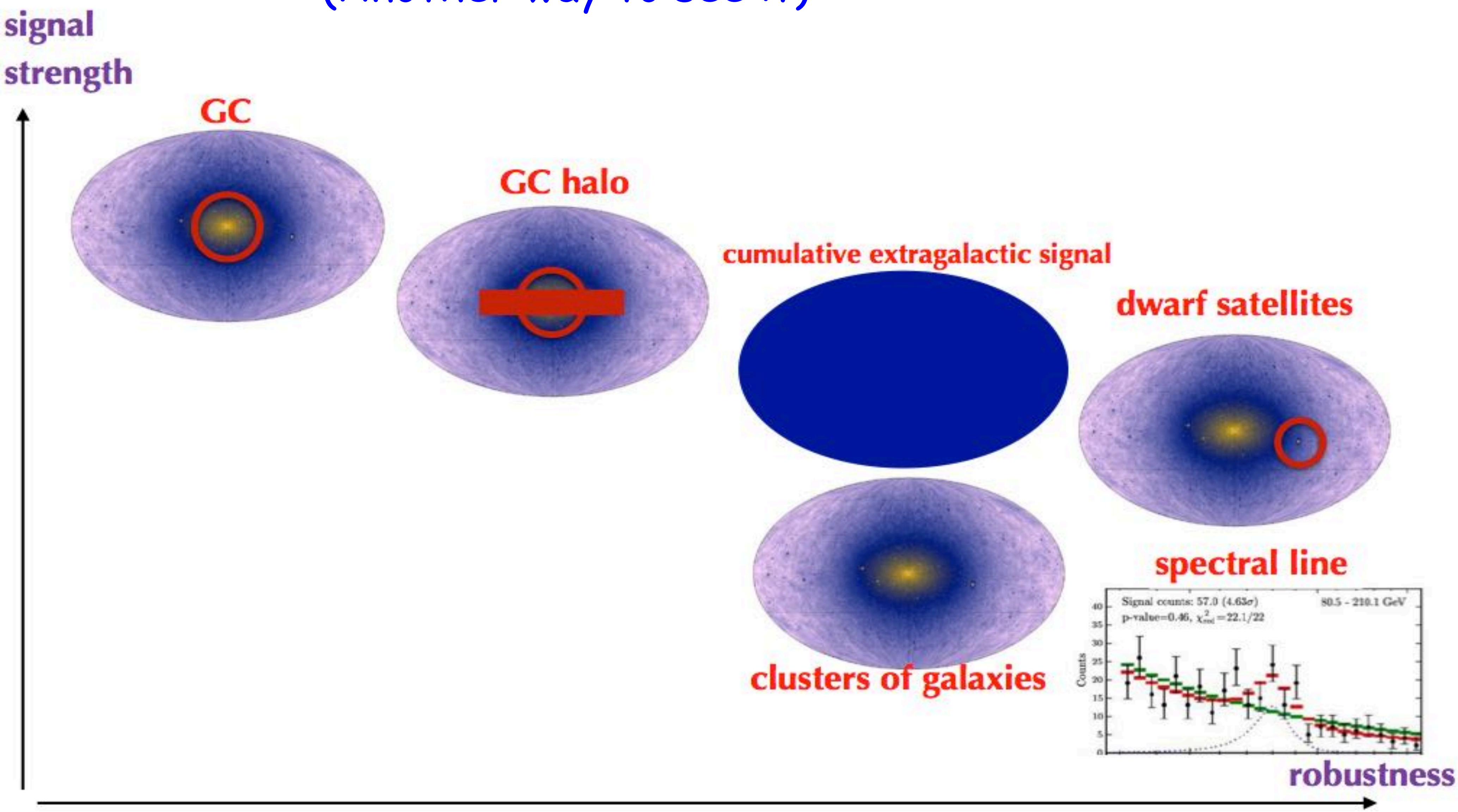
Galaxy Clusters

Low background, but low statistics

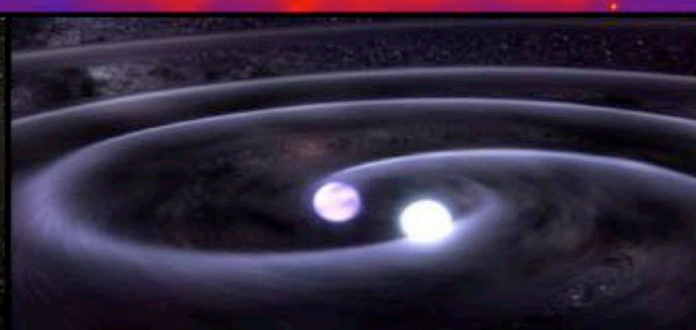
Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

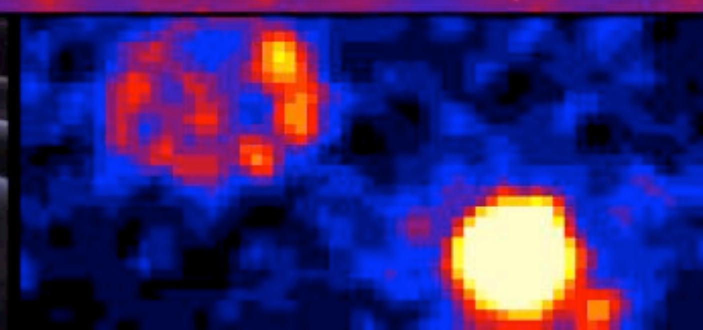
Dark Matter Search: Targets and Strategies

(Another way to see it)



Fermi Gamma-Ray Space Telescope





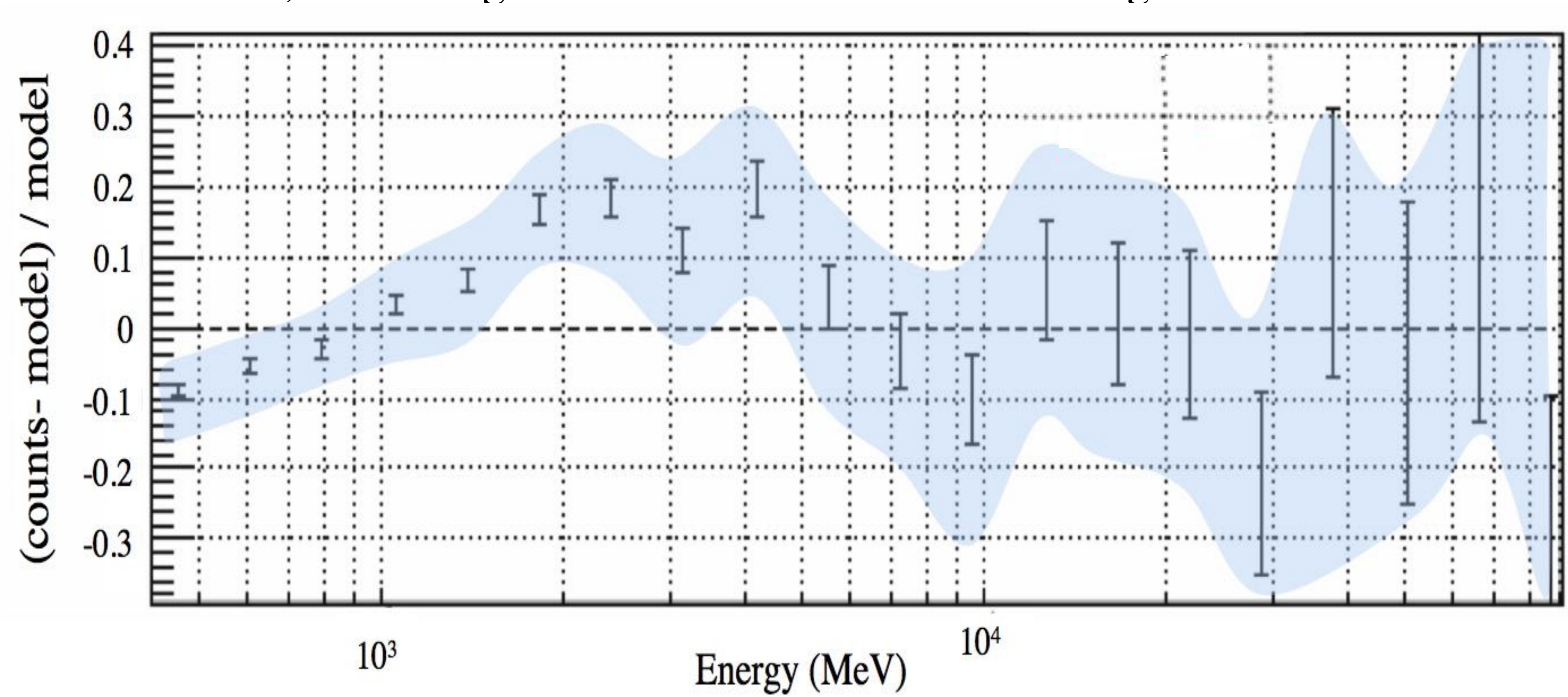

Fermi
Gamma-ray
Space Telescope
Happy 9th Birthday Fermi !!
11 June 2008

The GeV excess

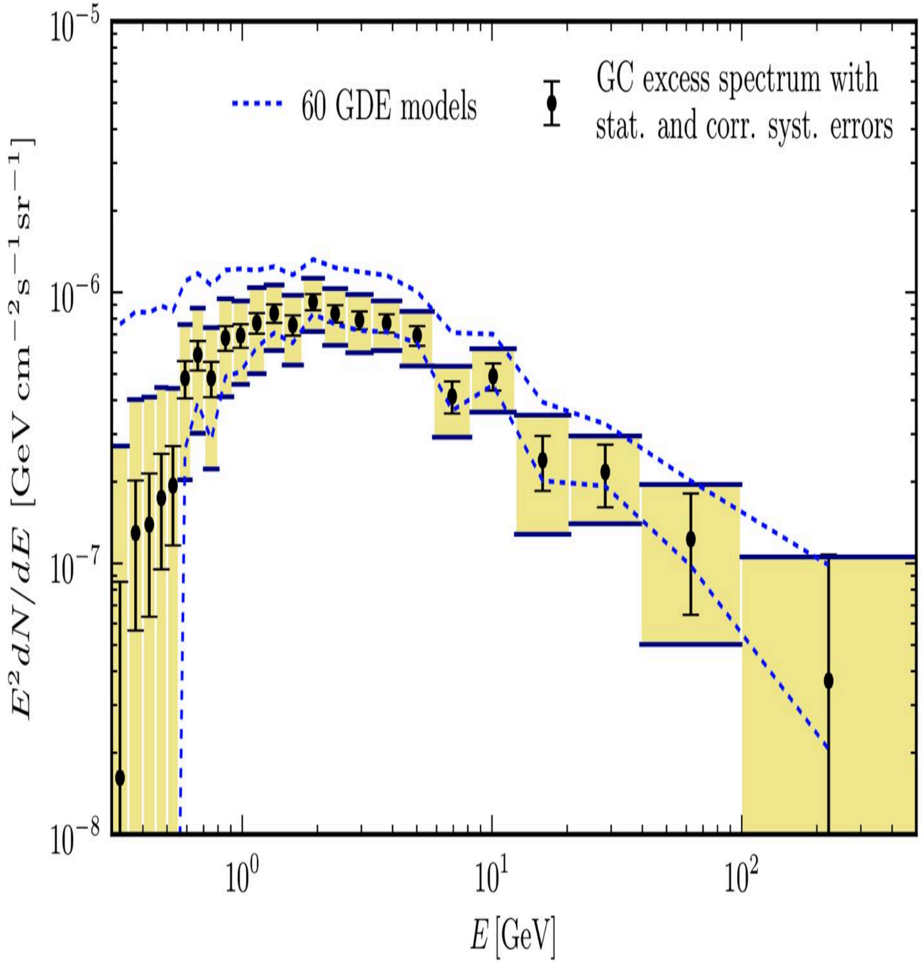
7°x7°region centered on the Galactic Center

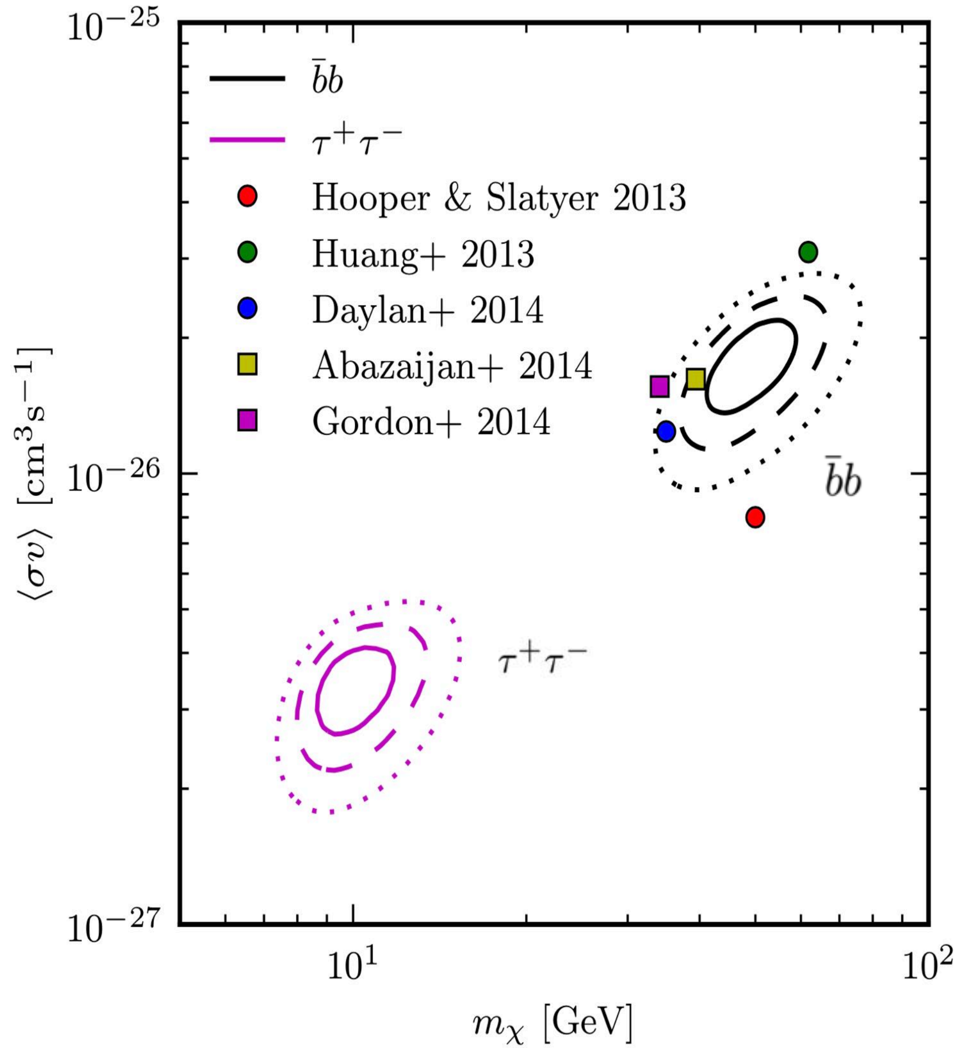
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



The GeV excess





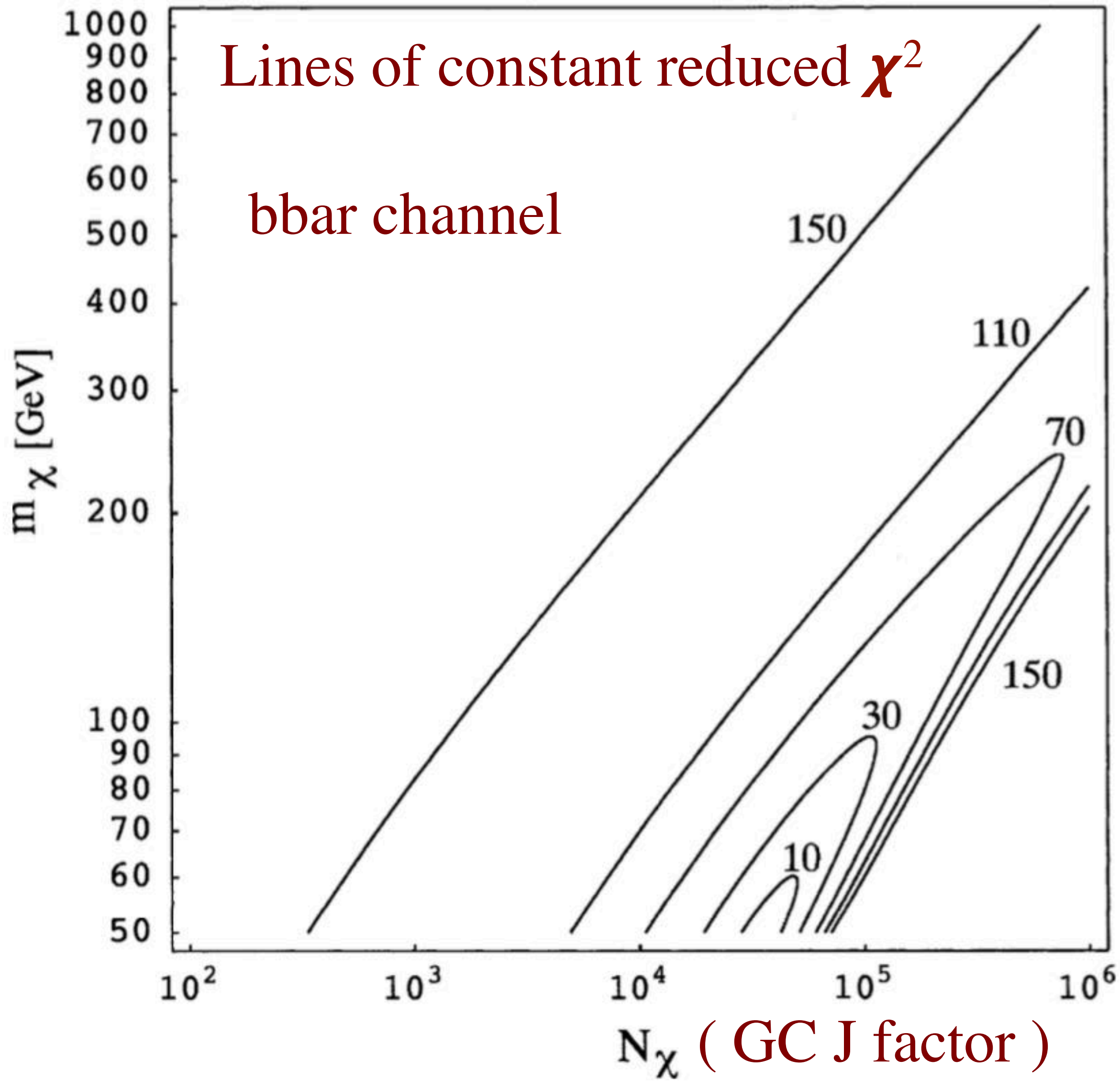
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

Calore et al, arXiv:1409.0042v1

Lines of constant reduced χ^2 corresponding to best fits of the EGRET GC excess

Very similar to the mass range found with the EGRET data in 2004 !

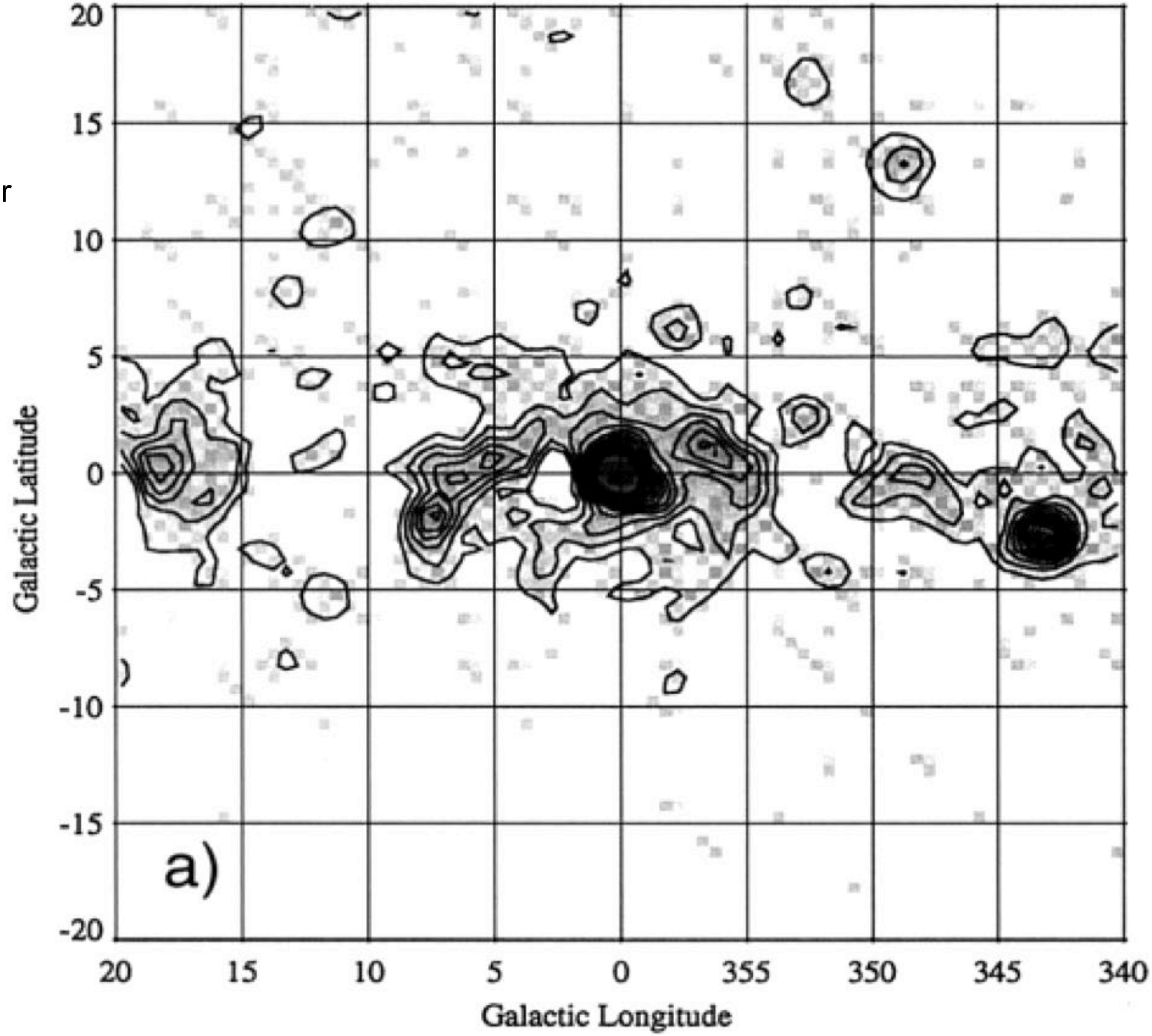
mass ~ 50- 80 GeV

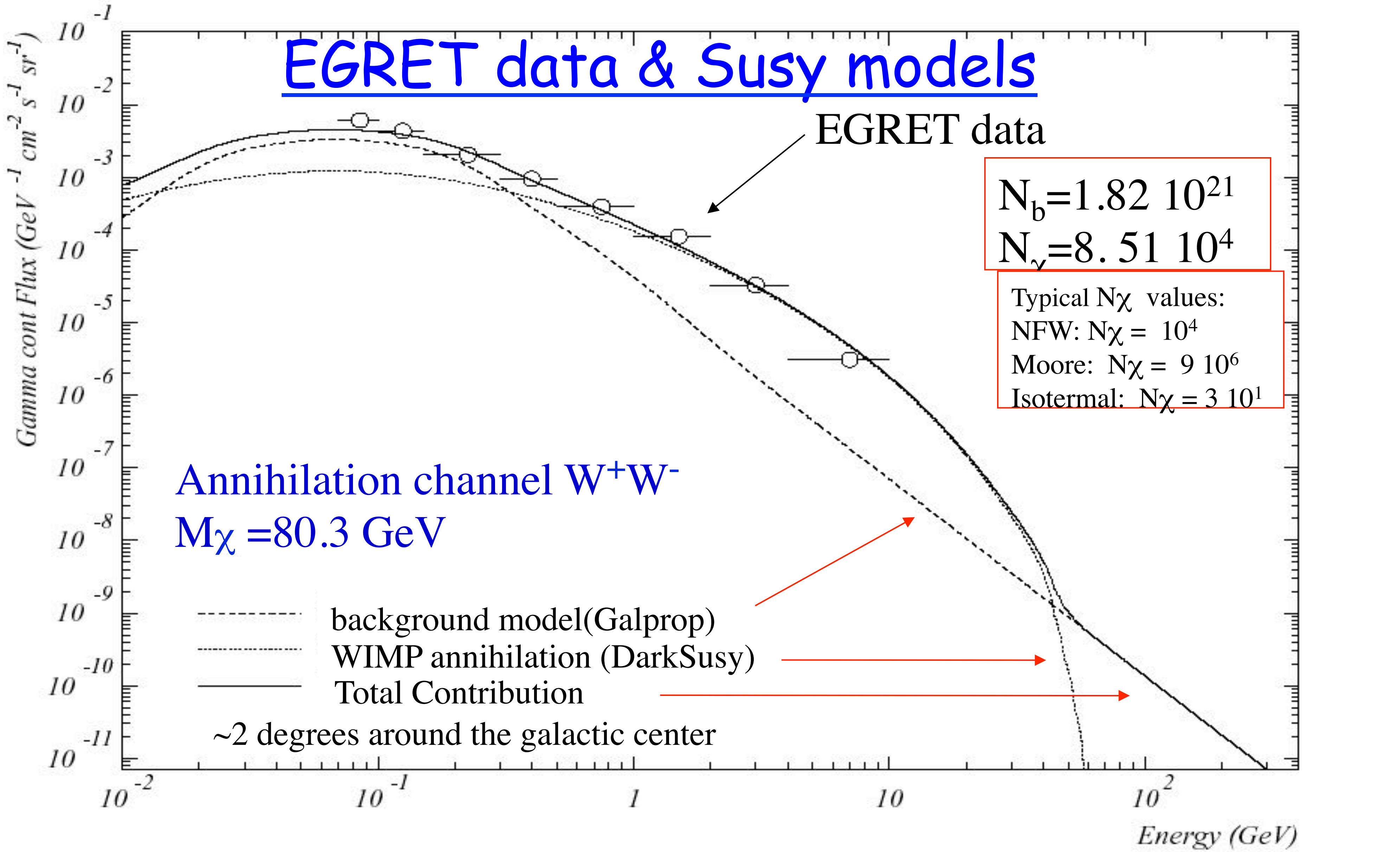


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

EGRET, E > 1GeV

Mayer-Hasselwander et al, 1998





A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nucl. Phys. B 113B (2002) 213-220 [astro-ph/0211327]

the GALACTIC CENTER : any hints of Dark Matter?

the beginning of the history :

The Galactic Center as a Dark Matter Gamma-Ray Source
A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nuclear Physics B 113B (2002) 213-220 [astro-ph/0211327]
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio Astroparticle Physics 21, 267-285, 2004 [astro-ph/0305075]

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope
Lisa Goodenough, Dan Hooper arXiv:0910.2998

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope
Vincenzo Vitale, Aldo Morselli, the Fermi/LAT Collaboration
Proceedings of the 2009 Fermi Symposium, 2-5 November 2009, eConf Proceedings C091122 **arXiv:0912.3828** **21 Dec 2009**

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi-LAT Collaboration NIM A 630 (2011) 147–150 (Available online 23 June 2010)

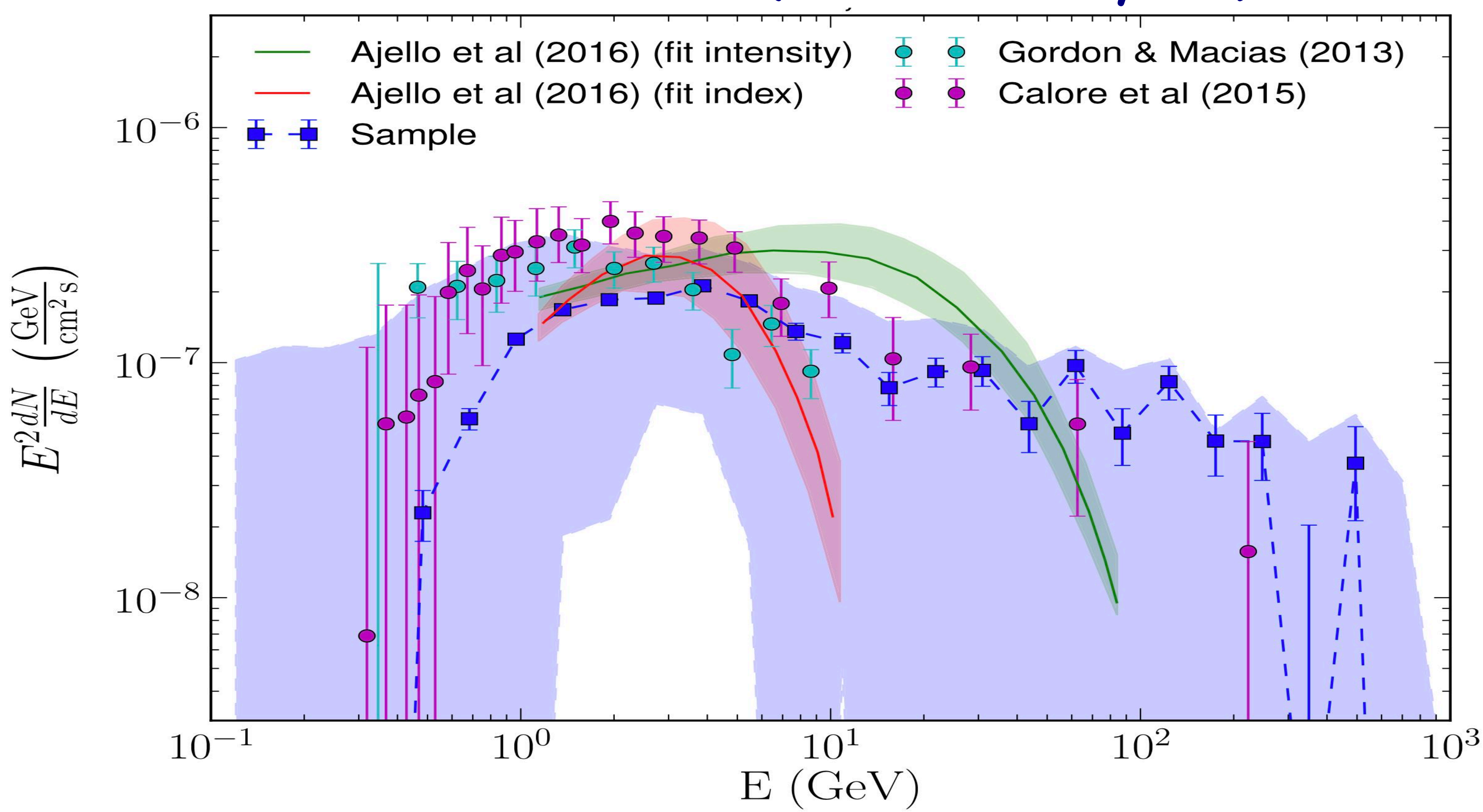
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

....

Background model systematics for the Fermi GeV excess
F.Calore, I. Cholis, C. Weniger JCAP03(2015)038 **arXiv:1409.0042v1**

Fermi–LAT observations of high-energy γ-ray emission toward the galactic centre
M. Ajello et al.[Fermi-LAT Coll.] **Apj 819:44 2016 arXiv:1511.02938**
(using Pass7, Pass8 analysis in progress)

The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

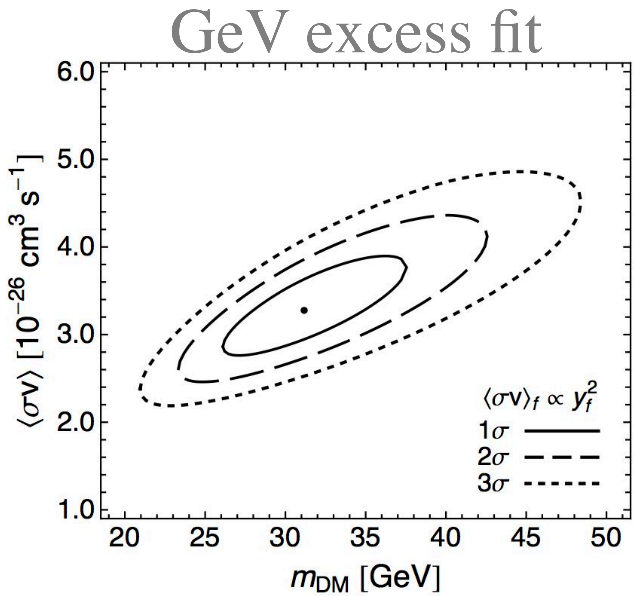
– Variation of GALPROP models – Distribution of gas along the line of sight

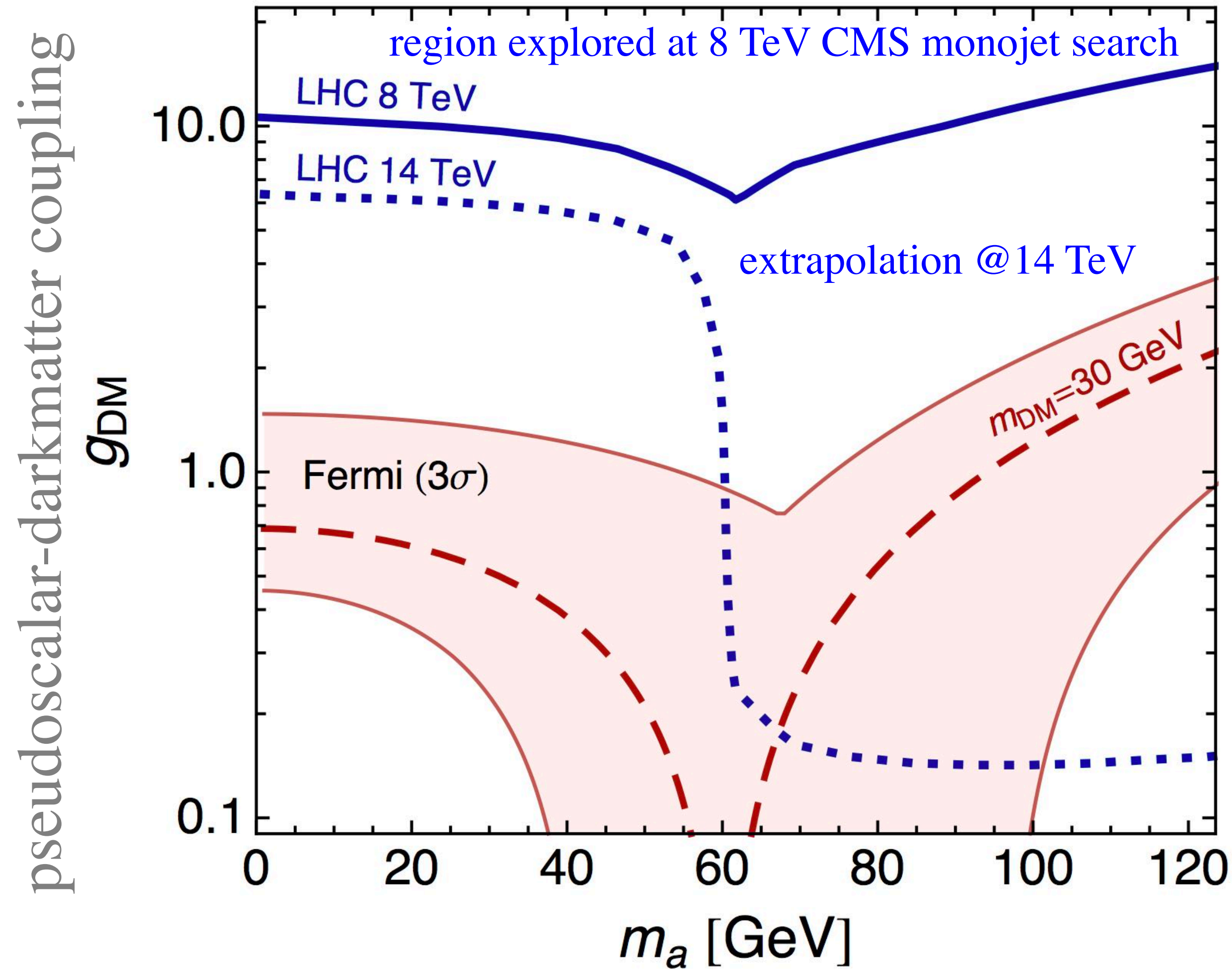
- **Most significant sources of uncertainty are:**

– Fermi bubbles morphology at low latitude – Sources of CR electrons near the GC

Fermi-LAT Collaboration Apj 840:43 2017 May 1 arXiv:1704.03910

Galactic Center and Dark Matter





note:this plot is valid only for a particular model of coy Dirac dark matter that annihilates primarily into b quarks via a pseudoscalar

Se non è vero è ben trovato

(If it is not true, it is well conceived)

Bœhm et al. JCAP05(2014)009

arXiv:1401.6458

The GeV excess : Other explanations exist

• past activity of the Galactic center

(e.g. Petrovic et al., arXiv:1405.7928, Carlson & Profumo arXiv:1405.7685)

• Series of Leptonic Cosmic-Ray Outbursts

Cholis et al. arXiv:1506.05119

• Stellar population of the X-bulge and the nuclear bulge

Macias et al. arXiv:1611.06644

• Molecular Clouds in the disk

De Boer et al. arXiv:1610.08926, arXiv:1707.08653 **(see Wim De Boer's talk)**

• Population of pulsars in the Galactic bulge

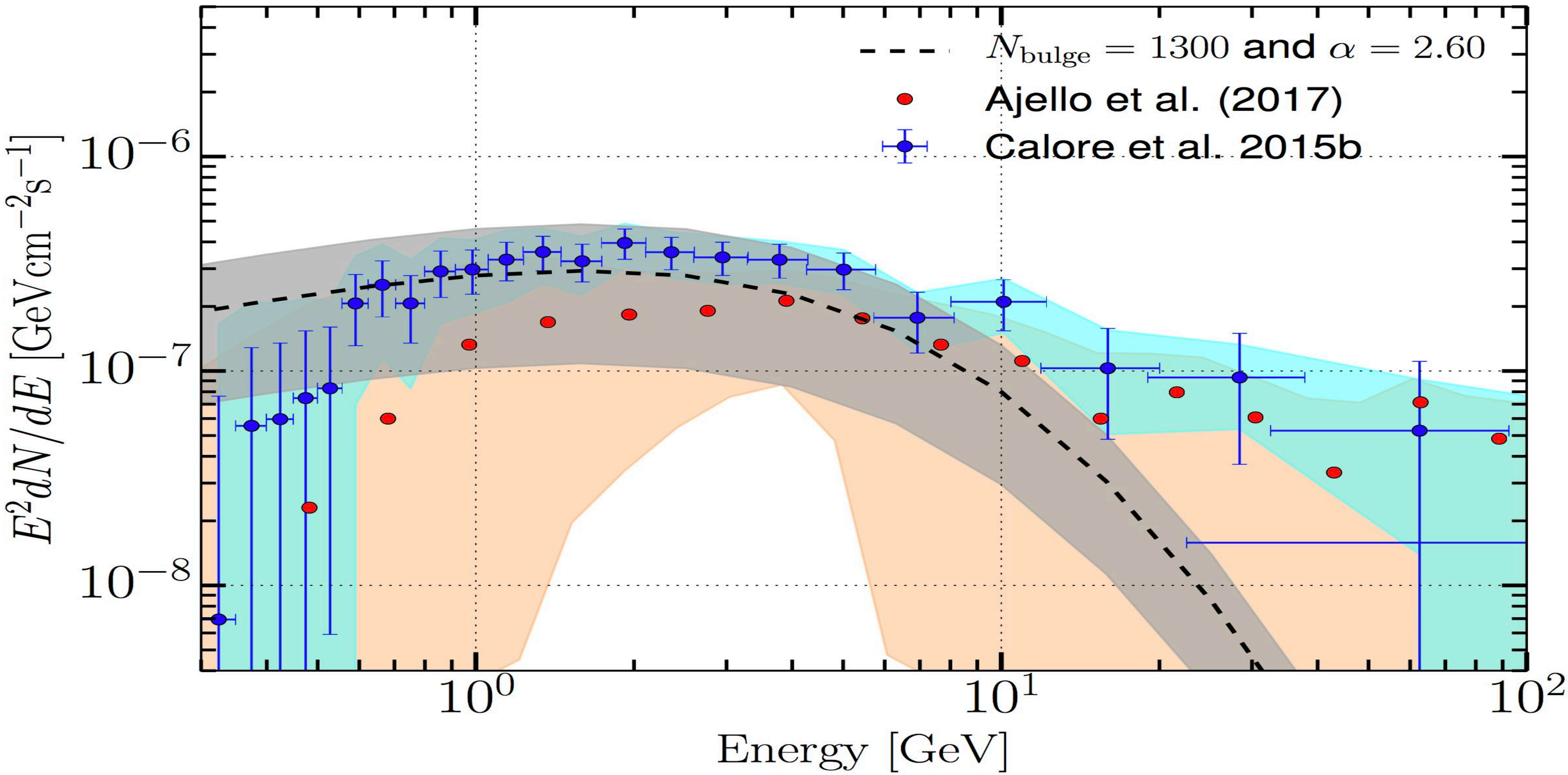
e.g. , Yuan and Zhang arXiv:1404.2318v1, Lee et al. arXiv:1506.05124, Bartels et.al. 1506.05104

M.Ajello et al. [Fermi-LAT Coll.] Phys. Rev. D 95, 082007 (2017) [arXiv:1704.07195]

....

How to discriminate between different hypothesis ?

Population of pulsars in the Galactic bulge and the GeV excess



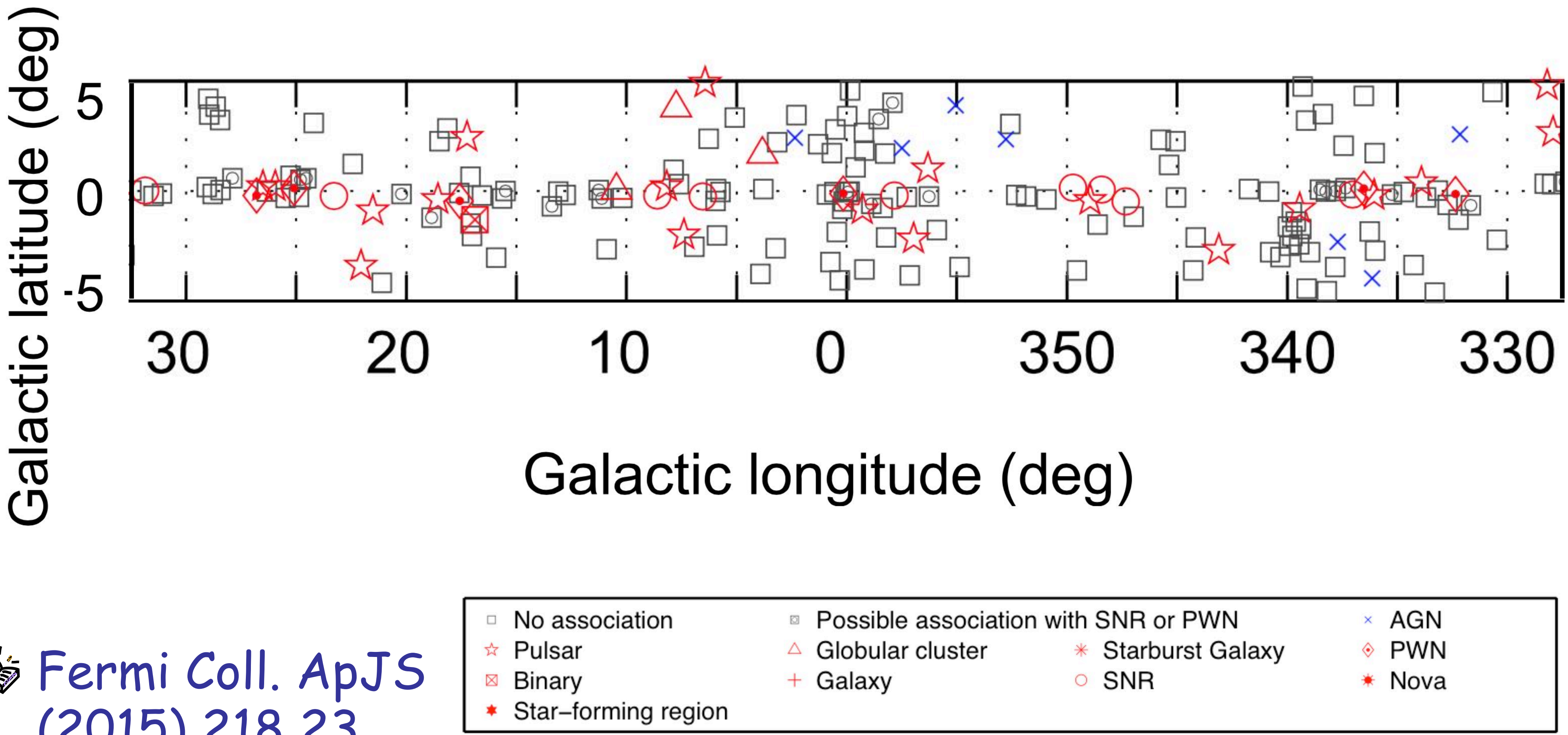
a population with about 2.7 γ-ray pulsars in the Galactic disk for each pulsar in the Galactic bulge is consistent with the population of known γ-ray pulsars as well as with the spatial profile and energy spectrum of the GC excess

M.Ajello et al. [Fermi-LAT Coll.] Apj sub. [arXiv:1705.00009]

The Fermi LAT 3FGL Inner Galactic Region

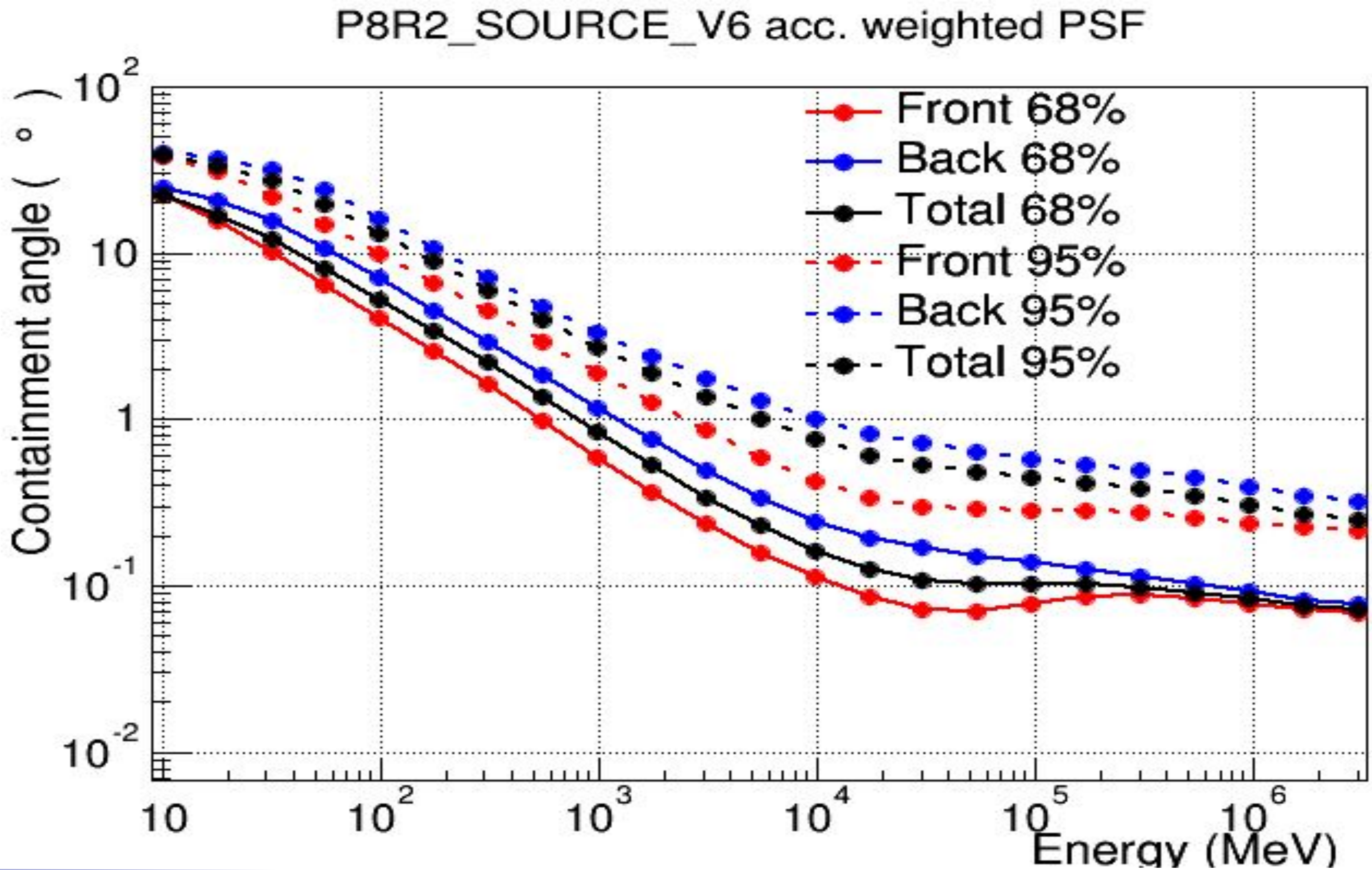
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range



Fermi Coll. ApJS (2015) 218 23
arXiv:1501.02003

Fermi-LAT Instrument Response Functions (Pass 8) Angular Resolution



How to discriminate between different hypothesis ?

eROSITA

- Modeling of the Fermi bubbles
- Look for correlated features near the Galactic center

HESS, MAGIC, CTA

- Fermi bubbles near the GC are much brighter
- Possible to see with Cherenkov telescopes?

Radio observations, MeerKAT, SKA

- Search for individual pulsars in the halo around the GC

Radio surveys, Planck

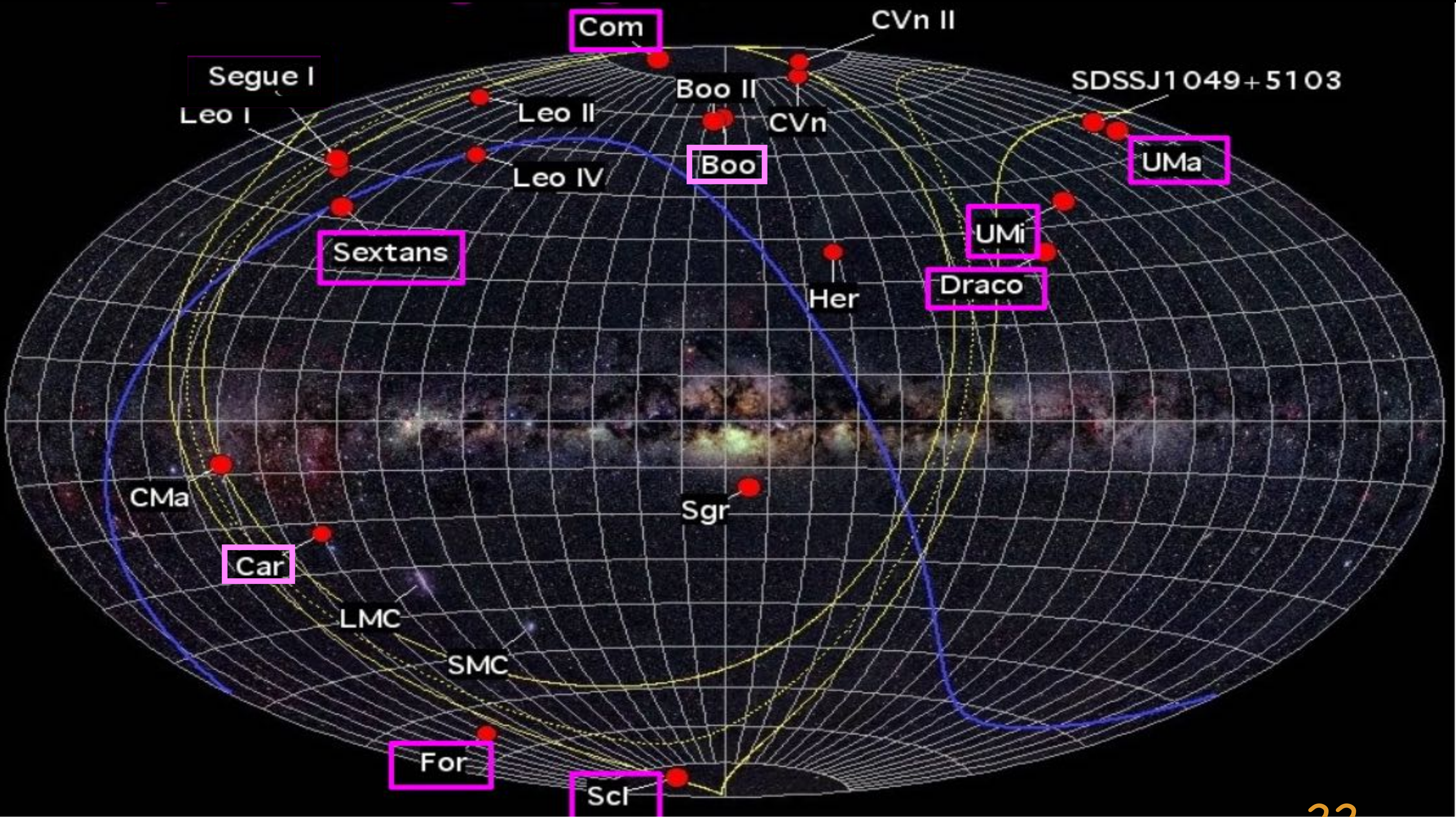
- Look for correlated synchrotron emission near the GC

More Fermi LAT analysis

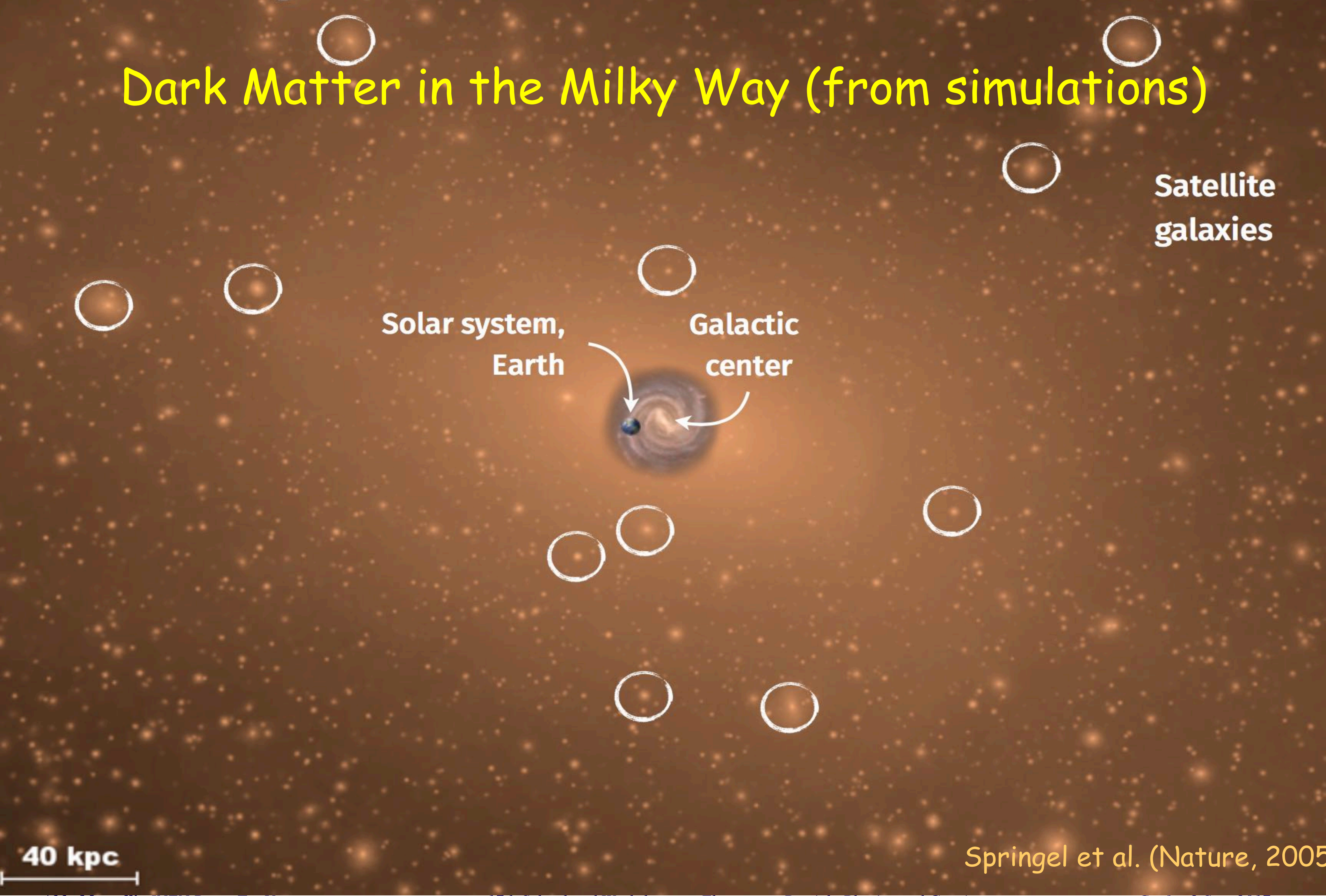
- Diffuse emission modeling
- Analysis of point sources near the GC

But ultimately We need a new experiment with better angular resolution below 100 MeV

Classical Dwarf spheroidal galaxies: promising targets for DM detection

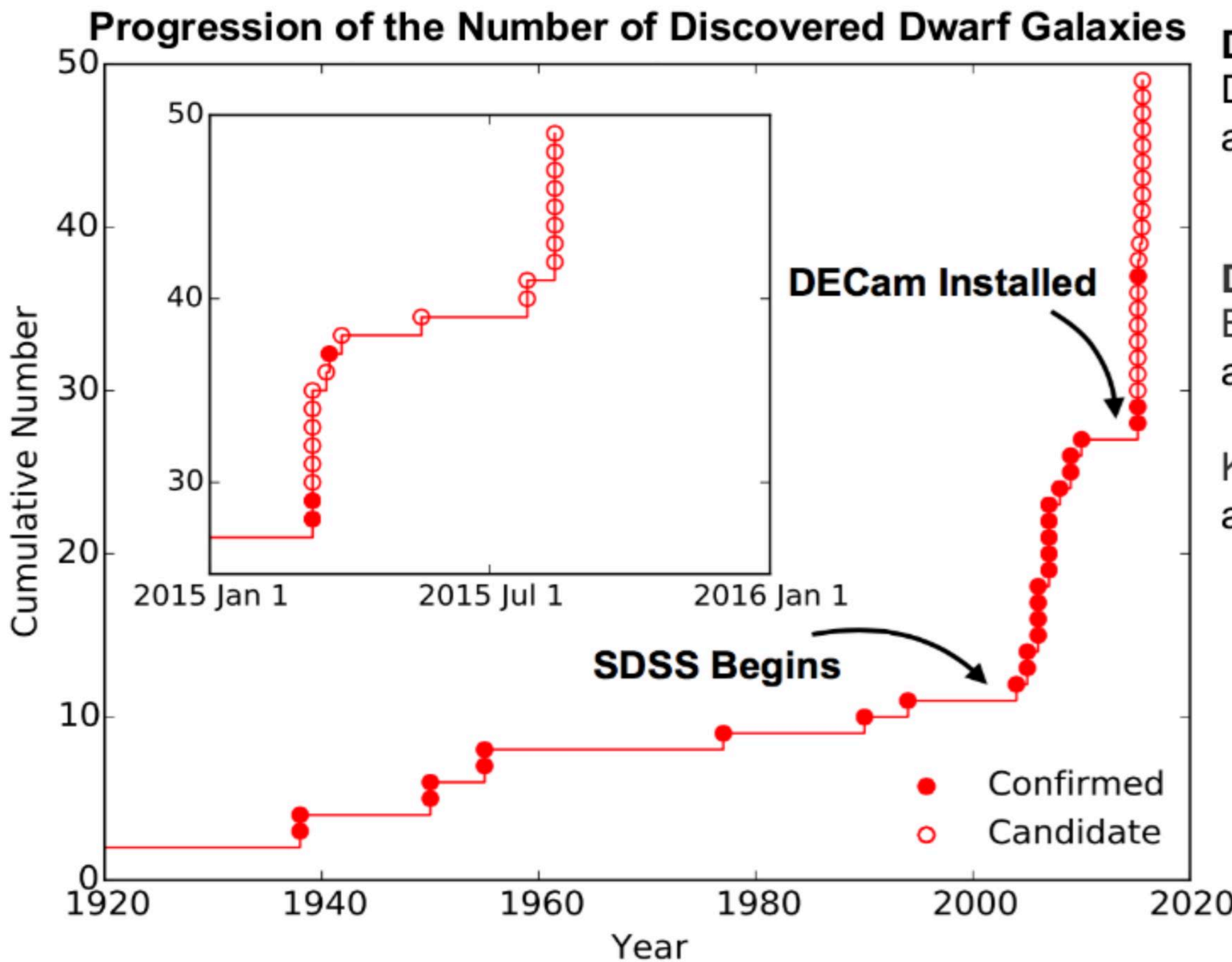


Dark Matter in the Milky Way (from simulations)



Springel et al. (Nature, 2005

Dwarf Spheroidal Galaxies: Growing number of known targets

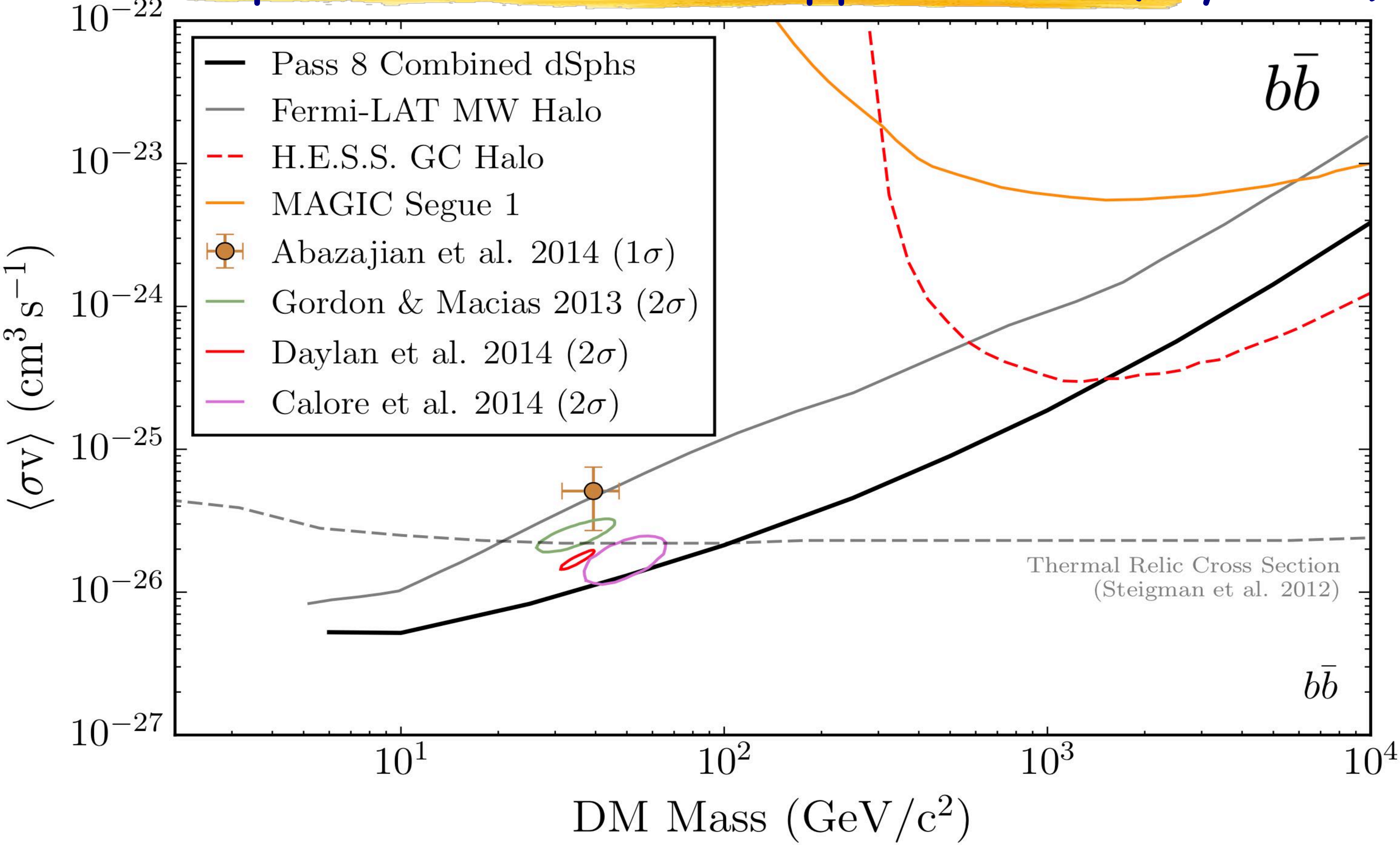


DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

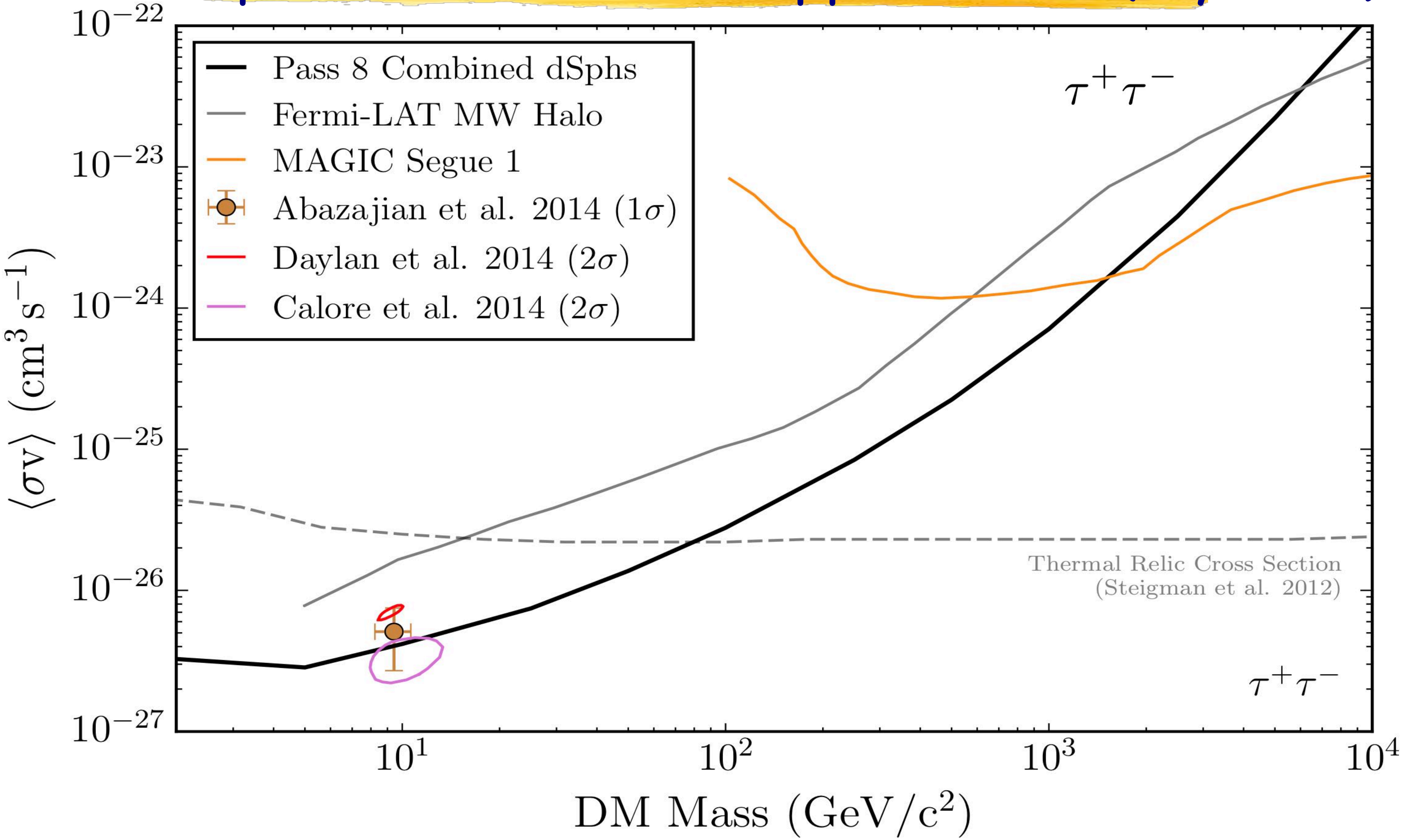
Koposov+:
arXiv:1503.02079

Dwarf Spheroidal Galaxies upper-limits (6 years)

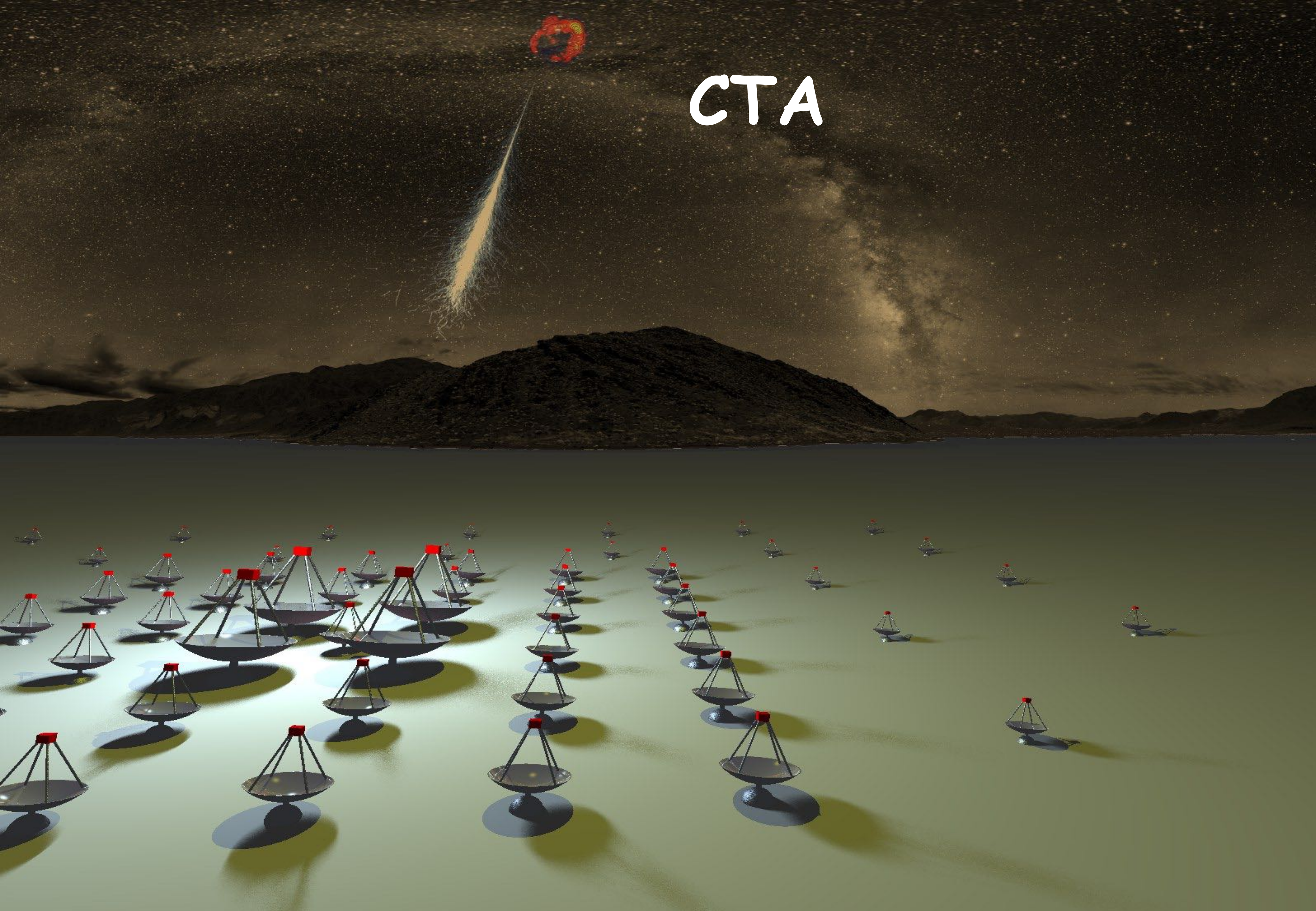


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Dwarf Spheroidal Galaxies upper-limits (6 years)



M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]


CTA

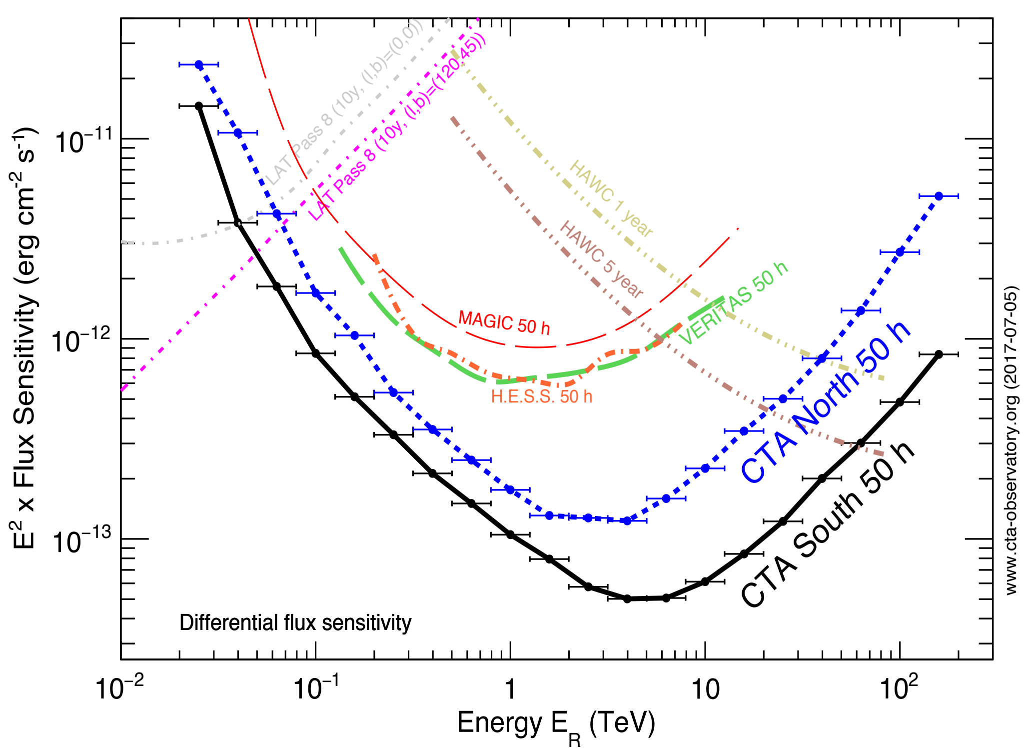
CTA PERFORMANCE

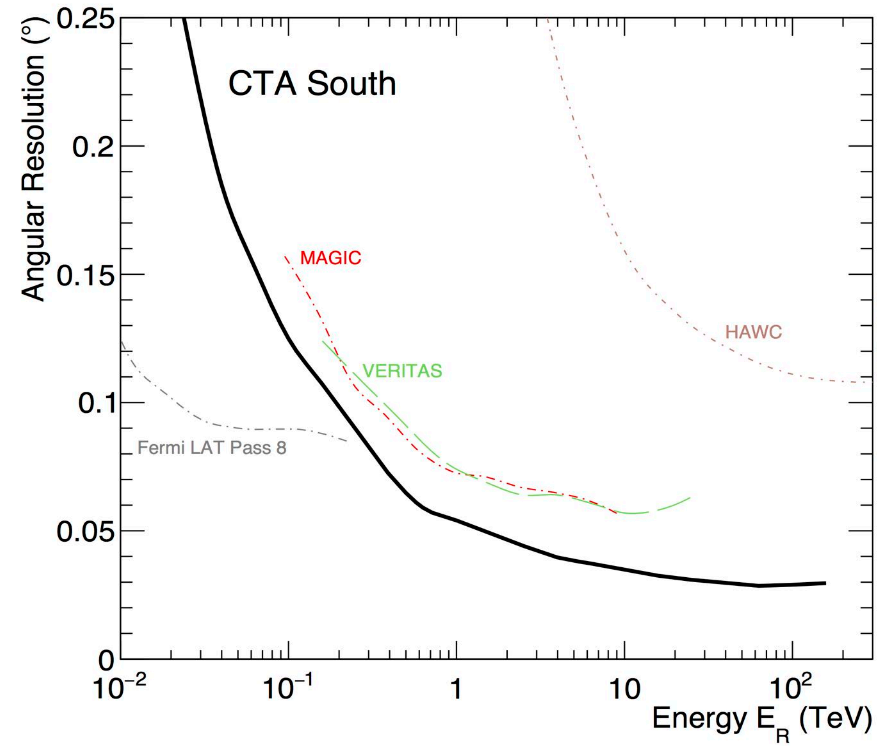
Southern Site:

- 4 Large-size telescopes
- 25 Medium-size telescopes
- 70 Small-size telescopes

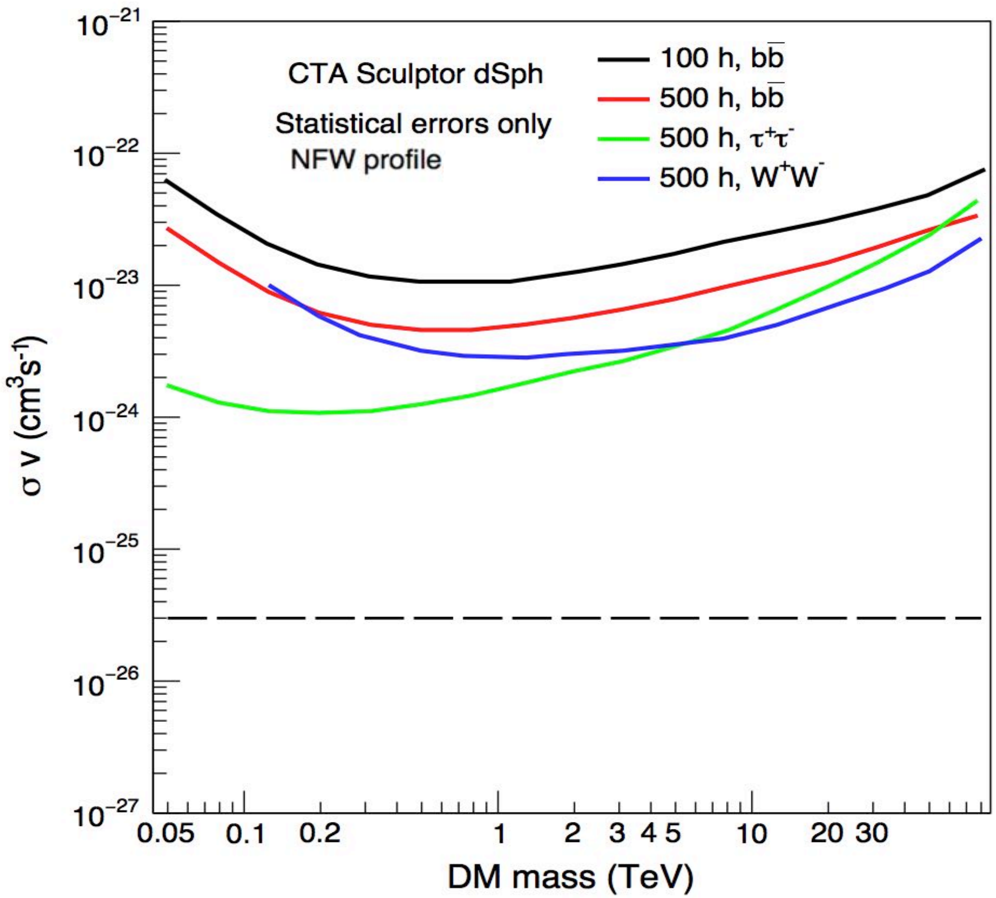
Northern Site:

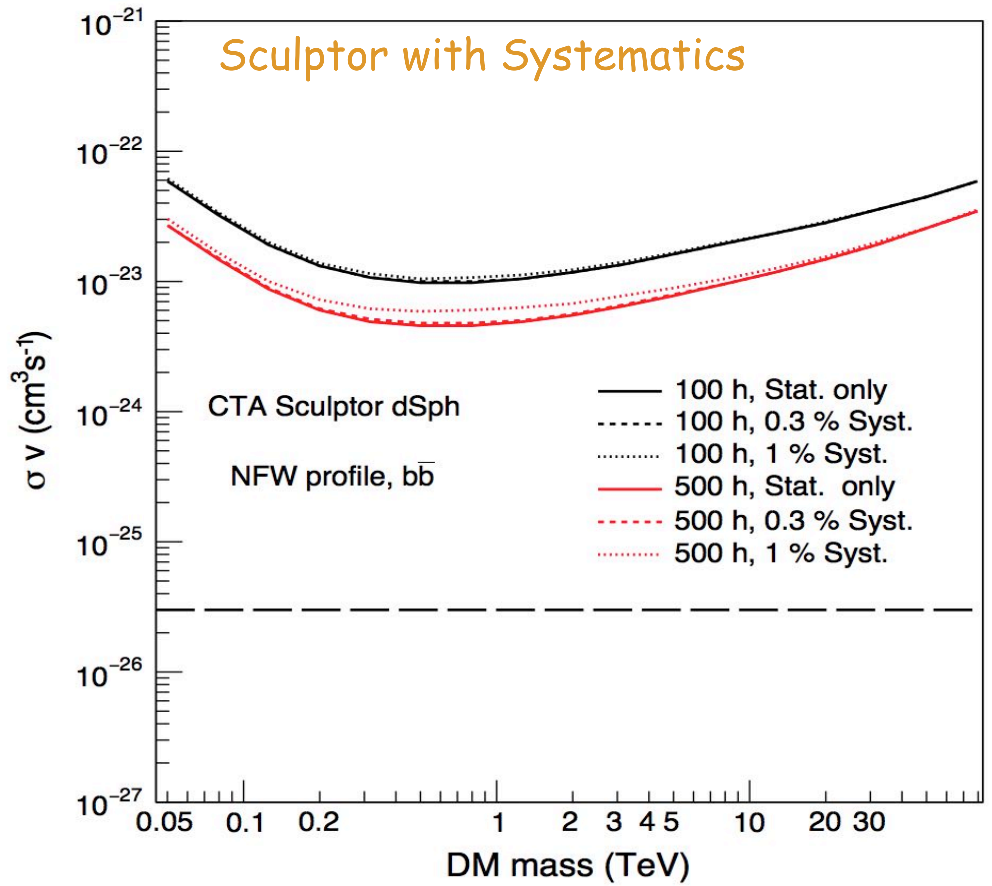
- 4 Large-size telescopes
- 15 Medium-size telescopes





Dwarf Spheroidal Galaxies: CTA Sensitivity

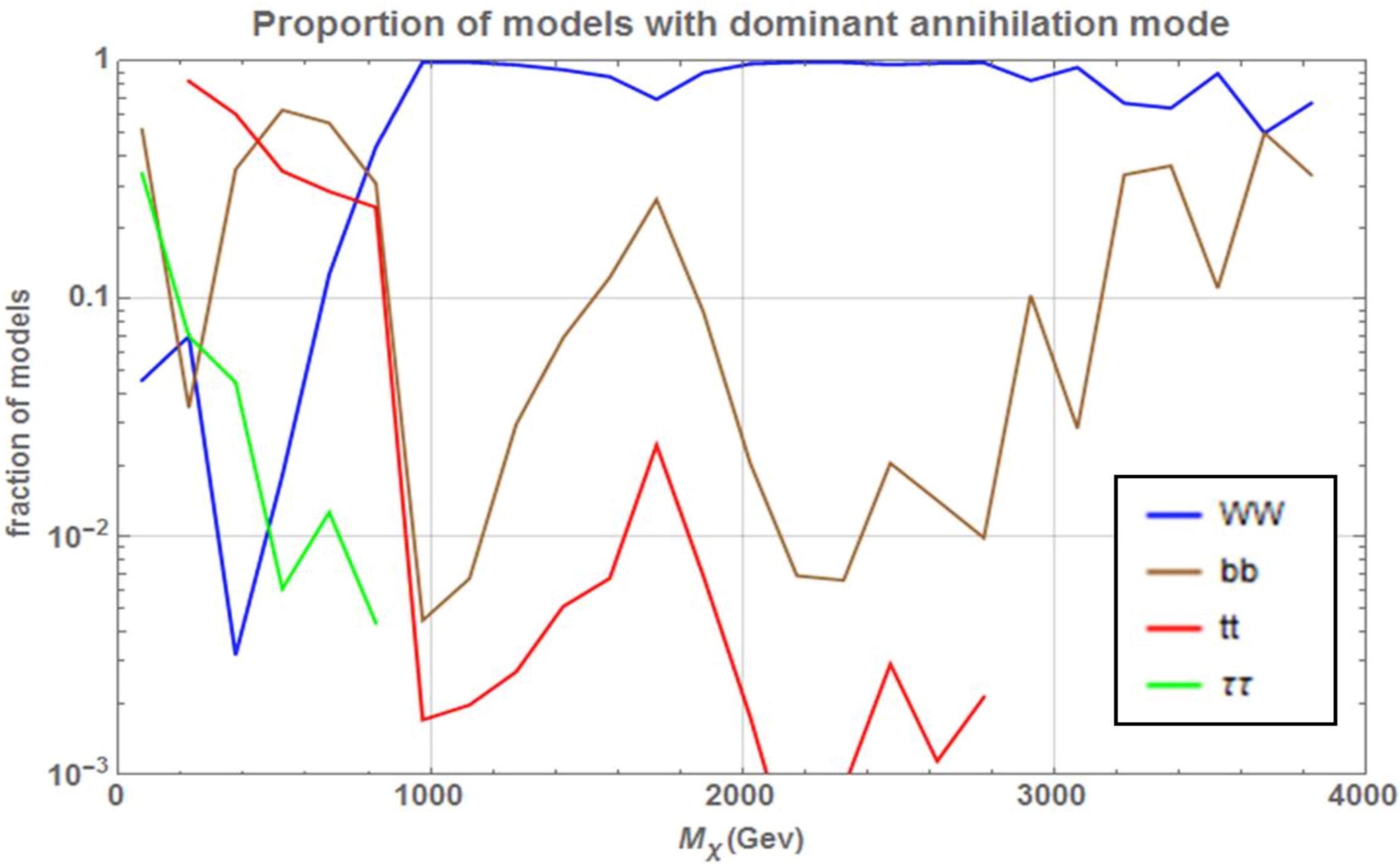




There are several of the newly discovered dSph that have a better case for being a promising target,

Will choose most promising targets before observations with the latest knowledge.

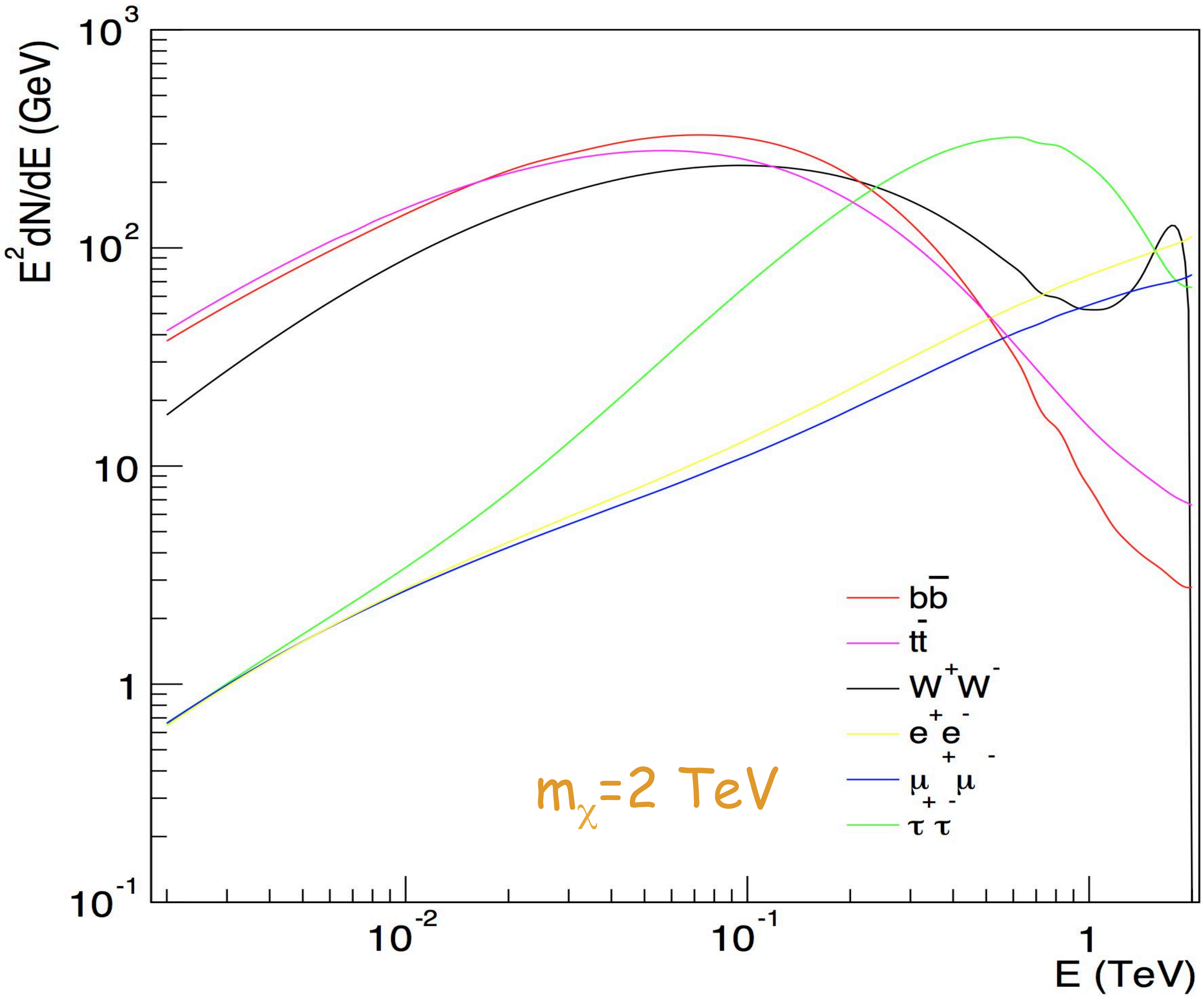
Which channel to choose?
Example: The dominant annihilation modes in the pMSSM scan



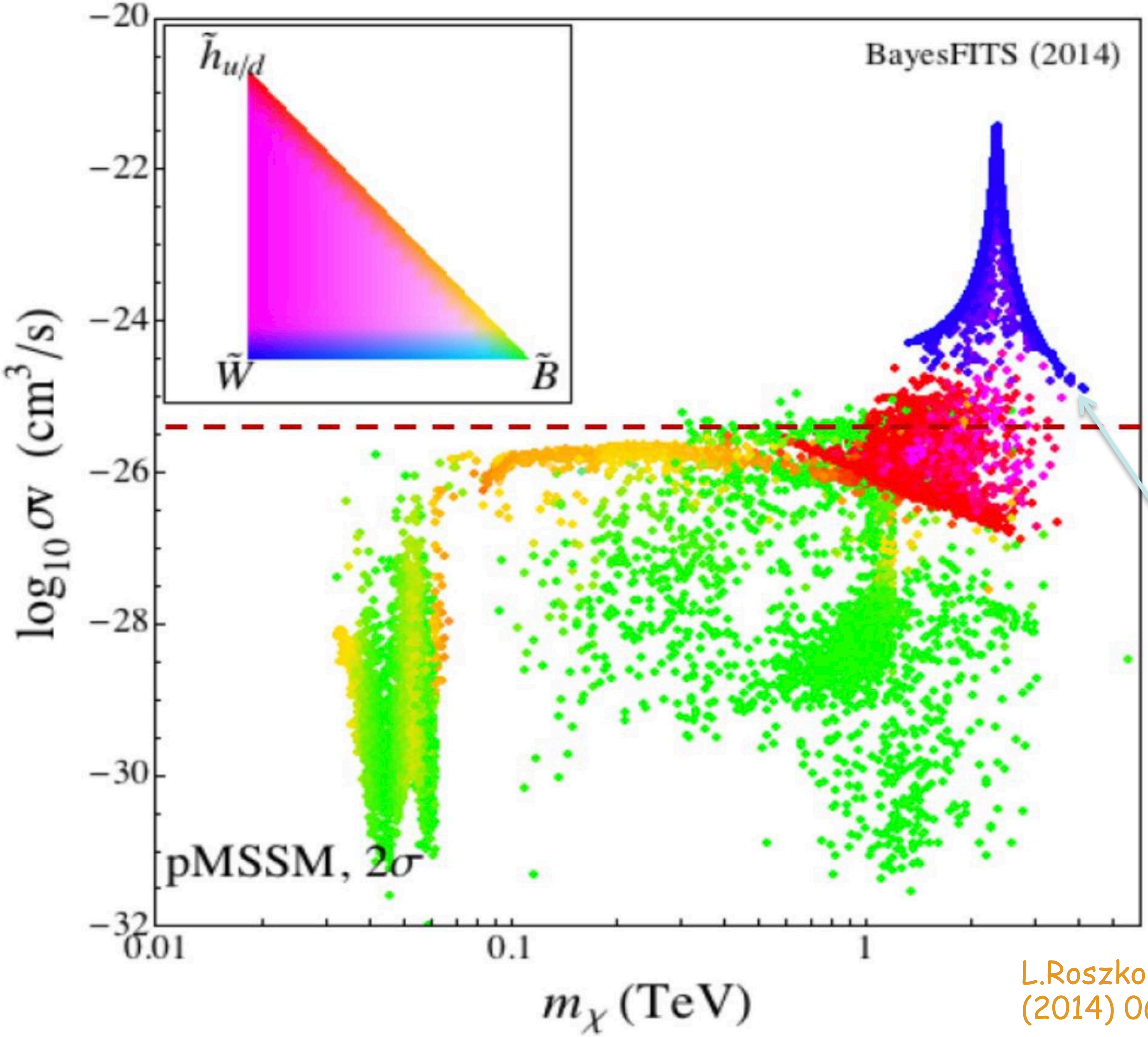
1405.4289]

Annihilation spectra for the continuum signals from the quark, lepton and gauge boson primary channels

The line-like feature expected from the virtual internal Bremsstrahlung process contribution is particularly prominent for the W^+W^- channel



note:the "thermal" cross section is only a reference value. The real cross section can be higher or lower

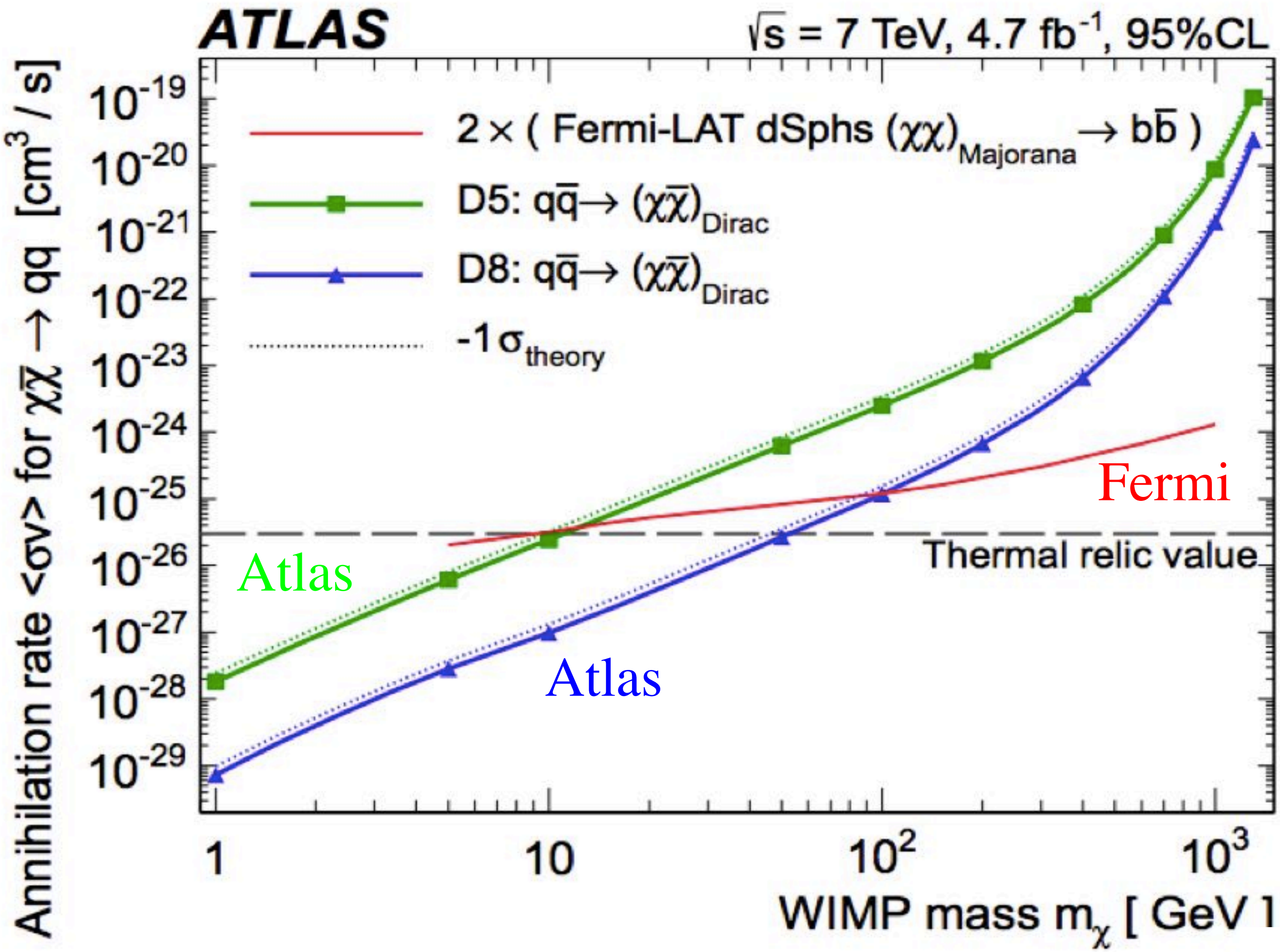


Example: Annihilation cross-section points from a 19 dimensional pMSSM fit

Note that a strong enhancement of the annihilation cross section occurs for winos around 2-3 TeV due to Sommerfeld enhancement.

L.Roszkowski et al., JHEP, 1408 (2014) 067 [arXiv:1405.4289]

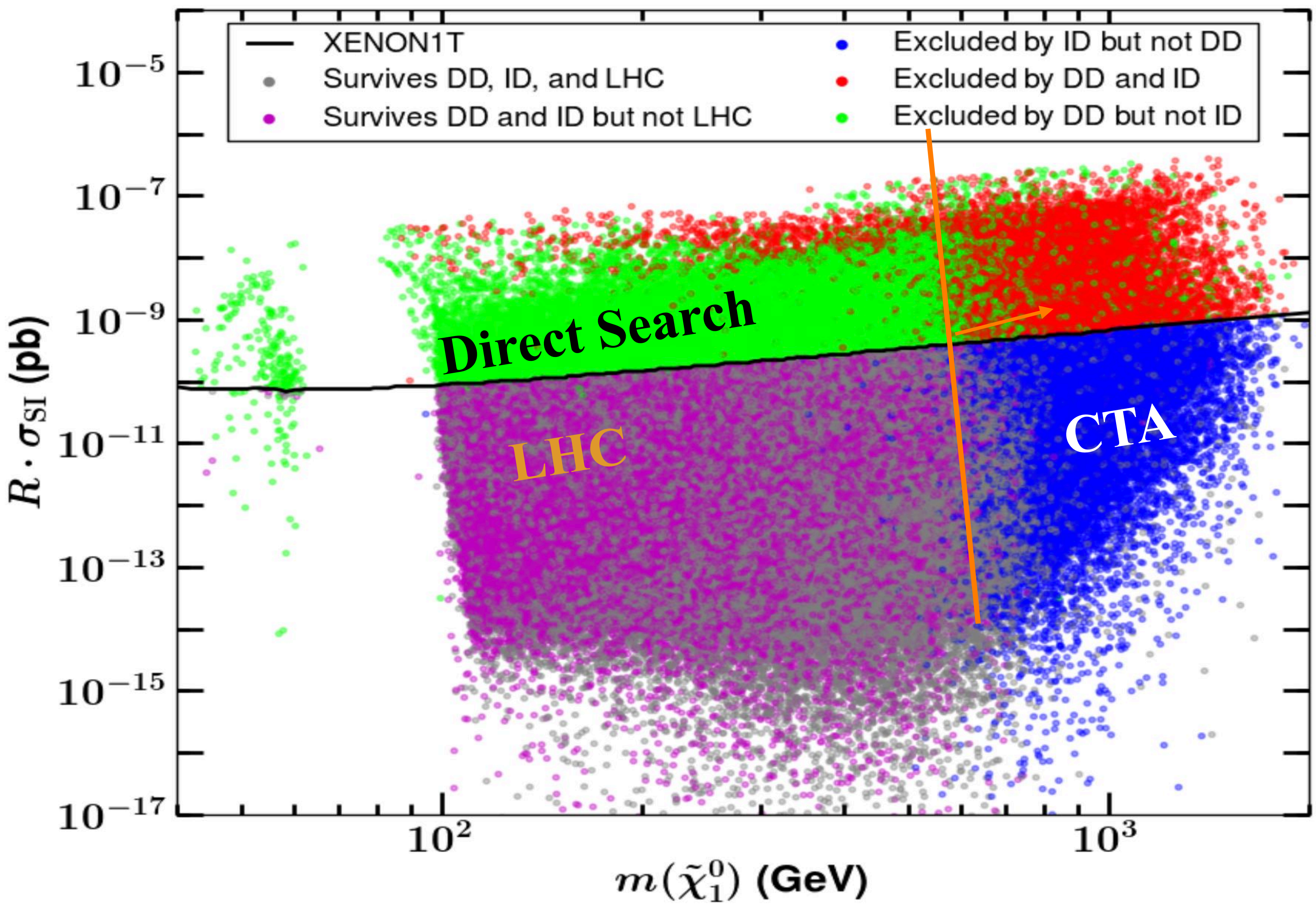
ATLAS-Fermi Results



note: ATLAS limits are for the four light quark flavours assuming equal coupling strengths for all quark flavours to the WIMPs

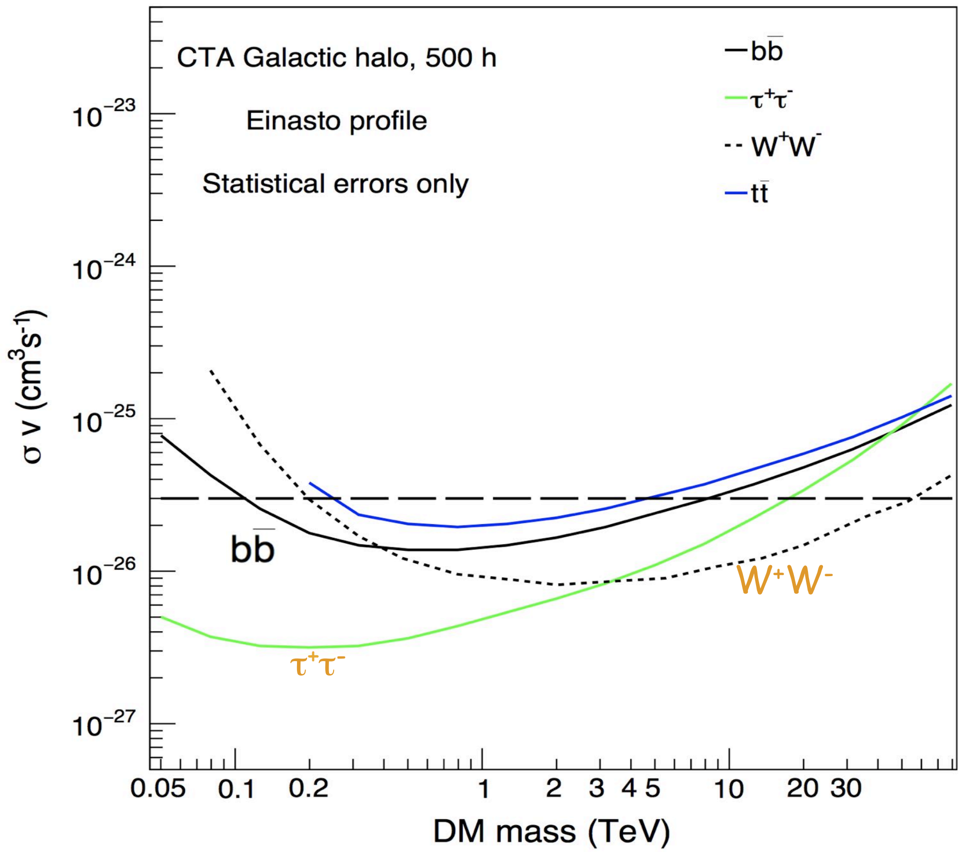
Atlas Coll. JHEP 1304 (2013) 075 arXiv:1210.4491

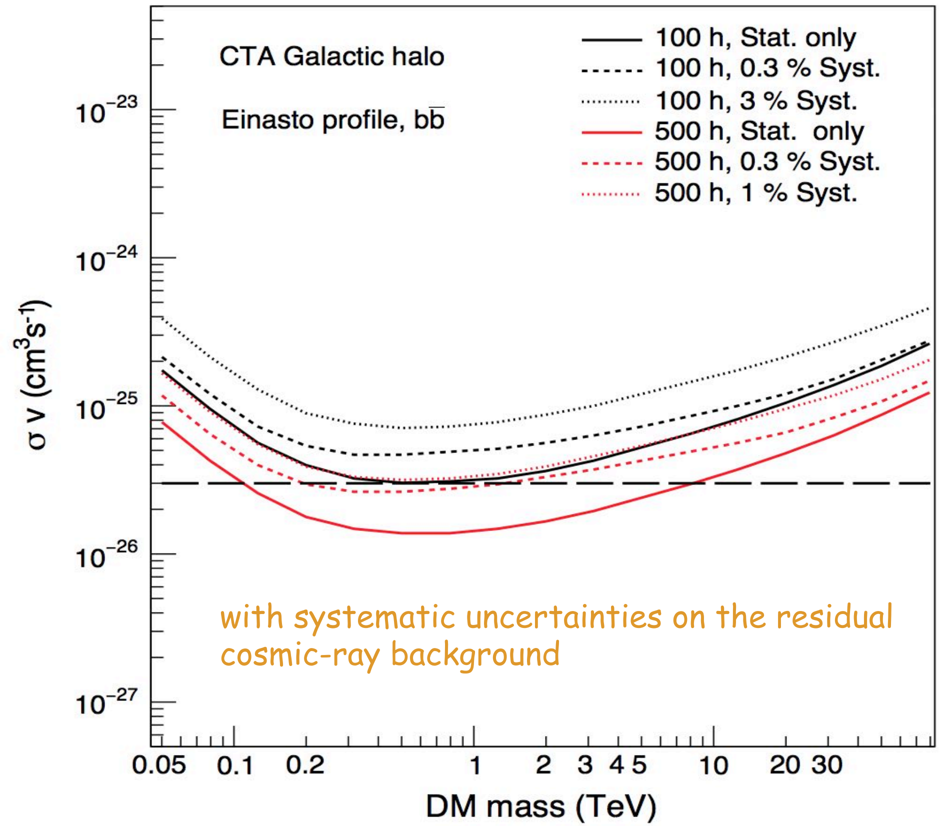
Complementarity and Searches for Dark Matter in the pMSSM



Cahill-Rowley et al. arXiv:1305.6921

CTA Galactic Halo DM upper-limits



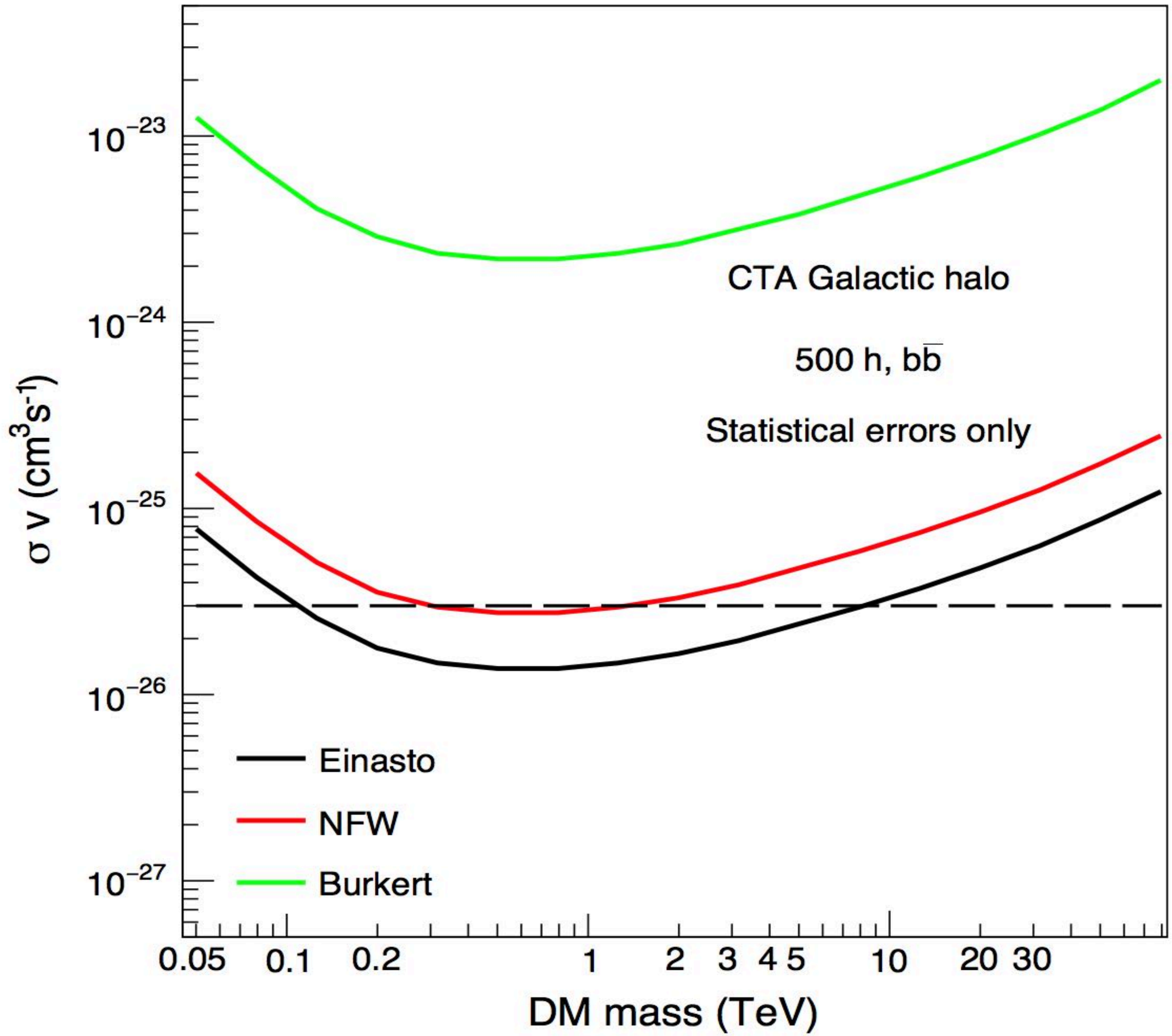


The predictions shown here can be considered optimistic, even when systematics errors are included, as we do not consider the effect of the Galactic diffuse emission as background for DM searches that can affect the results by ~ 50%

This will be investigated in detail in a forthcoming publication by the CTA Consortium.

CTA Galactic Halo DM upper-limits

Effect of the different Halo profiles

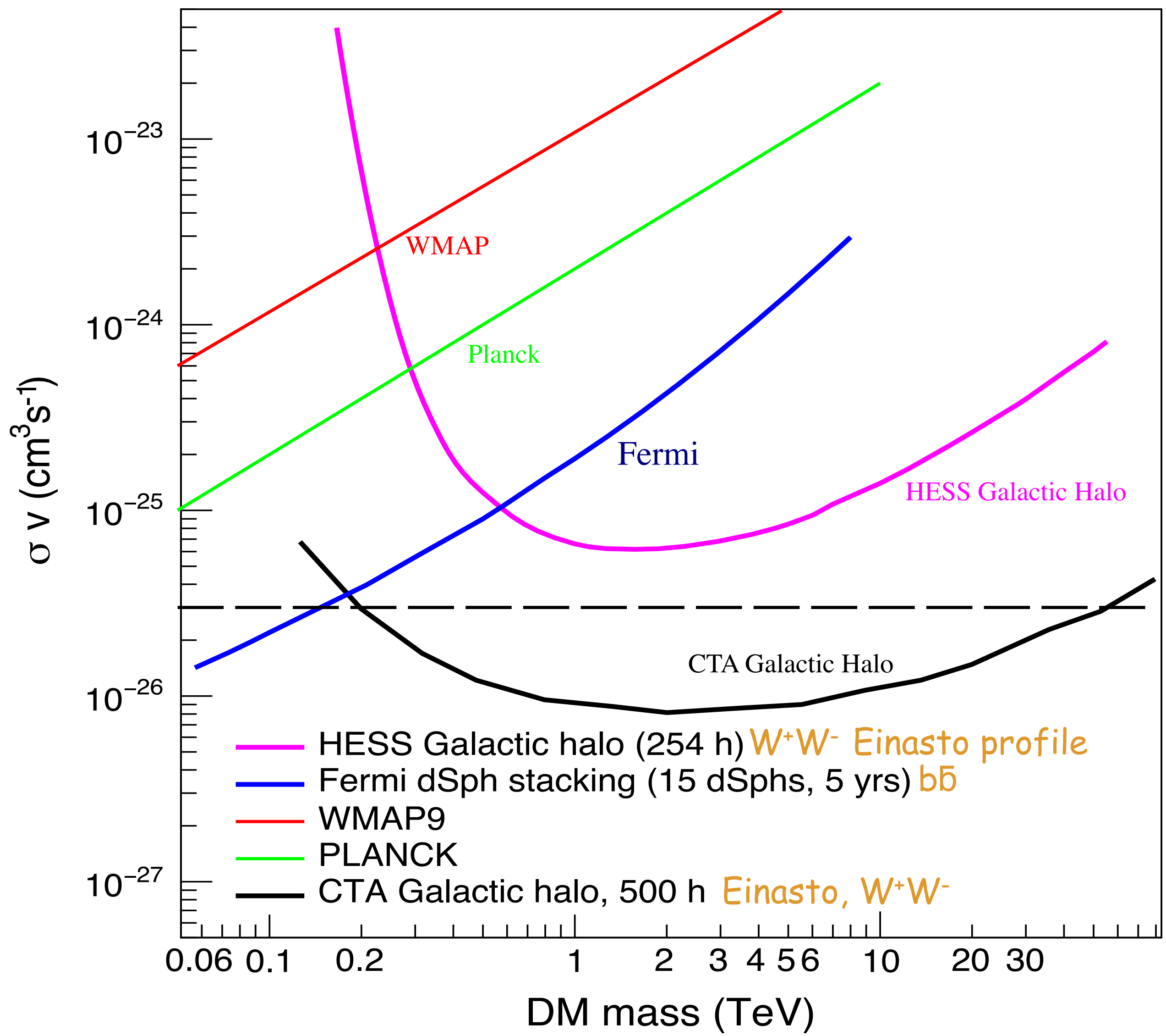


CTA, HESS, FERMI, PLANK DM upper-limits

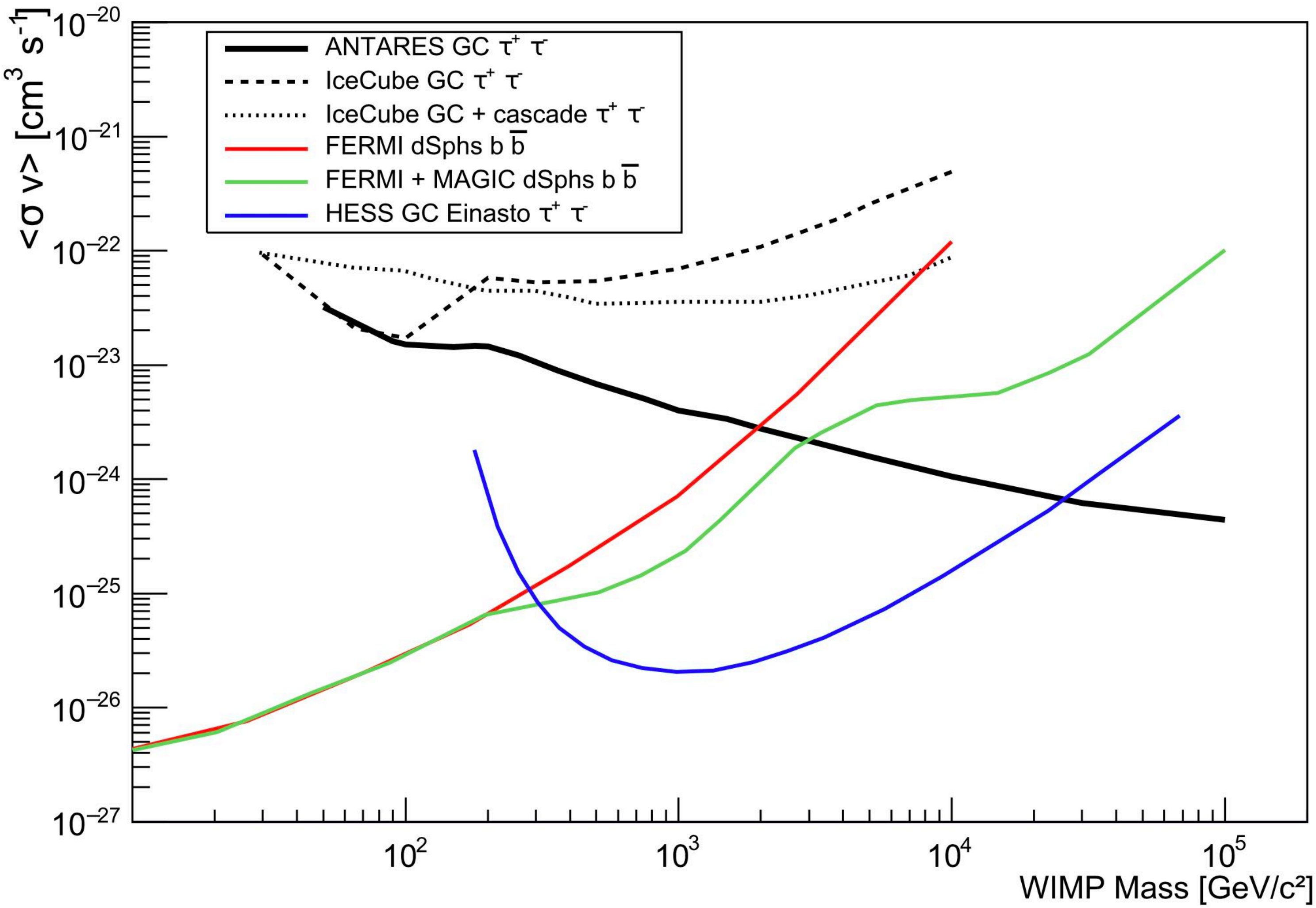
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

The expectation for CTA is for the Einasto profile and is optimistic as includes only statistical errors.

The effect of the Galactic diffuse emission can affect the results by ~ 50%

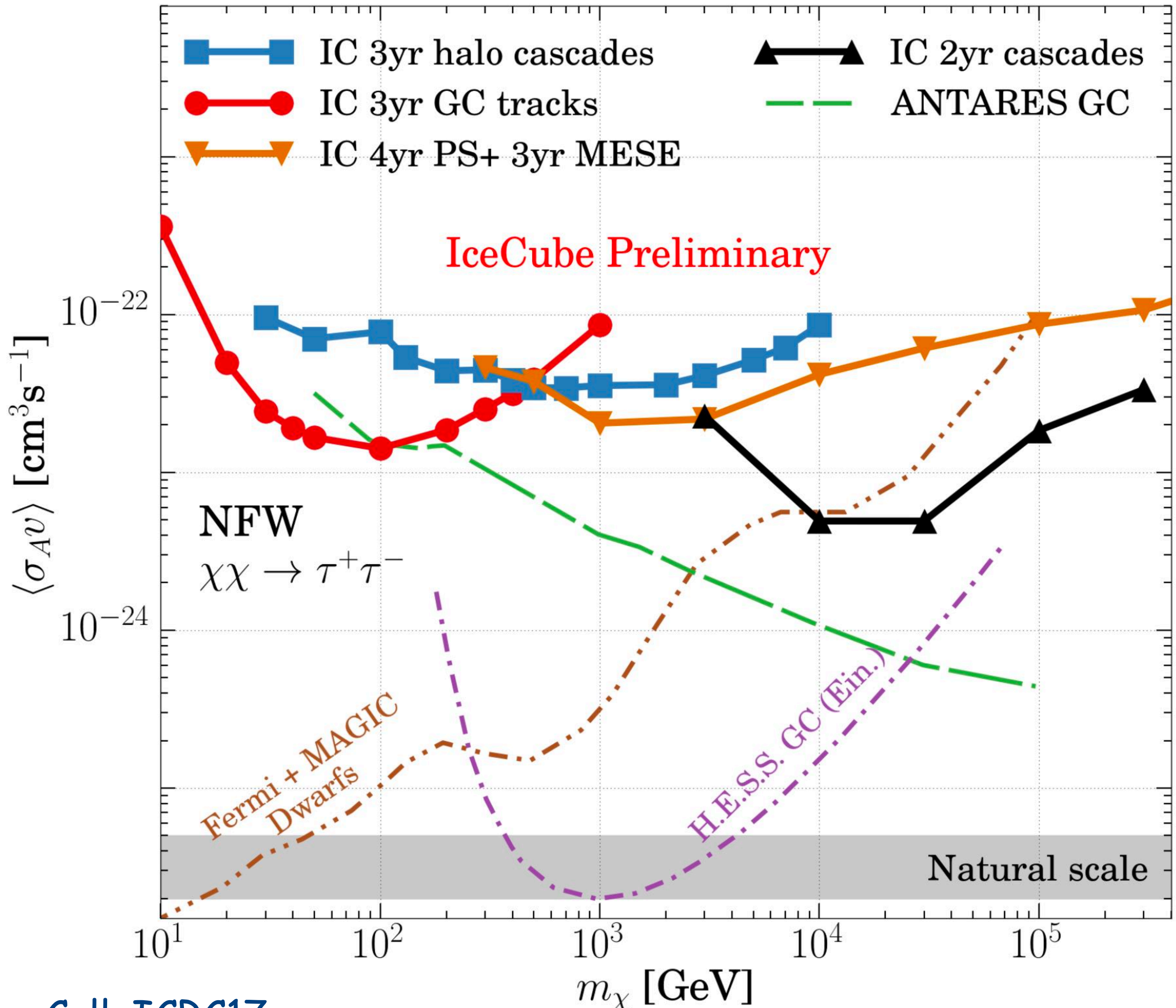


HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits



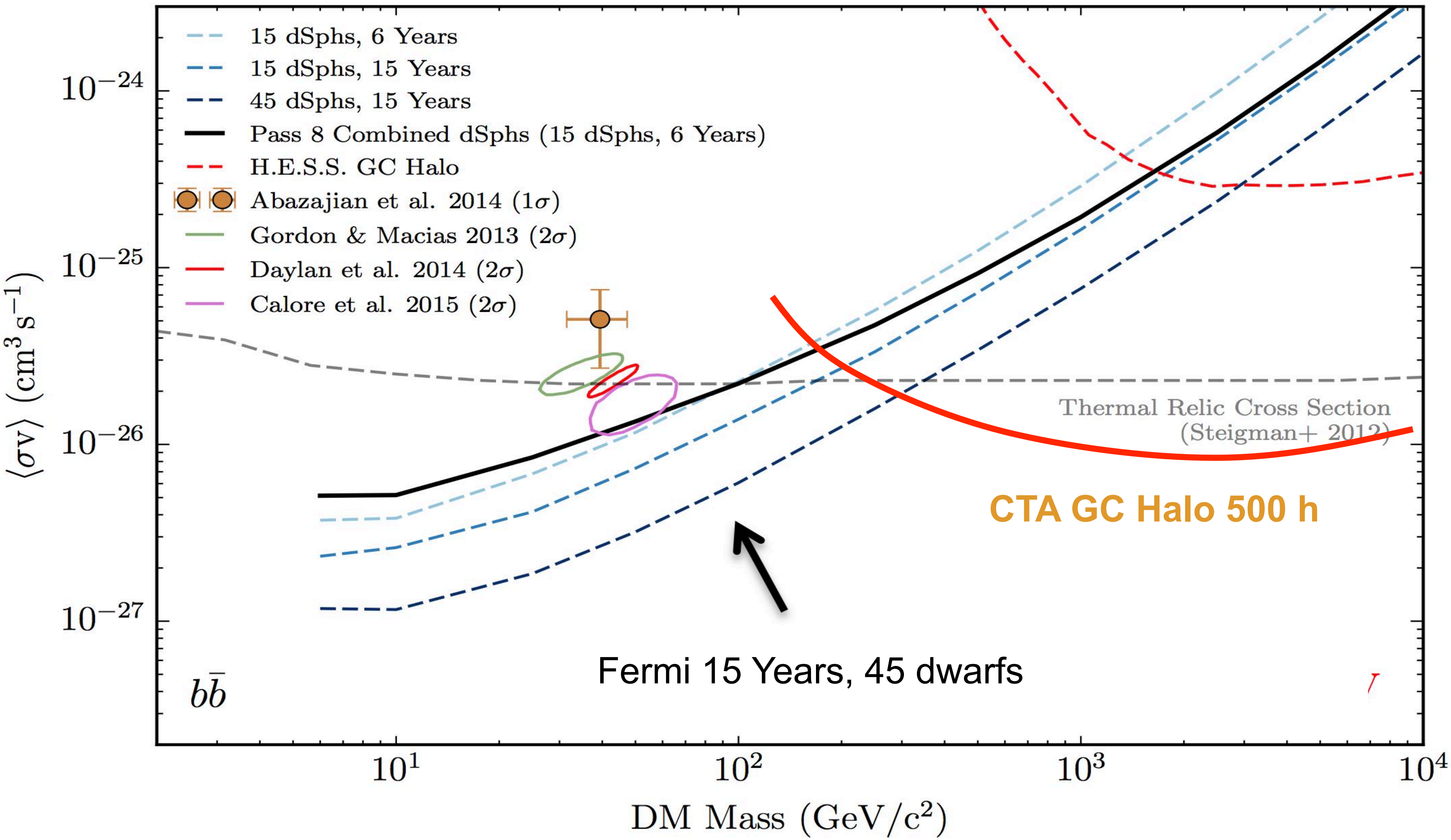
A. Albert, et al. ANTARES Coll. Physics Letters B 769 (2017) 249–254

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits update



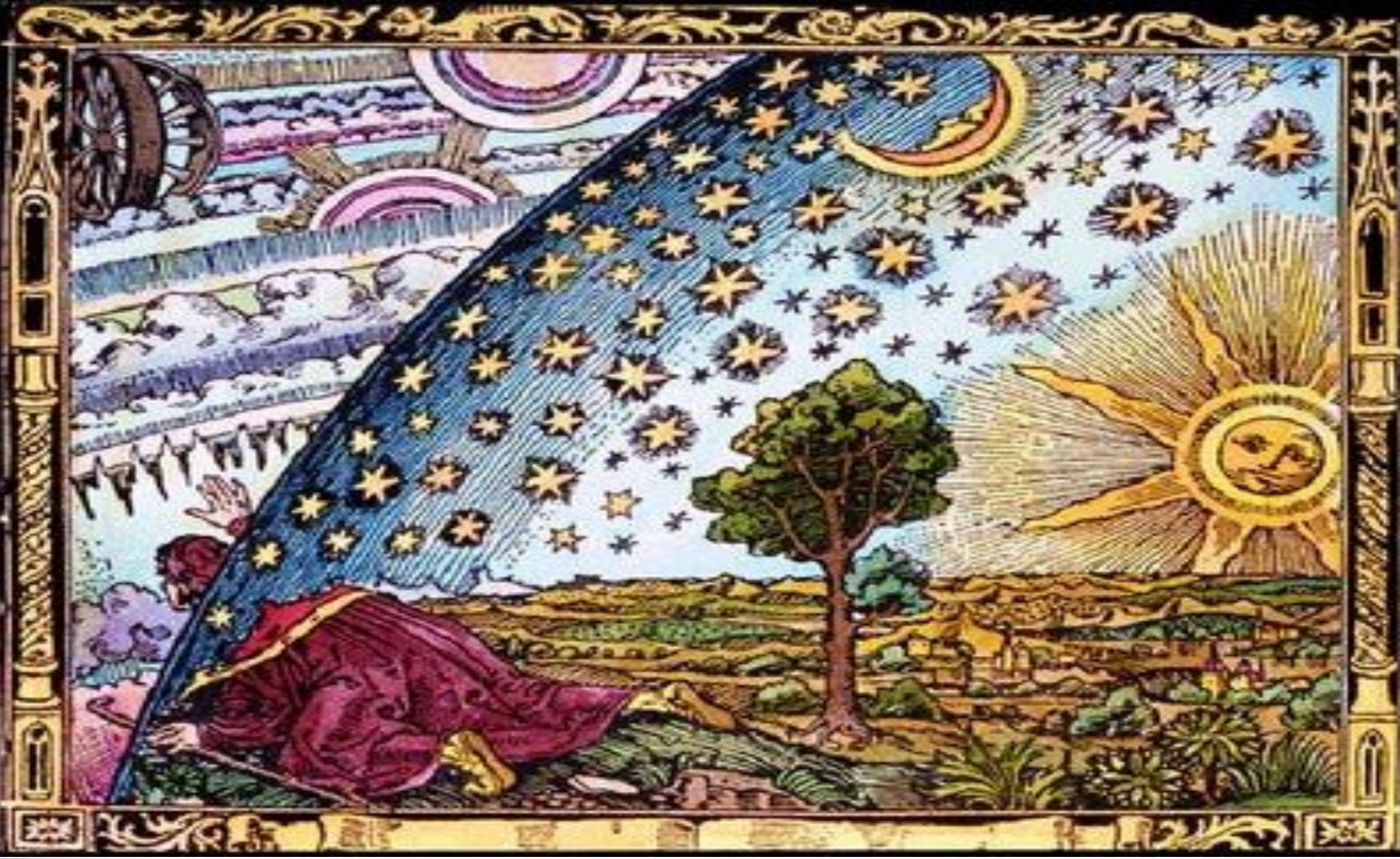
S.Flis for the Ice Cube Coll. ICRC17

DM limit improvement estimate in 15 years (2008- 2023)



Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

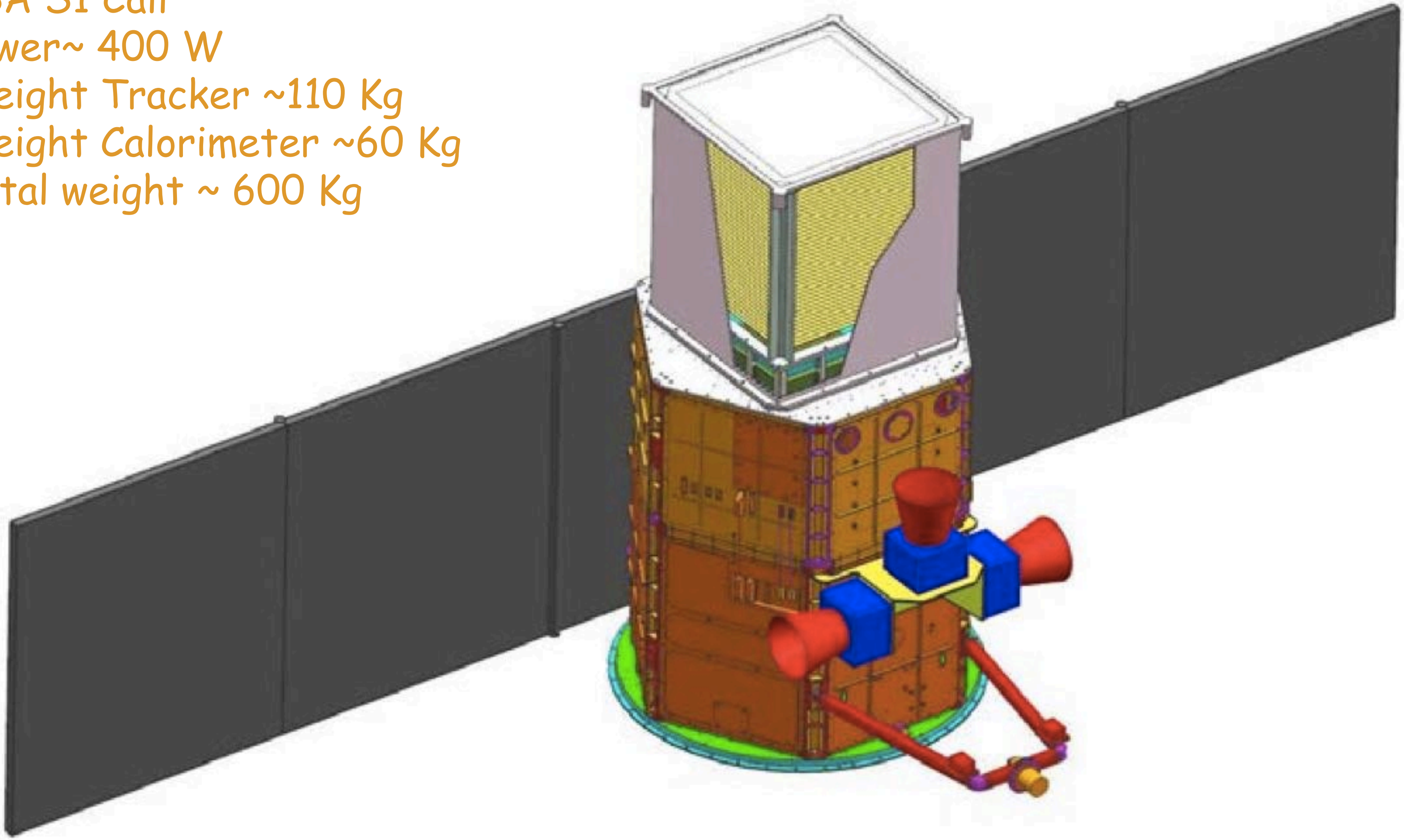
The Low Energy Frontier



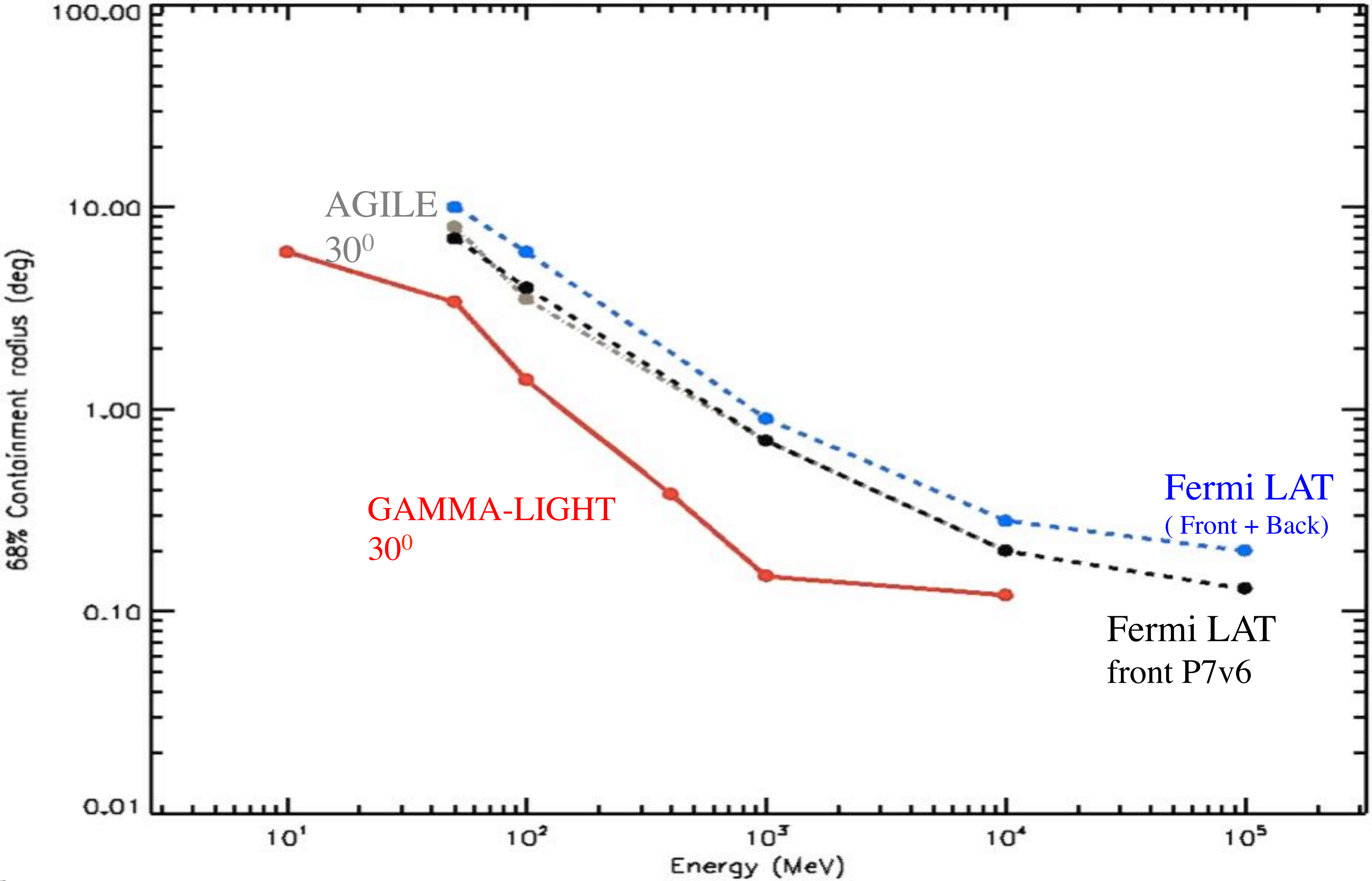
- 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Gamma-light project

ESA S1 Call
Power~ 400 W
Weight Tracker ~110 Kg
Weight Calorimeter ~60 Kg
Total weight ~ 600 Kg

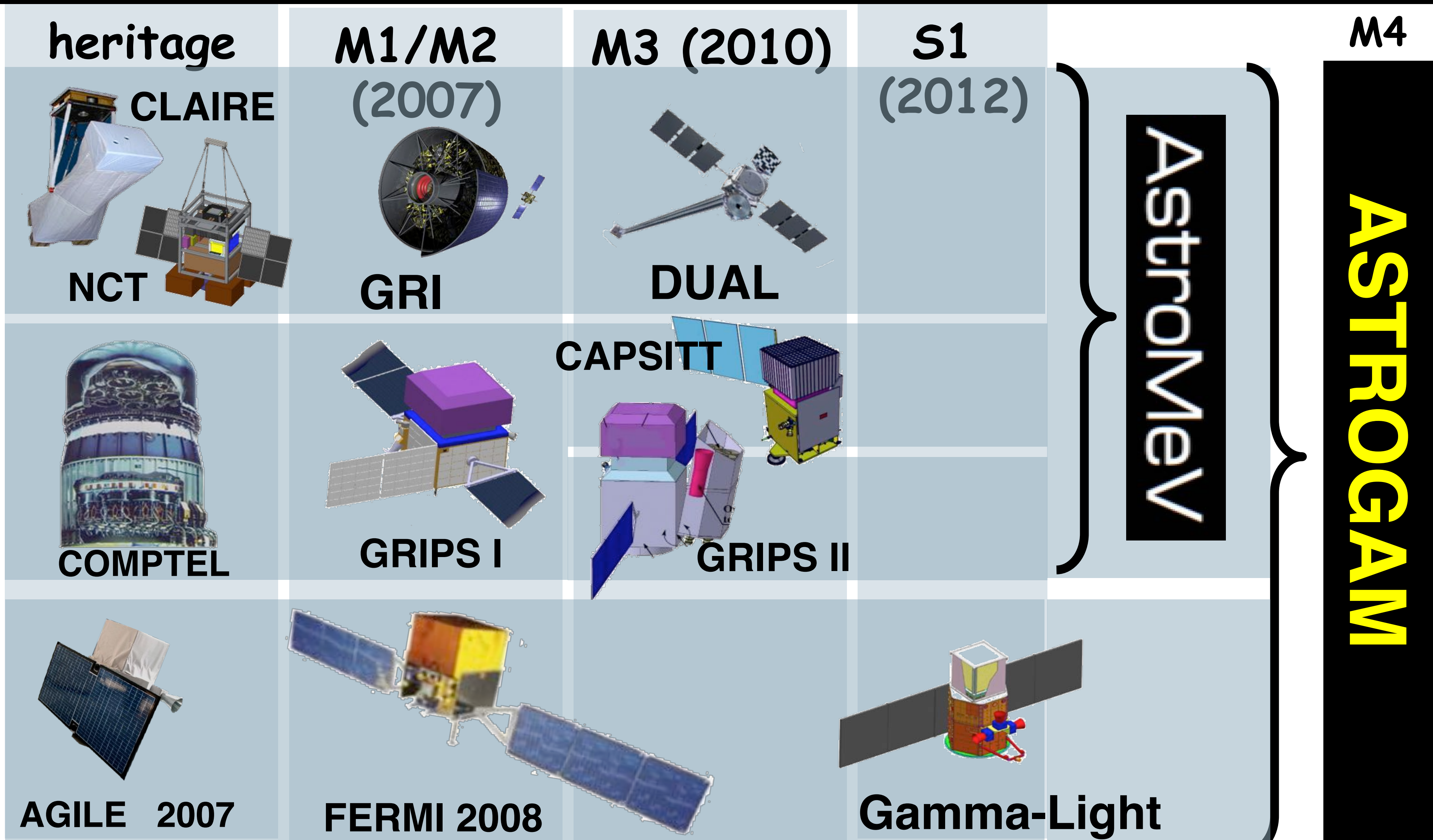


Gamma-Light Point Spread Function (angular resolution)



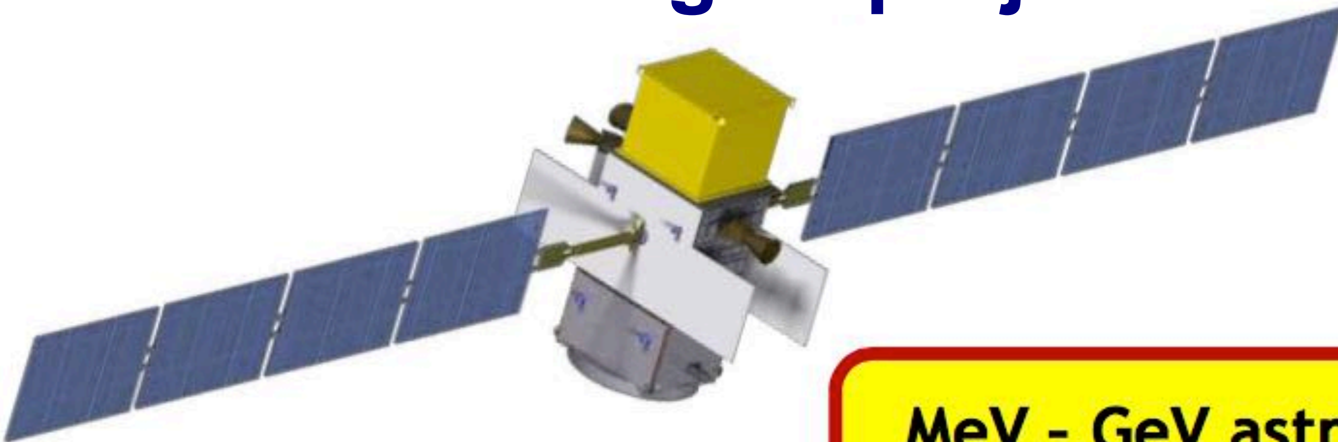
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

ASTROGAM a unified proposal from the entire gamma-ray community



The next gamma-ray MeV-GeV mission:

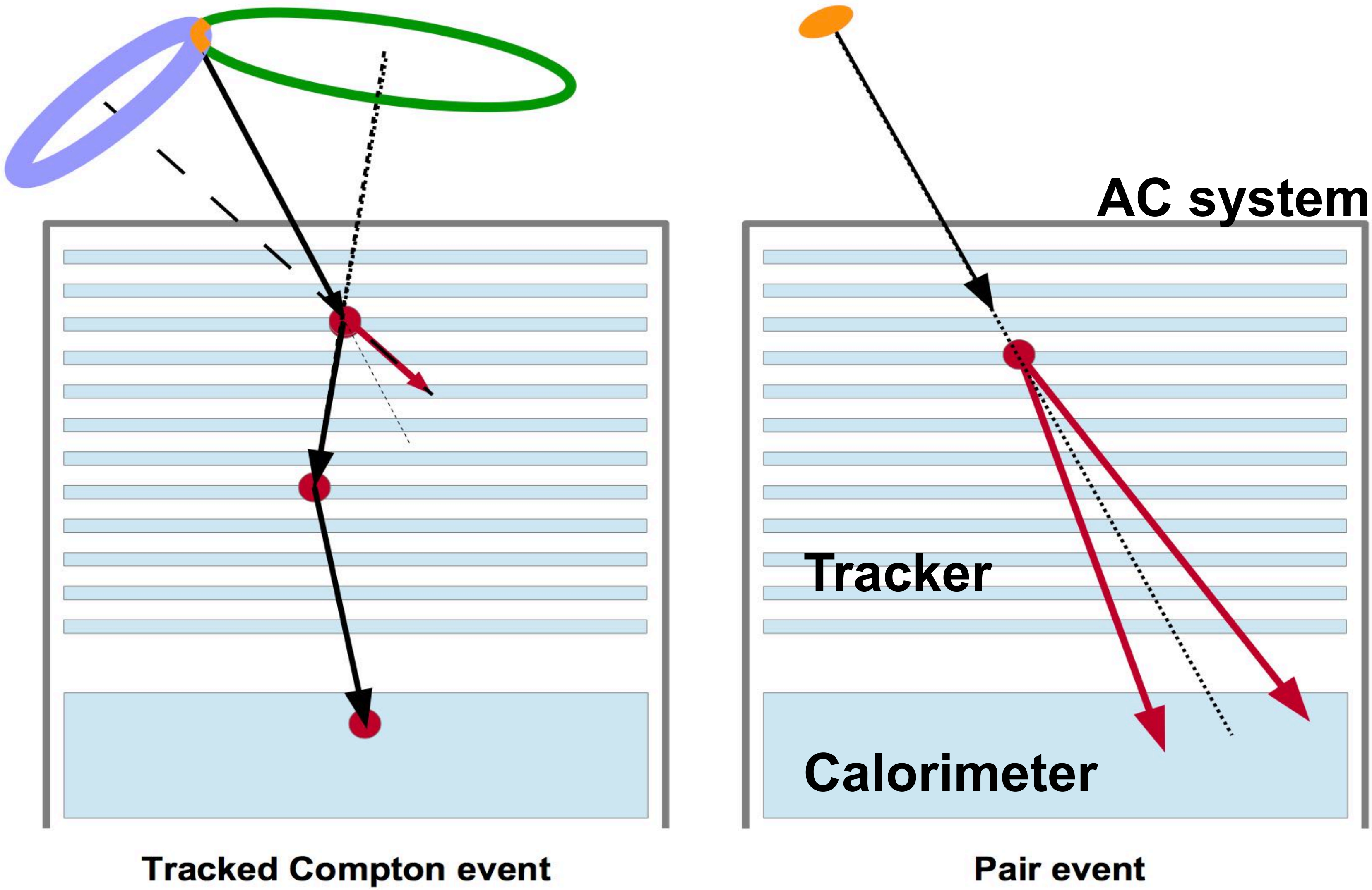
the e-Astrogam project



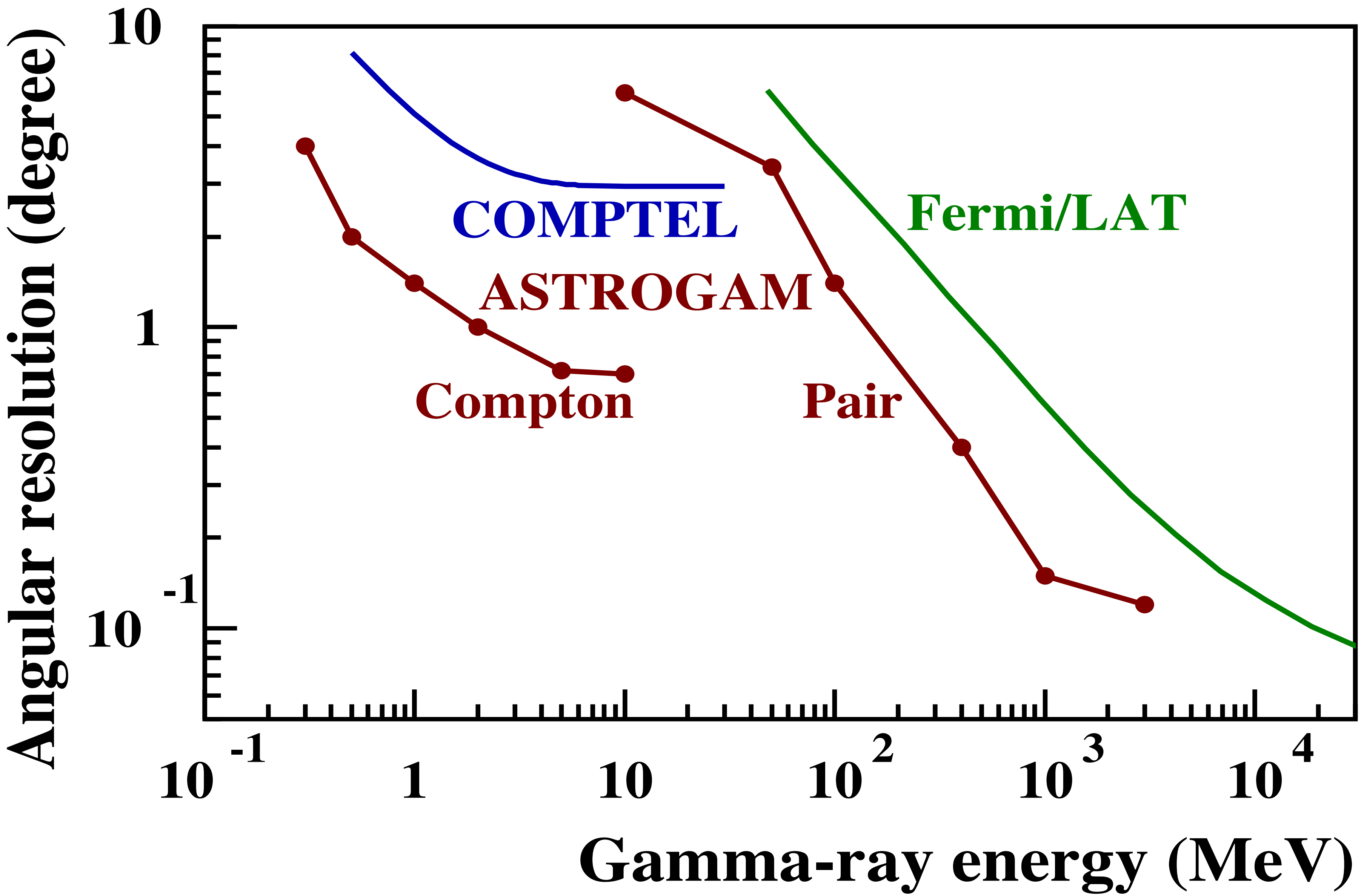
MeV - GeV astrophysics
MeV - GeV community

Proposed for the ESA M4 call; currently under study for enhancement and reconfiguration for the ESA M5 call. ASTROGAM is **focused on gamma-ray astrophysics in the range 0.3-100 MeV** with excellent capability also at GeV energies.

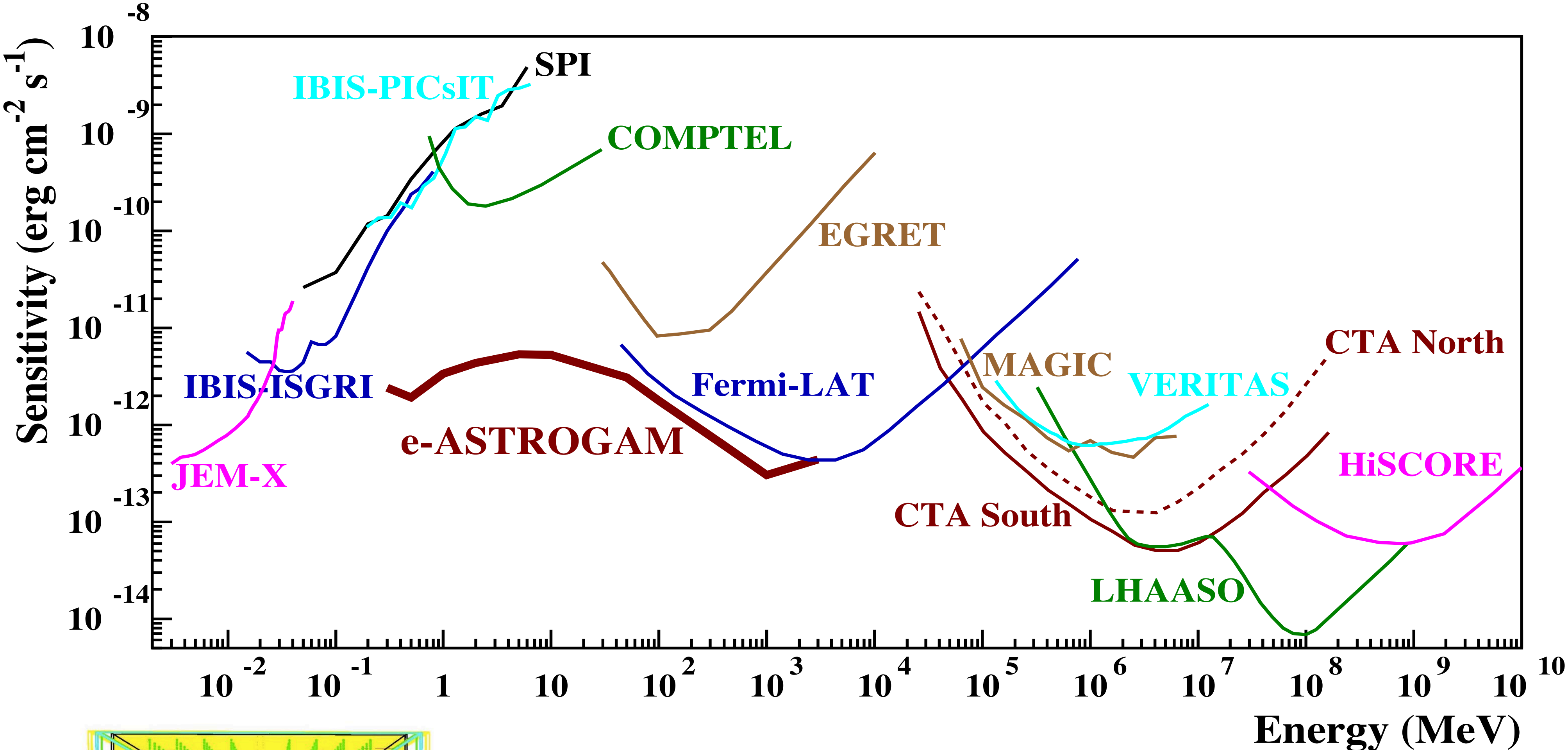
An instrument that combine two detection techniques

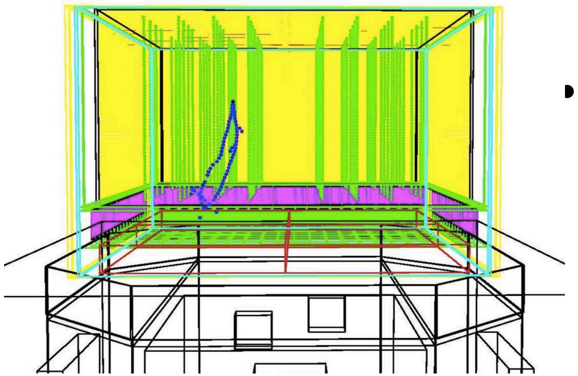


ASTROGAM Angular Resolution



Performance assessment



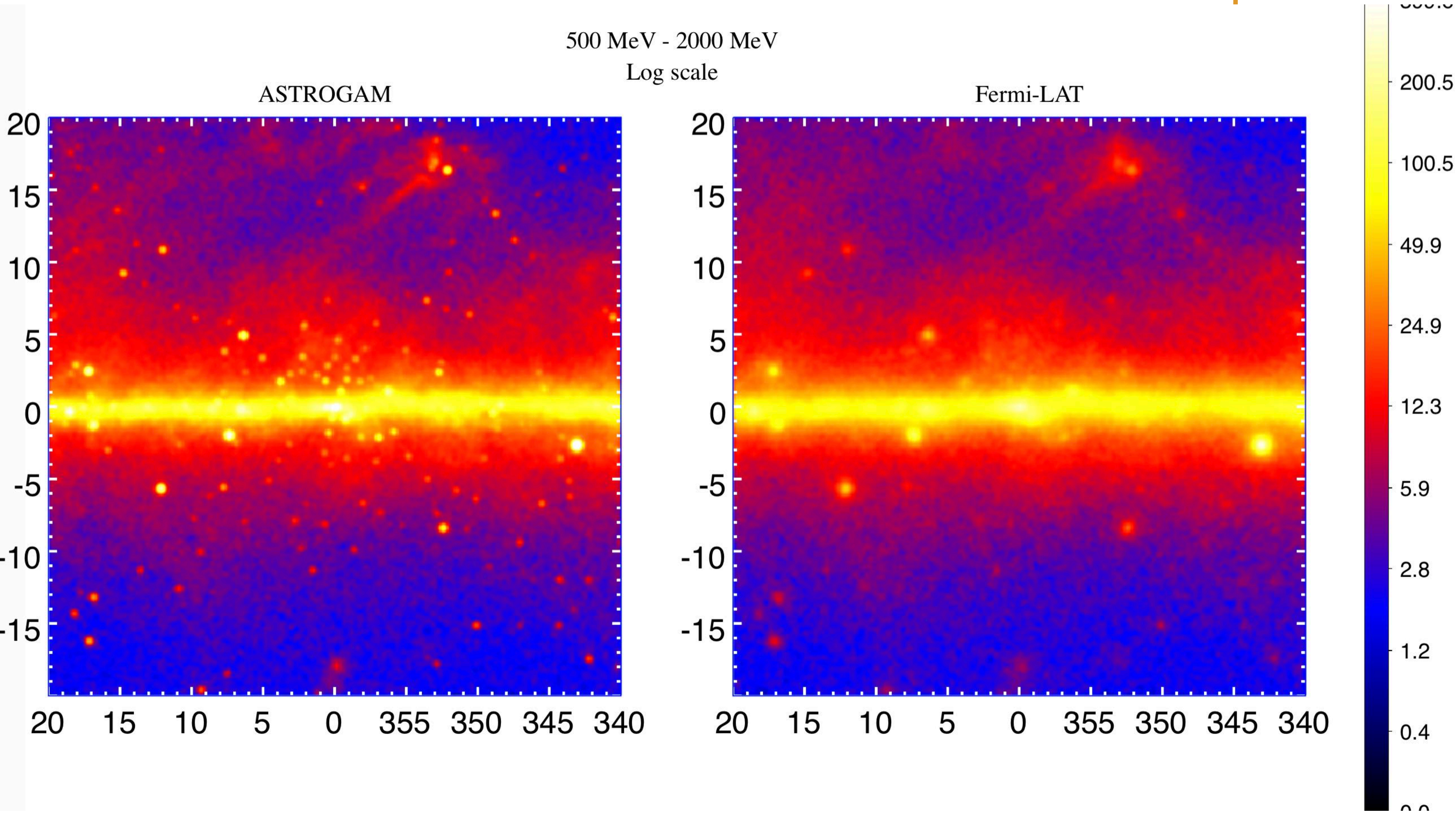


- e-ASTROGAM performance evaluated with **MEGAlib** and – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

e-Astrogam: arXiv:1611.02232

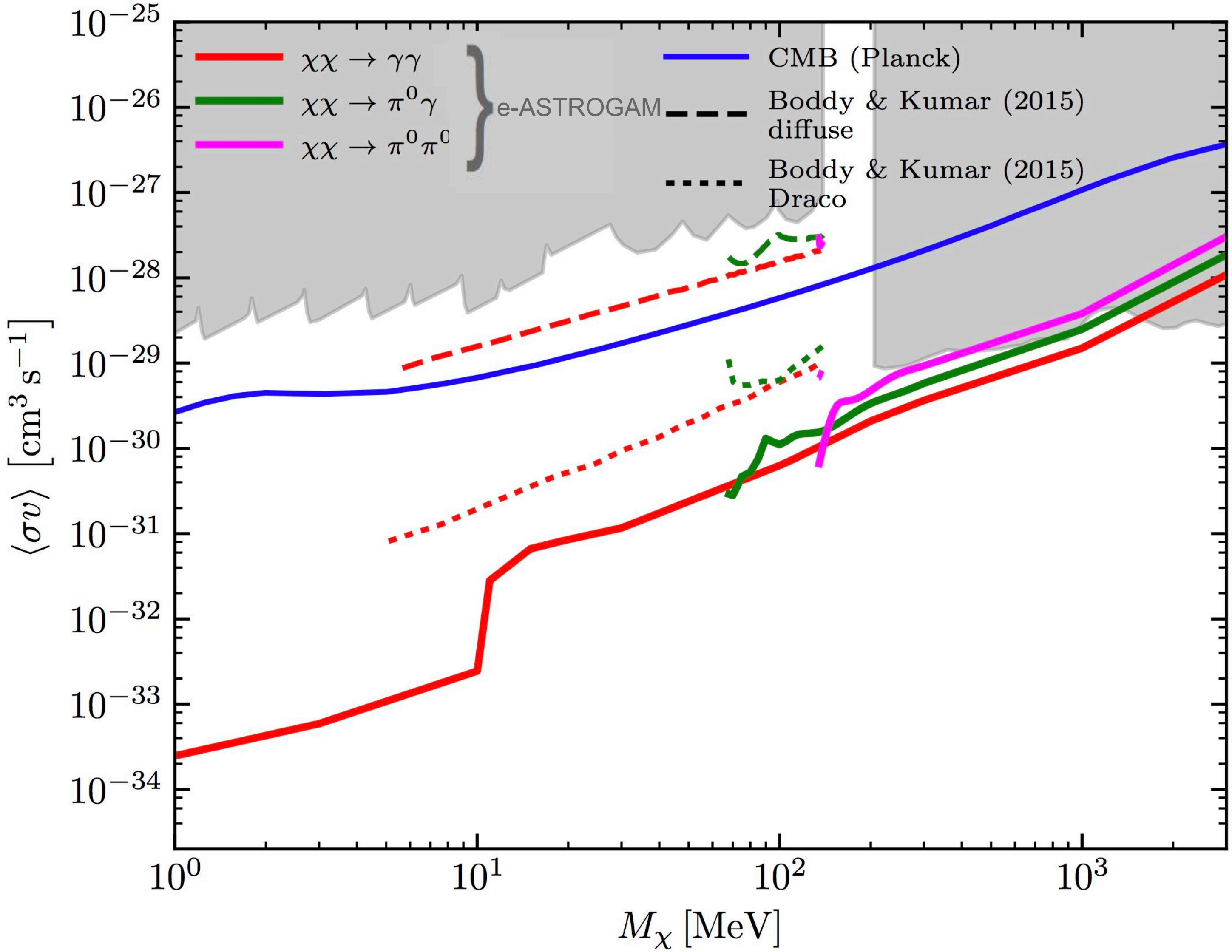
Galactic Center Region 0.5-2 GeV

Fermi PSF Pass7 rep v15 source

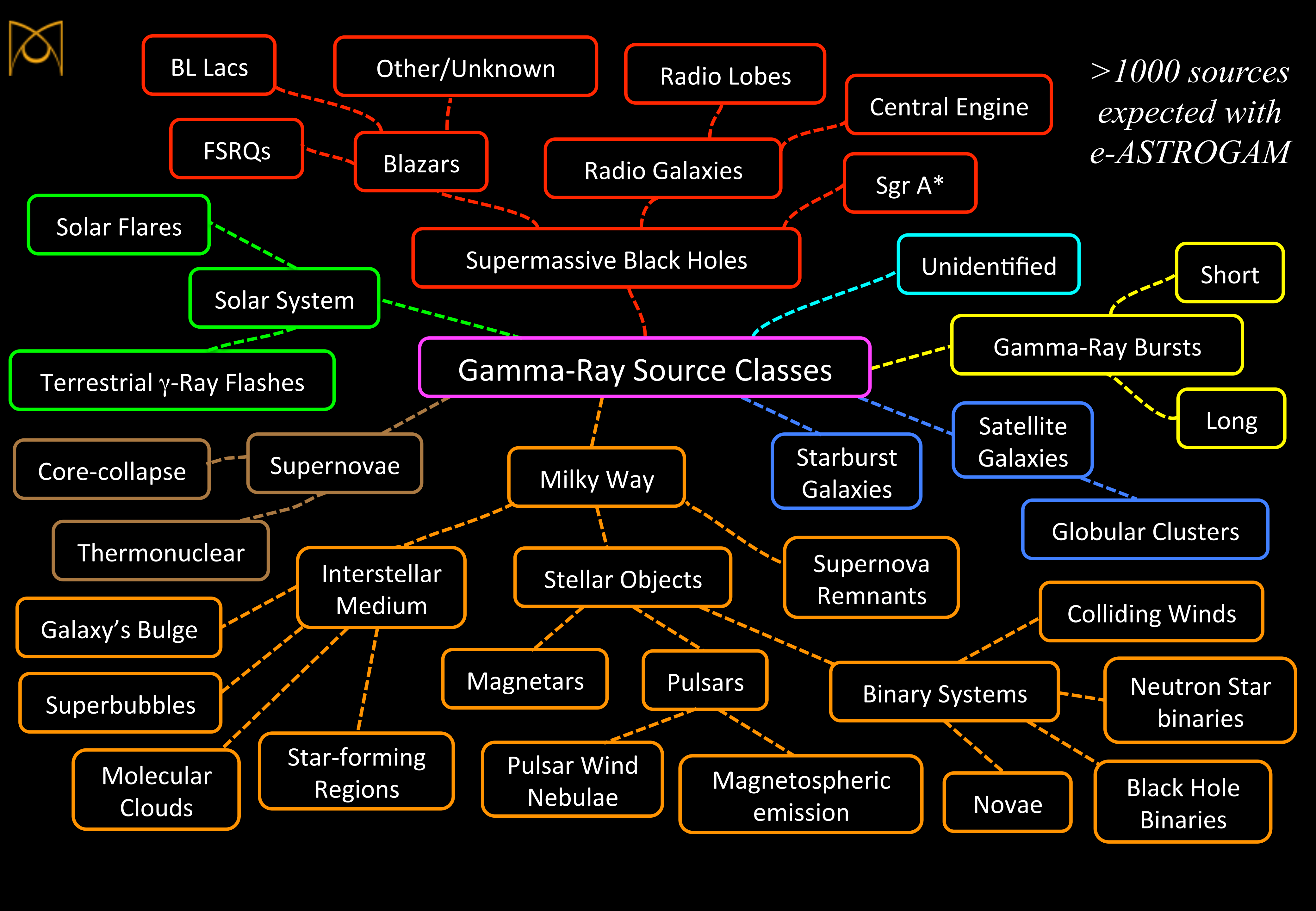


Morselli, Gomez Vargas, preliminary

DM limits with e-ASTROGAM in the MeV region

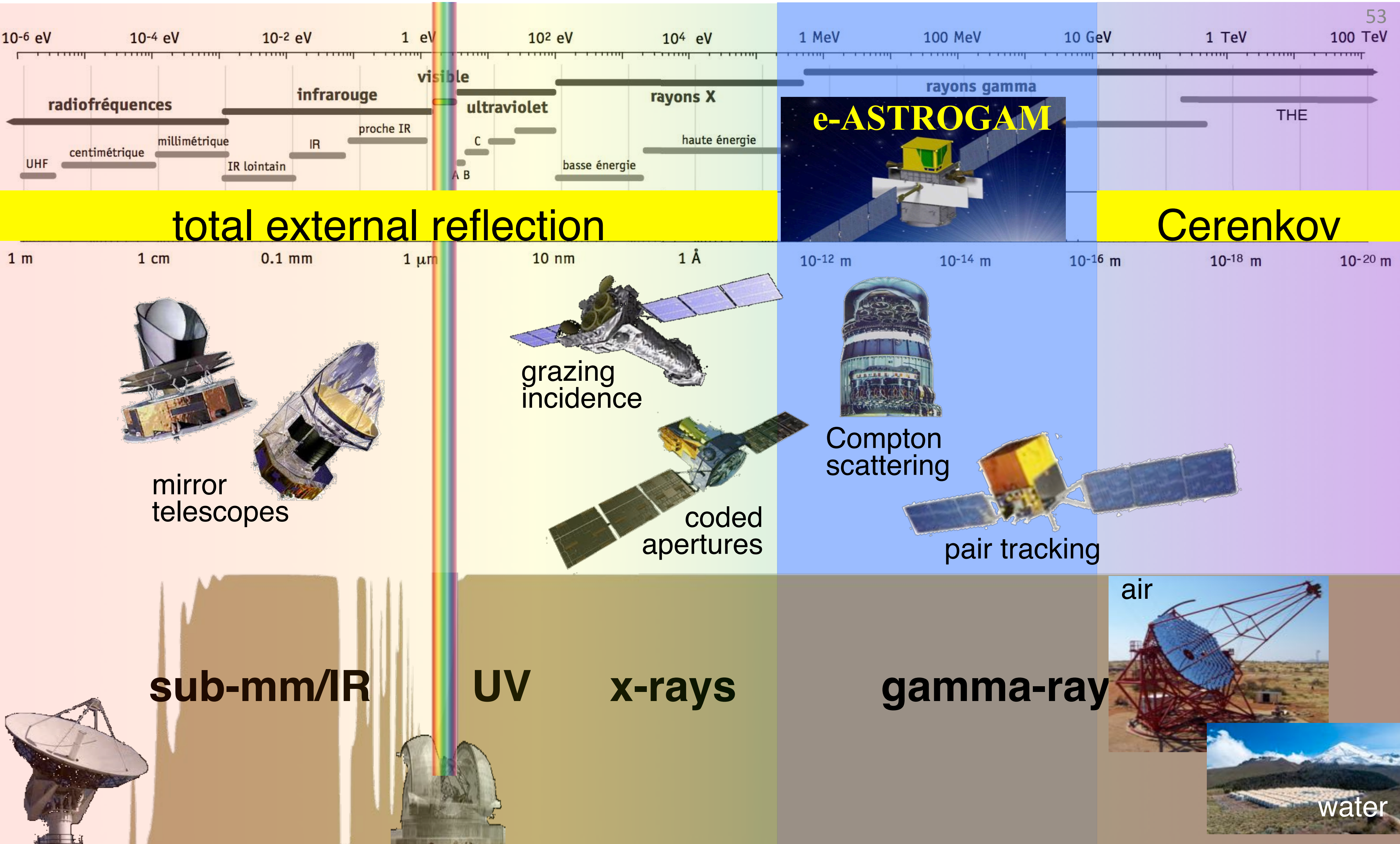


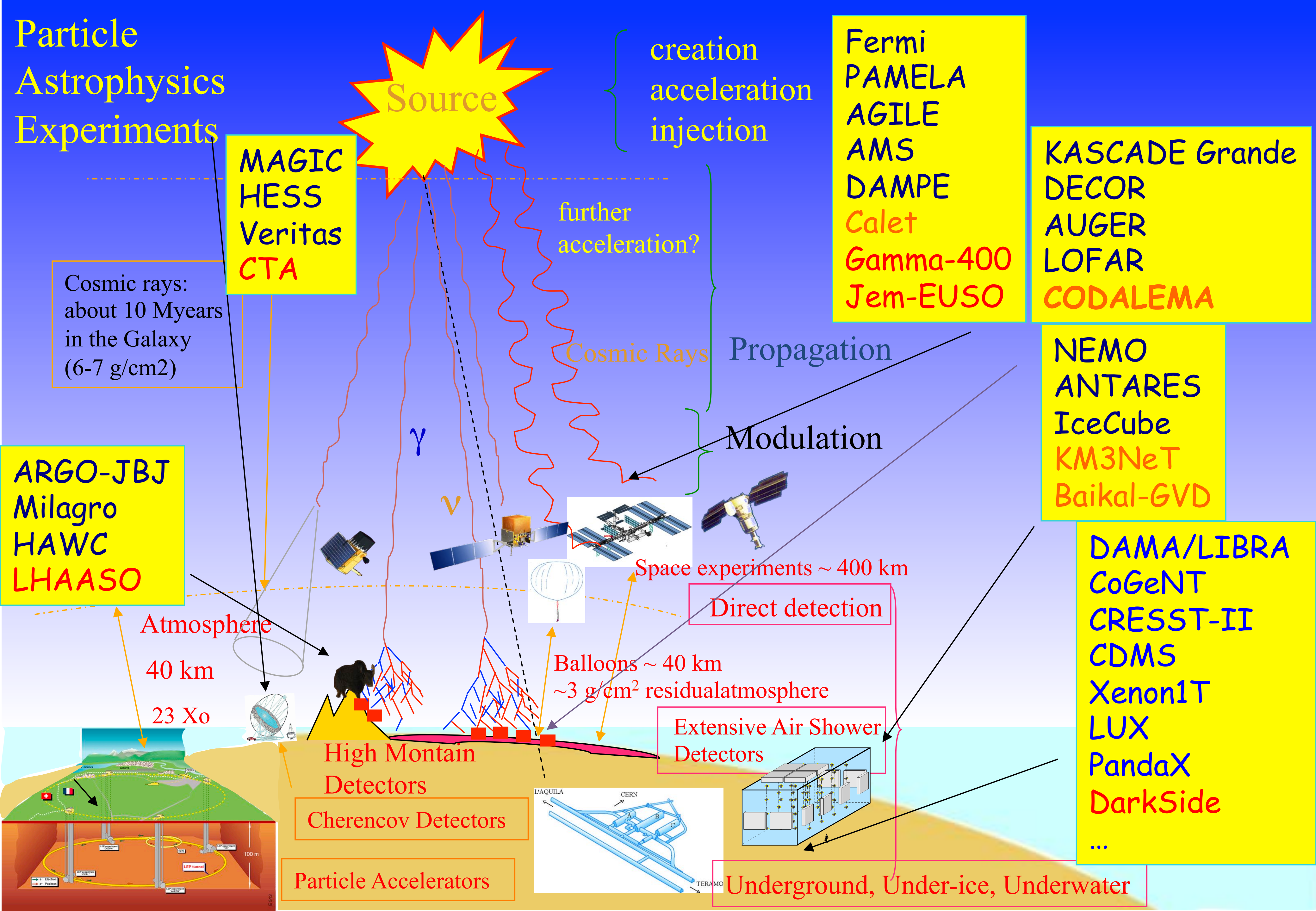
R.Bartels et al. arXiv:1703.02546



>1000 sources expected with e-ASTROGAM
Gamma-Ray Source Classes
Supermassive Black Holes
Blazars
BL Lacs
FSRQs
Other/Unknown
Radio Galaxies
Radio Lobes
Central Engine
Sgr A*
Unidentified
Gamma-Ray Bursts
Short
Long
Satellite Galaxies
Globular Clusters
Starburst Galaxies
Solar System
Solar Flares
Terrestrial γ-Ray Flashes
Supernovae
Core-collapse
Thermonuclear
Milky Way
Supernova Remnants
Interstellar Medium
Galaxy's Bulge
Superbubbles
Molecular Clouds
Star-forming Regions
Stellar Objects
Magnetars
Pulsars
Pulsar Wind Nebulae
Magnetospheric emission
Binary Systems
Colliding Winds
Neutron Star binaries
Novae
Black Hole Binaries

An instrument to complete the coverage of the electromagnetic spectrum




Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
Jem-EUSO
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
MAGIC
HESS
Veritas
CTA
further
acceleration?
Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)
Cosmic Rays
Propagation
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
Modulation
γ
ν
ARGO-JBJ
Milagro
HAWC
LHAASO
Space experiments ~ 400 km
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
...
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
Extensive Air Shower
Detectors
High Montain
Detectors
Cherencov Detectors
Particle Accelerators
Underground, Under-ice, Underwater

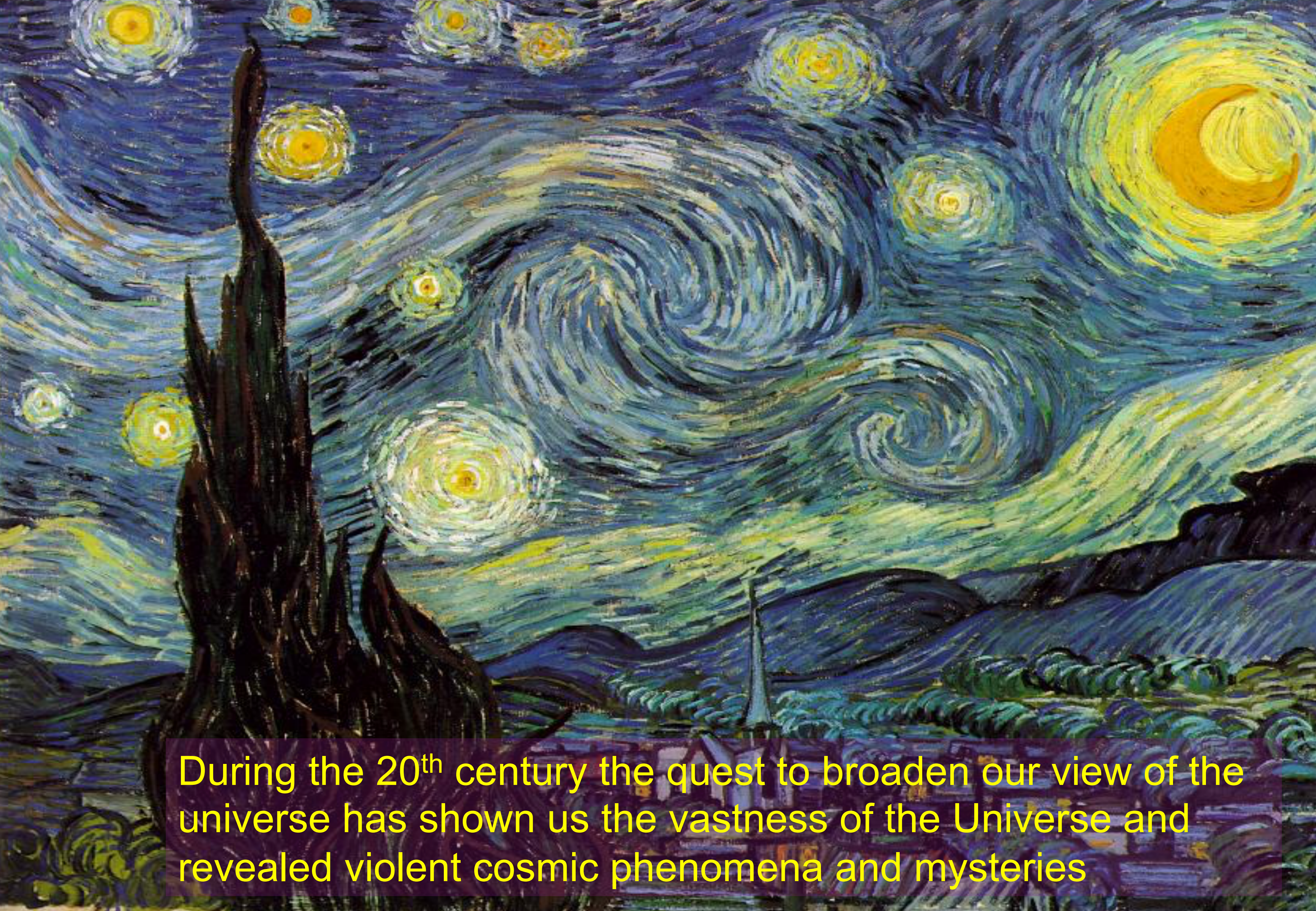
Conclusions

Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe (in synergy with the experiments at the LHC and in the underground laboratories).

In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies)
(e-AstroGAM, AMEGO)
and higher energies (CTA, HAWC)

Thank you !


Through most of history, the cosmos has been
viewed as eternally tranquil



During the 20th century the quest to broaden our view of the universe has shown us the vastness of the Universe and revealed violent cosmic phenomena and mysteries


The future?
Thank you !