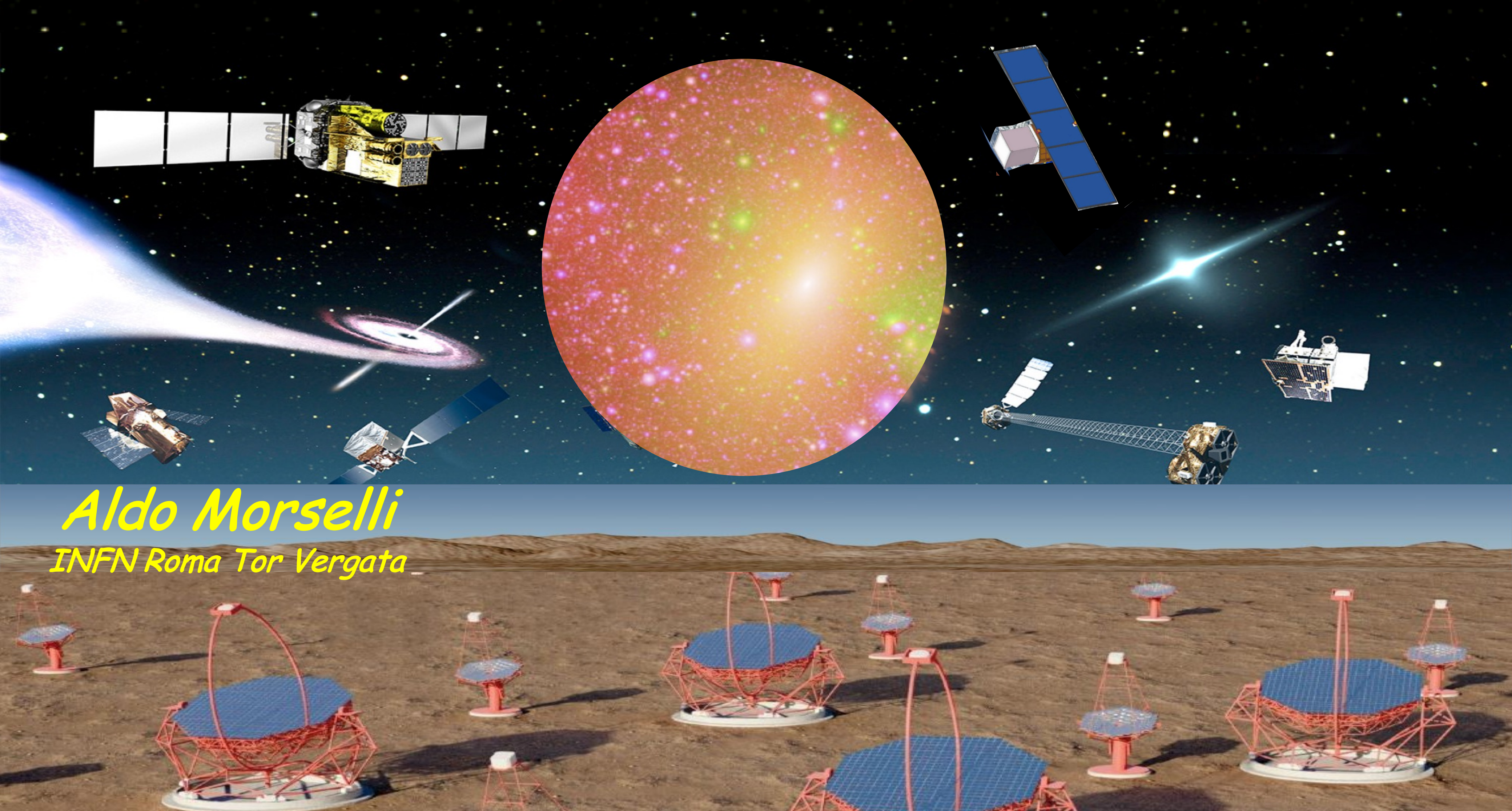
Indirect dark-matter searches with gamma-rays experiments : status and future plans from 300 KeV to 100 TeV



Aldo Morselli
INFN Roma Tor Vergata

Workshop on the Standard Model and Beyond

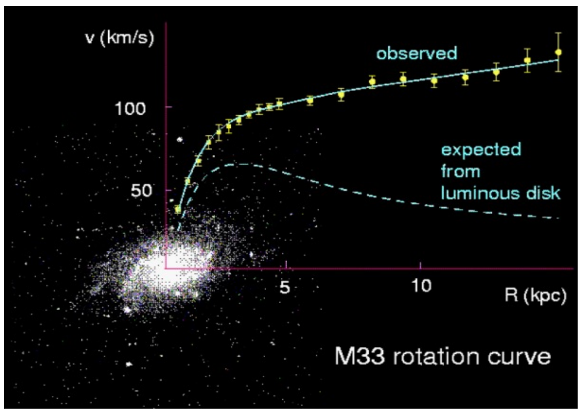
Corfu, September 2, 2022

Dark Matter EVIDENCE

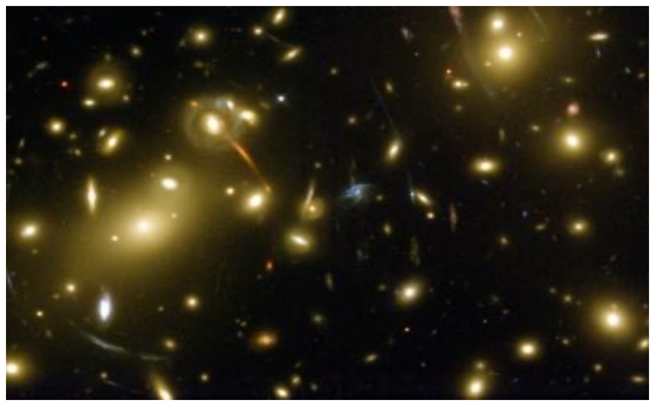
In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies.

Since then, even more evidence:

Rotation curves of galaxies

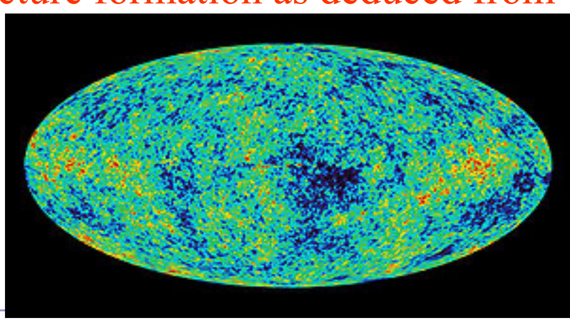


Gravitational lensing

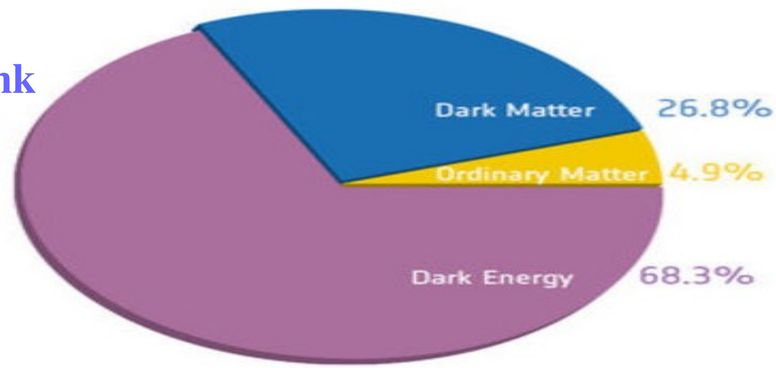


Bullet cluster

Structure formation as deduced from CMB



Data by Plank imply:



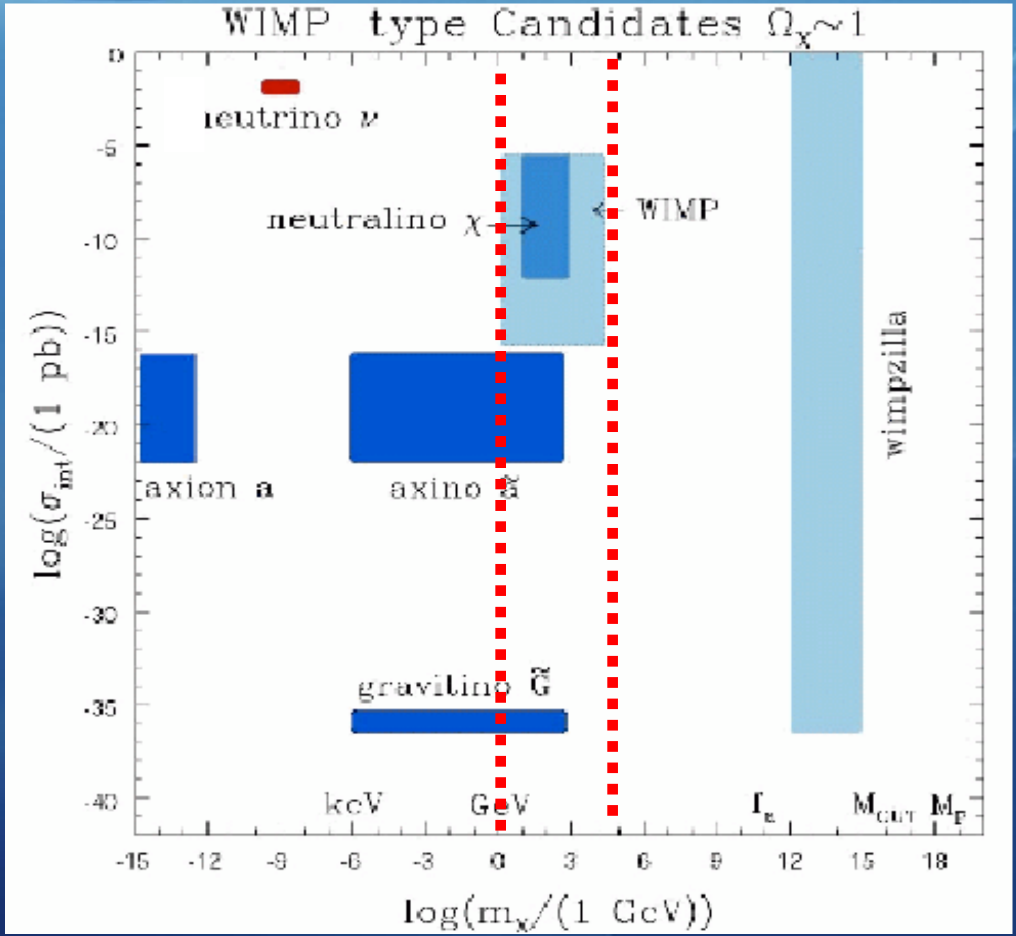
$\Omega_{DM} \approx 26.8\%$

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

Dark Matter

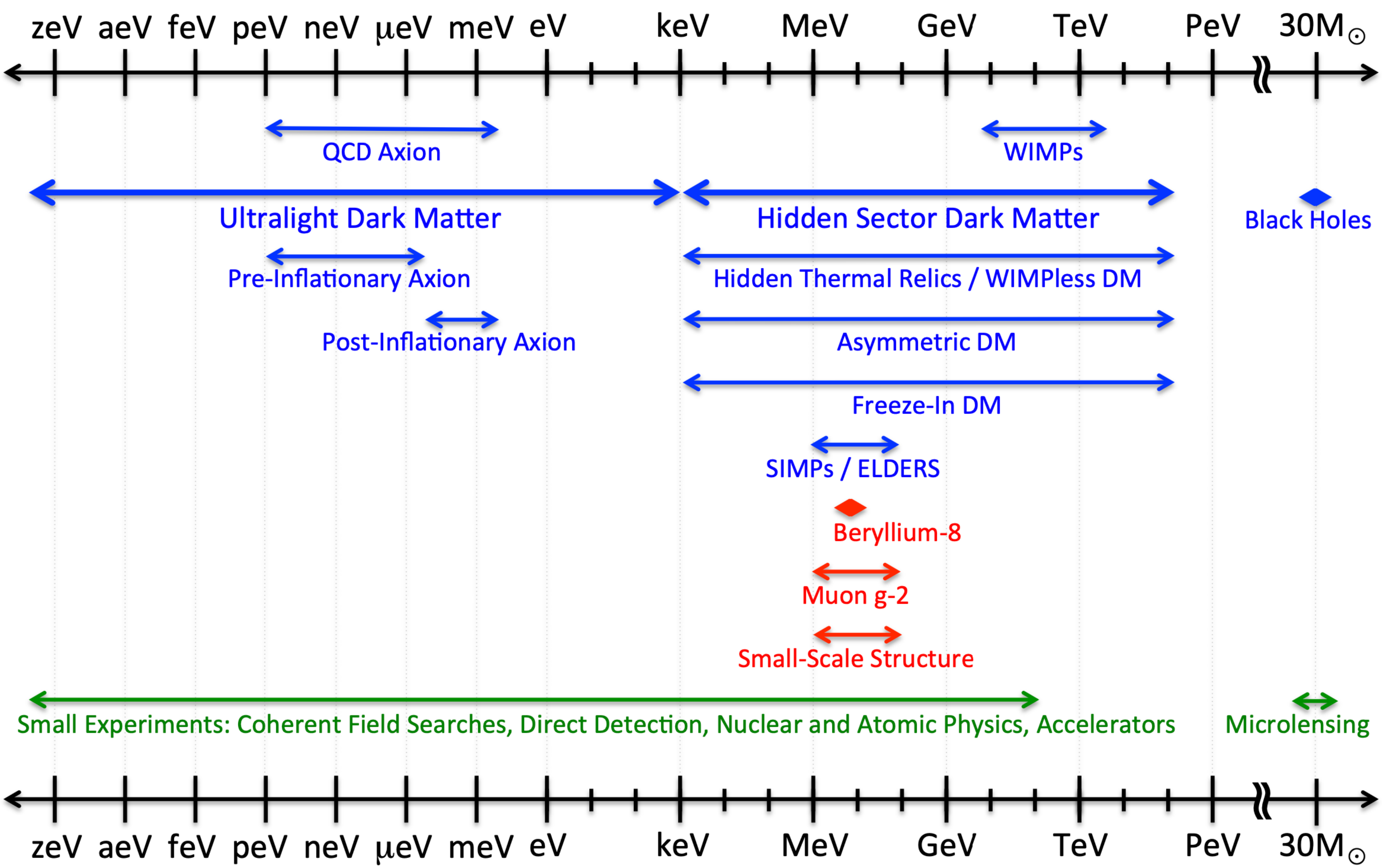
Dark Matter Candidates

- Kaluza-Klein DM in UED
- Kaluza-Klein DM in RS
- Axion
- Axino
- Gravitino
- Photino
- SM Neutrino
- Sterile Neutrino
- Sneutrino
- Light DM
- Little Higgs DM
- Wimpzillas
- Q-balls
- Mirror Matter
- Champs (charged DM)
- D-matter
- Cryptons
- Self-interacting
- Superweakly interacting
- Braneworld DM
- Heavy neutrino
- NEUTRALINO
- Messenger States in GMSB
- Branons
- Chaplygin Gas
- Split SUSY
- Primordial Black Holes



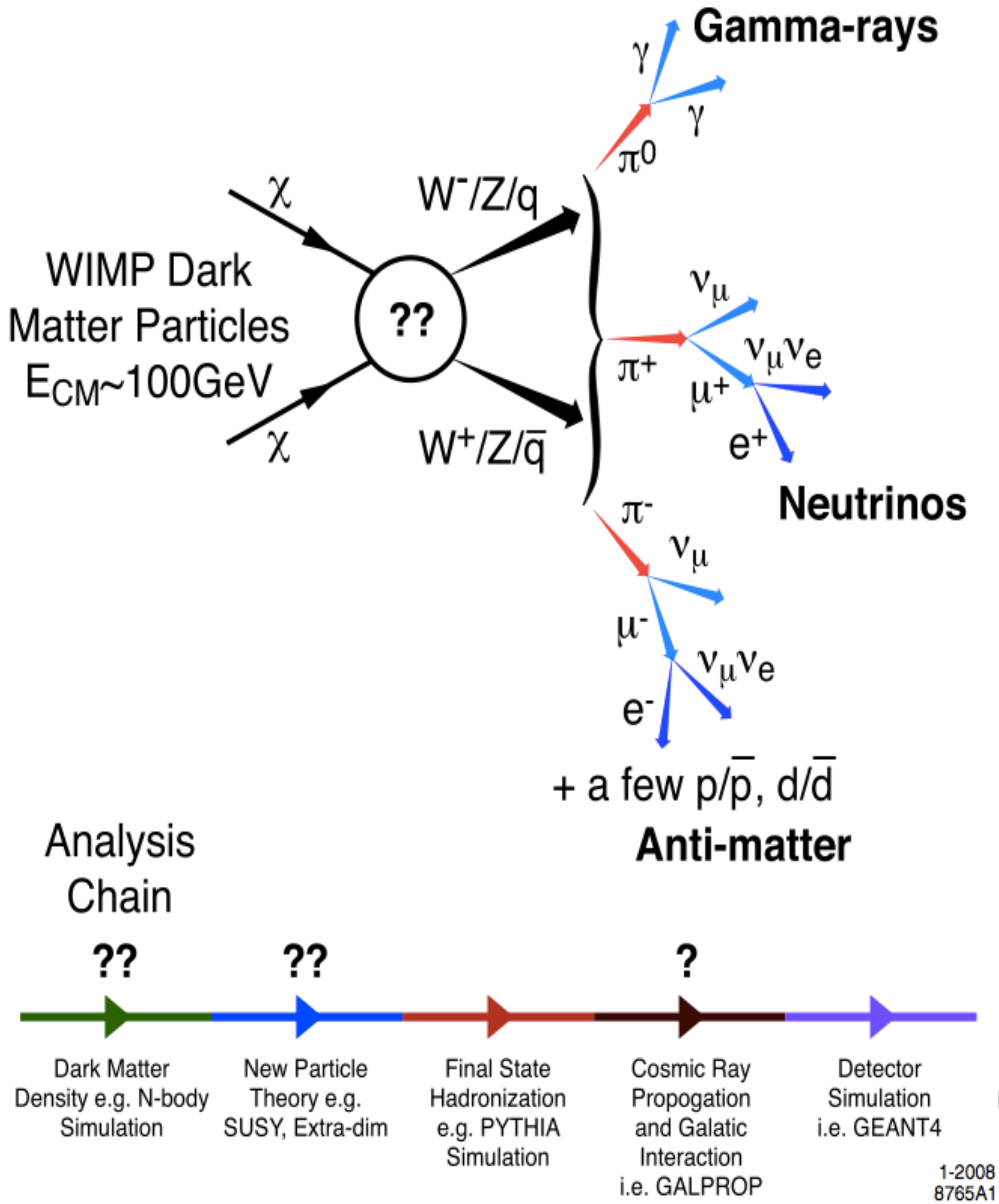
Dark Sector Candidates, Anomalies, and Search Techniques

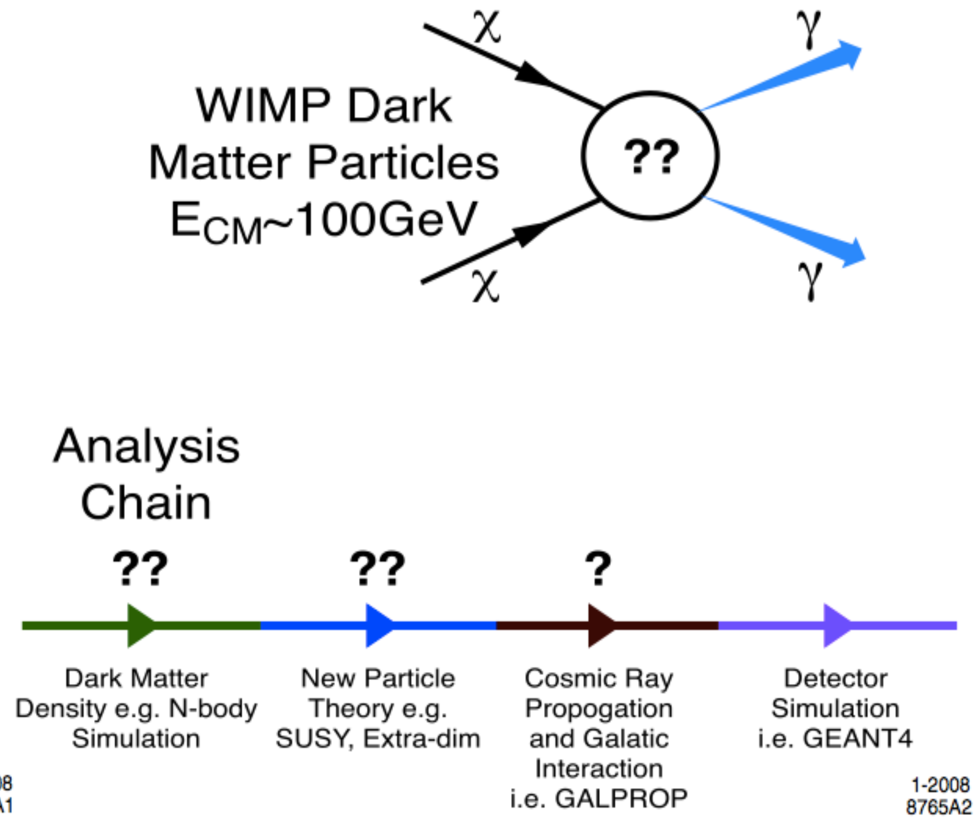
Dark Sector Candidates, Anomalies, and Search Techniques



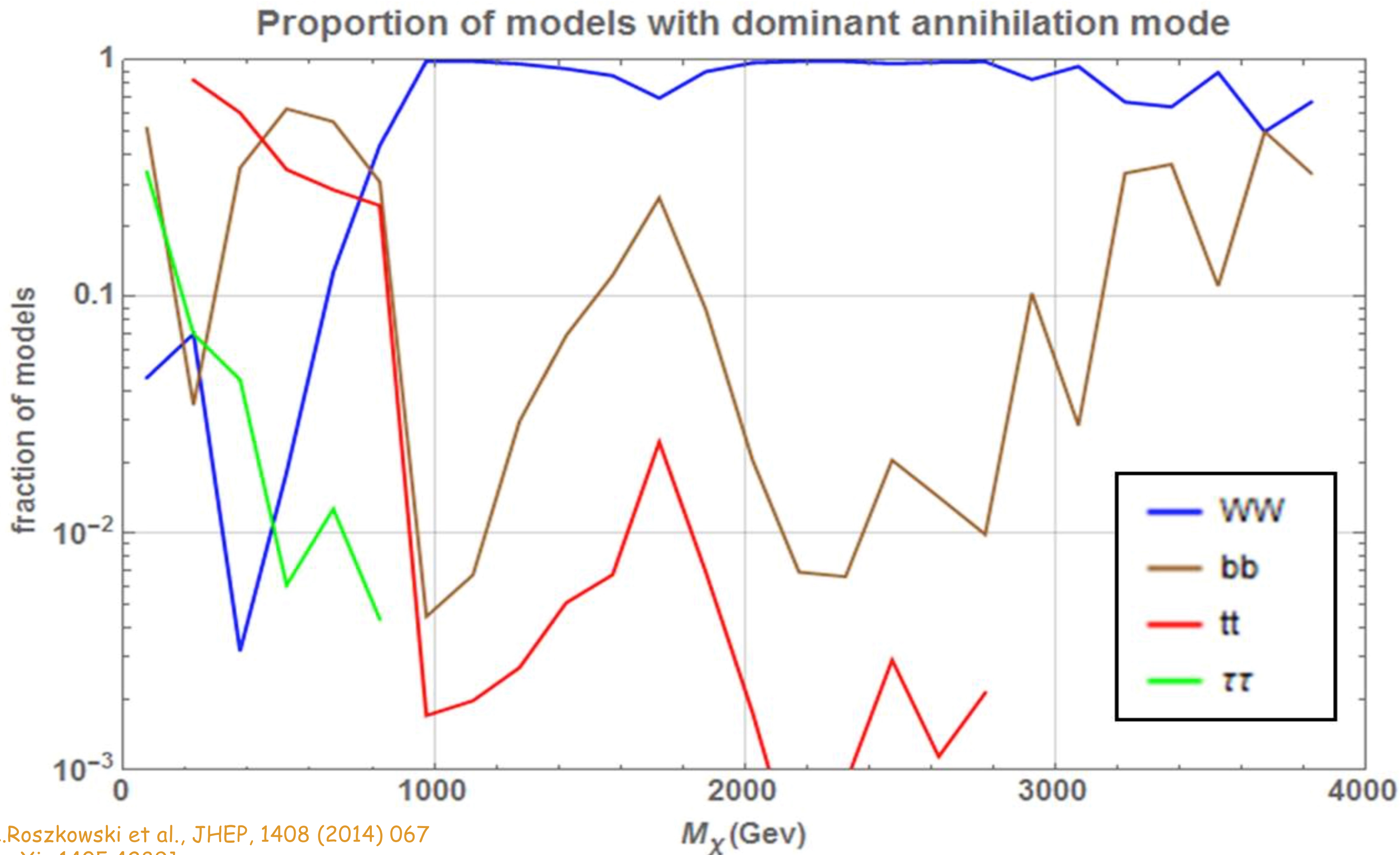
New Ideas in Dark Matter 2017 : Community Report arXiv:1707.04591

Annihilation channels





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



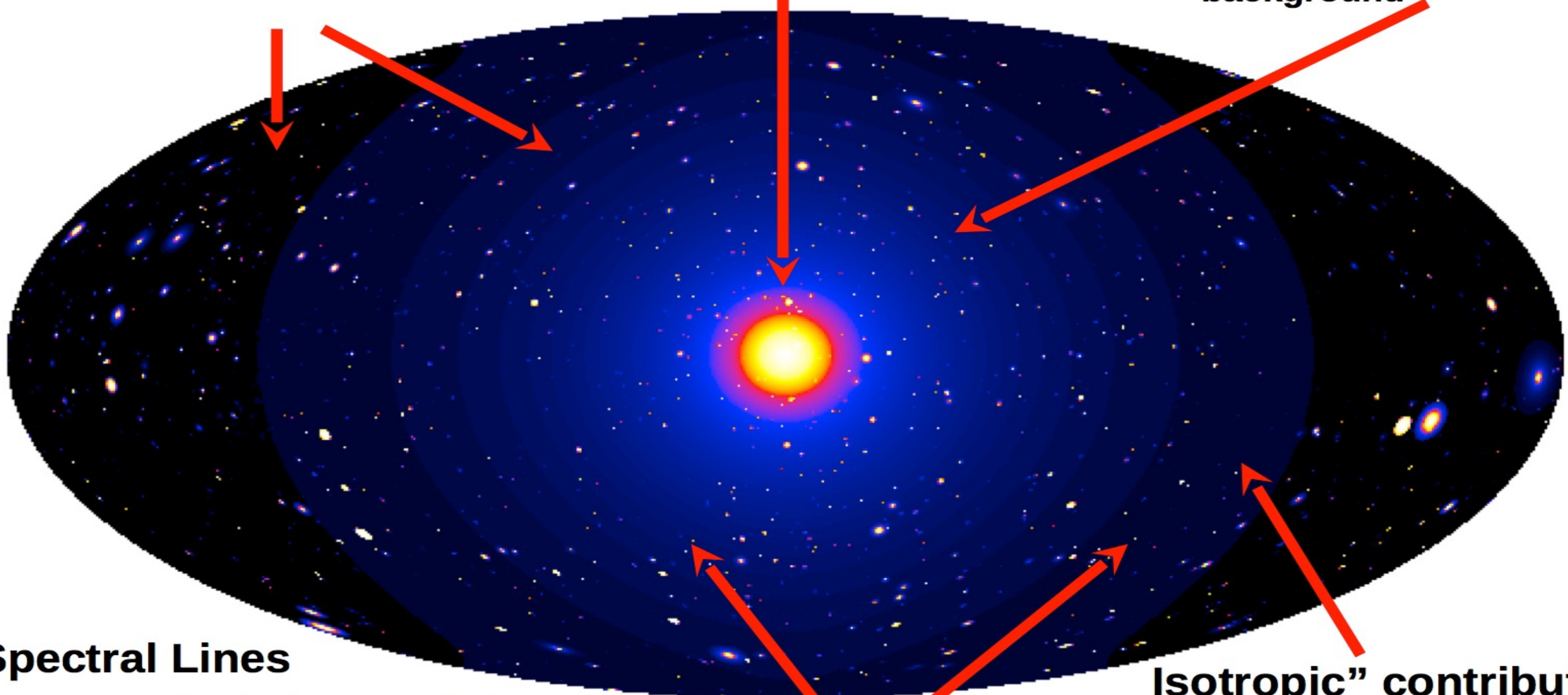
L.Roszkowski et al., JHEP, 1408 (2014) 067
[arXiv:1405.4289]

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, good source id, but low sensitivity because of expected small branching ratio

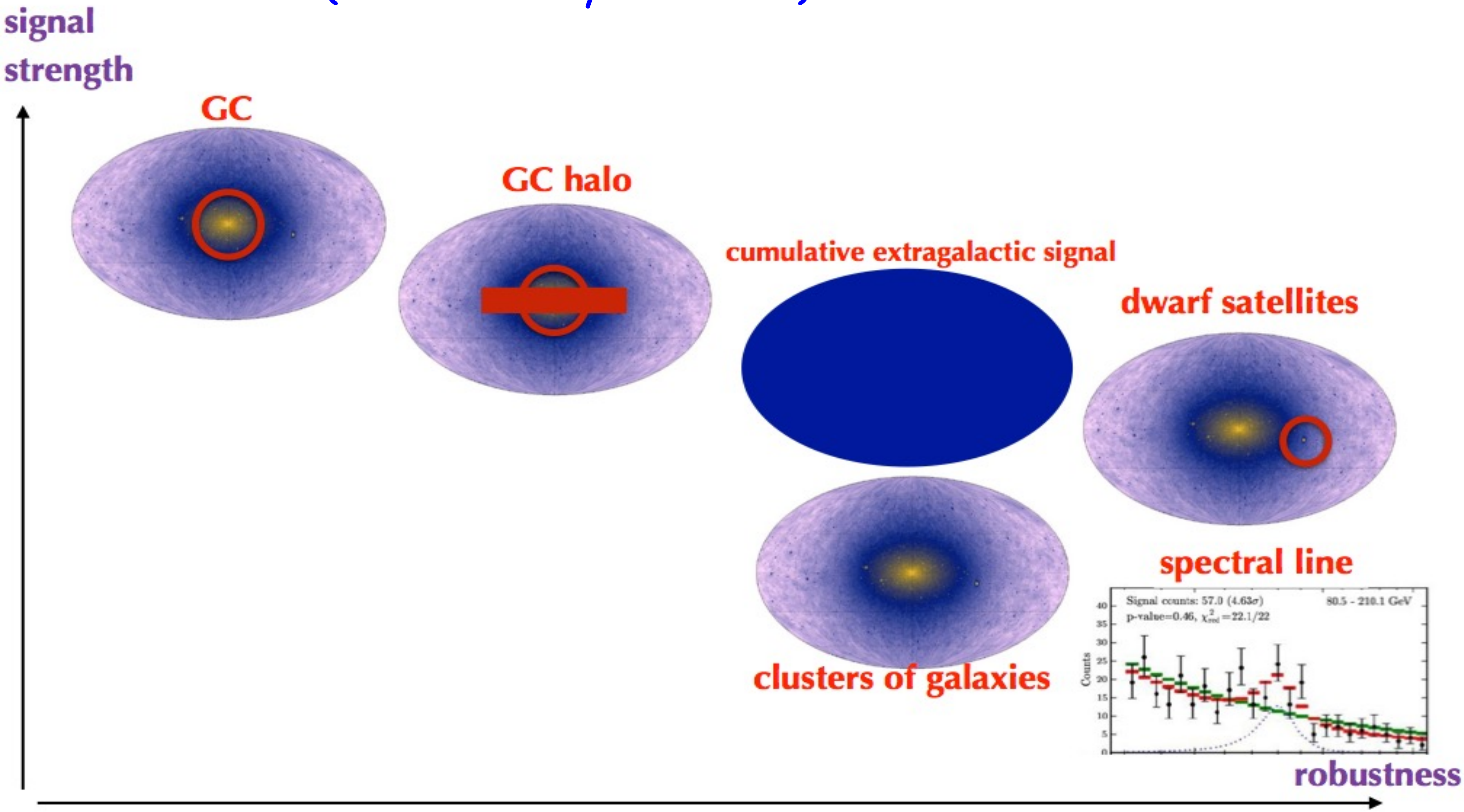
Galaxy Clusters
Low background, but low statistics

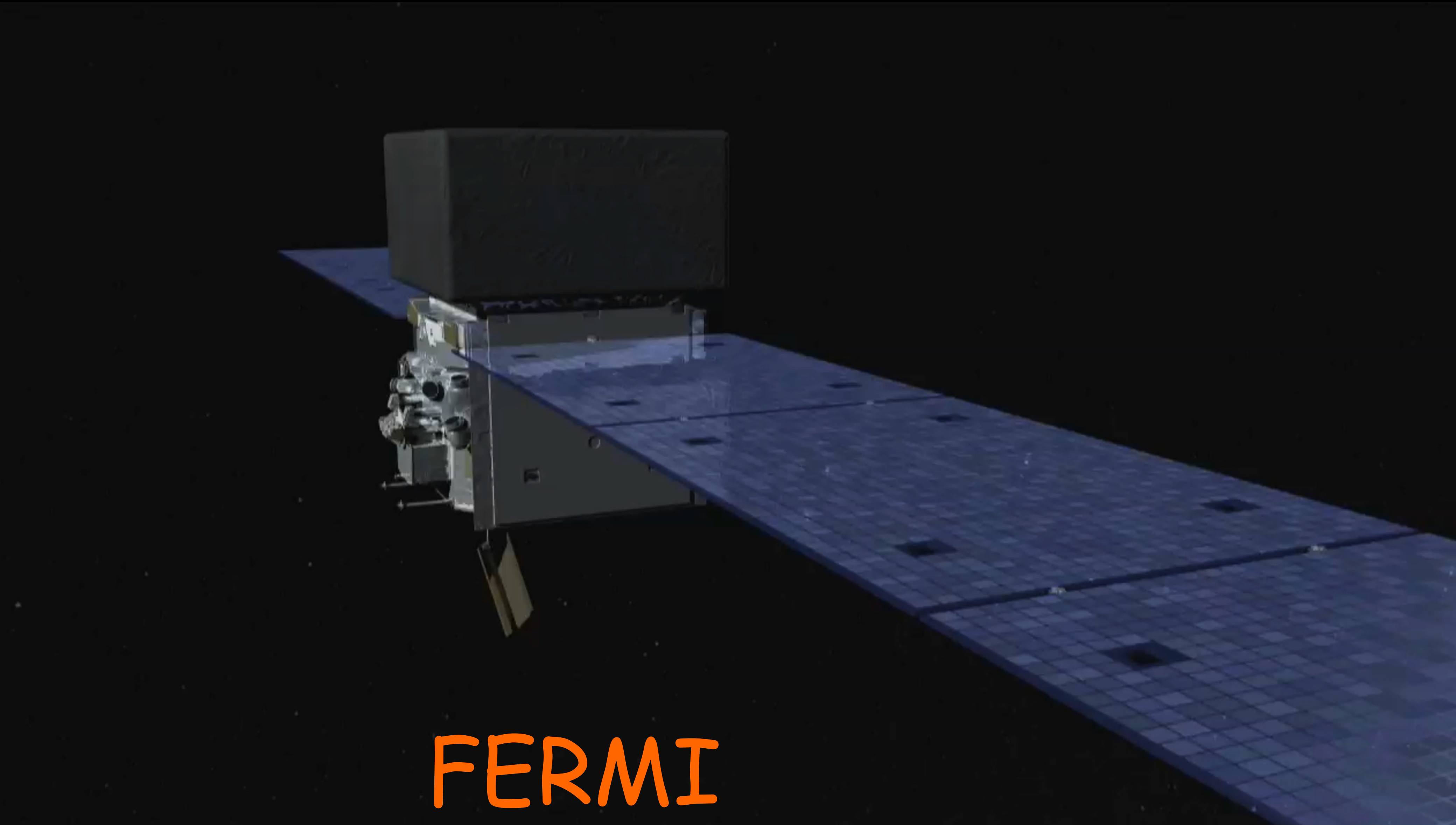
Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

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

Dark Matter Search: Targets and Strategies

(Another way to see it)



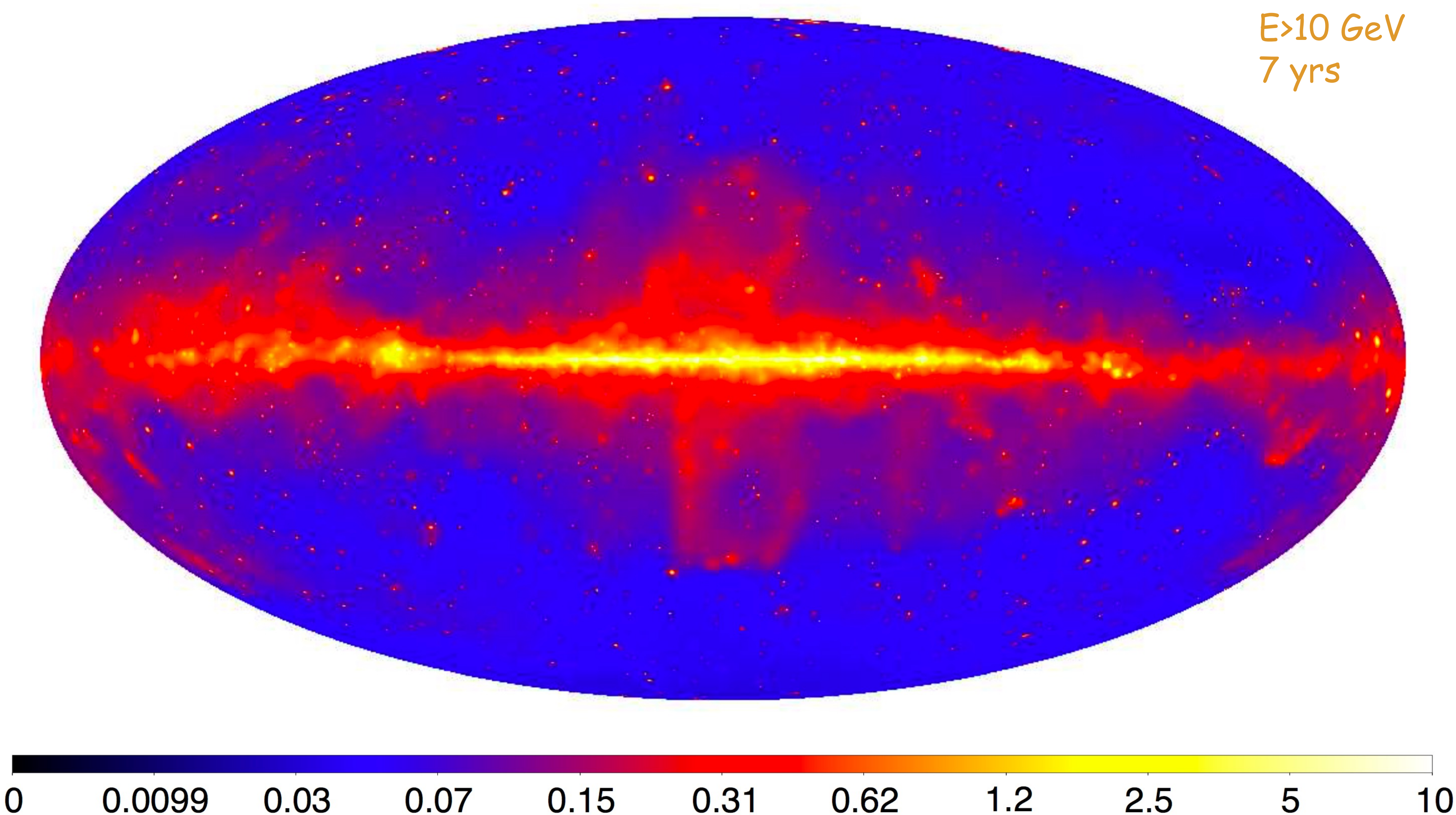


FERMI
Large Area Telescope

11 June 2008


Fermi
Gamma-ray
Space Telescope
Happy 14th Birthday Fermi !!
11 June 2008

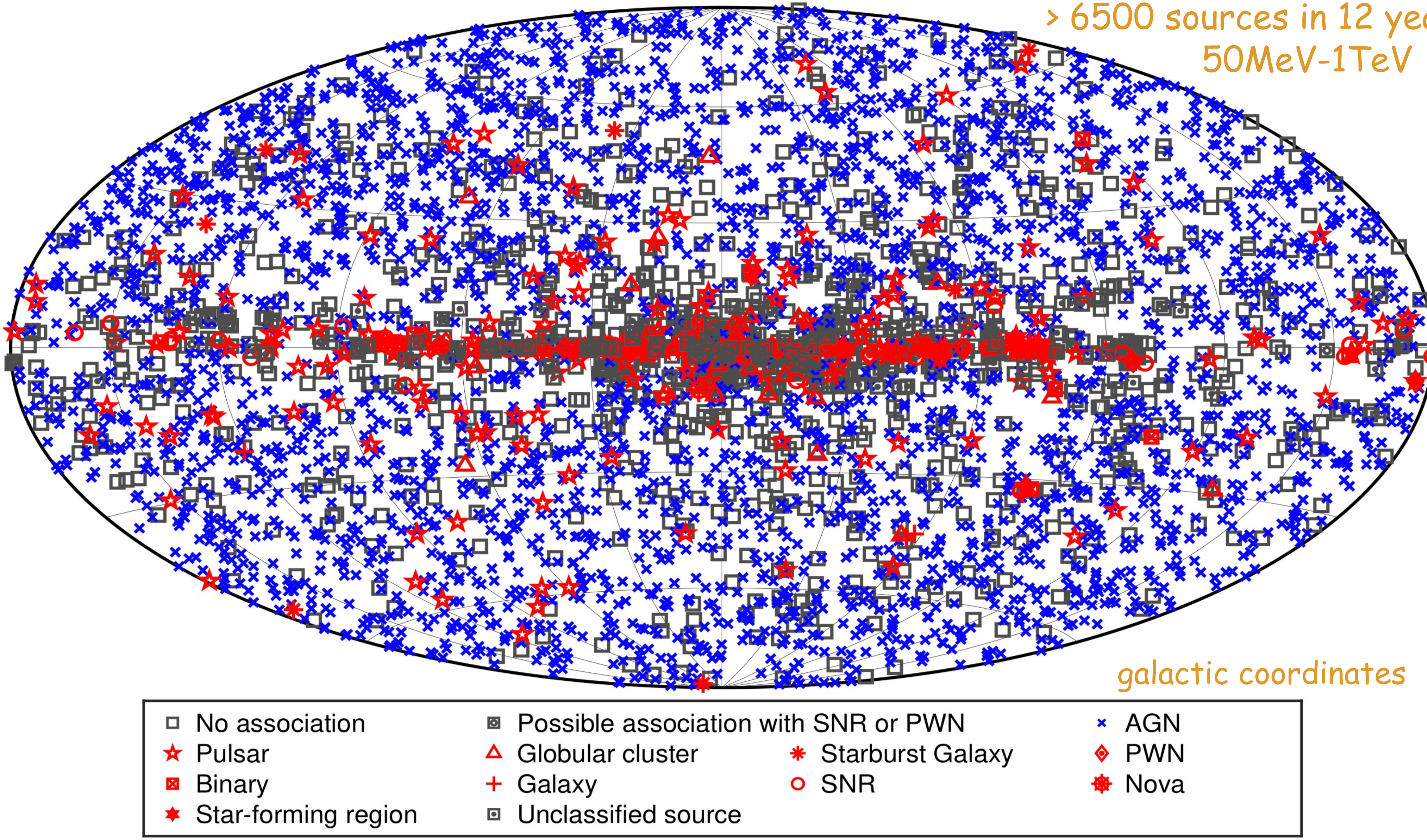
The sky in gamma-rays



M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources ApJS 2017 232 arXiv:1702.00664

The sky in gamma-rays 4th source catalog

> 6500 sources in 12 years
50MeV-1TeV

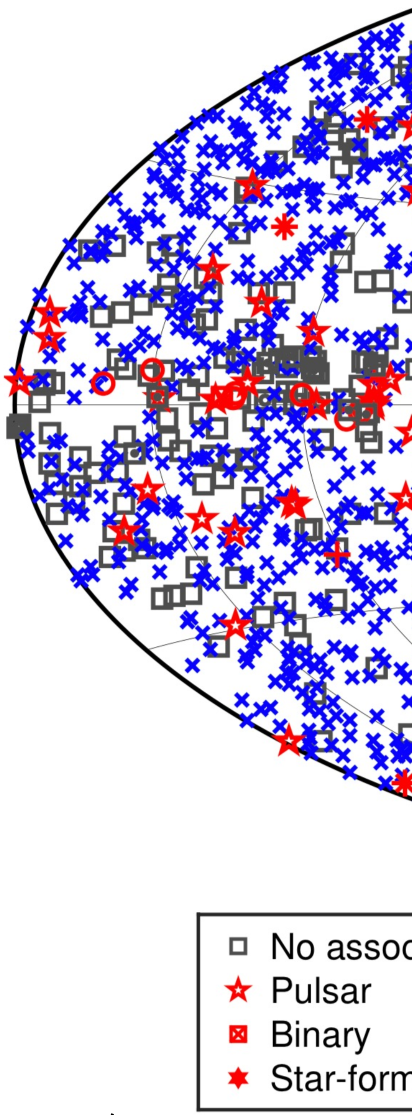


galactic coordinates

Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045]
+ Incremental Fermi Large Area Telescope Fourth Source Catalog arXiv:2201.11184

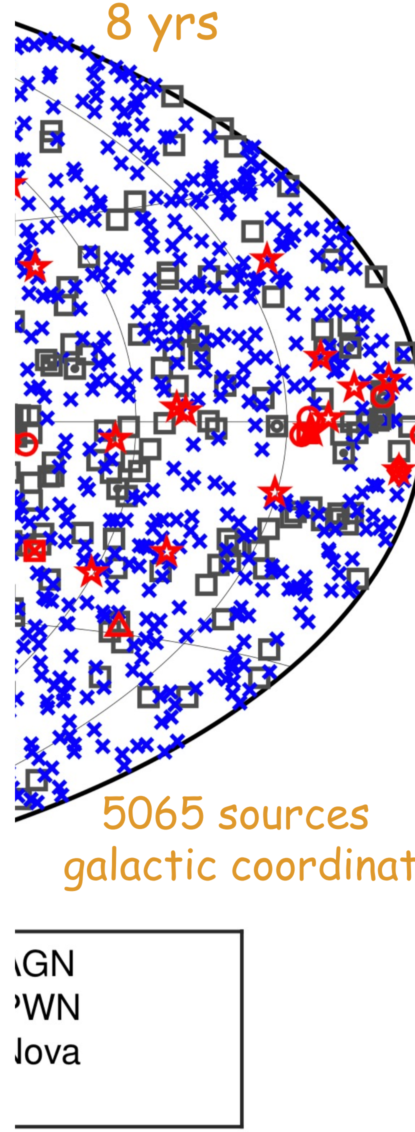
The sky in gamma-rays 4th source catalog

50MeV-1TeV
8 yrs



Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	229	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	10
Pulsar wind nebula	PWN	12	pwn	6
Supernova remnant	SNR	24	snr	16
Supernova remnant / Pulsar wind nebula	SPP	0	spp	90
Globular cluster	GLC	0	glc	30
Star-forming region	SFR	3	sfr	0
High-mass binary	HMB	5	hmb	3
Low-mass binary	LMB	1	lmb	1
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BLL	22	bll	1094
FSRQ type of blazar	FSRQ	42	fsrq	644
Radio galaxy	RDG	6	rdg	36
Non-blazar active galaxy	AGN	1	agn	17
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact Steep Spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	3	bcu	1327
Narrow line Seyfert 1	NLSY1	4	nlsy1	5
Seyfert galaxy	SEY	0	sey	1
Starburst galaxy	SBG	0	sbg	7
Normal galaxy (or part)	GAL	2	gal	2
Unknown	UNK	0	unk	92
Total	...	356	...	3388
Unassociated	...	...	...	1323

NOTE—The designation 'spp' indicates potential association with SNR or PWN. Designations shown in capital letters are firm identifications; lower case letters indicate associations.



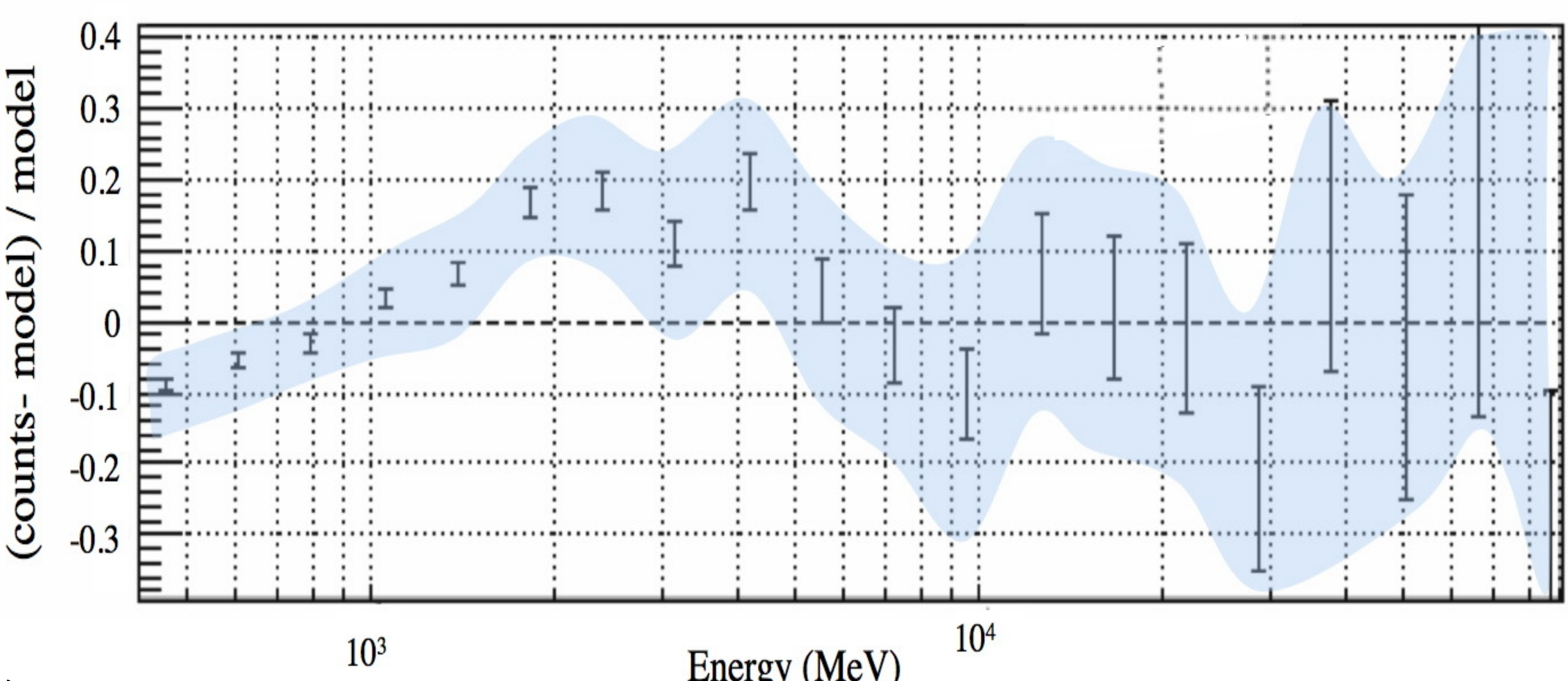
5065 sources
galactic coordinates

Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045]

The GeV excess 7° x7° region centered on the Galactic Center

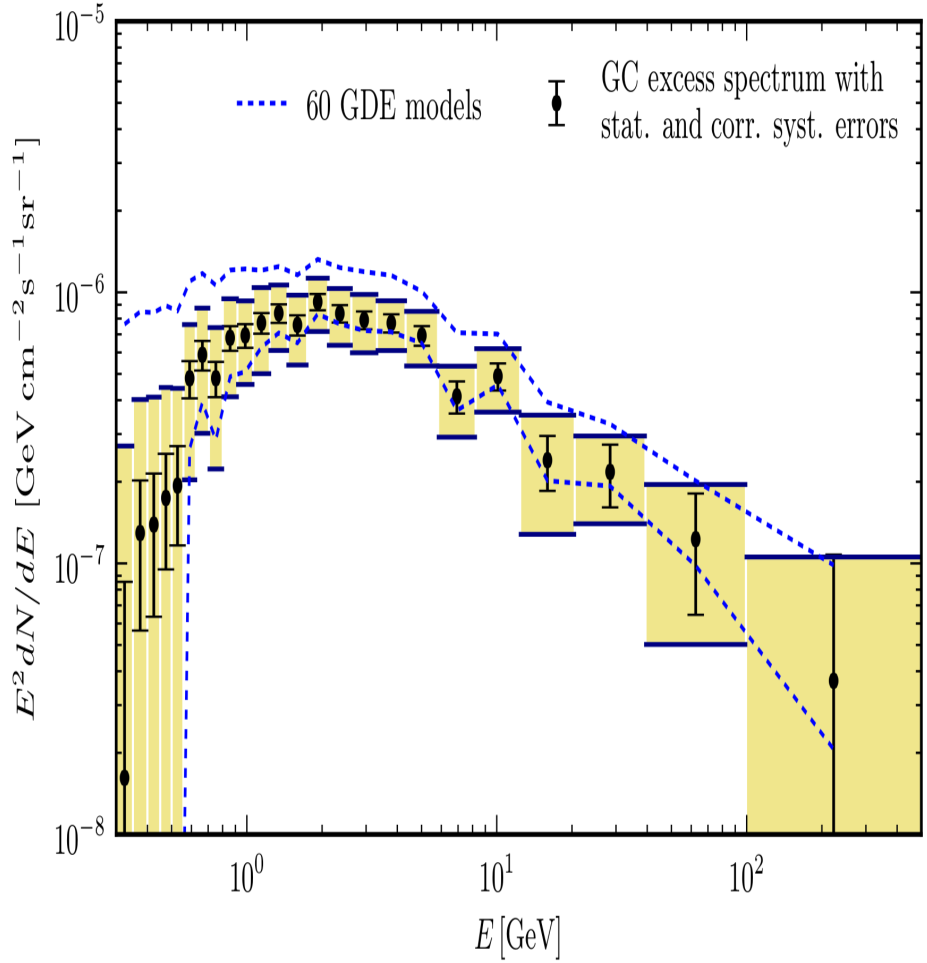
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

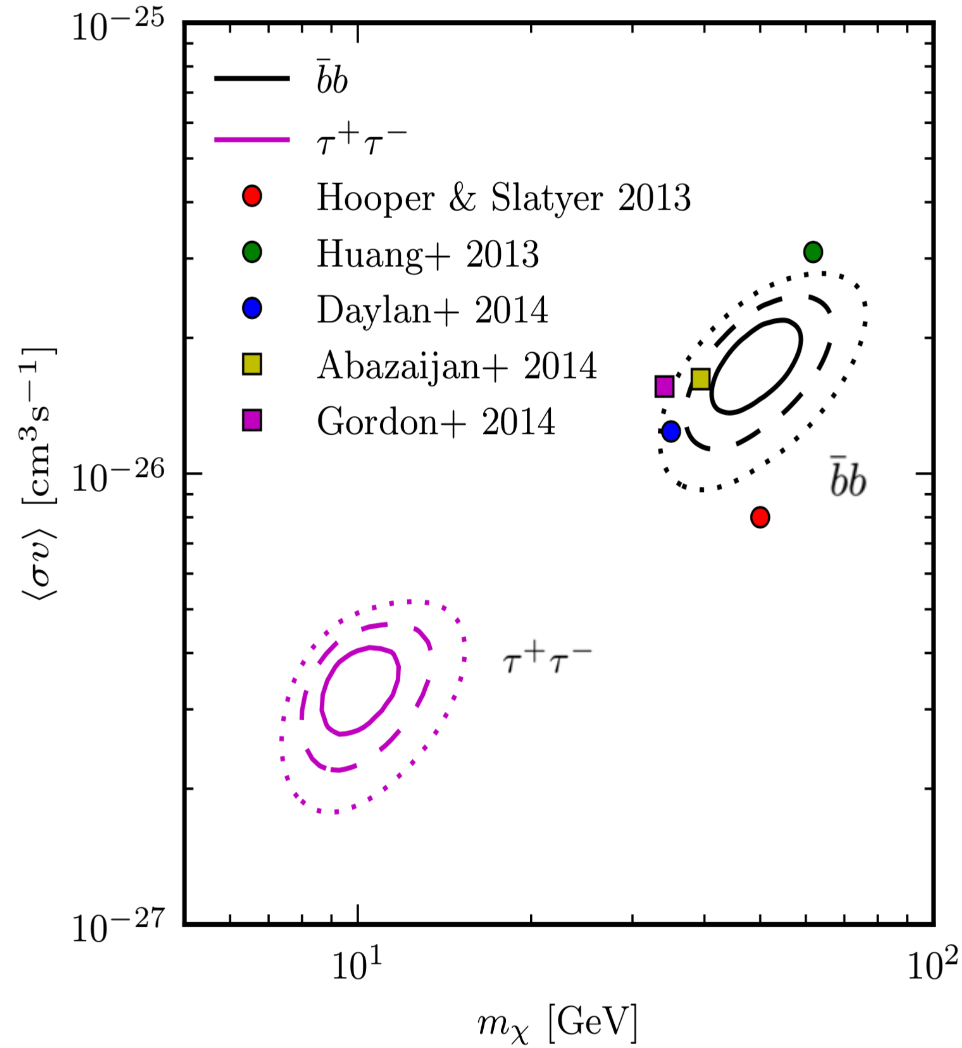
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



V.Vitale, A.Morselli, Fermi Coll. 2009 arXiv:0912.3828 Fermi Symposium eConf Proceedings C091122

The GeV excess

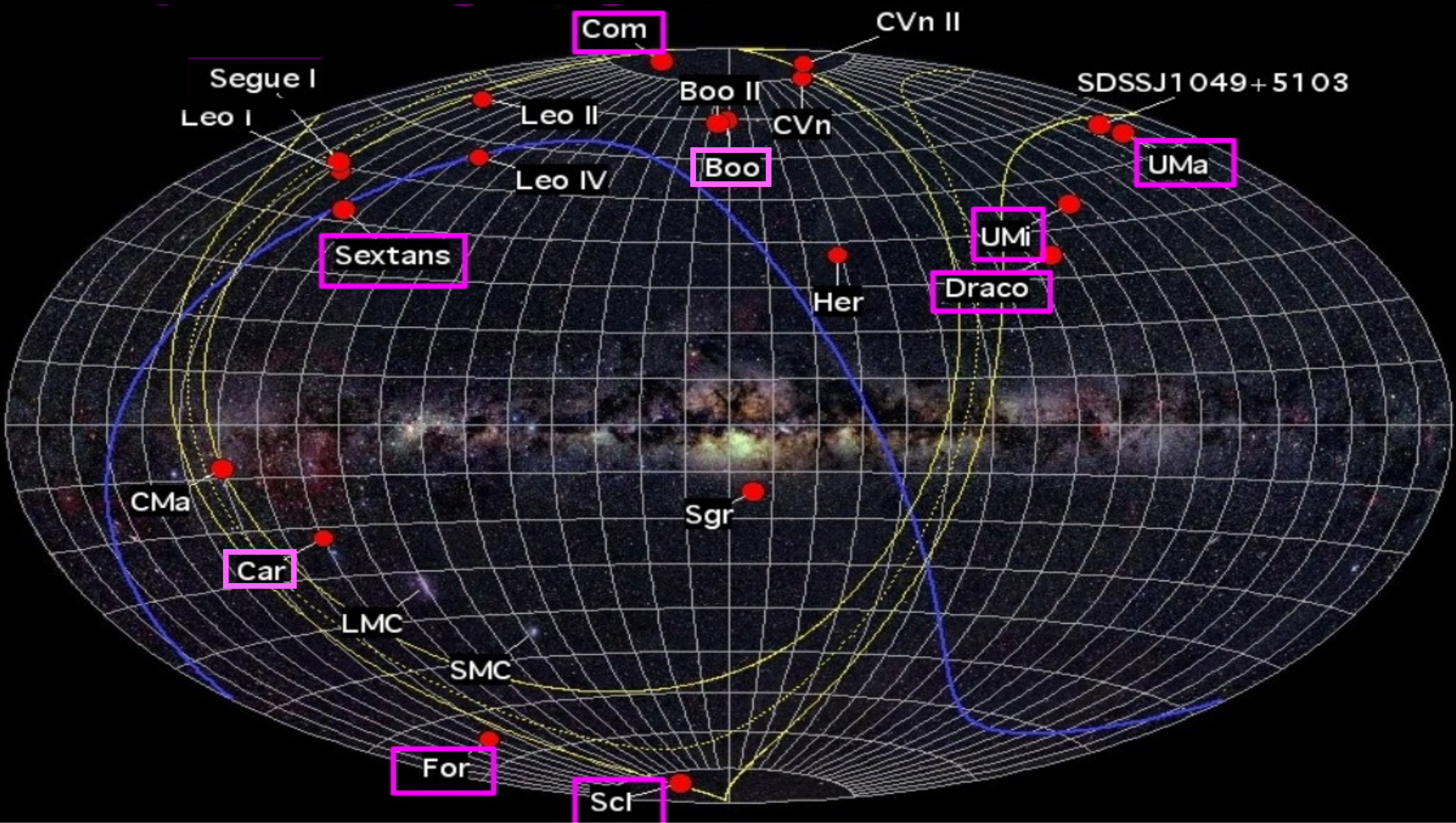




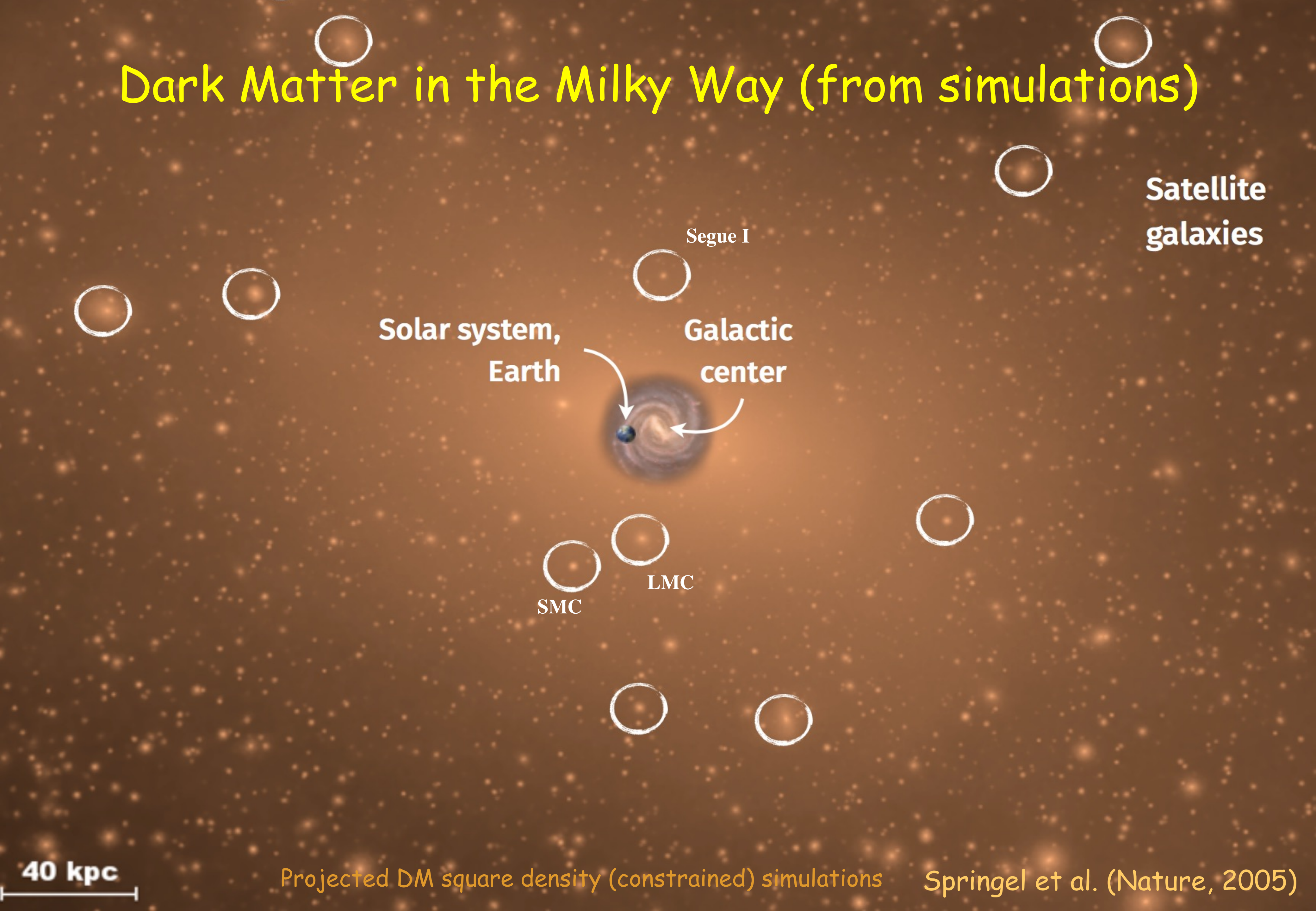
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

Calore et al, arXiv:1409.0042v1

Classical Dwarf spheroidal galaxies: promising targets for DM detection



Dark Matter in the Milky Way (from simulations)

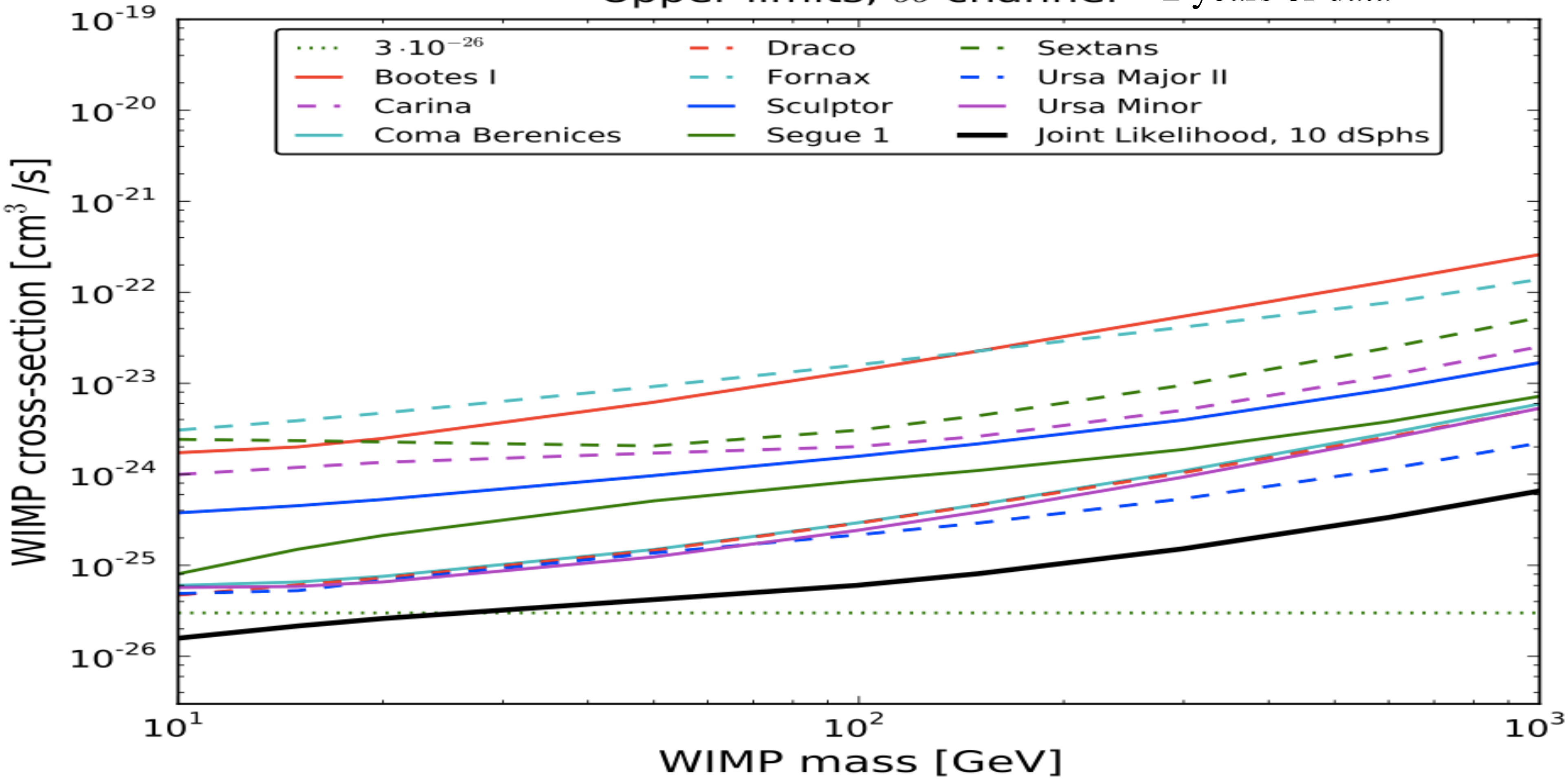


Projected DM square density (constrained) simulations

Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies combined analysis

2 years of data

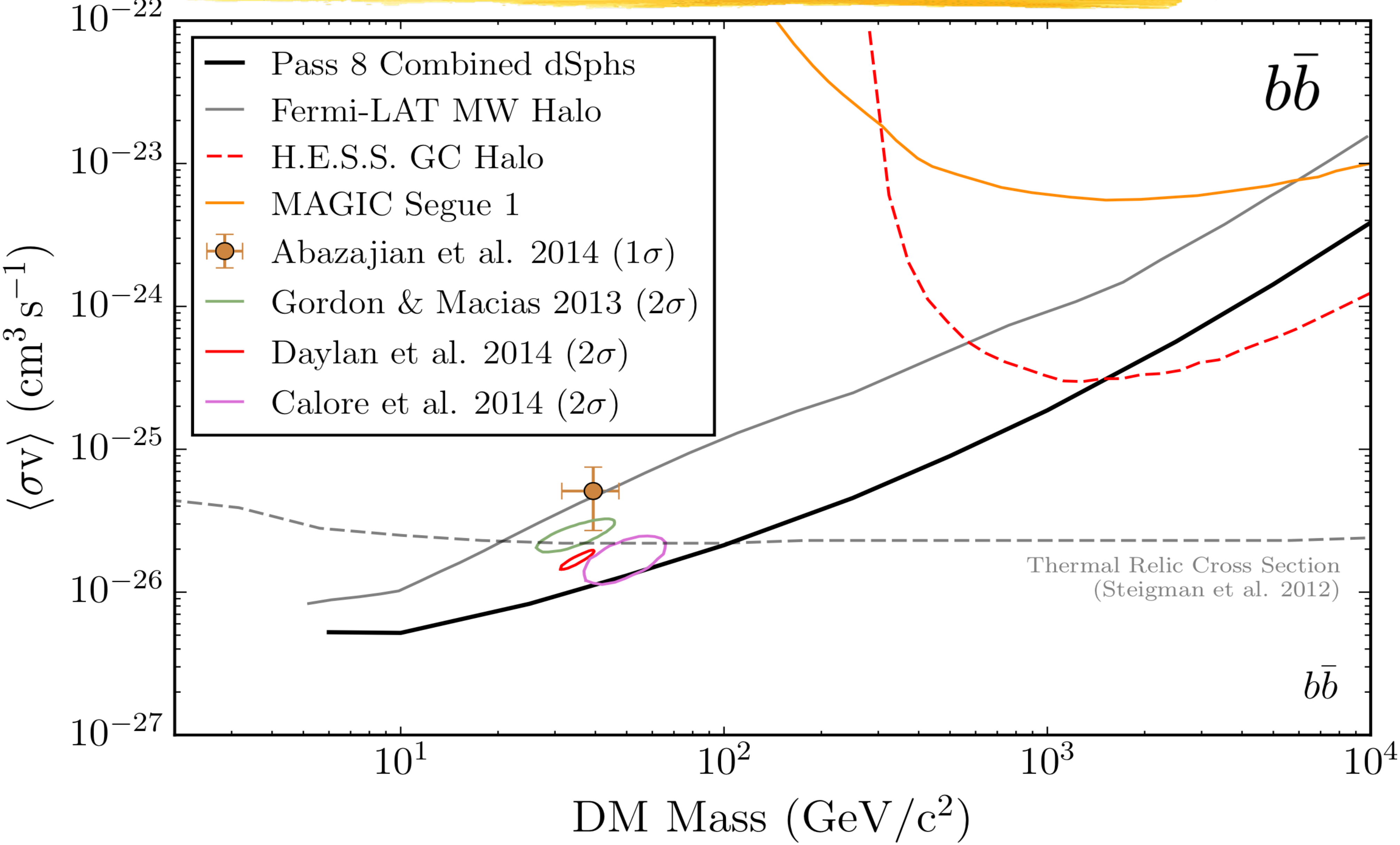


robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

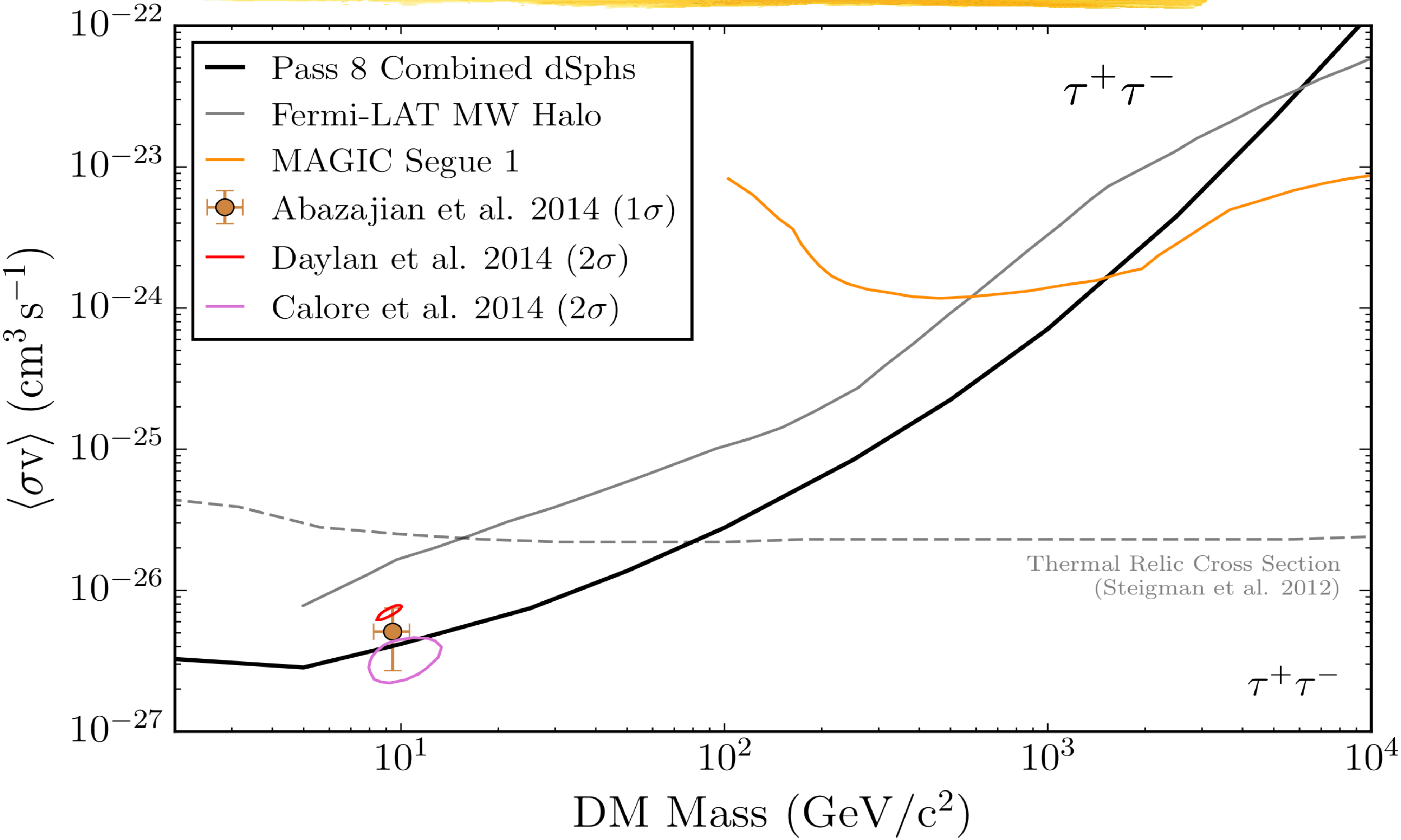
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

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)

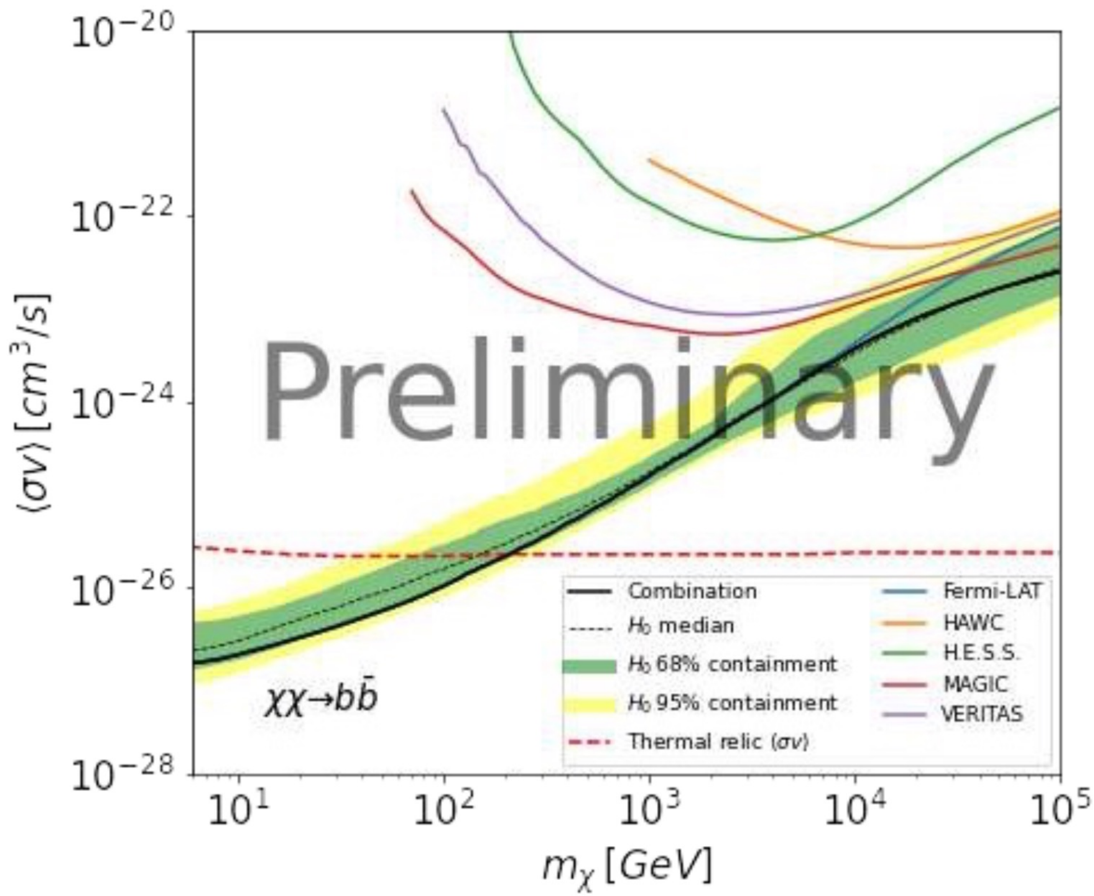


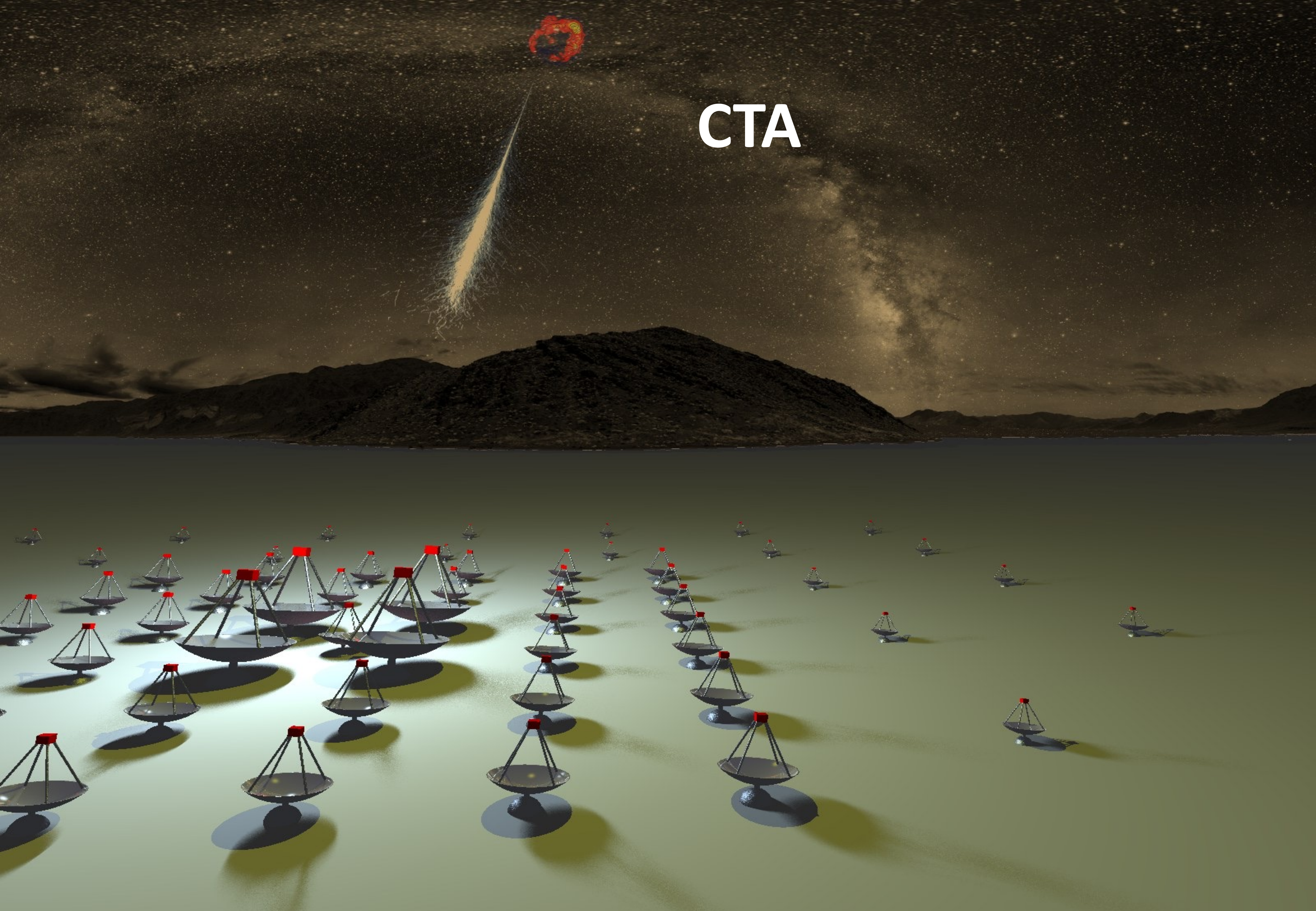
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Combining all dSph observations

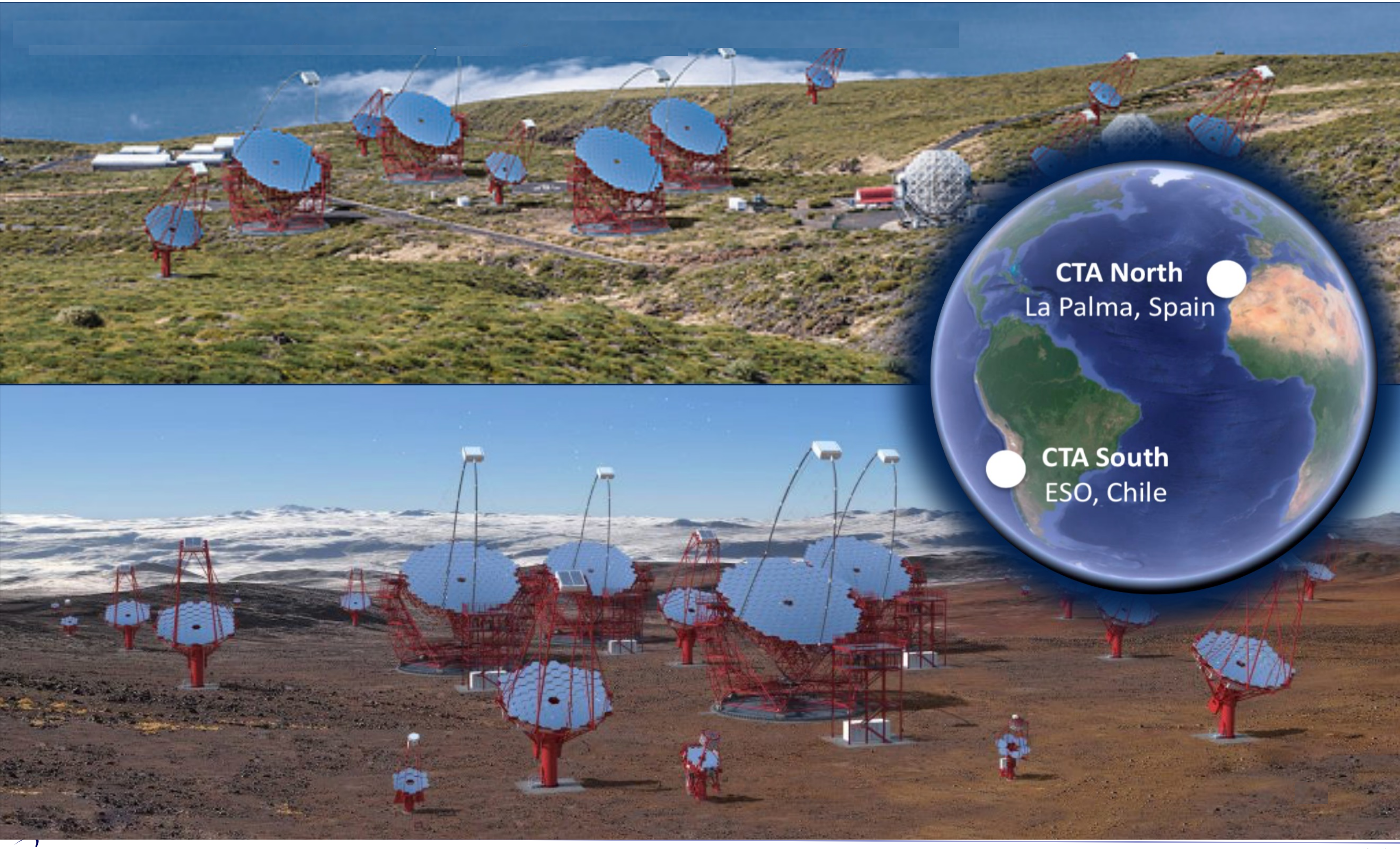
- Combination of the observation results towards 20 dwarf spheroidal galaxies (dSphs)
- Significant increase of the statistics
-> Increase the sensitivity to potential dark matter signals
- Cover the widest energy range ever investigated : 20 MeV – 80 TeV

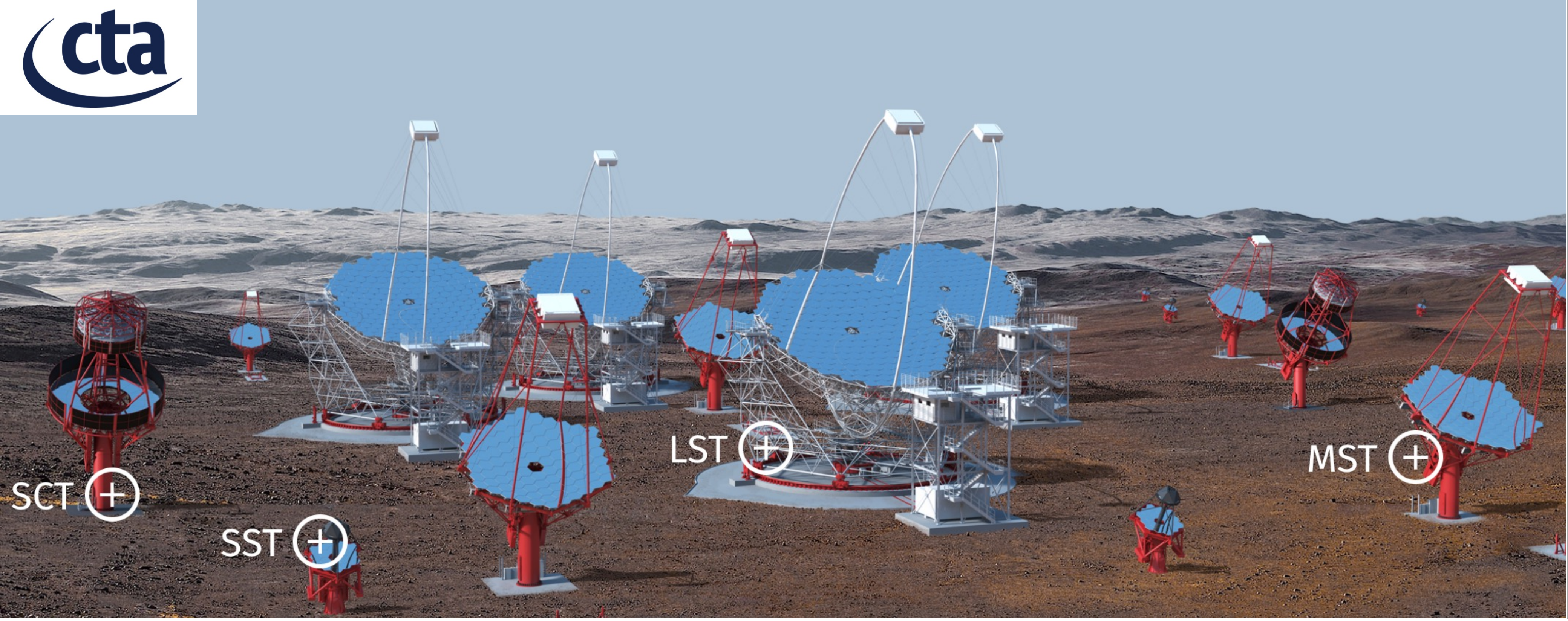
- Common elements :
- Agreed model parameters
- Sharable likelihood table formats
- Joint likelihood test statistic




CTA

1 Observatory - 2 array sites





The Alpha Configuration

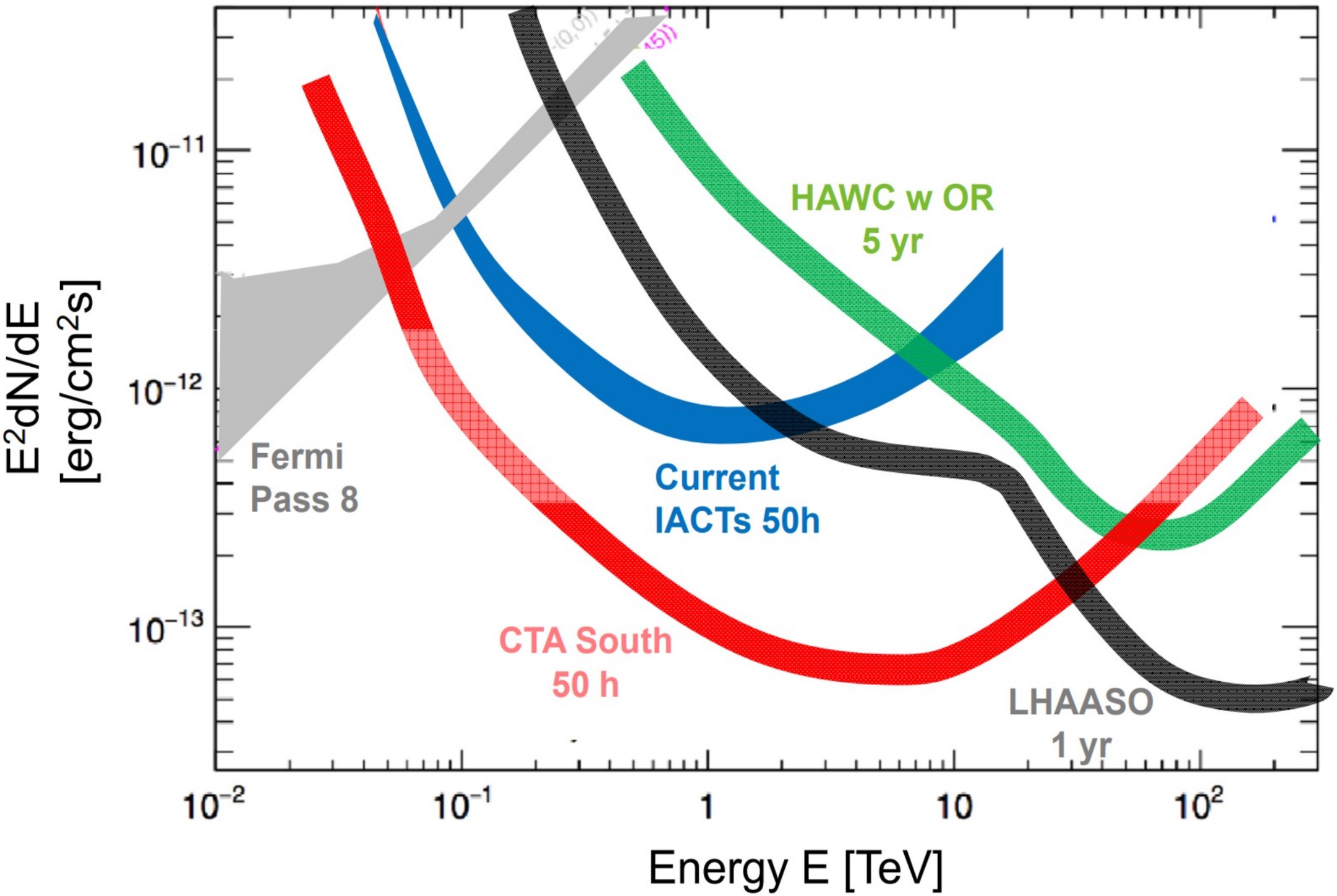
CTAO Northern Array

- **4 LSTs + 9 MSTs**
- 0,25 km² footprint
- focus on extra-Galactic science

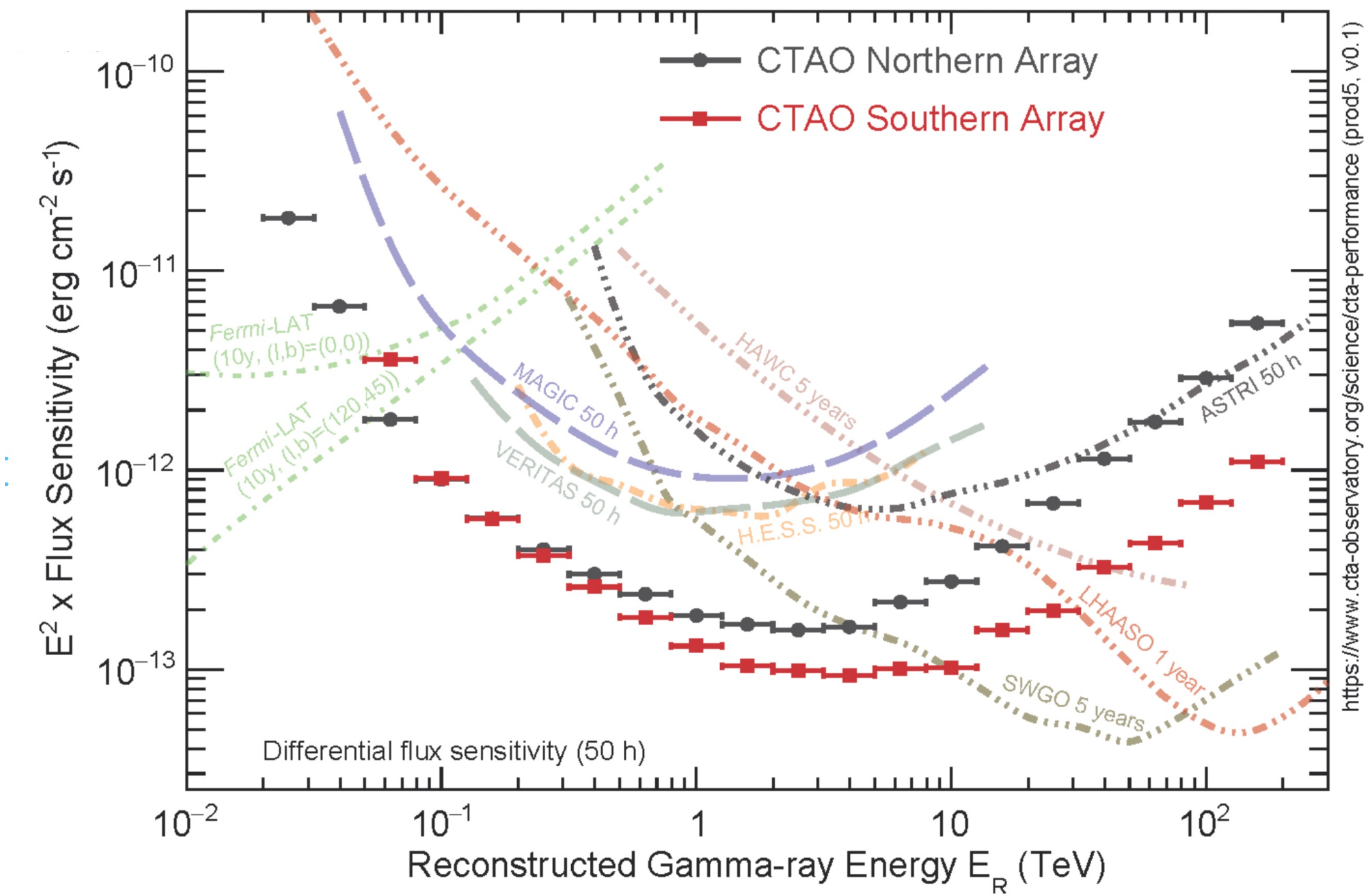
CTAO Southern Array

- **14 MSTs + 37 SSTs**
- 3 km² footprint
- focus on Galactic science

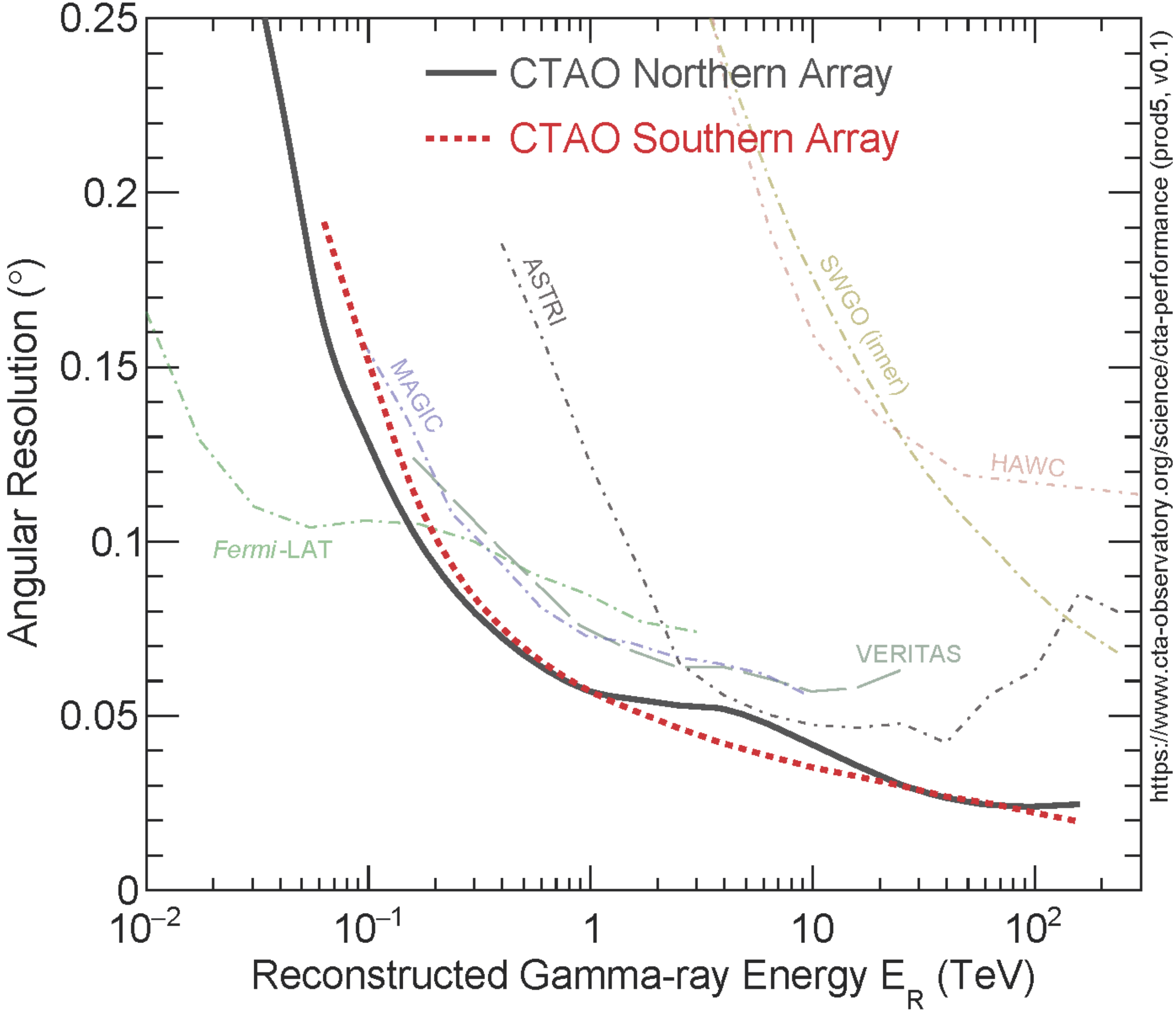
γ-ray detectors sensitivities



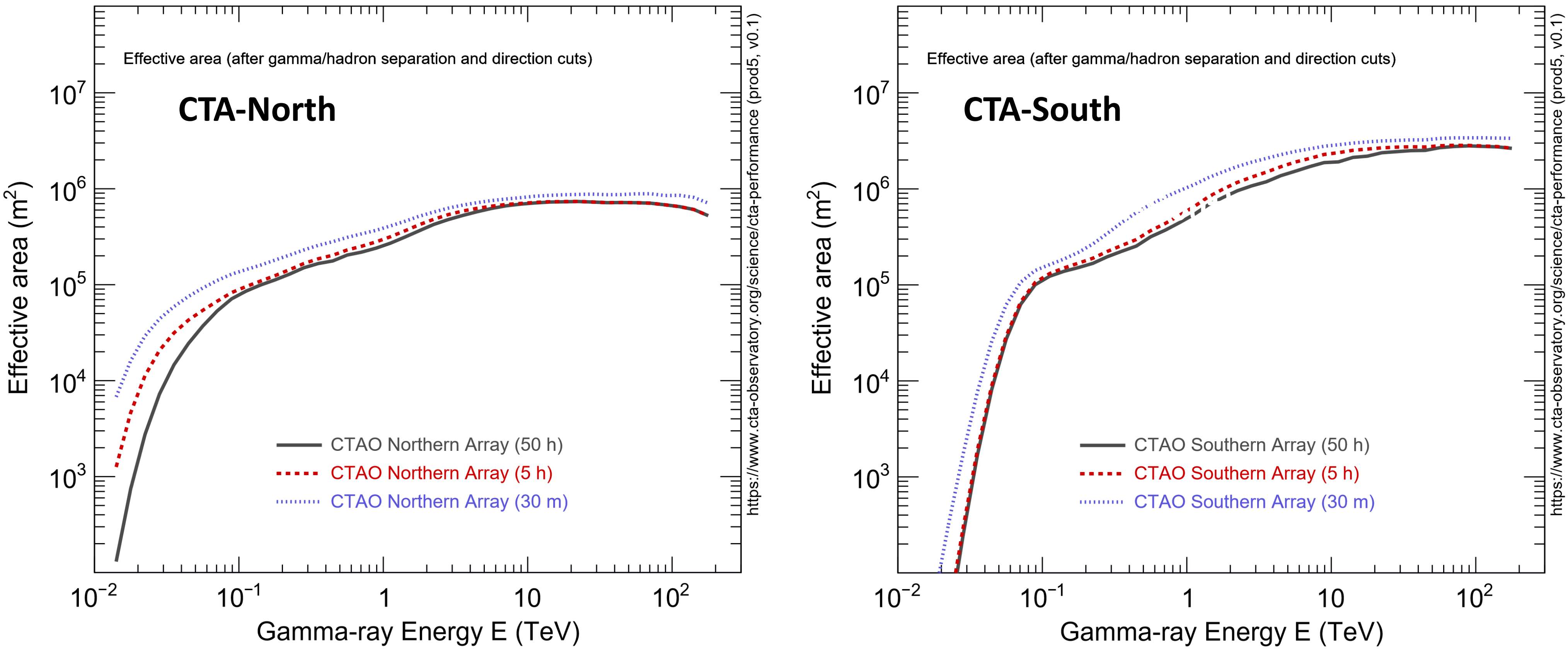
(more detailed) γ-ray detectors sensitivities



Angular resolution



Collection areas



CTA LST

The Science of CTA

CTA will target major science questions in high-energy astrophysics, through a large observational programme.

Sky Surveys

- Galactic and X-Gal Scan
- Dark Matter Programme
- Magellanic Clouds

Deep Targeted Observations

- PeVatrons
- Star-forming Systems
- Radio Galaxies & Clusters

Follow-ups of Transient and Multi-messenger events

Monitoring of Variability notably of AGN

Key Science Project Targets

- Galactic Center

high DM density but high astrophysical emissions

- dSph

no background but low signal

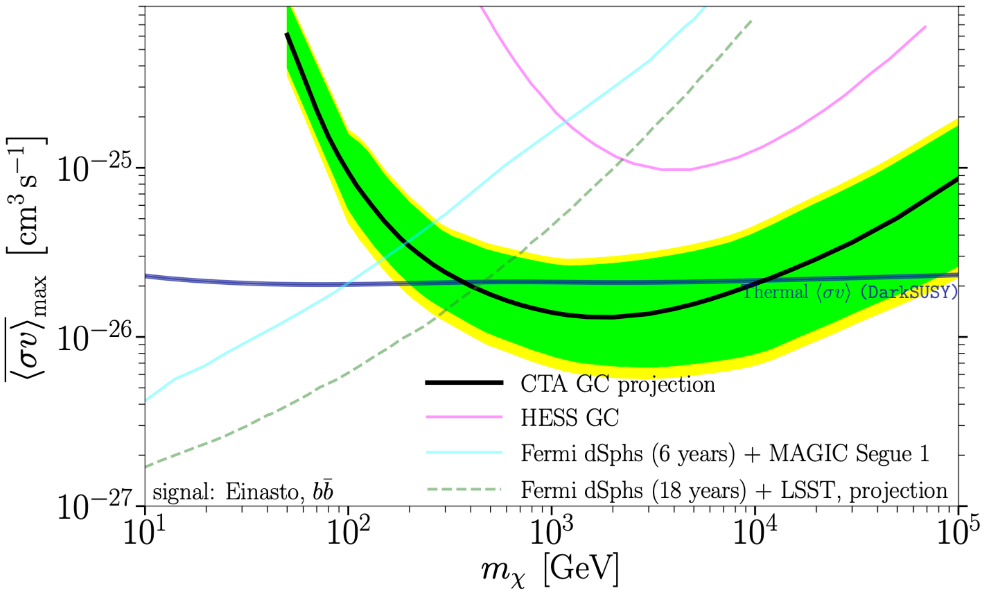
- LMC

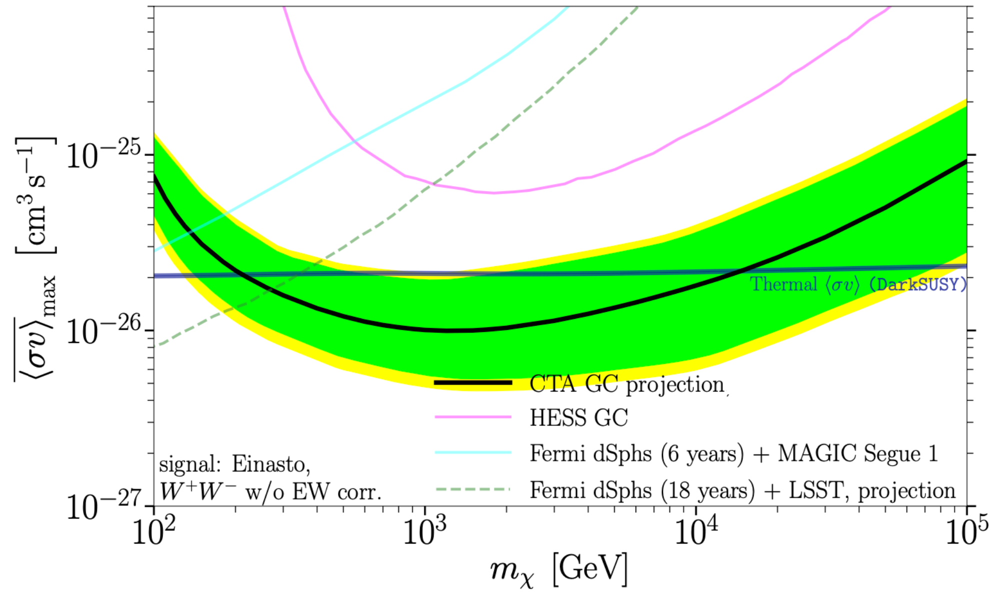
neaby & massive but astrophysical emissions

- galaxy cluster

very massive (best for decay)

Galactic center CTA Sensitivity





- Einasto profile

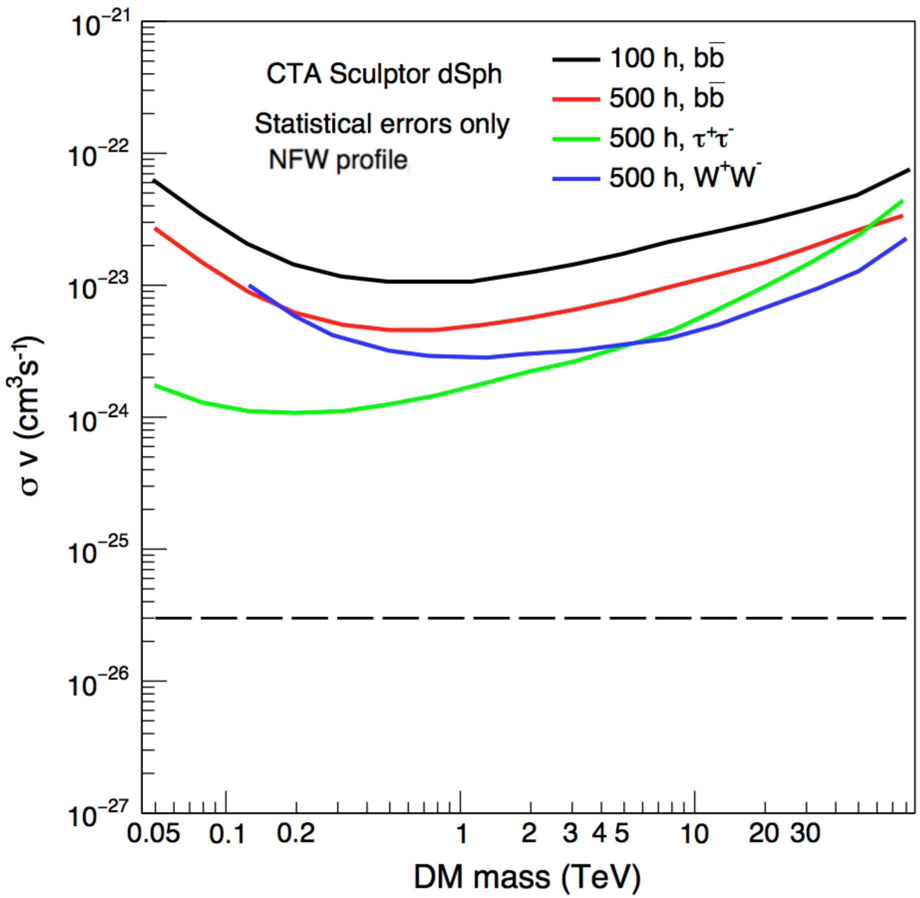
520 h

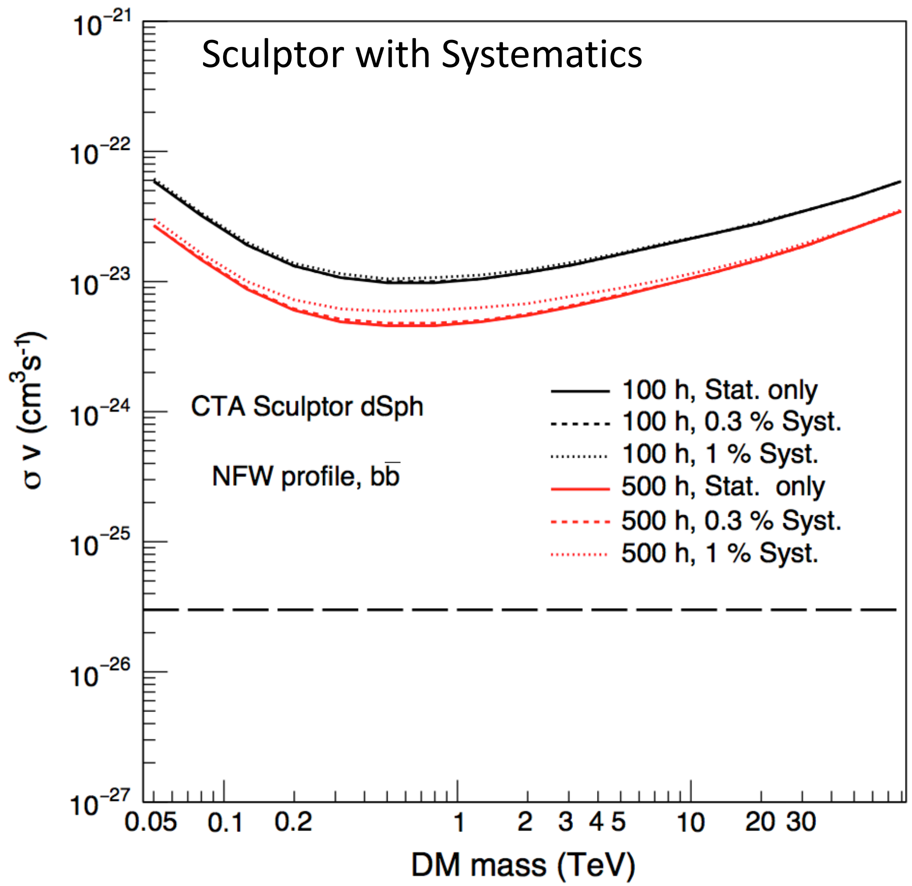
$$\rho_{\rm DM} = \rho_s \exp\left[-\frac{\alpha}{2}\left(\frac{r}{r_s}\right)^{\alpha} - 1\right], \; J \sim 7.1 \times 10^{22} {\rm GeV}^2/{\rm cm}^5$$

- Main source of background : sources, Fermi Bubble, interstellar γ, residual CR

The CTA Consortium JCAP01(2021) 057 January 27, 2021 [arXiv:2007.16129]

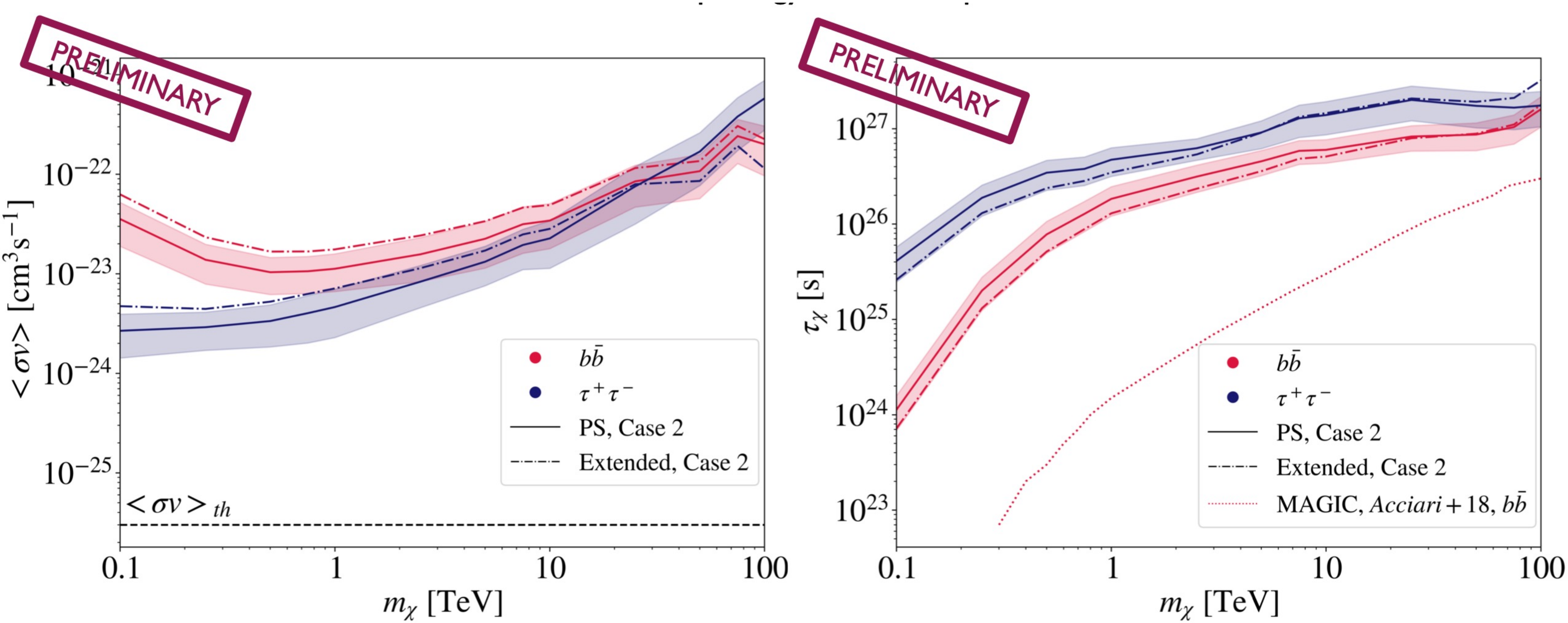
Dwarf Spheroidal Galaxies: CTA Sensitivity





updated & dedicated collaboration paper soon from the CTA dSph task force

Perseus Cluster : CTA Sensitivity



Judit Pérez-Romero et.al CTA Consortium in preparation

CTA DM Detection Strategy

(from the CTA science book, numbers can change)

Year	1	2	3	4	5	6	7	8	9	10
Galactic halo	175 h	175 h	175 h							
Best dSph	100 h	100 h	100 h							
				in case of detection at GC, large σv						
Best dSph				150 h	150 h	150 h	150 h	150 h	150 h	150 h
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of detection at GC, small σv						
Galactic halo				100 h	100 h	100 h	100 h	100 h	100 h	100 h
				in case of no detection at GC						
Best Target				100 h	100 h	100 h	100 h	100 h	100 h	100 h

First 3 years

- The principal target is the Galactic Center Halo (most intense diffuse emission regions removed)
- Best dSph as “cleaner” environment for cross-checks and verification (if hint of strong signal)

Next 7 years

- If there is detection in GC halo data set (525h)
    - Strong signal: continue with GC halo in parallel with best dSph to provide robust detection
    - Weak signal: focus on GC **halo** to increase data set until systematic errors can be kept under control
- If no detection in GC halo data set
    - Focus observation on the best target at that time to produce legacy limits.

CTA Search for Dark Matter beyond WIMP

Axion Like Particle (ALP) search prospects

γ + B -> a + B -> γ' + ...

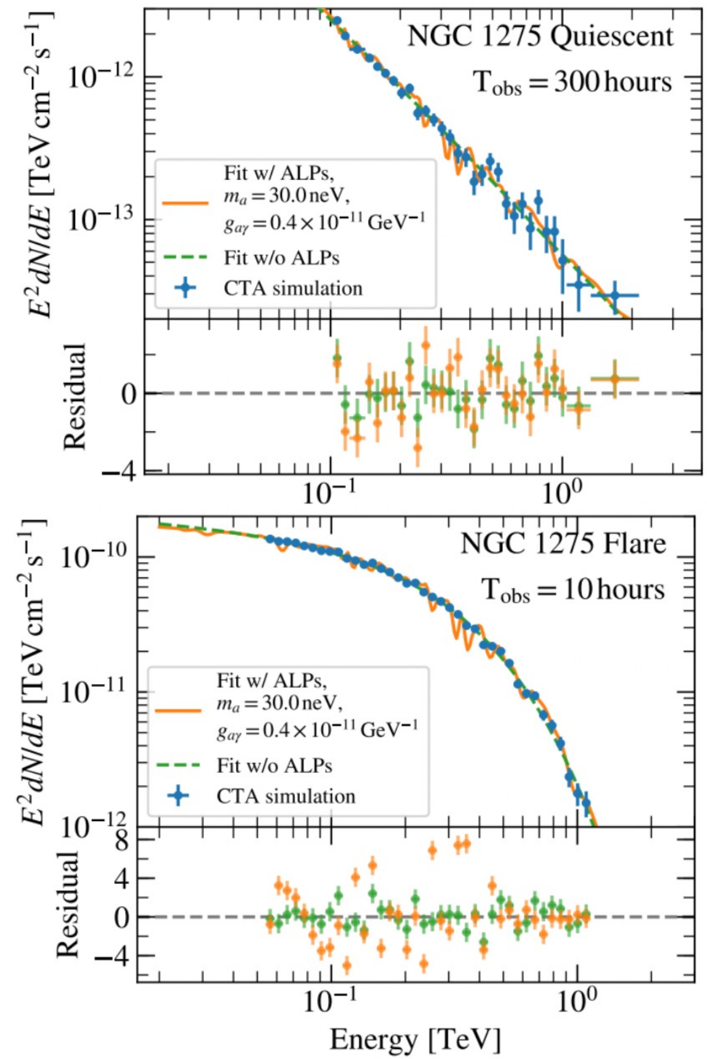
conversion probability ($E > E_{crit}$)

$$P_{a\gamma} \sim \sin^2\left(\frac{g_{a\gamma} B l}{2}\right),$$

$$E_{\rm crit} \sim 2.5\ \mathrm{GeV} \times \left(\frac{|m_a - \omega_{\rm pl}|}{1\mathrm{neV}}\right)^2 \left(\frac{B}{1\mu\mathrm{G}}\right)^{-1} \left(\frac{g_{a\gamma}}{10^{-11}\mathrm{GeV}^{-1}}\right)^{-1}$$

the observation is simulated without an ALP effect and is modeled both without ALPs and with a fixed set of magnetic-field realization and ALP parameters that are excluded at 95 % confidence level by the flaring state simulation

Simulated spectra of the radio galaxy NGC 1275



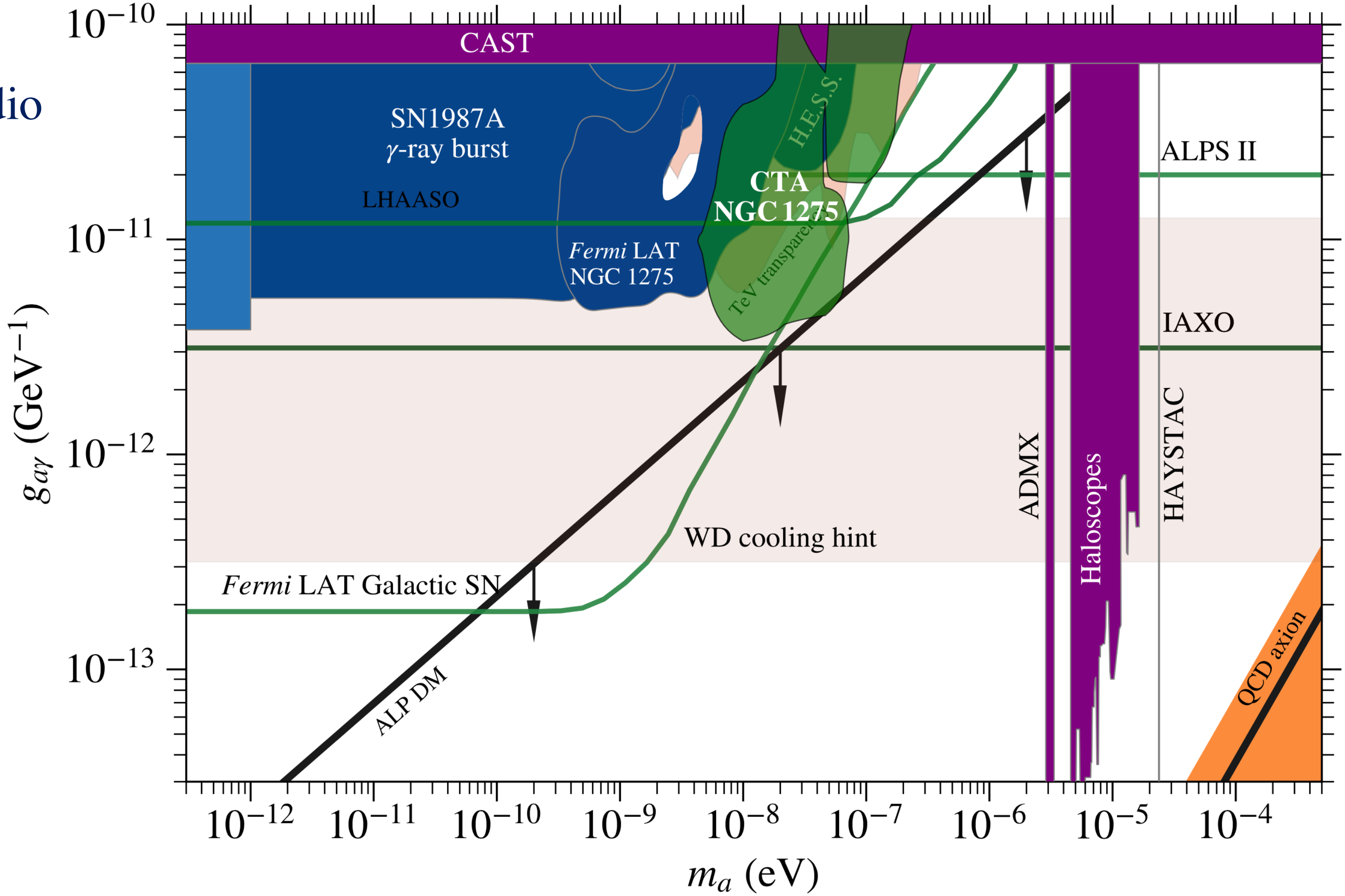
The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

CTA Search for Dark Matter beyond WIMP

Axion Like Particle search prospects

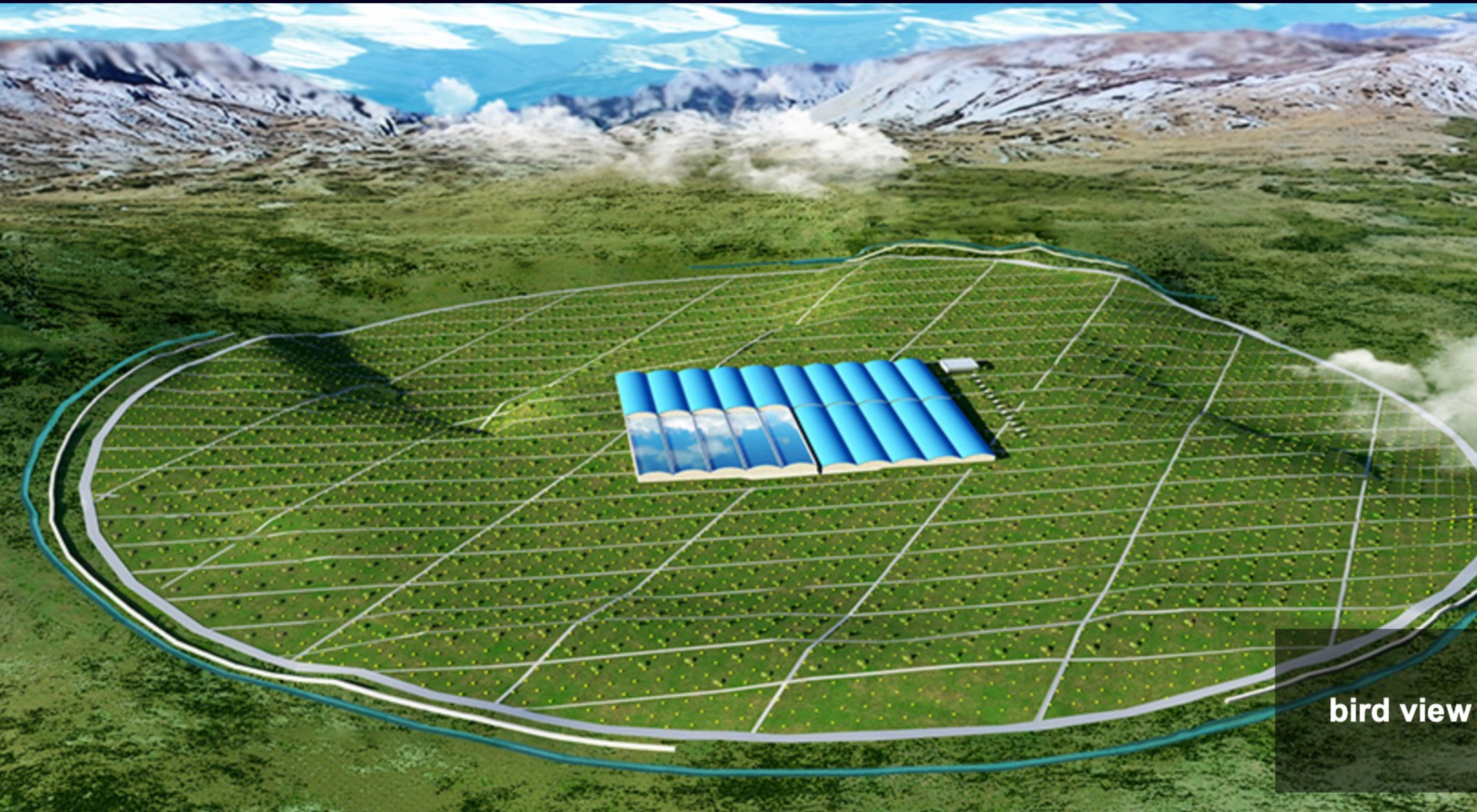
- Observation of a flaring state of the radio galaxy NGC 1275 inside the Perseus cluster

- Observations of several AGN can be combined to further improve the CTA sensitivity.

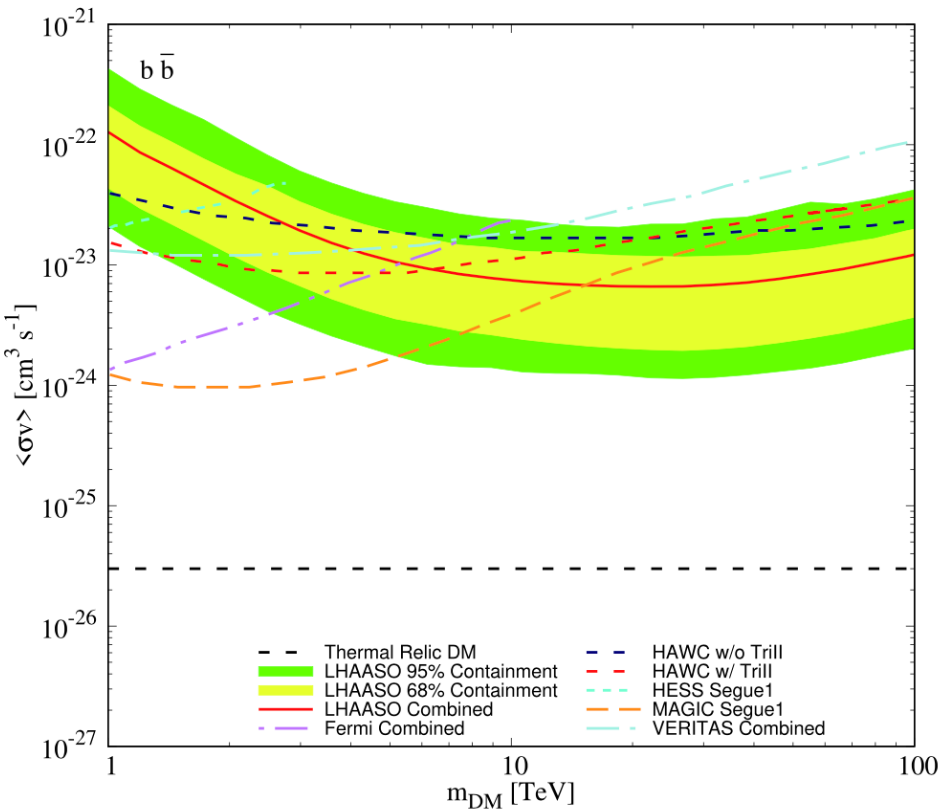


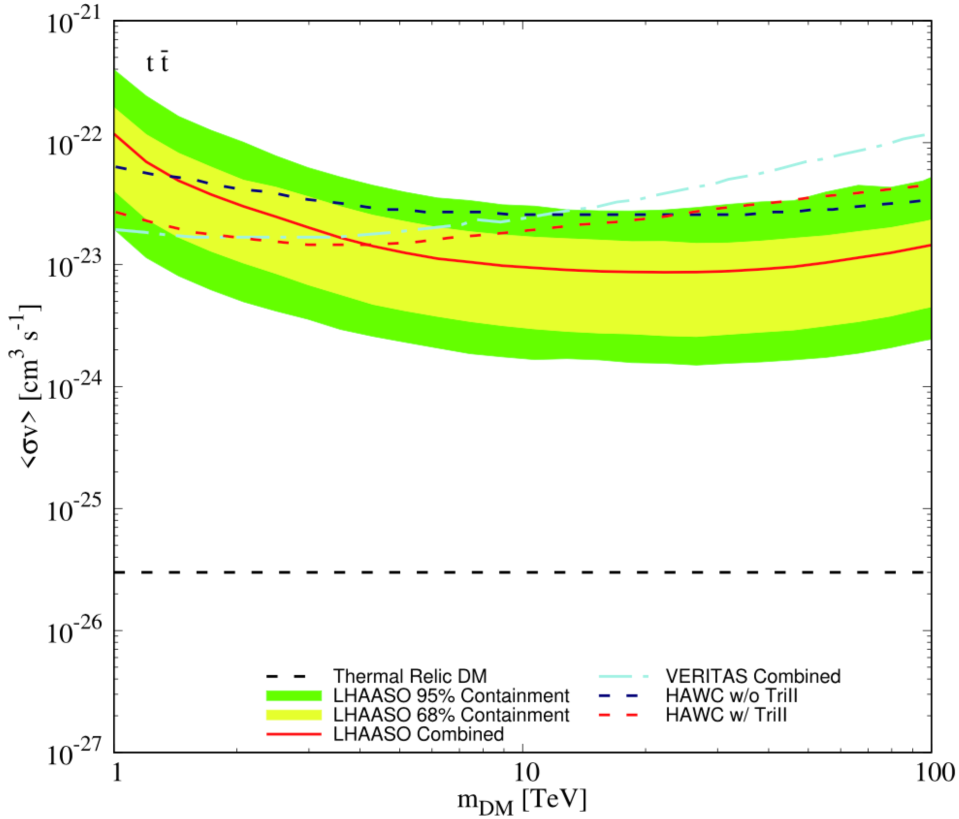
The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

LHAASO



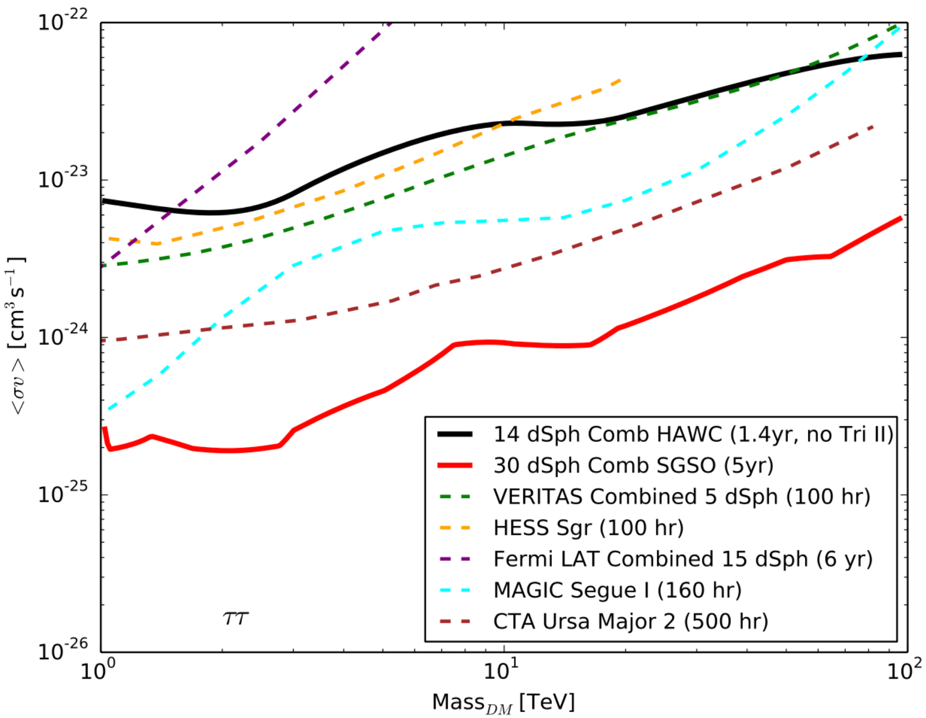
combined one-year LHAASO sensitivities

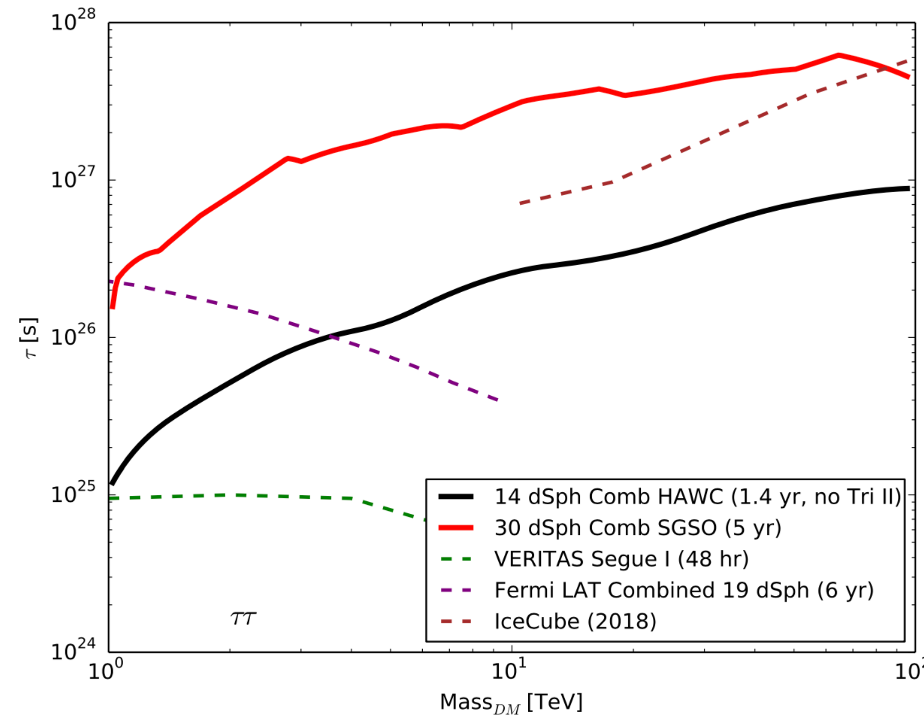




Dong-Ze He et al., Phys. Rev. D 100, 083003 (2019)

SWGO sensitivities





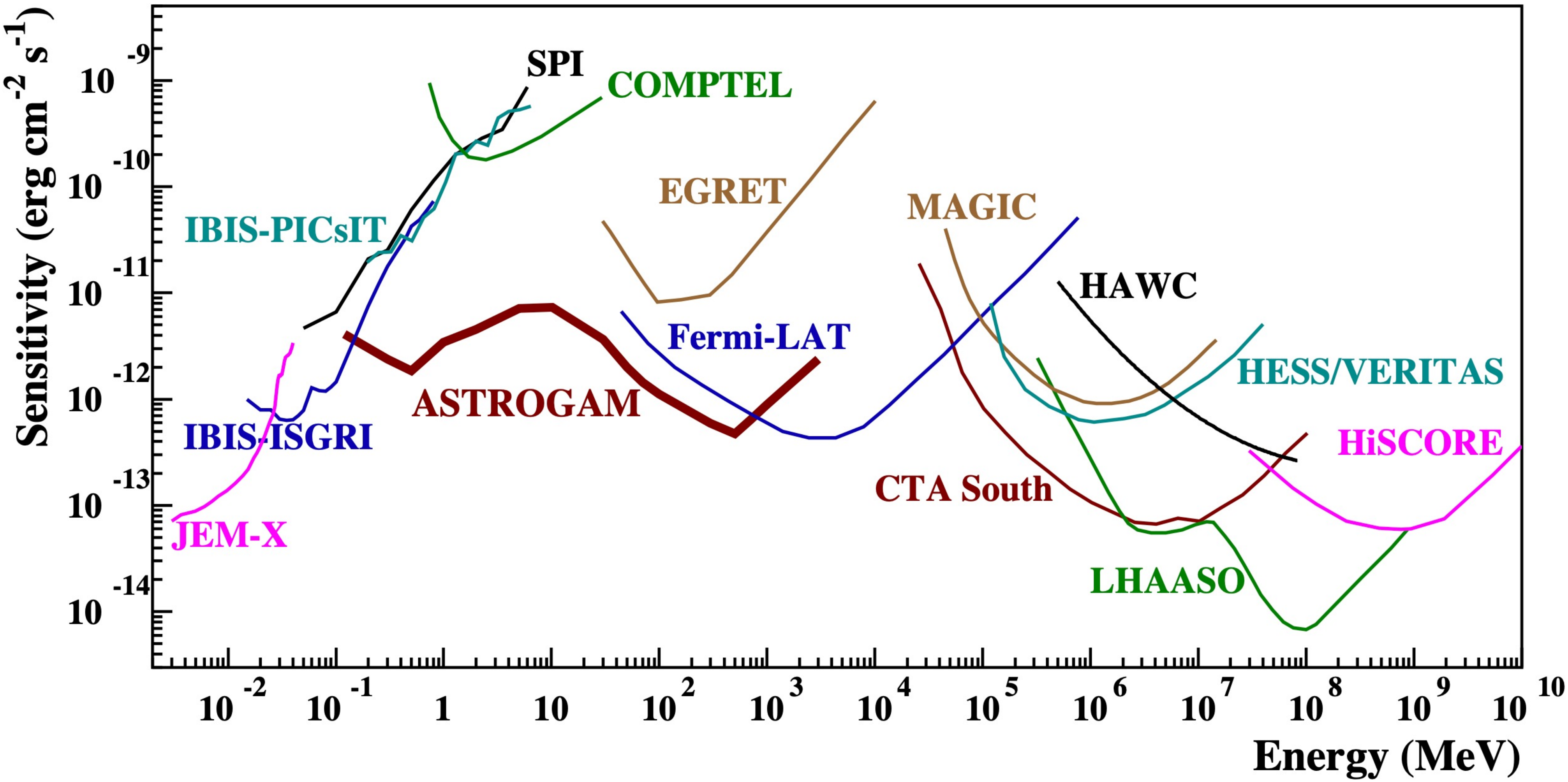
Assumed new dSph discovery and
J-factor and D-factor distributions of the new dSphs matches that of the previously known dSphs

SWGO White paper arXiv:1902.08429

The Low Energy Frontier


ASTROGAM
Selected for phase 2 of the ESA M7 Call
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (213 pages)

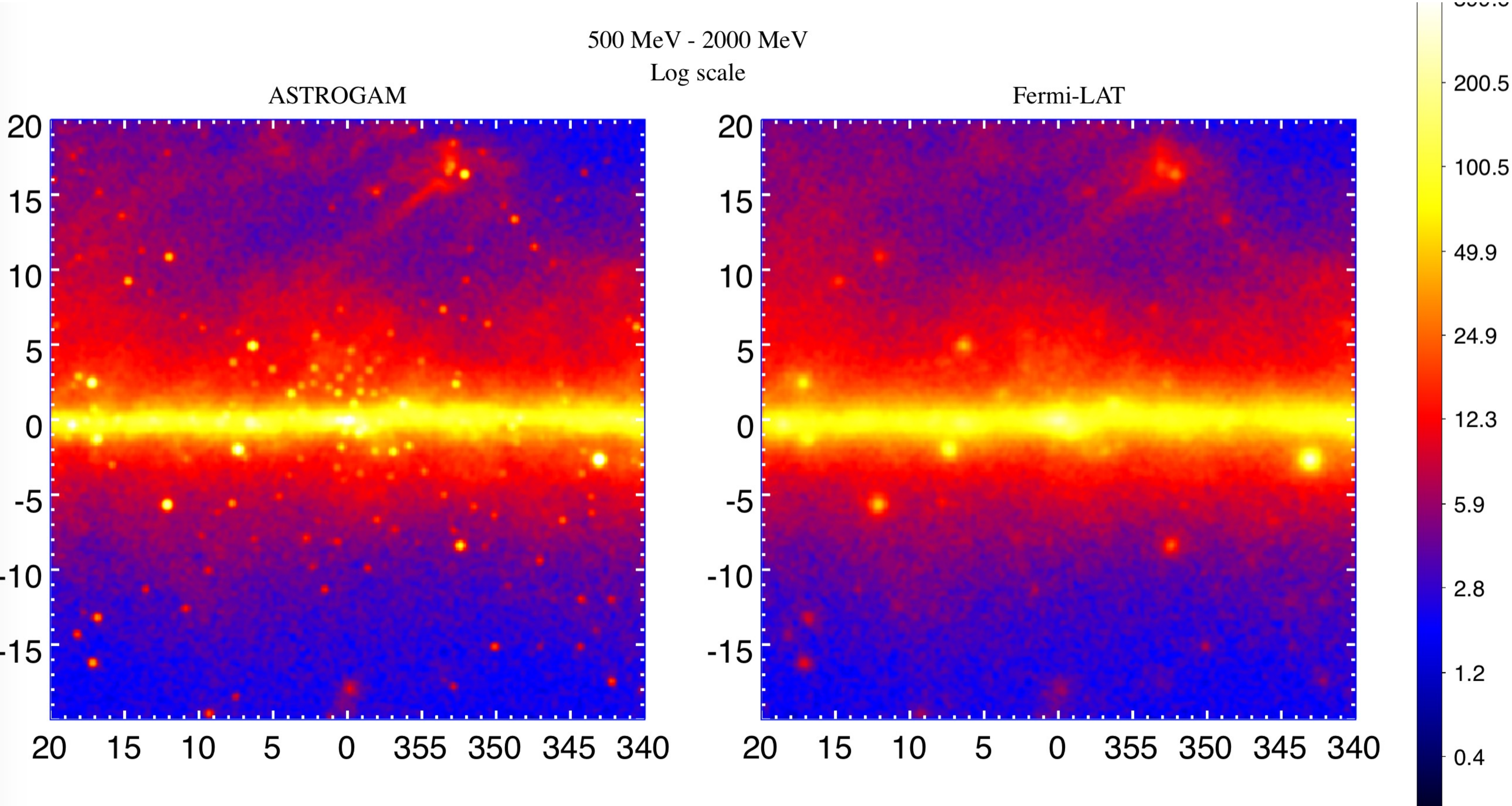
Astrogam Performance



Astrogam sensitivity for an effective exposure of two years at high galactic latitude

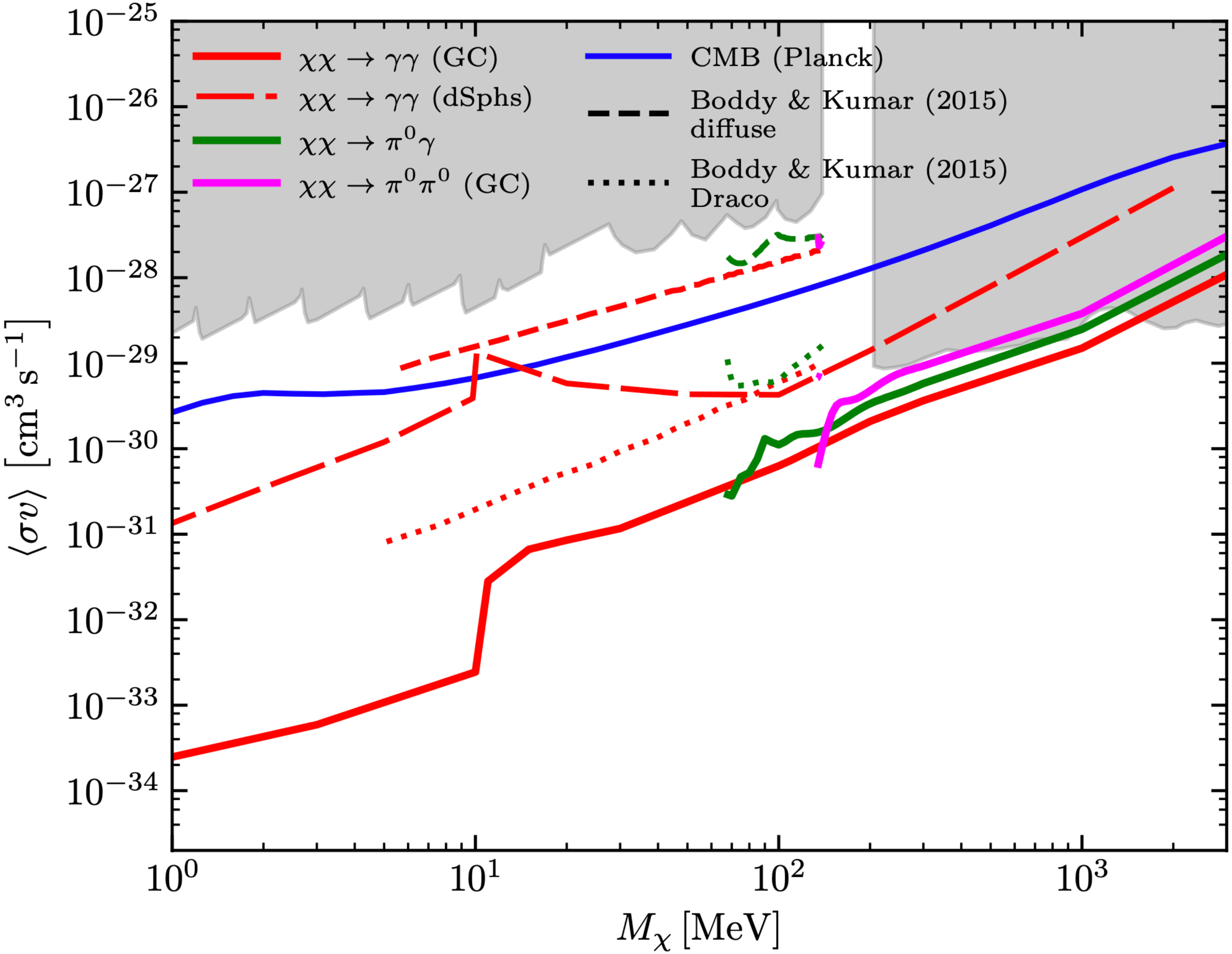
Galactic Center Region 0.5-2 GeV

Fermi PSF 8



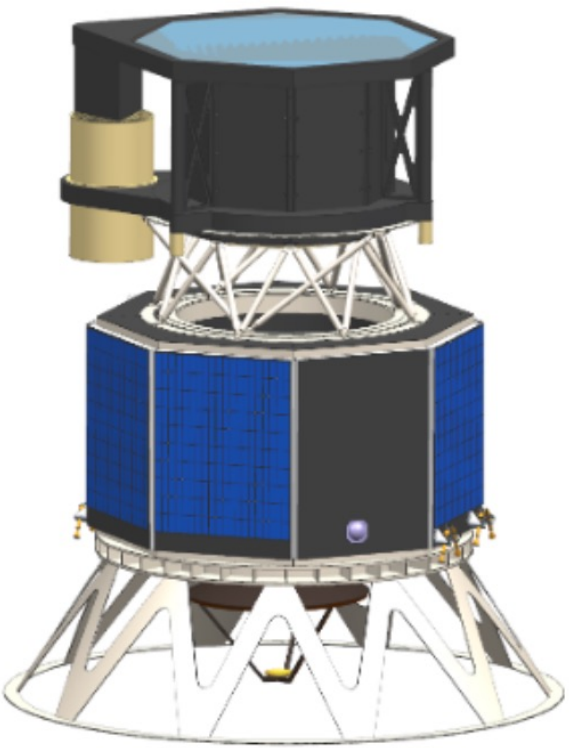
to see unresolved pulsars you need better angular resolution at GeV scale

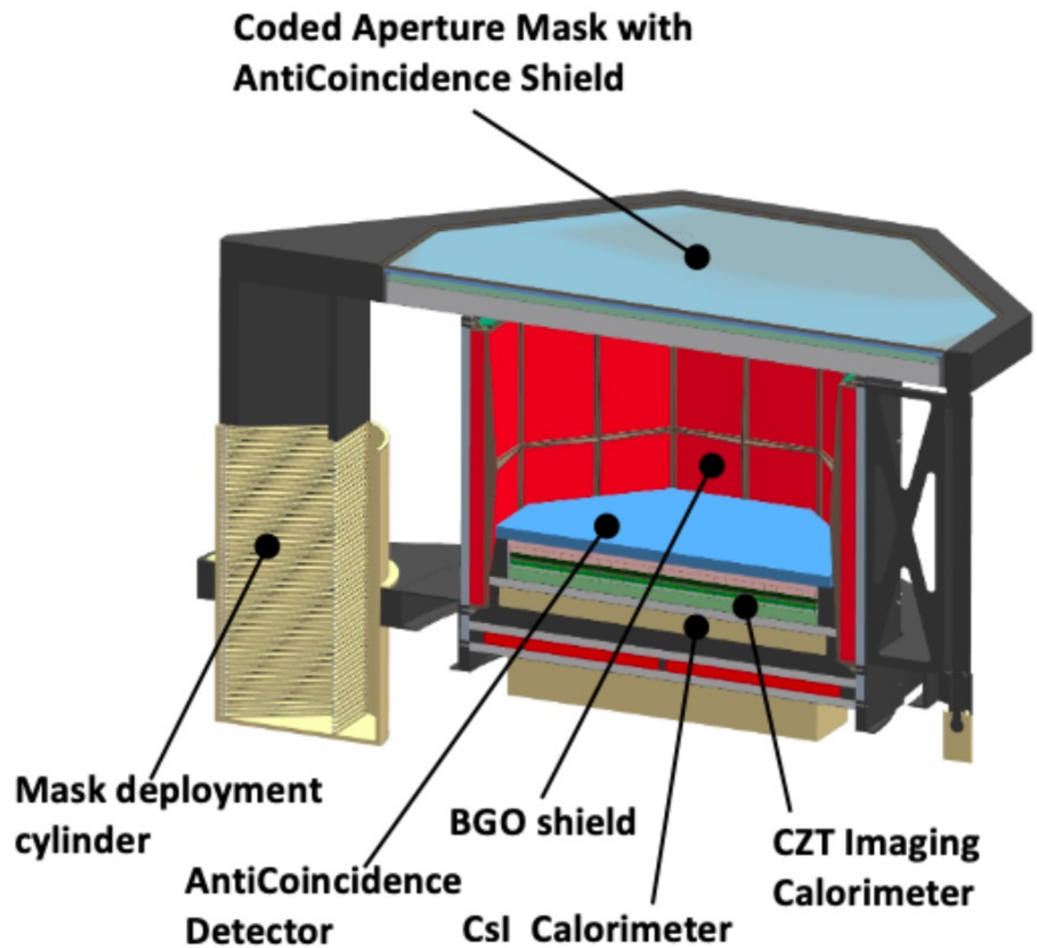
Astrogam Sensitivity for Dark Matter



ASTROGAM detectability of sub-GeV DM-induced gamma-ray signals from the GC and dSphs

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope





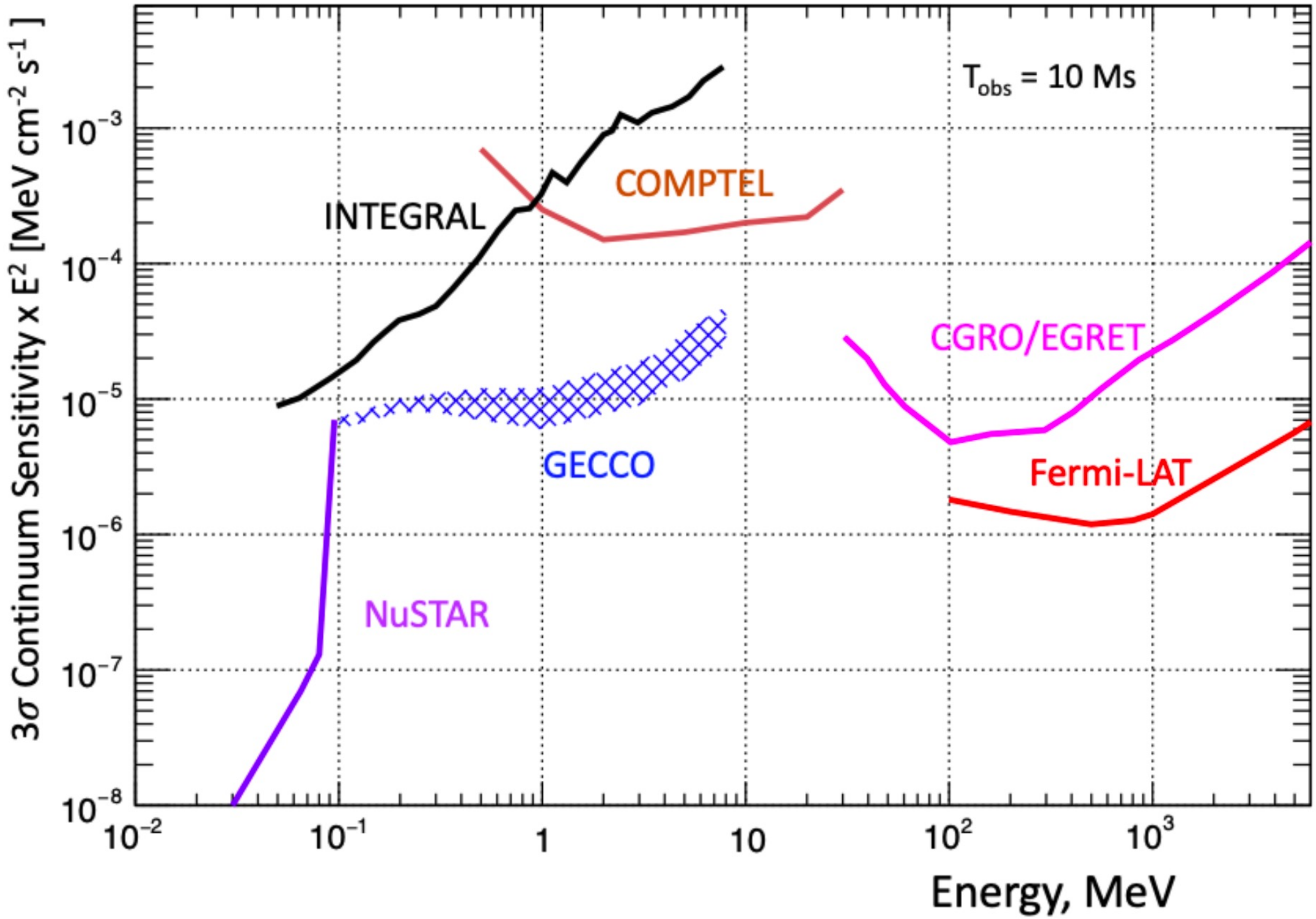
conceptual design | mask in stowed position | cutaway

diameter =90 cm

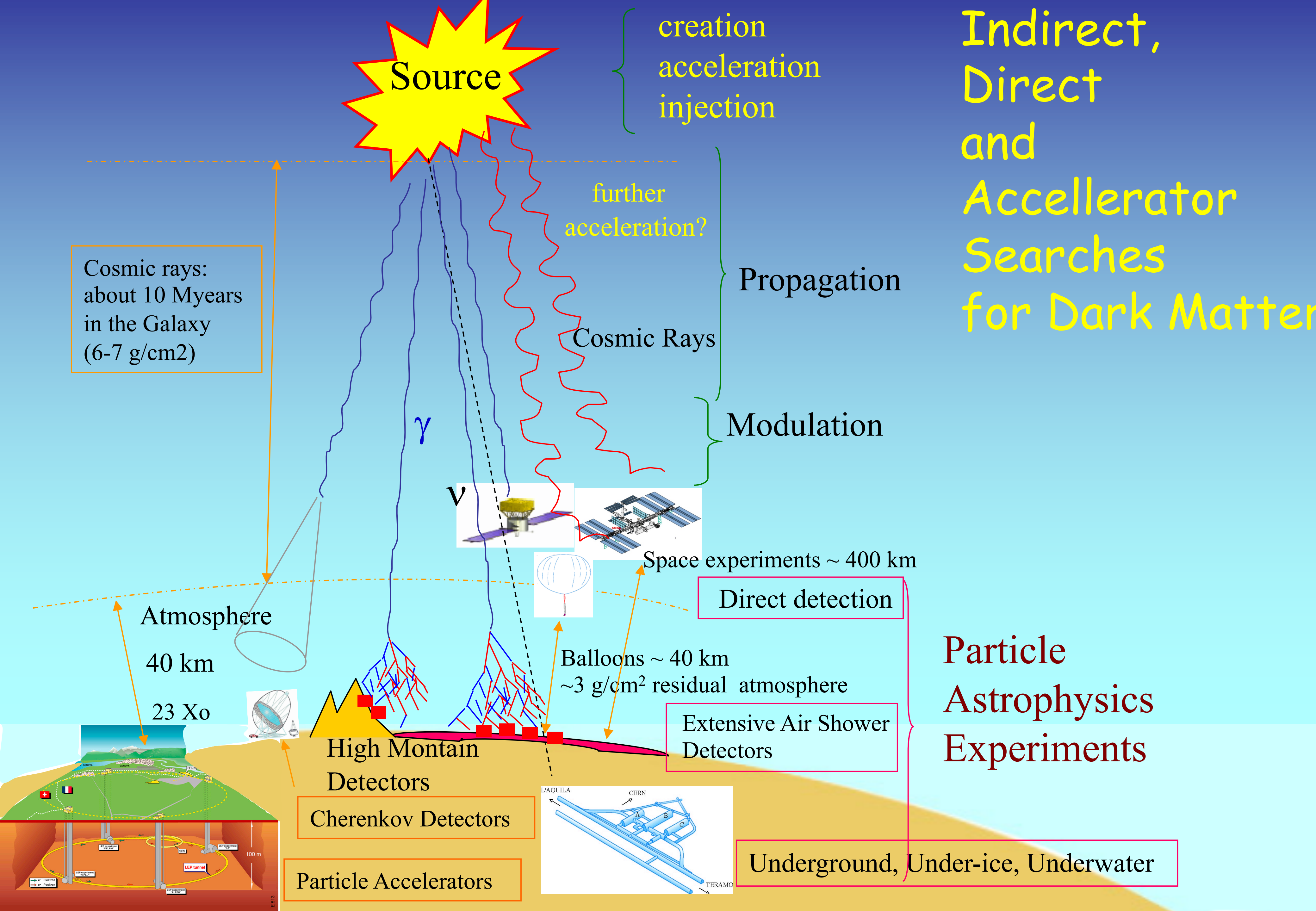
E.Orlando et al, GECCO Team, JCAP accepted arXiv:2112.07190

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

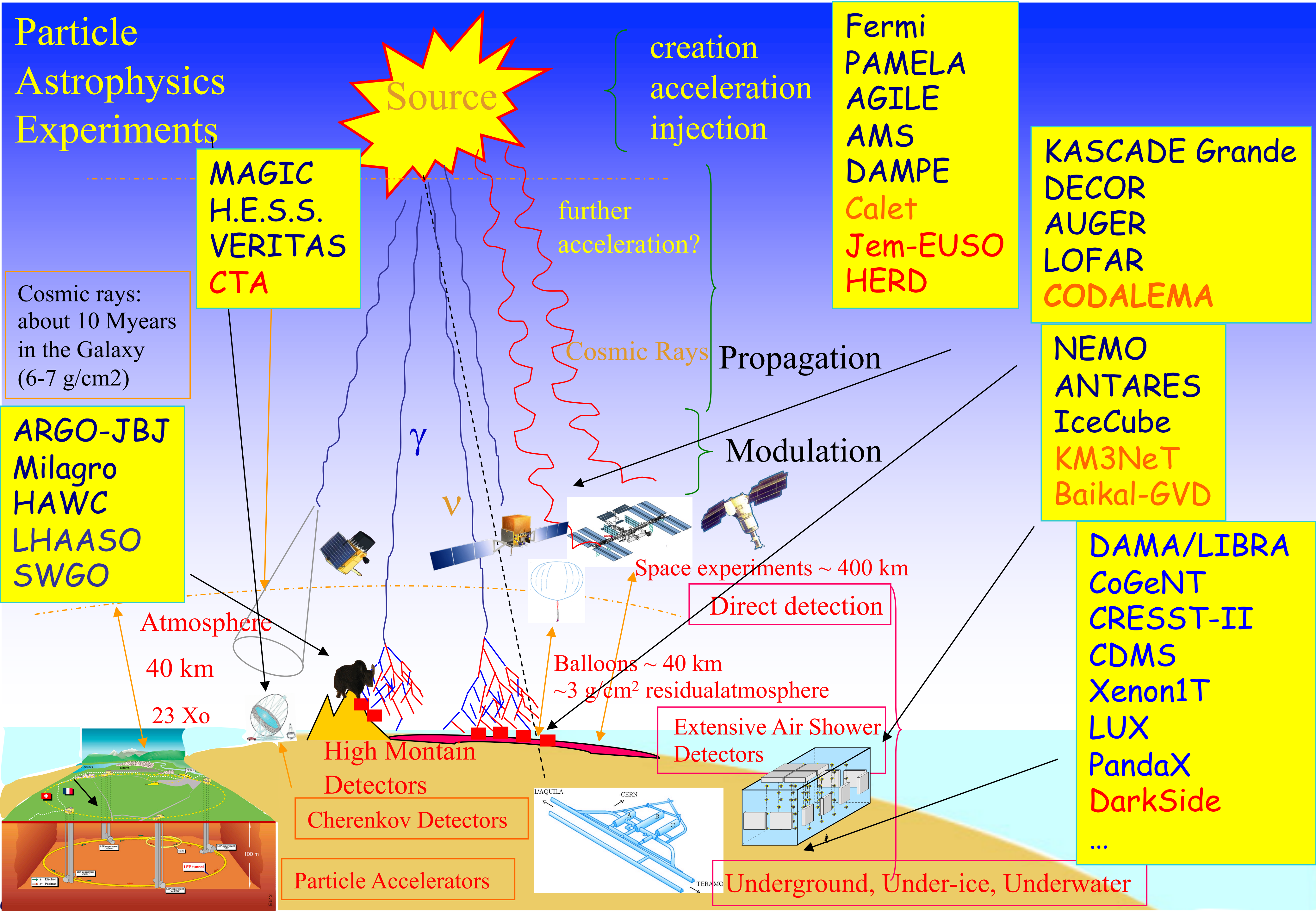
Sensitivity

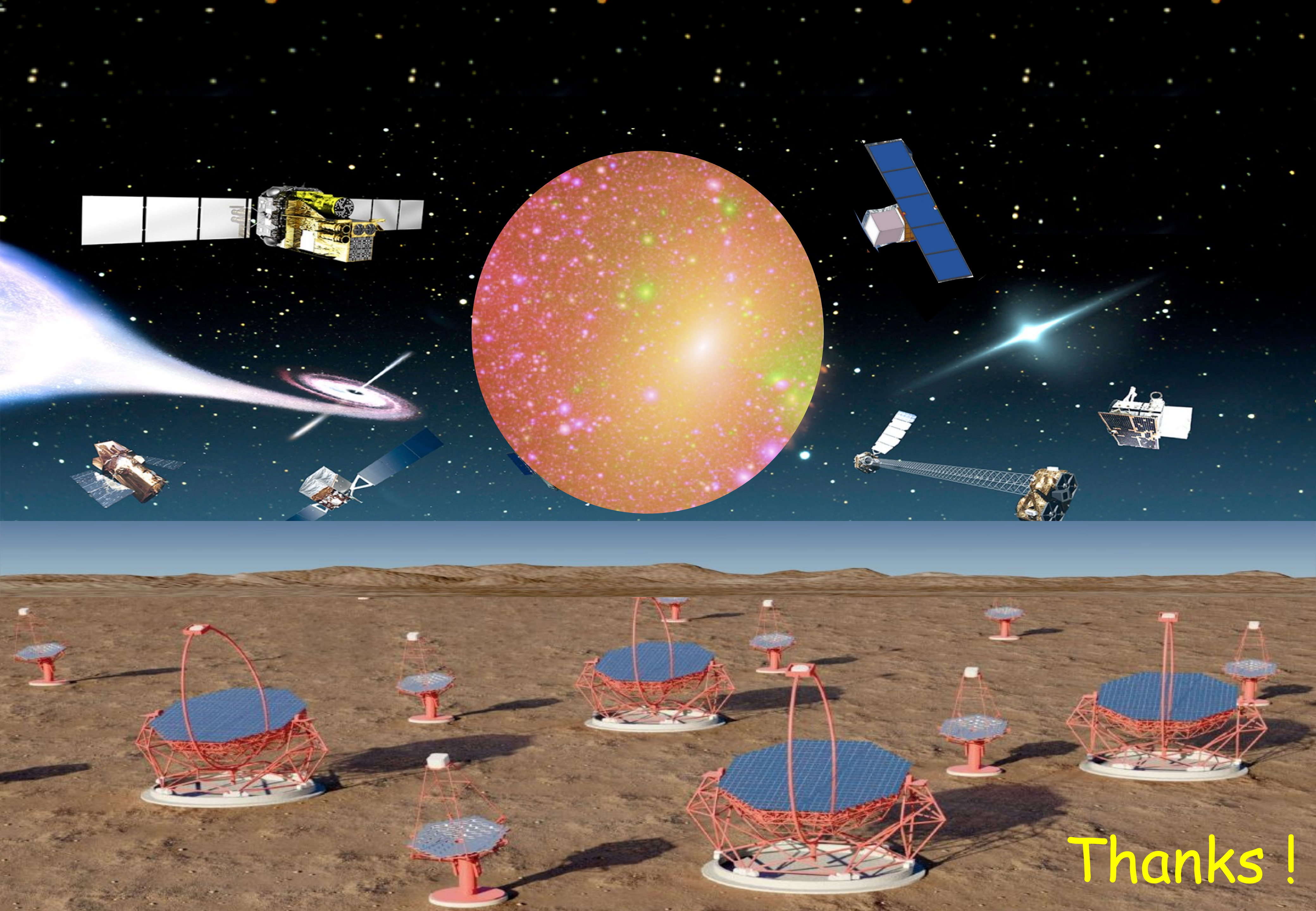


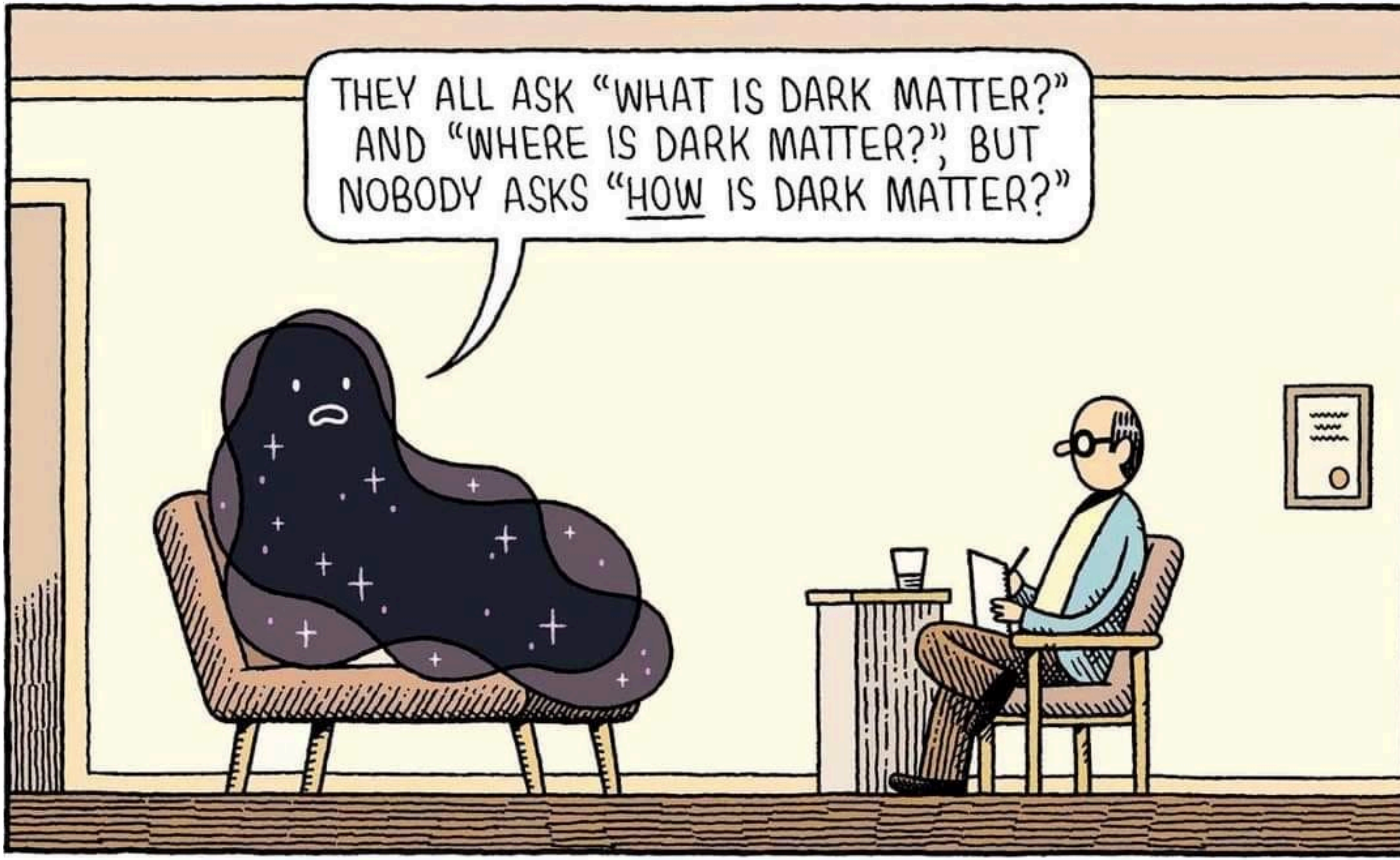
E.Orlando et al, GECCO Team, JCAP accepted arXiv:2112.07190



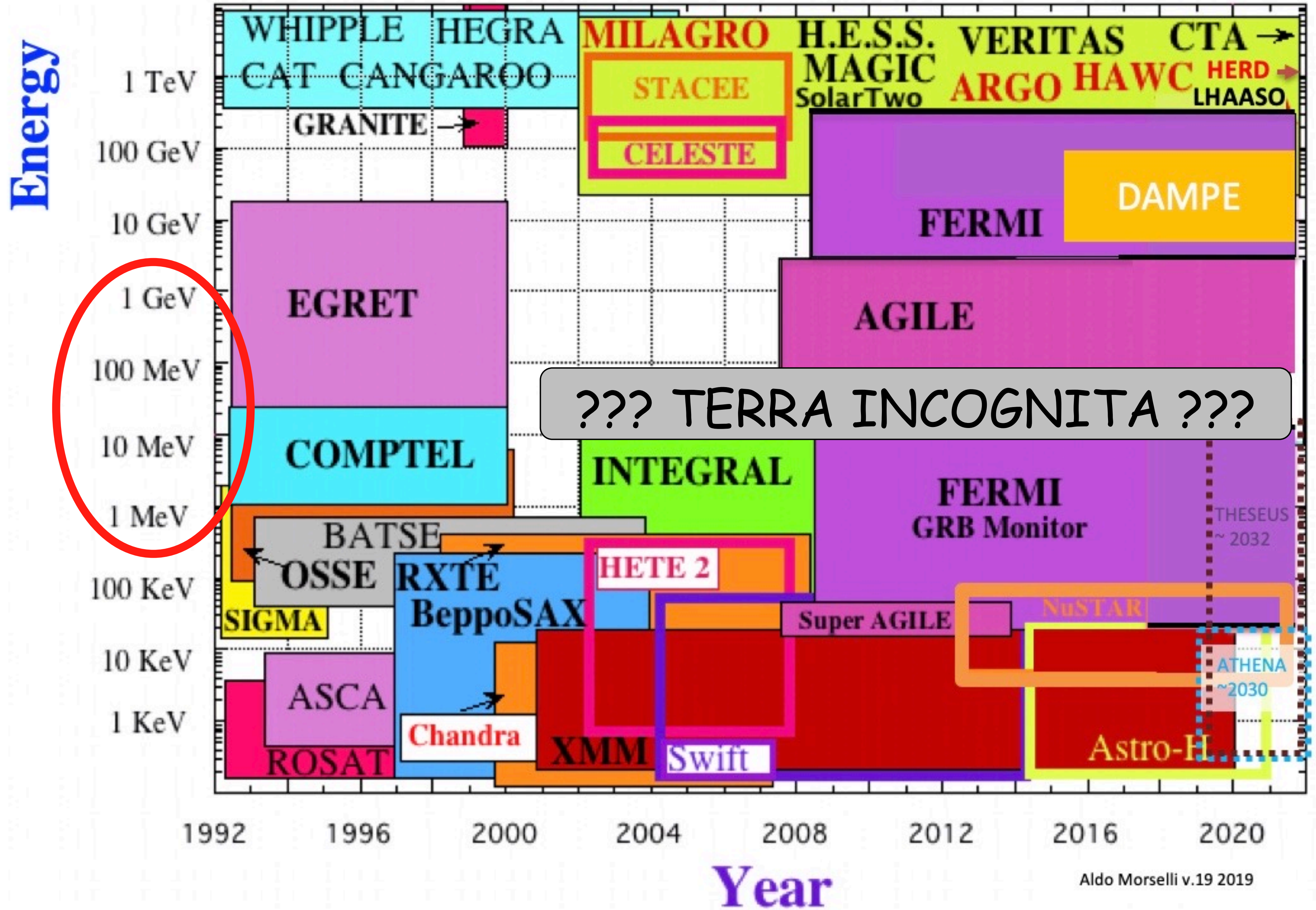
Indirect, Direct and Accellerator Searches for Dark Matter
Source
creation
acceleration
injection
further acceleration?
Propagation
Cosmic Rays
Modulation
γ
ν
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residual atmosphere
Extensive Air Shower Detectors
High Montain Detectors
Cherenkov Detectors
Particle Accelerators
Particle Astrophysics Experiments
Underground, Under-ice, Underwater
L'AQUILA
CERN
TERAMO


Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Jem-EUSO
HERD
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
MAGIC
H.E.S.S.
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
ARGO-JBJ
Milagro
HAWC
LHAASO
SWGO
γ
Modulation
ν
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
...
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm² residualatmosphere
Extensive Air Shower
Detectors
High Montain
Detectors
Cherenkov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater


Thanks !



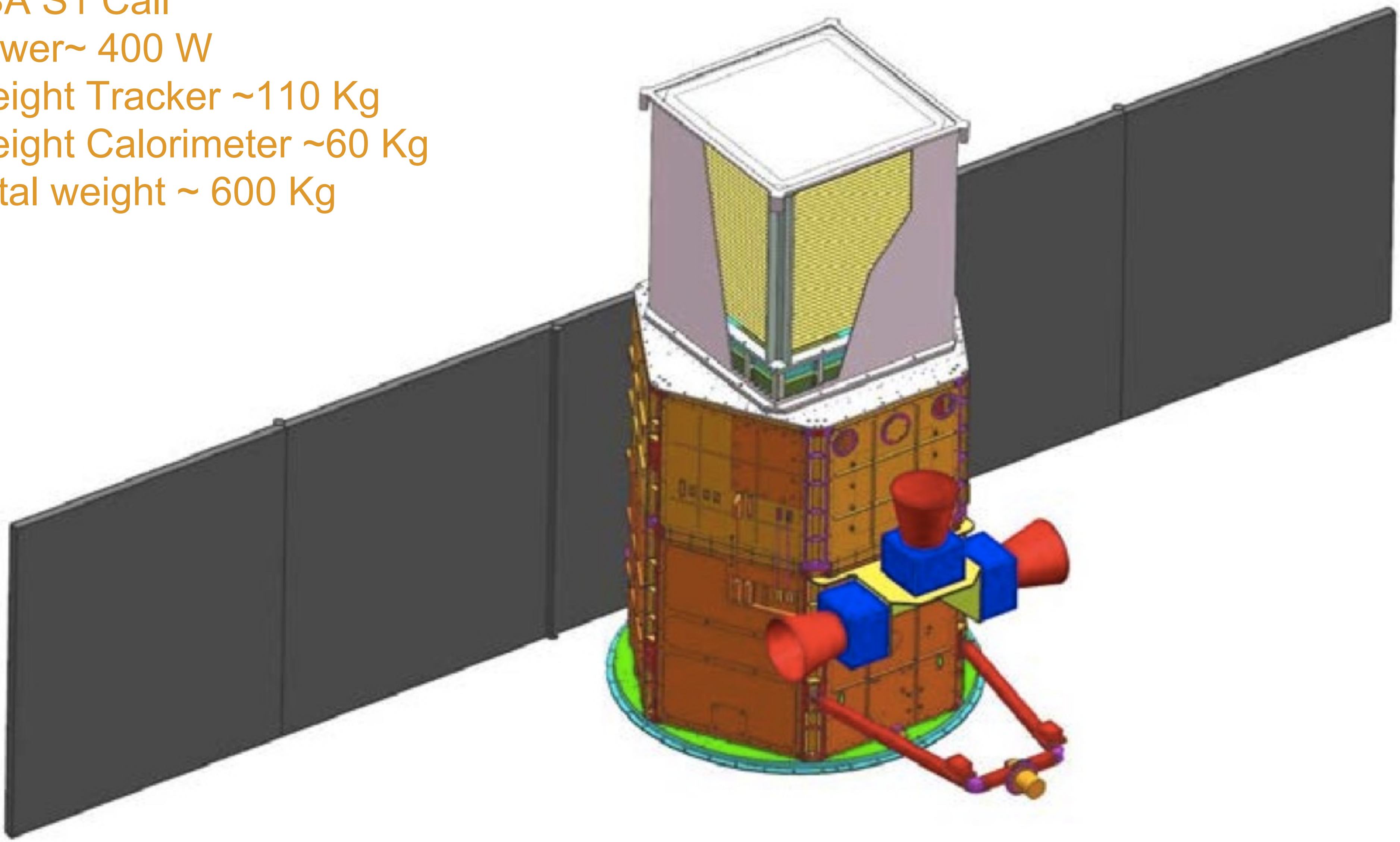
TOM GAULD for NEW SCIENTIST


Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE HEGRA
CAT CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
CTA
ARGO
HAWC
HERD
LHAASO
FERMI
DAMPE
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
THESEUS
~ 2032
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
NuSTAR
ATHENA
~2030
ASCA
Chandra
XMM
Swift
Astro-H
ROSAT
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli v.19 2019

- 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

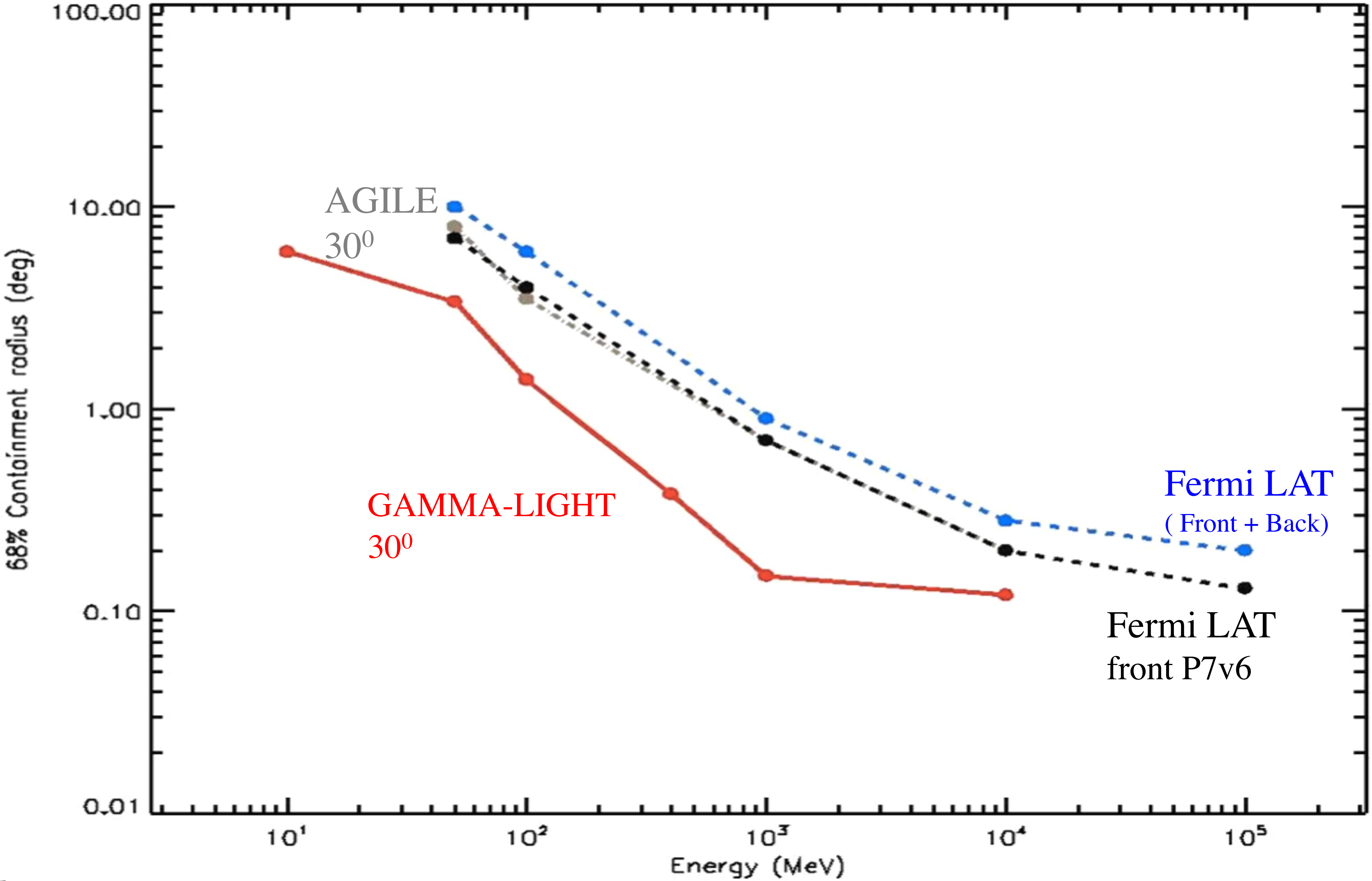
Gamma-light project

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



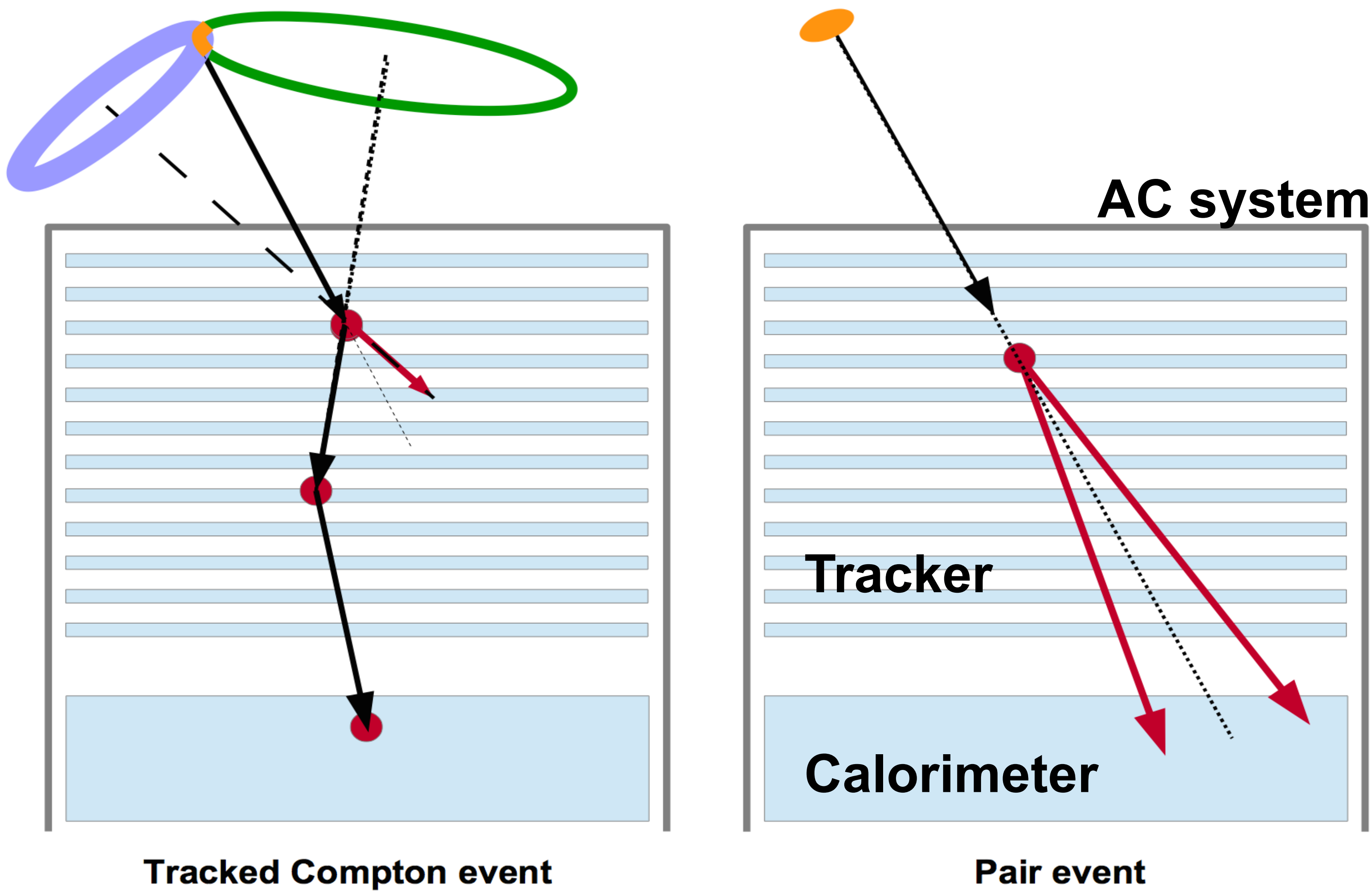
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

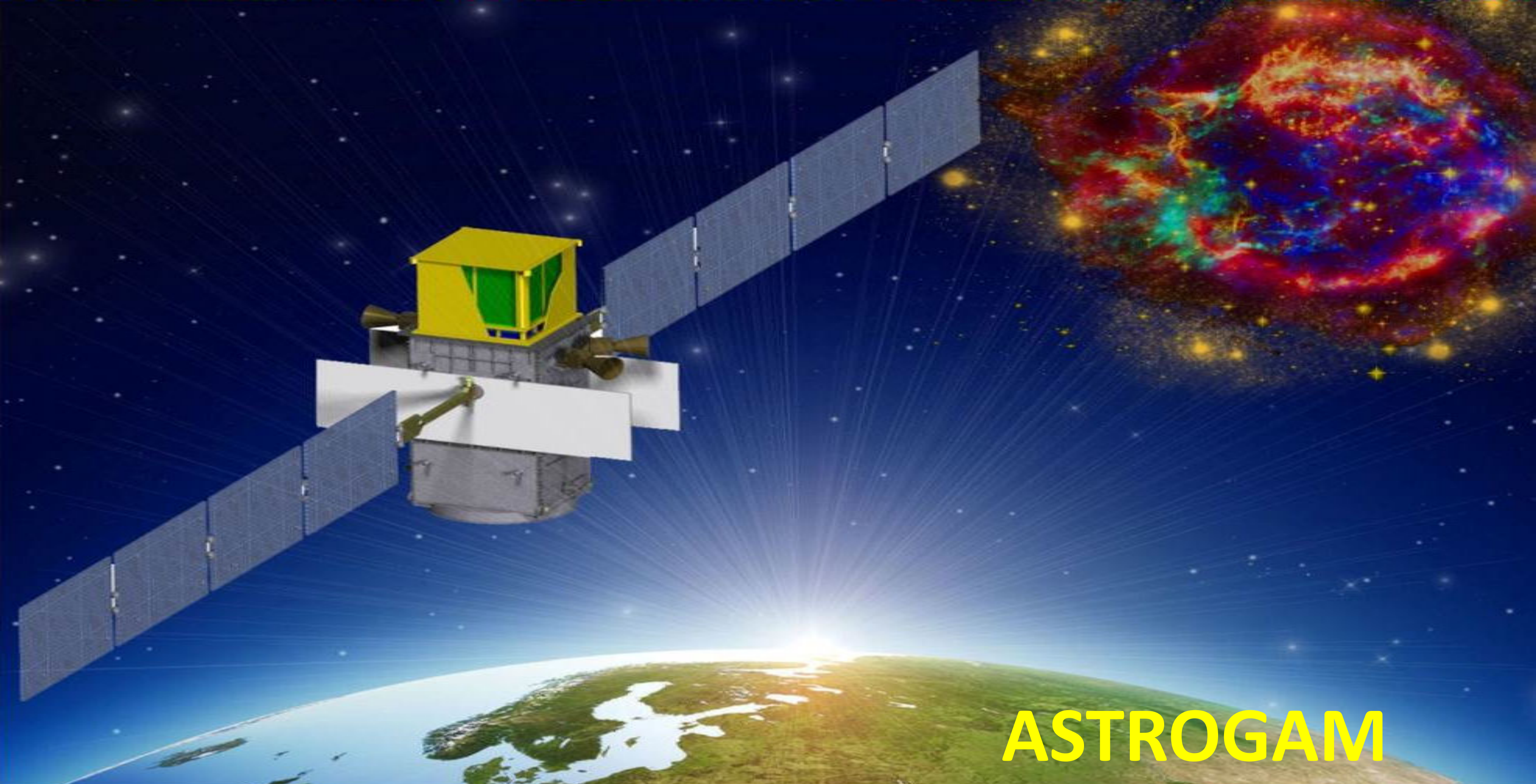
Gamma-Light Point Spread Function (angular resolution)



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

An instrument that combine two detection techniques



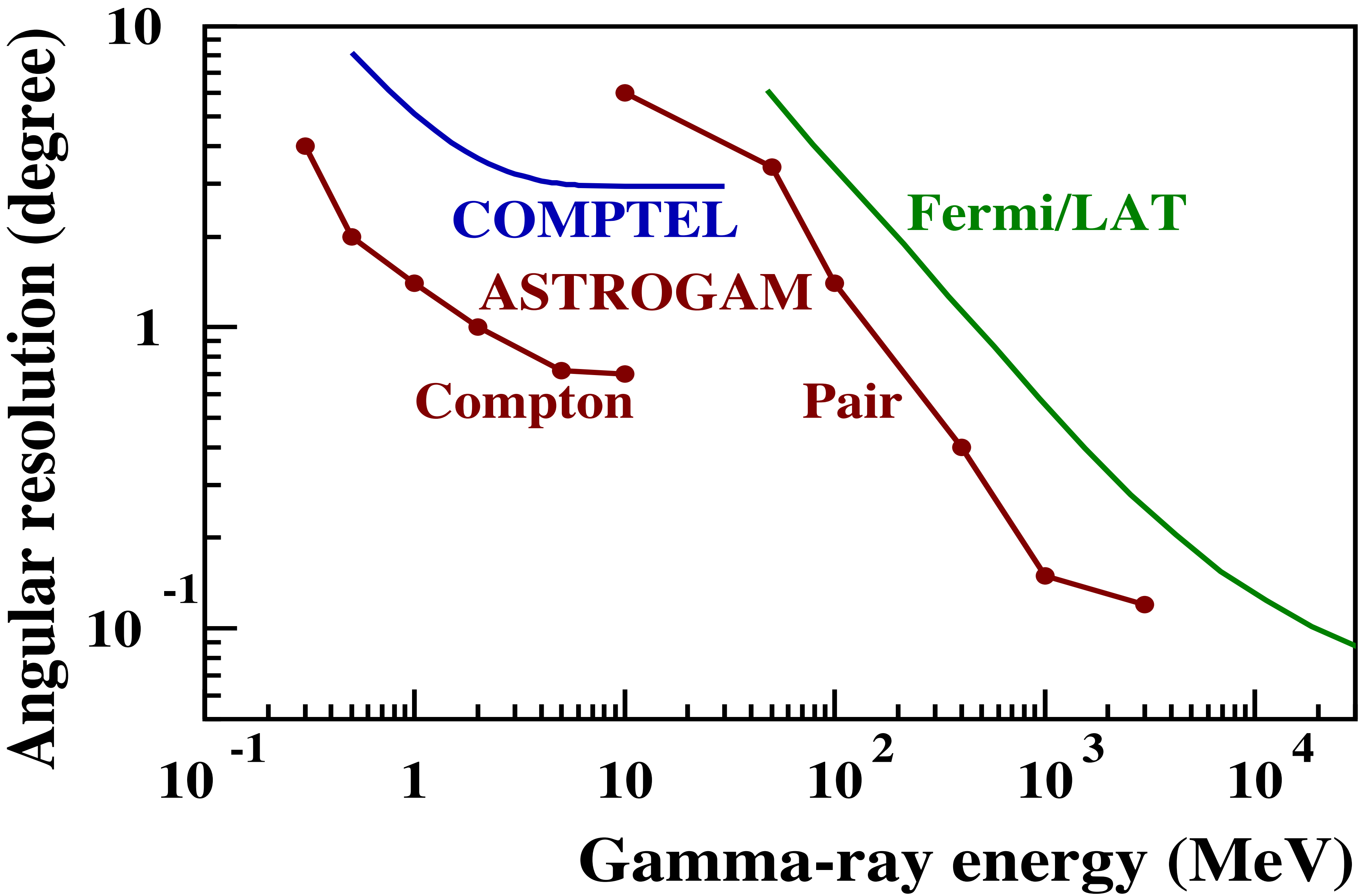


ASTROGAM

This proposal is the result of the merging of the ASTROMEV and GAMMA-LIGHT groups that submitted two separate LoIs. The proposal is presented on behalf of the ASTROGAM Collaboration by:

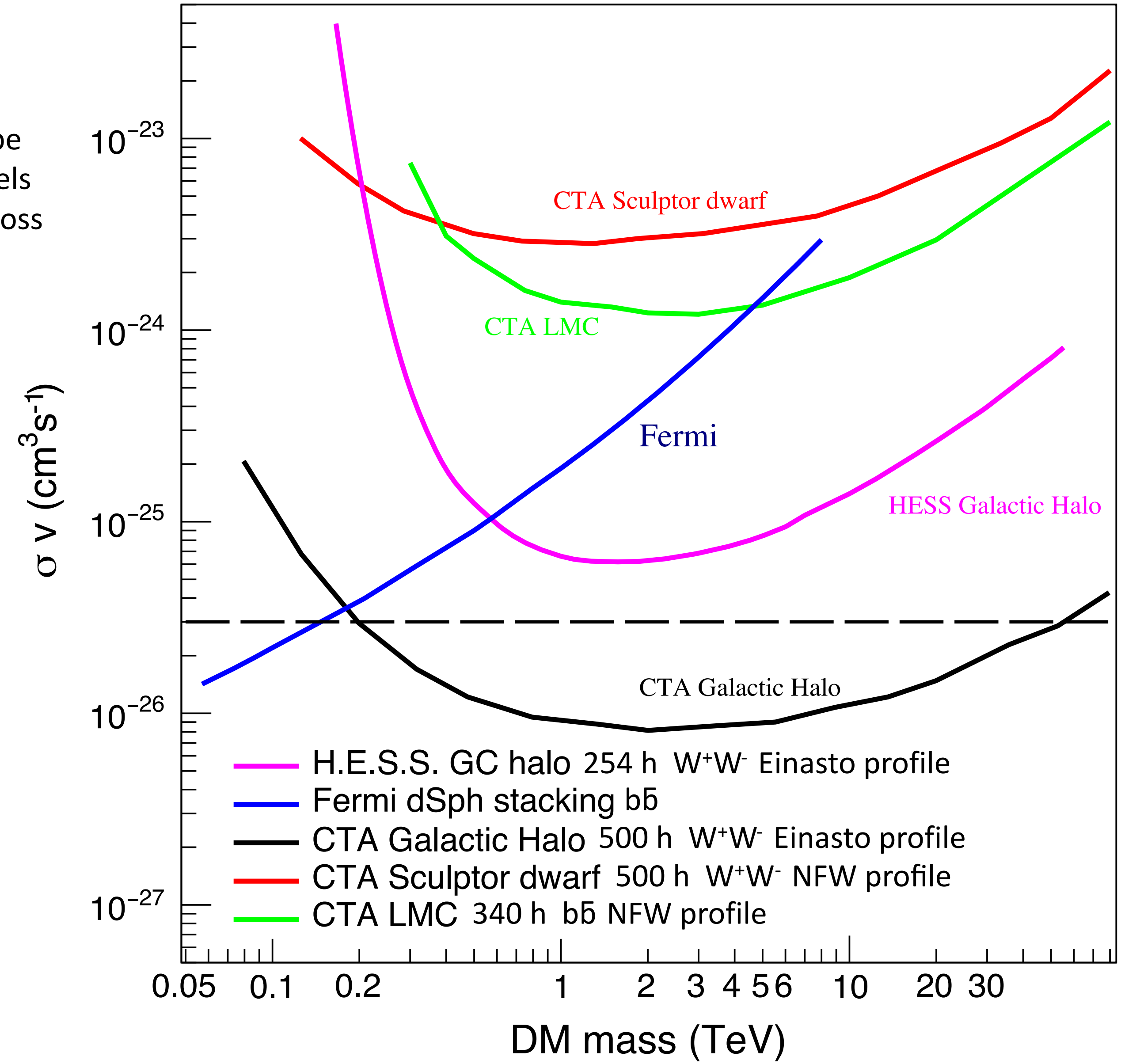
M. Tavani (INAF and University of Rome Tor Vergata, Italy)
V. Tatischeff (CSNSM, France)
P. von Ballmoos (IRAP, France)
C. Budtz-Jorgensen (DTU Space, Lyngby, Denmark)
A. Bykov (Ioffe Institute, St. Petersburg, Russia)
L. Hanlon (University College Dublin, Ireland)
D. Hartmann (Clemson University, USA)
M. Hernanz (ICE/CSIC-IEEC, Barcelona, Spain)
J. Isern (ICE/CSIC-IEEC, Barcelona, Spain)
G. Kanbach (MPI, Garching, Germany)
P. Laurent (APC, France)
J. McEnery (NASA, USA)
S. Mereghetti (INAF-IASF, Milano, Italy)
A. Morselli (INFN, Italy)
K. Nakazawa (The University of Tokyo, Japan)
U. Oberlack (Univ. of Mainz, Germany)
R. Walter, (Univ. of Geneva, Switzerland)
A. Zdziarski (NCAC, Poland)
A. Zoglauer (UC Berkeley, USA)

ASTROGAM Angular Resolution

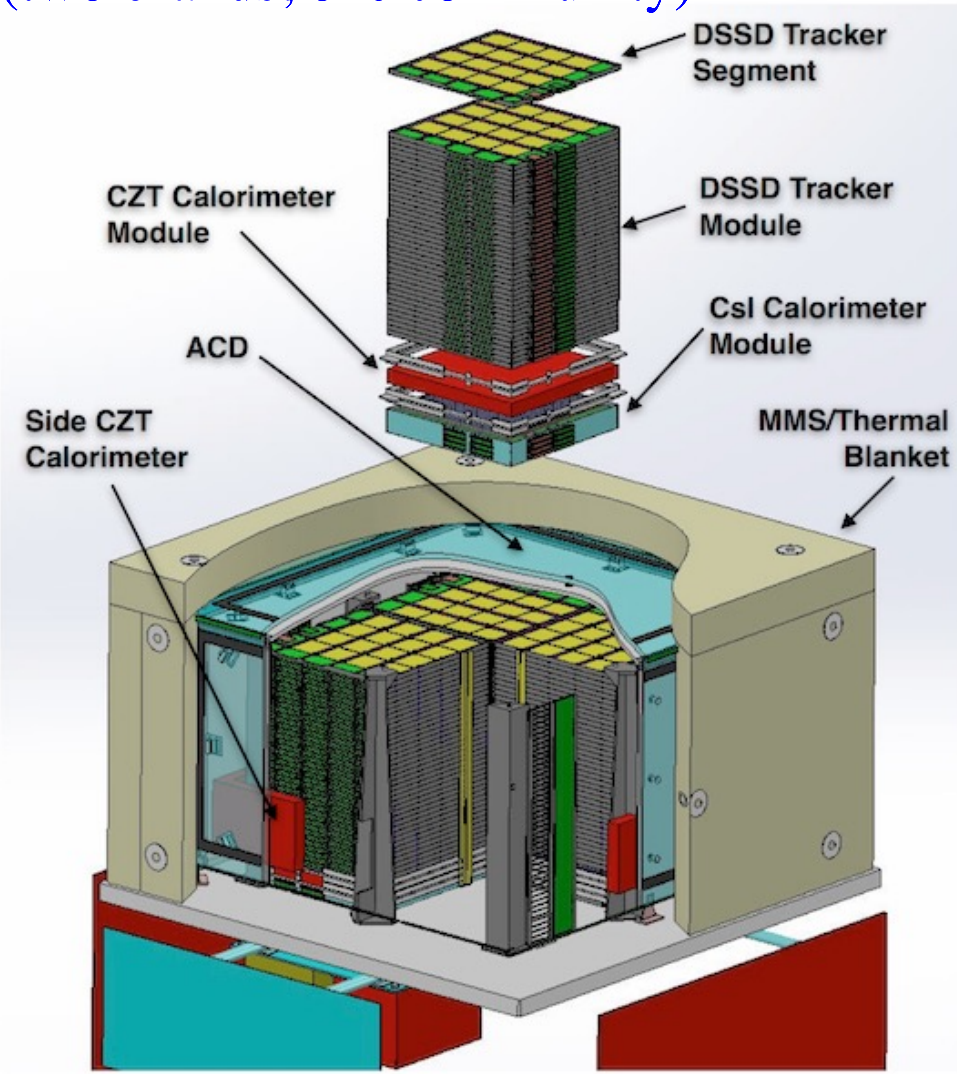


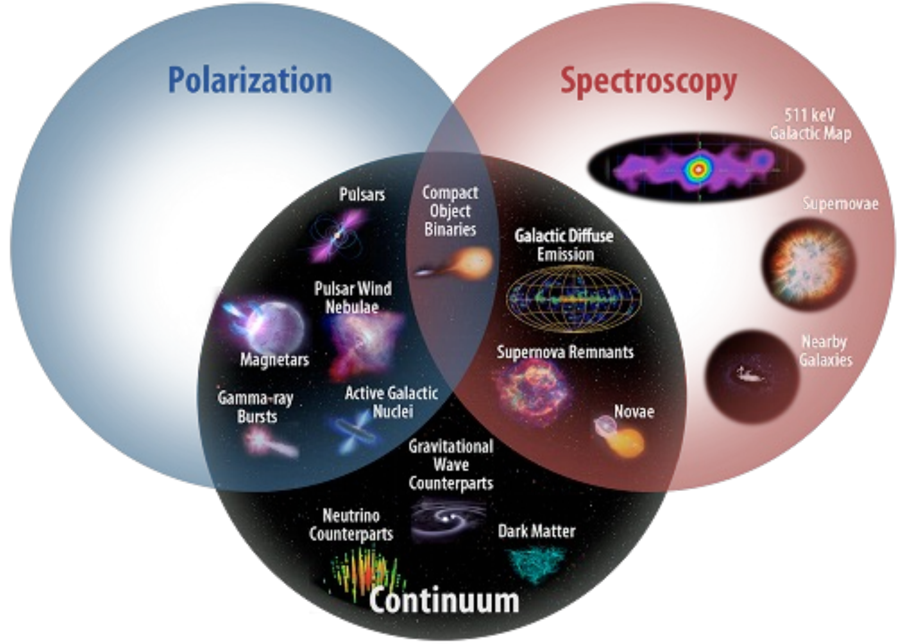
CTA, Fermi,HESS DM upper-limits

Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section
The expectation for CTA for the Galactic Halo
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%
As we saw in the previous slides the limits from dwarfs are much less dependent from the systematic uncertanties



Our sister experiment:
AMEGO (NASA)
(two brands, one community)



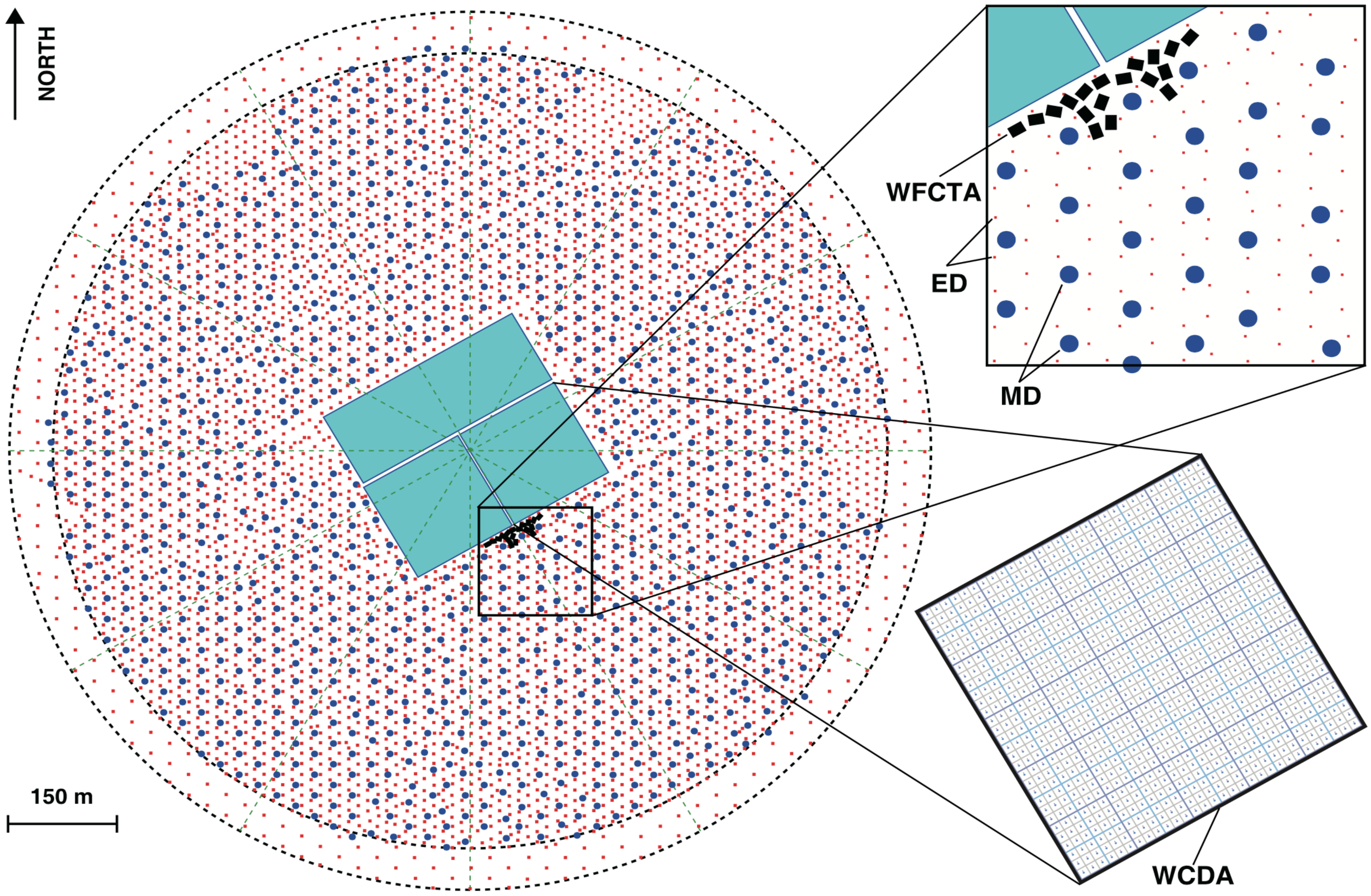


- ~20% smaller tracker
- CZT calorimeter layer

LHAASO

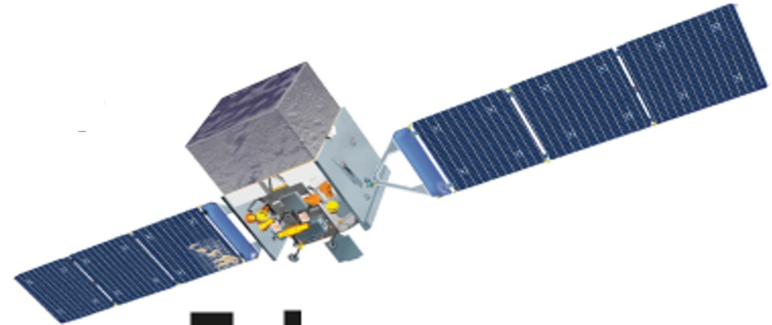
Mt. Haizi 4410 altitude

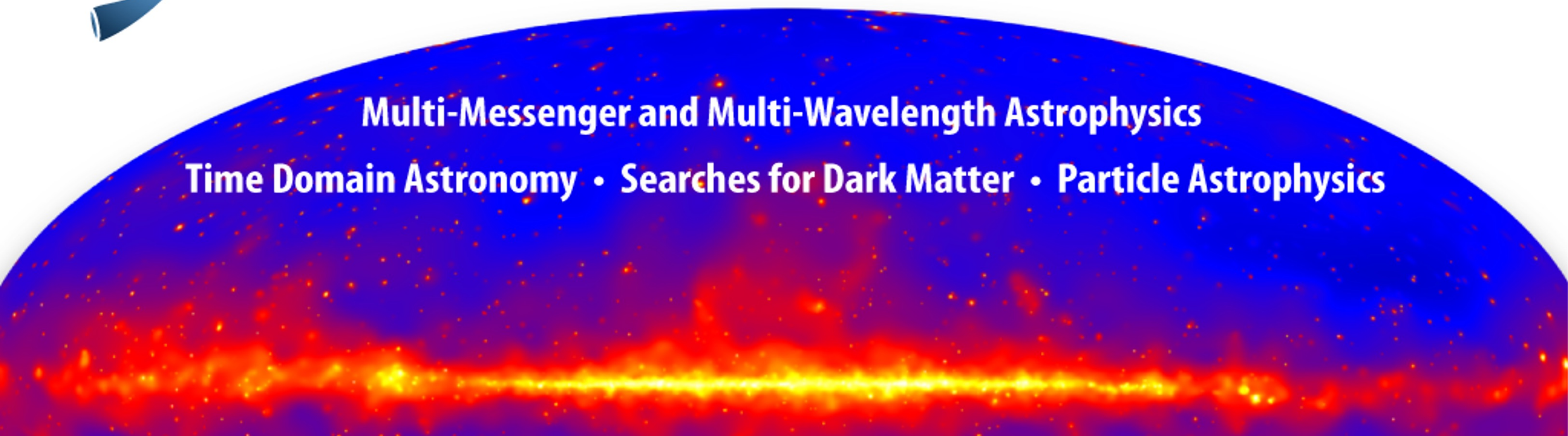
LHAASO

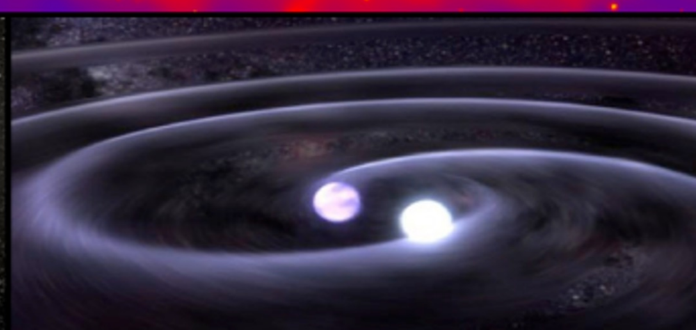


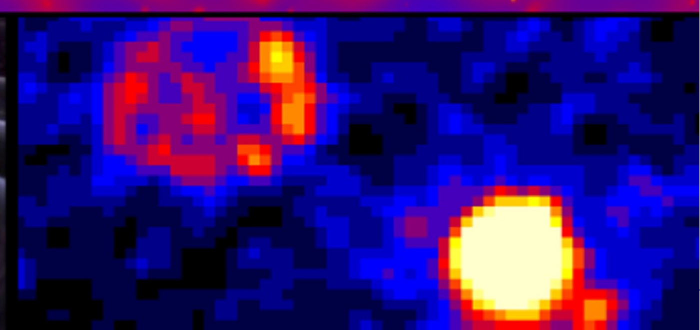
ED : electromagnetic particle detectors MD : muon detectors WCDA: water Cherenkov detector array
WFCTA :18 wide field-of-view air Cherenkov telescopes
Active Area: 78,000 m^2

Fermi Gamma-Ray Space Telescope









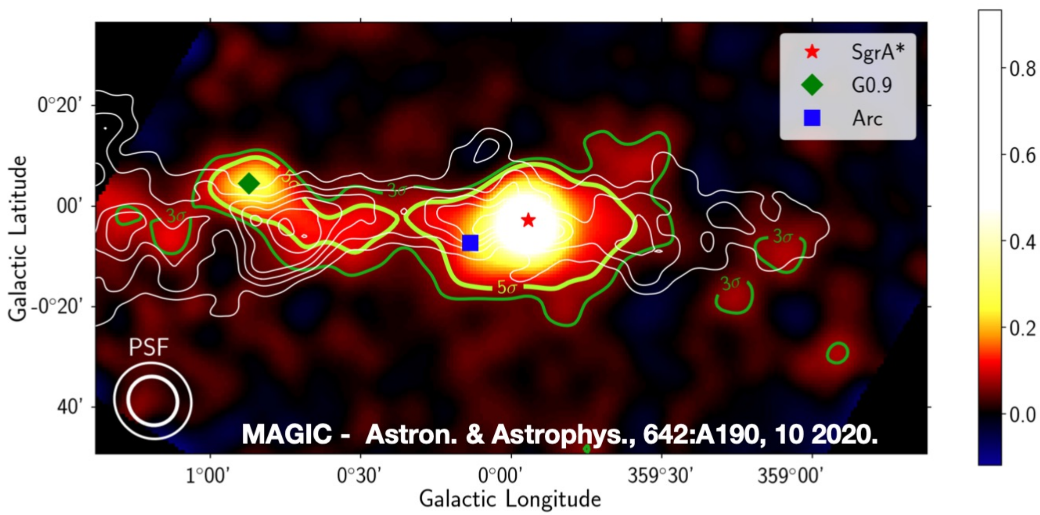
Pisa 15 March 2018

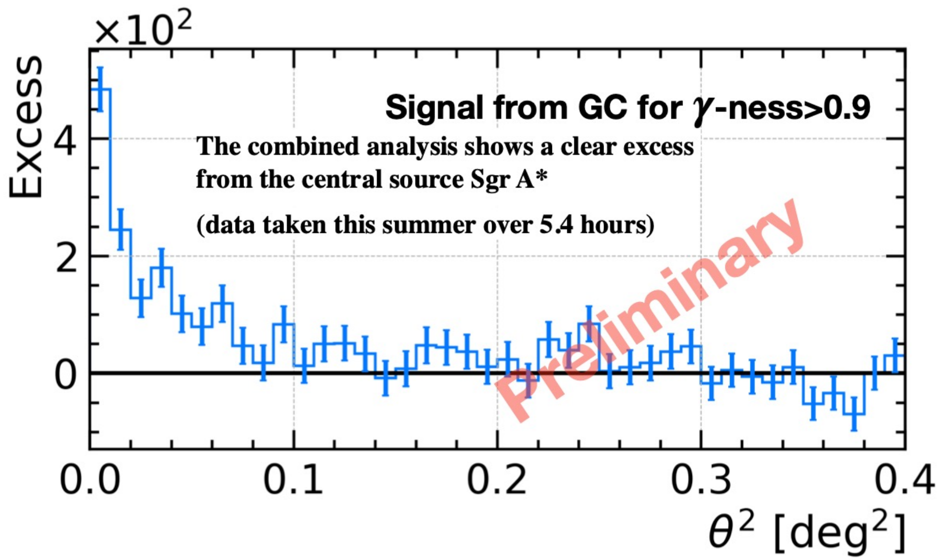
Joint MAGIC –LST 1 observation of Galactic Center

•The Galactic Center (GC) is one of the target regions for MAGIC + LST-1 observations, given the abundance of science targets (Sgr A*, Gal. diffuse emission and Dark Matter)

•The GC region culminates at large zenith angle of 58 degree seen at La Palma, thus enlarging the light pool and increasing the efficiency of the stereo triggering of LST array

•At the same time, the complexity of the area, requires improved the angular resolution in order to understand/constrain the origin of the gamma-ray emission

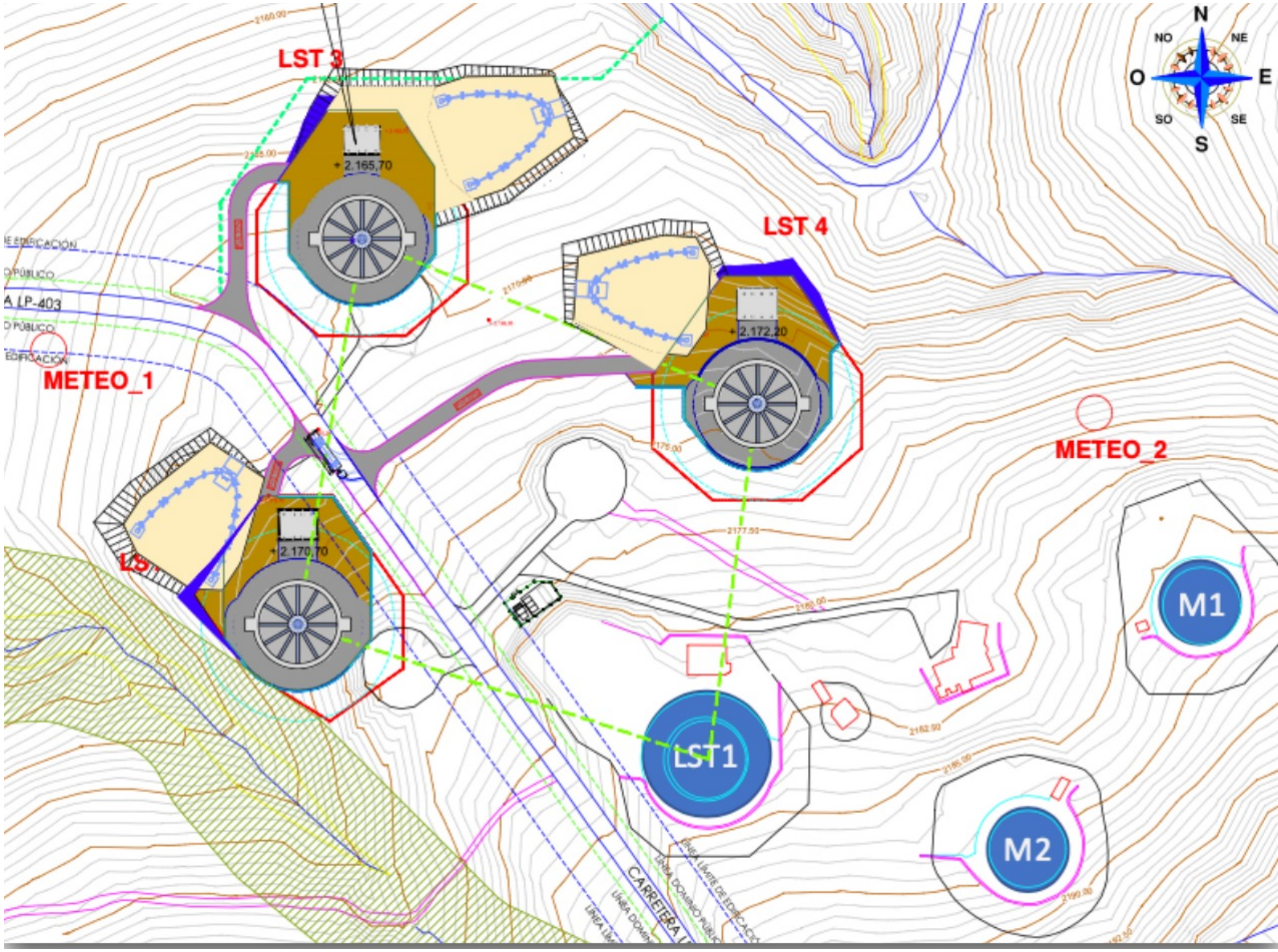




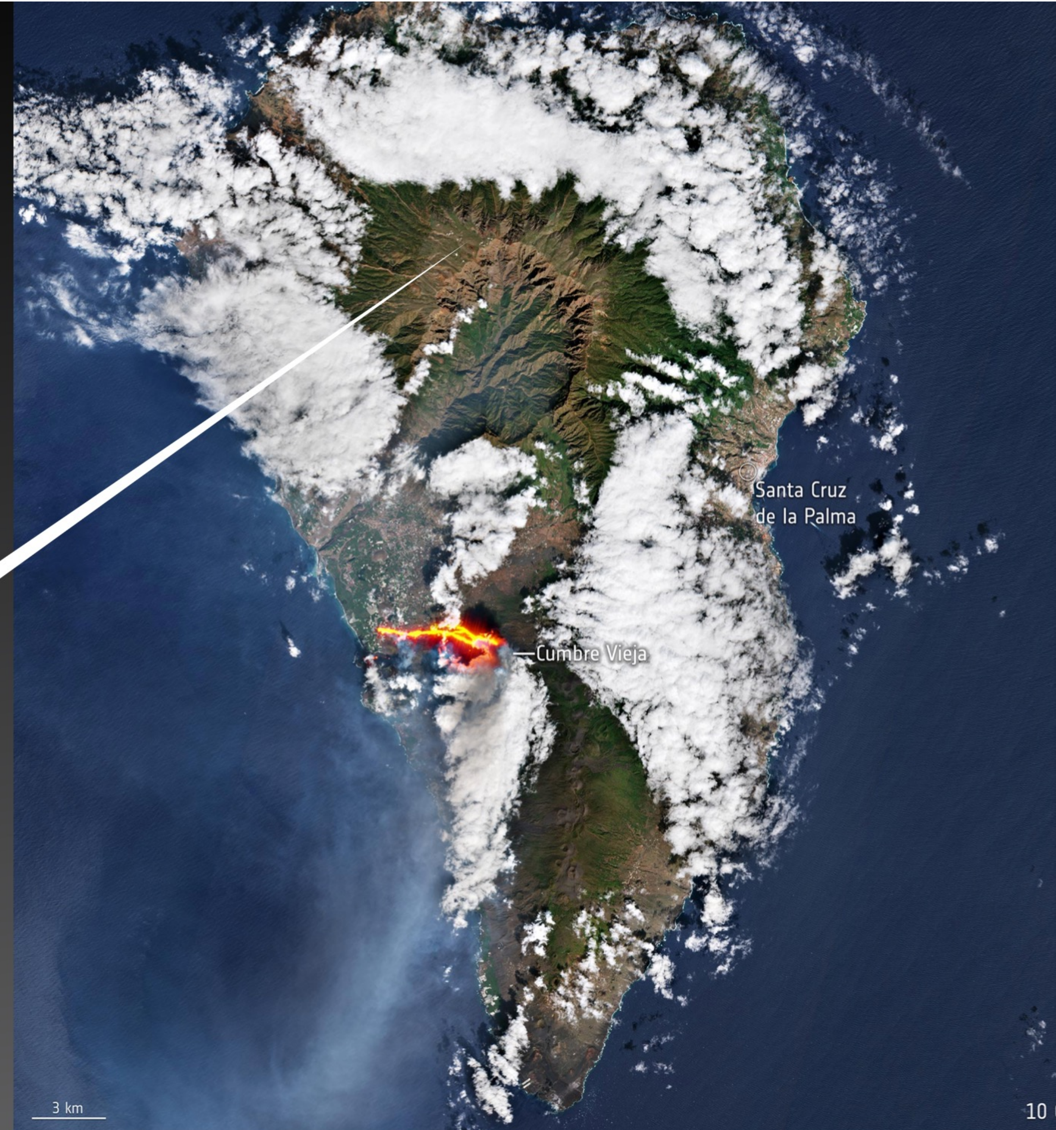
What's next

- Strong effort to complete LST1 Commissioning completion to release pressure and gain momentum for the LST2-4 construction.

- LST2-4 construction is about to start

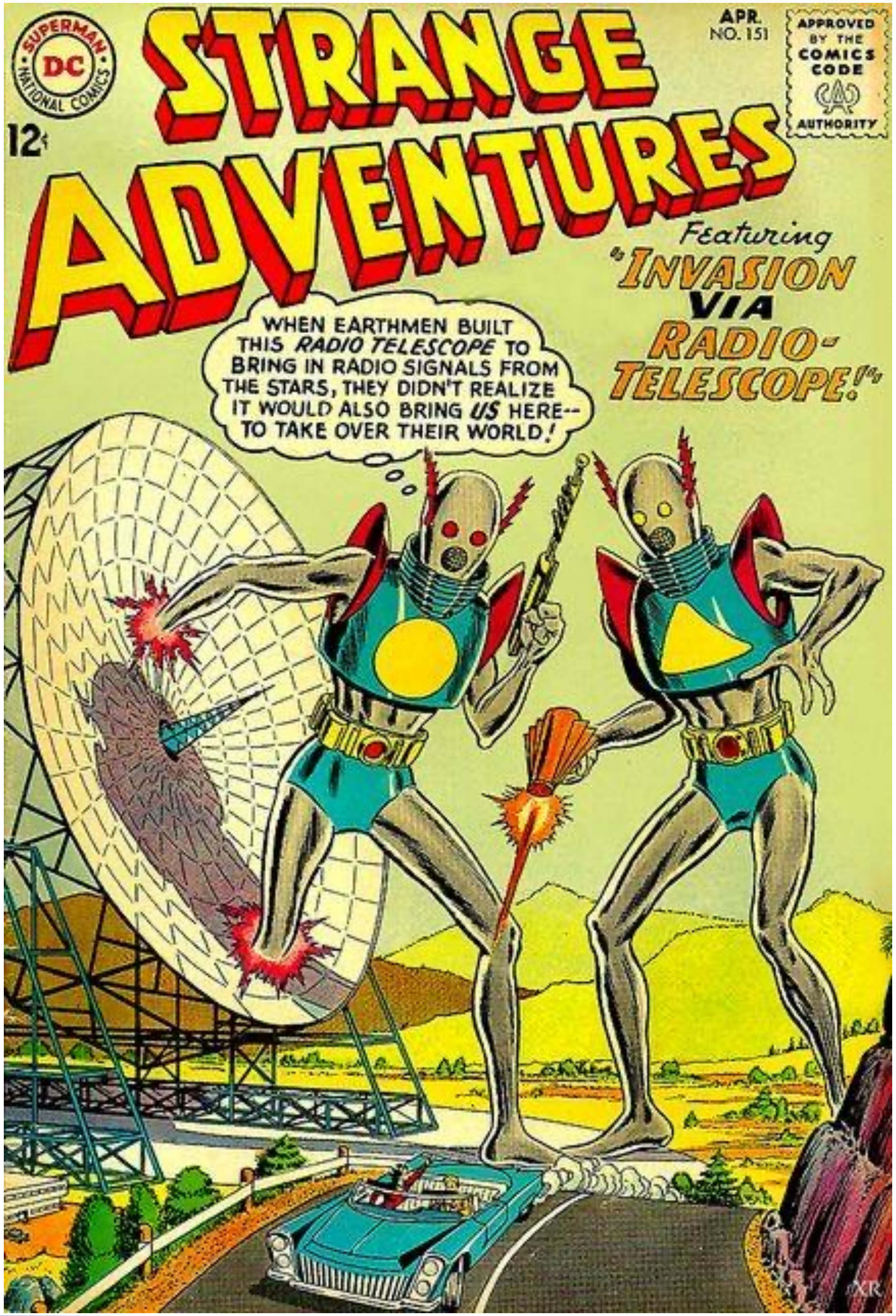


When Volcano will allow....



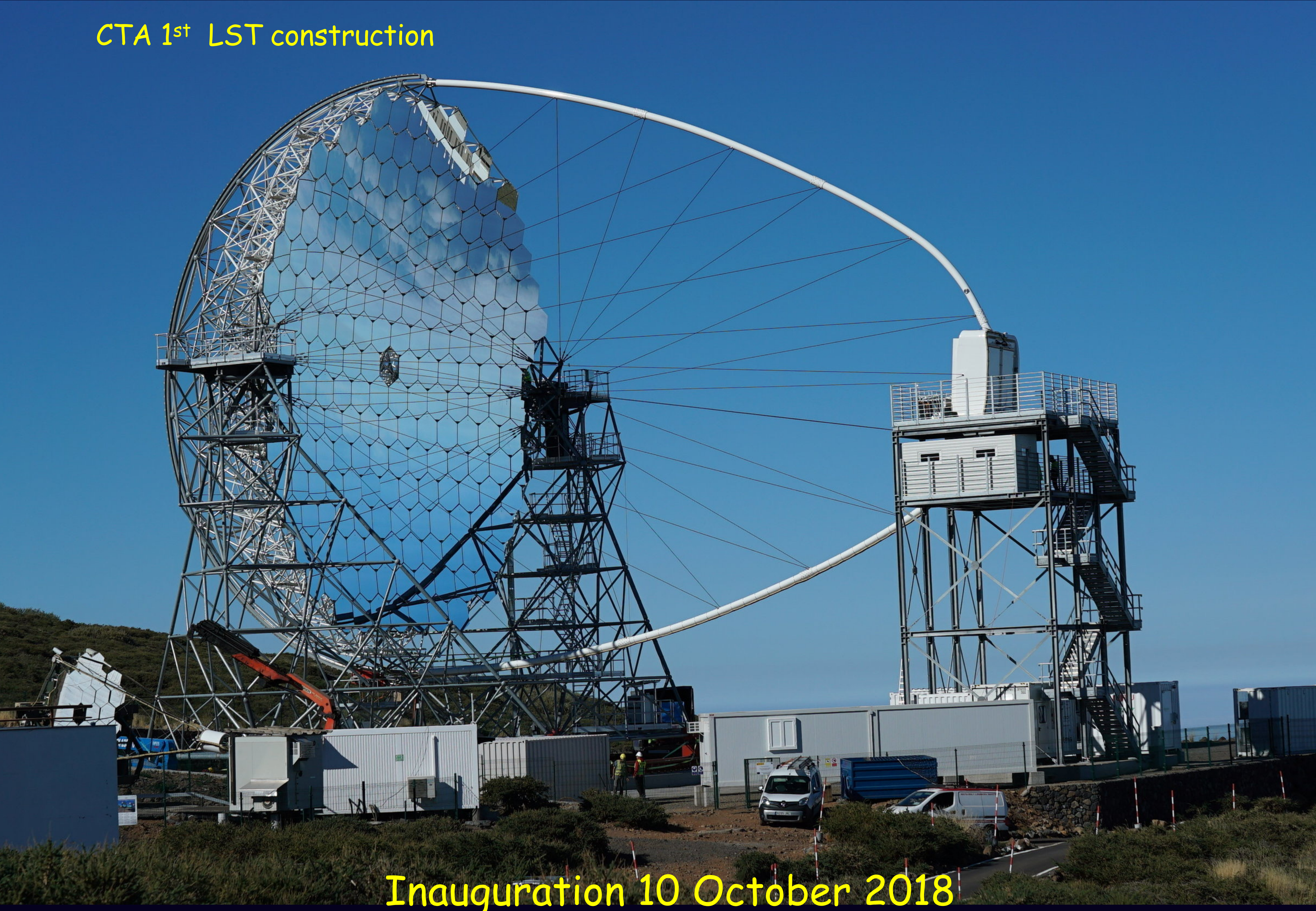
- On the 19th of September the Cumbre Veija erupted
- A major event, luckily no dead people but major impact on the territory
- Volcano is far away from ORM but ashes and gas emission can reach ORM.
- All activity are suspended until the eruption will stop

Cumbre Vieja volcano eruption seen from the Observatory Los Roques de los Muchachos there is always a risk ..



but hopefully this will not happen even with the new telescopes..

CTA 1st LST construction



Inauguration 10 October 2018

CTA 1st LST construction

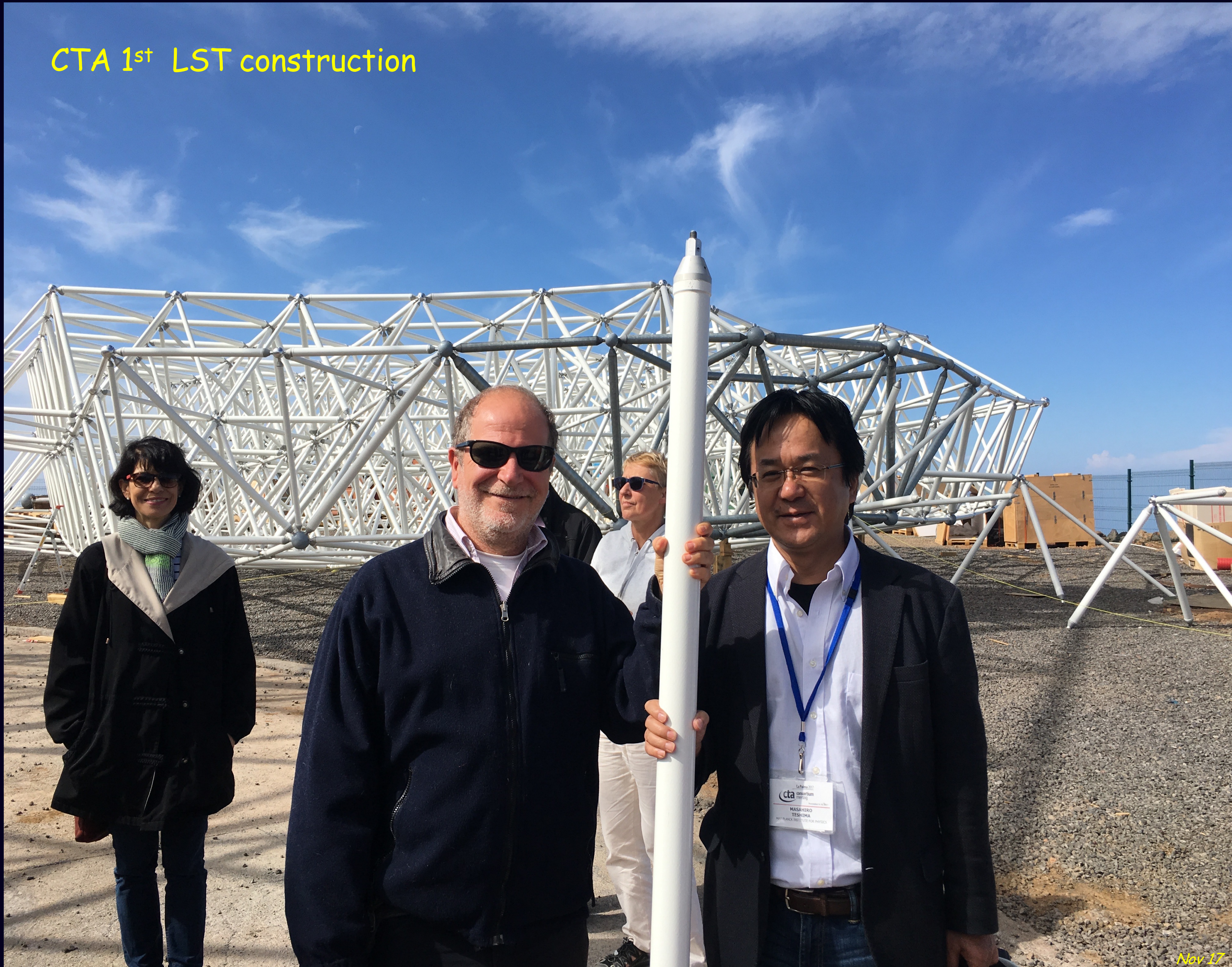
Camera Support Structure Installed
21 June 2018

CTA 1st LST construction

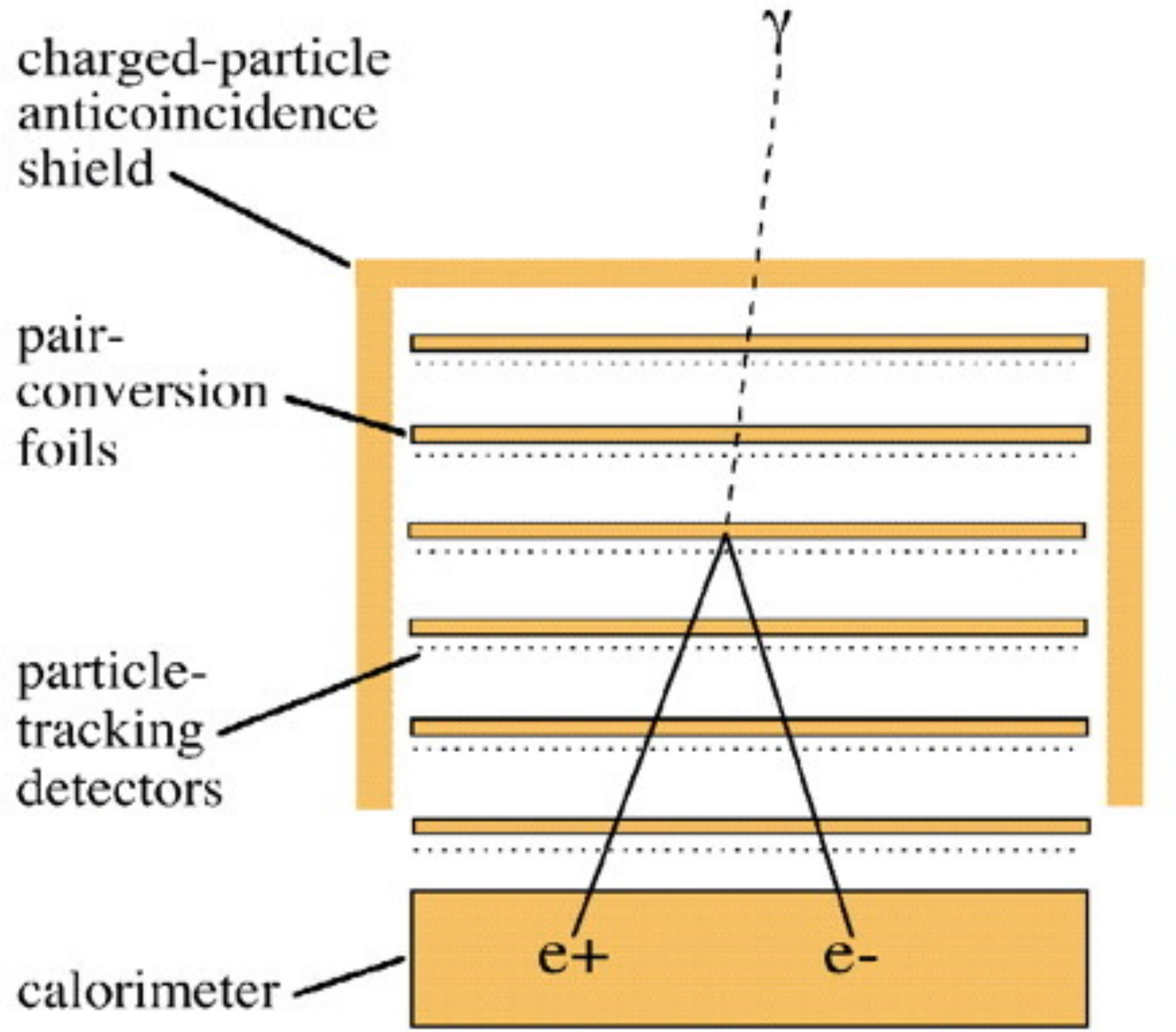
Feb 18
Photo Credit: Chiara Righi (MAGIC, INAF, Brera)

CTA 1st LST

CTA 1st LST construction



Elements of a pair-conversion telescope



(energy measurement)

- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

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)

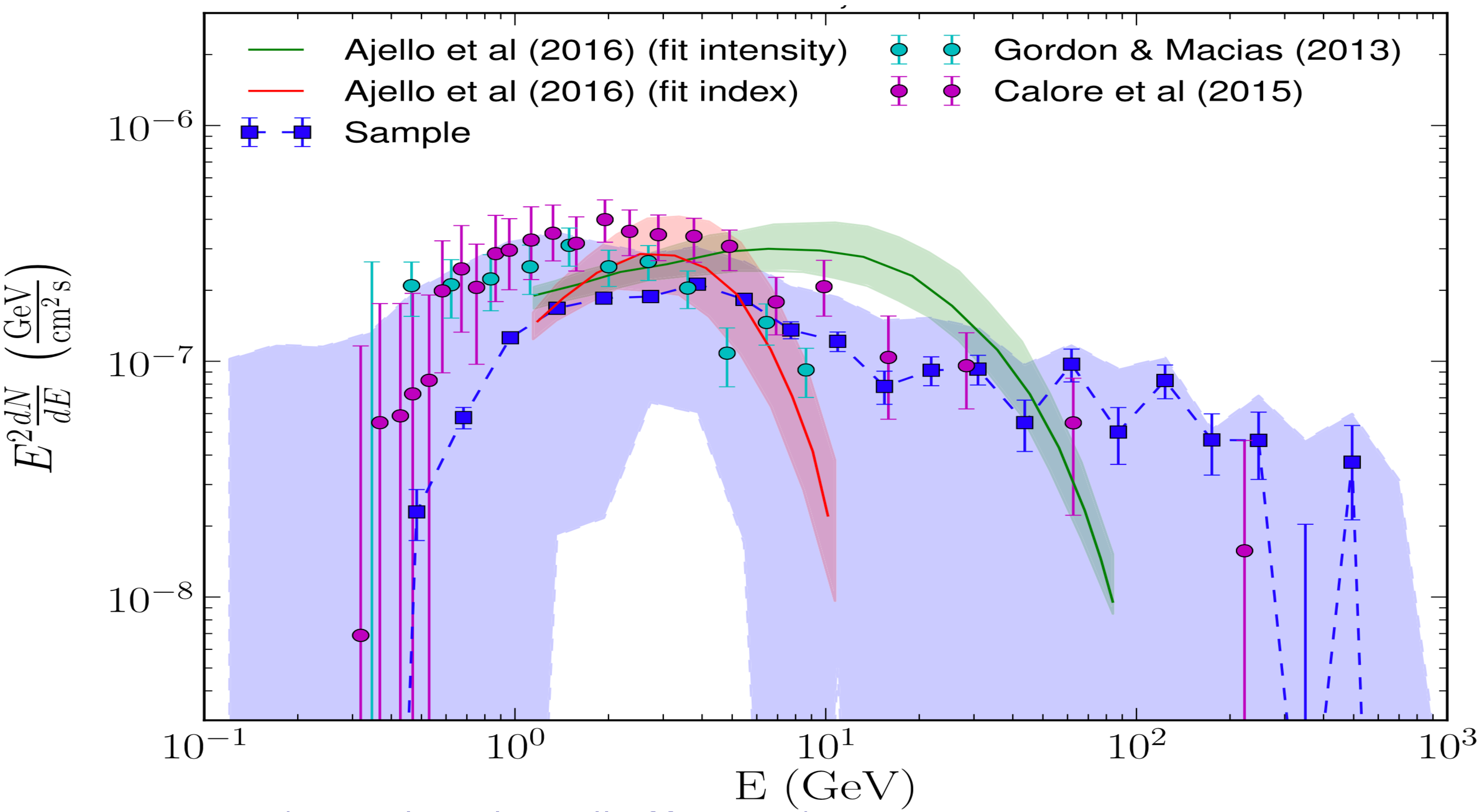
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

....

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

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

• 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]

•Millisecond Pulsars from Accretion Induced Collapse as the Origin of the Galactic Centre Gamma-ray Excess Signal, Gautam et al. arXiv:2106.00222

....

How to discriminate between different hypothesis ?

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

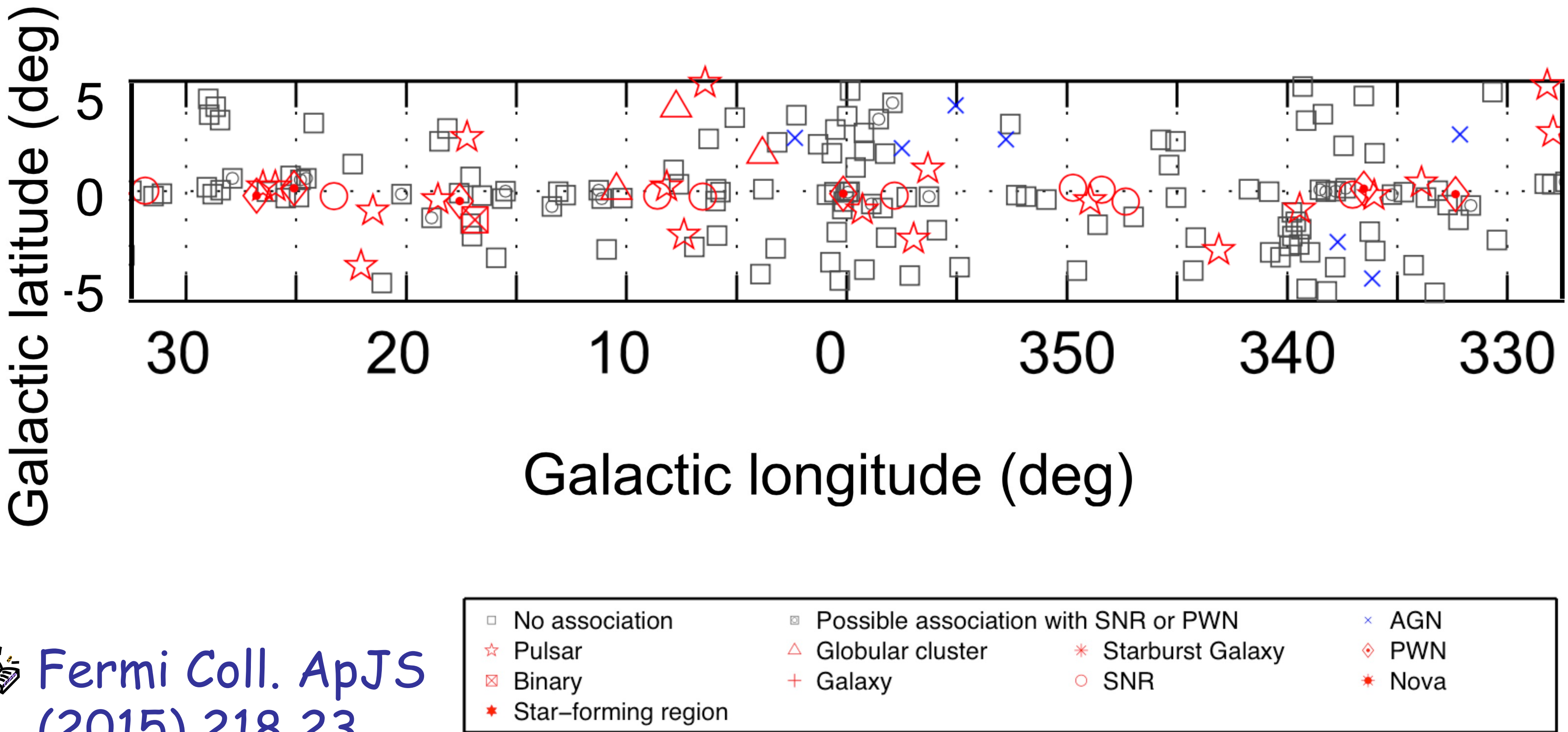
- Diffuse emission modeling
- Analysis of point sources near the GC

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

The Fermi LAT 3FGL Inner Galactic Region

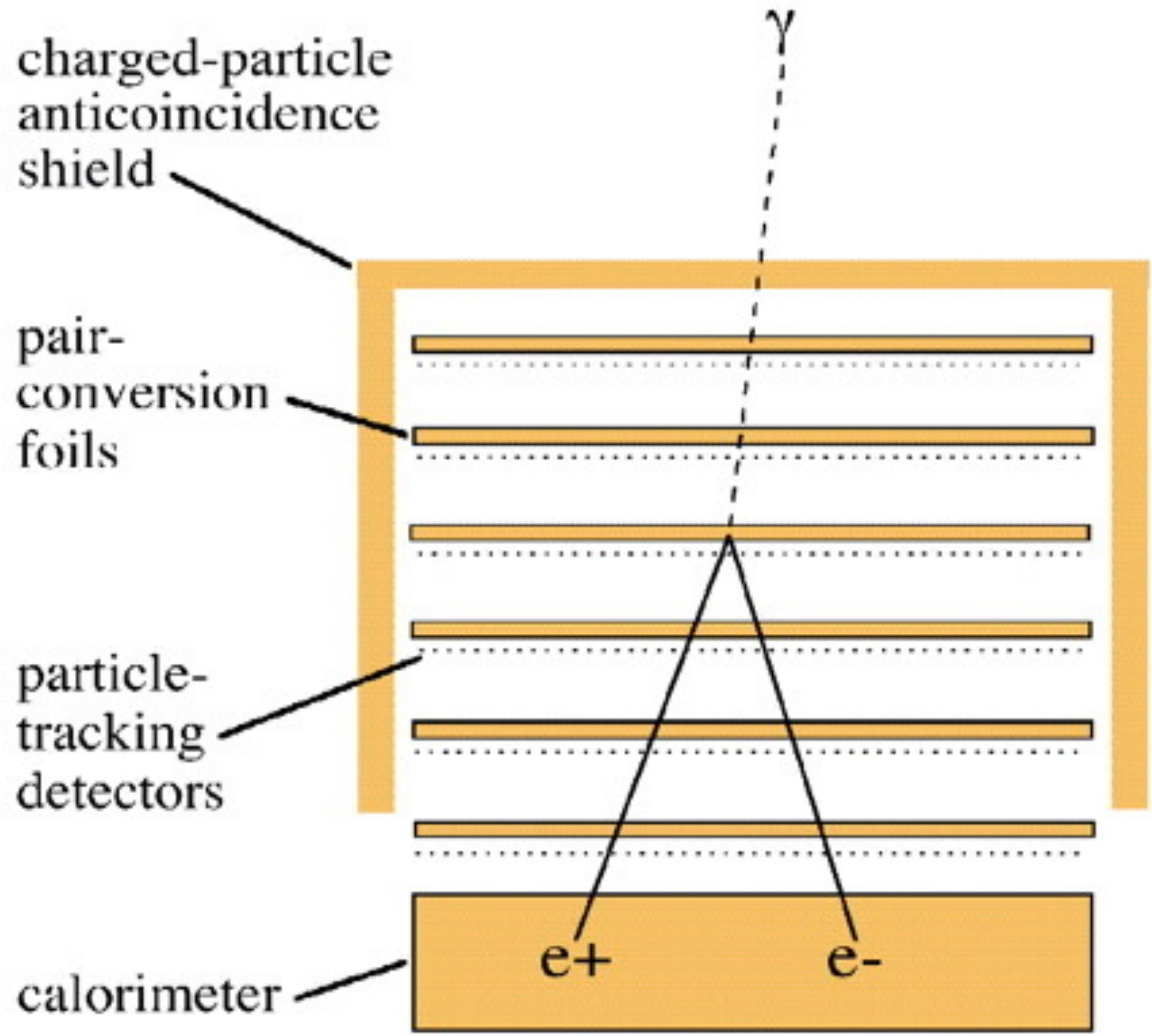
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range



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

Elements of a pair-conversion telescope



(energy measurement)

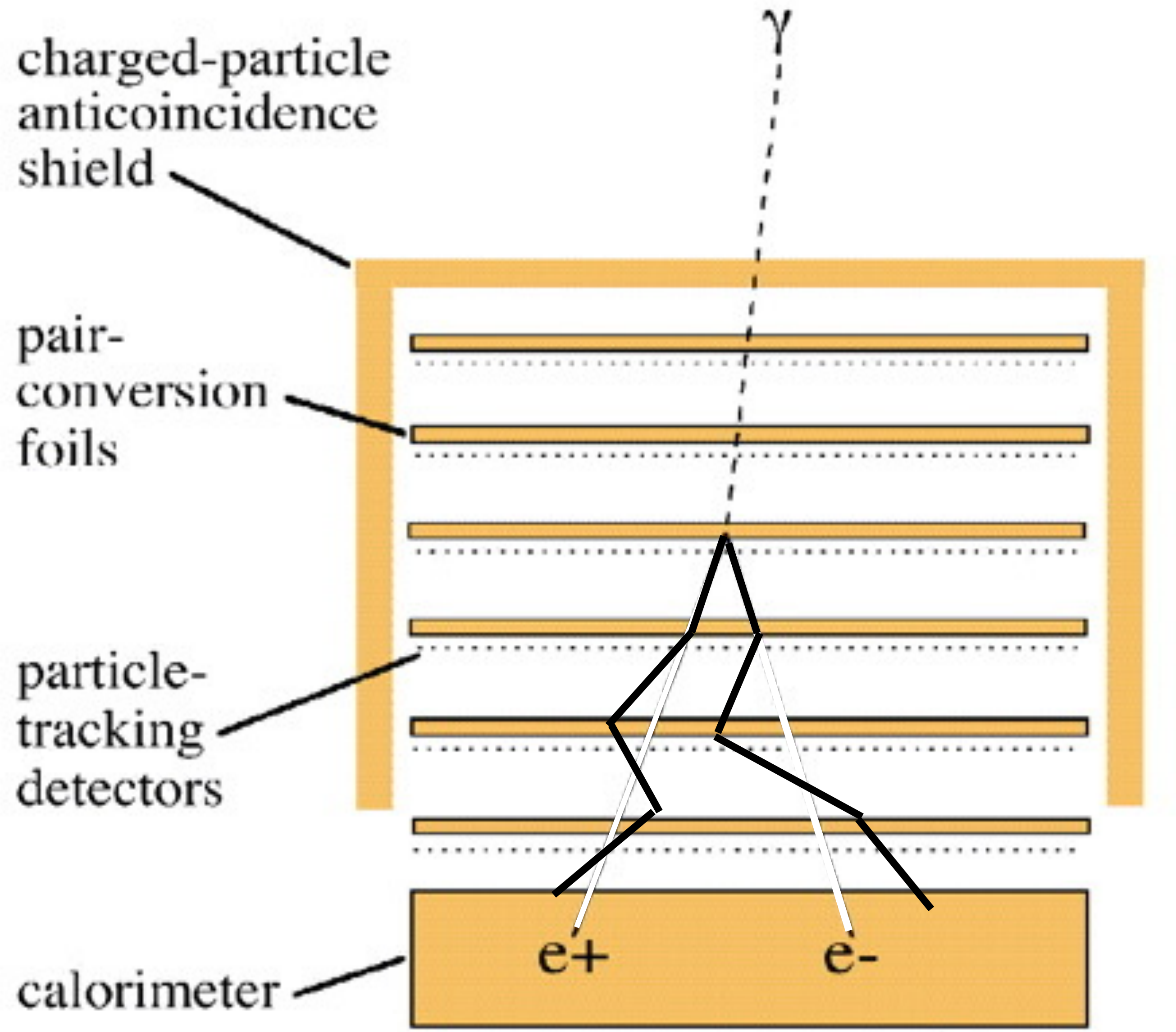
- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$

- electron and positron carry information about the direction, energy and polarization of the γ-ray

Elements of a pair-conversion telescope

(more realistic scheme)



(energy measurement)

- photons materialize into matter-antimatter pairs:

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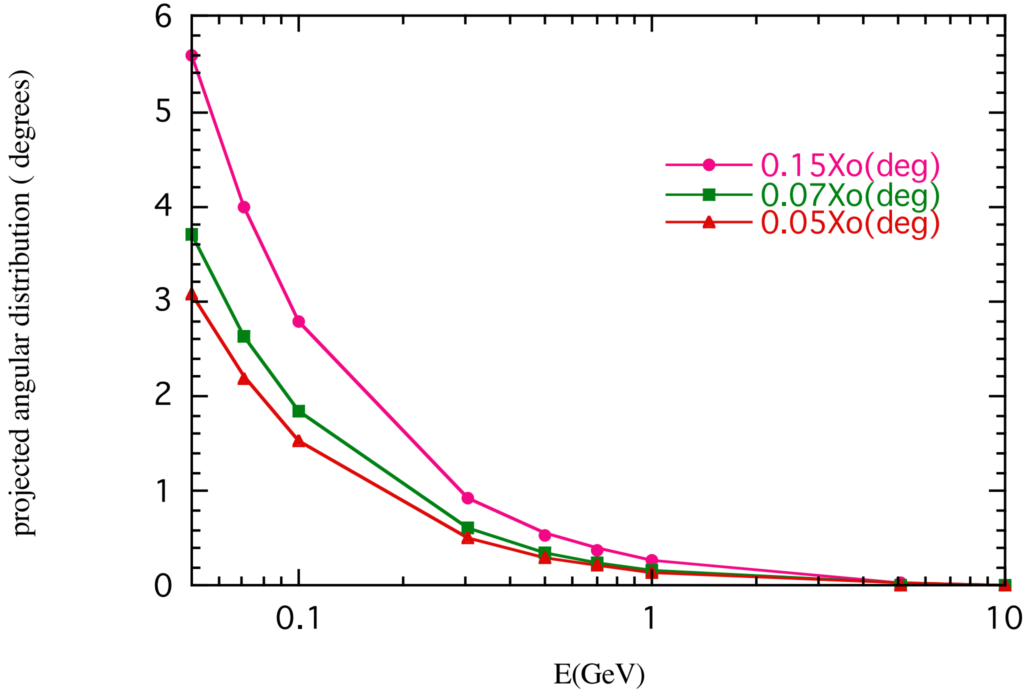
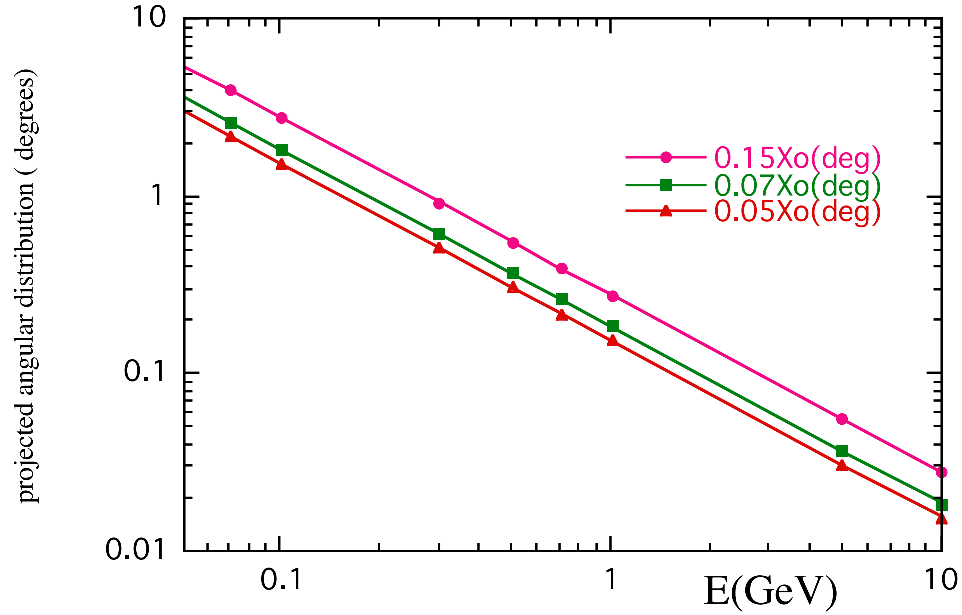
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering

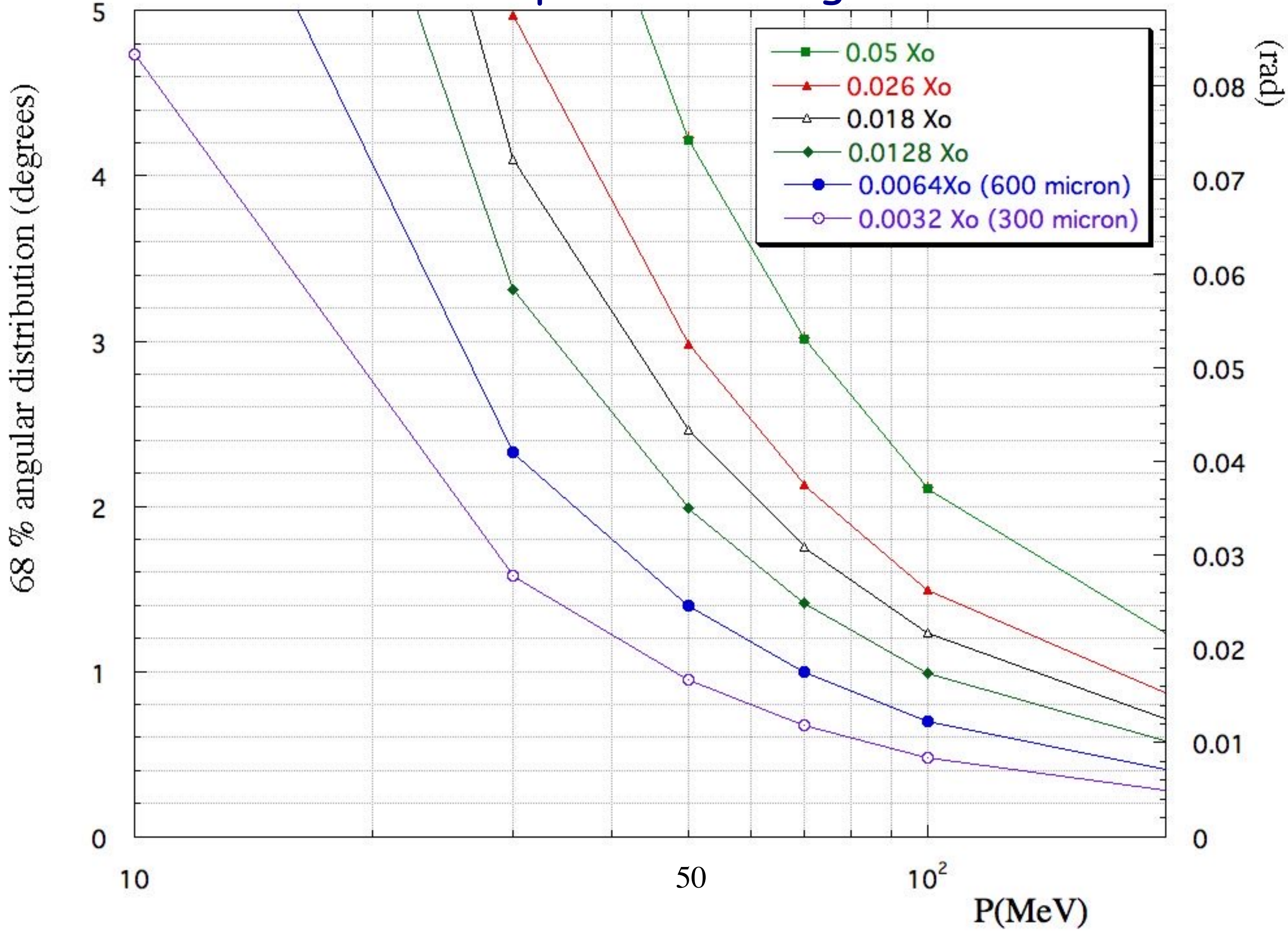




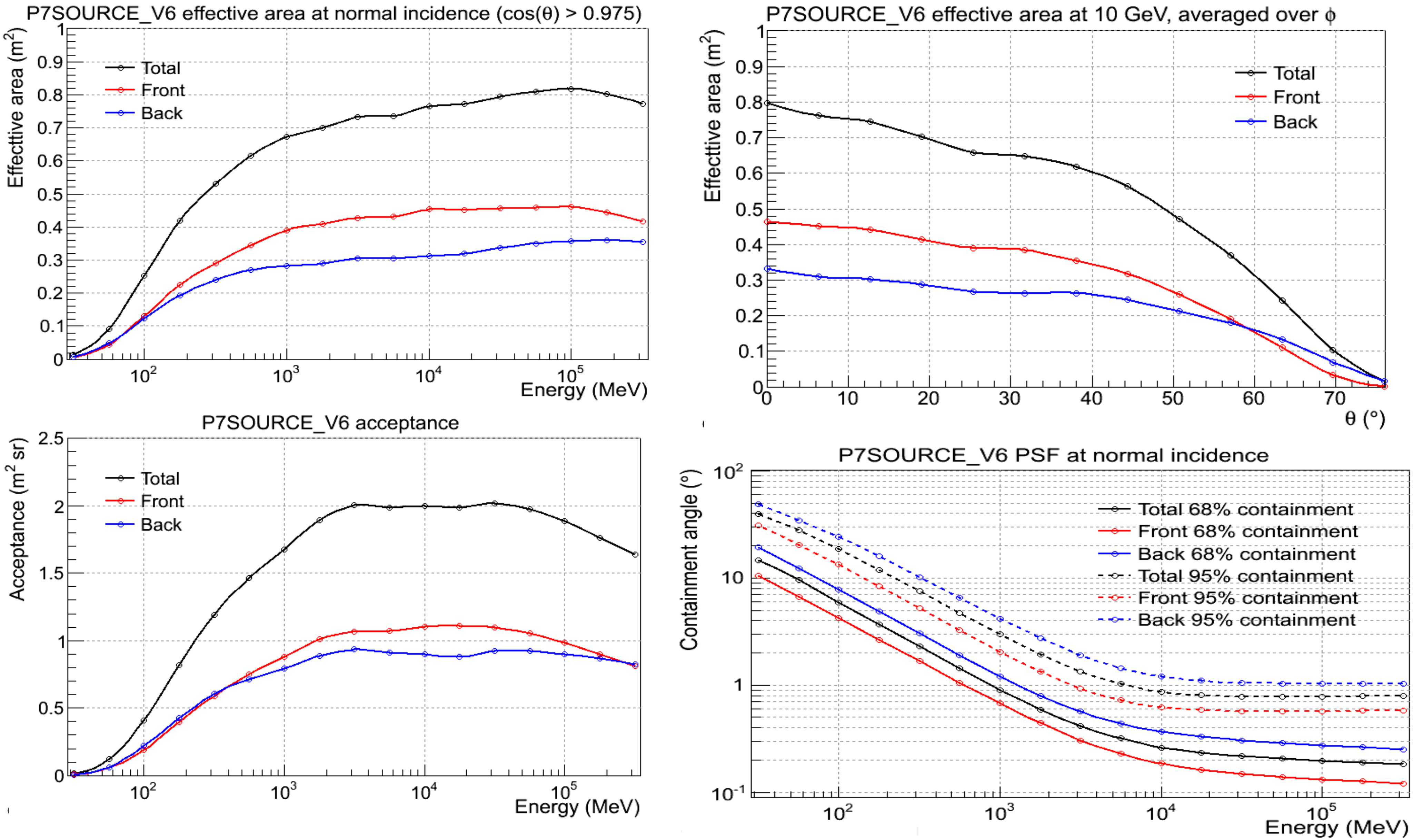
$$\theta_0 = \theta^{rms}_{plane} = \frac{1}{\sqrt{2}}\theta^{rms}_{space}$$

$$\theta_0 = \frac{13.6 MeV}{\beta c p} z \sqrt{x/X_0}\,[1 + 0.038 \ln(x/X_0)]$$

Multiple Scattering

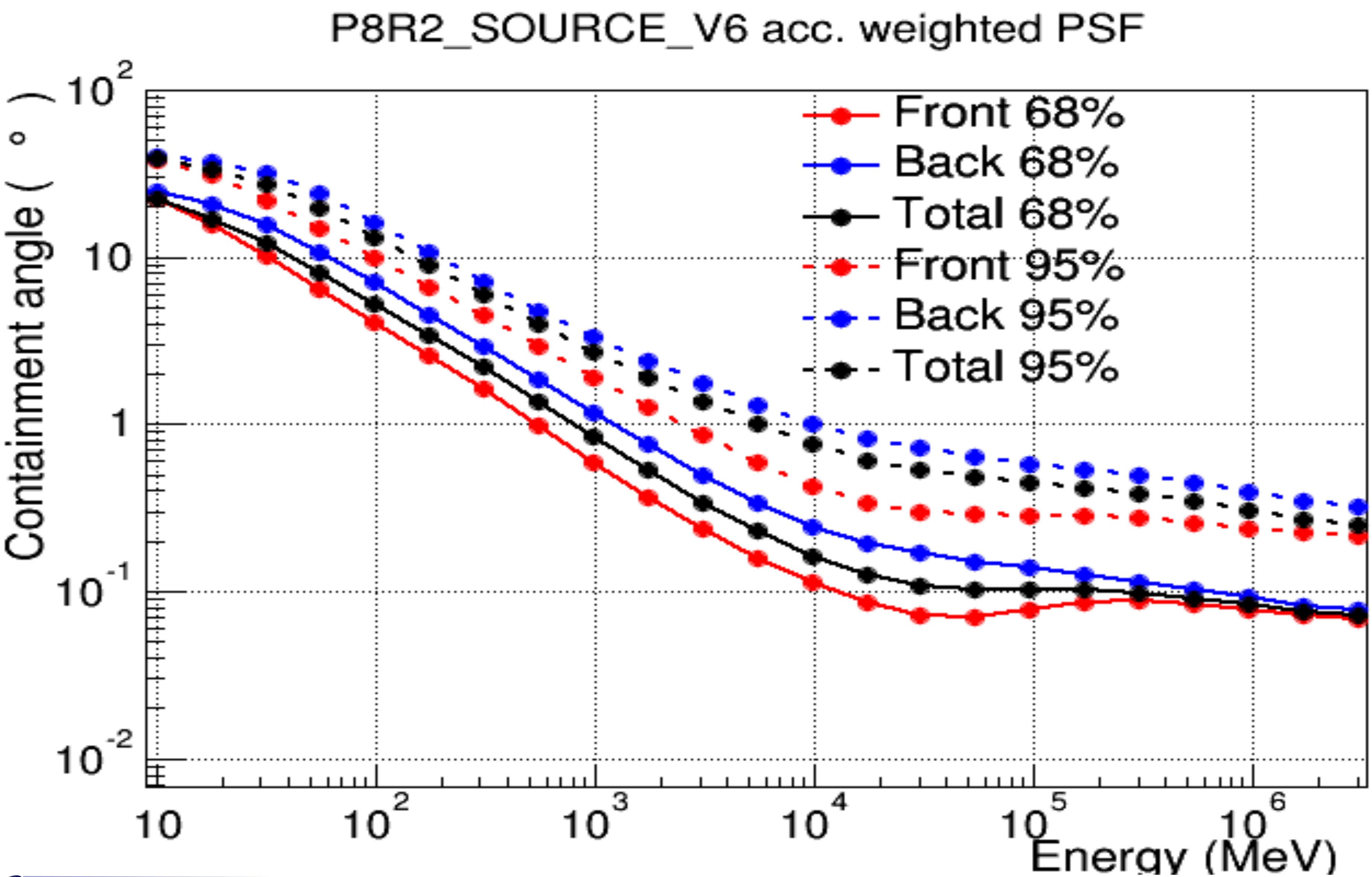


Fermi Instrument Response Function



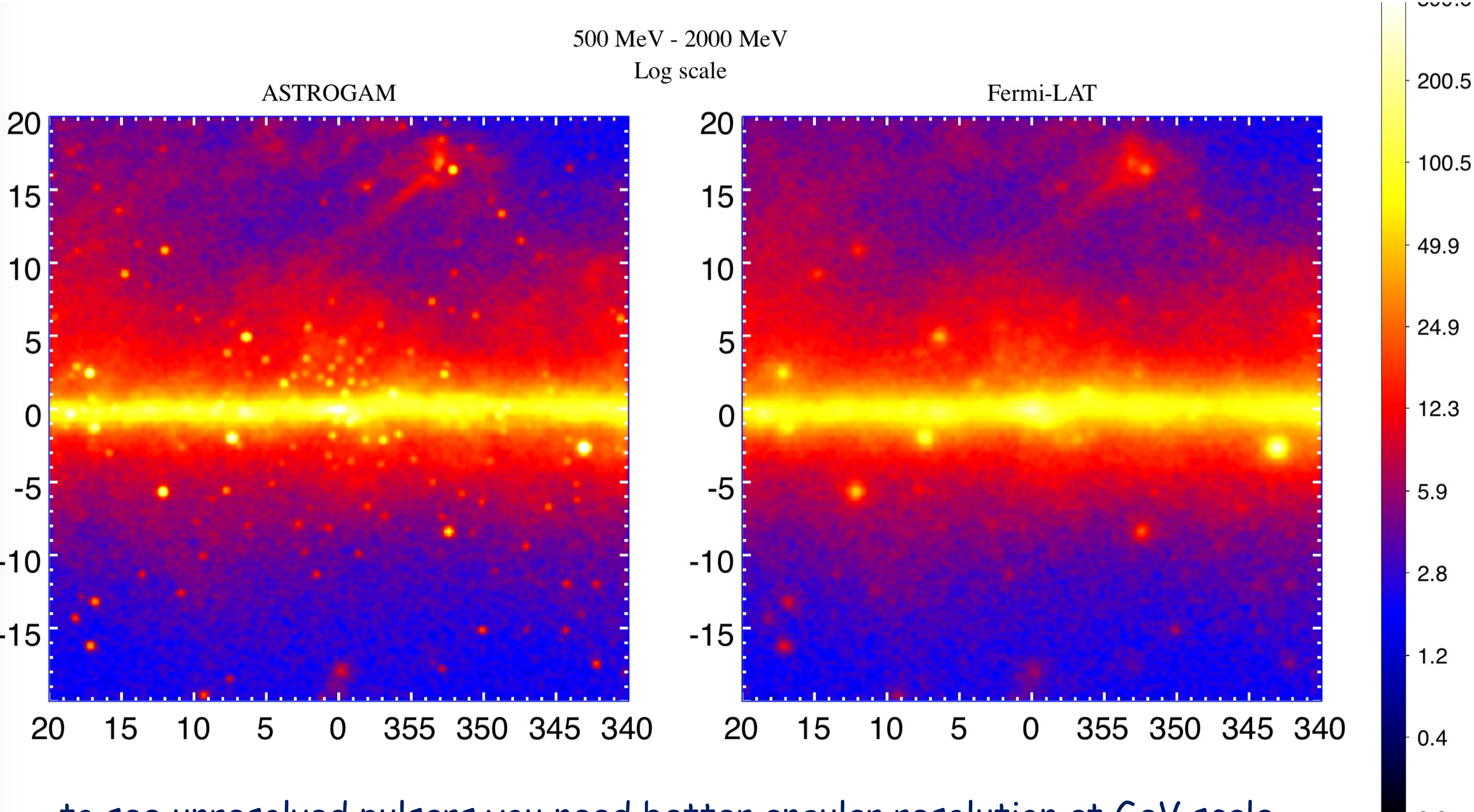
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

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



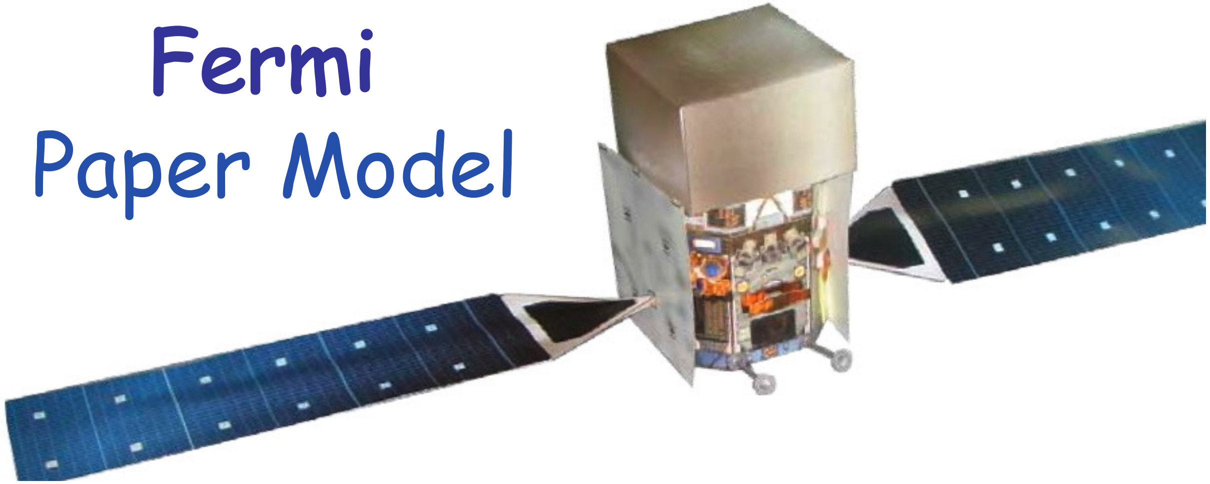
Galactic Center Region 0.5-2 GeV

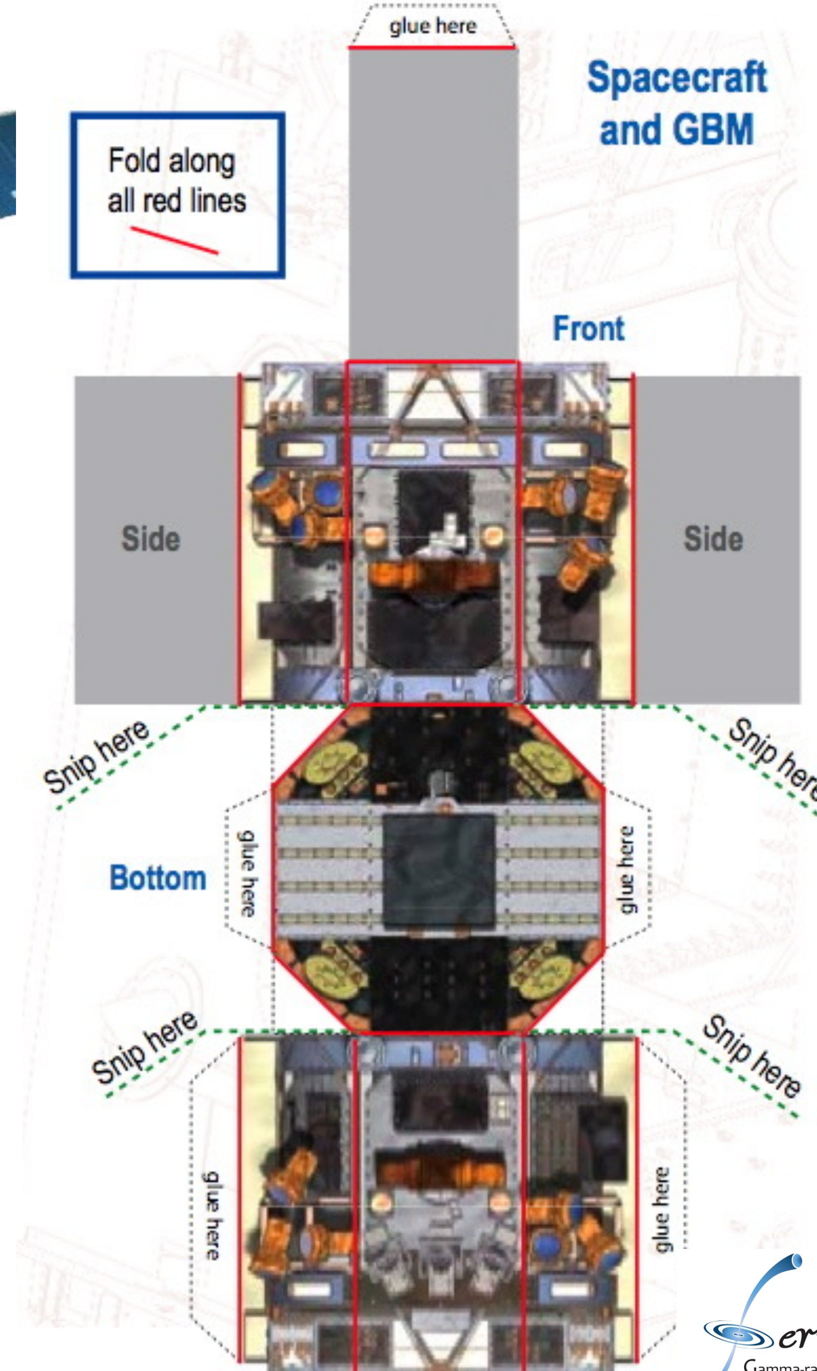
Fermi PSF 8



to see unresolved pulsars you need better angular resolution at GeV scale

Fermi Paper Model





https://owncloud.roma2.infn.it/index.php/s/yvpYj8NMDV2Bip7