Gamma-ray astronomy with satellites

Aldo Morselli

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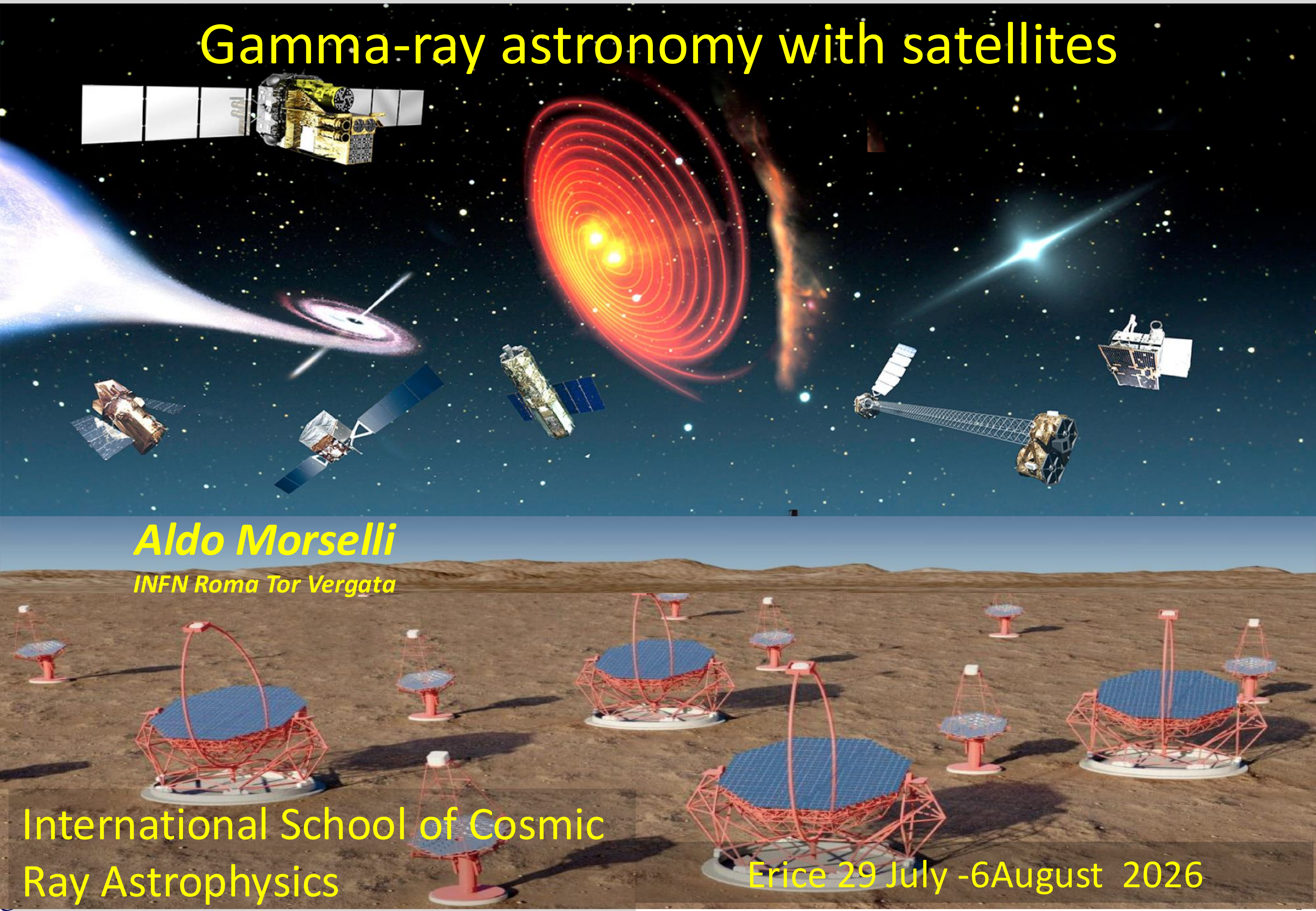
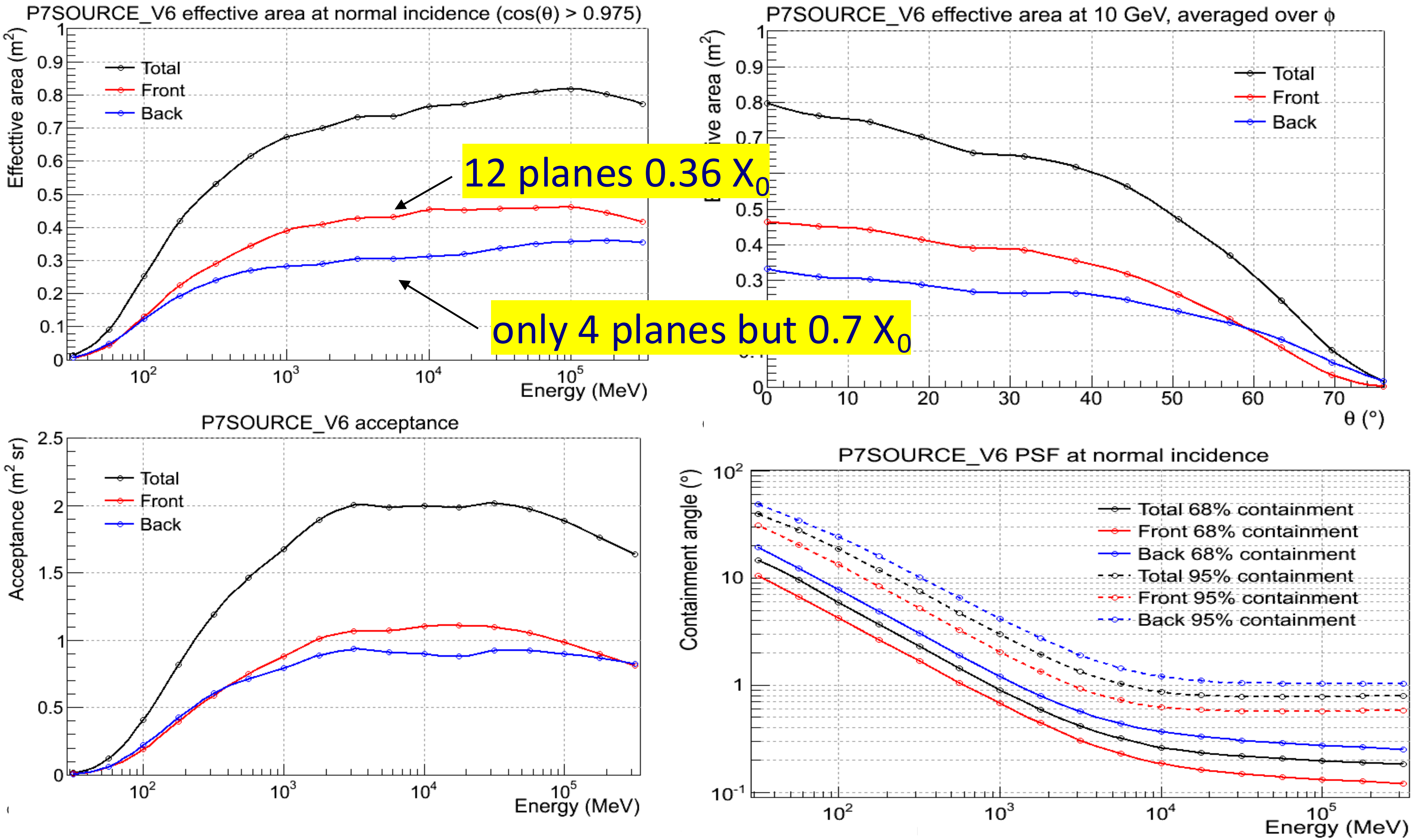


International School of Cosmic Ray Astrophysics

Erice 29 July -6August 2026

Fermi Instrument Response Function

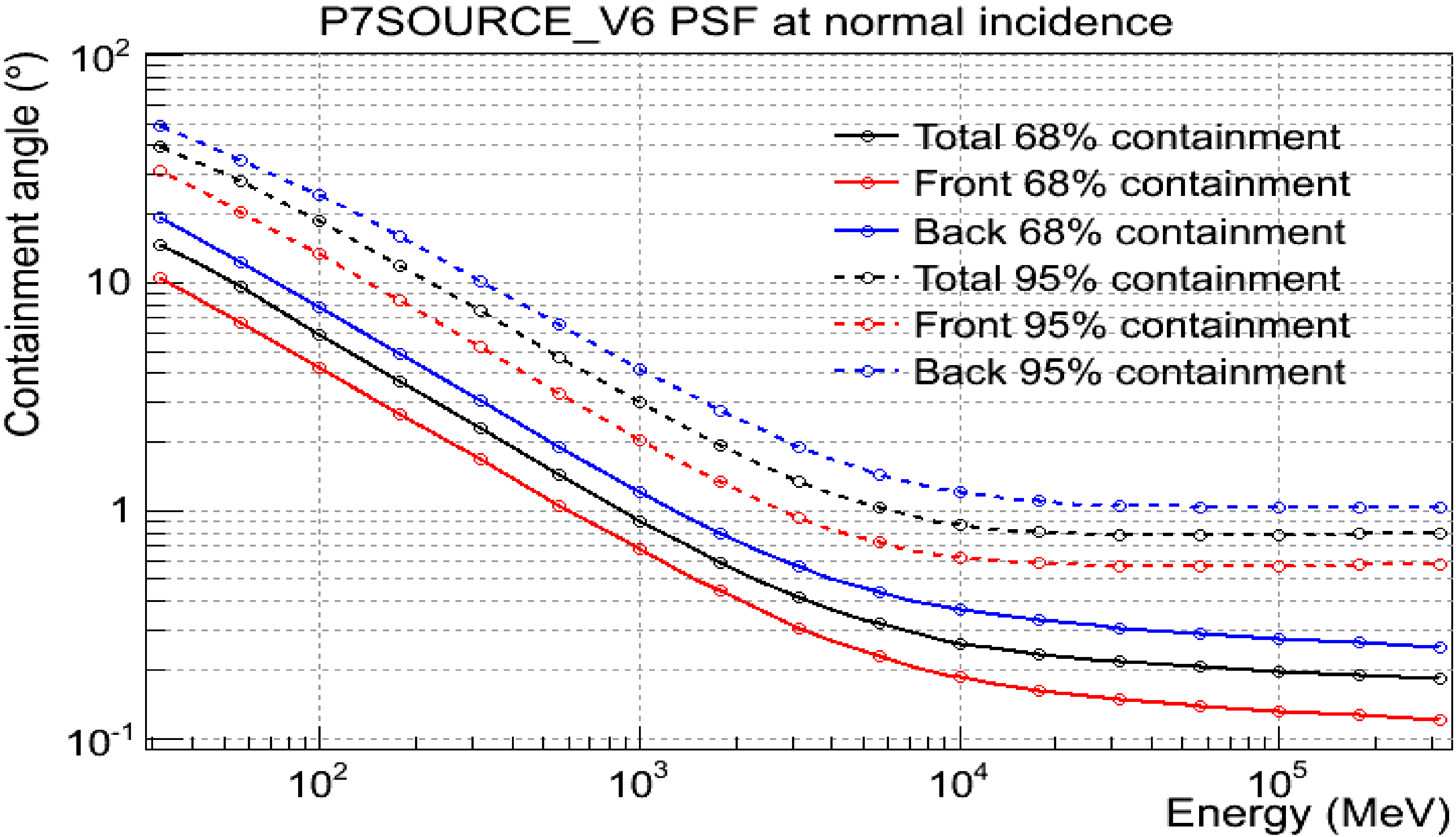


http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Now you know the difference between frontal and rear events. You can then select which events to analyze depending on what you are studying.
For example, if you are interested in regions with high flux and many sources, you can use only frontal events.

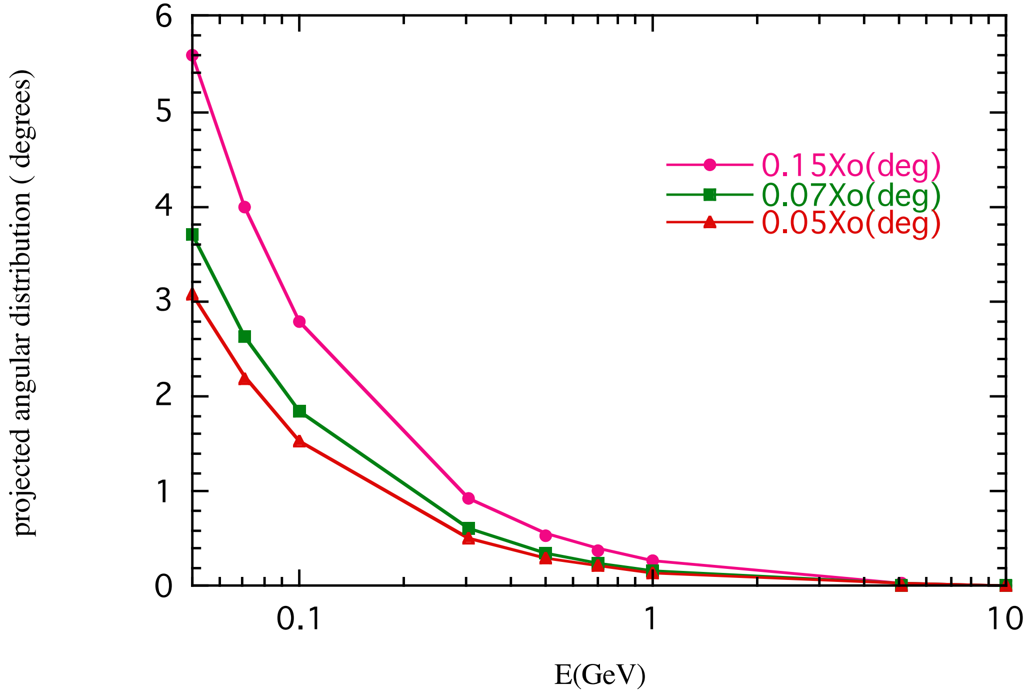
If you are interested in high-energy studies,
you can use all events (rear + frontal)
because at high energies, multiple scattering is negligible
and the statistics are low.

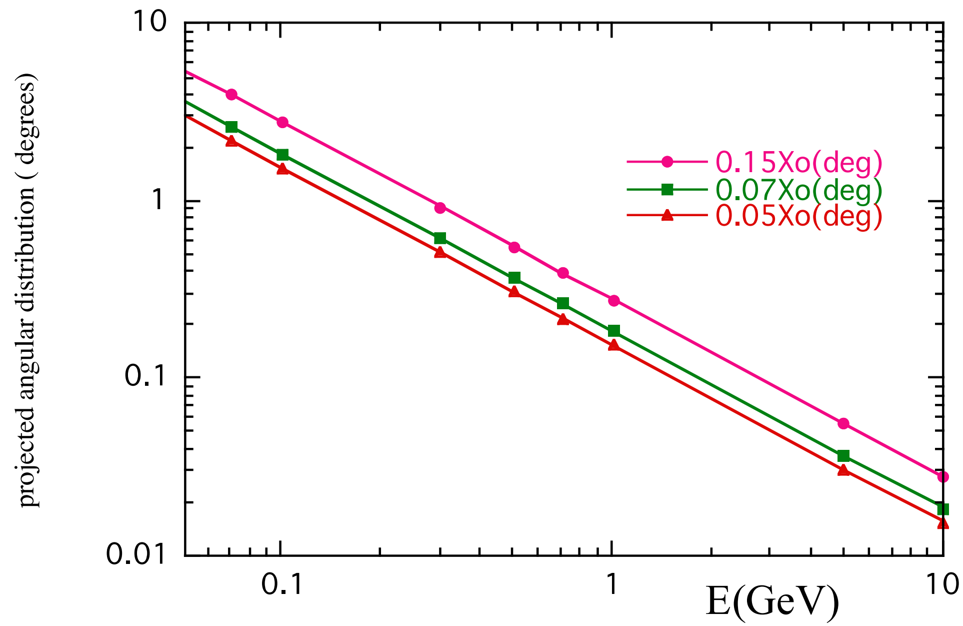
Fermi Instrument Response Function



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

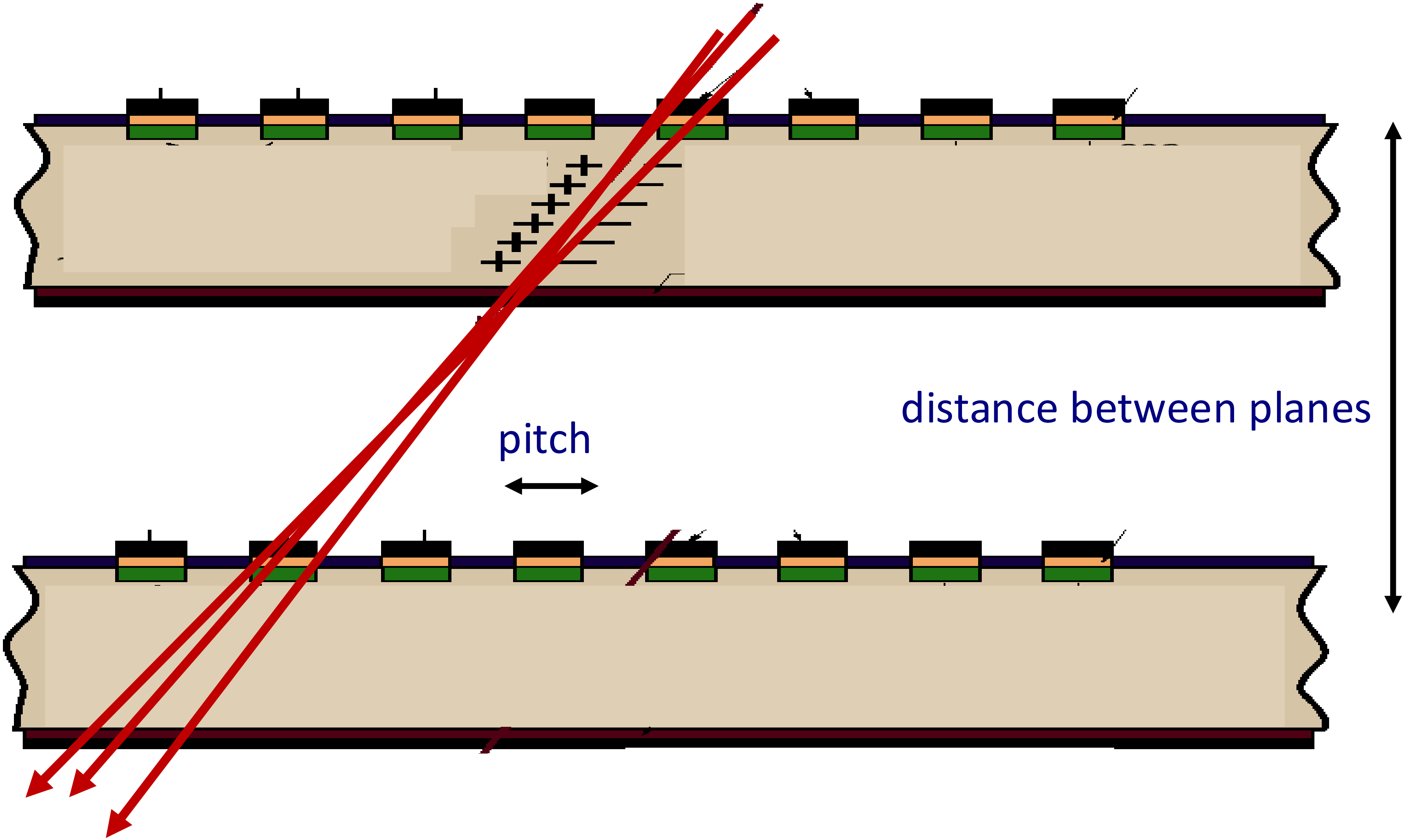
Multiple Scattering





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

$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\left[1 + 0.038\ln\left(x/X_0\right)\right]$$


pitch
distance between planes

The first part of the angular resolution curve is due to multiple scattering.
The second part is flat and depends on the geometric configuration.
i.e. depends on the ratio between the pich and the distance between the planes

$N\gamma_s$ = number of photons from source
$N\gamma_B$ = number of photons from background
$\Delta\Omega$ = solid angle around dth source
A_{eff} = Effective area (Area* efficiency)
x = converter plane in radiation lengh

Sensitivity

depends on field of view

$$N_{\gamma s} = \Phi_s(cm^{-2}) * A_{eff} * \Delta T$$

$$N_{\gamma B} = \Phi_B(cm^{-2}sr^{-1}) * \Delta\Omega * A_{eff} * \Delta T$$

depends on angular resolution

Sensitivity

number of σ

$$N_{\gamma s} \geq 5(N_{\gamma B})^{-\frac{1}{2}}$$

$$\Delta\Omega \sim \pi\theta^2 \sim \pi E^{-2} x$$

$$\Phi_s \geq \frac{5}{E}\left(\frac{\Phi_B * x}{A_{eff} * \Delta T}\right)^{-\frac{1}{2}}$$

good detector

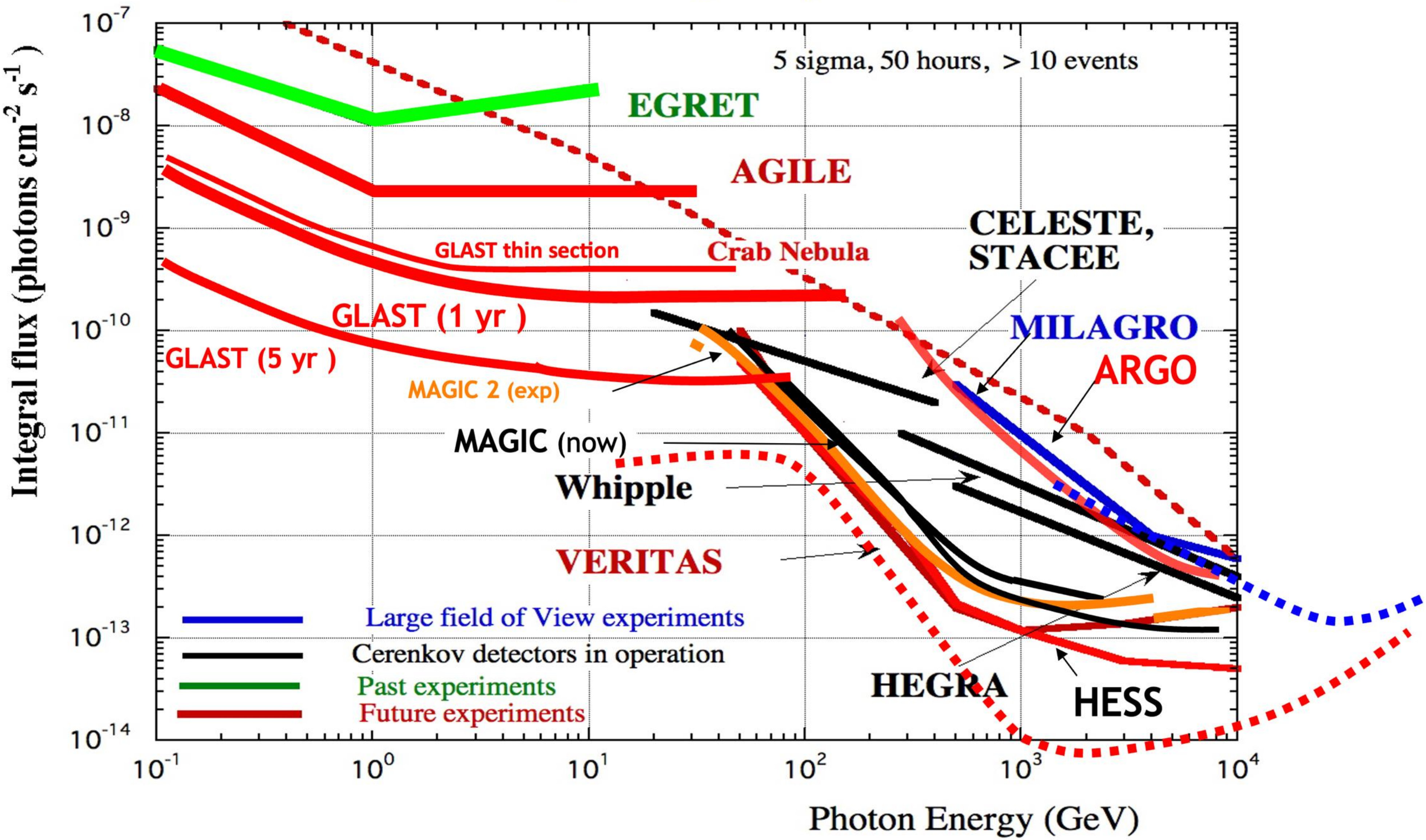
small converter plane

$$\Phi_s \geq \frac{5}{E}\left(\frac{\Phi_B * x}{A_{eff} * \Delta T}\right)^{-\frac{1}{2}}$$

large effective area
(large geometric area and large total conversion efficiency)

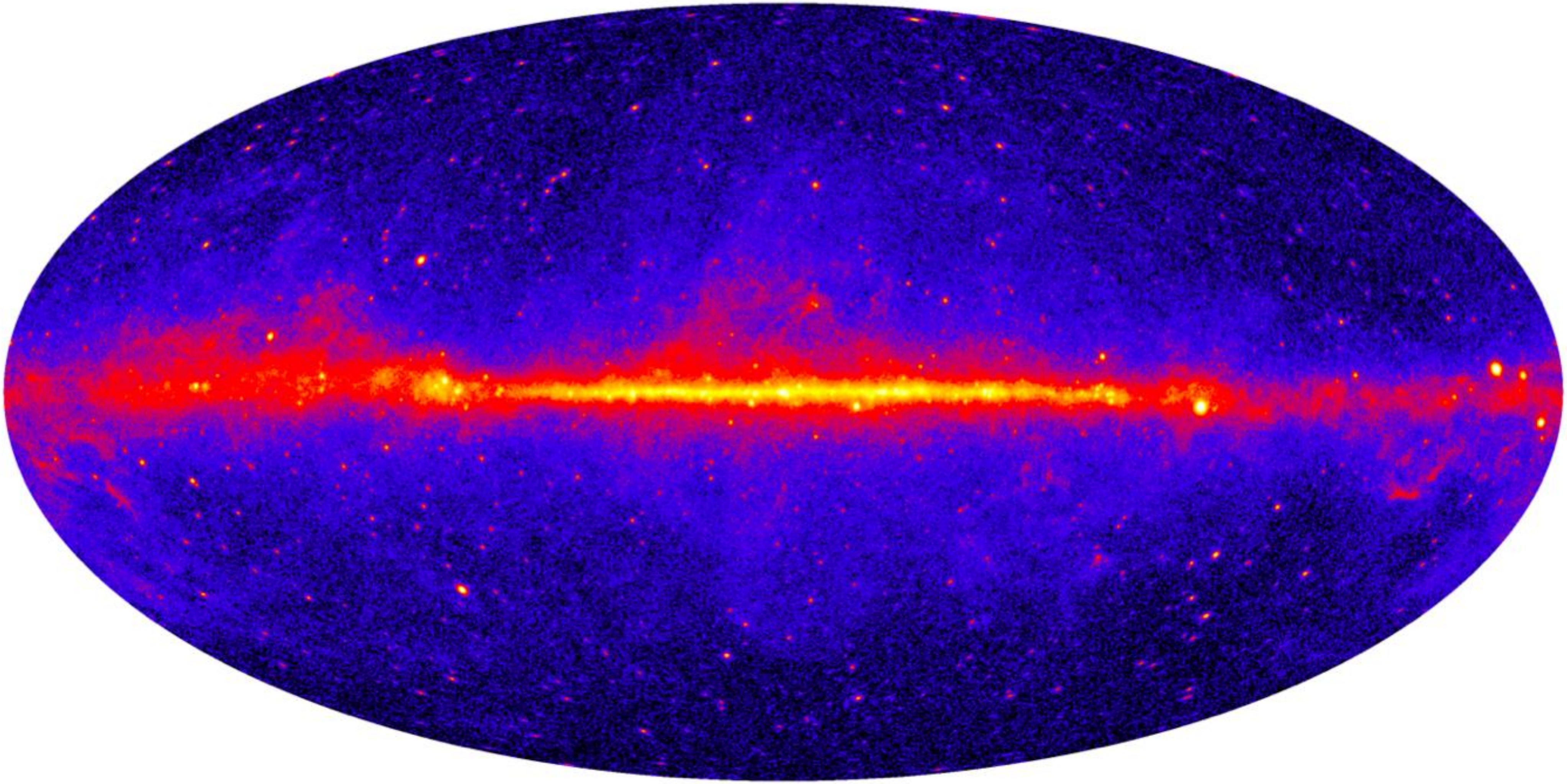
large field of view

Sensitivity of γ-ray detectors



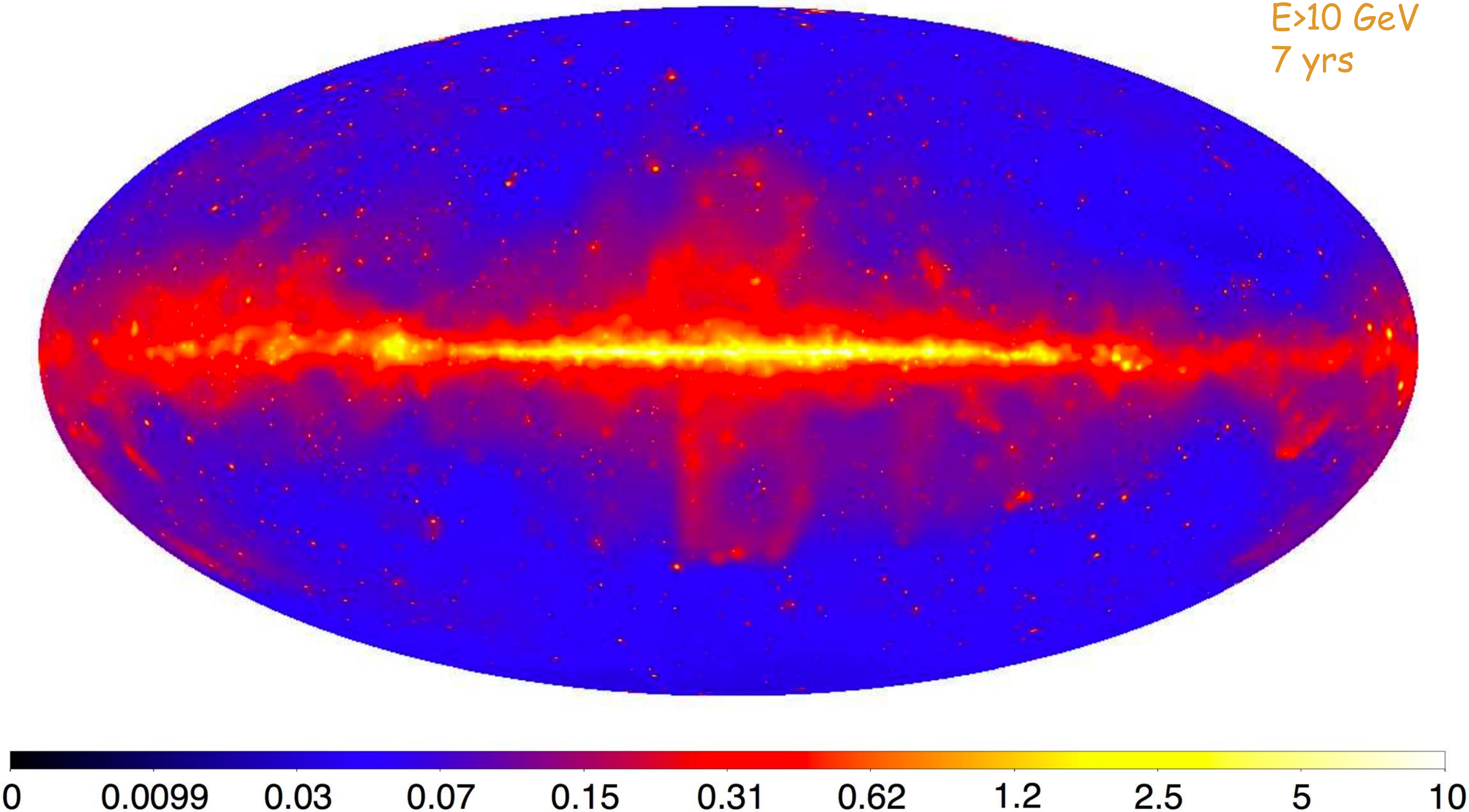
The Fermi LAT gamma-ray sky

3-year all-sky map, E > 1 GeV



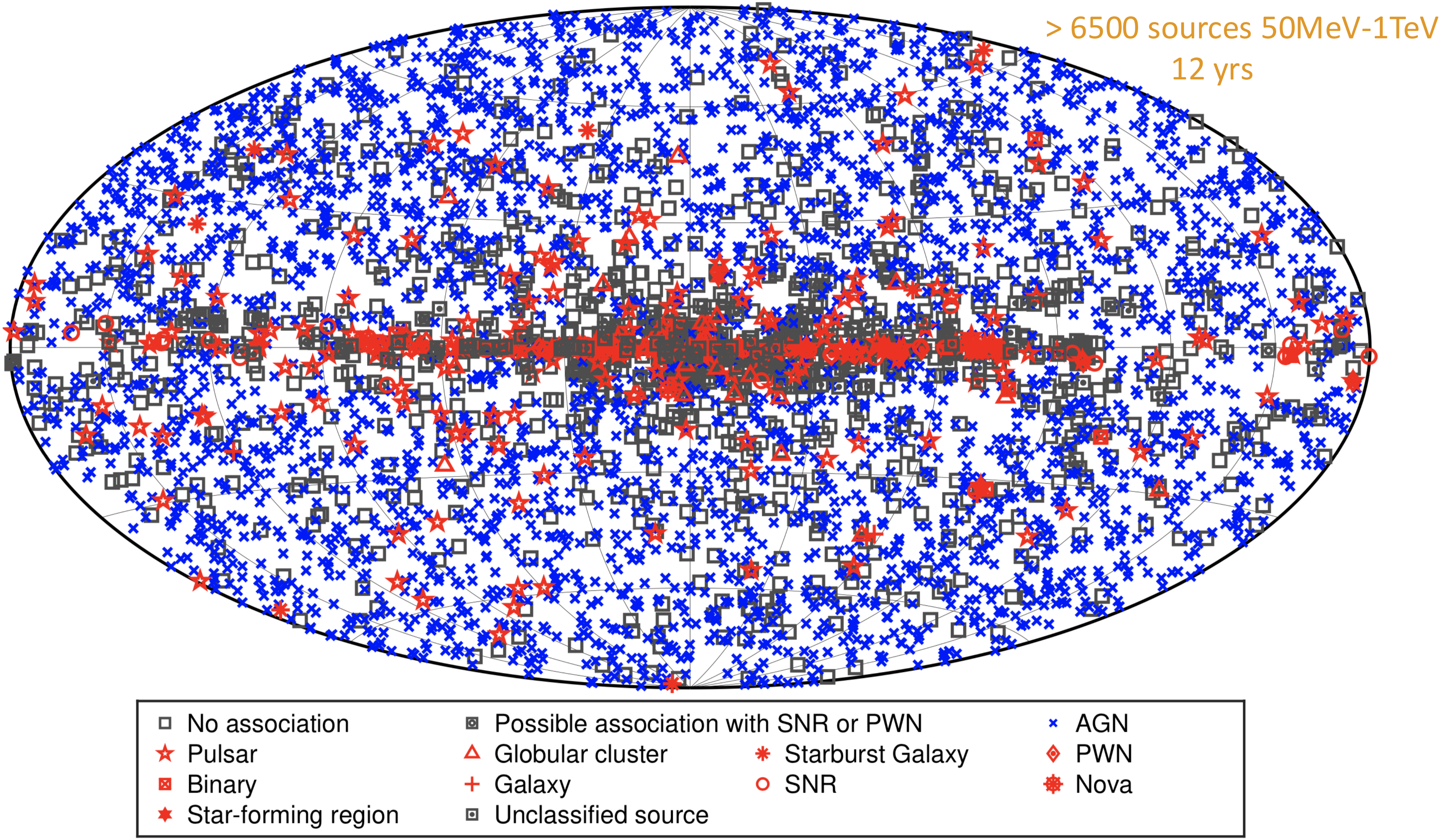
The sky in gamma-rays

E>10 GeV
7 yrs



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

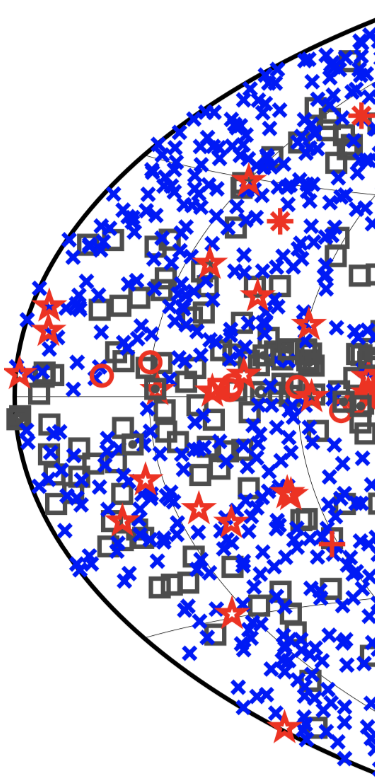
The sky in gamma-rays 4th source catalog



Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045 +Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

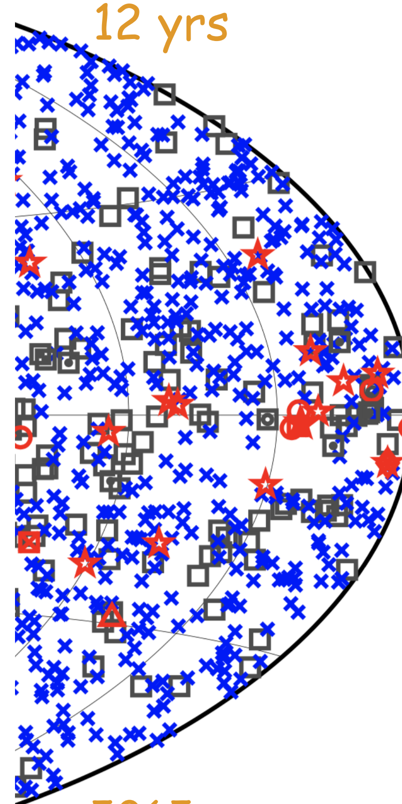
The sky in gamma-rays 4th source catalog

50MeV-1TeV
12 yrs



Description	Identified Designator	Identified Number	Associated Designator	Associated Number
Galactic center	GC	1	...	...
Young pulsars, identified by pulsations	PSR	135	...	...
Young pulsars, no pulsations seen in LAT yet	...	...	psr	2
Millisecond pulsars, identified by pulsations	MSP	120	...	...
Millisecond pulsars, no pulsations seen in LAT yet	...	...	msp	35
Pulsar wind nebula	PWN	11	pwn	8
Supernova remnant	SNR	24	snr	19
Supernova remnant / Pulsar wind nebula	SPP	0	spp	114
Globular cluster	GLC	0	glc	35
Star-forming region	SFR	3	sfr	2
High-mass binary	HMB	8	hmb	3
Low-mass binary	LMB	2	lmb	6
Binary	BIN	1	bin	6
Nova	NOV	4	nov	0
BL Lac type of blazar	BLL	22	bll	1435
FSRQ type of blazar	FSRQ	44	fsrq	750
Radio galaxy	RDG	6	rdg	39
Nonblazar active galaxy	AGN	1	agn	8
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact steep spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	1	bcu	1491
Narrow-line Seyfert 1	NLSY1	4	nlsy1	4
Seyfert galaxy	SEY	0	sey	2
Starburst galaxy	SBG	0	sbg	8
Normal galaxy (or part)	GAL	2	gal	4
Unknown	UNK	0	unk	134
Total	...	389	...	4112
Unassociated	...	...	...	2157

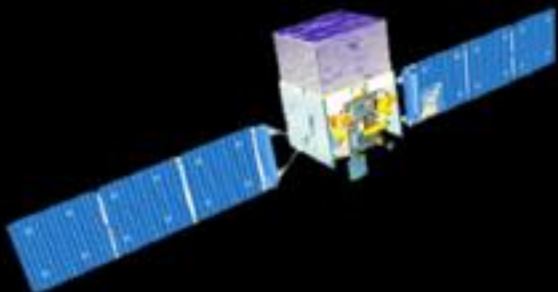
NOTE—The designation 'spp' indicates potential association with SNR or PWN. 'Unknown' are $|b| < 10°$ sources solely associated with the likelihood-ratio method from large radio and X-ray surveys. Designations shown in capital letters are firm identifications; lower-case letters indicate associations.

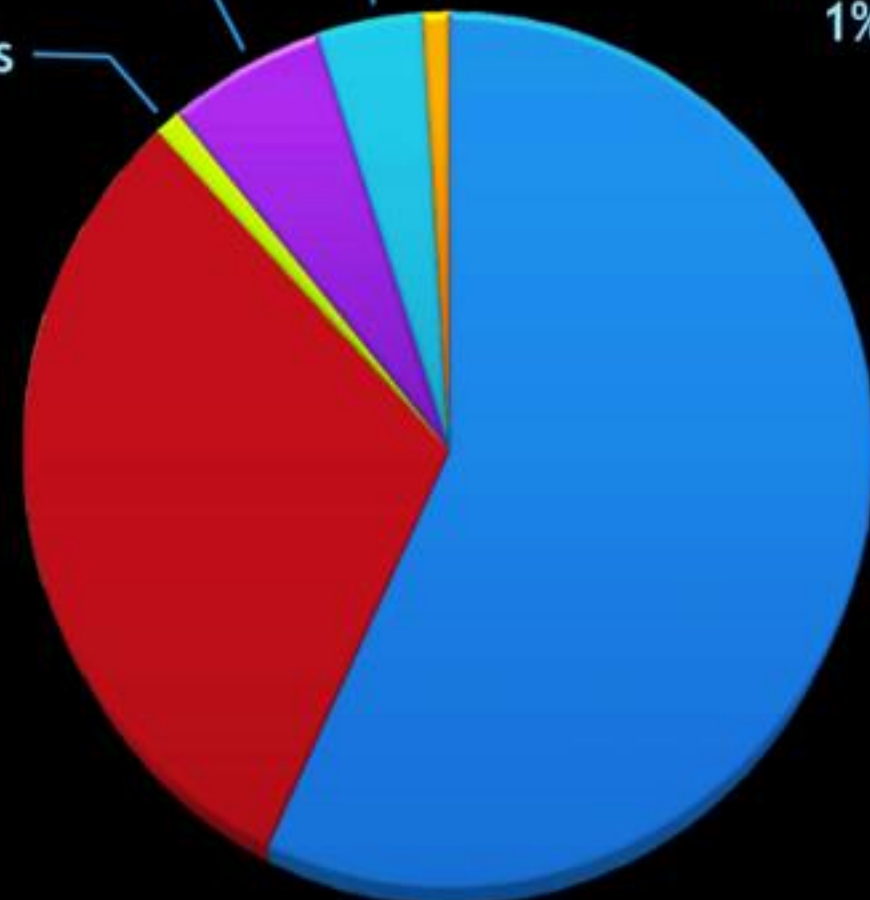


5065 sources
galactic coordinates

Fermi Fourth Source Catalog, The Astrophysical Journal ss, 247; 33 March 2020 [arXiv:1902.10045 +Incremental
Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

What has Fermi found: The LAT two-year catalog





Gamma Astronomy has revealed a a *very rich, fascinating landscape*

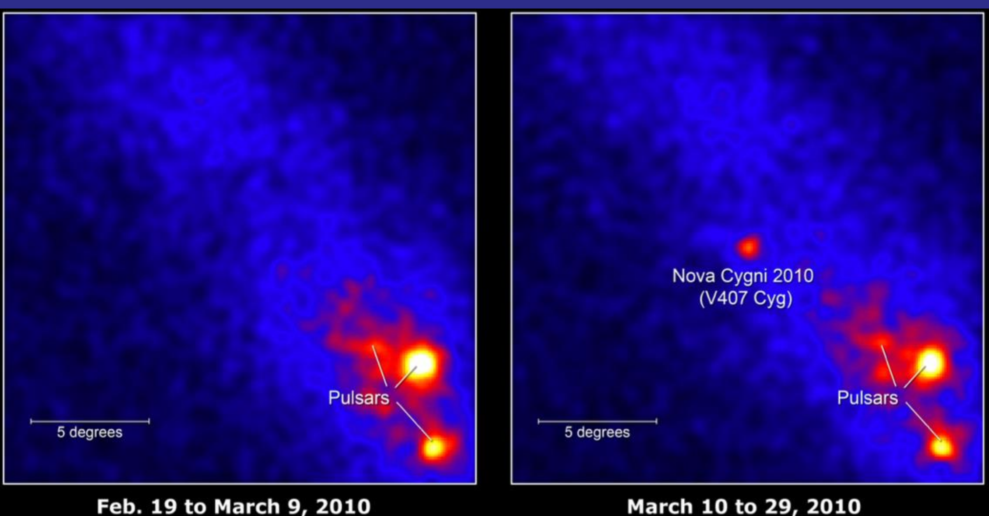
•Many sources have been identified [GeV , TeV ranges]

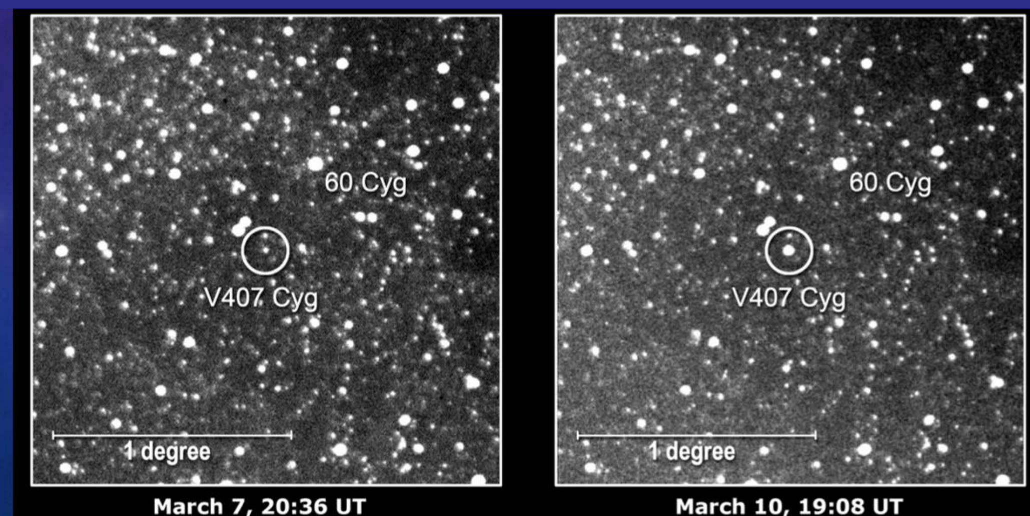
•Several classes of objects
[SNR, Pulsars, PWN, AGN, GRB, ...]

•Probably different acceleration mechanisms.

Still developing an understanding many questions remain open

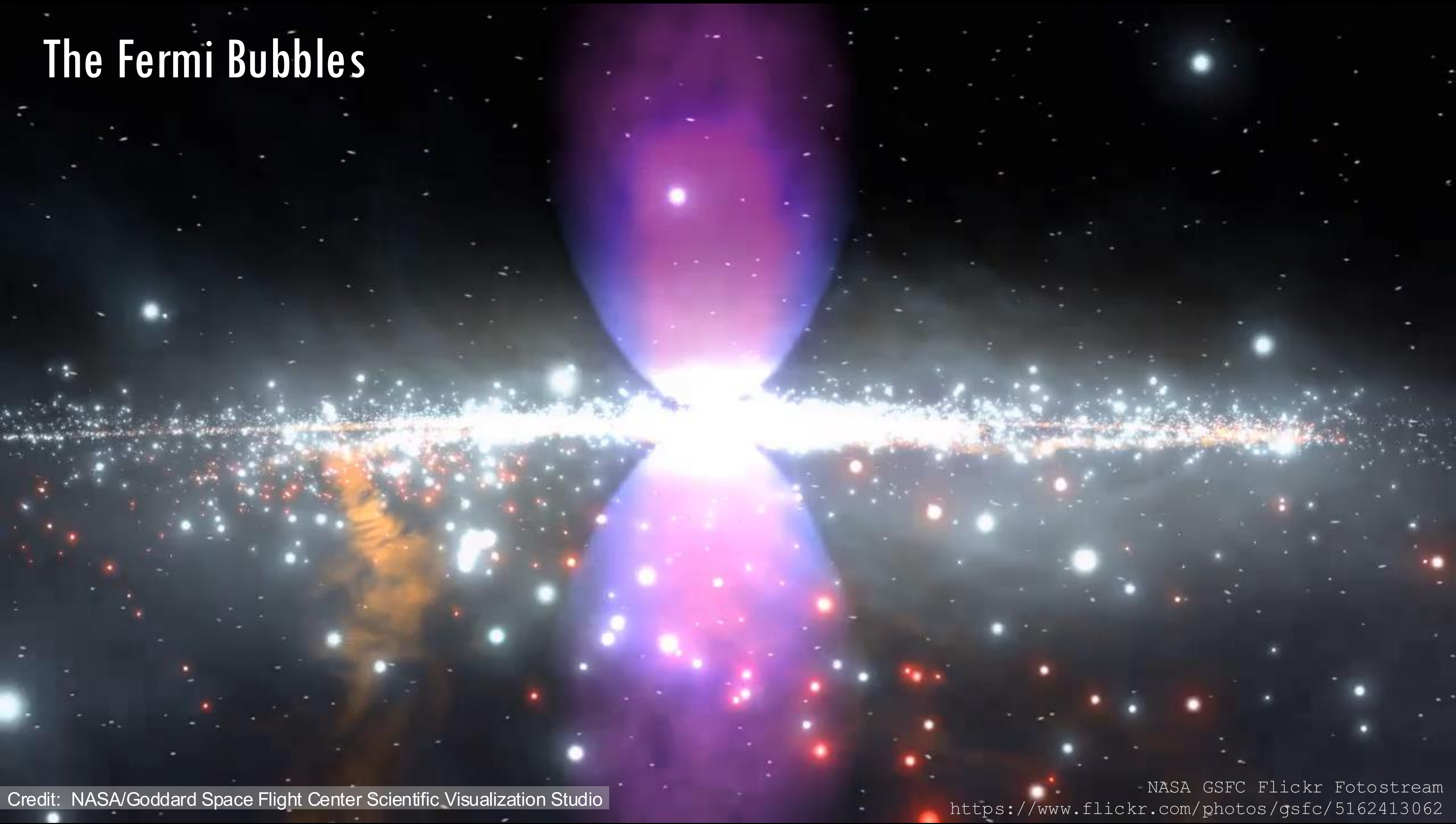
ASSOCIATION: SNR, PWN, BINARY AND NOVAE





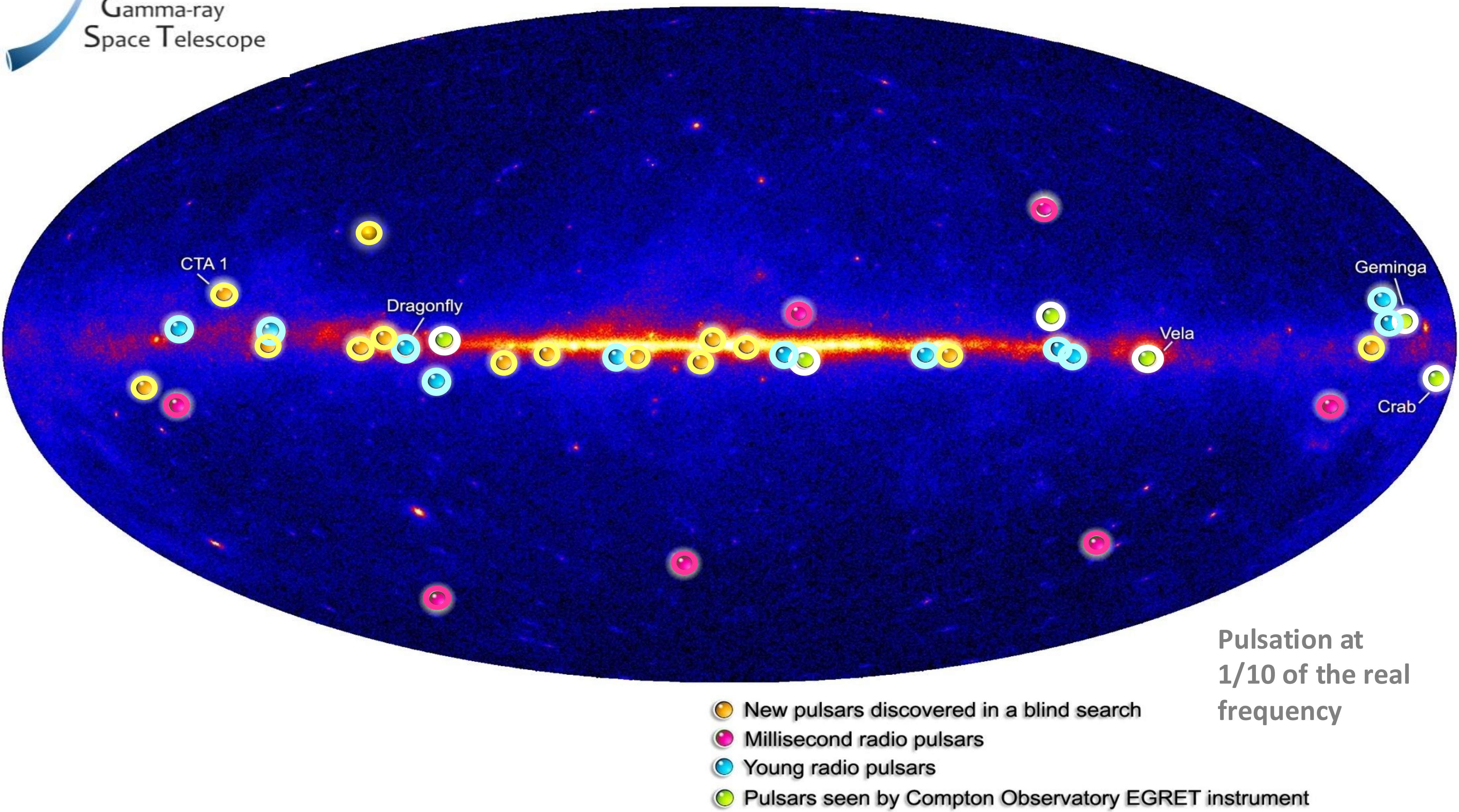
- for these classes of sources we rely on the images on optical and spatial coincidence

The Fermi Bubbles



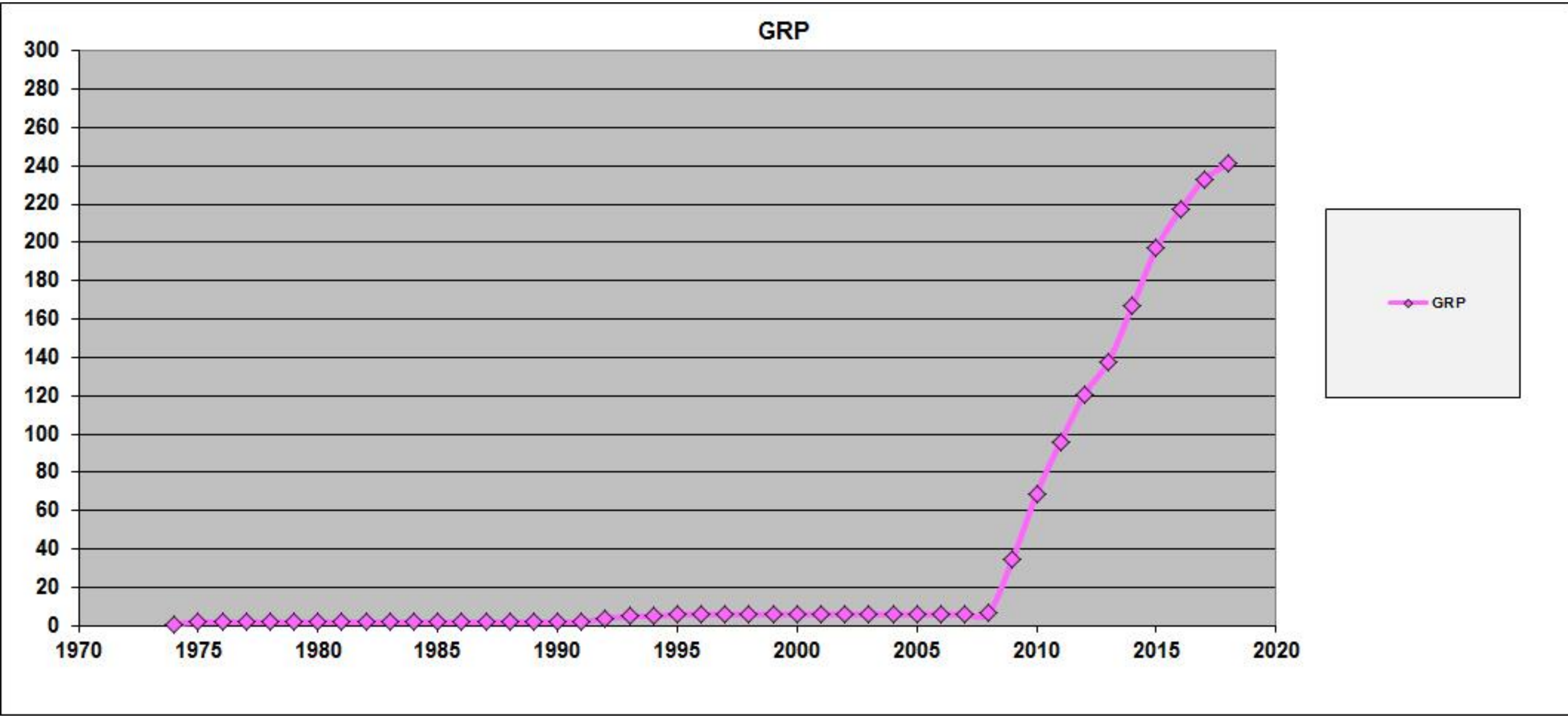
Fermi
Gamma-ray Space Telescope

The pulsating gamma rays sky



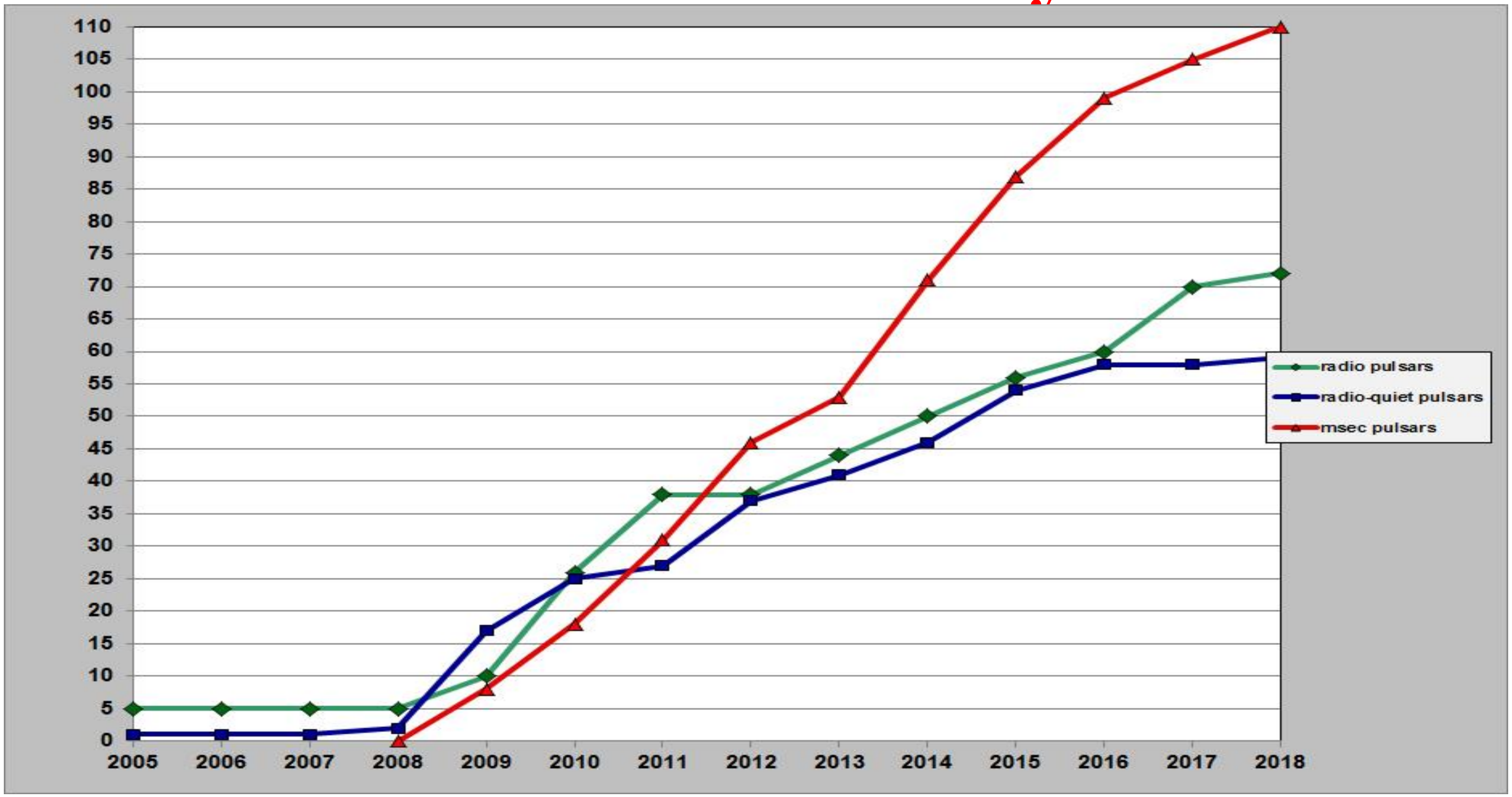
Pulsation at 1/10 of the real frequency

γ-ray PULSAR CENSUS



Not just an increase in number

Diverse Family

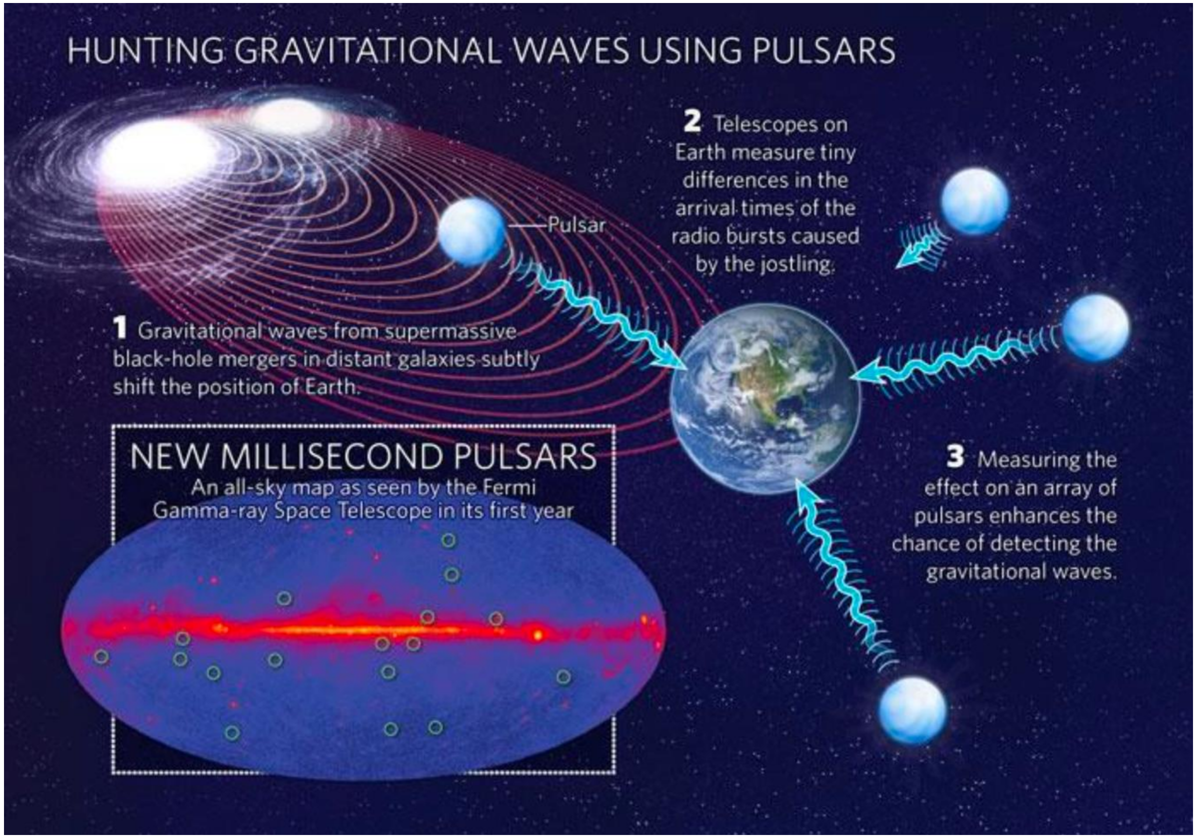


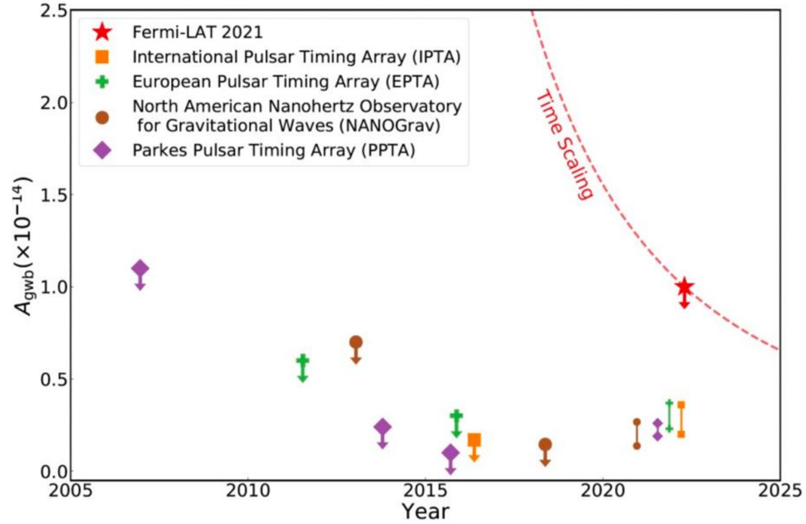
millisecond pulsars - can be explained by assuming that all of the millisecond pulsars were originally in orbit with another star. After the pulsar formed, matter was pulled from the companion star on to the pulsar. During this process the pulsar rotated faster and faster until it became one of the millisecond pulsars. Later, the companion star died and became either a white dwarf, neutron star or black hole depending on its original size. If the companion star remained in orbit with the pulsar, a binary millisecond pulsar system would be formed.

Fermi LAT pulsars

Gravitational waves can be detected by monitoring the times of arrival of the steady pulses from each pulsar, which arrive earlier or later than expected due to the spacetime perturbations.

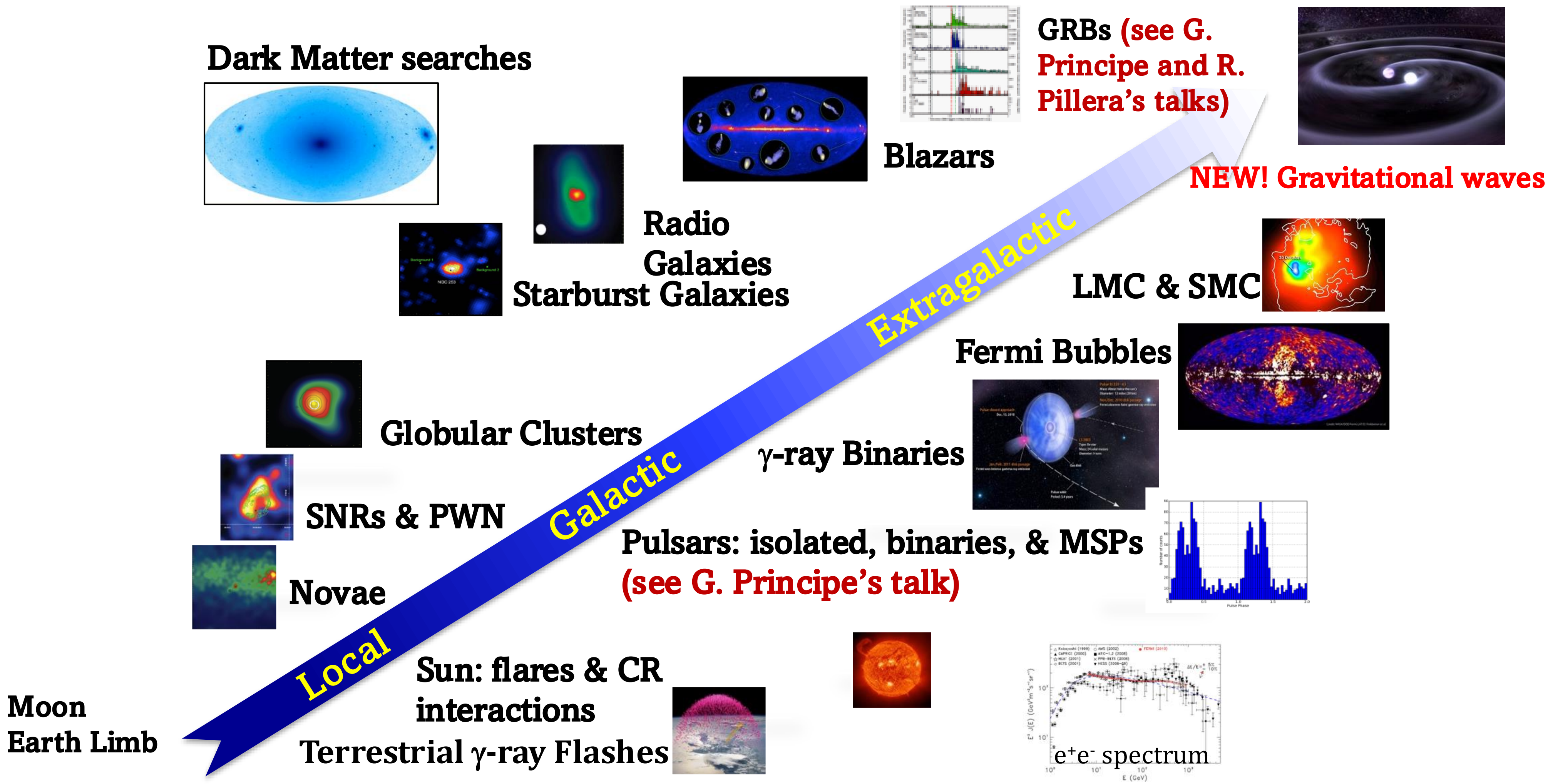
- After large galaxies merge, their central supermassive black holes (SMBH) are expected to form binary systems whose orbital motion generates a *gravitational wave background* (GWB) at nHz frequencies.
- Using 12.5 years of LAT data to form a gamma-ray pulsar timing array (PTA) formed by 35 bright gamma-ray pulsars, it was possible to constrain the emission from the gravitational wave background (GWB).





A gamma-ray pulsar timing array constrains the nanohertz gravitational wave background Science 376 (6592) April 2022 [arxiv:2204.05226]

Science with the Fermi-LAT



Dark Matter Search: Targets and Strategies

Satellites

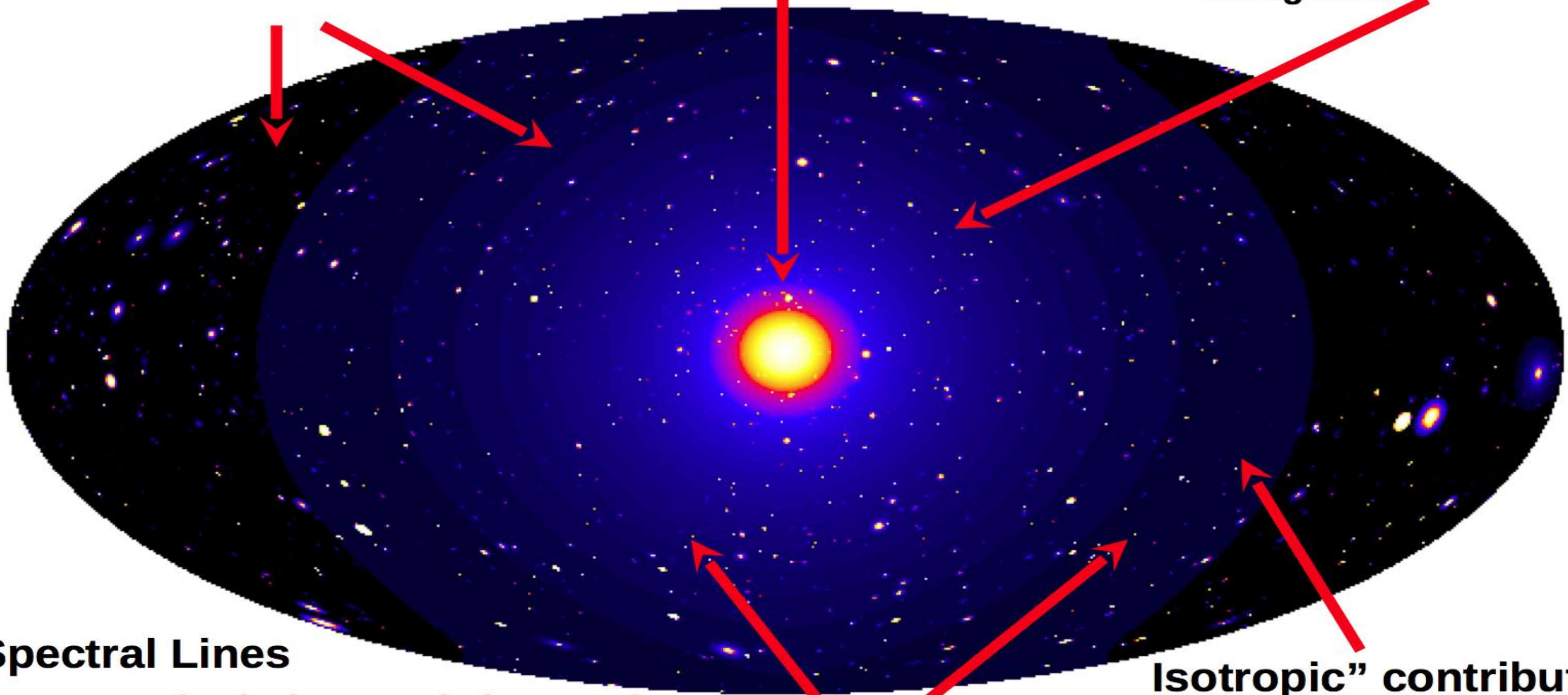
Low background and good source id, but low statistics

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

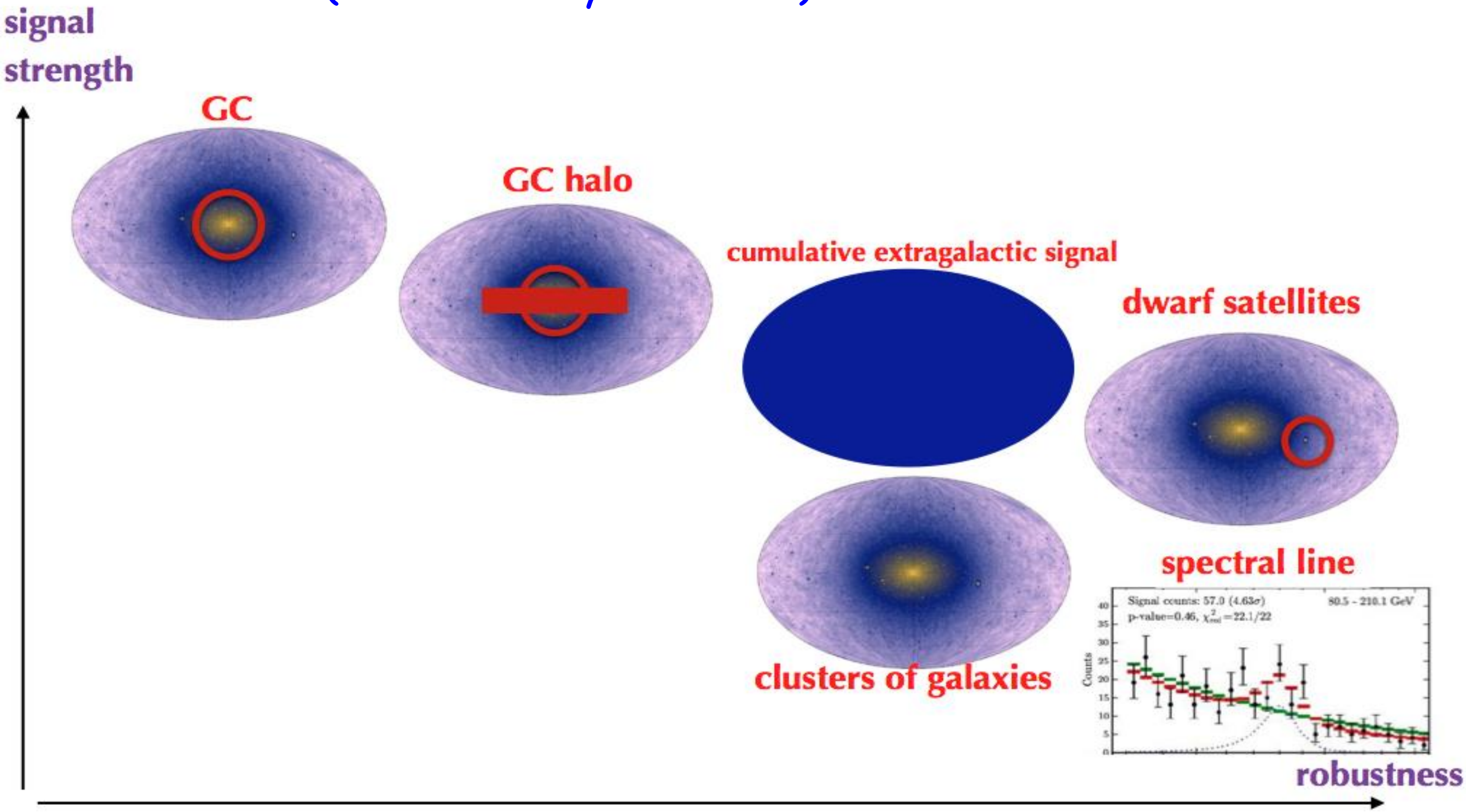
Isotropic” contributions

Large statistics, but astrophysics, galactic diffuse background

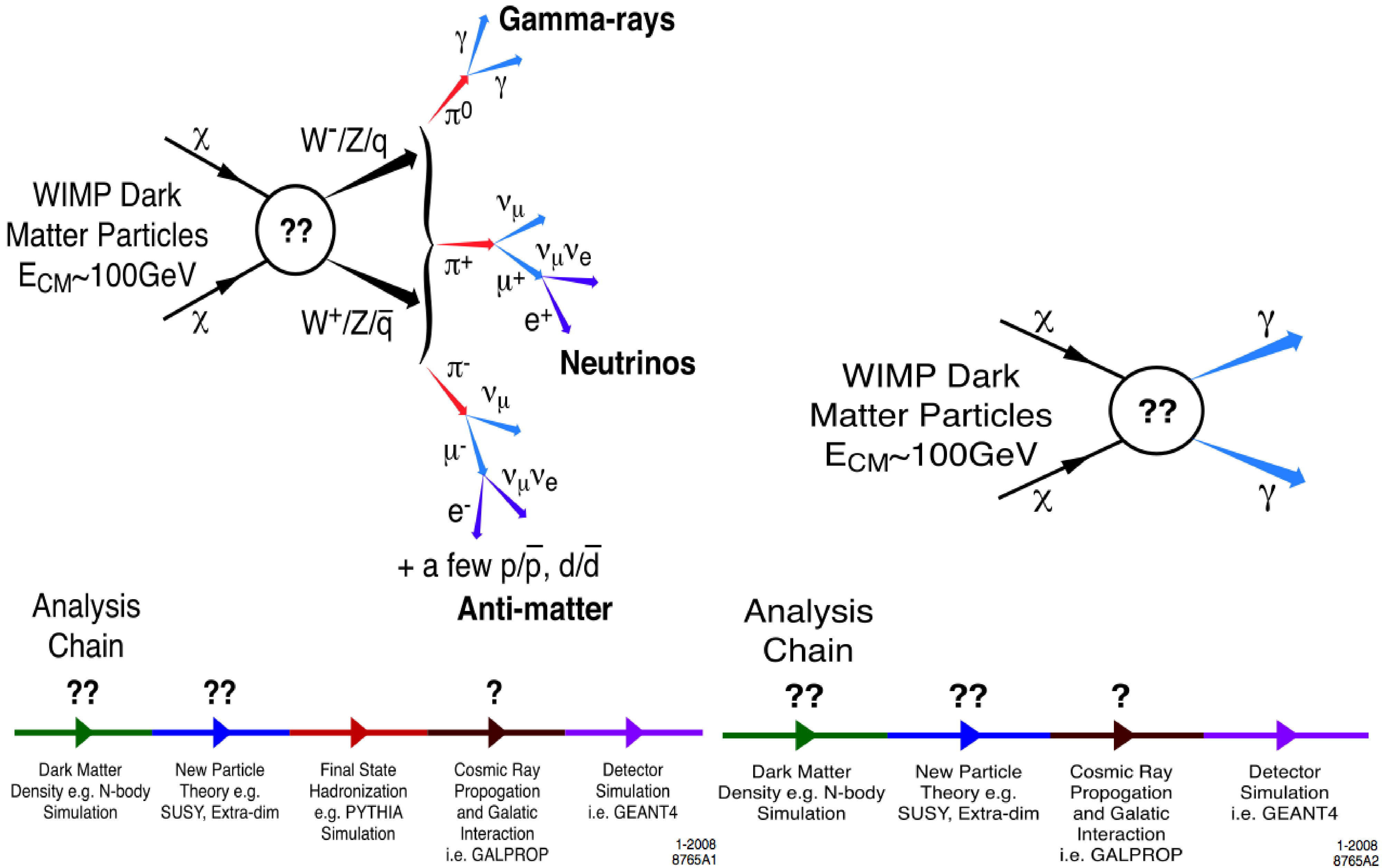
Dark Matter simulation: Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

(Another way to see it)



Annihilation channels

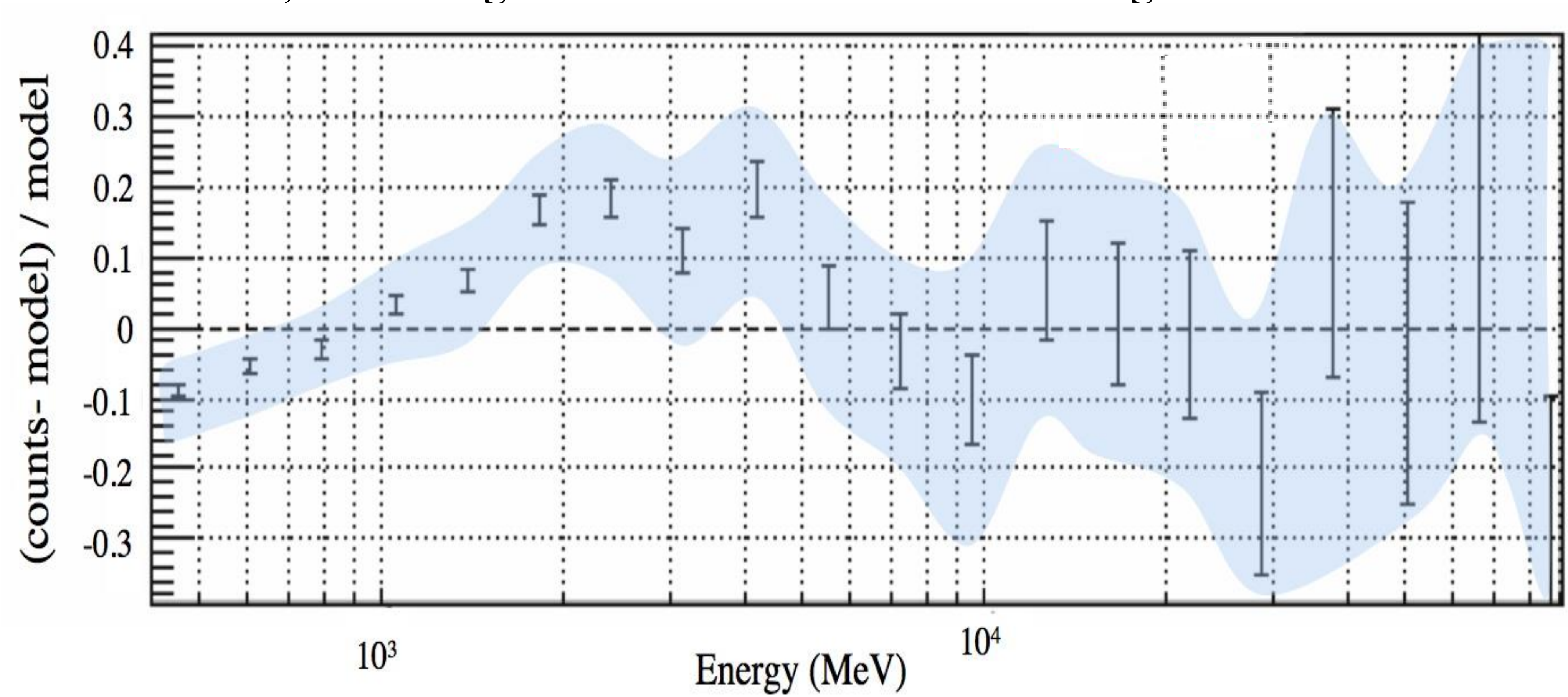


see the Dark matter lessons from Milena Crnogorcevic

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 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**
....

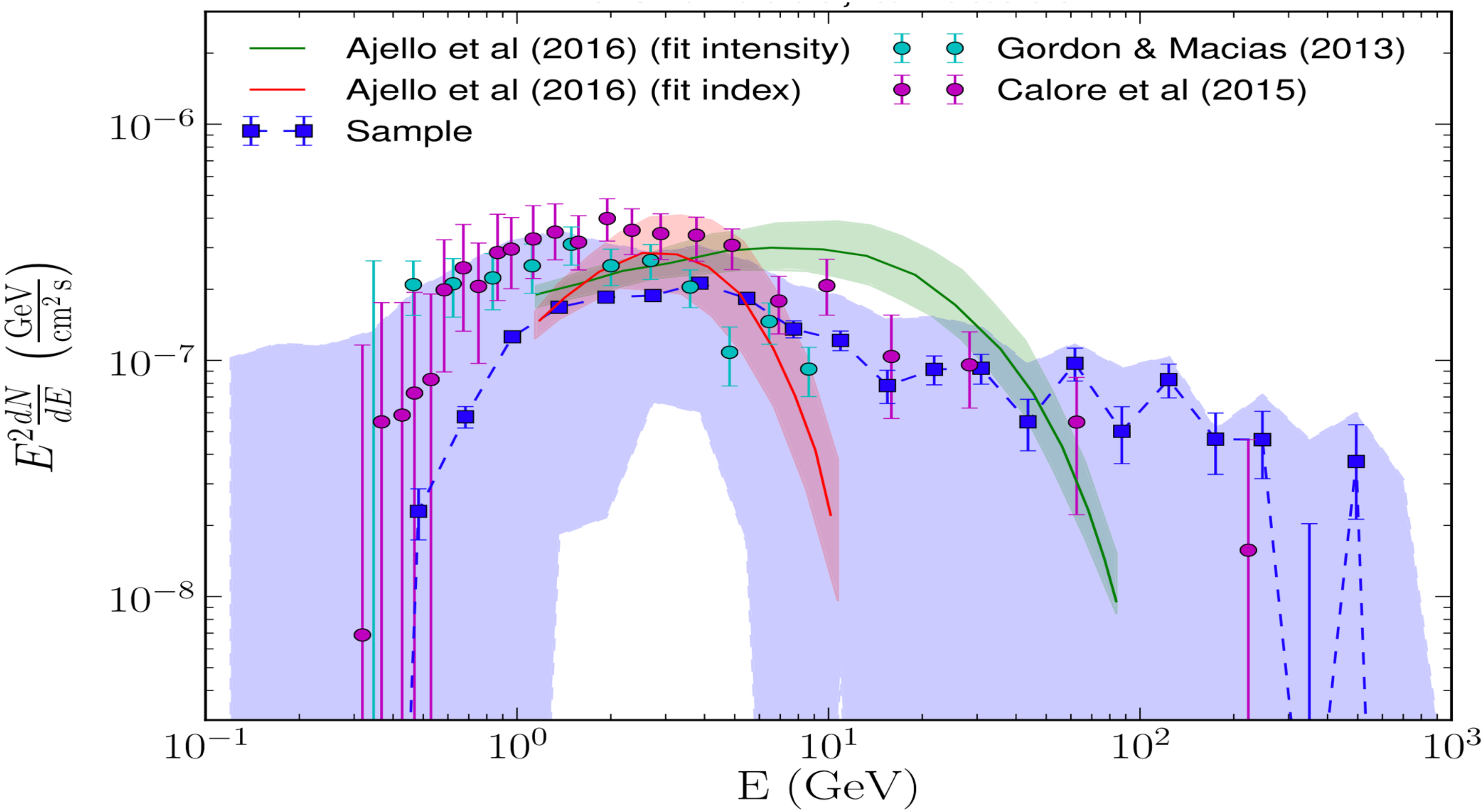
Background model systematics for the Fermi GeV excess
F.Calore, I. Cholis, C. Weniger JCAP03(2015)038 **arXiv:1409.0042v1**

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**

The Fermi galactic center GeV excess and implications for dark matter
M. Ajello et al.[Fermi-LAT Coll.] **Apj 819:44 2016 arXiv:1511.02938**

Revisiting the Gamma-Ray Galactic Center Excess with Multi-Messenger Observations
IC, Zhong, McDermott, Surdutovich, PRD 105, 103023 (2022)

The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

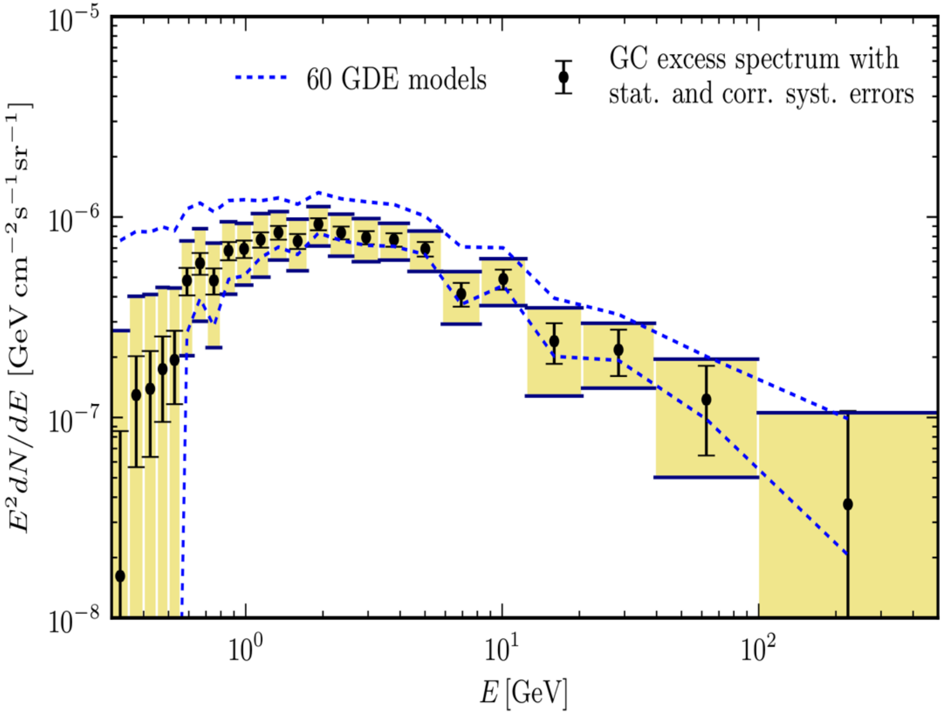
– Variation of GALPROP models – Distribution of gas along the line of sight

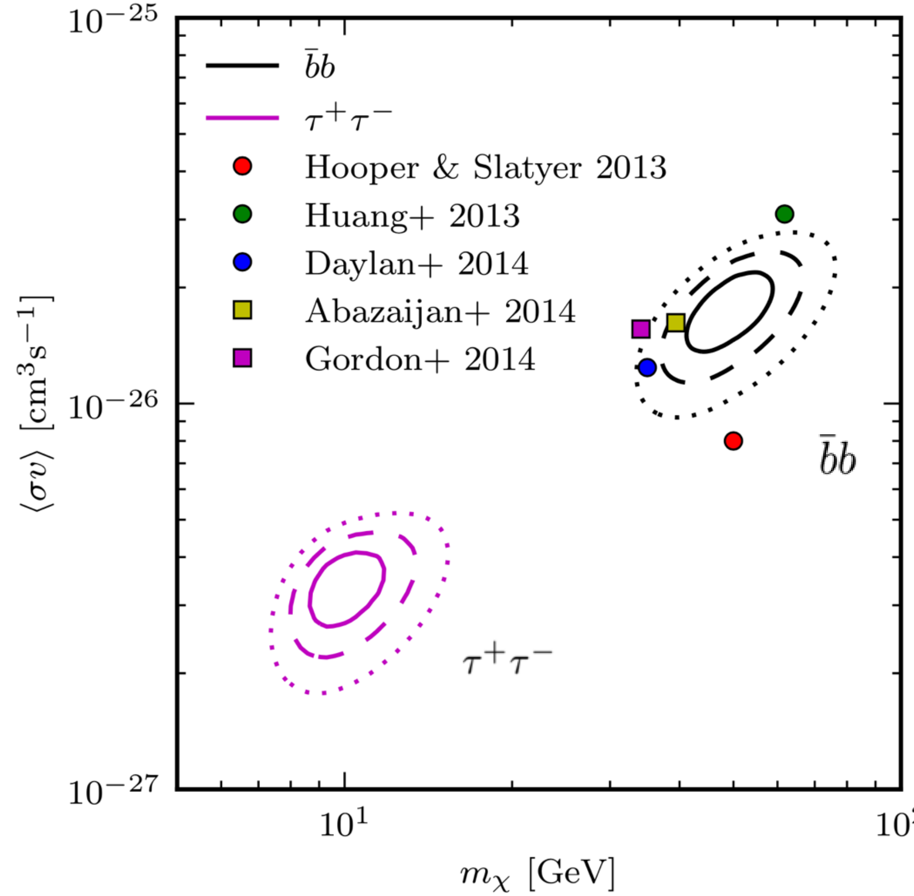
- **Most significant sources of uncertainty are:**

– 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

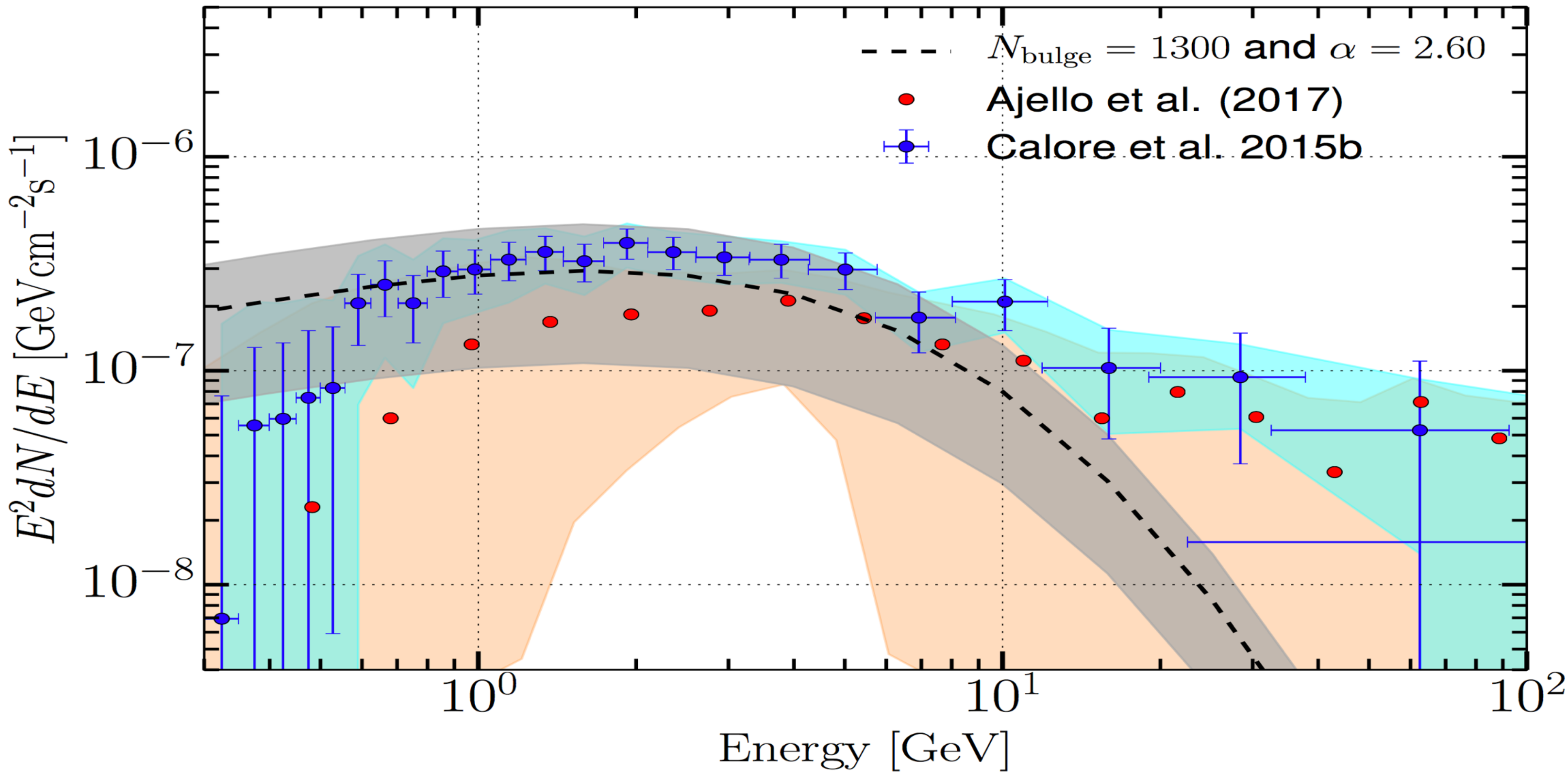




A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

Calore et al., arXiv:1409.0042
Cholis et al., Phys. Rev. D 105, 103023 (2022) arXiv:2112.09706

Population of pulsars in the Galactic bulge and the GeV excess



a population with about 2.7 ©-ray pulsars in the Galactic disk for each pulsar in the Galactic bulge is consistent with the population of known ©-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 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]

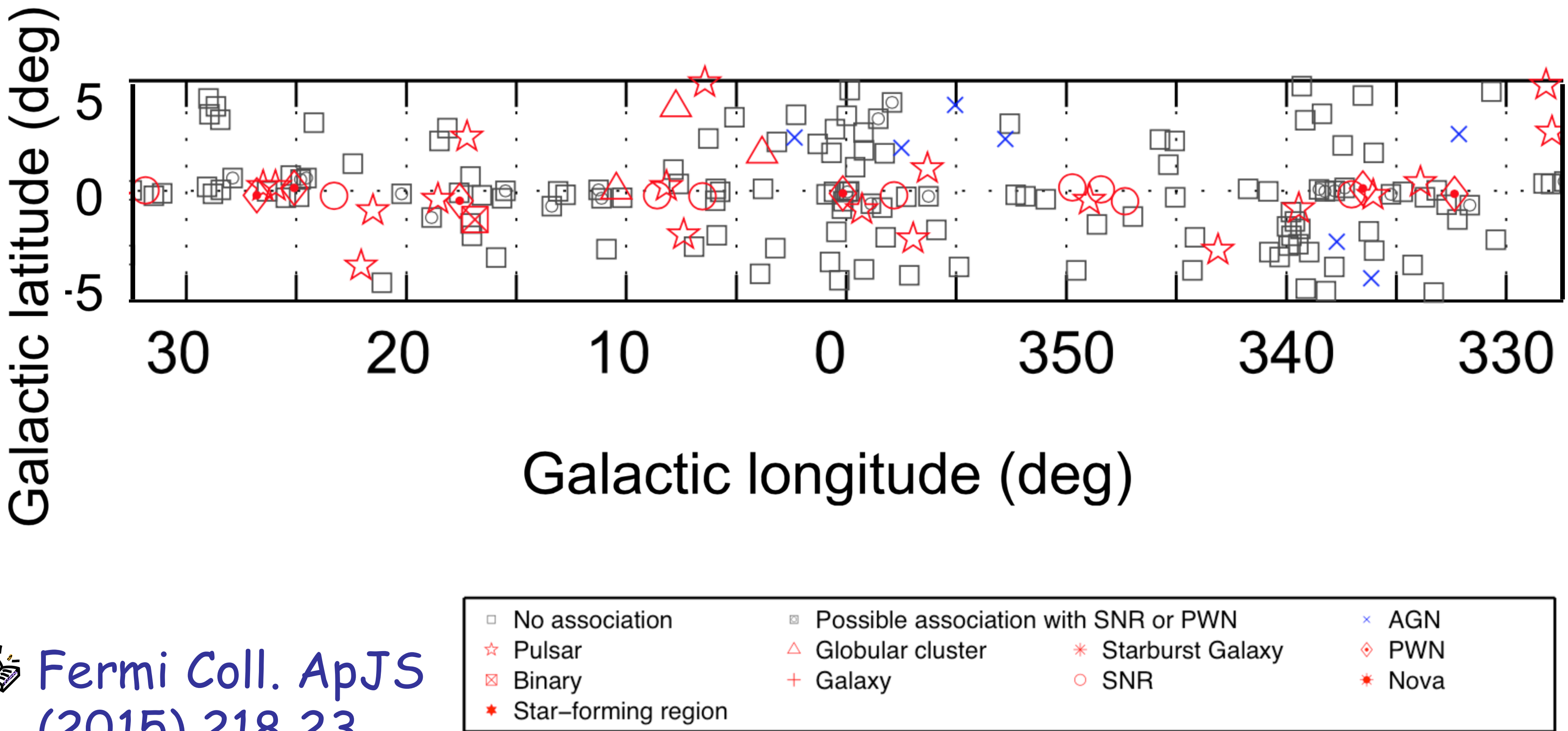
....

How to discriminate between different hypothesis ?

The Fermi LAT 3FGL Inner Galactic Region

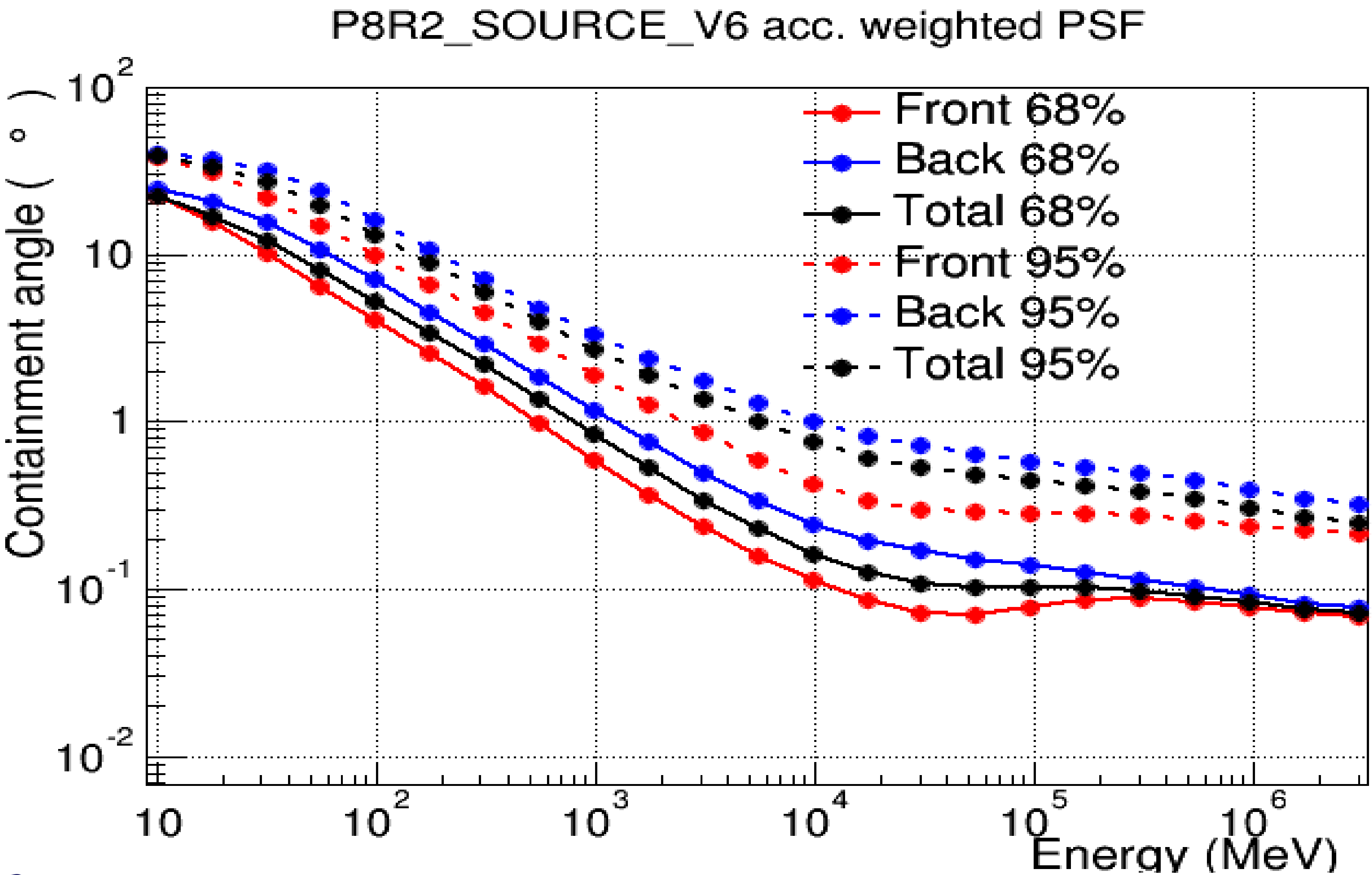
August 4, 2008, to July 31, 2010

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

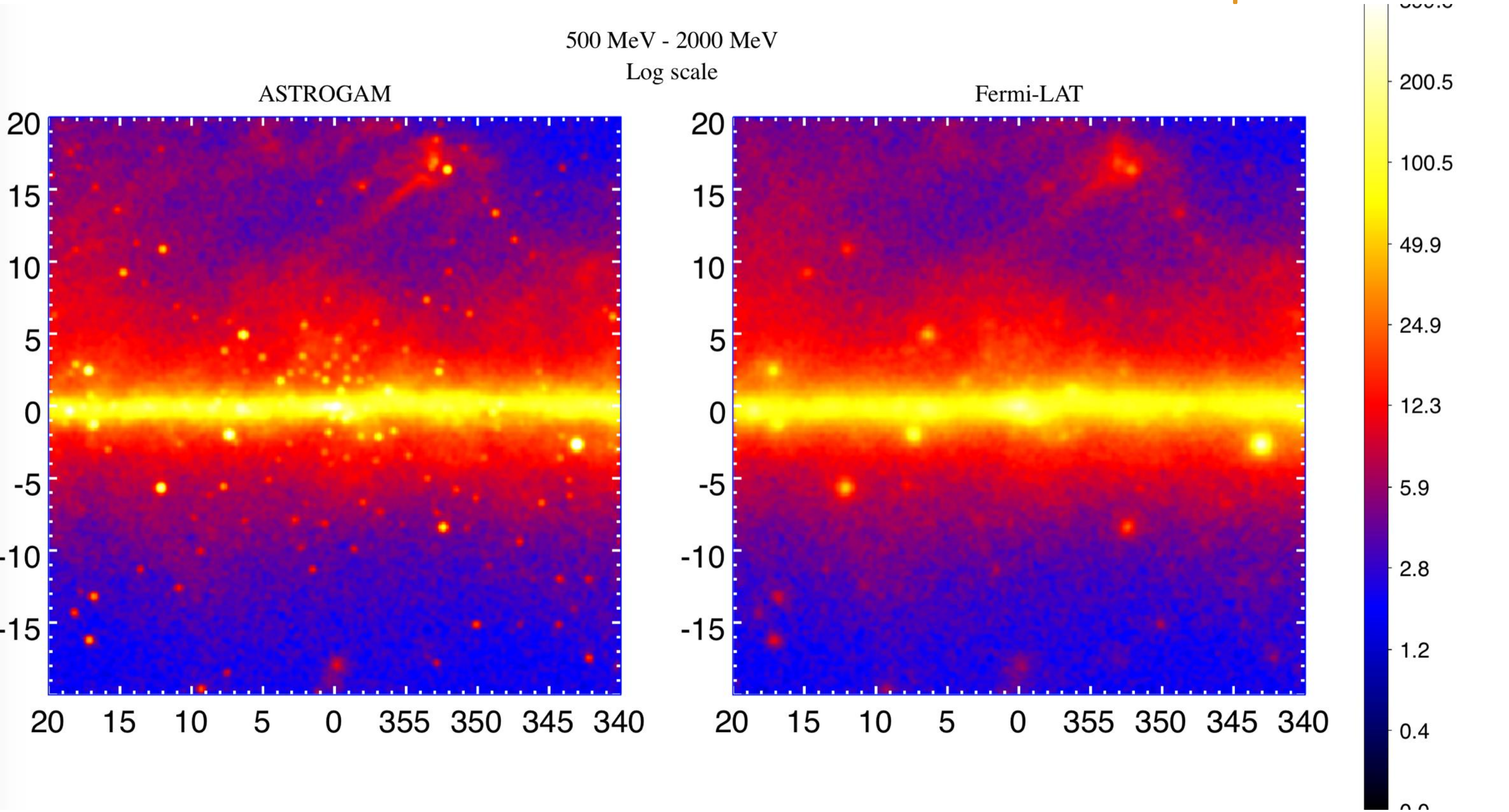
Diffuse emission modeling

Analysis of point sources near the GC

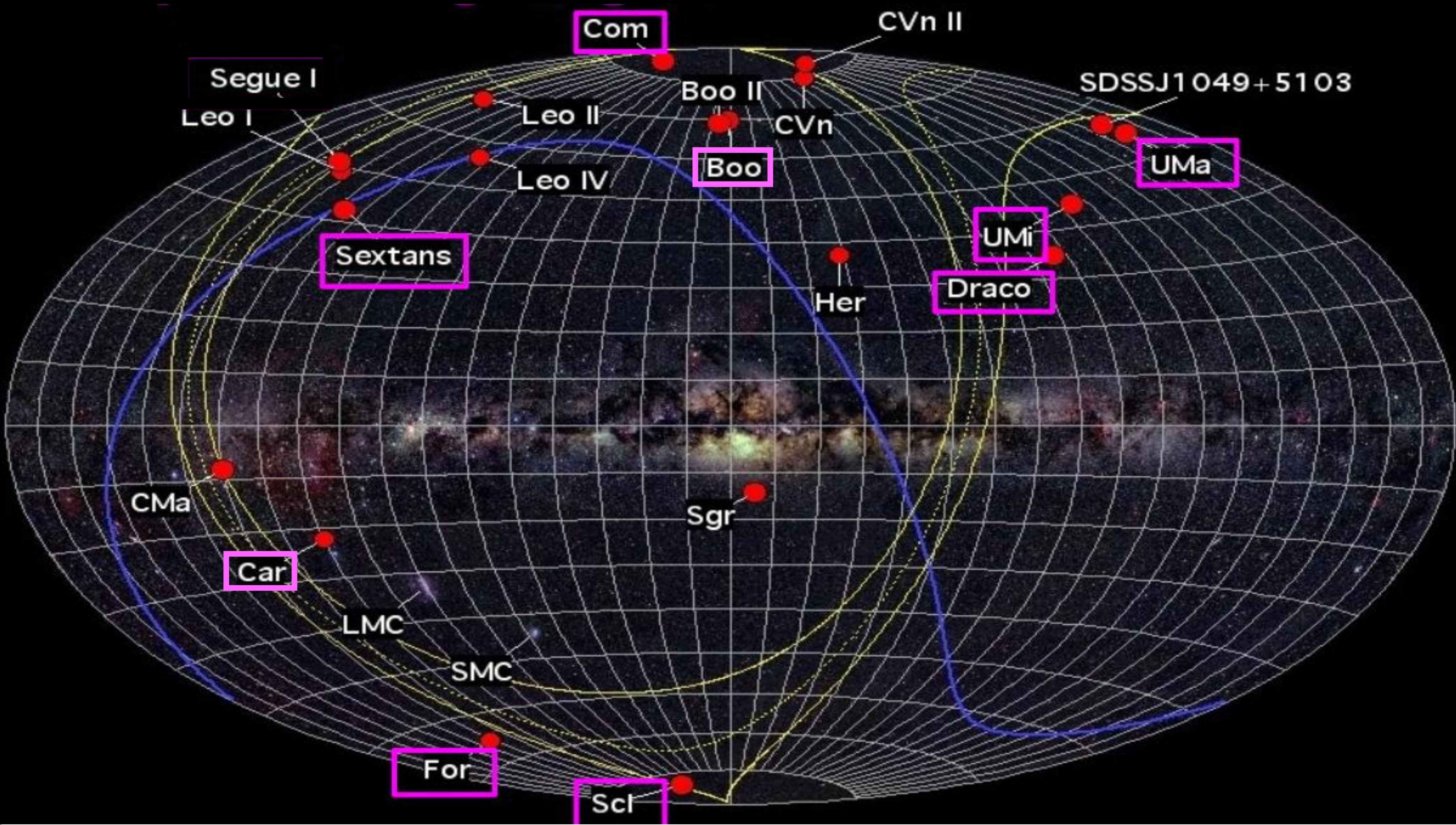
But ultimately We need a new experiment with better angular resolution below 100 MeV

Galactic Center Region 0.5-2 GeV

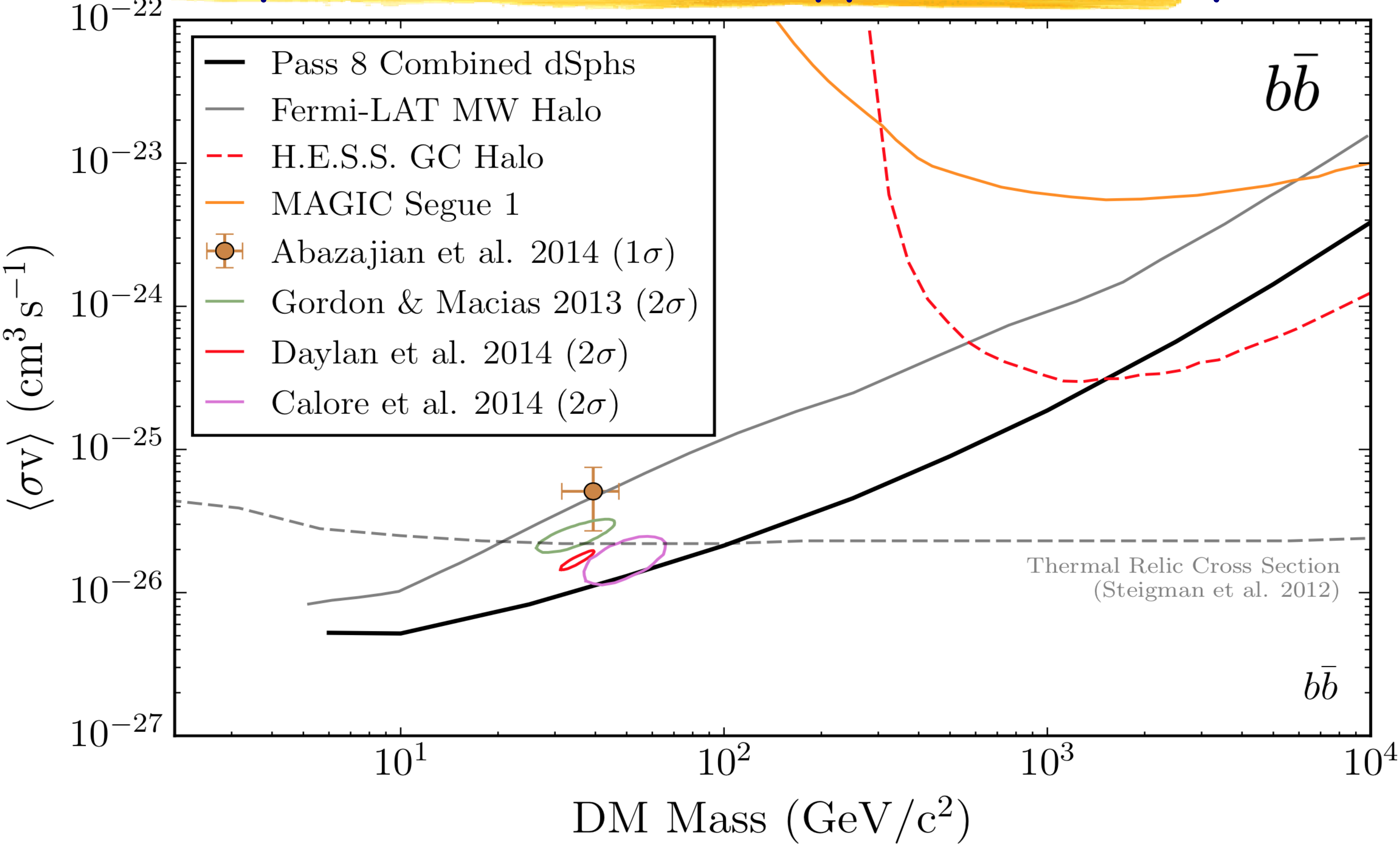
Fermi PSF Pass7 rep v15 source



Classical Dwarf spheroidal galaxies: promising targets for DM detection

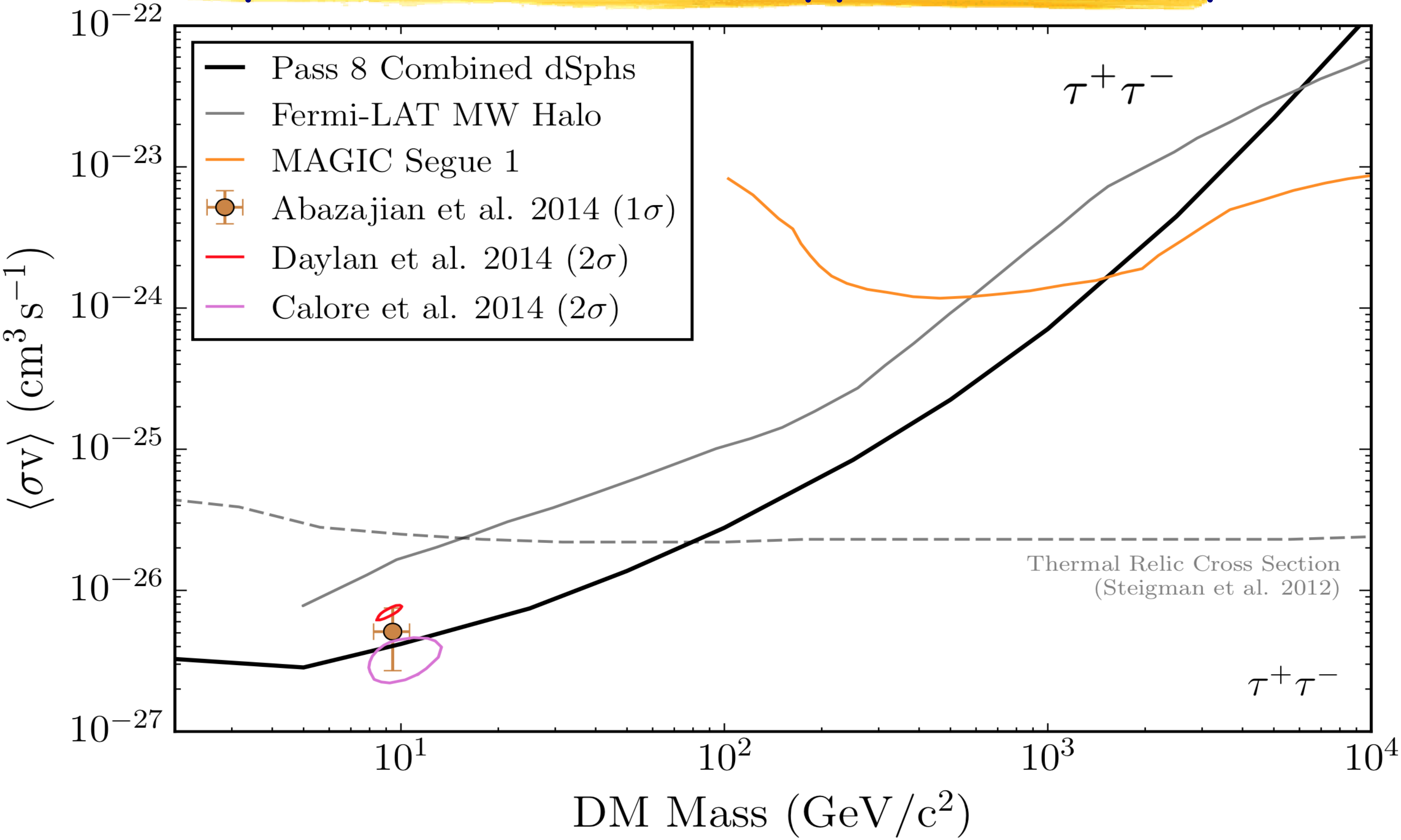


Dwarf Spheroidal Galaxies upper-limits (6 years)



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

Dwarf Spheroidal Galaxies upper-limits (6 years)

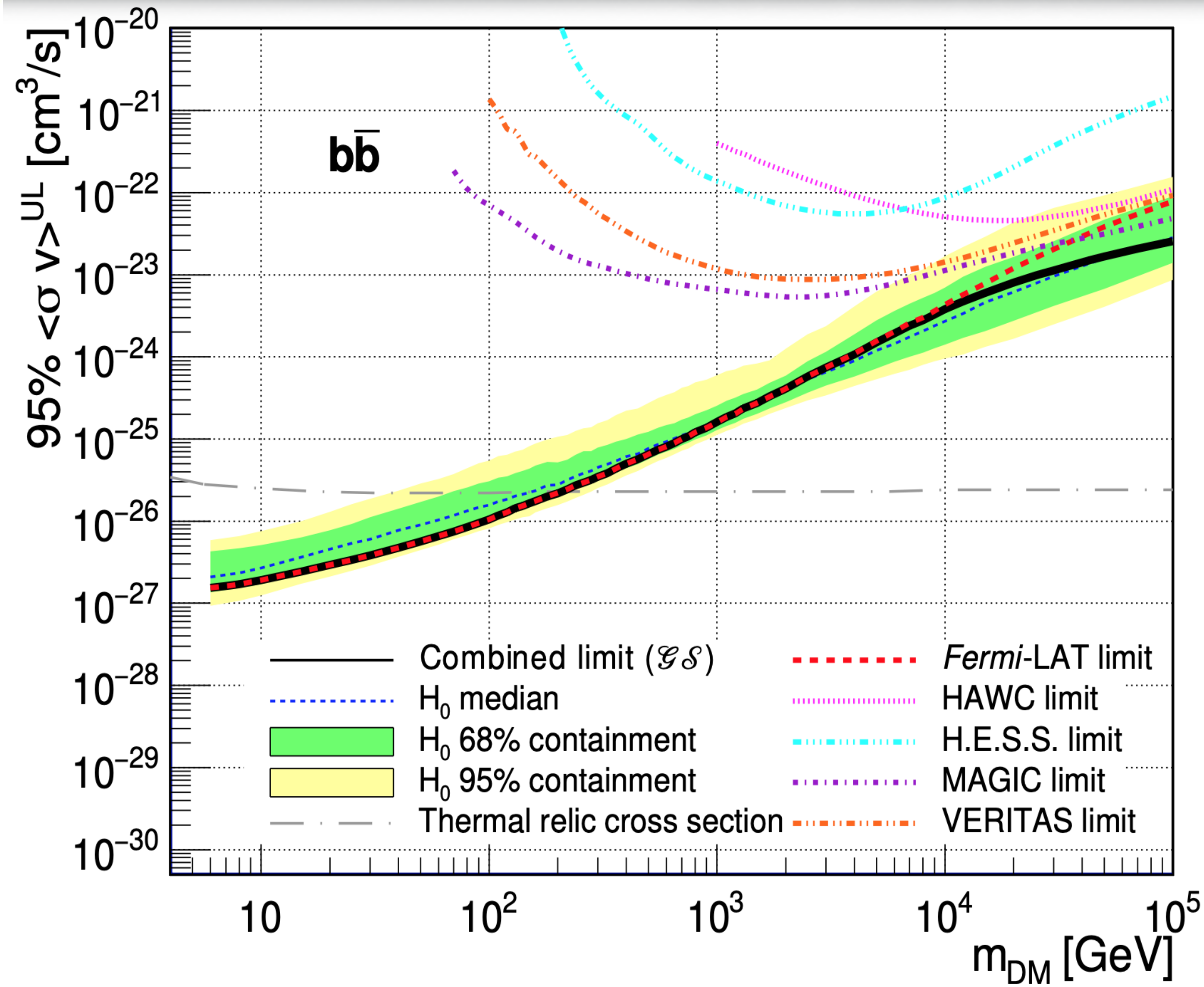


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Combining all dSph observations

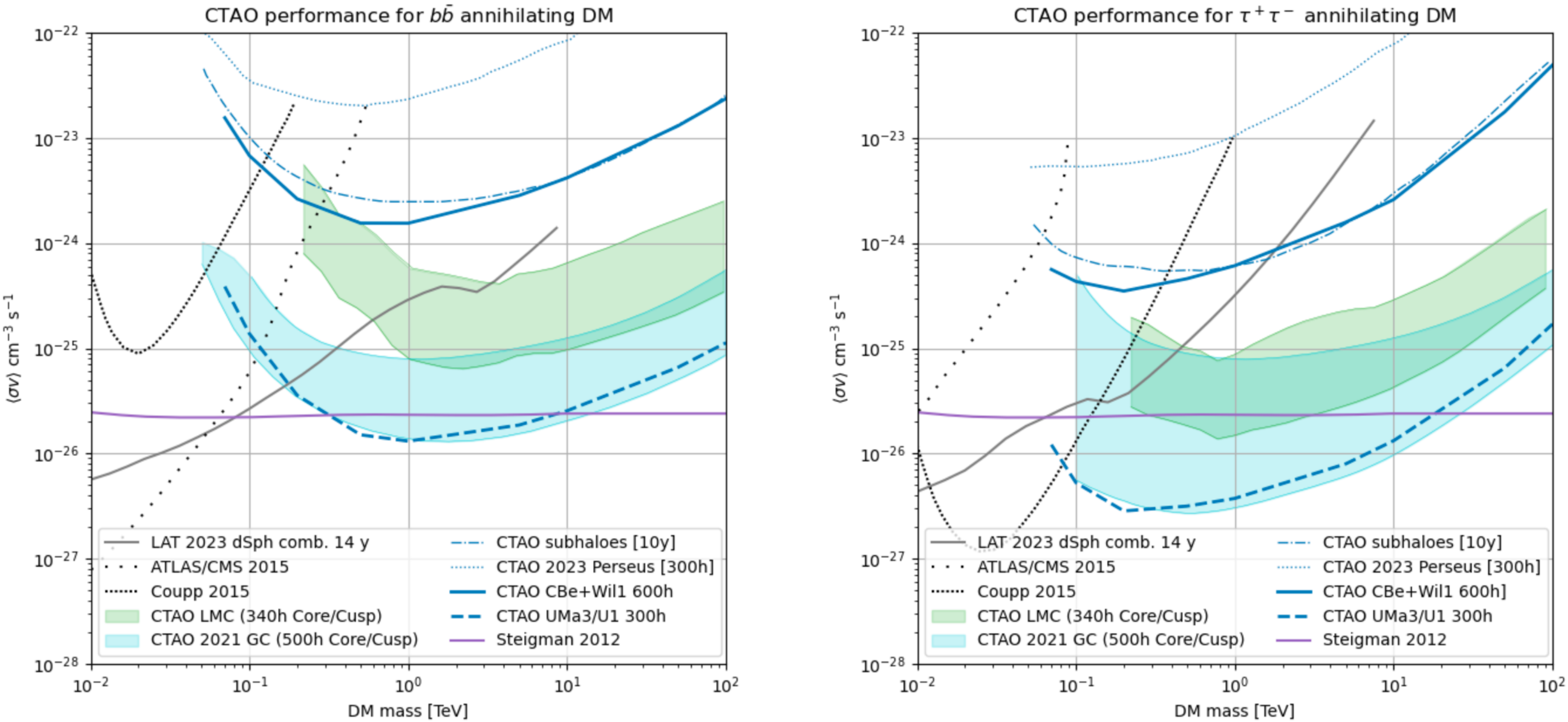
• Combination of the observation results towards 20 dwarf spheroidal galaxies (dSphs)
- Significant increase of the statistics
-> Increase the sensitivity to potential dark matter signals
- Cover the widest energy range ever investigated : 20 MeV – 80 TeV

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



Fermi, HAWC, H.E.S.S., MAGIC, and VERITAS Collaborations) JCAP 03 (2026) 035 [arXiv:2508.20229]

Dwarf Spheroidal Galaxies: CTAO Sensitivity compared with other targets and experiments



Prospects for dark matter observations in dwarf spheroidal galaxies with the Cherenkov Telescope Array Observatory
CTAO Consortium. c.a. M. Doro, A. Morselli, G. Rodríguez-Fernández, F. G. Saturni MNRAS 544, 2946–2986 (2025) arXiv:2508.19120

Search for Dark Matter beyond WIMP

Axion Like Particle (ALP) search prospects

γ + B -> a + B -> γ' + ...

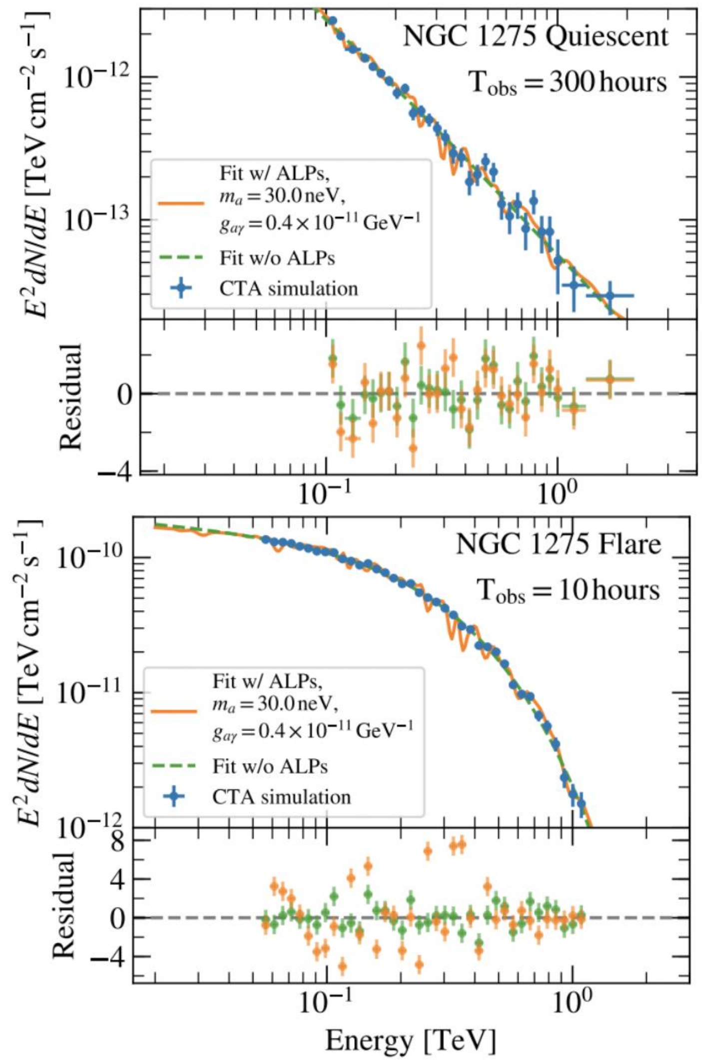
conversion probability ($E > E_{crit}$)

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

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

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

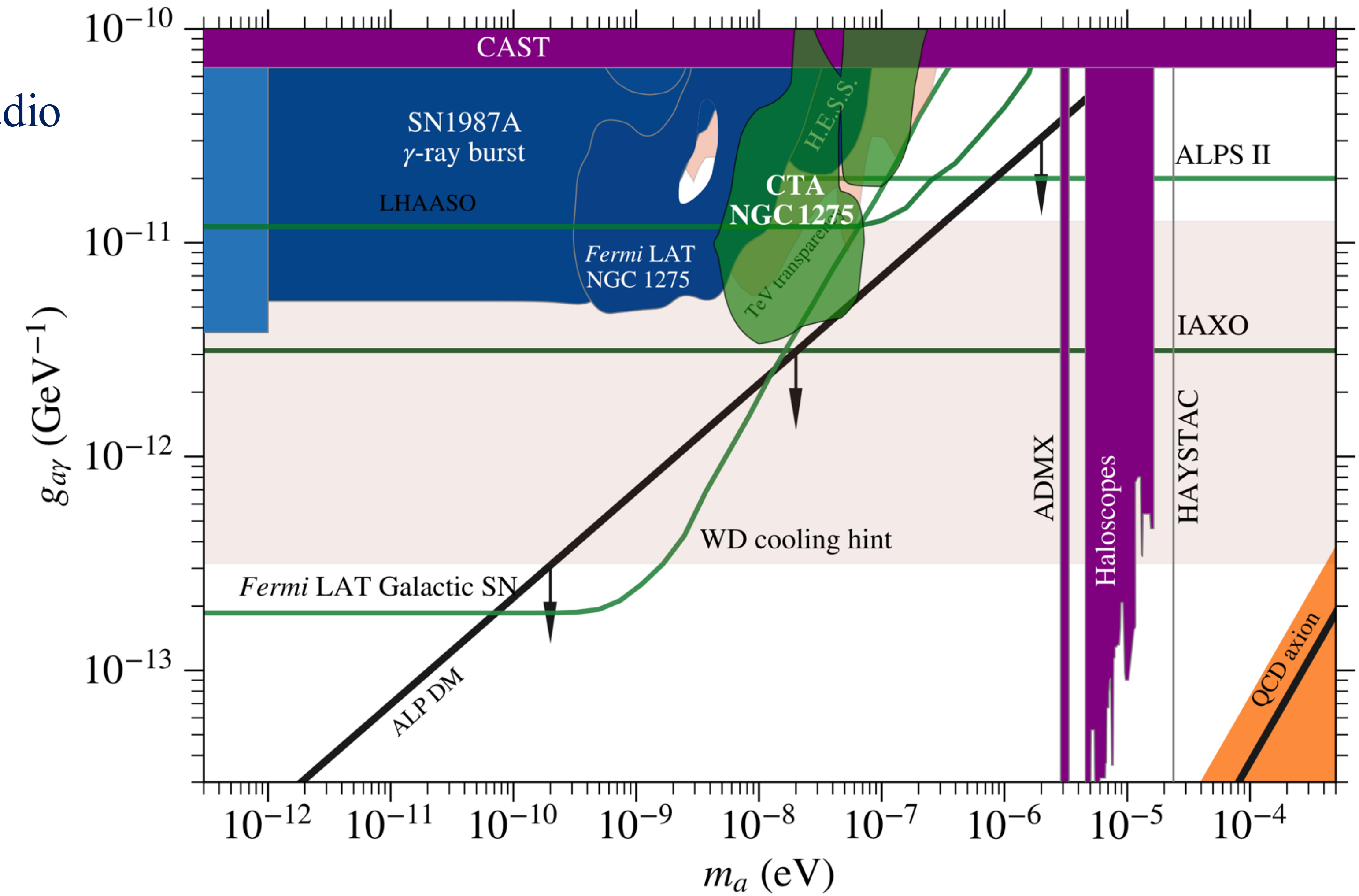


The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

Search for Dark Matter beyond WIMP

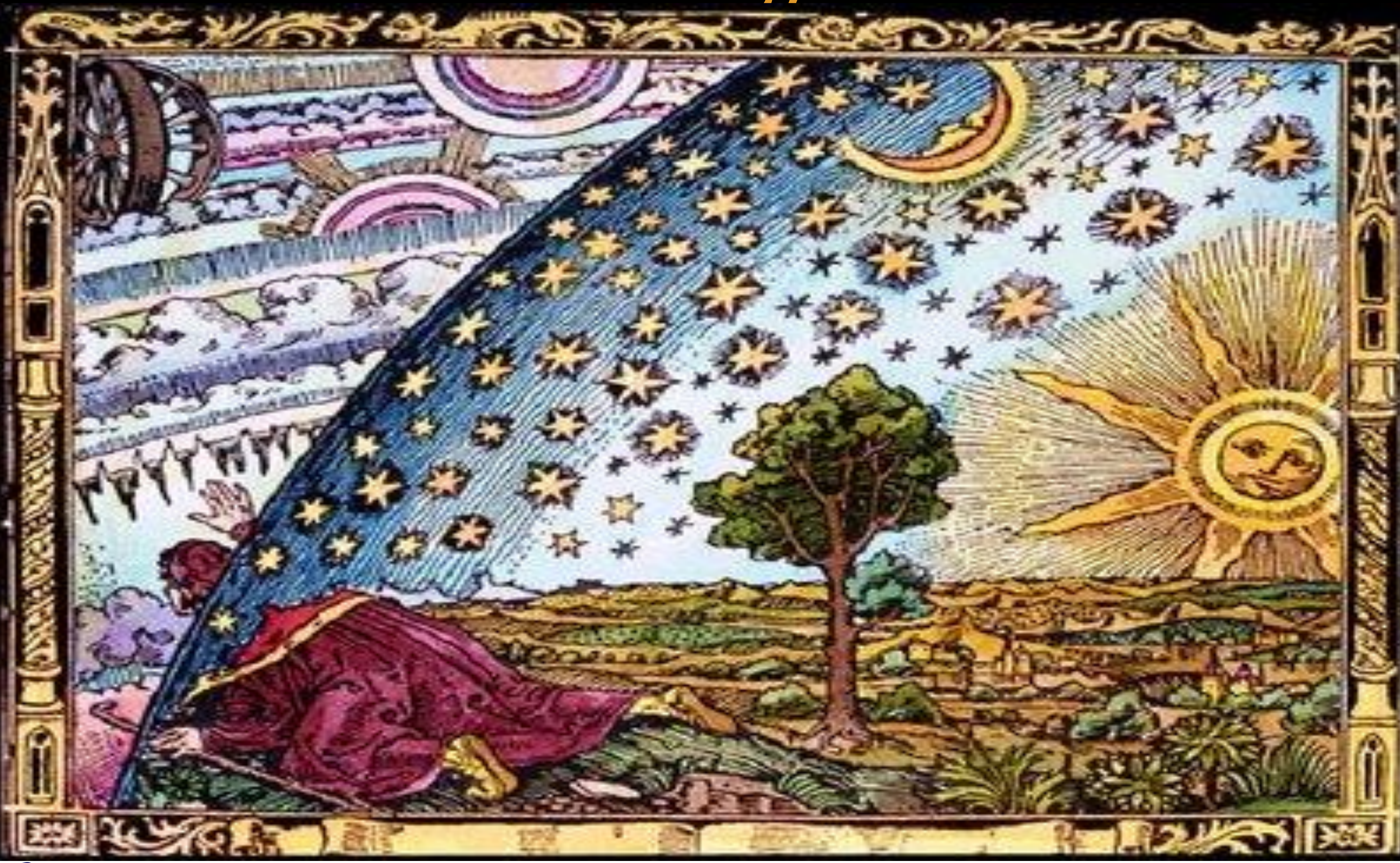
Axion Like Particle search prospects

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

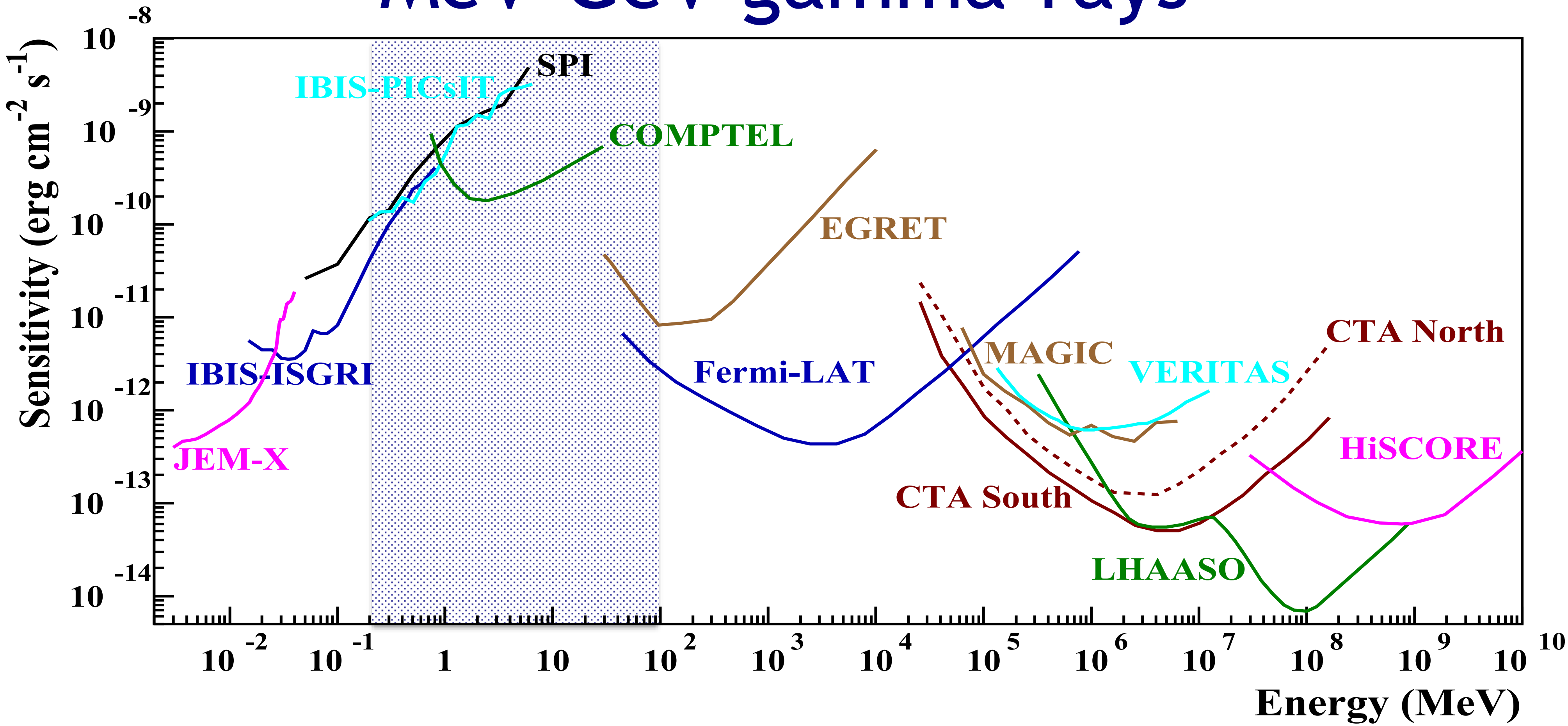


The CTA Consortium, JCAP 02 (2021) 048, 2021 [arXiv:2010.01349]

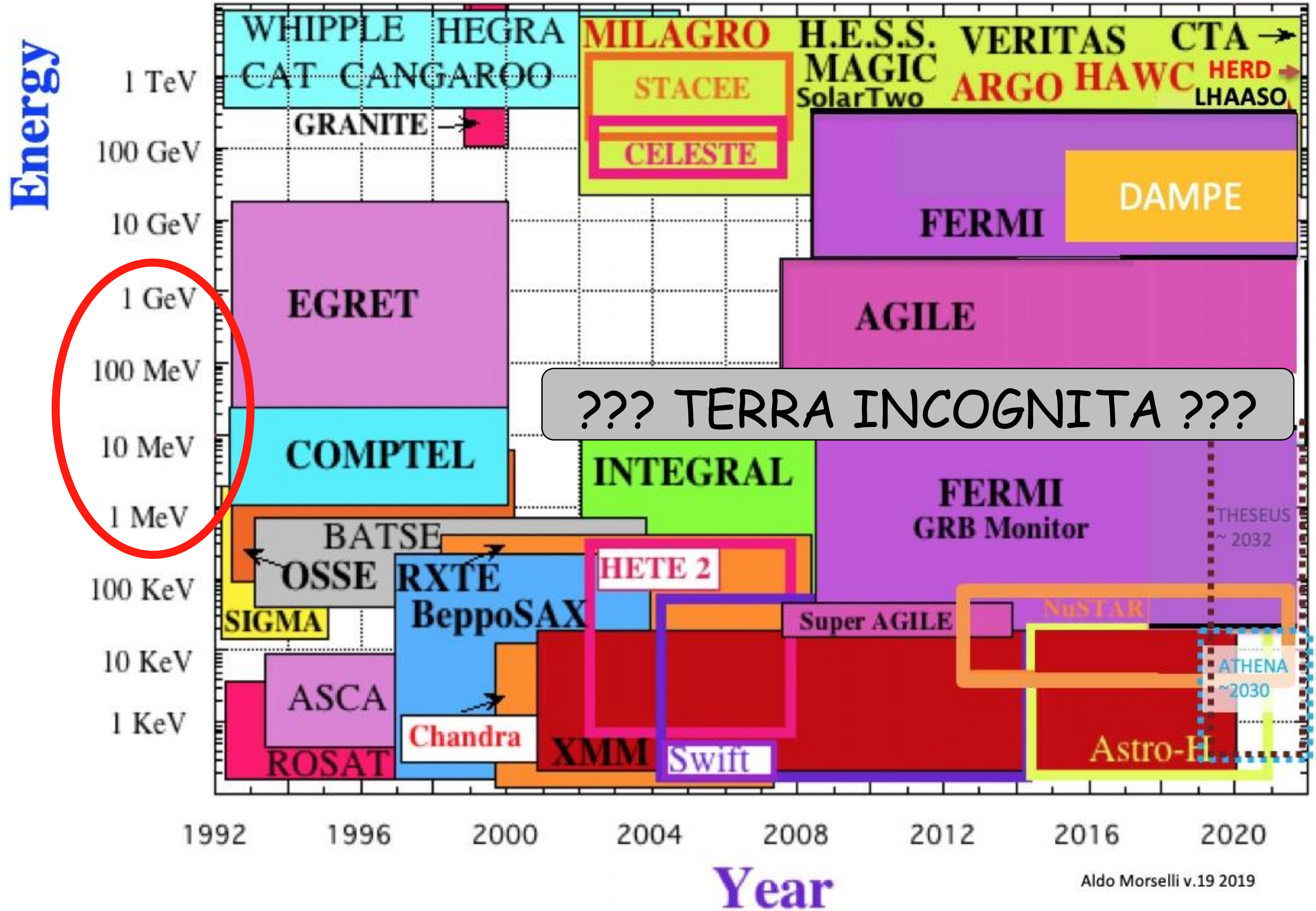
The Low Energy Frontier



MeV-GeV gamma-rays



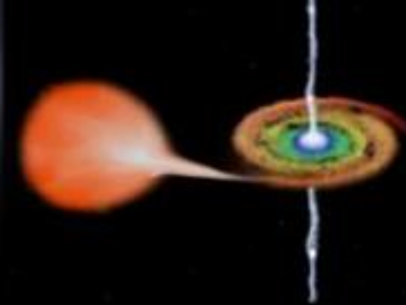
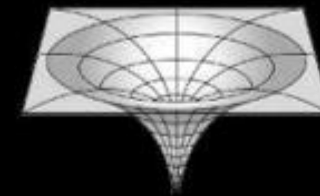
- Worst covered part of the electromagnetic spectrum in 0.1-100 MeV
- Many objects have their peak emissivity in this range (GRBs, blazars, pulsars...)
- The MeV range is the domain of nuclear gamma-ray lines (supernovae, nucleosynthesis and Galactic chemical evolution)



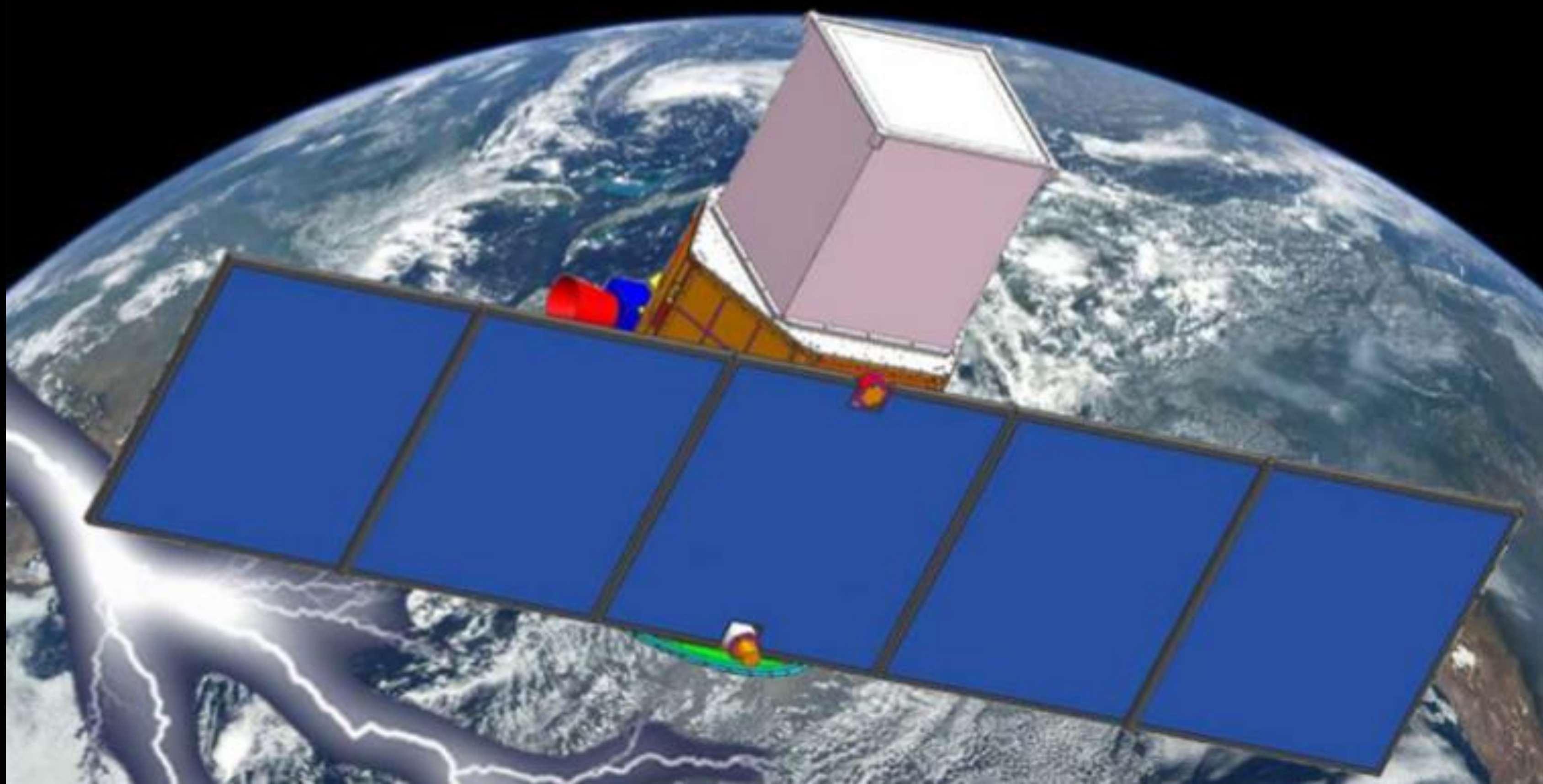
Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE HEGRA
CAT CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
CTA
HERD
LHAASO
FERMI
DAMPE
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
THESEUS
~ 2032
BATSE
OSSE
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



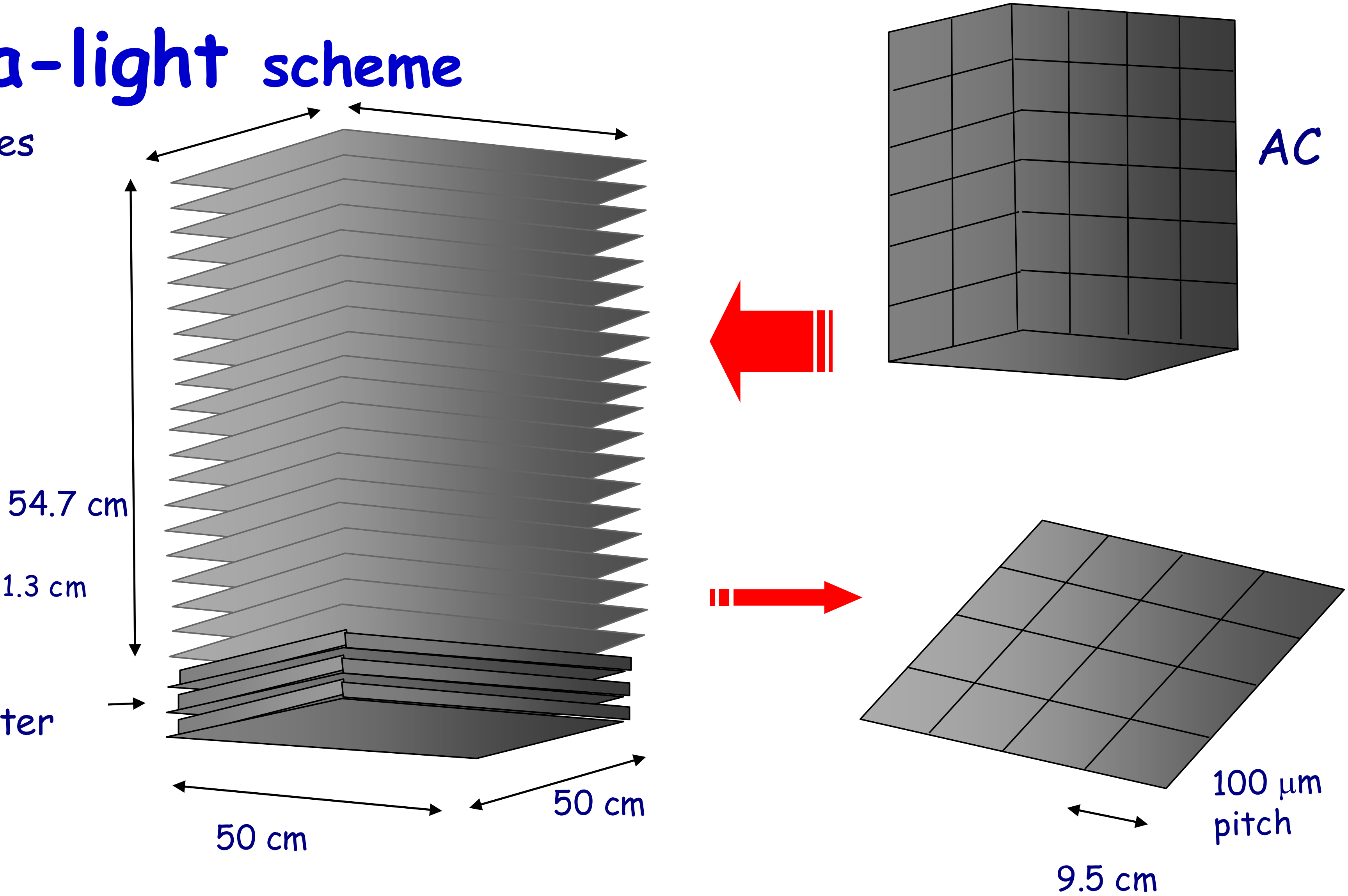
Gamma-light scheme

40+1 x-y planes
100 μm pitch
each
~0.025 X_0

Tot~ 1 X_0

height of a plane 1.3 cm

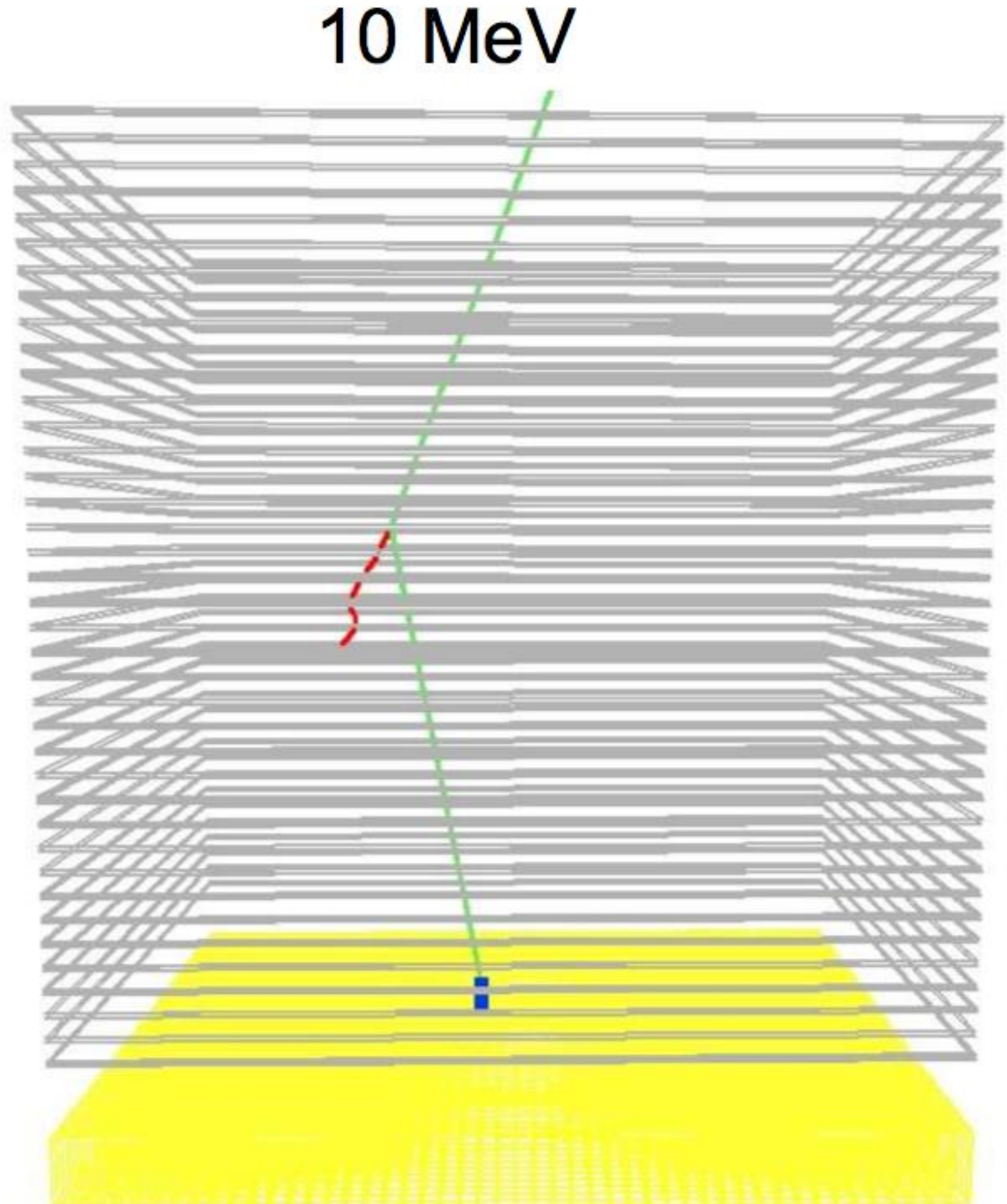
2 Xo Calorimiter



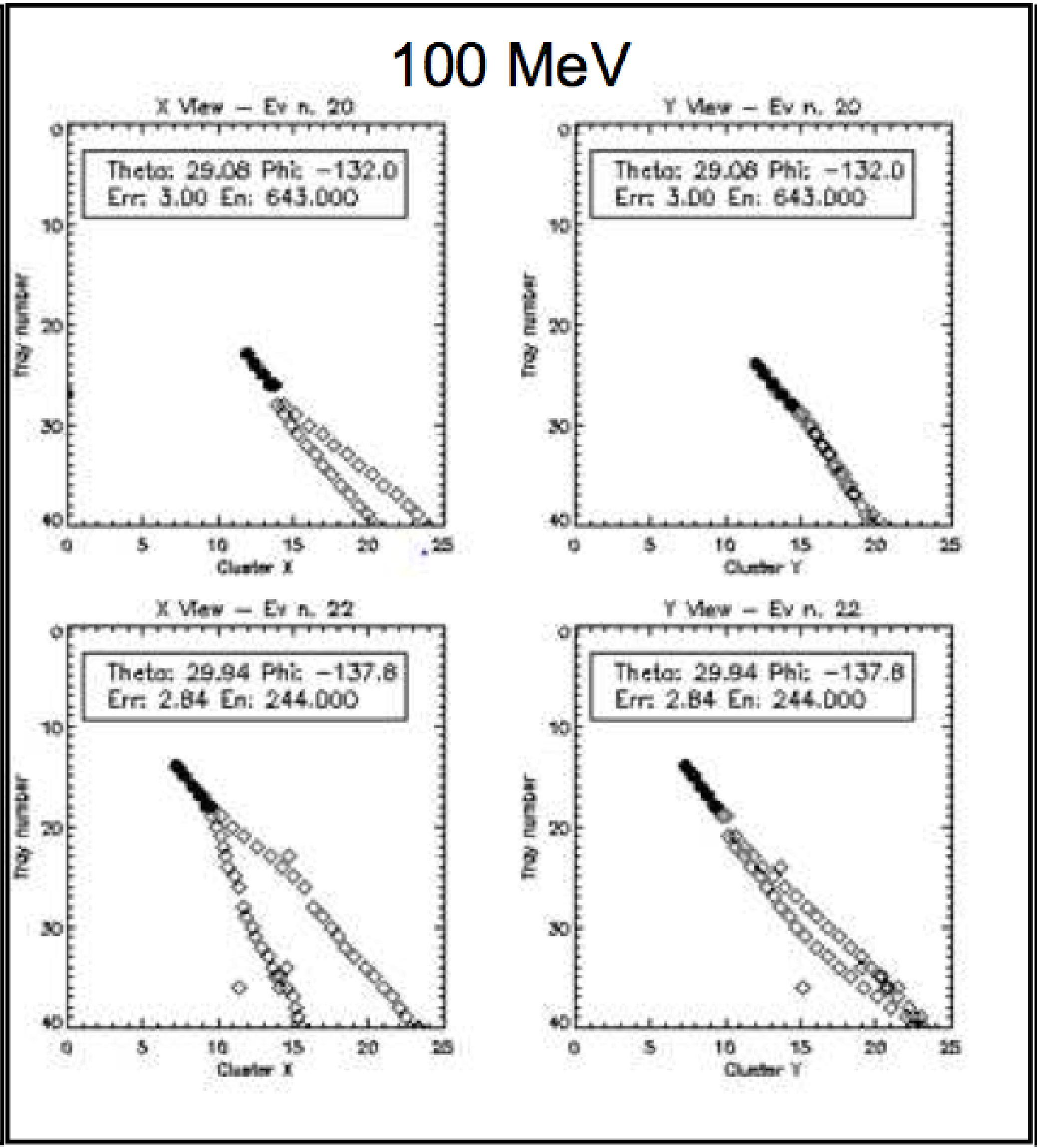
Compton scattering ***and*** *pair production telescope*

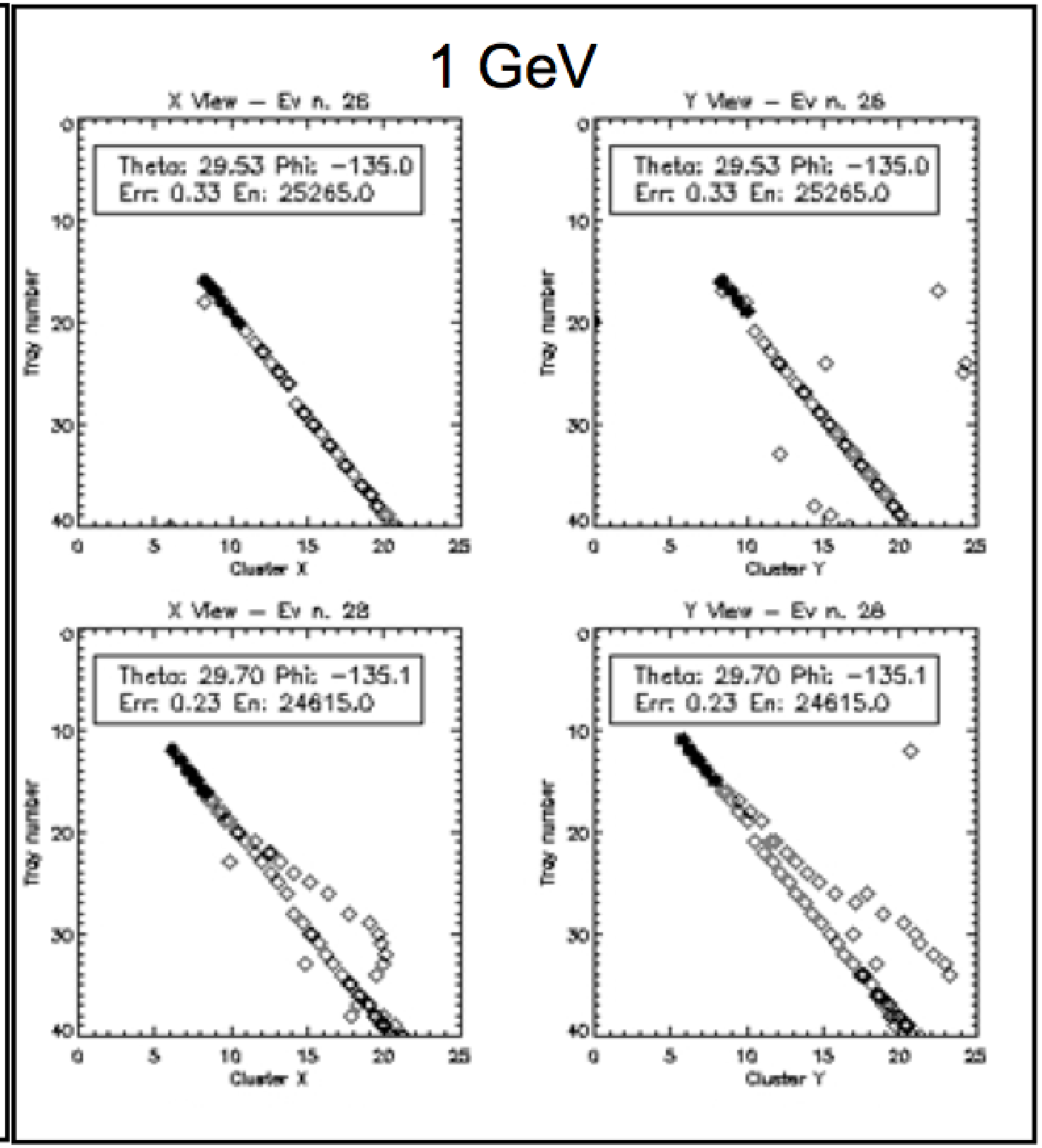
G-LIGHT Simulation

- *Compton interaction of a 10 MeV photon producing a low-energy single-track electron, and depositing energy in the Calorimeter for a 30^0 incidence*



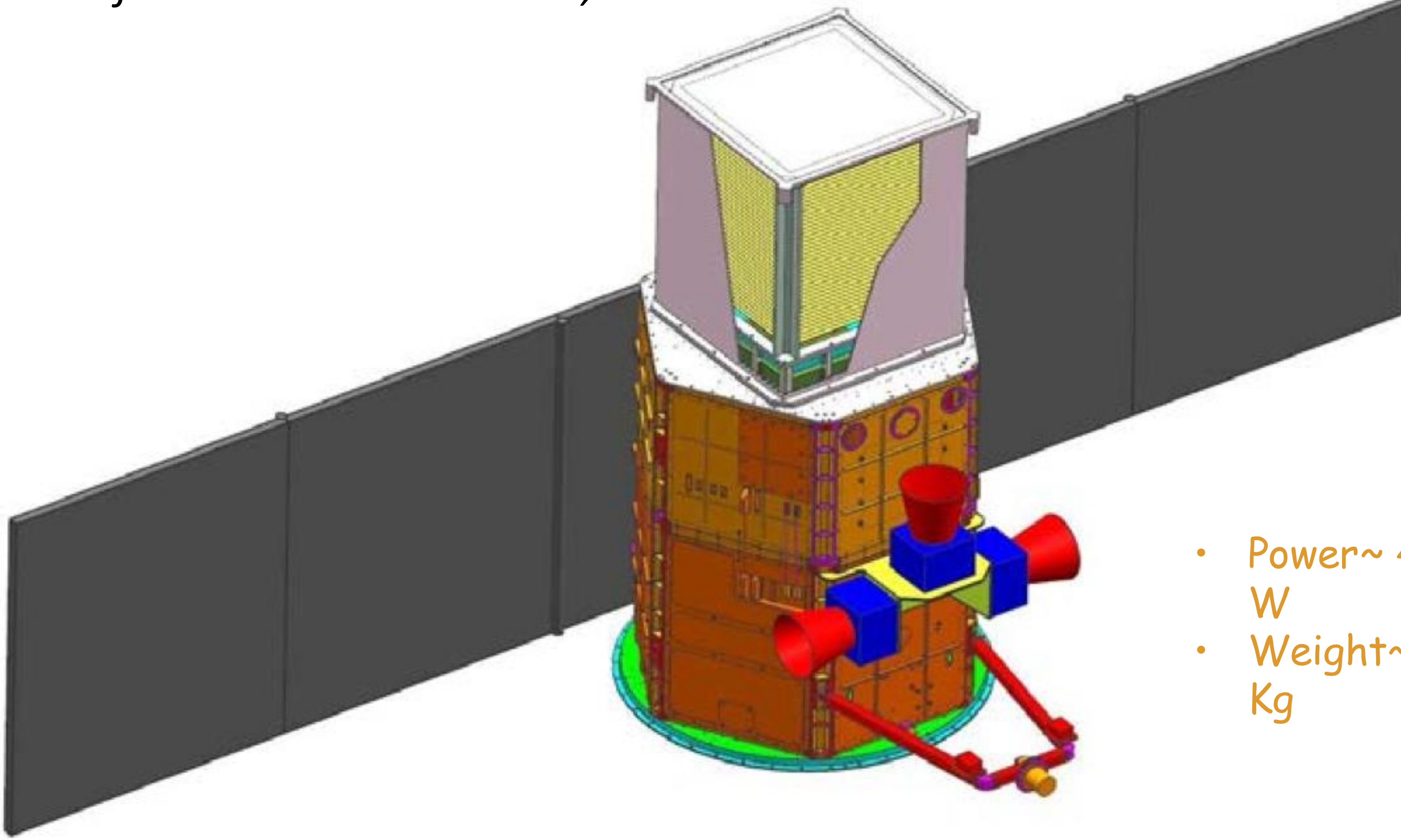
Gamma-light *Simulation*





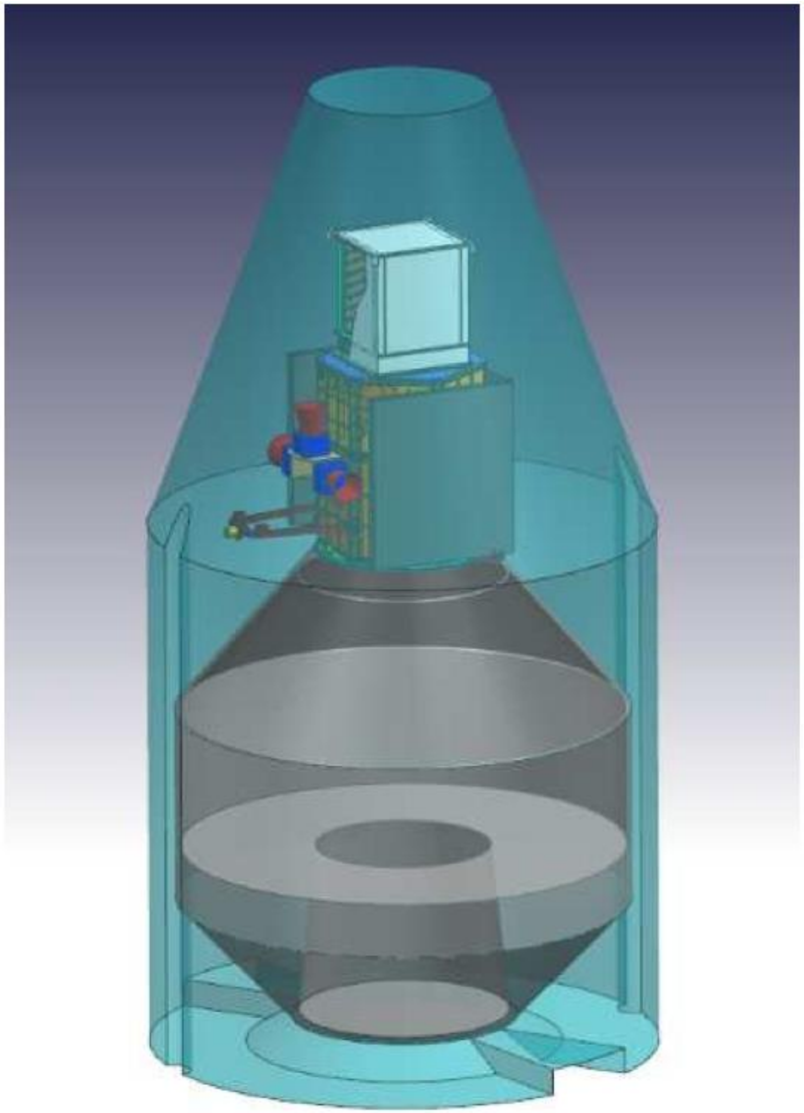
Gamma-light payload

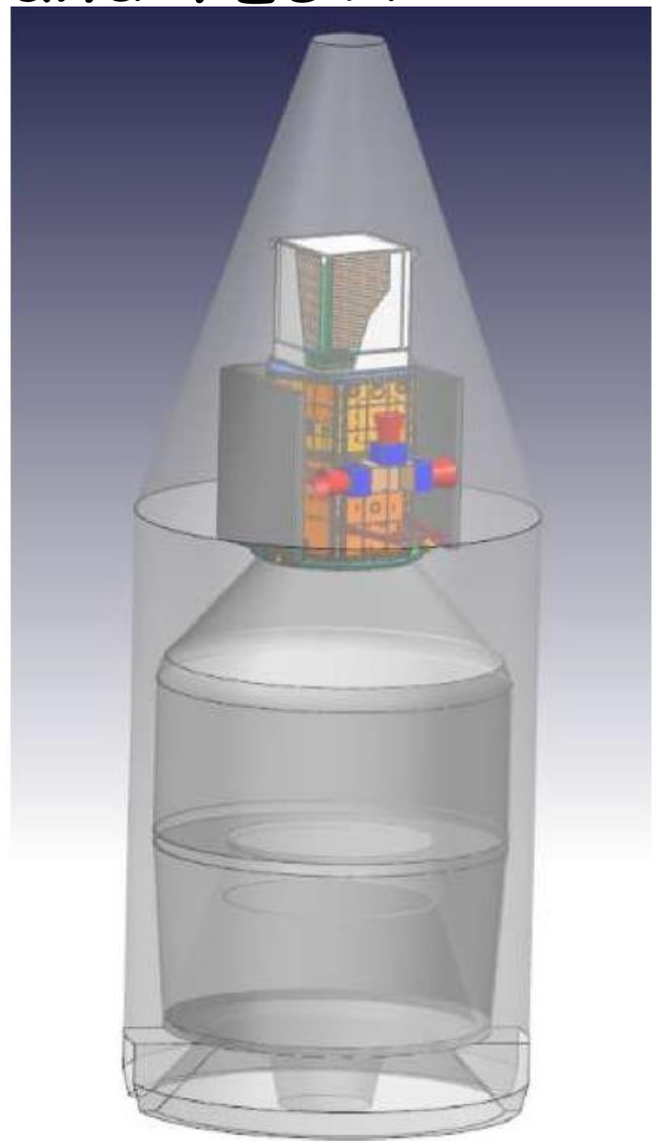
ESA Call for Small Missions: June, 2012



- Power~ 400 W
- Weight~600 Kg

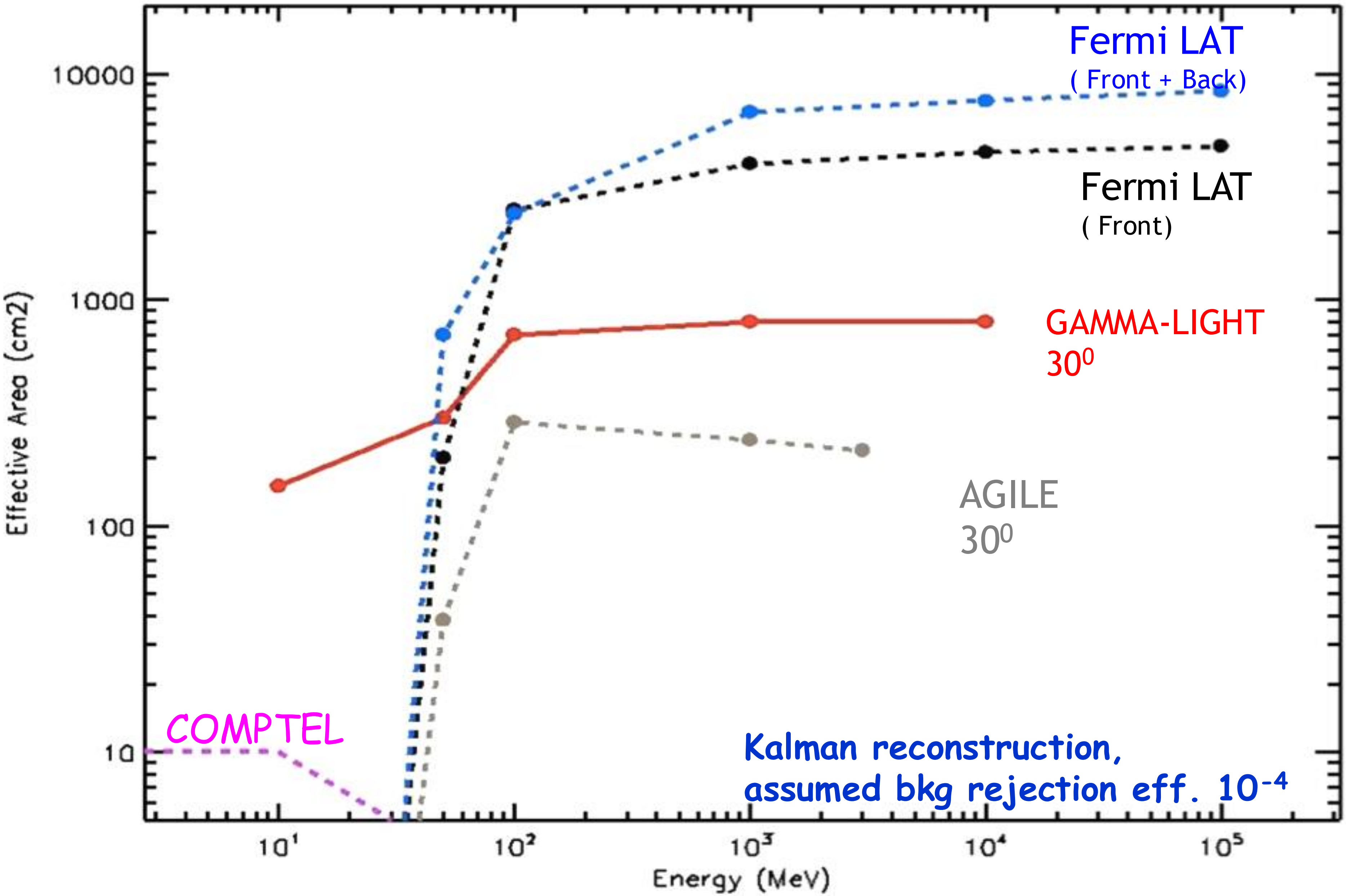
GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA





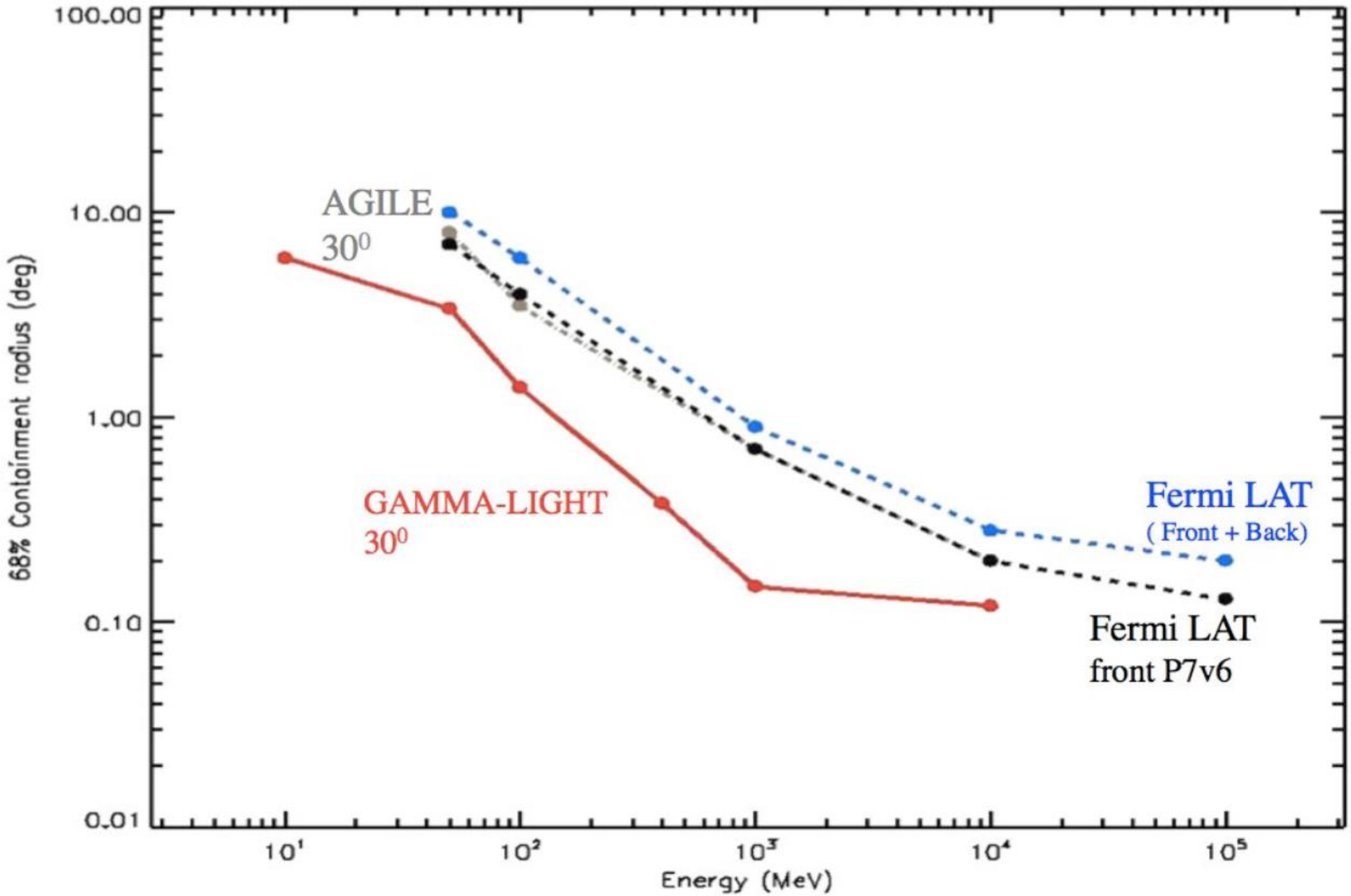
- a companion satellite similar to G-LIGHT can be accomodated.

Effective area



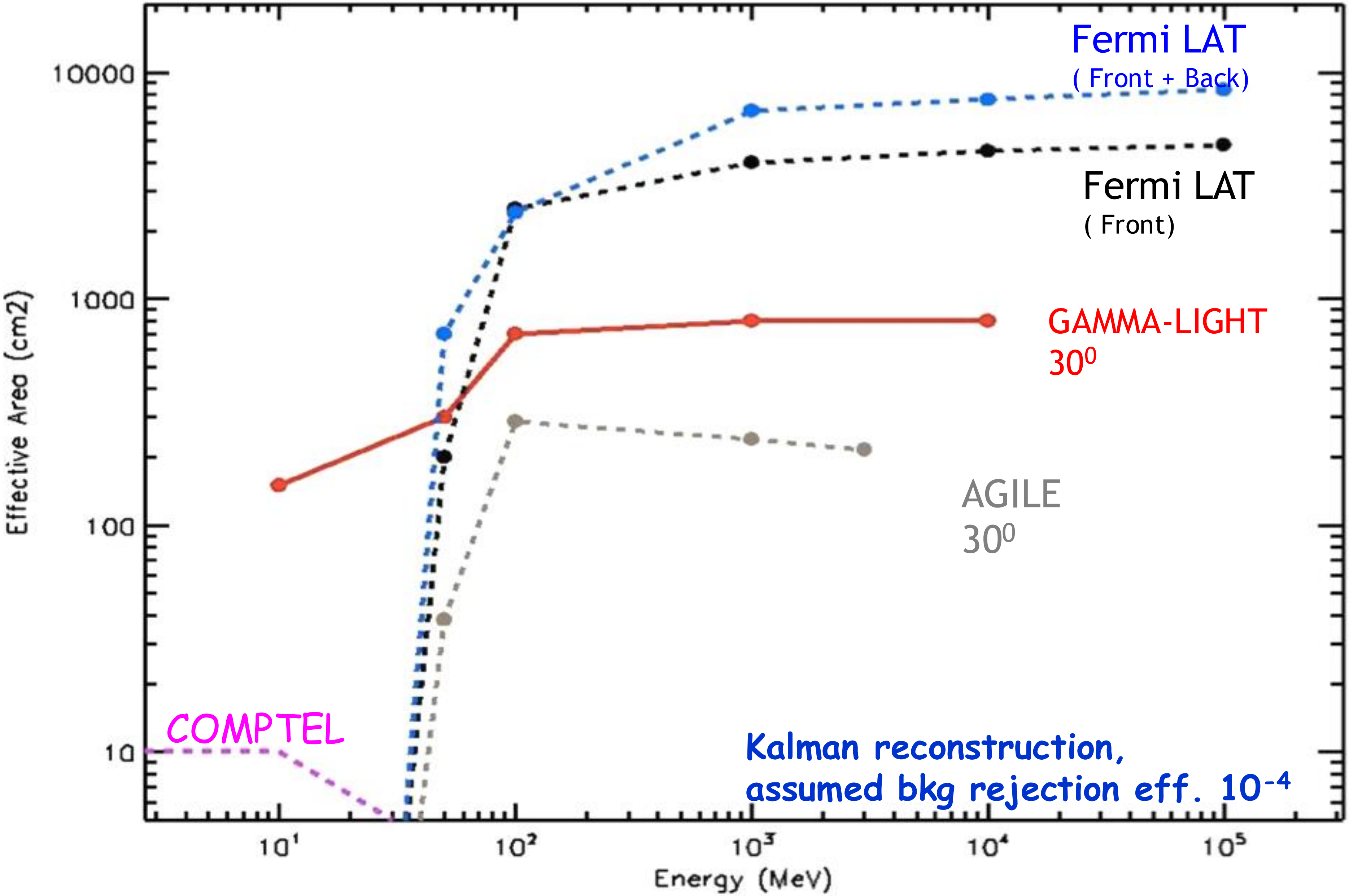
A.Morselli et al. Nuclear Physics B 239-240 (2013) 193-198 [arXiv:1406.1071]

PSF (68% containment radius)



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

Effective area



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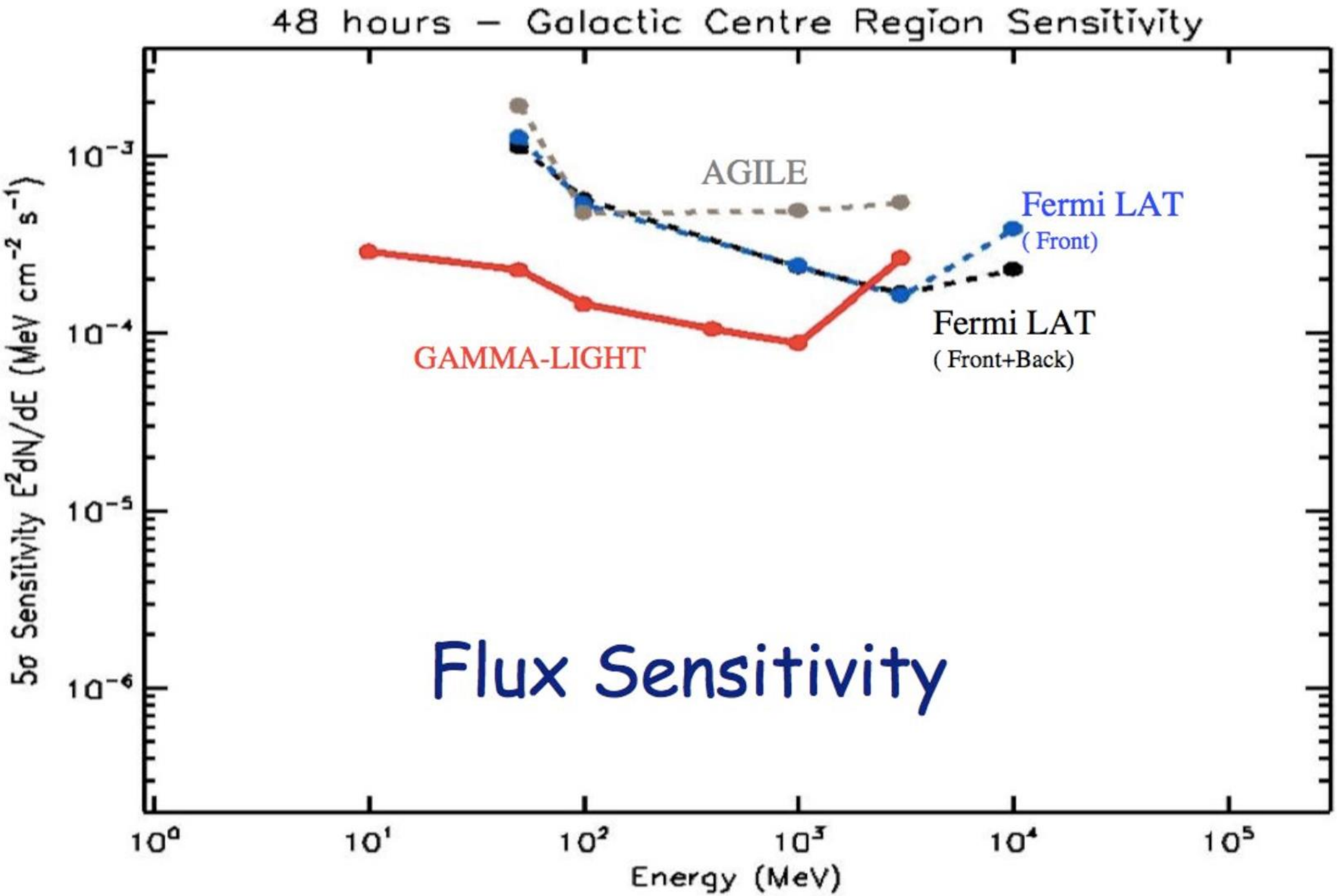
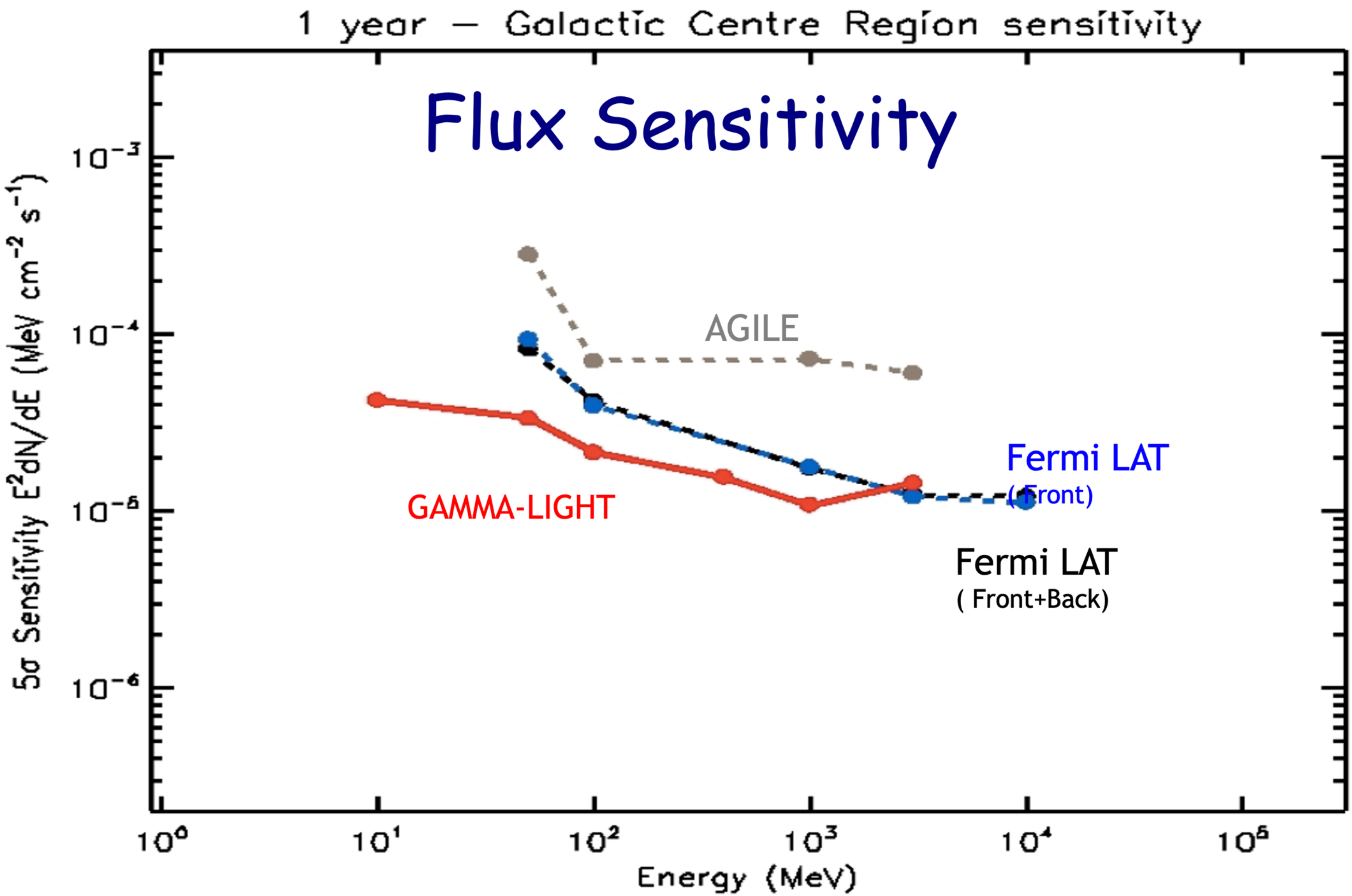
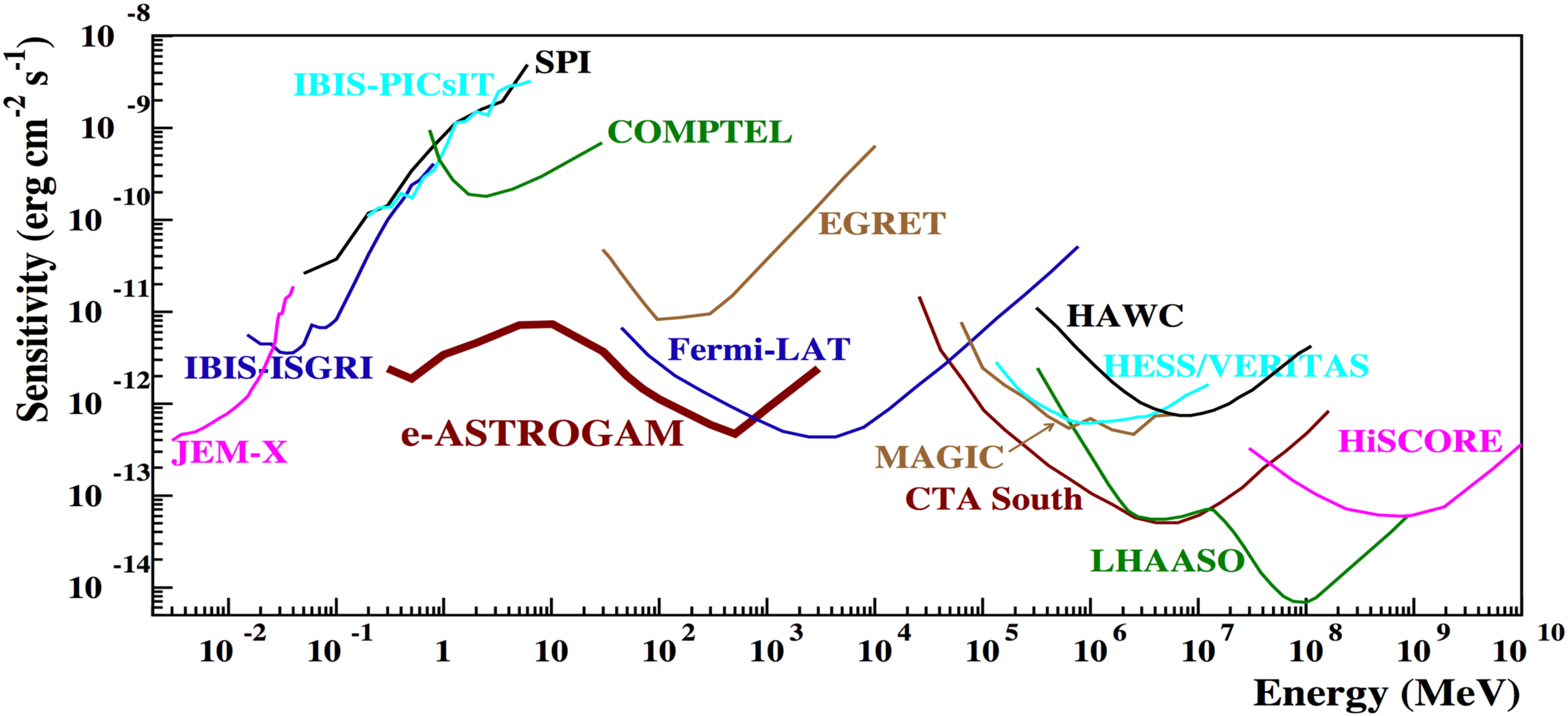


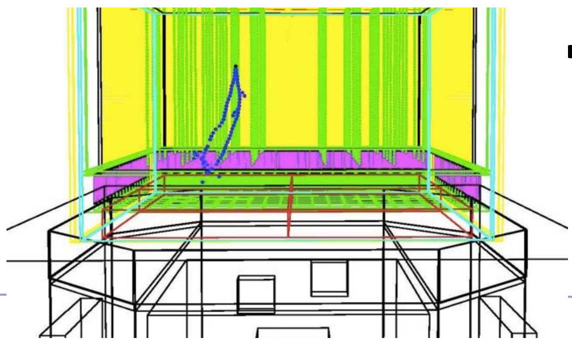
A.Morselli et al. Nuclear Physics B 239–240 (2013) 193-198 [arXiv:1406.1071]



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


e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (190 pages)

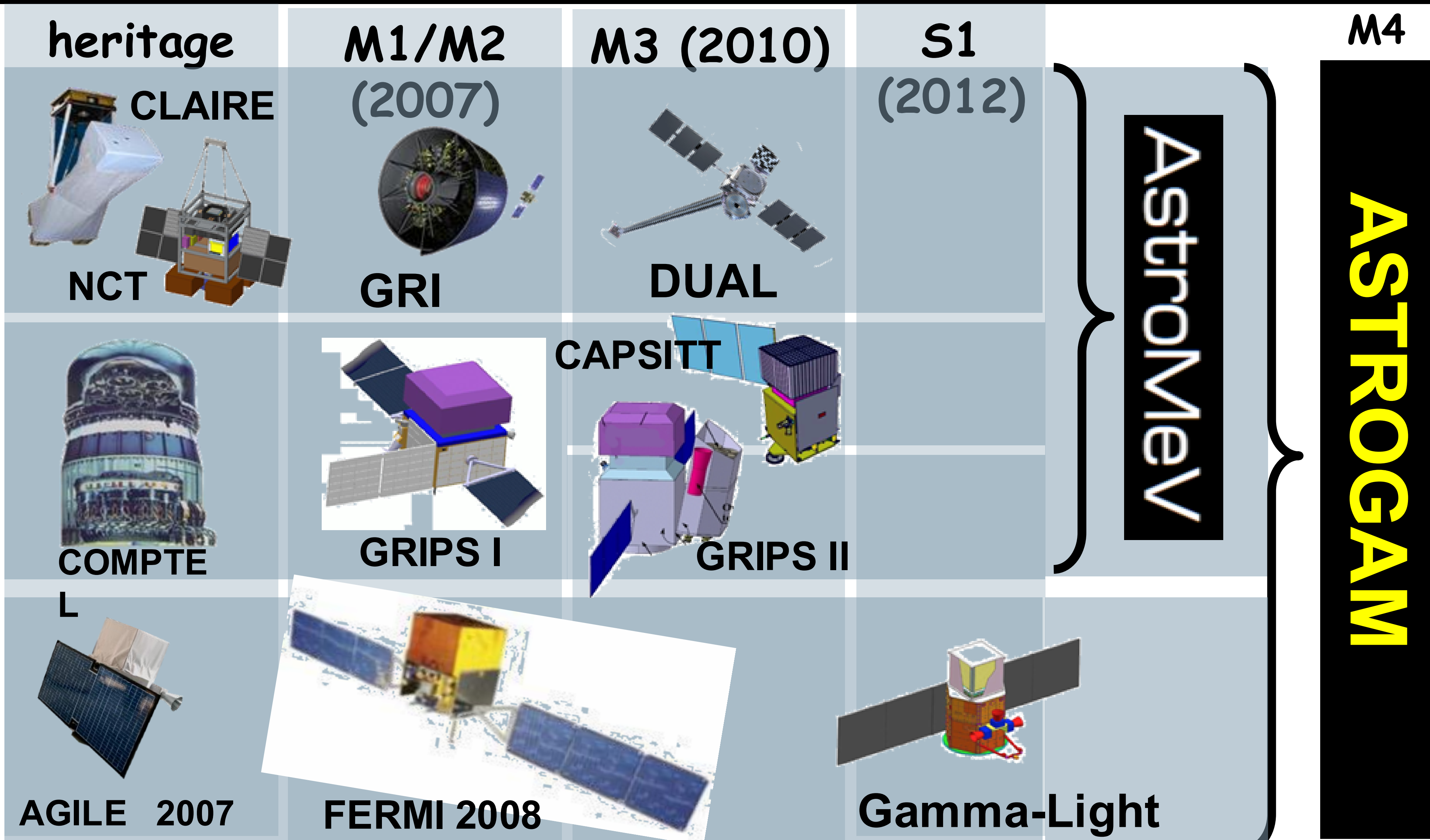




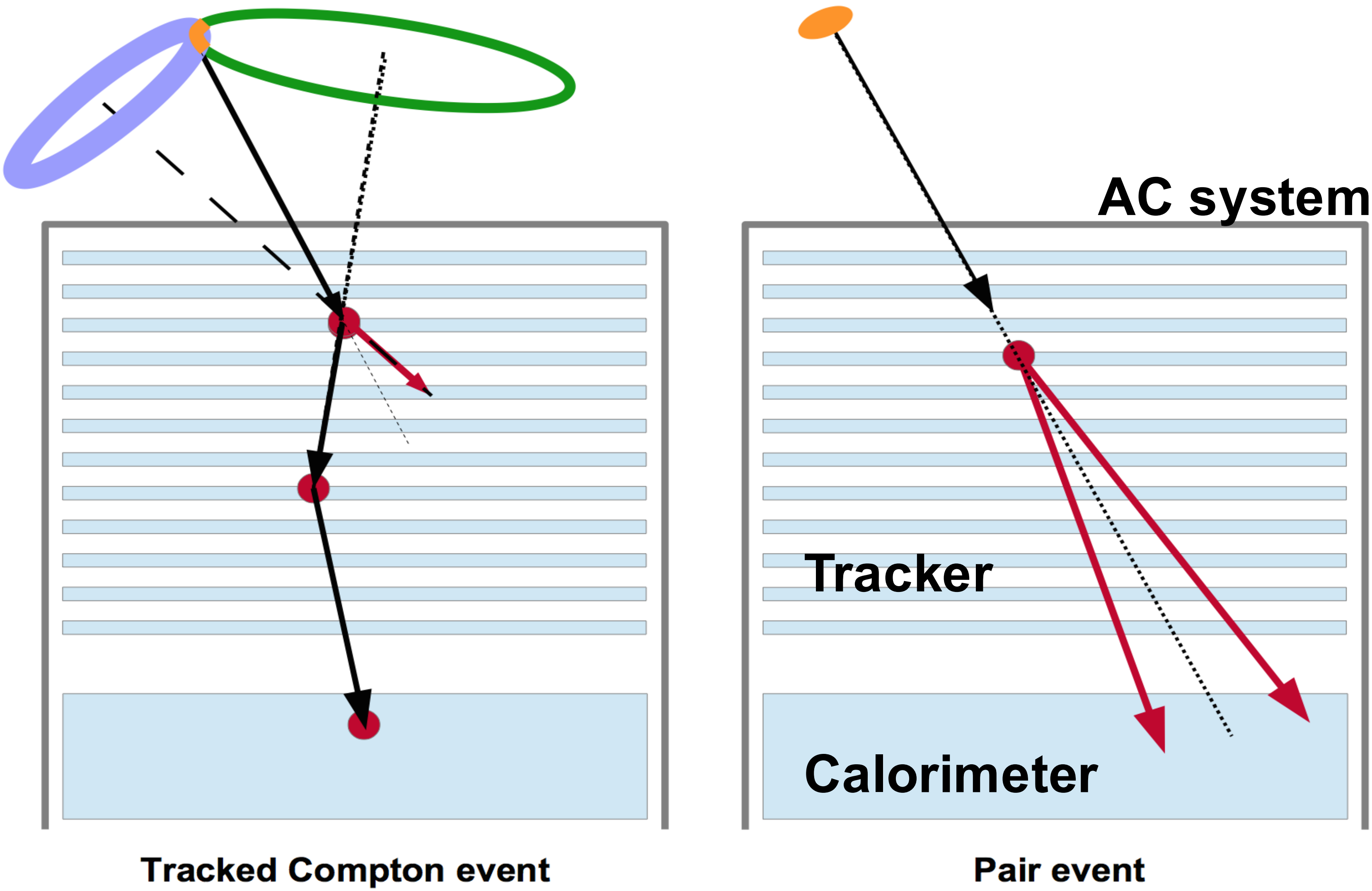
- e-ASTROGAM performance evaluated with **MEGAlib** and BoGem both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

e-Astrogam: arXiv:1711.01265

ASTROGAM a unified proposal from the entire gamma-ray community



An instrument that combine two detection techniques



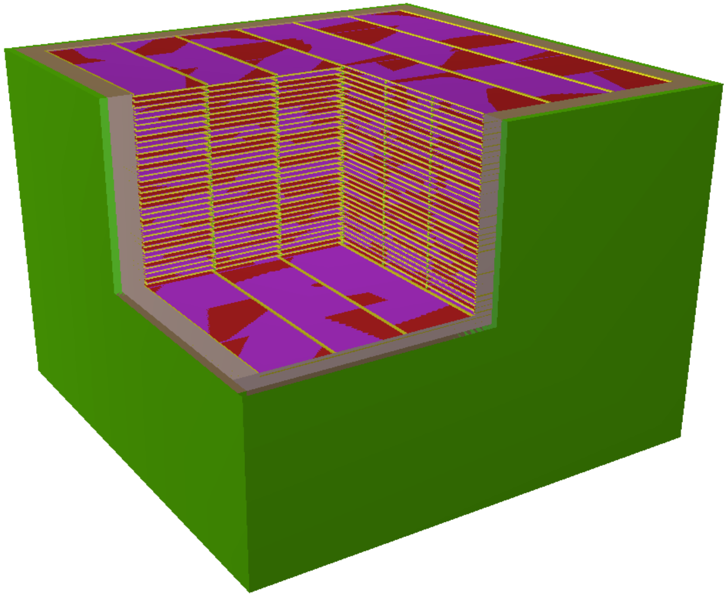
Silicon Tracker

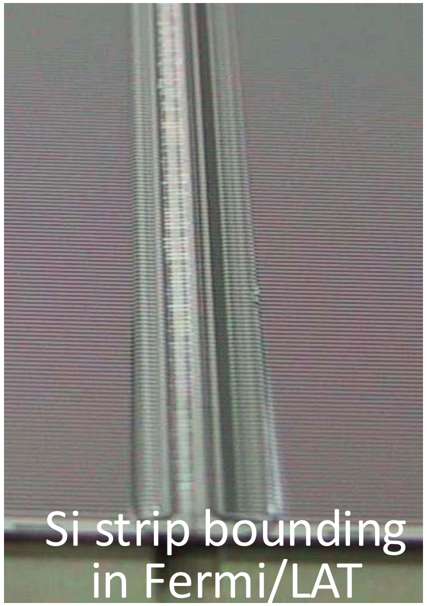
- 70 layers of 6 × 6 double sided Si strip detectors = 2520 DSSDs
- Each DSSD has a total area of 9.5 × 9.5 cm^2, a thickness of 400 μm, a strip width of 100 μm and pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm
- Spacing of the Si layers: 7.5 mm
- The DSSDs are wire bonded strip to strip to form 2-D ladders

⇒ 322 560 electronic channels

- DSSD strips connected to ASICs (32 channels each) through a pitch adapter (DC coupling)
- 144 ASICs (IDeF-X HD) per layer (72 per DSSD side)

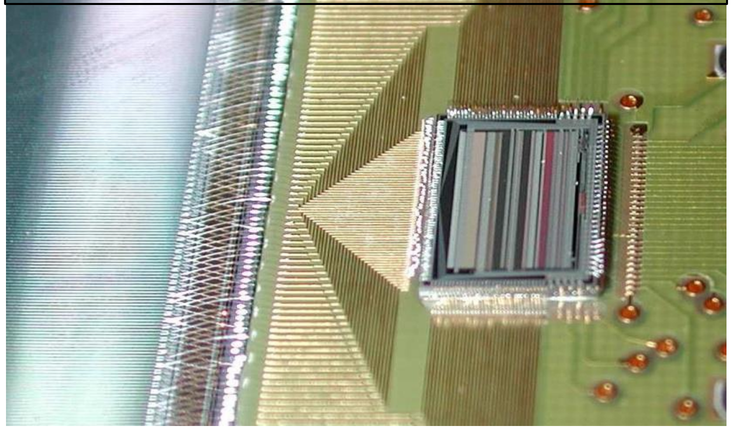
⇒ 10 080 ASICs total



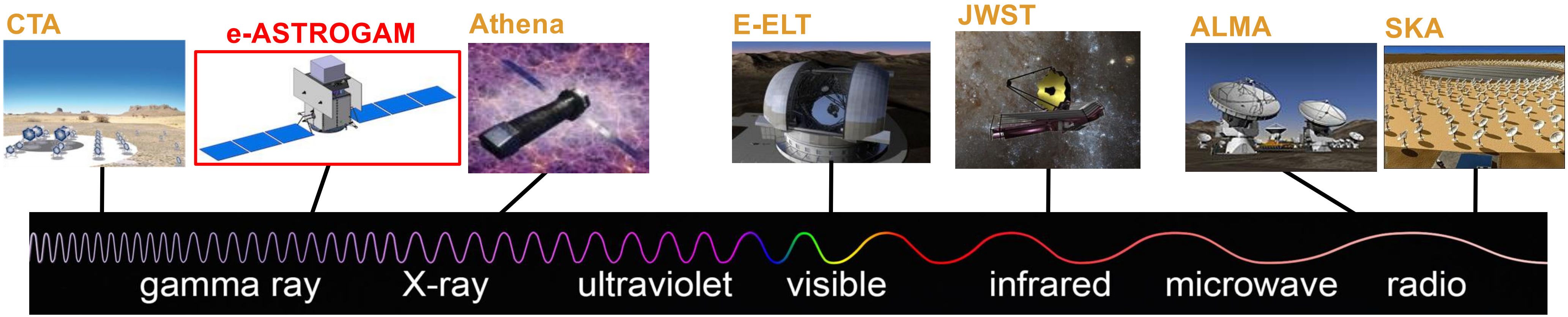


Si strip bounding in Fermi/LAT

Detail of the detector-ASIC bonding in the AGILE Si Tracker

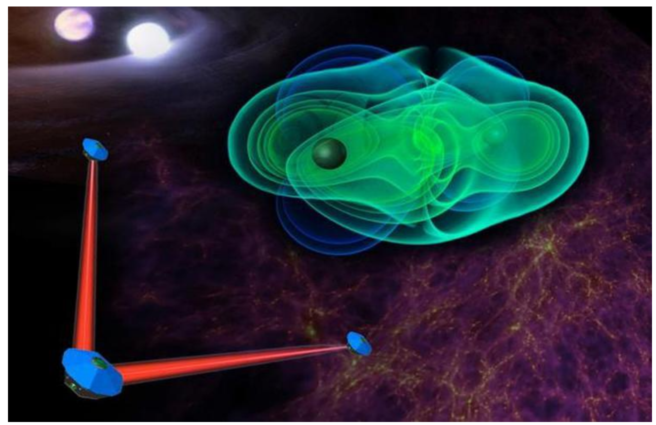


e-ASTROGAM: γ-ray astronomy in context

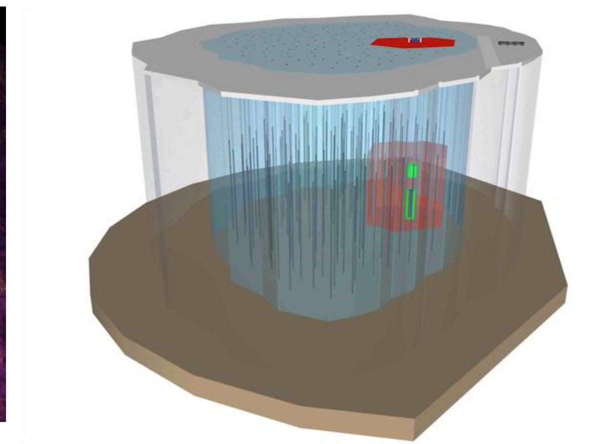


New Astronomies:
gravitational waves
neutrinos

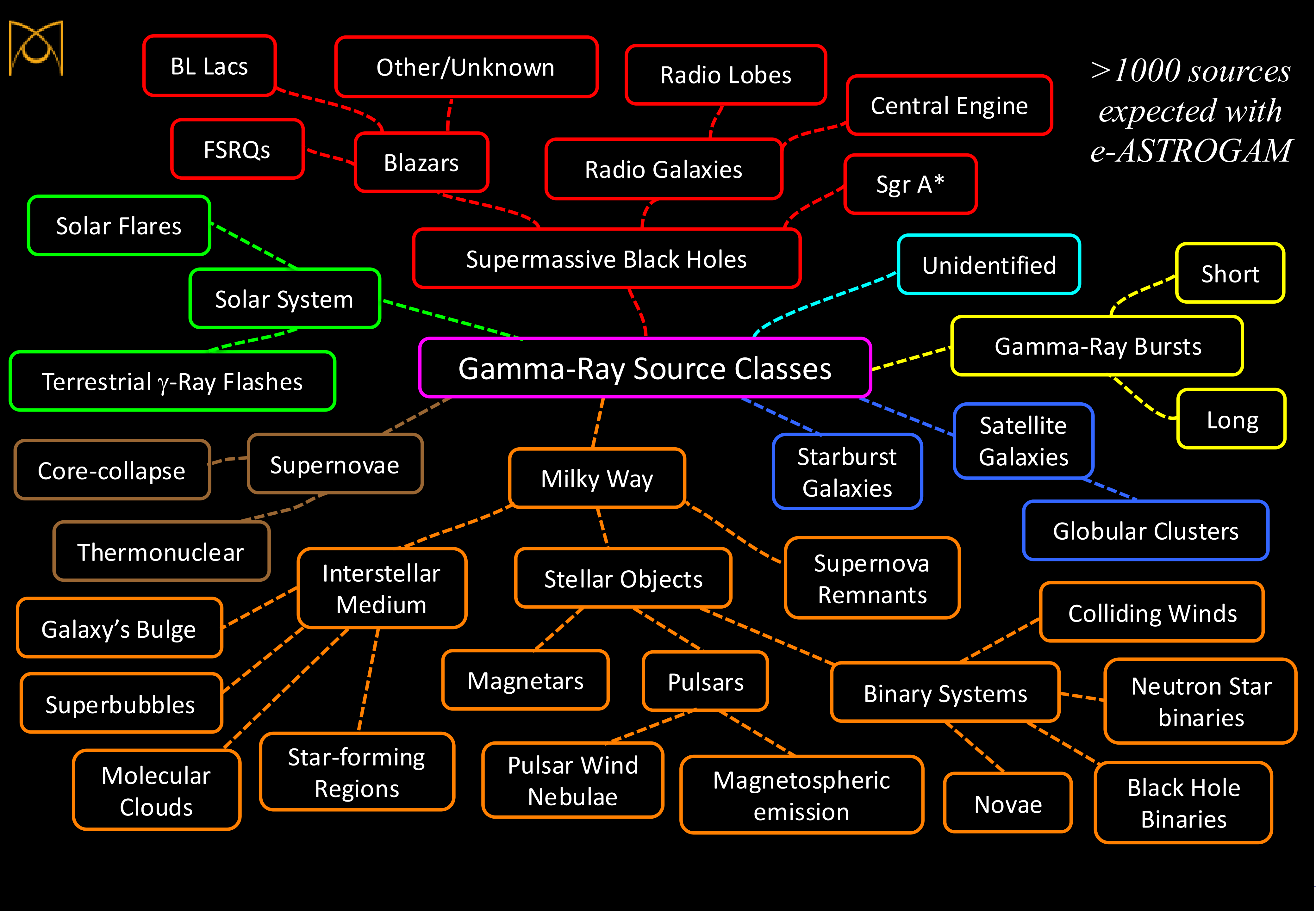
eLISA – Gravitational waves



Km3Net/IceCube-Gen2 - ν

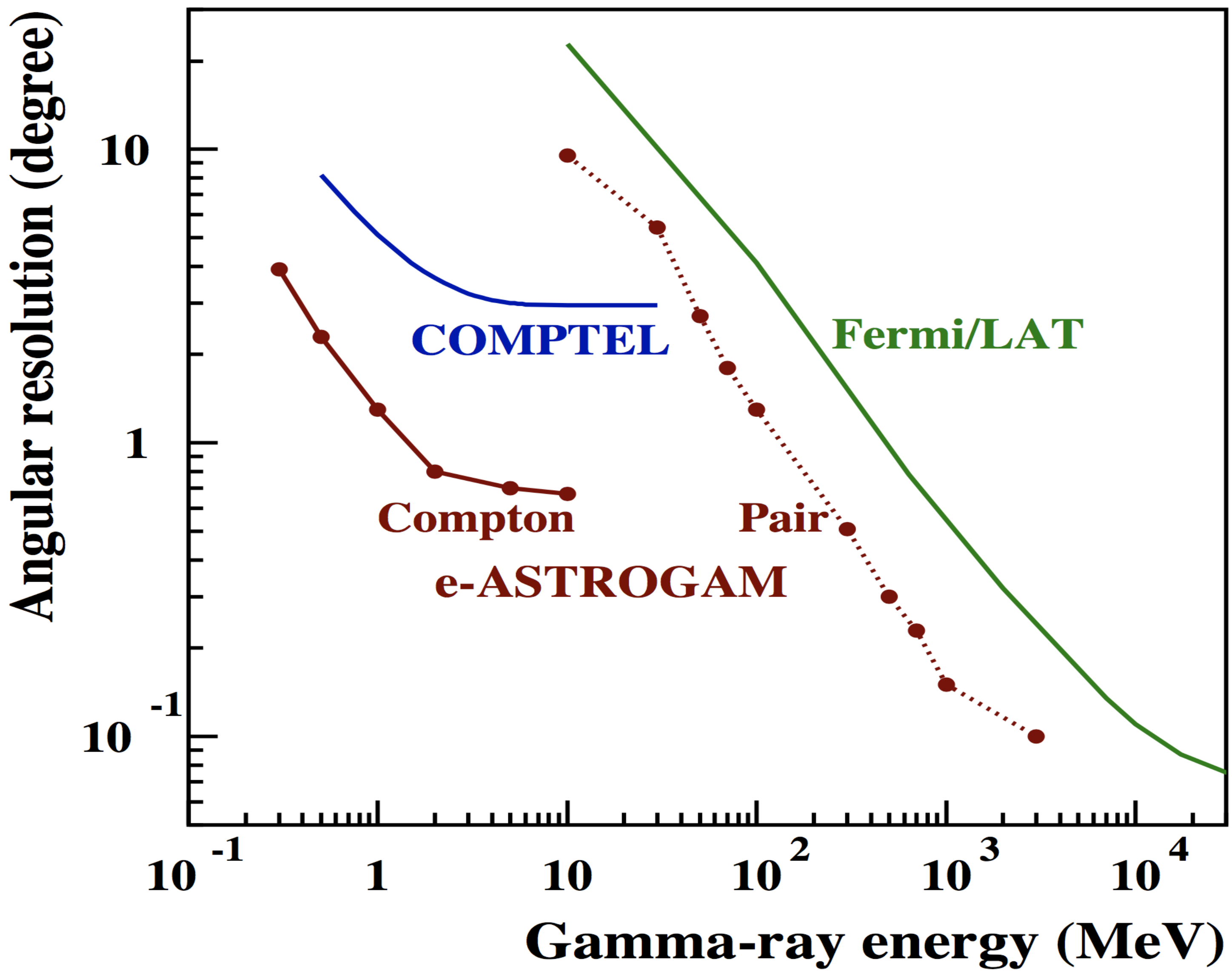


- e-ASTROGAM will be a sensitive, wide-field γ-ray space observatory operating at the same time as facilities like SKA and CTA, as well as eLISA and neutrino detectors, to get a coherent picture of the transient sky and the sources of gravitational waves and high-energy neutrinos

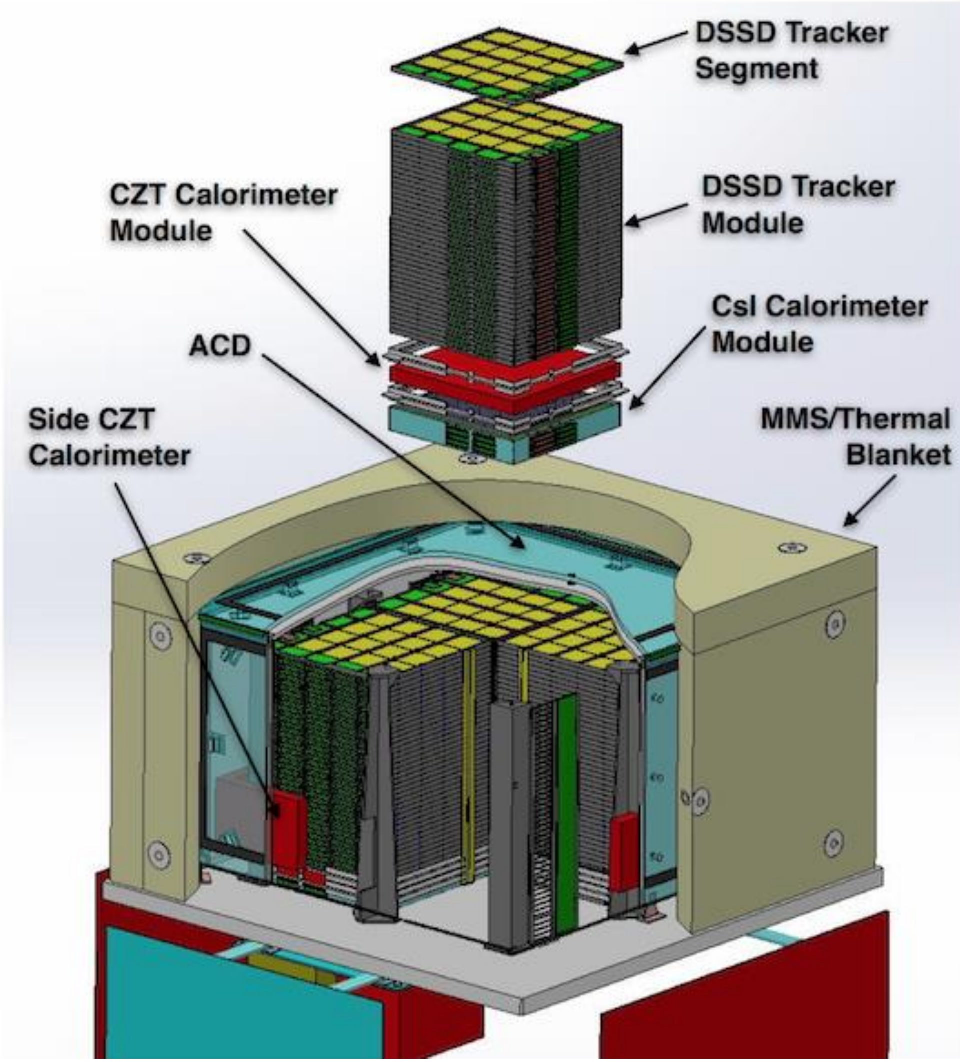


BL Lacs
Other/Unknown
Radio Lobes
Central Engine
>1000 sources expected with e-ASTROGAM
FSRQs
Blazars
Radio Galaxies
Sgr A*
Solar Flares
Supermassive Black Holes
Unidentified
Short
Solar System
Gamma-Ray Bursts
Terrestrial γ-Ray Flashes
Gamma-Ray Source Classes
Long
Satellite Galaxies
Core-collapse
Supernovae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

e-ASTROGAM Angular Resolution



Our sister experiment: AMEGO (NASA)



Status and Plans :
Resubmit in the next MIDEX round (~2027)

in the meantime:

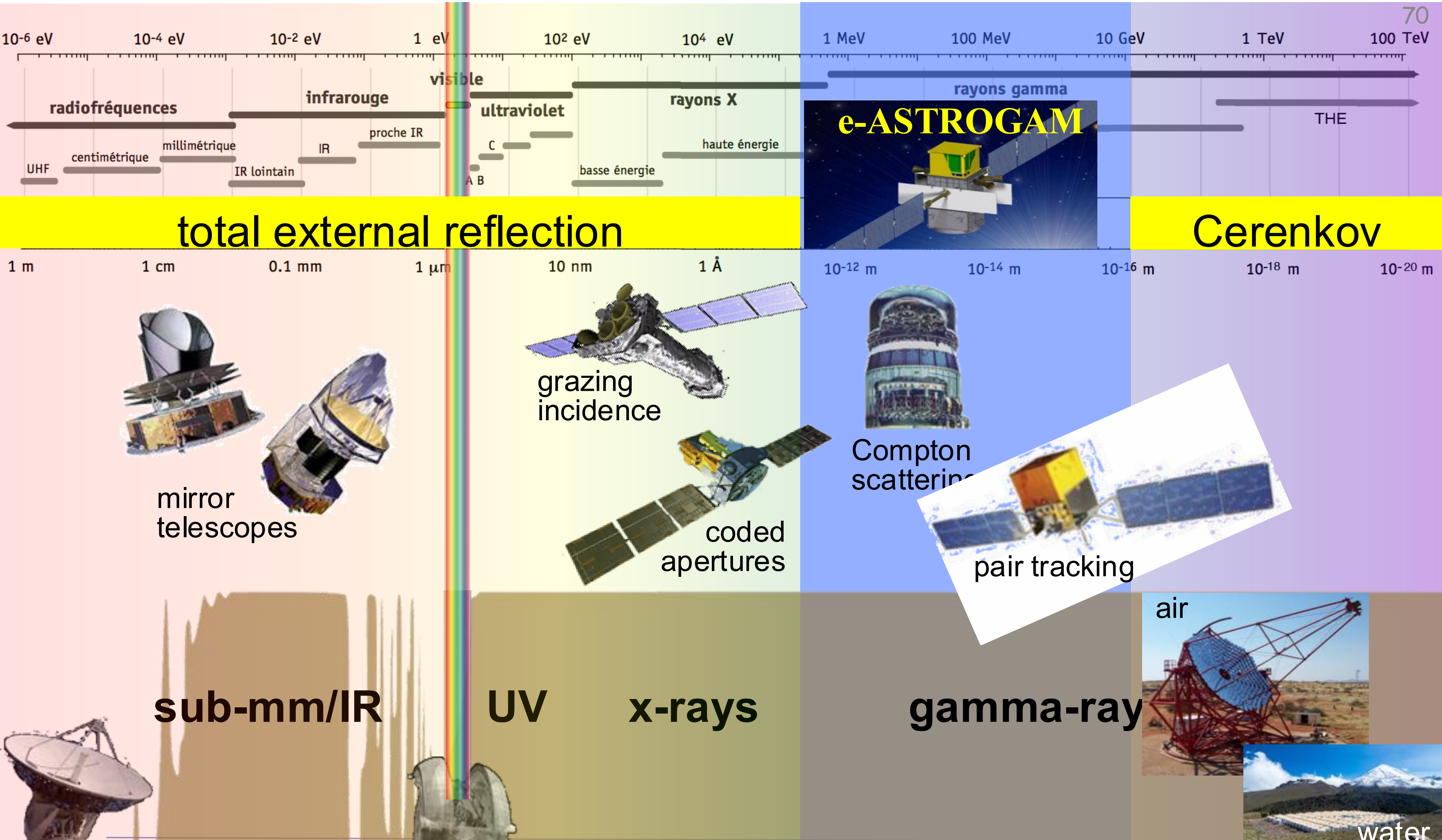
Advocate to NASA via the Physics of the Cosmos Program Analysis Group (PhysPAG). This is NASA's link to the community.

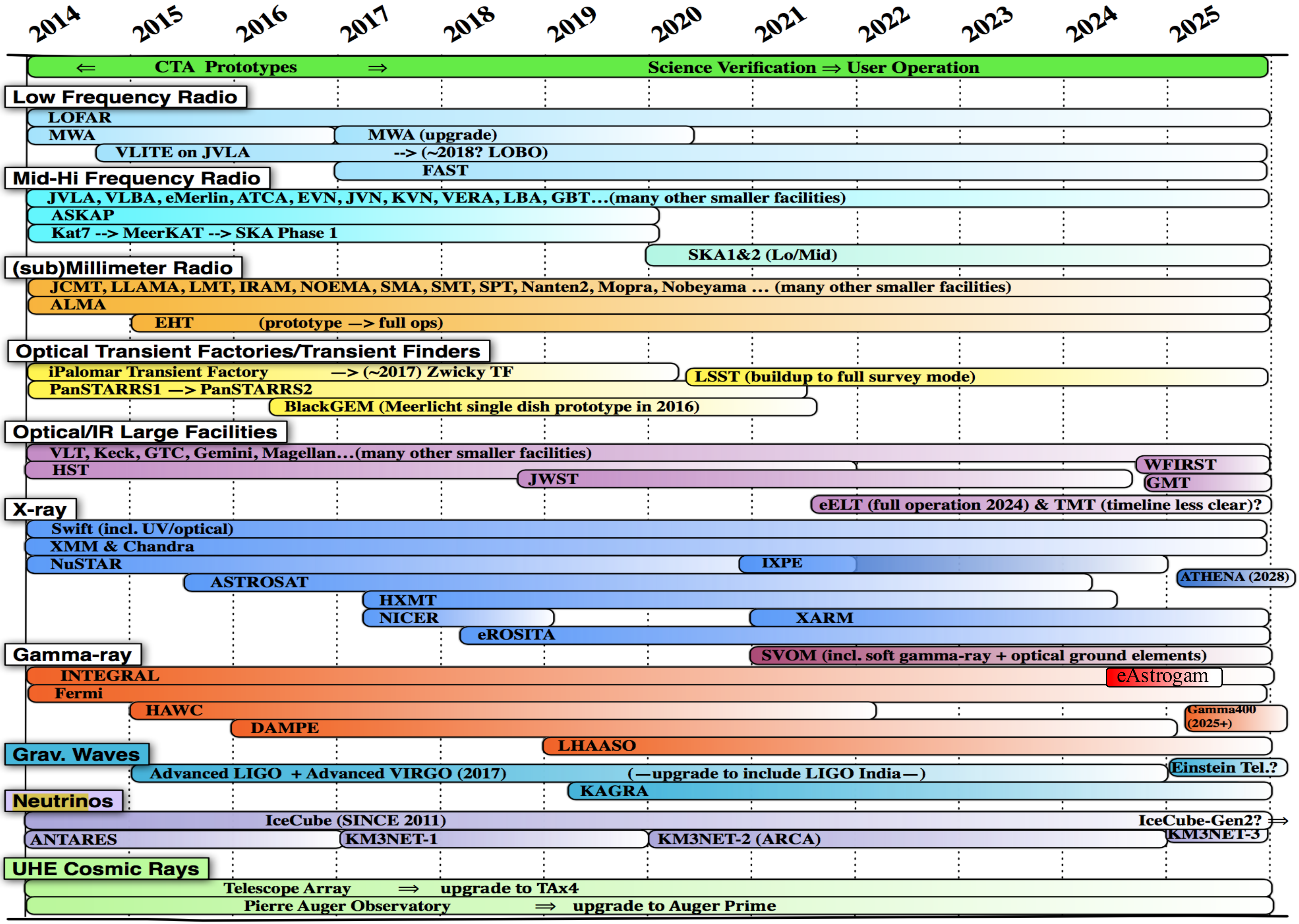
- Science gaps: https://pcos.gsfc.nasa.gov/physpag/science-gaps/science-gaps.php
- Technology gaps: https://pcos.gsfc.nasa.gov/news/2024/6_Technology_Gaps_Submissions_Due.php
- Join the Gamma-ray Science Interest Group (GammaSIG)
- https://pcos.gsfc.nasa.gov/sigs/grsig.php

Why eAstrogam is important for IceCube and KM3Net

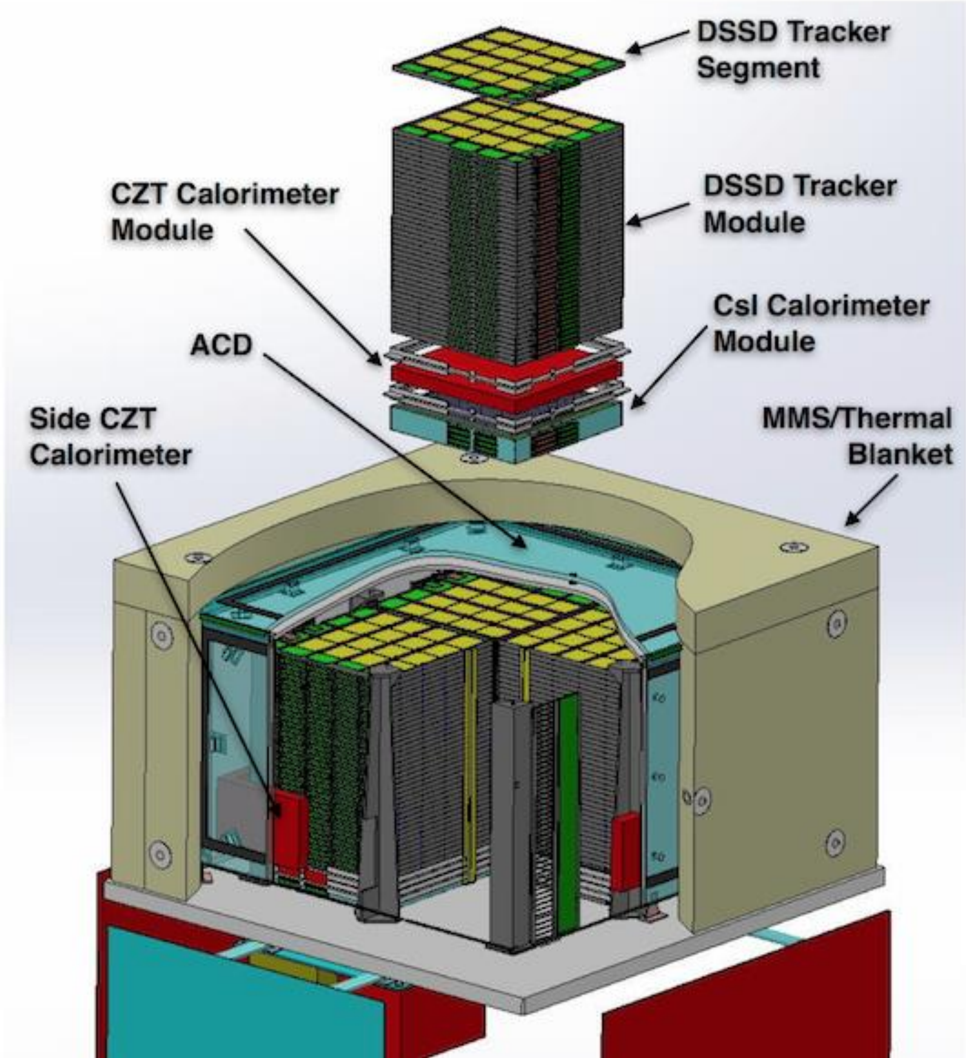
- Wide FoV (> 2.5 sr at 10 MeV) in survey mode.
- Sources of astrophysical neutrinos detected by IceCube may be opaque to 1–100 GeV gamma-rays but bright in the MeV domains (expecially if the neutrino flux originates from photo-hadronic processes)
- eAstrogam can select the best blazar candidates for a neutrino emission (looking at the MeV hump of the double-humped spectral energy distribution)
- Can constrain the population models of the EGB helping to discriminate between $p\gamma$ or pp processes

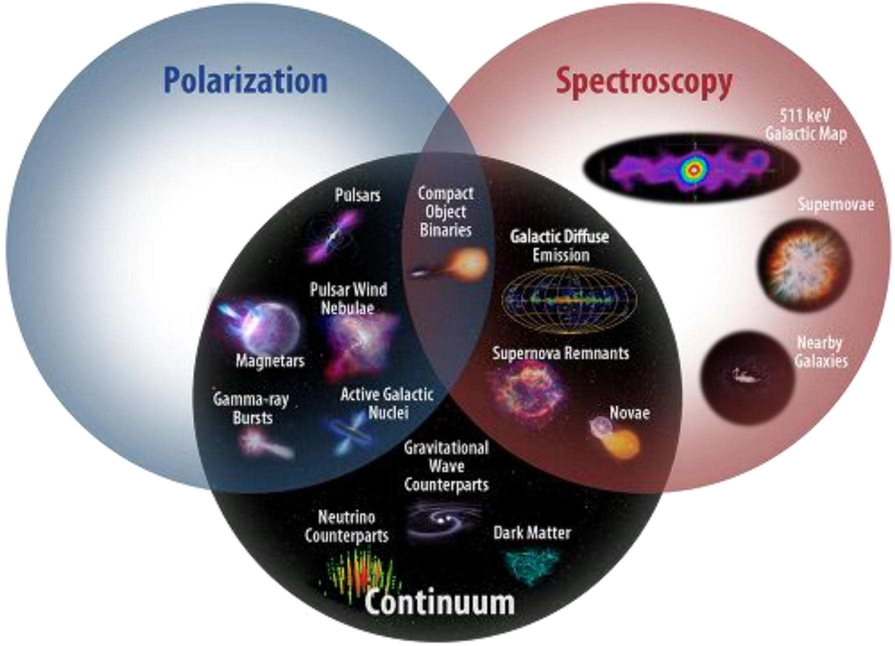
An instrument to complete the coverage of the electromagnetic spectrum




2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
⇐ CTA Prototypes ⇒
Science Verification ⇒ User Operation
Low Frequency Radio
LOFAR
MWA
MWA (upgrade)
VLITE on JVLA
--> (~2018? LOBO)
Mid-Hi Frequency Radio
FAST
JVLA, VLBA, eMerlin, ATCA, EVN, JVN, KVN, VERA, LBA, GBT…(many other smaller facilities)
ASKAP
Kat7 --> MeerKAT --> SKA Phase 1
SKA1&2 (Lo/Mid)
(sub)Millimeter Radio
JCMT, LLAMA, LMT, IRAM, NOEMA, SMA, SMT, SPT, Nanten2, Mopra, Nobeyama … (many other smaller facilities)
ALMA
EHT (prototype —> full ops)
Optical Transient Factories/Transient Finders
iPalomar Transient Factory —> (~2017) Zwicky TF
LSST (buildup to full survey mode)
PanSTARRS1 —> PanSTARRS2
BlackGEM (Meerlicht single dish prototype in 2016)
Optical/IR Large Facilities
VLT, Keck, GTC, Gemini, Magellan…(many other smaller facilities)
HST
WFIRST
JWST
GMT
eELT (full operation 2024) & TMT (timeline less clear)?
X-ray
Swift (incl. UV/optical)
XMM & Chandra
NuSTAR
IXPE
ATHENA (2028)
ASTROSAT
HXMT
NICER
XARM
eROSITA
Gamma-ray
SVOM (incl. soft gamma-ray + optical ground elements)
INTEGRAL
eAstrogam
Fermi
HAWC
Gamma400 (2025+)
DAMPE
LHAASO
Grav. Waves
Advanced LIGO + Advanced VIRGO (2017)
(—upgrade to include LIGO India—)
Einstein Tel.?
KAGRA
Neutrinos
IceCube (SINCE 2011)
IceCube-Gen2? ⇒
ANTARES
KM3NET-1
KM3NET-2 (ARCA)
KM3NET-3
UHE Cosmic Rays
Telescope Array ⇒ upgrade to TAx4
Pierre Auger Observatory ⇒ upgrade to Auger Prime

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





- ~20% smaller tracker
- CZT calorimeter layer

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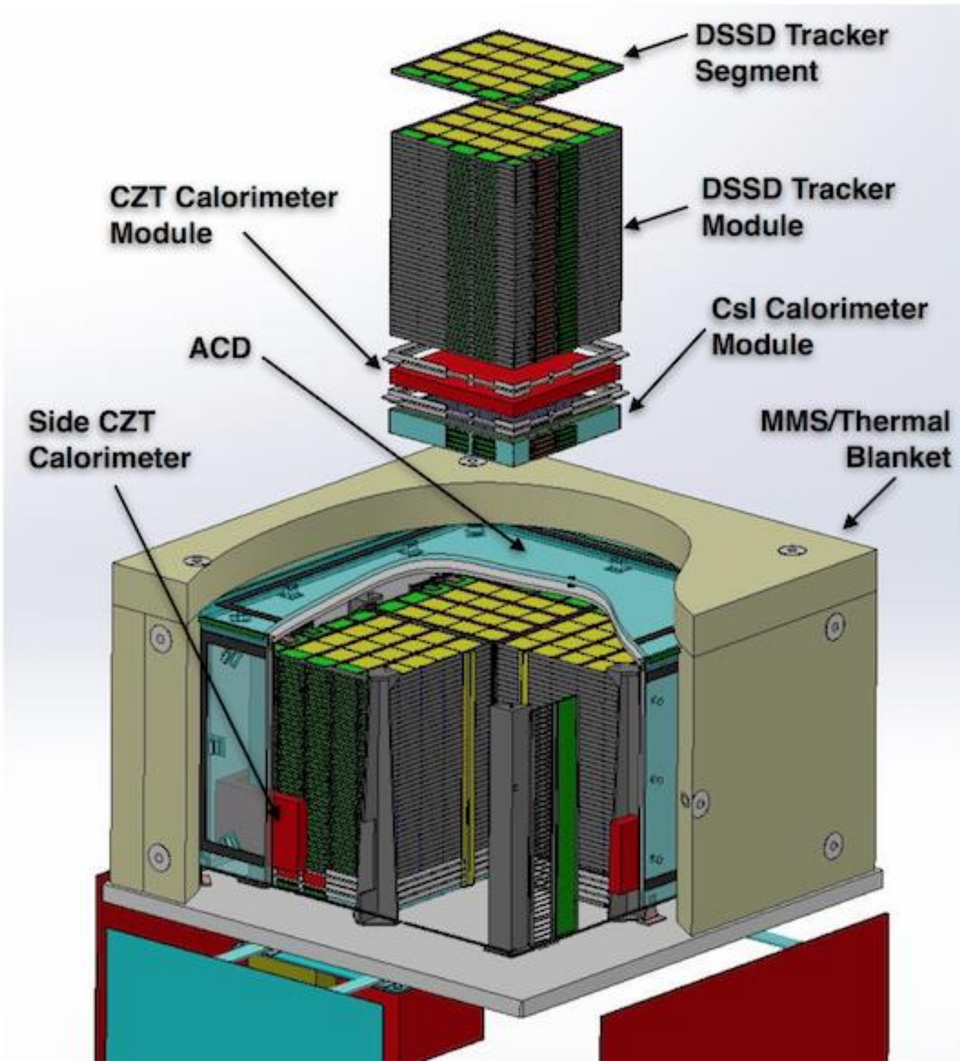
Our sister experiment: AMEGO (NASA)



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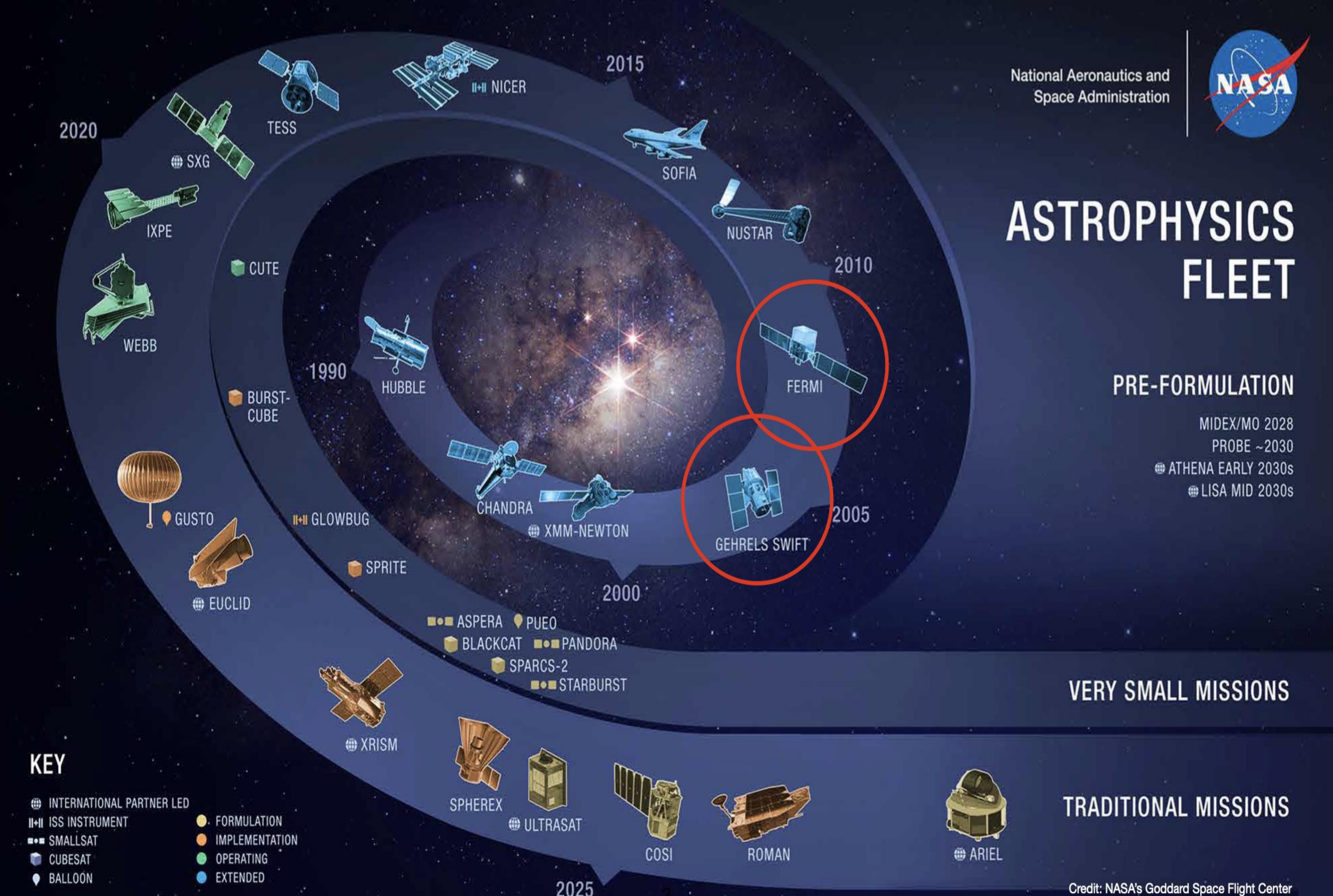


Updated June 2022

COSI The Compton Spectrometer and Imager

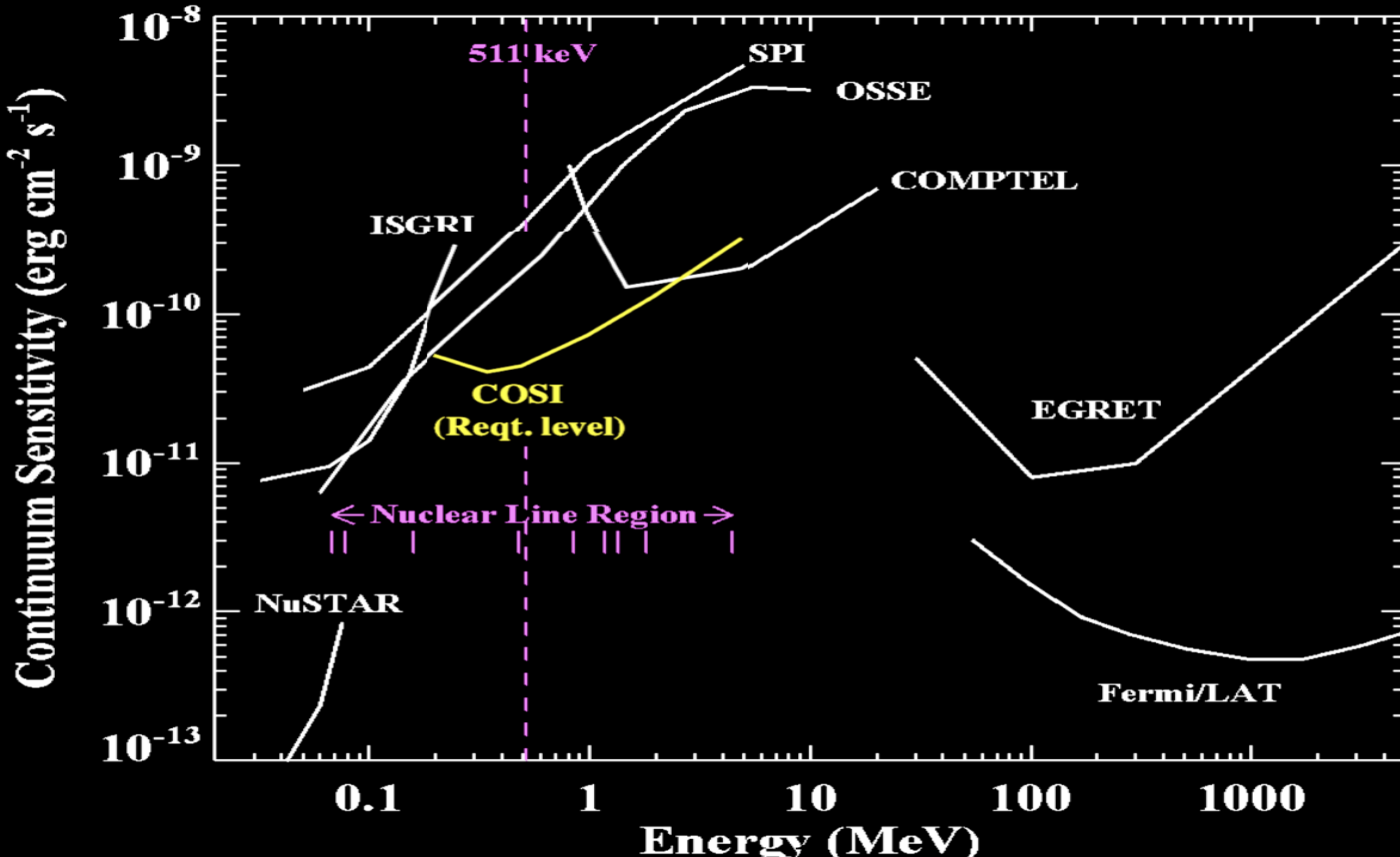
- COSI has been selected by NASA as a SMEX to launch in 2027

- a Compton telescope for observing 0.2-5 MeV gamma-rays

1. Key capabilities
   - Uses cryogenically-cooled germanium detectors (GeDs) to provide energy resolution (~1%)
   - Instantaneous field of view is >25%-sky and covers the whole sky every day

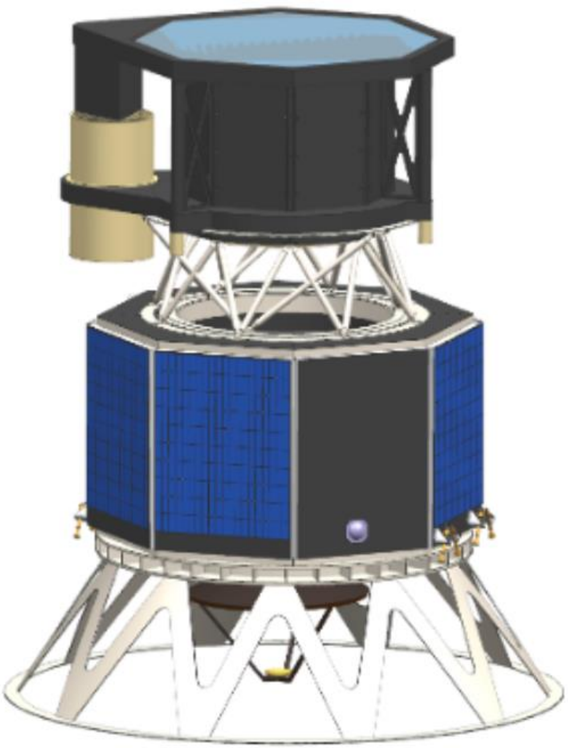
- Goal D emphasizes the connection to gravitational waves
- ▪Detects short gamma-ray bursts (GRBs) from merging neutron stars
  ▪Localizations to ~1° accuracy
  ▪Public alerts in <1 hour

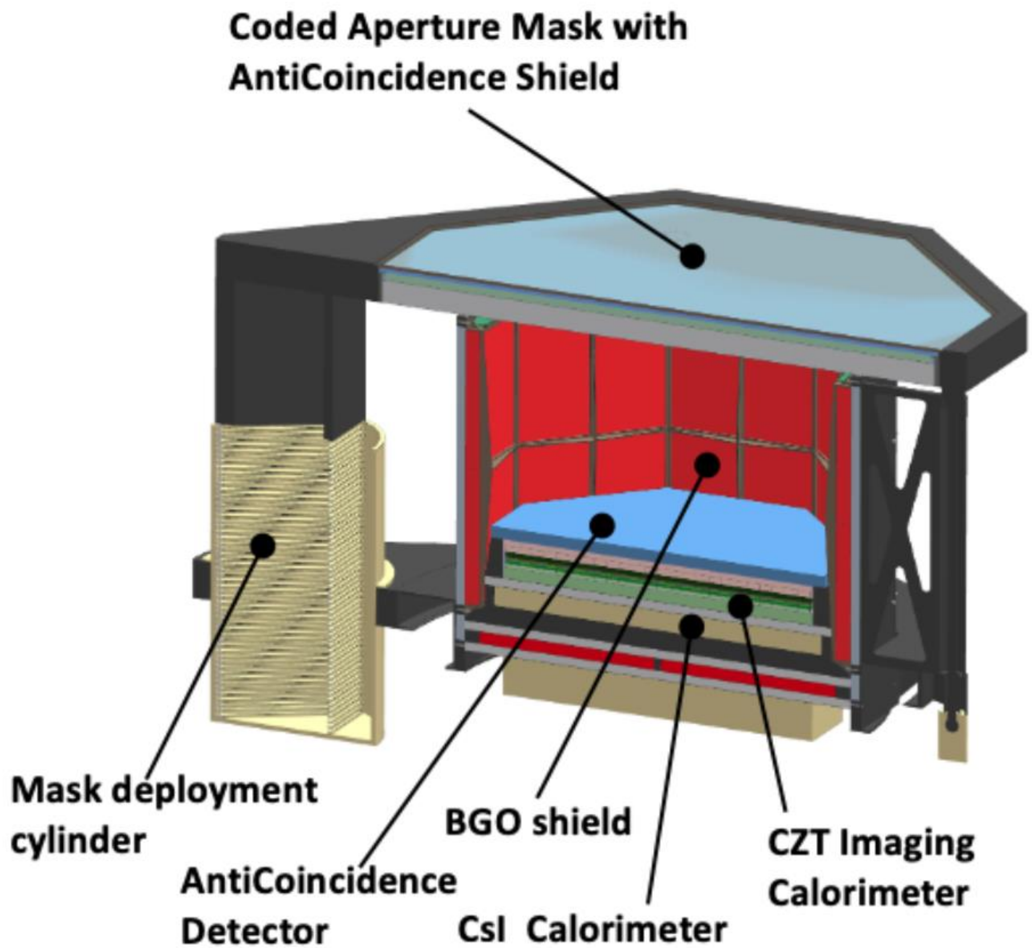
COSI



continuum emission sensitivity

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope



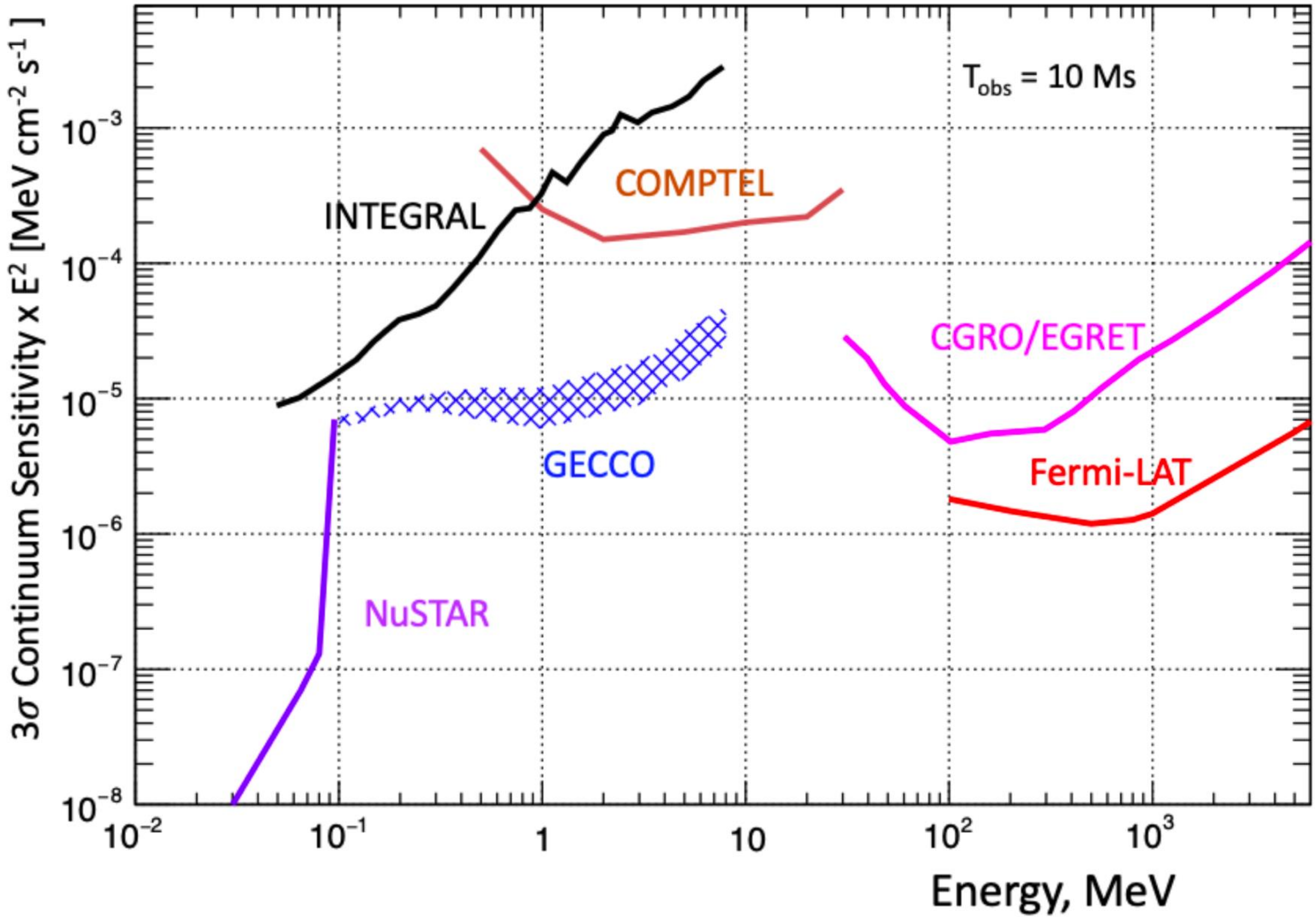


conceptual design mask in stowed position cutaway diameter =90 cm

GECCO Team, JCAP07(2022)036 arXiv:2112.07190

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

Sensitivity



GECCO Team, JCAP07(2022)036 arXiv:2112.07190

New opportunity: ASI Call for Small Missions

New ASI call

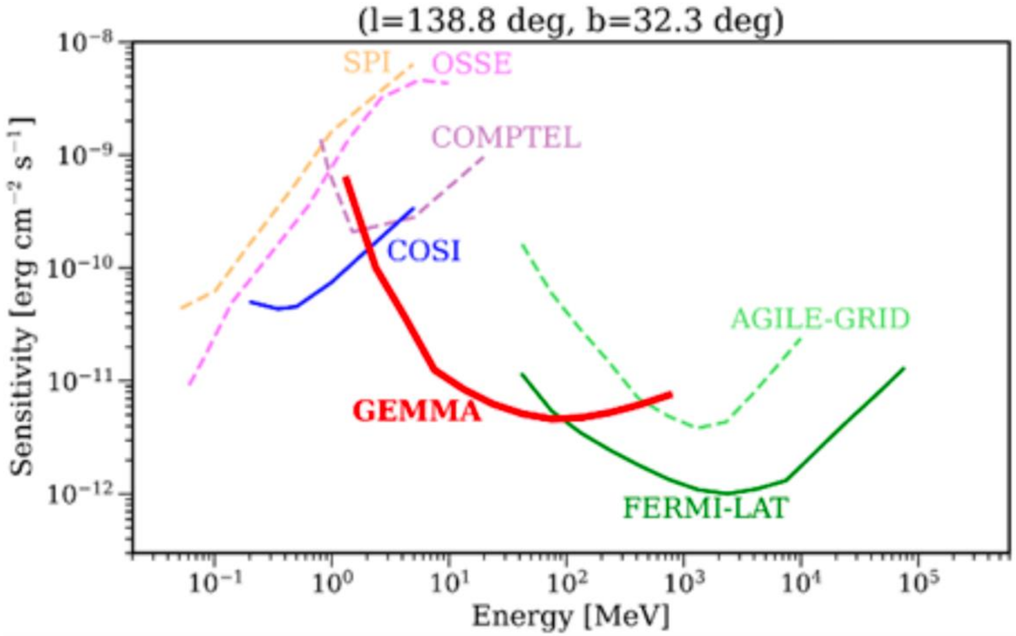
- 100 kg payload, 50 Meuros
- proposals due in April 2026
- Proposals currently under review

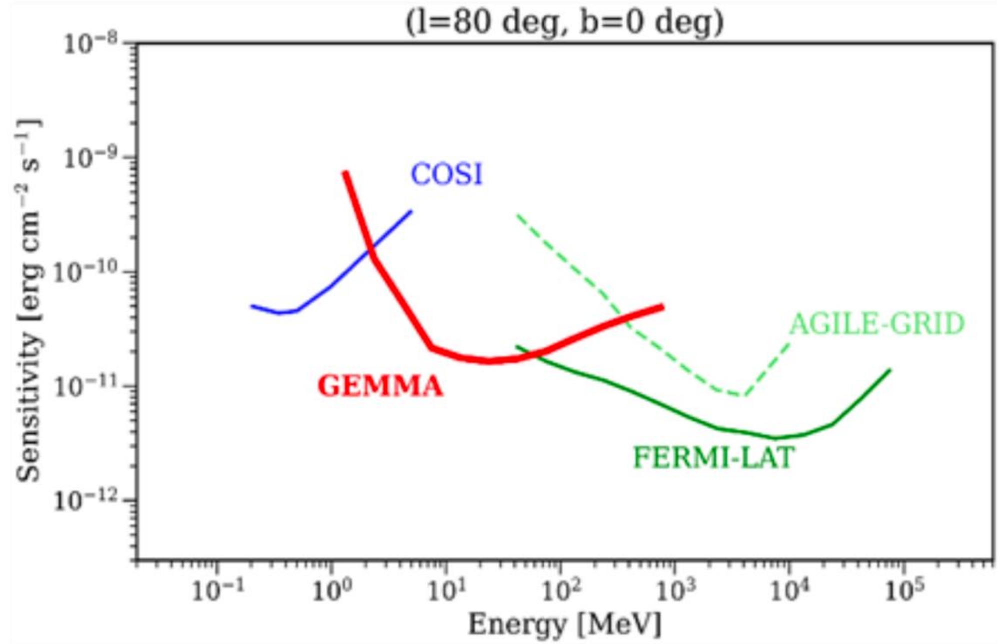
For this call we proposed

The Gamma-ray Explorer for Multi-Messenger and Cosmic Accelerators Project (GEMMA)

- MeV-GeV Mission,
- INAF-INFN partneship like AGILE and Fermi

The GEMMA window





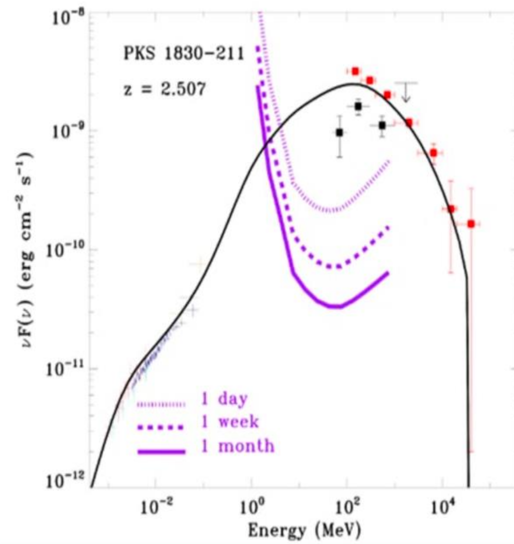
the detector is designed to operate in both the Compton and pair-production regimes from 1 MeV to beyond 1 GeV and it is composed by:

1) a Scintillating Fiber Tracker,
2) a highly segmented CsI(Tl) calorimeter
3) a segmented plastic anticoincidence

Why the MeV domain is essential?

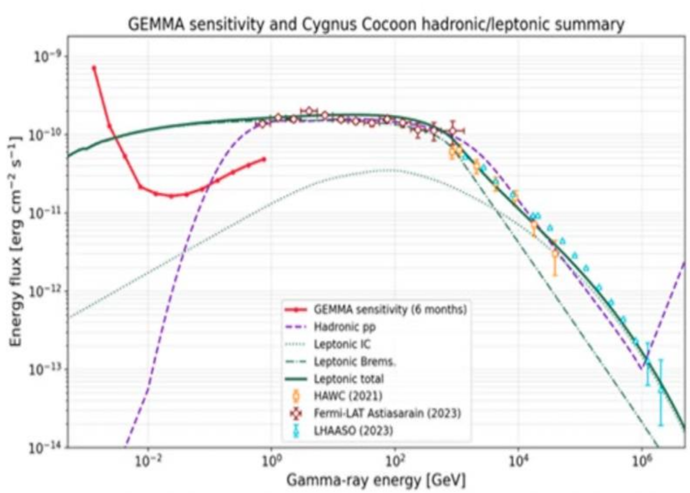
1. Cosmic-ray origin

- Origin of Galactic cosmic rays still unknown
- Hadronic vs leptonic processes unresolved
- **Pion bump (10–300 MeV) is the key diagnostic**



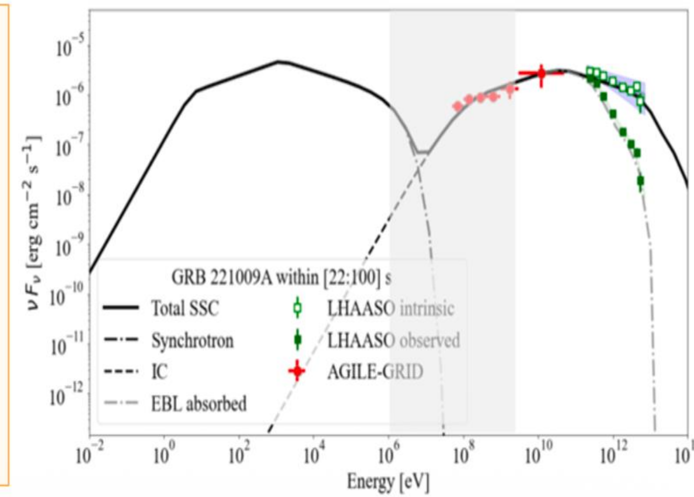
3. Multi-messenger astrophysics

- Counterparts of:
  - neutrinos
  - gravitational waves
- Hidden accelerators peak in MeV band



2. Jets & relativistic accelerators

- Transition between thermal and non-thermal emission
- Disentangling:
  - Bremsstrahlung
  - Inverse Compton
  - Hadronic emission



Only MeV observations disentangle particle acceleration processes

Summary

- AGILE ended data taking on 13 Feb 2024
- CTA, SWGO and LHAASO can explore the high -energy domain
- Fermi is still in orbit but we need a new mission

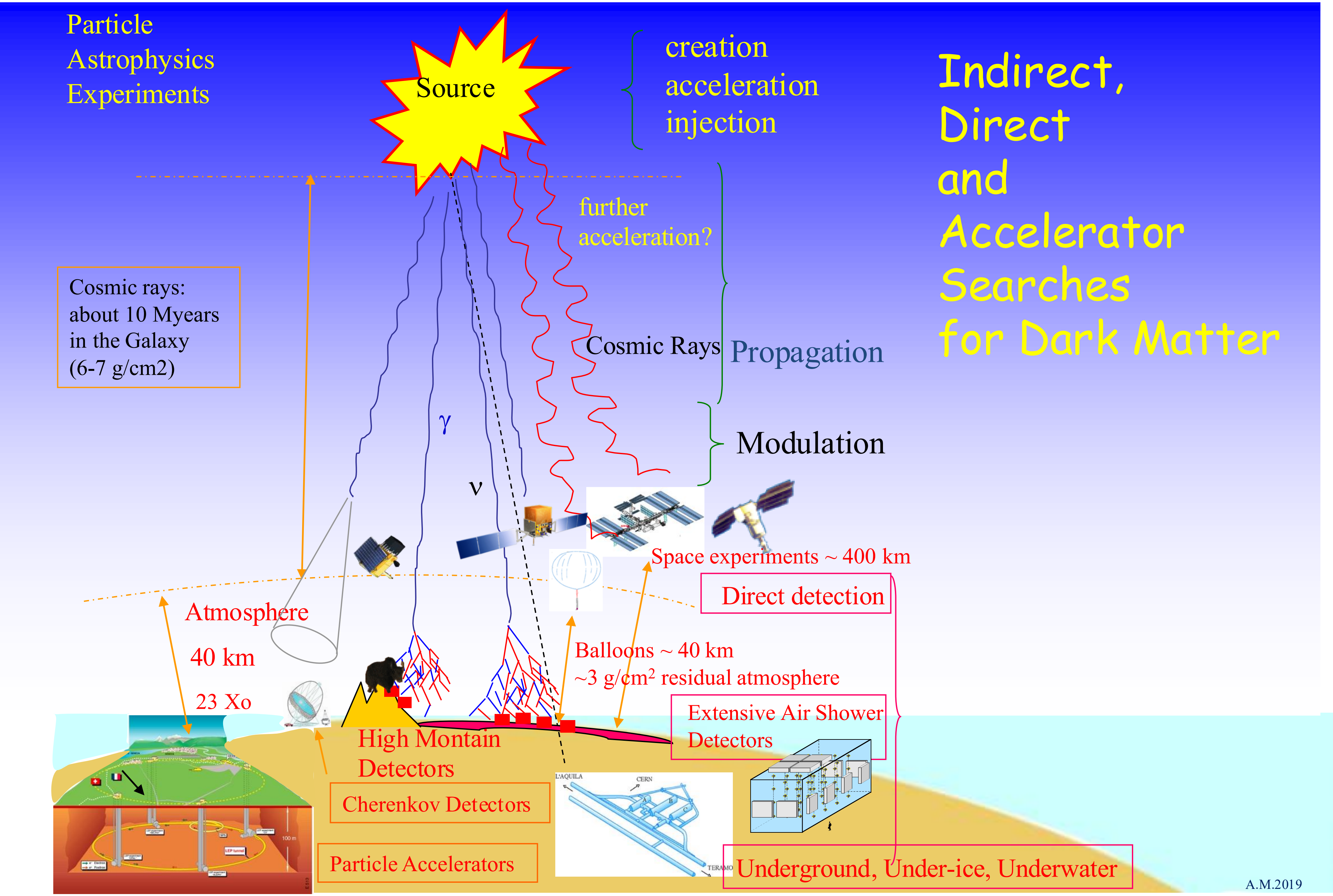
with a focus in the low energy range (below 100 MeV)

- The whole astroparticle-multimessenger community is expecting a mission after Fermi

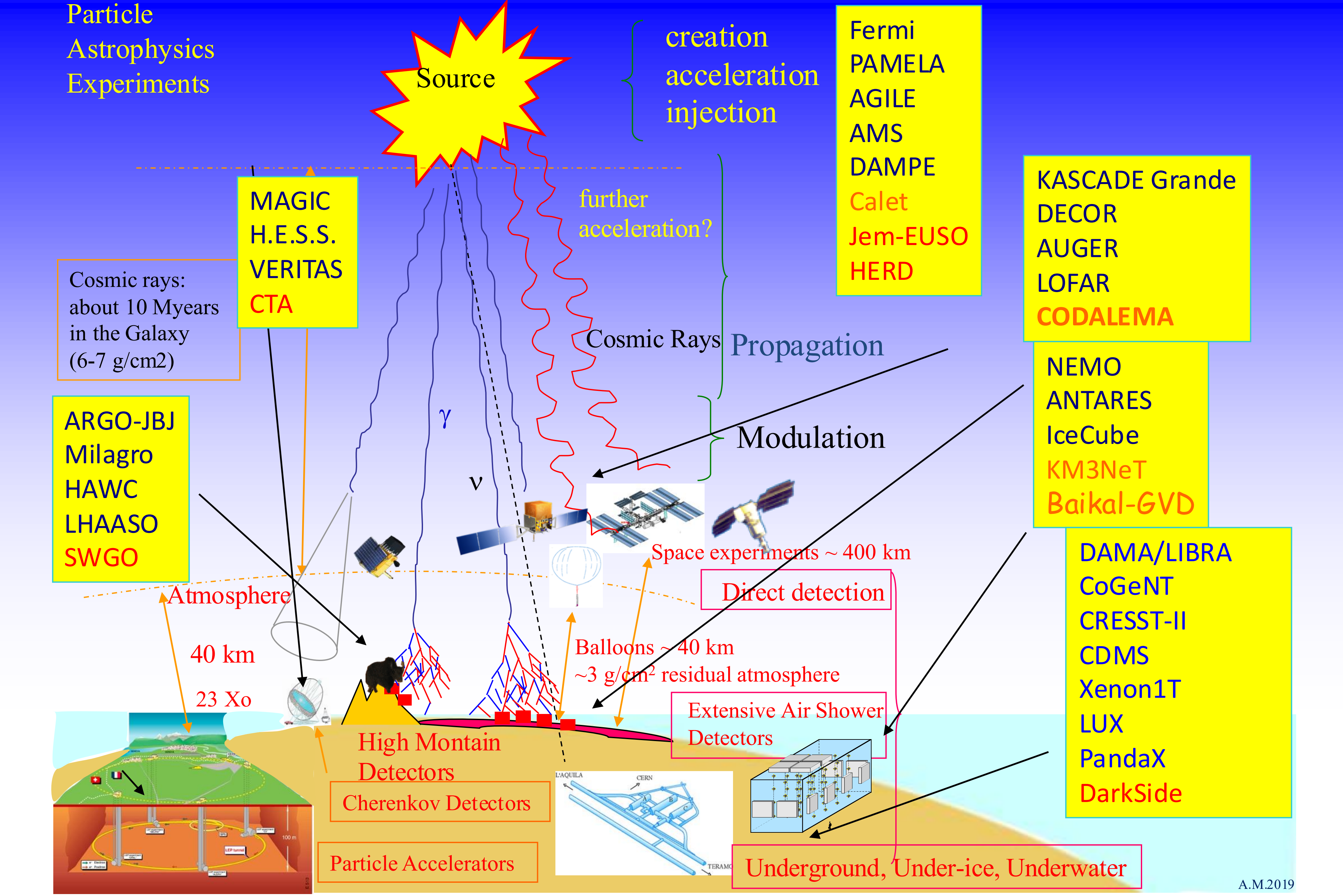
The energy band just below Fermi energy is not explored since Comptel.

We submitted Gemma to the ASI small mission program

We hope that everybody will help in any possible way to have that mission approved.



Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Indirect,
Direct
and
Accelerator
Searches
for Dark Matter
further
acceleration?
Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)
γ
ν
Cosmic Rays
Propagation
Modulation
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
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater
A.M.2019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DAMPE
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Jem-EUSO
HERD
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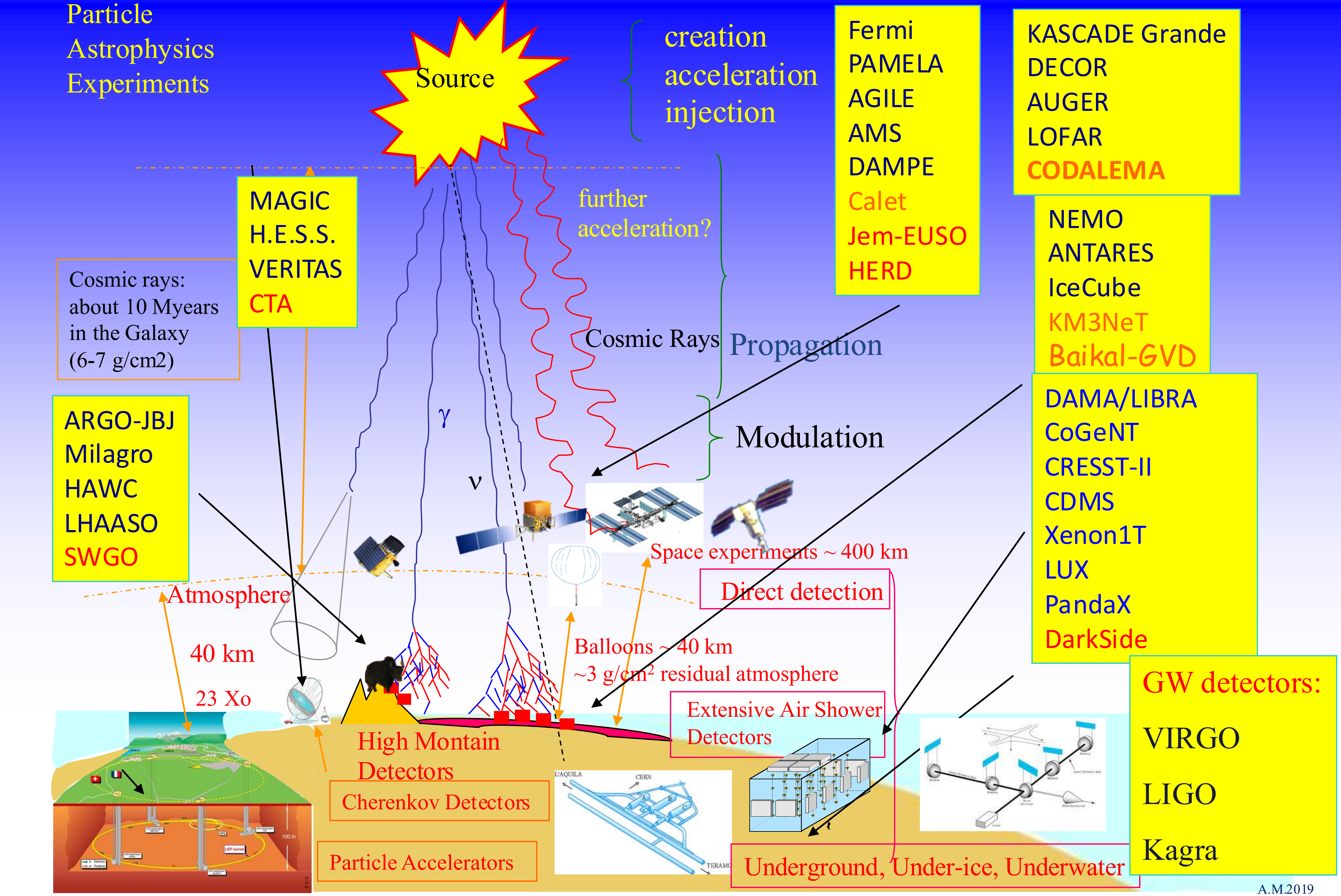
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100 m
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07–11 Sept 2026 see you in Roma La Sapienza for

RICAP 26

10th Roma International Conference on AstroParticle Physics

INFN Istituto Nazionale di Fisica Nucleare

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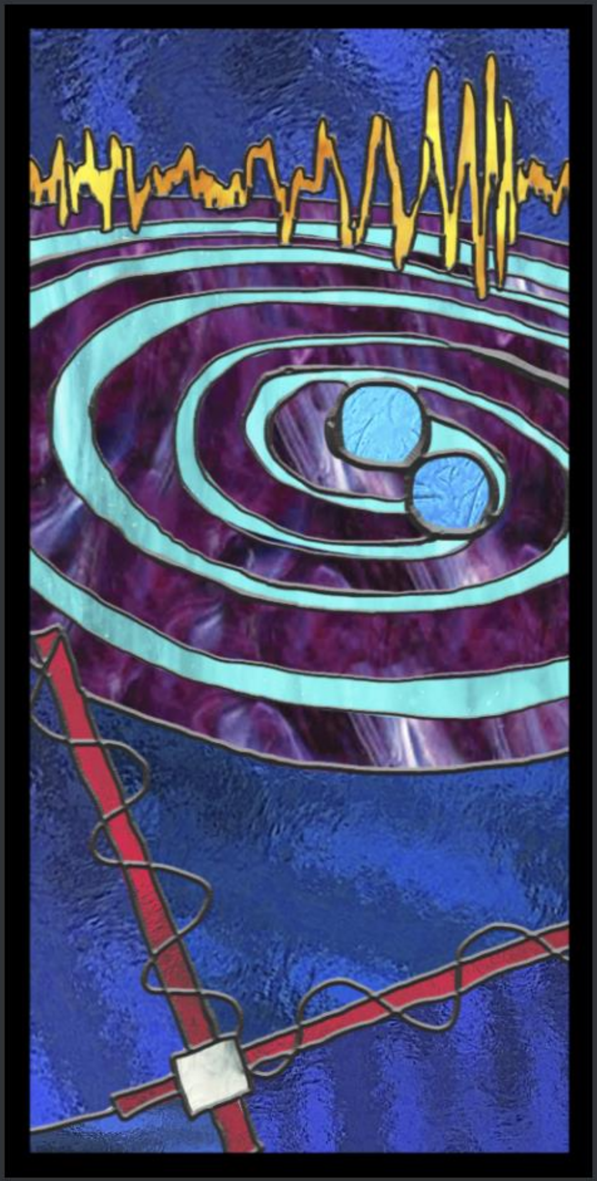
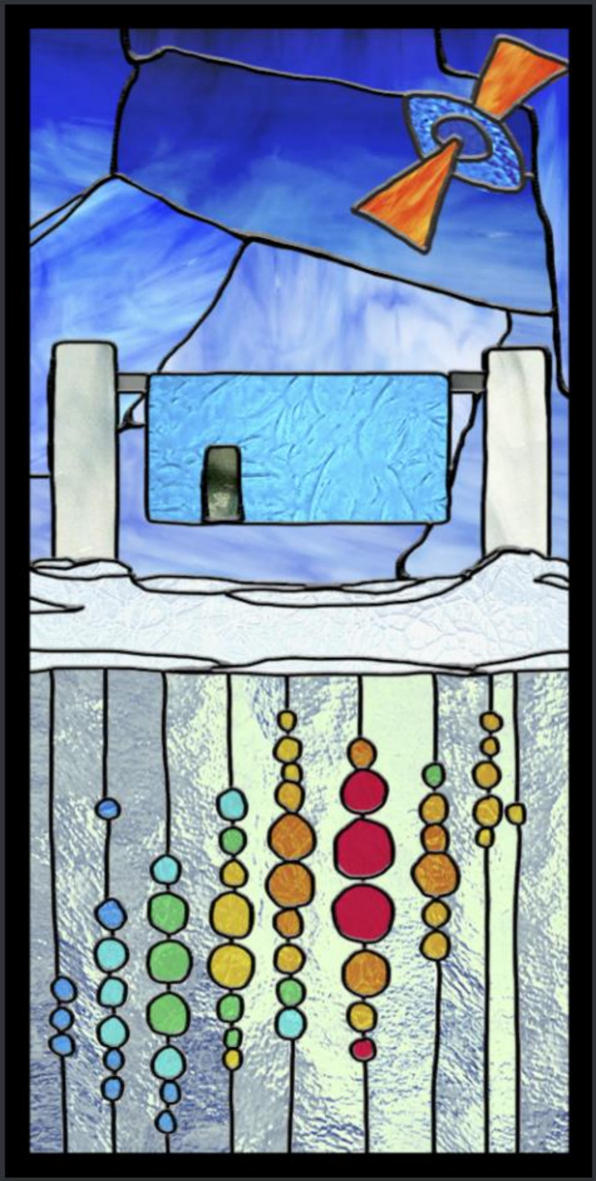
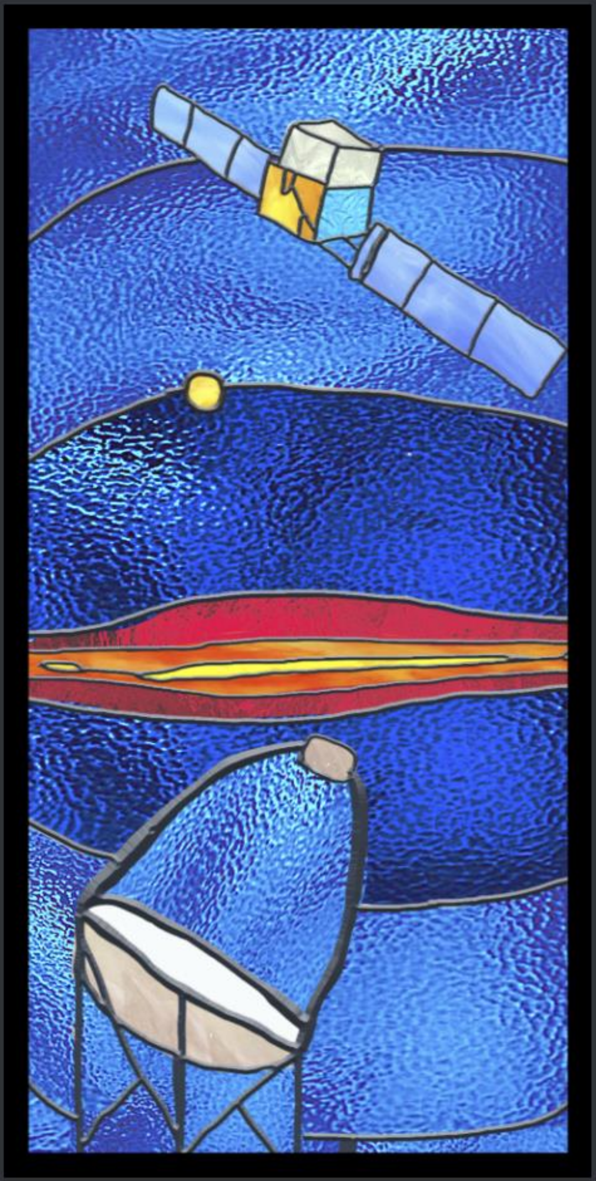
https://agenda.infn.it/event/51859/

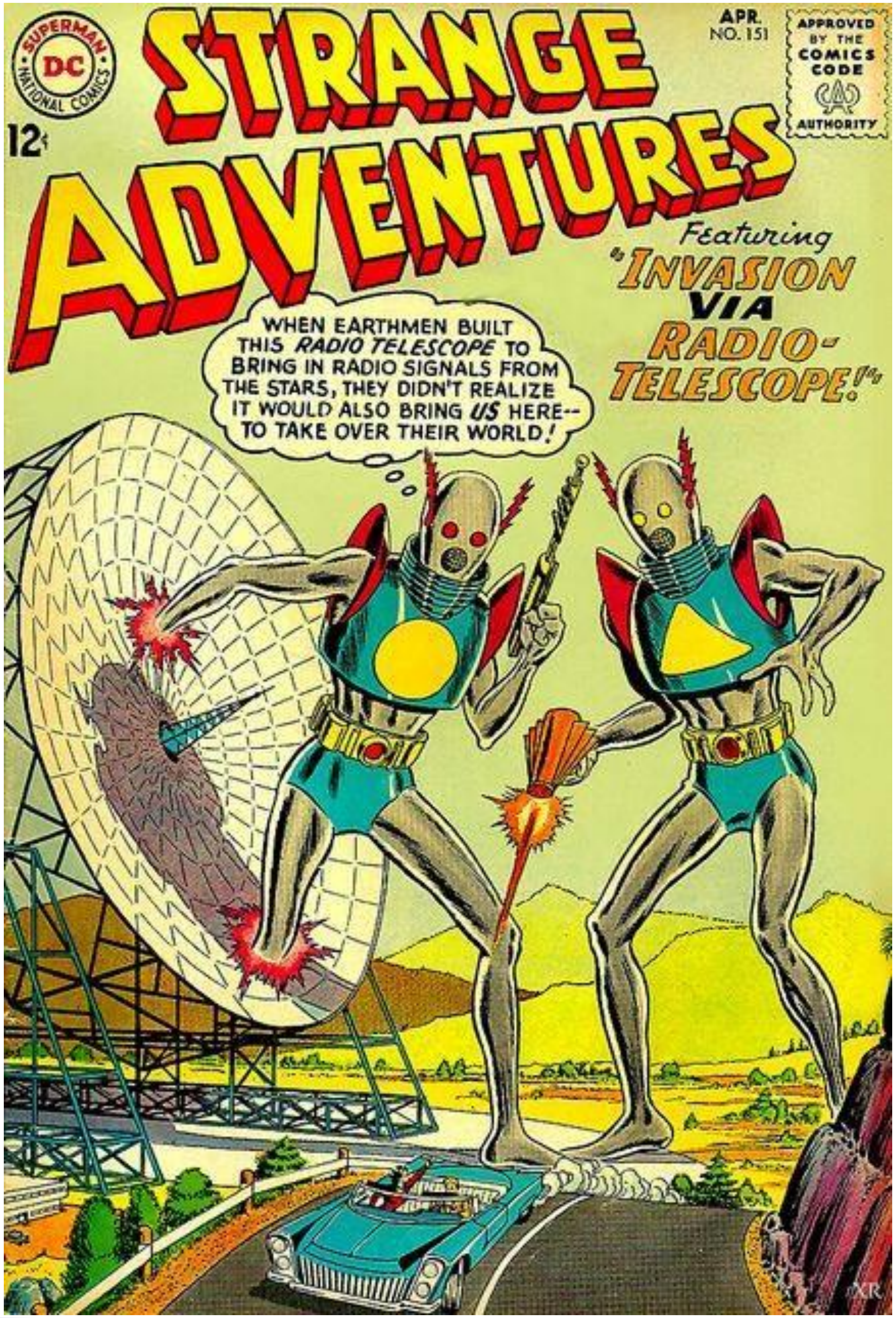
the multi-messanger era







there is always
a risk ..



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