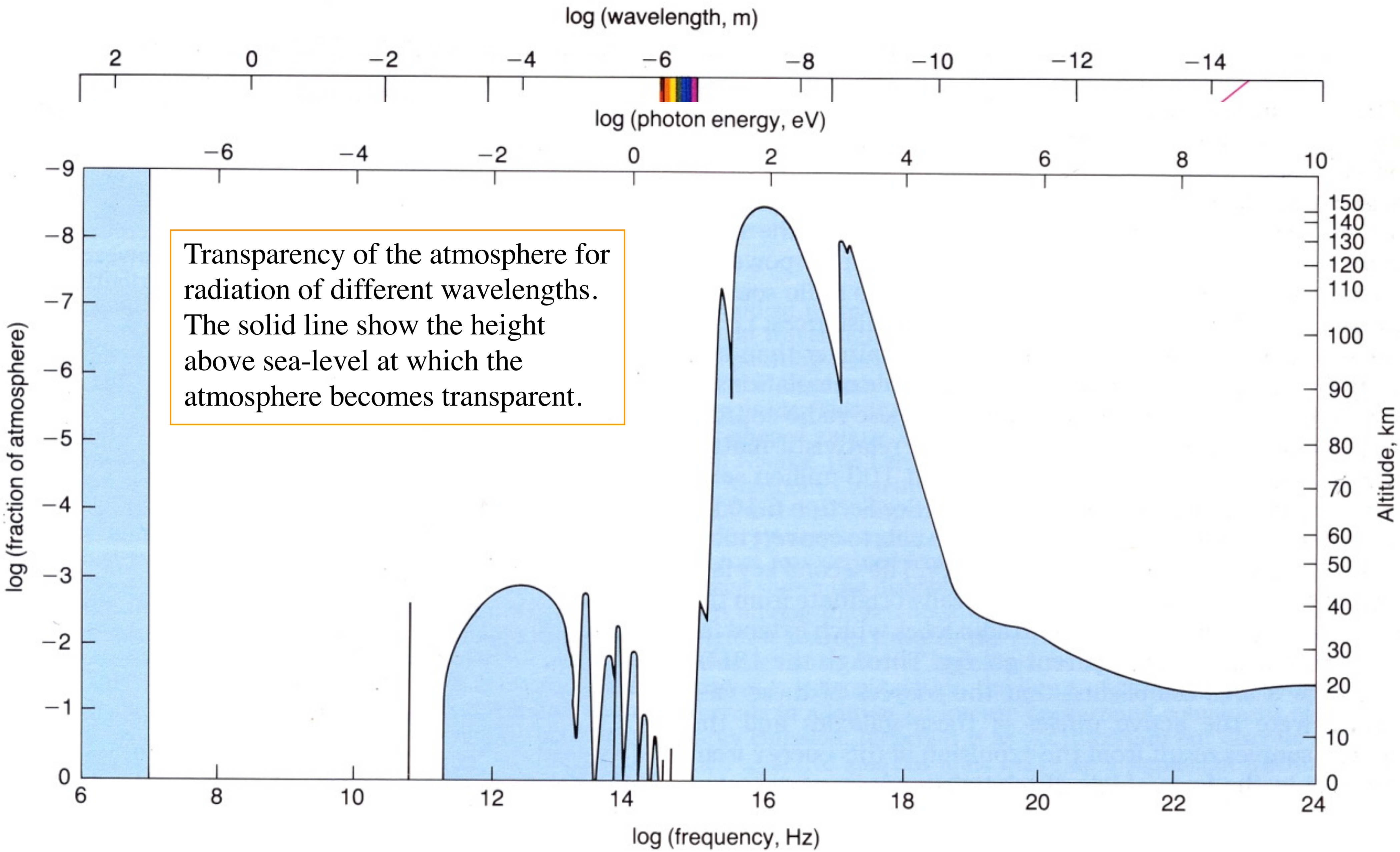
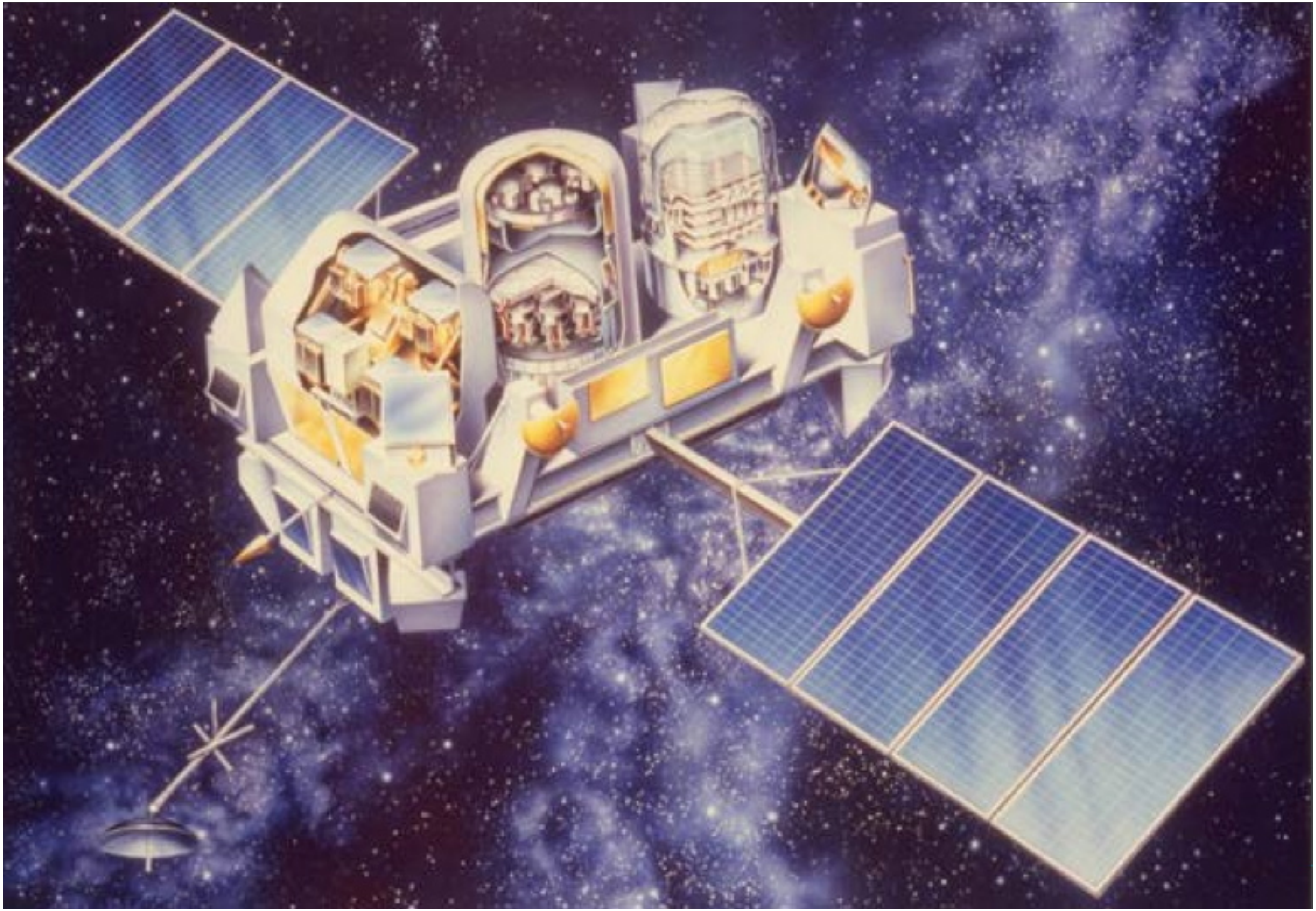
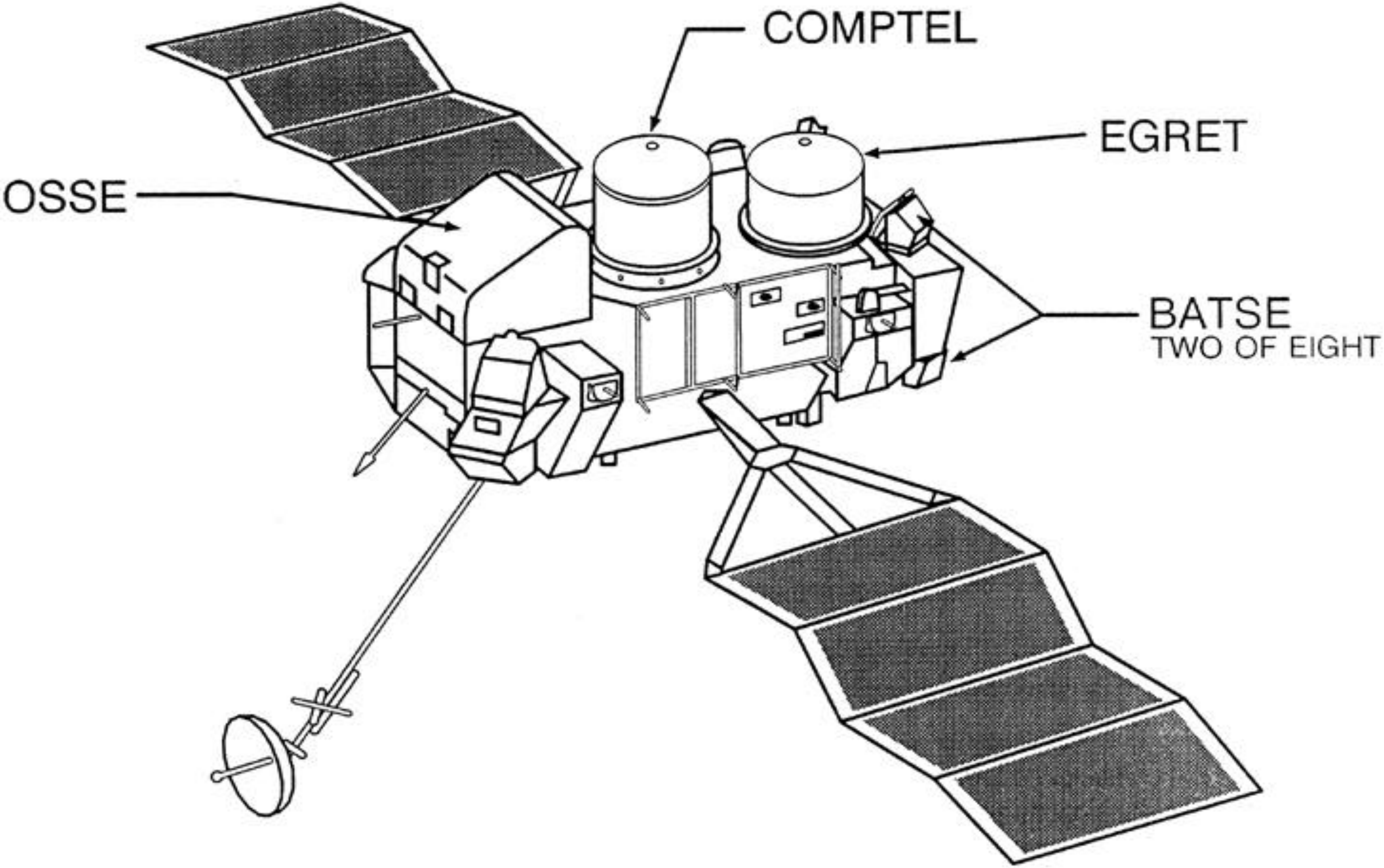

Indirect dark matter search from MeV to TeV and future missions
Aldo Morselli
INFN Roma Tor Vergata
TMEX-2020 16th Rencontres du Vietnam
5-11 January 2020 Quy Nhon

Gamma ray attenuation





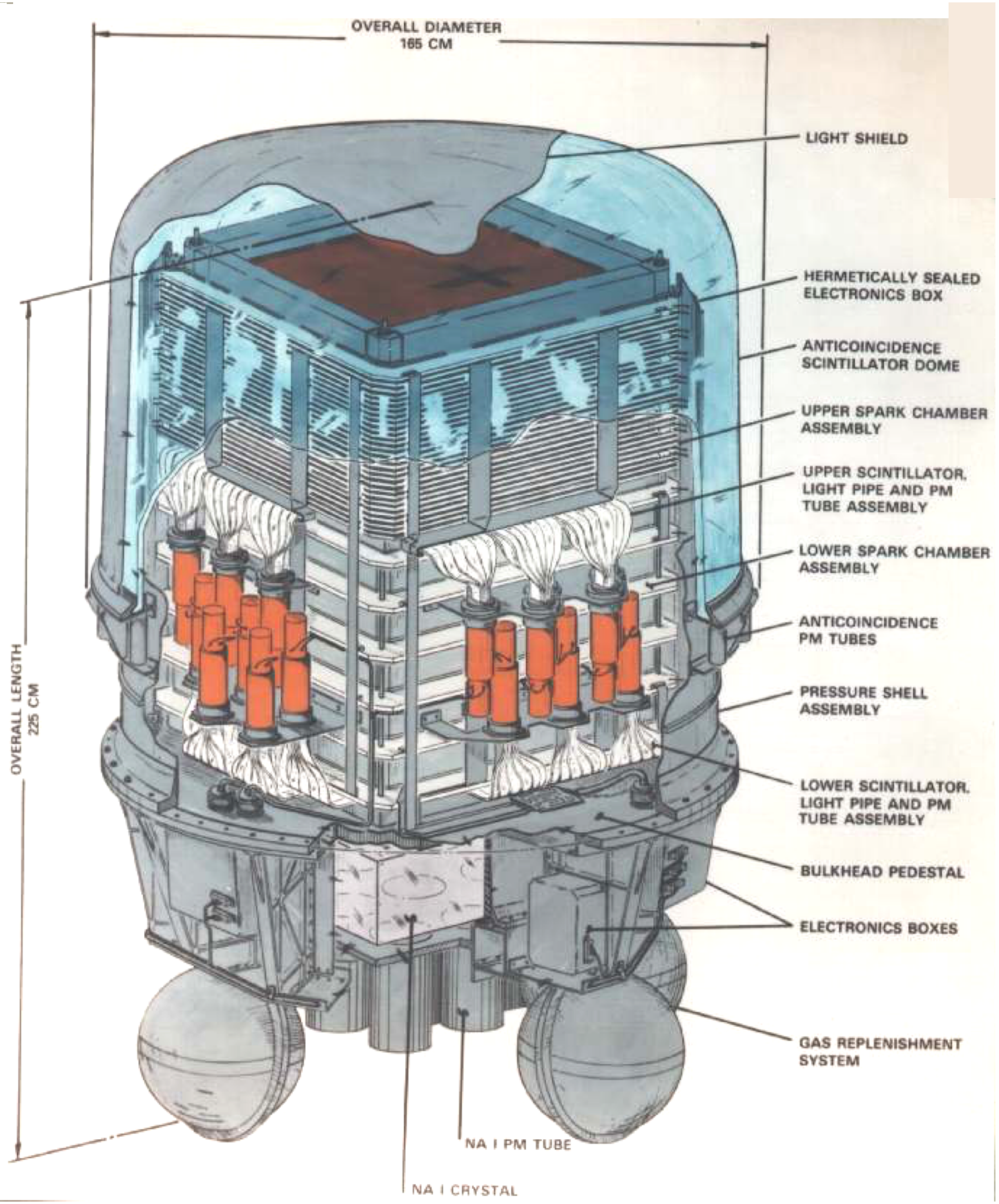
COMPTON OBSERVATORY INSTRUMENTS

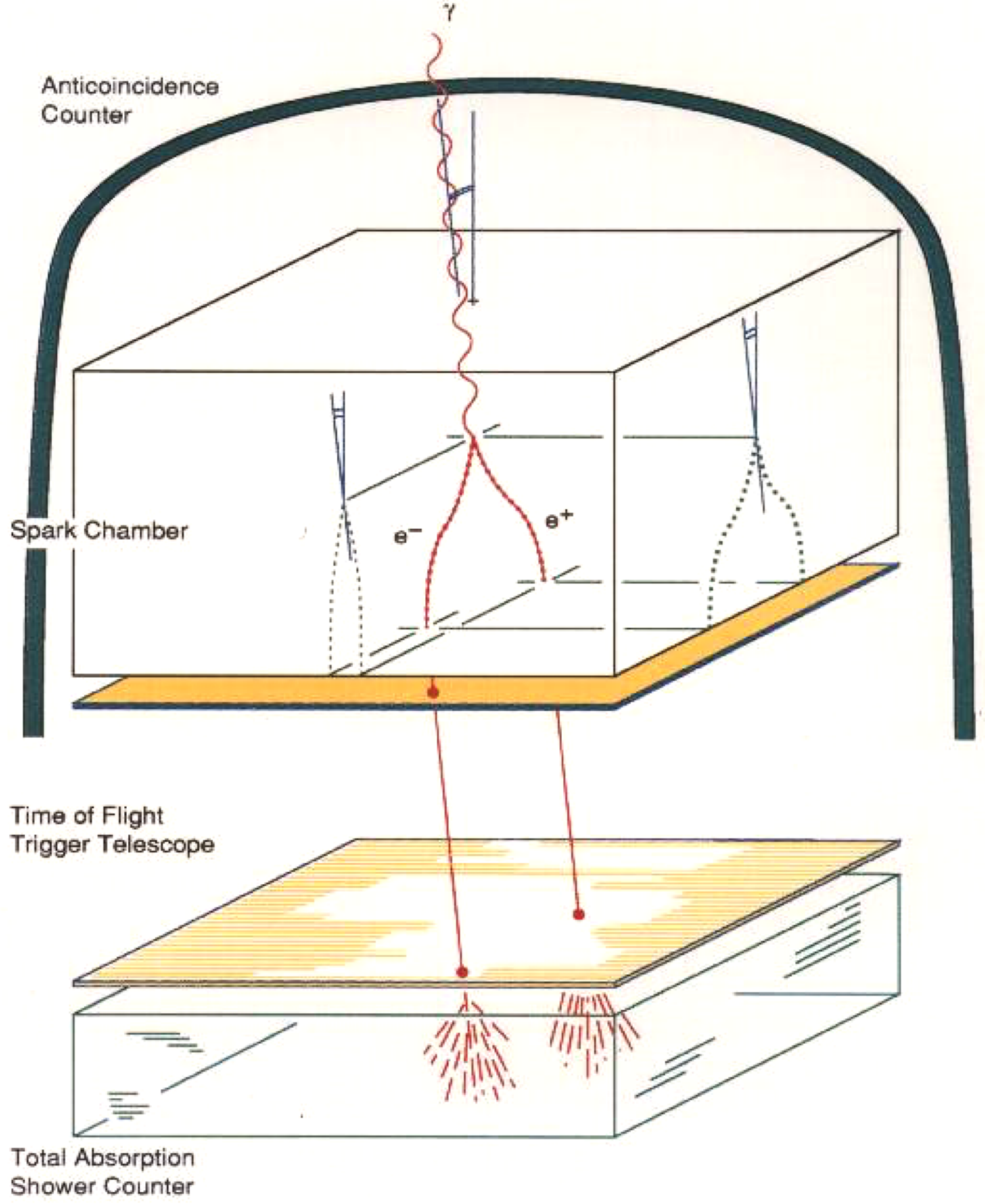


EGRET:the detector

Energy range:	20 MeV - 30 GeV
Weight:	1820 Kg
Power:	160 W
Field of view:	0. 5 sr
Dead Time:	100 ms
Effective Area (@1GeV)	1200 cm^2
Angular resolution (@100MeV)	5.8^o

Sensitivity	0.1 GeV	$5x10^{-8}$
for point	1 GeV	$1x10^{-8}$
sources	10 GeV	$2x10^{-8}$
(ph cm^{-2} s^{-1})*		





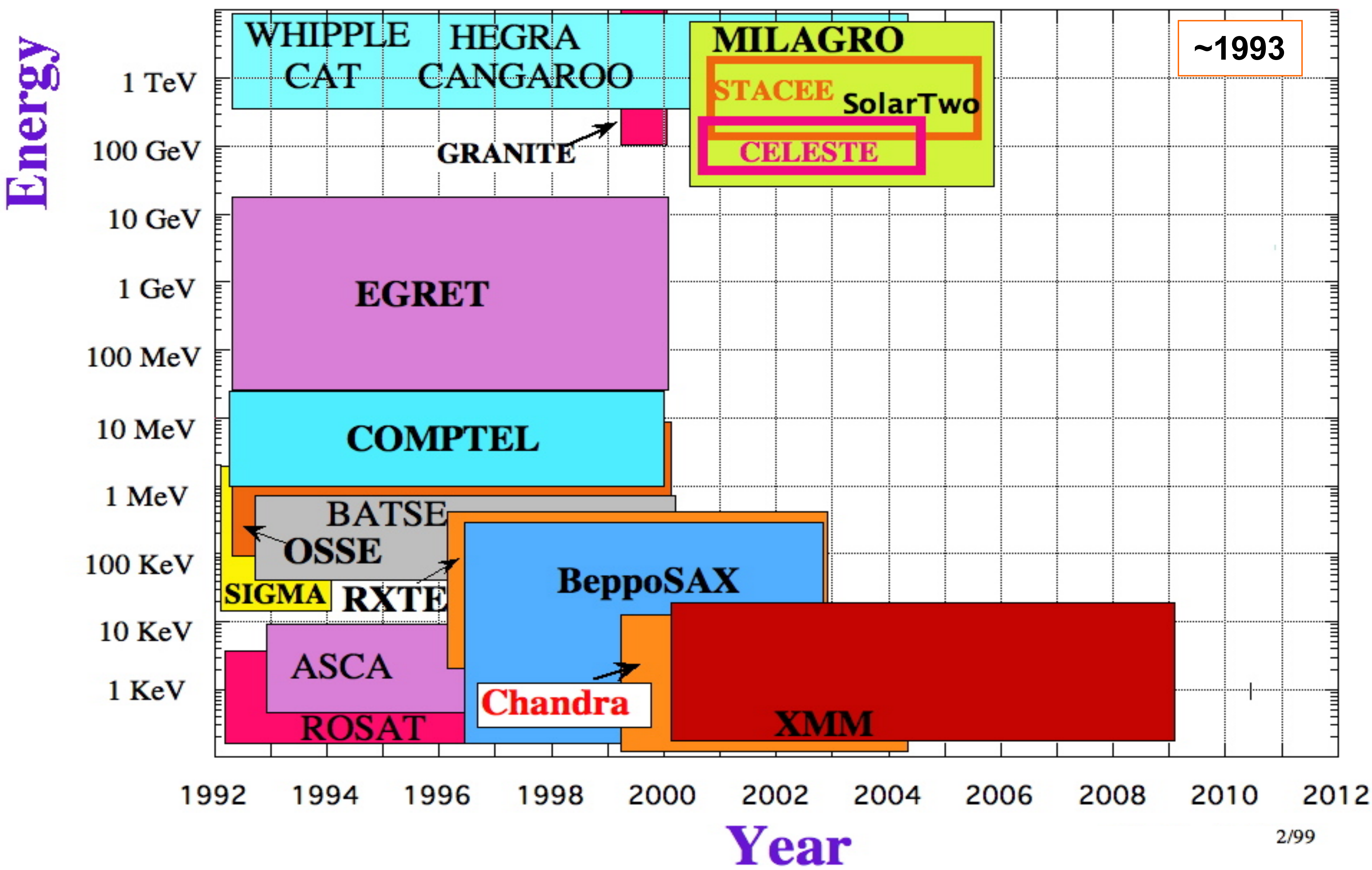
EGRET: Principle of Detection of High Energy Gamma Rays

EGRET – Principle of gamma ray detection

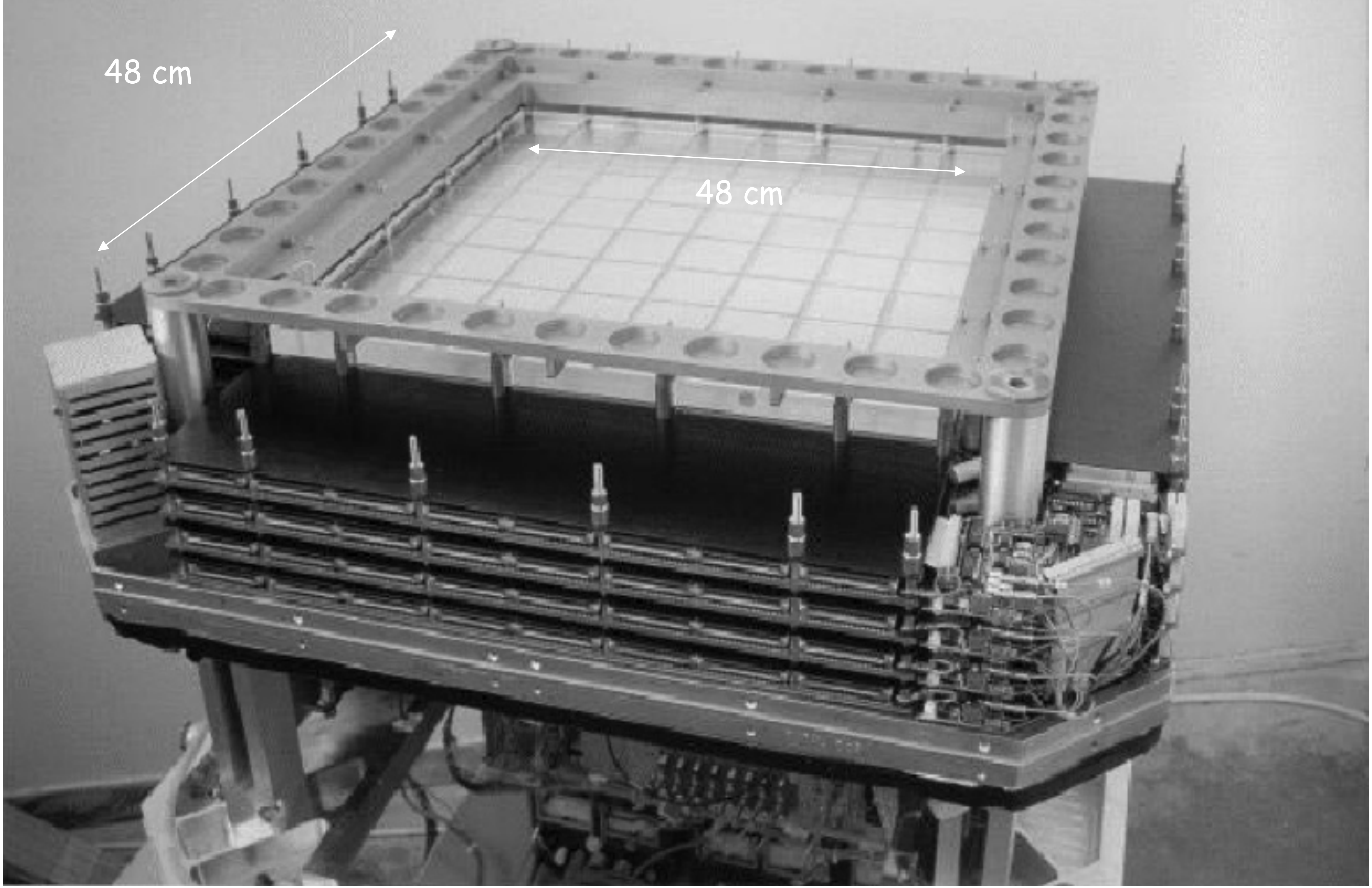
A γray which enters the top of the EGRET instrument will pass undetected through the large anticoincidence scintillator surrounding the spark chamber and has a probability 33% of converting into an electron positron pair in one of the thin tantalum (Ta) sheets interleaved between the 28 closely spaced spark chambers in the upper portion of the instrument.

Below the conversion stack are two 4 x 4 arrays of plastic scintillation detector tiles spaced 60 cm apart which register the passage of charged particles. If the timeofflight delay indicates a downward moving particle which passed through a valid combination of upper and lower scintillator tiles, and the anticoincidence system has not been triggered by a charged particle, the track information is recorded digitally. In this manner, a three dimensional picture of the path of the electronpositron pair is measured. The energy deposition in the NaI(Tl) Total absorption Shower Counter (TASC) located directly below the lower array of plastic scintillators is used to estimate the photon energy.

High Energy Gamma Experiments



The TS93 and CAPRICE silicon-tungsten imaging calorimeter.



Nuclear Physics B (Proc. Suppl.) 43 (1995) 253–256

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

A wide aperture telescope for high energy gamma rays detection

G. Barbiellini[a], M. Boezio [a],M.Candusso [b], M.Casolino[b], M. P. De Pascale[b], C. Fuglesang[c], A. M. Galper [d], A. Moiseev [d], A. Morselli[b*], Yu. V. Ozerov [d], P. Picozza[b], A. V. Popov [d], M. Ricci[e], R. Sparvoli[b], P. Spillantini[f], A. Vacchi[a], S.A. Voronov [d], V. M. Zemskov [d], V. G. Zverev[d]

[a] Dept. of Physics, Univ. of Trieste and INFN, Italy

[b] Dept. of Physics, Univ. of Rome "Tor Vergata" and INFN, Italy

[c] Royal Institute of Technology, Stockholm, Sweden

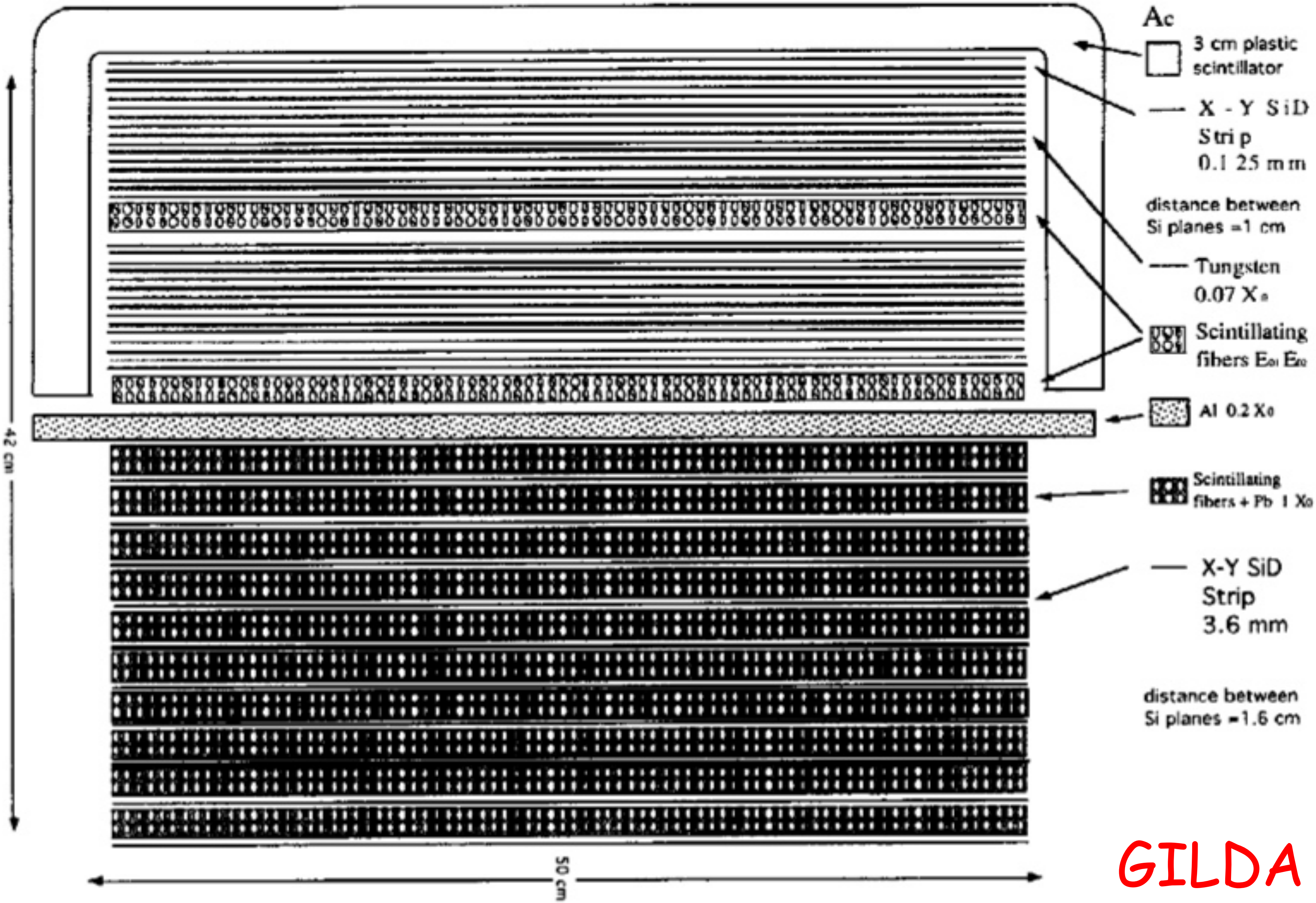
[d] Moscow Engineering Physics Institute, Moscow, Russia

[e] INFN Laboratori Nazionali di Frascati, Italy

[f] Dept. of Physics, Univ. of Firenze and INFN, Italy

In this paper new techniques for the realization of a high energy gamma-ray telescope are presented, based on the adoption of silicon strip detectors and lead scintillating fibers. The simulated performances of this instrument show that the silicon strip technology adopted by GILDA (Gamma-ray Imaging Large Detector for Astrophysics) could improve the performance of EGRET, which is so far the most successful experiment of a high energy gamma-ray telescope, though having less volume and weight.

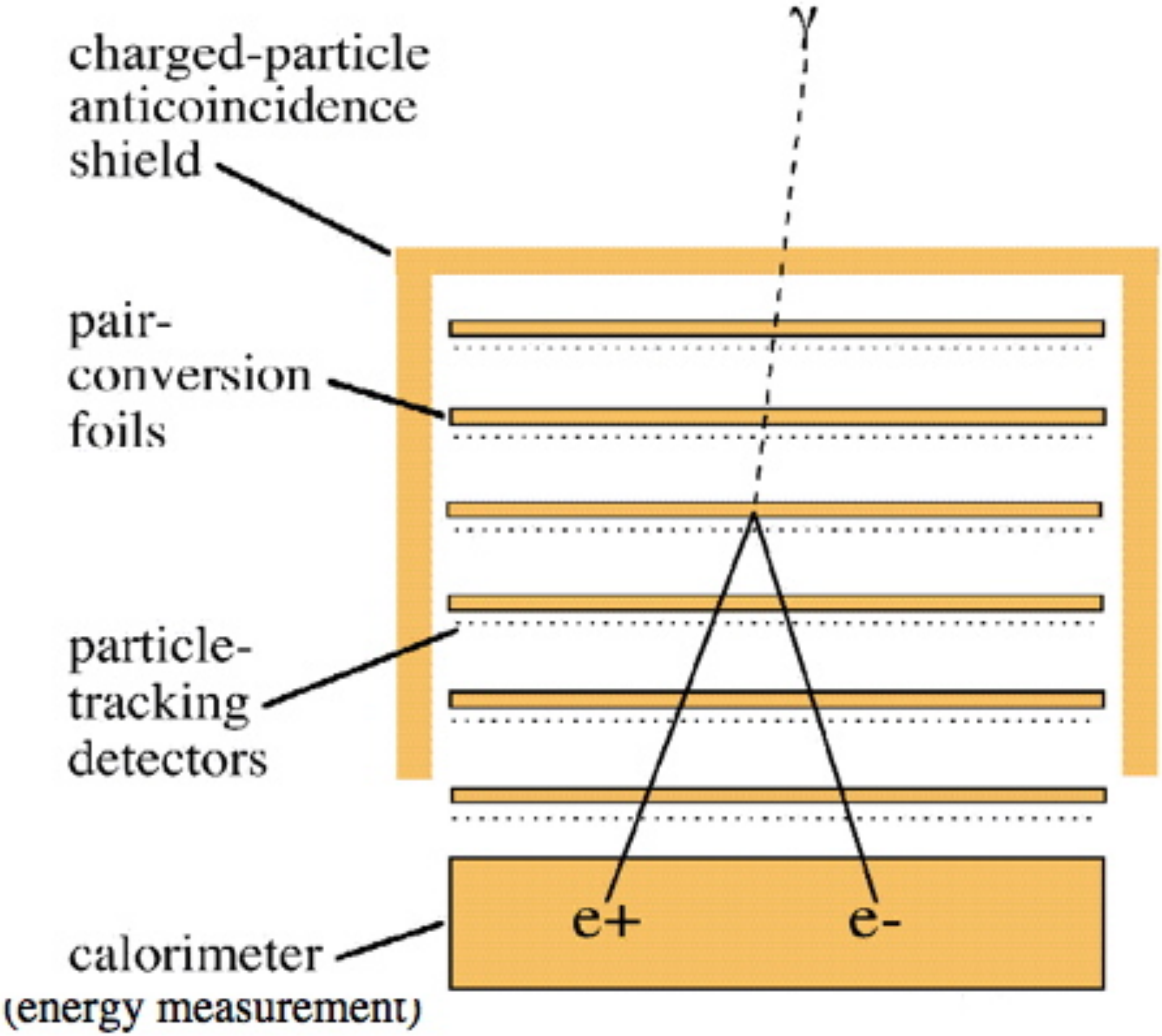
* Corresponding author.



GILDA

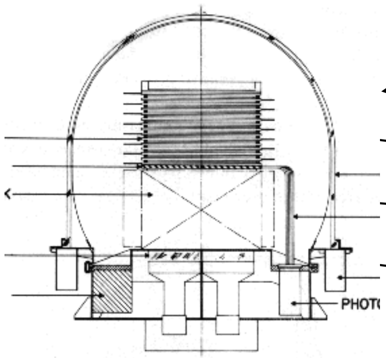
G.Barbiellini et al. Nuclear Instruments and Methods, A354, 547-552, (1995)

Elements of a pair-conversion telescope



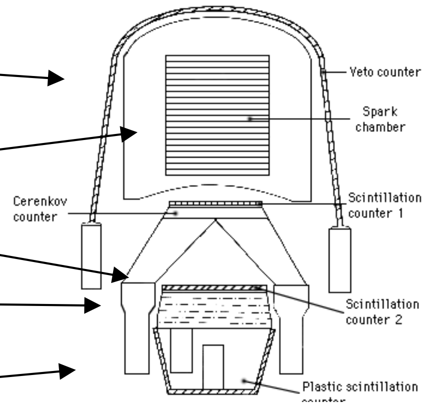
- photons materialize into matter-antimatter pairs:
  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$

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



SAS-2
11/1972-7/1973

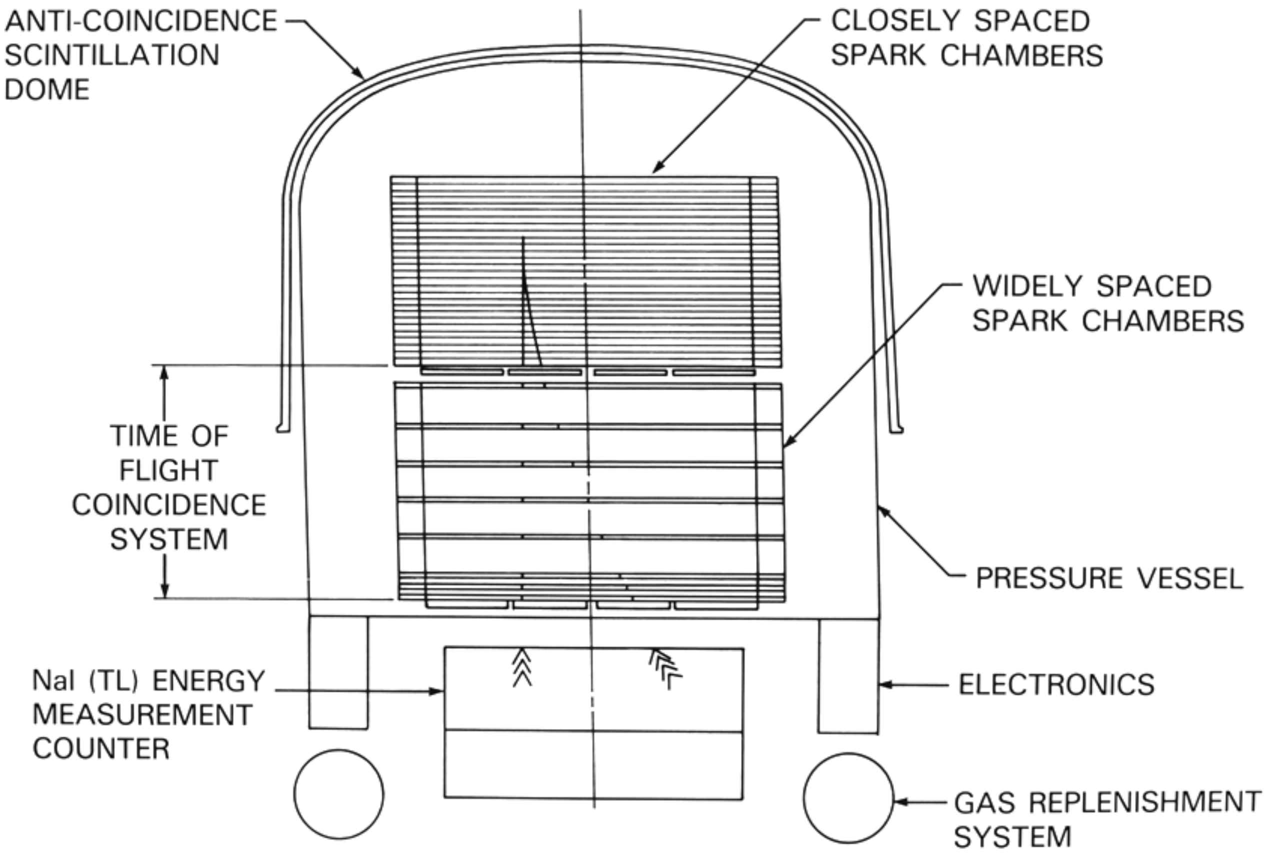
Anti-Coincidence Dome
Spark Chamber
Trigger Telescope
Cerenkov Counter
Energy Calorimeter



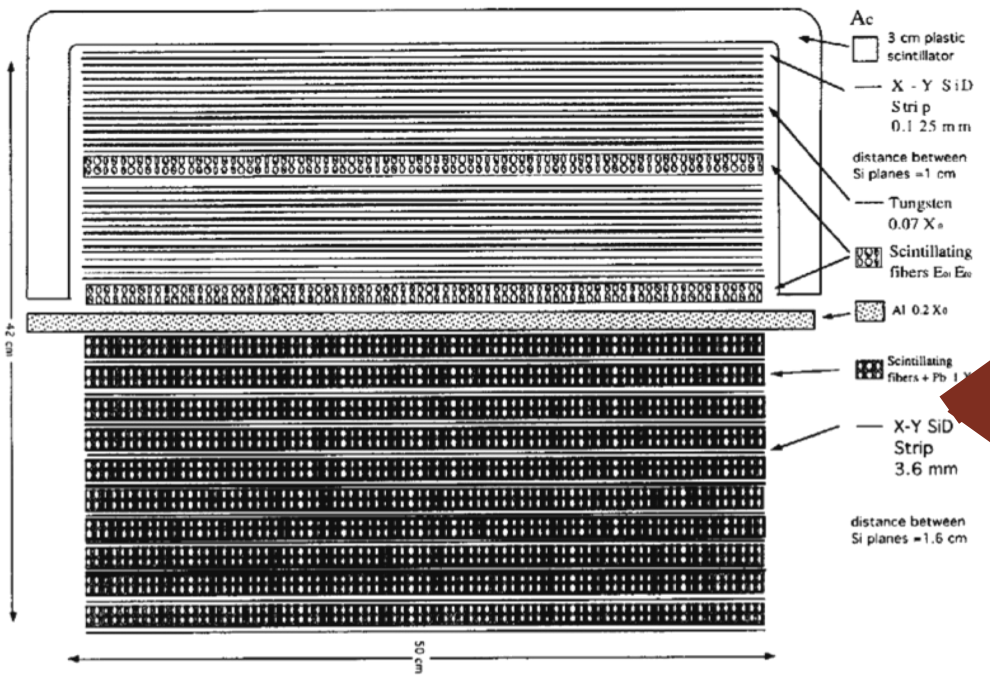
Cos-B
8/1975-4/1982

The gamma-ray missions

EGRET
4/1991-1999



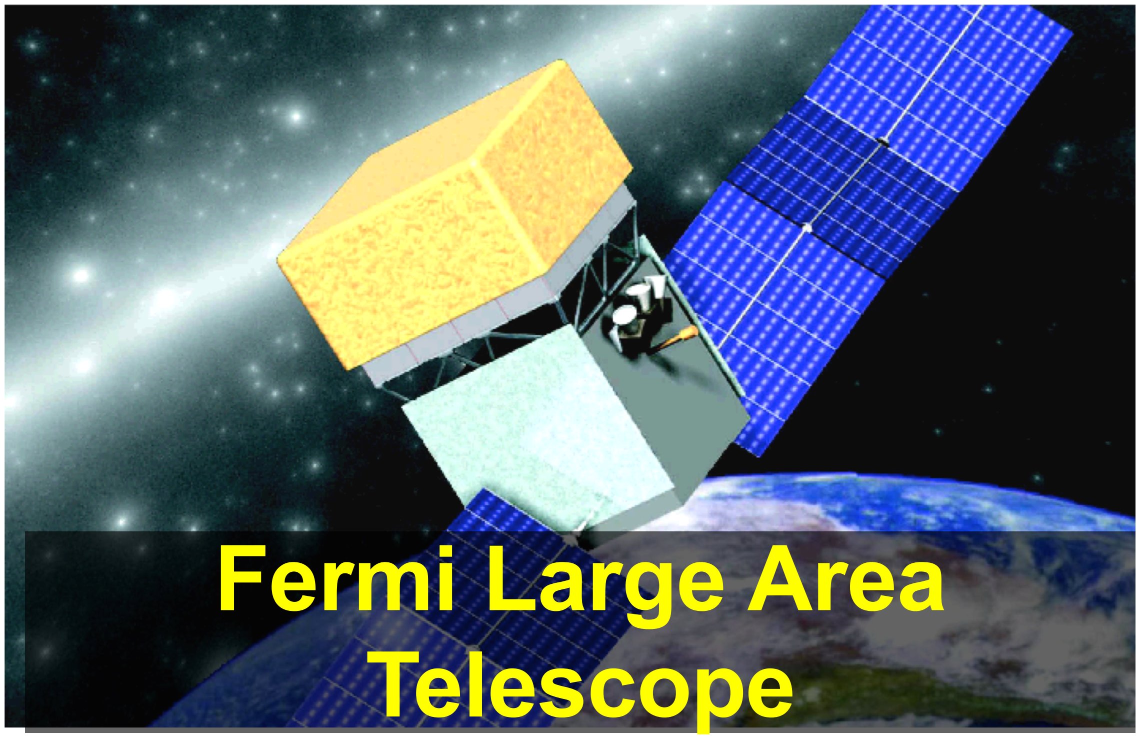
GILDA



Development of GLAST, a broadband High-Energy Gamma-Ray Telescope using Silicon Strip Detectors

P.Michelson, W.Atwood, E.Bloom, G.Godfrey, Y.Lin, P.Nolan, D.Bertsch, N.Gehrels, R.Hartman, S.Hunter, J.Norris, J.Ormes, R.Streitmatter, D.Thompson, E.Grove, P.Hertz, W.N.Johnson, M.Lovellette, G.H.Share, M.Wolff, K.S.Wood, R.Johnson, C.Couvault, R.Ong, M.Oreglia, J.Mattox, T.Burnett, C.Chenette, G.Nakano, L.Cominsky, H.A.Mayer-Hasselwander, G.Barbiellini, A.Colavita, A.Morselli, T.Kamae,
K.Kasahara

Proposal presented to NASA, Space Physics Division in response to "Proposal for High Energy Astrophysics Supporting Research and Technology Program", NRA 95-OSS-17




AGILE
23 April 2007
Happy 11th Birthday Agile !!


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

Pisa 15 March 2018

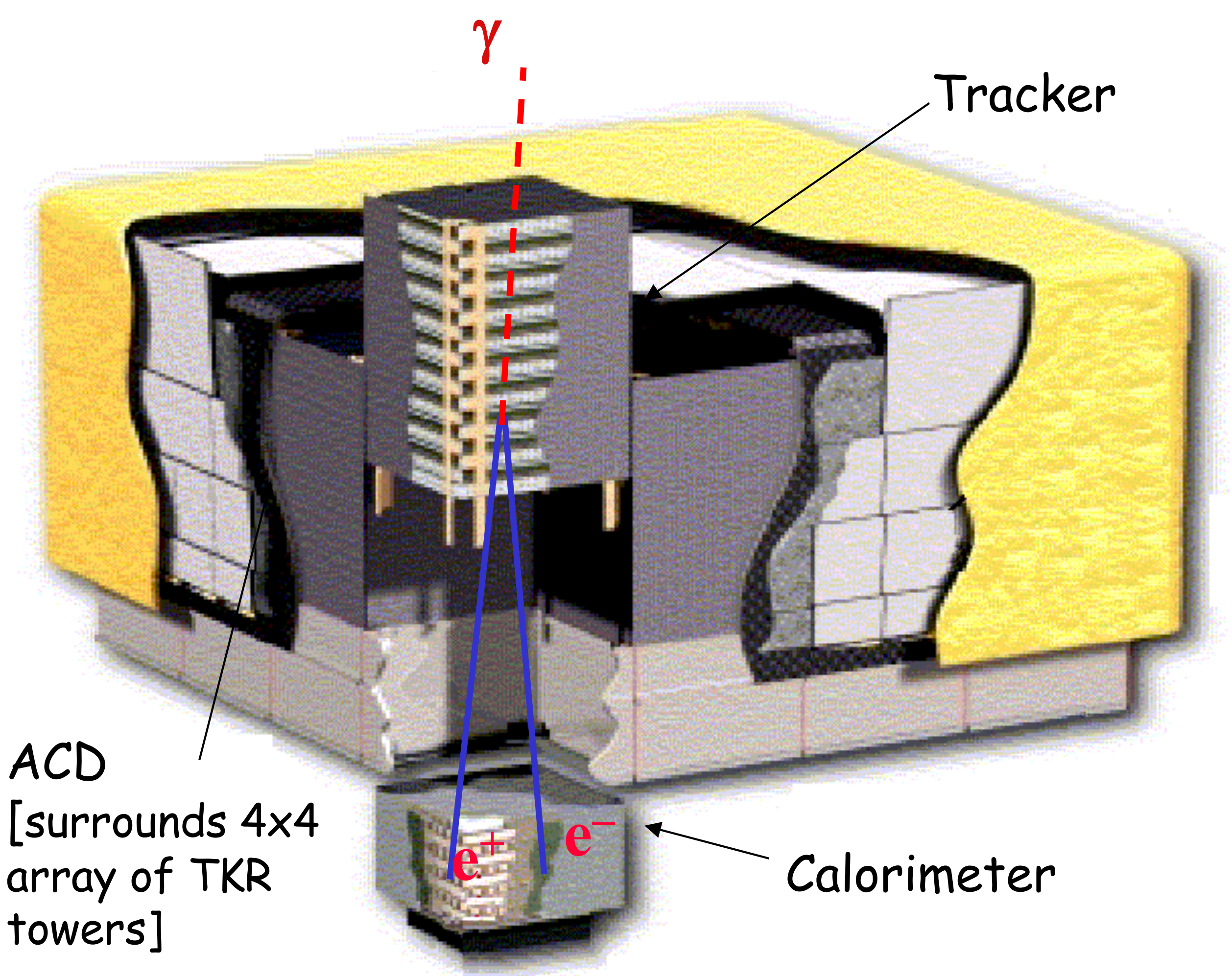
Fermi LAT: A Telescope Without Lenses

- Precision Si-strip Tracker (TKR)
  70 m^2 of silicon detectors arranged in 36 planes. 880,000 channels.

- Hodoscopic CsI Calorimeter(CAL)
  1536 CsI(Tl) crystals in 8 layers, total mass 1.5 tons.

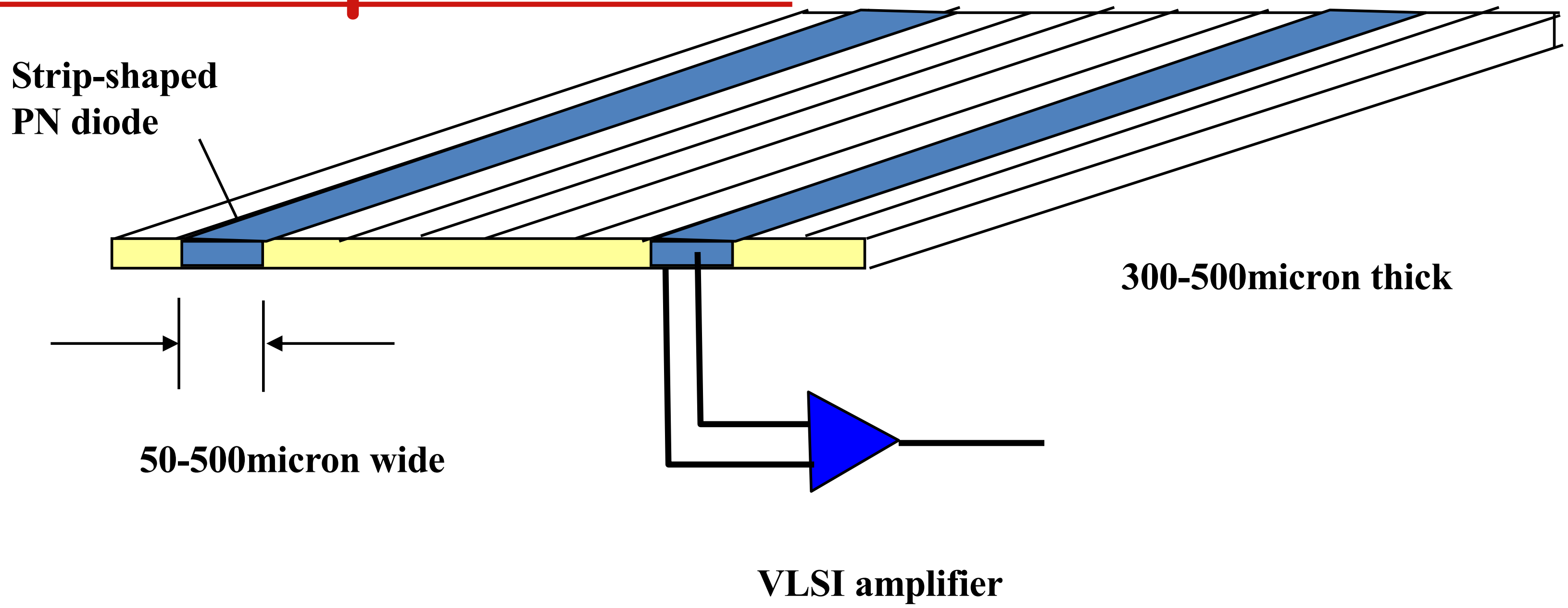
- Segmented Anticoincidence Detector (ACD) 89 plastic scintillator tiles.

- Electronics System Includes flexible hardware trigger and onboard computing.



New Detector Technology

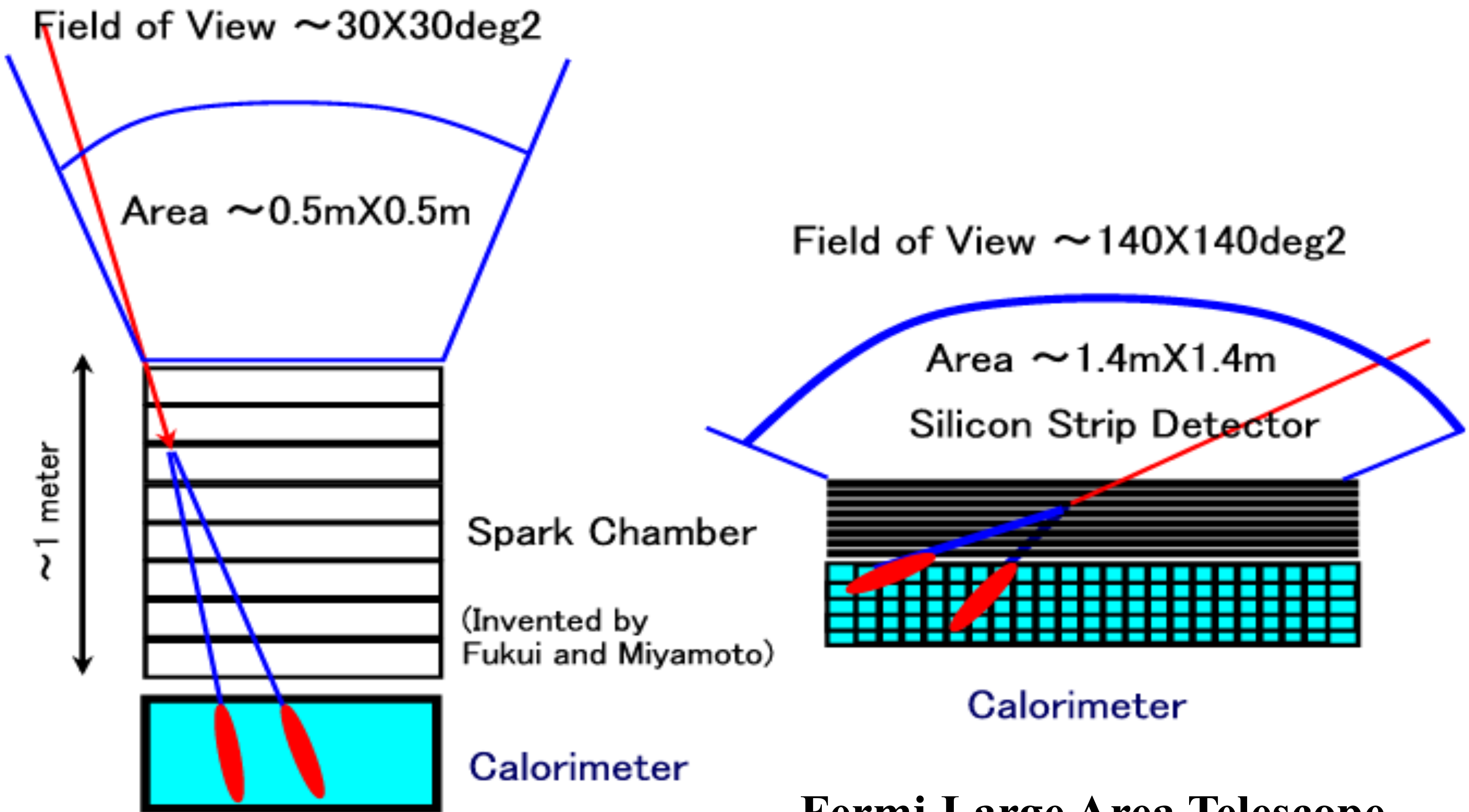
- **Silicon strip detector**



Stable particle tracker that allows micron-level tracking of gamma-rays

Well known technology in Particle Physics experiments.
Used by our collaboration in balloon experiments (MASS, TS93, CAPRICE), on MIR Space Station (SilEye) and on satellite (NINA)

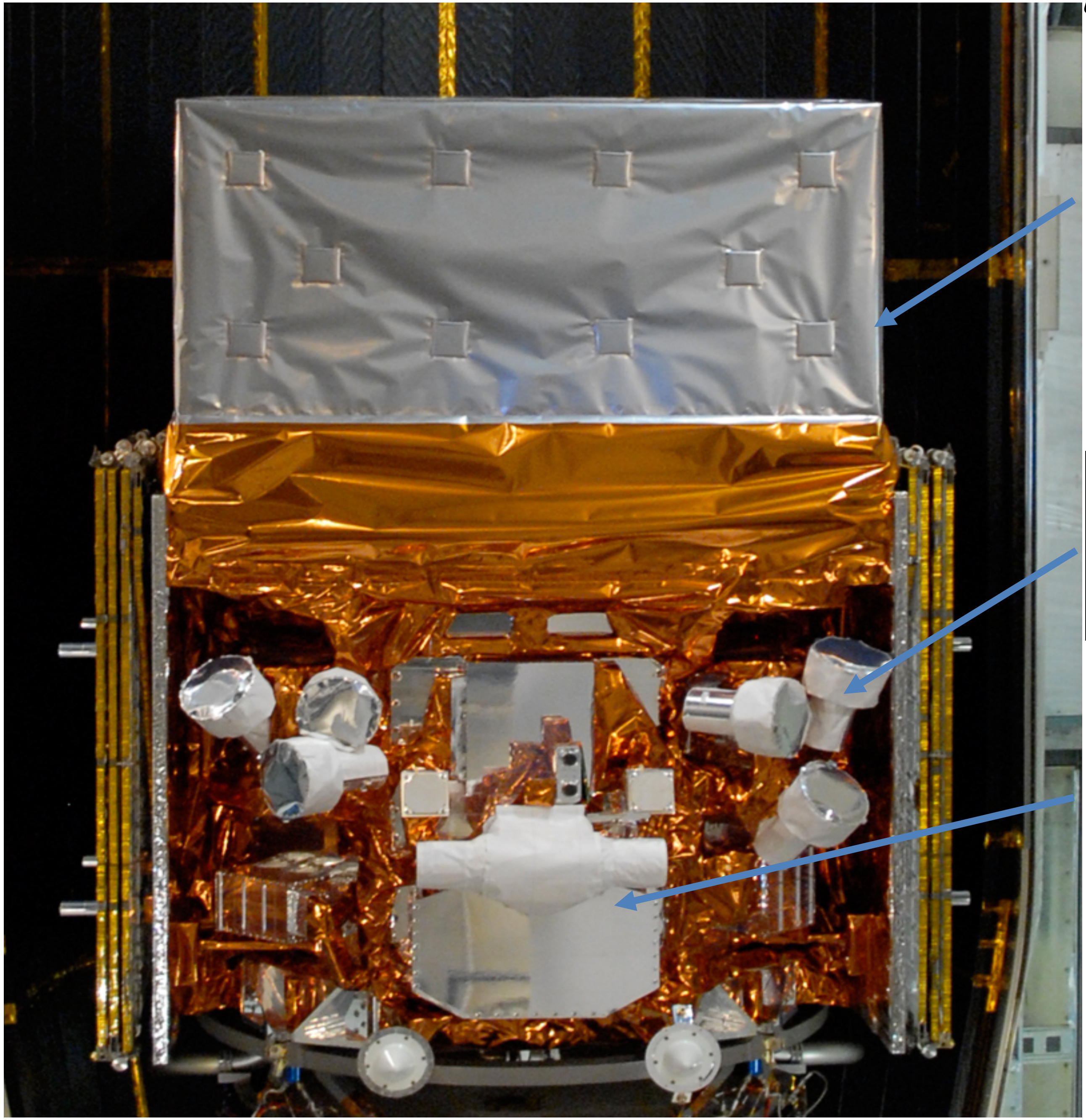
EGRET(Spark Chamber) VS. Fermi LAT (Silicon Strip Detector)



EGRET on Compton GRO
(1991-2000)

Fermi Large Area Telescope
(2008-2018)

The Fermi Observatory

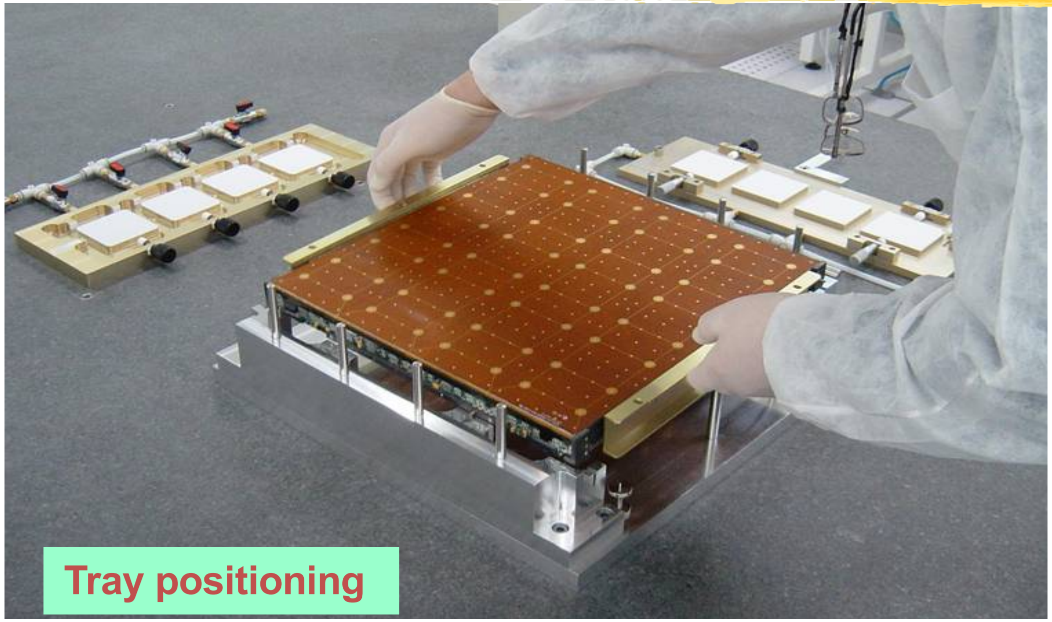


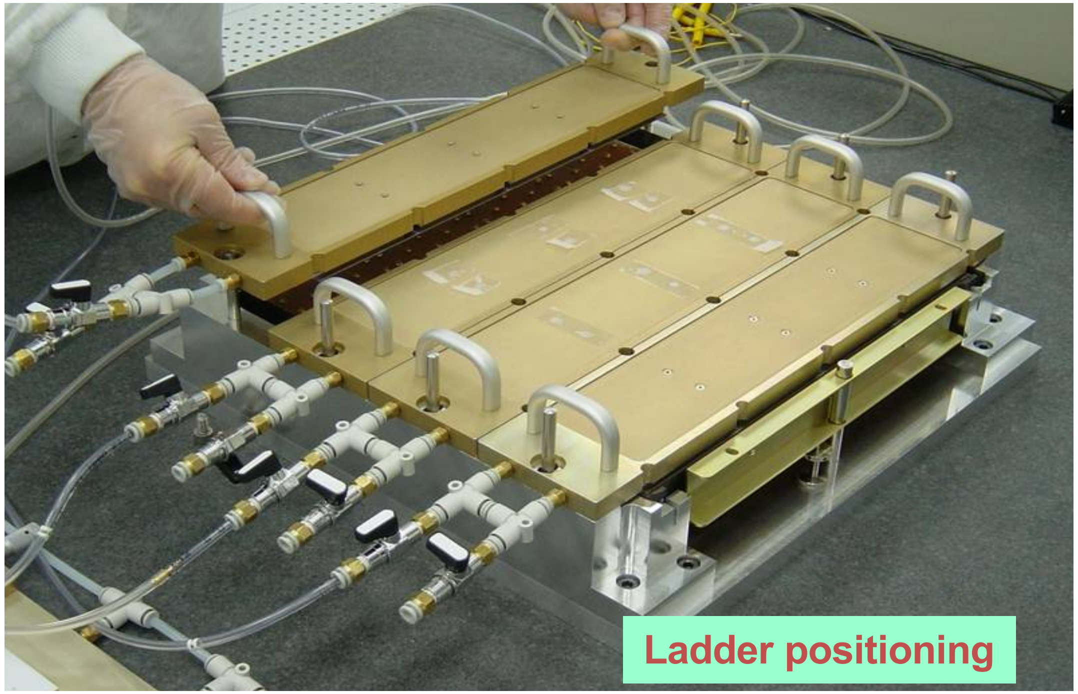
LAT
Large
Area
Telescope

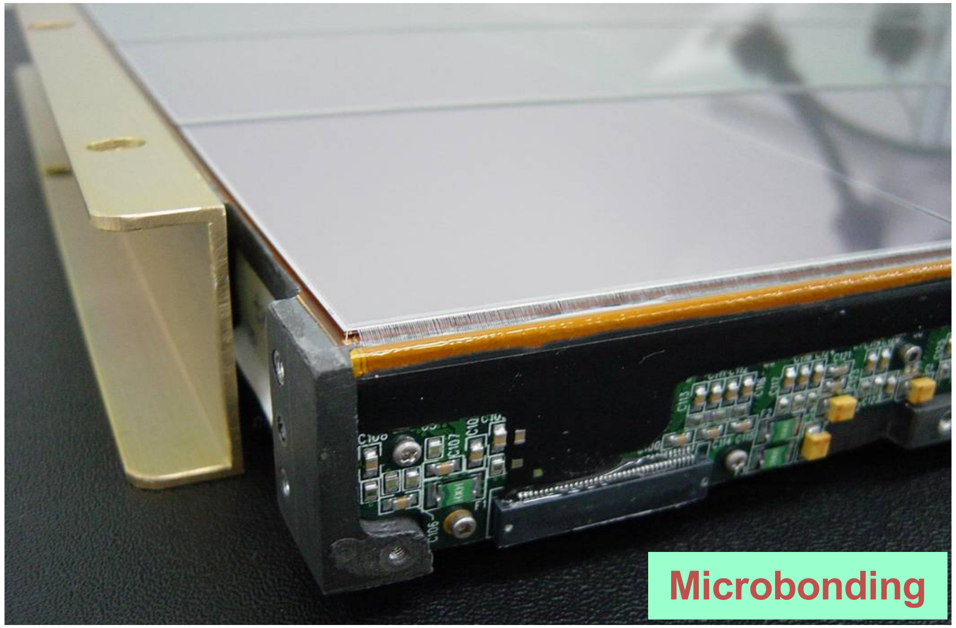
GBM
Sodium Iodide
Detector

GBM
Bismuth
Germanate
Detector

Tray assembly in G&A





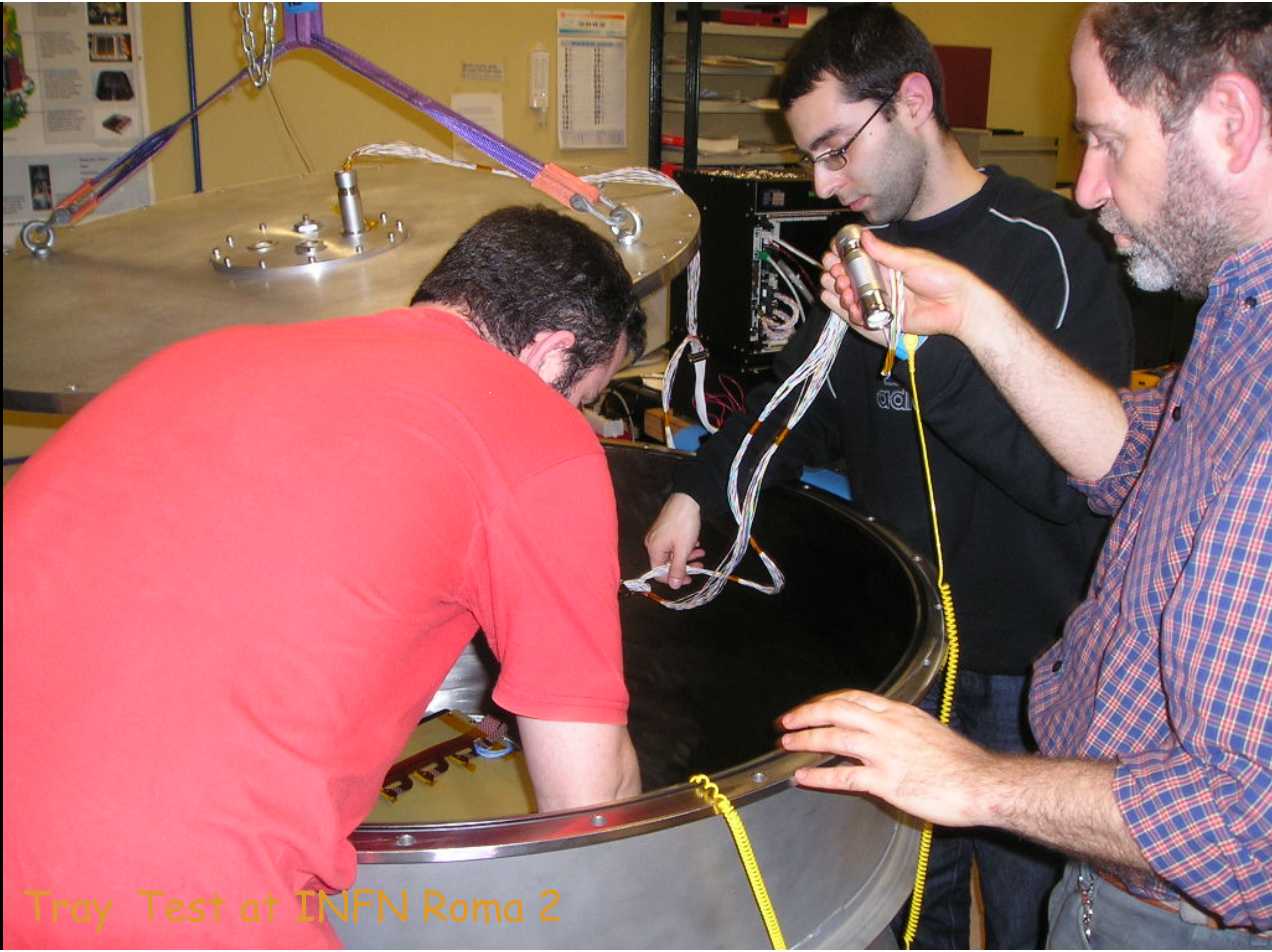


- 160 bare panels produced
- 100 tested and qualified for integration with ladders
- completed trays for 3.3 towers
- 6 assembly chain ready
- Max assembly rate : 3 trays/day/shift


EMERGENCY STOP

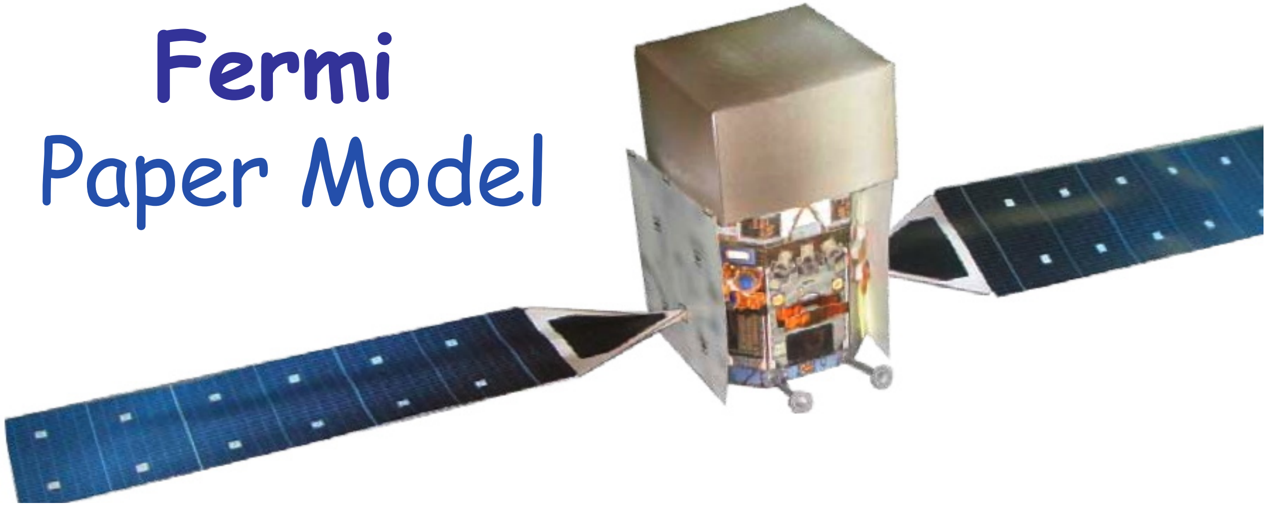
Tray Test at INFN Roma 2

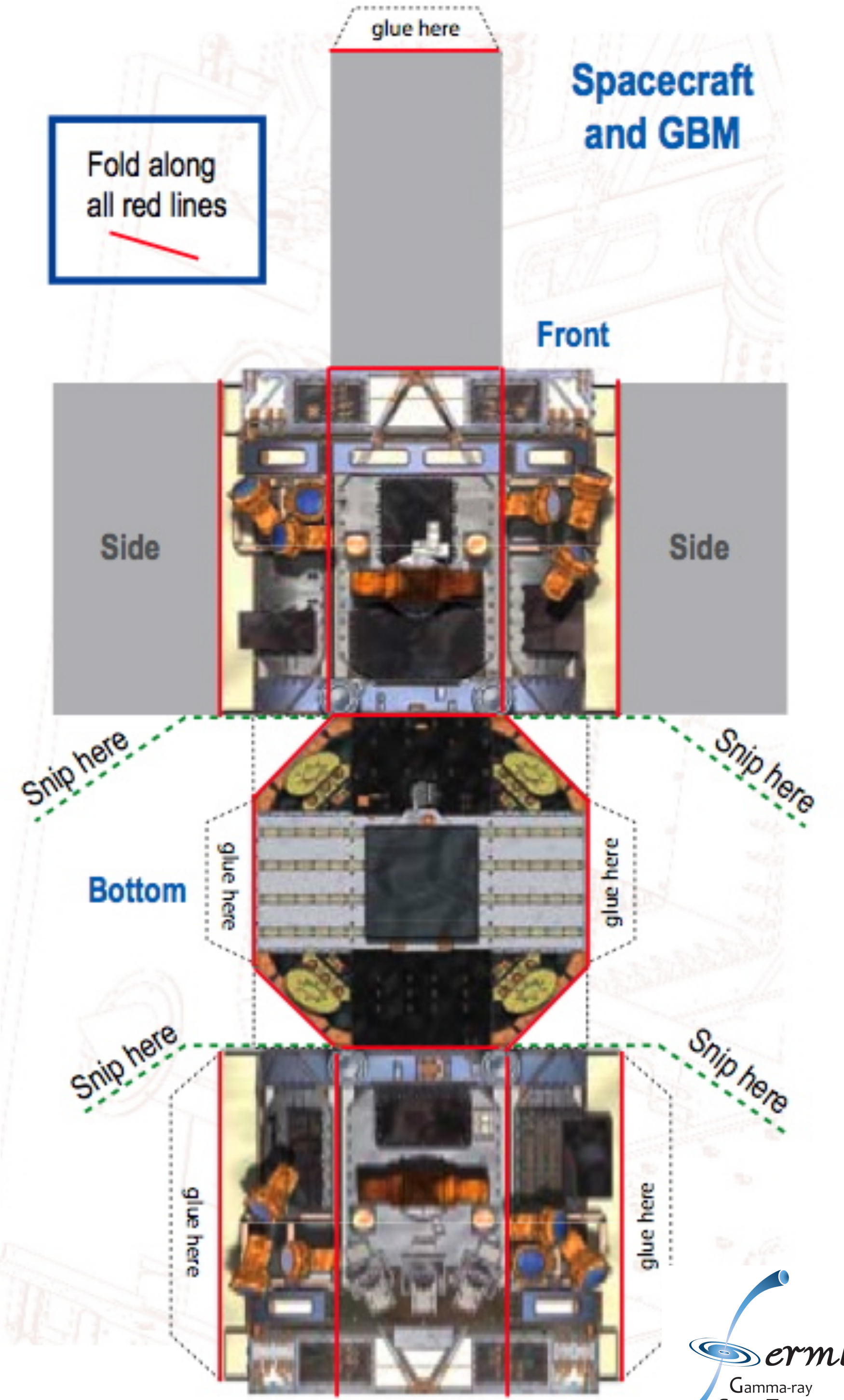
LAMINAR FLOW
ASALAIR 1200
LAMINAR FLOW
1200FLV
PROIBITO
FUMARE
VIETATO
L'ACCESSO
a chi non è
autorizzato



Tray Test at INFN Roma 2

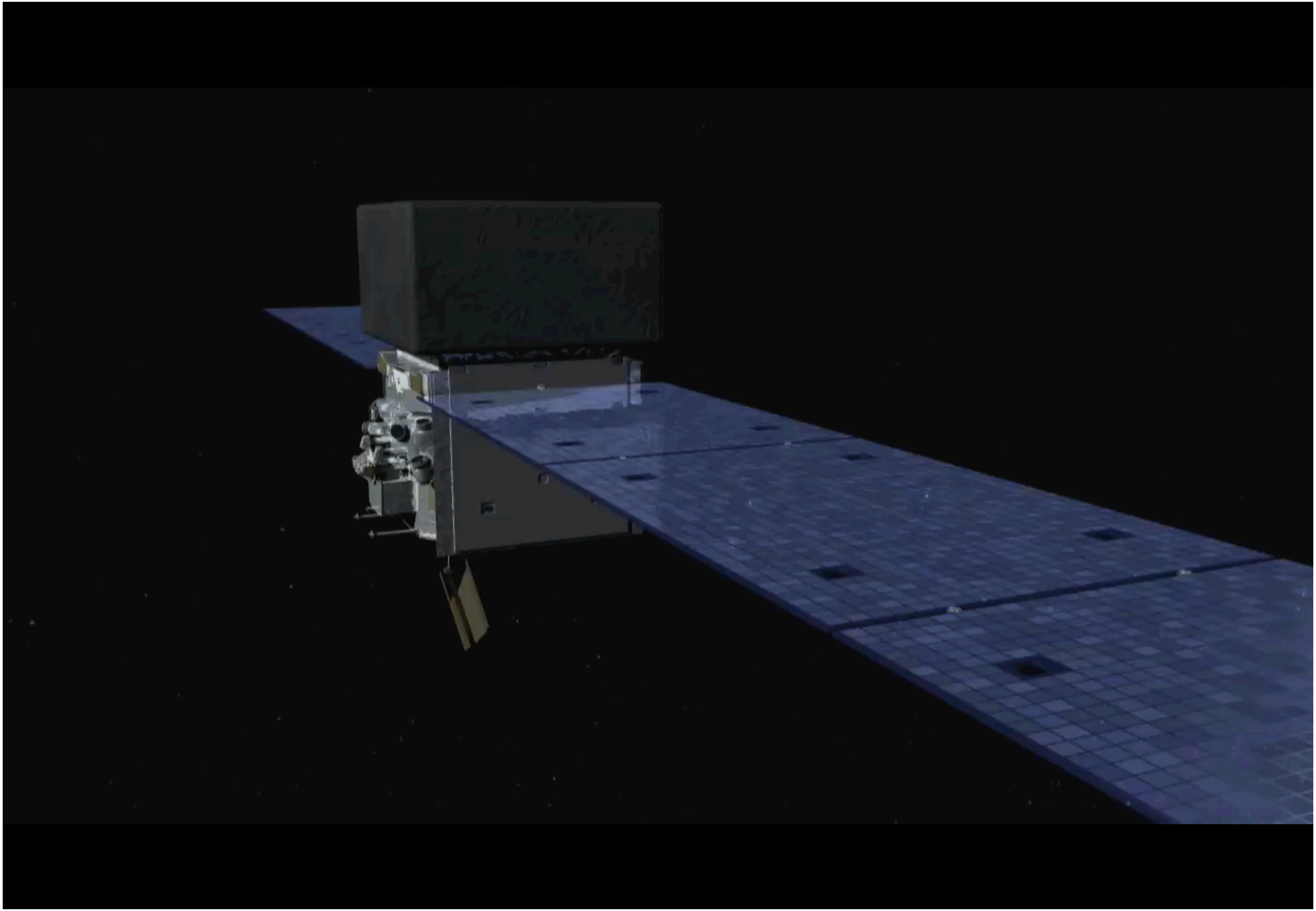
Fermi
Paper Model

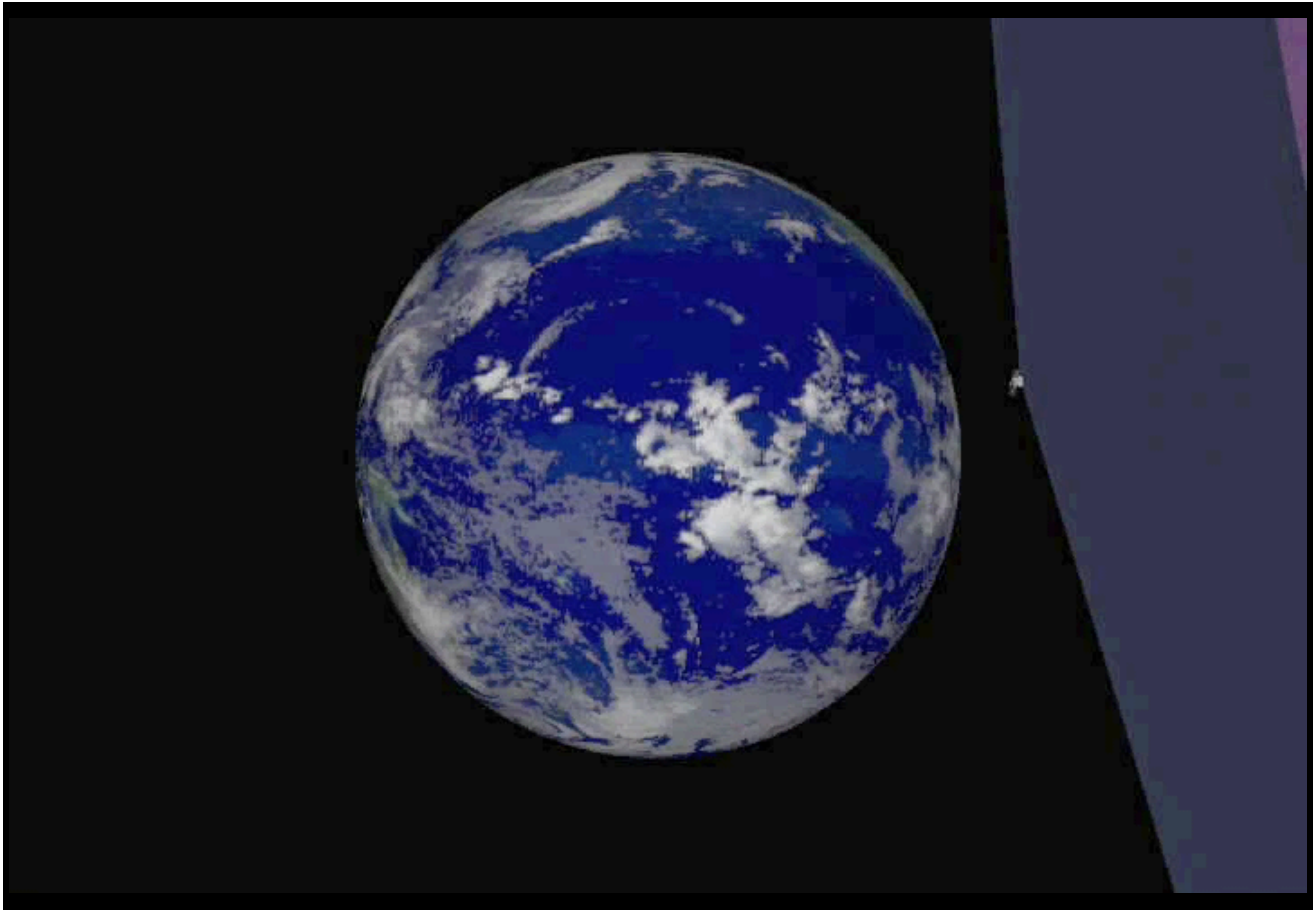




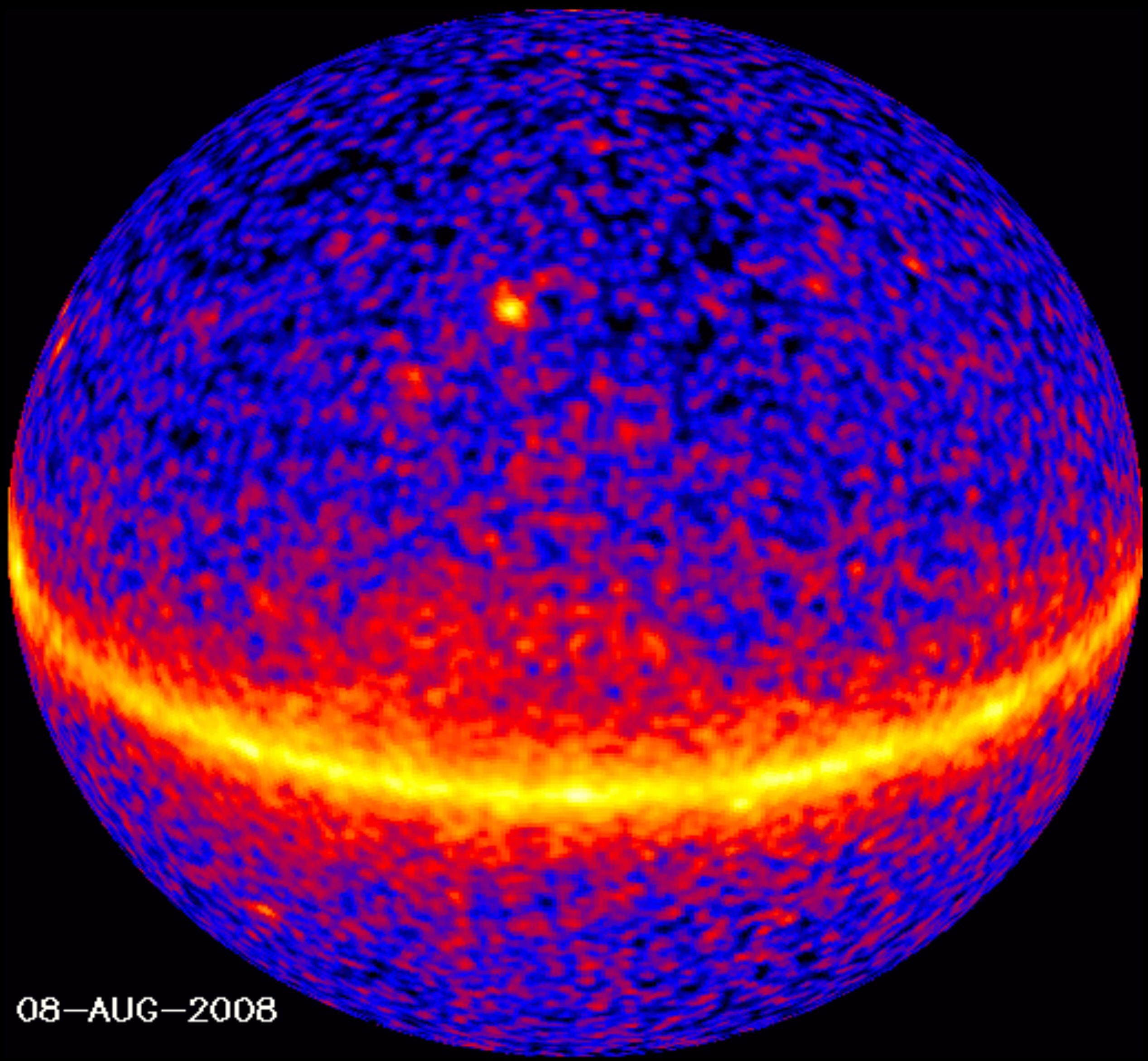
http://people.roma2.infn.it/~aldo/GLASTpaperModel.pdf

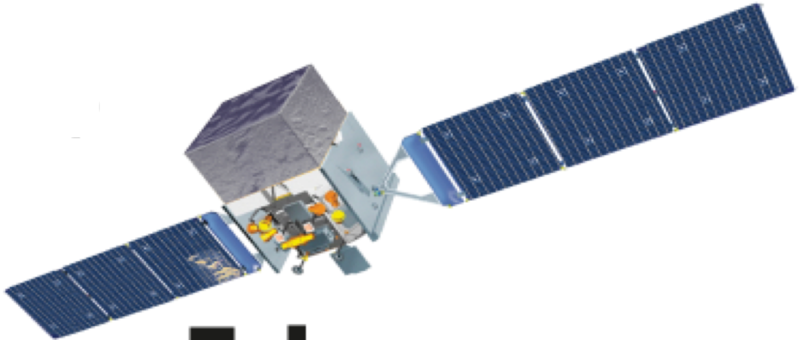
Fermi
Gamma-ray
Space Telescope



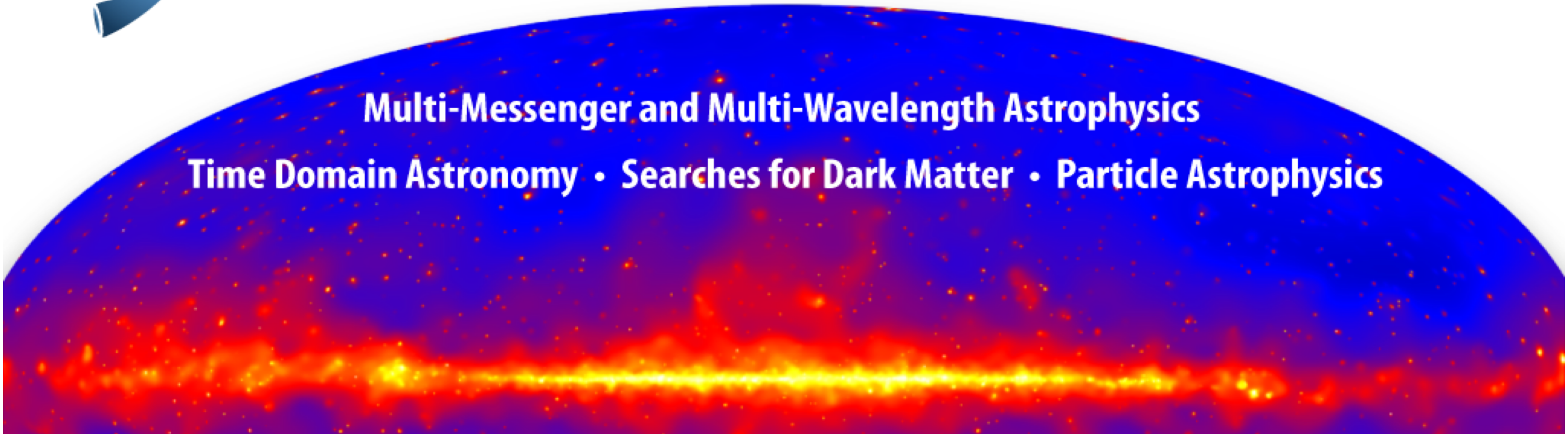


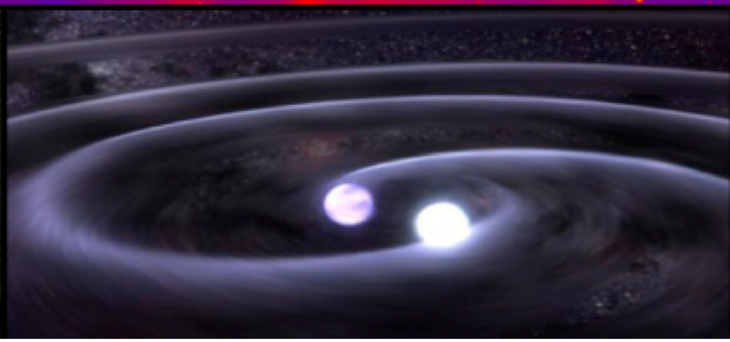
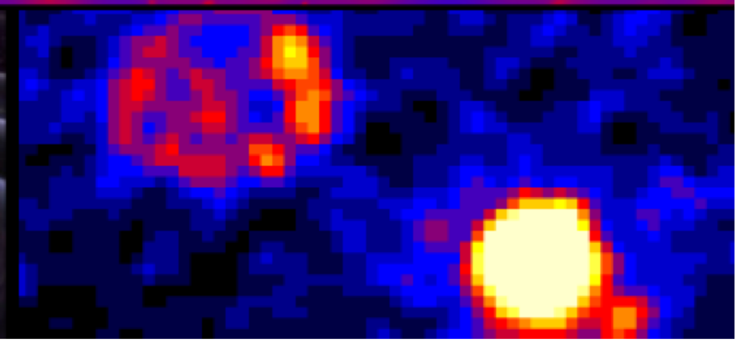
Daily Gamma-ray Sky





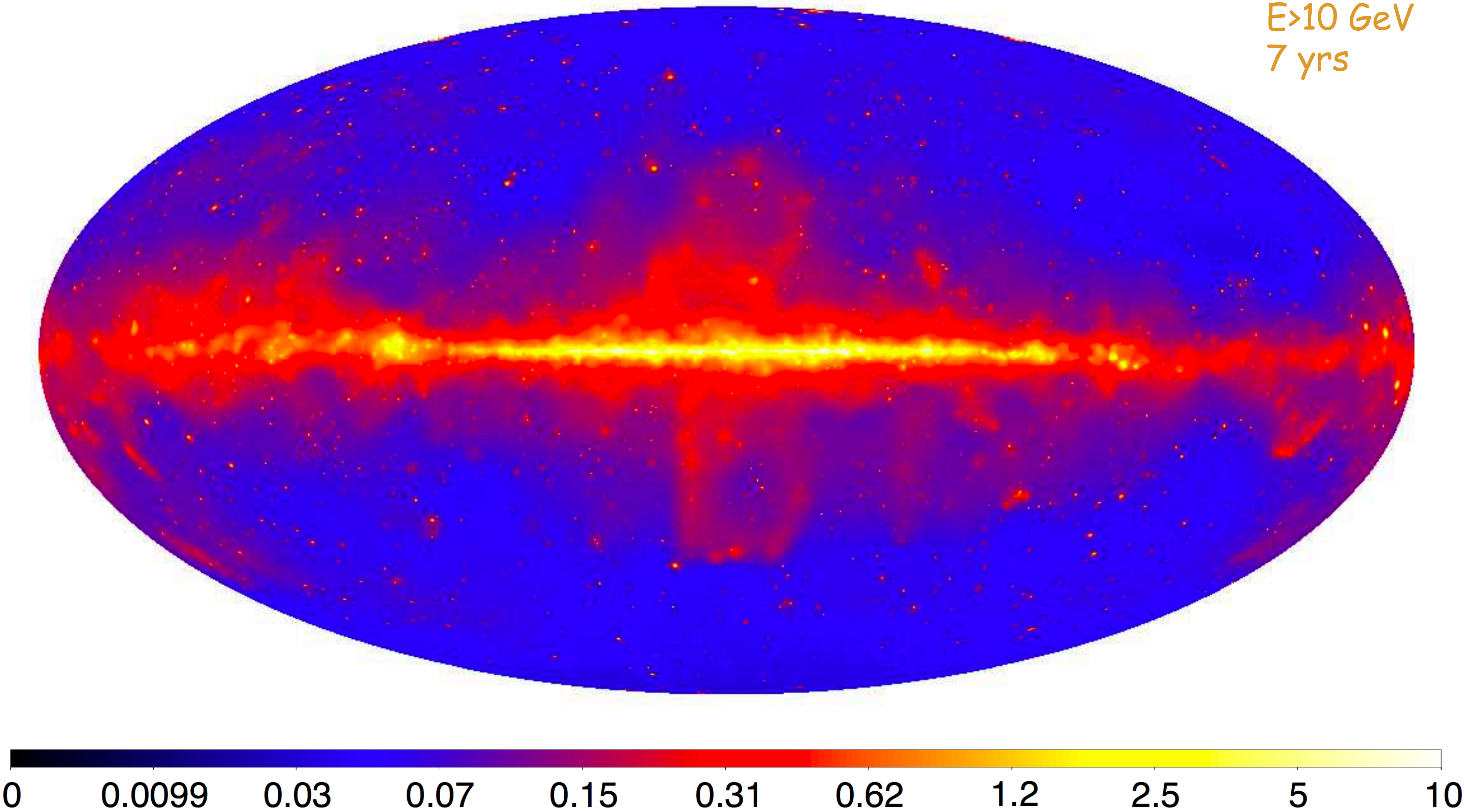
fermi Gamma-Ray Space Telescope



The sky in gamma-rays

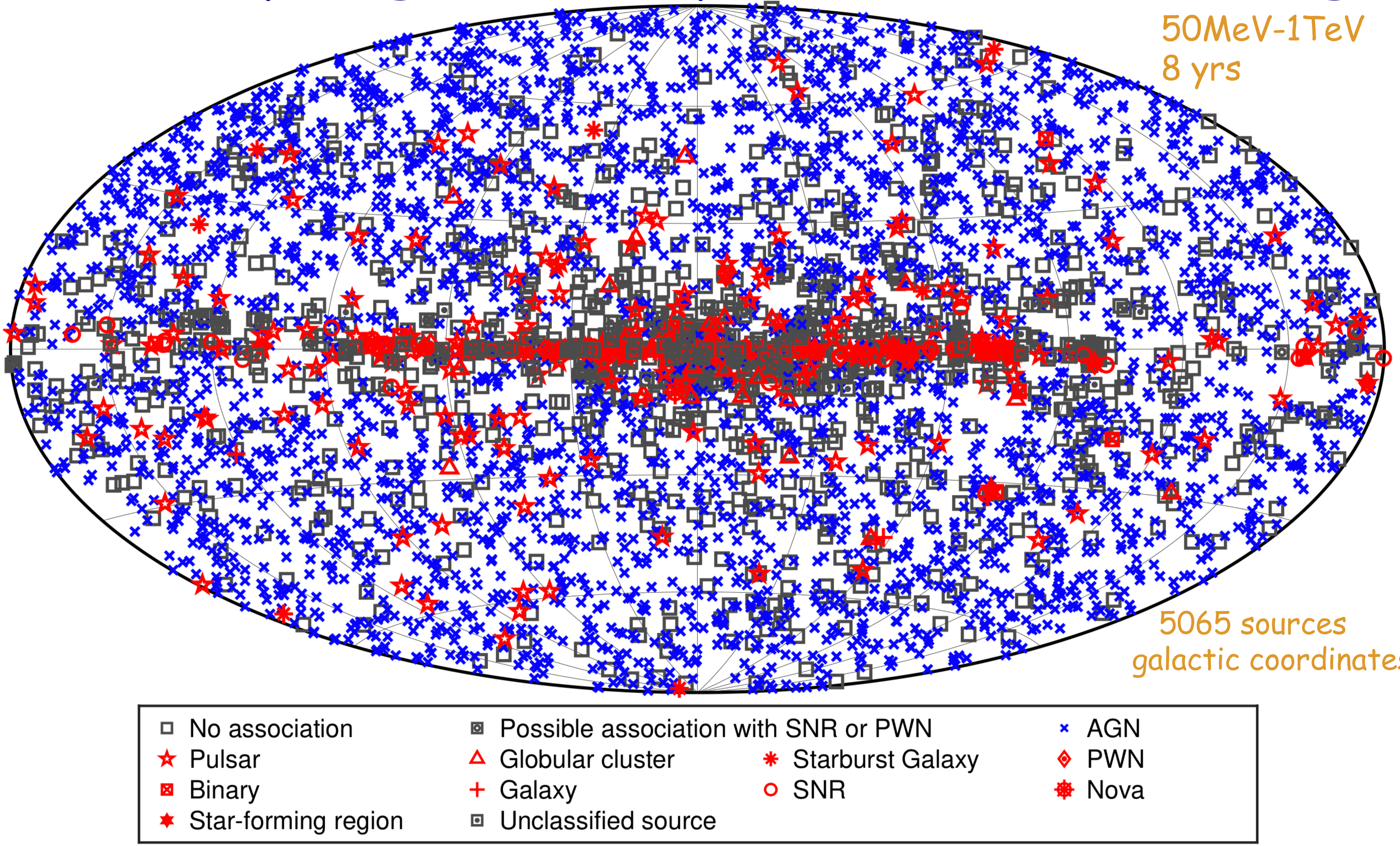
E>10 GeV
7 yrs



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

The sky in gamma-rays 4th source catalog

50MeV-1TeV
8 yrs

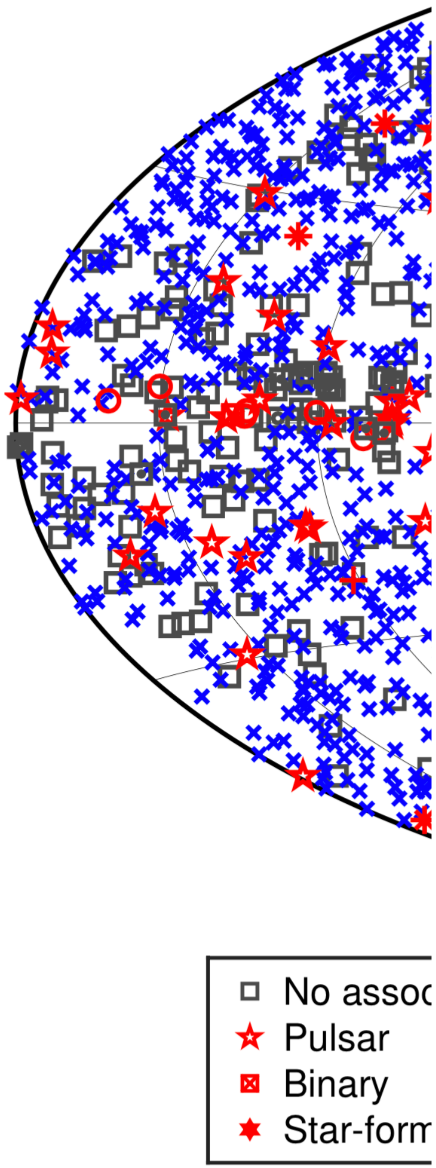


5065 sources
galactic coordinates

Fermi Fouth Source Catalog, arXiv:1902.10045_v3

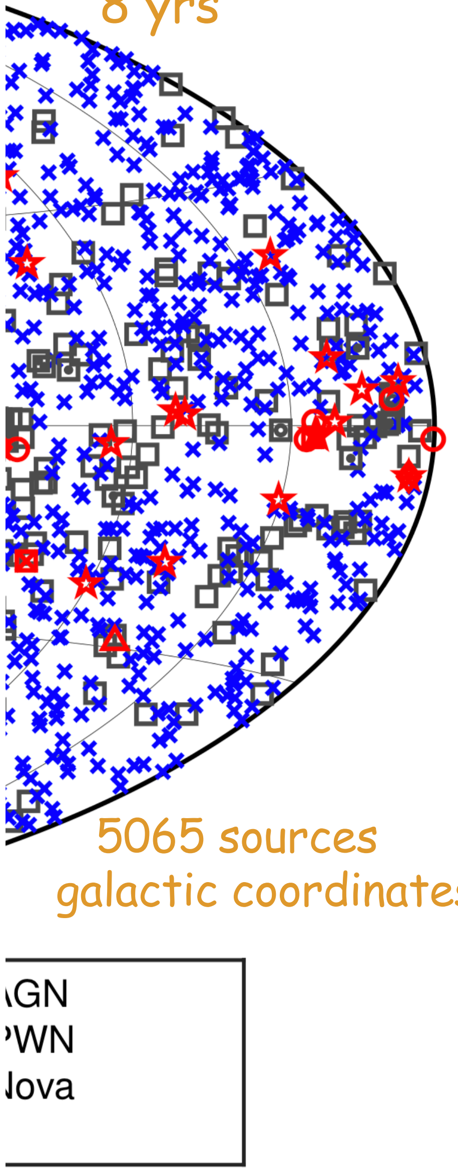
The sky in gamma-rays_ 4^{th} source catalog

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

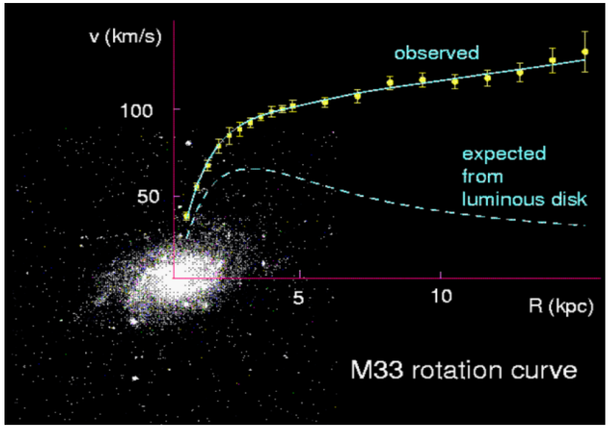
Fermi Fouth Source Catalog, arXiv:1902.10045_v3

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:

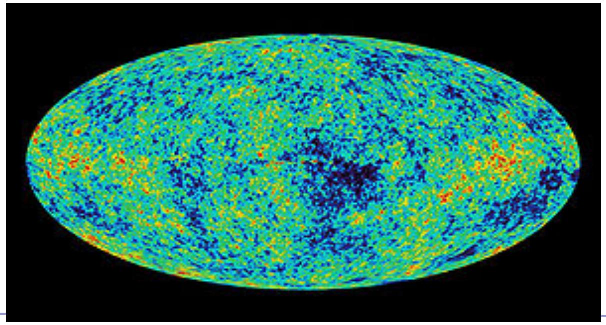
Rotation curves of galaxies



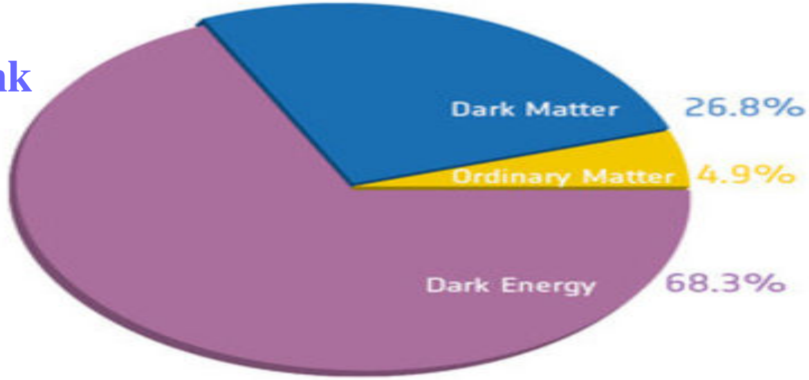
Gravitational lensing

Bullet cluster

Structure formation as deduced from CMB



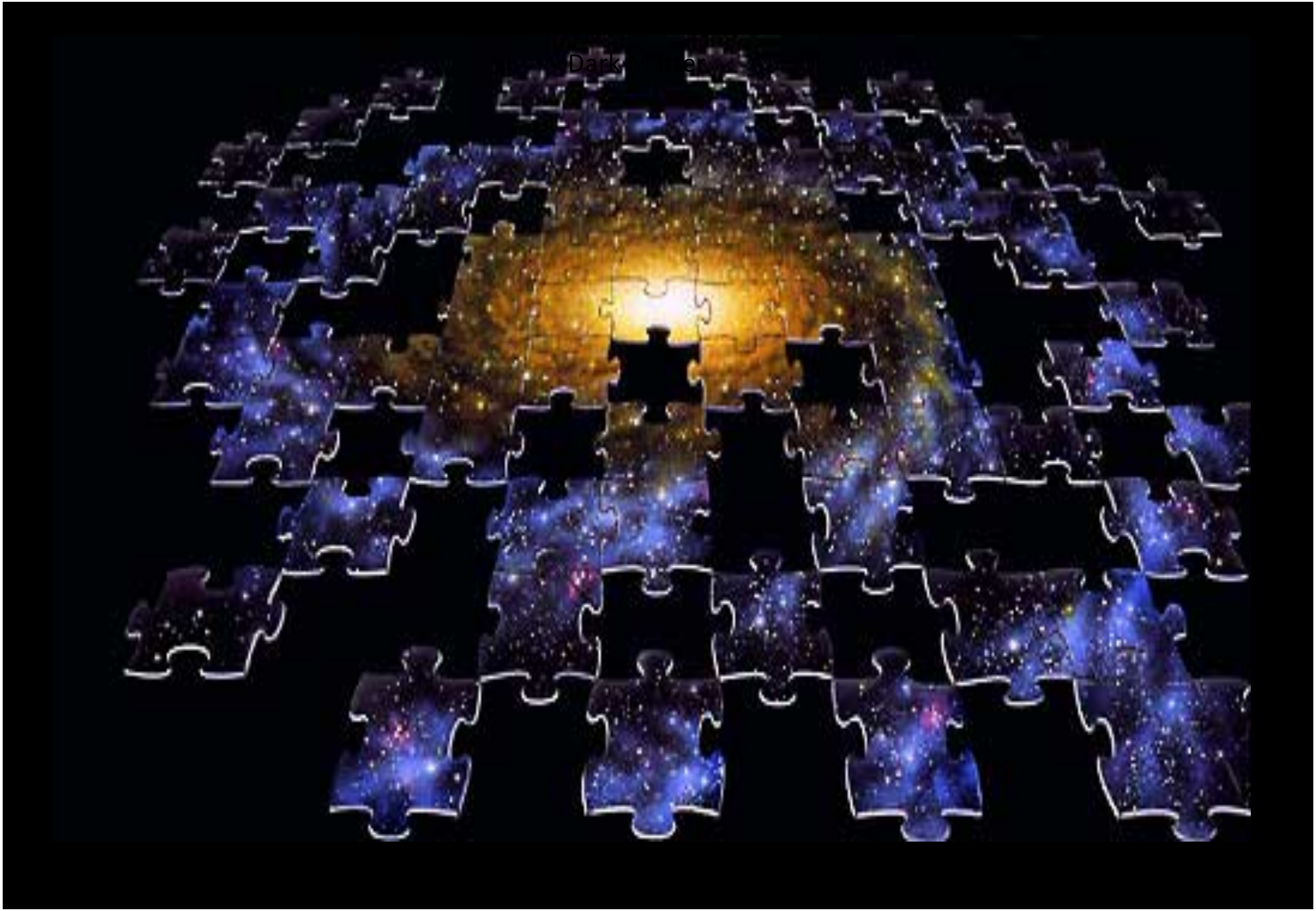
Data by Plank imply:



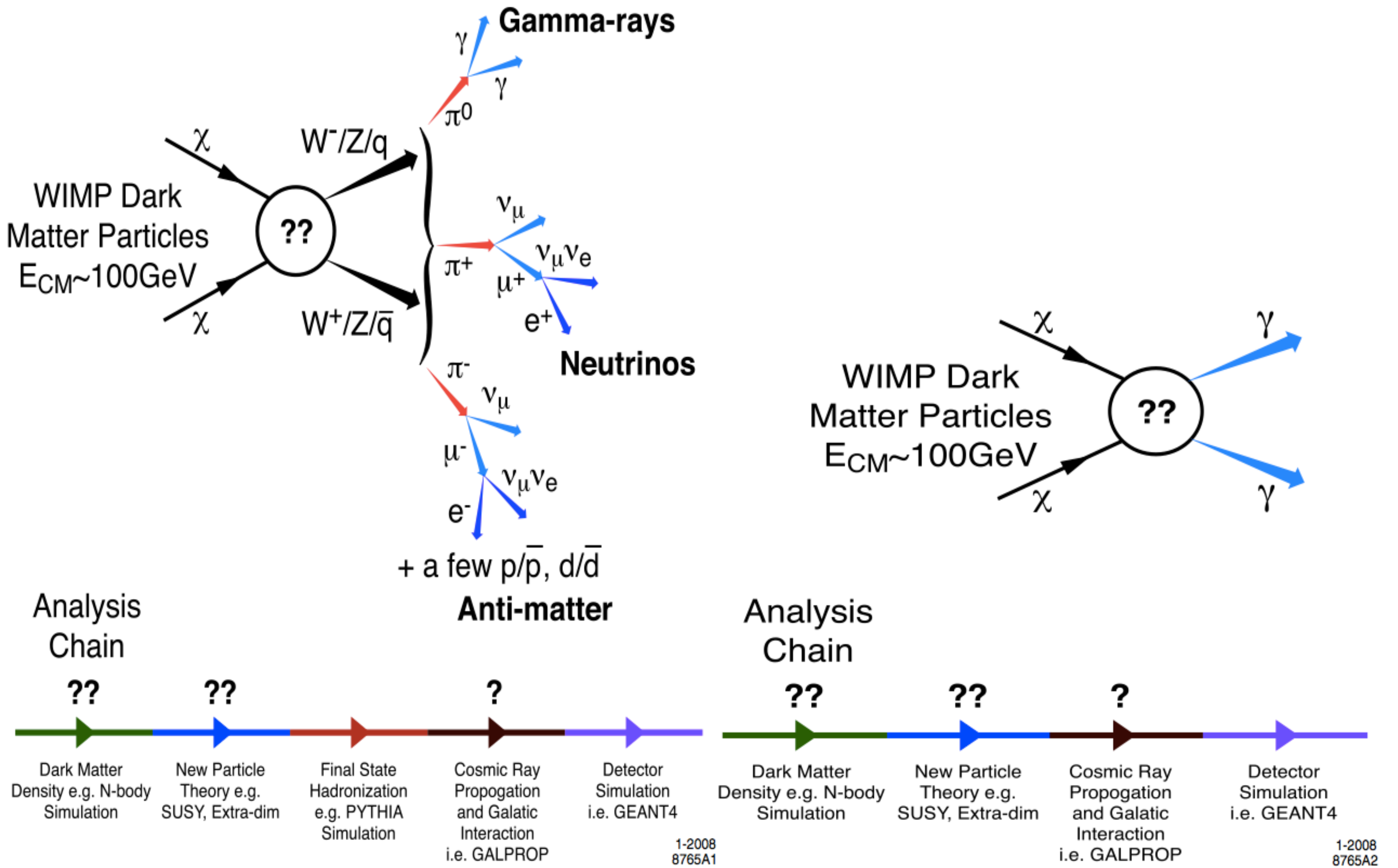
$\Omega_{DM} \approx 26.8\%$

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

Dark Matter



Annihilation channels

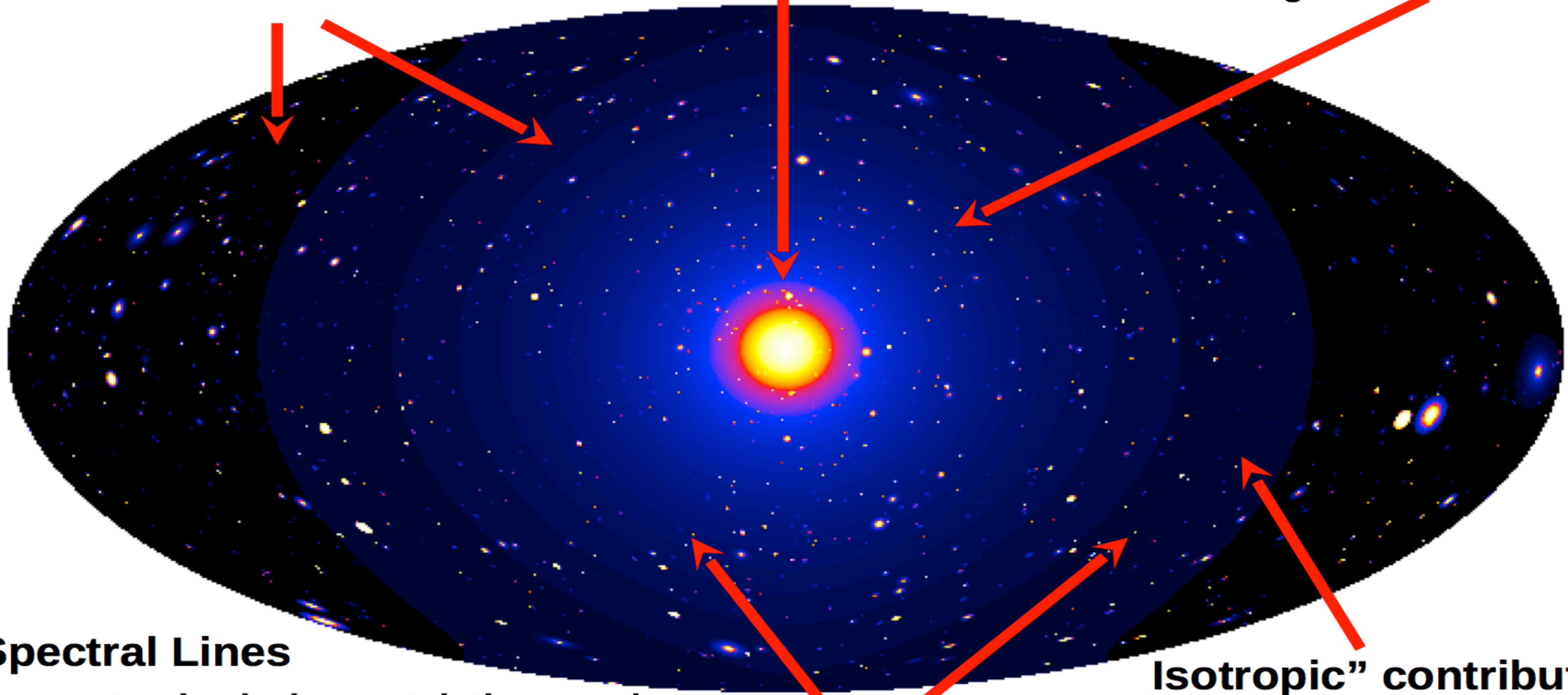


Dark Matter Search: Targets and Strategies

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

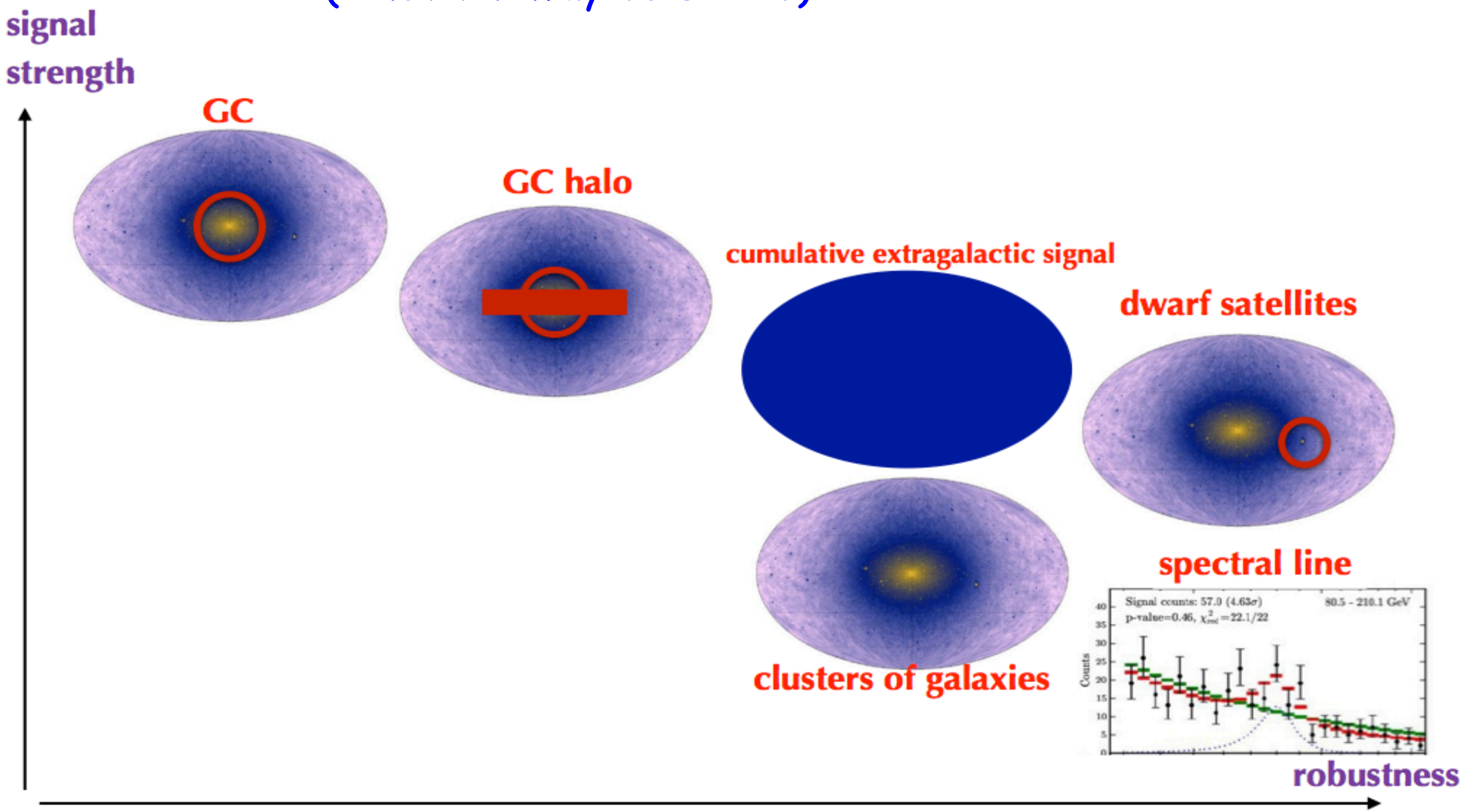
Isotropic" contributions
Large statistics, but astrophysics, galactic diffuse background

Galaxy Clusters
Low background, but low statistics

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

Dark Matter Search: Targets and Strategies

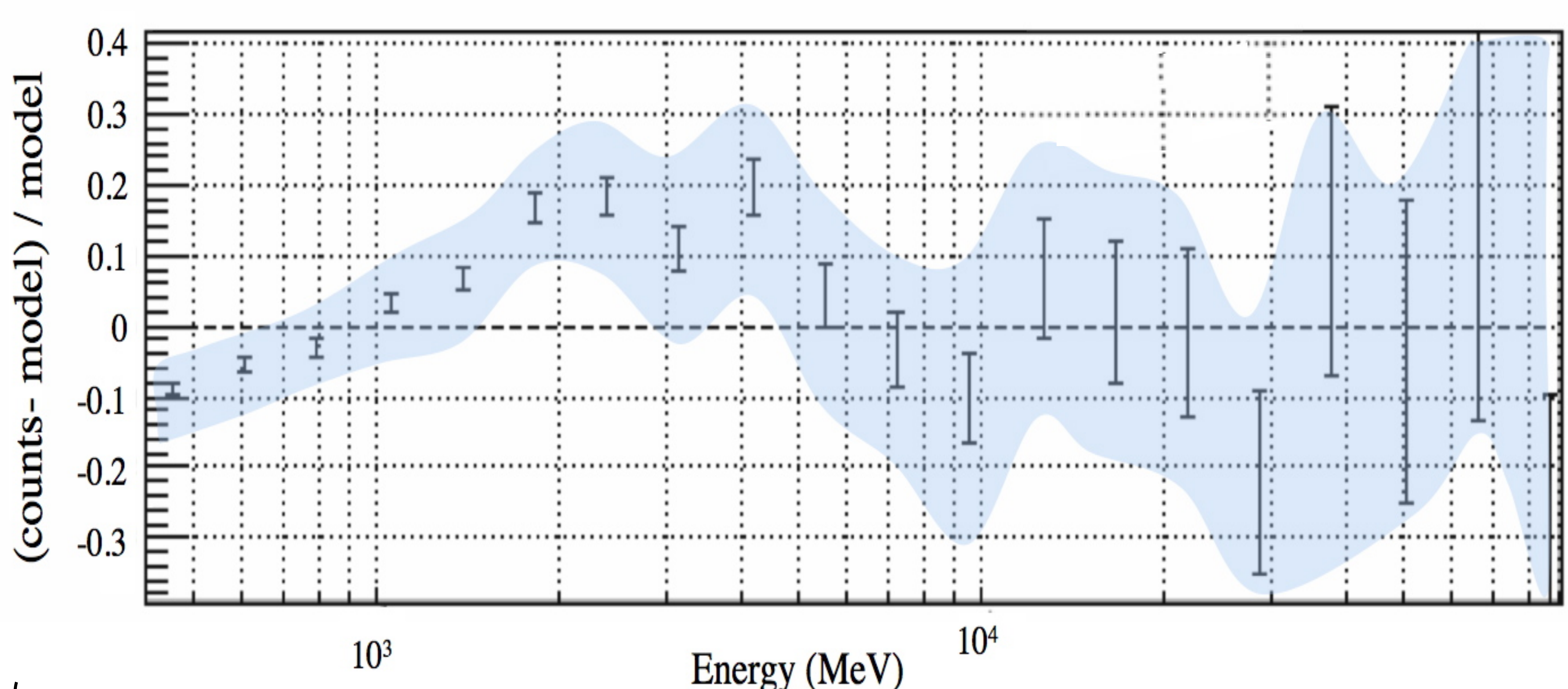
(Another way to see it)



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

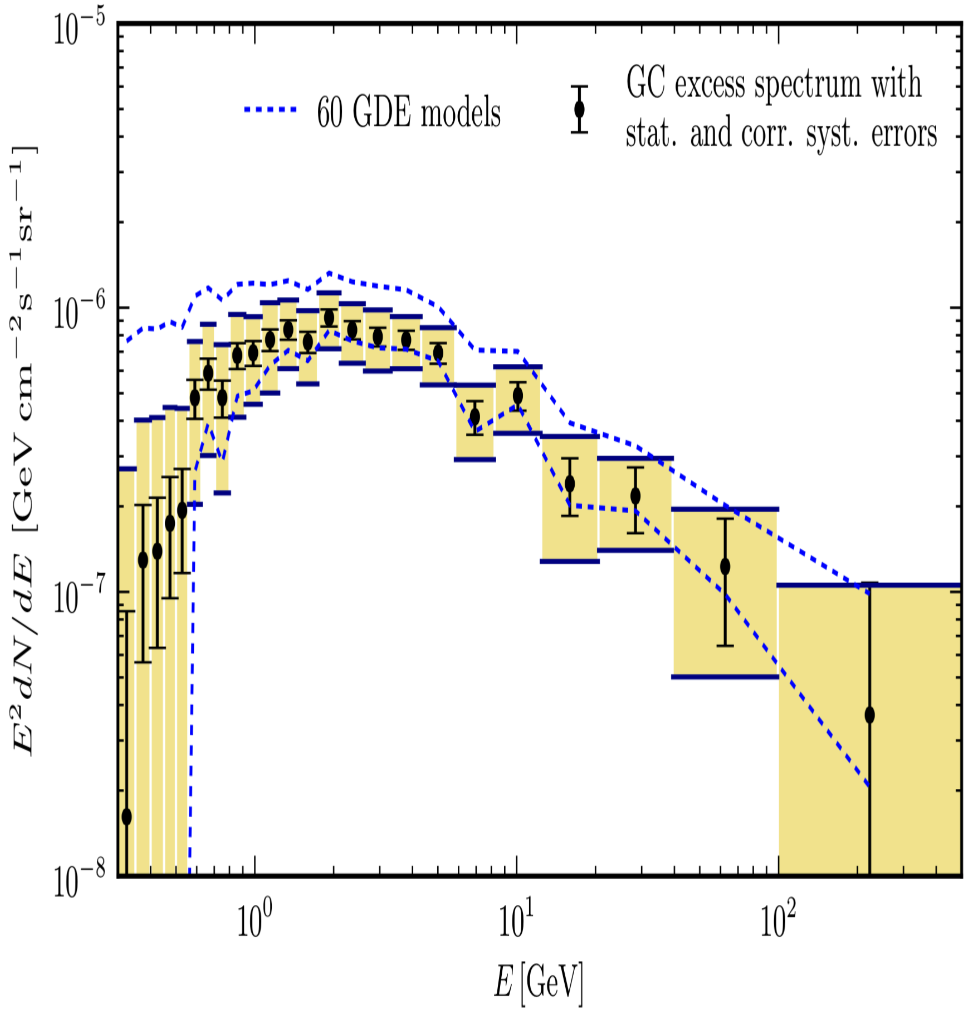
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

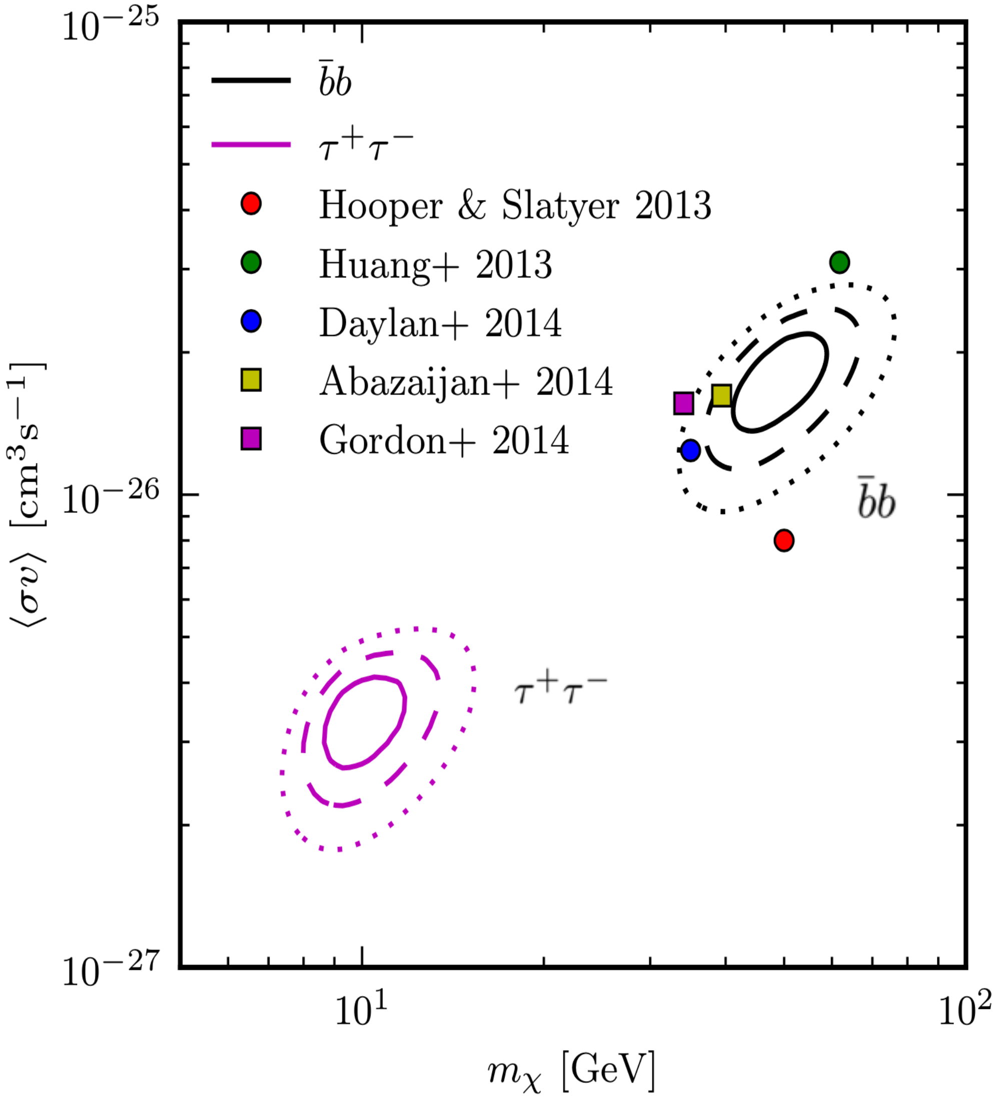
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



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

The GeV excess





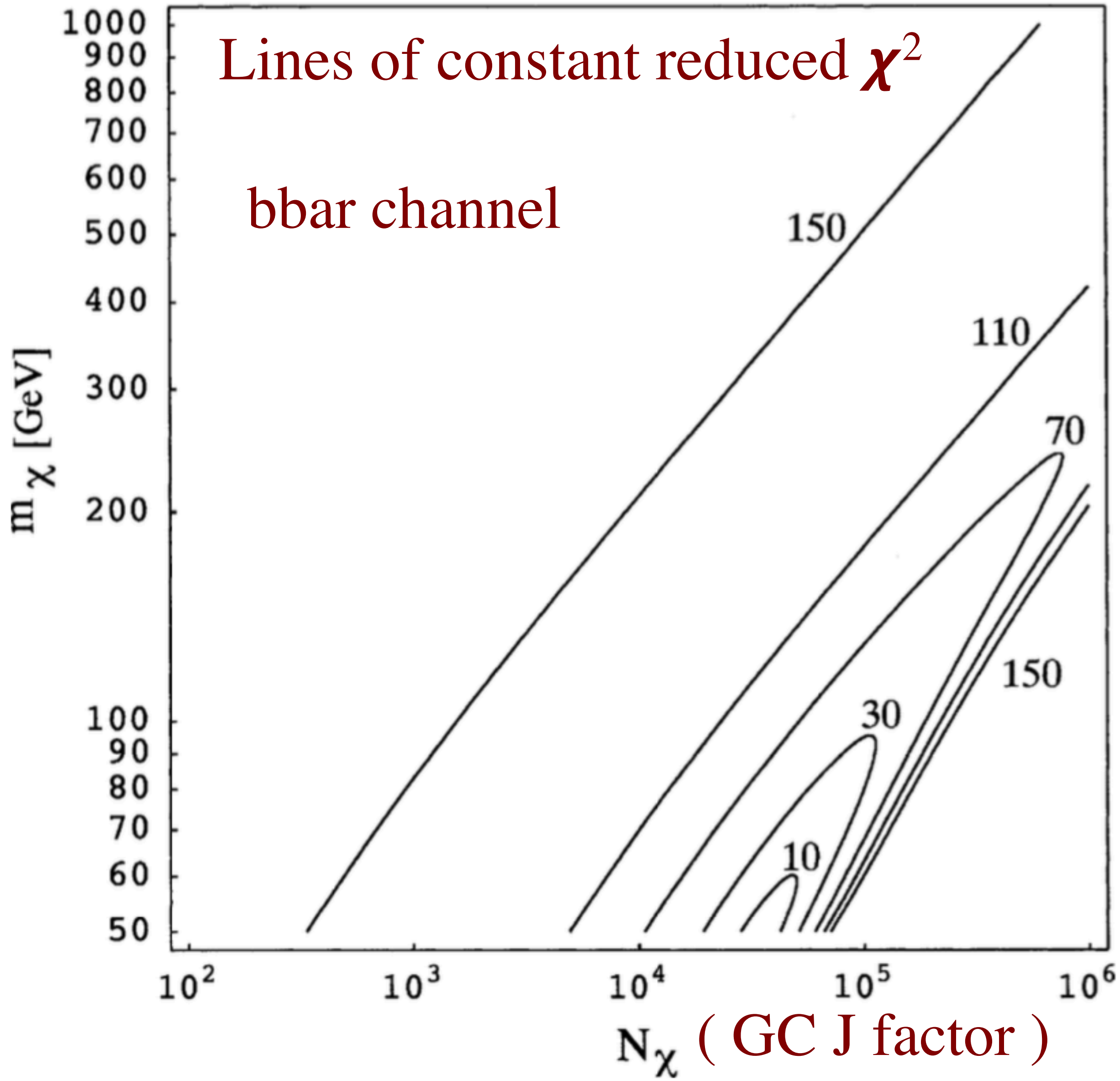
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

Calore et al, arXiv:1409.0042v1

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 !

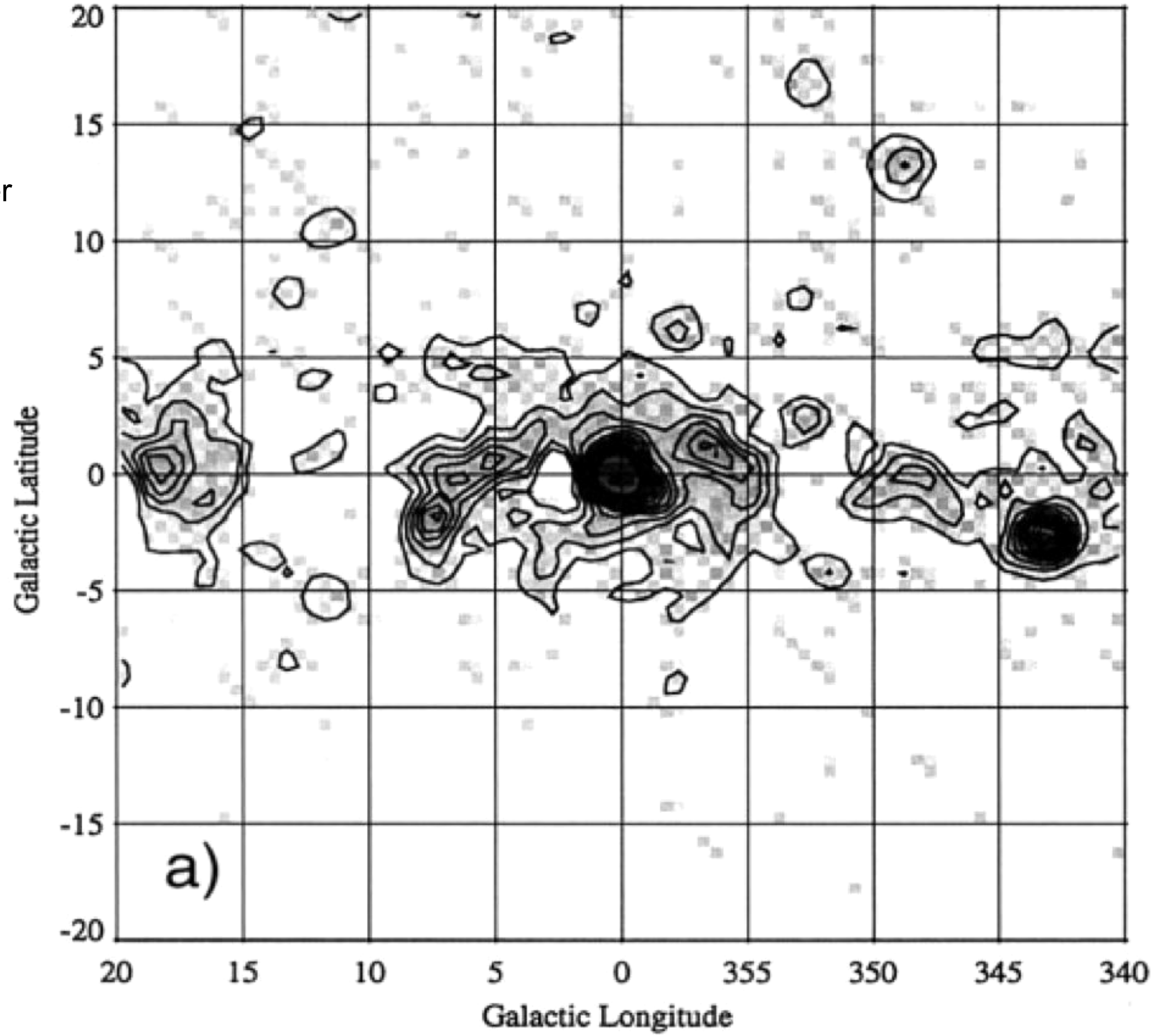
mass ~ 50- 80 GeV



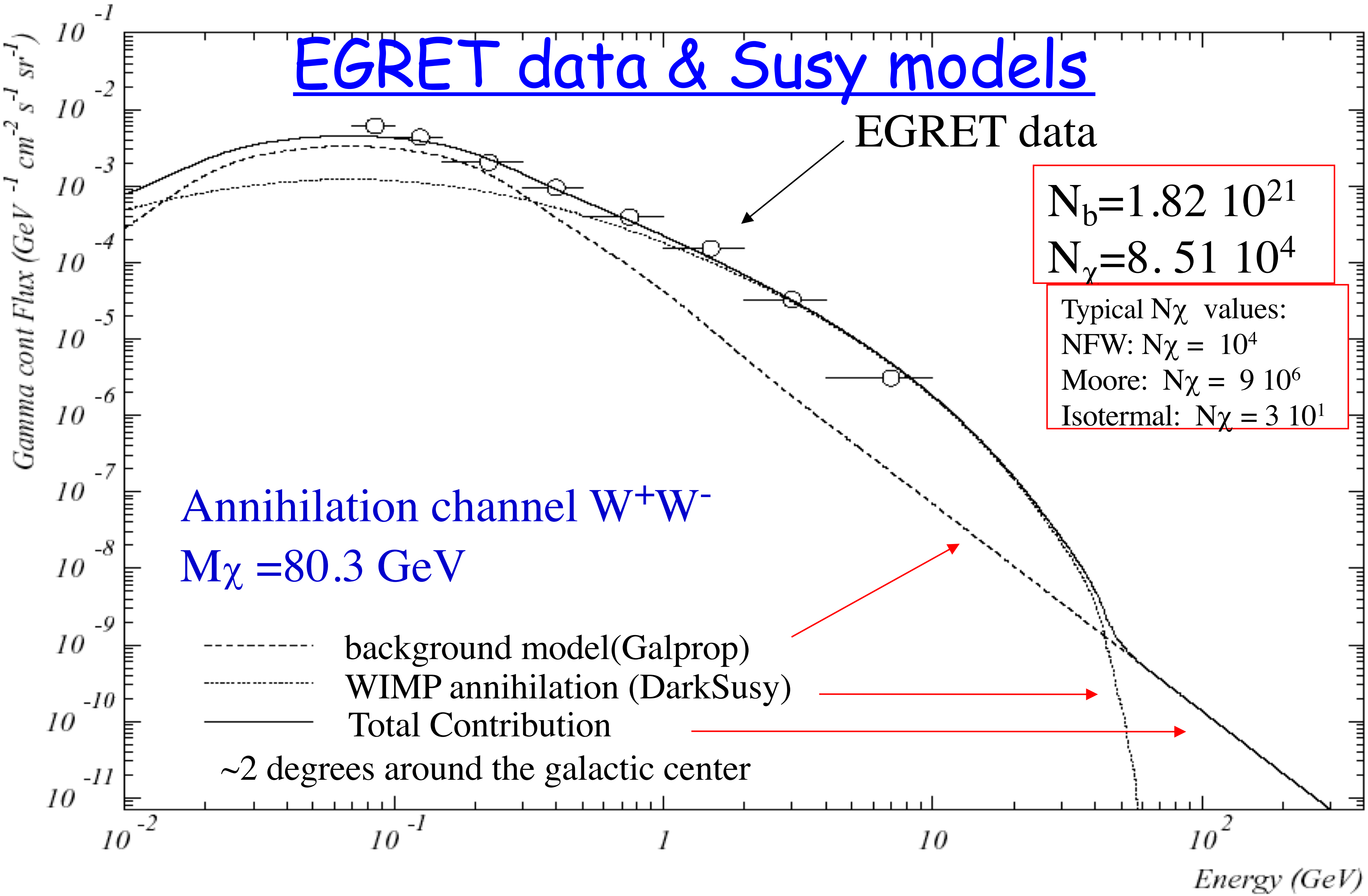
A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

EGRET, E > 1GeV

Mayer-Hasselwander et al, 1998



EGRET data & Susy models



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)

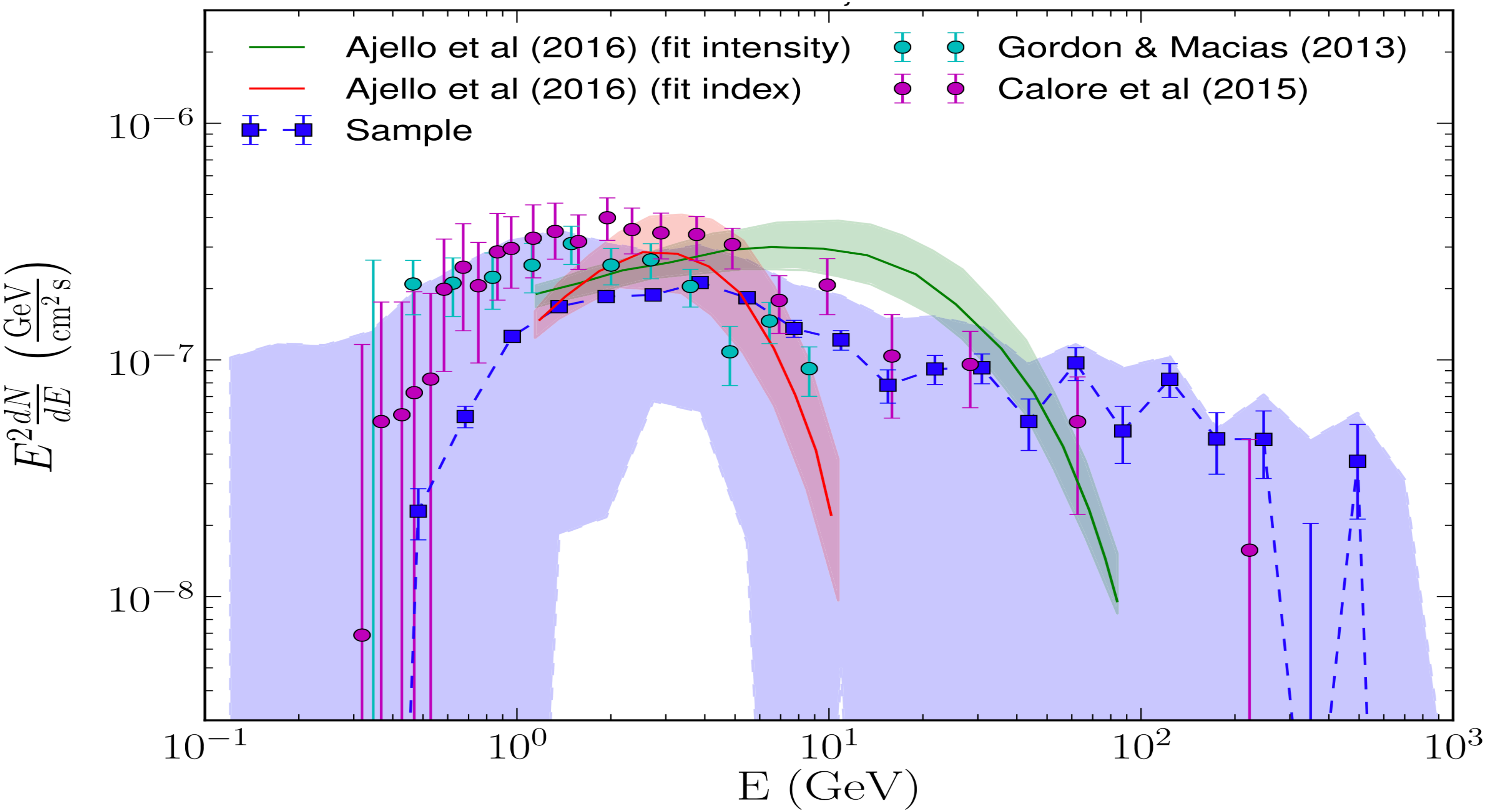
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

....

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

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 GeV excess

in 2016 two papers on Strong support for millisecond pulsars:

S. K. Lee et al., Evidence for Unresolved γ-Ray Point Sources in the Inner Galaxy, Phys. Rev. Lett. 116 (2016) 051103, [arXiv:1506.05124].

R. Bartels et al., Strong support for the millisecond pulsar origin of the Galactic center GeV excess Phys. Rev. Lett. 116 (2016) 051102, [arXiv:1506.05104].

but in Leane Slatyer, Dark Matter Strikes Back at the Galactic Center, arXiv:1904.08430 (Prl 123, 201101 (2019) it is shown that "large artificial injected dark matter signals are completely misattributed to point sources." so dark matter may provide a dominant contribution to the GCE after all.

then:
The Return of the WIMP: Missing Energy Signals and the Galactic Center Excess, Carena et al., arXiv:1905.03768
excess in tri-lepton events plus missing energy observed by the ATLAS experiment at the LHC could be interpreted as a signal of low energy supersymmetry. $M\chi$ =60 GeV (bb) compatible with the muon anomalous magnetic moment and consistent with the requirement of obtaining the correct Higgs mass in the Minimal Supersymmetric Standard Model (MSSM)

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?

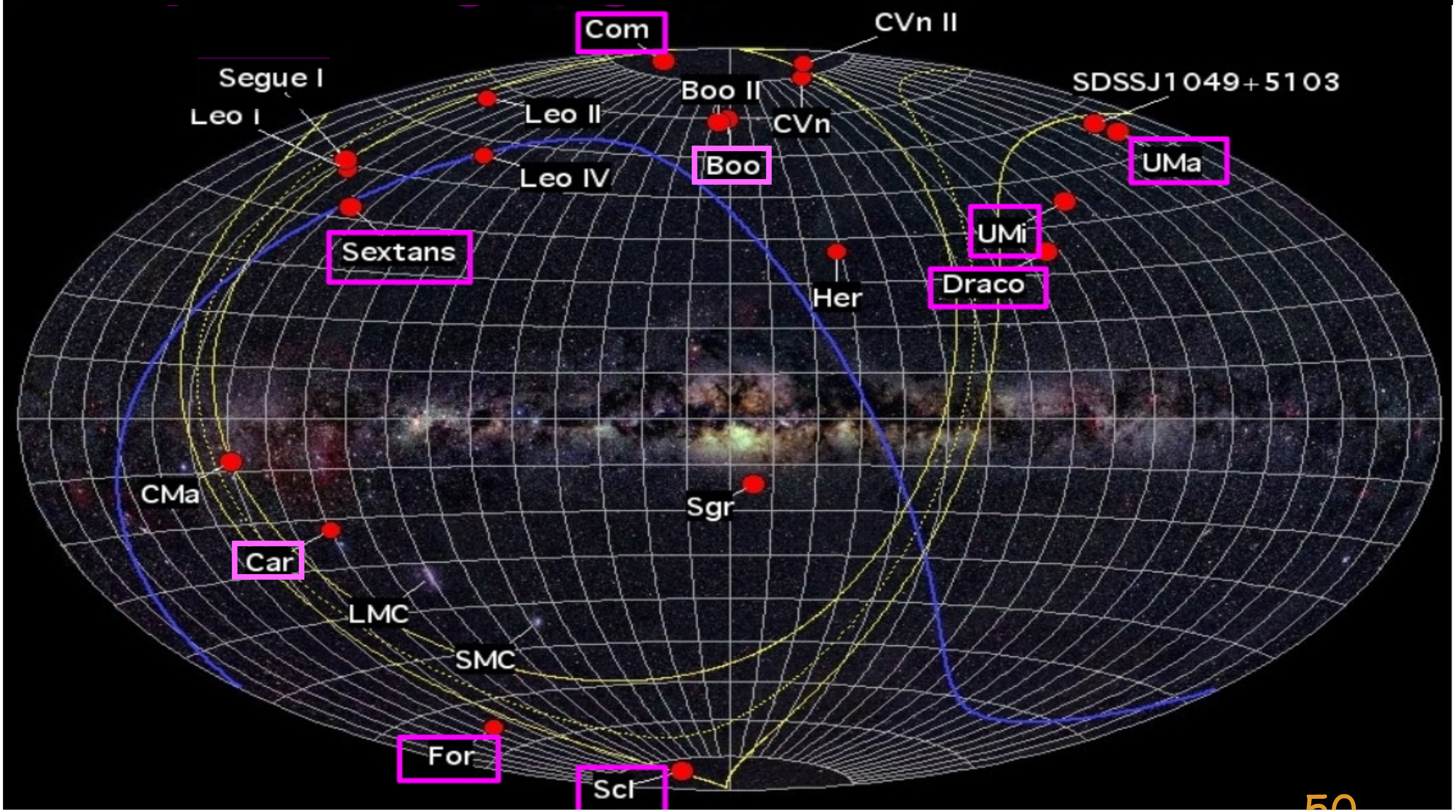
Radio observations, MeerKAT, SKA
- Search for individual pulsars in the halo around the GC

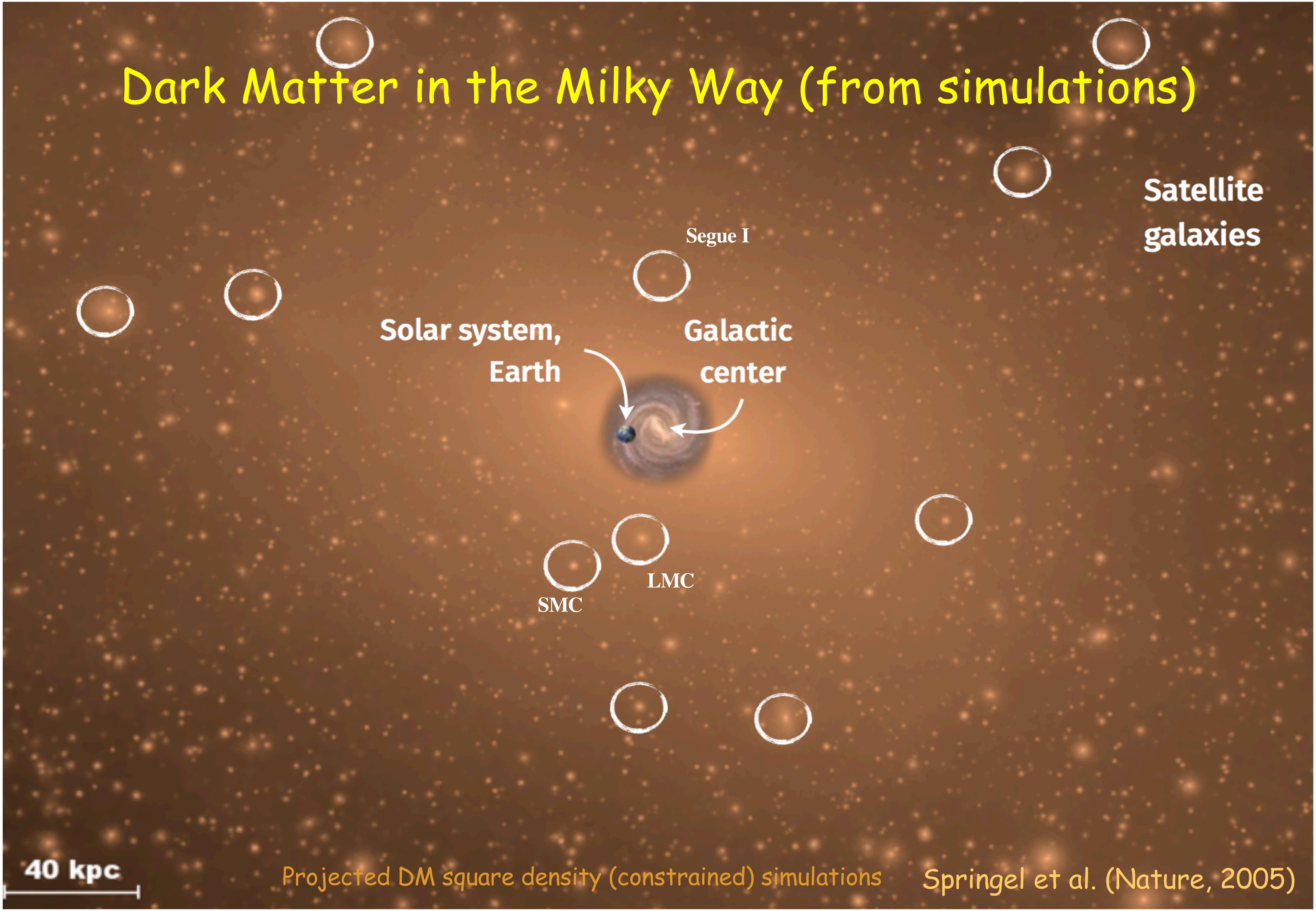
Radio surveys, Planck
- Look for correlated synchrotron emission near the GC

More Fermi LAT analysis
- Diffuse emission modeling
- Analysis of point sources near the GC

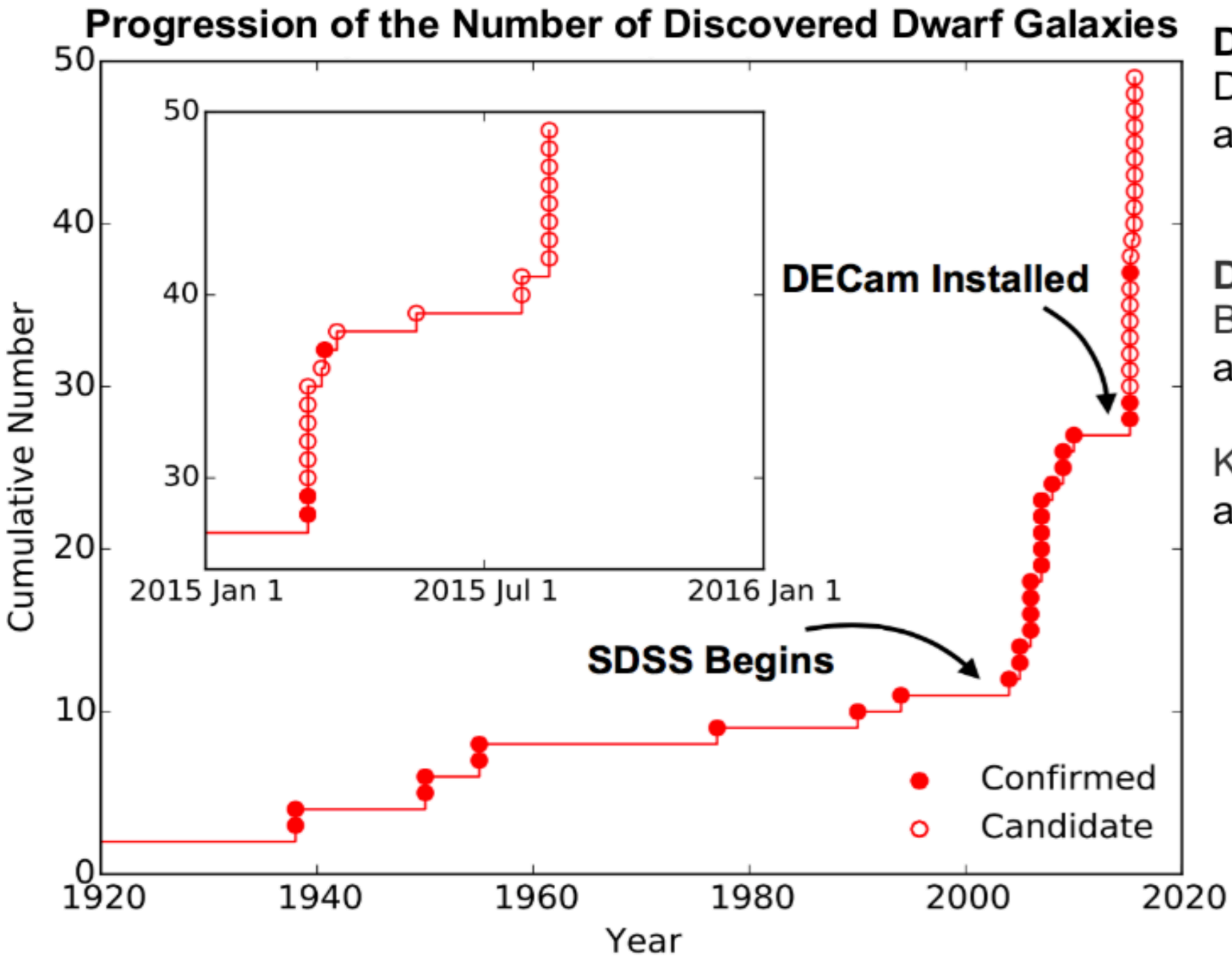
But ultimately We need a new experiment with better angular resolution below 100 MeV

Classical Dwarf spheroidal galaxies: promising targets for DM detection




Dark Matter in the Milky Way (from simulations)
Satellite galaxies
Segue I
Solar system, Earth
Galactic center
LMC
SMC
40 kpc
Projected DM square density (constrained) simulations
Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies: Growing number of known targets



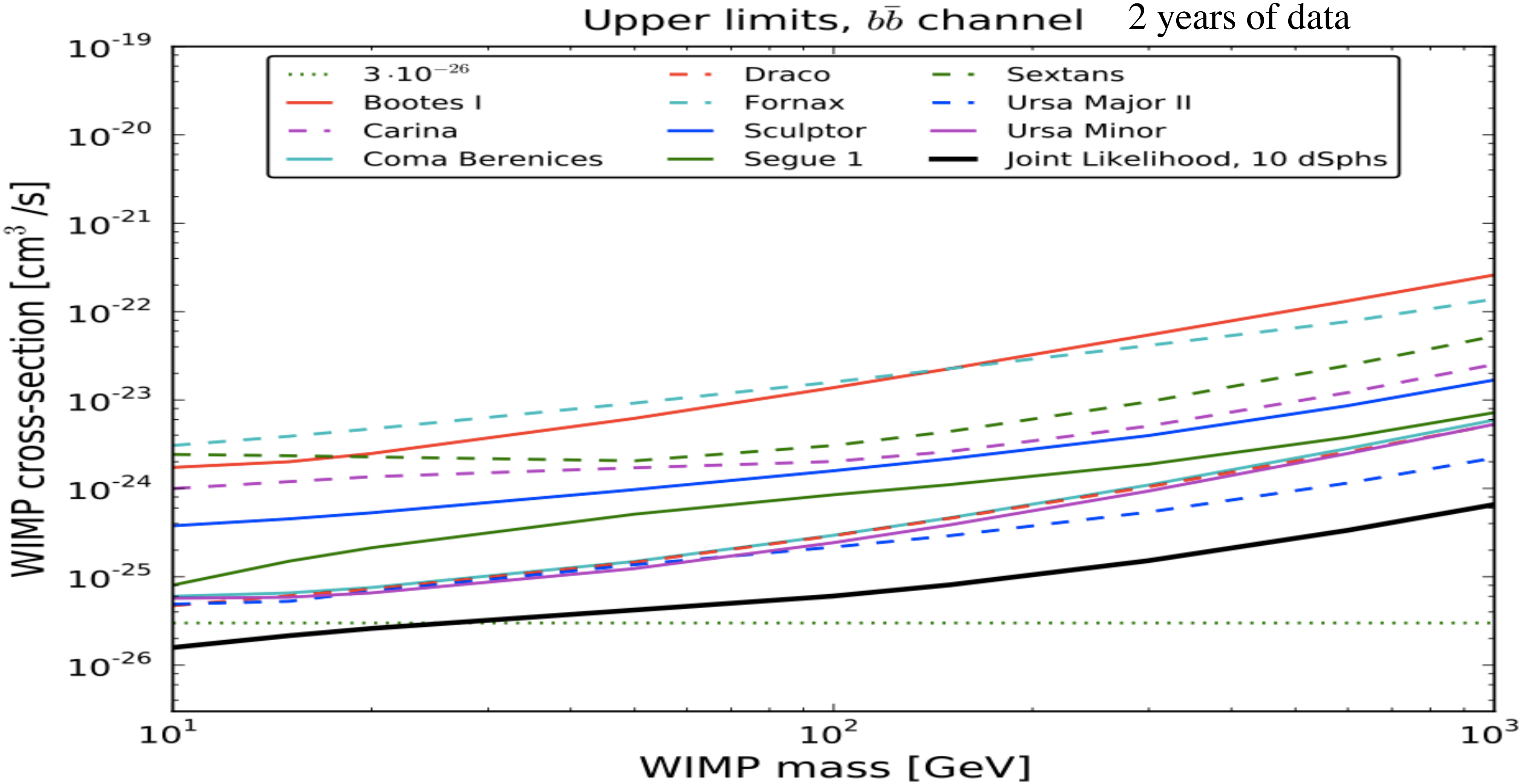
DES Year 2 Data: Drlica-Wagner+, arXiv:1508.03622

DES Year 1 Data: Bechtol+: arXiv:1503.02584

Koposov+: arXiv:1503.02079

Dwarf Spheroidal Galaxies combined analysis

2 years of data

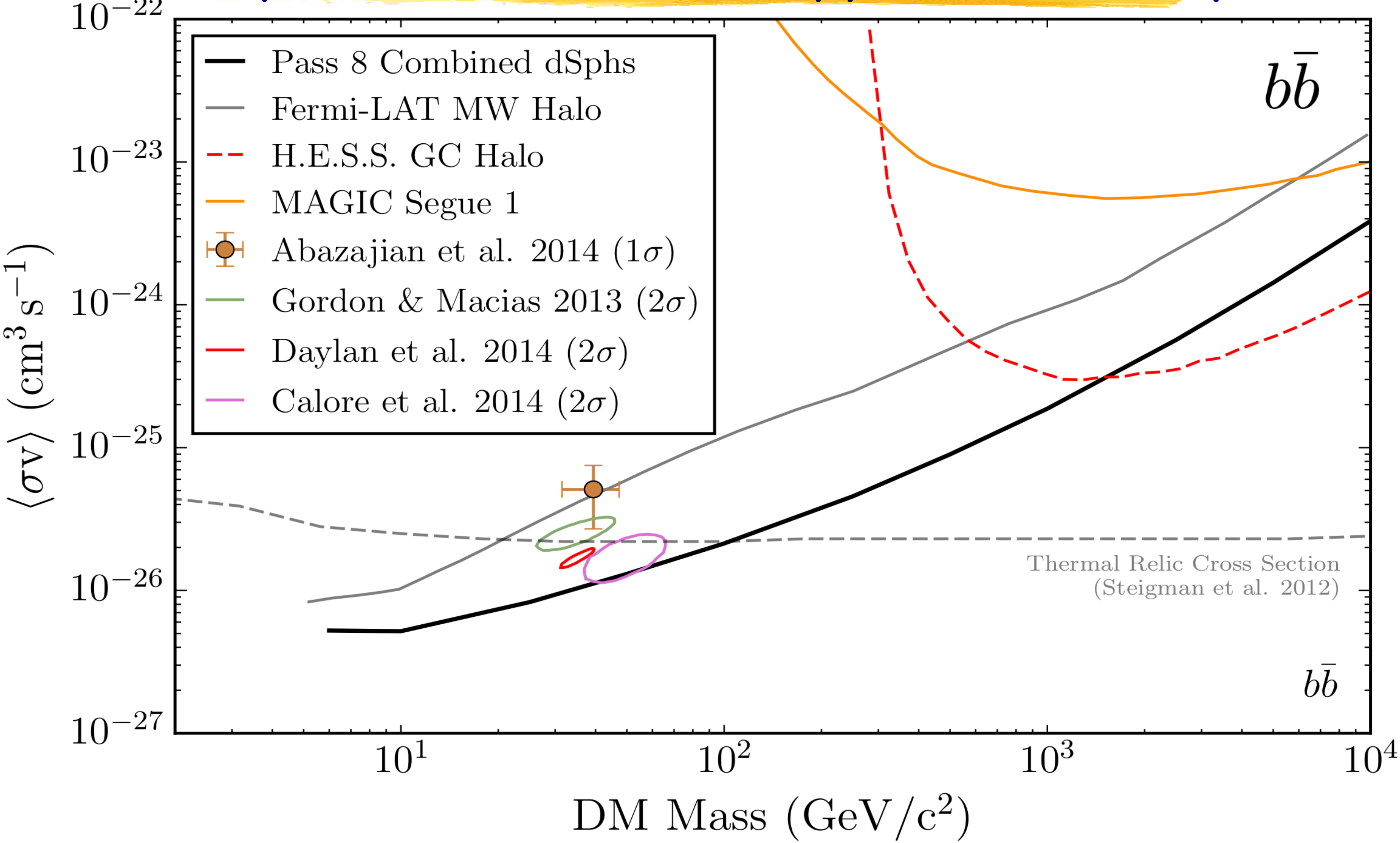


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

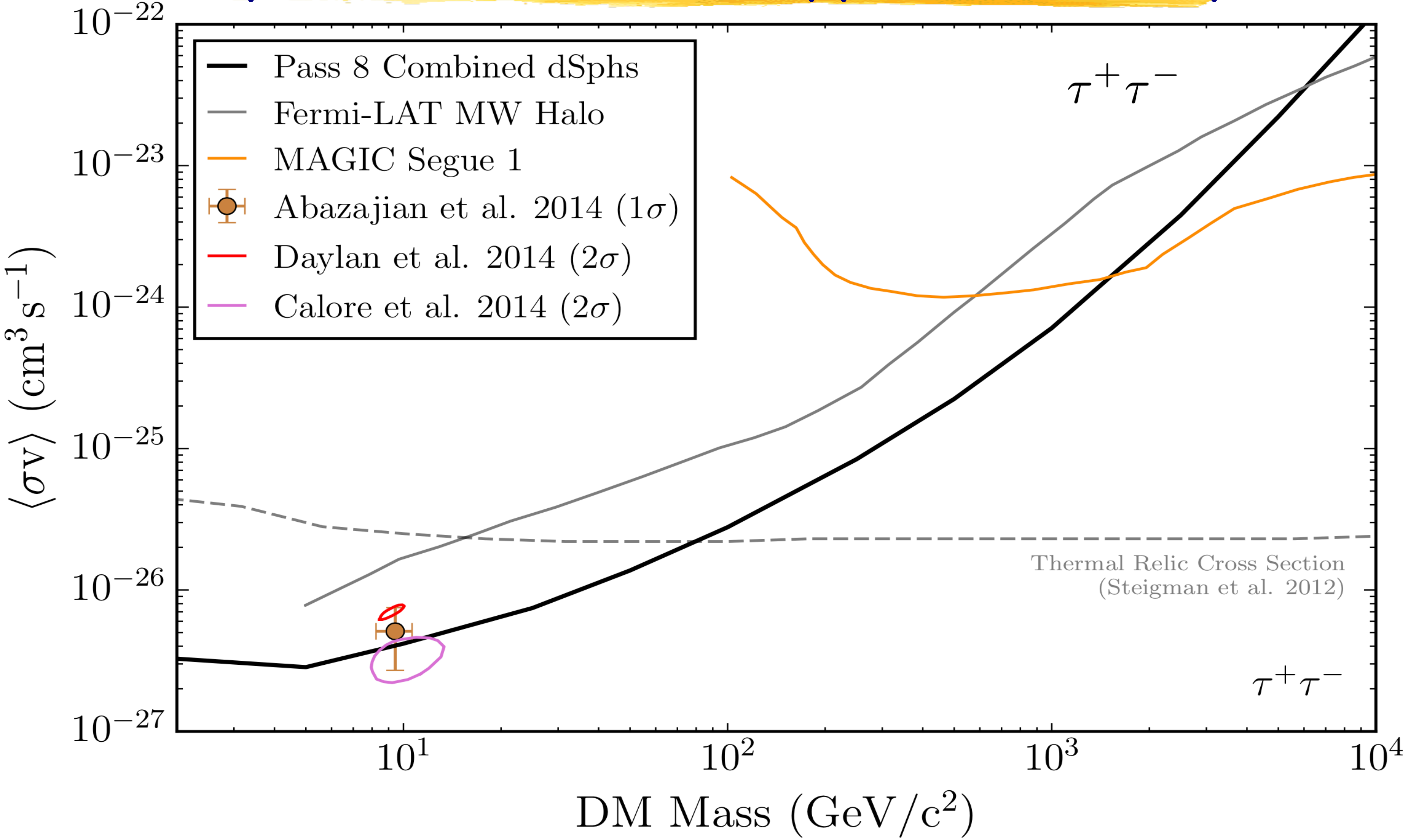
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)

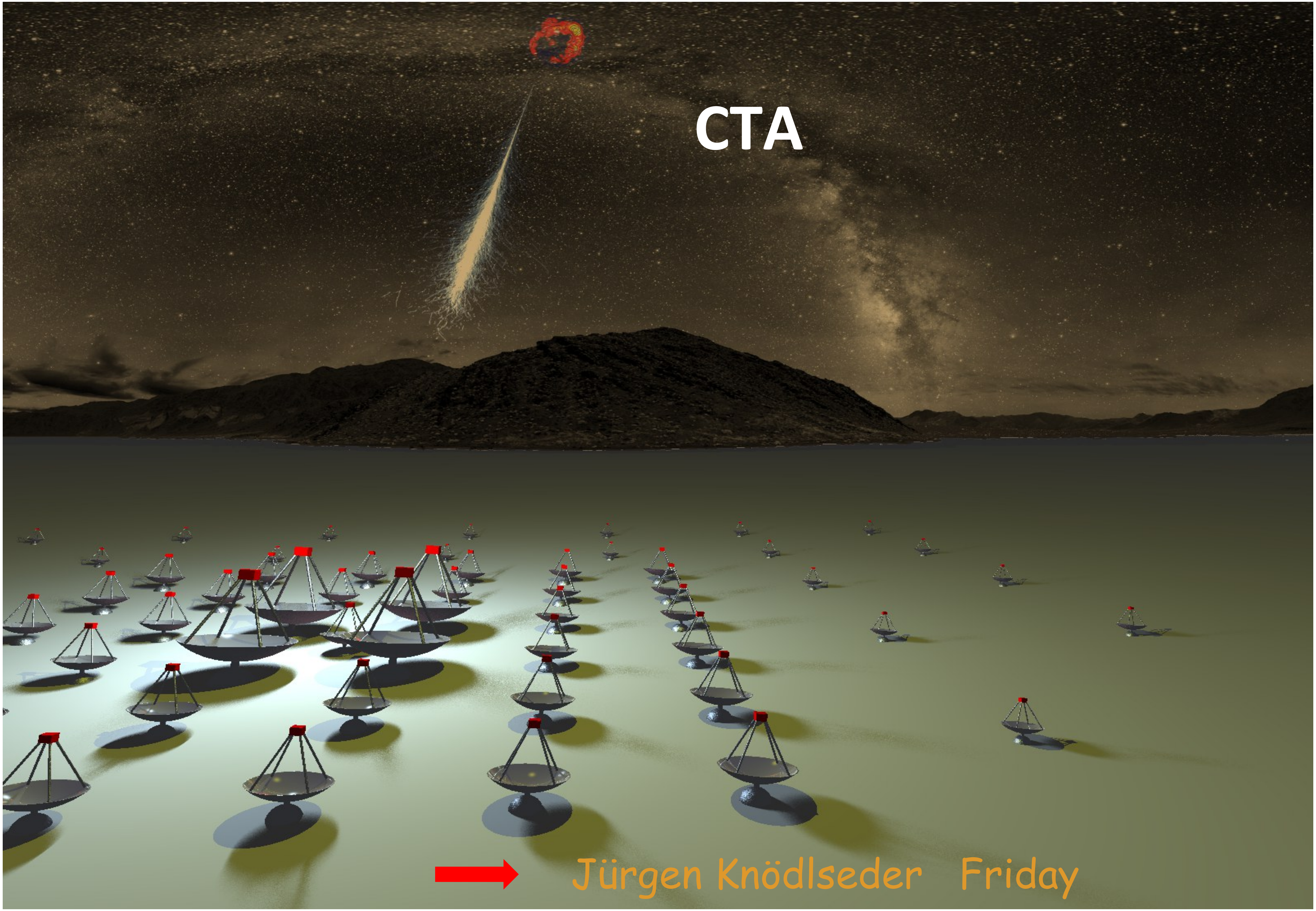


M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

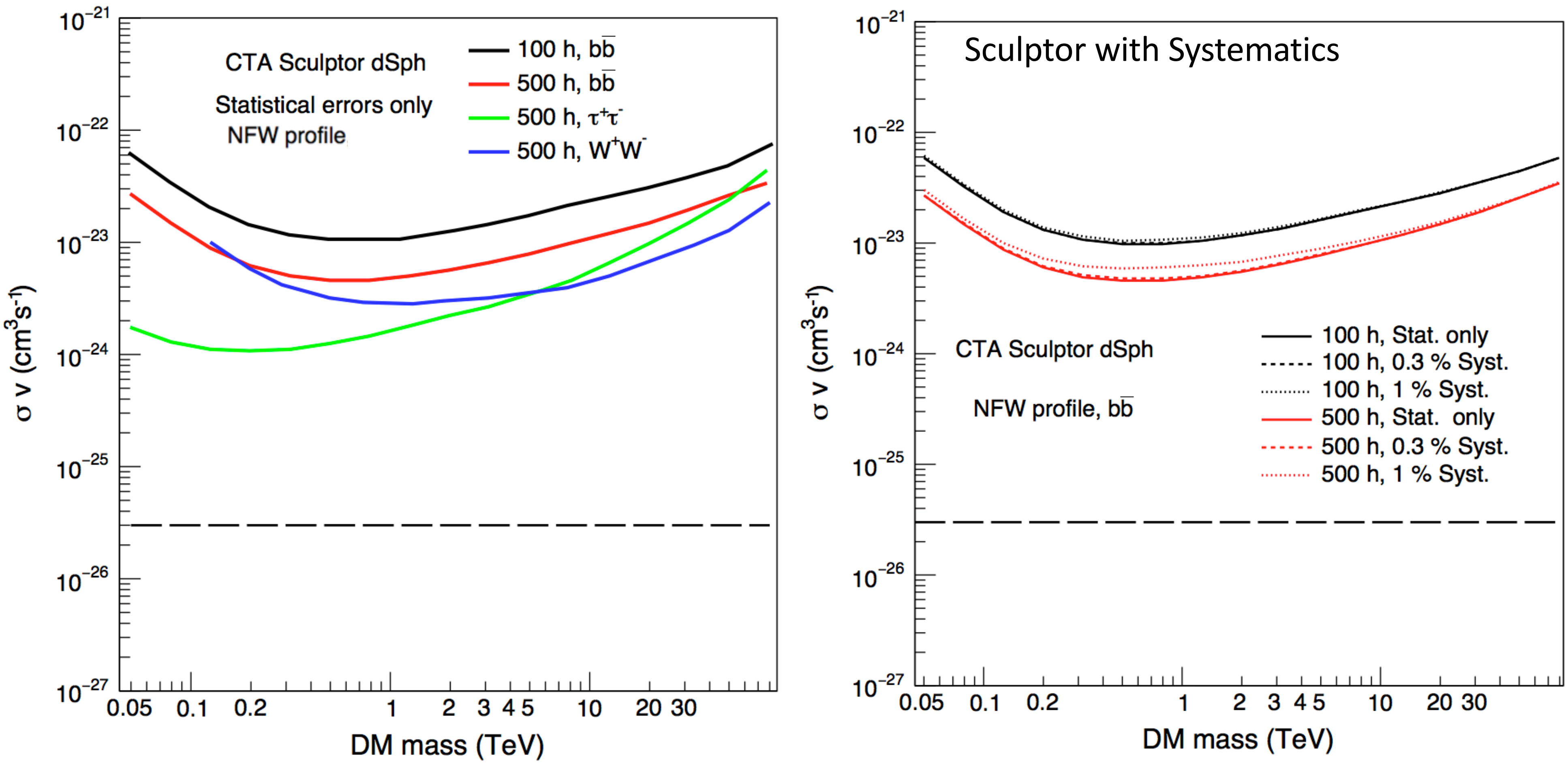
Dwarf Spheroidal Galaxies upper-limits (6 years)



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


CTA
Jürgen Knödlseder Friday

Dwarf Spheroidal Galaxies: CTA Sensitivity

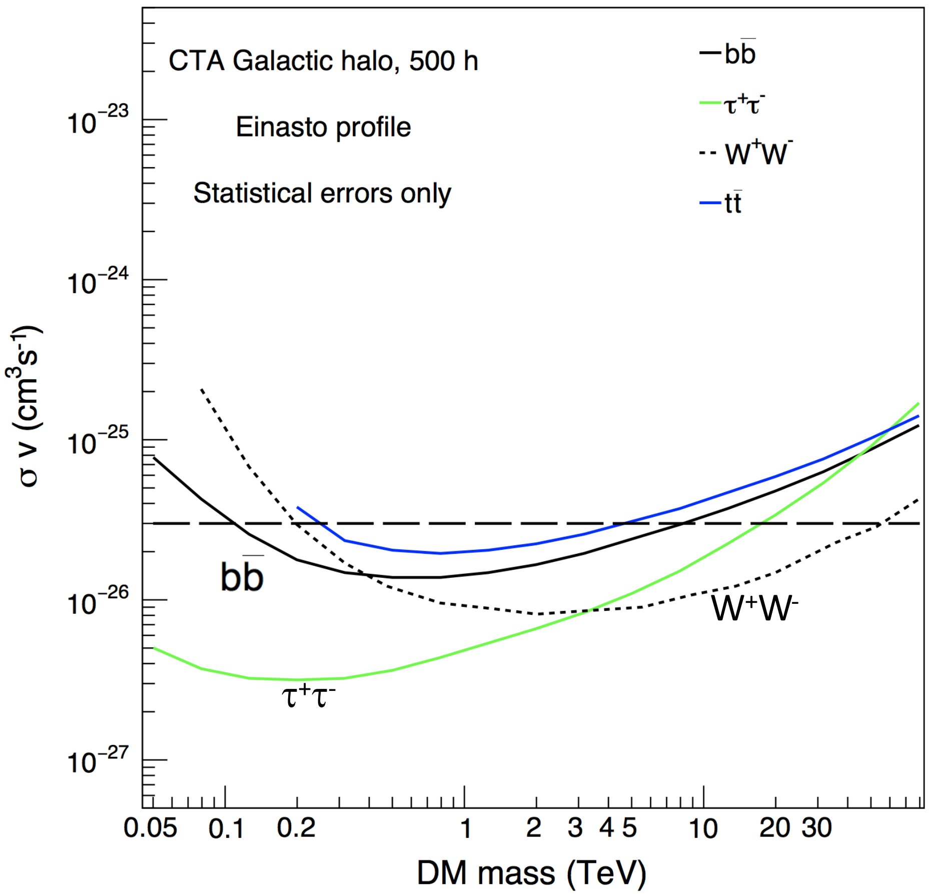


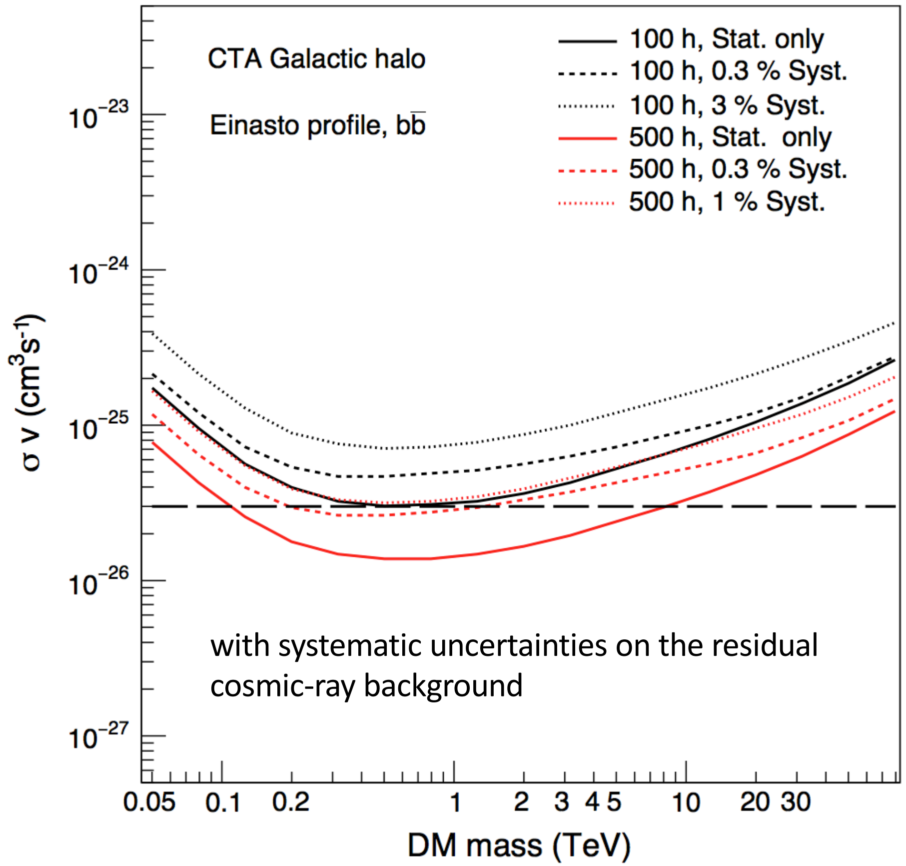
There are several of the newly discovered dSph that have a better case for being a promising target,

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

A.M. PoS(ICRC2017)921

CTA Galactic Halo DM upper-limits

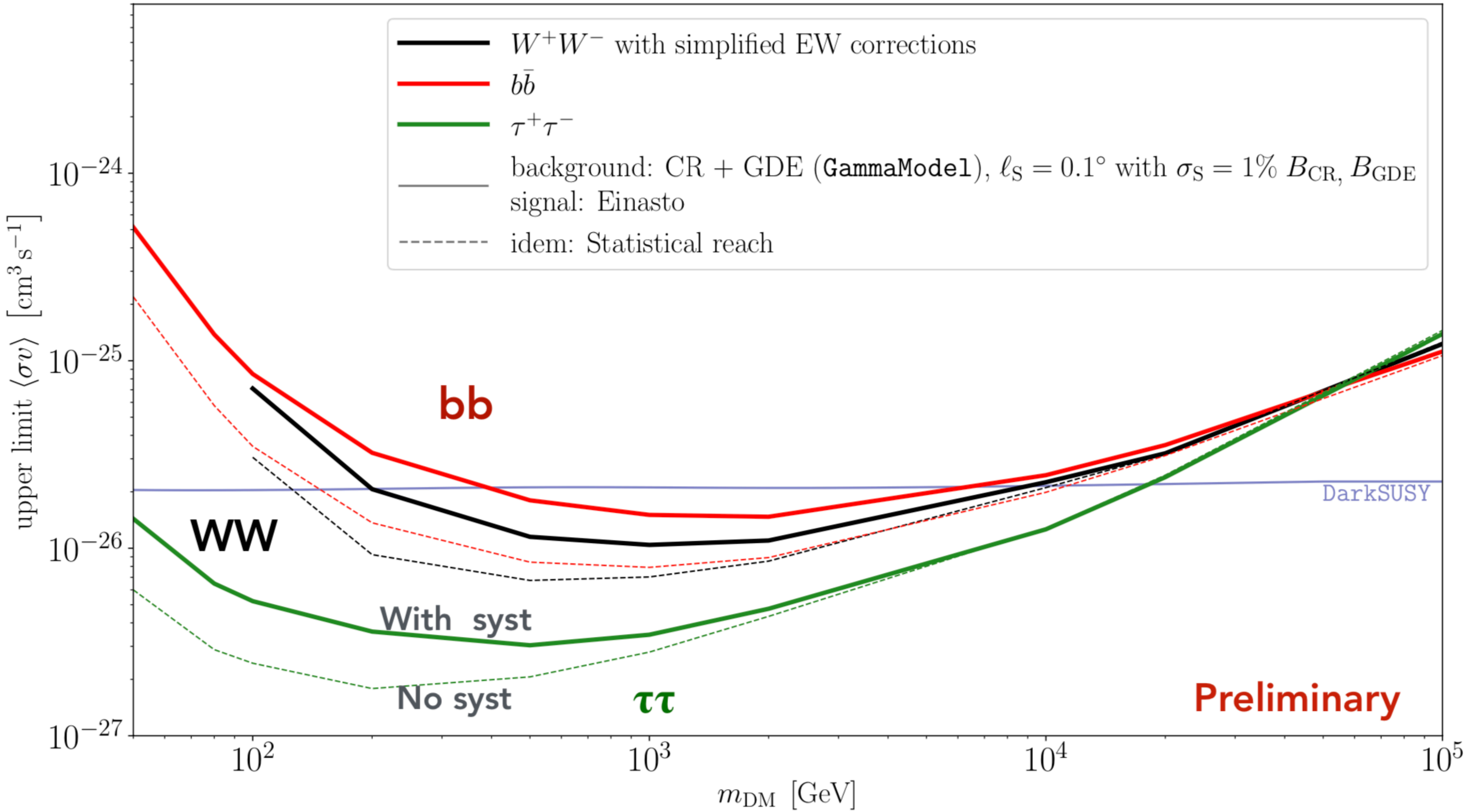




The predictions shown here can be considered optimistic, even when systematics errors are included, as we do not consider the effect of the Galactic diffuse emission as background for DM searches that can affect the results by ~ 50%

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

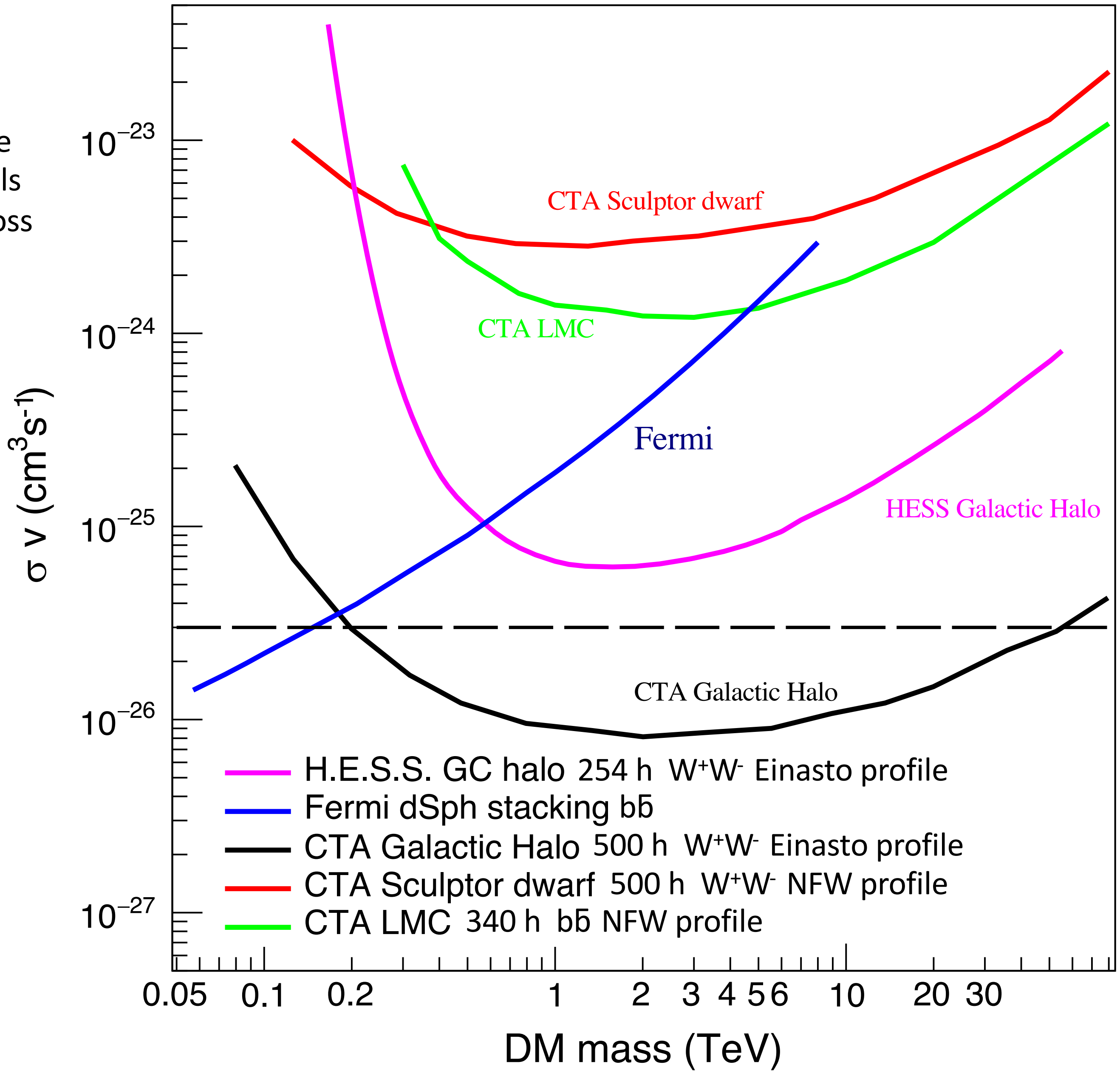
CTA GC Halo Sensitivity to various DM annihilation channels



- up-to-date ***astro and instrumental backgrounds*** *(galactic diffuse emission, interstellar emission and cosmic rays)*
- **systematics** worsens the sensitivity by a factor of ~2
- If profile has a **large core**, limits worsen by a factor of ~5.
- up to one order of magnitude 'enhanced' annihilation motivated for TeV DM: Sommerfeld enhancement, resonances

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



CTA DM Detection Strategy

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

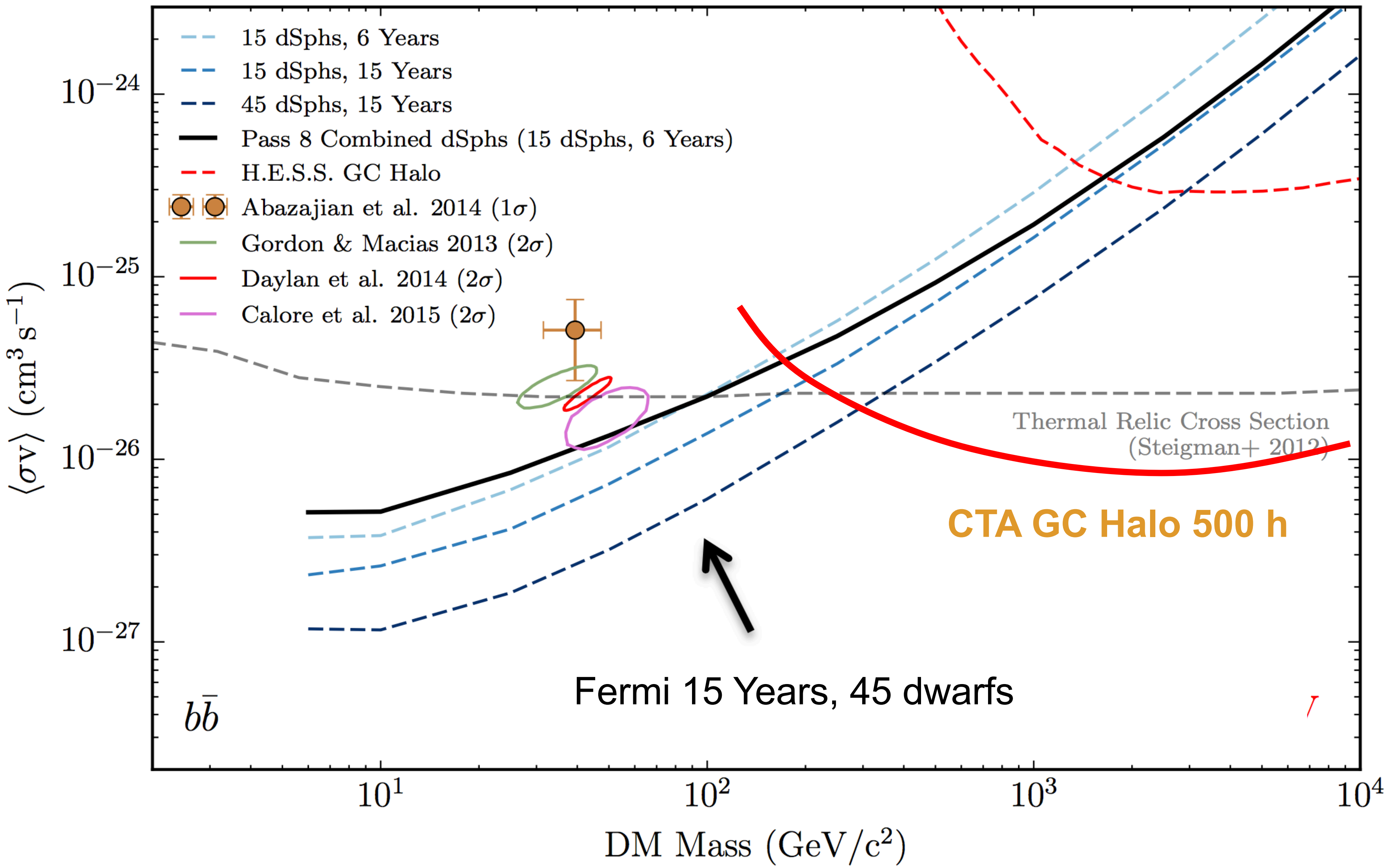
First 3 years

- 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 focus 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.

DM limit improvement estimate in 15 years



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

The Low Energy Frontier

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

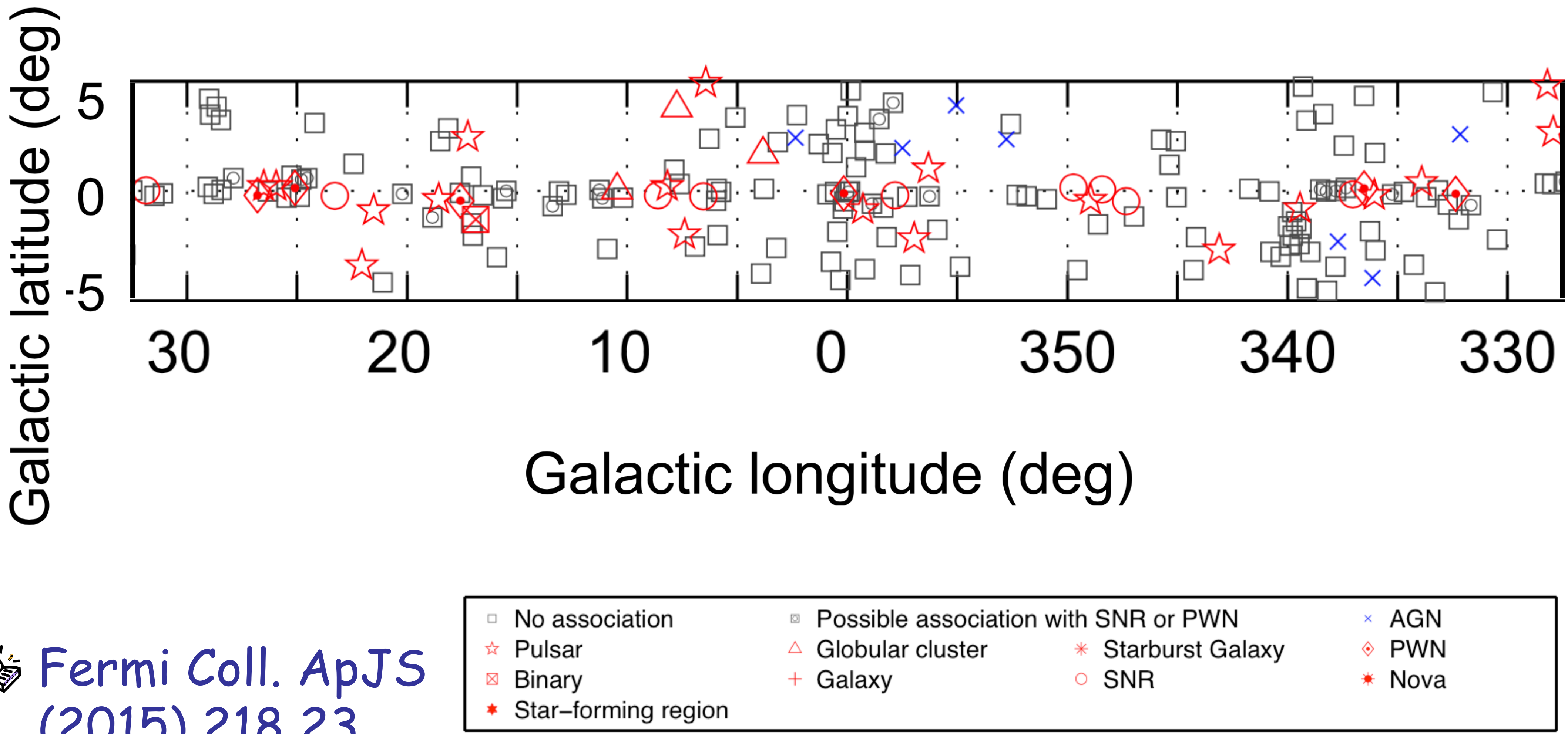
- Diffuse emission modeling
- Analysis of point sources near the GC

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

The Fermi LAT 3FGL Inner Galactic Region

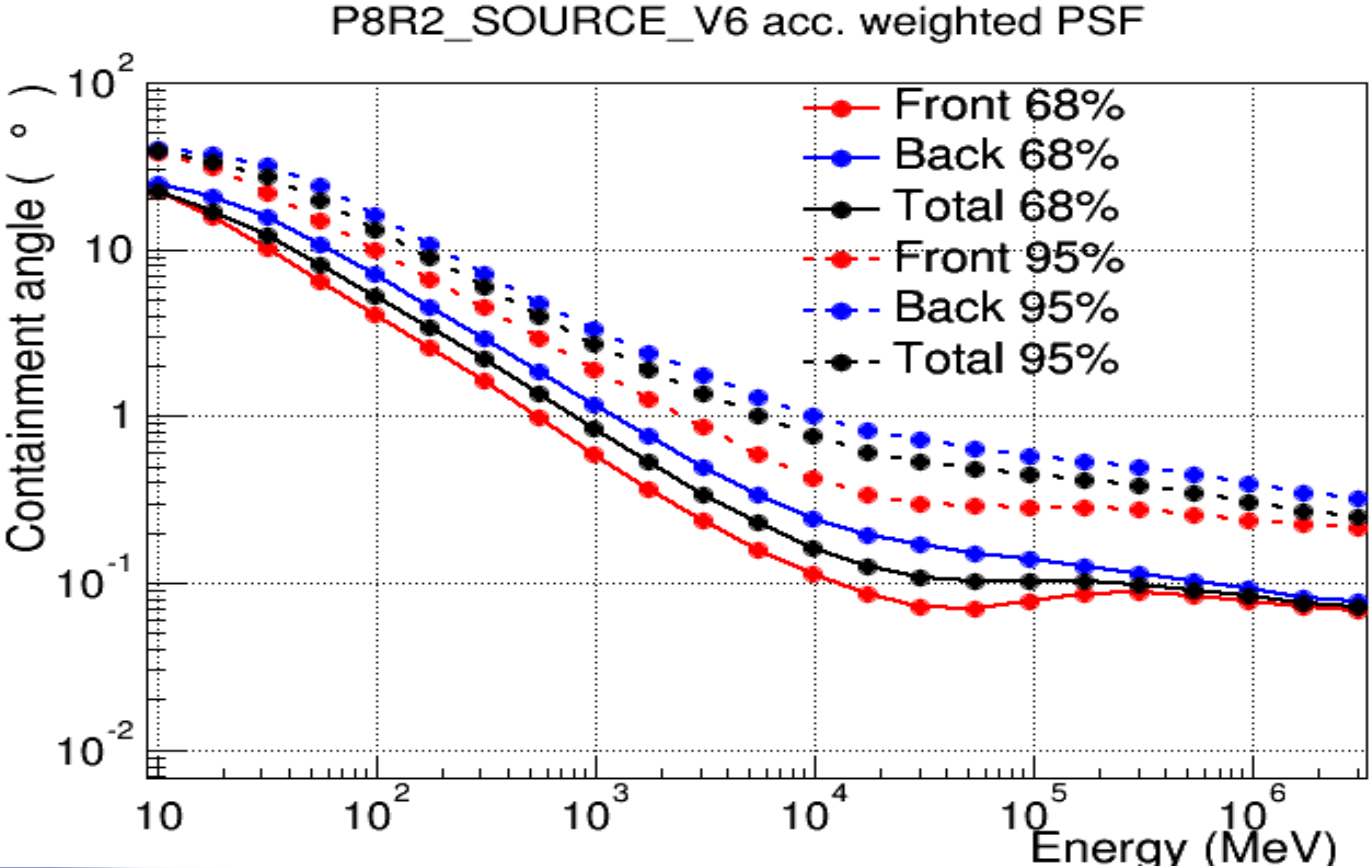
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range

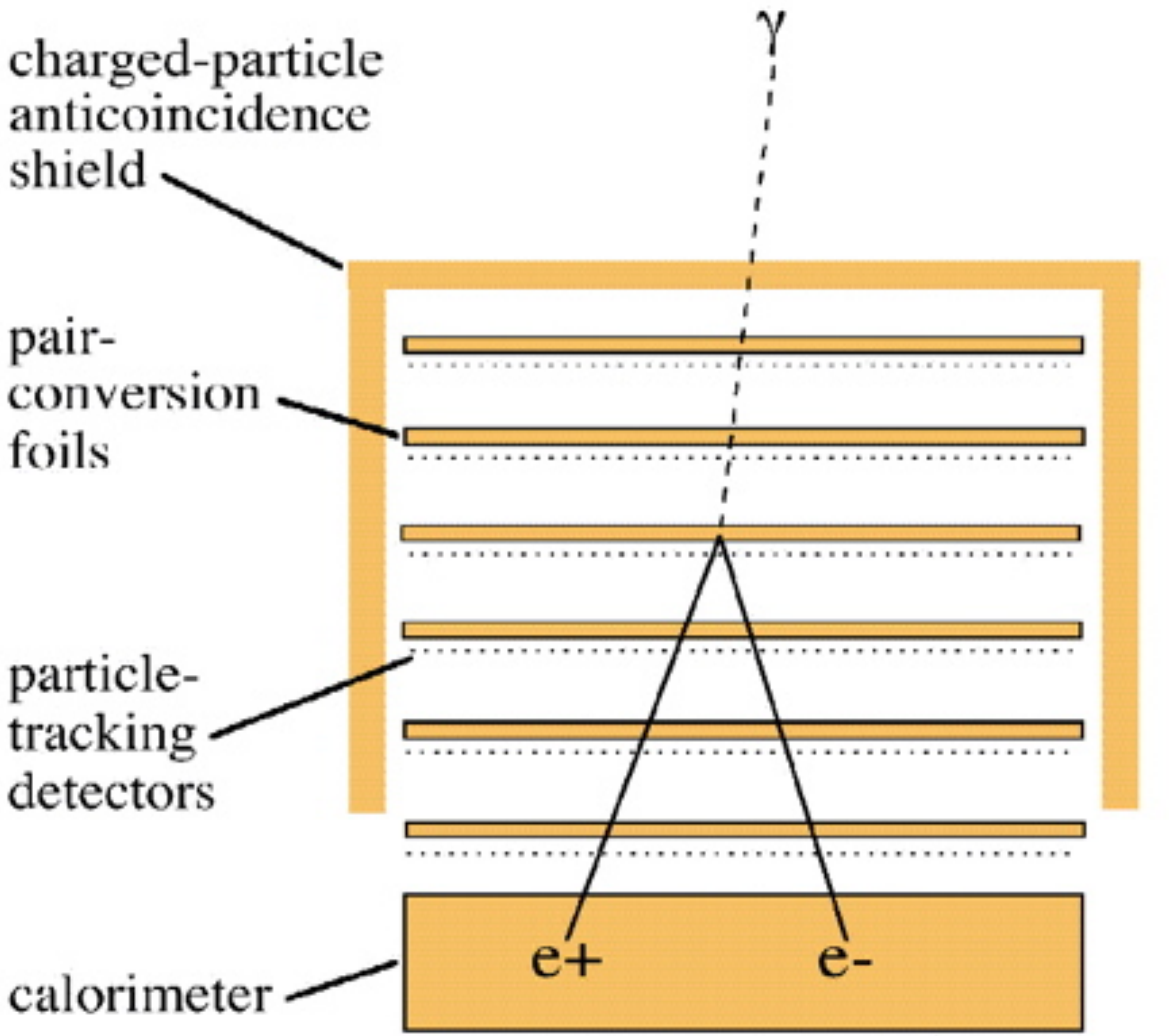


Fermi Coll. ApJS (2015) 218 23 arXiv:1501.02003

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



Elements of a pair-conversion telescope

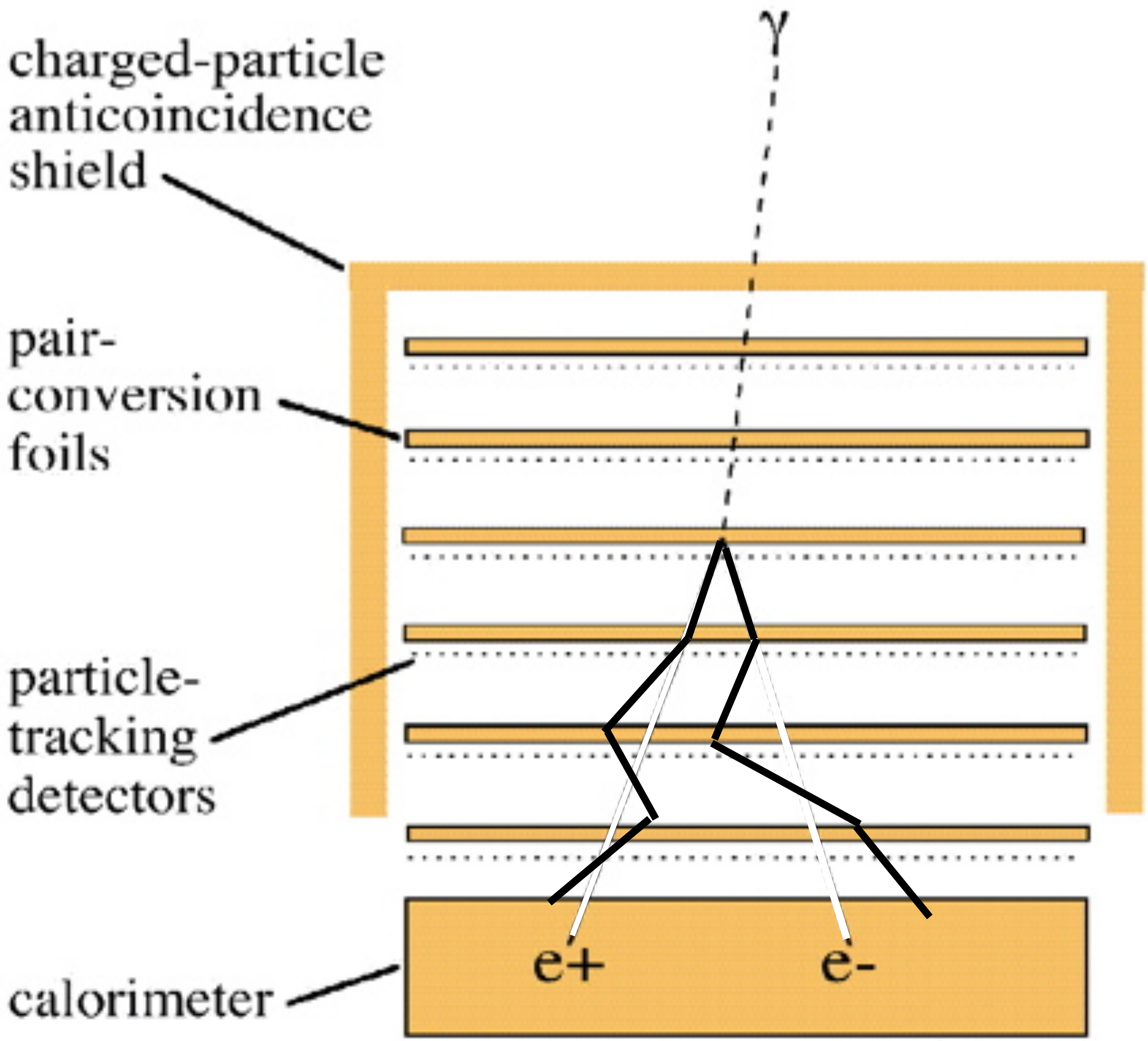


(energy measurement)

- photons materialize into matter-antimatter pairs:
  $E_\gamma \rightarrow m_{e^+}c^2 + m_{e^-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Elements of a pair-conversion telescope

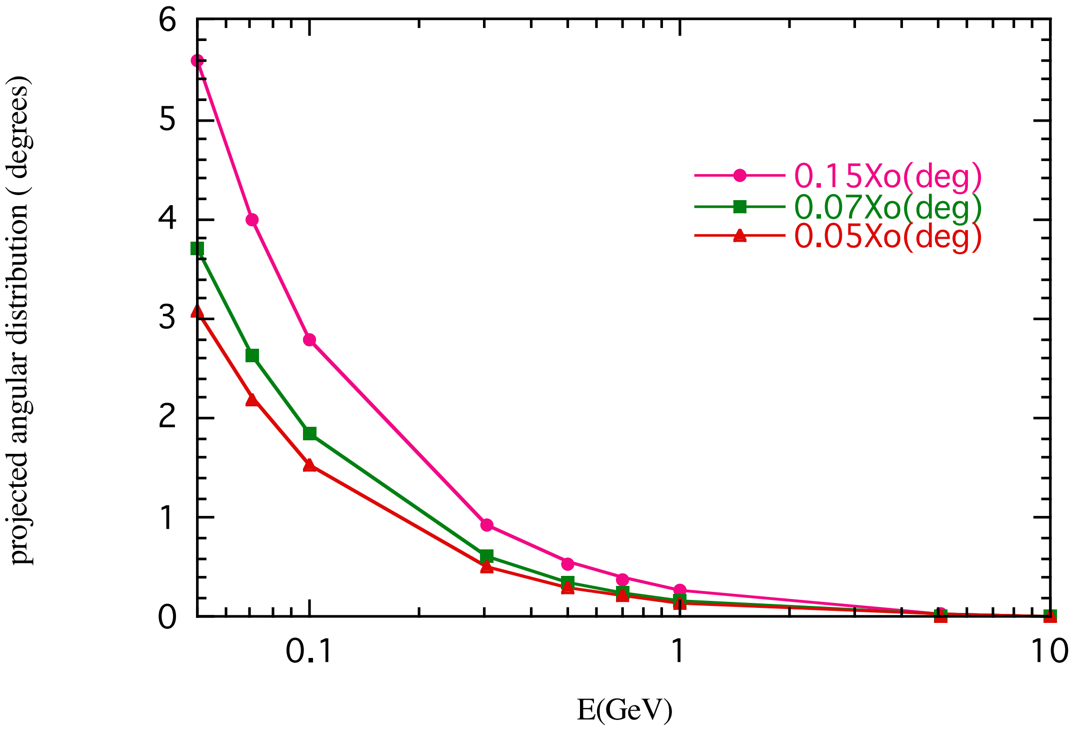
(more realistic scheme)

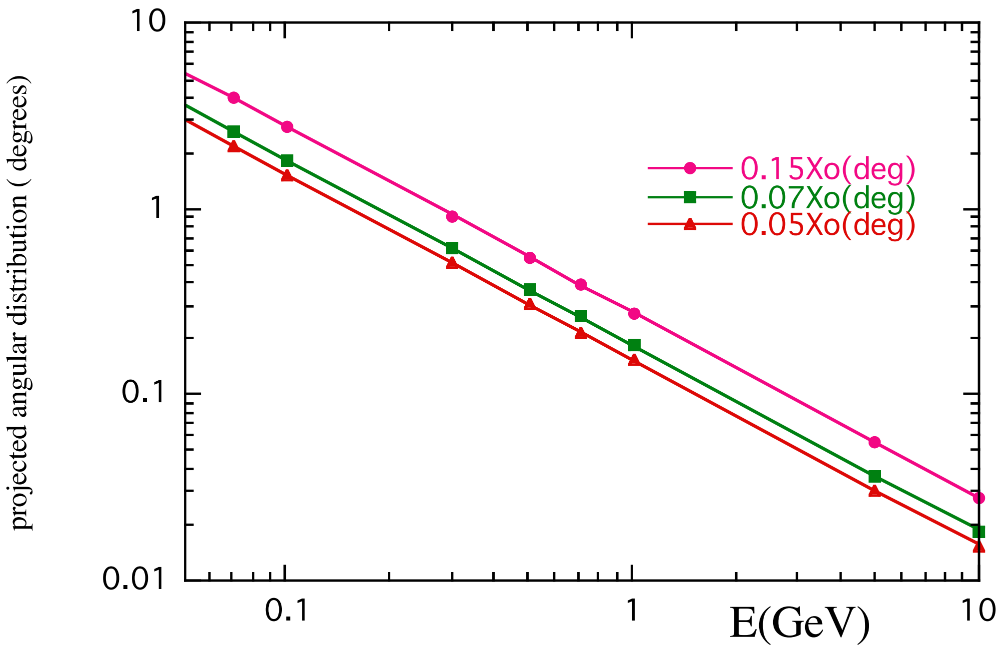


(energy measurement)

- photons materialize into matter-antimatter pairs:
  $E_\gamma \text{ --> } m_{e^+}c^2 + m_{e^-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Multiple Scattering

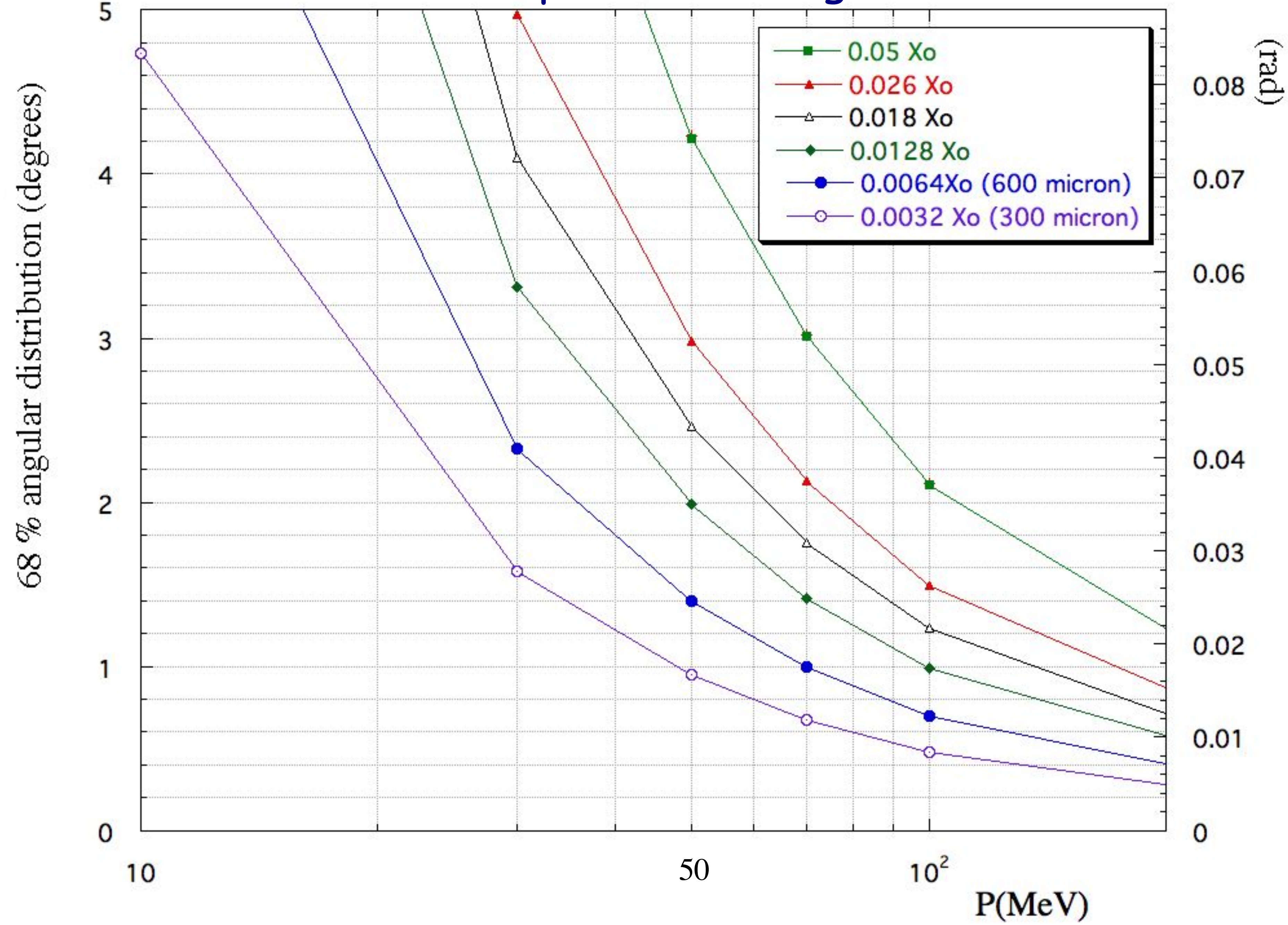




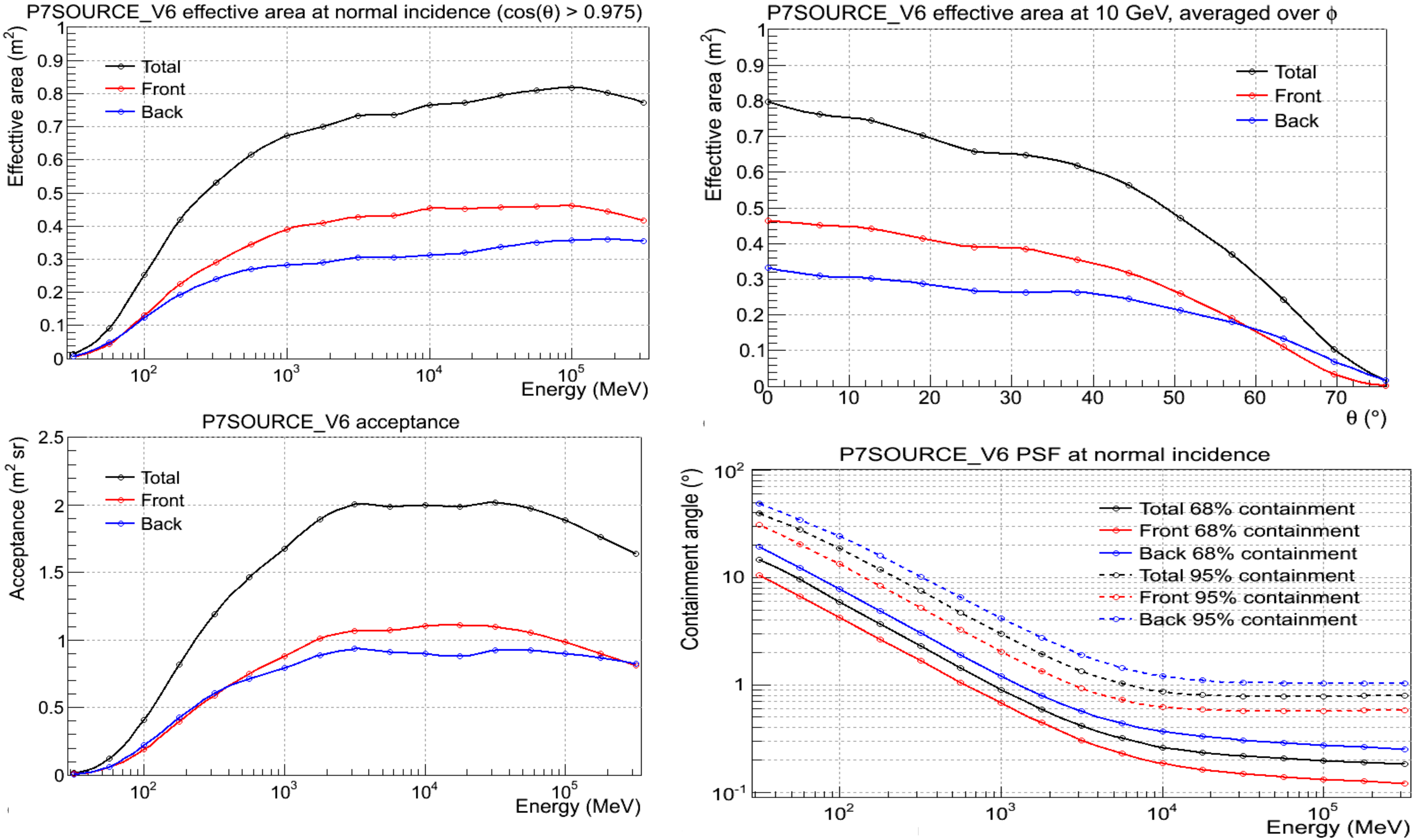
$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

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

Multiple Scattering

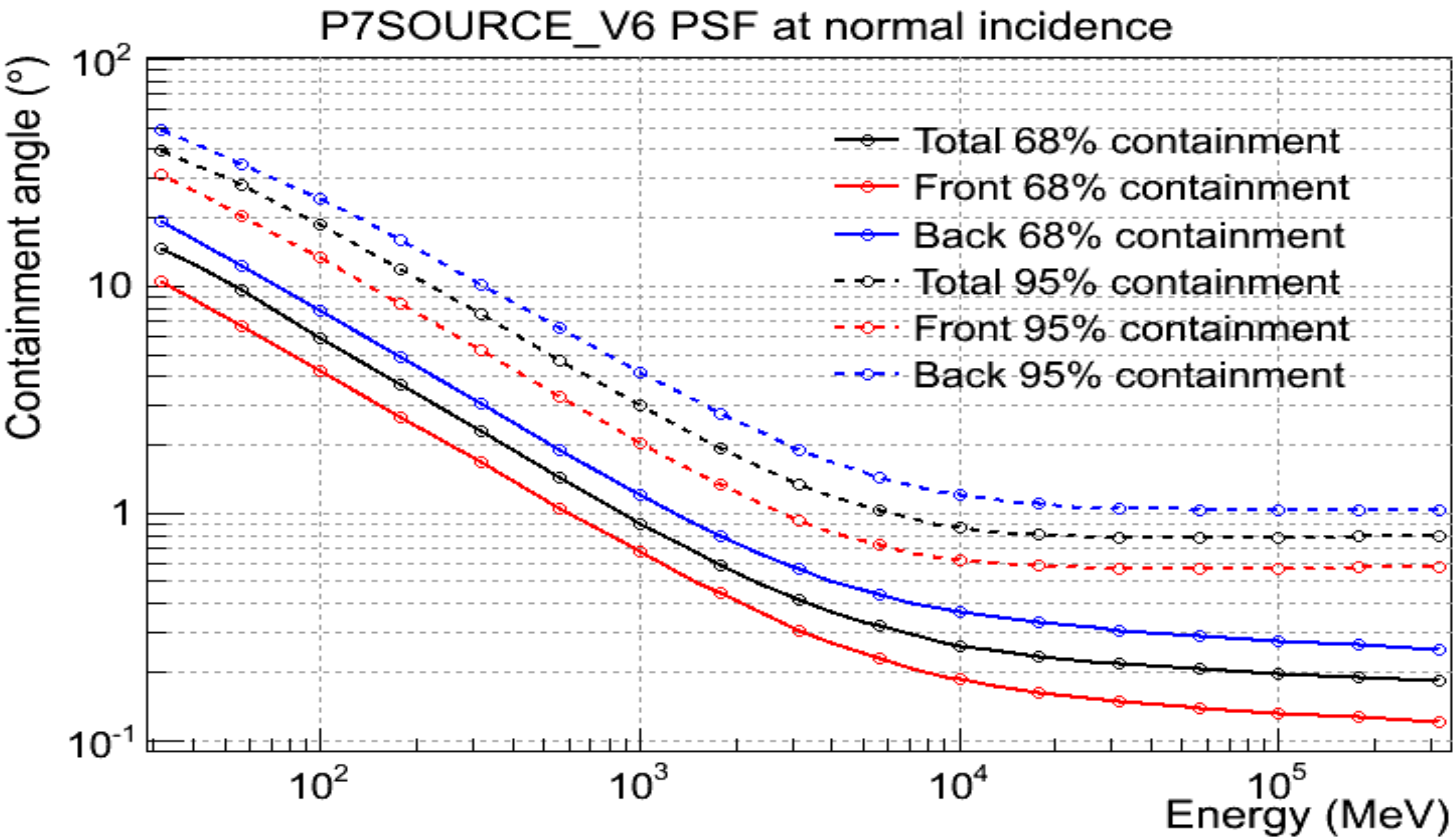


Fermi Instrument Response Function

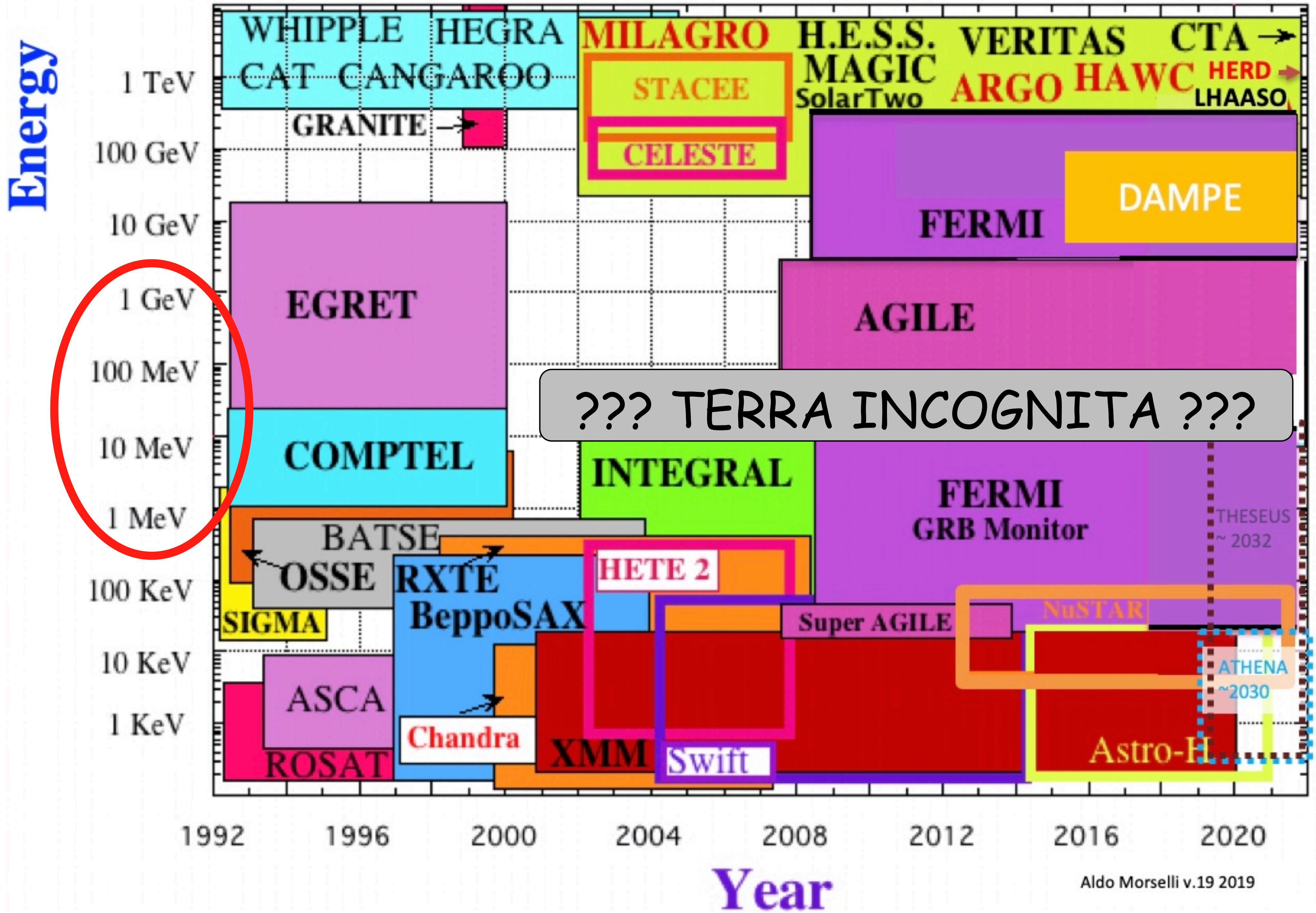


http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Fermi Instrument Response Function



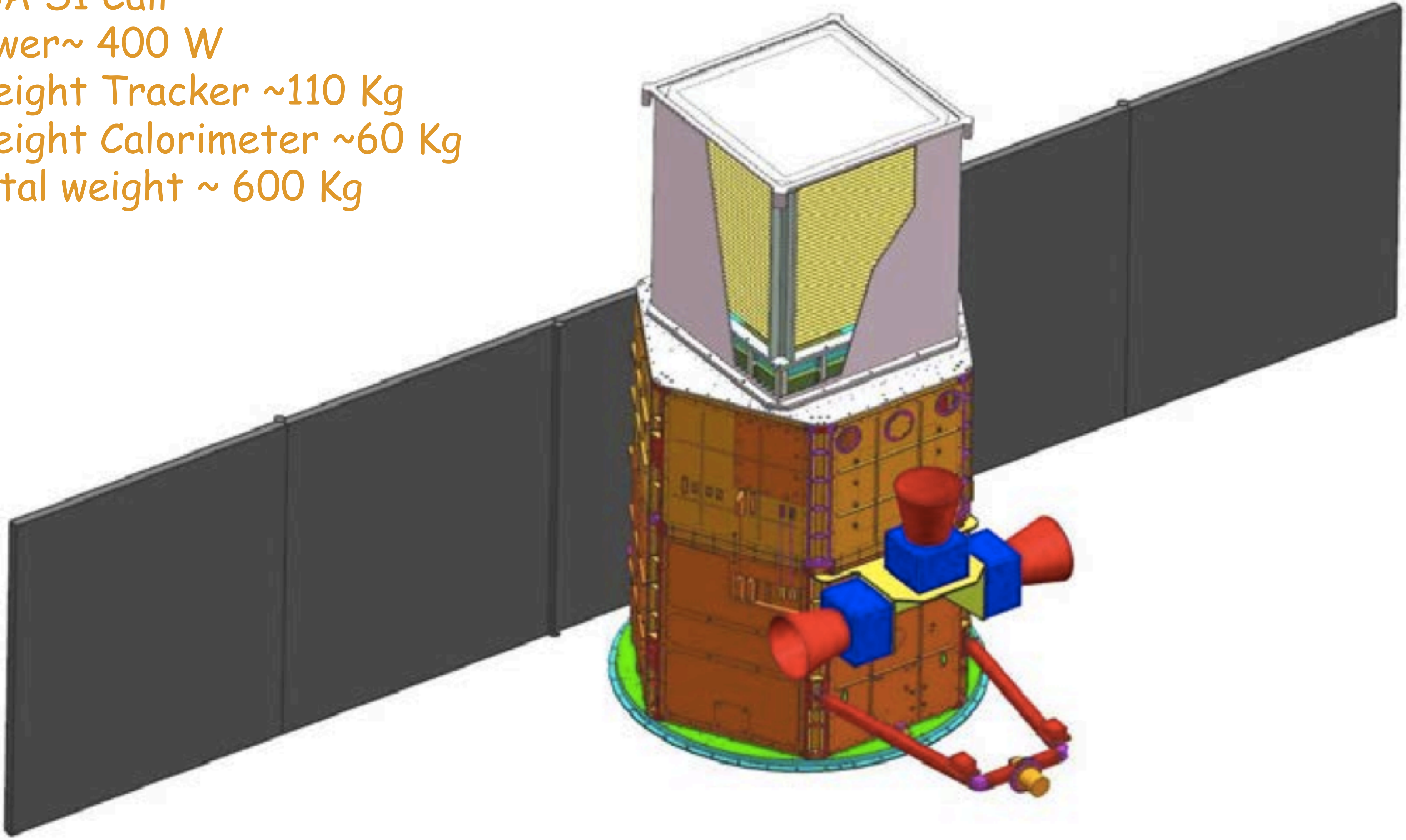
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm


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
HETE 2
BeppoSAX
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

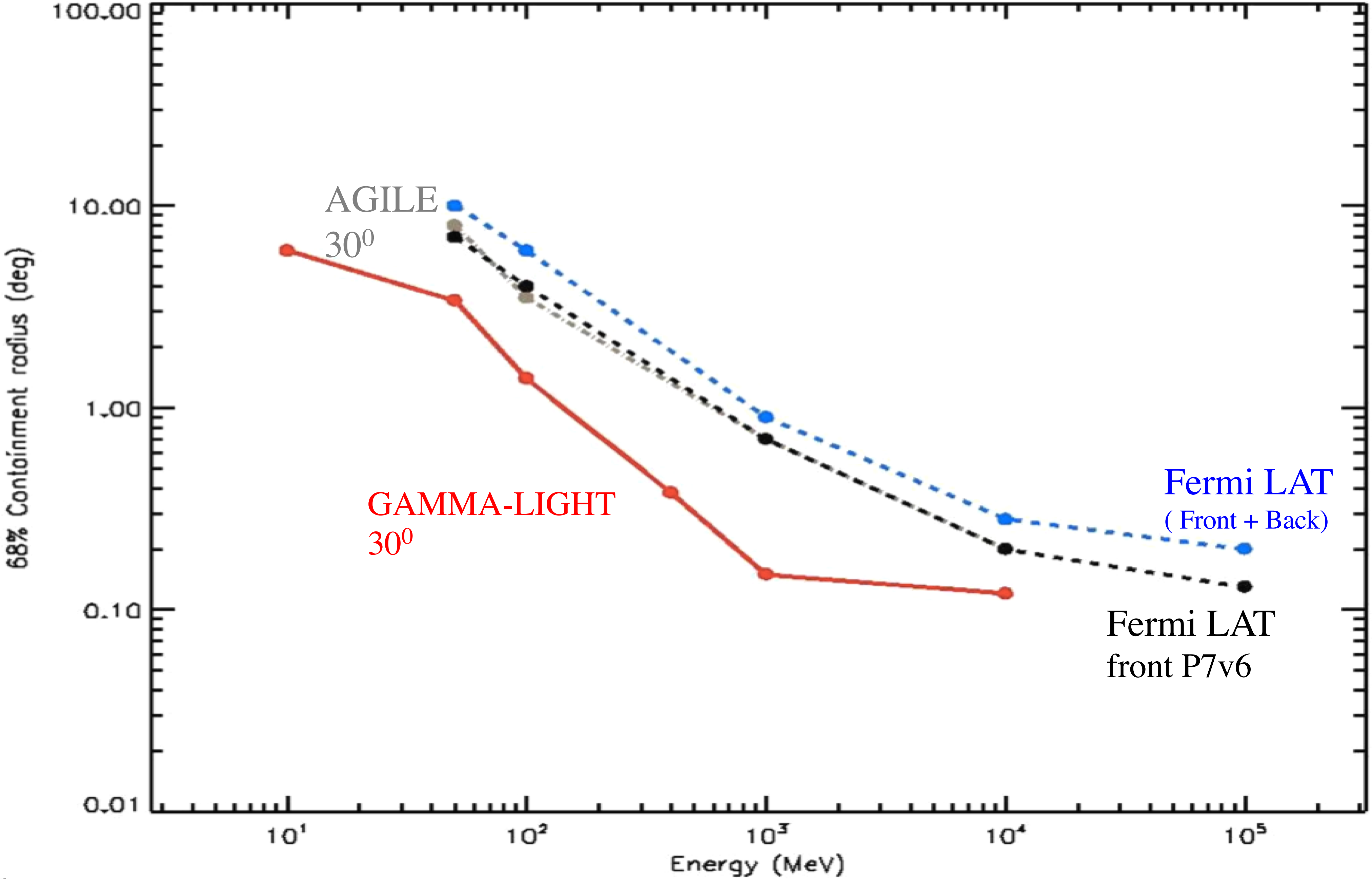
- 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Gamma-light project

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

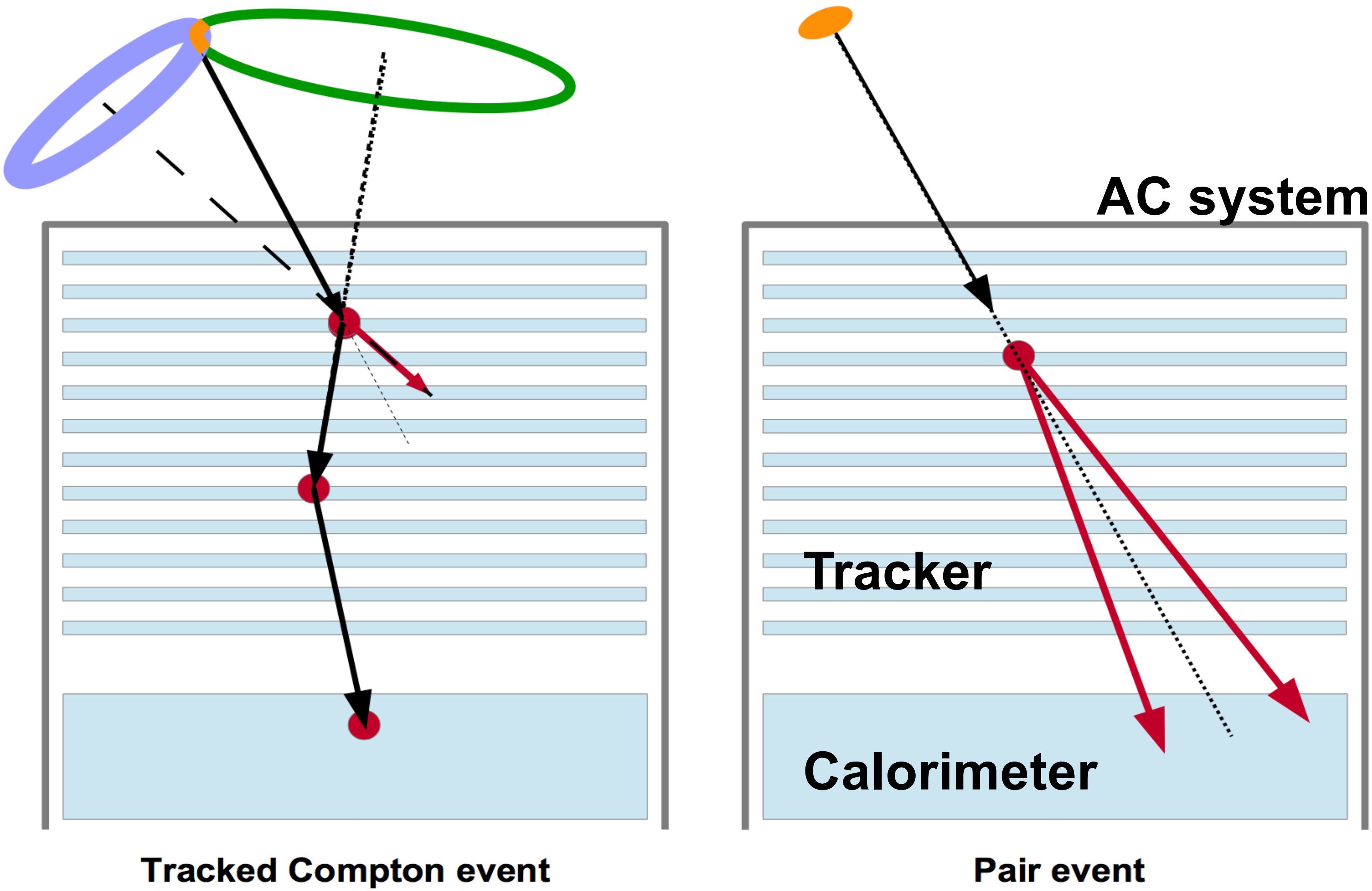


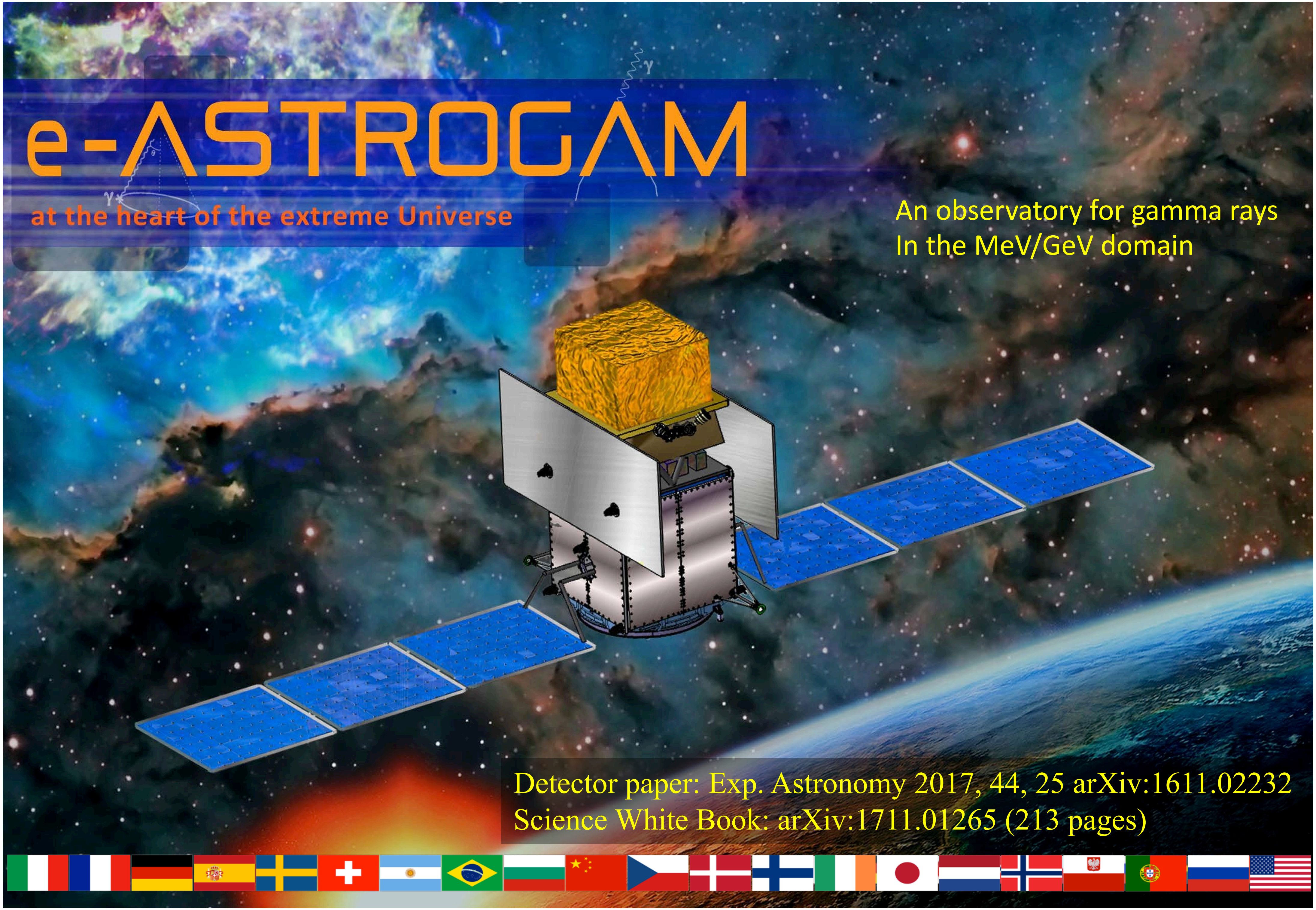
Gamma-Light Point Spread Function (angular resolution)



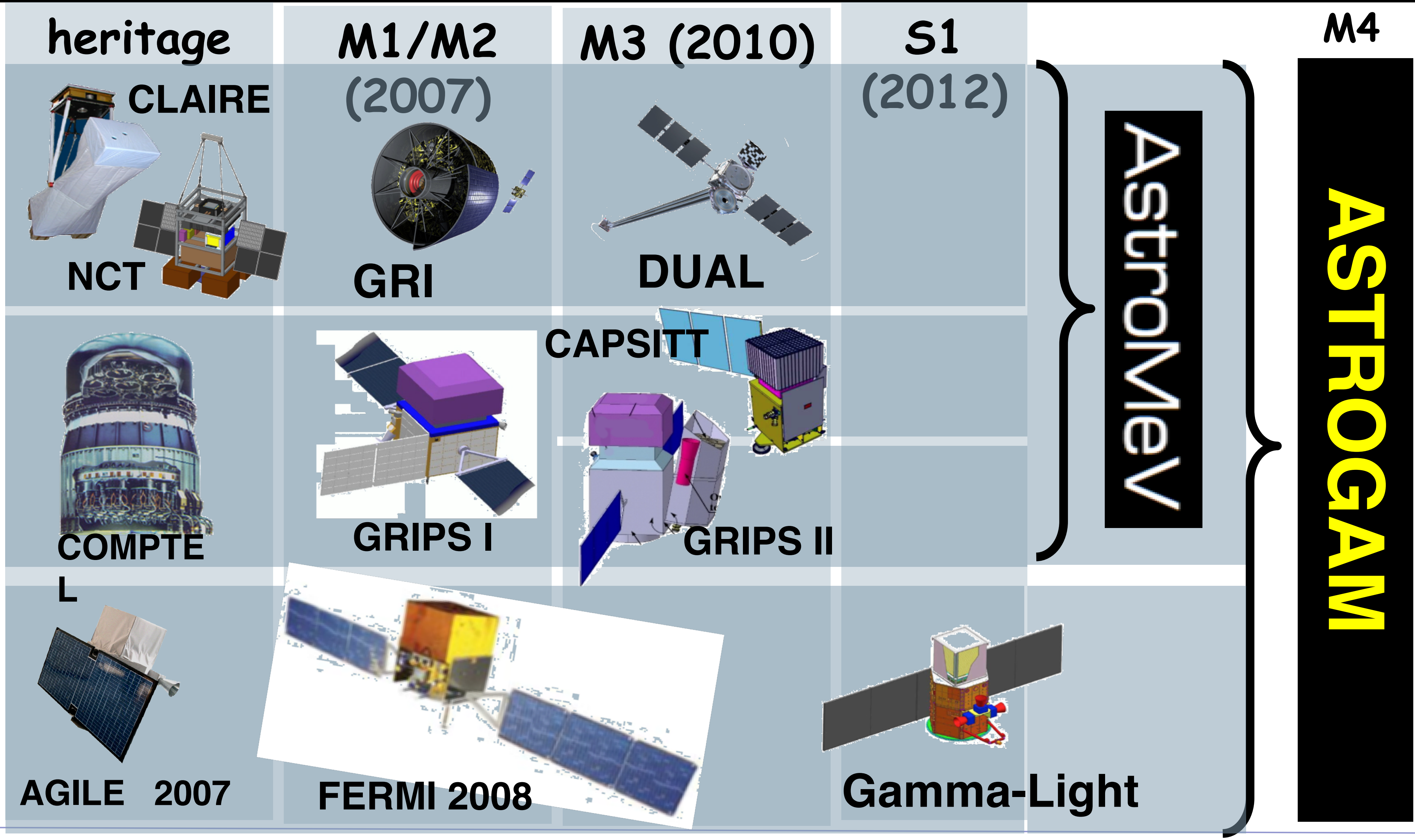
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

An instrument that combine two detection techniques

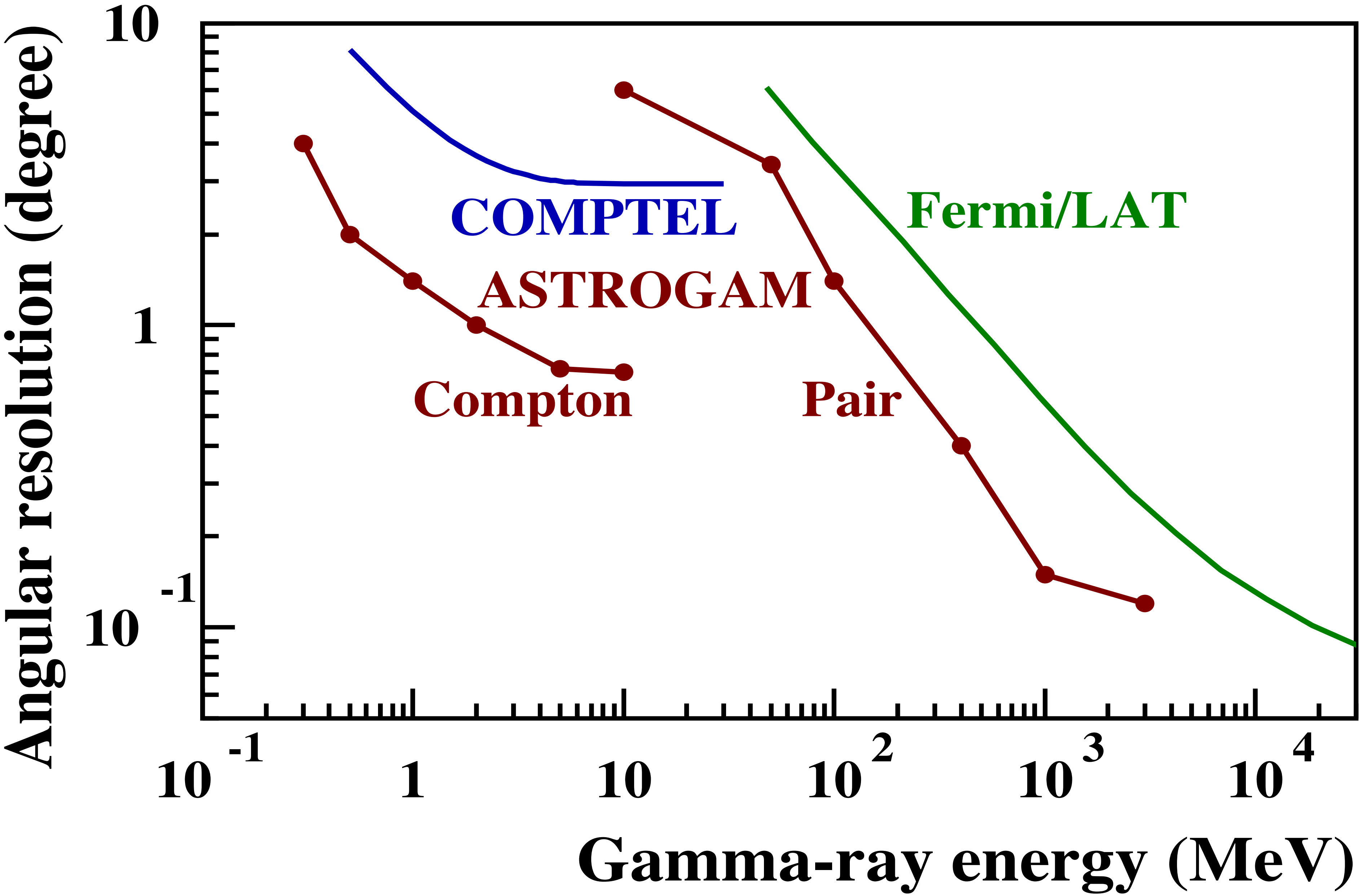



e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (213 pages)

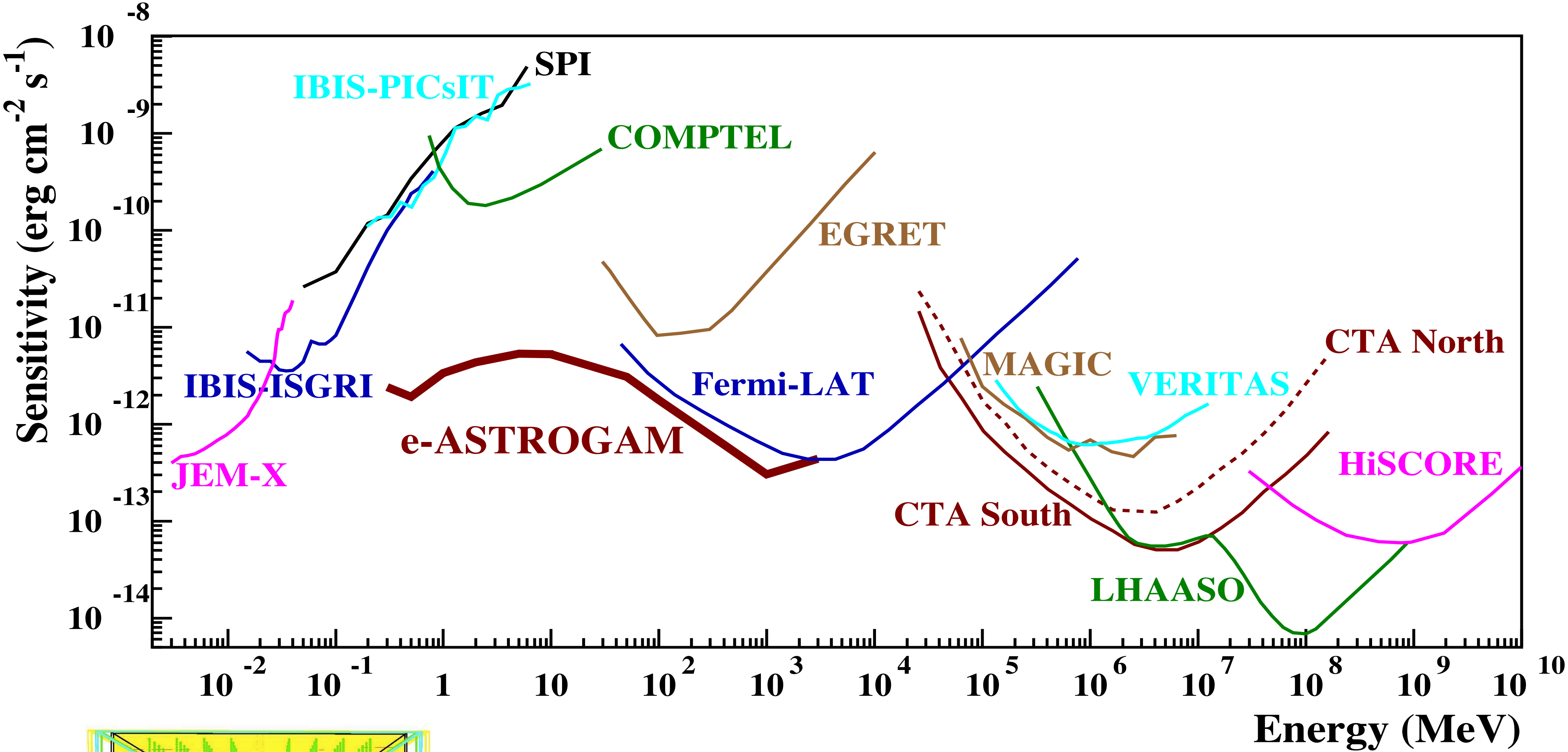
ASTROGAM a unified proposal from the entire gamma-ray community

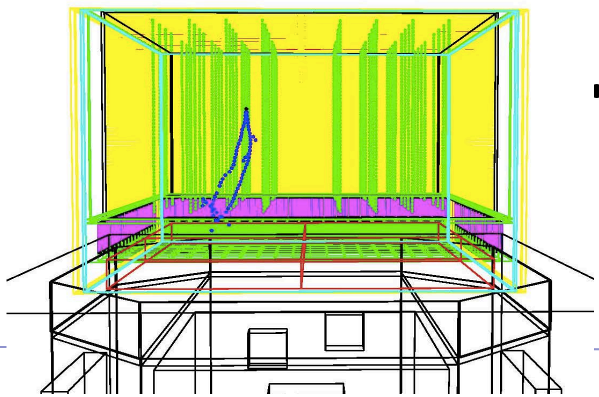


ASTROGAM Angular Resolution



e-ASTROGAM Performance assessment



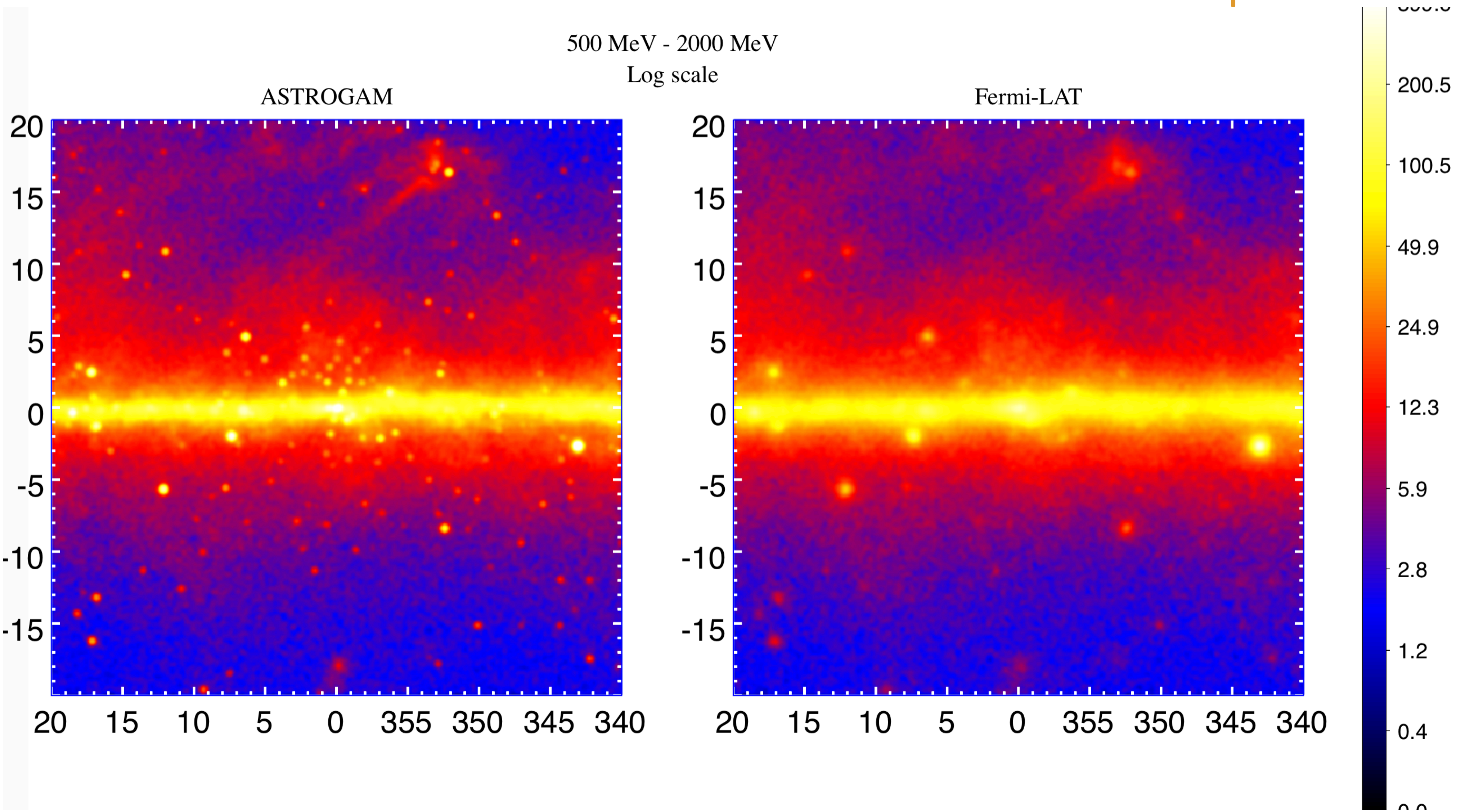


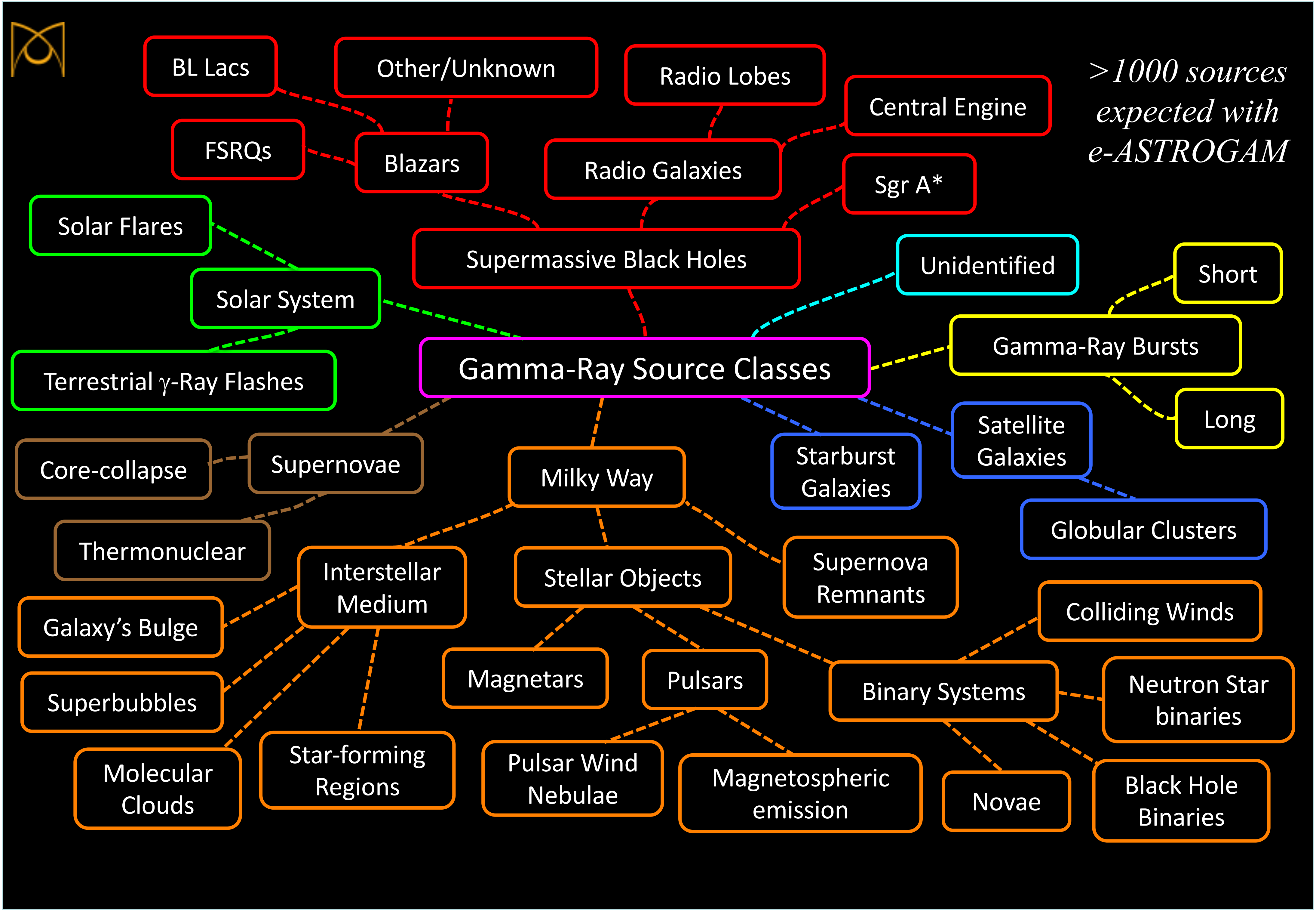
- e-ASTROGAM performance evaluated with **MEGAlib** and – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

e-Astrogam: arXiv:1611.02232

Galactic Center Region 0.5-2 GeV

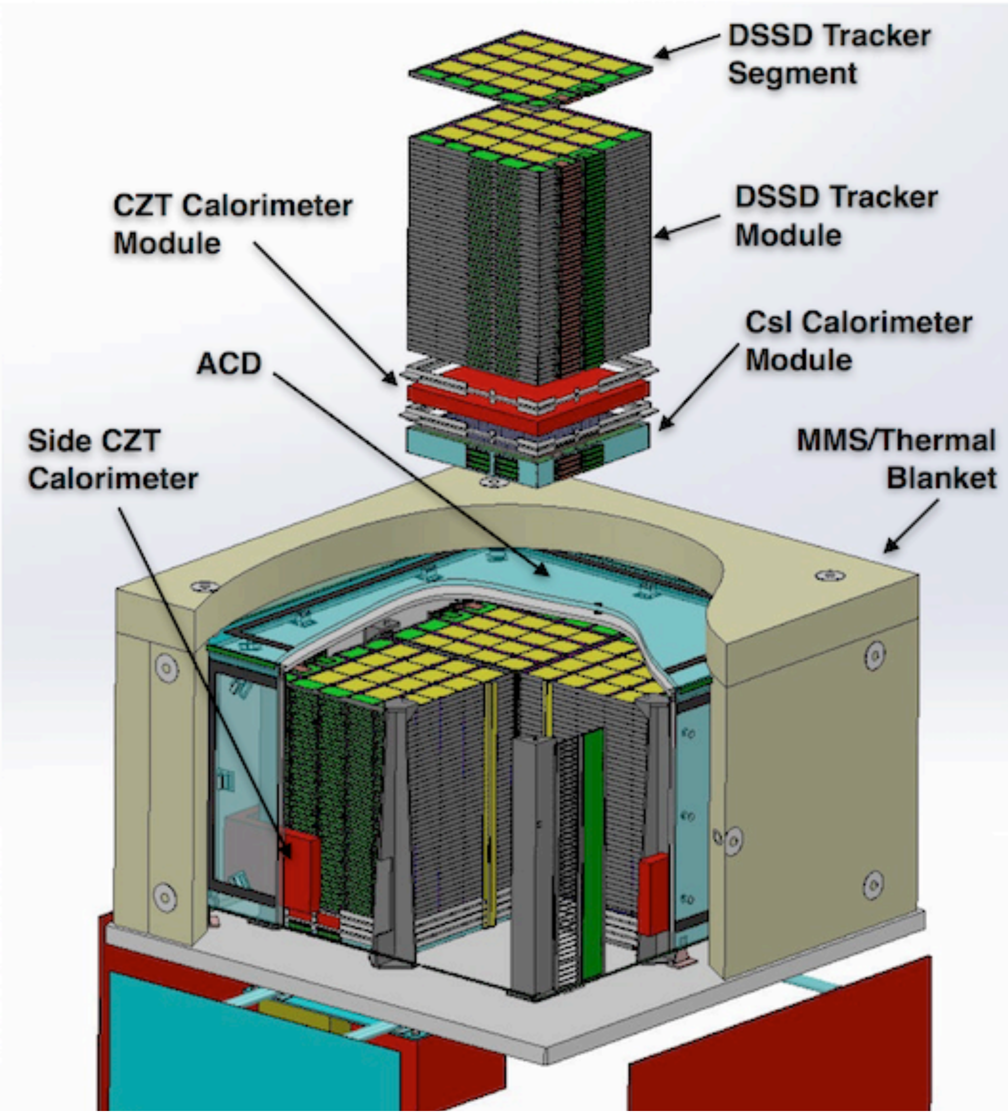
Fermi PSF Pass7 rep v15 source

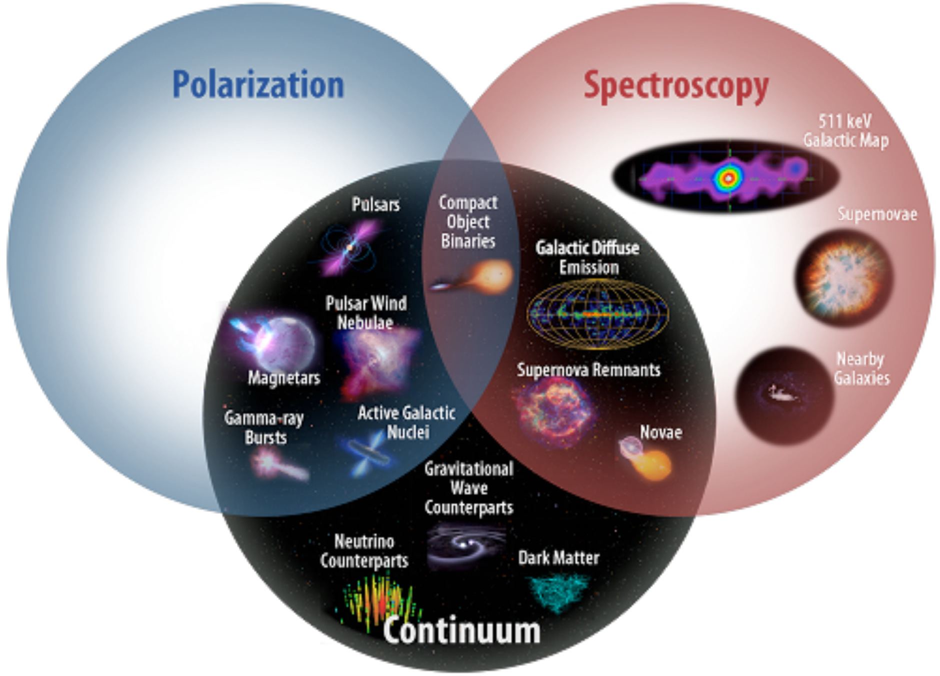




>1000 sources expected with e-ASTROGAM
Gamma-Ray Source Classes
Supermassive Black Holes
Blazars
BL Lacs
FSRQs
Other/Unknown
Radio Galaxies
Radio Lobes
Central Engine
Sgr A*
Solar Flares
Solar System
Terrestrial γ-Ray Flashes
Unidentified
Gamma-Ray Bursts
Short
Long
Satellite Galaxies
Starburst Galaxies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

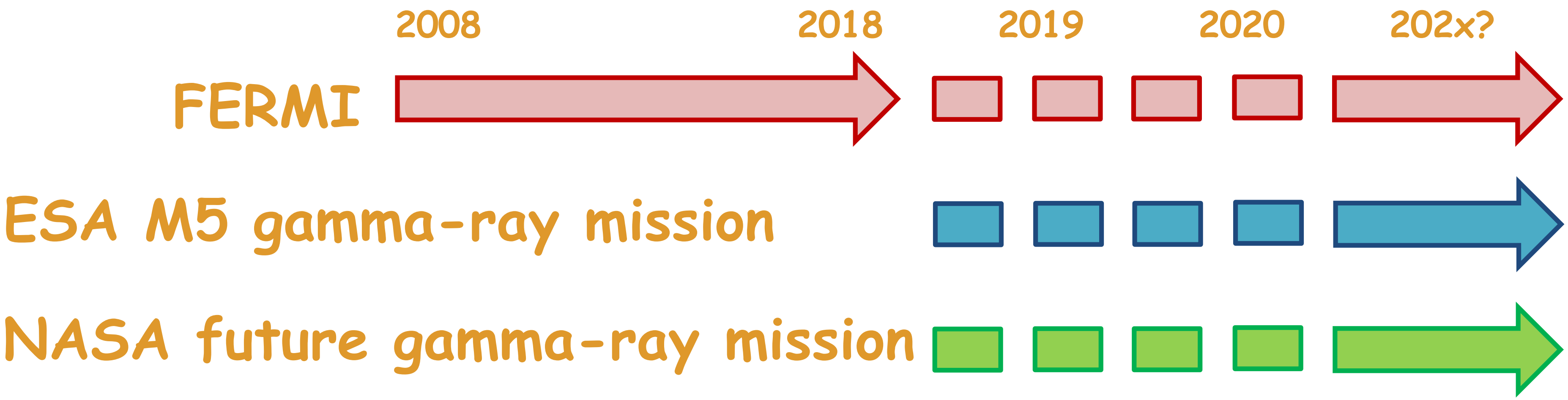
Our sister experiment: AMEGO (NASA)
(two brands, one community)





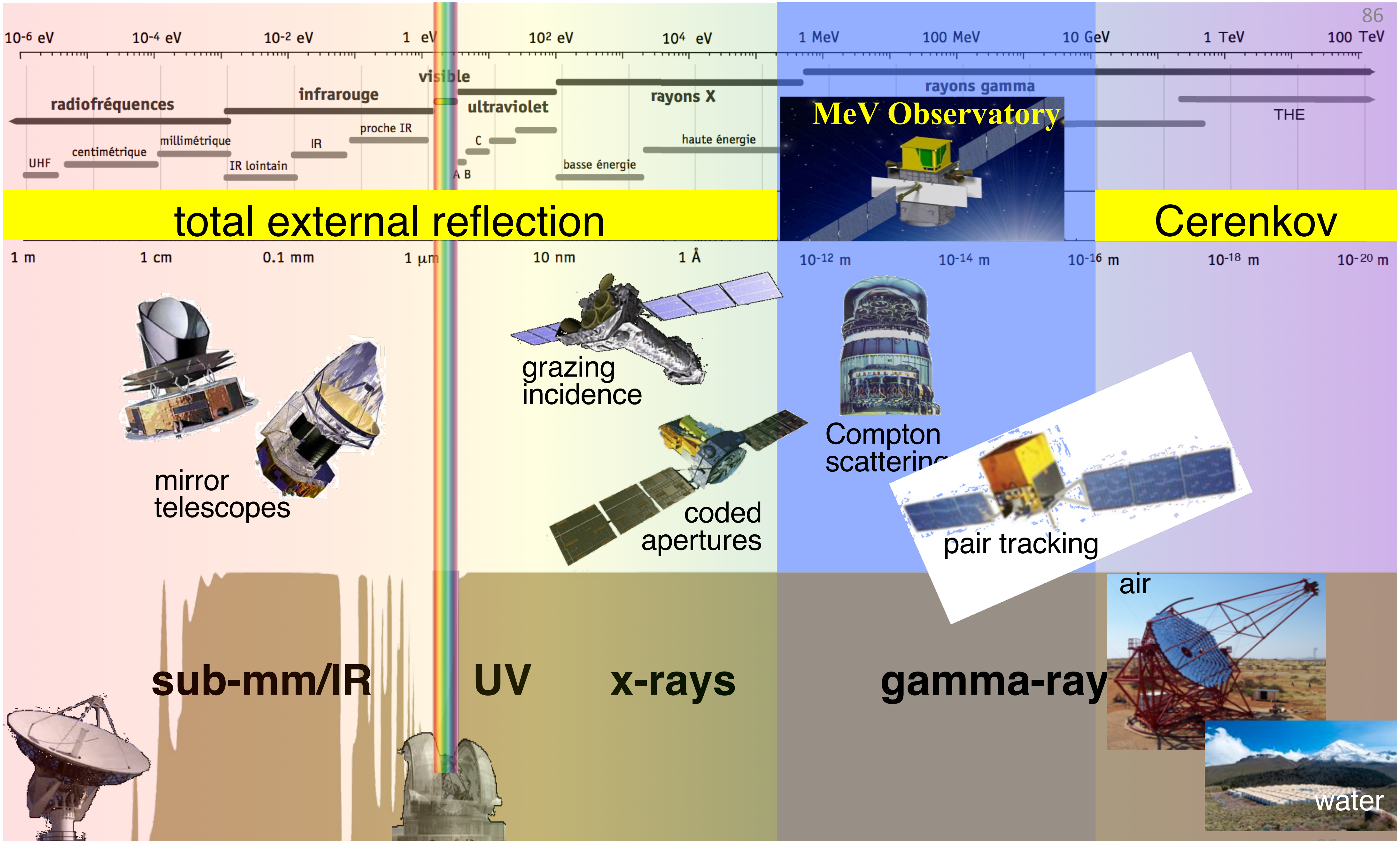
- ~20% smaller tracker
- CZT calorimeter layer

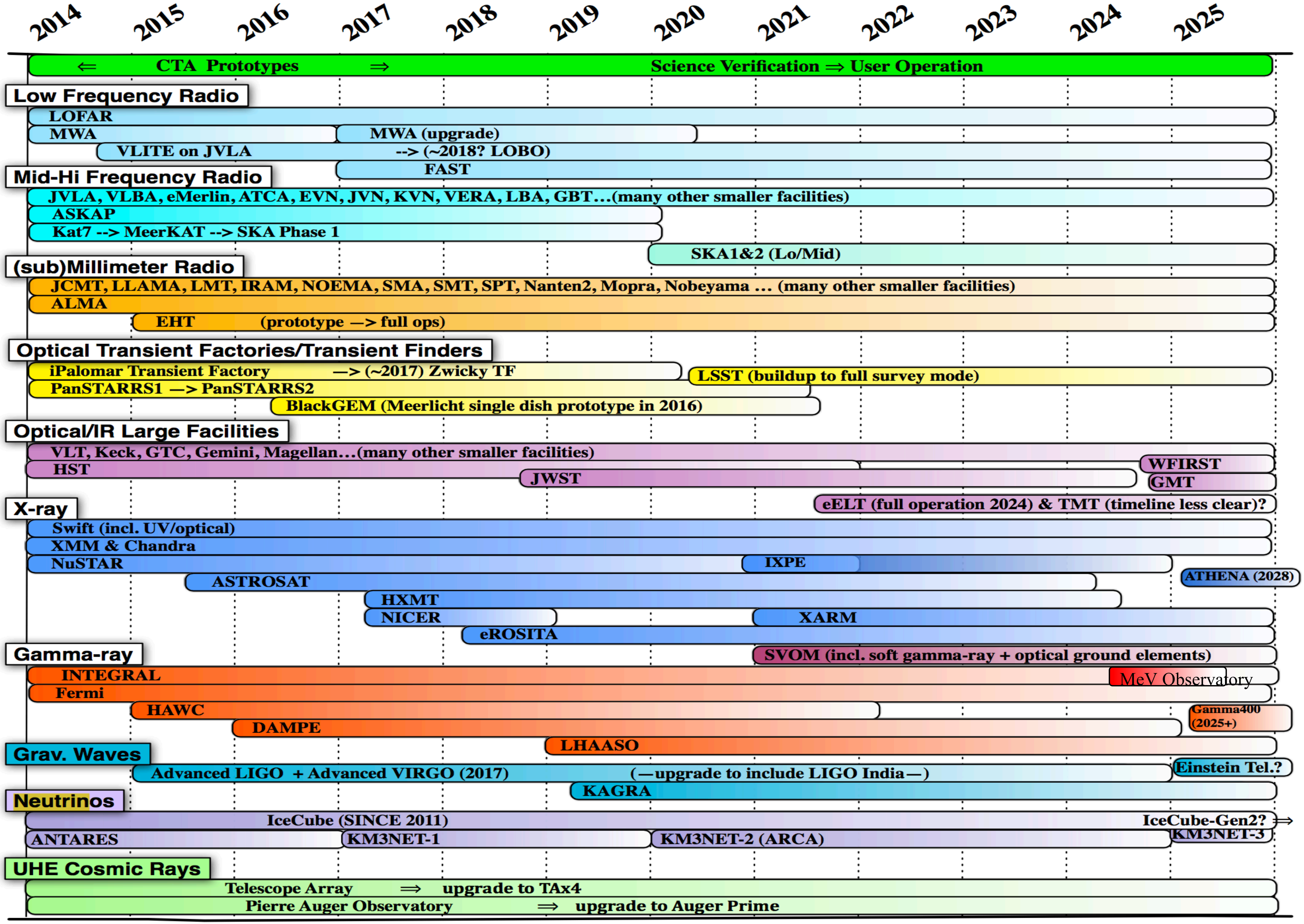
Space-based high energy gamma ray plan

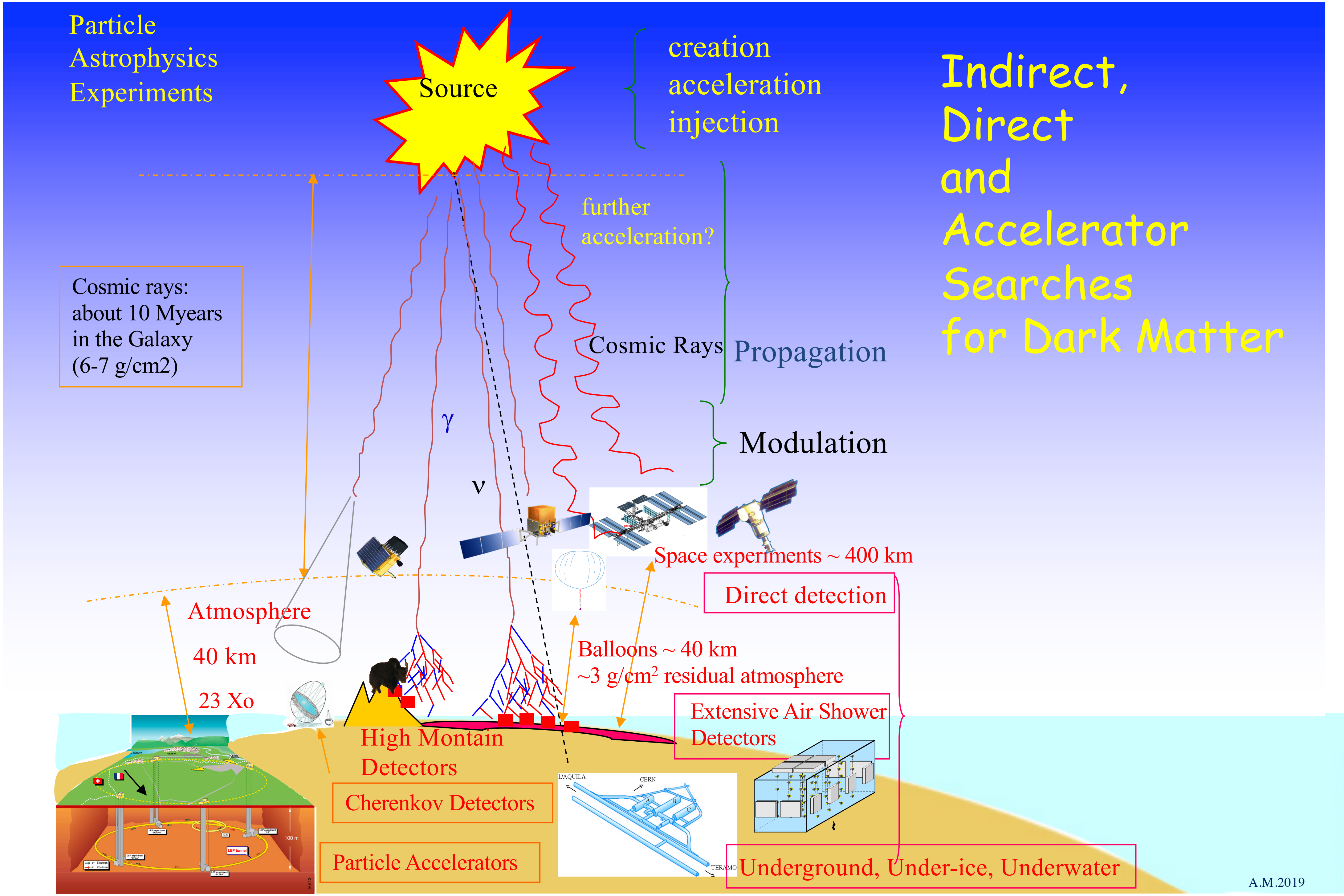


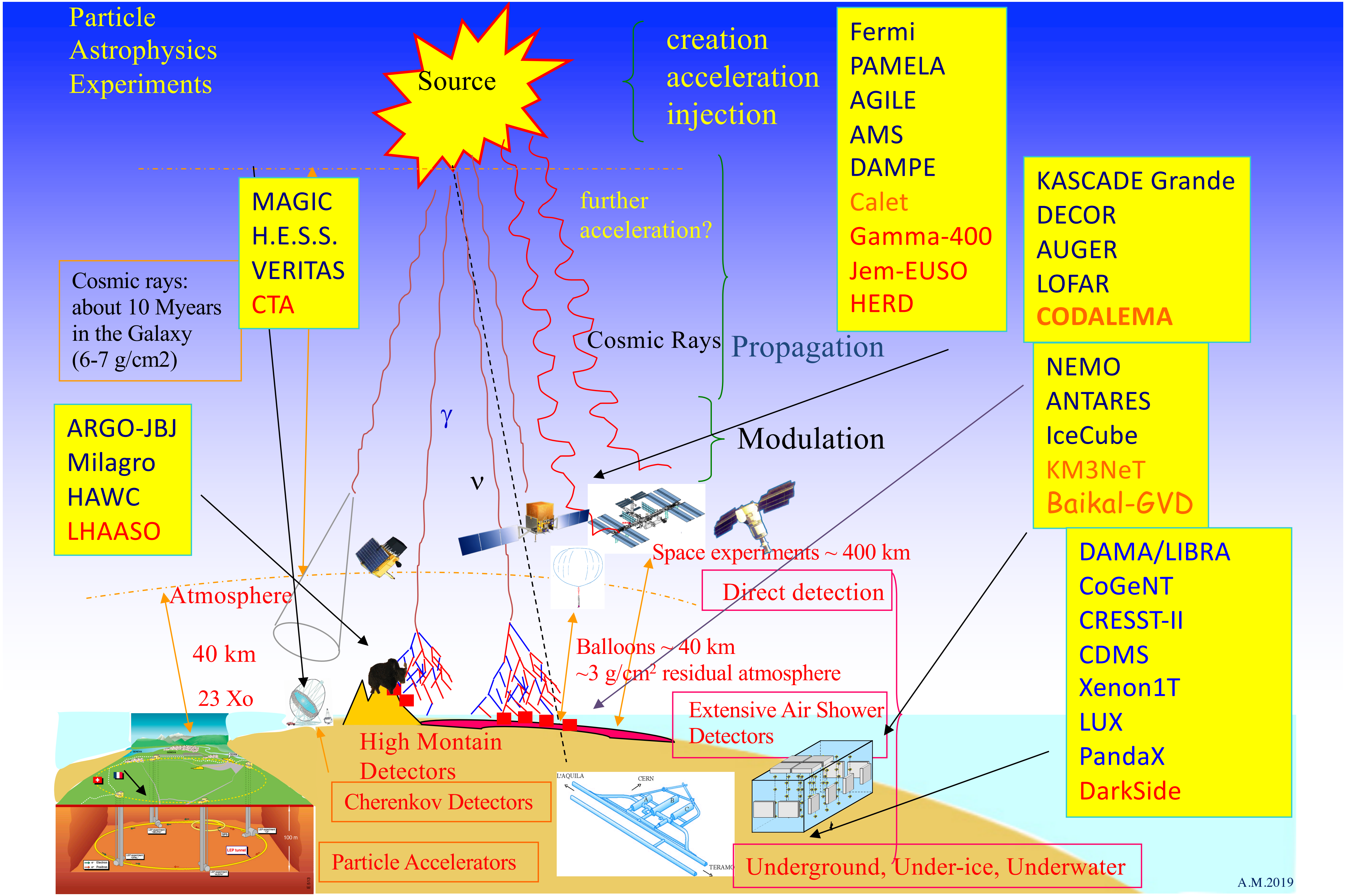
- M5 Phase A selection
  - 7 May 2018: ESA selects three new mission concepts for study:
    - A high-energy survey of the early Universe (Theseus), an infrared observatory to study the formation of stars, planets and galaxies (Spica) , and a Venus orbiter (EnVision) are to be considered for ESA's fifth medium class mission in its Cosmic Vision science programme, with a planned launch date in **2032**
  - e-ASTROGAM not selected for ESA M5
    - Excellent report, though; stressed challenging technical solutions
- Next chances:
  - AMEGO
  - Discussions for a possible integration in HERD
  - Discussions for a possible Russian launcher

An instrument to complete the coverage of the electromagnetic spectrum



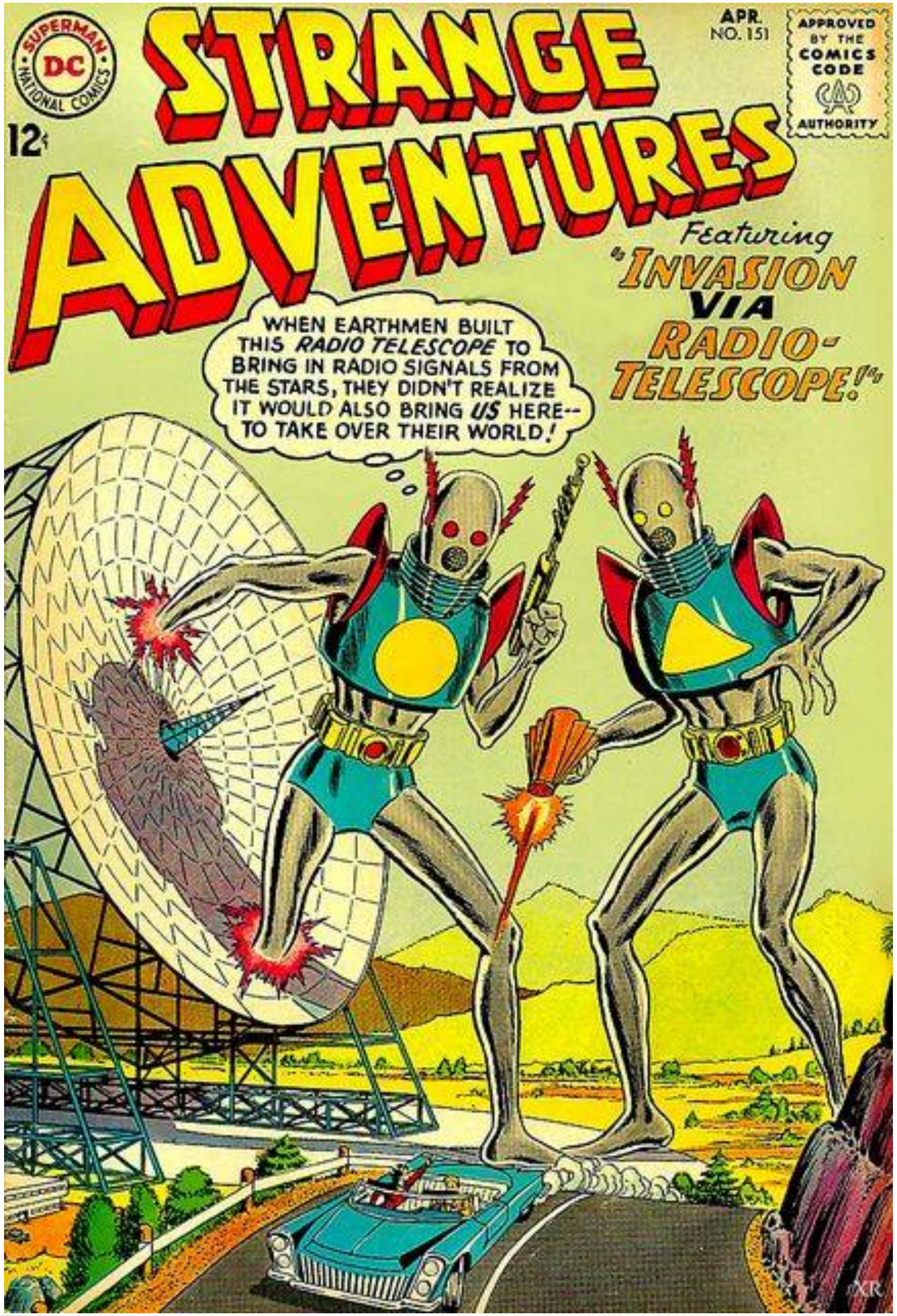

2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
⇐ CTA Prototypes ⇒
Science Verification ⇒ User Operation
Low Frequency Radio
LOFAR
MWA
MWA (upgrade)
VLITE on JVLA
--> (~2018? LOBO)
FAST
Mid-Hi Frequency Radio
JVLA, VLBA, eMerlin, ATCA, EVN, JVN, KVN, VERA, LBA, GBT…(many other smaller facilities)
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)
WFIRST
HST
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
MeV Observatory
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


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)
Cosmic Rays
Propagation
γ
Modulation
ν
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



Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
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
γ
Modulation
ν
Space experiments ~ 400 km
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
Atmosphere
Direct detection
40 km
Balloons ~ 40 km
~3 g/cm² residual atmosphere
23 Xo
Extensive Air Shower
Detectors
High Montain
Detectors
Cherenkov Detectors
L'AQUILA
CERN
TERAMO
Particle Accelerators
Underground, Under-ice, Underwater
A.M.2019

there is always
a risk ..



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